EERC
Energy & Environmental Research Center
UNIVERSITY OF NORTH DAKOTA
15 North 23rd Street — Stop 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181
Web Site: www.undeerc.org

November 1, 2011

Ms. Karlene Fine
North Dakota Industrial Commission
ATTN: Oil and Gas Research Program
State Capitol – Fourteenth Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: EERC Proposal No. 2012-0083 Entitled "CO_2 – Enhanced Bakken Research Program" in Response to the North Dakota Industrial Commission Oil and Gas Research Program Solicitation

The Energy & Environmental Research Center (EERC) is pleased to propose a research program designed to encourage and promote the use of new technologies that have a positive economic and environmental impact on oil and gas exploration and production in North Dakota.

Enclosed please find an original and one copy of the subject proposal along with a check for $100. The EERC, a research organization within the University of North Dakota, an institution of higher education within the state of North Dakota, is not a taxable entity; therefore, it has no tax liability.

This transmittal letter represents a binding commitment by the EERC to complete the project described in this proposal. If you have any questions, please contact me by telephone at (701) 777-5287, by fax at (701) 777-5181, or by e-mail at jsorensen@undeerc.org.

Sincerely,

James A. Sorensen
Senior Research Manager

Dr. Gerald H. Groenewold, Director
Energy & Environmental Research Center

JAS/bjr

Enclosures

Oil and Gas Research Program

North Dakota

Industrial Commission

Application

Project Title: CO_2 – Enhanced Bakken Recovery Research Program

Applicant: Energy & Environmental Research Center

Principal Investigator: James A. Sorensen

Date of Application: November 1, 2011

Amount of Request: $450,000

Total Amount of Proposed Project: $1,350,000

Duration of Project: 15 months

Point of Contact (POC): John A. Harju

POC Telephone: (701) 777-5157

POC E-Mail Address: jharju@undeerc.org

POC Address: 15 North 23rd Street, Stop 9018, Grand Forks, ND 58202

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ABSTRACT

Objective:

Total oil in place estimates for the Bakken Formation range from a minimum of 32 billion barrels (Bbbl) to over 400 Bbbl. Most estimates for primary recovery range from 3% to 5%. With such low primary recovery factors and such a large resource, small improvements in productivity could increase North Dakota's technically recoverable oil by billions of barrels. The Energy & Environmental Research Center (EERC) proposes a research program to evaluate the use of CO_2 to increase the ultimate recovery of Bakken oil. The objective is to use new and existing reservoir characterization and laboratory data integrated with reservoir modeling to determine the viability of CO_2 for enhanced oil recovery (EOR) in the Bakken Formation. The ultimate goal of the project is to generate previously unavailable knowledge enabling informed decisions by operators regarding the use of CO_2 for EOR in the Bakken Formation.

Expected Results:

The results of the proposed work will provide insight regarding relationships between Bakken oil, key reservoir attributes, and CO_2 under reservoir conditions toward the effecient use of CO_2 for EOR.

Duration:

The duration of the proposed project will be 15 months (February 1, 2012, to April 30, 2013).

Total Project Cost:

The total cost of the project is $1,350,000. The amount requested from the Oil and Gas Research Council (OGRC) is $450,000. Cofunding in the form of cash will be provided as follows: U.S. Department of Energy (DOE) = $450,000, and combination of cash and in-kind cofunding totaling *at least* $450,000 from a consortium of Bakken producers, including Marathon Oil Company, Denbury Resources Inc., and TAQA North Ltd.

Participants:

Participants include the EERC, DOE, and to date Marathon Oil Company, Denbury Resources Inc., and TAQA North Ltd.

PROJECT DESCRIPTION

Objectives:

Total oil in place reserve estimates for the Bakken Formation range from a minimum of 32 billion barrels (Bbbl) to over 400 Bbbl. Most estimates for primary recovery range from approximately 3% to 5% (LeFever and Helms, 2008). With such low primary recovery factors associated with this massive resource, even small improvements in productivity will add billions of barrels to the recoverable resource. The Energy & Environmental Research Center (EERC) intends to evaluate strategies for improving the ultimate recovery of oil from the Bakken petroleum system. Specifically, the objective of the proposed project is to use new and existing reservoir characterization and laboratory analytical data (e.g., core analyses, well logs, oil analyses, etc.) and state-of-the-art modeling to determine the viability of using CO_2 for enhanced oil recovery (EOR) in the Bakken Formation. The ultimate goal of the proposed project is to generate previously unavailable data and technical insight that will enable operators to make informed decisions regarding the use of CO_2-based technologies for Bakken EOR. If positive results are achieved, then the application of those results can have a significant positive effect on the ultimate recovery of oil from North Dakota's vast Bakken resources.

Methodology:

To achieve the objectives of the project, the EERC will form a consortium with initial members Marathon Oil Company, Denbury Resources Inc., TAQA North Ltd., the North Dakota Oil and Gas Research Council (OGRC), and the U.S. Department of Energy (DOE). Letters of support received as of the date of submission are provided in Appendix A. Additional members will be solicited over the next 30–60 days. The EERC, in close cooperation with its operating partners, will conduct a suite of activities to evaluate the petrophysical characteristics and reservoir fluids of selected Bakken reservoirs with respect to their interaction with CO_2. References cited in this proposal are presented in Appendix B. The activities will be organized within two tasks, as follows.

Task 1 – Detailed Characterization of Selected Bakken Fields. Detailed knowledge of reservoir properties (e.g., lithology, total organic carbon [TOC], water saturation, mineralogy, natural fractures, shale thickness, etc.) can be used to identify and exploit relationships between those properties and productivity (Sorensen and others, 2010). For example, the relationship between water saturation and production may help identify areas amenable to CO_2 EOR. Figure 1 shows the results of previous EERC work to examine that relationship. Similarly, data describing reservoir fluid and rock properties for a given location are crucial for predicting the effectiveness of any EOR scheme (Klins, 1984). Task 1 will focus on characterizing a minimum of three Bakken study pools (as determined by the participating operators) from the perspective of EOR. The concept of the project is to evaluate potential CO_2 EOR schemes in at least two different Bakken system regimes: 1) thermally immature, structurally controlled reservoirs such as those that occur in the northern-tier counties of North Dakota and 2) reservoirs in the thermally mature portion of the Bakken near the center of the basin. Table 1 summarizes the key activities to be conducted under Task 1.

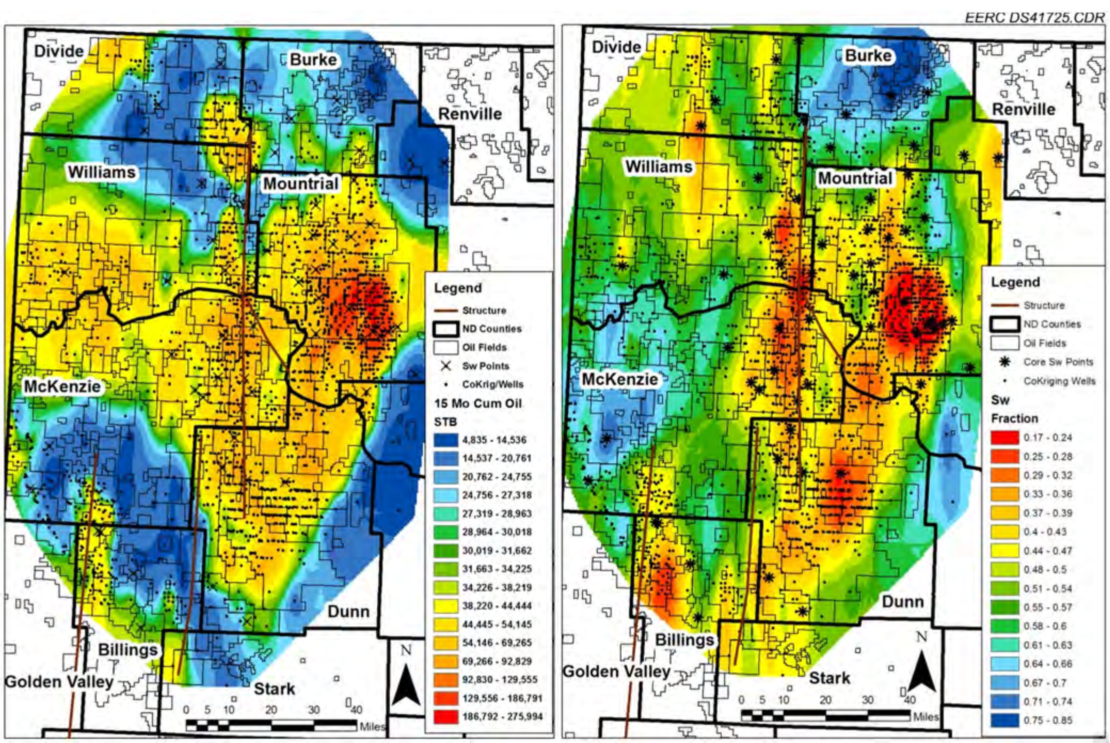


Figure 1. 15-month cumulative oil production (left) compared to water saturation (right).

Table 1 – Summary of Task 1 Activities and the Anticipated Resulting Data Sets

Task 1 Activities	Resulting Data Sets
Core-Based Lithofacies and Fracture Studies (descriptive, nondestructive evaluations of up to 10 wells per study pool)	o Detailed measurements and descriptions of macroscopic attributes (e.g., depositional and postdepositional features, fossils, fractures, etc.) of slabbed core samples. o Classification of lithofacies based on depositional environments.
Core-Based Petrographic Studies (three to five wells per study pool, with three to five thin sections per well to cover the key lithofacies)	o Detailed descriptions of mineral assemblages, rock fabric, fossils, and microstructure (including microfractures) through the use of standard optical techniques. o Verification and validation of mineral assemblages using X-ray diffraction (XRD) and/or scanning electron microscopy (SEM) analytical techniques.
Relative Permeability Testing of Core (maximum three per study pool)	o Generation of CO_2/water/oil relative permeability curves for a selected zone of the reservoir.
Comparison of Core to Well Log Data	o Correlation of log responses to key petrophysical attributes.
Integration of New Core/Log Data with Previously Generated Data Sets	o Application of geomechanical, mineralogical, and other data generated by previous EERC research activities toward the evaluation of the selected fields.
Static Geological Model Development (two to three fields will be selected)	o Creation of isopach maps and cross sections of key lithofacies. o Creation of a 3-D static model of the field or area of interest.

Task 2 – Examination of the Use of CO_2 for EOR in the Bakken. The challenges of EOR within the Bakken have to do with the mobility of traditional fluids (i.e., reservoir fluids and injected water vs. CO_2, polymers, or surfactants) through natural or induced fractures relative to very low matrix permeability, and the aversion of exposing swelling clays to water, which can reduce permeability and damage the formation. Further, the oil-wet nature of much of the Bakken system will dramatically minimize the effectiveness and utility of water flooding. With these issues in mind, the use of CO_2 as a fluid for EOR in the Bakken may be effective. To predict the performance of CO_2 EOR in the Bakken, the EERC will conduct a suite of experimental and modeling activities to help quantify phase behavior and fluid properties under reservoir conditions. The data generated by Task 2 activities will be integrated with data and static models generated in Task 1 to conduct dynamic simulation modeling for at least two Bakken reservoirs. Table 2 summarizes the activities to be conducted under Task 2.

Anticipated Results:

While the use of CO_2 in conventional reservoirs is a widely applied and well understood practice (Jarrell and others, 2002), its use for EOR in tight oil reservoirs is a relatively new concept. In conventional

Table 2 – Summary of Task 2 Activities and the Anticipated Resulting Data Sets

Task 2 Activities	Resulting Experimental Materials and/or Data Sets
Acquisition of Reservoir Fluids (to be provided by operators)	o Crude oil samples from the selected study pools for use in analytical and experimental activities.
Laboratory Determination of Key Bakken Oil Properties Relevant to CO_2-Based EOR	o Standard fluid properties, including formation volume factor for gas and oil, viscosity for gas and oil, and solution gas-to-oil ratio (GOR) o Oil composition o API (American Petroleum Institute) gravity o Thermodynamic minimum miscibility pressure (MMP) o Crude oil swelling o Crude oil viscosity reduction o Single- and multiple-contact phase volumes
Dynamic Modeling	o Phase equilibrium modeling of the reservoir fluid/CO_2 system under relevant conditions. o Core scale simulations based on Task 1 and 2 data.

reservoirs, vertical heterogeneity and relative permeability characteristics can have a significant effect on the effectiveness of an EOR scheme, and fracture networks are considered to be detrimental to EOR operations (Jarrell and others, 2002). In tight oil reservoirs such as the Bakken, which rely on a sustained fracture network for the bulk of their productivity, the conventional notions of positive and negative attributes may or may not apply. The results of the proposed work will provide insight regarding the relationships of the Bakken system and injected CO_2 under reservoir conditions.

The Bakken Formation comprises a series of complex lithofacies with variable distribution and properties. Vertical heterogeneity in the Bakken is directly tied to the occurrence and nature of those lithofacies. Understanding the presence and nature of fractures within and across the various lithofacies is also critical to developing an accurate model of a Bakken reservoir and predicting the effectiveness of CO_2 injection for EOR. Detailed descriptions of core will allow for the identification and quantification of facies and fracture distribution within a given area. Petrographic analyses of rock thin sections will help to improve the basic understanding of the petrographic properties that contribute to the productivity of a reservoir. The knowledge gained from studies of lithofacies and attendant petrographic properties will provide guidance in the assessment of reservoirs with respect to the application of CO_2-based EOR techniques, particularly when applied to the development of static geologic models.

The proposed activities will yield data such as MMP, oil swelling and viscosity reduction, and single- and multiple-contact phase volumes. These will be generated by applying standard pressure–volume–temperature (PVT) studies and the vanishing interfacial tension (VIT) technique to Bakken oil samples. Because understanding the pressure regime of a reservoir is a critical component in predicting the effectiveness of CO_2 for EOR, and areas of the Bakken are known to be overpressured (Meissner, 1978), the EERC will also mine publicly available well files and other data sources to develop detailed maps of the pressure regime within the Bakken system. Taken as a whole, the data generated will provide the critical information necessary to evaluate the viability of CO_2 for EOR in the Bakken Formation.

Facilities:

Testing will be conducted at the EERC's Applied Geology Laboratory (AGL), Natural Materials Analytical Research Laboratory (NMARL), and Analytical Research Laboratory (ARL). The AGL conducts geomechanical, petrographic, geochemical, and customized core sample-related experiments designed to solve targeted problems in the oil and gas industry. The NMARL includes XRD, x-ray fluorescence (XRF) and SEM systems. The ARL conducts wet-chemistry and advanced trace elemental analyses. The EERC's experienced staff encompass the geology, chemistry, physics, and engineering disciplines. These laboratories have decades of experience and have been instrumental in conducting a broad range of research to support previous Bakken research activities and reservoir condition experimental work in support of the EERC's Plains CO_2 Reduction (PCOR) Partnership Program.

Resources:

The project team includes personnel from the EERC. Cost share committed to date for the project will be provided by Marathon Oil Company, Denbury Resources Inc., TAQA North Ltd., and DOE through its Cooperative Research and Development Partnership Program with the EERC. The proposed methodology has been designed to achieve the project objectives while allowing the flexibility to perform research and analysis-based findings that could influence the scope of laboratory testing and modeling. The project team will work closely with OGRC and other project partners through project meetings and quarterly reporting to ensure project quality and timeliness. The educational contribution of the project will be fulfilled by a number of conference presentations and publications, including for the Society of Petroleum Engineers (SPE), for the Williston Basin Petroleum Conference, and public reporting to DOE and OGRC.

Techniques to Be Used, Their Availability and Capability:

Core-based lithofacies and fracture studies will be conducted on slabbed core samples that are readily available for examination at the North Dakota Geological Survey Core Library (NDGS-CL) in Grand Forks. All core-based analytical activities (including petrographic studies and relative permeability testing) will be conducted at the EERC. Specifically, the EERC will use currently available thin-section manufacturing equipment, optical microscopes, relative permeability testing equipment, and XRD and SEM systems (see Appendix C for detailed description of relevant EERC capabilities).

The EERC will experimentally determine MMP for recombined live oil with 99.9% pure CO_2 at reservoir temperature using the VIT technique according to the methods described by Saini and Rao (2010), provided in Appendix D. Recombined live oil for the MMP testing will be generated by an experienced commercial laboratory using Bakken oil samples. The VIT technique relies on the measurements of gas/oil interfacial tension (IFT) at several pressures and reservoir temperature. A high-pressure, high-temperature optical cell (HPHTOC) apparatus will be used to perform the VIT technique. The EERC will fabricate a HPHTOC apparatus for the purpose of this project.

Static and dynamic modeling activities will be conducted using industry standard software. The modeling activities will be conducted on computer hardware currently existing at the EERC. Modeling hardware at the EERC includes a high-performance computer cluster that is designed and dedicated to serve the needs of advanced reservoir modeling and simulations.

Environmental and Economic Impacts while Project Is Under Way:

No significant environmental or economic impacts are anticipated as a result of these activities.

Ultimate Technological and Economic Impacts:

The North Dakota Department of Mineral Resources estimates that original oil in place (OOIP) for the Bakken petroleum system (including the Three Forks) is approximately 170 Bbbl. If the application of CO_2 for EOR could improve the recovery factor by a modest 1.1%, that improvement in recovery would translate to an additional 1.87 Bbbl of oil production from the Bakken/Three Forks. Assuming an average oil price of $80/bbl, this would equate to approximately $150 billion worth of oil.

Why the Project Is Needed:

While the facts of current productivity in the Bakken system are bullish and appear sustainable for at least the coming decade, maximizing the productivity of the Bakken system and prolonging the productive life of the play are essential to maintaining long-term economic growth of the oil industry in North Dakota. Already in Montana, the prolific production fields of Elm Coulee are rapidly approaching bubble point. In essence, without a qualified EOR strategy, the bountiful oil resource of the Bakken system will not be fully realized. The tight, unconventional nature of the Bakken system requires innovative approaches to EOR, and the proposed research activities are necessary to expand the critical knowledge base regarding the potential use of CO_2. The results of the project will provide industry and the state of North Dakota with a foundation for developing a pathway to efficiently and economically improve Bakken oil recovery.

STANDARDS OF SUCCESS

Success will be measured according to the timely achievement of project milestones and development of deliverables that meet the goals of the project. The value to North Dakota is improved understanding of the Bakken with respect to future EOR and potentially improved oil production from the Bakken. Results may directly influence industry practices and lead to improved oil recovery, with a potential of over 1 Bbbl of incremental recovery. It has been estimated that a 10-to-20 year life span for the Bakken play in North Dakota will equate to 3000 to 3500 long-term jobs (Helms, 2010). Successful development of EOR technologies for the Bakken play would extend the life span of those jobs for at least another decade. Commercial use of the project's results will rely not only on the nature of those results, but also on the availability of commercial CO_2. While current CO_2 supplies in the Williston Basin are limited, projects to bring additional CO_2 to the EOR marketplace are in various stages of development, with the Boundary Dam power plant in southeastern Saskatchewan scheduled to begin capturing over 1 million tons/year of CO_2 in 2013. Success of the project will also be based on the development of previously unavailable data sets and production of technical documents for public dissemination. The EERC will produce high-quality publications to be downloadable from the OGRC Web site and technical publications peer-reviewed by organizations such as SPE targeted to the oil and gas audience.

BACKGROUND/QUALIFICATIONS

Resumes of key personnel are provided in Appendix D. James Sorensen, EERC Senior Research Manager, will be the project manager and a co-principal investigator (PI) on the project. Darren Schmidt, EERC Senior Research Advisor and Professional Engineer, will serve as the other co-PI. Other key personnel include Charles Gorecki (Senior Research Manager, static and dynamic modeling leader), Steven Smith (Research Manager, leader of the EERC AGL), Dr. Dayanand Saini (Research Engineer, MMP testing leader) and John Harju (EERC Associate Director for Research).

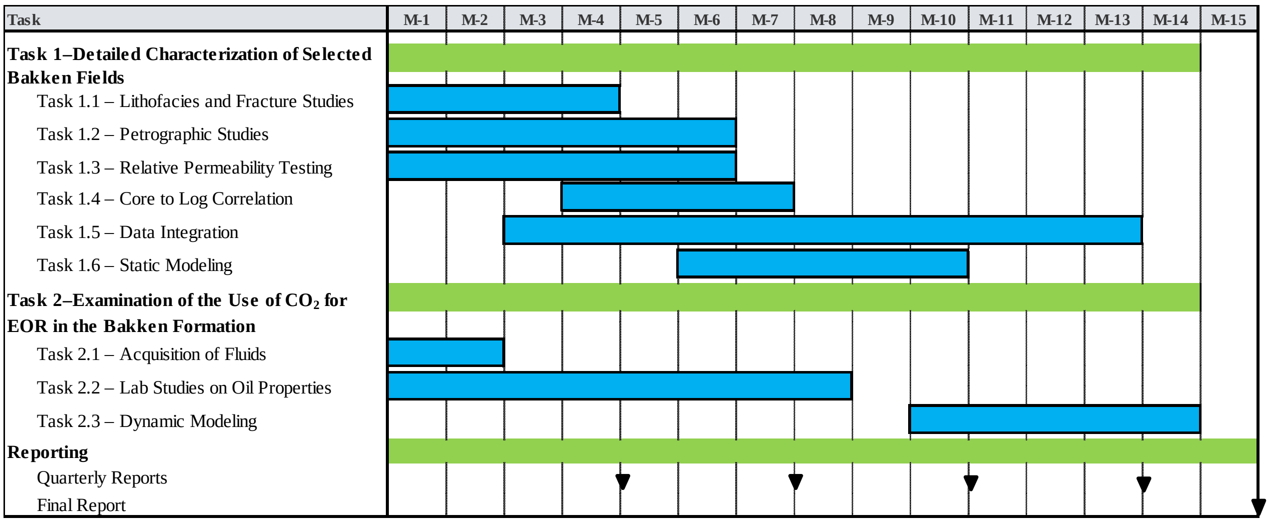
The EERC is a high-tech, nonprofit branch of the University of North Dakota (UND). The EERC operates like a business; conducts research, development, demonstration, and commercialization activities; and is dedicated to moving promising technologies out of the laboratory and into the commercial marketplace. The EERC's oil and gas experience is housed within its Center for Oil and Gas and the PCOR Partnership. The Center for Oil and Gas is a specialized technical group at the EERC focusing on design and implementation of new approaches to the exploration, development, and production of oil and gas. Practicing under the long-standing EERC philosophy of collaboration and an interdisciplinary approach, the group's success is based on developing effective partnerships with the oil and gas exploration and production industry and government agencies. The projects conducted in the past include studies focused on the Powder River, Denver–Julesburg, Williston, and Alberta Basins.

Since 2008, the EERC has conducted a series of multidisciplinary research projects, funded at a level of more than $1 million by DOE, to identify key attributes of successful Bakken wells and provide technically based guidance to stakeholders regarding future exploitation efforts. The EERC's Bakken Research Program has integrated field- and laboratory-based data sets to evaluate and compare key attributes of the Bakken play in North Dakota. The four primary topic areas upon which the research program focused are geology, geochemistry, geomechanics, and engineering. The Bakken Program included the development of a Web-based geographic information system (GIS) database of well drilling, completion, stimulation, and production statistics. A variety of laboratory-generated data on the mineralogical, geochemical, and geomechanical properties of samples from over 80 locations and several of the most widely used proppant materials were also generated and applied to the evaluations. The results of the program have been published in two final reports to DOE (Sorensen and others, 2010 and Schmidt and others, 2011) and an SPE peer-reviewed paper (Bremer and others, 2010).

MANAGEMENT

The EERC manages on the order of 300 contracts annually with 1170 clients in 51 countries and all 50 states. Best practices and dedicated professional staff are provided to EERC project managers and clients in regard to fund accounting, budget reporting, contract milestone tracking, and contract services. The deliverables of this proposal will be incorporated into a contractual agreement ensuring timely delivery of milestones and fund management on a cost-reimbursable basis. Progress reports will be prepared on a quarterly basis and will serve as a means of evaluating the project with respect to budget, schedule, and technical achievement. The evaluation points are identified in the following Gantt chart.

TIMETABLE



BUDGET

Project Associated Expense	NDIC's Share	EERC DOE Share	Industry Sponsor's Share	Total Project
Labor	$ 404,669	$ 289,346	$ 358,400	$ 1,052,415
Travel	$ 2,820	$ 10,125	$ 10,883	$ 23,828
Equipment > $5000	$ -	$ 114,000	$ -	$ 114,000
Supplies	$ 15,000	$ 5,250	$ 10,400	$ 30,650
Communication	$ 356	$ 353	$ 445	$ 1,154
Printing & Duplicating	$ 1,050	$ 429	$ 800	$ 2,279
Food- Partner Meetings	$ 750	$ 300	$ 800	$ 1,850
Natural Materials Research Lab	$ 19,356	$ 6,452	$ -	$ 25,808
GC/MS Lab	$ -	$ 8,034	$ 64,272	$ 72,306
Graphics Support	$ 5,999	$ 2,856	$ 4,000	$ 12,855
Research Information Systems	$ -	$ 12,855	$ -	$ 12,855
Total Project Cost	$ 450,000	$ 450,000	$ 450,000	$ 1,350,000

The total cost of the project is $1,350,000. The amount requested from the OGRC is $450,000. Cofunding in the form of cash will be provided as follows: DOE = $450,000, and combination of cash and in-kind cofunding totaling *at least* $450,000 from a consortium of Bakken producers, including Marathon Oil Company, Denbury Resources Inc., and TAQA North Ltd. Further budget justification can be found in Appendix F.

The labor and analytical expenses associated with Task 1, the modeling expenses associated with Task 2, and expenses associated with overall project management and reporting are based on EERC experiences in conducting similar projects, including the EERC's Bakken Research Program. The Task 2 activities using the HPHTOC apparatus will require the fabrication and operation of that apparatus. Expenses associated with the fabrication of the apparatus and operation are based on EERC experience in developing similar systems for experimental work conducted under the PCOR Partnership and Dr. Dayanand Saini in conducting MMP testing as part of his Ph.D. work at Louisiana State University. If the requested amount of funding is not available, then the project's objectives will be unattainable because project success is directly tied to the integration of the various technical activities.

CONFIDENTIAL INFORMATION

There is no confidential information.

PATENTS/RIGHTS TO TECHNICAL DATA

Patents or rights do not apply to this proposal.

STATUS OF ONGOING PROJECTS (IF ANY)

The EERC has previously been awarded OGRC funding for four different projects. Projects that have been funded include the PCOR Partnership, an assessment of Bakken water opportunities, and investigations to improve proppant applications. The status of those projects is presented in Appendix G.

APPENDIX A

LETTERS OF SUPPORT

EERC
Energy & Environmental Research Center
UNIVERSITY OF NORTH DAKOTA
15 North 23rd Street — Stop 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181
Web Site: www.undeerc.org

November 1, 2011

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Cost Share for EERC Proposal No 2012-0083 Entitled "CO_2-Enhanced Bakken Recovery Research Program"

The Energy & Environmental Research Center (EERC) is conducting complementary research and development efforts under a multimillion-dollar 5-year Cooperative Agreement with the U.S. Department of Energy (DOE) entitled "Joint Program on Research and Development for Fossil Energy-Related Resources." Through this joint program, nonfederal entities can team with the EERC and DOE in projects that address the goals and objectives of the DOE's Office of Fossil Energy.

The proposed project to the North Dakota Industrial Commission (NDIC) Oil and Gas Research Council entitled "CO_2-Enhanced Bakken Recovery Research Program" is a viable candidate for funding under this program. Therefore, the EERC intends to secure $450,000 of cash cost share for the proposed project thorough its Cooperative Agreement with DOE providing NDIC commits $450,000 cash cost share and $450,000 is secured from various oil producers.

Once the EERC has commitment from all nonfederal partners to the project, the EERC will submit a proposal to DOE for its concurrence. Initiation of the proposed work is contingent upon the execution of a mutually negotiated agreement or modification to an existing agreement between the EERC and each of the project sponsors.

If you have any questions, please contact me by phone at (701) 777-5157 or by e-mail at jharju@undeerc.org.

Sincerely,

John A. Harju
Associate Director for Research

JAH/bjr

Russ Buettner
Bakken Asset Subsurface Manager

Marathon Oil Company
5555 San Felipe
Houston, TX 77056
Telephone 713.296.3621
Mobile 713.408.2554
rbuettner@marathonoil.com

Marathon Oil

October 27, 2011

Mr. John A. Harju
Associate Director for Research
Energy & Environmental Research Center
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Dear John:

Marathon Oil Company (Marathon) is pleased to enumerate its intent to provide $50,000 cash funding to support the Energy & Environmental Research Center's (EERC's) proposed effort entitled "CO_2 – Enhanced Bakken Recovery Research Program." Additionally, Marathon will provide in-kind support, the value of which will be enumerated in conjunction with the contributions of the other project stakeholders. We understand that the EERC is seeking the support of the North Dakota Industrial Commission's Oil & Gas Research Council (NDIC-OGRC), the U.S. Department of Energy (DOE), and two additional oil and gas producers with assets in North Dakota's Williston Basin. We are confident that the proposed effort will greatly expand the critical knowledge base regarding the Bakken Formation and, in turn, its EOR potential. The concept focuses on developing a pathway to efficiently and economically improve Bakken and Three Forks hydrocarbon recovery in an environmentally sustainable manner.

Marathon's in-kind contribution will likely include the provision of well logs, specific geologic characterization data, oil and/or core samples, and attendant production data. Contingent on Marathon's Upstream Technology and Asset Management approval, in-kind contribution will also include selected results of Marathon's internal Bakken EOR research. Specific details regarding Marathon's in-kind contribution will be developed in conjunction with the EERC project team and the other in-kind providers toward maximization of the project objectives.

Marathon's commitment is, of course, contingent on the EERC's attainment of the necessary funding from NDIC-OGRC and DOE, along with the other two oil and gas producers, and the negotiation of attendant agreements that are acceptable to all key parties. Please do not hesitate to contact me if you need further clarification or would like to discuss this effort further.

Sincerely,

Russell Buettner
Marathon Oil Company
Bakken Asset-Subsurface Manager

Denbury

October 27, 2011

Mr. John A. Harju
Associate Director for Research
Energy & Environmental Research Center
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Dear John:

Denbury Onshore, LLC (Denbury) is considerinig to provide some cash funding to support the Energy & Environmental Research Center's (EERC's) proposed effort entitled "CO_2 – Enhanced Bakken Recovery Research Program". If Denbury participates, Denbury will provide in-kind support, the value of which will be enumerated in conjunction with the contributions of the other project stakeholders. We understand that the EERC is seeking the support of the North Dakota Industrial Commission's Oil & Gas Research Council (NDIC-OGRC), the U.S. Department of Energy (DOE), and two additional oil and gas producers with assets in North Dakota's Williston Basin. We are confident that the proposed effort will greatly expand the critical knowledge base regarding the Bakken Formation and, in turn, its EOR potential. The concept focuses on developing a pathway to efficiently and economically improve Bakken and Three Forks hydrocarbon recovery in an environmentally sustainable manner.

Regardless of funding level, Denbury is willing to contribute in information, including well logs, specific geologic characterization data, oil and/or core samples, and attendant production data. Specific details regarding Denbury's in-kind contribution will be developed in conjunction with the EERC project team and the other in-kind providers toward maximization of the project objectives.

Denbury's commitment is, of course, contingent on the EERC's attainment of the necessary funding from NDIC-OGRC and DOE, along with the other oil and gas producers, and the negotiation of attendant agreements that are acceptable to all key parties. Please do not hesitate to contact me if you need further clarification or would like to discuss this effort further.

Sincerely,

Robert L Cornelius

Robert Cornelius
Senior Vice President, CO_2 Operations

TAQA NORTH Ltd.
www.taqaglobal.com

October 27, 2011

Mr. John A. Harju
Associate Director for Research
Energy & Environmental Research Center
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Dear John:

TAQA North, Ltd. (TAQA), is pleased to enumerate its intent to provide $150,000 cash funding to support the Energy & Environmental Research Center's (EERC's) proposed effort entitled "CO_2 – Enhanced Bakken Recovery Research Program." Additionally, TAQA will provide in-kind support, the value of which will be enumerated in conjunction with the contributions of the other project stakeholders. We understand that the EERC is seeking the support of the North Dakota Industrial Commission's Oil & Gas Research Council (NDIC-OGRC), the U.S. Department of Energy (DOE), and two additional oil and gas producers with assets in North Dakota's Williston Basin. We are confident that the proposed effort will greatly expand the critical knowledge base regarding the Bakken Formation and, in turn, its EOR potential. The concept focuses on developing a pathway to efficiently and economically improve Bakken and Three Forks hydrocarbon recovery in an environmentally sustainable manner.

TAQA's in-kind contribution will likely include the provision of well logs, specific geologic characterization data, oil and/or core samples, and attendant production data. Specific details regarding TAQA's in-kind contribution will be developed in conjunction with the EERC project team and the other in-kind providers toward maximization of the project objectives.

TAQA's commitment is, of course, contingent on the EERC's attainment of the necessary funding from NDIC-OGRC and DOE, along with the other two oil and gas producers, and the negotiation of attendant agreements that are acceptable to all key parties. Please do not hesitate to contact me if you need further clarification or would like to discuss this effort further.

Sincerely,

Peter Harrington,
Development Manager, Saskatchewan/US
TAQA North

cc. William D. Barnhart, Research Manager/Engineer, Williston Basin Development

P.O. Box 2350, Stn M Calgary, AB Canada T2P 2M6 Tel 403 724-5000 Fax 403 724-5001
2100 308 4th Ave SW Calgary AB Canada T2P 0H7 www.taqaglobal.com

EERC
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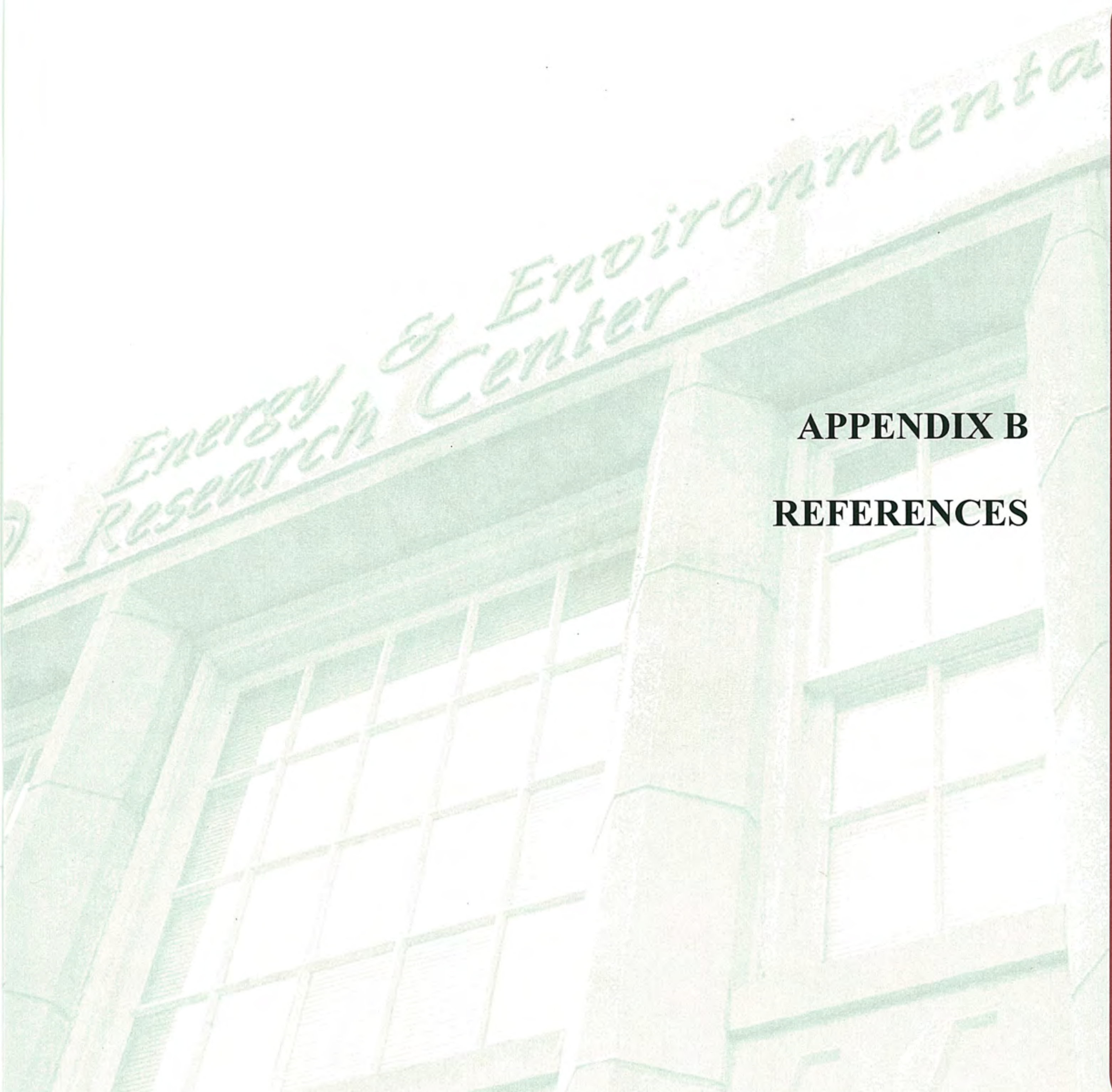

APPENDIX B

REFERENCES

REFERENCES

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APPENDIX C

RELEVANT EERC LABORATORY CAPABILITIES

RELEVANT EERC LABORATORY CAPABILITIES

Applied Geology Laboratory

- Full preparation laboratory, including slab saw, core drills, micronizing mill, and thin-section mill
- Petrographic microscopes utilizing plane- and cross-polarized transmitted light
- Nanovea PS 50 optical profilometer
- Forney 20+-ton universal compression frame
- Trautwein-Geotac flexible wall permeameter
- Hoek-style triaxial and core-flood cells
- Teledyne Isco high-pressure fluid pumps
- Gas porosimeter/pycnometer
- Terraplus RS125 supergamma spectrometer
- Dead weight consolidation frames
- Thermal dilatometer
- Ion chromatograph
- Distillation, saturation, and chemistry equipment

Natural Materials Analytical Research Laboratory

- 4200-square-foot laboratory facility
- JEOL 5800 scanning electron microscope with NORAN instruments energy-dispersive spectrometer (EDS) detector system, GW Electronics enhanced backscatter detector, and NORAN instruments microanalysis system
- JEOL 5800 LV with Princeton Gamma-Tech Spirit Instruments EDS and microanalysis system and a HKL Technology electron backscatter diffraction system.
- QEMSCAN®
- Rigaku ZSK Primus II x-ray fluorescence system
- Bruker AXS D8 advanced x-ray diffraction system

Analytical Research Laboratory

- 4200-square-foot, fully equipped, exceedingly clean laboratory with seven fume hoods
- VG PQ ExCell inductively coupled plasma–mass spectrometer (ICP–MS) with collision cell technology
- PS Analytical Millennium Merlin cold-vapor atomic fluorescence spectrometer (CVAFS)
- PS Analytical Millennium Excalibur hydride generation atomic fluorescence spectrometer (HGAFS)
- Varian Spectra AA-880Z graphite furnace atomic absorption spectrometer (GFAAS)
- Mitsubishi TOX-100 chlorine analyzer with oxidative hydrolysis microcoulometry
- Perkin Elmer Optima 2100 ICP–AES
- Dionex ISC3000 ion chromatograph (IC) with conductivity detection
- Dionex 2020i IC with UV–VIS, conductivity, and electrochemical detection
- CEM MDS 2100 microwave with temperature and pressure control
- Pyrohydrolysis/ion-specific electrode for fluorine analysis of fossil fuels

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APPENDIX D

SPE 132389 (SAINI AND RAO, 2010)

SPE 132389

Experimental Determination of Minimum Miscibility Pressure (MMP) by Gas/Oil IFT Measurements for a Gas Injection EOR Project

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This paper was prepared for presentation at the Western North America Regional Meeting held in Anaheim, California, USA, 26–30 May 2010.

Abstract

Reliable knowledge of minimum miscibility pressure (MMP) plays a key role in the design and implementation of any miscible gas injection enhanced oil recovery (EOR) project. Various theoretical methods but few experimental methods are available for confidently determining the MMP at reservoir conditions using actual reservoir fluids.

The present experimental study reports on the determination of minimum miscibility pressure (MMP) for recombined live oil with 99.9 % pure CO_2 at reservoir temperature using the vanishing interfacial tension (VIT) technique. VIT technique relies on the measurements of gas/oil interfacial tension (IFT) at several pressures and reservoir temperature. MMP is then obtained by extrapolation of the measured data to zero interfacial tension. In the present study, IFT between two recombined live oil samples and CO_2 was measured at reservoir temperature of 289°F and at several pressures above the bubble point pressure of 2593 psia using the pendant drop method and the capillary rise technique. The pressure was then increased in steps to approach a near zero gas/oil IFT condition. The MMP that corresponds to the pressure of zero IFT was obtained by extrapolating the measured values of gas/oil IFT to zero on IFT versus pressure plot. Such extrapolation yielded MMPs of 3533 psia and 3543 psia for the two recombined live oil samples.

This study was conducted to aid in the implementation of a proposed miscible CO_2 flood in a newly discovered oil field in Mississippi by comparing the results of an independently conducted equation-of-state (EOS) modeling study based on vanishing tie-line method. Measured VIT-MMP was slightly lower (~4%) compared to the EOS-estimated dispersion-free MMP (3685 psia). This experimental study reinforces the use of VIT technique as a robust experimental method for determining the MMP and its possible use to validate the EOS models for using them in compositional simulation studies.

Introduction

The MMP is defined as the lowest pressure at which injection gas stream becomes miscible with the reservoir crude oil to form a single phase through dynamic mass transfer interactions between reservoir crude oil and injected gas. At miscibility condition, capillary forces are eliminated that results in no capillary trapping of oil and consequently higher oil recoveries. To achieve the complete miscibility condition in the reservoir, displacement pressure should be higher than MMP. Hence, accurate knowledge of MMP is vital for designing and implementing any miscible gas injection EOR project.

Both theoretical and experimental approaches have been reported in the petroleum engineering literature to predict and/or measure the MMP. Theoretically, MMP is estimated using analytical methods based on phase equilibrium calculations and numerical methods those rely on the equation of state (EOS) based compositional simulation of a miscible gas flooding process (Johns et al. 1993, Wang and Orr 1997, Jessen et al. 1998, Yuan and Johns 2005). Different correlations (Yellig and Metcalfe 1980, Ghomian et al. 2008) have also been reported in the literature to predict the MMP.

Recently, Mogensen et al. (2009) have provided a quick literature review of various methods to predict MMP. They presented a comparison of various MMP prediction methods for number of synthetic fluid compositions with CO_2 as injection gas. MMP predictions from all the methods were also compared with the measured MMP (slimtube experiments) for actual fluid compositions. Comparison results exhibited a wide spread in the predicted dispersion-free MMP using CO_2 as injection gas. According to their observations, empirical correlations generally over-predicted the MMP for light oils and underestimated the MMP for heavy oils. Various tie-line methods using the same tuned EOS model provided different estimates of the MMP and some of them experienced convergence problems for low API oils. They concluded that no prediction method was able to replace the experimentally measured MMP.

Slimtube experiments offer a simple way to experimentally measure the MMP, but multiple slimtube experiments are time consuming and expensive as well. Another experimental method named VIT technique (Rao, 1997) has been reported in recent literature for rapid and cost effective estimation of MMP. It relies on the measurement of gas/oil IFT at several pressures steps at reservoir temperature and by making a plot of the IFT against the pressure, the minimum miscibility pressure (MMP) was then obtained by extrapolation to zero interfacial tension. At elevated pressure and reservoir temperature, when CO_2 or any injected gas stream comes in contact with reservoir crude oil, IFT between the gas and oil diminishes as the miscibility is approached and the interface between the two eventually disappears at miscibility (Stalkup 1983; Holm 1987) i.e. the IFT becomes zero. Hence, a minimum pressure condition of zero gas/oil IFT at reservoir temperature is the true MMP for any injected gas/live reservoir crude oil system.

Sequeira et al. (2008) successfully used the VIT technique to determine both first-contact miscibility pressure (FCMP) and multiple-contact miscibility pressure for a recombined live oil/CO_2 system. He also demonstrated the compositional independence of VIT-determined equilibrium MMP as well as the ability of VIT technique to characterize the governing mass transfer mechanisms for miscibility development.

Jessen et al. (2008) attempted to simulate the VIT approach assuming that gas/oil IFTs can be calculated with a parachor expression. In their study, no case was presented for which measured IFT data was available. Hence, their comments about the validity of the VIT technique, which is entirely based on "measured" gas/oil IFT, appear to be invalid. For reservoir crude oil/solvent systems, gas/oil IFT computed using conventional parachor models shows a wide variation from measured gas/oil IFT and only shows an agreement with measured gas/oil IFT at 50+50 mole% of solvent and oil (Ayirala et al., 2004).

In the present study, the VIT technique was used to experimentally determine the MMP values for a proposed miscible CO_2 flood by measuring IFT between 99.9 % pure CO_2 and two recombined live reservoir crude oils at reservoir temperature of 289°F. The results of an independently conducted equation-of-state (EOS) modeling study based on vanishing tie-line method (Yuan and Johns, 2005) were also compared with the experimental results.

Description of fluids used

The reservoir crude oil included in the present study was light oil (45.8°API). Two recombined live oil samples (A and B) prepared by a commercial service lab were used for conducting IFT experiments. The reported bubble point pressure for the supplied recombined live oil samples was 2593 psia at the reservoir temperature of 289°F. Other reservoir fluid properties are given in Table 1. Instrument grade CO_2 (99.9 % pure) was used as the gas phase.

Measurement techniques used for determining gas/oil IFT

In the present experimental study, both pendant drop method and capillary rise technique were used to measure the IFT for CO_2/recombined live oil system at reservoir temperature of 289°F and various pressures above the bubble point pressure (2593 psia). A brief description of both the techniques used in the present study is given below.

Pendant drop method

In the pendant drop method, few drops of live crude oil are introduced through a metal capillary tube into the gas filled optical cell and images of pendant drops are captured and analyzed using an image analysis technique to obtain the gas/oil IFT. The commercial image analysis software named drop shape analysis (DSA) was used for determining the IFT for CO_2/recombined live oil system investigated in the present study.

Capillary Rise Technique

When a glass tube of small internal diameter is inserted below the interphase of a two phase system with one of the phases being liquid (denser phase) and the other being gas, the liquid will rise in the capillary glass tube above the height of liquid and will exhibit a concave interface with respect to the denser phase. This rise is due to the attractive force (interfacial tension) between the tube and the liquid and the small weight represented by the column of liquid in the tube. The liquid will rise in the tube until the total force acting to pull the liquid upward is balanced by the weight of the column of liquid being supported in the tube. The equations governing the capillary rise in a circular glass tube are well-known. The force balance in a capillary is given by:

$$2\pi r\gamma\cos\theta = \frac{\pi r^2 h(\rho_l - \rho_v)g}{g_c} \quad \text{.......... (1)}$$

Solving for interfacial tension (γ), gives;

$$\gamma = \frac{rh(\rho_l - \rho_v)g}{2g_c\cos\theta} \quad \text{.......... (2)}$$

Where, γ is the interfacial tension (mN/m) between oil and gas phase, r is the internal radius of capillary tube (cm), h is height of capillary rise (cm), ρ_l and ρ_v are the densities (g/cm^3) of liquid and gas phase respectively, cos θ = equilibrium contact angle in degrees, g is acceleration due to gravity (980 cm/s^2) and g_c is the conversion factor (10^{-5} g.cm/sec^2.N).

Measured density values of both the equilibrated fluid phases and observed capillary rise heights during the experiments were used to determine the gas/oil IFT using Eq. 2. A contact angle of $\theta = 0$ was used during the IFT calculations as it is reasonable to assume that the liquid wet the glass surface completely in the presence of a gas phase. The use of the capillary rise technique at elevated temperatures and pressures to measure gas/oil IFT was successfully demonstrated by Ayirala et al. (2005). Sequeira et al. (2008) reported the measured CO_2/live oil IFT at various pressures and reservoir temperature using this technique. This technique is particularly useful to measure low values of gas/oil IFT, where IFT can not be measured using pendant drop method due to the irregular shapes of pendant oil drops and their disappearance into the gas phase as the miscibility pressure is approached.

Experimental apparatus and procedure

The experimental setup used in the present study consists of a high-pressure high-temperature optical cell, made of Hastelloy, with sapphire glass windows on opposite sides. It has a metal capillary tube made of Hastelloy at the top through which oil drops are allowed to hang as pendant drops within the surrounding gas phase. The optical cell also housed a glass capillary tube of 1.164 mm internal diameter (I.D.) and 2.000 mm outer diameter (O.D.).This glass capillary tube was used to measure low gas/oil IFT using the capillary rise technique. Figure 1 shows the inside of optical cell with Hastelloy capillary tube at top and glass capillary tube held by side arm of the optical cell.

The glass windows allow the capture of drop profile and height of capillary rise using a light source on one side and a camera system on the opposite side. The camera is connected to an image recording system consisting of a video recorder, monitor and a computer equipped with image analysis software (DSA) to analyze the captured pendant drop images. Images of capillary rise were analyzed using a simple digital ruler technique. The optical cell is kept in an insulated enclosure to achieve the desired temperature by circulating the hot air generated by an oven. Desired pressures are achieved through the use of fluid handling system consisting of floating piston type high pressure transfer vessels and high pressure hand pumps.

The optical cell and other wetted parts of the experimental setup were first thoroughly cleaned with toluene and acetone and were dried by blowing nitrogen gas. The cell was first heated to 289°F using the temperature control of the heating oven and later was filled with pure CO_2 gas using the Ruska hand pump to obtain the desired pressure of 2800 psia. This pressure was maintained by adjusting the amount of CO_2 in the optical cell. Then, the recombined live oil from a transfer vessel maintained at the reservoir temperature was injected into the cell to form few pendant oil drops. The images of pendant oil drops were captured and recorded using the image recording system. After forming 5-10 pendant oil drops, an addition amount of recombined live oil was introduced into the cell to see the capillary rise in the glass tube already stationed in the optical cell. An aging period of about an hour was allowed for the fluid phases to equilibrate in the cell. The capillary rise observed in the glass tube was then recorded using the image recording system. The equilibrated liquid and gas phases were allowed to flow through the density meter maintained at desired temperature for density measurements. These measurements were then repeated at each pressure step. After recording the capillary rise, the pressure in the cell was increased by 100 psia by injecting a small amount of gas phase. An approximate gas oil volume ratio of 90:10 was maintained during the experiment. The same measurements were then repeated at increased pressure (2900 psia). This procedure was repeated until no more pendant drops of live oil could be formed and oil drops started to disappear into the gas phase due to pressure approaching the MMP of the system. At this stage, pressure was further increased by 75-100 psia and capillary rise height was then measured. A small capillary rise height at this pressure was the indication that the system had approached its MMP.

Results and discussion

Density measurements of pure CO_2 and recombined live oil samples

Prior to the density measurements of equilibrated oil and gas phases during the IFT experiments, high-pressure high-temperature density meter (Anton Paar DMA HP) was calibrated at 289°F by using instrument grade CO_2 (99.9% pure) and deionized water as standard fluids in the pressure range of 1500 psia to 9500 psia. Then the densities of two recombined live oil samples and 99.9 % pure CO_2 were measured. The measured density values of pure CO_2 and two recombined live oil samples at various pressures are given in Tables 2 and 3, respectively. The measured density values of pure CO_2 were compared with the published (NIST web book) density values of CO_2. The measured live oil density at initial reservoir pressure of 9145 psia was compared against the measured density values reported by the commercial service lab which prepared the recombined live oil samples to use them in the present study. A good agreement between the measured and reported density value at initial reservoir pressure (9145 psia) indicates the satisfactory calibration of the density meter used. The two live oil samples showed a slight difference in their measured density values. The measured density data was then fitted using simple linear regression. A plot of measured densities versus pressure with regression equations for both the live oil samples is shown in Figure 2. The coefficients of determination (R^2) values were above 99.9 % indicating good correlation of data. The regression equations were then used to determine the live oil density at pressures where no measured value was available.

Determination of MMP for CO_2/recombined live oil systems

The measured densities of equilibrated fluid phases, capillary rise heights and IFT values for the CO_2/recombined live oil systems investigated in the present study are given in Tables 4 and 5, respectively. Gas/oil IFT at pressures above 3000 psia could not be measured using the pendant drop method due to irregular shapes of pendant oil drops because of near miscibility condition (Figures 3 and 4). Hence IFT calculated from the capillary rise heights (Figures 5 and 6) was used to make the plots of gas/oil IFT against pressure for determining the MMP for both the CO_2/recombined live oil systems at 289°F. At higher pressures (around 3400 psia), pendant drops started to disappear into the surrounding gas phase and oil streaks were clearly visible (Figures 3 and 4). The small capillary rise height (0.024 cm) at 3500 psia was also an indication of the attainment of near miscibility by the system at 289°F.

The measured IFT for CO_2/recombined live oil (Sample A) and CO_2/recombined live oil (Sample B) systems are plotted against pressure and are shown in Figures 7 and 8, respectively. As evident from the plots, a good linear relationship between IFT and pressure can be seen with R^2 value greater then 97.4 %. The fitted regression lines to the measured data along with the regression equations are also shown in the figures. The extrapolation of these regression lines (IFT versus pressure) to zero IFT gives a VIT MMP of 3533 psia for the recombined live oil (sample A) and a VIT MMP of 3543 psia for the recombined live oil (sample B). The IFT versus pressure data for both the CO_2/recombined live oil systems are compared in Figure 9.

Equation-of-state (EOS) simulation of VIT experiments

CO_2/recombined live oil (Sample B) system exhibited a slightly higher IFT at lower pressures compared to CO_2/recombined live oil (Sample A) system. This slight difference in IFT value may be attributed to the fluctuations in the gas oil volume ratio (GOR) during the experiment for individual system although efforts were made to maintain the GOR approximately at the same level of 90:10. But both systems converged to zero IFT at pressures ranging from 3533 to 3543 psia. This shows that the measured VIT MMP was unaffected by the fluctuation in GOR for a particular gas/oil system. A gradual increase in density of equilibrated gas phase (Tables 4 and 5) indicates the presence of vaporizing drive mechanism in attaining the gas/oil miscibility for this reservoir system. The measured MMP from the VIT technique was lower by 4 % than the dispersion-free MMP estimated for the same system in an independently conducted EOS modeling study (tuned to match black oil property data set with 15 components) based on the vanishing tie line method.

The results of present experimental study strongly refute the conclusions made by Jessen et al. (2008) on IFT measurements to estimate MMP. Jessen et al. (2008) used a version of parachor model described by Schechter and Guo (1998) to calculate the gas/oil IFT for various gas/oil mixtures for which experimental slimtube MMP were available. They computed gas/oil IFT at various pressures for four constant compositions of 20+80, 50+50, 80+20 and 95+5 mol% of solvent and oil, respectively. Then, they performed extrapolation from pressures where the IFT became significantly small (10^{-3} mN/m). Interestingly, in each case reported in their study, only for the 50+50 mol % gas/oil mixtures, the MMP obtained from the extrapolation of conventional parachor model based calculated gas/oil IFT showed an agreement with the experimental slimtube MMP. According to their calculations, estimated MMP from the parachor based model for calculating gas/oil IFT for the mixtures with lagers gas fractions (> 65%) showed significant deviation (in some cases reported errors exceeded by 100%) from the measured slimtube MMP.

The comparison of the results presented in the present experimental study (for gas/oil systems with gas fraction around 90%) with the dispersion-free MMP obtained from an independently conducted EOS modeling study clearly demonstrates the inadequacy of conventional parachor models in predicting measured gas/oil IFT.

Summary

The IFT between two recombined live oil samples prepared from the stock tank oil of a Mississippi oil field and 99.9 % pure CO_2 was measured at reservoir temperature of 289°F and at various pressures above the bubble point pressure of 2593 psia. This measured gas/oil IFT data were used to determine the MMP for the CO_2/recombined live oil system at reservoir temperature of 289°F. A close agreement in the MMP values for both the live oil samples (3533 and 3543 psia) shows the repeatability and accuracy of VIT technique used in the present experimental study. This MMP from the VIT technique is lower by 4 % than the reported MMP of 3685 psia obtained in an independently conducted EOS modeling study of the same system at 289°F.The MMP was computed using black oil properties. To make it more rigorous, the future work should compare the results with the laboratory MMP measurements.

The present experimental study also highlights the necessity of using more robust theoretical models for computing gas/oil IFT.

Acknowledgements

We acknowledge with gratitude the financial support of Tellus Operating Company. The authors thank Chris W. Jones of Tellus Operating Company for his support and encouragement. Authors are also thankful to Anil Chopra, Vineet Marwah and H. Yuan of Petrotel for sharing the results of their modeling work. Any opinions, findings, conclusions or recommendations expressed herein are of the authors and do not necessarily reflect the views of supporting agencies. Help of Abdallah Kadadha with lab equipment is greatly appreciated.

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Table 1. Reservoir fluid properties

Sample Depth	15,061 - 15,132	Ft. MD Perforations
Res. Temperature	289	°F
Res. Pressure	9145	psia @ 289 °F
API Gravity (from SOF)	45.8	°API at 60°F (water free)
Solution gas oil ratio	598.7	Scf/sto
Density @ Res. Press. and temp	0.675	g/cm^3
Viscosity@ Res. Press. and temp	1.47	cP
Sat. Pressure	2593	psia @ 289 °F
Density@ Sat. Press. and temp	0.612	g/cm^3
Viscosity@ Sat. Press. and temp	1.623	cP

Table 2. Density of CO_2 at 289°F

Pressure	Reported density (NIST)	Measured density
psia	gm/cc	gm/cc
2000	0.2196	0.2194
2800	0.3275	0.3333
3000	0.3548	0.3610
3200	0.3810	0.3867
3400	0.4064	0.4138
3800	0.4540	0.4660

Table 3. Density values of recombined live oil samples at 289°F

Pressure	Measured density (Sample A)	Measured density (Sample B)	Reported density (commercial service lab)
psia	gm/cc	gm/cc	gm/cc
2593	0.6258*	0.6160*	0.612
2800	0.6376	0.6292	-
3000	0.6403	0.6319	-
3200	0.6432	0.6347	-
3400	0.6457	0.6374	-
9145	-	0.6899	0.675

* Calculated

Table 4. Summary of fluid phase densities, capillary rise heights and measured IFT for CO_2/recombined live oil (Sample A) system at 289°F

Pressure (psia)	Equilibrated fluid phase density (gm/cc)		capillary rise (cm)	IFT (mN/m)
	Oil	Gas		
2900	0.71708	0.35171	0.207	2.16
3000	0.72200	0.36387	0.157	1.60
3100	0.72340	0.39470	0.139	1.30
3200	0.72555	0.40140	0.125	1.16
3300	0.72610	0.41940	0.075	0.66
3400	0.72671	0.42368	0.065	0.56
3500	0.72730	0.45421	0.024	0.19

Table 5. Summary of fluid phase densities, capillary rise heights and measured IFT for CO_2/ recombined live oil (Sample B) system at 289°F

Pressure (psia)	Equilibrated fluid phase density (gm/cc)		capillary rise (cm)	IFT (mN/m)
	Oil	Gas		
2800	0.7205	0.3355	0.282	3.09
2900	0.7211	0.3517	0.223	2.35
3000	0.7218	0.3639	0.207	2.11
3100	0.7230	0.3947	0.192	1.79
3200	0.7237	0.4014	0.163	1.50
3300	0.7256	0.4194	0.093	0.81
3375	0.7265	0.4204	0.083	0.73

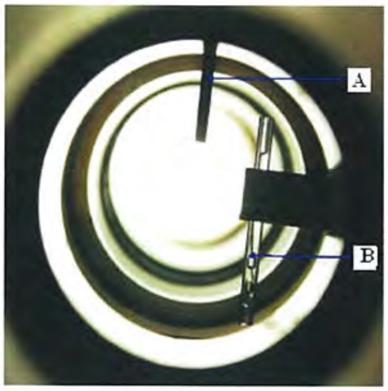


Figure 1. Inside view of High-Pressure High-Temperature Optical Cell (A: Hastelloy capillary tube; B: Glass capillary tube)

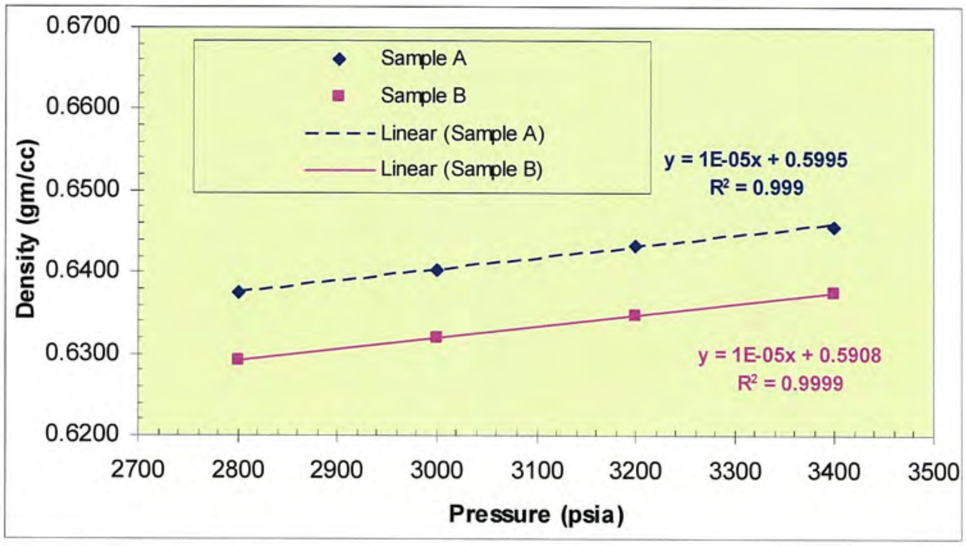
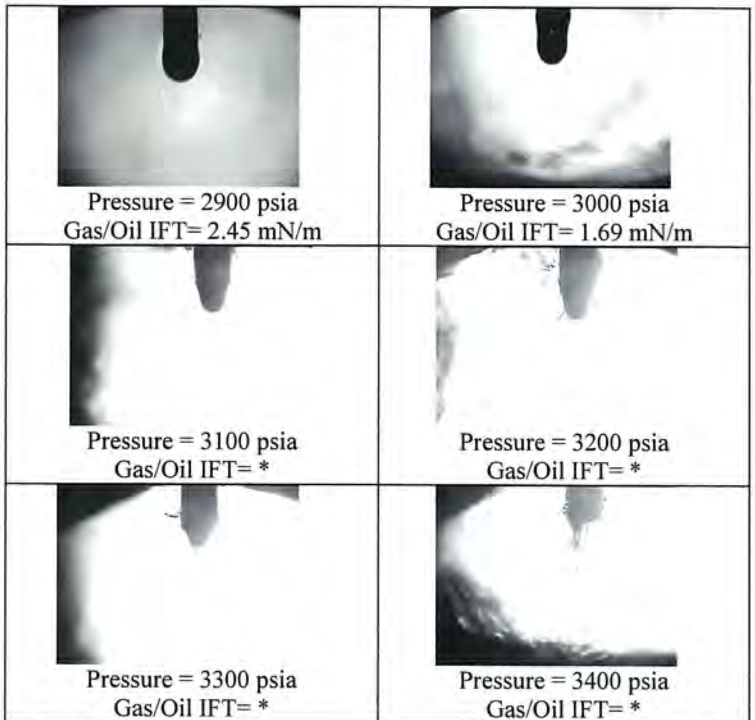
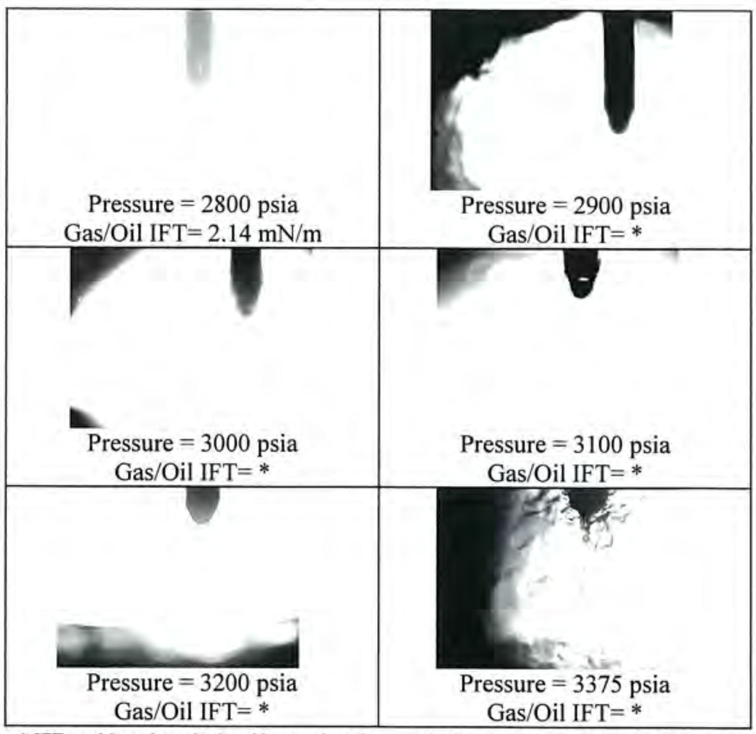


Figure 2. Measured density data for recombined live oil samples



* IFT could not be calculated by pendant drop method because of the irregular shape of the drops

Figure 3. Pendant drop images for CO_2 / recombined live oil (Sample A) system at 289°F



* IFT could not be calculated by pendant drop method because of the irregular shape of the drops

Figure 4. Pendant drop images for CO_2 / recombined live oil (Sample B) system at 289°F

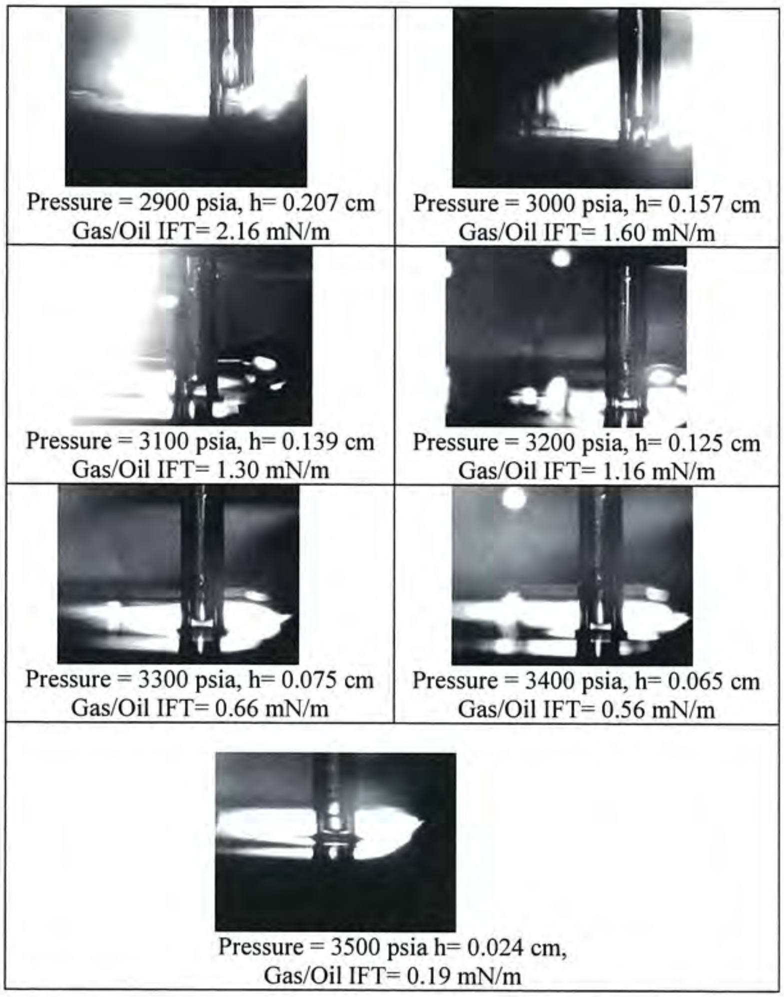


Figure 5. Capillary rise heights for CO_2 / recombined live oil (Sample A) system at 289°F

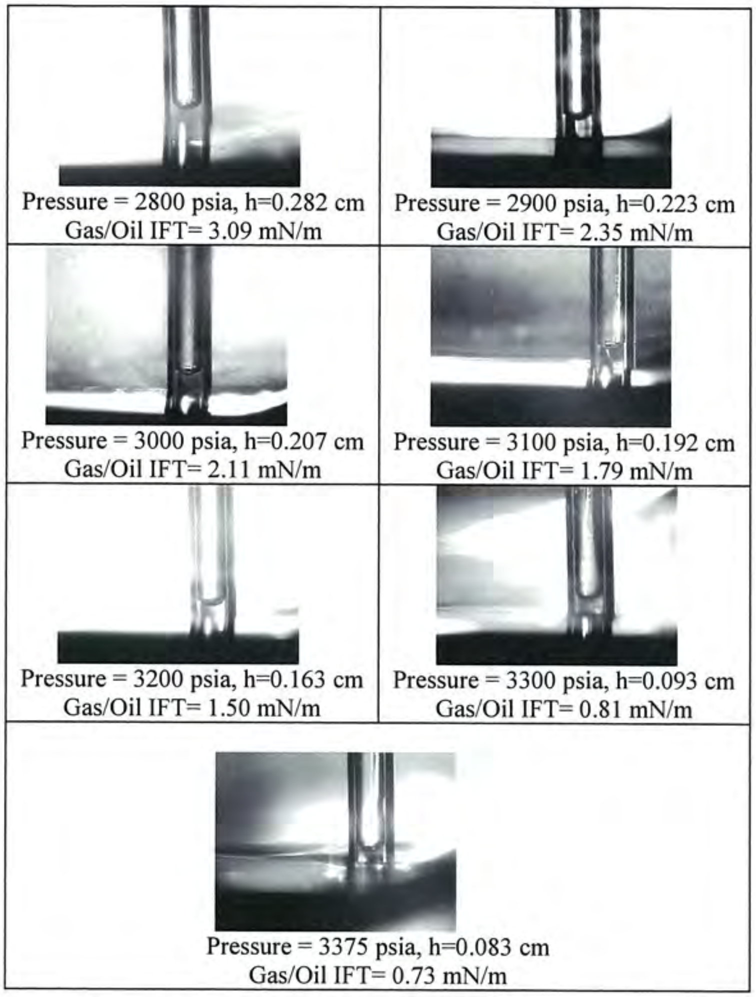


Figure 6. Capillary rise heights for CO_2 / recombined live oil (Sample B) system at 289°F

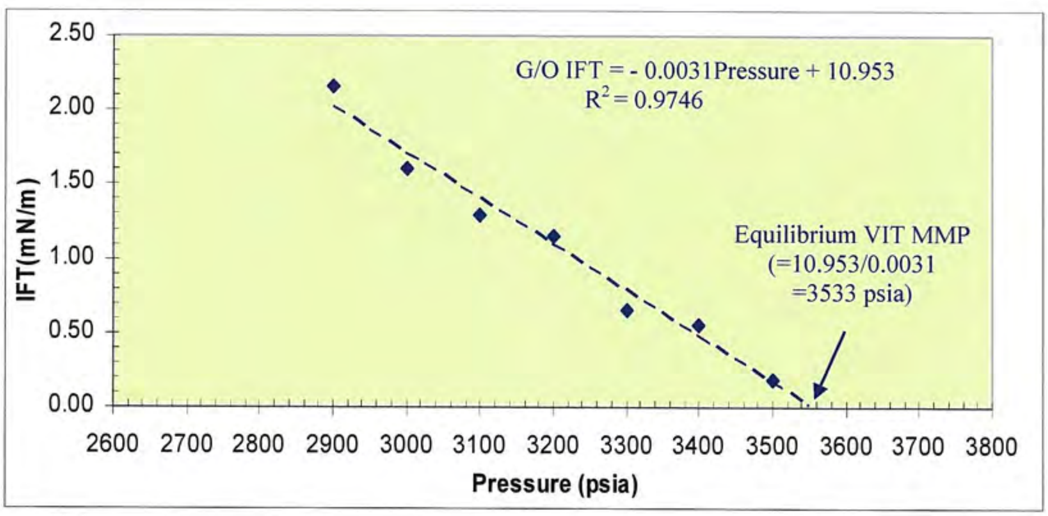


Figure 7. Determination of VIT MMP from IFT versus pressure plot for CO_2 / recombined live oil (Sample A) system at 289°F

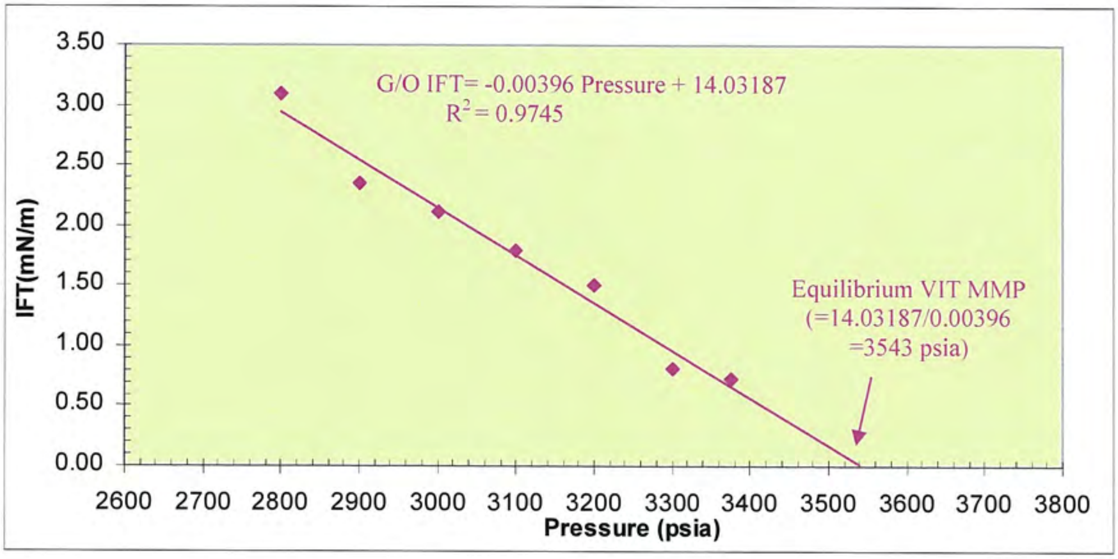


Figure 8. Determination of VIT MMP from IFT versus pressure plot for CO_2 / recombined live oil (Sample B) system at 289°F

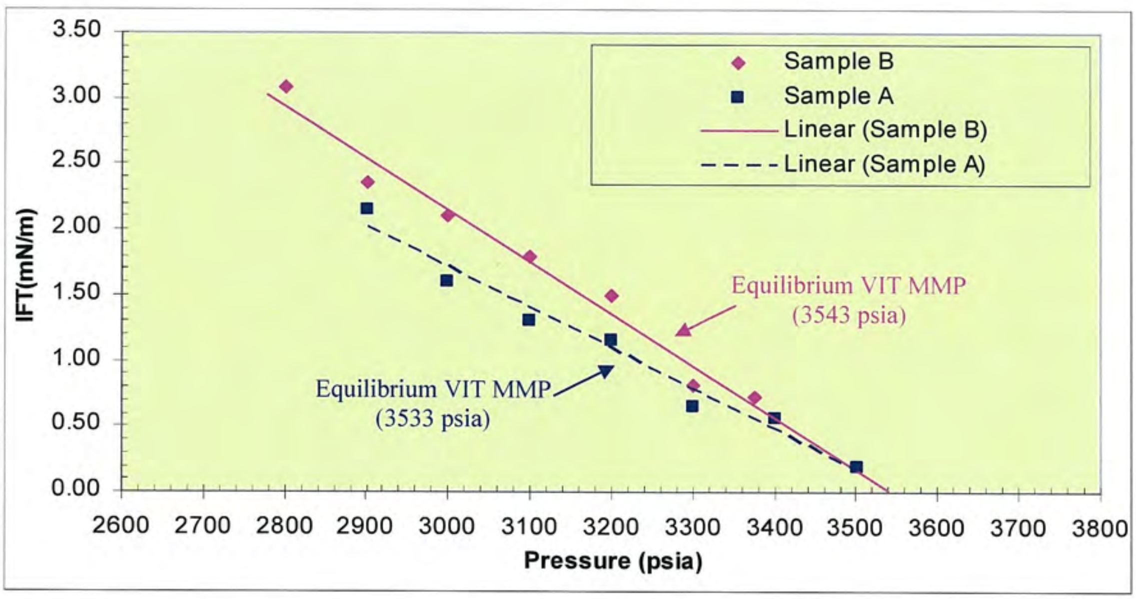
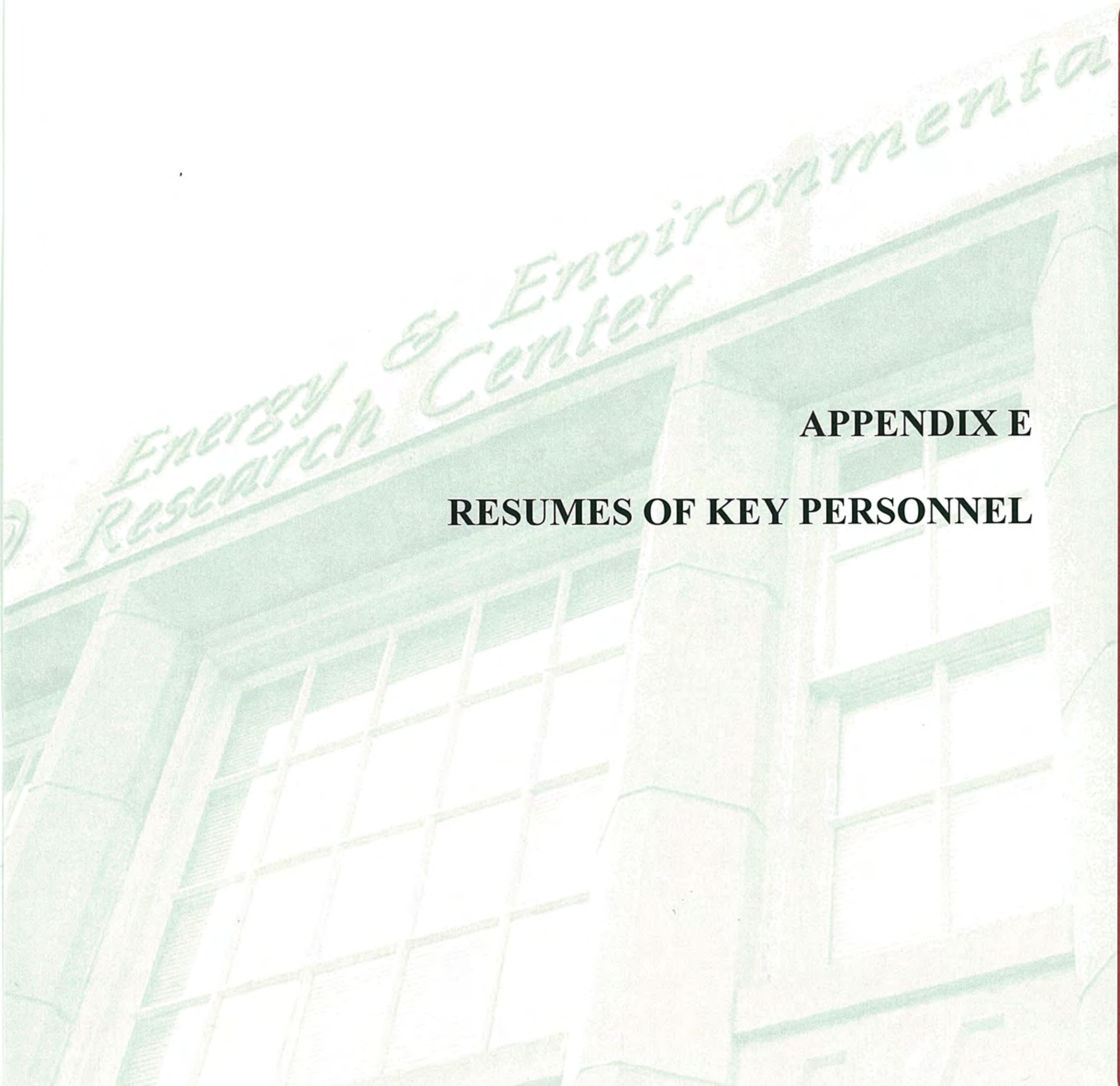


Figure 9. Comparison of IFT versus pressure data for both the recombined live oil samples (A&B) at 289°F



APPENDIX E

RESUMES OF KEY PERSONNEL

JAMES A. SORENSEN
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Principal Areas of Expertise

Mr. Sorensen's principal areas of interest and expertise include geologic storage of carbon dioxide, petroleum geology, subsurface transport and fate of organic and inorganic contaminants associated with the natural gas industry, research program management, technical report writing, and presentations.

Education

B.S., Geology, University of North Dakota, 1991.

Postgraduate course work in Hydrogeology, Advanced Geomorphology, Groundwater Monitoring and Remediation, Geochemistry, and Contaminant Hydrogeology, 1993–1995.

Professional Experience

1999–Present: Senior Research Manager, EERC, UND. Mr. Sorensen currently serves as manager and coprincipal investigator for several research programs, including the Plains CO_2 Reduction (PCOR) Partnership, a multiyear, multimillion-dollar program focused on developing strategies for reducing carbon dioxide emissions in nine states and four Canadian provinces. Responsibilities include supervision of research personnel, preparing and executing work plans, budget preparation and management, writing technical reports and papers, presentation of work plans and results at conferences and client meetings, interacting with clients and industrial contacts, and proposal writing and presentation.

1997–1999: Program Manager, EERC, UND. Mr. Sorensen managed projects on topics that included treatment of produced water, environmental fate of mercury and natural gas-processing chemicals, coalbed methane, and gas methane hydrates.

1993–1997: Geologist, EERC, UND. Mr. Sorensen conducted a variety of field-based hydrogeologic investigations throughout the United States and Canada. Activities were primarily focused on evaluating the subsurface transport and fate of mercury and natural gas-processing chemicals associated with natural gas production sites.

1991–1993: Research Specialist, EERC, UND. Mr. Sorensen assembled and maintained comprehensive databases related to oil and gas drilling, production, and waste management.

Professional Memberships

Society of Petroleum Engineers

Publications and Presentations

Has coauthored numerous publications.

DARREN D. SCHMIDT
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Principal Areas of Expertise
Mr. Schmidt's principal areas of interest and expertise include Bakken Formation activities in the Williston Basin, geologic CO_2 storage, enhanced hydrocarbon recovery, associated gas utilization, distributed power systems, emission control, energy efficiency, and gasification.

Qualifications
B.S., Mechanical Engineering, West Virginia University, 1994
Registered P.E.
Certified Energy Manager
Certified Green Building Engineer

Professional Experience
2008–Present: Senior Research Advisor, EERC, UND. Mr. Schmidt is currently responsible for procurement and execution of research projects related to the Bakken Formation in the Williston Basin. Recent projects include utilization of associated gas in drilling operations, laboratory investigation of conductivity associated with proppants, fracturing fluids, and rock formations, enhanced production from coalbed methane, geologic storage of CO_2, and oil field drilling, production, and workover operations. Additionally, Mr. Schmidt is an advisor to distributed biomass gasification development and contributes to the organization's revenue through research proposals, publications, and intellectual property.

1998–2008: Research Manager, EERC, UND. Mr. Schmidt's responsibilities include securing research contracts, managing projects, and performing engineering tasks in the areas of cofiring and biomass power systems, including combustion, fluidized-bed, gasification, microturbine, and internal combustion engine generators; energy efficiency; ground-source heat pumps; hydrogen production from biomass; and researching the behavior of biomass in combustion systems relative to ash fouling and trace elements.

1994–1998: Mechanical Engineer, Research Triangle Institute (RTI), Research Triangle Park, North Carolina. Mr. Schmidt's responsibilities included serving as project leader for a $3M Cooperative Agreement with the U.S. Environmental Protection Agency (EPA) to demonstrate electricity production using a 1-MW wood gasification technology. Significant experience included permit, design, installation, operations, and reporting. Other activities at RTI included support of marketing activities and coauthoring publications.

Summer 1993: Internship, EERC, UND, Grand Forks, ND. Support of combustion and coal ash studies.

Summer 1992: Internship, Foster Wheeler Development Corporation, Livingston, New Jersey. Support of gasification research and development.

Publications and Presentations
Has authored or coauthored numerous publications.

JOHN A. HARJU
Associate Director for Research
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
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Principal Areas of Expertise
Mr. Harju's principal areas of interest and expertise include carbon sequestration, enhanced oil recovery, waste management, geochemistry, technology development, hydrology, and analytical chemistry, especially as applied to the upstream oil and gas industry.

Qualifications
B.S., Geology, University of North Dakota, 1986.
Postgraduate course work in Management, Economics, Marketing, Education, Climatology, Weathering and Soils, Geochemistry, Geochemical Modeling, Hydrogeochemistry, Hydrogeology, Contaminant Hydrogeology, Advanced Physical Hydrogeology, and Geostatistics.

Professional Experience
2002–Present: EERC, UND, Grand Forks, North Dakota.
2011–Present: Associate Director for Research. Mr. Harju oversees the activities of a team of scientists and engineers focused on research, development, demonstration, and commercialization of energy and environmental technologies. Strategic energy and environmental issues include zero-emission coal utilization; CO_2 capture and sequestration; energy and water sustainability; hydrogen and fuel cells; advanced air emission control technologies, emphasizing SO_x, NO_x, air toxics, fine particulate, and mercury control; renewable energy; wind energy; water management; flood prevention; global climate change; waste utilization; energy efficiency; and contaminant cleanup.

2003–2011: Associate Director for Research. Mr. Harju's responsibilities included developing and administering programs involving petroleum technology, natural resource evaluations, water management and contamination cleanup and building industry–government–academic teams to carry out research, development, demonstration, and commercialization of energy and environmental products and technologies.

2002–2003: Senior Research Advisor. Mr. Harju's responsibilities included development, marketing, management, and dissemination of market-oriented research; development of programs focused on the environmental and health effects of power and natural resource production, contaminant cleanup, water management, and analytical techniques; publication and presentation of results; client interactions; and advisor to internal staff.

1999–2002: Vice President, Crystal Solutions, LLC, Laramie, Wyoming. Mr. Harju's firm was involved in commercial E&P produced water management, regulatory permitting and compliance, and environmental impact monitoring and analysis.

1997–2002: Gas Research Institute (GRI) (now Gas Technology Institute [GTI]), Chicago, Illinois.
2000–2002: Principal Scientist, Produced Water Management. Mr. Harju's responsibilities included development and deployment of produced water management technologies and methodologies for cost-effective and environmentally responsible management of oil and gas produced water.

1998–2000: Program Team Leader, Soil, Water, and Waste. Mr. Harju's responsibilities included project and program management related to the development of environmental technologies and informational products related to the North American oil and gas industry; formulation of RFPs, proposal review, and contract formulation; technology transfer activities; and staff and contractor supervision. Mr. Harju served as Manager of the Environmentally Acceptable Endpoints project, a multiyear, $8MM effort focused on a rigorous determination of appropriate cleanup levels for hydrocarbons and other energy-derived contaminants in soils. He also led GRI/GTI involvement with numerous industry environmental consortia and organizations, including PERF, SPE, AGA, IPEC, and API.

1997–1998: Principal Technology Manager, Soil and Water Quality.
1997: Associate Technology Manager, Soil and Water Quality.

1988–1996: EERC, UND, Grand Forks, North Dakota.
1994–1996: Senior Research Manager, Oil and Gas Group. Mr. Harju's responsibilities included the following:

- Program Manager for program to assess the environmental transport and fate of oil- and gas-derived contaminants, focused on mercury and sweetening and dehydration processes.
- Project Manager for field demonstration of innovative produced water treatment technology using freeze crystallization and evaporation at oil and gas industry site.
- Program Manager for environmental transport and fate assessment of MEA and its degradation compounds at Canadian sour gas-processing site.
- Program Manager for demonstration of unique design for oil and gas surface impoundments.
- Director, National Mine Land Reclamation Center for Western Region.
- Co-Principal Investigator on project exploring feasibility of underground coal gasification in southern Thailand.
- Consultant to International Atomic Energy Agency for program entitled "Solid Wastes and Disposal Methods Associated with Electricity Generation Fuel Chains."

1994: Research Manager.
1990–1994: Hydrogeologist.
1989–1990: Research Specialist.
1988–1989: Laboratory Technician.

Professional Memberships
National Petroleum Council
Interstate Oil & Gas Compact Commission, Chairman, Energy Resources, Research and Technology Committee
U.S. Department of Energy Unconventional Resources Technology Advisory Committee
Rocky Mountain Association of Geologists

Publications and Presentations
Has authored and coauthored numerous publications.

CHARLES D. GORECKI
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Principal Areas of Expertise
Mr. Gorecki's principal areas of interest and expertise are reservoir engineering, geologic modeling and simulation, CO_2 enhanced oil recovery (EOR), and geologic CO_2 storage. He has led efforts focused on developing storage capacity estimates and methodologies for deep saline formations, developed detailed site characterization activities for both enhanced oil recovery projects and CO_2 storage operations in deep saline formations, and leads activities associated with the nexus of water and CO_2 storage.

Qualifications
B.S., Geological Engineering, University of North Dakota, 2007.

Professional Experience
2011-present: Senior Research Manager, EERC, UND. Mr. Gorecki currently works on activities associated with the Plains CO_2 Reduction (PCOR) Partnership and is the technical lead for the Bell Creek CO_2 EOR Field Demonstration. Mr. Gorecki continues to lead the geologic modeling and simulation efforts for the EERC and national and international efforts associated with the nexus of water carbon capture and storage.

2010–2011: Research Manager, EERC, UND. Mr. Gorecki led the modeling and monitoring and water working group tasks for Phase III of the PCOR Partnership Program. He led the EERC's geologic modeling efforts, coordinating a multidisciplinary team to develop detailed geologic models and run predictive simulations for CO_2 storage, CO_2 EOR, and unconventional oil and gas plays. Mr. Gorecki is also the facilitator of the Regional Carbon Sequestration Partnership Water Working Group, where he leads discussion on the nexus of water and carbon capture and storage.

2007–2010: Research Engineer, EERC, UND. Mr. Gorecki worked with the PCOR Partnership at the EERC to develop models to describe the behavior of CO_2 prior to injection into saline formations and oil fields. Mr. Gorecki led a joint venture funded by the IEA Greenhouse Gas R&D Programme and the U.S. Department of Energy (DOE) to develop storage capacity/ resource coefficients to determine CO_2 storage capacity/resource estimates in saline formations. As a result of Mr. Gorecki's work in developing storage capacity/resource estimates, he served on the expert review panel on the U.S. Geological Survey's CO_2 Capacity Methodology; advised and helped to develop methodologies for the North American Energy Working Group's CO_2 storage capacity efforts between the United States, Canada, and Mexico; and advised the DOE National Energy Technology Laboratory on the third edition of the Carbon Sequestration Atlas of the United States and Canada.

Professional Memberships
American Association of Petroleum Geologists (AAPG), 2009–Present
Society of Petroleum Engineers (SPE), 2007–Present

Publications and Presentations
Has authored and coauthored several technical publications and presentations.

STEVEN A. SMITH
Research Manager
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Principal Areas of Expertise
Mr. Smith's principal areas of interest and expertise are petroleum geology and geological sequestration of carbon dioxide (CO_2).

Qualifications
B.S., Geology, University of North Dakota, 2001.

Professional Experience
2010–Present: Research Manager, EERC, UND. Mr. Smith is currently working with a multidisciplinary team collaborating on research activities devoted to furthering our understanding of the subsurface geological environment. He is currently managing the Applied Geology Laboratory, which is actively pursuing research into the derivation of the physical properties of rocks and encompasses the disciplines of petrophysics, geochemistry, and geomechanics. The primary focus of the laboratory is the oil and gas industry and carbon capture and storage marketplace.

2004–2010: Research Scientist, EERC, UND. Mr. Smith's responsibilities included developing and implementing a work plan for acid gas monitoring, verification, and accounting (MVA) for the Zama acid gas disposal and enhanced oil recovery (EOR) project in Alberta; coordinating engineering, geological, geomechanical, and geochemical characterization activities for the Zama project; developing and maintaining a database of oil-bearing geologic reservoir characteristics as they pertain to CO_2 storage in the states and provinces of the Plains CO_2 Reduction (PCOR) Partnership region; evaluating saline aquifer systems and determining their potential for CO_2 sequestration; and developing estimates of the CO_2 storage capacity within oil-bearing and saline strata of the Williston, Alberta, Powder River, and Denver–Julesberg Basins. He also worked as a well site geologist in the Williston Basin.

2001–2003: Well Site Geologist, Subcontractor, Baker, Montana. Mr. Smith's responsibilities included overseeing all of the oil company's interests, with respect to the geologic decisions on location; preparing morning report and geologic strip logs to summarize well progression; directing interaction with oil company upper management; evaluating sample cuttings, gas, and drill times while project well was drilling; performing structural geologic correlation with offset wells; and working in close communication with directional driller and rig crew to maintain accuracy in completion of well.

1994: Staff Geologist Intern, R.E. Wight Associates, Inc., Middletown, Pennsylvania. Mr. Smith's responsibilities included system checks and operation at groundwater remediation sites, hazardous materials sampling and preparation, well purging, sampling, and recharge calculations.

Professional Memberships
Society of Petroleum Engineers

Publications and Presentations
Has coauthored several publications.

DR. DAYANAND SAINI
Research Engineer
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Principal Areas of Expertise
Dr. Saini's principal areas of interest and expertise include enhanced oil recovery, pressure transient analysis, and rock–fluid interactions.

Qualifications
Ph.D., Petroleum Engineering, Louisiana State University, 2011.
B.S., Chemical Engineering, Chaudhary Charan Singh University, India, 2000.
B.S., Mathematics, Chaudhary Charan Singh University, India, 1996.

Professional Experience
April 2011–Present: Research Engineer, EERC, UND. Dr. Saini's responsibilities include developing geophysical models of the subsurface; running dynamic simulations to determine the long-term fate of produced/injected fluids, including hydrocarbons, CO_2, and brine; and using oil and gas industry simulation software.

2006–2011: Graduate Research Assistant, Department of Petroleum Engineering, Louisiana State University. Dr. Saini's responsibilities included investigating rock–fluids interactions in petroleum reservoirs at elevated pressures (up to 15,000 psi) and elevated temperatures (up to 300°F). His responsibilities also included numerical modeling of new enhanced oil recovery processes.

2011–2006: Reservoir Engineer, Oil and Natural Gas Corporation, Limited, India. Dr. Saini's responsibilities included analyzing and interpreting pressure transient data for oil and gas wells, formulating exploitation strategies for new and developed oil and gas fields, and analyzing pressure and production data for the wells on artificial lift (SRP [sucker rod pumping] or gas lift) for production optimization.

Professional Memberships
Society of Petroleum Engineers, 2005–Present
Pi Epsilon Tau (Petroleum Engineering Honor Society)

Publications and Presentations
Has author several publications and presentations.

TERRY P. BAILEY
Senior Geologist
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
Phone: (701) 777-6194, Fax: (701) 777-5181, E-Mail: tbailey@undeerc.org

Principal Areas of Expertise
Mr. Bailey has over 30 years of industry experience in oil and gas and development activities.

Qualifications
M.S., Geology, University of Colorado, 1977.
B.S., Geology, University of North Dakota, 1970.

Professional Experience
July 2007–Present: Senior Geologist, EERC, UND, Grand Forks, North Dakota. Mr. Bailey is currently working with the Plains CO_2 Reduction (PCOR) Partnership at the EERC developing petrophysical models of the subsurface to determine geologic geometries, formation parameters, and storage volumes and their relationship to CO_2 sequestration. Other projects include building a petrophysical model of the Bakken Shale over a portion of Dunn County, North Dakota.

February–June 2007: Earth Science Adviser, PPI Technology Services Nigeria Ltd., Mr. Bailey was contracted to Chevron Oil Company's Nigeria Mid-Africa Business Unit, Lagos, Nigeria, where he estimated original gas in place (OGIP) and created a depletion plan for the Awodi Field, one of several gas fields comprising the Nigerian Olakola liquefied natural gas (LNG) project. His work included 3-D seismic interpretation, structure and isopach mapping, risk assessment, determining optimum development well locations, and selecting the logging (wire-line or MWD), coring, and testing programs for these wells.

March–June 2006: Geologist, Swift Technical Services LLC. Mr. Bailey was contracted to Chevron Oil Company's Nigeria Mid-Africa Business Unit, Houston, Texas, where he determined optimum development plans for several Chevron gas fields making up the Nigerian Olakola LNG project. Olakola is one of the largest LNG projects in the world, and Chevron's project design calls for delivering 2.3 billion cu ft of gas a day to the LNG plants. The development plans included determining the number and locations of wells required to optimally drain reserves and selecting the logging (wire-line or MWD), coring, and testing programs for these wells.

January–March 2006: Consultant Geologist, Syntroleum Corporation – Houston, Texas. Mr. Bailey provided geologic evaluation and risk assessment of development options for two relinquished lease concessions in Nigeria, Africa (Ibigywe and Ajapa discoveries). His work included seismic interpretation, construction of structure (top and base of sand), net sand isopach and net oil isopach maps, and volumetric estimation of original oil in place (OOIP) and OGIP.

2002–2005: Geologist, Reservoir Management Team, Chevron Nigeria Mid-Africa Business Unit, Houston, Texas. Mr. Bailey completed geological studies of Chevron's major oil and gas reservoirs in onshore ("swamp" area) and offshore Nigeria. These studies were conducted to determine primary development and infill drilling locations, assess field deepening opportunities, and evaluate secondary recovery potential. Reservoirs studied are located in the Makaraba, Abiteye, Okan, Meji, and Sonam Fields. The studies included:

- Geological evaluation (well to well correlations, 3-D seismic interpretation, structure, and isopach mapping) utilizing Landmark (primarily SeisWorks and StratWorks), VoxelGeo, and proprietary Chevron geological and geophysical applications.
- Construction of earth models using GOCAD software.
- Determination of OOIP and OGIP (reservoir reserve size 10 MM to 140 MM OEG).
- Identification of drill locations.
- Documentation and presentation of results.

Mr. Bailey also provided geologic exhibits of studied reservoirs (primarily structure and isopach maps) to auditors for reserve certification and mentored other earth scientists in the construction of GOCAD faulted S grids.

1998–2002: Senior Staff Earth Scientist, CalTex Petroleum Corporation, Duri, Indonesia.

- Mr. Bailey completed integrated geological interpretations of Central Sumatra Basin oil fields (reserve size 10 MMBO to 750 MMBO OOIP) under the jurisdiction of the Petani Asset Management Team (AMT) and utilized Geoframe (including IESX, Stratlog, and CPS3) and Voxel Geo interpretation workstation applications.
- He constructed geologic models of major assets using GOCAD software applications and assisted in reservoir simulation studies. He utilized GOCAD and "real time" LWD data from horizontal wells to "steer" well paths to optimum target reservoir locations.
- Mr. Bailey identified areas of bypassed oil opportunities in mature assets and proposed development drill locations (including high angle slant, horizontal, and vertical wells) to maximize reserve recovery and provided well site duty on critical wells. Petani AMT Earth science champion for horizontal wells. Number of horizontal wells drilled by Petani AMT increased from one in 1998 to 11 in 2000. Production from these horizontal wells averages three times that of typical vertical well.
- He used Geolog for formation evaluation of electric logs, recommended initial completion intervals and identified workover opportunities.
- Mr. Bailey mentored national earth scientists in sequence stratigraphic concepts, structure mapping, application of horizontal well technology, and use of quality control techniques to verify geologic interpretations. He used strong teamwork skills to become a valued member of all national AMT.

1988–1998: Staff Geologist and Senior Development Geologist, Chevron Production Company, Lafayette, Louisiana.

- Mr. Bailey utilized subsurface geological and geophysical data to optimize Gulf of Mexico oil and gas fields (High Island, West Cameron, East Cameron, and Vermilion areas) economics by recommending successful drill locations and well work-over potential. He used Landmark (including Seisworks 2-D and 3-D, Seiscube, Syntool, Stratworks), Voxel Geo, and Coherency Cube software to generate comprehensive and accurate maps. Mr. Bailey also

incorporated sequence and parasequence stratigraphy concepts into interpretations and applied his knowledge of geochemistry, Allan mapping, and smear/gouge ratios to assess fault seal capacities.
- He supervised electric logging operations offshore GOM.
- Mr. Bailey served as lead trajectory analysts on Chevron's West Cameron Profit Center's Oil Spill Response Team. This position required proficient use of World Wide Oil Spill computer model and Hazwoper (Hazardous Waste Operations) certification.
- He evaluated farm-in/farm-out opportunities and monitored offset lease activity.
- Mr. Bailey was also involved with field sales and alternate funding efforts

1982–1988: Senior Geologist, Tenneco Oil Company, Lafayette, Louisiana. Mr. Bailey used geological and geophysical data to generate interpretations necessary for the development (new drills/workovers/recompletions) of oil and gas fields in the South Pass and Ship Shoal areas of the GOM. He supervised offshore electric logging operations and evaluated well logs in assigned areas. Mr. Bailey also evaluated and made recommendations for leasing of acreage offsetting assigned fields and evaluated "transition zone" acreage in the South Pass and Main Pass areas for lease acquisitions.

1981–1982: Consultant Geologist, Rego Associates, Williston, North Dakota. Mr. Bailey represented clients as well the site geologist; examined well cuttings, prepared sample lithology description logs, recorded and reported shows, recommended core and DST intervals, described cores, and evaluated electric well logs. He evaluated acreage for acquisition/drill/farm-in.

1980–1981: Development Geologist, Amerada Hess Corporation, Williston, North Dakota. Mr. Bailey worked in well site geology. He examined and described well cuttings, reported shows, recommended core and DST zones, described cores, and recommended drill locations.

1976–1980: Geological Engineer, Shell Oil Company, New Orleans, Louisiana. Mr. Bailey proposed over 30 development drill locations in several offshore GOM gas fields (High Island, Sabine, and East Cameron areas) with cumulative recoverable reserves of 550 BCF. His success rate was 94% from these drills. Mr. Bailey also represented Shell at field unitization determinations.

Professional Memberships
- American Association of Petroleum Geologists, Certified Petroleum Geologist
- Lafayette Geological Society Second Vice President 1997–1998

JORDAN M. BREMER
Research Scientist
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Principal Areas of Expertise
Mr. Bremer's principal areas of interest and expertise include mineralogy, geochemistry, engineering, drilling, CO_2 storage and utilization, lab testing, and field testing.

Qualifications
B.S., Geology, University of North Dakota, 2005.
Field Camp, South Dakota School of Mines and Technology, 2004.
Certified Geologist-in-Training, ASBOG (National Association of State Boards of Geology)

Professional Experience
2008–Present: Research Scientist, EERC, UND. Mr. Bremer is currently working for the Plains CO_2 Reduction (PCOR) Partnership to evaluate the potential for carbon dioxide storage in geologic formations and the Oil and Gas Group to examine enhanced oil recovery. He is also involved with the Applied Geology Laboratory, where he assigns, analyzes, and tests geological materials.

2007–2008: Staff Geologist, Interstate Drilling Services, Grand Forks, North Dakota. Mr. Bremer's responsibilities included supervising drilling operations and logging subsurface conditions, sample collection, data processing, report writing, surveying, project management, field testing, safety and compliance management, serving as a drill rig hand, Web site design, creating and updating forms, assisting with mechanics and fabrication, equipment operation, and welding.

2005–2007: Staff Geologist, Geotechnical Engineering Department, Consolidated Engineers & Materials Testing, Gillette, Wyoming. Mr. Bremer's responsibilities included supervising drilling operations and logging subsurface conditions, geotechnical and mineral resource coring and sampling, running various ASTM International and AASHTO (American Association of State Highway and Transportation Officials) laboratory and field tests, overseeing laboratory functions, data processing, report writing, surveying, assisting with Phase 1 Environmental Site Assessments, construction testing, and serving as a drill rig hand.

2004–2005: Department of Geology and Geological Engineering, UND, Grand Forks, North Dakota. Mr. Bremer ran borehole climate change models, including downloading, processing, and presenting data using Microsoft Excel.

2003–2004: Teaching Assistant and Lab Instructor, Geology 101 and 203 Labs, Department of Geology and Geological Engineering, UND, Grand Forks, North Dakota. Mr. Bremer's responsibilities included administering labs and tests, answering questions, grading, and record keeping.

2003–2005: Teaching Assistant, Environmental Issues, National Parks, and Minerals, Gems, and Gold, Department of Geology and Geological Engineering, UND, Grand Forks, North Dakota. Mr. Bremer's responsibilities included grading and proofreading papers and writing lab assignments.

2004: Wetland Surveying and Research, Department of Geology and Geological Engineering, UND, Grand Forks, North Dakota. Mr. Bremer's responsibilities included surveying, data processing and analysis, mapping, and research.

Professional Memberships
American Association of Petroleum Geologists
Society of Petroleum Engineers
Society of Core Analysts

Publications and Presentations
Has coauthored several publications.

DAMION J. KNUDSEN
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Principal Areas of Expertise
Mr. Knudsen's principal areas of interest and expertise include stochastic and dynamic simulation of subsurface petrophysical properties for uncertainty management of reservoir characterization, fluid injections, and enhanced oil recovery (EOR) projects.

Qualifications
B.S., Geosciences, North Dakota State University, 2005.
30-hour geostatistical course taught by GSLIB author Dr. Clayton Deutsch
60 hours of Computer Modeling Group (CMG) reservoir engineering courses
5 years as an Earth and Reservoir Modeling Geologist

Computer Skills
- Schlumberger Petrel 2010, 2000+ hours producing multiple stochastic realizations for probability mapping and risk analysis
- GOCAD petroleum reservoir-modeling program, 300+ hours
- CMG reservoir dynamic simulators
- CMOST reservoir simulation manager
- GSLIB geostatistical software library
- SGEMS open source geostatistical program
- Interactive Petrophysics petrophysical analysis program
- Techlog petrophysical analysis program
- ArcGIS 8.3 to 9.3, ArcInfo, AutoCAD Land Desktop with some 3.x experience,5000+ hours, GIS experience, 3-D analyst, spatial analyst, geostatistical analyst, arctoolbox scripts, arcscan, spatial adjustment, georeferencing, and conversions between CAD, GIS, and 3-D vector formats such as solidview and VRML with some ArcInfo Scripting
- CTECH EVS, 1000+ hours of experience with 2-D and 3-D geostatistics, volumetrics, exporting 3-D shapefiles to arcscene and arcmap, 3-D subsurface geological and impacted sediment mapping/modeling using curvilinear structured grids, importing surfer, 3-D multivariate, and indicator grids
- Rockworks, 4000+ hours, experience producing access-based geologic databases and using 3-D modeling and geostatistical modules
- Surfer 8.0, 3000+ hours, with some experience applying and programming macros
- Sketch Up/Google Earth, 1000+ hours, with experience in 3-D modeling at North Dakota State University for the Google Earth "Model Your Campus in 3-D Contest"
- RSI ENVI remote-sensing platform for multi- and hyper-spectral aerial image analysis
- Adobe products (Acrobat Professional, Photoshop, and Illustrator)

- Minitab statistical program
- WinGSLIB Windows GUI for GSLIB
- Tecplot 3-D vector-plotting software
- SolidView 3-D vector model-viewing program
- WinJade XRD-plotting software

Professional Experience

2008–Present: Research Scientist,EERC, UND. Mr. Knudsen's responsibilities include mentoring geomodelers and support staff in methods and techniques to produce and support static reservoir models and modeling; producing stochastic simulations using Petrel and GSLIB of petrophysical, geophysical, and geochemical properties using the popular sequential gaussian simulation (sGs) algorithm; production of three-dimensional probability volume maps to aid uncertainty management with prospective CO_2 storage, and EOR projects; production of static compositional models for injected CO_2 reactive transport species flow simulations; wireline log normalization; neural-network production of synthetic logs; multi-mineral petrophysical analysis with calibrations using x-ray diffraction (XRD) and QEMSCAN core analysis data; multimineral petrophysics analysis with core to wireline log fracture characterization using neural networks; well top production through petrophysical correlation; facies model production of both clastic and carbonate depositional systems using sequential indicator simulation (SIS) and advanced geostatistical algorithms such as the single normal equation simulation (SNESIM) or FILTERSIM multipoint geostatistics (MPS) algorithms; three-dimensional fracture modeling using discrete fracture networks (DFN); 4-D seismic inversion modeling; single- and dual-permeability/porosity CO_2 injection and EOR production dynamic fluid simulations with the CMG dynamic simulation suite; near wellbore modeling and history matching; sensitivity and uncertainty analysis, optimization, and history matching using CMG CMOST; sensitivity and uncertainty analysis using experimental design in Minitab.

2005–2008: Graduate Research Assistant/Geoscientist Intern, Geosciences Department, North Dakota State University, Fargo, North Dakota. Mr. Knudsen specialized in high-resolution geostatistical 3-D modeling, and his responsibilities included acquiring and georeferencing aerial and satellite images from Google Earth and other sources and draping them over SRTM 90m and SDTS/NED 30/10m Digital Elevation Models (DEM) and light detection and ranging data; developing a 3-D Earth System Simulator (ESS) similar to the Stanford V reservoir data set; assisting professors and students in 2-D and 3-D GIS techniques; scanning, georeferencing, and vectorizing paper maps using ArcScan and other raster to vector conversion techniques in ArcGIS 9.X; converting raster and vector data between geographical coordinate systems (WGS-84, NAD-83, NAD-27) to projected state plane coordinate systems in feet; and modeling in 3-D surface and subsurface features.

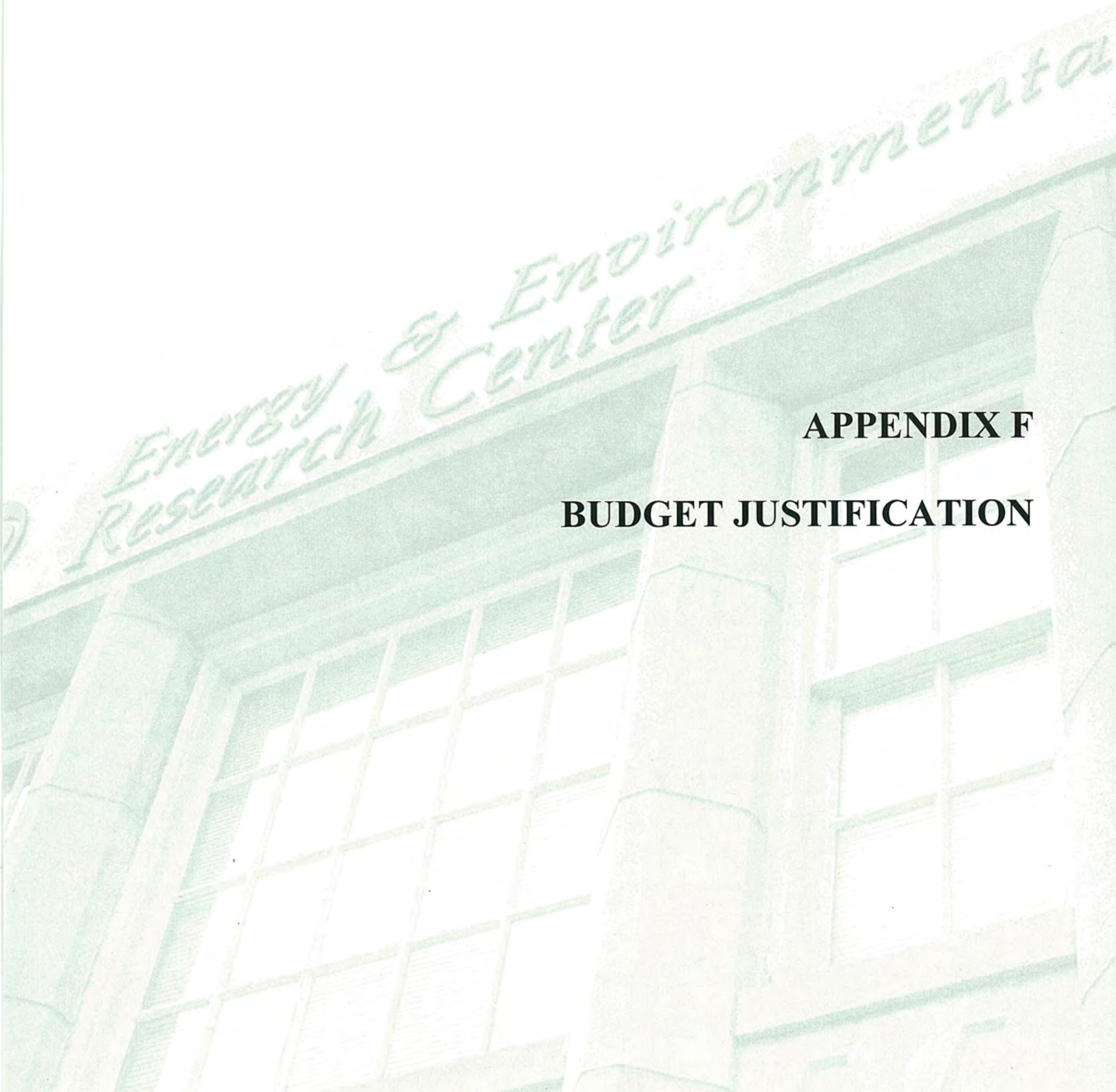
2005–2006: Earth Modeling Geoscientist, Dakota Technologies, Inc. Mr. Knudsen's responsibilities included modeling in 3-D surface and subsurface features derived from direct push, direct-sensing instruments such as CPT and LIF, and assisting with field LIF data collection with a direct push Geoprobe.

Professional Memberships

Society of Petroleum Engineers (SPE)

American Association of Petroleum Geologists (AAPG)
Society of Petrophysicists and Well Log Analysts (SPWLA)

Publications and Presentations
Has authored or coauthored several publications.



APPENDIX F

BUDGET JUSTIFICATION

BUDGET JUSTIFICATION

ENERGY & ENVIRONMENTAL RESEARCH CENTER (EERC)

BACKGROUND

The EERC is an independently organized multidisciplinary research center within the University of North Dakota (UND). The EERC receives no appropriated funding from the state of North Dakota and is funded through federal and nonfederal grants, contracts, and other agreements. Although the EERC is not affiliated with any one academic department, university faculty may participate in a project, depending on the scope of work and expertise required to perform the project.

INTELLECTUAL PROPERTY

If federal funding is proposed as part of this project, the applicable federal intellectual property (IP) regulations may govern any resulting research agreement. In addition, in the event that IP with the potential to generate revenue to which the EERC is entitled is developed under this agreement, such IP, including rights, title, interest, and obligations, may be transferred to the EERC Foundation, a separate legal entity.

BUDGET INFORMATION

The proposed work will be done on a cost-reimbursable basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, etc.) is for planning purposes only. The project manager may, as dictated by the needs of the work, incur costs in accordance with Office of Management and Budget (OMB) Circular A-21 found at www.whitehouse.gov/omb/circulars. If the Scope of Work (by task, if applicable) encompasses research activities which may be funded by one or more sponsors, then allowable project costs may be allocated at the Scope of Work or task level, as appropriate, to any or all of the funding sources. Financial reporting will be at the total-agreement level.

The cost of this project is based on a specific start date indicated at the top of the EERC budget. Any delay in the start of this project may result in a budget increase. Budget category descriptions presented below are for informational purposes; some categories may not appear in the budget.

Labor: Estimated labor includes direct salaries and fringe benefits. Salary estimates are based on the scope of work and prior experience on projects of similar scope. Salary costs incurred are based on direct hourly effort on the project. Fringe benefits consist of two components which are budgeted as 55% of direct labor. The first component is a fixed percentage approved annually by the UND cognizant audit agency, the Department of Health and Human Services. This portion of the rate covers vacation, holiday, and sick leave (VSL) and is applied to direct labor for permanent staff eligible for VSL benefits. Only the actual approved rate will be charged to the project. The second component is estimated on the basis of historical data and is charged as actual expenses for items such as health, life, and unemployment insurance; social security; worker's compensation; and UND retirement contributions. The following table represents a breakdown by labor category and hours for technical staff for the proposed effort.

Labor Categories	Labor Hrs
Research Scientists/Engineers	8,653
Research Technicians	509
Senior Management	219
Undergraduate Students	800
Technical Support Services	260
	10,441

Travel: Travel is estimated on the basis of UND travel policies which can be found at www.und.edu/dept/accounts/policiesandprocedures.html. Estimates include General Services Administration (GSA) daily meal rates. Travel may include site visits, field work, meetings, and conference participation as indicated by the scope of work and/or budget.

Equipment: If equipment (value of $5000 or more) is budgeted, it is discussed in the text of the proposal.

Supplies: Supply and material estimates are based on prior experience and may include chemicals, gases, glassware, nuts, bolts, and piping. Computer supplies may include data storage, paper, memory, software, and toner cartridges. Maps, sample containers, minor equipment (value less than $5000), signage, and safety supplies may be necessary as well as other organizational materials such as subscriptions, books, and reference materials. General purpose office supplies (pencils, pens, paper clips, staples, Post-it notes, etc.) are included in the facilities and administrative cost.
Subcontracts/Subrecipients: Not applicable.

Professional Fees/Services (consultants): Not applicable.

Other Direct Costs

Communications: Telephone, cell phone, and fax line charges are generally included in the facilities and administrative cost. Direct project costs may include line charges at remote locations, long-distance telephone, postage, and other data or document transportation costs.

Printing and Duplicating: Photocopy estimates are based on prior experience with similar projects. Page rates for various photocopiers are established annually by the university's duplicating center.

Food: Expenditures for project meetings, workshops, and conferences where the primary purpose is dissemination of technical information may include costs of food, some of which may exceed the institutional limit.

Operating Fees and Services – EERC Recharge Centers, Outside Labs, Freight: EERC recharge center rates for laboratory, analytical, graphics, and shop/operation fees are established and approved at the beginning of the university's fiscal year.

Laboratory and analytical fees are charged on a per sample, hourly, or daily rate, depending on the analytical services performed. Additionally, laboratory analyses may be performed outside the university when necessary.

Graphics fees are based on an established per hour rate for production of such items as report figures, posters, and/or PowerPoint images for presentations, maps, schematics, Web site design, professional brochures, and photographs.

Shop and operation fees are for expenses directly associated with the operation of the pilot plant facility. These fees cover such items as training, personal safety (protective eyeglasses, boots, gloves), and physicals for pilot plant and shop personnel.

Freight expenditures generally occur for outgoing items and field sample shipments.

Facilities and Administrative Cost: The facilities and administrative rate of 50% (indirect cost rate) included in this proposal is approved by the Department of Health and Human Services. Facilities and administrative cost is calculated on modified total direct costs (MTDC). MTDC is defined as total direct costs less individual capital expenditures, such as equipment or software costing $5000 or more with a useful life of greater than one year, as well as subawards in excess of the first $25,000 for each award. The facilities and administrative rate has been applied to each line item presented in the budget table.

APPENDIX G

STATUS OF ON-GOING PROJECTS

STATUS OF ONGOING PROJECTS (IF ANY)

1. G-005-014 "Plains CO_2 Reduction Partnership Program – Phase II"; OGRC funding $500,000; total project cost $21,487,892; presentation completed June 26, 2007; final report submitted December 30, 2009. Status: project completed.
2. G-015-030 "Plains CO_2 Reduction Partnership Program – Phase III"; OGRC funding $500,000; total project cost $135,731,052; status: project ongoing. Phase III is a 10-year project running from October 1, 2007, to September 30, 2017. The activities for Phase III of the PCOR Partnership include two large-volume CO_2 storage demonstrations. Regional characterization and outreach activities to support the two demonstrations are under way.
3. G-018-036 "Bakken Water Opportunities Assessment"; OGRC funding $110,000; total project cost $230,000. This project is part of the Northern Great Plains Water Consortium® Program and is the investigation of the recycling of water flowback after Bakken fracture stimulation. Status: project ongoing. A final report for Phase 1 was issued April of 2010, and Phase 2 activity is ongoing to test upgrading of water from a saline aquifer for potential fracturing fluid use in the Bakken Formation.
4. G-023-051 "Investigation of Improved Conductivity and Proppant Applications in the Bakken"; OGRC funding $150,000; total project cost $332,432. The project is a laboratory-based effort to improve the lateral and vertical drainage of hydrocarbons from the Bakken/Three Forks by identifying factors that lead to the collapse of propped fractures. Status: project ongoing. A status report was issued July 31, 2011, and activity is ongoing to test whether more durable fracture conductivity can be achieved by altering the fracturing fluids, proppant types, and proppant concentrations.