The EERC's CO_2 Enhanced Bakken Recovery Research Program

North Dakota Legislative Council
Energy Development and Transmission Committee Meeting

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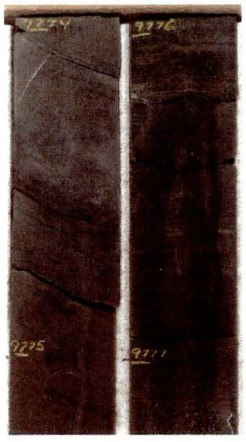
EERC Energy & Environmental Research Center (EERC)...

The Bakken Is a Tight Oil Formation – What Is Tight Oil?

- "Tight" refers to the extremely low permeability of the reservoir rock, which impedes the ability of the oil in the formation to flow freely.
- Tight oil is found in rock formations associated with organically rich shale at unminable depths.
- While oil may be produced directly from its shales, a vast majority of Bakken oil production is from low-permeability siltstones, sandstones, and carbonates that are closely associated with the oil-rich shale.



Core from Bakken Middle Member

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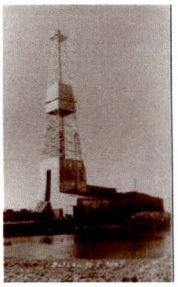
Bakken Production History

- Average cumulative production:
  - 1960s – Early verticals
    - IPs around 150 to 450 bpd.
    - Typical cumulative production = 85,000 bbl/well
  - 1990s – Early horizontals
    - IPs around 230 to 500 bpd.
    - Typical cumulative production = 145,000 bbl/well
  - 2005 to the present – Multistage completions
    - IPs over 1500 bpd are common.
    - Typical cumulative production unknown, too early to tell.
    - 550,000 bbl/well?



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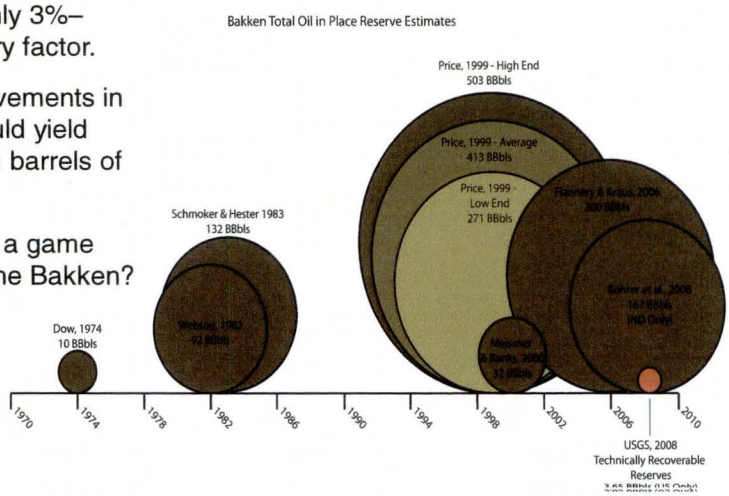
How Much Bigger Can Bakken Get?

- Currently, only 3%–10% recovery factor.
- Small improvements in recovery could yield over a billion barrels of oil.
- Can CO_2 be a game changer in the Bakken?



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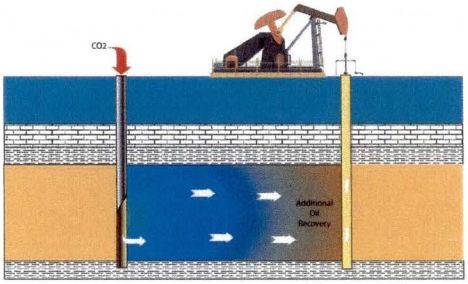
Conventional CO_2 Enhanced Oil Recovery (EOR) – *How It Works*

- CO_2 dissolves in oil, lowers oil viscosity, and swells the oil, thereby allowing oil to flow more freely.
- CO_2 injection repressurizes the reservoir, thereby reestablishing a drive mechanism.
- A portion of the injected CO_2 will be produced with the oil and water, separated at the surface, and recycled to be used again in the reservoir.
- Typically 90%–100% of the purchased CO_2 volume is retained in reservoir (dead end pores and channels).



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Key Reservoir Characteristics Required for CO_2 EOR

- **Minimum reservoir pressure of 1100 psi**
  - (ND Bakken >4000 psi)
- **Reservoir temperature between 90° and 250° F**
  - (ND Bakken range from 150° to 240° F)
- **Oil gravity between 27° and 48° API**
  - (ND Bakken ranges from 36° to 44° API)
- **Oil saturation greater than 25%**
  - (ND Bakken typically >75%)
- **Nature of porosity and permeability**
  - (Bakken reservoir permeability typically <0.1 mD)
- **Waterflood performance**
  - (ND Bakken has not undergone waterflooding)

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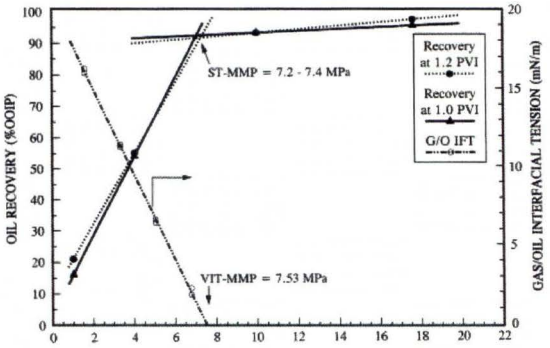
Importance of MMP in CO_2 EOR

- As minimum miscibility pressure (MMP) is approached, high recoveries (~90%) can be achieved.



(Rao and Lee, 2002)

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Comparison of Reservoir Characteristics

Typical McKenzie County Bakken reservoir vs. two conventional oil fields currently undergoing CO_2 flood EOR

	McKenzie County Bakken	Seminole San Andres Unit West Texas	Weyburn Unit Saskatchewan
Depth (ft)	11,200	5300	4800
MMP (psi)	**Data Not Available**	1300	1740
Temperature (deg. F)	170	104	139
Ultimate Recovery Factory w/ CO_2 (%OOIP)	**Too Early to Know**	>63	36
Tertiary Recovery Factor (%OOIP)	**Too Early to Know**	14	10
Oil Gravity (deg. API)	42	35	25–34
Permeability (mD)	<0.1	9	10–30
Porosity (%)	12	12	15–26
Initial Water Saturation (%)	17	16	32

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CO_2 Enhanced Bakken Recovery Research Program in a Nutshell

- Laboratory- and modeling-based examination of the potential use of CO_2 for EOR in the Bakken Formation.
- Activities managed and conducted by the Energy & Environmental Research Center (EERC)
- Total cash contributions to the project: $1,350,000.
- Contributing partners:
  - U.S. Department of Energy (DOE) through the EERC's cooperative agreement for fossil energy research
  - North Dakota Industrial Commission Oil and Gas Research Council
  - TAQA North, Ltd.
  - Marathon Oil Company
- Project duration: 17 months.
- Project initiated in June 2012.

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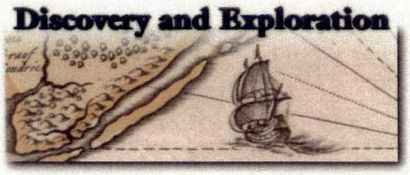
Where Are We Going with This?

- Previous attempts using "conventional" CO_2 huff 'n' puff for EOR in the Bakken have met with marginal success.
- The ultimate goals of this program are to use the insight developed by our research to:
  - Design a viable implementation approach for CO_2-based EOR.
  - Improve our understanding of the potential for tight oil formations to store CO_2.
- The end game is to be involved with at least one of our partners in a follow-on field test within 2 years.



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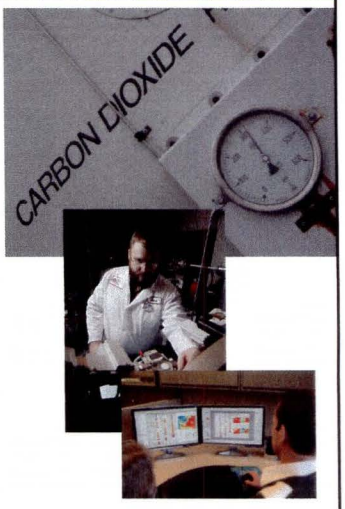
Project Goals

- The goal is to predict the performance of CO_2 EOR in the Bakken based on lab experiments coupled with modeling.
  - Quantify phase behavior and fluid properties under reservoir conditions.
  - Data from three Bakken pools will be used to compare different types of Bakken reservoirs.
  - Lab analyses include:
    - Detailed analyses of Bakken reservoir rocks.
    - Determination of key Bakken oil properties relative to CO_2 using PVT (pressure, volume, temperature) and VIT (vanishing interfacial tension) testing.
  - Modeling will integrate well file data and experimentally derived data to:
    - Generate geologic reservoir models.
    - Conduct dynamic simulation modeling.



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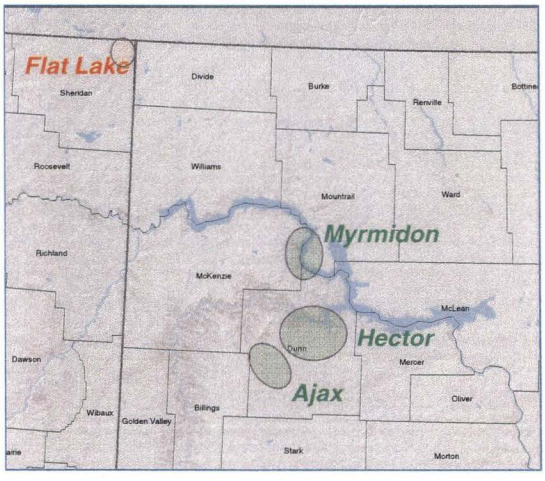
Project Study Fields



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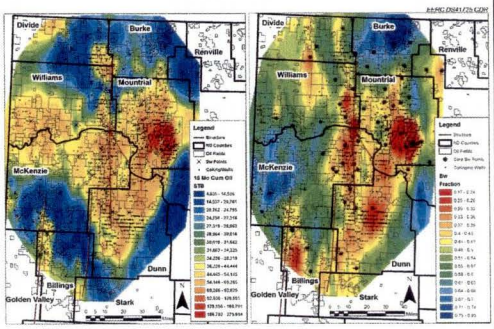
Approach – Task 1

- Task 1 – Detailed Characterization of Selected Bakken Fields
  - Previous work has identified relationships between reservoir properties and productivity.
  - Relationship between water saturation and production may help identify areas amenable to CO_2 EOR.
  - Reservoir fluid and rock properties for a given location are crucial to predict EOR effectiveness.
  - Minimum of three Bakken study pools:
    - Thermally immature, structurally controlled reservoirs in northern-tier counties.
    - Thermally mature reservoirs in basin center.



15-month cumulative oil production (left) compared to water saturation (right).

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Task 1 Activities

- Core-Based Lithofacies and Fracture Studies
  - Results in detailed measurements and descriptions of macroscopic attributes and classification of lithofacies
- Core-Based Petrographic Studies
  - Three to five wells per study pool (thin sections, x-ray diffraction [XRD], scanning electron microscopy [SEM])
  - Result in detailed descriptions of key rock properties
- Relative permeability testing of core
  - Maximum three per study pool
  - Results in CO_2/water/oil relative permeability curves
- Comparison of core to well log data
  - Results in correlation of log responses to key rock attributes
- Integration of new core/log data with previously generated data
  - Results in robust data sets upon which to base static models
- Static geologic model development
  - Results in isopach maps, cross sections, and 3-D models

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Approach – Task 2

- Task 2 – Examination of the Use of CO_2 for EOR in the Bakken
  - Challenges to EOR within the Bakken
    - Mobility of "traditional" EOR fluids through fractures relative to very low matrix permeability.
    - The aversion of exposing swelling clays to water.
    - Oil-wet nature of much of the North Dakota Bakken will minimize effectiveness of water flooding.
    - These issues suggest CO_2 may be effective.
  - Experimental data and modeling will be used to predict performance of CO_2 for EOR in the Bakken.
    - Quantify phase behavior and fluid properties under reservoir conditions.
  - Integrate lab data with static models to conduct dynamic simulation modeling for at least two Bakken reservoirs.

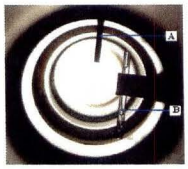
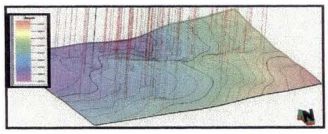


Image taken from Sequeira, 2006, LSU MS Thesis.



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Task 2 Activities

- Acquisition of reservoir fluids
  - Crude oil samples from the selected study pools for use in experimental and analytical activities.
- Laboratory determination of key Bakken oil properties relevant to CO_2-based EOR
  - Standard fluid properties
    - Formation volume factor for gas and oil
    - Viscosity for gas and oil
    - Solution gas-to-oil ratio (GOR)
  - Oil composition
  - API gravity
  - Thermodynamic MMP
  - Crude oil swelling
  - Crude oil viscosity reduction
  - Single- and multiple-contact phase volumes
- Dynamic modeling
  - Phase equilibrium modeling of the reservoir fluid/CO_2 system under relevant conditions
  - Core scale simulations based on Task 1 and 2 data

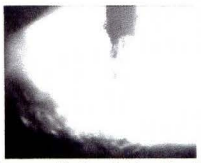
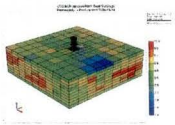
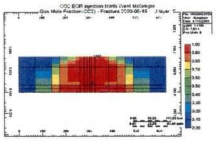


Image modified from Saini and Rao, SPE 132389 presentation, WRM, 2010.





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Expected Results and Products

Results

- Guidance for future laboratory and field activities.
- Previously unavailable insight regarding Bakken oil MMP.
- Previously unavailable insight regarding Bakken relative permeability to CO_2.
- Insight into the potential use of CO_2 for EOR in the Bakken.
- Insight to the potential storage of CO_2 not only in the Bakken, but in tight oil formations in general.

Products

- Quarterly reports summarizing progress, challenges, solutions to challenges, next steps.
- Final report presenting results, implications of results to the use of CO_2 for Bakken EOR, and recommendations for path forward.
- Reports and selected data sets made available on EERC Bakken Decision Support System.
- Posters and/or presentations at one to two technical conferences.

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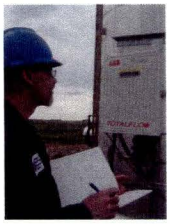
Ultimate Impact to North Dakota

Technologic and Economic Impact

- Department of Mineral Resources estimates that ND OOIP for the Bakken and Three Forks combined is approximately 170 billion barrels (Bbbl).
- If the application of CO_2 for EOR can improve recovery by just 1%, that improvement would translate to an additional 1.7 Bbbl of oil production.
- Assuming an average oil price of $88/bbl, this would equate to approximately $150 billion worth of oil.
- Application of CO_2 EOR could also prolong the life of the Bakken oil fields by decades.

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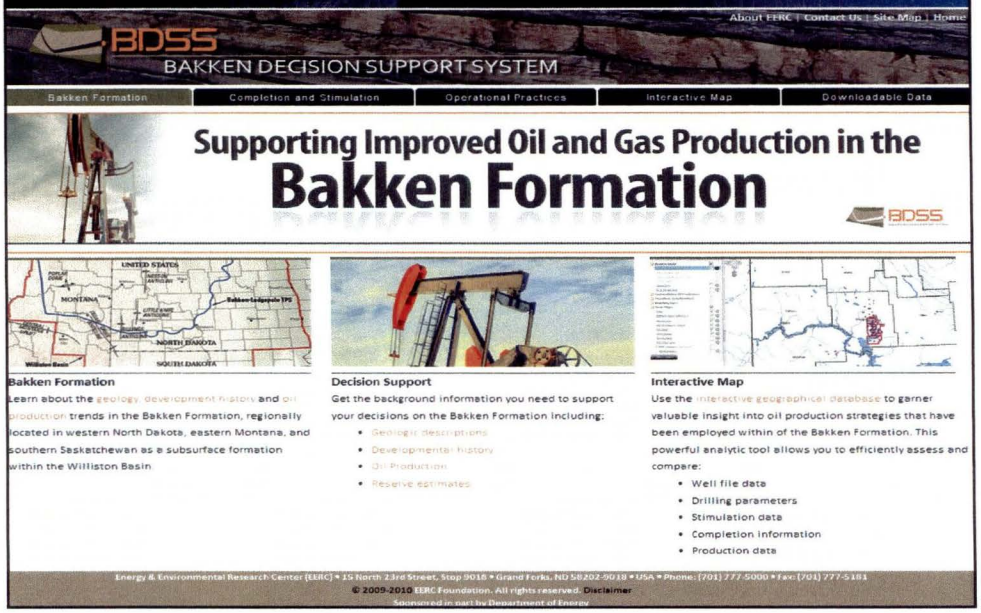
Dissemination of Key Results



Accomplishments to Date

- Working with the Bakken technical teams of Marathon and TAQA North to obtain relevant historical lab and field data.
- Working with Marathon and TAQA North to obtain fresh oil samples for planned lab activities.
- Working with Marathon, TAQA North, and North Dakota Geological Survey to obtain core plug samples.
- Identifying oil properties data that already exist with Marathon and TAQA.
- Working with Marathon and TAQA to acquire relevant reservoir fluid samples.
- Finalizing design of EERC laboratory apparatus for MMP work.

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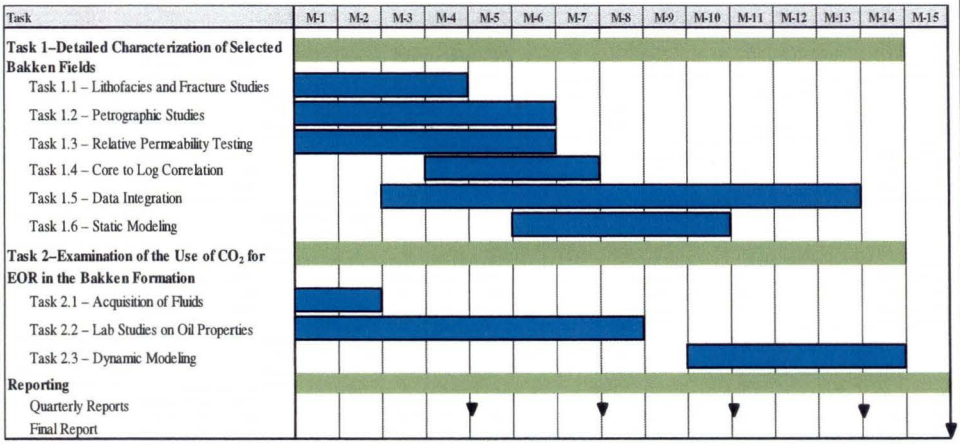
Project Timetable



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