FINAL SCIENTIFIC / TECHNICAL REPORT

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

REPORTING PERIOD

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DISCLAIMER

ABSTRACT

The project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge. This project proposed to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2.

Blackhorse Energy, LLC planned to conduct a parallel CO_2 oil recovery project in the First Wilcox Sand.

The primary focus of this project was to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This was to be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand.

The project was terminated at the request of Blackhorse Energy LLC on October 22, 2014.

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY 5

2.0 PROJECT PLANNING 5

2.1 PROJECT SCHEDULE 5

2.2 SUBCONTRACTORS 6

2.3 REPORT PREPARATION 7

2.4 UNIVERSITY RESEARCH OBJECTIVES 7

2.4.1 LOUISIANA STATE UNIVERSITY (LSU): 7

2.4.2 UNIVERSITY OF TEXAS: 9

2.4.3 RICE UNIVERSITY: 11

3.0 PROJECT RESULTS AND DISCUSSION 11

3.1 UNIVERSITY RESEARCH 11

3.1.1 LOUISIANA STATE UNIVERSITY 11

3.1.2 UNIVERSITY OF TEXAS RESEARCH 12

3.1.3 RICE UNIVERSITY RESEARCH 12

3.2 SEISMIC SURVEY 12

3.2.1 STRAND ENERGY SURVEY 12

3.2.2 SCHLUMBERGER SURVEY 13

3.3 WELL DESIGN 13

4.0 CONCLUSION 15

5.0 REFERENCES 16

6.0 LIST OF ACRONYMS AND ABBREVIATIONS 17

7.0 APPENDICES 18

7.1 APPENDIX A – LSU CONFERENCE PAPER 18

7.2 APPENDIX B – FINAL REPORT LSU PROJECT 2: FOAM MODELING 35

7.3 APPENDIX C – RESERVOIR MODELING OF LIVINGSTON FIELD 37

7.4 APPENDIX D – FINAL REPORT FROM THE RICE/UT CO2 FOAM R&D CONSORTIUM 77
7.5 APPENDIX E – INITIAL PRE-SHOOT SEISMIC EVALUATION **79**
7.6 APPENDIX F – OBSERVATION WELL DIAGRAMS **87**
7.7 APPENDIX G - BLACKHORSE INJECTION WELL - DRILLING PLAN VERSION 1.1 .... **89**
7.8 APPENDIX H – PUBLIC OUTREACH PLAN **103**
7.9 APPENDIX I – CHARACTERIZATION / MODELING / MONITORING PLAN 123
7.10 APPENDIX J – QUALITY ASSURANCE PROJECT PLAN 143
7.11 APPENDIX K – PERMITTING ACTION PLAN 170
7.12 APPENDIX L – SITE DEVELOPMENT / OPERATIONS / CLOSURE PLAN 193
7.13 APPENDIX M – RISK ASESSMENT PLAN 206
7.14 APPENDIX N – MONITORING, VERIFICATION AND ACCOUNTING PLAN 212
7.15 APPENDIX O – RESERVOIR MODELLING PLAN 233

1.0 EXECUTIVE SUMMARY

The proposed project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This project proposed to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strandplain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets in saline reservoirs.

Blackhorse Energy, LLC planned to conduct a parallel CO_2 oil recovery project in the First Wilcox Sand.

The primary focus of this project was to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This was to be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring was to be deployed in the project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design was to test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the project wells was to be assessed in light of data collected from two vertical injection wells. Field production wells were to be leveraged for data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair project can provide.

It was intended that this high-profile project would demonstrate the attractiveness of CO_2 enhanced oil recovery to other small operators in Louisiana and the Gulf Coast area, thus enhancing and encouraging CO_2 sequestration operations. Enhanced oil recovery currently represents the most profitable, and therefore attractive, means of sequestering CO_2.

2.0 PROJECT PLANNING

2.1 PROJECT SCHEDULE

Project activities were initiated following completion of the cooperative agreement between Blackhorse Energy, LLC and the Department of Energy (DOE). The agreement to proceed was signed on February 1, 2013.

The following amendments were issued by the DOE:

Amendment 1	September 25, 2012
Amendment 2	February 1, 2013
Amendment 3	March 28, 2013
Amendment 4	June 7, 2013
Amendment 5	August 22, 2013
Amendment 6	October 28, 2013
Amendment 7	December 17, 2013.

The Project Period for this award was October 1, 2011 through September 30, 2016 consisting of the following Budget Periods:

Budget Period No.	Start Date	End date
1	October 1, 2011	September 30, 2014
2	October 1, 2014	September 30, 2015
3	October 1, 2015	September 30, 2016

On July 2, 2014, the DOE notified Blackhorse Energy that DOE was suspending all activities on this project.

On September 22, 2014, Blackhorse Energy notified the U.S. Department of Energy and all subcontractors that Blackhorse Energy was terminating the Award effective as of that date.

Detailed planning was done on the three observation wells and on the injector. Observation well designs are complete (see Appendix F). A detailed drilling plan was prepared for the injector (see Appendix G).

Louisiana State University (LSU) presented a paper at the 13th Annual Carbon Capture, Utilization and Storage Conference, April 28-May 1, Pittsburgh, Pennsylvania. The paper was titled "Geochemical Properties of Reservoir Rock Affecting Storage Capacity of CO2 Utilized for EOR".

2.2 SUBCONTRACTORS

Contracts were completed with the following subcontractors:

Sandia Technologies	April 4, 2013
LSU University	July 3, 2013
Schlumberger	September 9, 2013
University of Texas	October 10, 2013
Rice University	January 23, 2014

2.3 REPORT PREPARATION

The following reports were prepared and submitted to the DOE:

Public Outreach Plan	September 11, 2013
Characterization / Modelling / Monitoring Plan	September 26, 2013
Quality Assurance Project Plan	October 25, 2013
Permitting Action Plan	November 12, 2013
Site Development / Operations / Closure Plan	January 28, 2014
Risk Assessment Plan	February 11, 2014
Monitoring, Verification and Accounting Plan	February 20, 2014
Reservoir Modelling Report	March 3, 2014

These are included as Appendices H-O, respectively.

2.4 UNIVERSITY RESEARCH OBJECTIVES

2.4.1 LOUISIANA STATE UNIVERSITY (LSU):

LSU Project 1 – Geochemical Evaluation

Project Objectives

The interaction of CO_2, minerals found in sandstone reservoir rocks (especially carbonates and clays), and brine/water can produce geochemical changes which in turn can affect reservoir/cap rock properties. A common example found in natural systems is the interaction of carbonic acid (H_2CO_3) with feldspar to form kaolinite, which results in additional porosity, lower permeability, reduced pore throat sizes. In addition, carbonate minerals present in sandstone will most likely be unstable under low pH conditions and this can potentially change porosity/permeability and therefore injectivity of CO_2. The purpose of this project is to identify and quantify such geochemical changes under laboratory conditions and provide the data for models capable of predicting behavior of the reservoir rock in the field.

Project Description

These processes will be studied in the Injection Project in a manner similar to that employed by Shell at the Denver Unit CO_2 Pilot (Mathis and Sears, 1984).

- Cores obtained at various depths before CO_2 injection will be examined to obtain plugs for petrophysical analysis. A duplicate set of plugs will be obtained at each depth, from the reservoir rock and adjacent cap rock. This procedure will be carried out on existing cores (already obtained by LSU from Black Horse Energy) as well as from the newly drilled well.
- Petrophysical properties on one set will be measured by a commercial laboratory, as planned during kickoff meeting (Weatherford). Thin section, Electron Microscopy (E/SEM) X-ray diffraction (XRD), and X-ray Computed Tomography (CT) analysis will be performed at LSU.

- A subset of the second set of plugs will then be used for a flow-through experiments, where each core would be exposed to CO_2 and reservoir brine at the required temperature. Following this exposure, complete set of materials characterization analysis will then be determined on this second set of plugs, to determine the effects of CO_2-water-rock interaction.
- Special set of analysis would be carried out using Electron Probe Analysis for quantitative geochemical evaluation, based on which we can predict reaction rates/products at an early stage and cut down time of flow-through experiments.
- We recommend new core be obtained in close proximity to the first set after the injection has been underway for some time (1 year). This core will be correlated geologically with the first, and plugs taken from similar intervals. This will provide a field scale look at the interaction of CO_2 with the reservoir and cap rocks, and a basis for comparison with the laboratory studies.

LSU Project 2 –CO2 Foam Modeling

Project Objectives

In addition to CO_2 injection, it is intended to use about 150,000 lbs of surfactants to produce CO2 foams in the reservoir. This attempt, if successful, is expected to delay the breakthrough of injected fluids and improve sweep efficiency by overcoming or mitigating reservoir heterogeneity, gravity segregation, and viscous fingering. Such a success in the field trial requires tailor-designed surfactant chemicals and foam rheological properties meeting the characteristics of the fields of interest, including rock and fluid properties, chemical-rock interactions, foam stability influenced by reservoir fluids and wettability, thermal degradation of chemicals and so on, to name a few.

This research component aims to achieve a reliable evaluation and implementation of mobility-control foam processes and an accurate up-scaling of laboratory flow tests to field-scale flooding by understanding foam rheological properties during foam displacement in the reservoir. A mechanistic foam modeling technique based on foam catastrophe theory is a key aspect to meet these goals.

Project Description

LSU's foam modeling study contributes to this project in the following manner:

(i) Help decide what types of laboratory experiments should be conducted under what conditions in which order throughout the project period;

(ii) Understand how foam displacement mechanism works in the media of interest at different injection and reservoir conditions in the laboratory, and how such a mechanism can be translated into the evaluation of sweep efficiency by analyzing recovery history;

(iii) Build and extend mechanistic foam modeling techniques to up-scale laboratory experimental data to large field-scale treatments, dealing with heterogeneity and dimensionality; and

(iv) Help implement the foam modeling techniques into the existing framework of reservoir simulations for pilot tests or full field applications.

This foam modeling study is to be performed, interacting with other research groups who work in parallel on the development of surfactants and chemicals, measurements of CO_2 foam properties at conditions relevant to reservoir pressure and temperature, and simulations of reservoir-scale EOR/sequestration treatments.

2.4.2 UNIVERSITY OF TEXAS:

UT Austin Project 1: Inexpensive Monitoring and Uncertainty Assessment of CO2 Plume Migration using Injection Data

Project Objectives: The overall objective of this project is to develop a new computational approach for monitoring the location of CO2 during injection. The proposed approach has two notable advantages: it is very inexpensive, and it quantifies the uncertainty in the plume location. The former advantage arises because the method can work with data that will be measured in every storage project, namely injection rates and pressures at each well versus time. The latter advantage arises because the approach abandons traditional pixel-based methods of parameter estimation and instead yields multiple geologically consistent models that reflect the injection characteristics observed at wells. The method is geologically based and inherently flexible enough to use other types of data, such as surface deflection or seismic, to infer plume location with greater accuracy. The objectives of the main research tasks are to develop the mathematical formulation for a model-based approach (as opposed to current pixel-based approaches), to develop modular software that can be readily integrated with existing flow simulators and with frameworks for monitoring and verifying plume location, and to demonstrate the approach on field datasets.

Project Description:

We will adopt a new paradigm for the classical problem of parameter estimation (also known as history matching). Instead of varying properties of an aquifer at the level of individual pixels, we will vary models (aquifer-sized aggregates of pixels). The initial range of models will correspond to a range of plausible geologic descriptions or settings for the aquifer. This approach is particularly well suited for the likely situation in CO2 storage, when relatively little data will be available. We will devise algorithms for generating models within random function space, for rapidly computing a proxy for the response of the models using a continuous-time-random-walk method, and for performing a multivariate analysis of the results that yields a metric for similarity between models.

Once the classification of models is completed, the cluster closest to the observed injection characteristics will be selected using a Bayesian algorithm. The selected cluster will be further refined by iterative application of the classification-selection process. We will verify the algorithms on a series of synthetic cases, focusing on the situation when only injection data are available. We will integrate these algorithms into a self-contained software package that can be interfaced with existing full-physics simulators and with current and future frameworks for monitoring plume displacement. We will apply the approach to data from the Blackhorse Energy EOR/Sequestration project.

UT Austin Project 2: Alterations in mechanical properties of rocks due to CO2 injection -- implications for field scale monitoring of sequestration processes.

Project Objectives

The primary focus here is to relate the changes in elastic properties of the host formation observed at the laboratory scale to larger field or seismic scale changes. This upscaling process has important bearing on the development of seismic techniques for monitoring the progress of the CO2 plume post-injection. To accomplish this objective, we propose to develop extensions to the current effective media models to incorporate velocity anomaly induced by frame alteration of the rock. In conjunction, our research objective is also to develop high-resolution seismic inversion capability using basis pursuit and very fast simulated annealing that incorporate improved forward models reflecting the rock physics associated with CO2 injection in the subsurface.

Project Description

The effects of CO2 injection both in carbonate and sandstone reservoirs will be studied using a combination of laboratory experiments and numerical models. Specifically, we propose carrying out three primary tasks:

(1) laboratory measurements of elastic stiffness of cores for example from the Livingston CO2 injection site,

(2) development of an effective medium model for modeling the unusual behavior of rocks observed in the laboratory and to mapping those properties to the field scale, and

(3) development of advanced seismic inversion techniques to improve resolution of subsurface images.

Laboratory measurements done to date show that compressional and shear wave velocities decrease as a function of CO2 saturation caused by chemical changes in the rock matrix and porosity. This unusual behavior can be modeled very well using an extended effective medium model that can incorporate changes in the rock matrix (containing fractures and pores) and patchy and uniform saturation of CO2. Fractures and chemical precipitates are modeled as inclusions and the effective

Echelby tensor corresponding to these inclusions is computed. Further, since our model is frequency dependent, we are able to predict changes in wave velocities at seismic frequencies (field scale).

We propose to incorporate these improved rock physics models in conjunction with advanced techniques for seismic inversion based on a basis pursuit algorithm on a time lapse data set (for example the Livingston data set) to predict CO2 displacement in the reservoir. We would like to quantify the effect of incorporating improved models for rock frame alteration on the time-lapse inversion process.

2.4.3 RICE UNIVERSITY:

Rice University Project 1A: Identify a surfactant for CO2 mobility control at Livingston

Adsorption of surfactant on reservoir minerals: This is complex - The reservoir is a mixture of the sandstone, clays and highly concreted zones where carbonates and clays have precipitated in the otherwise clean beach sand.

Dynamic and static adsorption studies on minerals are required to quantify potential surfactant loss, governing mechanisms, sacrificial agents (if required) and surfactant selection and slug size.

Rice University Project 1B: Study transport of surfactant and foam

Surfactant partitioning behavior is an important aspect of surfactant transport and possible chromatographic separation. Phase behavior and partitioning studies of surfactant between CO2, brine and oil will be used recognize surfactant chromatographic separation and transport.

UT Austin Project 3: High Pressure CO2 Foam Experiments (included in Rice University contract)

Quoc Nguyen is developing surfactants for mobility control and will supervise high pressure CO2 foam flooding experiments.

Oil displacement flow experiments at reservoir conditions are required to confirm the viability of the surfactant selection and optimize slug size for reservoir design and application.

3.0 PROJECT RESULTS AND DISCUSSION

3.1 UNIVERSITY RESEARCH

3.1.1 LOUISIANA STATE UNIVERSITY

Mileva Radonjic, Steve Sears, Christopher Allen and Farrell Diliberto presented a paper at the 13th Annual Carbon Capture, Utilization and Storage Conference, April 28-May 1, Pittsburgh, Pennsylvania. The paper was titled "**Geochemical Properties of Reservoir Rock Affecting Storage Capacity of CO2 Utilized for EOR".** The summary of the paper was:

Livingston Field, LA has been selected for a CCS/EOR CO2-foam injection project in Louisiana and cores obtained in the 1980s were used to provide geochemical analysis of reservoir rock. The preliminary investigations were carried out for basic petrophysical characterization, microstructure and fabric of the rock, bulk mineralogical evaluation and spatial geochemical print of the rock. The data obtained during flow-through experiments at elevated temperature and low pH brine will enable the validation of geochemical models which are being developed.

A copy of the Conference paper is included in Appendix A.

A status report on Project 2 is included as Appendix B.

3.1.2 UNIVERSITY OF TEXAS RESEARCH

A status report is included as Appendix C. The research group led by Dr Sanjay Srinivasan made excellent progress toward achieving their research goals.

3.1.3 RICE UNIVERSITY RESEARCH

Blackhorse Energy received a final report on work accomplished under the Rice sub-contract on February 12, 2015. This latter report provided our first insight into the work subcontracted to the University of Texas (UT) and the first summary of work done at Rice.

This report is included as Appendix D. The results reported suggest that the Rice University research group was unable to find a surfactant which produced a usable foam. The combination of high temperature, high salinity and high hardness made a successful solution very difficult to find.

3.2 SEISMIC SURVEY

3.2.1 STRAND ENERGY SURVEY

Strand Energy conducted a large 3D seismic survey of an area that covered part of the Livingston field. As part of the Blackhorse Energy permit, we were entitled to get data from the survey covering our unit. Raw data is considered to be proprietary to Strand, but interpreted data can be shared.

The survey was interpreted by Sam LeRoy of Earthview, LLC under contract to Sandia Technologies.

Their report is included as Appendix E and has been very helpful to Blackhorse Energy.

3.2.2 SCHLUMBERGER SURVEY

The Army Corps of Engineers permit was issued on April 21, 2014 with approval to shoot a 3-D seismic survey for geotechnical exploration to include drilling shot holes along source lines and establishing receiver lines for data recording located within a 6.2 square mile area, North of I-12, in Louisiana, in Livingston Parish.

There were two special conditions:

1. The Chitimacha Tribe of Louisiana has stated that the project area is part of the aboriginal Chitimacha homelands. If during the course of work at the site, prehistoric and / or historic aboriginal cultural materials are discovered, the permittee will contact the Tribe.
2. Construction activities shall not cause more than minimal and temporal quality degradation of any adjacent wetland, stream or water body.

A State of Louisiana Department of Environmental Quality permit was received on March 28. The permit concluded that the requirements for a Water Quality Certification have been met by plans to place fill material for backfill of charge locations in approximately 202 locations.

At the end of the quarter, 978 surface permits had been identified and sent to agents. Of these, 513 are signed and 189 were rejected.

3.3 WELL DESIGN

Well designs have been completed for all three observation wells. Diagrams of the wells is included in Appendix F.

Purchase orders for all equipment and materials have been prepared.

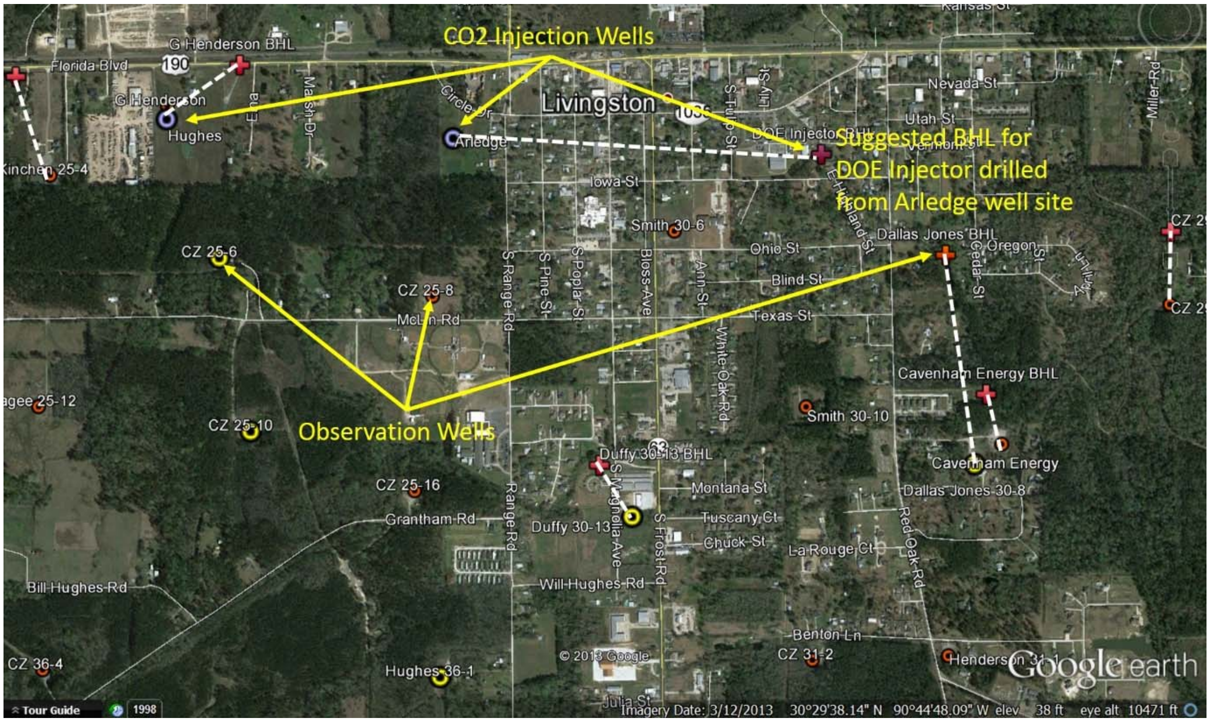
The observation wells will also serve as producers. Artificial lift will be with jet pumps. Tubing will be 2 7/8” 6.4 lb/ft. An inner string will be 1 ¼”, 1.315” OD coupled tubing. Power fluid will be pumped down the inner string with production up the tubing annulus. Metallurgy for all downhole equipment will be 13 chrome.

Note that this task has been accelerated into Budget Period 1 in order to keep the project on schedule. Began initial work on injection well planning, including preparation of a critical path schedule (Microsoft Project) through start of field activities.

Built preliminary wellbore path from the Arledge well pad. A Google Earth map of the location is shown in the following figure:

The location coincides with the existing Arledge well on acreage already owned by Blackhorse Energy. (This location was included in Blackhorse Energy's original application for NEPA review.) Preliminary review indicates a Corps of Engineers wetlands permit will not be required.

Bottom hole location has been established south of the bounding fault to the north and approximately midway between existing producers Smith 30-6 and Dallas Jones 30-8. This location was determined with the assistance of seismic data from a survey conducted by Strand Energy as a condition of their permit with Blackhorse Energy.



Reviewed monthly rig report for wells in southeastern Louisiana and made contact with potential drilling vendors. Prepared preliminary well casing design for the injection well, including an option for a single protection casing string to be run to total well depth.

Began initial discussions with EPRI on integrating their "Distributed Fiber Optic Arrays: Integrated Temperature and Seismic Sensing for Detection of CO2 Flow, Leakage and Subsurface Distribution" DOE project, which was awarded in August, 2013. Discussed changes that may be required for deployment of their distributed temperature and distributed acoustic fiber optic cable versus our planned distributed temperature fiber optic cable.

A plan for the injection well is included in Appendix G.

4.0 CONCLUSION

A viable plan was developed to determine the capacity of Wilcox sands in Southern Louisiana to store CO2. The study was in conjunction with a parallel CO2 recovery project conducted in the same reservoir.

Unfortunately, the project was terminated on October 22, 2014 due to changes in the oil industry.

5.0 REFERENCES

R.L. Mathis (Shell Western E and P Inc.), and S.O. Sears (Shell Offshore Inc.) (1984), “Effect of CO_2 Flooding on Dolomite Reservoir Rock, Denver Unit, Wasson (San Andres) Field, TX”, SPE Paper 13132, presented at the SPE Annual Technical Conference and Exhibition, 16-19 September, Houston, Texas, 1984

6.0 LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three dimensional, as in a seismic survey
CCS	Carbon capture and sequestration
CCUS	Carbon capture, utilization and sequestration
CO2	Carbon dioxide
EOR	Enhanced oil recovery
DOE	Department of Energy
EPRI	Electric Power Research Institute
LSU	Louisiana State University at Baton Rouge
NEPA	National Environmental Policy Act
OD	Outside diameter
R&D	Research and development
UT	The University of Texas at Austin

7.0 APPENDICES

7.1 APPENDIX A – LSU CONFERENCE PAPER

The Thirteenth Annual Carbon Capture Utilization & Storage Conference

Geochemical Properties of Reservoir Rock Affecting Storage Capacity of CO_2 Utilized for EOR, Livingston Field, Louisiana, US

By: Mileva Radonjic, Stephen Sears, Farrell Diliberto, and Christopher Allen, Louisiana State University

Abstract

Livingstone Field, LA has been selected for a first EOR CO_2-foam injection project in Louisiana. The main purpose of this study was to investigate existing cores obtained during initial drilling in the 1980s and perform some preliminary modeling of the effect of CO_2 and brine on the reservoir rock. The motivation for this work was to establish the response of the reservoir rock upon contact with low pH brine rich in CO_2, determine the potential effect this may have on dissolution/precipitation of minerals and the overall effectiveness of CO_2 injection.

A preliminary examination was made on core samples from the Wilcox Sandstone in the Livingston Field, Louisiana. The purpose was to document composition, texture, and petrophysical properties as a starting point for geochemical and geophysical experiments related to the planned CO_2 flood. Potential geochemical reactions that may occur from introduction of CO_2 to the reservoir are identified, as a basis for planning experiments. The samples were collected from the field core storage facility in April, 2013.

The preliminary investigation included basic petrophysical characterization, microstructure and fabric of the rock, bulk mineralogical evaluation and spatial geochemical print of the rock. Three wellbores/cores were identified based on the presence of the carbonate minerals, which is the weakest component in terms of stability at low pH, and the potential impact their dissolution may have on the porosity/permeability and therefore injectivity and sweep efficiency of CO_2.

The results showed that the collected samples have an average porosity of 22%. X-ray diffraction reveals that the dominant minerals present in addition to quartz are feldspars, major clay minerals and approximately 5-8wt% of carbonate minerals. The spatial distribution of these minerals and the overall architecture of the rock showed clays present as surface coatings on quartz and feldspar grains as well as pore-lining material. The electron probe geochemical results suggest that the carbonate fraction is dispersed in form of microcrystalline calcite/dolomite rather than concentrated in larger grains. In addition, the feldspar-group is another potential site of mineral dissolution with unclear consequence on the post-injection fabric of the reservoir rock. Finally, backscattered imaging clearly showed interconnectedness and presence of different pore sizes.

The next phase in this research is to subject the cores to flow-through experiments at elevated temperature and low pH brine with the addition of CO_2. Changes in the effluent composition as well as post- experimental geochemical evaluation will enable us to validate geochemical models being developed with the overall intention to use them in predicting reservoir behavior over extended period of time.

Key words: geochemical evaluation, microstructure, carbonate dissolution, EOR

Introduction

The United States Department of Energy has recently focused on evaluating small scale reservoirs as potential locations for combined Enhanced Oil Recovery and carbon storage sites near industrial sources of CO_2 emissions. The appeal of such locations is primarily for more accurate data gathering, monitoring and documentation. A specific Gulf Coast reservoir will be the focus of this paper, although many such locations exist in the region. In the actual reservoir, the CO_2 being injected into the reservoir will mix with the brine in place to form a low pH fluid, a solution of carbonic acid. The low pH fluid will preferentially react with calcium carbonate in place, which will lead to a change in the geochemical compositions of the reservoir.

The geochemical changes of the reservoir can have an impact on the porosity and permeability of the rock matrix leading to potential problems in the EOR operation. Khurshid et al. (2013) found that during CO_2 injection, a high rate of dissolution occurs near the wellbore and precipitation of particles further away from the wellbore that can reduce oil and gas productivity along with CO_2 injectivity. As calcium carbonate is dissolved, pores may become enlarged and lead to higher permeability; most likely near the wellbore. Problems arise when the solution becomes saturated, allowing calcium carbonate to precipitate in different locations. The precipitation of calcium carbonate will lead to choked or completely plugged pore holes leading to a lower permeability. Khurshid el al. (2013) also found that if precipitation occurs, a higher pressure gradient across the reservoir will occur. In addition, dissolution of feldspar and formation of clay minerals can also cause petrophysical changes and therefore impact injectivity and effectiveness of EOR operations.

Several parameters have been identified as potentially impactful on the rock-fluid interaction during EOR. Mohamed et al. (2011) found that brine salinity and composition play a significant role in geochemical reactions between the CO_2, brine, and the reservoir rock. The pH of the injected fluid was also reported in several studies as a driving factor for reaction rates in rock-fluid reactions under EOR conditions. The temperature of the system is also important because for example the reaction between the carbonic acid and calcium carbonate is significantly slower above ambient conditions. To a lesser extent than when compared to temperature, pressure plays a role as well, as reservoir conditions can vary depending on the age of the field and the amount of injected/produced fluids.

The flow rate (injection rate) is also critical for the transport phenomena and rate of reactions. Mangane et al. (2013) used ICP to monitor calcium concentrations and used a mass balance to determine to the porosity change rate with time. Furthermore, in some experiments with horizontally oriented core plugs the permeability decreases at the beginning, and after a certain CO_2 injection the curve is stabilized, porosity settles above the original level for a long time and the carbon dioxide does not move as easily to the other side of the core plug forming carbonic acid near the inlet part of the core (Izgec et al. 2005). Sensitivity and alterations of pore structure in contact with CO_2 brine was reported by Olabode and Radonjic, (2014).

The results obtained from this preliminary evaluation of the reservoir rock and its geochemical nature as well as core flood experiment and accompanying geochemical modeling could be extended to make predictions of what may occur in the reservoir which then leads to a better EOR operation, following the workflow principles as shown in Figure 1, below.

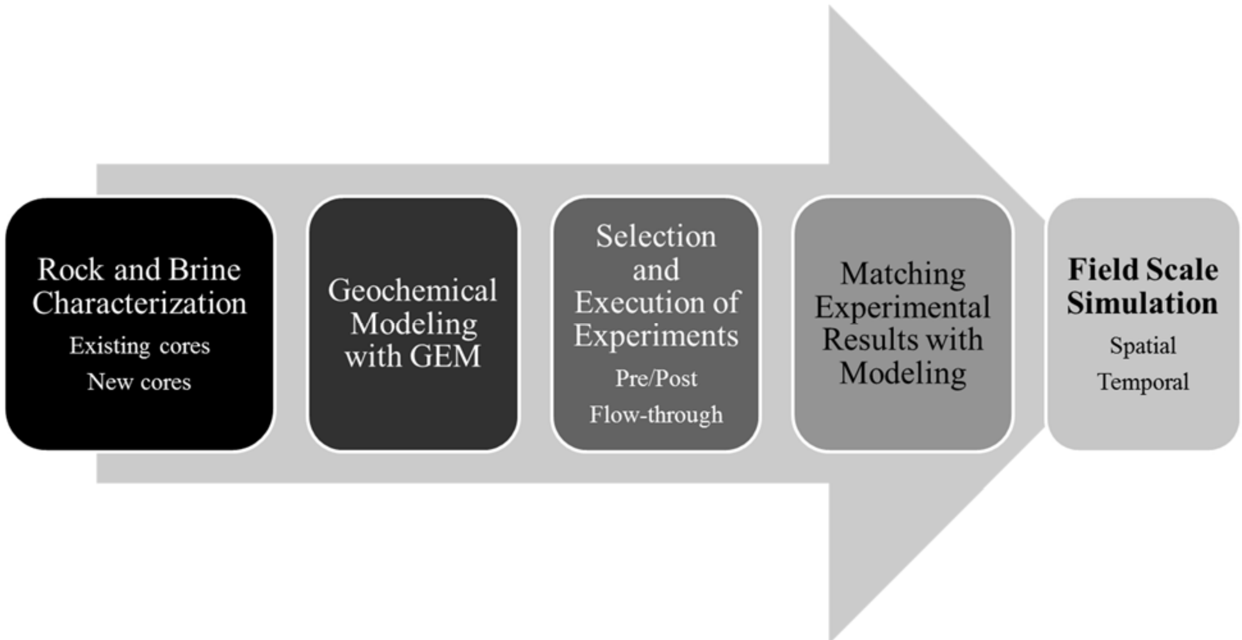


Figure 1. Workflow process for geochemical evaluation of rock-brine interactions and their potential impact on petrophysical properties of reservoir rock, from micro to macro scale, over different time scales. The overall goal is an optimized EOR process with a limited impact of rock-fluid reactions on permeability and potential for carbon storage within the reservoir rock. From left to right, darker filled boxes outline accomplished tasks. Final point on the right will be addressed both with the lab studies and field observations once the injections starts.

Experimental Methods

Plugs were drilled from slabs of core material from the wells noted below as depicted in schematic, see Figure 2. Wells sampled:

- Crown Zellerbach 26-16 #1, 10036 feet. (Goddard et al, 2001)
- Crown Zellerbach 25-6 #1, 10022 feet.
- Henderson 31-1 10051 feet.

Weatherford Laboratories carried out permeability measurements (vertical and horizontal), X-ray diffraction analysis, and preparation of thin sections. Composition was determined by point counting the thin sections 300 points per slide. Porosity was determined on the plugs in LSU Petroleum Engineering Laboratories. Samples adjacent to the plugs were coated with platinum and analyzed by the Scanning Electron Microscope in the LSU College of Engineering. Additional thin sections were analyzed by electron microprobe at Earth Sciences, University of Bristol, UK, running line profiles and elemental mapping, at 20 keV, spot size 3microns, analysis performed at every 5 microns.

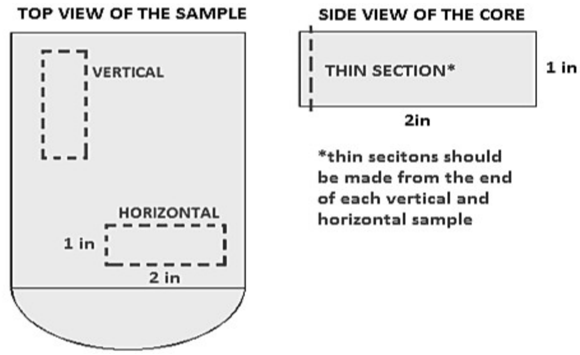


Figure 2. Schematic description of orientation of plugs drilled from the core slabs retrieved from the original drilling in Livingston (1980s). Thin sections were also prepared depicting horizontal and vertical orientation of stratigraphic depositional layers

Flow-through experiment: The CO_2 brine mixture was made daily; 20,000 ppm salinity brine was used. After mixing 40.392 grams of NaCl and 0.69 grams of KCl into 2,000 mL of deionized water, the brine was placed in a mixing chamber where 25 psi of CO_2 was applied for one hour. The average pH obtained was 3.7.

The core was contained inside the Hassler core holder within a rubber sleeve that restricted flow through the core. Water was placed between the rubber sleeve and core holder to keep the rubber sleeve from expanding while also allowing a hot bath to keep the core at 185 °F. 2,000 L of brine was made daily. The brine was fed to a pump that pushed the CO_2 brine through the system at 1 mL/min. The mixture went through 1/8 inch tubing, entered the core holder, exited through 1/8 inch tubing, and then entered a backpressure valve.

The backpressure valve was set for 400 psi, although the average pressure in the core was measured to be 295 psi. The effluent was collected downstream of the backpressure valve, as shown on the diagram below. A block diagram of the experimental set up is provided in Figure 3.

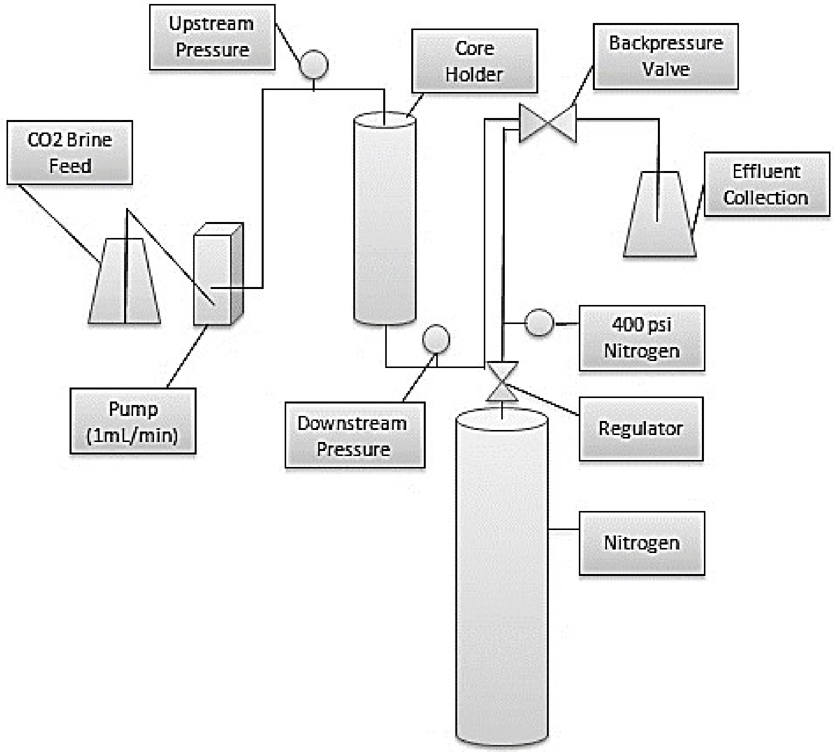


Figure 3. Block diagram of flow through experiment

The core holder was covered in aluminum foil tape with a silicone rubber heat tape wrapped around the core holder below it. This allowed for the core to reach a temperature of 185 °F within the holder. The temperature was measured daily with an average value of 185 °F. It is important to note that heat was not added to the experiment until day 15 of the flow through experiment (March 11th, 2014). The pressure averaged about 295 psi. This pressure was well short of the reservoir pressure in this preliminary study.

The core used was a two by one inch core containing approximately 5% calcium carbonate along with 50% quartz, 35% feldspars, and 10% clays. The porosity of the core was found using a helium porosimeter to be 21.18%. The weight of the core was 53.72 grams.

Daily effluent samples were taken immediately from the outlet in order to avoid contamination or potential precipitate forming. The pH of the effluent samples was measured immediately from the outlet in order to capture values as close as possible to the fluid in contact with minerals. More accurate measurement would have to be done with a pH probe capable of measuring insitu fluids.

Microscopic Evaluation: Optical and Scanning Electron Microscopy

The samples are very fine grained, sublithic sandstones (Figure 4). Average grain size in the three thin sections analyzed ranged from 70 to 125 microns. Detrital grains are predominantly monomineralic quartz and feldspar, and rock fragments. Minor amounts of mica, calcite fossil fragments, and glauconite are present, as shown in optical microscopy micrographs presented in Figures 4 and 5.

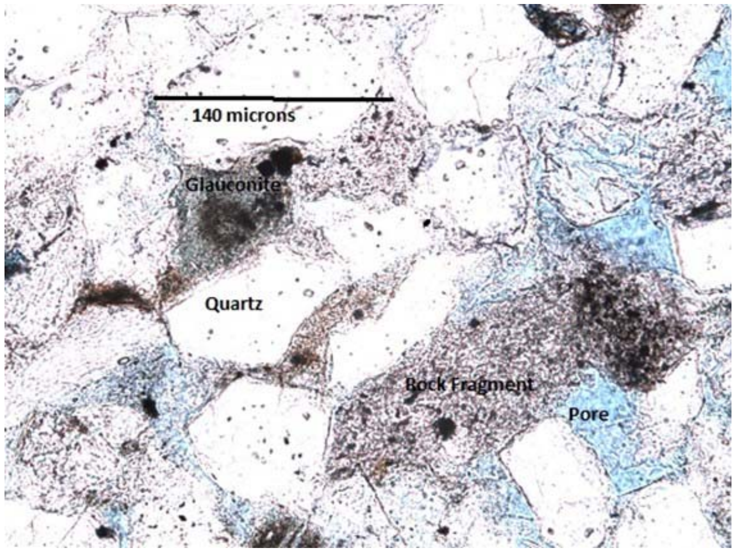


Figure 4. Composition of Wilcox Sand. Crown Zellerbach 25-6 No. 1, 10,022 feet (100x).

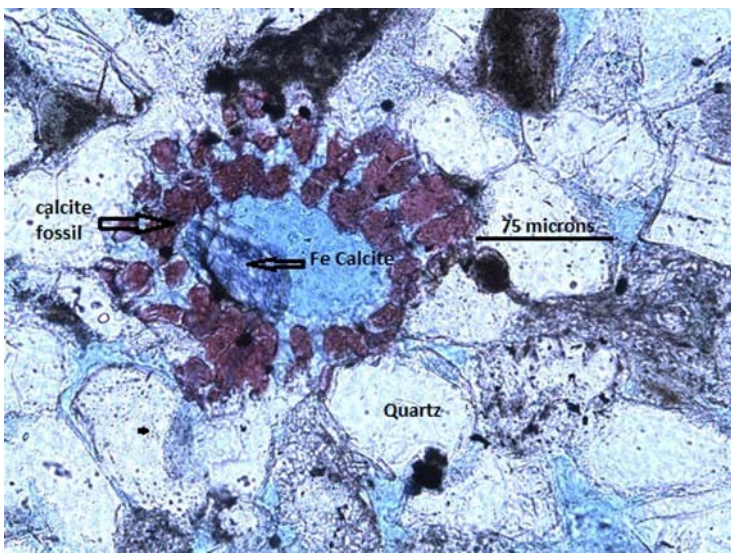


Figure 5. Crown Zellerbach 25-6 No. 1, 10,022 feet (400x). Calcite fossil (red) and high Fe carbonate cement (dark blue).

Laminations are evident in some thin sections, resulting from a higher concentration of rock fragments and clay. These laminations are presumed to be responsible for the higher horizontal compared to vertical permeability measurements discussed below and presented in Figure 6. Permeability measurements showed on average vertical permeability to be 60% less than the horizontal permeability.

Figure 6. Henderson 31-1, 10,036 feet (12.5x). Lamination in the center of the thin section, reflecting a higher concentration of clay and rock fragments.

Authigenic clay minerals include kaolinite (Fig. 7), chlorite (Fig. 8), and mixed layer illite/smectite. The presence of the clay minerals was established by both X-ray diffraction analysis and SEM photographs. Chlorite is present both as detrital glauconite (Figs. 4 and 5) and as authigenic clay. Mica, which has the same X-ray diffraction characteristics as illite, is also present both as detrital mica grains and as authigenic illite. Mixed layer illite/smectite is also present.

Based on stratigraphic position and petrophysical properties, all samples are interpreted to represent the beach/upper shoreface interval as described by Goddard et al. (2002).

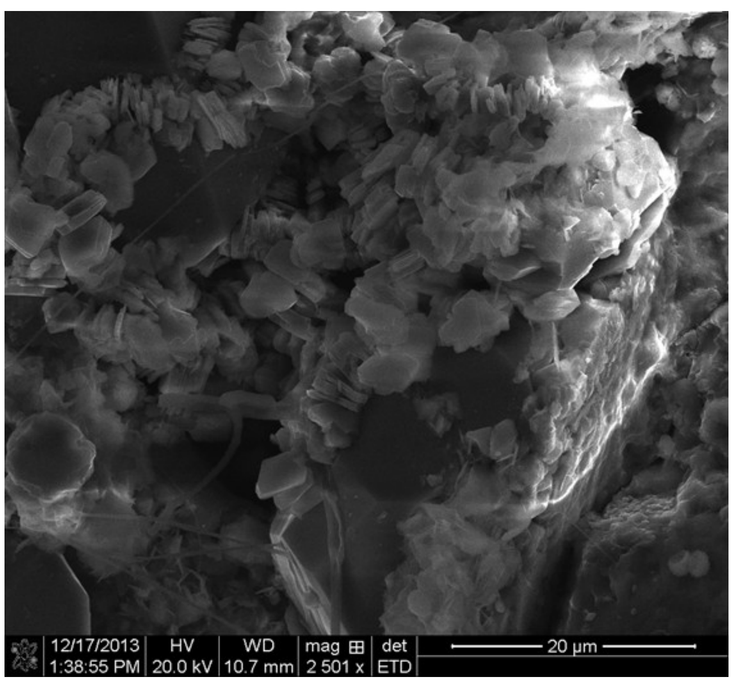


Figure 7. Henderson 31-1, 10,036 feet. Kaolinite, presumably from alteration of feldspar. (2,500x).

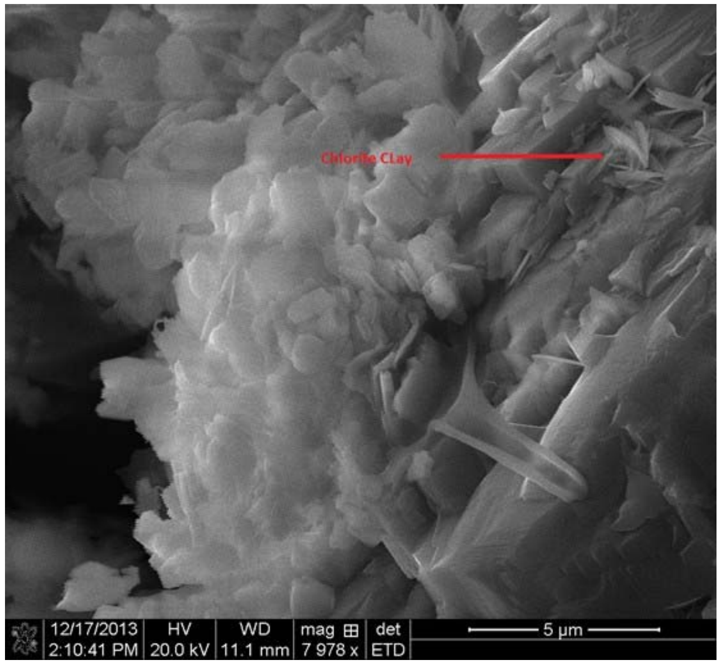


Figure 8. Crown Zellerbach 25-6 No. 1, 10,051 feet. Chlorite Clay.

SEM photographs show a considerable amount of microporosity (less than 2 microns in diameter). The rock fragments have partially altered to clay in many instances, which also produces microporosity between clay particles, as well as microporosity created by partially dissolving the original components of the rock such as feldspar (Fig. 9).

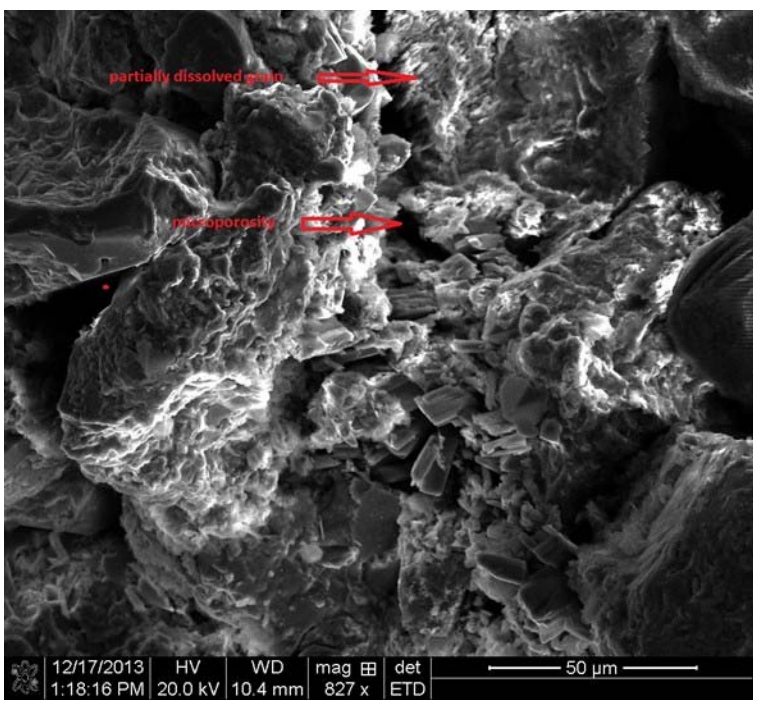


Figure 9. Crown Zellerbach 25-6 No. 1, 10,022 feet. Rock Fragments and microporosity (827x).

Quartz and feldspar are present both as grains composed of a single crystal and as components of multicrystalline rock fragments. The percentages of these minerals indicated by x-ray diffraction include both modes of occurrence. Illite/mica is present both as detrital grains and as an authigenic clay. Chlorite is present predominantly as detrital glauconite particles, presumably resulting from alteration of fecal pellets, but is also present in trace amounts as authigenic clay. Kaolinite and mixed layer illite/smectite are both present as authigenic minerals resulting from the alteration of feldspar and rock fragments.

The results are in general agreement with Johnston and Johnson (1987), except that more rock fragments were observed in this report. Their criteria for differentiating rock fragments in thin section is not documented. They also state that the present day porosity is the result of large scale removal of calcite from the interparticle pore space by CO_2. There is no definite evidence of this in these samples (it is difficult to prove that something was once present and now removed): and this is believed to not be the case. The unaltered condition of the fossil fragments still present indicates that large scale dissolution of calcite has not occurred.

Petrophysical Properties: Porosity and Permeability

Petrophysical properties averaged over several analyzed cores are summarized in Table 1. Total porosity in Table 1 is that measured by helium porosimetry, and includes all pore space, including microporosity in clays and partially dissolved rock fragments.

Table 1. Petrophysical Properties of the Wilcox sandstone samples.

Parameter	Value
Total Porosity	~21%
Macroporosity	~13%
Microporosity	~8%
Permeability	18-50 md

Porosity visible in thin section and measured by helium porosimetry is denoted as macroporosity in Table 2, and includes pores greater than approximately 2 microns in diameter. The remaining porosity is microporosity with pore diameters of 2 microns or less, present within altered rock fragments and clay. The macroporosoity porosity is presumed to contribute to the permeability for hydrocarbons, while the microporosity does not. Since approximately 40% of the pore space is microporosity, this explains the relatively low permeabilities compared to the total porosities.

Mineralogical Composition of Reservoir Rock

The average rock composition of the samples, based on thin section, SEM, and X-ray diffraction analysis, is shown on Table 2.

Table 2. Composition of the Wilcox sandstone samples.

Component	Percent Bulk Volume
Quartz	30
Feldspar	10
Rock Fragments	30

Carbonate minerals	2-4
Clay (kaolinite, chlorite, illite/smectite)	5-10
Glauconite-Mica	6

Electron Microprobe Analysis for Geochemical Evaluation of Reservoir Rock

Electron Probe Micro Analyser (EPMA) is traditionally used for detailed geochemical analysis when subtle differences in composition of minerals are present. The sample has to be a polished thin section in order to avoid any contribution from topological effect of the sample surface on the quantitative accuracy of chemical analysis. The average area of thin section was selected for 100 points analysis. The random analysis were performed using 3micron spot size, at 20kV and 20ms dwell time, using image at magnification x50. As shown in Figure 10, mass % of non-Si oxides is predominantly Al, Na, K and Mg. The Ca presence is detected through entire analyzed area although at various quantities, from near 0 to 7.5%.

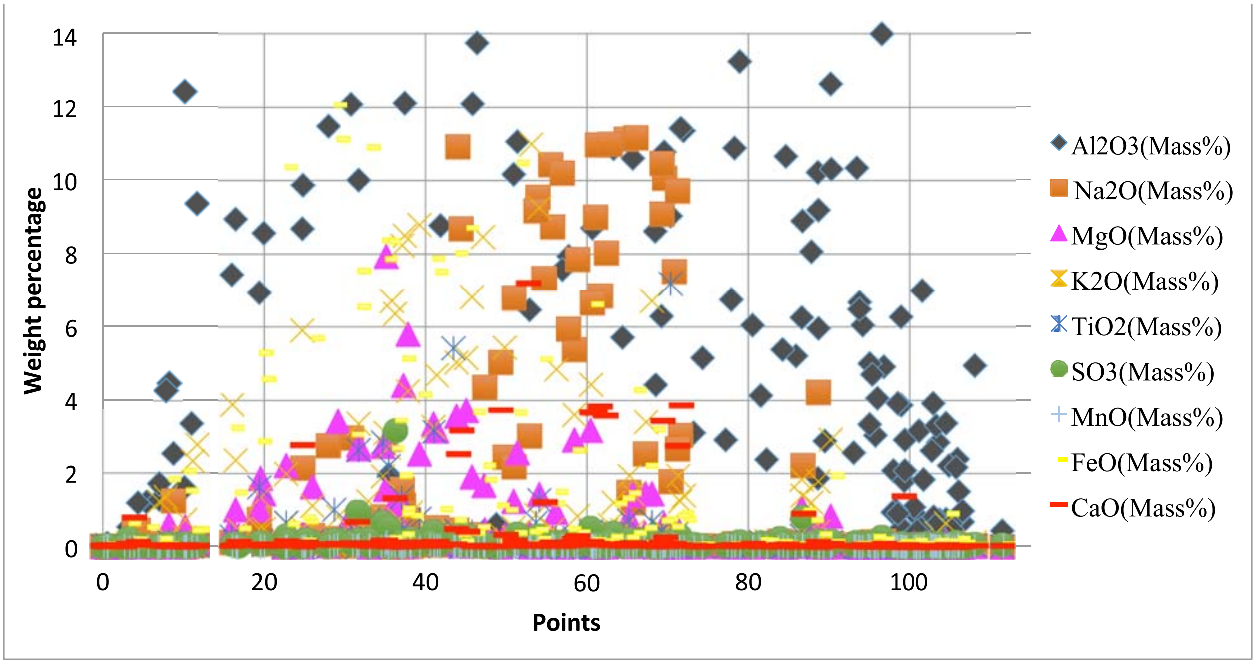


Figure 10. Electron Microprobe line profile (100 points analysed) across polished thin section show quantitative elemental composition of control sample of reservoir rock. SiO_2 was removed in order to have clear display of low-percentage values, and observe presence of Ca, Al, and Mg rich phases, as ones more susceptible to interaction with CO_2 rich brine.

When the line profile is for example projected on the Backscattered electron micrograph, as shown below in Figures 11 and 12, it confirms the anisotropic nature of the rock fabric, with various mineralogical enriched areas such as clays, feldspars or S-rich minerals. To better establish spatial correlation of different minerals, elemental maps can be acquired from the polished sections.

Elemental spatial distribution provides information on both, distribution and size, of Ca-rich minerals, as they are most susceptible to dissolution in contact with CO_2-rich brine. The effect of location and size of these minerals is important in understanding the mechanism

and potential effect the fluid-mineral interaction on porosity and permeability.
Images in Figure 13 represent various elemental maps (the bright color is high concentration of element present) and when displayed as a composite image it serves to observe how for example Al and Si maps overlap where alumino-silicates are present. This correlation would provide a valuable insight when reservoir rock is characterized before and after contact with CO_2-brine.

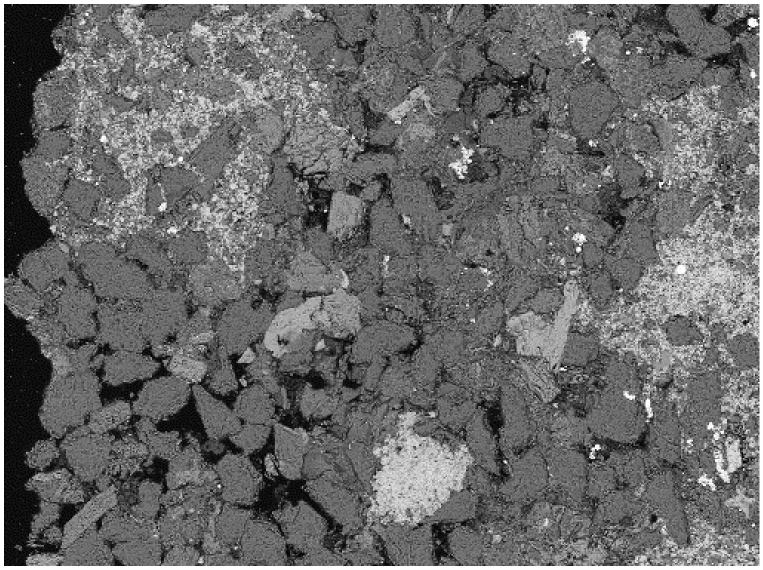


Figure 11. Backscattered scanning electron (BSE) micrographs reveal detailed architecture of the reservoir rock. Magnification x150 The BSE mode distinguishes between different compositions based on atomic mas bright areas represent higher atomic mas, such as Fe rich minerals (pyrite). Black regions are porosity, which appears to be much larger in areas with no clays present such as lower left corner. Rock- fragments and feldspars associated with smaller (micro) porosity.

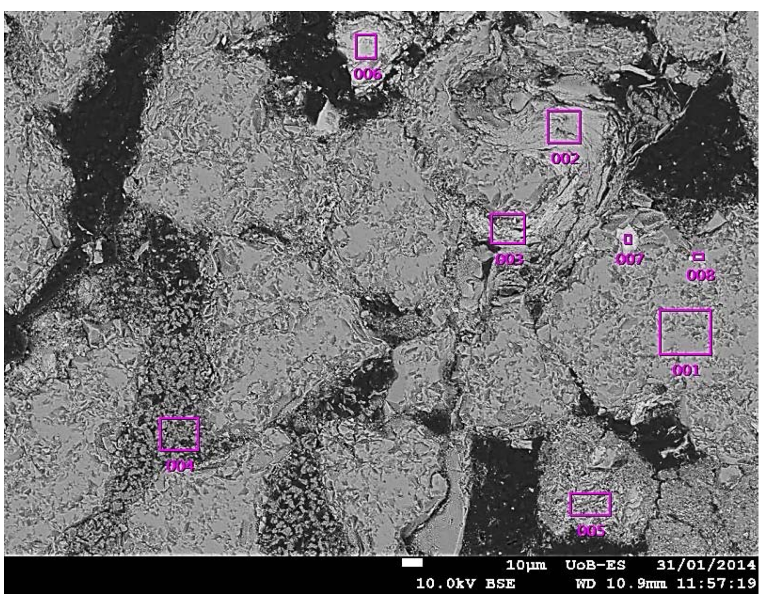
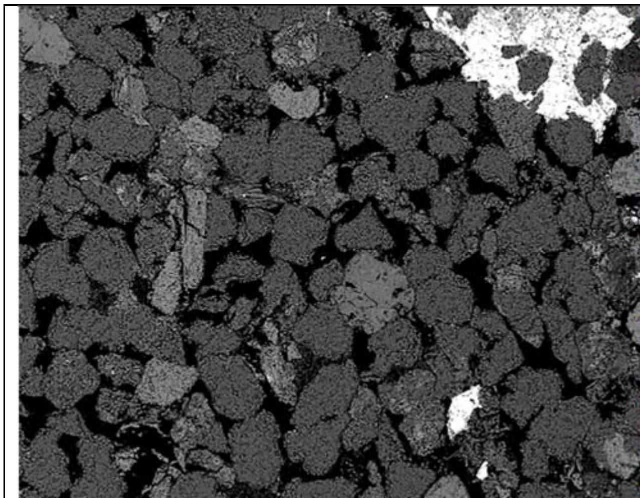
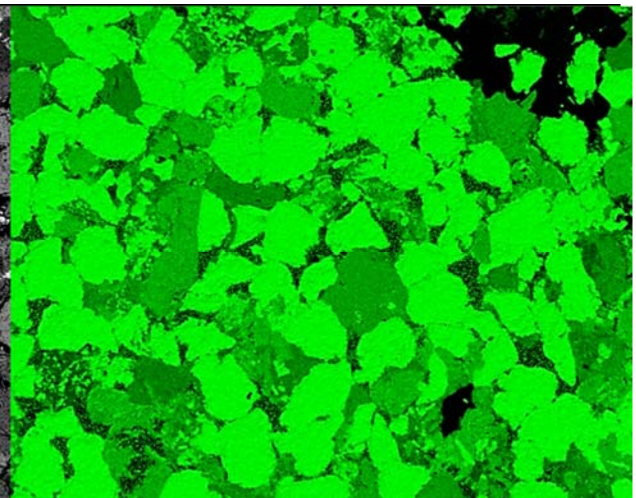


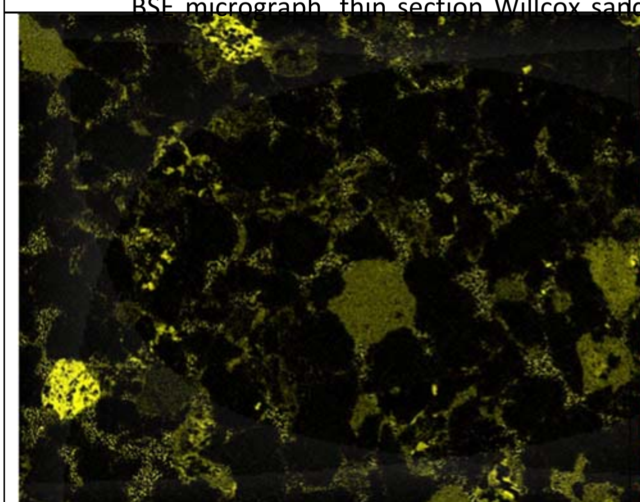
Figure 12. Backscattered scanning electron (BSE) micrograph obtained at higher magnification focused on clay particles that envelop quartz grains. In addition some of the platy lay crystals show physical deformation (S-shape agglomeration in the upper right corner of the image).

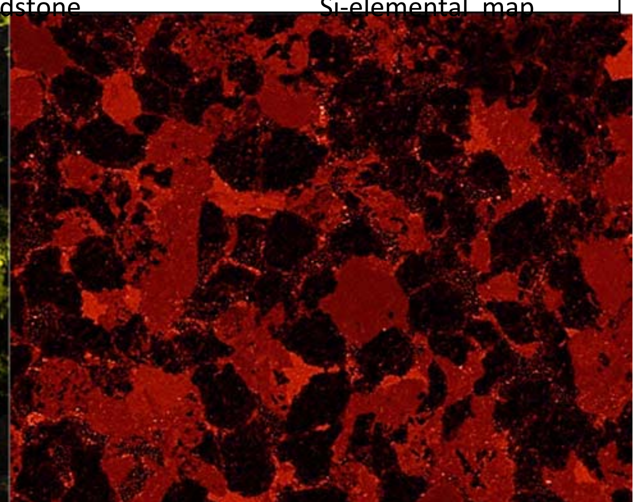


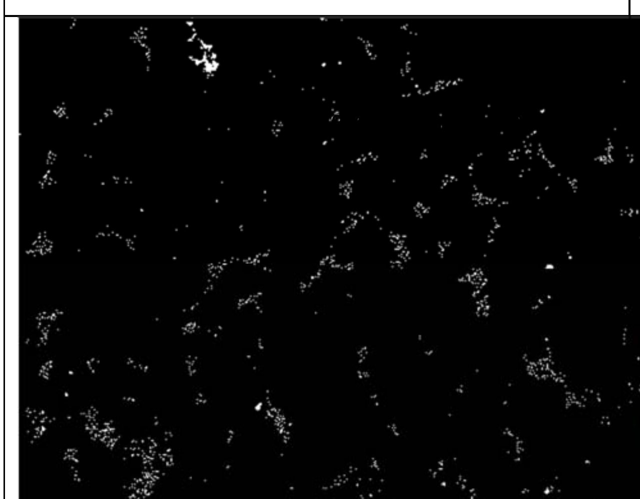
BSE micrograph, thin section Willcox sandstone

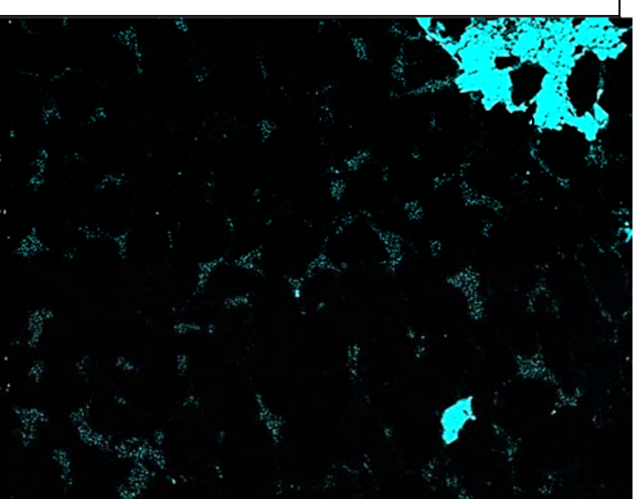


Si-elemental map









Ca-elemental map S-elemental map

Figure 13. Backscattered electron micrograph with accompanying elemental maps of Si, Mg, Al, K, Ca, Mg. These maps provide an insight on the spatial distribution of various minerals, and in the case of carbonate it is useful to know where potential dissolution will take place, and how it may impact porosity. Area shown is 500microns field of view.

Geochemical Modelling

The geochemical simulator, GEM-GHG, (GEM, 2008) a product of Computer Modeling Group (CMG), was used to model fluid/rock interaction with a core representative of the Wilcox Sandstone. The modeled core consists of 102 grid cells, with each grid cell maintaining the same dimensions of 4.5 m x 4.5 m in cross section and 0.5 m in length. Two injection wells are placed in the first grid cell while a production well is placed in the last cell. Of the two injectors, one injection well serves as a brine injector and another serves as a CO_2 injector, facilitating the concurrent injection of brine and CO_2, similar to the lab core experiments. Simulation parameters are shown on Table 3. A brine composition of 0.5M NaCl was used in the models. This is based on the original brine salinity in the Livingston Field, calculated from resistivity measurements.

Table 3. Simulation Parameters used in the GEM model.

Simulation Parameter	**Rock System**
Temperature (38^{o}C)	38
Pressure (MPa)	21.5
Initial Brine Saturation (%)	99
Initial CO_2 Saturation (%)	1
Porosity	0.2135
Permeability (mD)	32.3
CO_2 Injection Rate (m^3/day)	7.34
e Injection Rate (m^3/day)	7.34
Simulated time (days)	300

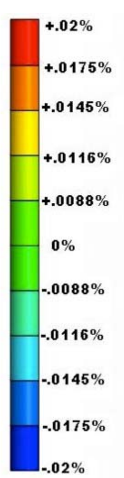
To establish a baseline, a simulation was performed without the injection of CO_2. An additional simulation was then performed in which the system is kept closed for the first seven days of simulation to allow aqueous ion concentrations to come to equilibrium with the core. Simultaneous injection of CO_2 and brine then begins on the eighth day and continues for 100 days. Based on the rock composition described above, the following reactions were included in the model (Table 4).

Thermodynamic and kinetic data are from the LLC Data Base (Delany and Lundeen, 1990) and Helgeson (1969).

Table 4. Mineral Reactions.

	Mineral precipitation and dissolution reactions	log10 keq	Âβ (m^2/m	Ea (J/mol	Initial Volum
[1]	Chlorite + $16H^+$ = $5 Mg2^+$ + Al^{3+} + $3H_4SiO_4$ + $6H_2O$	73.2010	80	90,000	0.030
[2]	Kaolinite + $6H^+$ = $5H_2O$ + SiO_2 + $2Al^{3+}$	6.8101	17,600	62,760	0.028
[3]	Illite+ $8H^+$ = $5H_2O$ + $.6K^+$ + $.25Mg^{2+}$ + $2.3Al^{3+}$	9.0260	26,400	58,620	0.027
[4]	Calcite + H^+ = Ca^{2+} + HCO_3^-	1.8487	88	41,870	0.025
[5]	Quartz = SiO_2 (aq)	-3.9930	7,128	87,500	0.590
[6]	K-Feldspar + $4H^+$ = $2H_2O$ + K^+ + Al^{3+} + $3SiO_2$	-0.2763	176	67,830	0.100
[7]	Albite + H^+ = Al^{3+} + SiO_2 + H_2O	4.0832	88	67,830	0.100
[8]	Anorthite + $8H^+$= $4H_2O$ + Ca^{2+} + $2Al^{3+}$ + $2SiO_2$	26.5780	88	67,830	0.100

The baseline simulation performed without the injection of CO_2 showed dissolution and precipitation of minerals was minimal yet evident. Because the pH of the initial water filled core was around 6, a small amount of calcite is expected to dissolve. The 3D simulation results, displayed in Figure 11, coincide with the expected dissolution.



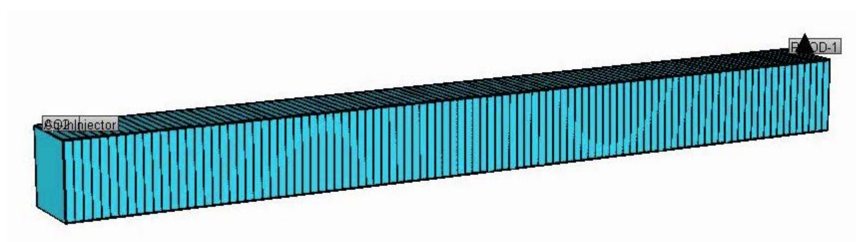
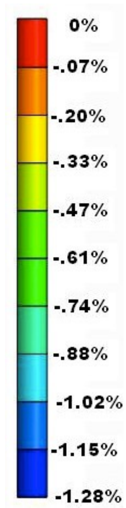


Figure 14. Calcite Dissolution without Injection of CO_2 at 11 days

Figure 14 demonstrates the calcite dissolution at 15 days from the beginning of the simulation. The pH of the initial system, 6, causes calcite to dissolve 0.0145% per grid block throughout the core.

A much more aggressive dissolution of calcite is expected when CO_2 is injected into the core. Figure 15 below demonstrates calcite dissolution after injection of CO_2.



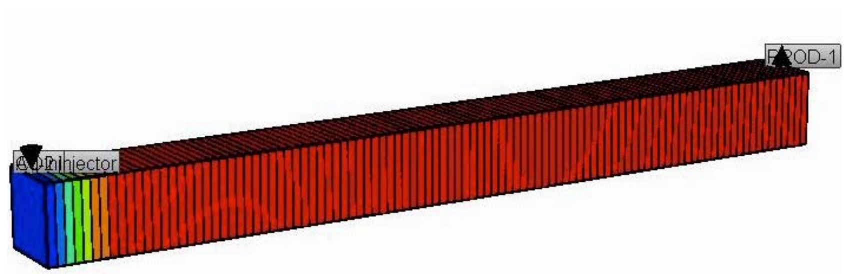


Figure 15. Calcite dissolution with Injection of CO_2 at 11 days.

The figure 15 depicts calcite dissolution 3 days after CO_2 and brine injection begins. There is greater calcite dissolution with an interaction with CO_2. The CO_2 front is represented by the larger amounts of dissolution near the injection site. 1% of calcite is dissolved in the second grid cell, whereas 0.20% is dissolved at grid block 7. The front will propagate through the core, flowing to the production site (right), increasing dissolution throughout the core.

Additionally, small amounts of kaolinite precipitated throughout the core after CO_2 injection, evidence of alteration of feldspar to kaolinite. The geochemical modelling suggests that exposure of the Wilcox Sandstone to CO_2 and water will result in the dissolution of carbonate minerals, which would increase both porosity and permeability. It could also result in the alteration of feldspar to kaolinite, which would result in a minimal increase in porosity and a decrease in permeability. Further modeling is planned both to understand the potential geochemical reactions and to select conditions for series of coreflood experiments in the laboratory.

Preliminary Coreflood Results

Over a 29 day period, the percent of calcium carbonate within the core decreased from 5% by weight, to something between 4.15% and 4.58% assuming all of Ca originated from carbonate mineral. The flow rate through the core was 1 mL/min, which would be extremely high in a reservoir away from the injection or production well. So these findings are probably best applied to near the injection wellbore region.

Further away from the injection site, it is likely that reaction rates will be slower as the flow rates decreases. It also appears that there might be a front of calcium that forms and is pushed downstream of the injection well if the reservoir calcium concentration follows the trend in Figure 16. Further away from the injection well, the pressure is likely to be less; therefore CO_2 may escape from the brine. If this happens, and the fluid is saturated with calcium from upstream reactions, precipitation of calcium carbonate can occur. This means that potentially pore throats can be plugged and as the consequence this will lower permeability.

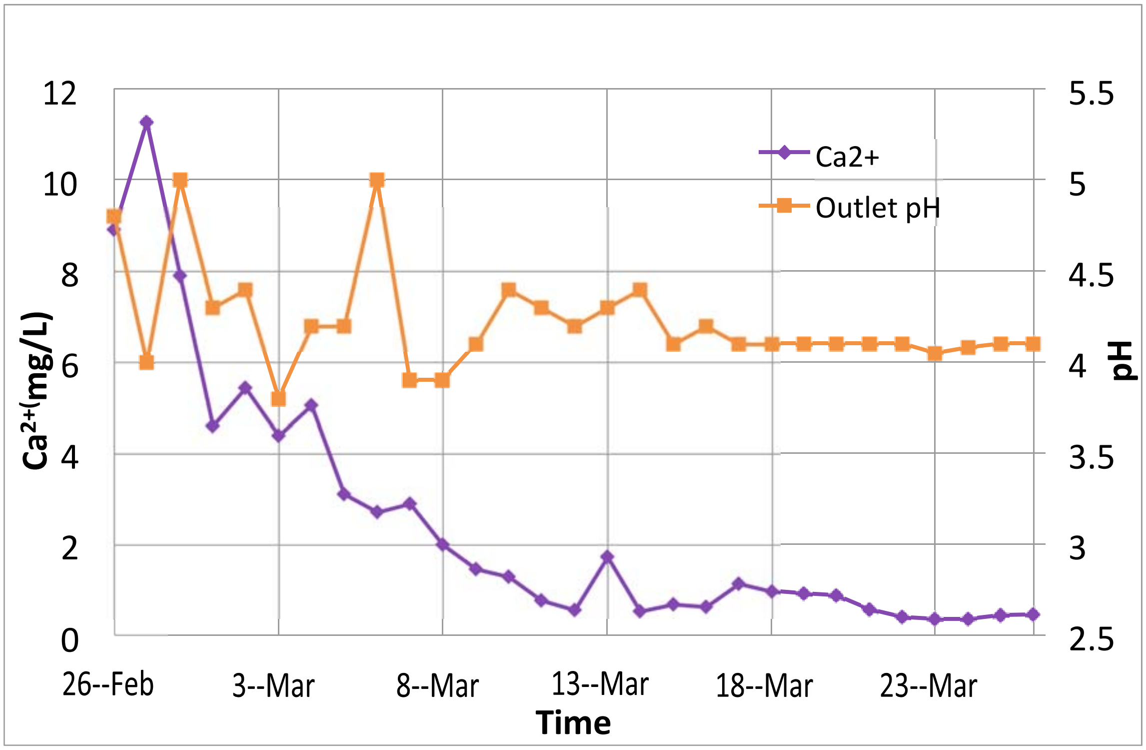


Figure 16. Ca-rich minerals within reservoir rock undergo dissolution as shown with the amount of Ca2+ detected in the effluent over 30days core flooding experiment. The effluent pH becomes stable in the last two weeks of the rock-fluid interaction.

Conclusions

- Geochemical Evaluation of the reservoir rock suggests that in addition to carbonate other mineral assemblages can undergo dissolution and potentially increase permeability (such as feldspars)
- Precipitation of kaolinite can potentially decrease permeability
- Modeling geochemical reactions prior to laboratory experiments can save time and address most relevant parameters (T, pH, P, salinity)
- Evaluating core samples from different depths in the reservoir will provide more complete prediction of the long-term behavior and EOR efficiency in this type of reservoir rock.

Acknowledgement

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and C. Windsor of Weatherford Laboratories.

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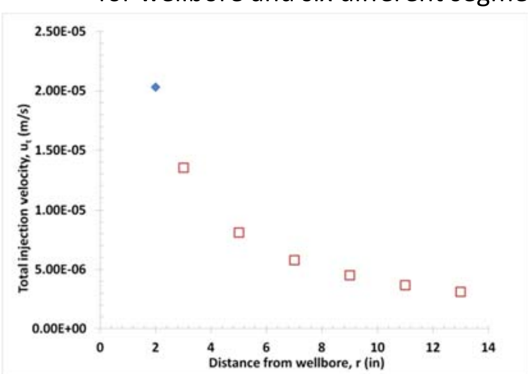
7.2 APPENDIX B – FINAL REPORT LSU PROJECT 2: FOAM MODELING

Research Direction

- Field-scale foam EOR and sequestration processes require an understanding of complex foam rheology, especially how foam rheology changes as foam propagates deep into the reservoir.
- This can be investigated by focusing on foam mechanisms based on bubble population balance model that can handle three different foam states and two steady-state strong-foam regimes.
- Such a model is in the literature, but it has never been stretched to field-scale multi-dimensional space.
- The resulting mechanisms obtained from mechanistic foam modeling can be implemented into local-steady-state foam modeling and existing commercial software.

Work Accomplished

- Foam injection into a radial geometry (pancake shaped, r_w = 2 inches, r_e = 14 inches, h = 4 inches) consisting of 6 segments with the total injection rate, $q_t = 6.58 \times 10^{-7}$ m^3/s is considered.
- The results in terms of total velocity, water saturation, relative gas permeability, trapped gas saturation, gas viscosity, mobility reduction factor, pressure gradient, and pressure for wellbore and six different segments are obtained as shown below.



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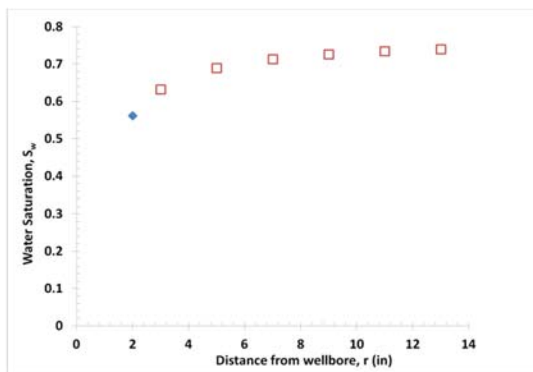

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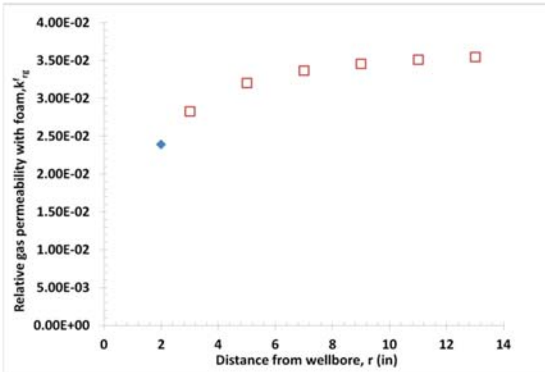

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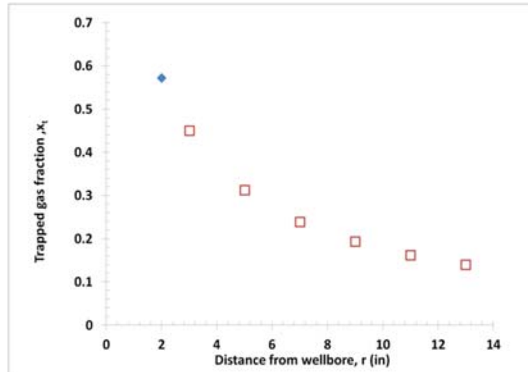

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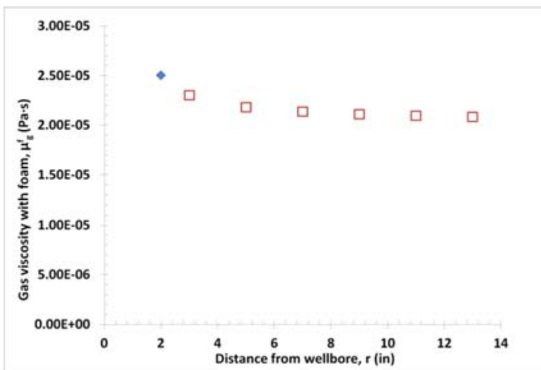
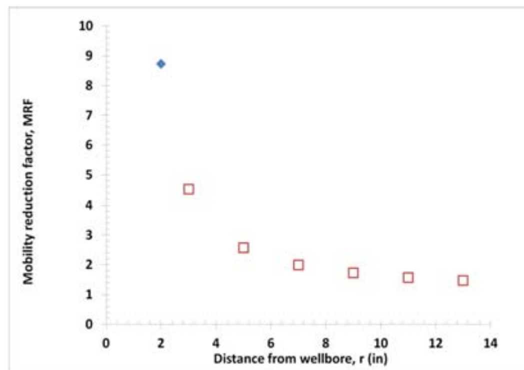
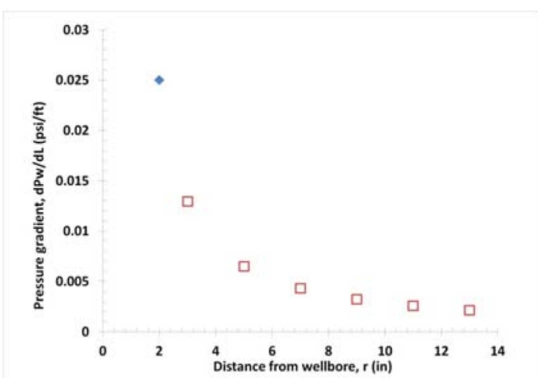


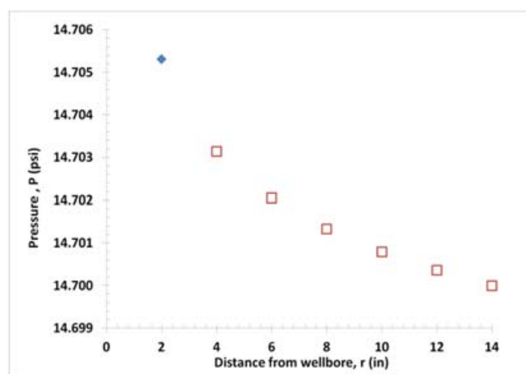
(e)



(f)



(g)



(h)

Figure 1. Foam properties across the radial system (a) Total injection velocity (b) Water saturation (c) Relative gas permeability (d) Trapped gas saturation (e) Gas viscosity (f) Mobility reduction factor (g) Pressure gradient (h) Pressure

7.3 APPENDIX C – RESERVOIR MODELING OF LIVINGSTON FIELD

Reservoir Modeling of Livingston Field, Louisiana

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Center for Petroleum & Geosystems Engineering
University of Texas at Austin

1. Introduction

The objective of this research is to build petrophysical models of the Livingston Field, located in Livingston Parish, Louisiana, and use these models within a model selection framework to select a few models that reflect the dynamic characteristics of the reservoir. The selected models can be subsequently used for predictive modeling of:

- CO_2 plume migration corresponding to different injection schemes
- Rock property alterations induced by geochemical reactions in the subsurface when the CO_2 dissolved in brine reacts with the carbonate facies present in the reservoir

Figure 1.1 shows the location of the Livingston field. For facies modeling, the geological features of the reservoir are being realized by SGeMS (Stanford Geostatistical Modeling Software), which is an open-source computer package for solving problems involving spatially related variables (Remy et al., 2007). For compositional reservoir simulation with coupled geochemistry, the CMG© simulator GEM is being used. In order to perform the flow simulation, the geological model is converted to a petrophysical model using information obtained at wells (core, logging) and by tuning the models using the observed dynamic data (history matching).

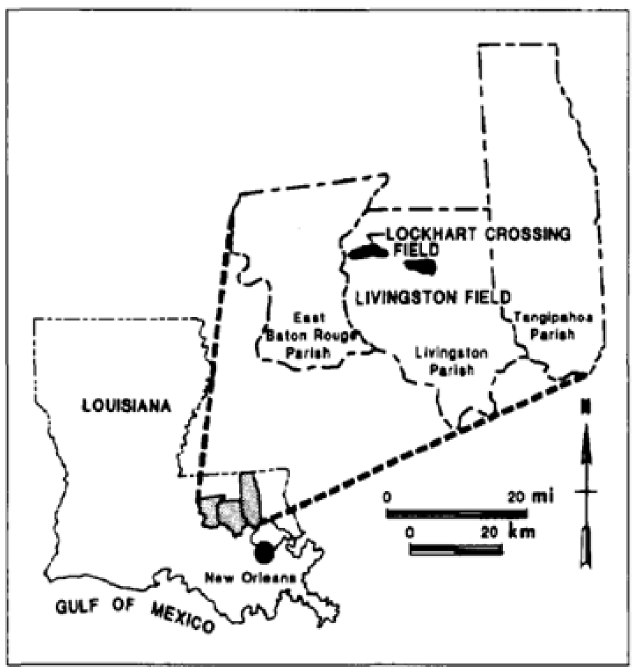


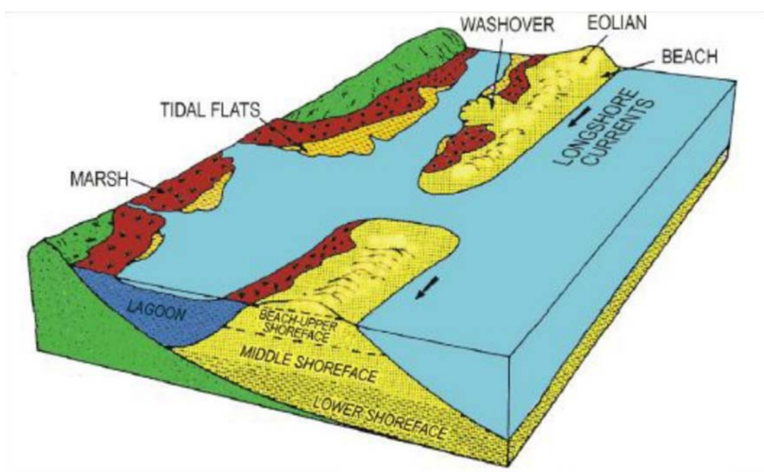
Figure 1.1 Location of Livingston field, Louisiana (Johnston and Johnson, (1987)

2. Field Description

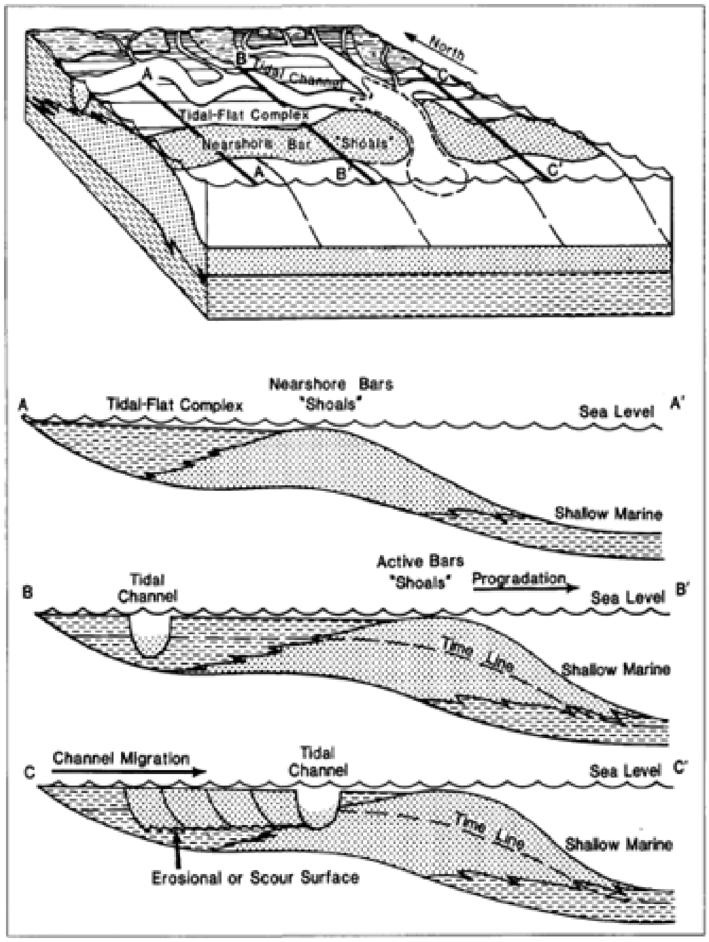
The Livingston field, discovered in 1983, has produced oil by primary (pressure depletion) and secondary recovery (waterflooding). The operator, Blackhorse Energy LLC., has a plan to perform WAG approximately for 30 years from 2013.

The reservoir exists within the 1st Wilcox sandstone formation. As shown in Figure 2.1, the depositional environment of the reservoir is a marine barrier island (upper, middle, and lower shoreface) partially eroded by a tidal channel. This shoreface system is similar to that of the neighboring Lockhart crossing field in the same 1st Wilcox formation, of which depositional environments is marine bar (upper, middle, and lower shoreface) with a marine channel (Self et al., 1986). The structure of the reservoir is a rollover anticline that follows a west-east trend. No-flow boundary system is assumed due to the faults around the reservoir. The tidal channel, consisting of low permeable sandstone and shale, cuts in the eastern part of the reservoir, thereby playing a role of a barrier that interrupts a fluid flow from the west to the east.

The productive zone exists from the eolian to upper shoreface, occasionally from the middle shoreface; because of an irregularity in oil-water contact (OWC) within the upper 5 ft of the middle shoreface. The drive mechanism is a solution gas drive with a water influx from the side and bottom aquifers. The initial pressure and bubble point pressure is 4,660 psia and 3,550 psia (under-saturated oil), respectively. Oil viscosity is 42 API.



(a) Johnston and Johnson (1987) (cited from Moslow and Reinson, 1984)



(b) Self et al. (1986)

Figure 2.1 Depositional environment of the 1st Wilcox sandstone formation.

3. Facies Modeling

3.1. Overview

A facies model was built using SGeMS, which is an open-source computer package software for geological modeling. The input data was gathered from LAS data files for 29 existing wells, CMG GEM input data file, and reference report that are provided from the Blackhorse Energy LLC. (Kulha, 2013). We re-evaluated the logging data and aim to rebuild a GEM input data file for enhancing the reliability of the reservoir simulation.

The anticline structure of the reservoir model was stratigraphically-transformed to a layer-cake model in order to better estimate and model the spatial continuity of facies and to distribute them appropriately in the depositional environments. SISIM (Sequential Indicator Simulation), a conventional two-point statistics, was applied for the facies distribution. The depositional model was composed of 15 layers from the top of the upper shoreface to the bottom of the lower shoreface. Logging data were inserted as point set conditioning information, and a Cartesian grid system was used to perform the spatial simulations. The grid dimension was assumed to be 92 x 39 x 15 with a grid size of 264 ft x 264 ft x 0.067 (dimensionless). The thickness of the grid is standardized from 0 to 1. All the gridblocks were categorized into five facies as follows: upper shoreface, middle shore face, lower shoreface, tidal channel fill mud, and limestone baffle.

Petrophysical data are subsequently allocated to the gridblocks consistent with the facies distribution. Afterwards, the structural model will be built as a new input data file of CMG GEM.

3.2. Comparison to the current CMG GEM input data file

The current GEM input data file consists of 20 layers: top 5 layers describe cap rock (lagoonal shale) and the other 15 layers represent the shoreface. The GEM input data file delineates the facies distribution as follows:

- Layer 1-5: Cap rock
- Layer 6-13: USF (upper shoreface + middle shoreface)
- Layer 14-20: LSF (lower shoreface)

In contrast, the model proposed in this report is made up of 15 layers describing the pay zone. An impermeable cap rock will be assumed to overlay the pay zone and marine shale will be assumed to be the basement rock. Thus, the total number of gridblocks is reduced from 71,760 to 53,820. According to the LAS data files, any gridblock showing positive volume of clay (limestone) are regarded as a limestone baffle. Most of the baffle is fully saturated with brine water.

3.3. Facies modeling

Figure 3.1 shows the reservoir boundary and the distribution of 27 wells used for facies modeling: 24 actual wells and 3 synthetic wells. The vertically aligned bars indicate the wells. The 24 wells are the actual wells that not only have logging data (LAS files) but also are included in the current CMG GEM input data file. According to the reference (Kulha, 2013), the facies codes are allocated to the 21 actual wells as follows: 1 is upper shoreface; 2 is middle shoreface; 3 is lower shoreface; 4 is channel fill mud; and 5 is limestone. In Figure 3.1, the other three actual wells having no facies information are expressed as gray colors.

It is reported in the reference that the eastern part of the target reservoir is filled with tidal channel fill mud. However, there are no wells to explicitly condition this part of the reservoir and render it a non-pay region. For this reason, three synthetic wells were set up along the eastern boundary of the reservoir for modeling the channel.

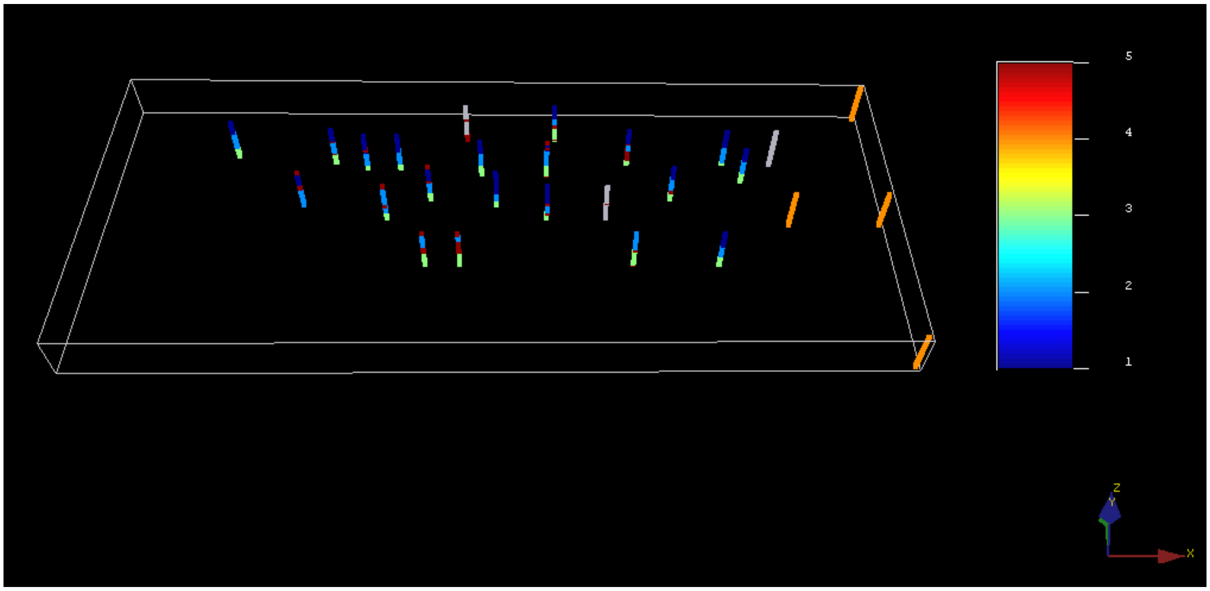


Figure 3.1 Well distributions with facies data in the depositional model.

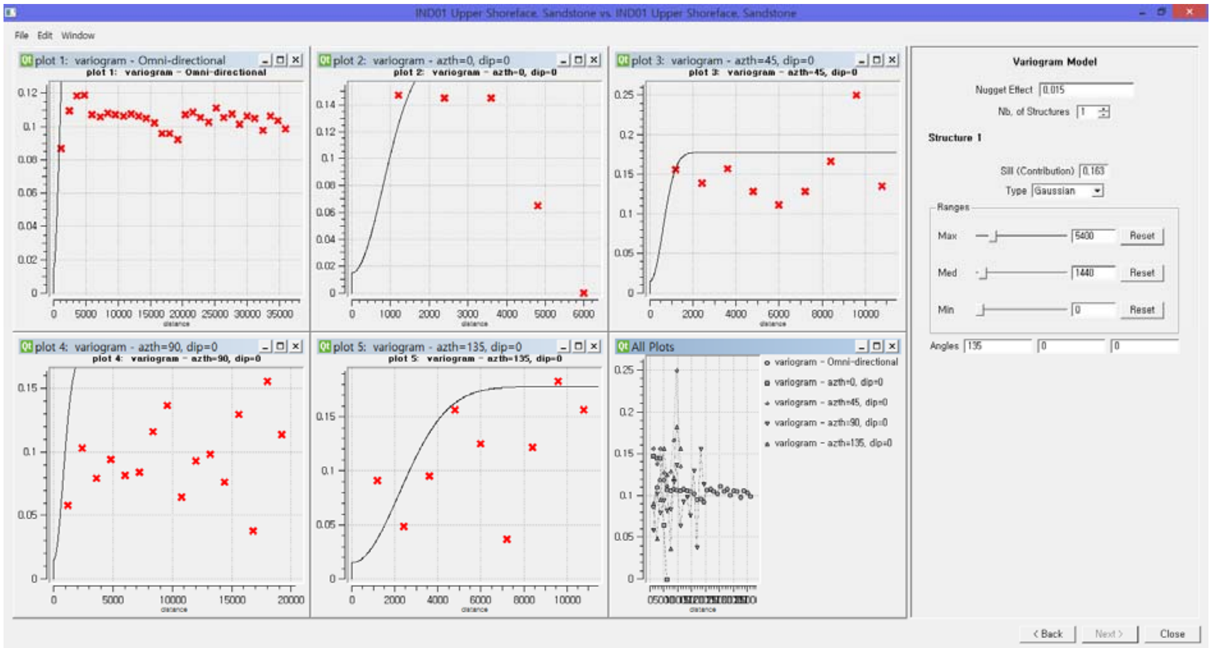
Table 3.1 summarizes the statistical parameters of the variogram models of each facies. Figures 3.2 through 3.5 show the indicator variogram models for each facies except the tidal channel fill mud. The red dot indicates the experimental variogram values and black solid line does the theoretical variogram model, respectively. All information shown in these figures, e.g., the maximum and median ranges from the horizontal variograms, the minimum ranges from the vertical variograms, sill (sample variance), the types of variogram model (Exponential, Gaussian, Spherical), the azimuth angles, are used for facies distribution using SISIM.

Anisotropy is characterized by an ellipsoid with three directions (azimuth, dip, rake) and the ranges (maximum, median, minimum) along each direction. Both dip and rake angles are zero based on the assumption of essentially flat structures. It seems that the shoreface facies exhibit continuity along an azimuth of 135 degree with different ranges. It is noted that this SE-NW trends might result from the lack of well data along the N-S direction compared to the W-E direction (see Figure 3.1).

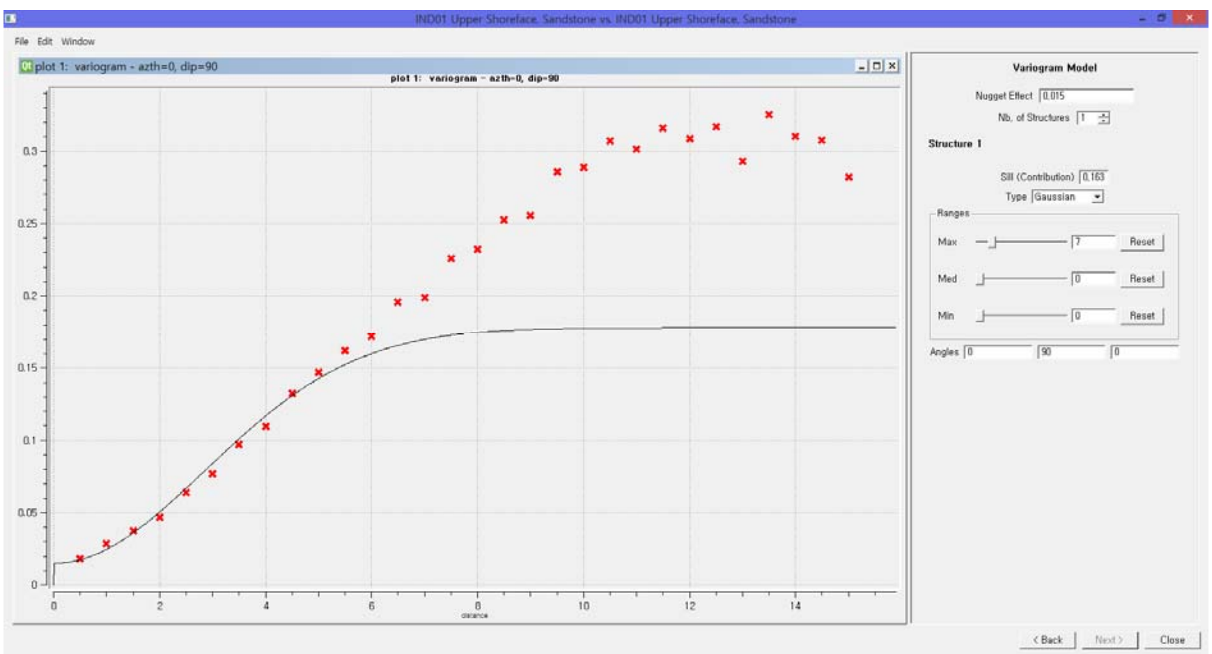
The vertical variograms of the shorefaces shows a trend in the vertical direction because of the intrinsic characteristics of the depositional environment (see Figures 3.2(b), 3.3(b), and 3.4(b)). For the limestone, the cyclicity is observed in the vertical direction because these baffles are interbedded in the shorefaces (see Figure 3.5(b)).

Table 3.1 Indicator variogram parameters of four facies

Facies	Mean	Variance	Nugget	Model	Model contribution	Azimuth (degree)	Max (ft)	Med (ft)	Min (-)
Upper shoreface	0.231	0.178	0.015	Gauss	0.163	135	5400	1440	7.0
Middle shoreface	0.287	0.205	0.020	Gauss	0.185	135	3630	3300	4.2
Lower shoreface	0.201	0.161	0.005	Gauss	0.156	135	4800	3600	6.5
Limestone	0.100	0.090	0.005	Spherical	0.085	45	2520	2520	3.1

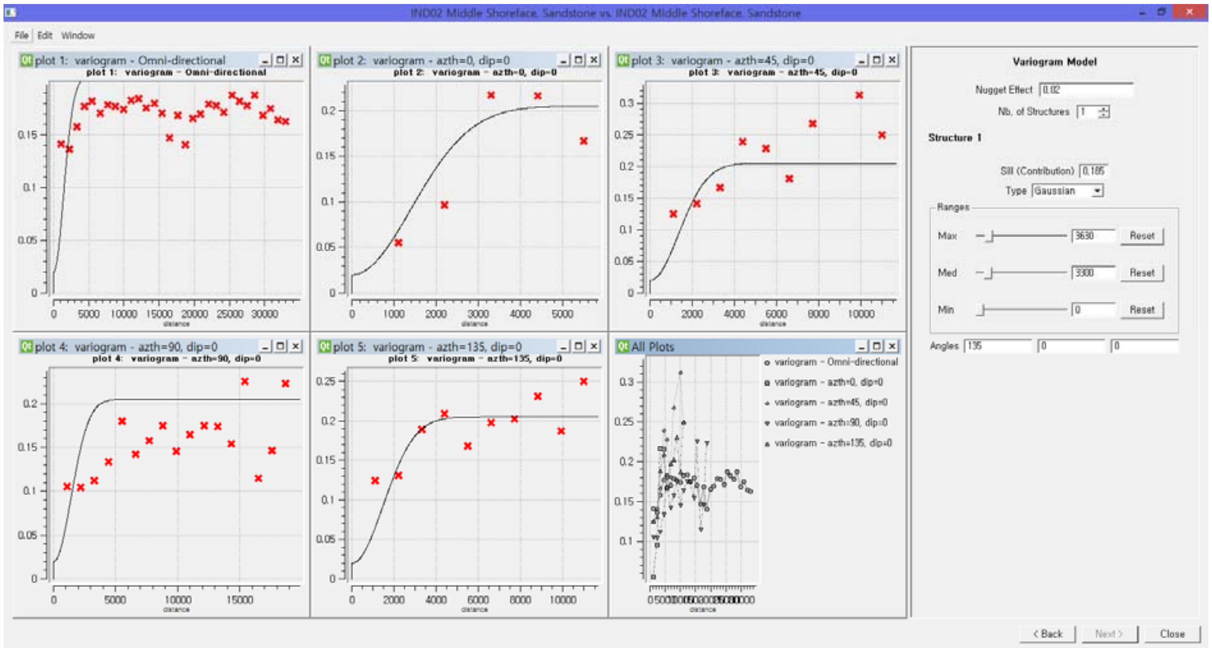


(a) Horizontal variogram

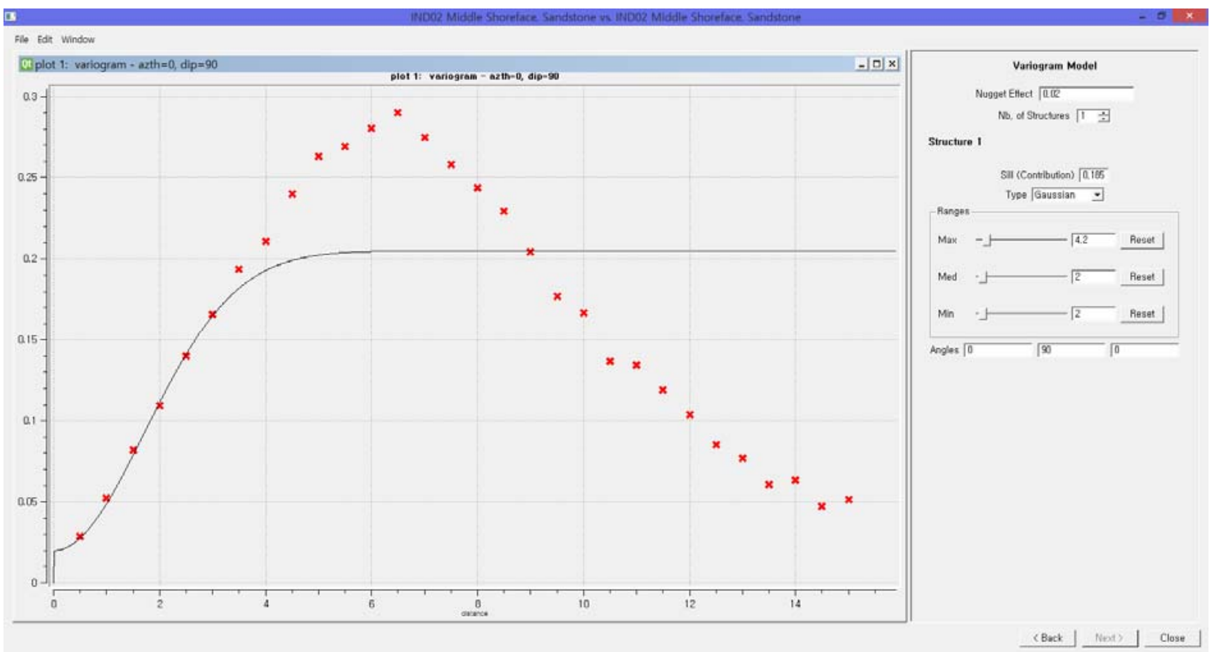


(b) (b) Vertical variogram

(c) Figure 3.2 Indicator variogram for the upper shoreface.

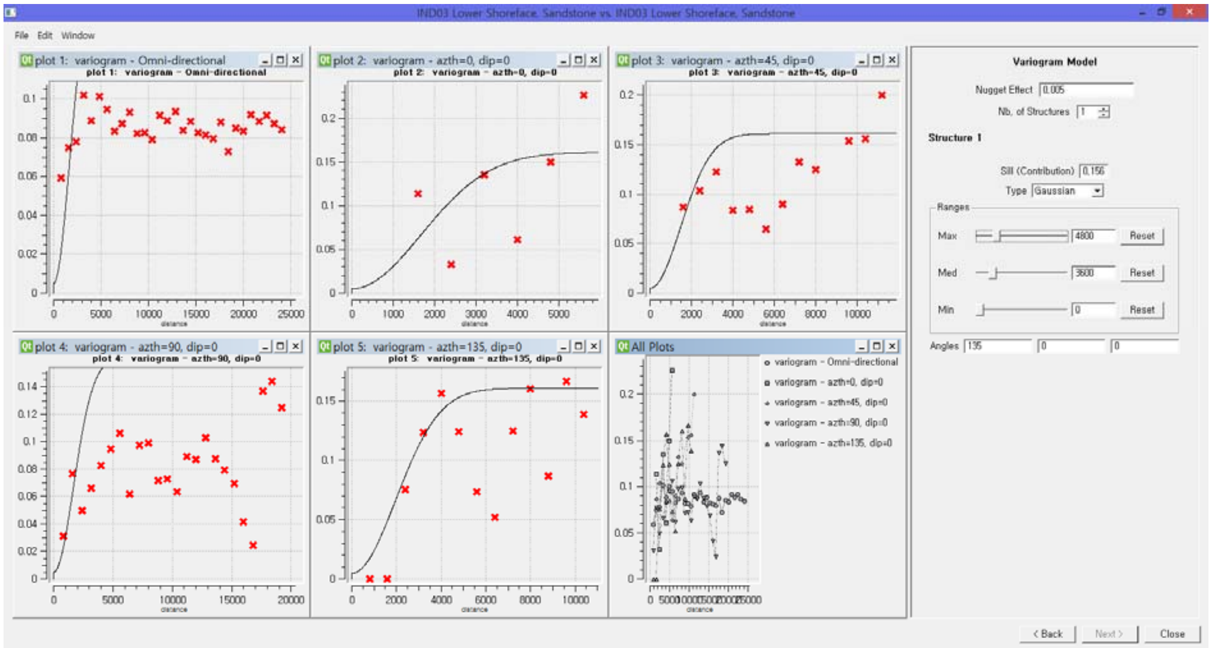


(a) Horizontal variogram

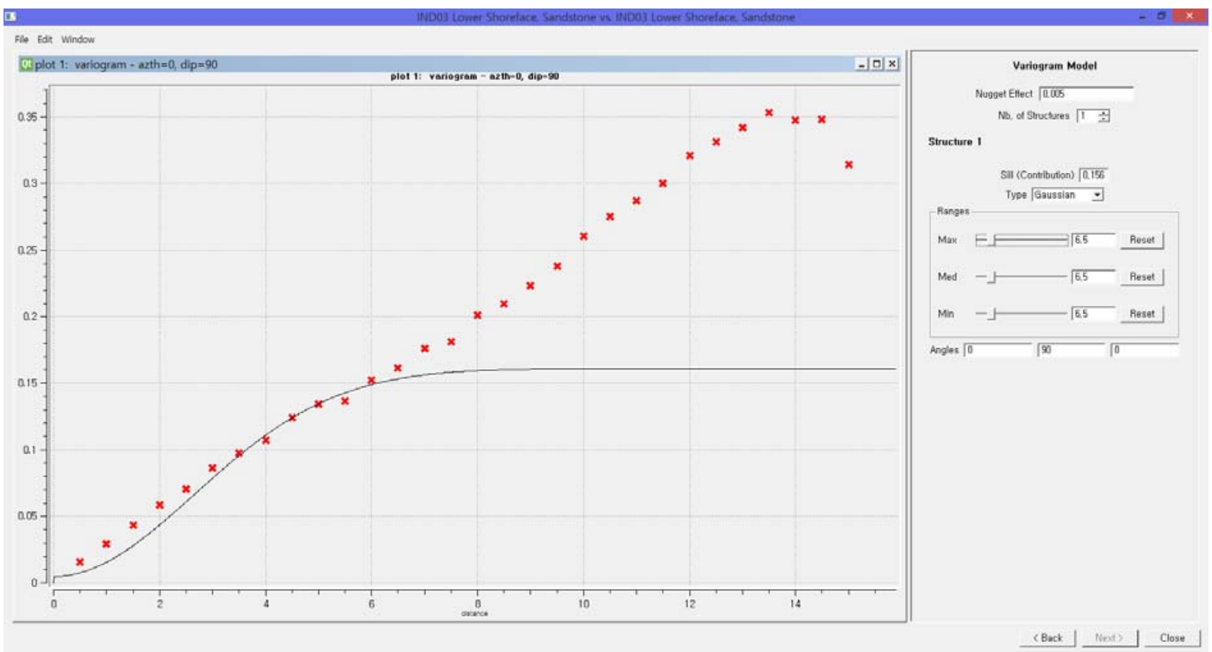


(b) Vertical variogram

Figure 3.3 Indicator variogram for the middle shoreface.

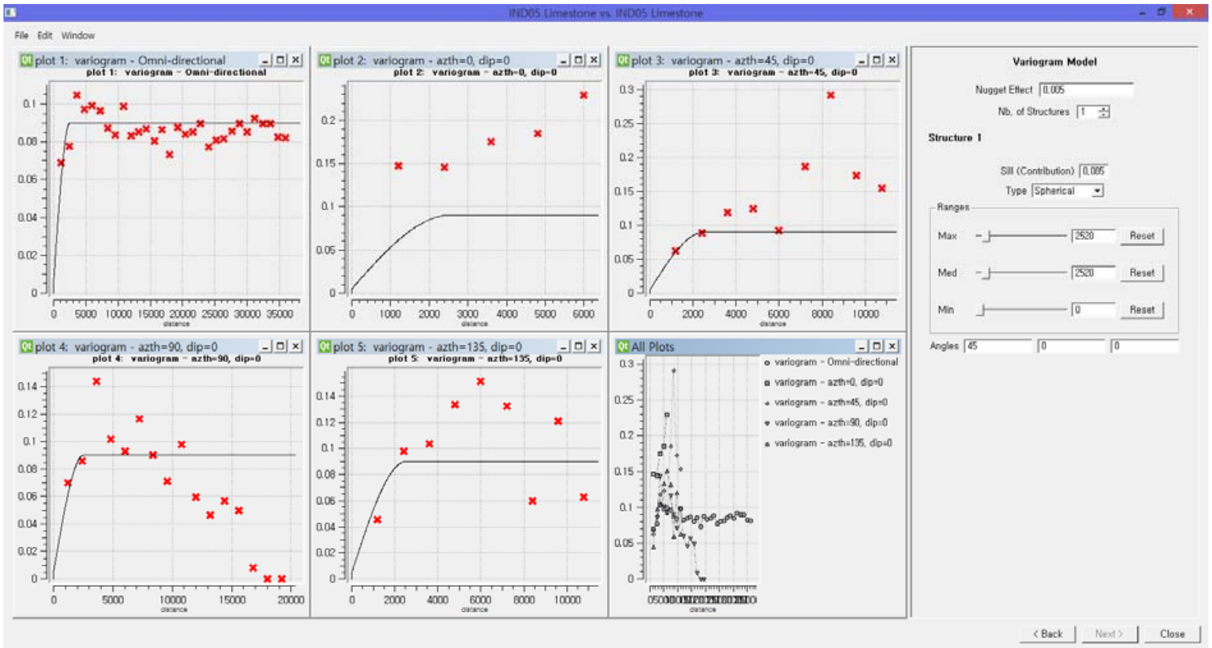


(a) Horizontal variogram

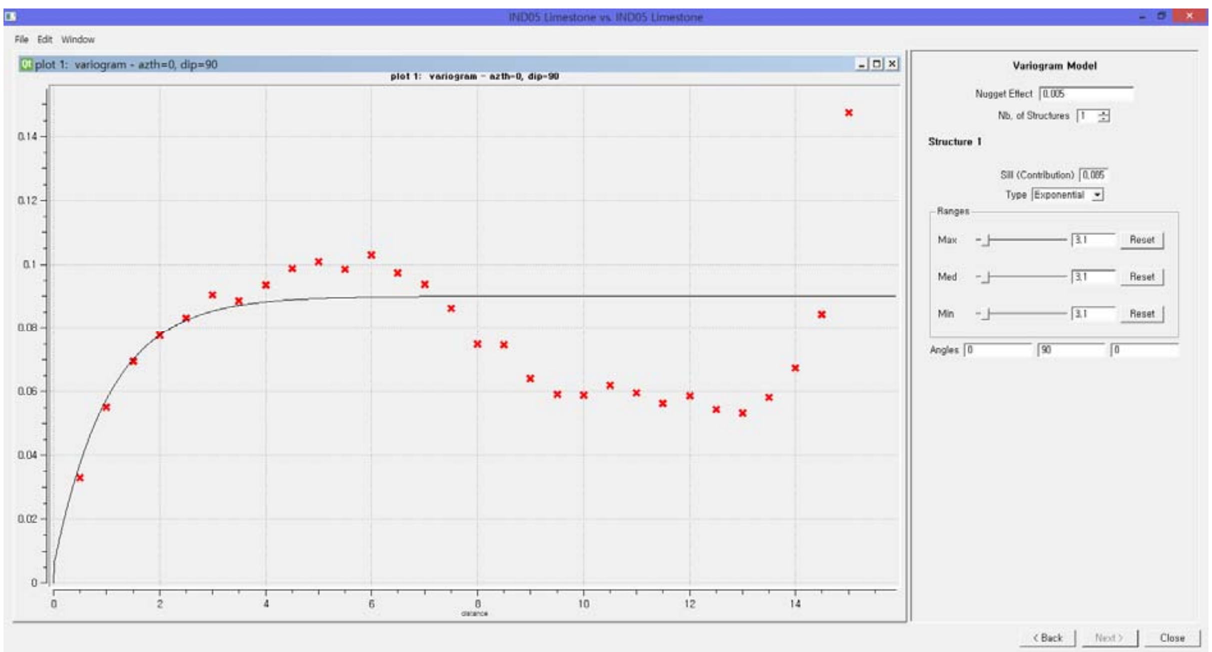


(b) Vertical variogram

Figure 3.4 Indicator variogram for lower shoreface.



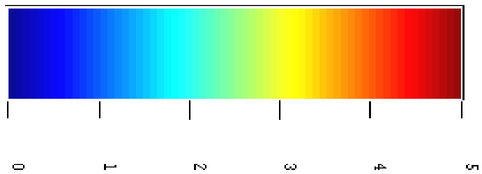
(a) Horizontal variogram



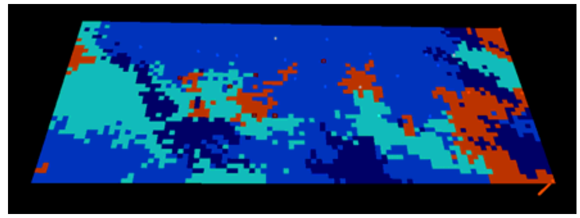
(b) Vertical variogram

Figure 3.5 Indicator variogram for the limestone.

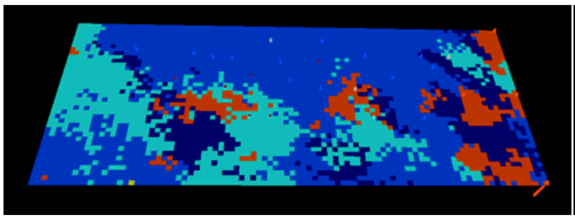
Five different facies models were generated from SISIM. Figure 3.6 depicts cross-sections of one realization of the facies model from the 1st layer (top, the shallowest) to the 15th layer (bottom, the deepest). In this figure, the vertically aligned sticks indicate the wells. The figure also provides the scale bar representing the facies code: 0 is unknown facies; 1 is upper shoreface; 2 is middle shoreface; 3 is lower shoreface; 4 is channel fill mud; and 5 is limestone. The cross-sections of the generated facies model conserved facies information of the wells obtained from LAS data files. SISIM, however, yielded regions having unknown facies code, resulting from the lack of well data since few wells were located in the southern or eastern regions of the target reservoir. These regions are regarded as no pay zone. The eastern part is assumed as channel fill mud region and the southern region is assumed to be fully saturated with brine water. Furthermore, SISIM hardly captured the continuity of channel fill mud due to the lack of well data that can provide the channel facies information even though three synthetic wells were set up along the eastern boundary of the reservoir model. Several other realizations of the facies are included in the Appendix C-1 to the report.



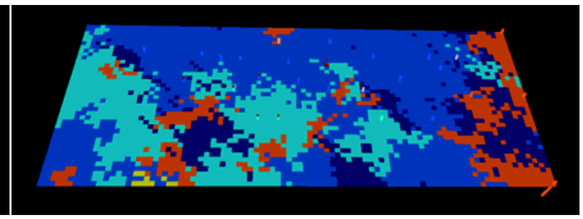
(a) Scale



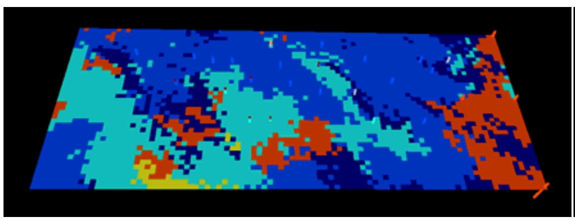
(b) 1st layer (the shallowest)



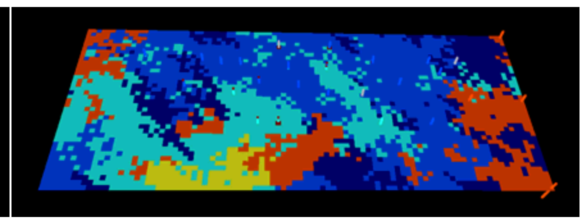
(c) 2nd layer



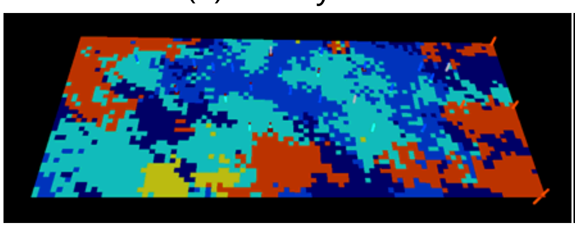
(d) 3rd layer



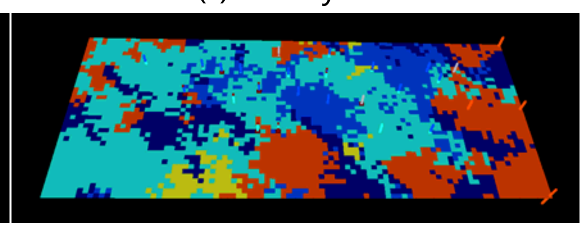
(e) 4th layer



(f) 5th layer

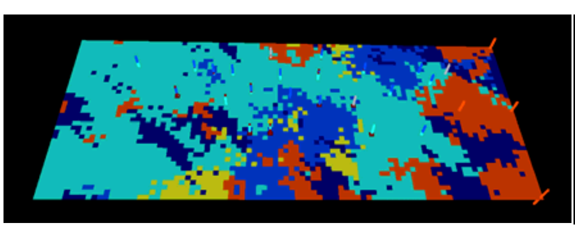


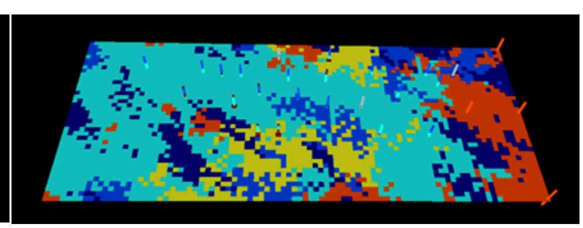
(g) 6th layer



(h) 7th layer

Figure 3.6 Plain view of the 1st facies model: 0: unknown (non-pay facies); 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.





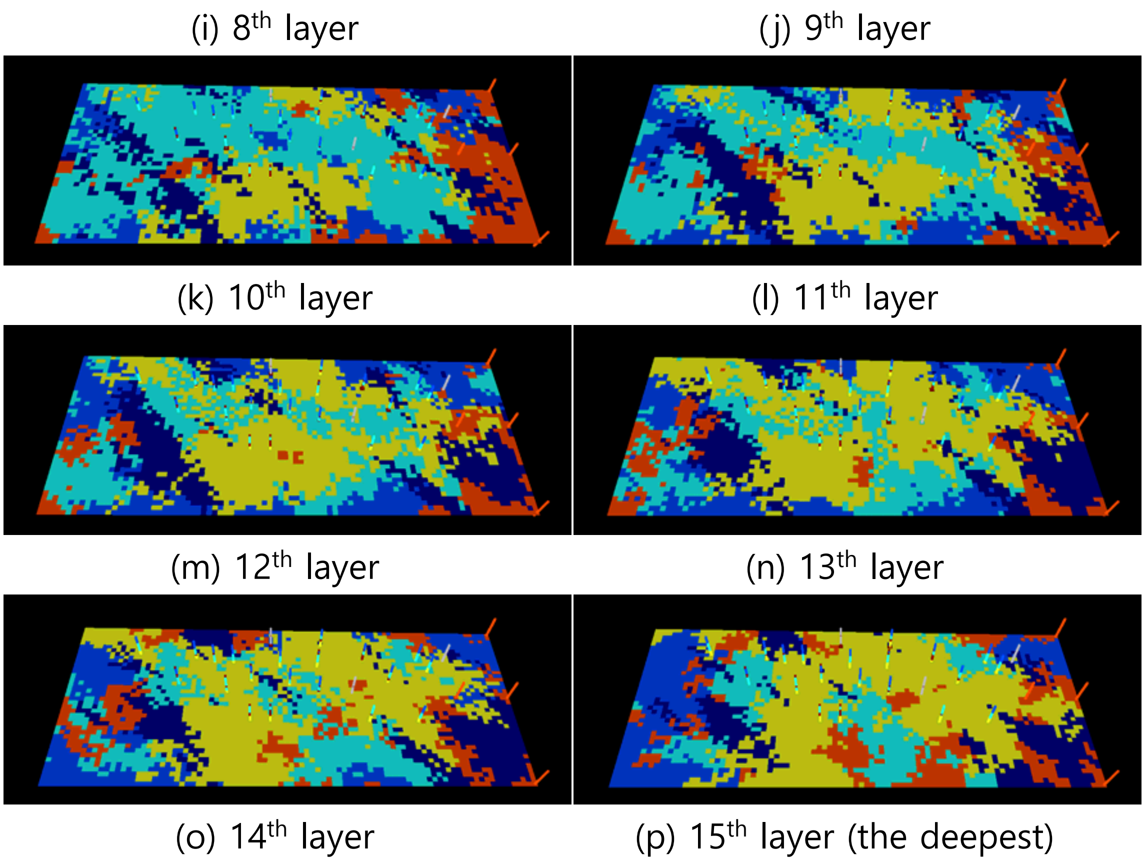
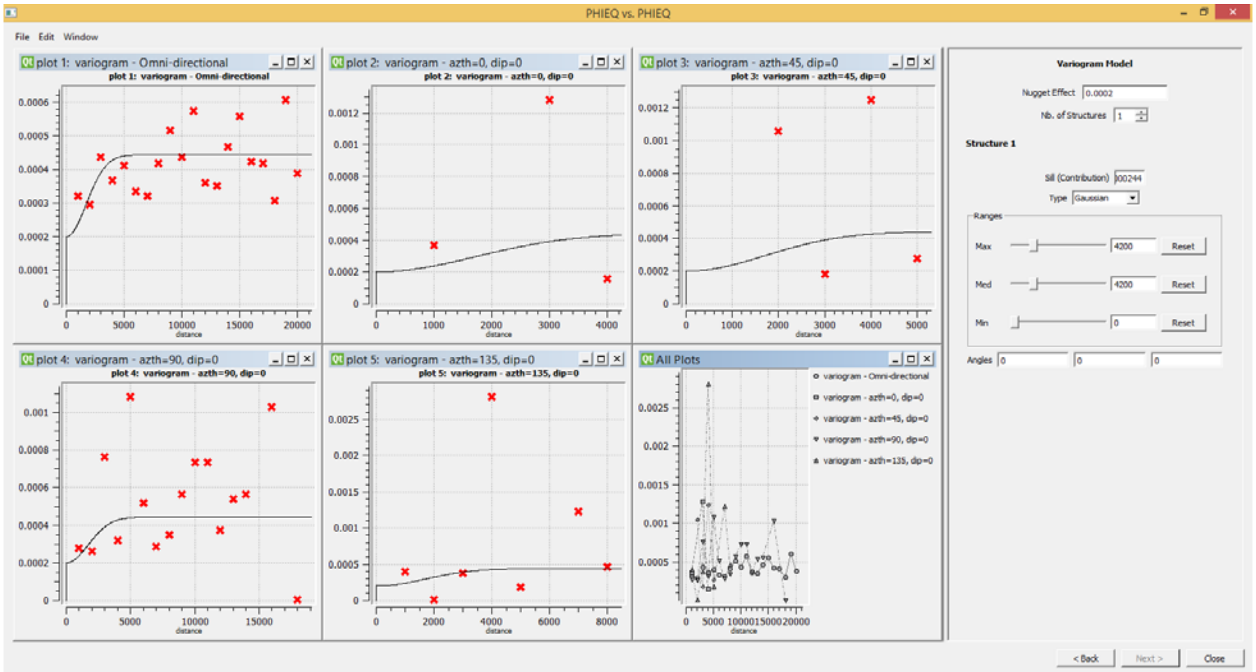


Figure 3.6 (continued): Plain view of the 1st facies model: 0: unknown (non-pay facies); 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.

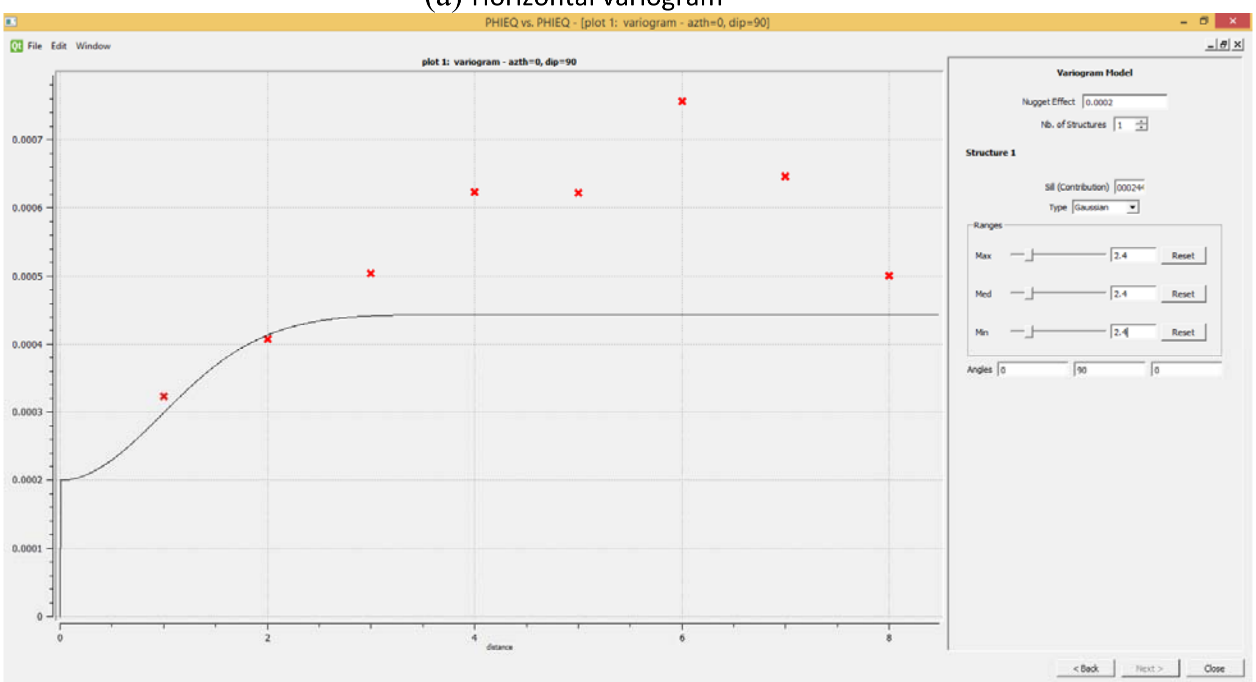
3.4. Petrophysical modeling

For the five facies model, their porosity distributions were generated by performing SGSIM (Sequential Gaussian Simulation). Omni-directional Gaussian variogram model were assumed for porosity modeling of the identical facies. Figures 3.7 through 3.10 show the variogram of effective porosity for the four facies. The porosity of the tidal channel fill mud is assumed to be constant as 0.046, the arithmetic mean of the porosity for the clay obtained from LAS data files. Figures 3.11 depicts cross-sections of effective porosity distribution from the 1st layer (top, the shallowest) to the 15th layer (bottom, the deepest). The gray region indicates the unknown facies region due to the lack of well data as shown in Figure 3.6. Several realizations of the porosity are included in the Appendix C-2.

The distribution of estimated porosity is dependent upon the distribution of the facies. In this study, the results of facies and the corresponding porosity modeling revealed the weakness in modeling the channel fill mud due to the lack of data.

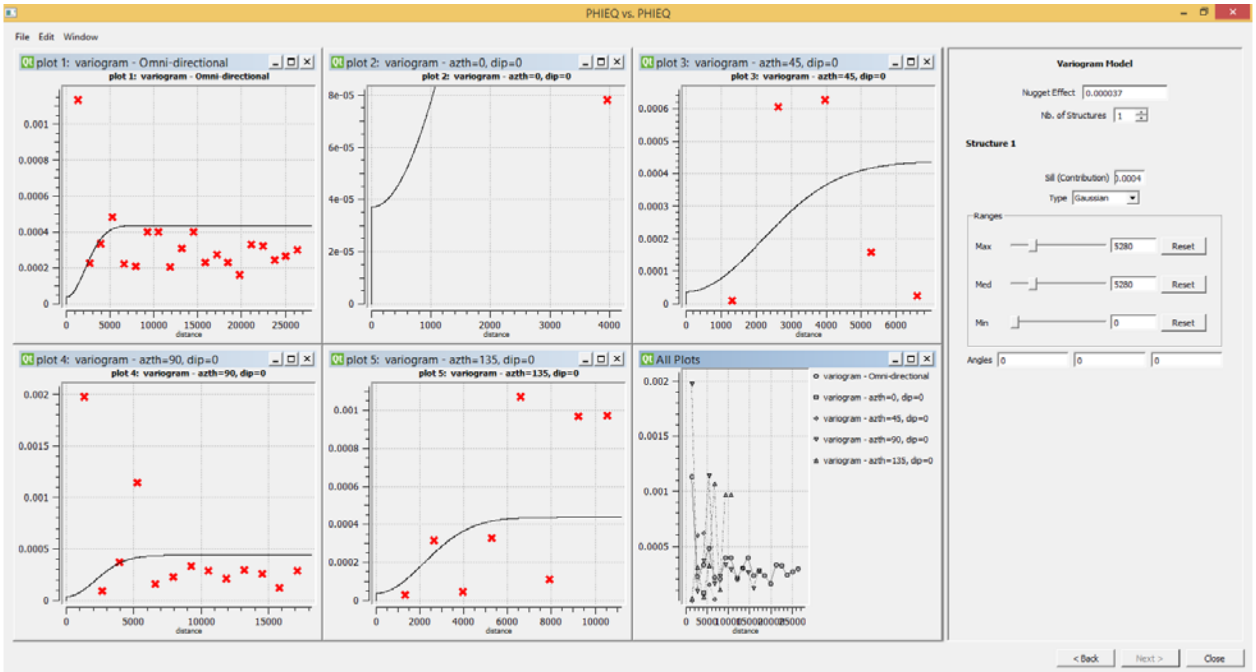


(a) Horizontal variogram

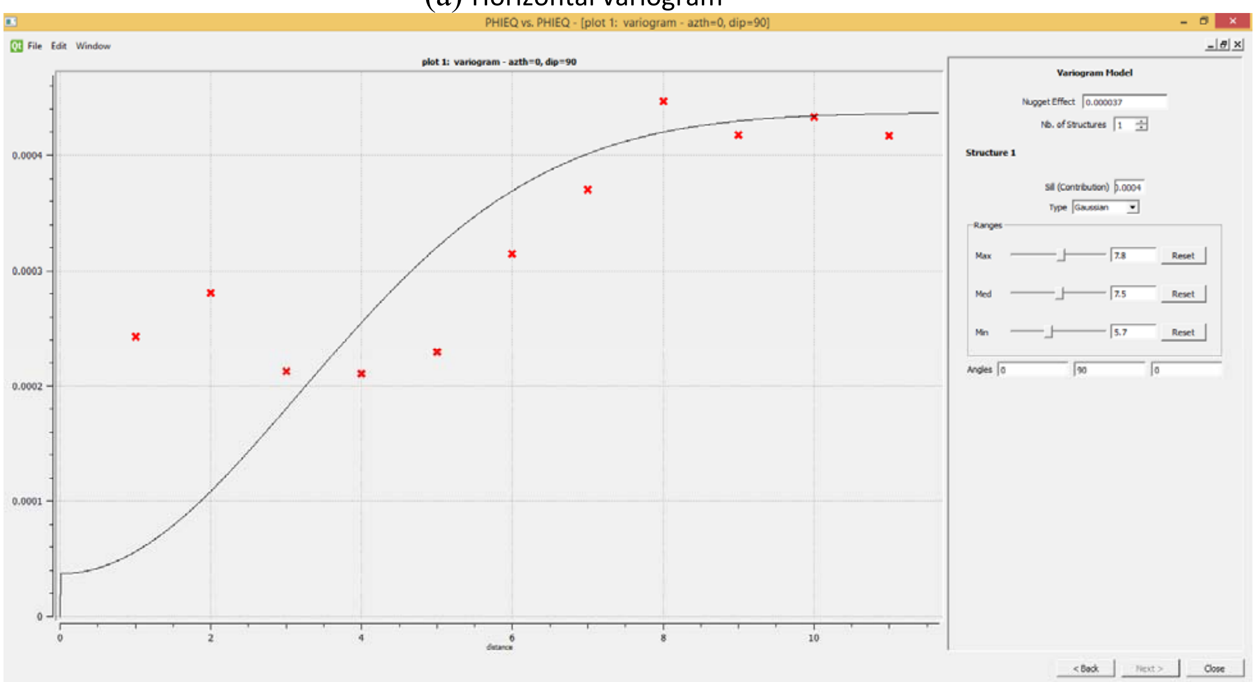


(b) Vertical variogram

Figure 3.7 Variogram of effective porosity for the 1st facies: upper shoreface.

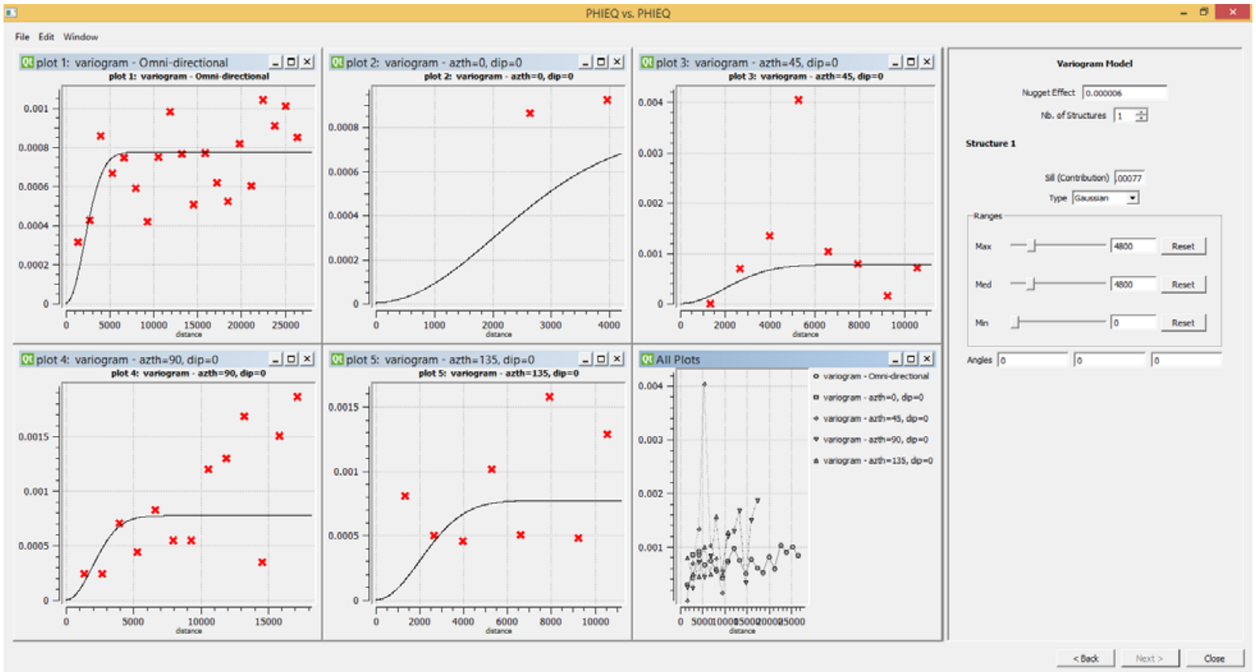


(a) Horizontal variogram

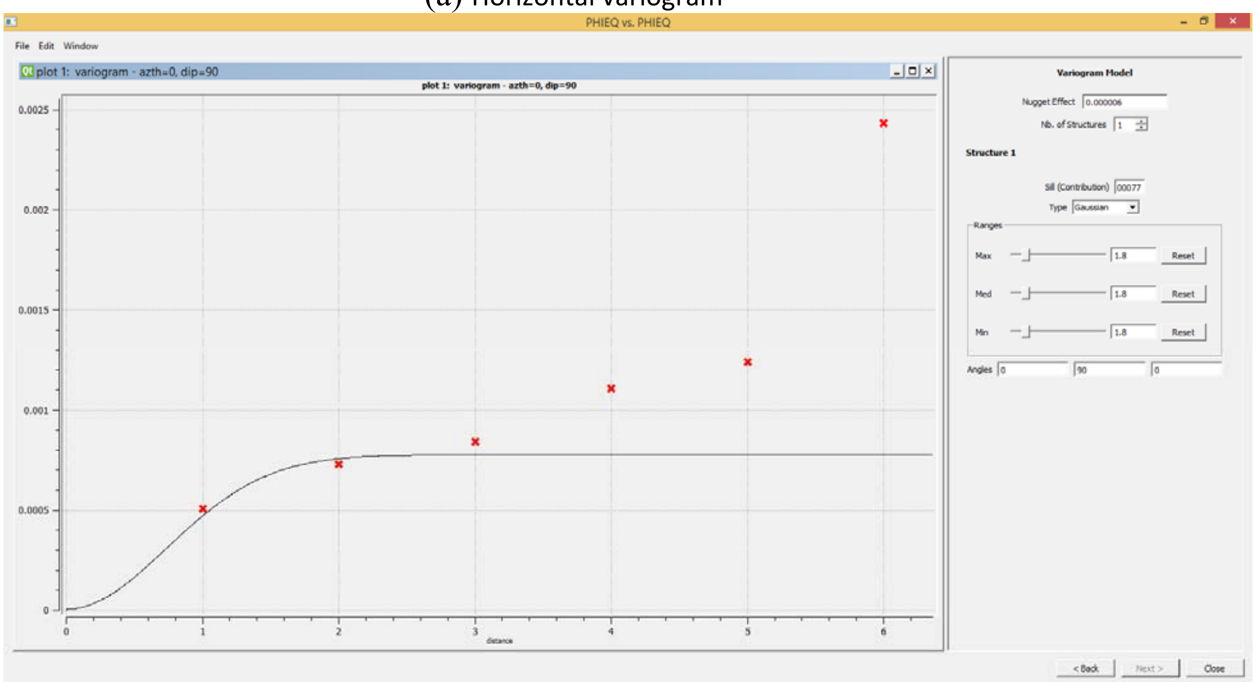


(b) Vertical variogram

Figure 3.8 Variogram of effective porosity for the 2nd facies: middle shoreface.

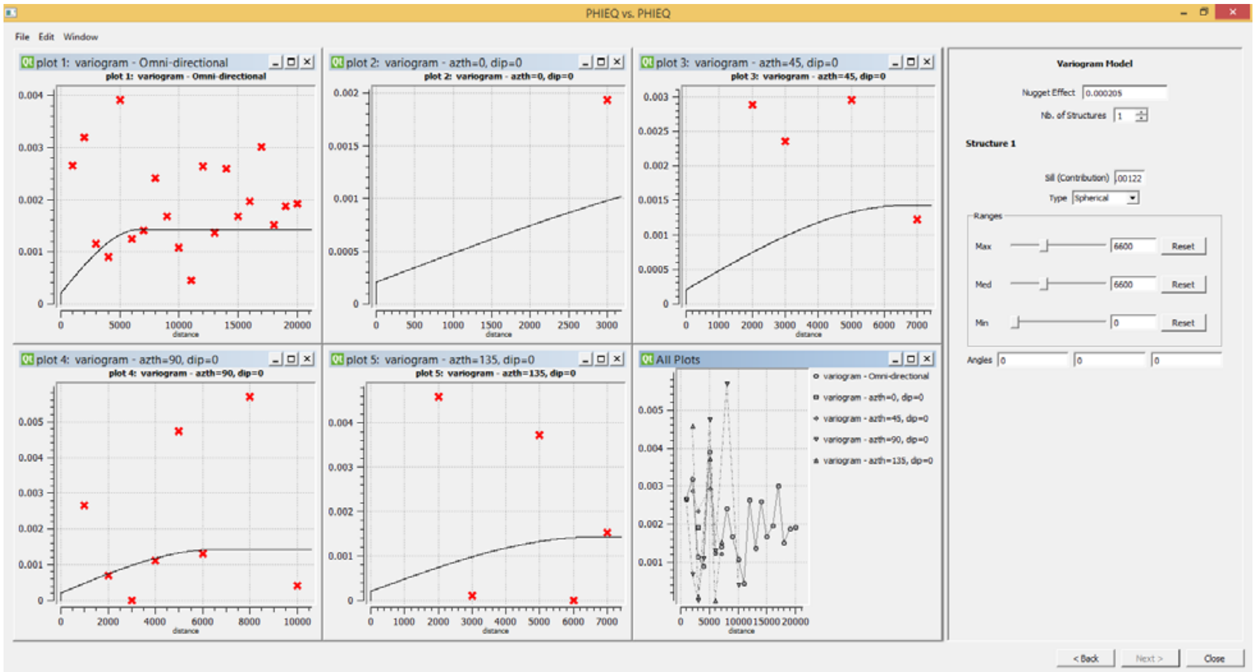


(a) Horizontal variogram

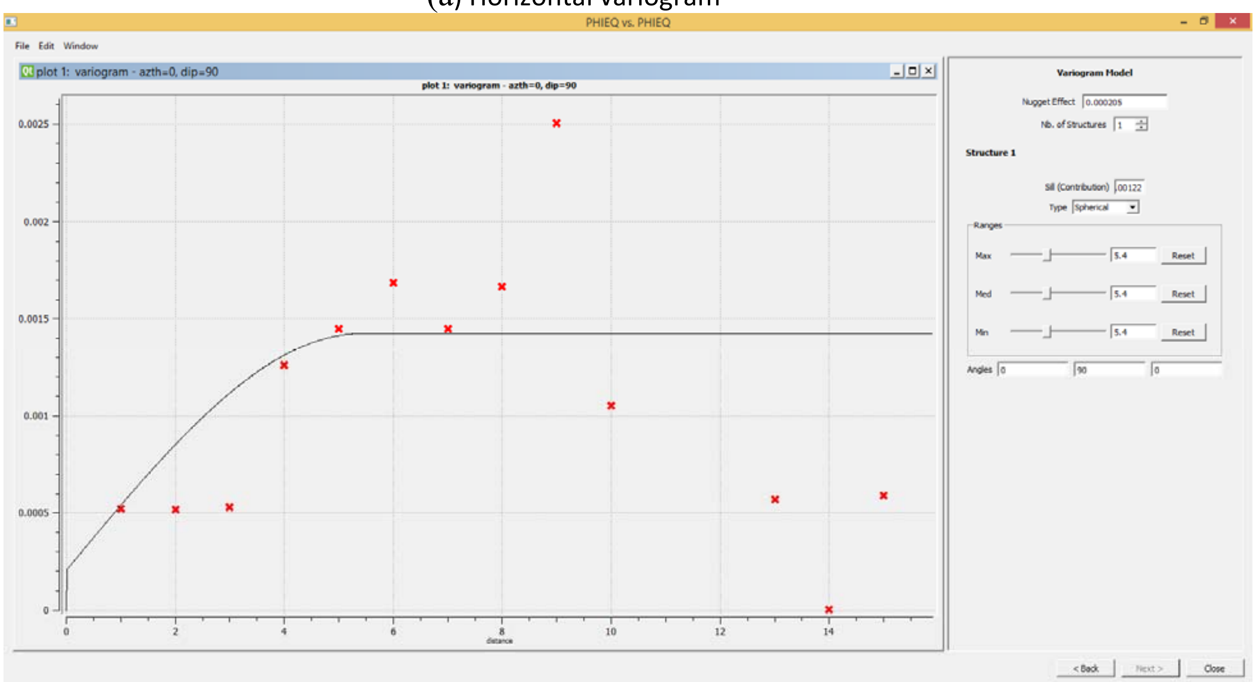


(b) Vertical variogram

Figure 3.9 Variogram of effective porosity for the 3rd facies: lower shoreface.

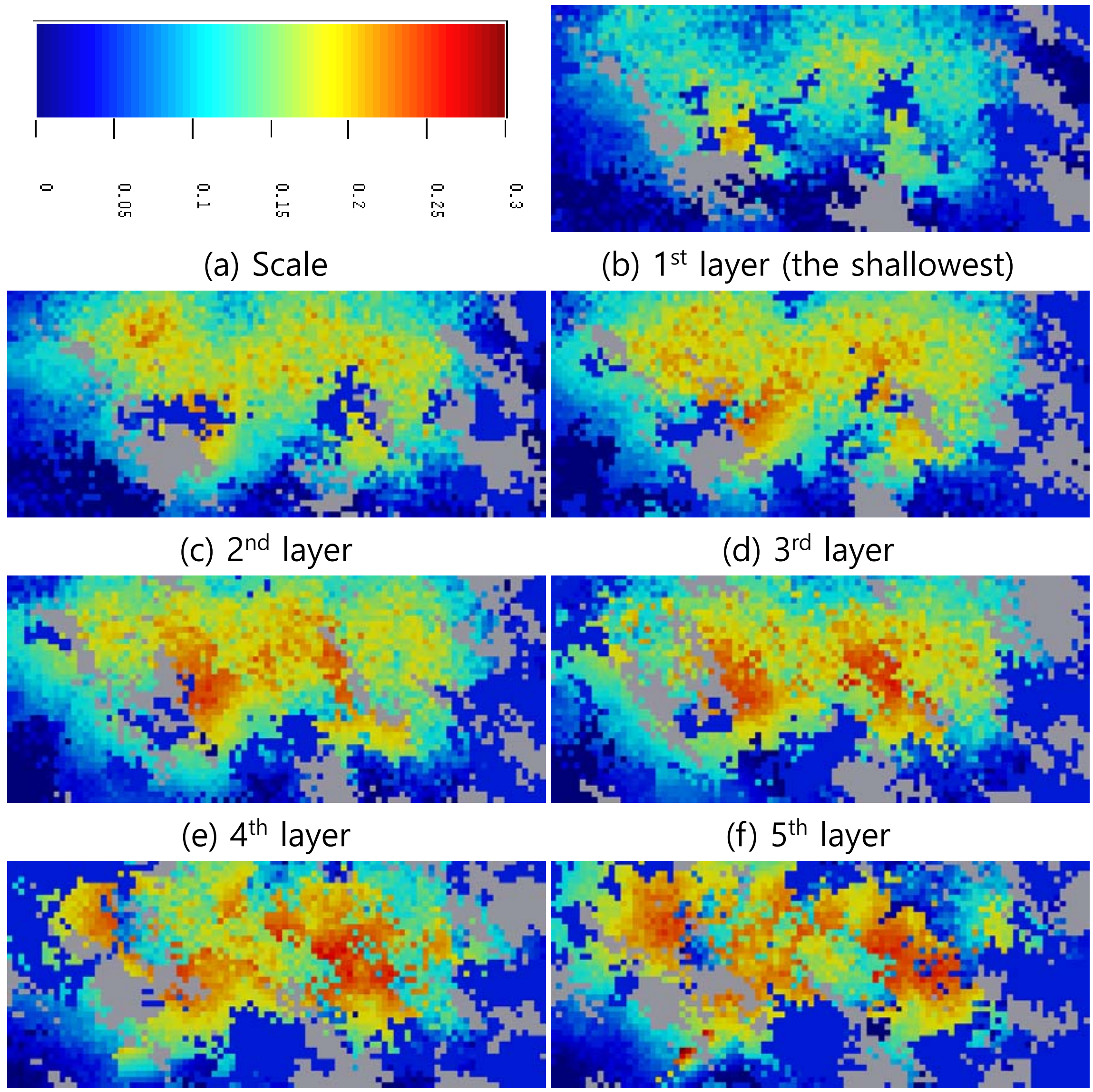


(a) Horizontal variogram



(b) Vertical variogram

Figure 3.10 Variogram of effective porosity for the 4th facies: limestone.



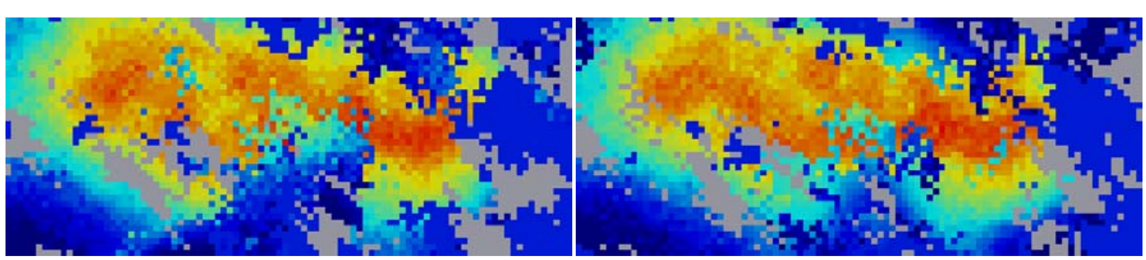
(a) Scale　　(b) 1st layer (the shallowest)

(c) 2nd layer　　(d) 3rd layer

(e) 4th layer　　(f) 5th layer

(g) 6th layer　　(h) 7th layer

Figure 3.11 Plain view of effective porosity distribution of the 1st facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.



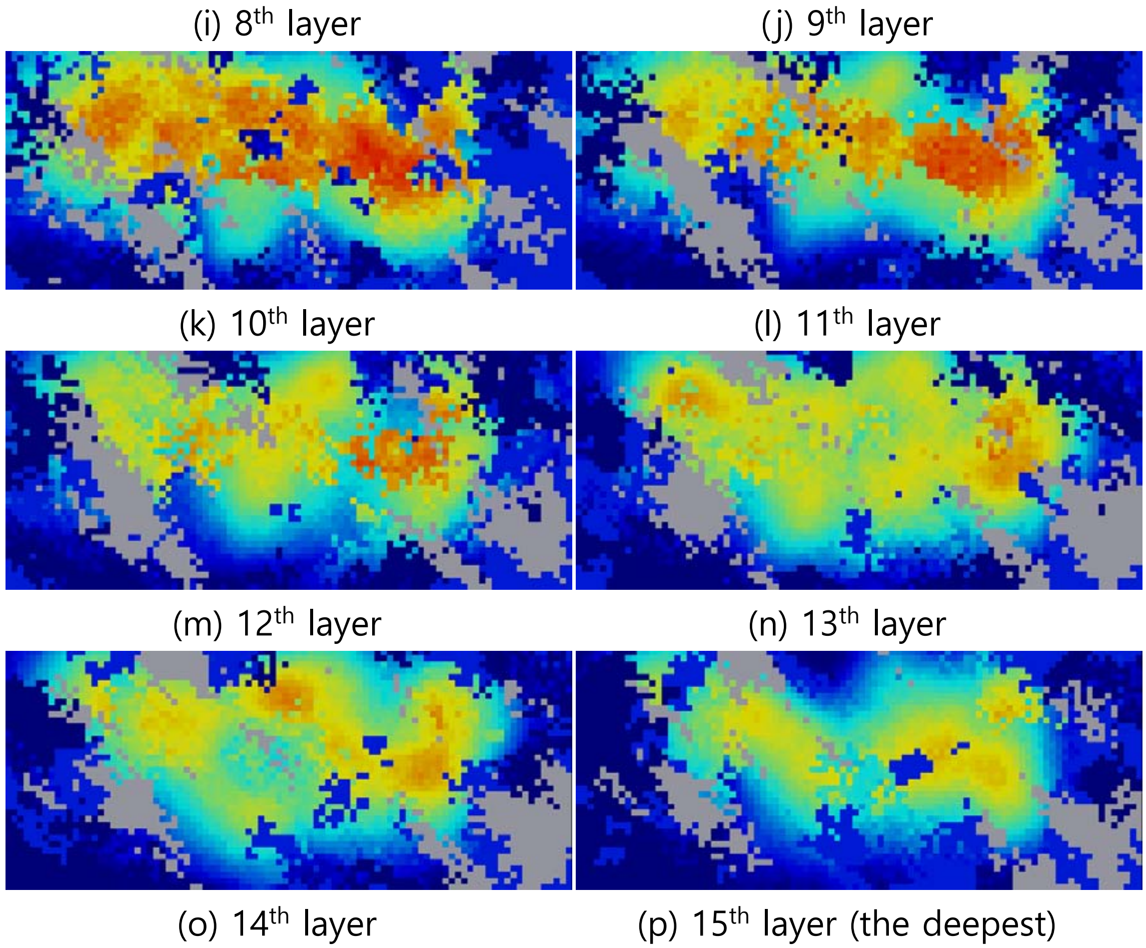
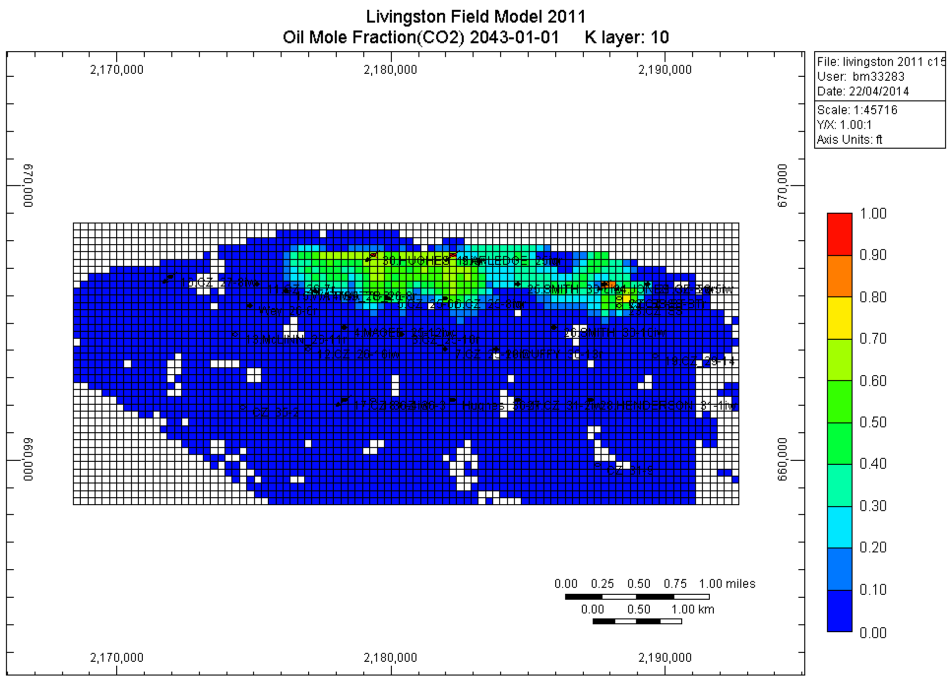


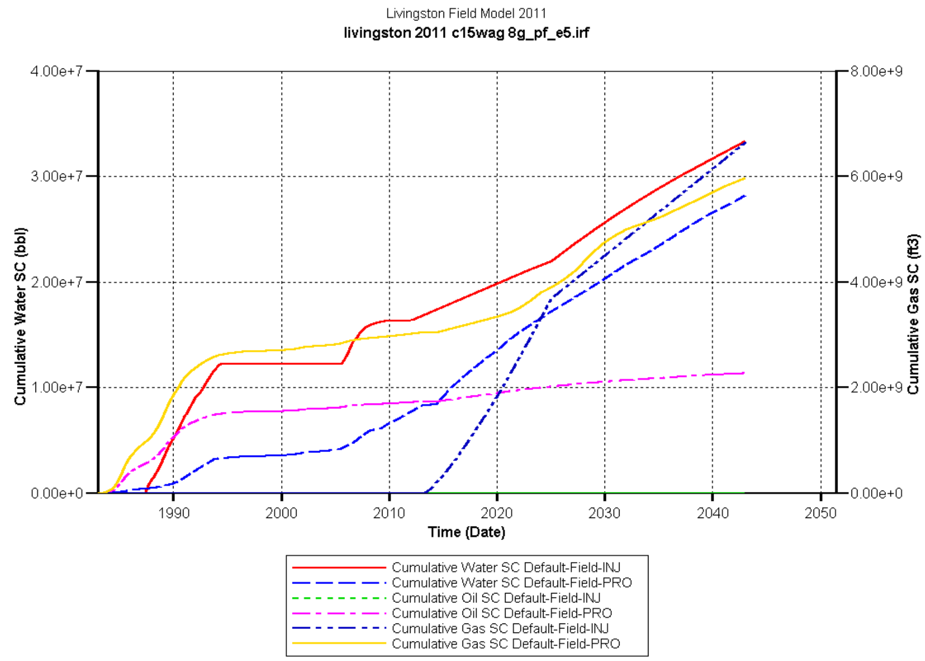
Figure 3.11 (continued): Plain view of effective porosity distribution of the 1st facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.

4. Modeling the flow and transport of CO_2

An initial attempt to model flow and transport of CO_2 in the reservoir models was made. The fluid and rock-fluid interaction parameters in the current flow model were utilized for the flow modeling. Numerical instability issues were encountered when the flow model was executed for the actual specified CO_2 injection rate. Figures 4.1 and 4.2 present some snapshots of CO_2 mole-fractions and production profiles for gas, water and oil at rates that are a fraction of the actual injection rates used in the current numerical simulation model. In an attempt to solve these numerical problems, we are pursuing several strategies including introducing grid refinement around wells and at transitions between facies exhibiting widely different permeability values and also revisiting the porosity-permeability transform used to transform the porosity values to permeability.

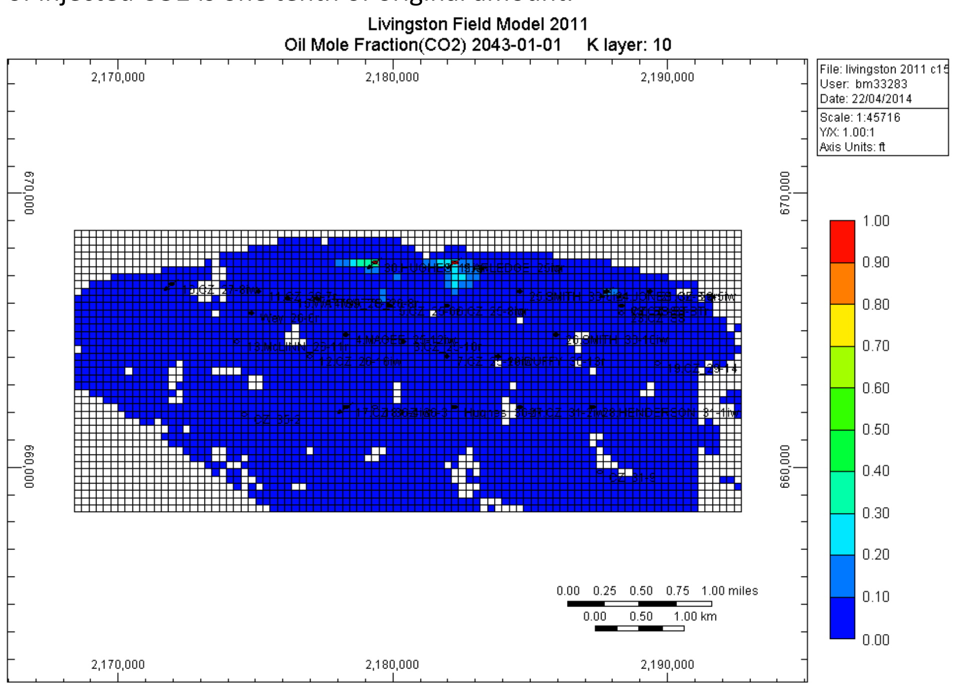


(a) CO_2 plume

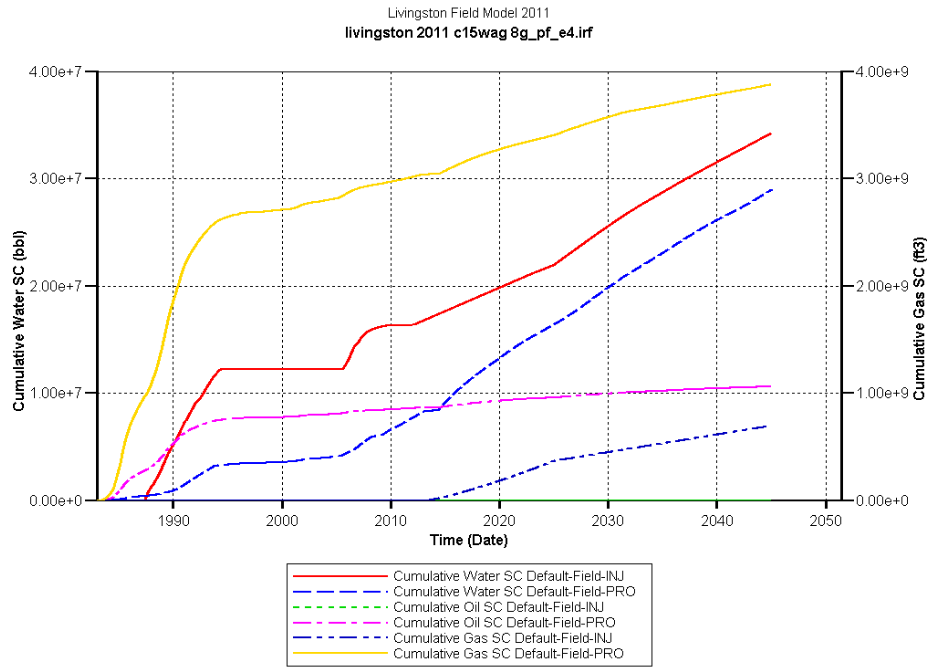


(b) Cumulative production and injection of oil, water, and gas

Figure 4.1 Production behavior of Livingston field. No chemical reaction is assumed. The amount of injected CO2 is one tenth of original amount.



(a) CO2 plume



(b) Cumulative production and injection of oil, water, and gas

Figure 4.2 Production behavior of Livingston field. No chemical reaction is assumed. The amount of injected CO2 is one hundredth of original amount.

Modeling Rock-Fluid Chemical Interactions

The modeling of CO2 flooding processes involves the equations for geochemistry: chemical reactions between the aqueous species and mineral precipitation and dissolution (Nghiem, 2004). This research will investigate the effect of geochemistry for CO2 injection strategy after petrophysical modeling. This modeling will show the migration of CO2, the dissociation of CO2, and it subsequent conversion into carbonate minerals.

Table 4.1 shows the intra-aqueous chemical-equilibrium reactions (1) to (3) and the mineral dissolution/precipitation reactions (4) to (6). The chemical-equilibrium are homogenous reactions that involve only components in the aqueous phase. Mineral dissolution/precipitation are heterogeneous reactions that involve mineral species and aqueous species. It is assumed a mineral reacts only with aqueous species and not with other minerals. The reactions of Calcite (CaCO3), Kaolinite (Al2Si2O5(OH)4), and Anorthite (CaAl2Si2O8) will be investigated in this research.

Table 4.1 Chemical reactions for geochemistry for CO2 flooding

Reaction	Equations	
Chemical-equilibrium	$H_2O = H^+ + OH^-$	(1)
	$CO_2 + H_2O = 2H^+ + CO_3^{2-}$	(2)
	$CO_2 + H_2O = H^+ + HCO_3^-$	(3)
mineral dissolution & precipitation	$CaCO_3 = Ca^{2+} + CO3^{2-}$	(4)
	$Al_2Si_2O_5(OH)_4 + 6H^+ = H_2O + 2H_4SiO_4 + 2Al^{3+}$	(5)
	$CaAl_2Si_2O_8 + 8H^+ = Ca^{2+} + 2H_4SiO_4 + 2Al^{3+-}$	(6)

Planned Work

The following is our plan of work for the next few months:

- Complete flow modeling without reactions and evaluate sensitivity of the flow model to parameters such as permeability transforms, relative permeability model etc.
- Utilize injection-production data to perform the model selection procedure and obtain a set of posterior reservoir models that reflect the dynamic characteristics observed in the field. A software developed in-house called UTGS will be used to implement the model selection procedure.
- Utilize the posterior set of models to assess the uncertainty in CO2 flood performance and make recommendations regarding monitoring/measurement protocol.
- Update if necessary, the reservoir model to incorporate the new seismic data.
- Perform flow-transport simulation with geochemical reactions using parameters obtained from the LSU group making measurements regarding reaction rates etc.

References

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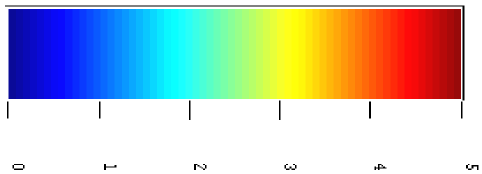
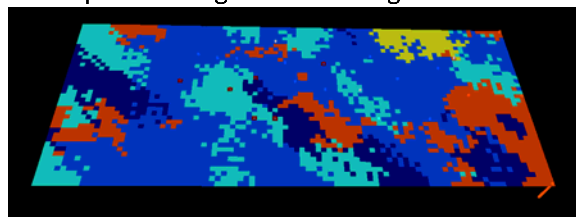
Appendix C-1

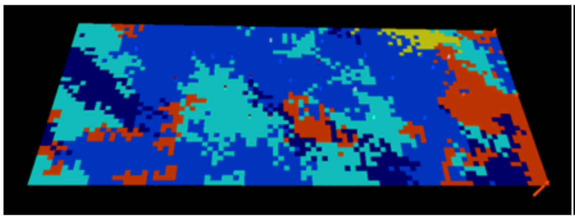
Several realizations of the indicator facies model are depicted in Figure A.1 through A.4.



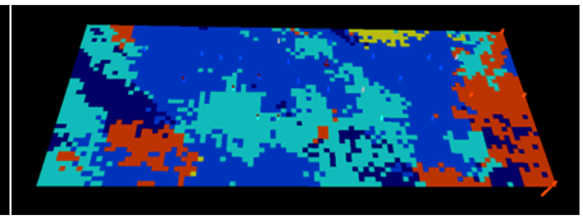
(a) Scale



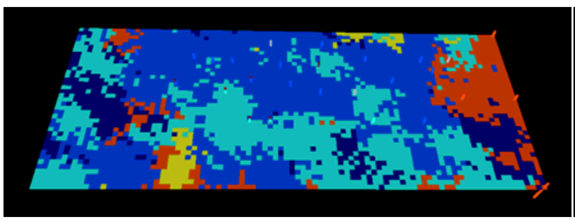
(b) 1st layer (the shallowest)



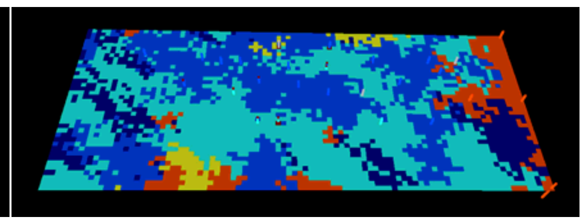
(c) 2nd layer



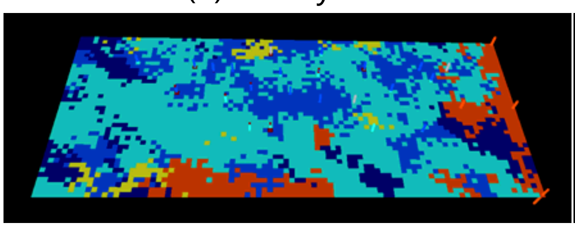
(d) 3rd layer



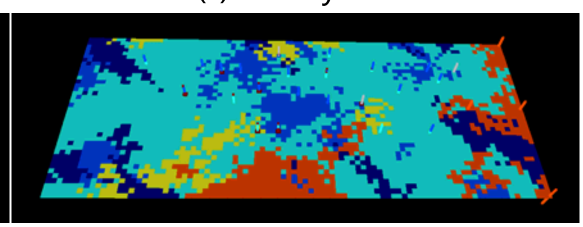
(e) 4th layer



(f) 5th layer

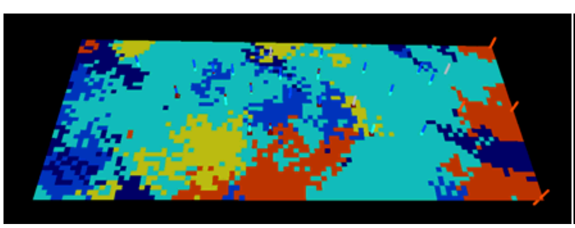


(g) 6th layer

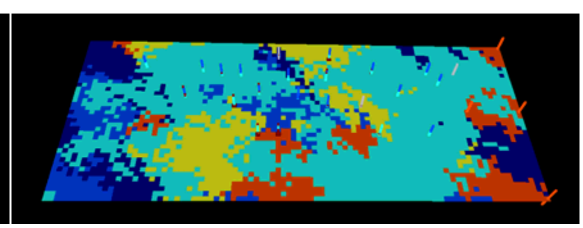


(h) 7th layer

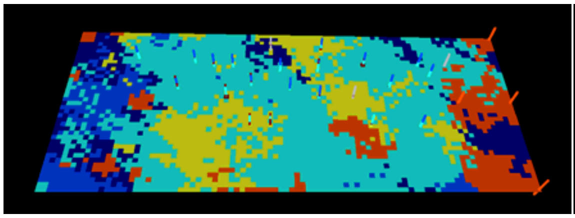
Figure A.1 Plain view of the 2nd facies model: 0: unknown (non-pay facies); 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.



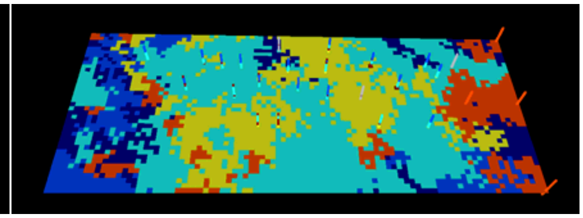
(i) 8th layer



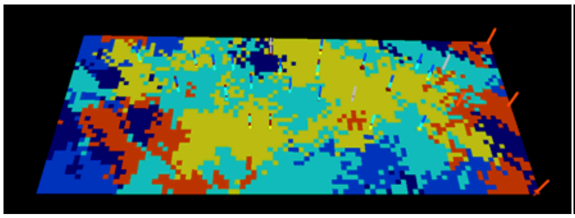
(j) 9th layer



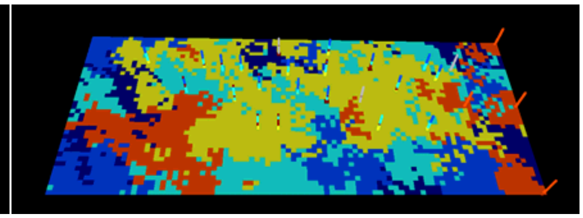
(k) 10th layer



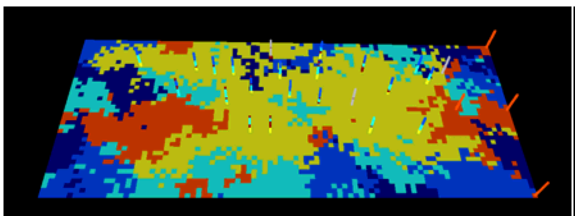
(l) 11th layer



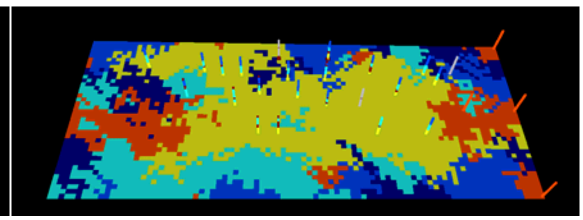
(m) 12th layer



(n) 13th layer

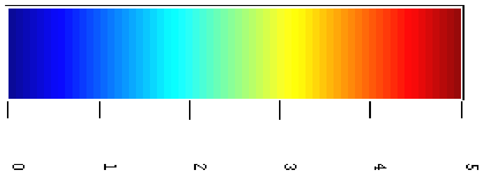


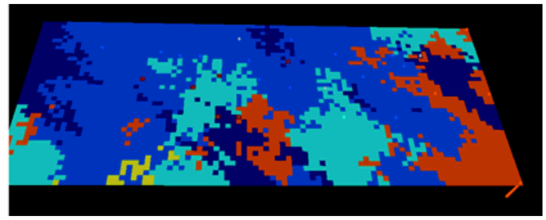
(o) 14th layer



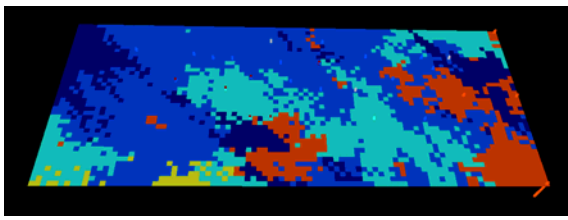
(p) 15th layer (the deepest)

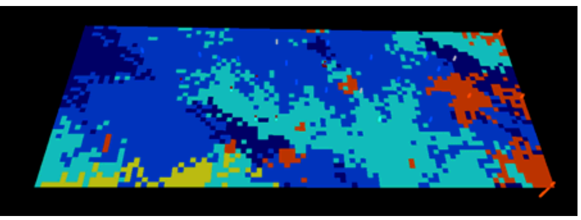
Figure A.1 (continued): Plain view of the 2nd facies model: 0: unknown (non-pay facies); 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.



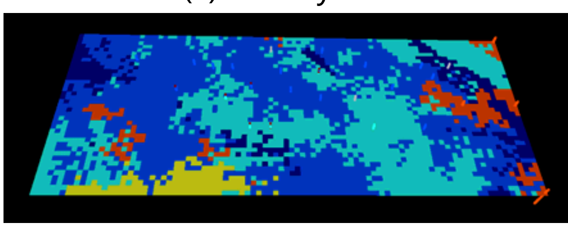


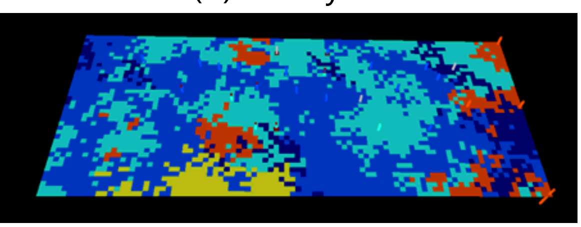
(a) Scale (b) 1st layer (the shallowest)



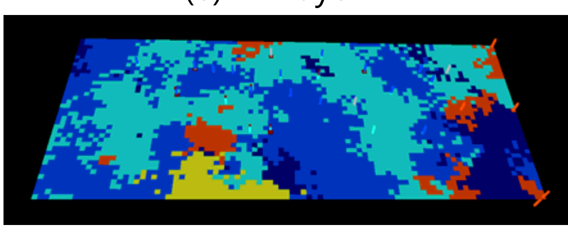


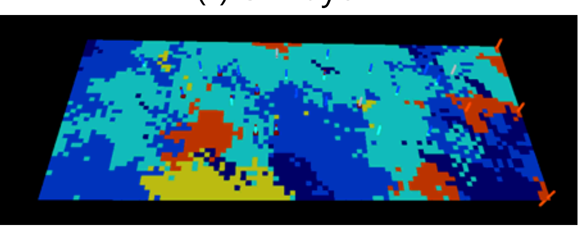
(c) 2nd layer (d) 3rd layer





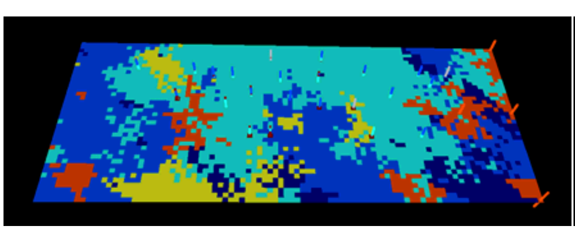
(e) 4th layer (f) 5th layer

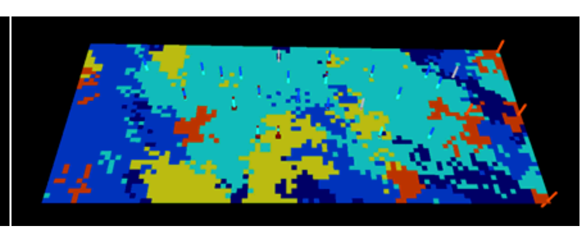




(g) 6th layer (h) 7th layer

Figure A.2 Plain view of the 3rd facies model: 0: unknown; 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.





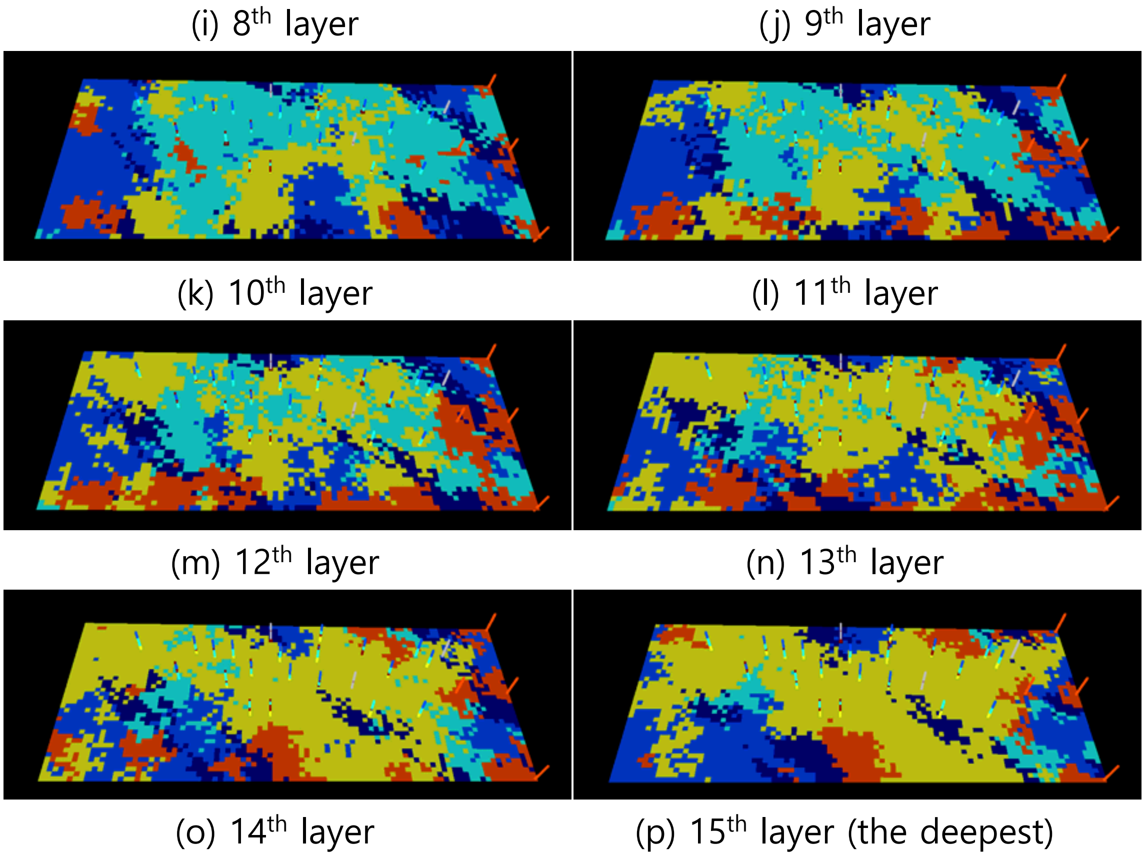
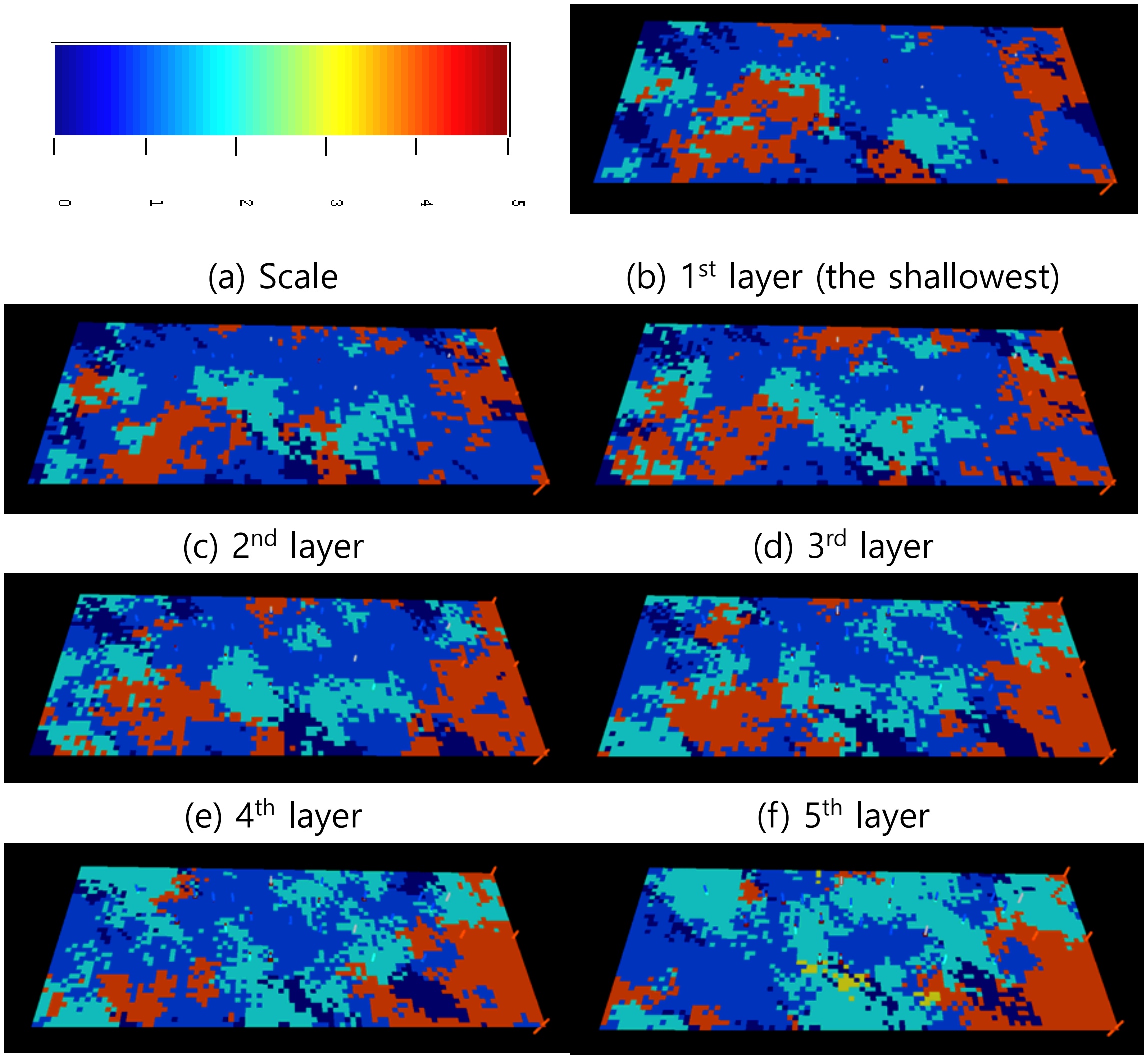


Figure A.2 (continued): Plain view of the 3rd facies model: 0: unknown; 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.



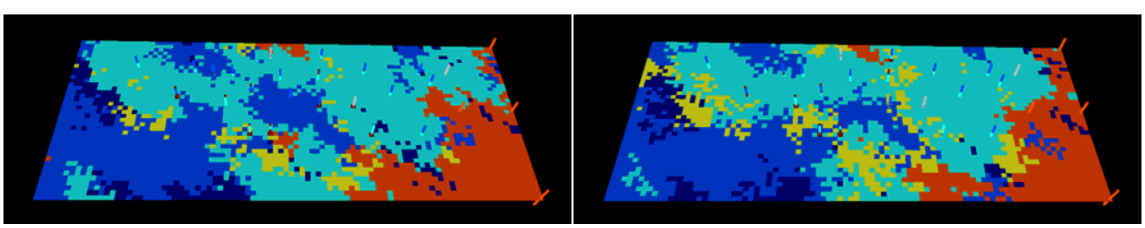
(a) Scale (b) 1st layer (the shallowest)

(c) 2nd layer (d) 3rd layer

(e) 4th layer (f) 5th layer

(g) 6th layer (h) 7th layer

Figure A.3 Plain view of the 4th facies model: 0: unknown; 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.



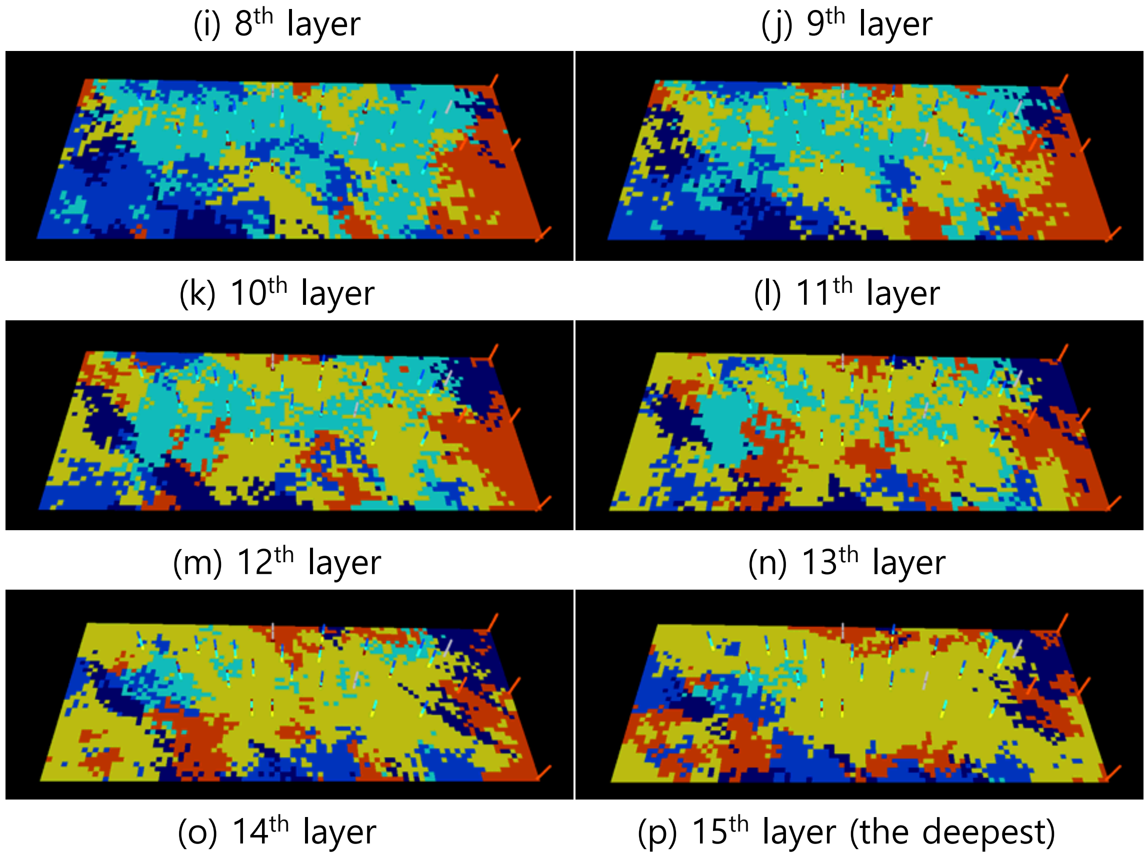
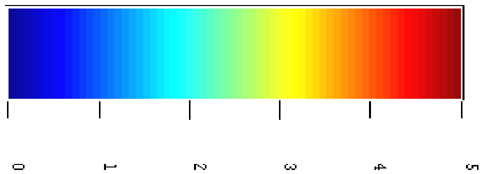
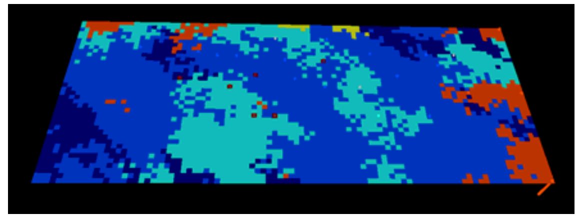


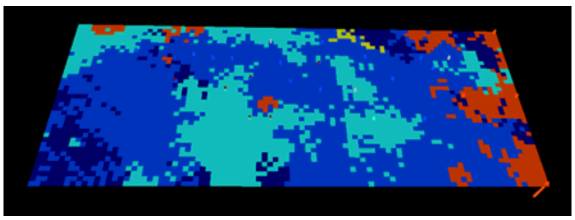
Figure A.3 (continued): Plain view of the 4th facies model: 0: unknown; 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.



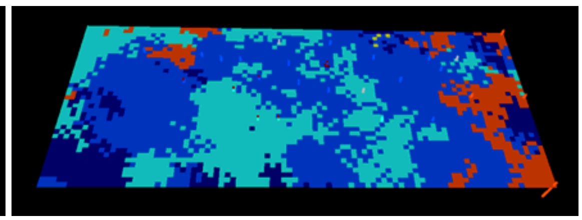
(a) Scale



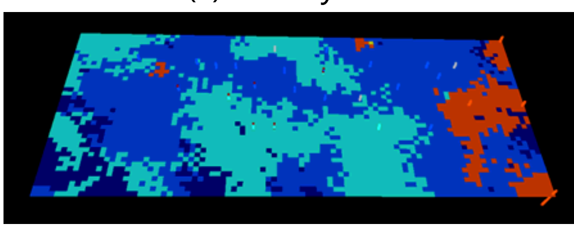
(b) 1st layer (the shallowest)



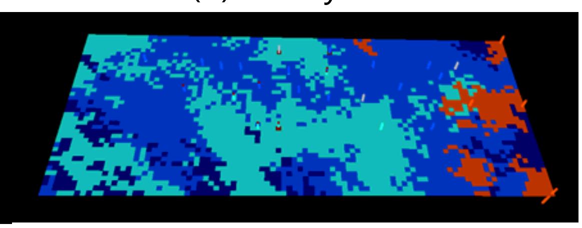
(c) 2nd layer



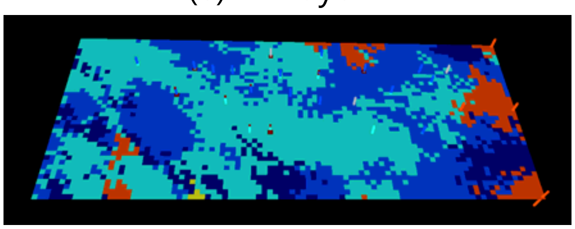
(d) 3rd layer



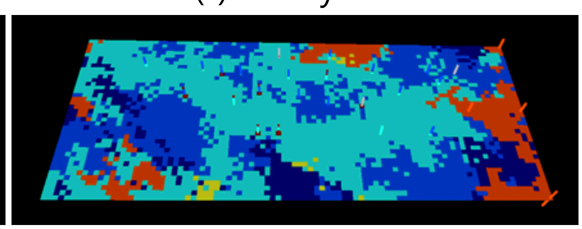
(e) 4th layer



(f) 5th layer

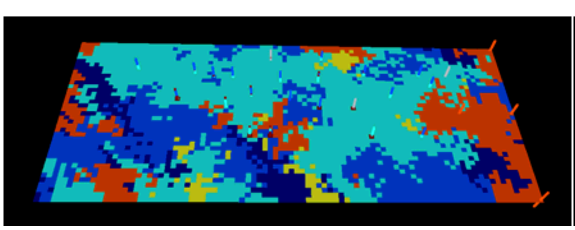


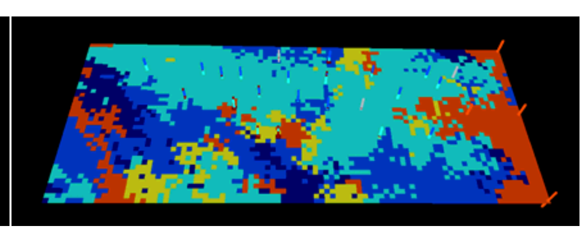
(g) 6th layer



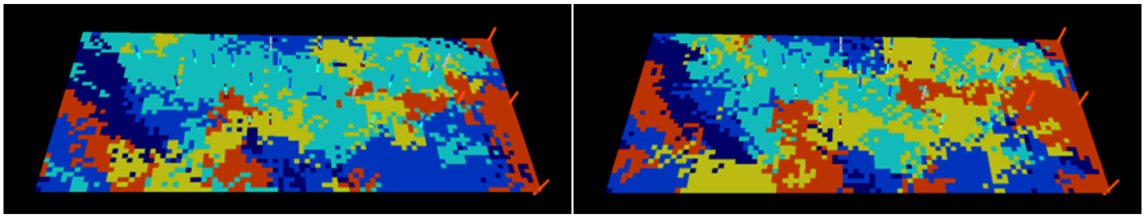
(h) 7th layer

Figure A.4 Plain view of the 5th facies model: 0: unknown; 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.

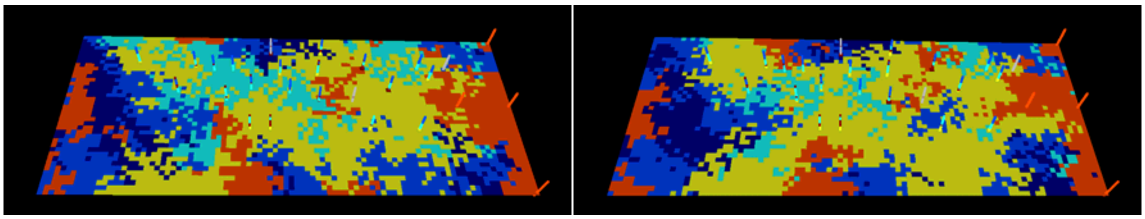




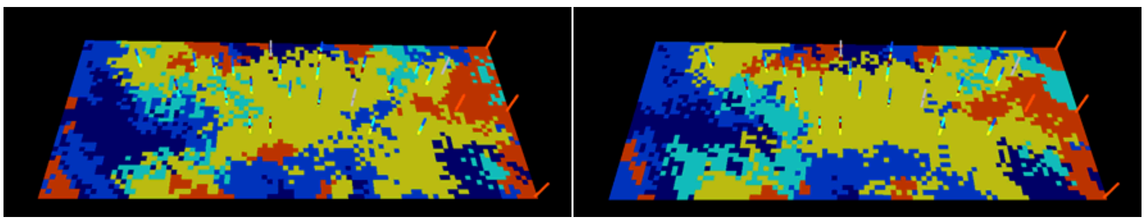
(i) 8th layer (j) 9th layer



(k) 10th layer (l) 11th layer



(m) 12th layer (n) 13th layer

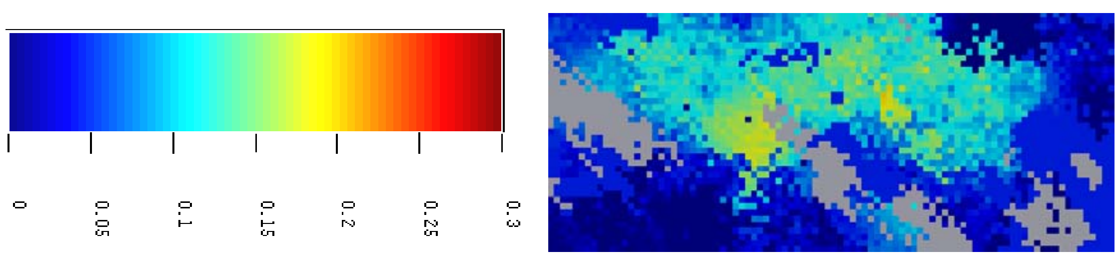


(o) 14th layer (p) 15th layer (the deepest)

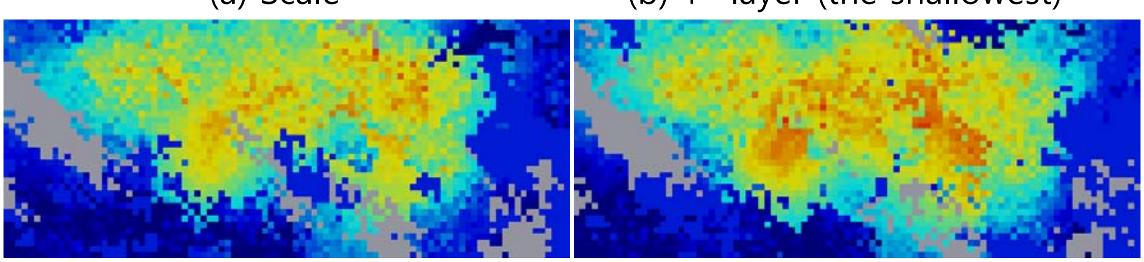
Figure A.4 (continued): Plain view of the 5th facies model: 0: unknown; 1: upper shoreface; 2: middle shoreface; 3: lower shoreface; 4: channel fill mud; and 5: limestone.

Appendix C-2

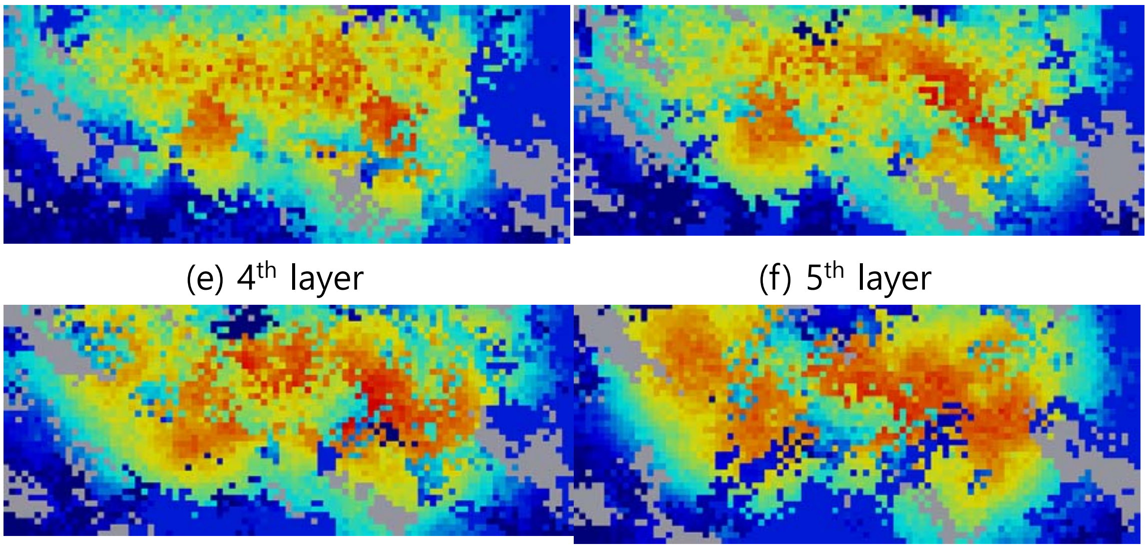
Several realizations of the effective porosity model are depicted in Figures B.1 – B.5.



(a) Scale (b) 1st layer (the shallowest)



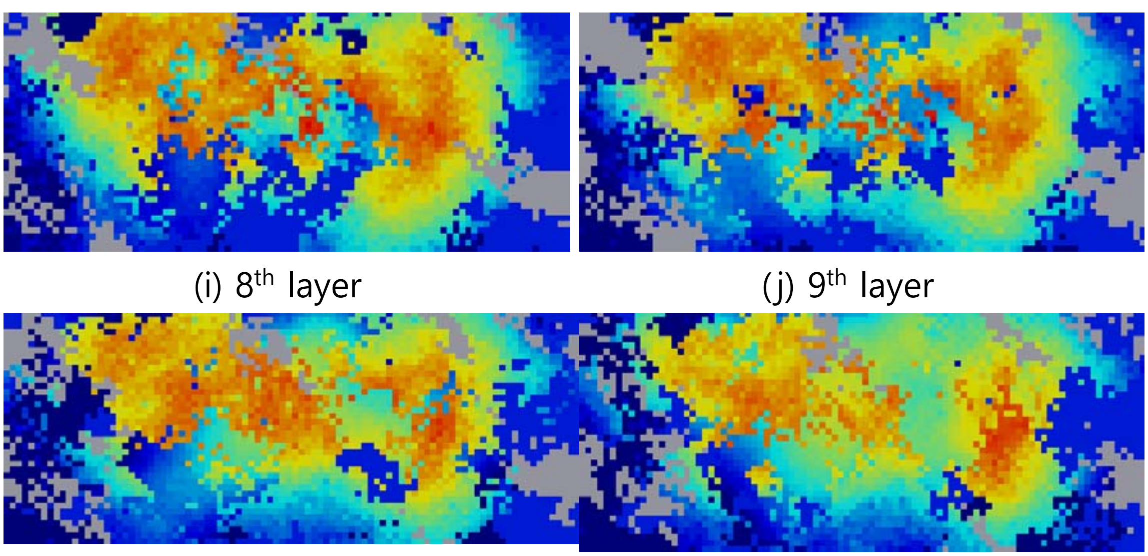
(c) 2nd layer (d) 3rd layer



(e) 4th layer (f) 5th layer

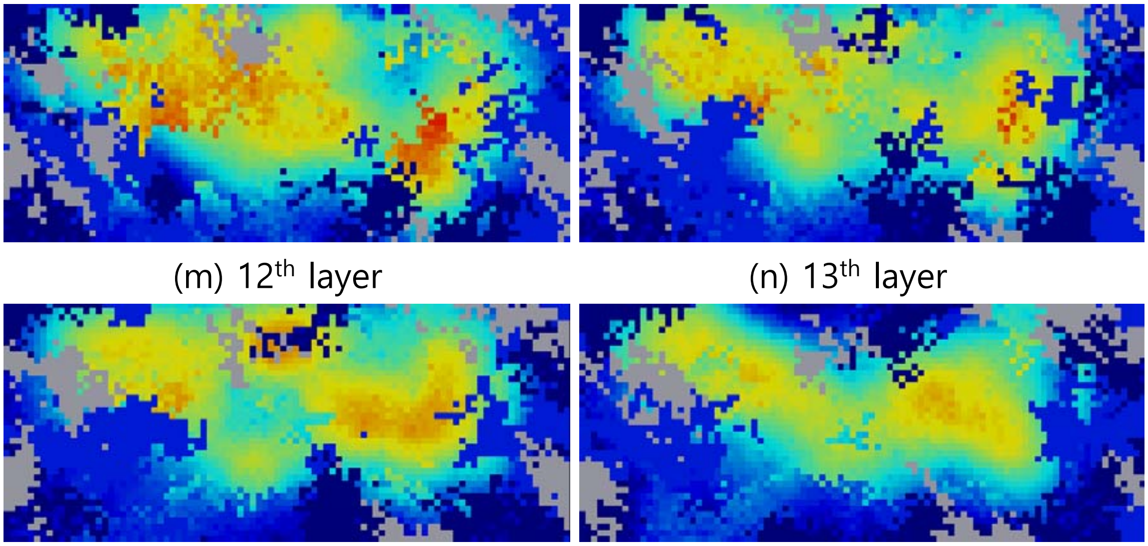
(g) 6th layer (h) 7th layer

Figure B.1 Plain view of effective porosity distribution of the 2nd facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.



(i) 8th layer (j) 9th layer

(k) 10th layer (l) 11th layer



(m) 12th layer (n) 13th layer

(o) 14th layer (p) 15th layer (the deepest)

Figure B.1 (continued): Plain view of effective porosity distribution of the 2nd facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.

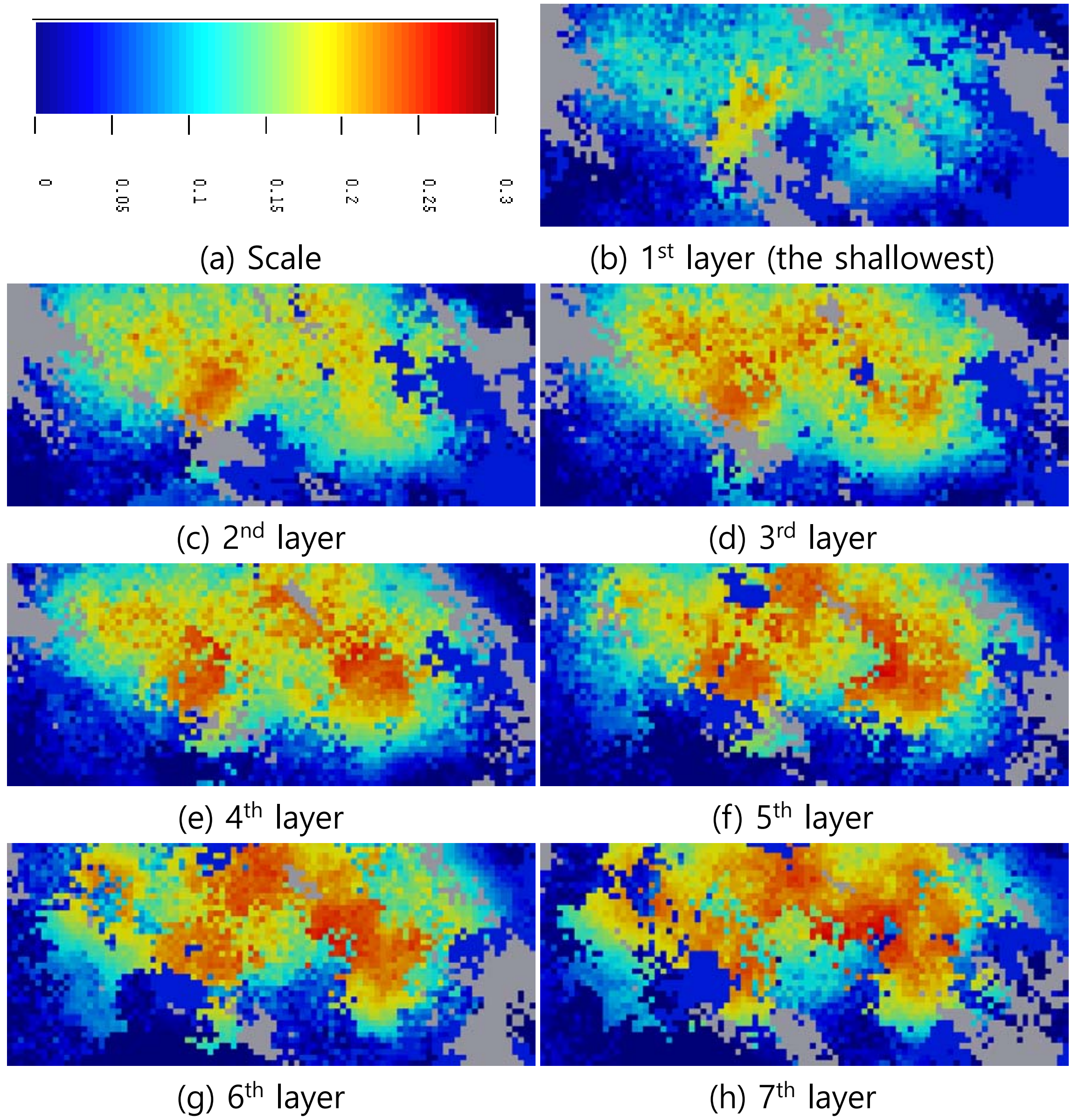
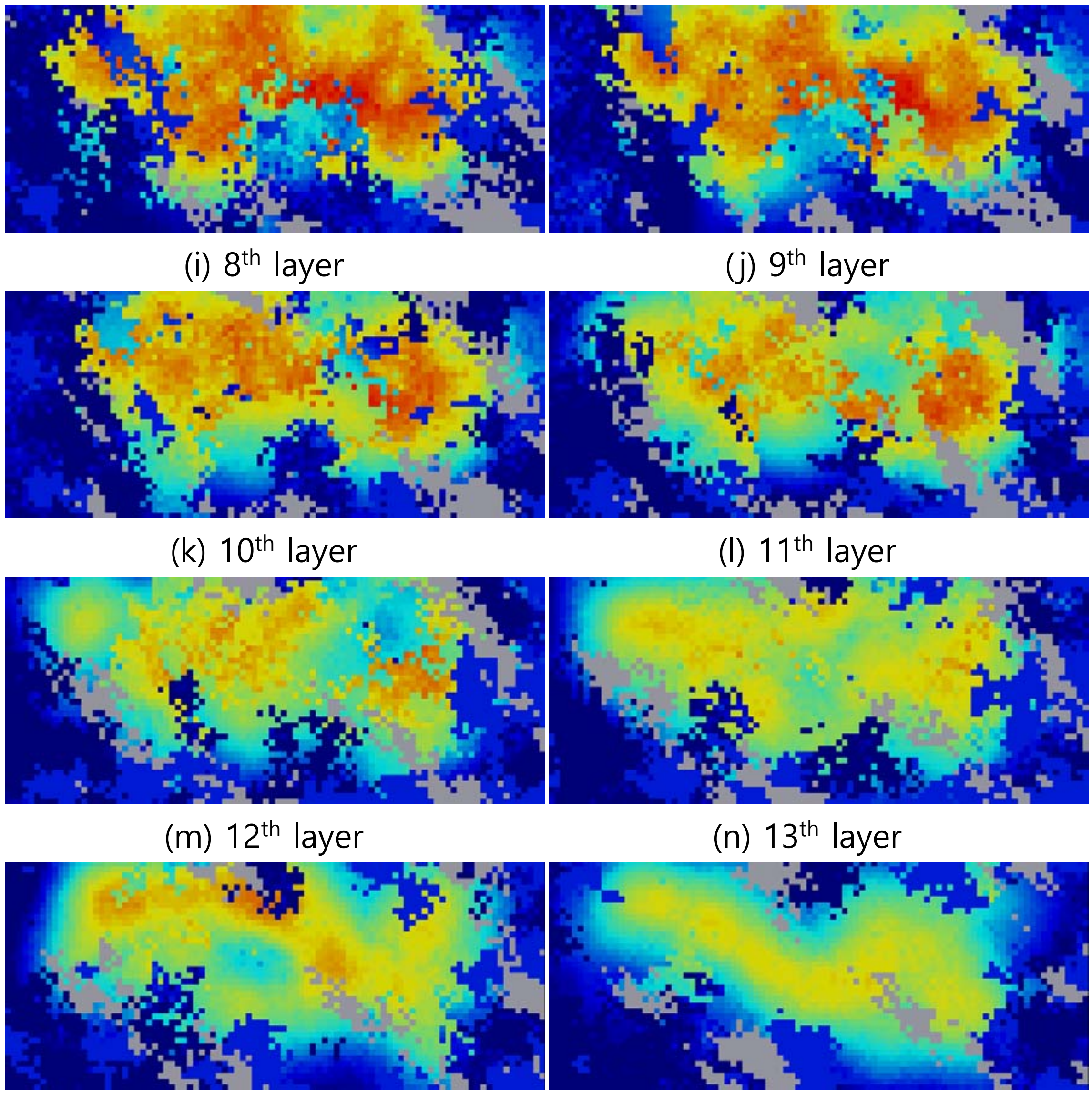


Figure B.2 Plain view of effective porosity distribution of the 3rd facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.



(i) 8th layer (j) 9th layer

(k) 10th layer (l) 11th layer

(m) 12th layer (n) 13th layer

(o) 14th layer (p) 15th layer (the deepest)

Figure B.2 (continued): Plain view of effective porosity distribution of the 3rd facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.

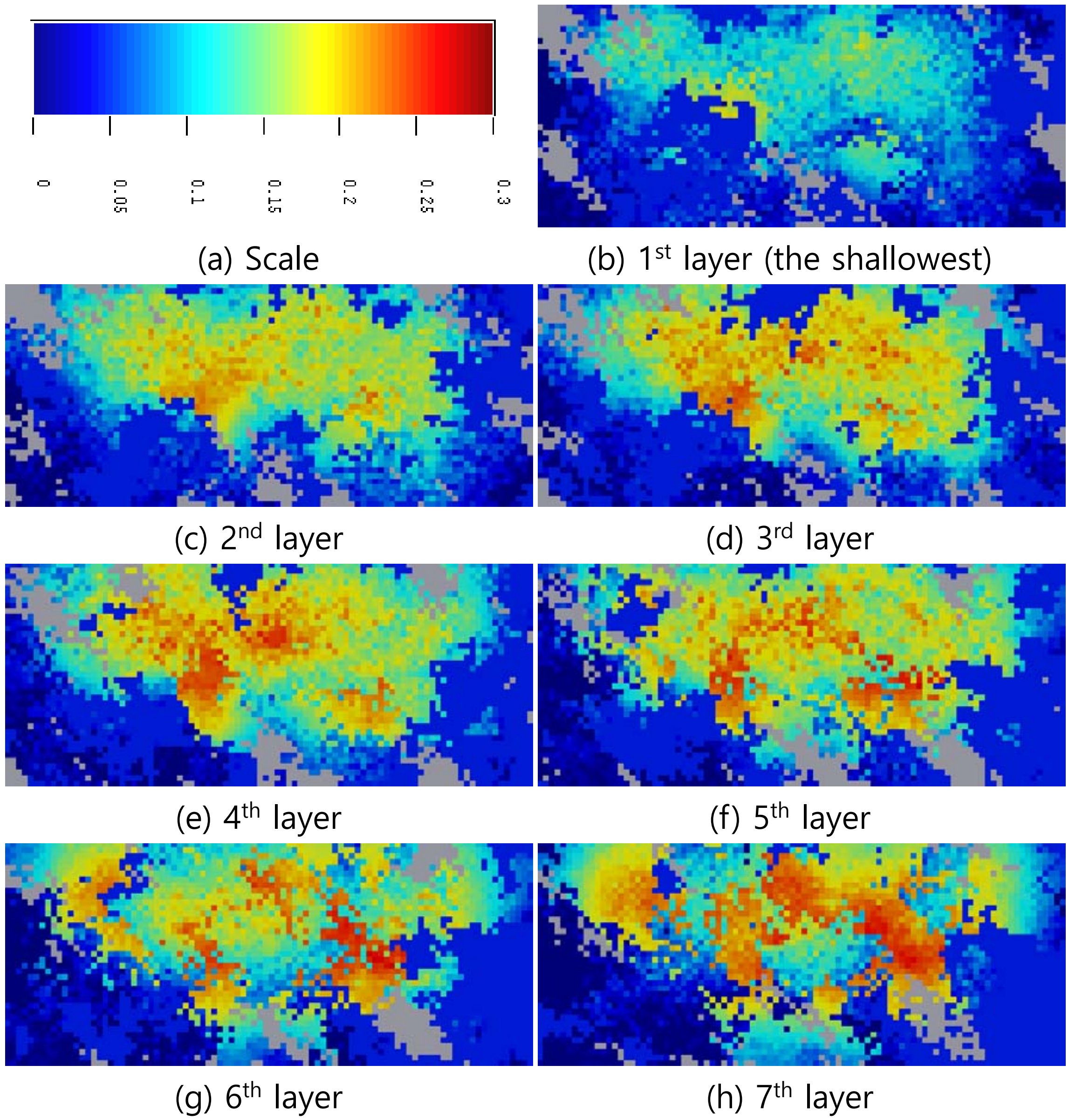


Figure B.3 Plain view of effective porosity distribution of the 4th facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.

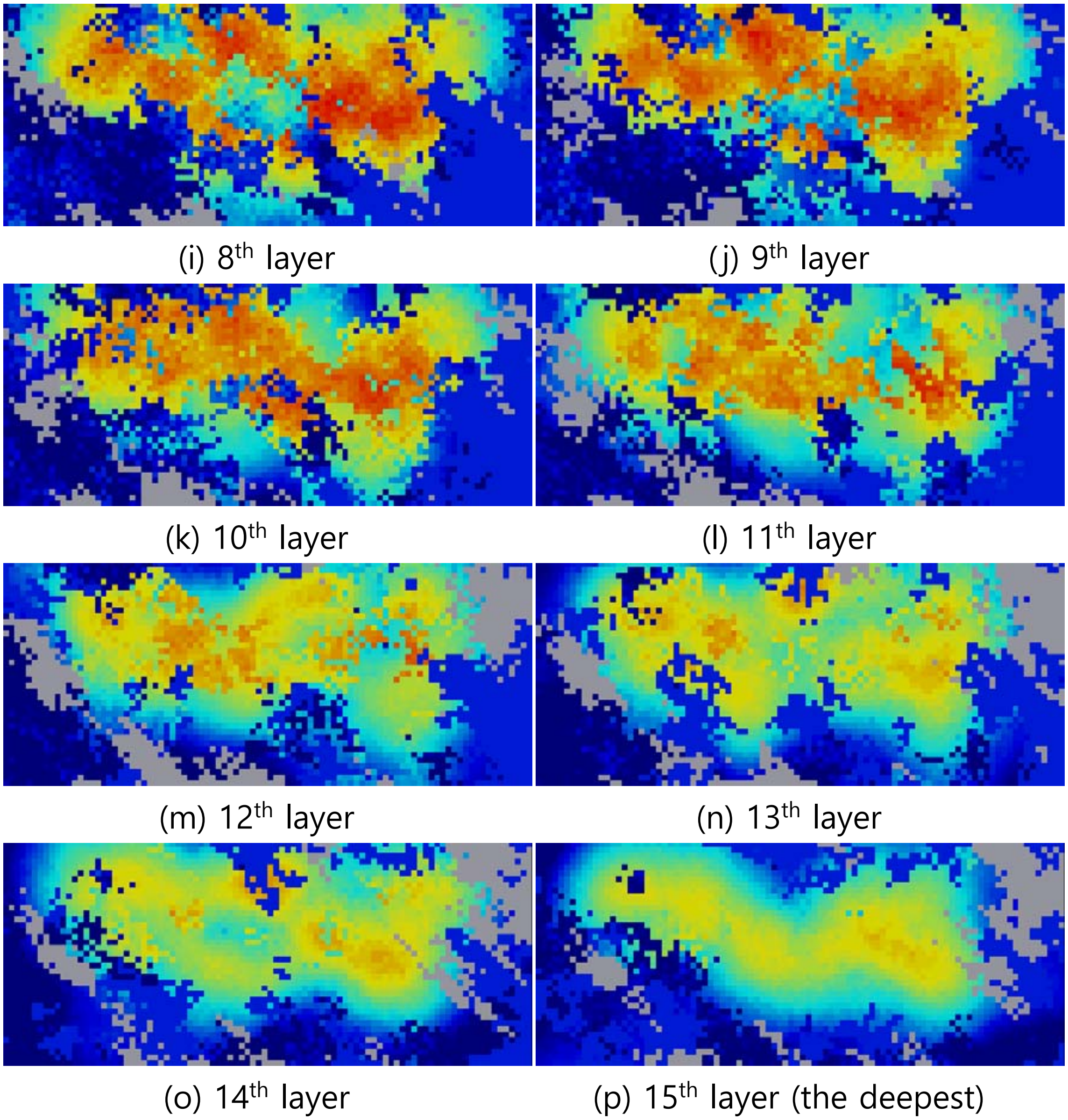


Figure B.3 (continued): Plain view of effective porosity distribution of the 4th facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.

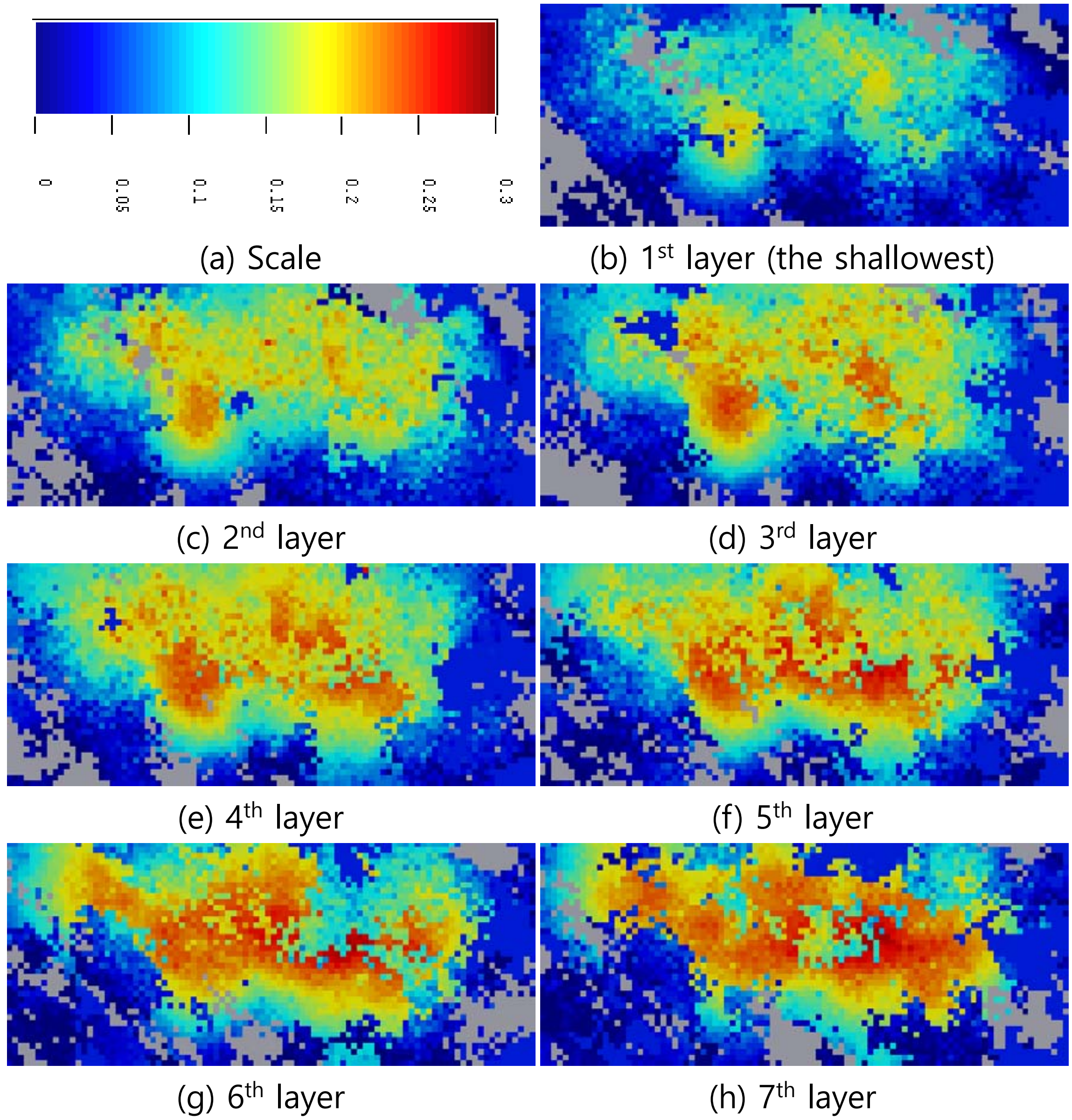
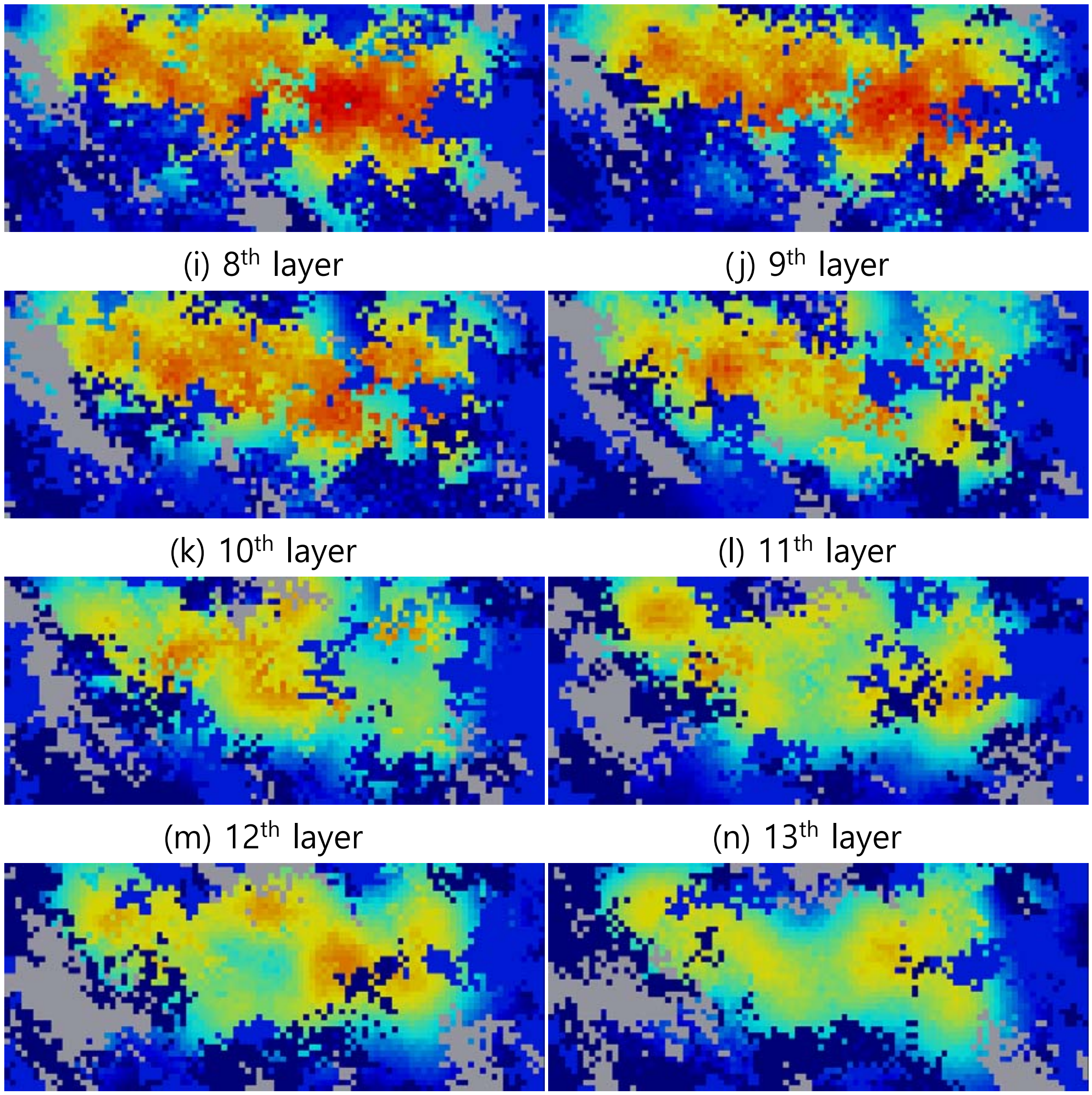


Figure B.4 Plain view of effective porosity distribution of the 5th facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.



(i) 8th layer (j) 9th layer
(k) 10th layer (l) 11th layer
(m) 12th layer (n) 13th layer
(o) 14th layer (p) 15th layer (the deepest)

Figure B.4 (continued): Plain view of effective porosity distribution of the 5th facies model. The gray region indicates the unknown facies resulting from the intrinsic limitation of the two-point geostatistics.

7.4 APPENDIX D – FINAL REPORT FROM THE RICE/UT CO2 FOAM R&D CONSORTIUM

RESERVOIR MODELING OF LIVINGSTON FIELD

By Biswal, S.L., Hirasaki, G.J., Nguyen, Q.P., Puerto, M.C., Jian, M.G. and Wellington, S.L.

Summary

Five Alpha Olefin Sulfonates (AOS), four Internal Olefin Sulfates (IOS), two Lauryl Betaines (LB), and two non-ionic surfactants were screened separately and in selected blends for generating CO2 foam for mobility control in the South Louisiana EOR/Sequestration Project.

For future surfactant quality control analysis, an effort was made to individually characterize several AOS surfactants using a special salinity-scan and phase behavior procedure. Reservoir and softened reservoir brines; along with sodium chloride only brine were used in the surfactant screening tests to elucidate the effect of hardness on surfactant foaming ability and phase behavior. Two temperature regimes, 25C to allow comparison with other data, and 100C the reservoir temperature, were used in the phase behavior tests.

CO2 interacts with formation minerals, especially limestone, causing changes in the brine composition. The CO2 also alters the pH of the brine. Geochemical phase behavior simulation software was used to account for CO2 mineral interactions and pH change at Livingston reservoir conditions. A buffered brine composition was formulated to allow surfactant testing under simulated CO2 injection conditions. A buffered sodium chloride brine of equivalent ionic strength to the reservoir brine was used to compare the sensitivity of the surfactants to multivalent ions and pH. The pH of the brine has a significant effect on AOS surfactant behavior.

The preliminary results using aqueous stability phase behavior screening tests showed that a co-surfactant with more EO groups, C12-15 (EO)12-sulfate, improved the solubility of the C15-18 IOS at 100°C. High concentrations of divalent cations drastically decrease the salinity tolerance of the IOS surfactant. Results from the aqueous stability experiment show that the solubility is improved by softening the injection brine. The IOS surfactants (i.e., sulfates) are not chemically stable at Livingston reservoir conditions of temperature and CO2 pH injection conditions. However, their foaming ability is well known making them useful as initial laboratory test surfactants and chemically stable analogs (i.e., sulfonates) may be commercially manufactured.

The results of the foam stability tests using C15-18 IOS and C7-8(EO)5-sulfate solution showed that oil reduced the foam column height by half compared to that of the surfactant solution by itself at lower temperatures. This trend can also be identified for the non-ionic system at lower temperatures. In contrast, C12-16 AOS with C7-8(EO)5-

sulfate shows a decrease of only 15% in the foam column height in the presence of oil compared to that of the AOS surfactant by itself. The solution of C12-16 AOS with C7-8(EO)5-sulfate created the strongest foam when in contact with oil.

The Stepan AOS 12 and its blends with LB from Rhodia performed well in the screening tests under CO2 flooding conditions of salinity and pH. As such the Stepan AOS 12 and its blends with LB from Rhodia; and the C12-16 AOS blends with C7-8(EO)5-sulfate were selected for foam-flow testing at Livingston Reservoir conditions.

The core flooding tests and reservoir scale-up simulations that depend on the results from the flooding experiments were not completed due to project termination. Heretofore surfactants for foam generation in high temperature, high salinity and hardness reservoirs are not reported. This study indicates that it is possible to use selected blends of surfactants to achieve foam mobility under these difficult reservoir conditions. Successful application of foam mobility control in this type reservoir is expected to significantly and economically enhance both oil recovery and CO2 sequestration.

CONCLUSIONS

Salinity Scans

A special testing of phase behavior by salinity scans was applied to obtain values of optimal salinity (Cø) and Solubilization Parameters (V/Vs) for few of the AOSs tested...

Main conclusions were

1. The procedure developed could be a tool for quality control because it could be used to determine reproducibility of products being remade a. TIORCO AOS14-16 and Stepan AOS14-16 of different lot # were almost identical
2. Optimal Salinity increased with temperature for Stepan AOS14-16 and Shell AOS16-18 but V/Vs decreased and it was drastically decreased for the Stepan's
3. Shell AOS14-16 is much more water soluble than Stepan AOS14-16 and this could indicate that their synthesis procedures were dissimilar

Blend Scans

- AOS14-16 is sensitive to divalent ions at 100°C, compare NaCl with AS IS. More testing is needed to determine the exact boundary of sensitivity
- pH has a significant effect on surfactant behavior; this finding was unexpected with respect to AOSs
- Several suitable compositions with potential to be field tested has been identified- See all that appear in green at both 25°C and 100°C
- Stepan AOS 12 and its blends with LB from Rhodia should be the selected composition to start foam-flow testing at Blackhorse conditions: --- 3/7, 2/8, 1/9 and 0/10--- The selection was made based on the LB/AOS-blend with the more combinations of suitable compositions with AS IS and buffered brine at 25°C and 100°C
- Lauryl Betaine from Lubrizol appeared to be different than that from Rhodia

7.5 APPENDIX E – INITIAL PRE-SHOOT SEISMIC EVALUATION FOR BLACKHORSE CO2 SEQUESTRATION PROJECT LIVINGSTON FIELD, LIVINGSTON PARISH, LOUISIANA

Preliminary Report

Figure 1. Location of Livingston Field

January 07, 2014

Introduction

Livingston Field is the site of a CO_2 sequestration project and is located approximately 26 miles east of Baton Rouge, Louisiana (Figure 1). The proposed sequestration reservoir is the Eocene age Wilcox 2 Sand present at a depth of approximately 10,000 feet.

This preliminary report reviews currently available seismic data control for reservoir structure and the feasibility of using planned 3-D seismic acquisition to delineate reservoir distribution, faulting, and sand conditions from new 3-D seismic data. Currently five legacy 2-D seismic lines and one six square mile data 'cut-out' from an adjacent 3-D seismic survey (the South Lockhart 3-D Survey) are available.

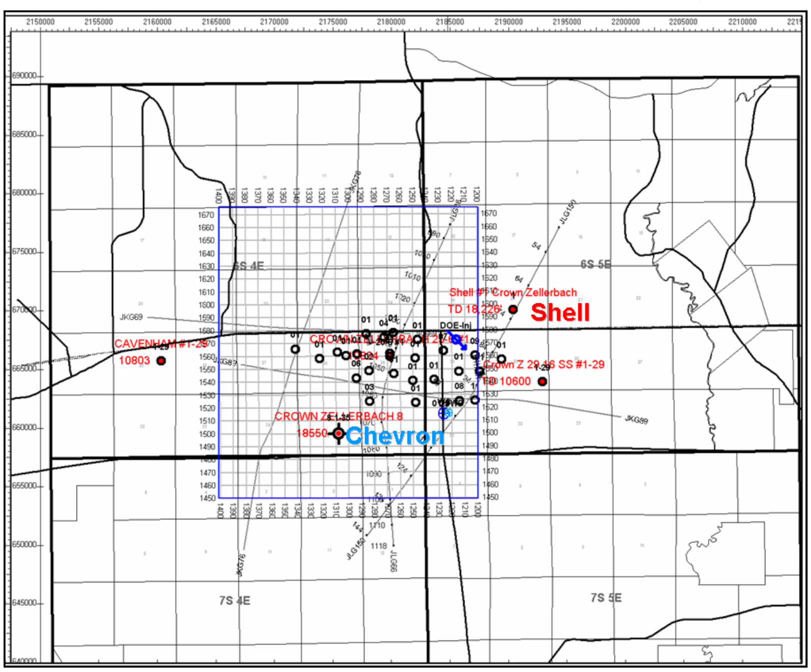


Figure 2. Livingston Field base map.

Two wells are currently being used for time-to-depth control: the Shell Crown Zellerbach #1 situated northeast immediately outside of the pre-existing 3D survey, located along 2D Line JLG150, and the Chevron Crown Zellerbach 8 #1-35 south of the main field (Figure 2).

Synthetic Seismic Well Tie

A seed velocity function was estimated from a check-shot survey obtained from the Shell well. This was then compared to the Time-to-depth relationship generated with an integrated sonic-log from the Chevron well inside the existing 3D seismic volume.

It was found that the best seismic to well tie could be obtained with a bulk time shift of this synthetic model that nearly matches the Shell time-to-depth function, as shown in Figure 3.

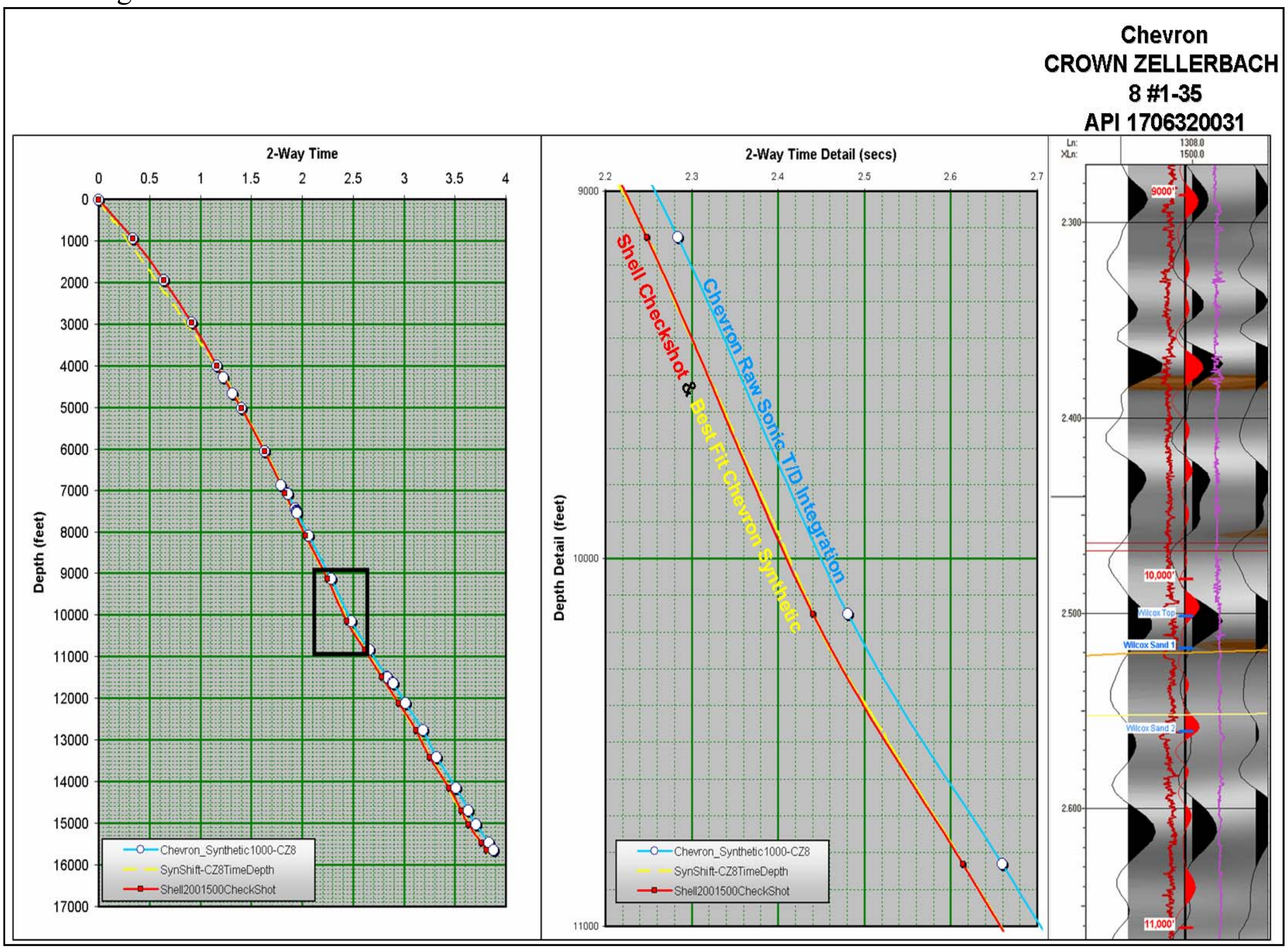


Figure 3. Time-to-Depth Functions for testing well ties to 3D Seismic.

The total difference between the integrated Chevron sonic log and the Shell well check shot depth estimates show variability of 1.6% at 10,000 feet below the sea-level datum used in the seismic surveys. This means that seismic velocities observed across the new 3D seismic data acquisition to the east can be expected to more closely match those that are observed in the Shell Crown Zellerbach #1. Optimum stacking and migration velocities are predicted to be between 100 to 105% of these velocities due to horizontal component ray-path effects.

Additional Figures 4 through 7 below, present details of the well to seismic ties and the synthetic seismograms generated and used in this initial evaluation of the seismic and structural setting of this project.

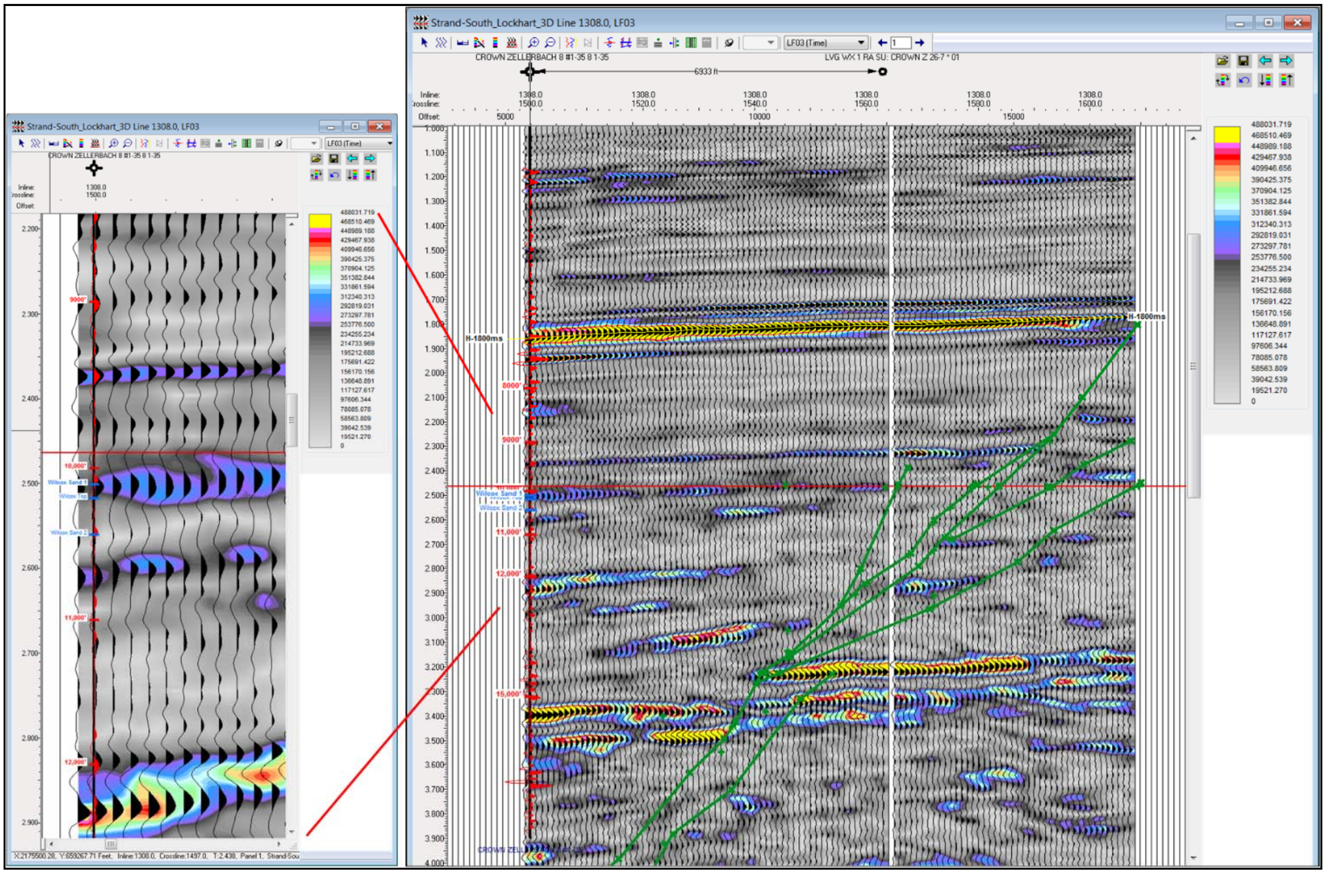


Figure 4. Synthetic seismic compared to 3D data volume.

Wiggle trace attribute shown is amplitude, color attribute is LF03, a multi-attribute indicator that combines reflection strength with a measure of attenuation of high frequencies. The first look interpretation of the pre-existing 3D seismic data volume indicates the presence of a fairly complex fault system along the northern boundary of the Livingston Field as confirmed from both geology and seismic definition. The Wilcox 2 Sand is represented at 2.56 ms, with brighter reflectors below representative of Cretaceous age sediments.

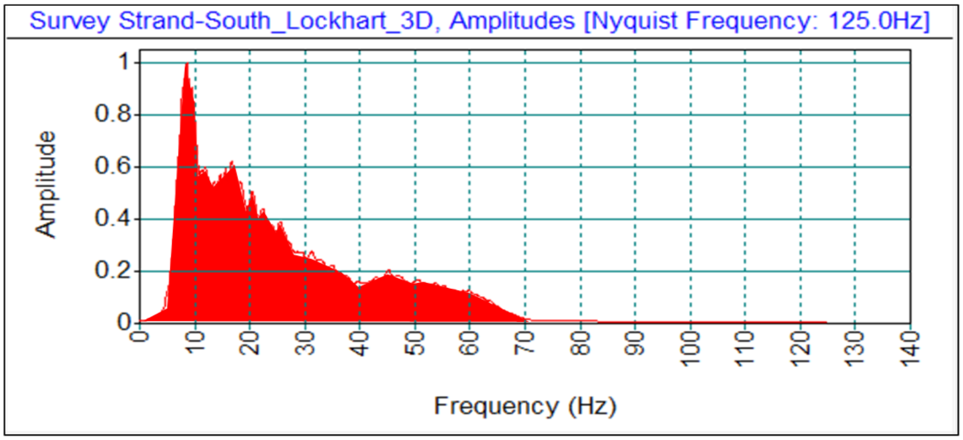


Figure 5. Long Window Frequency spectrum of the Strand South Lockhart 3D Survey.

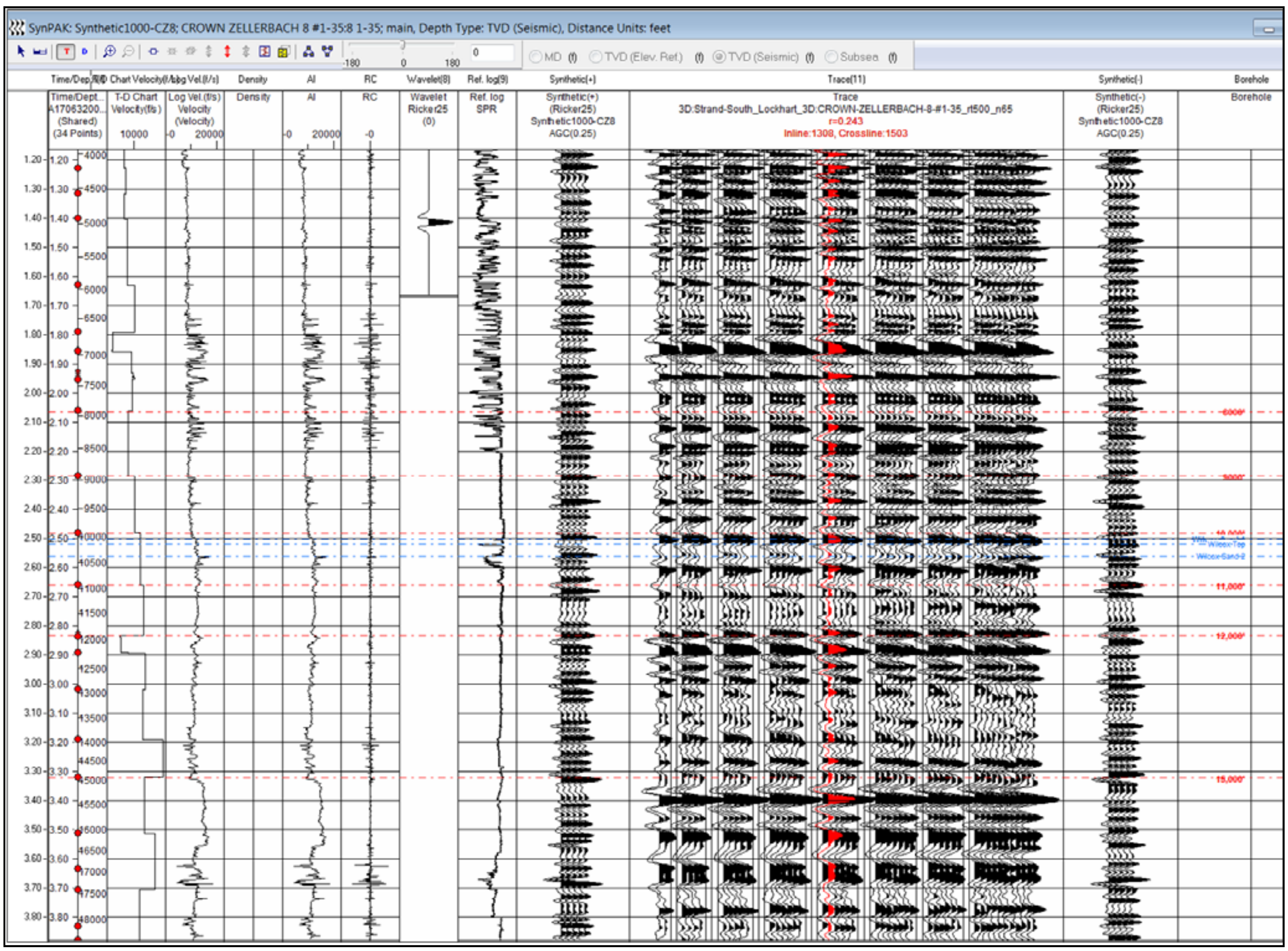


Figure 6. Long window synthetic seismic calculation for the Chevron Crown Zellerbach 8 #1-35.

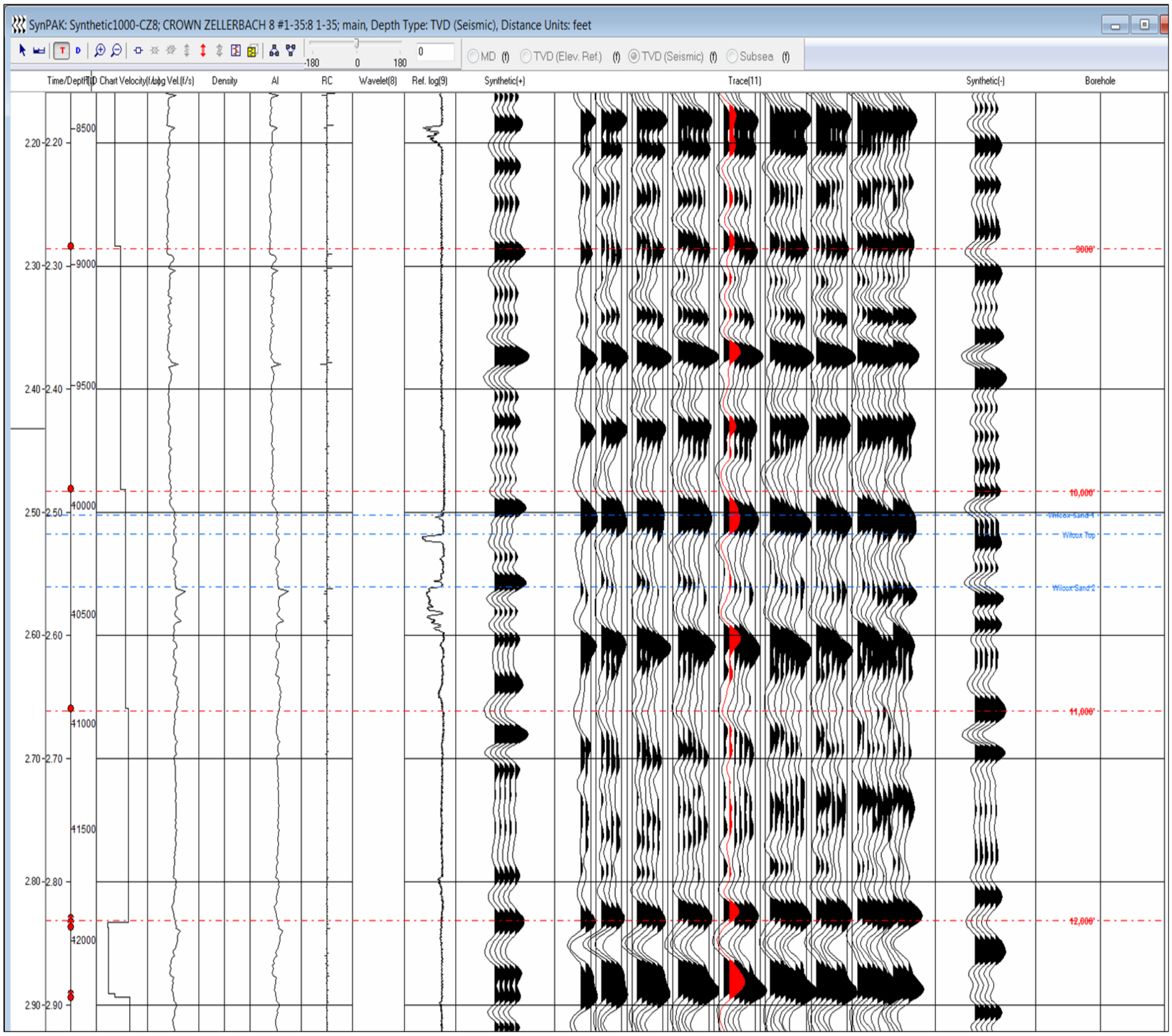


Figure 7. Detail of Chevron Crown Zellerbach 8 #1-35 synthetic across the Wilcox 1 and 2 Sands.

The synthetic seismogram character match at these levels (red wavelets compared to background black) is adequate to identify the upper Wilcox reservoirs, with marker tops present at approximately 2.50 ms for the Wilcox Sand 1, and 2.56 ms for Wilcox Sand 2.

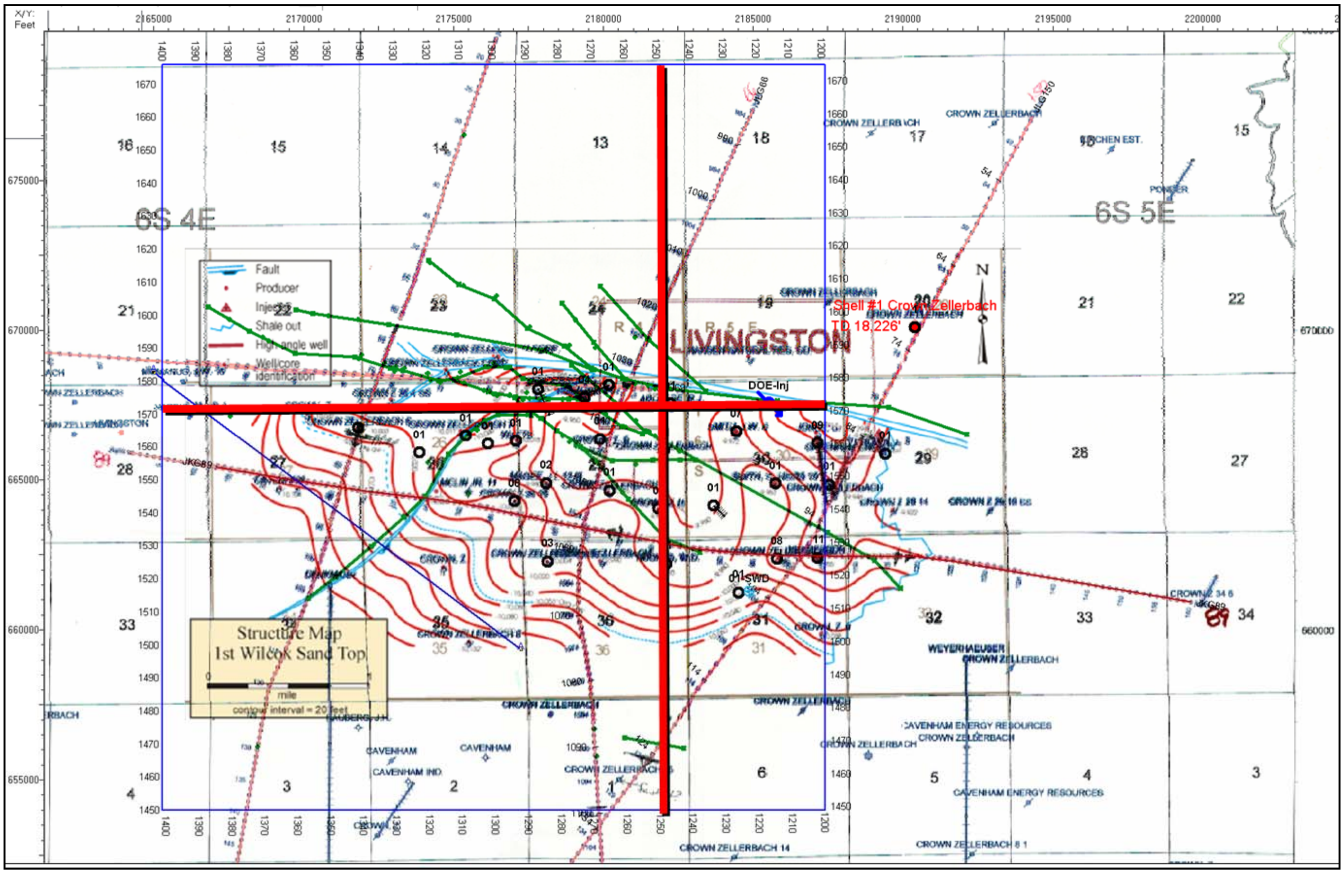


Figure 8. Comparison of original structural interpretation of the Upper Wilcox Sand (red for structural contours and light blue for fault traces) with the identified and interpreted more complex fault pattern apparent on the Strand Energy, South Lockhart 3-D survey data cut-out.

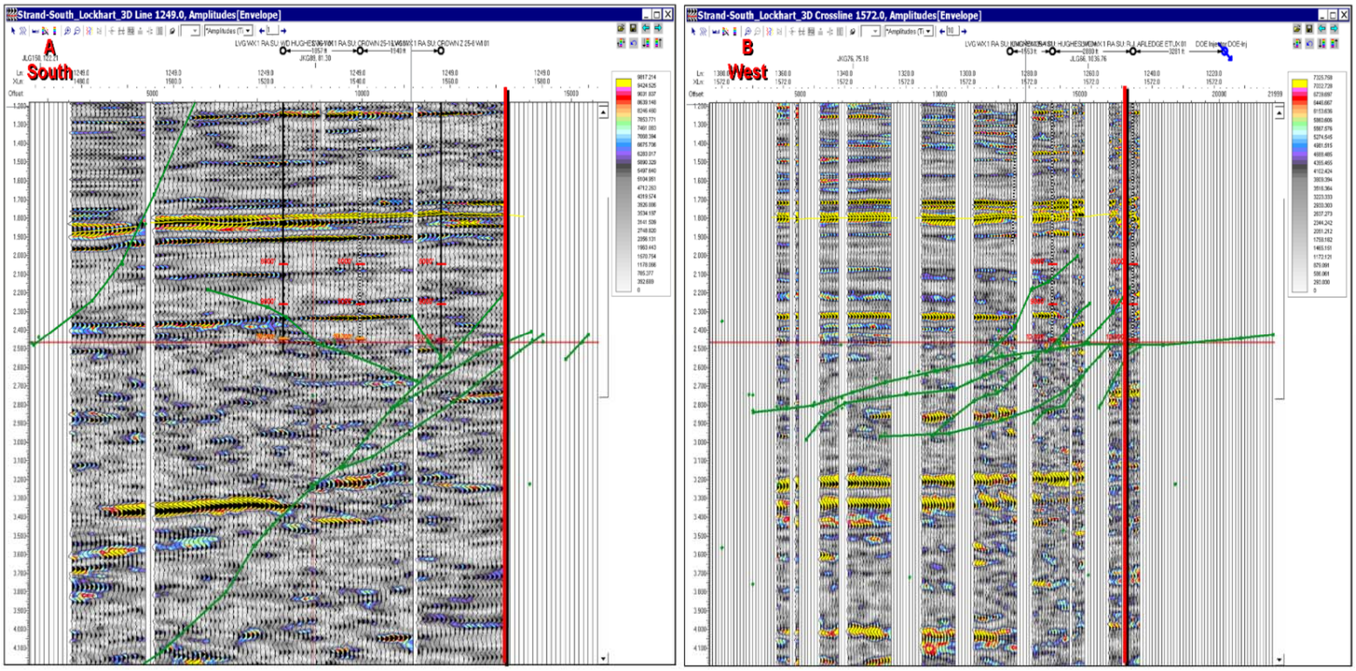


Figure 9. 3-D seismic lines from the (Strand Energy) South Lockhart 3-D survey.

Locations of the arbitrary lines of seismic section are highlighted in red in Figure 8, with apparent seismic defined fault traces mapped as green lines. The Wilcox Sands are present from 2.50 to 2.60 ms in the section. Deeper Cretaceous age sediments with mappable reflectors are present from 3.35 to 3.60 ms.

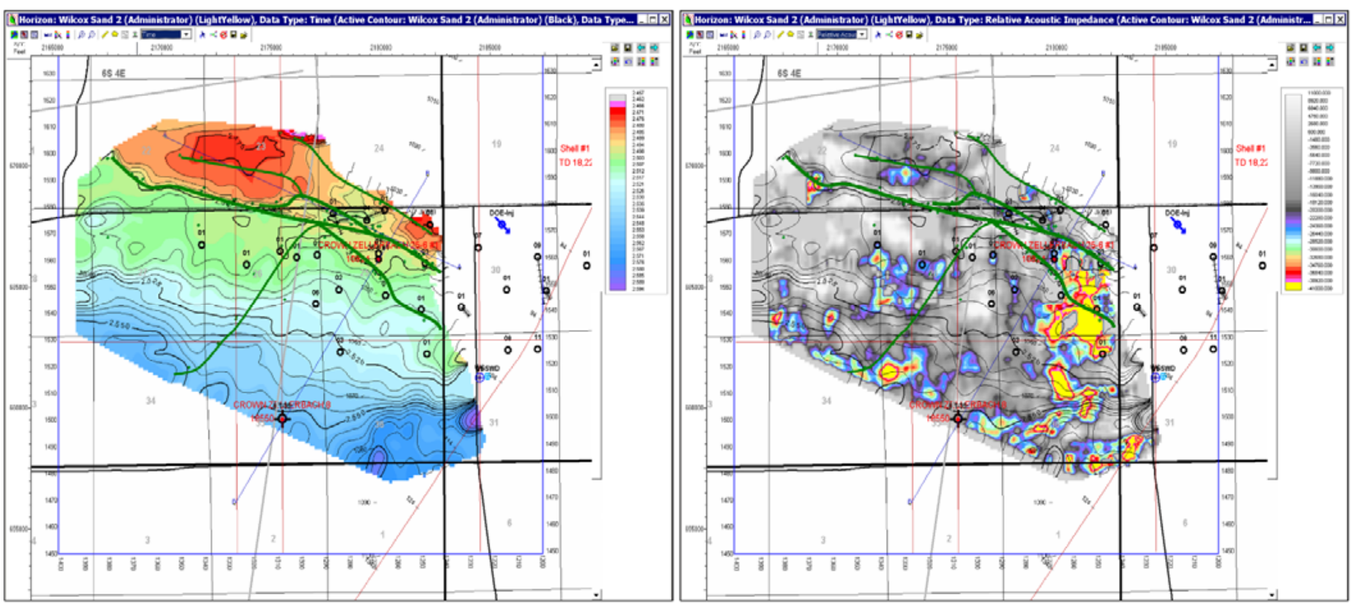


Figure 10. Left map presents time-structure on the Wilcox 2 Sand as interpreted from the Strand Energy provided data cut-out from the South Lockhart 3-D survey. The right map highlights negative values of the relative acoustic impedance attribute along the top of this interval.

Conclusions Derived from Seismic Observations after the Initial Well Tie

Following the initial well tie-in, and generation of synthetic seismograms from available sonic and check shot surveys in the Livingston field area, the following conclusions can be offered:

1. Seismic data from the Strand Energy provided South Lockhart 3-D survey indicates that subsurface structural features at the Wilcox level in the Livingston Field can be well imaged on the 3-D data set.

2. Interpretation of seismic data from the Strand Energy South Lockhart 3-D survey indicates that stratigraphic variations can be delineated at the Wilcox Sand level. This means that we will likely be able to successfully map lateral variations in reservoir conditions within the Wilcox 2 Sand reservoir.

3. Seismic data from the provided legacy 2D surveys have proven inadequate for imaging the complex fault patterns apparent on the 3-D data. The 2D data also appears to be less than desirable in terms of imaging stratigraphic details and attempting to predict reservoir structure and conditions. This may be due to variations in source and fold parameters present between the legacy 2D surveys (Table 1).

2D Line	Source Interval	Group Interval	Fold	Channels	Date Shot	Source	Acquired by
JKG-69	666	330	12	48	1976	Vib.	Teledyne
JKG-76	440	220	24	96	1977	Dyn.	Amoco
JKG-89	440	220	48	96	1979	Dyn.	Teledyne
JLG-66	440	220	24	96	1979	Dyn.	Teledyne
JLG-150	330	330	18	36	1969	Dyn.	Pan Am

Table 1. Summary of legacy 2D lines.

4. The portion of the study area currently covered by 3-D seismic data indicates that the fault system present at the Wilcox Sand reservoir levels is more complex than initially believed from earlier subsurface evaluations (Figures 4, 8, 9, and 10).

5. A detailed review of the data present in Section 30, where the proposed CO2 injection well location is, will be performed as next steps to evaluate bottomhole location, distance to faulting and well direction and placement.

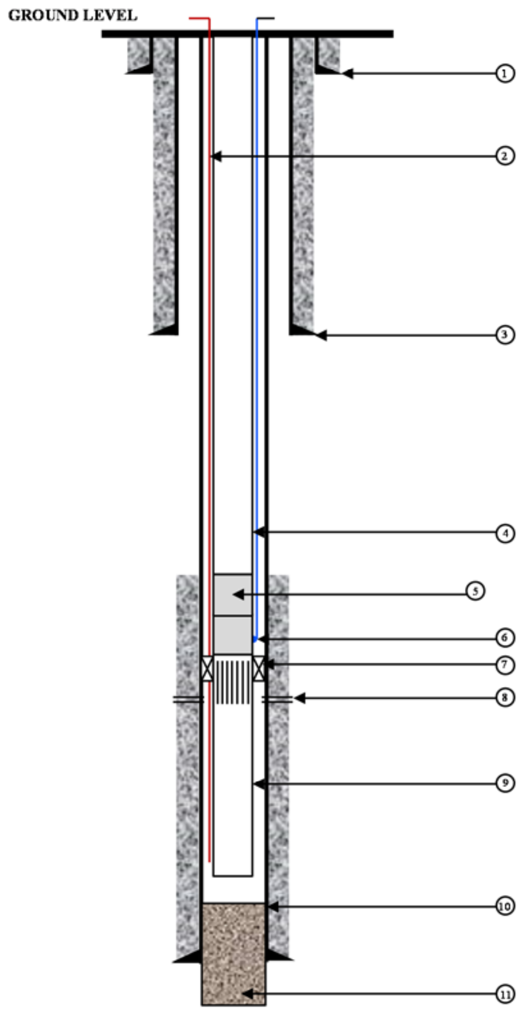
7.6 APPENDIX F – OBSERVATION WELL DIAGRAMS

Legal loc: Sec 25 T6S – R5E
Serial Number: 189152
API Num: 17063201600000
Lease Num: 6120

Blackhorse Energy, LLC

BlackHorse Energy – Livingston Field
LVG WX1 RA SU CZ 25-6 #1
Wellbore Diagram
Status: Active

KB =
DF =
GL =



COMPLETION DETAIL

1. **Drive pipe:** 16" set from surface to 90'
2. **DTS Line:** distributed temperature fiber optic cable set to base of the tailpipe (passes through the packer.) Well head exits (sealed) required for each line
3. **Surface Casing:** 10-3/4", 45.5 ppf, K-55, LT&C, set from surface to 4,014'
4. **Well Tubing**
5. **Pump:** Setting depth to be determined
6. **Pressure Temperature gauge:** Setting depth to be determined. Externally strapped to injection tubing with protectors at the connection. Pressure/Temperature set just above the packer. Well head exits (sealed) required for each line
7. **Packer:** Set at10,000' Packer will contain one pass-through for the distributed temperature cable
8. **Perforations:** 10,011' to 10,042'
9. **Perforated/Slotted:** Approximately 60' of perforated tail pipe tubing below the packer with 100' of blank pipe below the First Wilcox Sand for the Distributed Temperature fiber cable
10. **Production Casing:** 7", 26.0 ppf, Set from surface to 10,815'
11. **PBTD**

PBTD	10,673
TD	11,000

Sandia Technologies, LLC
6731 Theall Road Houston, TX 77066 USA
Tel: (832) 286-0471 Fax: (832) 286-0477

Drawn by: KDS	Date: 1/31/2014	*Drawing not to scale*

Figure 1: Crown Zellerbach 25-6 Well Schematic

Blackhorse Energy, LLC

Legal loc: Sec 25 T6S – R4E
Serial Number: 185664
API Num: 17063201000000
Lease Num: 6120

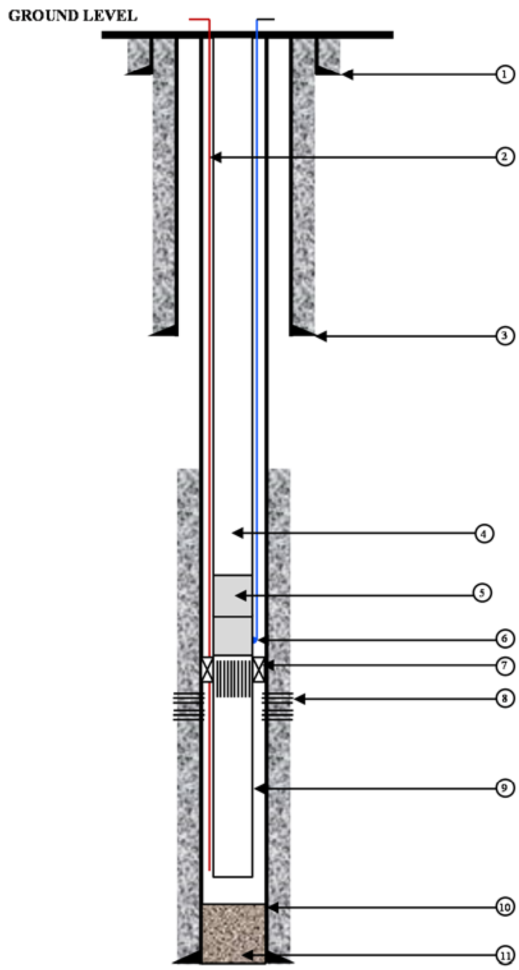
BlackHorse Energy – Livingston Field

LVG WX1 RA SU CZ 25-8 #1

Wellbore Diagram

Status: Active

KB =
DF =
GL =



COMPLETION DETAIL

1. **Drive pipe:** 16" set from surface to 95'
2. **DTS Line:** distributed temperature fiber optic cable set to base of the tailpipe (passes through the packer.) Well head exits (sealed) required for each line
3. **Surface Casing:** 10-3/4", 45.5 ppf, K-55, LT&C, set from surface to 4,014'
4. **Well Tubing**
5. **Pump:** Setting depth to be determined
6. **Pressure Temperature gauge:** Setting depth to be determined. Externally strapped to injection tubing with protectors at the connection. Pressure/Temperature set just above the packer. Well head exits (sealed) required for each line
7. **Packer:** Set at 10,000' Packer will contain one pass-through for the distributed temperature cable
8. **Perforations:** 10,012' to 10,033'
   10,037' to 10,040'
9. **Perforated/Slotted:** Approximately 60' of perforated tail pipe tubing below the packer with 100' of blank pipe below the First Wilcox Sand for the Distributed Temperature fiber cable
10. **Production Casing:** 7", 26.0 ppf, set from surface to 10,815'
11. **PBTD**

PBTD	10,673'
TD	10,815'

Sandia Technologies, LLC
6731 Theall Road Houston, TX 77066 USA
Tel: (832) 286-0471 Fax: (832) 286-0477

Drawn by: KDS	Date: 1/31/2014	*Drawing not to scale*

Figure 3: Crown Zellerbach 25-8 Well Schematic

7.7 APPENDIX G - BLACKHORSE INJECTION WELL - DRILLING PLAN VERSION 1.1

GENERAL INFORMATION

Surface Location:	Latitude: 30°30'N, Longitude 90°45'W
Elevation:	KB = 25 ft GL
Total Depth:	11,700 ft KB (10,045 ft TVD)
Completion Interval:	First Wilcox Sand

Estimated Formation Tops (BGL):

Vicksburg	8,600 ft
Cockfield	9,000 ft
Sparta	9,650 ft
Wilcox	10,200 ft

General Notes

- All depths referenced are approximate and are based on the expected log depth.
- Actual depths may vary based on lithology of local formations.

Section	Description
1.0	Drilling Procedure
2.0	Casing Program
3.0	Location Preparation
4.0	Drilling Fluids Program
5.0	Formation Evaluation Program
6.0	Cementing Program
7.0	Directional Drilling Program
8.0	Contingency Planning

1.0 DRILLING PROCEDURE

1.1 CONDUCTOR HOLE

1. Prepare surface location (Refer to Section 3.0 for Location Preparation details).

2. Mobilize drive pipe installation equipment to location and drive 16" OD (0.375" wall, PELP) conductor pipe to approximately 100 ft below ground level (125 ft KB). See Section 2.0 for details on conductor pipe.

3. Drill mousehole and rathole according to rig's specifications.

4. Mobilize drilling rig. Perform safety audits during rig-up to ensure that rig-up meets minimum criteria for acceptance.

1.2 SURFACE HOLE

1. Install weld-on bell nipple and flow line onto 16" conductor and route to rig's fluids return tank.

2. Mix spud mud as detailed in the Drilling Fluids Program (Section 4.0) of this well plan.

3. Pick up 14-3/4" bit and BHA. Drill 14-3/4" surface hole to 3,800 ft KB (+/) using spud mud. Take deviation surveys approximately every 500 ft. Maximum allowable deviation from vertical is 5°, and maximum allowable deviation between surveys is 1°. Upon reaching total depth of surface hole section, circulate and condition mud for logging. Make short trip, drop totco survey tool, and retrieve workstring from wellbore.

4. Rig up wireline equipment and run open hole electric logs as listed in the Formation Evaluation Program (Section 5.0) of this plan. *Note: If logging procedure is extended and/or hole becomes sticky or unstable during logging, make wiper trip(s) and circulate and condition mud. In preparation for casing running and cementing job, an additional wiper trip may be required if hole conditions warrant.*

Note: Notify LDNR of upcoming cement job.

5. Run 10-3/4" surface casing to 3,800 ft KB (+/-). Refer to Section 2.0 (Casing Program) of the well plan for a detailed description of the casing. *(Note: Reduce mud levels on surface and have additional tanks on hand to recover any excess mud or cement that may be circulated to the surface.)*

6. Lower workstring into wellbore with stab-in nipple and engage stab-in float collar. Circulate wellbore to ensure the wellbore is stable and to condition the drilling mud. Rig up cementing equipment and pressure-test lines. Cement casing in place and retrieve workstring from the wellbore. Refer to the Cementing Program (Section 6.0) of the well plan for details. *Note: Staging cement storage vans or tanks on location may be required during the drilling of the surface hole.*

7. After waiting on cement to harden for a minimum of 8 hours, cut off the surface and conductor pipe and install a 10-3/4" X 11" 5M slip-on-weld casing head and pressure test.

8. Nipple up 11" BOPs (Pipe-Blind-Annular) and ancillary equipment and pressure test to 250/3000 psig. *Note: Test annular to 70% of rated capacity*.

9. Install bell nipple and rig up flowline to return tank.

1.3 PRODUCTION HOLE

1. Pick up a 9-7/8” bit and BHA and trip in the hole to the float collar. Drill out collar and cement to within 10 ft of float shoe.

2. Close pipe rams and pressure-test the surface casing to 1,000 psi for 30 minutes.

3. Drill out casing shoe and 5 ft of formation. Conduct leak-off test.

4. Drill a 9-7/8” hole from surface casing depth to approximately 11,700 ft KB (+/-). Drill directional hole to target formation as per Directional Drilling Program (Section 7.0). Take inclination surveys every 500 ft in the vertical section of the hole and a minimum of every 100 feet in directional section of wellbore. Collect 30 ft x 4” OD conventional cores in confining zone and in injection zone. Make short trips as hole conditions dictate. Upon reaching total depth, circulate and condition the mud for logging. Retrieve the workstring, measuring each stand of pipe to verify well depth.

5. Rig up wireline and run geophysical logs. Refer to Section 5.0 (Formation Evaluation) of the well plan for details. Make wiper trip(s) as necessary to maintain integrity of hole.

6. Lower drilling assembly to total depth. Wash/ream through any tight spots until able to trip through without any noticeable drag. Circulate out any fill and condition mud for running casing. Retrieve workstring, laying down drill pipe and collars.

Note: Notify LDNR of upcoming cement job.

7. Rig up casing running and intelligent instrumentation install equipment. Run 7” casing to the planned casing point (11,700 ft KB +/-). Refer to the Casing Program (Section 2.0) of the well plan for a detailed description of the casing. Refer to the Intelligent Instrumentation Program (Section ??) of the well plan for a detailed description of the intelligent instrumentation, clamps, and related equipment.

- Make up pressure/temperature gauge and DTS-DAS assemblies to casing and run control lines along exterior of casing using clamp-on connectors.

- Have a casing swage available in the event the casing must be washed to bottom.

8. Once the casing is on bottom, rig up and circulate the hole for a minimum of one hole volume to clear the floats and cool the formation sufficiently for cementing. Condition the mud as appropriate to facilitate mud removal and cement placement. Cement casing using lead and tail slurries as detailed in the Cementing Program (Section 6.0).

9. Terminate control lines at surface.

10. Nipple down the BOP stack and hang off the 7” casing in tension (same hookload as when originally cemented in place). Nipple up the tubing head (11” 3M x 7-1/16” 5M) and test the seals according to the manufacturer’s specifications.

11. Rig down and demobilize drilling rig and ancillary equipment from site.

2.0 CASING PROGRAM

TUBULAR	Depth (ft)	Size (in)	Weight (lb/ft)	Grade	Thread	Collapse/Burst	Tensile Body/Joint (X 1000 lbs)
CONDUCTOR	0-125	16	62.6	Welded	PELP	571/1648	328
SURFACE CASING	0-3800	10-3/4	45.5	K-55	STC	2090/3580	715/528
PRODUCTION CASING	0-11700	7	26	P-110	LTC	6210/9960	830/693

2.0 CASING PROGRAM (continued)

10-3/4” Surface Casing Float Equipment and Casing Jewelry

1. Double Valve Float Shoe
2. Stab-In Float Collar, 1 joint above the float shoe
3. Tag in Adapter for Workstring
4. Drill Pipe Centralizer w/stop collar
5. 34 Hinged Bow Spring Centralizers
    - Centralizer 10’ above the float shoe, straddling a stop collar
    - Centralizer 6’ above float collar, straddling a stop collar
    - Centralizer 1 joint above float collar, straddling casing collar
    - Centralizer every 3rd joint to surface, straddling casing collar.

7” Production Casing Float Equipment and Casing Jewelry

1. Double Valve Float Shoe
2. Float Collar, 2 joints above the float shoe
3. Bottom Wiper Plug
4. Top Wiper Plug
5. +/- 67 Hinged Bow Spring Centralizers
    - Centralizer 10’ above the float shoe, straddling a stop collar
    - Centralizer straddling a casing collar 40’ above the float shoe
    - Centralizer 6’ above the float collar, straddling a stop collar
    - Centralizer every 2 joints, straddling casing collars, up to 3,800 ft
    - Centralizer every 3 joints, straddling casing collars, up to surface
    - One Hinged Rigid Bar Centralizer - on last joint of casing below ground surface - set between two stop collars

3.0 LOCATION PREPARATION

1. Clear and level surface location area of approximately 125 ft x 250 ft.
2. Install culvert across ditch (if needed);
3. Build ring levee around location (if needed); Install sump at corners of location to enable pumping of liquids from levee;
4. Install 5 ft diameter x 4 ft deep cellar using corrugated tin to provide shoring support.
5. Lay mats (3-ply) over surface location (as per rig specifications), plus additional mats at entrance wing (if needed);
6. Add additional board lumber (or mats) in designated strongback area of drilling rig;

4.0 DRILLING FLUIDS PROGRAM

Note: A detailed drilling fluids program will be developed based on input and recommendations from the drilling fluids contractor selected for the work, and will replace the preliminary information presented in this section.

Surface Hole

Depth (ft)	Mud Type	Weight (lb/gal)	PV (cp)	Yield Point (lb/100 ft^2)	Fluid Loss (cc/30 min)
0-3800	LSND	8.6-9.0	4 - 9	12-18	No control

Notes

1) LSND = Low Solids Non-Dispersed.
2) Solids content to be maintained in 3 to 5 percent range.
3) Lost circulation material (LCM) will be on location to treat for fluid losses in top hole sands. The fluid system will be pre-treated with LCM before encountering any known or suspected loss zones.
4) High-viscosity sweeps will be used to assist hole cleaning.

Production Hole to Casing Shoe

Depth (ft)	Mud Type	Weight (lb/gal)	PV (cp)	Yield Point (lb/100 ft^2)	Fluid Loss (cc/30 min)
3800 - 11700	Polymer	9.0 -9.5	6 - 12	8-14	< 6

Notes

1) Solids content to be maintained in 3 to 5 percent range.
2) Lost circulation material (LCM) will be on location to treat for fluid losses. The fluid system will be pre-treated with LCM before encountering any known or suspected loss zones.
3) High-viscosity sweeps will be used to assist hole cleaning.

5.0 FORMATION EVALUATION PROGRAM

14-3/4-Inch Surface Hole

Open Hole Logs

- Gamma Ray
- Spontaneous potential
- Induction Resistivity
- Compensated Neutron/Lithodensity
- 4-arm Caliper w/Gyroscopic Telemetry

Cased Hole Logs

- none

9-7/8-Inch Production Hole

Open Hole Logs

- Gamma Ray
- Spontaneous Potential
- Induction Resistivity
- Compensated Neutron/Lithodensity
- 4-arm Caliper w/Gyroscopic Telemetry
- Formation Microscanner
- Rotary Sidewall Cores (optional)
- Elemental Capture Sonde
- Combinable Magnetic Resonance

Cased Hole Logs

- Ultrasonic Cement Bond
- Gamma Ray
- Ultrasonic Casing Inspection
- Casing Collar Locator
- Platform Multifinger Imaging Tool
- Isolation Scanner
- Vertical Seismic Profile

Note: Additional diagnostic logs may be run at the discretion of geological consultant.

6.0 CEMENTING PROGRAM

Note: A detailed cementing program will be developed based on input and recommendations from the cementing contractor selected for the work, and will replace the preliminary information presented in this section.

Surface Casing

- 10-3/4" in 14-3/4" hole at 3800'
- cement to surface
- estimated 50% excess over bit size in open hole sections only
- actual volume to be calculated from caliper log plus 20% excess

	Weight lb/gal	Yield ft^3/sx	Volume sx
Lead Cement: 3500' of fill	12.9	1.53	1888
Light std "A" cement + 3% salt + ¼ lb/sx LCM additive			
Tail Cement: 300 ft of fill Class A cement	15.6	1.18	231

Production Casing

- 7" in 9-7/8" hole at +/- 11700'
- cement to 7500'
- estimated 30% excess over bit size in open hole sections only
- actual volume to be calculated from caliper log plus 20% excess

	Weight lb/gal	Yield ft^3/sx	Volume sx
Lead Cement: 3000' of fill Modified Light Premium "H" + 3% salt + 0.4% retarder + ½ lb/sx LCM additive	12.5	2.04	506
Tail Cement: 1200 ft of fill Premium cement + 10% salt + 0.4% fluid loss additive + 0.1% retarder	16.4	1.11	390

7.0 DIRECTIONAL DRILLING PROGRAM

Note: A detailed directional drilling program will be developed based on input and recommendations from the directional contractor selected for the work, and will replace the preliminary information presented in this section.

Surface Hole

- 14-3/4” hole to 3800’
- Straight hole drilling using pendulum or packed assembly; maintained at less than 5 degrees inclination.

Proposed Directional Drilling Program for 9-7/8” Production Hole

Objective: Drill horizontally in Wilcox formation for a length of 100 to 500 feet. Bottomhole location should be in Wilcox formation a closure distance of approximately 2,500 feet from surface location.

Sample Directional Program

- Drill out surface casing (set at 3,800 ft) with directional assembly and begin angle-building section at 4,000 ft with hole azimuth of 105°;
- Increase hole angle to 17° by 4,800 ft and hold angle at 17° until 8,600 ft while maintaining hole azimuth at 105°;
- Increase hole angle to 90° by 11,600 ft while maintaining dogleg severity at or below 2.5°/100 ft. Maintain hole azimuth at 105°;
- Maintain 90° hole angle and same direction to planned total depth of 11,700 ft.

8.0 CONTINGENCY PLANNING

In the event that unforeseen events occur, detailed plans to remedy the specific problem will be implemented. The following are general contingency plans to address specific problems.

Lost Circulation
No zones of moderate or severe lost circulation have been identified by review of local offset data. Some fluid losses are anticipated during the drilling of the surface hole, as permeable sands are uncovered, and will be treated as necessary by the addition of sized lost circulation material during the drilling of the hole. Low mud weights and solids concentration in the drilling fluid will assist in minimizing losses to the hole. Lost circulation pills will be spotted in the event that losses are excessive. Lost circulation material will be stored on location to allow quick response to any loss conditions.

Over-pressured Zones
A review of the area has indicated no over-pressured zones present in the local subsurface geology. During the drilling of the well, the following will be used to control/contain formation pressure:

- Hydrostatic pressure exerted by drilling/completion fluid
- Well Control (BOP) equipment

Stuck Pipe
The possibility of stuck pipe exists due the presence of sand layers and gummy shales in the well path. Drilling jars will be used in the drilling of the protection hole to assist in freeing stuck pipe. Fluid loss control of the drilling fluid will be maintained to reduce the possibility of differential sticking of the workstring. In the event that the workstring becomes stuck in the hole, some of the following procedures may be utilized to free the pipe.

- Circulate a spotting fluid in the well to assist in removal of the stuck pipe
- Rig up wireline and run a freepoint survey to determine the location of free pipe.
- Back off the section of free pipe using wireline detonation charges
- Engage the stuck portion of the workstring with an overshot and fishing jars and attempt to jar the pipe free.
- Wash over the stuck pipe and remove it from the hole
- Sidetrack the hole above the section of stuck pipe. *(TCEQ notification and consent must be obtained before sidetrack operations are implemented.)*

7.8 APPENDIX H – PUBLIC OUTREACH PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

September 11, 2013

WORK PERFORMED UNDER AGREEMENT

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SUBMITTED TO

U. S. Department of Energy
National Energy Technology Laboratory

Table of Contents

1.0 INTRODUCTION 105

2.0 OUTREACH OBJECTIVES 106

3.0 LOCAL CONDITIONS 107

3.1 LIVINGSTON HISTORY 107

3.2 LIVINGSTON PARISH MASTER PLAN 107

3.3 LIVINGSTON PARISH QUALITY OF LIFE SURVEY 108

3.4 LIVINGSTON PARISH TAX BASE 110

3.5 LIVINGSTON OIL PRODUCTION 111

4.0 STATE OF LOUISIANA 112

4.1 OIL REVENUE 113

4.2 EOR POTENTIAL 114

5.0 CCS OUTREACH EXPERIENCE 114

5.1 NETL BEST PRACTICES 114

5.2 CARBON CAPTURE AND STORAGE EXPEIENCE 115

6.0 PUBLIC OUTREACH PLAN 116

6.1 OUTREACH TEAM 117

6.2 CONTACTS 117

6.5 MESSAGES 118

6.5.1 SEISMIC SURVEY 118

6.5.2 FIELD OPERATIONS 119

6.5.3 LESSONS LEARNED 120

REFERENCES 122

1.0 INTRODUCTION

The proposed project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This project proposes to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strandplain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets in saline reservoirs.

Blackhorse Energy, LLC will be conducting a parallel CO_2 oil recovery project in the First Wilcox Sand.

The primary focus of this project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the project wells will be assessed in light of data collected from the two vertical injection wells. Field production wells will be leveraged for data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair project can provide.

It is likely that this high-profile project will demonstrate the attractiveness of CO_2 enhanced oil recovery to other small operators in Louisiana and the Gulf Coast area, thus enhancing and encouraging CO_2 sequestration operations. Enhanced oil recovery currently represents the most profitable, and therefore attractive, means of sequestering CO_2.

Blackhorse Energy, LLC (BHE) will manage and administer the Public Outreach Plan initiated under this project.

2.0 OUTREACH OBJECTIVES

Responsibility for the creation of a Public Outreach Plan will rest with the Project Steering Team. Priorities of the plan will be to develop key messages, identify target stakeholders and provide insight into their concerns, and ensure the accurate and timely dissemination of information about the project to affected stakeholders.

Communications are expected to take the form of presentations at scientific and policy meetings; fact sheets; news releases; display posters; and reports. Materials for the project will be developed, tailored to the needs and concerns of target audiences, from policymakers to scientists to community members in the project's vicinity. Ongoing updates will reflect progress made during the project budget periods. Releases for major project activities, including: select meetings; events; and milestones will be coordinated with DOE. Some members of the Project Steering Team will participate in the DOE's annual meeting and will participate in other professional conferences to present the project and report on project research.

This Public Outreach Plan (POP) is intended to meet the following objectives:

1. Provide sufficient information to the local community to assure acceptance of our project.
2. Identify and respond to public concerns
3. Build support for DOE's sequestration R&D program
4. Build confidence in Blackhorse Energy as a responsible corporate citizen

Livingston Parish already has a CO_2 flood in the Parish. Denbury has been operating the Lockhart Crossing CO_2 flood since December, 2007. What may be new in the community is the concept of CO_2 sequestration – the idea of storing CO_2 in an old oil reservoir indefinitely. While this is integral to the Lockhart Crossing flood, it may not be fully understood by the community.

3.0 LOCAL CONDITIONS

3.1 LIVINGSTON HISTORY

Figure 1

Livingston Parish is one of the Florida Parishes, originally part of West Florida in the 18th and early 19th centuries. These are the Parishes north and east of the Mississippi River (East Baton Rouge, East Feliciana, Livingston, St. Helena, St. Tammany, Tangipahoa, Washington, and West Feliciana). They were annexed into the US in 1810 and eventually formed part of the State of Louisiana in 1812. Livingston Parish was established in 1832.

Livingston Parish consists of 642 square miles and is 32 miles long by 30 miles wide. Population in 2010 was 128,000. It is the fasted growing Parish in Louisiana. Hurricane Katrina had a dramatic effect on the population in Livingston Parish. Many displaced families of the affected Parishes moved into the area and as a result, the population of the parish has increased significantly. Population has increased 30% in the last 20 years and is anticipated to double by 2030.

The town of Livingston was originally a company town entirely owned by the Lyon Lumber Co., established in 1903. The records reveal that "when all the timber was cut, about 1931, the company closed and everyone moved away except about twelve families. The company sold everything – even the church". The present town was incorporated in 1955. Livingston became the Parish seat in 1941.

3.2 LIVINGSTON PARISH MASTER PLAN

On March 1, 2011, Livingston Parish began work on its first-ever parish-wide comprehensive master plan. The purpose of the Comprehensive Master Plan is to encourage growth in Livingston Parish in a way that will achieve residents' goals. The Comprehensive Master Plan will help the Parish prioritize needed improvements over the next 10 to 20 years in transportation, water and sewer, recreation, housing, commercial, and other areas. *The plan will be useful to coordinate the work of various Parish departments — so the "right hand knows what the left hand is doing."*

Why a Comprehensive Master Plan? To learn from the past, look to the future.

A few other reasons to have a master plan:

- Growth affects taxes and costs of services. How and where growth occurs impacts the parish's costs for constructing and maintaining the infrastructure needed to serve existing and new development.

- Planning is actually good for business. Most businesses want predictability—to know growth will occur, to know where water sewer and drainage will be, and to know that someone will not be putting an incompatible use next door.
- To help coordinate improvements. For example, if we know where new roads are going to be needed, we can also plan for water and sewer lines before the roads go in.
- To address problems ahead of time. If we know where roads will be need to be wider someday, we can set the buildings back further so we don't have to tear them down or lessen their value when widening occurs.
- To qualify for grants and other outside funding. Many funding agencies require that a community have a plan in place before they agree to distribute funds.
- In sum, to encourage the kind of growth we want, and discourage the kind we do not want, and then have an action plan to get us to the desired future.

Ideally, the comprehensive master plan will guide us to make better decisions and bring about a Livingston Parish we want to live in and can afford. Livingston Parish faces a diversity of issues, which need to be addressed comprehensively. Over the last decade, Livingston Parish was one of the fastest growing parishes in Louisiana! Residents complain about increased traffic, congestion, crowded schools, a need for sewer systems in some areas, etc. And yet, Livingston is a diverse parish. Some parts of the parish have been facing rapid population growth, traffic congestion, crowded schools, loss of rural character, and a need for sewer systems. Other parts of the parish have grown little or very slowly. They face different challenges such as jobs, schools, services and a desire to preserve things the way they are.

Some have observed that the parish has a one-size-fits-all approach to policies and regulations. The comprehensive master plan can help identify the different conditions in the parish and encourage regulations and policies that reflect them.

The complex issues facing Livingston Parish cannot be solved one-at-a-time because most of them are interrelated. Hence the need for a comprehensive approach. The tool to accomplish this is a comprehensive master plan.

3.3 LIVINGSTON PARISH QUALITY OF LIFE SURVEY

Southeastern Louisiana University performed a Quality of Life survey of residents of Florida Parishes in 2008. It was designed to provide tangible materials for connecting citizens with regional planning efforts and to help elected officials, planners, nonprofit organizations and others work cooperatively in developing solutions to identified problems.

This survey was conducted from June through September 2008 by the Southeastern Social Sciences Research Center (SSSRC). Responses were solicited from 5,000 randomly selected residents in the five north shore parishes of Livingston, St. Helena, St.

Tammany, Tangipahoa and Washington. The mail survey had a 25% response rate, totaling 1,150 completed questionnaires.

Interestingly, nearly seven out of every ten respondents indicated they were satisfied or very satisfied with the overall quality of life in the area. However, the results differ significantly when examined on a parish-by-parish level, with Livingston and St. Tammany parishes registering the highest levels of satisfaction compared to Washington, where less than half expressed satisfaction with their quality of life. Responses from Tangipahoa Parish generally fell between the two extremes.

When asked about the state of their respective parishes in the three years preceding the survey, approximately half of all respondents indicated that their parish had become a worse or much worse place to live, while only 30% indicated their parish had become better or much better. However, more residents anticipated that the quality of life in their specific parishes would improve over the next three years than those who anticipate a decline.

In the study, respondents were asked to rate various types of services, the effects of rapid growth and change in their communities, environmental conditions, and their perceptions on levels of crime.

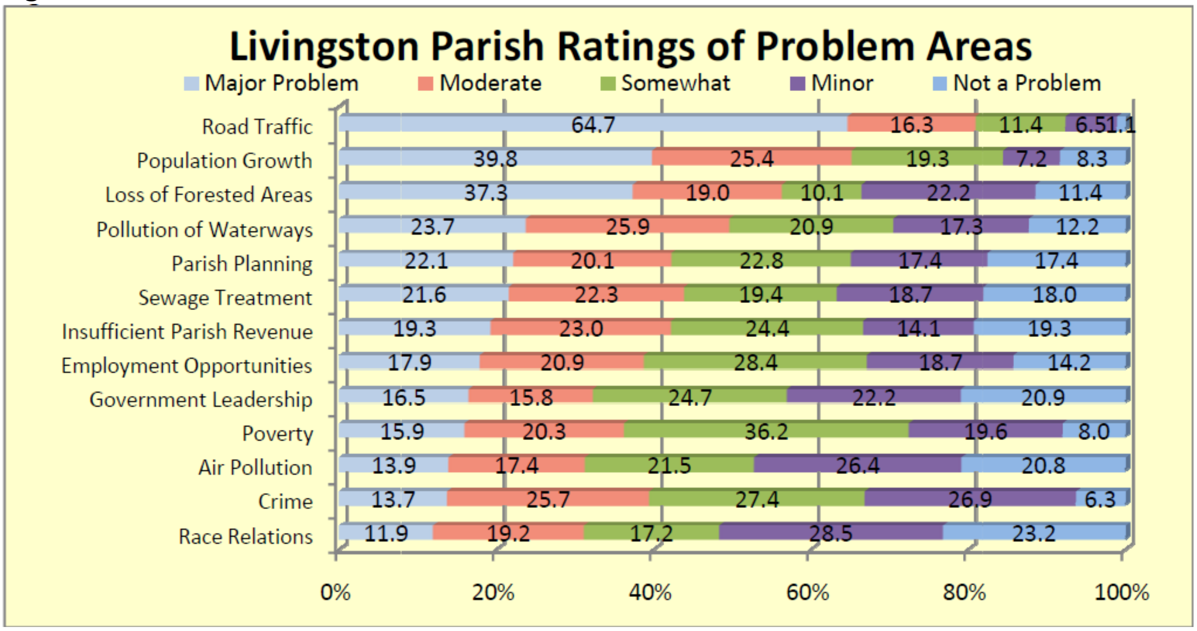
Overall, the majority of respondents rated education, child care, health care, parks and recreation as excellent or good. On the other hand, similar majorities rated affordable housing, care for the elderly and public transportation as only fair or poor. The most favorably regarded services at the parish level were fire and police protection, emergency preparedness, parks and recreation and general government services. Planning for business development, attracting jobs, traffic safety, streets, roads, and drainage had less favorable ratings.

Other major findings in the survey include these:

- A vast majority of respondents indicated they feel safe or very safe walking in their neighborhood during the day; only 16 percent indicated they venture outside less often, while 69 percent of all respondents said they became less trusting of strangers in the preceding three years.
- Road traffic, population growth, and loss of forested areas were considered moderate-to-major problems for the quality of life among most respondents. The problems seen as least of a concern, comparatively, were insufficient parish revenue, race relations and air pollution.
- Differences across parishes, however, were noteworthy. Perceptions of the quality of primary and secondary public education institutions were good-to excellent by most respondents, due in part to the high ratings given to the schools in St. Tammany and Livingston parishes. Private education across the board was seen overwhelmingly as good-to-excellent.

An analysis of the respondents' demographics indicates that annual family income is a significant factor in looking at quality of life. Respondents with higher reported family incomes reported higher general satisfaction with the overall quality of life in their

Figure 2



respective parishes.

Respondents were asked to rate thirteen different problem areas in their parish. Figure 2 shows the results for residents of Livingston Parish. Problems at the top were seen by the greatest number as major problems; problems at the bottom were seen as major problems by the least number of people.

Clearly the biggest problem for respondents in Livingston Parish is road traffic. Next was population growth. Employment opportunities and insufficient Parish revenue were seen as moderate problem areas. Air pollution, and presumably the related issue of global warming, was a relative minor problem area.

The study was not specific to any particular industry. As such, it did not test attitudes towards the oil industry.

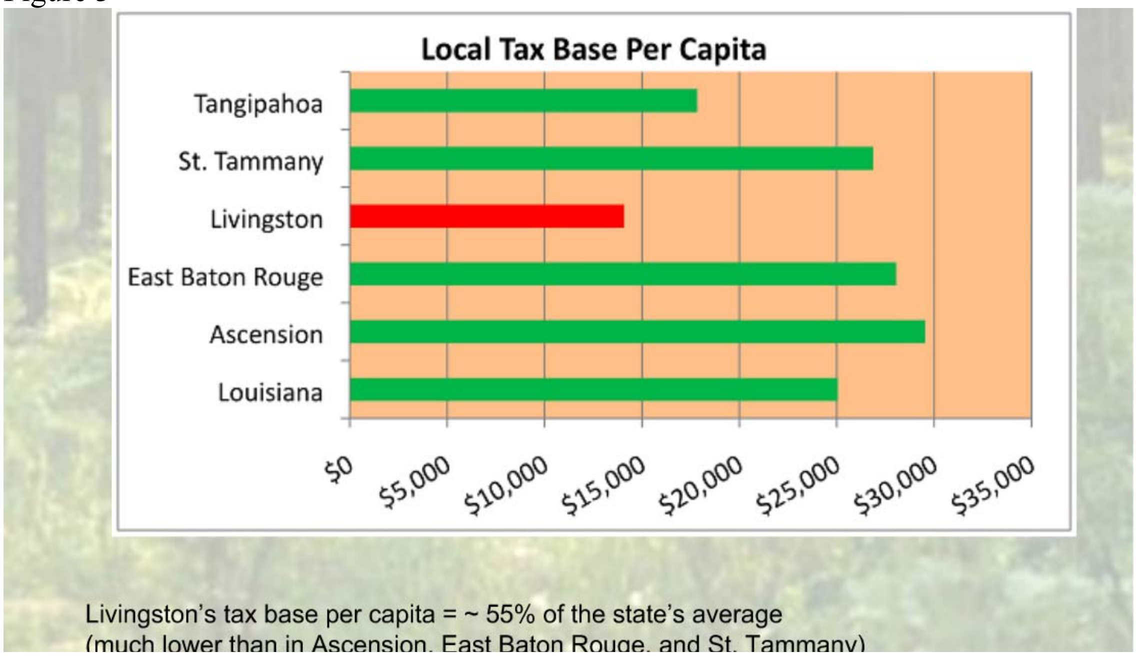
It is worth noting that this survey was taken five years ago, before the recent downturn in the economy and before the Obama administration took office. Since then, national attention has turned to jobs, federal debt, taxes and entitlement reform.

3.4 LIVINGSTON PARISH TAX BASE

Livingston Parish has a relatively low tax base compared to surrounding Parishes. Figure 3 is taken from the Master Plan materials and shows the tax base for the Parish.

With a population of 128,000 and a tax base of $14,000 per capita, the total tax base is

Figure 3



around $ 1.8 billion. Total investment for this project, including the DOE sequestration project and the EOR project, will approach $ 0.1 billion.

3.5 LIVINGSTON OIL PRODUCTION

Figure 4

Organization Name	Crude Oil	Condensate	Oil Total	ısinghead G	Natural Gas	Gas Total
DENBURY ONSHORE, LLC	751,226	0	751,226	21,392	0	21,392
YUMA E & P COMPANY, IN	26,232	0	26,232	0	0	0
HILCORP ENERGY COMPAI	0	13,486	13,486	0	320,496	320,496
BLACKHORSE ENERGY, LLC	13,032	0	13,032		0	
BOOHER ENERGY, LLC	7,382	0	7,382		0	
FLASH GAS & OIL SOUTHV	5,336	0	5,336	0	0	0
SPINDLETOP DRILLING CO.	0	4,126	4,126	0	3,660	3,660
METAIRIE ENERGY COMPA	50	0	50	0	0	0
TPE TIGER, LLC	44	0	44	0	0	0
BWM OF LOUISIANA, LLC	0	0	0	0	0	0
DESTIN RESOURCES LLC	0	0	0	0	0	0
SOUTHERN NATURAL GAS	0	0	0	0		
Total	803,302	17,612	820,914	21,392	324,156	345,548

Last year (2012) about 820,000 barrels of crude and condensate were produced in the Parish.

The largest producer by far is Denbury Onshore. They have been operating a CO_2 flood at Lockhart Crossing since December, 2007. Total production was just over 2000 B/D, down from a peak of 2900 B/D in 2011. Lockhart Crossing is an analog reservoir about 10 miles due west of Livingston. The reservoir is the same formation at the same depth as Livingston. Oil properties are identical.

Livingston oil production should peak at around 1500 B/D within a few years of initiation of the CO_2 flood.

3.6 LOCAL CONDITIONS SUMMARY

Both Livingston Parish and the Town of Livingston have experience significant population growth recently and are expecting population to double by 2030. Livingston Parish has adopted a Master Plan to guide them in dealing with this growth. At the same time Livingston Parish has the lowest tax base of six surrounding parishes. Oil production in the parish has been declining with the majority of the production now being produced as the results of a CO_2 flood operated by Denbury Onshore, LLC. In a quality of life survey conducted in 2008 nearly seven out of every ten respondents indicated they were satisfied or very satisfied with the overall quality of life in the area. The major concern for the future was road traffic.

Blackhorse Energy, LLC intends to conduct our projects in a manner that will minimize disturbances to the quality of life the residence have become accustomed to enjoying. We will make every effort to comply with the Livingston Parrish Master Plan. Our projects should add to the tax base in the community and increase oil production in the parish. Additionally, we will endeavor over the life of the project to make sure that as much of our spending as is practical flows back to the community by utilizing local contractors and suppliers.

Our public outreach plan will illustrate the above benefits as factually as possible.

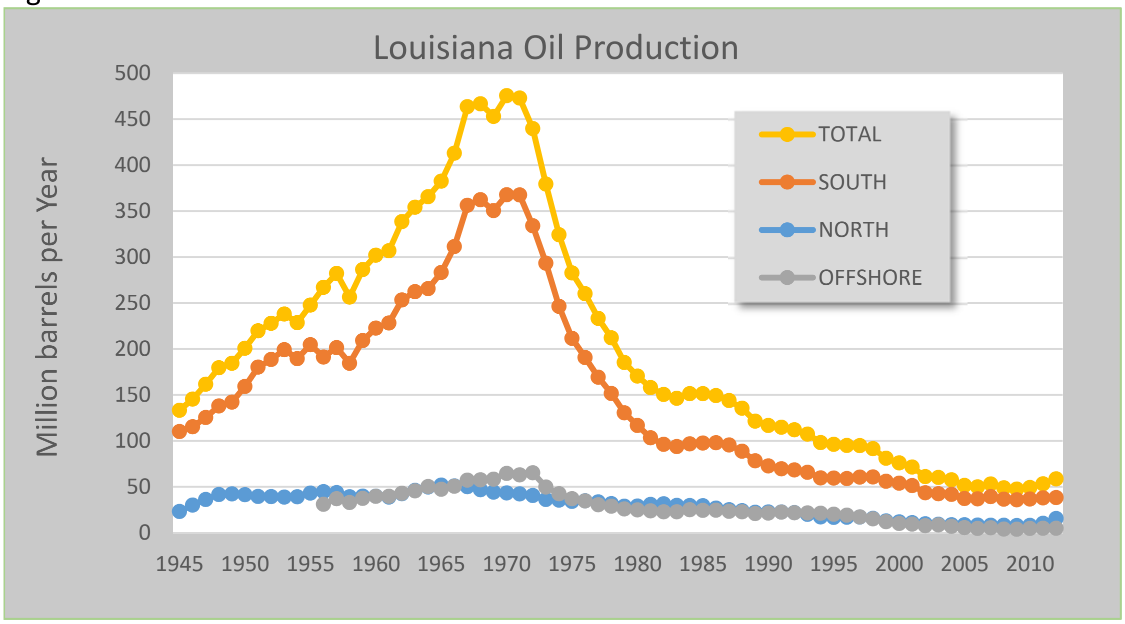
4.0 STATE OF LOUISIANA

Louisiana is Proud to Be a Hub of Industry. Doing Business Here Has Never
Been Smarter.
For more than a century, Louisiana has proudly served as a hub of the oil and gas industry, and with a renewed focus on customer service and process efficiency, our future has never been brighter! See http://dnr.louisiana.gov/assets/docs/hub-of-business_brochure.pdf .

4.1 OIL REVENUE

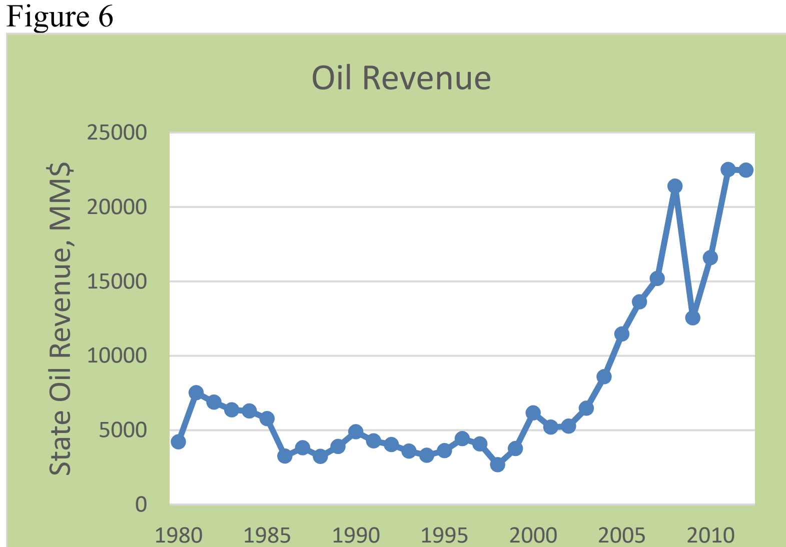
The Office of Mineral Resources was established to manage the state's mineral assets and to provide staff to advise the State Mineral and Energy Board in granting and administering leases on state-owned lands and water bottoms for the development and production of minerals, primarily oil and gas, for the purpose of optimizing revenue to the State of Louisiana from the royalties, bonuses and rentals generated therefrom.

Figure 5



The Office of Mineral Resources is one of the largest receivers of state revenues. The office receives revenues from royalties, bonuses, rentals, interest, and fees for leases on state-owned lands and water bottoms. Revenues from these sources comprise approximately 15% of the state general fund. In addition to the general fund, revenues collected also provide major sources of funding for parish governments, school boards, the Department of Wildlife

Figure 6



and Fisheries, the Coastal Protection and Restoration Authority, and the Department of Natural Resources.

Oil production in Louisiana has been declining over the past few decades. Figure 5 shows production history for the onshore north, onshore south and offshore production areas.

Because of the recent oil price increases, state revenue from oil production has increased in recent years.

4.2 EOR POTENTIAL

In a study commissioned by the DOE, the Advanced Resources International performed a number of Basin Oriented Strategies for CO_2 Enhanced Oil Recovery, one of which was for the onshore gulf coast.
The onshore gulf coast oil and gas producing region of Louisiana, Mississippi, Alabama and Florida have an original oil endowment of over 44 billion barrels. Of this, nearly 17 billion barrels or 38% will be recovered with primary and secondary (waterflooding) oil recovery. As such, nearly 28 billion barrels of oil will be left in the ground, or "stranded", following the use of traditional oil recovery practices. A major portion of this "stranded oil" is in reservoirs technically and economically amenable to enhanced oil recovery (EOR) using carbon dioxide (CO_2) injection.

To study the issue, they created a data base that included 178 reservoirs in the State of Louisiana. Of these 128 were judged to be amenable to CO_2 flooding. In their assessment, application of traditional practices in CO_2 flooding would recover an additional 1.43 billion barrels of oil. Application of more advanced practices could increase that amount to 3.25 billion barrels. At 100 $/B, this amounts to a $ 143-325 billion opportunity for the State.

5.0 CCS OUTREACH EXPERIENCE

5.1 NETL BEST PRACTICES

This Public Outreach Plan (POP) will follow the guidelines set forth in the NETL manual, "Best Practices for: Public Outreach and Education for Carbon Storage Projects".

Early CO_2 storage projects have been highly visible and their success will likely impact future CO_2 storage projects. The primary lesson learned from experience is that public outreach should be an integrated component of project management. Conducting effective public outreach will not necessarily ensure project success, but underestimating its importance can contribute to delays, increased costs, and community ill will. Effective public outreach involves listening, sharing information, and addressing concerns through proactive community engagement. The intent of the contributors to these best practices is to facilitate project success and boost the effectiveness of outreach efforts. The following best practices represent a framework for designing an outreach program associated with a CO_2 storage project. Based on the specific characteristics of a planned project, the project developers, and the community in which the project is planned, some of these best practices may be more relevant than others.

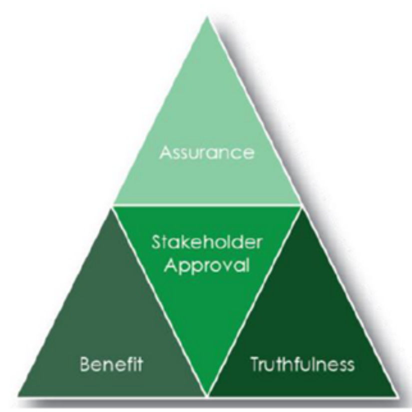
- *Best Practice 1: Integrate Public Outreach with Project Management*
- *Best Practice 2: Establish a Strong Outreach Team*
- *Best Practice 3: Identify Key Stakeholders*
- *Best Practice 4: Conduct and Apply Social Characterization*
- *Best Practice 5: Develop an Outreach Strategy and Communication Plan*
- *Best Practice 6: Develop Key Messages*
- *Best Practice 7: Develop Outreach Materials Tailored to the Audiences*
- *Best Practice 8: Actively Oversee and Manage the Outreach Program throughout the Life of the CO_2 Storage Project*
- *Best Practice 9: Monitor the Performance of the Outreach Program and Changes in Public Perceptions and Concerns*
- *Best Practice 10: Be Flexible – Refine the Public Outreach Program as Warranted*

5.2 CARBON CAPTURE AND STORAGE EXPEIENCE

Practical advice comes from the Global CCS Institute.

As all communications professionals know, gaining stakeholder approval is essentially a three-way balancing act. First, there must be an actual or perceived direct or indirect **benefit** to the individual or group – 'What's in this for me, my friends, colleagues or neighbors? Do we gain any tangible or potentially tangible advantage? ' Second, there must be **assurance** – 'Is the advocate listening to my concerns, or will they listen to me and make changes if I voice concerns in the future?' And third, the stakeholder must perceive that the advocate is being **truthful** – 'Do I believe and/or trust the person or organization making these claims?'

Figure 7



There is a delicate and dynamic interplay between these three elements. Different stakeholders will place emphasis on different aspects of the triangle. Some stakeholders will accept that while there may be little personal benefit to them in supporting a CCS project, they may well choose not to oppose it because they believe the project developer's assurances that it will be operated safely. Other stakeholders may rank benefit more highly. If the project will create local jobs or improve the local economy they may be more trusting or more positively disposed towards the developer. Another group of stakeholders may not rank benefit or assurance at all. For them the decision to support or oppose a project will be wholly based on whether they think the developers are telling the truth and can be trusted.

All of the case studies analyzed for this report revealed remarkably similar findings when it came to examining this triumvirate of benefit, assurance and truthfulness.

6.0 PUBLIC OUTREACH PLAN

Responsibility for the creation of a Public Outreach Plan will rest with the Project Steering Team. Priorities of the plan will be to develop key messages, identify target stakeholders and provide insight into their concerns, and ensure the accurate and timely dissemination of information about the project to affected stakeholders.

The objective of the public outreach plan is to insure that all stakeholders (public officials, royalty owners, working interest owners, contractors and residents) are informed in advance about what activities are planned and the potential impacts on them are understood and impact mitigation plans are adequately developed.

The Livingston CO_2 Flood and the Livingston / CO_2 Sequestration R&D Project will be developed simultaneously but separately in the Livingston field. Each project will pass through several major phases.

It is envisioned that the public outreach efforts will be staged to coincide with the beginning of major phases of each project. Public officials, royalty owners and residents will be informed of planned work and impacts at the beginning of each phase of each project and at other times during the execution of the two projects as the need arises.

The type of communication and the target audience will be determined at each stage but it is envisioned that the Parish Government, City Government, Royalty Owners, contractors and local residents are will be the primary targets. It is also envisioned that we will utilize a "top down" approach talking first to selected top Parish Officials and then working down to other Parish / City officials and ultimately residents, incorporating their suggestions and guidance each step of the way.

Major events for which communications and/or informational meetings will be held are:

1. Commencement of 3D seismic survey
2. Drilling of new injection well
3. Construction of new pipelines and facilities
4. Beginning of CO2 injection

Documents / information to be presented at each session will include:

1. Overall description of the both projects
2. Detailed work to be done in next phase (i.e. 3D seismic, drilling well etc.)
3. Potential impacts on community and mitigation steps to be taken
4. Benefits to community (royalty owners, local contractors/businesses and citizens)

6.1 OUTREACH TEAM

Blackhorse Energy has assembled a strong outreach team, working together to assure stakeholder acceptance as all levels.

Participants include:

- Roger Hite, Principal Investigator and VP Engineering with Blackhorse Energy
- Lee Blanton, President of Blackhorse Energy
- Dan Collins, Project Integrator
- Steve Sears, Professional in Residence, Petroleum Engineering, LSU
- Mileva Radonjic, Professor, Petroleum Engineering, LSU
- Tanya Allen, Allen Energy Group

6.2 CONTACTS

Stakeholders include the

- residents of the town of Livingston,
- oil field workers and suppliers
- leadership in the town of Livingston
- leadership in Livingston Parish
- State of Louisiana legislators and regulators
- Federal congressmen from Louisiana

The following public officials will be contacted, notified of our plans and ask for their input on who and how we should address community concerns:

- Layton Ricks, Livingston Parish President, (225) 686-2266
- Chance Parent, Livingston Parish Councilman representing District 1 (Livingston), (225)686-3027 , cparent@lpcgov.com
- Ricky Goff, Chair, Livingston Parish Council Committee on Emergency Preparedness, also Chair, Livingston Parish Council Committee on Engineering, (225)686-3027, rgoff@lpcgov.com
- Randy Rogers, President and CEO, Livingston Economic Development Council, 20355 Government Boulevard, Suite E, Livingston, LA 70754, (225) 686-3982, randy@ledc.net
- Jason Ard, Livingston Parish Sheriff, 20180 Iowa Street, Livingston, LA, (225) 686-2241

- Mark Harrell, Director, Livingston Parish Office of Homeland Security and Emergency Preparedness, (225) 686-3066, lohsep1@lpgov.com

Our interface with the public will be guided by the advice we receive from these contacts.

6.5 MESSAGES

6.5.1 SEISMIC SURVEY

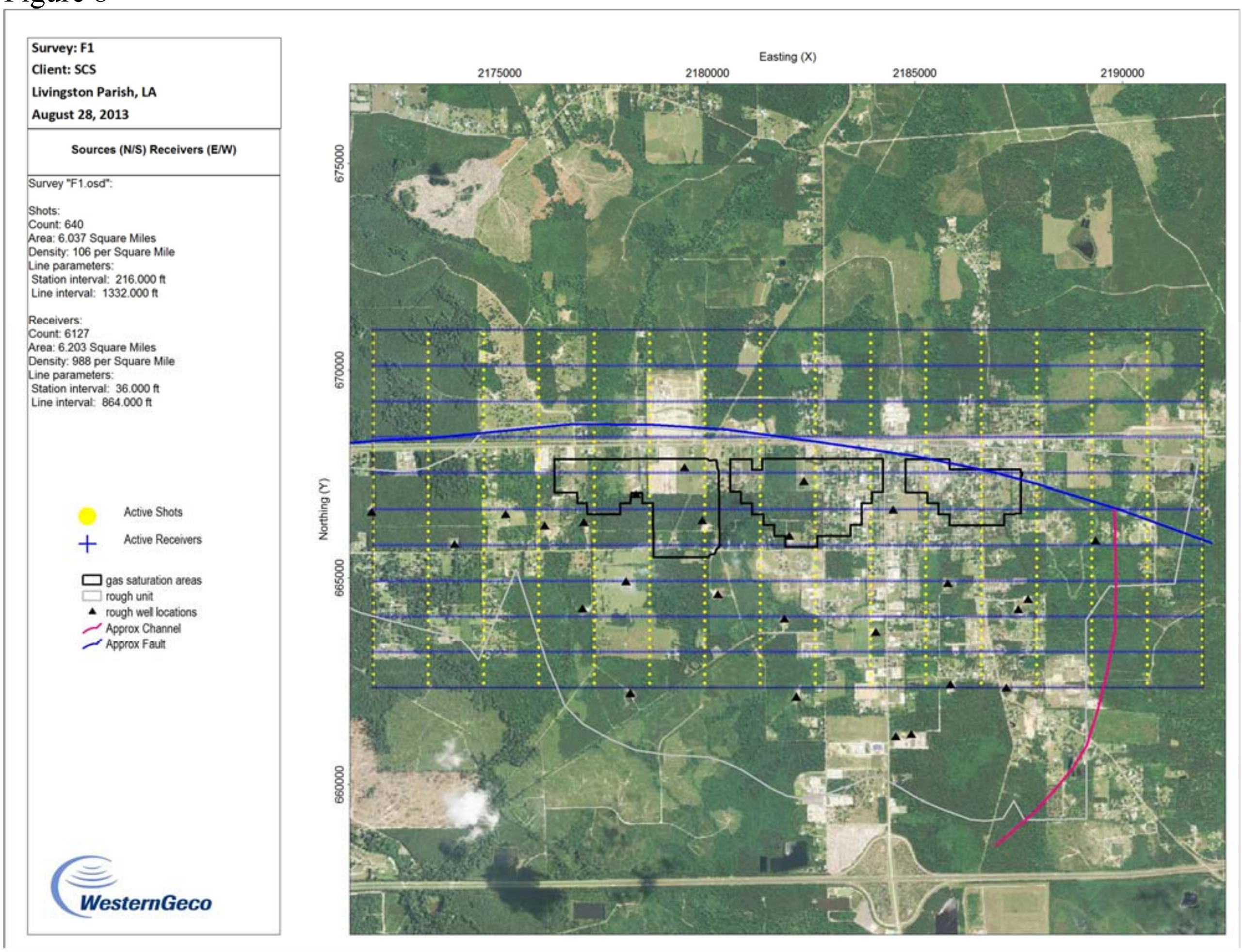
As part of the initial project characterization efforts at the site, a 3D surface seismic survey will be acquired at the site in late-2013.

Permitting is being managed by St Croix Seismic. Lesle Wright is the permitting agent. William Hancock with WesternGeco is serving as Project Manager. Permits will be sought from Louisiana Department of Wildlife and Fisheries, US Corp of Engineers, Louisiana Department of Natural Resources, and Parish Department of Homeland Security, among others. Permitting from surface and mineral owners will also be sought.

A City of Livingston public meeting has been scheduled for October 9. An announcement is being published in the local newspaper. The meeting will be an overview of the project and an introduction to seismic acquisition.

Based on the depth of the target and results from preliminary reservoir simulations for the project, the expected survey size required to meet the objectives of the project is shown in Figure 8.

Figure 8



6.5.2 FIELD OPERATIONS

Brochures and news releases will present a coordinated message to the community as follow:

- Blackhorse Energy will be implementing a CO2 flood in the Livingston Oil Field starting in 2014.
- This will be very much like other CO2 floods throughout the country. The oil industry currently produced around 350,000 barrels of oil per day through CO2 injection. Projects already exist in Louisiana, Mississippi, Texas, Oklahoma, North Dakota and Wyoming. The industry has a good

track record of operating these projects in a way that benefits the community.

- At Livingston CO2 will be injected deep underground to increase oil production. The reservoir is about two miles beneath the surface.
- The CO2 comes from a plant along the Mississippi River. Instead of venting the CO2 into the atmosphere, it will be injected underground. This reduces the risk of global warming and enhances our environment.
- Oil and gas have existed in the reservoir for millions of years. CO2 will be trapped there, just like the oil and gas.
- Because the government is interested in observing CO2 behavior in the reservoir, the Department of Energy has given Blackhorse Energy a grant to monitor how CO2 interacts with the reservoir and where it stays. The grant will bring engineers and scientists to our community to study operations. Specialists from LSU in Baton Rouge, from University of Texas is Austin and from Rice University in Houston will be involved. This information will demonstrate that CO2 can be safely kept underground.
- Such projects bring many benefits to the community – jobs for individuals, income to royalty owners, stimulation to the local economy with increased business and increased taxes to local governments.
- A first step in the project is to conduct a seismic survey. This will be done by Schlumberger on our behalf. Every precaution will be taken to minimize disruption in the community, much like other surveys taken in the recent past.
- A next step is to replace all of our facilities currently located on highway 63, near where it intersects Interstate 12 and to refurbish well sites throughout the oil field.
- In a year or so, we will drill a new CO2 injector. The surface location will be near an existing well west of downtown Livingston and just south of highway 190. The location was chosen to minimize inconvenience to our neighbors.

6.5.3 LESSONS LEARNED

Communications are expected to take the form of presentations at scientific and policy meetings; fact sheets; news releases; display posters; and reports. Materials for the project will be developed, tailored to the needs and concerns of target audiences, from policymakers to scientists to community members in the project's vicinity. Ongoing updates will reflect progress made during the project budget periods. Releases for major project activities, including: select meetings; events; and milestones will be coordinated with DOE. Some members of the Project Steering Team will participate in the DOE's annual meeting and will participate in other professional conferences to present the project and report on project research.

All publications will conform to Attachment 3 "Reporting Requirements" included with the Cooperative Agreement.

When an event results in the need to issue a written or verbal statement to the local media, the statement will be cleared first, if possible, and coordinated with NETL Office of Public Affairs, the DOE Project Manager and the Contracting Officer.

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Southeastern Louisiana University, "The Quality of Life in Louisiana's Florida Parishes", Southeastern Social Science Research Center, College of Arts, Humanities and Social Sciences, October 2009. See http://envisionlivingston.com/wp-content/uploads/2011/03/FLParishSurvey.pdf

7.9 APPENDIX I — CHARACTERIZATION / MODELING / MONITORING PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

September 26, 2013

WORK PERFORMED UNDER AGREEMENT

DE-FE0006823

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U. S. Department of Energy
National Energy Technology Laboratory

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY 126

2.0 RESERVOIR CHARACTERIZATION 128

2.1 Reservoir Characterization Team Charge 128

2.2 Existing Data and Information 128

2.2.1 Log Data 128

2.2.2 Core Data 128

2.2.3 Depositional Facies 129

2.2.4 Seismic Data 129

2.2.5 Well Data 129

2.2.6 Production and Injection Data 129

2.2.7 Pressure Data 129

2.2.8 Engineering Reports 130

2.2.9 Fluid Data 130

2.3 Plans for Additional Data 130

2.3.1 Log Data 131

2.3.2 Core Data 131

2.2.3 Seismic Data 132

2.2.4 Geochemistry Data 134

2.2.5 CO_2 Foam Design Data 134

3.0 RESERVOIR MODELING PLAN 136

3.1 Reservoir Modeling Team Charge 136

3.2 Improved Geostatistical Modeling: 136

3.3 Incorporation of Seismic Data: 137

3.4 New Modeling Technique: 137

4.0 RESERVOIR MONITORING PLAN 139

4.1 Surveillance Team Charge 139

4.2 Observation Well(s) 139

4.3 Injection Well....139

5.0 CONCLUSIONS....141

6.0 REFERENCES....142

1.0 EXECUTIVE SUMMARY

The proposed South Louisiana Small-scale Sequestration Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This Project proposes to evaluate an early Eocene-aged Wilcox sand oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the Livingston Field operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strandplain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets in saline reservoirs.

Blackhorse Energy, LLC will direct the Project through a Project Steering Team. The Project Steering Team will be comprised of the:

a. Principal Investigator for the Project, Dr. J. Roger Hite (Vice President Engineering and former Director of Production Research for Shell USA).
b. The Sandia Project Integrator, Dan Collins
c. The Technical Advisory Team Leader, Dr. Myron Kuhlman, and
d. The Blackhorse Energy CEO and Operations Manager, Lee Blanton

The Technical Advisory Team for this Project is led by Myron Kuhlman, and includes participants from the Louisiana State University, University of Texas, Rice University, the Computer Modeling Group, Weatherford, and Schlumberger Carbon Services.

Blackhorse Energy, LLC will be conducting a parallel CO_2 oil recovery project in the First Wilcox Sand.

The primary focus of this Project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the Project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the Project wells will be assessed in light of data collected from the two field vertical injection wells. Field production wells will be leveraged for data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair can provide.

It is likely that this high-profile Project will demonstrate the attractiveness of CO_2 enhanced oil recovery to other small operators in Louisiana and the Gulf Coast area, in general, thus enhancing and encouraging additional CO_2 sequestration operations. Enhanced oil recovery currently represents the most profitable, and therefore attractive, means of sequestering CO_2.

This Reservoir Characterization, Modeling and Monitoring Plan is intended to describe how reservoir and fluid data will be collected and incorporated into a dynamic model of the reservoir. A companion plan, the MVA Plan, will describe how data and information will be gathered to verify the Project objectives - to understand CO_2 behavior and migration in a beach/barrier near shore bar depositional environment. Data gathering, compilation and interpretation will be guided by the standards established in the Quality Assurance Project Plan.

2.0 RESERVOIR CHARACTERIZATION

2.1 Reservoir Characterization Team Charge

The Reservoir Characterization Team will update and populate the initial conceptual geologic models with specific data gathered during the project, including from the 3-dimensional seismic survey and from well drilling and testing of the injection well. The revised integrated models shall also be used to form the basis for final estimates by the Modeling Team of injection capacity and flow prior to the start of CO_2 injection.

Once the horizontal injector has been drilled, the Reservoir Characterization Team (Led by Dr. Myron Kuhlman of Blackhorse Energy, LLC) will coordinate lab testing of fluid and core samples with input from Sandia Technologies, LLC (and its affiliates).

2.2 Existing Data and Information

The following subsections contain an assessment of existing data and information about the Livingston Field. This analysis is consistent with Statement of Project Objectives (SOPO) Task 3.1 **-** Analyze Existing Data.

2.2.1 Well Log Data

There are 37 well logs in and around the area surrounding the Livingston Field lease and 21 of these have digitized. These digitized well logs are available on the Project FTP site FTP://blackhorse-energy.com in .las format. The remaining wells will be digitized as part of the Project and will be added to the FTP site. Once all of the wells have been digitized, they will be normalized in order to be used quantitatively.

2.2.2 Core Data

Conventional core data from the First Wilcox sand is available on 18 wells in the Livingston Field. A copy of the core analyses data is available on the Project FTP site FTP://blackhorse-energy.com. There is additional sidewall core data from the field wells, which has not been analyzed to date. Sidewall data is generally not as reliable or as good as conventional core data. In view of the abundant conventional core data, little use has been made of the sidewall data.

2.2.3 Depositional Facies

A study of depositional facies of the Wilcox sand was conducted by Larry Frizzell, VP Exploration with TMR Exploration, Inc. A copy of the study is available on the Project FTP site FTP://blackhorse-energy.com. Goddard, et al (2002) presents a field study of Livingston Field that includes a discussion of depositional environment for the First Wilcox Sand. The stratigraphic sequence shows a progradational barrier island system with eolean, beach, and shoreface deposits sealed below by marine shale and above by lagoonal shale. Johnson and Johnson (1987) describe the mineralogy of the sandstone and detail the role of diagenesis on reservoir quality.

2.2.4 Seismic Data

A 3-dimensional seismic survey was conducted by Strand Energy in 2013 covering a large area south of the Livingston Field. The survey extended into the southern and western parts of the field, in areas distant from suburban congestion. Blackhorse Energy has the rights to the raw data covering the field and a half mile boundary surrounding the field.

Aside from the Strand survey, there are a number of proprietary, non-exclusive 2-dimensional seismic lines that have been shot over or near Livingston Field but these are ov various vintage and quality. License to these data are available from seismic brokers.

2.2.5 Well Data

Well information is available from the State of Louisiana, Department of Natural Resources web site, SONRIS (see http://sonris.com/). The Livingston Field ID code is 6120. The Livingston Parish code is 32.

2.2.6 Production and Injection Data

Monthly production and injection data by well has been placed on the Project FTP site FTP://blackhorse-energy.com.

2.2.7 Pressure Data

There is sparse data on reservoir pressures over time. The data is available in Blackhorse Energy well files:

Well	Date	Depth (Feet)	Reservoir Pressure (psig)	Reservoir Pressure at 10,000 Feet Datum (psig)
Henderson 31-1	August 2012	10,015	3,284	3,277
Hughes 36-1	May 2012	10,026	2,800	2,788
CZ 25-8	November 1987	9,700	3,023	3,158
CZ 25-8	November 1987	9,700	2,730	2,865
CZ 25-8	December 1985	10,036	2,113	2,097
			Initial	4,660

A careful pressure fall-off and buildup test was run on Hughes 36-1 field well in April and May, 2012. Results were not clear due to operational considerations. The raw data is available for further analysis.

2.2.8 Engineering Reports

Several engineering reports have been prepared by Blackhorse Energy staff. There is also an earlier study prepared by Amoco in 1988. These are available on the Project FTP site FTP://blackhorse-energy.com.

2.2.9 Fluid Data

Callon Petroleum, one of the original developers of the field, commissioned five oil fluid studies by Core Labs in the mid-80's. They include a low temperature distillation analysis of the oil, pressure-volume-temperature (PVT) data, and viscosity data.

More recently, as part of our corrosion control program, Blackhorse Energy collected data on produced water samples.

These are available on the Project FTP site FTP://blackhorse-energy.com.

2.3 Plans for Additional Data

During the Project, Blackhorse Energy will be conducting a 3-dimensional survey over Livingston Field and will be drilling an injection well with a short horizontal lateral section in the First Wilcox Sand. These tasks will allow for the collection of additional data on the reservoir. Additionally, enhancements to the existing data will be made for more accurate quantitative analysis.

2.3.1 Well Log Data

The quality of the Livingston model will be improved by digitizing the remainder of the existing logs and normalizing all of the field well logs using industry standard petrophysical software.

During construction of the injection well, Schlumberger will conduct advanced open-hole logging of the open-hole sections. Logging planned for the well include a combination of standard tools, the Platform Express (Spontaneous Potential/Gamma Ray/ Resistivity/Neutron Porosity/Density Porosity), and advanced logging tools, including the Formation Micro-Imager, Continuous Magnetic Resonance, Array Acoustic Imager, and Elemental Capture Sonde. The logs will be calibrated with formation core data to provide full borehole, reservoir characteristics, rock mechanics data, and lithologic identification.

The Well Design and Construction Team (Led by Sandia Technologies, LLC) will work with Schlumberger to design and implement a detailed borehole lithologic, geophysical logging, and well testing program for obtaining and acquiring quality reservoir and formation data for formation and subsurface characterization from the new horizontal injector. At a minimum, it is expected that the final logging program will include standard industry and advanced logging tools. A vertical seismic profile will be performed to tie the new horizontal injection well into the 3-dimensional seismic survey.

2.3.2 Core Data

Whole core will be obtained from the horizontal injector to be drilled during Budget Period 2. National Oilwell Varco will be contracted to conduct continuous coring of the overlying lagoonal shales and the First Wilcox Sand in the Project injection well. Collection of new core will allow for both routine and advanced laboratory testing to determine petrophysical and geochemical characteristics of both the overlying seal formation and the reservoir. Mineralogy will be analyzed by Weatherford Laboratories, using thin-section microscopy, bulk x-ray diffraction (XRD), and full digestion ICP-MS methods. Other petrophysical parameters will also be determined, including cation and anion exchange capacity, specific surface area (BET), bulk density, permeability, and porosity. The whole core program may be supplemented with horizontal rotary sidewall cores obtained during open-hole logging, to fill in sampling gaps due to poor core recovery or aid in more characterization coverage of additional potential sequestration reservoirs.

The Reservoir Characterization Team will retain the services of Weatherford Laboratories to measure, at a minimum, total porosity, permeability, grain and bulk density, and lithologic description on recovered core samples. Further measurements on select core samples may include: 1) relative permeability; 2) vertical caprock permeability; 3) mercury injection capillary pressure; 4) x-ray diffraction mineralogy; and 5) qualitative thin-section analysis.

2.2.3 Seismic Data

Blackhorse Energy, LLC will solicit and contract with a seismic data acquisition company (with concurrence and approval from the DOE Project Officer) who shall perform a baseline 3-dimensional seismic survey to more accurately delineate the structure beneath the project site in order to resolve the structural uncertainties. The survey will also be used to determine the baseline response for the follow-up survey to be conducted during final project monitoring for determining the extent of the injected CO_2 plume.

Blackhorse Energy, LLC will solicit and contract with a seismic data interpretation company (with concurrence and approval from the DOE Project Officer) who will integrate the field well log data and 3-dimensional seismic survey into a comprehensive "pre-injection" geo-cellular model of the Livingston Field area.

The Seismic Acquisition, Processing, and Imaging Team (led by Sandia Technologies, LLC (and its affiliates)) has prepared technical specifications for the 3-dimensional reconnaissance seismic survey across Livingston Field. The survey will be used to define the subsurface geology and assist in identifying the final Project injection well location. At a minimum, the technical specifications identified the design elements and survey area needed to image the First Wilcox Sand, located at a depth of 10,000 feet. Specifications included preliminary seismic source interval, frequency, and sweep parameters to be used (vibroseis, explosives, etc.), the number of source points, interval, and their location/configuration, receiver location/configuration, recording parameters (sample interval, etc.), and post-acquisition processing. These specifications formed the basis of the bid package used to solicit and contract the data acquisition company.

The survey will be contracted and carried out in the field in late 2013. The contracted seismic company will be responsible for securing all applicable state and local permits and access agreements to conduct the survey, which must be submitted to the Principal Investigator prior to mobilization. Crews will be mobilized to the field to survey routes and define any impediments along the proposed survey; deploy, plant, and troubleshoot the receiver array; record the survey; and pickup all deployed equipment at the completion of the survey. The contracted seismic company will perform initial processing and prepare an acquisition report documenting Project details and all processing approaches and methods.

In addition, Blackhorse Energy has confirmed its willingness to grant EPRI access to the DOE-funded injector at the Livingston Field for testing of certain down-hole, fiber-optic-cable-deployed sensors (FOA-0000732). EPRI will deploy two fiber-optic sensor assemblies in our injection well. The first line is a heat-pulse monitoring cable that is ideally suited to measure the distribution of CO_2 along the axis of the well to measure the allocation and injection rate of fluid flowing into the formation. The temperature resolution is about ±0.1°C. The second fiber-optic sensor assembly will include a single-mode fiber used to measure acoustic responses from seismic sources. Silixa's iDAS™ data acquisition system has the ability to sample a 10 km fiber at 10 kHz, which equates to one acoustic measurement per meter of fiber. This fiber-optic acoustic array has the potential to be used like a continuous string of mechanical geophone receivers placed along the entire length of the well. Standard seismic sources (e.g., drop weights or vibroseis trucks) will used to generate the acoustic signal for a vertical seismic profile (VSP). Access will be subject to the execution of a satisfactory agreement between Blackhorse Energy and EPRI that addresses reimbursement of incremental costs incurred by Blackhorse Energy in support of the EPRI-led effort.

Researchers at the University of Texas will focus on relating the changes in elastic properties of the host formation observed at the laboratory scale to larger field or seismic scale changes. This up-scaling process has important bearing on the development of seismic techniques for monitoring the progress of the CO_2 plume post-injection. To accomplish this objective, they propose to develop extensions to the current effective media models to incorporate velocity anomalies induced by frame alteration of the rock. In conjunction, other research objectives are to develop high-resolution seismic inversion capability methods using basis pursuit and very fast simulated annealing that incorporate improved forward models reflecting the rock physics associated with CO_2 injection in the subsurface.

2.2.4 Geochemistry Data

The interaction of CO_2, minerals found in sandstone reservoir rocks (especially carbonates and clays), and brine/water can produce geochemical changes which in turn can affect reservoir/cap rock properties. A common example found in natural systems is the interaction of carbonic acid (H_2CO_3) with feldspar to form kaolinite, which results in additional porosity, lower permeability, reduced pore throat sizes. In addition carbonate minerals present in sandstone will most likely be unstable under low pH conditions and this can potentially change porosity/permeability and therefore injectivity of CO_2. Researchers at Louisiana State University will identify and quantify such geochemical changes under laboratory conditions and provide this data for use in models capable of predicting behavior of the reservoir rock in the field.

2.2.5 CO_2 Foam Design Data

In addition to CO_2 injection, it is intended to use about 150,000 lbs of surfactants to produce CO_2 foams in the reservoir. This attempt, if successful, is expected to delay the breakthrough of injected fluids and improve sweep efficiency by overcoming or mitigating reservoir heterogeneity, gravity segregation, and viscous fingering. Such a success in the field trial requires tailor-designed surfactant chemicals and foam rheological properties meeting the characteristics of the fields of interest, including rock and fluid properties, chemical-rock interactions, foam stability influenced by reservoir fluids and wettability and thermal degradation of chemicals. Researchers at Louisiana State University will develop a reliable evaluation process for implementing mobility-control foam processes and an accurate scale-up process for laboratory flow tests to field-scale flooding by understanding foam rheological properties during foam displacement in the reservoir. A mechanistic foam modeling technique based on foam catastrophe theory is a key aspect to meet these goals.

Researchers at the University of Texas are developing surfactants for mobility control and will supervise high pressure CO_2 foam flooding experiments. Oil displacement flow experiments at reservoir conditions are required to confirm the viability of the surfactant selection and optimize slug size for reservoir design and application. Researchers at the University of Texas and Rice University have established a proven record of collaboration to understand the governing chemistry and fluid flow behavior of foams in porous media. The methods they have developed will be used and hopefully will yield an effective foam mobility control system for the Project

Adsorption of surfactant on reservoir minerals is complex. The reservoir matrix is a mixture of the sandstone, clays and highly concreted zones where carbonates and clays have precipitated in the otherwise clean beach sand. Dynamic and static adsorption studies on minerals are required to quantify potential surfactant loss, governing mechanisms, sacrificial agents (if required) and surfactant selection and slug size.

Surfactant partitioning behavior is an important aspect of surfactant transport and possible chromatographic separation. Phase behavior and partitioning studies at Rice of surfactant between CO_2, brine and oil will be used to recognize surfactant chromatographic separation and transport.

3.0 RESERVOIR MODELING PLAN

3.1 Reservoir Modeling Team Charge

The Modeling Team, consisting of the Computer Modeling Group, Schlumberger and key staff from the Louisiana State University, Rice University, and the University of Texas at Austin, will be led by Dr. Myron I. Kuhlman. The team will develop a final "pre-injection" conceptual geologic model of the Project site and characteristics for CO_2 storage (using a geo-cellular model also known as a geo-statistical model) to be used in Computer Modeling Group, Ltd's Generalized Equation-of-State Model Compositional Reservoir Simulator (GEM) or University of Texas's foam model.

The Modeling Team will develop initial Project simulators for fluid flow and geochemistry, identify key data and time-lapse data required for the continuing modeling effort, identify characterization data "gaps", refine Project scientific laboratory and modeling goals during the initial phases of the Project, and ensure that the final designed program will meet the laboratory, modeling, and simulation objectives.

The Modeling Team will perform periodic reviews of the Project during execution, to ensure that the scientific objectives remain achievable, are being met within the defined timeframe of the Project schedule, and will take the lead to redefine methodologies should it appear that specific scientific objectives are not being met.

The conceptual model will be used to develop the framework for preparing early-estimates of CO_2 capacity and final injection well location. The data will be integrated into a GIS database containing the stratigraphic, hydrologic, and water quality data gathered during this phase. The GIS database will allow for easy access to Project information by interested parties and will be shared and integrated into SECARB and NATCARB datasets. Sandia Technologies, LLC (and its affiliates) will be the Project liaison with SECARB and NATCARB.

3.2 Improved Geostatistical Modeling:

Porosity was distributed in previous models using the geostatistical package in Builder. Current plans are to have Vijay Srinivasan of the University of Texas help us in building new models. Either Builder or Petrel can be used to build the models. Several models can be built since a geostatistical model is just one of many equally probably outcomes. In addition, a contour model can be generated, since contours are just the average of all geostatistical outcomes. In any event we will have several models to test in GEM.

3.3 Incorporation of Seismic Data:

Seismic data will be the last information available and probably can only be used in our final model of Budget Period 1. Since the pay zone is only 20 to 25 feet thick, seismic is probably incapable of resolving features inside the pay zone, but may be able to help us identify differences between the upper and lower shore face, or some thicker portions of the carbonate layer and the faults on the north, west and possibly southern parts of the field as well as the low-porosity channel fill on the eastern edge of the field. Thus, seismic data will help us validate and refine our model, but we will not delay the model to wait for this data.

3.4 New Modeling Technique:

Researchers at the University of Texas will develop a new computational approach for monitoring the location of CO_2 during injection. The proposed approach has two notable advantages: it is very inexpensive, and it quantifies the uncertainty in the plume location. The former advantage arises because the method can work with data that will be measured in every storage project, namely injection rates and pressures at each well versus time. The latter advantage arises because the approach abandons traditional pixel-based methods of parameter estimation and instead yields multiple geologically consistent models that reflect the injection characteristics observed at wells. The method is geologically based and inherently flexible enough to use other types of data, such as surface deflection or seismic, to infer plume location with greater accuracy. The objectives of the main research tasks are to develop the mathematical formulation for a model-based approach (as opposed to current pixel-based approaches), to develop modular software that can be readily integrated with existing flow simulators and with frameworks for monitoring and verifying plume location, and to demonstrate the approach on field datasets.

4.0 RESERVOIR MONITORING PLAN

4.1 Surveillance Team Charge

The Surveillance Team will collect continuous operating and downhole pressure/temperature and distributed temperature data from the injection well. Similar data will be collected from the instrumented observation wells. On at least an annual basis, advanced Reservoir Saturation Tool logging runs and bottomhole fluids sampling will be performed in the offset observation wells by Schlumberger. Data will be accessible to the Modeling Team so that the project models can be updated at least on an annual basis. Integrity of the project injection well will be monitored via the distributed temperature system and via the tubing/casing annulus pressure.

4.2 Observation Well(s)

The Surveillance Team (led by Sandia Technologies, LLC (and its affiliates)) will prepare technical specifications and bid documents, purchase, and direct installation of downhole pressure/temperature and distributed temperature monitoring sensors into an initial observation well in Budget Period 1 and two additional observation wells during the early stages of Budget Period 2. Downhole pressure/temperature transducers will be placed as close as practical to the observation well perforations and will continuously record parameter changes in the First Wilcox Sand. The Surveillance Team will investigate the efficacy and options for redundant monitoring should there be system failures during the project. These data will be analyzed and incorporated into the ongoing modeling effort to track the injected CO_2 plume. The distributed temperature system will be tubing deployed and extend through the base of the First Wilcox Sand. Early instrumentation deployment will allow for accumulation of longer duration baseline data prior to initiation of CO_2 injection. In addition, a baseline Reservoir Saturation Tool will be run in the observation wells to define initial saturation conditions.

4.3 Injection Well

A pressure/ temperature sensor will be deployed on the surface casing of the project injection well to continuously monitor a saline reservoir sand beneath the lowermost underground source of drinking water to verify “no impact” to potential water sources.

The Surveillance Team will collect continuous operating and downhole pressure/temperature and distributed temperature data from the injection well. Similar data will be collected from the instrumented observation wells. On at least an annual basis, advanced Reservoir Saturation Tool logging runs and bottomhole fluids sampling will be performed in the offset observation wells by Schlumberger. Data will be accessible to the Modeling Team so that the project models can be updated on at least an annual basis. Integrity of the project injection well will be monitored via the distributed temperature system and via the tubing/casing annulus pressure.

In the unlikely event of possible CO_2 mitigation plans to control leakage will be developed in consultation with DOE to effectively manage CO_2 leakage into shallower horizons and/or to the surface.

5.0 CONCLUSIONS

This Reservoir Characterization, Modeling and Monitoring Plan describes how reservoir and fluid data will be collected and incorporated into a dynamic reservoir model. The model will be used to estimate CO2 sequestration volumes in barrier bar deposits and to establish best practices for doing so.

The Project Team will collate final internal, sponsored University, and vendor reports into a comprehensive final conceptual geologic model of the project site and characteristics determined for CO_2 storage. The final model will be used to develop the final estimates of CO_2 storage capacity by the Modeling Team. These data will be presented to DOE/NETL as part of subtask 16.3.

Three-dimensional model data will be integrated into a GIS database containing the stratigraphic, hydrologic, and water quality data gathered during the project. The GIS database will allow for easy access to project information by interested parties and will be shared and integrated into SECARB and NATCARB datasets. Sandia Technologies, LLC (and its affiliates) will be the project liaison with SECARB and NATCARB.

The Project Team will be responsible for helping to develop a best practices manual based on project activities. This manual will describe the objective of the project, description of the geology, risk management, investigative methods used, and a summary the results. This manual will include a lessons learned section on the site characterization, drilling, well installation, and CO_2 injection operations. Additionally, the manual will include an overall assessment of the project.

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7.10 APPENDIX J — QUALITY ASSURANCE PROJECT PLAN

SOUTH LOUISIANA

EOR/SEQUESTRATION RESEARCH & DEVELOPMENT PROJECT

QUALITY ASSURANCE PROJECT PLAN

FOR

U.S. DEPARTMENT OF ENERGY

DE-FOA-0000441

Prepared

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October, 2013

Blackhorse Energy, LLC

SOUTH LOUISIANA

EOR/SEQUESTRATION RESEARCH & DEVELOPMENT PROJECT

QUALITY ASSURANCE PROJECT PLAN

Table of Contents

DISTRIBUTION LIST 146

1.0 INTRODUCTION 148

2.0 APPLICATION 150

3.0 GUIDING PRINCIPLES AND CRITERIA 151

3.1 Conformance with DOE Order 414.1 Quality Assurance 151

3.2 Consistency with DOE's Criteria 151

4.0 MANAGEMENT FUNCTION 152

4.1 Program 152

4.2 Personnel Training and Qualifications 153

4.3 Quality Improvement 154

4.4 Documents and Records 155

5.0 PERFORMANCE FUNCTION 156

5.1 Work Processes 156

5.2 Design 157

5.3 Procurement 159

5.4 Inspection and Acceptance Testing 161

6.0 ASSESSMENT FUNCTION 163

6.1 Management Assessment ... 163

6.2 Independent Assessment ... 164

7.0 PROJECT SUB-TASK QAPS ... 166

7.1 Budget Period 1 Tasks ... 166

7.1.1 Project Planning ... 166

7.1.2 Site Characterization and Monitoring Planning ... 166

7.1.3 Baseline 3-D Seismic Survey ... 166

7.1.4 Geologic-Reservoir-Seismic Model Framework ... 166

7.1.5 Baseline Initial Observation Well Surveillance, Planning, Contracting ... 166

7.1.6 Injection Well Services Contracting ... 167

7.2 Budget Period 2 Tasks ... 167

7.2.1 Injection Well Installation ... 167

7.2.2 Baseline Testing ... 167

7.2.3 CO_2 Injection ... 167

7.2.4 Surveillance Monitoring ... 167

7.3 Budget Period 3 Tasks ... 168

7.3.1 Field Verification ... 168

7.3.2 Data Analysis ... 168

7.3.3 Project Wrap-Up ... 168

8.0 REFERENCES ... 169

Blackhorse Energy, LLC

SOUTH LOUISIANA

EOR/SEQUESTRATION RESEARCH & DEVELOPMENT PROJECT

QUALITY ASSURANCE PROJECT PLAN

PROJECT ELEMENTS IMPLEMENTED FOR THE DOE CO_2 SEQUESTRATION PROJECT

TITLE and APPROVAL SHEET

Project Title: DE-FOA-0000441

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Blackhorse Energy, Houston, Texas

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1.0 INTRODUCTION

This Quality Assurance Project Plan (QAPP) developed for Blackhorse Energy, LLC (Blackhorse) is consistent with U.S. Department of Energy (DOE-NETL) and U.S. Environmental Protection Agency (EPA) accepted practices, protocols and guidance documents for projects of this type.

Blackhorse's approach on the project will follow (where applicable), and be consistent with quality assurance (QA) requirements of DOE Order (O) 414.1D, Quality Assurance, dated 4-25-11, and 10 C.F.R. Part 830, Subpart A, Quality Assurance Requirements, and DOE O 414.1C, Quality Assurance, dated 6-17-05. Additionally, all work performed on this project will be accomplished in a safe manner, minimizing potential hazards to the public, the site, or facility workers, and the environment.

Portions of the plan also incorporate relevant elements and procedures developed from EPA QA documents: *EPA Guidance for Quality Assurance Project Plans (EPA QA/G-5)*, and by factoring Data Quality Objectives (DQOs) identified in *EPA Guidance for the Data Quality Objectives Process (EPA QA/G-4)*.

Elements from the Quality Assurance Project Plan provide direct procedures and guidance to Blackhorse Energy, LLC for data acquisition, comprehensive evaluation and research data utilization techniques in managing and overseeing various aspects of the project. The plan encompasses all elements of the CO_2 Enhanced Oil Recovery (EOR) and Sequestration project such as project planning, data acquisition, compilation, interpretation, field elements such as seismic acquisition, and comprehensive methodology for evaluation of field information acquired during the installation of a proposed new CO_2 injection well at Blackhorse Energy, LLC's Livingston Oil Field in Louisiana.

This QAPP has been developed with standardized elements offering comprehensive umbrella coverage with site specific tasks present in sub-tasks of the field and sub-contractor portion of the project, covering project planning stages to implementation and data evaluation.

In this project, Blackhorse Energy, LLC is responsible for the management and oversight functions covering a broad range of work activities, under individual DOE budget periods:

Budget Period 1 – Planning/Characterization/Baseline Seismic;

Work Activities: Varied project work activities include: project planning, site characterization and monitoring planning, baseline 3-D seismic survey, geologic-reservoir-seismic model framework, baseline initial observation well surveillance, well planning, and well services contracting.

Approval for Project Continuation

Budget Period 2 – Well Installation/Baseline Testing/CO_2 Injection/Surveillance Monitoring;

Work Activities: Varied project work activities include: project management, baseline offset observation well surveillance, injection well installation, well data analysis & interpretation, post-drilling site model update.

Go-No-Go Decision Point

CO_2 injection operations, surveillance monitoring.

Approval for Project Continuation

Budget Period 3 – Field Verification/Data Analysis/Project Wrap-Up

Work Activities: Varied project work activities include: project management, completion of surveillance/monitoring program, final 3-D Seismic Survey, Project Reporting, Site Commercialization Plan.

2.0 APPLICATION

Blackhorse Energy, LLC's and Sandia Technologies, LLC its contractor, have prepared this Quality Assurance Project Plan to implement and use on the South Louisiana Enhanced Oil Recovery/Sequestration Demonstration Project received in response to Funding Opportunity Announcement No. DE-FOA-0000441, "Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage."

An umbrella coverage Quality Assurance Program (QAP) and customized Quality Assurance Project Plan was developed to be implemented on all aspects of the project, while being consistent with all contractor requirements, regulations, and orders. It consists of methods to document and implement the QAP while maintaining consistency of Quality Assurance Order and Rules.

This Quality Assurance Project Plan and document is weighted and oriented toward higher impact project areas consisting of field testing, seismic surveys, well workovers/instrumentation, injection well installation, and CO_2 injection, considered to be where the greatest amount of data acquisition and collection sources exist, and where the largest variability and chances for potential collection and incorporation of sub-standard data and compilation may be found.

In-place Quality Assurance Rules, and Orders are followed using DOE and EPA guidance, and best industry practices, incorporating and using appropriate standards.

The specific and relevant QAP content in the QAPP is customized to Blackhorse's business model, being a CO_2-EOR oil and gas technology company, and covers the extent of the DOE Project with its milestones, deliverables, responsibilities, products/services, hazards and customer expectations.

All relevant portions of DOE's QAP Quality Assurance Criteria, consisting of Management, Performance and Assessment Functions are present and have been addressed in the Blackhorse QAPP.

3.0 GUIDING PRINCIPLES AND CRITERIA

Blackhorse developed this umbrella coverage Quality Assurance Program (QAP) and customized Quality Assurance Project Plan consistent with all contractor requirements, regulations, and orders. It consists of methods to document and implement the QAP while maintaining consistency of Quality Assurance Order and Rules.

3.1 Conformance with DOE Order 414.1 Quality Assurance

The plan is consistent with and conforms with DOE Order 414.1 Quality Assurance under the following principles:

- The Blackhorse organization is committed to achieve, maintain and continuously improve quality
- Minimize safety, environment, and health risks and impacts while maximizing reliability and performance
- Ensure planning, organization, direction, control and support to achieve the project objectives
- Review, evaluate, and improve overall performance, including that of site support contractors, using an assessment process based upon approved quality policies.

3.2 Consistency with DOE's Criteria

The NETL QA Program consists of 10 criteria categorized into three separate functional areas as recommended by DOE Guide 414.1-2, Quality Assurance Management System Guide for Use with 10 CFR 830 Subpart A and DOE Order 414.1, Quality Assurance. These functional areas consist of management, performance, and assessment, which are further subdivided into Criterion, which are explained in detail in Sections 4, 5, and 6 respectively, of this plan.

Functional Areas	Criterion
4.0 Management	Program Personnel, Training and Qualifications Quality Improvement Documents and Records
5.0 Performance	Work Processes Design Procurement Inspection and Acceptance Testing
6.0 Assessment	Management Assessment Independent Assessment

4.0 MANAGEMENT FUNCTION

4.1 Program

Blackhorse's management will work within the DOE NETL system, and assist NETL to deliver high quality research and development services and products from this project. The data collected from the project utilizing the quality assurance program will be delivered to NETL and meet the programmatic needs and goal of the project and the laboratory. In order to perform this task, Blackhorse and its contractor, Sandia Technologies, LLC will conduct detailed project planning, performing, and assessing of the adequacy of work, including all work delegated or assigned to site support contractors. This will meet NETL Order 414.1, Quality Assurance, providing the policy and requirements under the NETL Quality Assurance Program.

4.1.1 NETL Project Responsibility and Accountability

Although Blackhorse is project manager, DOE NETL management retains the responsibility and accountability for the scope and implementation of the program and will work closely with Blackhorse management to facilitate the project objectives.

Blackhorse management and its site support contractor employees are responsible for achieving quality in the project activities, and will provide and cultivate the achievement and improvement of quality at all office and field levels, thus helping to ensure that this QAPP is understood, implemented and followed.

4.1.2 Project Graded Approach

Blackhorse will use a graded approach in the project scope, determining the depth, and rigor of specific application of requirements to actual project activities. This ensures that the selection of controls and verifications applied to work activities and project items are consistent with their importance to the mission, the environment, the safety, the cost, project schedule, and meeting objectives to insure the overall success of the program. This graded approach will be used to evaluate hazards or risks and to determine the appropriate controls needed to address them. This process is accomplished by deliberate planning and is based on activity-specific factors, which include:

- The relative importance of the specific activity to safety or to the production of critical data,
- The magnitude of any hazards or risks involved,
- The life-cycle stage of an activity,

- Impact/consequences on the programmatic mission of NETL,
- The particular characteristics of the activity,
- Adequacy of existing safety documentation,
- Complexity of products or services involved, and
- History of problems for the activity.

4.2 Personnel Training and Qualifications

In order to effectively accomplish the objectives of the project and insure success of the goals and NETL mission, Blackhorse will insure that all employees on the project are capable of performing their assigned tasks and have the necessary experience to provide appropriate services. The quality of a finished item, process, or product is directly related to the training and experience of those individuals completing the task. Blackhorse will insure that qualification and training processes are in place for all contractors to ensure that all hired personnel have achieved and maintained the required capabilities. Site support contracts will be reviewed to insure that specific requirements are in place for site support contractor employees.

4.2.1 Review of Training and Subcontractor Policies

Blackhorse management will review subcontractor information for adequate training and policies that indicate the organization has committed resources to provide the training and qualification processes for personnel. This ensures that any personnel hired or transferred into positions meet the specified requirements.

4.2.2 Policies for Training

Policies and procedures that describe personnel selection, training, and qualification requirements are established for each function that directly impacts the environment, the safety, the cost, the schedule, and the success of the program. These include the minimum applicable requirements for education, experience, skill level, and physical condition. Before personnel are allowed to work independently, management ensures those personnel have the necessary experience, knowledge, skills, and abilities. Personnel may be qualified based on:

- Previous experience, education, and training.
- A performance demonstration or test to verify previously acquired skills.
- Completion of a training or qualification program.
- On-the-job training.

4.2.3 Training Goals and Plans

Training goals, plans, and other training materials are consistently developed, reviewed by experienced personnel, approved by management, and used to deliver training. Training plans are prepared by the project manager for all personnel, including those responsible for managing, planning, and controlling work. Continual training maintains and promotes improved job performance. Training plans will consider changes in hazard conditions, technology, work methods, and job responsibilities on the project. Training procedures will also specify the type of training records to be maintained.

4.3 Quality Improvement

Blackhorse will utilize feedback from customers, employees, and stakeholders and project members to improve all aspects of the project, including all items, and services, and the processes that produce them. This project feedback is important, and is also used to address non-conformities and opportunities for improvement that are discovered through internal and external assessments during the process. Some of the processes that Blackhorse will follow are identified below:

- Identify quality problems with employees, including site support contractor employees.
- Prioritize and focus resources on corrective and preventive actions, identifying those quality issues that have the greatest potential for posing adverse risks to human health, the environment, or those directly impacting the safety of personnel, and having an effect on the reliability of research and critical data.
- Provide and maintain quality improvement as a management principle that is carried out to improve a process that results in the production of critical data. Continuous improvement will be present in all aspects of work activities, with the management system subject to a thorough assessment and feedback process.
    - Share identified improvement actions with appropriate employees and organizational elements.
    - Track actions to ensure that they are providing the anticipated improvements.
- Encourage reporting of quality issues, with senior project managers determining the significance of the issue and corrective actions required.
- Determine appropriate method for identifying the significance of an issue and the process for handling that issue, including the process to prevent reoccurrence.
- Involve management in resolving and approving corrective or preventive actions for significant quality issues and setting up audits to insure no repeats.

- For improvement of quality, a disciplined management process will be used, based on the premise that all work is planned, performed, measured, and improved. Blackhorse will focus on improving the quality of processes and research data by establishing priorities, promulgating policy, promoting cultural aspects, allocating resources, communicating operating experience, and resolving significant management issues and problems that may hinder the achievement of project objectives.
- Blackhorse believe that employees are the best resource for contributing ideas for improving work processes, products, and services, and they will be involved in work process design and evaluation and in providing any feedback necessary for improvement.

4.4 Documents and Records

Blackhorse will keep good indexed, redundant set of project documents and records to effectively manage, perform, assess work and provide a basis for project decisions and actions.

All documents and records will provide a basis for reviewing applicable requirements to indicate that work has been properly specified and accomplished. Document control procedures that identify documents and records have been developed and controlled by the project manager. Sufficient resources are committed to ensure that documents and records are maintained, indexed, traceable, and accessible at all times.

- The document control system will be secure and maintain and provide access to project documents.
- Project records and documents come in a variety of forms (e.g., electronic, written or printed) and are compiled into an overall records management system that ensures appropriate records are maintained as part of the project.
- The system includes provisions for records retention, protection, preservation, change, traceability, accountability, and retrievability.
- While in storage, records are protected from damage, loss, and deterioration.
- The Records Management Program has schedules for records retention and disposition.

5.0 PERFORMANCE FUNCTION

5.1 Work Processes

Blackhorse will perform each project task or work process uniformly, consisting of a series of planned actions that are carried out by qualified workers using specified procedures and equipment. This will be supervised under Blackhorse project management and technical team personnel using administrative, technical, and environmental controls approved by management to achieve final project results.

All Blackhorse project work processes will be documented with specific plans, procedures, and work programs authorized by DOE NETL and maintained with associated records. Blackhorse management will ensure that processes are in place to clearly identify and convey to workers on the project, prior to beginning the work, the following information on potential project hazards:

- Project hazards associated with the Research & Development program, support operations, and facilities.
- Technical standards applicable to all project activity.
- Safety, administrative, technical, and environmental controls to be implemented during the work.
- Data requirements and results derived from the work.
- Acceptance criteria applicable to the data and associated processes.

Blackhorse management will ensure that its employees and subcontractors have the necessary work experience, qualifications, equipment, procedures, and resources needed to accomplish the work in a safe manner to meet the objectives. This will include documenting all administrative work processes, work orders with scope, schedule and budget, and deliverables.

The scope and detail of documentation is commensurate with the complexity and importance of the work, the skills required to perform the work, and the hazards, risks or consequences of quality problems in the product, process, or service. Blackhorse will control all project processes, clearly specifying all skills, hazards, and equipment, with direct understanding by all subcontractors. This process will be documented for each project task element as per NETL project guidance.

All contracted workers will be responsible for the quality of the work on the project, and Blackhorse will strive for them to perform the work in accordance with established procedures and work instructions provided in a quality manner and with set organization principles.

Blackhorse will utilize a screening and review process for identification and control of any purchased or manufactured items to prevent the use of incorrect or defective items, identifying, controlling and disposing of suspect or counterfeit items, and to provide for oversight and control and maintenance of such items. This identification and control process will apply to manufactured items or products for use in field well systems. The process will directly QA/QC and identify and configure control of items in accordance with specified requirements.

Blackhorse will insure a physical identification of items employed on the project, using accepted practices for suitable identification. This information will include a serial number, unique part, lot, heat, model, version, of the item, including direct manufacturing records traceable to the item. Specific work processes protect items in accordance with specified technical standards and administrative controls to prevent their damage, loss, or deterioration. These work processes also specify protective methods for sensitive or perishable items, such as special handling, shipping, and storage controls for precision instrumentation and limited shelf-life items and for items requiring special protective environmental controls, such as for temperature or humidity. Blackhorse will ensure via work processes and review that equipment used for process monitoring and data collection is of the proper type, range, precision, and accuracy. Such equipment will be calibrated and maintained in accordance with Inspection and Acceptance Testing.

5.2 Design

Blackhorse will utilize a formal set of project design processes, using NETL guidance on the tasks of this project, using a series of internal directives that will provide control of design inputs, outputs, verifications, configurations, and changes. These technical and administrative interfaces are appropriate to the importance of the design work and will be documented when changes occur. All project design work is based on sound engineering judgment with scientific principles, as well as incorporating all approved industry codes, standards, and guidelines.

Blackhorse will review, evaluate and define all of the engineering designs for systems, instruments for use in the injection wells and for long term monitoring. The project team will make recommendations based on application, material, cost, protection of system and likelihood of meeting project objectives. Some of the specific considerations Blackhorse will review and evaluate are listed below:

(1) Design of items for use in well and monitoring structures, systems, and components that involve a significant level of risk, are subject to more definitive design, control, and verification requirements.

(2) Designs provide appropriate inspection, testing, and maintenance to ensure continuing reliability and safety of the items. The selection of design will consider the use and life expectancy of the items to allow appropriate disassembly and disposal requirements.

(3) Design records will include documentation of design input, output, changes, and verifications, as well as all supporting documents and records.

(4) Design input will be based upon end-user requirements with the design technically correct and complete. Design input includes information such as design bases, health and safety considerations, expected life cycle, and performance parameters, as well as requirements for codes, standards, and reliability.

(5) The design process translates design input into design output documents that are technically correct and compliant with the end-user's requirements. Aspects critical to the performance, safety, or reliability of the designed items will be identified during the design phase. Design output documents prepared will support other processes, such as procurement, fabrication, assembly, construction, testing, inspection, maintenance, and decommissioning.

(6) Technical and administrative interfaces will be identified and methods established for control and distribution of design requirements.

(7) Computer software used to originate or analyze design solutions during the design process will be validated for intended use.

(8) Design verification is performed to ensure that design output documents meet design input requirements, with all changes approved and documented, and a control of all supporting records during this process.

(9) Design verification is a formal, documented process for ensuring that the resulting items will comply with the project or task requirements. Design verification methods will include, but will not be limited to, technical reviews, peer reviews, and alternate calculations. When appropriate, the verification process considers previous verifications of similar designs or verifications of similar features of other designs.

(10) Design verification will be performed by a technically knowledgeable project team separate from those who performed the design. Interim verifications may occur at pre-determined stages of design development. The extent and number of design verifications is based on a graded approach and should depend on the designed product's complexity and importance to safety and project success.

(11) Verified design output to support other work, such as procurement, manufacturing, construction, or research will be used. When the verification cannot be achieved in time for these activities, unverified portions of the design are identified and controlled. Design verifications are completed before relying on the system, structure, or component to perform its function and before installation becomes irreversible.
(12) As-built and shop drawings will be maintained after production or construction to show the actual configuration.
(13) Design changes, including field changes and non-conforming items dispositioned for use-as-is or repair, are controlled by measures commensurate with those applied to the original design. Temporary modifications receive the same level of control as the designs of permanent modifications.
(14) Responsibilities are assigned for design output documents, including the as-built, marked-up, and updated during construction and operation phases documents, as well as for document control and records management.
(15) The completed final design will be controlled, and the design records will include all controlled records generated during the design process.

5.3 Procurement

Blackhorse will ensure that the procurement process with vendors will provide the requirements and expectations of goods, services and products for benefit of the project. The procurement process will be planned and controlled to ensure that the end-user's requirements are accurately, completely, and clearly communicated to the supplier; supplier, and designer. In addition, the end-user requirements should be met during the production phase; and the proper product is delivered on time and maintained until use. Blackhorse will manage the selection of services and purchased items following all procurement requirements commensurate with the importance of the items or service.

Blackhorse will ensure that:

1) Procurement documents include any specifications, standards, and other records referenced in the design documents. Critical parameters and requirements, such as submittal, product-related documentation, problem reporting, administrative documentation, personnel or materials qualifications, tests, inspections, acceptance criteria, and reviews, are clearly specified.

(2) Potential suppliers are identified early in the design and procurement process to determine their capabilities. Prospective suppliers are evaluated to verify their capability to meet performance and schedule requirements. An effective evaluation method is an assessment of personnel and processes

conducted at the supplier's facilities (a quality assurance program evaluation). This method may be used in combination with:

- A review of the supplier's history in providing identical or similar items or services.
    - A review of shared supplier quality information.
    - An evaluation of certifications or registrations awarded by nationally accredited third parties.
    - An evaluation of documented qualitative and quantitative information provided by the supplier.
- Inspection--The inspection verifies that items were not damaged during shipment. Inspection may include the following methods:
    - Inspection of materials or equipment at the supplier's plant.
    - Receipt inspection of the shipped items.
    - Review of objective evidence, such as certifications and reports.
    - Verification or testing of items prior to or following shipment.

(3) The qualified supplier's performance is evaluated periodically. Suppliers are monitored to ensure that acceptable items or services are produced and schedule requirements are met. Monitoring may include: Surveillance of work activities, inspection of facilities and processes, review of plans and progress reports, processing of change information, review and disposition of non-conformances, selection, qualification, and performance monitoring of sub-tier suppliers. This will include a Blackhorse review of the supplier's history in providing identical or similar items or services as part of the original selection process.

(4) The procurement process helps to identify the need for inspections and tests. Requirements for inspections and tests are obtained from design documents. Blackhorse will ensure that inspections provide conformance with purchase requirements, including the verification that specified documentation has been provided by the supplier.

(5) Critical or important acceptance parameters and other requirements, such as inspection/test equipment or qualified inspection/test personnel, are specified in the design documentation.

(6) The selection of suppliers and the purchase of commercial-grade materials are evaluated to prevent the procurement of suspect or counterfeit items and to detect them before they are released for use. These steps are used to minimize the possibility of procuring suspect or counterfeit items.

(7) Blackhorse will follow all NETL guidelines to assist in the procurement of quality items. Using DOE guidance to avoid the procurement and use of suspect or counterfeit items.

(8) Supplier-generated documents are accepted through the procurement system and controlled and processed by Blackhorse. These documents may include certificates of conformance, drawings, analyses, test reports, maintenance data, non-conformances, corrective actions, approved changes, waivers, and deviations. Some of the checks Blackhorse will provide are: A review of shared supplier quality information, an evaluation of certifications or registrations awarded by nationally accredited third parties, an evaluation of documented qualitative and quantitative information provided by the supplier.

5.4 Inspection and Acceptance Testing

Blackhorse will follow NETL guidance that conducts inspections and tests to verify that physical and functional aspects of items, services, and processes meet all requirements and are fit for use. Inspections and tests are identified early in the design process and specified in the design output documents.

Blackhorse will use accepted NETL directives that provide specific details and processes for inspection and acceptance testing of materials, data and manufactured items. Blackhorse personnel will check items prior to their use to ensure that the items are correct and suitable for their intended application. These same personnel will check the processes output to verify that they meet or exceed specified requirements. Inspection and test planning is performed, and appropriate sections of approved codes or standards are used for acceptance requirements, inspections, and test methods. Blackhorse inspection and test planning contains provisions for at least the following: identification of characteristics to be examined, required qualifications of individuals who perform the examination, a description of examination methods, including equipment and calibration requirements, acceptance and rejection criteria, suitable environmental conditions, required safety measures, and mandatory hold points, when applicable.

Inspections and tests are to be performed by Blackhorse technically qualified personnel who have the authority to access appropriate information and facilities to verify acceptance. These qualified personnel are independent of the activities being inspected or tested and have the freedom to report the results of the inspections and tests.

The inspection or test process identifies the status of items, services, and processes requiring examination to ensure that only those with acceptable inspection and test results are used. The process provides for review and re-inspection or retest of changed inspection or test parameters. Final inspections are usually distinct from inspections conducted during the work process. Final inspection confirms that the item, service, or process is ready for acceptance testing and/or operation. As such, it includes completeness, cleanliness, identifications and markings, calibration, alignment and adjustment, adequate records, or other characteristics indicating conformance to requirements.

Any measuring and test equipment (M&TE) used for inspections, tests, and monitoring or data collection will be calibrated and maintained using a documented process. M&TE will also be checked prior to its use to ensure that it is of the proper type, range, accuracy, and precision, that it is uniquely identified, and that its calibration data are traceable. M&TE is calibrated to standards traceable to the National Institute of Standards and Technology (NIST) or to other nationally-recognized standards, when available and appropriate. If no nationally-recognized calibration method exists, the basis for calibration will be approved by Blackhorse line management and documented.

6.0 ASSESSMENT FUNCTION

6.1 Management Assessment

Blackhorse will use the comprehensive umbrella coverage in the Quality Assurance Program (QAP) and the components of this customized Quality Assurance Project Plan. This will allow management to be consistent with all contractor requirements, regulations, and orders.

Blackhorse management will continuously review and assess the performance of its project functions to determine compliance with requirements, expectations, and mission objectives, so that improvements can be made. These assessments can take the form of member project meetings and reviews, Environmental, Safety and Health inspections, informal reviews and observations, budget reviews and planning, or other management functions that serve as checks and assessment tools. Blackhorse believes that direct participation by managers is essential to the success of the assessment process, because they are in a unique position both to evaluate the functions within the DOE NETL project structure and to effect change as required. Additionally, Blackhorse will identify strengths and weaknesses affecting the achievement of the project objectives so that meaningful action can be taken to improve processes. The areas that present the greatest consequences of failure or the greatest benefit from improvements will receive particular emphasis. Management assessments focus on identifying and resolving both singular and systemic management issues and problems that may prevent customer requirements and expectations from being met. Results from internal or external independent assessments are used as input to the management assessment.

Blackhorse management also will assess its internal processes for planning, organizing interfaces (both internal and external to the organization), integration of management systems (e.g., safety, quality), use of performance metrics, training and qualifications, and supervisory oversight and support to provide improvement where necessary and sustain highest quality.

Blackhorse's direct observation of work is used as an assessment method to make management aware of interactions at a work location. Other feedback methods include worker and customer interviews, as well as safety and performance documentation reviews. Performance measurement is based on objective standards, clearly defined goals, and results-oriented metrics, as well as meaningful review and feedback processes.

NETL management assessment results are documented and used as input to the organization's improvement process. Periodic review of performance metrics at appropriate management levels are used to validate organizational performance.

6.2 Independent Assessment

Blackhorse management maintains a process to obtain an independent assessment of its programs, projects, contractors, and suppliers. This type of assessment will be used to evaluate the performance of work processes with regard to requirements and expectations of customers, as well as coordinate efforts required to achieve the DOE NETL project objectives and goals.

Results of these independent assessments provide an objective form of feedback to Blackhorse management for use in confirming acceptable performance and to identify improvement opportunities on the project.

A performance-based approach is used in the independent assessment process to focus on results. Performance-based assessments are conducted on activities that relate directly to final objectives, emphasize safety and reliability, and measure data quality directly.

Blackhorse will periodically perform independent assessments of its work and the work of its site support contractors to ensure that requirements are being met. Site support contractors also will conduct independent assessments of their work and the work of their subcontractors to ensure that project standards and requirements are being met. The use of independent assessments provide direct feedback to Blackhorse management on the quality of the processes, data, and deliverables produced by from the project.

Any personnel performing independent assessments have the necessary technical knowledge to accurately observe and evaluate activities being assessed. They should have no direct responsibility for the assessed work or organization to allow for independence and proper review. The type and frequency of independent assessments will be based upon the status of the project and from Blackhorse management directives, weighing the project complexity, risk, and importance of the activities or processes being assessed. The criteria used for assessments describe acceptable work performance and promote improvement of the process or activity.

Any assessments can also address management processes that affect work performance, such as planning, program support, and training and these assessments may use methods such as monitoring operations, inspections, peer and technical reviews, previous assessment results, surveillance, end-user interviews, or combinations thereof. The assessment will focus on improving data quality and process effectiveness by emphasizing improvement methods, with independent assessment personnel basing the evaluation on the approved system only without any reinterpretation or redefinition of the requirements.

Independent assessor responsibilities may include evaluating work performance and process effectiveness, evaluating compliance to the management system requirements, identifying abnormal performance, identifying strengths and weaknesses affecting the quality of data or process outputs, identifying opportunities for improvements, documenting and reporting results, and verifying effective resolution of reported problems.

Blackhorse's process of independent assessment will verify the adequacy of corrective actions, including actions identified to prevent recurrence or to otherwise improve performance. Independent assessments that confirm acceptable performance in specific areas of the project may reduce the frequency and depth of future assessments, but any areas of marginal or questionable performance may receive increased attention in future assessments.

The results of Blackhorse's documented assessment results will become part of the project records, and are provided to the appropriate levels of management for review. Strengths and weaknesses affecting the quality of data or process outputs are identified so that management can take action to improve quality. Blackhorse management will evaluate the assessment results to identify improvement actions and determine whether similar quality problems may exist elsewhere throughout other areas of the project.

7.0 PROJECT SUB-TASK QAPS DOCUMENTS

7.1 Budget Period 1 Tasks

Under Budget Period 1, various project work activities are present that include: project planning, site characterization and monitoring planning, baseline 3-D seismic survey, geologic-reservoir-seismic model framework, baseline initial observation well surveillance, well planning, and well services contracting.

Individual sub-QAPs will be generated for each major Budget Period (BP) work task and work scopes, incorporating and utilizing key vendor information on quality processes, standards, concerning acquired data, interpretation of data and reporting of results.

7.1.1 Project Planning

Blackhorse will perform standard project planning employing best practices and approaches in previous DOE projects, and other office and field projects of this type.

7.1.2 Site Characterization and Monitoring Planning

For site characterization and monitoring planning activities, Blackhorse will utilize a project team member reviewed program approach that incorporates many areas of the Quality Assurance Program elements.

7.1.3 Baseline 3-D Seismic Survey

Blackhorse's seismic contractor, Schlumberger Western Geco will use best-practices in survey land access permitting from accepted petroleum industry methods to

Sub-QAPP completed 10-23-13

7.1.4 Geologic-Reservoir-Seismic Model Framework

Blackhorse will develop a customized sub-QAP under the comprehensive umbrella coverage contained in the Quality Assurance Program.

Geologic-Reservoir-Seismic Model Sub-QAPP TBP pending final work scope

7.1.5 Baseline Initial Observation Well Surveillance, Planning, Contracting

Blackhorse will develop a customized sub-QAP under the comprehensive umbrella coverage contained in the Quality Assurance Program.

Initial Observation Well Planning Sub-QAPP TBP pending final work scope

7.1.6 Injection Well Services Contracting

Blackhorse will develop a customized sub-QAP under the comprehensive umbrella coverage contained in the Quality Assurance Program.

Injection Well Services Contracting Sub-QAPP TBP pending final work scope and design.

7.2 Budget Period 2 Tasks

Under Budget Period 2, various project work activities are present that include: project management, baseline offset observation well surveillance, injection well installation, well data analysis & interpretation, post-drilling site model update.

7.2.1 Injection Well Installation

Blackhorse will perform standard project planning employing best approaches in previous DOE projects, and other office and field projects of this type.

Customized Sub-QAPP TBP pending final work scope and design.

7.2.2 Baseline Testing

Blackhorse will perform standard project planning employing best approaches in previous DOE projects, and other office and field projects of this type.

Customized Sub-QAPP TBP pending final work scope and testing plan.

7.2.3 CO_2 Injection

Blackhorse will perform standard project planning employing best approaches in previous DOE projects, and other office and field projects of this type.

Customized Sub-QAPP TBP pending final work scope and Go-No-Go decision.

7.2.4 Surveillance Monitoring

Blackhorse will perform standard project planning employing best approaches in previous DOE projects, and other office and field projects of this type.

Customized Sub-QAPP TBP pending final work scope and monitoring plan.

7.3 Budget Period 3 Tasks

Under Budget Period 3, various project work activities are present that include: project management, completion of surveillance/monitoring program, final 3-D Seismic Survey, Project Reporting, Site Commercialization Plan.

7.3.1 Field Verification

Blackhorse will perform field verification methods using standard project best approaches utilized in previous DOE projects, experience, and other office and field projects of this type.

Customized Sub-QAPP TBP pending final work scope and monitoring/verification plan.

7.3.2 Data Analysis

Blackhorse will perform standard project data acquisition, and data analysis employing best practices and approaches used in previous DOE projects, and other office and field projects of this type.

Customized Sub-QAPP TBP for data analysis, and release pending implementation of the plan.

7.3.3 Project Wrap-Up

Blackhorse will perform standard project planning employing best approaches in previous DOE projects, and other office and field projects of this type.

Customized Sub-QAPP TBP for project reporting, wrap-up, and data release pending final plan.

8.0 REFERENCES

U.S. DOE Guidance Documents

a. DOE Guide 414.1-1, Management and Independent Assessments Guide.

b. DOE Guide 414.1-2, Quality Assurance Management System Guide.

c. NETL Order 224.2, Auditing of Programs and Operations.

d. NETL Order 243.1, Records Management Program.

e. NETL Order 251.1, Directives Program.

f. NETL Order 360.1, Federal Employee Education, Training, and Development.

g. NETL Order 420.3, Conduct of Operations.

h. NETL Order 421.1, Safety Analysis and Review System.

U.S. EPA QAP Guidance Documents

EPA Guidance for Quality Assurance Project Plans (EPA QA/G-5),

EPA Guidance for the Data Quality Objectives Process (EPA QA/G-4)

7.11 APPENDIX K – PERMITTING ACTION PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

November 12, 2013

WORK PERFORMED UNDER AGREEMENT

DE-FE0006823

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U. S. Department of Energy
National Energy Technology Laboratory

TABLE OF CONTENTS

1.0 INTRODUCTION 172

2.0 NATIONAL ENVIRONMENTAL POLICY ACT 174

2.1 NEPA Compliance 174

3.0 SEISMIC OPERATIONS 175

3.1 Permits and Requirements for Seismic Operations 175

3.1.1 Louisiana Department Wildlife and Fisheries 175

3.1.2 Army Corps of Engineers 175

3.1.3 Department of Homeland Security 175

3.1.4 Livingston Parish 176

4.0 WELL OPERATIONS 177

4.1 Permits and Requirements for Drill Pad and Surface Facilities 177

4.1.1 Permits and Requirements for Access Roads, Drill Pads, and Surface Facilities 177

4.2 Permits for Drilling and Converting Existing Wells 179

4.2.1 Requirements for Surveying Well Sites 179

4.2.2 Injection Well/Observation Well Forms and Permits 179

4.3 Permits for Transporting Heavy Equipment 183

4.4 Permits and Requirements to Plug Wells 183

5.0 PERMIT TO CONSTRUCT A CO_2 PIPELINE 186

5.1 Livingston Parish Pipeline Requirements 187

5.2 Pipeline Construction 190

6.0 PROPOSED PERMITTING SCHEDULE 192

1.0 INTRODUCTION

The proposed South Louisiana Small-scale Sequestration Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This Project proposes to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the Livingston Field operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strand plain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets in saline reservoirs.

The primary focus of this Project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the Project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the Project wells will be assessed in light of data collected from the two field vertical injection wells. Field production wells will be leveraged for data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair can provide.

This Permitting Action Plan's objective is to prepare, submit, and receive approved local, state, and federal permits which are required to conduct the proposed CO_2 sequestration project and the proposed CO_2 enhanced oil recovery project in the First Wilcox Sand in Livingston Parish, Louisiana. The specific permits required and the anticipated regulatory approvals are dependent upon the selected design necessary to implement the injection projects. These specific permits and regulatory approvals are discussed in this plan and include the following:

- National Environmental Policy Act (NEPA) compliance;
- Permits to survey well sites;
- Permits and requirements for seismic operations;
- Permits and requirements for drill pad and surface facility;
- Permits to drill project Injection Wel1;
- Permits to convert existing wells to CO_2 Observation/Recovery Wells;
- Permit and requirements to construct CO_2 pipeline;
- Permits to transport heavy equipment;
- Underground Injection Control permit for CO_2 injection and/or fluid injection;
- Permits and requirements for reclamation, plugging, and abandonment of injection and observation wells (if needed).

2.0 NATIONAL ENVIRONMENTAL POLICY ACT

2.1 NEPA Compliance

Department of Energy's (DOE) procedures for implementing the National Environmental Policy Act (NEPA) require careful consideration of the potential environmental consequences of all proposed actions early in the project planning process. DOE must determine, at the earliest possible time, whether such actions require preparation of an Environmental Assessment (EA), an Environmental Impact Statement (EIS), or are categorically excluded (CX) from further NEPA review. Subsequent to the award of the project, Blackhorse Energy, LLC completed an Environmental Questionnaire (EQ) that applied to the planning and site characterization steps being carried out under Phase I of the project. Blackhorse Energy, LLC received a categorical exclusion notice from DOE that authorized the project team to perform project planning, preliminary site characterization, and acquisition of a three-dimensional seismic survey. Information presented in the site specific environmental questionnaire was based upon project tasks required for the duration of the project. A 'go/no go' decision point will be made at the completion of installation of the Injection Well. Injection of the CO_2 will not commence until the research team and DOE have determined that subsurface geologic conditions (proposed storage and sealing formations) have favorable properties that would allow for injection and long term storage of CO_2. Additionally, all necessary regulatory approvals, as well as land, mineral, and project access agreements, must be finalized and obtained before CO_2 injection commences.

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3.0 SEISMIC OPERATIONS

3.1 Permits and Requirements for Seismic Operations

Seismic operations require permits from a wide range of different agencies, including Livingston Parish. Permits must be issued before operations can be initiated. The primary agency that covers seismic activities is the Louisiana Department of Wildlife and Fisheries. Right of Entry Permits will need to be obtained from all owner(s) of mineral rights within the seismic survey area, including the California Northern Railroad (CNRR) property and any impacted State Highway.

3.1.1 Louisiana Department of Wildlife and Fisheries

Louisiana Department of Wildlife and Fisheries requirements include: a historic review, public notice placed in a local newspaper, letter(s) of permission from the affected landowner(s) to conduct seismic operations on privately owned land, and placement of a bond. A plat map and a list of landowners within the boundaries of the operations must to be submitted with the public notice.

3.1.2 Army Corps of Engineers

The Army Corps of Engineers require a permit in response to wetlands affected within the program boundaries. After receiving the application, the Army Corps of Engineers will then send the application to various agencies to confirm what other requirements will need to be met.

3.1.3 Department of Homeland Security

The Department of Homeland Security and Emergency Preparedness require the development of an Emergency Operation Plan (EOP). The EOP includes the following elements: emergency response procedures (ERP); approval of all Livingston Parish Roads being utilized during operations by the Livingston Parish Homeland Security and Emergency Preparedness; and a one hundred dollar fee is required to be submitted with the EOP.

Any owner, operator, contractor, or subcontractor placing an explosive magazine within the Livingston Parish boundaries must apply for a permit from the Livingston Parish Office of Homeland Security and Emergency Preparedness. Therefore, the shot hole drilling company will need to apply for an Explosive Magazine Permit. The permit needs to be submitted 30 days prior to placement of the magazine, and must meet all parish, state, and federal regulations.

3.1.4 Livingston Parish

Parish requirements are codified in *Livingston Parish Regulations Booklet: Oil, Gas, and Hydrogen Wells/Explosives/Pipelines/Emergency Response/Emergency Operations Plan Review*. The document covers requirements and restraints placed on oil and gas related operations within developed and undeveloped portions of the parish. Requirements that may impact project operations during the project are:

- **Time Restraint**: The Livingston Parish Regulations Booklet Section 2(b) covers time restraints placed on oil and gas related operations. With the exception of drilling, completion, and workover operations; all other work related to oil and gas operations conducted in the Livingston Parish, must meet specific time restraints based on distance from the nearest residence, church, commercial or public building, hospital, school, or public park. The critical distances are: within 500 feet (8 a.m. to 5 p.m. - Monday through Saturday); 500 to 2,500 feet (7 a.m. to 7 p.m. - Monday through Saturday); 2,500 feet to 5,000 feet (5 a.m. to 10 p.m. - Monday through Saturday); and greater than 5,000 feet (24 hours - Monday through Saturday). Note that operations on Sundays are prohibited.
- **Ambient Noise**: Livingston Parish Regulations Booklet Section 2 requires preparation of a Noise Management Plan to be submitted to the Office of Homeland Security and Emergency Preparedness. Requirements are outlined in Section 2(c)(2-7) which sets the standard and limitations of the ambient noise level. An initial ambient noise survey/test will need to be conducted prior to commencement of any operations. Noise mitigation measures, following standard industry practices, may be required in order to be in compliance with parish requirements.
- **Public Hearing**: A public hearing with the Town of Livingston was conducted on October 9, 2013. The hearing covered the seismic operations plan, map of operation area, and permits needed for operations.

4.0 WELL OPERATIONS

Anticipated well operations include the installation of the CO_2 Injection Well and recompletion of the three project Observation Wells. Permits and requirements for associated activities are detailed in the following subsections.

4.1 Permits and Requirements for Drill Pad and Surface Facilities

This project requires the re-use of an older drill pad and facilities within the limits of the Livingston Parish. The facility (facilities), facility equipment, and drill pad will have to meet the regulations of the Livingston Parish, Homeland Security, Department of Natural Resources, and the Army Corp of Engineers. The facility and pad will require modifications in order to meet current standards identified as follows:

- **Abatement of Dust, Vibration, Odors, or Fumes**: The Livingston Parish Regulations Booklet Section 1(c) & (e) covers local regulations pertaining to dust, vibration, odors, or fumes. Goal is to minimize to the lowest extent possible, dust, vibration, and odors/fumes from the work site.
- **Positioning of Lighting Equipment**: The Livingston Parish Regulations Booklet Section 1(d) sets standards for the positioning of lights during after daylight operations. In general, lighting should be directed downward within the work site so as to minimize glare.
- **Signage:** Proper signage is required to be posted per Livingston Parish Regulations Booklet Section 1 (g). Signage must include: Well name, well number, name of operator, and 24-hour emergency number.

4.1.1 Permits and Requirements for Access Roads, Drill Pads, and Surface Facilities

A permit is required for the construction of an access road to connect a project site to municipal, county or state roads. An access connection is required and is described as any physical connection between a state roadway and private or public property which allows the ingress and egress of vehicles to or from said property. The Louisiana Department of Transportation and Development (LA DOTD) requires the project operator to do the following:

- Complete Preliminary Access Connection Request Form;

- Provide a survey or plat of property that shows the proposed access point, nearest existing driveway, and median opening (if applicable);
- Only one access road is permitted for a location;
- Provide proof of ownership or the executed access agreement for the land where the proposed work is scheduled to take place.

Any street or road entrance must be kept free and cleaned in accordance with the Livingston Parish Regulations Booklet Section 1 (o).

Fencing and screen requirements are specified under Livingston Parish Regulations Booklet Section 4 (a) and (b). This section states that with the exception of during drilling operations, a permanent chain link fence with a secured gate are required and must be installed at each well. The chain link fence must meet the following requirements:

- At least six feet in height;
- Support post shall be set in concrete at a depth sufficient to maintain a stable fence. Temporary fence points do not need to be set in concrete, as long as stability is maintained;
- The post, rails, adjustable tighteners, and tension bars have set minimums which are covered in Section 4(a)(4);
- A Knox padlock or Knox box with the key shall be provided to the Livingston Parish Office of Homeland Security and Emergency Preparedness;
- Locations within urban areas may be subjected to additional screening and security measures, based on the Livingston Parish Office of Homeland Security and Emergency Preparedness.

The Livingston Parish Regulations Booklet Section 2(b) covers time restraints placed on oil and gas related operations. With the exception of drilling, completion, and workover; any work conducted in the Livingston Parish that is related to oil and gas operations, must meet specific time restraints, as shown in Section 3.1.4 of this Permit Action Plan.

Livingston Parish Regulations Booklet Section 2(c)(2-7) sets the standard and limitations of the ambient noise levels during operations. An initial survey/test needs to be conducted prior to commencement of any operations. The testing should cover the following:

- No well can be drilled, re-drilled, or any equipment operated on location which exceeds the ambient noise level by more than seven decibels at a distance of 500 feet;
- Operator must establish (based on a survey and report to the Livingston Parish Office of Homeland Security and Emergency Preparedness) the pre-drilling ambient noise level prior to initial operations at site;
- Continuous monitoring of ambient noise;
- Soundproofing shall comply with accepted industry standards;
- Sound level meter used in conducting noise evaluations shall meet the American National Standard Institute's standard for sound meters or an instrument and the associated recordings and analyzing equipment which will provide equivalent data.

Other noise requirements are included in Section 3.1.4.

4.2 Permits for Drilling and Converting Existing Wells

4.2.1 Requirements for Surveying Well Sites

Louisiana Code Title 43, Part XIX. Subpart 17. §4103 & §103 requires business entities to present a survey plat for proposed wells to the Office of Conservation for approval. All nearby geologically significant wells and the proposed well should be located on the ground, with locations based on the Lambert Plane Coordinate System, or other recognized control, such as section corners. The survey should be submitted to the Office of Conservation, located in Baton Rouge, for approval.

4.2.2 Injection Well/Observation Well Forms and Permits

This project will require the drilling of a CO_2 capable injection well. Permits are required to drill the injection well, but are not required to perform well conversion modification activities on the Observation Wells if they are not going to be recompleted in a manner that changes the perforated interval(s). However, Blackhorse Energy, LLC may elect to prepare and submit the forms for the Observation Wells so that the changes are documented.

Under Louisiana Code Title 43, Part XIX § 405, a permit to drill or modify an enhanced oil recovery (EOR) injection well has to be obtained from the Louisiana Department of Natural Resources (LDNR). LDNR requires that the following forms be completed as part of the permit application submittal package. These permit application forms must be submitted to and approved by the LDNR prior to the commencement of any well activity.

1. **Form UIC-2 EOR**: This form is required for enhanced oil recovery projects as per Louisiana Code Title 43, Part XIX 407. Form UIC-2 EOR is used for newly drilled wells and for wells being converted for injection. Each Form UIC-2 EOR that is filled out, must include a two hundred and fifty-two dollar fee. The UIC-2 EOR form includes:

   a) Operator's Information:
      - Operator's name and address;
      - Lease, or group of leases, and units involved;
      - Details of the type of well to be drilled;
      - Details of the formation;
      - Proposed plan of development of the area.

   b) **Form MD-10-R-1 (yellow)**: This form is the application for permit to drill (all wells) as per Louisiana Code Title 43, Part XIX 103. The Form includes:
      - The company name, address, and code number.
      - Parish and its code number.
      - Field name and code number.
      - Well Details (location, true vertical depth, etc.).
      - Designated contact name and phone number.
      - **Other Requirements**:
        - Well plat must be prepared in accordance with Louisiana Code Title 43 Part XIX. Subpart 17. §4103 & §103.
        - Applicable Fee as determined by Statewide Order 29-R-10/11 Rule LAC 43: XIX § 703.
        - Pre-Entry Notice Statewide Order 29-B Rule LAC 43:XIX.103.

- o Must provide certificate of deposit if operator doesn't meet the financial security requirements in Statewide Order 29-B LAC 43: XIX. §104.A.

c) **<u>Form MD-10-R-A-1 (pink)</u>**: This form needs to be filled out in conjunction with the UIC-2 EOR form, and is used in the conversion of existing wells to an injection well as per Statewide Order 29-B, Rule LAC 43:XIX.407. Before operating an existing well newly converted to enhanced recovery injection or disposal, the casing needs to be tested under the supervision of the Office of Conservation

2. **<u>Form MD-11-R</u>**: The completion of this form is required for applications for permits to repair, abandon, and any type of well workover covered in Statewide Order 29-B, Rule LAC 43:XIX.105.
3. **<u>Form MD-4-R</u>**: This form needs to be completed with any workover permit.
4. **<u>MD-10-R-AO</u>:** This form is used in compliance with Statewide Order 29-Q-1 for any person who assumes the liability of oil and gas wells. The application may be filed in lieu of Form MD-10-RA, where multiple wells are involved, for change of operator.
5. **<u>Form AFLN-1</u>**: This form is an affidavit of compliance as per Statewide Order 29-B, Rule LAC 43:XIX.103 and Louisiana R.S. 30:28 (I). The pre-entry notice is used for the surface owner written consent and needs to be given at least thirty days prior to operations.
6. **<u>Form WH-1</u>:** This form is used to cover a well history and work resume report.
7. **<u>Form PLT-1</u>:** Packer Leakage Test Form is used in compliance with packer leakage test and must be filed with the appropriate DNR District Office.
8. **<u>Form CSG T</u>:** This form is an affidavit for testing the casing in the well.
9. **<u>Form Comp</u>:** This form is to be filled out in conjunction with Form MD-10-R-A; it covers the well completion or recompletion report.

In addition to the above forms, applicants must post a bond to guarantee that funds are available for site reclamation and well plugging should the operator fail to perform the work.

a) **<u>Form PBMW</u>:** A performance bond form must filled out to guarantee the fulfillment of the contract for site reclamation and well plugging should the operator fail to perform the work.

b) **<u>Form FS-CDMW</u>:** A Pledge of Certificate of Deposit (FS-CDMW) is required to provide financial security that is acceptable to the commissioner to ensure the proper site reclamation and well plugging if the operator failed to perform the work.

c) **<u>Form LCMW</u>:** An Irrevocable Letter of Credit (LCMW) will be filled out to certify that the amount of the draft is payable in accordance with LSA-R.S. 30:1 et seq.

d) **<u>Blanket-10 Well Form</u>:** This form will be attached to each financial security document which lists the wells associated with the coverage.

Within six months of the completion of the drilling or workover of any permitted well, the operator (generator) will certify to LDNR, by filing Form ENG-16 the types and number of barrels of nonhazardous oilfield waste (NOW) generated, disposition of such waste, and further certify that such disposition was conducted in accordance with applicable rules and regulations of the Office of Conservation.

In addition to LDNR requirements, certain operations fall under Livingston Parish regulations. These include:

1. **<u>Public Water Supplies</u>:** The Livingston Parish regulations (Section 1(k)) prohibit use of public water supplies for drilling and production operations.
2. **<u>Noise Management Plan</u>:** Livingston Parish regulations (Section 2(c)), previously discussed, require the operator to submit a noise management plan, prior to operations, to the Livingston Parish Office of Homeland Security and Emergency Preparedness. The noise management plan requirements:
   a. Identify operation noise impacts.
   b. Provide documentation establishing the pre-drilling ambient noise level.
   c. Detail how the impacts will be mitigated. Specific site characteristics are listed in Section 2(c)(1)(c)(1 to 4).
3. **<u>Ambient Noise</u>:** Livingston Parish regulations (Section 2(c)(2 to 7)) set the standard and limitations of the ambient noise level. An initial test will be conducted prior to commencement of any operations on location, and the test will cover:

a) No well shall be drilled or re-drilled or any equipment operated on location which exceeds the ambient noise level by more than seven decimals at a distance of 500 feet;
b) Operator must establish and report to the Livingston Parish Office of Homeland Security and Emergency Preparedness the pre-drilling ambient noise level prior to initial operations at site;
c) Continuous monitoring of ambient noise;
d) Soundproofing shall comply with accepted industry standards;
e) Sound level meter used in conducting noise evaluations shall meet the American National Standard Institute's standard for sound meters.

4.3 Permits for Transporting Heavy Equipment

The Louisiana Department of Transportation and Development (LA DOTD) issues hauling permits that authorize movement of overweight and/or abnormal vehicle configurations on the state highway system. Each permit contains routing information, travel regulations, and safety requirements. If the vehicle configuration is reduced to its smallest possible dimensions and still exceeds the maximum size limit, a hauling permit must be obtained prior to traveling on Louisiana highways. The drilling rig and associated storage tanks needed for the project will likely require hauling and specialty permits.

4.4 Permits and Requirements to Plug Wells

Under Louisiana Code Title 43, Part XIX § 137, once any well or core hole drilled by the operator ceases to operate, the well must be plugged in a manner required by the regulations in force at the time of plugging. It is not anticipated that any project well will need to be plugged during the project. However, information is being included in case one of the wells needs to be plugged.

A well plugging permit is considered to be a modification of an existing active permit and hence, the process of obtaining the plugging permit is similar to that for obtaining the drilling permit discussed earlier.

1. **<u>Form DM-1-R</u>**: Operator is required to file another work permit for plugging and must submit a schematic with the new permit. If the well has not been restored to service after six months, it needs to be included on the Semiannual Inactive Well Report.

2. **<u>Form INACT WR-1</u>**: Operator is required to submit this report to show the status of the well and include:

   a) Field, well name, well number, and other pertinent data;

   b) Classify whether the well does or does not have future utility;

   c) Proposed plugging plan that, along with an attached schematic, describes the depth and details of various formations encountered, diameter of the hole, casing size, and material to be used in various intervals to plug the well.

The operator is required to submit a detailed plugging plan to the Department of Conservation, and plugging activities may only commence once the plan is approved.

1. **<u>Plugging an Open Hole Well or an Open Hole Section of the Well</u>:** An open hole section of the well does not contain any casing and needs to be plugged in the following manner:

   a) **<u>Mineable Coal Seam</u>**s: A class "A" cement plug is placed from at least 50 feet below the base of the coal seam to 50 feet above the top of the coal seam. If two or more seams are closely separated, then the cement plug is placed at least 50 feet below the bottom coal seam to at least 50 feet above the top coal seam;

   b) If a source of ground water is encountered below the depth of ground water casing, a 100 foot cement plug is placed below the base of lowest ground water source;

   c) A cement plug of a minimum length of 100 feet shall be placed across the shoe of the ground water protection casing. The plug shall be placed in such a manner that there will be approximately equal lengths in the open hole and inside the casing. If the well is without surface casing, a continuous cement plug shall be placed from at least 50 feet below the base of the lowest known aquifer or a depth of 300 feet, whichever is deeper;

d) All intervals below and between the cement/bridge plugs are required to be filled with drilling mud or gel.

2. **<u>Plugging in a Cased Well</u>:**

a) When plugging a cased well, all perforations must be either squeeze cemented or isolated from the rest of the well by placing a plug across or right above the perforated interval.

i. A cement plug placed across the perforations should extend to at least 50 feet above the perforations;

ii. Cement plugs placed above the perforations should be at least 100 feet in length;

iii. If a bridge plug, packer, or a cement retainer is used, then at least a 20 foot cement plug should be placed on top of the tool used.

b) **<u>Mineable coal seams</u>:** Mineable coal seams that contain coal protection casing will require a class A cement plug to be placed from a depth of at least 50 feet below the base of the coal seam to 50 feet above the top of the coal seam. If two or more seams are closely separated, then the cement plug is placed from at least 50 feet below the bottom coal seam to at least 50 feet above the top coal seam.

c) After placing the 30 foot cement plug minimum in the top of the well, the operator is required to cut the casing a minimum of two feet below plow depth.

5.0 PERMIT TO CONSTRUCT A CO_2 PIPELINE

Louisiana Code Title 43, Part XI. Subpart 4. §703, §705, & §707 covers the operation, construction, extension, acquisition, interconnection, or abandonment of carbon dioxide facilities. To meet these requirements of the Louisiana Code, the process may include hearings, notices, conferences, and orders. A CO_2 pipeline requires an application to the commissioner for issuance of an order or a certificate of public convenience and necessity. Applicant's current financial statement or such other information can be submitted by the applicant and accepted by the commissioner. The information submitted should concern the applicant's ability to construct, acquire, or operate the proposed facility. The name, title, and mailing address of the person or person to whom communications concerning the application need to be addressed.

The application must be submitted in writing, be verified under oath, and should include the following elements:

1. **Table of Contents:** listing all exhibits and documents filed with the application.
2. **Legal name of applicant:** whether an individual, partnership, corporation, or otherwise; the state under the laws of which applicant was organized or authorized.
   a. **Corporations:** a certificate of good standing and authorization to do business from the Secretary of State of Louisiana. The location and mailing address of applicant's registered office, the name and post office address of each registered agent in Louisiana, and the names and addresses of all its directors and principal officers.
   b. **Partnership or Similar Organization:** the names and addresses of its partners of record, officer or other responsible parties of record.
3. **Existing Operations:** a concise description of applicant's existing operations.
4. **Proposed Operations:** a concise description of proposed operations
5. **Map:** A map(s) of its pipeline system(s), which shall reflect the location and capacity of all compressor sites, all points of connection between such system(s), and pipelines, or pipeline system(s) of other persons, the date of such connections, and all major points of supply.

6. **<u>Disposition Points</u>:** A listing of applicant's points of CO_2 disposition to secondary and tertiary oil and gas recovery projects.
7. **<u>Interconnection Points</u>:** The points of proposed interconnection with other carbon dioxide transporters, for which approval is sought together with a statement of reasons for said interconnection.
8. **<u>Amounts of CO_2</u>:** The anticipated volumes to be transported, transferred, or exchanged.
9. **<u>Interested Parties</u>:** A list of the names and addresses of all interested parties; accordingly, the results will show that a reasonable effort has been made to obtain this list.
10. **<u>Approving Order</u>:** A copy of the order of the commissioner approving the pertinent enhanced recovery project(s)
11. **<u>Application for Orders</u>:** Application for orders as provided for in Louisiana Code Title 43, Part XI. Subpart 4. §703.A, B, or C or for the issuance of a certificate of public convenience and necessity as provided for in §703.D, shall be made in writing to the commissioner and shall be in such form and contain such information as herein after required. An order shall be issued to any qualified applicant therefore, authorizing the whole or any part of the operations, services, construction, extension, or acquisition covered by the application, if it is found

The applicant must show that it is able and willing to perform the services proposed and to conform to all the applicable provisions of Title 30 of the Louisiana Revised Statutes and rules and regulations of Louisiana Code Title 43, Part XI. Subpart 4. The applicant must further show that it proposes to construct and/or operate facilities for the transmission of carbon dioxide for injection in connection with a secondary or tertiary recovery project for the enhanced recovery of liquid or gaseous hydrocarbons, which has been approved by the commissioner pursuant to the provisions of Title 30 of the Louisiana Revised Statutes and rules and regulations of Louisiana Code Title 43, Part XI. Subpart 4.

5.1 Livingston Parish Pipeline Requirements

Livingston Parish requirements Section 4(a to e) and (j)(1) specify that an application for permits must be made in writing to the Livingston Parish Office of Homeland Security and Emergency

Preparedness prior to submission to the Parish Permitting Department. Such an application may be in the form of a letter and must contain the following:

1. **General Conditions:** General conditions include:
    a. Clear description of the facility and its purpose.
    b. Site plans, specifications, location description, and map of location.
    c. Name and Address of owner and/or a representative designated by such owner. The individual may be contacted by the parish on all future matters related to construction, maintenance, and installation of the facility.
    d. The application shall be followed by a credit card, business check, certified or cashier's check, and/or cash in the amount of $250 in a non-high consequence area or $500 if the project is in a high consequence area.
    e. Permit is required to be available where and when work is being conducted.
    f. Emergency Operations Plan.
2. **Insurance:** Livingston Parish Requirements Explosive/Pipelines Section 4(c) requires liability insurance coverage of one million and no/100 ($1,000,000.00) dollars, or satisfactory evidence of financial responsibility in a like amount. Proof of insurance must be furnished to the Parish. The insurance coverage should cover anything that arises under the workman's compensation laws of the State of Louisiana and/or under any statute of the United States of America.
3. **ENG Form 4345:** The U.S. Army Corps of Engineers requires an application form to apply for a permit. Some offices may use a slightly modified form for joint processing with state agencies. The Engineer form 4345 is used to determine the appropriate form of authorization and to evaluate your proposal. Typical process/procedure for a standard individual permit includes:
    a. Pre-application consultation (optional).
    b. Submit ENG Form 4345 to district regulatory office.
    c. Application received and assigned identification number.
    d. Public notice issued (within 15 days of receiving all information).
    e. 30 day comment period depending upon nature of activity.
    f. Proposal is reviewed by Corps and other regulatory agencies.

g. Corps considers all comments and other Federal Agencies consulted, if appropriate.
h. District engineer may ask applicant to provide additional Information.
i. Public hearing held, if needed.
j. District engineer will make the decision to issue or deny the permit.

4. **Pipeline construction requirements and specification:** are covered in Livingston Parish Requirements Explosive/Pipelines Section 4(e), which details the specification, materials, and states that installation must comply with all parish, state, and federal guidelines and procedures. The Livingston Parish Office of Homeland Security and Emergency Preparedness will conduct inspections, both during and after completion.

During construction of a CO_2 pipeline, the operator is required to comply with Louisiana Code Title 43, Part XI. Subpart 4, Chapter 15. All pipeline systems must be constructed in accordance with the written specifications of this regulation. Construction records need to be kept in accordance with the Louisiana Code Title 43, Part XI. Subpart 4, Ch. 15 §1559 which includes:

a. Girth welds, nondestructively tested, number of rejected, and disposition of each reject.
b. The amount, location, and covering of each size pipe installed.
c. Locations of each crossings of pipelines, and utility.
d. Location of each valve, weighted pipe, corrosion test station, or other item connected to the pipe.

Louisiana Code Title 43, Part XI, Subpart 4, Ch. 17 requires the hydrostatic pressure testing of carbon dioxide pipelines. The Louisiana Code sets minimum requirements for hydrostatic testing of newly constructed steel carbon dioxide pipelines. A record of each of the hydrostatic tests must be retained as long as the tested pipeline is in use. The record that is retained should include:

a. Operator’s name, the name of the person responsible for making the test, and the name of the company used, if any; appropriate parts shall be kept at locations where operations and maintenance activities are conducted.

b. Date and time of test.
c. Minimum test pressure and the test medium.
d. Description of the facility tested, and explanation of any pressure discontinuities that appear on the chart.

5.2 Pipeline Construction

The Livingston Parish Regulations Booklet Section 1 (j) covers the installation of pipelines or flowlines on, under, or across public property. Section 1(j) requires a plat be turned into the Livingston Homeland Security and Emergency Preparedness office covering pipelines crossing over, under, along, or across public street or alley, which includes the following:

a. Location of such pipelines or flowlines.
b. GIS information to locate the pipelines or flowlines.
c. Beginning and end points, including sufficient points in between the pipelines or flowlines.
d. Depth of the covering over the pipelines or flowlines.
e. Detailed cross section drawing for all public right of way and easement crossings as allowed by the parish.

Note that failure to provide detailed GIS information effectively releases the parish from responsibility for any damages or cost of repairs to the pipelines or flowlines. Installation of such pipelines and flowlines must comply with parish codes and regulations.

The Livingston Parish Regulations Booklet Explosives/Pipelines Section 3 (b)(2) and Louisiana R.S. 40:1749.15 require a notification of planned excavation be served to the regional notification center or centers serving the area of the planned excavation. The Louisiana One Call in Baton Rouge should receive the information through telephonic or electronic notice which includes and requires:

a. At least a forty-eight hour notice, but not more than one hundred twenty hours, excluding holidays listed in section 3(b)(2).
b. Name, address, and telephone number of the person filing the notice of intent, and if different, the person responsible for the excavation.

c. The date, anticipated duration, description of specific type of excavation, and a specific description of the proposed excavation.

If the excavation is part of a larger project, the notice shall be retained by the regional notification center for a three-year period from the date of notification.

Pipeline construction requirements and specifications are covered in Livingston Parish Requirements Explosive/Pipelines Section 4(e) and in the Statewide Order 29-B, Rule LAC 43:XIX.103, which states that the specification, materials, and installation shall comply with all parish, state, and federal guidelines and procedures. An inspection by the Livingston Parish Office of Homeland Security and Emergency Preparedness, both during and after completion, is required. CO_2 Pipeline construction should follow the American Public Works Association Guidelines.

Thirty days after completion of any pipeline facility for which a permit is required, Blackhorse Energy, LLC must file a notice of completion with the Parish, through the Livingston Parish Office of Homeland Security and Emergency Preparedness. The notice should include:

a. A sworn declaration of completion properly identified with the application and permit.
b. The notice of completion should certify that the construction and installation are in accordance with the plans and specifications approved by the permit or any supplement permit that may have been issued.
c. Accompanying the declaration a map or plat, in a form acceptable to the Parish, will be including showing the location of the portion or portions of the facility which are located on public property.
d. An inspection by the Livingston Parish Office of Homeland Security and Emergency Preparedness, both during and after completion.

6.0 PROPOSED PERMITTING SCHEDULE

Permit Type	Submit Permit	Receive Approved Permit	Commence Field Work
Access Road *	May 2014	July 2014	July 2014
Grading Permit*	May 2014	July 2014	July 2014
Drilling - Injection Well	March 2014	July 2014	July 2014
Dispose Pit Fluids*	May 2014	July 2014	July 2014
Workover – Observation Wells	May 2014	June 2014	July 2014
CO_2 Pipeline	To be Determined from CO_2 Procurement Plan	2nd Quarter 2013	October 2014
Transport Drilling Rig**	July 2014	July 2014	July 2014

*If needed

**responsibility of drilling company

7.12 APPENDIX L – SITE DEVELOPMENT / OPERATIONS / CLOSURE PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

January 28, 2014

WORK PERFORMED UNDER AGREEMENT

DE-FE0006823

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SUBMITTED TO

U. S. Department of Energy
National Energy Technology Laboratory

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY 195

2.0 SITE DEVELOPMENT 197

2.1 Location 197

2.2 Wells 197

2.3 Facilities 200

3.0 SITE OPERATIONS 203

3.1 Project Schedule 203

3.2 Seismic Surveys 204

4.0 SITE CLOSURE 205

1.0 EXECUTIVE SUMMARY

The South Louisiana Enhanced Oil Recovery/Sequestration R&D Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This Project proposes to evaluate an early Eocene-aged Wilcox sand oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the Livingston Field operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strandplain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets in saline reservoirs.

Blackhorse Energy, LLC will direct the Project through a Project Steering Team. The Project Steering Team will be comprised of the:

e. Principal Investigator for the Project, Dr. J. Roger Hite (Vice President Engineering and former Director of Production Research for Shell USA).
f. The Sandia Project Integrator, Dan Collins
g. The Technical Advisory Team Leader, Dr. Myron Kuhlman, and
h. The Blackhorse Energy CEO and Operations Manager, Lee Blanton

The Technical Advisory Team for this Project is led by Myron Kuhlman, and includes participants from the Louisiana State University, University of Texas, Rice University, the Computer Modeling Group, Weatherford, and Schlumberger Carbon Services.

Blackhorse Energy, LLC will be conducting a parallel CO_2 oil recovery project in the First Wilcox Sand.

The primary focus of this Project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the Project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the Project wells will be assessed in light of data collected from the two vertical injection wells. Field production wells will be leveraged for data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair can provide.

It is likely that this Project will demonstrate the attractiveness of CO_2 enhanced oil recovery to other small operators in Louisiana and the Gulf Coast area, in general, thus enhancing and encouraging additional CO_2 sequestration operations. Enhanced oil recovery currently represents the most profitable, and therefore attractive, means of sequestering CO_2.

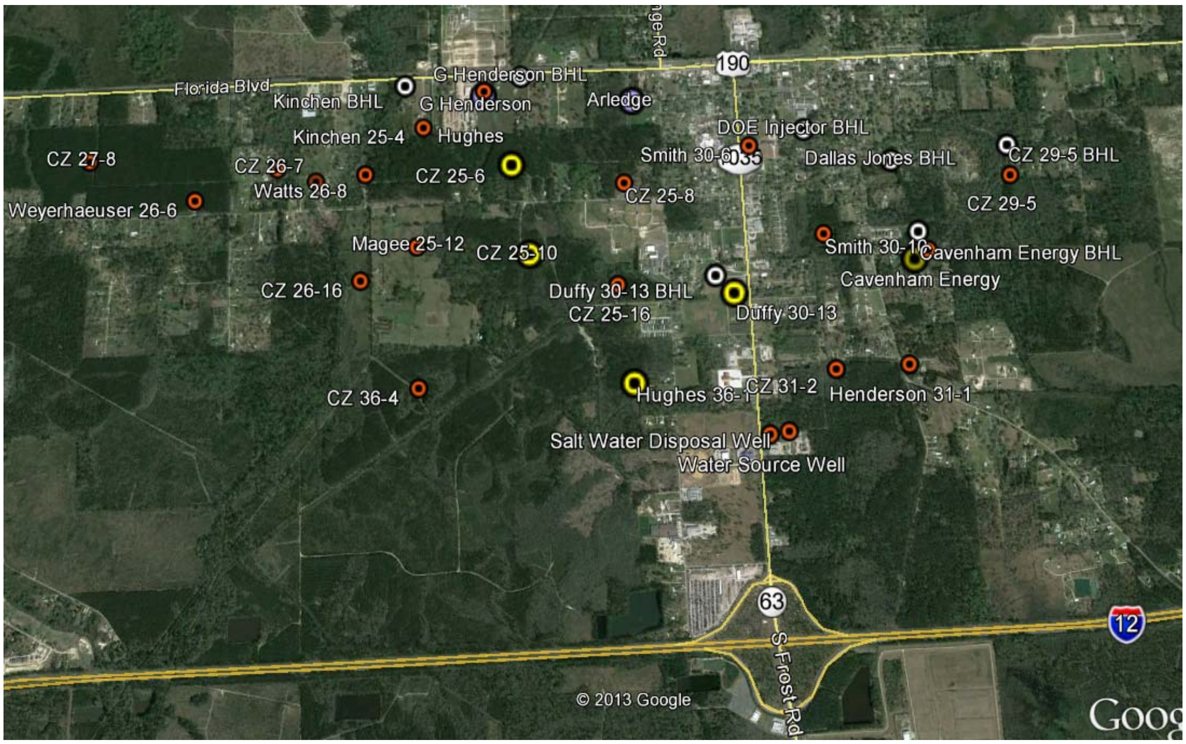
This Site Development/Operations/Closure Plan is intended to cover all aspects of project implementation, coordination, and execution. This report describes the details of the site development, operations, and closure. It has been developed during Budget Period 1 of the project so that the Recipient and DOE understand the requirements for the management of the infrastructure of the site. A list of available infrastructure in and around the Livingston Field related to small scale CO_2 injection has been compiled as part of this report. The report also identifies all major activities, roles of responsibility, and environmental health and safety issues that the Recipient will face during all stages of the project.

2.0 SITE DEVELOPMENT

2.1 Location

The South Louisiana Enhanced Oil Recovery/Sequestration R&D Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the small town of Livingston.

The following map shows the location of the field:



Blackhorse Energy, LLC has secured 100% of the working interest in the Livingstone field production unit. The field was discovered in 1983 and was unitized for waterflooding purposes in 1986. The field is in the Wilcox Formation at a depth of 10,000 feet. The field had approximately 28.6 million barrels (bbls) of original oil in place (OOIP). To date, through primary and secondary water flood recovery efforts, the field has produced 8.2 million bbls (29% of OOIP).

2.2 Wells

There are 28 wells operated by Blackhorse Energy, LLC in the Livingston Field as listed in the following table, drawn from the Louisiana Department of Natural Resources web site, SONRIS, http://sonris.com/:

Wells by Field ID

Field ID
6120 Livingston

Well Ser	Well Name	Well Num	Status	Class	Class Type	API Number	Org ID	Permit Date	Sect	Tshp	Rng	Parish
185664	LVG WX 1 RA SU;CROWN Z 25-8	5	9	II	9-IW	17063201000000	B354	4/27/1987	25	06S	04E	32
187663	LVG WX 1 RA SU;SMITH 30-10 WI	7	9	II	9-IW	17063201190000	B354	4/28/1987	30	06S	05E	32
187857	LVG WX 1 RA SU;HENDERSON 31-1	9	9	II	9-IW	17063201200000	B354	3/31/1987	31	06S	05E	32
189152	LVG WX 1 RA SU;CROWN Z 25-6	1	10			17063201260000	B354	11/22/1983	25	06S	04E	32
191209	LVG WX 1 RA SU;CROWN Z 25-10	1	10			17063201410000	B354	3/23/1984	25	06S	04E	32
191307	LVG WX 1 RA SU;CROWN Z 31-2 WI	8	9	II	9-IW	17063201430000	B354	3/16/1987	31	06S	05E	32
192209	LVG WX 1 RA SU;WATTS 26-8	1	33			17063201460000	B354	5/29/1984	26	06S	04E	32
192454	LVG WX 1 RA SU;CROWN Z 25-16	1	9	II	9-IW	17063201480000	B354	6/8/1984	25	06S	04E	32
192941	LVG WX 1 RA SU;SMITH 30-6 WI	6	9	II	9-IW	17063201520000	B354	5/7/1987	30	06S	05E	32
194621	LVG WX 1 RA SU;CROWN Z 26-16WI	2	9	II	9-IW	17063201590000	B354	5/4/1987	26	06S	04E	32
195632	LVG WX 1 RA SU;D JONES 30-8	1	10			17063201640000	B354	10/16/1984	30	06S	05E	32
195633	LVG WX 1 RA SU;W D HUGHES 36-1	1	10			17063201650000	B354	10/16/1984	36	06S	04E	32
196271	LVG WX 1 RA SU;CROWN Z 26-7	1	33			17063201720000	B354	11/8/1984	26	06S	04E	32
198835	LVG WX 1 RA SU;CROWN Z 27-8 WI	1	9	II	9-IW	17063201810000	B354	5/4/1987	27	06S	04E	32
199380	LVG WX 1 RA SU;CROWN Z 36-4	1	9	II	9-IW	17063201690000	B354	3/16/1987	36	06S	04E	32
200058	LVG WX 1 RA SU;MAGEE 25-12 WI	4	9	II	9-IW	17063201880000	B354	5/7/1987	25	06S	04E	32
200689	WX 1 RA SUEE;CROWN Z 27-2	1	31			17063201940000	B354	7/31/1985	27	06S	04E	32
201071	LVG WX 1 RA SU;CROWN Z 29-5	1	33	II	9-IW	17063201960000	B354	5/7/1987	29	06S	05E	32
205150	LVG WX 1 RA SU;RJ ARLEDGE ETUX	1	33			17063202250000	B354	12/19/1986	25	06S	04E	32
205994	LVG WX 1 RA SU;G HENDERSON	1	33			17063202290000	B354	5/29/1987	25	06S	04E	32
215090	LVG WX 1 RA SU;CAVENHAM ENERGY	1	33			17063200930000	B354	10/20/1992	30	06S	05E	32
230574	LVG WX 1 RA SU;DUFFY 30-13	1	10			17063202900000	B354	12/17/2004	30	06S	05E	32
230803	LVG WX1 RA SU;WEYERHAEUSER26-6	1	33			17063202910000	B354	1/31/2005	26	06S	04E	32
230994	LVG WX 1 RA SU;WATTS FIVE 26-8	1	33			17063202920000	B354	3/9/2005	26	06S	04E	32
231111	LVG WX 1 RA SU;KINCHEN 25-4	1	33			17063202930000	B354	3/30/2005	25	06S	04E	32
971389	LIVINGSTON SWD	1	9	II	5	17063880040000	B354	11/16/1984	31	06S	05E	32
971724	LIVINGSTON WATER SOURCE	1	73			17063880170000	B354	9/24/1986	31	06S	05E	32
971857	LVG WX 1 RA SU;HUGHES WI	11	9	II	9-IW	17063880190000	B354	9/25/1987	25	06S	04E	32

The Field ID code for the Livingston Field is 6120. The organization ID code, B354, is for BLACKHORSE ENERGY, LLC OF TEXAS, the name used by Blackhorse Energy, LLC, as operator in Louisiana. Well status codes are listed in the following table. Twenty-five of the wells are contained within a unit, LVG WX 1 RA SU, with the LUW Code of 043931.

Well Status Code Description

9	ACTIVE- INJECTION
10	ACTIVE - PRODUCING
31	SHUT-IN DRY HOLE -FUTURE UTILITY
33	SHUT-IN PRODUCTIVE -FUTURE UTILITY
73	WATER

The water source well and the salt water disposal well, both located within the Central Facilities site, are completed in shallower sands. Well CZ 27-2 was a dry hole and was plugged and abandoned on August 23, 1985. The well was drilled to 10,000 feet, with 10 ¾ casing set to 3,500 feet. On abandonment, a cement plug was set from 3,370 to 3,660 feet using 150 sacks of cement.

Additional data is available on the Louisiana Department of Natural Resources web site.

Five wells are currently in operation as producers – CZ 25-6, CZ 25-10, Duffy 30-13, Dallas Jones 30-8 and Hughes 36-1.

At the initiation of the CO_2 EOR Project, seven additional wells will be put on production – CZ 25-16, CZ 25-8, CZ 26-7, CZ 29-5, Smith 30-6, Smith 30-10, and Watts 26-8. The Smith 30-6 well is close to the injectors and will be converted to CO_2 service in 2014. Watts Five 26-8 will be put on production in 2015 and CZ 31-2 will be put on production in 2016. The remainder will be put on production as response is anticipated.

Producers CZ 25-8, CZ 25-6 and Dallas Jones 30-8 will also be used as observation wells for the DOE sequestration R&D project. The locations (surface and bottomhole) of these three production/observation wells, in relation to the DOE Injector Well, are shown below:

Within the field, CO_2 injection will be into the Arledge and Hughes 11 wells. The new DOE Injector well will be placed in service as an injector when it is completed.

Wells G. Henderson and Kinchen 25-4 are located very far updip, close to the CO_2 injectors. Due to their proximity to the CO_2 injection wells, they will be P&A'd in 2014.

Responsibility for all well activities rest with Blackhorse Energy, LLC. Funding will be provided by Blackhorse, with the exception of the 3-D seismic surveys, equipping the observation wells, and drilling, logging and completing the horizontal injection well.

All wells will be fenced and gated for security and safety purposes.

2.3 Facilities

The existing surface facilities at Livingston were built in the 1980's to handle waterflooding. They are not in good condition and are not designed to handle large volumes of high pressure CO_2-contaminated gas. New fit-for-purpose facilities will be built to provide for high pressure (2,000 pounds per square inch gauge (psig)) CO_2 injection, production well testing, oil/water /gas separation, produced water and oil storage, oil sales, gas recompression, and distribution and gathering lines.

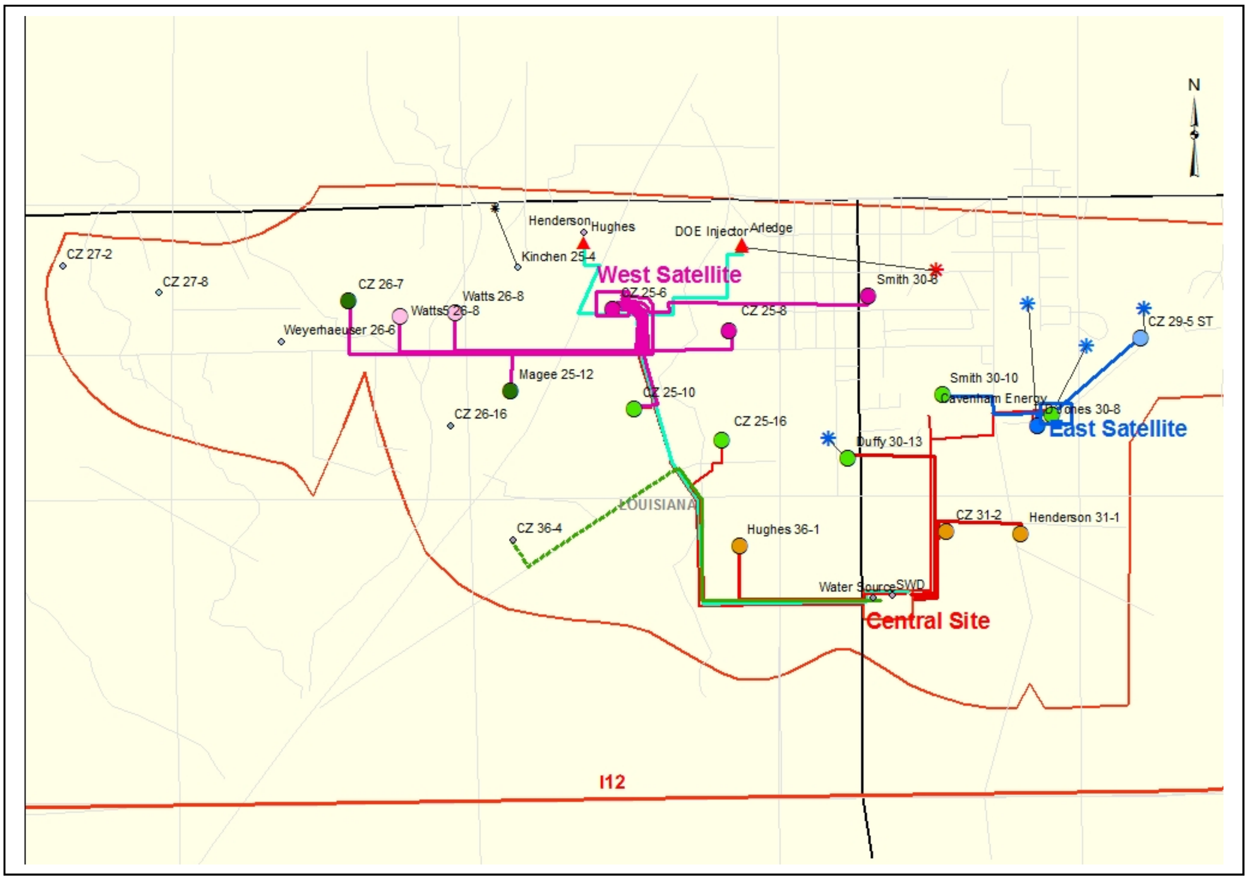
The field will be redeveloped for the CO_2 flood in stages as the flood response dictates. The first stage, undertaken in the first year, will consist of building the West Satellite Facility and connecting new flow lines into it from the wells that are expected to respond earliest to the CO_2 flood. The West Satellite will be located in the north central part of the field (see map below) so as to keep flow lines as short as possible. The satellite will consist of well test equipment, gas/liquid separation and gas recycle compression. A CO_2 interconnect line will connect the central site to the west satellite. The first two injector wells will be equipped for injection in the first year.

The second year's program will be to construct the East Satellite Facility and connecting the flow lines from nearby wells. The East Satellite will include well test equipment only. The gas/liquid separation and recycle compression for the east side of the field will be located at the central site. Final water/oil separation will also be located at the central site.

The third year's investment program will be located at the central site and will consist of additional well testing equipment, new gas/liquid separation equipment, recycle compression, oil/water separation/dehydration and oil storage tanks. The existing production handling system will be used at the central site for the first two years. Flow lines from nearby wells will also be connected to the central site in year three. Existing produced water treating and injection equipment at the central site will continue to be used. The central facilities sit on 10 acres of land leased from one of Blackhorse Energy's owners.

Facilities will be fenced and gated for security and safety purposes.

The map below depicts the staged development of Livingston Field.



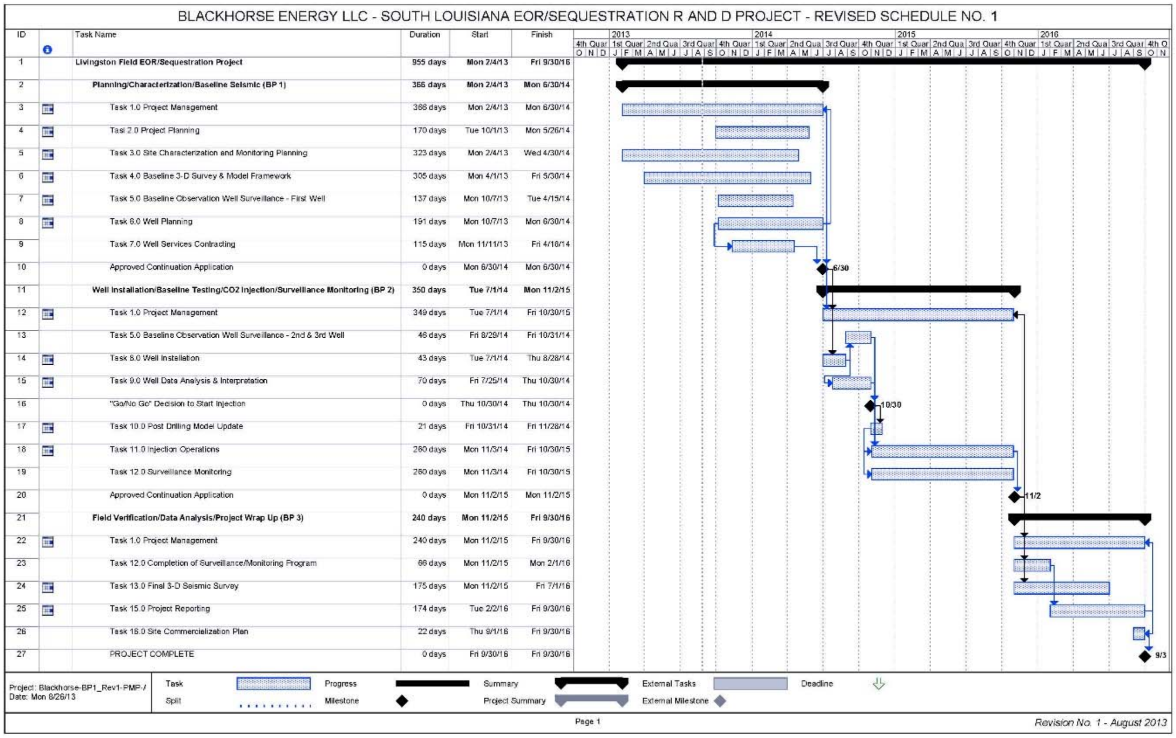
One of the first steps in the EOR project is to commission a detailed engineering design. Specific equipment lists and design parameters will become available at that time.

Design and construction of field facilities is the responsibility of Blackhorse Energy, LLC.

3.0 SITE OPERATIONS

3.1 Project Schedule

The project schedule is outlined in the following Gantt Chart:



There are four basic steps in the project:

1. Initial 3-D seismic survey in Budget Period 1
2. Drill injector well in Budget Period 2
3. Inject CO_2 in Budget Period 2
4. Final 3-D seismic survey in Budget Period 3

The first step is underway. Permitting, acquisition, processing and interpretation of the 3-D seismic survey are scheduled to be completed by year end 2014. The DOE Injector will be drilled in 3Q 2014 and ready for injection by 4Q 2014. It will take approximately 280 days to inject 1 Bcf CO_2. Final seismic survey will begin in 4Q 2015. The project ends September 30, 2016.

3.2 Seismic Surveys

Three dimensional seismic surveys will be conducted before and after injecting 1 Bcf of CO_2. Both surveys will be permitted, acquired and processed by Schlumberger Carbon Services (by its affiliate Western Geco). Earthview has been contracted to do the interpretation.

In addition to the project 3-D seismic surveys, Blackhorse Energy, LLC has acquired rights to some legacy seismic data. Strand Energy conducted a 3D survey over a large area in Livingston Parish in 2011, which cover the western and southern portion of our project. Several 2-D seismic lines have also been acquired.

4.0 SITE CLOSURE

At the termination of the DOE project, responsibility for DOE funded wells and equipment will be transferred to Blackhorse Energy, LLC. It is anticipated that most will be put into service in the ongoing EOR project. The EOR project is expected to continue for approximately 30 years.

7.13 APPENDIX M – RISK ASESSMENT PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

January 10, 2014

WORK PERFORMED UNDER AGREEMENT

DE-FE0006823

PREPARED BY

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TABLE OF CONTENTS

1.0 INTRODUCTION 208

2.0 PROJECT RISK EVALUATION 210

2.1 Risk Identification 210

2.2 Risk Characterization 210

2.3 Risk Evaluation 211

1.0 INTRODUCTION

The proposed South Louisiana Small-scale Sequestration Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This Project proposes to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the Livingston Field operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strand plain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets in saline reservoirs.

The primary focus of this Project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the Project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficiency of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the Project wells will be assessed as data is collected from the two vertical injection wells. Field production wells will be leveraged for data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair can provide.

This Risk Assessment Plan's objective is to identify, analyze, and evaluate the risks associated with geologic sequestration of CO_2. Throughout the risk management process, risks will be proactively reassessed whenever there are revisions to the site characterization framework or the Well Drilling and Installation Plan. This Risk Assessment Plan will be updated accordingly (i.e., maintained as an "evergreen document"). Where feasible, risks will be mitigated to the extent possible. As a last resort, engineering controls will be used to minimize risk and potential exposures.

2.0 PROJECT RISK EVALUATION

2.1 Risk Identification

The risk analysis process, while undertaking this CO_2 sequestration project, involves identifying pertinent risks, estimating their impacts, and developing procedures to mitigate the impacts from such risks. Events or processes that could contribute to unplanned CO_2 migration are identified to help prevent the chance of migration from occurring. A risk register was developed to act as a log for all of the risks identified thus far in the project and can be found in Appendix A. It contains information such as the individual(s) responsible, causes, consequences, and action plans for each risk identified.

Knowing the risks involved is key to lowering the level of uncertainty in this project. However, with such a broad project it is possible to overlook potential risks initially. As this project develops, potential risks that are not in the register may arise. The project will be proactively reassessed and risks will be logged, discussed, and alleviated before they become an issue. The risks logged in the register were identified in areas such as capacity and injectivity, containment, monitoring, permitting, wellbore failure, and overall project risks.

2.2 Risk Characterization

A qualitative prioritization of the potential consequences identified is the next step of the risk analysis process. The risks identified are categorized and ranked in terms of likelihood and magnitude of consequences. The areas impacted by the consequences of the potential risks include the environment, health and safety, cost, reputation, and the project schedule. A risk matrix for this CO_2 sequestration project can be found in Appendix B. By applying the risk matrix to the risks identified, the high priority risks that require immediate responses were identified and plans for mitigating or controlling them were developed.

The new injection well and the offset wells have the greatest risk of being leak sources for CO_2. The potential problems that could arise while either drilling the new well or injecting the CO_2 were considered. The wellbore management plan was essential in helping to mitigate potential risks from migration of CO_2 through the new injection well.

2.3 Risk Evaluation

With the risks identified and ranked in terms of likelihood and severity, risk treatment actions were determined to help mitigate the consequences. The action plans for the potential risks that can be encountered while executing this project will help to reduce or eliminate the consequences. Risks that were considered to be very probable and have the most severe consequences were evaluated further.

7.14 APPENDIX N – MONITORING, VERIFICATION AND ACCOUNTING PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

February 20, 2014

WORK PERFORMED UNDER AGREEMENT

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TABLE OF CONTENTS

1.0 INTRODUCTION 215

2.0 LIVINGSTON FIELD SUMMARY 217

3.0 MONITORING PROGRAM 220

3.1 Baseline and Post-injection 3-Dimensional Seismic Surveys 220

3.2 Monitoring Strategy at the Project Injection Well 221

3.2.1 Injection Well Monitoring Activity/Equipment 222

3.3 Monitoring Strategy at the Project Observation Wells 226

3.3.1 Observation Well Monitoring Activity/Equipment 226

4.0 MVA MONITORING PLAN MATRIX 229

5.0 PROJECT ACCOUNTING 230

FIGURES

Figure 1 Proposed Project Injection Well

Figure 2 Proposed Observation Well – Crown Zellerbach 25-6 No. 1

Figure 3 Proposed Observation Well - Crown Zellerbach 25-8 No. 1

Figure 4 Proposed Observation Well – Dallas Jones 30-8 No. 1

Figure 5 Proposed Observation Well Locations in relation to the Livingston Field CO_2 Injection Wells

1.0 INTRODUCTION

The proposed South Louisiana Small-scale Sequestration Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This Project proposes to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the Livingston Field operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strandplain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets into saline reservoirs.

The primary focus of this Project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the Project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the Project Injection Well will be assessed in light of data collected from two vertical injection wells. In addition to the three converted Observation Wells, field production wells will be leveraged for additional data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair can provide.

This Monitoring, Verification, and Accounting Plan's objective is to outline the strategy and equipment required to perform the monitoring at Livingston Field.

2.0 LIVINGSTON FIELD SUMMARY

The Livingston Field was discovered in 1983, by the Callon Petroleum Company, with the completion of the Crown Zellerback No. 1 well in the First Wilcox Sand. Livingston Field discovery followed production from the First Wilcox Sand at Lockhart Crossing Field, located eight miles to the west. The Eocene-aged First Wilcox Sand appears to be a beach barrier/near-shore marine bar which displays excellent horizontal continuity. The First Wilcox Sand has been mapped as being approximately 8 to 10 miles wide (north to south) and can be traced for tens of miles along strike (Self et al., 1986).

Callon initially operated most of the Livingston Field as part of a 50/50 Area of Mutual Interest agreement (AMI) with Amoco. Amoco took over operatorship of the field in August 1985, once primary development had been completed. Amoco sold its interest in the field to Force Energy Gas in March 1995. Force Energy Gas changed its name to Force Energy in May 1996. They sold their interest in the field to Hilcorp in May 1999. TMR bought that interest in May 2000. Blackhorse Energy acquired the field in 2011.

Amoco placed the original oil/water contact at approximately -10,053 feet subsea (Gillham, 1988). However, based on re-evaluation of the field well logs, the oil/water contact was likely closer to -10,040 feet subsea. A reservoir-wide unit was formed in November 1986, for the purpose of water flooding the field, and water injection began in May 1987. Primary production had peaked in April 1985, at 3,700 barrels of oil per day (BOPD), and declined to 1,100 BOPD by the start of water flooding. Water flood production peaked at 3,450 BOPD in September 1988. Cumulative oil production (primary and secondary) in the field is approximately 8.1 MM Bbls, or about 0.12 pore volumes. Cumulative water injection is approximately 15.9 million barrels (MM Bbls), or about 0.20 pore volumes. Average current producing gas-to-oil ratio (GOR) is 0.49 thousand cubic feet of gas per barrel (Mcf/Bbl) of oil.

The trapping mechanism at Livingston Field is a combination of faulting and stratigraphy, which will contain the CO_2 that is injected during the Enhanced Oil Recovery/Sequestration Project. According to Johnston and Johnson (1987), the field is bounded on the north by a major down-to-the-basin fault that places the Wilcox juxtaposed against impermeable marine shale. The eastern field boundary is formed by a low permeability tidal channel that cuts through the reservoir. The reservoir fluid is a black oil, with an average American Petroleum Institute (API) gravity of 35 (Goddard, et al., 2002). Oil properties vary across the field. From east to west, the fluid becomes lighter and contains more natural gas. Solution GOR is approximately 400 cubic feet of gas per barrel of oil (cf/Bbl), consistent with an average producing GOR of 0.49 Mcf/Bbl. Oil formation volume factor is 1.23. Minimum miscibility pressure was determined by Amoco to be around 2,400 pounds per square inch (psi).

Within the Livingston field, there may be post-depositional faults. Johnston and Johnston (1988) identified several synthetic and antithetic faults that approximately parallel the major down-to-the-south field fault. These smaller faults, mapped by Johnston and Johnson (1987), have throws of about 25 feet and are not thought to sealing (i.e., do not completely offset the reservoir). However, they identified an antithetic fault along the western portion of the field, which has a throw of about 75 feet. This fault appears to isolate a segment of the First Wilcox Sand from the rest of the field. The southern boundary of the field is formed by an east-west oriented fault, and no production has been found south of the fault.

The Livingston field wells were extensively cored during drilling, which provides significant characterization data. The First Wilcox Sand appears to be a well-consolidated shaly sand that contains 40 to 90 percent quartz, with minor amounts of feldspar, calcite, ferro-dolomite, and pyrite. Clay content, as high as 20 percent, is also found and consists primarily of kaolinite, illite, and chlorite. Core data shows that only the upper 20 feet of the First Wilcox Sand interval has good permeability, perhaps associated with the aeolian and upper shoreface depositional facies. Permeabilities in this upper part of the sand range from 40 millidarcies up to 290 millidarcies (Goddard et al., 2002), with upper end porosities of 24 percent. Therefore, the First Wilcox Sand is expected to have good to excellent injectivity characteristics, as confirmed with the injection of over 15.9 MMBbls of saltwater.

Permeability in the First Wilcox Sand decreases with depth, consistent with a coarsening upward depositional environment. The lower part of the First Wilcox Sand interval has low permeabilities (less than 15 millidarcies) and porosities on the order of 15 percent, perhaps associated with the middle and lower shoreface facies types (Goddard et al., 2002). The reason for the difference between petrophysical properties at the top of the interval and the bottom is not entirely clear. For a given porosity, the permeability is higher in the top section than in the bottom section. Likewise, for a given shale content, the permeability in the top section is much higher than in the bottom section, different by a factor of three. The difference may lie in micro-porosity, due to the presence of clay coatings on sand grains, which is not identified with either the existing log or core descriptions. Even small differences in micro-porosity are known to have a large impact on permeability and capillary pressure.

Underground sources of drinking water (less than 10,000 milligrams/liter (mg/l) total dissolved solids (TDS)) occur from near-surface down to approximately 3,500 feet, within the Miocene-aged strata. Deeper Miocene and Oligocene-aged sands occur down to a depth of about 8,500 feet. Cockfield and Sparta shales essentially form a 1,400 foot thick, low permeability confining zone down to the top of the Wilcox, located at a depth of approximately 9,900 feet. The upper Wilcox consists of low permeability lagoonal shales, which form the primary seal above the reservoir. The First Wilcox Sand occurs at a depth of 10,000 feet in the field and had an original pore pressure of 4,580 psi, equivalent to an 8.8 pounds per gallon mud weight, and a temperature of approximately 212 ºF. These reservoir conditions fall well within that necessary for storing CO_2 as a supercritical dense phase (i.e., sequestration window). A review of scout ticket information and well log records shows that geopressure (overpressure) occurs below a depth of 15,000 feet in the Selma-Austin Chalk interval, well below our project depth.

3.0 MONITORING PROGRAM

The monitoring program for the small-scale sequestration project is outlined in the following subsections. Emphasis is placed on subsurface monitoring of CO_2 in the First Wilcox Sand, enhanced with monitoring for potential out of zone movement of the injected CO_2.

3.1 Baseline and Post-injection 3-Dimensional Seismic Surveys

In order to track the extent of the injected CO_2, monitoring from surface using seismic methods will be used. Surface seismic methods are highly advanced due to their extensive use by the petroleum industry, and the method has proved useful at several other sequestration sites. The advantage to using a surface survey is the ability to image a large portion laterally across the field, extending well beyond the dimensions of expected CO_2 plume movement during the DOE project. That is factored against the loss of resolution inherent in having both the sources and receivers at the surface, especially at the depth of the First Wilcox Sand (+/-10,000 feet below ground). In addition, by imaging the full geologic column, movement of CO_2 into shallower formations may also be detectable.

The Livingston wells are located too far apart for crosswell seismic to be practical, and time-lapse and/or walk-away vertical seismic profiling requires well intervention to deploy the geophone sensor string into one or more active wells, or dedicated well(s). In addition, individual vertical seismic profiles are 2-dimensional in nature, requiring a “shotgun” distribution to the surface source locations in order to provide a 3-dimensional aspect to the survey.

An initial 3-dimensional reconnaissance seismic survey will be performed across Livingston Field during Budget Period 1. In addition to providing a baseline to the after injection survey, the initial survey will be used to refine the subsurface structural interpretation within the field. The survey is expected to be carried out in the field during the late winter 2013, or the early spring of 2014. Western Geco (under a contract to Schlumberger Carbon Services) will be responsible for securing all applicable state permits and access agreements to conduct the survey. Verification that all required permits and permissions have been obtained will be submitted to the Principal Investigator prior to authorization of mobilization to the field. Crews will be mobilized to the field to survey routes and define any impediments along the proposed survey; deploy, plant, and troubleshoot the receiver array; record the survey; and pickup all deployed equipment at the completion of the survey. Field operations are anticipated to take three weeks. Following processing by Western Geco, the initial seismic survey will be evaluated by Earthview, Inc. A structural evaluation will be used to refine field characteristics and evaluate complexity of faulting and/or stratigraphic changes within the field.

The initial survey will serve as the baseline for comparison to the final seismic survey to be run following completion of injection of 1 billion cubic feet (BCF) of CO_2 into Livingston Field (project target volume). The 3-dimensional seismic survey will be repeated using the same surface source points and geophone receiver locations as used in the initial survey. Purpose of the repeat survey will be to image the extent of injected CO_2 using the seismic difference technique from the initial survey. Time-lapse imaging of injected CO_2 has been successfully demonstrated at Sleipner, a large-scale CO_2 sequestration project (Bickle et al., 2007), however, other time-lapse survey results have been more complex and uncertain (Ivanova, et al., 2012; Ditkof et al., 2013).

Initial pre-shoot seismic screening of Livingston Field has been conducted by Earthview, Inc. The dataset utilized in the screening consists of legacy 2-dimensional data, three dip lines and two strike lines, that cross Livingston Field, and a 4,000 acre cut out from a large 3-dimesional seismic survey. The 4,000 acre cut out in the 3-dimensional survey covers the western two-thirds of Livingston Field and was shot in 2012 and 2013. The screening by Earthview, Inc. shows that structural features at the Wilcox First Sand level can be successfully imaged. Additionally, attribute analysis indicates that variations can be delineated within the Wilcox. Since our 3-dimensional survey is expected to be of higher resolution, which should improve our imaging quality, it is likely that we will be able to define lateral fluid variations within the First Wilcox Sand.

3.2 Monitoring Strategy at the Project Injection Well

The project is proposing to install a short-radius horizontal lateral completion (500 to 1,000 feet in length) in the First Wilcox Sand. The well will be located east of the two Blackhorse injection wells, with the horizontal lateral section located within the upper-middle portion of Section 30. The well pad for the Arledge injection well will be used, and the Project Injection Well will be drilled with surface casing set to +/-3,800 feet below grade to seal off all underground sources of drinking water. The well will then be drilled to build wellbore angle to the east-southeast of the surface location, becoming horizontal as it enters the First Wilcox Sand. A near horizontal borehole will intersect the First Wilcox Sand, and a 500 to 1,000 foot lateral will be drilled in the upper 20 feet of the sand. The open hole will be extensively logged for baseline and characterization purposes, and whole core will be taken from the overlying confining lagoonal shale and the First Wilcox Sand. Protection casing will be set from surface to the toe end of the horizontal lateral. The lateral will be perforated and stimulated, if necessary, to ensure injectivity into the First Wilcox Sand. The completion is expected to consist of 2-7/8-inch tubing (or 2-3/8-inch tubing) set on a mechanical packer with pass-through capability. Below the packer, slotted tailpipe will be run through the entirety of the protection casing to the toe of the well. The tailpipe will provide the structure to support and run any internal monitoring equipment below the packer and provide a path of cased hole logging.

A working design for the Project Injection Well is included as Figure 1.

3.2.1 Injection Well Monitoring Activity/Equipment

Wellhead instrumentation will include monitoring of tubing pressure and tubing temperature, and casing-tubing annulus pressure via sensors on or near the wellhead. These sensors will ensure compliance with applicable state permit conditions and serve as a redundancy to the downhole instrumentation. Injection into the Project Injection Well will be accurately metered via a coriolis-type mass flow meter located on the injection flow line to the wellhead. The wellhead pressure and temperature sensors will likely be wireless transmitters and, with the coriolis-type mass flow meter, will feed to a surface data storage box located on the well pad (equipped with back-up data storage). The data box will have remote data transmitting capability (satellite/cell tower) for remote data transmission and viewing/analysis from the office. The system will be tied into the Blackhorse SCADA system at the Central Facility for recording, archiving, and project data storage.

Downhole monitoring in the Project Injection Well includes tools run periodically on wireline and continuous monitoring using permanently installed downhole equipment. As with seismic techniques, monitoring via wireline tools is highly advanced due to extensive development and their use in the petroleum and product storage industries. The project will employ pulsed neutron tool technology (Schlumberger's Reservoir Saturation Tool) for monitoring saturation changes with time across the horizontal completion. The Project Team is currently evaluating the use of a downhole tractor to enable running Schlumberger's Reservoir Saturation Tool down to the toe of the horizontal section of the Project Injection Well. In addition to a baseline pass (following completion of the well) for comparison to later runs of the tool, key monitoring times are expected to include: 1) just prior to the start of surfactant and CO_2 (foam) injection and 2) following stabilization of surfactant (foam) injection.

Dedicated downhole monitoring equipment for the Project Injection Well will include permanent installation of a Distributed Temperature System (fiber-optic cable), installed from the wellhead down to the toe of the horizontal lateral, and permanent installation of dual surface read-out down hole pressure temperature/gauges to be set at the heal and toe of the horizontal lateral completion section of the Project Injection Well. The Distributed Temperature System ensures essentially continuous monitoring of the temperature along the length of the wellbore. Temperature is recorded at a sampling interval of approximately every three feet, which will result in excess of 3,600 data monitoring points along the Project Injection Well. The Distributed Temperature System will allow for determination of flow distribution across the completion interval of the horizontal lateral, as well as any changes in flow distribution with time during CO_2 injection. A key transition in flow distribution is expected during initiation and stabilization of surfactant (foam) injection, midway through the project. Additionally, the Distributed Temperature System can be used to monitor for above-zone flow, ensuring in-zone CO_2 retention. The two pressure/temperature gauges will allow for continuous monitoring of injection pressure across the horizontal completion section.

An "above zone" pressure/temperature gauge will be set at an approximate below ground depth of 8,200 feet, just above the Vicksburg Formation. This gauge will allow for lateral monitoring across the field and containment by the 1,500 foot thick primary seal above the First Wilcox Sand, ensuring that the injected CO_2 is retained in the Wilcox.

The Project Team is evaluating risk/reward and efficacy of deploying the downhole equipment on the tubing string (higher chance of successful deployment) versus deploying the equipment on the protection casing (better coupling to the formation and less complicated packer design). Cost, robustness, and redundancy of either deployment will also be considered during the evaluation.

Project Injection Well monitoring components will include:

Monitoring Location	Monitoring Activity/Equipment
Surface/Wellhead Permanent	- Coreolis Mass Flow Meter - Annulus Pressure Transducer - Tubing Pressure/Temperature Transducer
Downhole Permanent	- Distributed Temperature Fiber Optic Cable - Surface Read-out Pressure/Temperature Gauges
Downhole Periodic	- Reservoir Saturation Tool profile (if technically practical)

3.2.1.1 Co-project with EPRI

The scope of work in the Electric Power Research Institute's (EPRI) agreement with DOE (DE-FE00127000) consists of designing, fabricating, and acquiring monitoring data from a fiber-optic cable installed in the Project Injection Well at the Livingston Field. The fiber-optic cable supplied by EPRI will include multiple single- and multi-mode fibers and heater elements used to measure downhole changes in temperature (Distributed Temperature System) and acoustic (Distributed Acoustic System) responses caused by CO_2 flow, changes in bulk fluid composition, and/or formation saturation. Once installed, EPRI will have scientists from Lawrence Berkeley National Laboratory (LBNL) conduct vertical seismic profile surveys, along with heat-pulse and temperature profile surveys (distributed thermal perturbation sensing).

Silixa's sensor unit, referred to as the intelligent Distributed Acoustic Sensor (iDAS™), utilizes a novel opto-electronics architecture that uniquely measures the modulation of the backscattered light from the Distributed Acoustic Sensing fiber-optic cable. An acoustic field around the fiber exerts tiny pressure/strain changes onto the fiber. The iDAS™ measures these pressure changes at a rate of up to several kilohertz and thus, can be used to measure the acoustic field. The system digitally records both the amplitude and phase of the acoustic fields, up to tens of kilohertz at every location and, can "listen" to every point along the fiber, offering three-foot spatial resolution with a wide dynamic range of more than 90 dB and without cross-talk. The EPRI/LBNL project team will design a vertical seismic profile survey, using the Distributed Acoustic Sensor fiber in the well as the receiver array and selecting 6-12 offset source locations at land surface. Offset source locations have yet to be determined, but they are likely be co-located with source points from the baseline 3-dimensional survey performed by Blackhorse. This will maximize the likelihood of survey success and minimize project risk/exposure. The EPRI/LBNL project team plans on performing two vertical seismic profile seismic surveys during the life of the project. The first survey will be conducted after installing the fiber-optic sensors and before CO_2 injection starts. This will serve as the baseline vertical seismic profile survey. A go, no-go decision point (execution) will occur after collecting and analyzing the first round of survey data. A second vertical seismic profile survey will be conducted after completion of CO_2 injection, and the results will be compared to the baseline survey to determine if the position of the CO_2 can be successfully imaged. Both vertical seismic profile surveys will use the same source locations for repeatability.

Distributed Temperature Sensing using fiber optics has been deployed by the oil and gas industry in wells for approximately 20 years. The EPRI/LBNL sensor assembly uses a heater loop and the distributed temperature sensor fiber to detect changes in fluid saturation and flow allocation. Referred to as heat-pulse monitoring, the EPRI/LBNL system works by applying current to the heater for a short period of time, creating a pulse of heat along the entire length of the wellbore. Temperature in the well is simultaneously registered using the Distributed Temperature Sensing array. By taking advantage of the difference in thermal conductivity between supercritical CO_2 and formation fluids (brine and oil), the heat-pulse Distributed Temperature Sensing system can be used to detect changes in fluid composition inside the well and changes in formation saturation outside of the well. The heat-pulse monitoring method can also be used to measure injection rates and flow distribution in a CO_2 injection well, similar to a hot-wire anemometer. Heat applied by the cable is transferred to the fluid flowing past the Distributed Temperature Sensing fiber; the amount of heat transferred can be related to the velocity of the flowing fluid. Therefore, the Distributed Temperature Sensing system captures a high resolution map of the heat being transferred (i.e., flow allocation) from the well into the formation. Plans are to perform at least one heat-pulse test per month for the duration of the project.

3.3 Monitoring Strategy at the Project Observation Wells

The project is proposing to convert three existing field wells to Observation Wells. The Observation wells, from west to east, are the Crown Zellerbach 25-6 No. 1 well, Crown Zellerbach 25-8 No. 1 well, and the Dallas Jones 30-8 No. 1 well. The Dallas Jones 30-8 No. 1 well is the closest to the Project Injection Well, and the two Crown Zellerbach wells are located near the Blackhorse Injection Wells.

In the conversion to Observation Wells, each well will be reentered, and the current completion will be pulled from the wells. It is expected that the Crown Zellerbach 25-6 No. 1 well will be converted near the end of Budget Period 1, and the two remaining wells will be converted early in Budget Period 2 (ahead of CO_2 injection). Artificial lift will be installed during well conversion and the Observation Wells will be produced until they begin to self-lift. All downhole instrumentation will be run on the tubing string.

A working design for each of the Observation Wells is presented as Figures 2, 3, and 4. Relative locations between the field injection wells, the Project Injection well, and the three Observation Wells are shown in Figure 5.

3.3.1 Observation Well Monitoring Activity/Equipment

Wellhead instrumentation on the Observation Wells will include monitoring of tubing pressure and tubing temperature, and casing-tubing annulus pressure via sensors on or near the wellhead of each Observation Well. These sensors will ensure compliance with applicable state permit conditions and serve as a redundancy to the deployed downhole instrumentation. Production volumes will be metered at surface on the production flow line leading from each wellhead. Flow data is needed on oil, water, and gas flow rates, and CO_2 concentration in the gas phase. Additional information includes salinity and pH of produced water. Each well will have a sampling port near the wellhead to obtain periodic samples for laboratory analysis. It is expected that wellhead pressure and temperature sensors will be wireless transmitters and, with the surface flow metering, will feed to a surface data storage box located on the well pad (equipped with back-up data storage). The data box will have remote data transmitting capability (satellite/cell tower) for remote data transmission and viewing/analysis from the office. The system will be tied into the Blackhorse SCADA system at the Central Facility for recording, archiving, and project data storage.

Downhole monitoring in the Observation Wells includes tools run periodically on wireline and continuous monitoring using permanently installed downhole equipment. As discussed earlier, monitoring via wireline tools is highly advanced due to extensive development and their use in the petroleum and product storage industries. The project will employ pulsed neutron tool technology (Schlumberger's Reservoir Saturation Tool) for monitoring saturation changes with time across the First Wilcox Sand. Each of the Observation Wells are sufficiently vertical that running on standard wireline will be sufficient to enable running Schlumberger's Reservoir Saturation Tool down to the bottom (below the First Wilcox Sand) of each well. In addition to a baseline pass (following completion of each well) for comparison to later runs of the Reservoir Saturation Tool, key monitoring times are expected to include: 1) stabilization of well after self-lift; and 2) at the end of project injection. Following initiation of self-lift, it is expected that the wells will be allowed to produce through the remainder of the project without further need to employ artificial lift. Downhole fluid samples will be taken in the Observation Wells at the same time that the Reservoir Saturation Tool is run. A pressure-volume-temperature (PVT) type downhole sampler will be used to maintain pressure on the recovered sample, and the sample cylinder will be shipped to Schlumberger's Oilphase Laboratory for analysis. Downhole fluid sampling events will coincide with running Schlumberger's Reservoir Saturation Tool.

Dedicated downhole monitoring equipment for the Observation Wells will include permanent installation of a Distributed Temperature System (fiber-optic cable), installed from the wellhead down below the completion perforations (60 to 90 feet below the base of the First Wilcox Sand), and permanent installation of a surface read-out down hole pressure temperature/gauge to be set just above the packer and ported into the tubing string. The Distributed Temperature System ensures essentially continuous monitoring of the temperature along the length of the wellbore. Temperature is recorded at a sampling interval of approximately every three feet, which will result in excess of 3,300 data monitoring points along each of the Observation Wells. The Distributed Temperature System will allow for determination of inflow distribution across the perforated interval in the First Wilcox Sand, as well as any changes in inflow distribution with time. Additionally, the Distributed Temperature System can be used to monitor for above-zone flow, ensuring in-zone CO_2 retention. The pressure/temperature gauge will allow for continuous monitoring of pressure at each Observation Well.

Project Observation Well monitoring components will include:

Monitoring Location	Monitoring Activity/Equipment
Surface/Wellhead Permanent	- Metered production flow - Annulus Pressure Transducer - Tubing Pressure/Temperature Transducer - Sampling port
Downhole Permanent	- Distributed Temperature Fiber Optic Cable - Surface Read-out Pressure/Temperature Gauge
Downhole Periodic	- Reservoir Saturation Tool profile - Downhole Fluid Samples

4.0 MVA MONITORING PLAN MATRIX

Table 1 presents a "monitoring matrix" for the South Louisiana Small Scale Sequestration Project. The matrix shows the locations, methodologies, proposed devices/equipment, and frequency of the activity. Note that the Monitoring Plan Matrix includes the Co-project with EPRI/LBNL.

5.0 PROJECT ACCOUNTING

The results of the monitoring program will be used to update the field model for the saturations and extent of CO_2 with time. First Wilcox Sand reservoir is confined within the field operating unit, by both stratigraphy and faulting, Historical field performance indicates a lack of a strong water drive, indicating limited fluid influx from the edges of the field, thereby enhancing the ability for careful monitoring, verification, and accounting opportunities using a material balance approach.

In addition to the monitoring program, the project will track the following:

- Mass of CO_2 received;
- Mass of CO_2 injected into the subsurface (all wells);
- Mass of CO_2 produced;
- Mass of CO_2 emitted by any surface releases;

Where possible, data obtained from flow meters will be used, however, other data sources may be acceptable where flow meters are unavailable. Standard flow meter calibration and requirements following manufacturer's specifications will be followed. A series of mass balance equations will be used to correctly determine all mass flow values. The remaining mass will be allocated to the formation (includes mass retained and the mass in transit).

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Figure 5 Proposed Observation Well Locations in relation to the Livingston Field CO_2 Injection Wells

7.15 APPENDIX O – RESERVOIR MODELLING PLAN

South Louisiana Enhanced Oil Recovery/Sequestration R&D Project
Small Scale Field Tests of Geologic Reservoir Classes for Geologic Storage

March 3, 2014

WORK PERFORMED UNDER AGREEMENT

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Table of Contents

List of Figures ... 236

List of Tables ... 239

1.0 Introduction ... 240

1.1 Reservoir Description: ... 241

1.2 Depositional Environment: ... 241

1.3 Reservoir Structure: ... 241

1.5 Oil-water Contact. ... 245

2.0 CO_2 EOR ... 246

2.1 Mechanisms: ... 246

2.2 What does MMP mean? ... 246

3.2 – Log Analysis: ... 249

3.3 Facies Mapping: ... 252

2.4 – Creating a Static Model: ... 252

4.0 Modeling Primary and Waterflood ... 254

4.1 PVT: ... 254

4.2 Relative Permeability: ... 256

4.5 Reservoir Pressure ... 259

5.0 CO_2 EOR Project ... 260

5.1 CO_2 injection and Recycle with Two Injectors: ... 260

5.1.1 Effect of Miscible Residual (SORM): ... 261

5.1.2 – CO_2 Solubility in Water: ... 263

5.2 - Performance with Horizontal Injector: ... 264

5.2 Tapered WAG: ... 266

6. Discussion ... 269

6.1 Results for Two and Three Injectors: ... 269

6.2 Continuous CO_2 and Tapered WAG: ... 272

7 Conclusions ... 275

6.1 – Results for Two and Three Injectors:

6.2 – Continuous CO_2 and Tapered WAG:

List of Figures

Figure 1.1 - Location of the Livingston Oil Reservoir

Figure 1.2 - Depositional Model for Wilcox Sandstone Barrier Island

Figure 1.3 - Johnston and Johnson Structure Map

Figure 1.4 - Goddard Structure Map

Figure 1.5 - TMR Structure Map

Figure 1.6 - TMR Structure Map with Cross-Sections

Figure 1.7 - Correlation of Calcite Layers E-W across the Reservoir

Figure 1.8 - Blackhorse Energy Structure Map

Figure 1.9 - Correlation of Calcite Layers E-W across the Reservoir

Figure 1.10 - Correlation of Calcite Layers E-W across the Reservoir

Figure 2.1 - Correlation for CO_2 MMP as a Function of Temperature

Figure 2.2 - Closed Ternary Diagram Low Methane Wasson Crude Oil

Figure 2.3 - Banded Ternary Diagram Calculated for Livingston from MMP Simulations

Figure 3.1 - Vertical Structure of Livingston Reservoir

Figure 3.2 - Porosity (a) and Permeability (b) of Livingston Cores

Figure 3.3 - Wells with Digitized Logs in 2011

Figure 3.4 - V-shale calculated from Gamma Ray Data for Well Arledge 25

Figure 3.5 - Examples of Effective Porosity and V-Shale from Logs and Cores

Figure 3.6 - Thickness of Beach Rock Layer in Livingston Reservoir

Figure 3.7 - Thickness of Upper Shoreface in Livingston Reservoir

Figure 3.8 - Thickness of Sand with More Than 10 md Permeability

Figure 3.9 - Capillary Pressure Assigned for Different Quality Rock

Figure 3.10 - Porosity Distribution in the First Wilcox Sand

Figure 3.11 - Permeability Distribution in the First Wilcox Sand

Figure 3.12 - Permeability Distribution in Cross Section the Model

Figure 3.13 - Initial Oil Saturation Distribution in the First Wilcox Sand

Figure 4.1 - Characteristics of Krow and Krw Used in Waterflood Model

Figure 4.2 - Waterflood Injectors

Figure 4.3 - Reservoir Pressure with (a) and Without (b) Sealing Fault

Figure 4.4 - Reported and Predicted Oil and Water Production

Figure 4.5 - Reported and Predicted Cumulative Liquid Production

Figure 4.6 - Transmissibility Modifiers Used in 2005 to 2009 Waterflood

Figure 4.7 - Reported and Predicted Reservoir Pressure

Figure 5.1 - Location of Existing CO_2 Injectors

Figure 5.2 - Developed Miscible Displacement in Micro-visual Model

Figure 5.3 - Miscible Displacement in Micro-visual Model with Lower Liquid

Figure 5.4 - Effect of Miscible Residual (SORM) on Oil Production Rate

Figure 5.5 - Distribution of CO_2 Dissolved in Water at End of CO_2 Project

Figure 5.6 - Effect of CO_2 Dissolved in Water on Fluid Production and Injection

Figure 5.7 - Possible Location of Horizontal Injector

Figure 5.8 - Effect of Horizontal Injector on Production and Injection

Figure 5.9 - Effect of Miscible Residual on Production and Injection with 3 Injectors

Figure 5.10 - Effect of SORM on WOR and GOR

Figure 5.11 - Effect of SORM on Production and Retention

Figure 5.12 - Production and Injection with No WAG

Figure 5.13 - Gas Injection and Production with No WAG

Figure 5.14 - Injection and Production with WAG

Figure 5.15 - Gas Injection and Production with WAG

Figure 5.16 - Cum Oil Production and Net Gas Injected with WAG

Figure 5.17 - Oil Saturation at End of WAG Simulation

Figure 5.18 - Effect of WAG Ratio on Oil Production and Net CO_2 Storage

Figure 5.19 - Effect of CO_2 Rate on Oil Production and Net CO_2 Storage

Figure 6.1 - Effect of Reservoir Pressure and Number of Injectors on Oil Production

Figure 6.2 - Effect of Reservoir Pressure and Number of Injectors on Aquifer Influx

Figure 6.3 - Effect of Reservoir Pressure and Number of Injectors on CO_2 Storage

Figure 6.4 - Effect of Reservoir Pressure and Number of Injectors on CO_2 Utilization

Figure 6.5 - Effect of HC PV of Gas Injected and Number of Injectors on Oil Production

Figure 6.6 - Effect of HC PV of Gas Injected and Number of Injectors on CO_2 Storage

Figure 6.7 - Oil Production versus HCPV Injected for WAG and Continuous Injection

Figure 6.8 - CO2 Stored versus HCPV for WAG and Continuous Injection

Figure 6.9 - Oil Production versus Reservoir Pressure for WAG and Continuous CO_2

Figure 6.10 - Effect of HCPV on Reservoir Pressure for WAG and Continuous CO_2

List of Tables

Table 1 - Median Permeability and Dykstra Parsons Coefficient for First Wilcox Sands

Table 2 - Parameters and Composition for WINPROP EOS of Livingston Oil

Table 3 - Characteristics of Krow and Krw Used in Waterflood model

Table 4 – Effect of Miscible Residual (SORM) on Fluid Rates with Two Injectors

Table 5 – Effect of CO_2 Dissolved in Water on Fluid Production and Injection

Table 6 – Effect of Horizontal Injector on Fluid Production and Injection

Table 7 – Effect of Miscible Residual on Production and Injection with 3 Injectors

1.0 Introduction

The proposed South Louisiana Small-scale Sequestration Project site is located in Livingston Parish, Louisiana, approximately 26 miles due east of Baton Rouge, near the most heavily industrialized corridor of Louisiana. This Project proposes to evaluate an early Eocene-aged Wilcox oil reservoir for permanent storage of CO_2. The beach/barrier near-shore marine bar reservoir is confined within the Livingston Field operating unit by both stratigraphy and faulting, thereby allowing for careful monitoring, verification, and accounting opportunities during the small-scale pilot. These strandplain-type deposits are identified by the Department of Energy as high-potential geologic formations for sequestration, and this test will fill in an identified gap in this depositional play type. The First Wilcox Sand displays excellent vertical and horizontal continuity. Existing regional data indicates that the First Wilcox Sand can be traced for tens of miles along trend and is four to six miles in width, therefore, representing a significant sequestration opportunity. Additional Wilcox sands occur below the First Wilcox Sand (Second through Fifth Wilcox Sands), which provide supplementary sequestration targets into saline reservoirs.

The primary focus of this Project is to examine and prove the suitability of South Louisiana geologic formations for large-scale geologic sequestration of CO_2 in association with enhanced oil recovery applications. This will be accomplished through the focused demonstration of small-scale, permanent storage of CO_2 in the First Wilcox Sand. In-zone and remote time-lapse monitoring will be deployed in the Project wells to measure, track, and assess effectiveness of the overlying zones to contain the injected CO_2, assess the physical and geochemical fate of CO_2 in the reservoir, and refine the storage resource estimate. Innovative injection well design will test the efficacy of increased sequestration using short-radius horizontal reach well technology to emplace CO_2 more effectively in the reservoir. Data results from the Project Injection Well will be assessed in light of data collected from two vertical injection wells. In addition to the three converted Observation Wells, field production wells will be leveraged for additional data gathering, effectively increasing the number of observation points beyond what a single injection well/observation well pair can provide.

The Livingston oil field in Livingston Parish Louisiana has been selected for study in a DOE sponsored four year sequestration study that will take place concurrently with a CO_2 EOR project which will store approximately 20 BCF (1 million metric tons) of CO_2 in the first Wilcox sand at an approximate depth of 10,000 feet over its 30 year life.

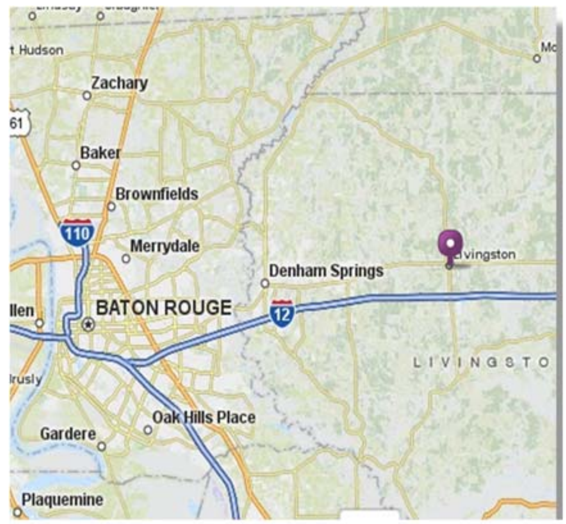
The purpose of this report is to describe the status of the geological, geocellular and dynamic models of the reservoir at the start of the DOE project. The Livingston reservoir has been modeled several times. The first was reported in a engineering study[1] in 1983 by the company operating the reservoir unit. The purpose of the first study was to optimize the water flood and scout a CO_2 EOR project. A second model was produced by the Petroleum Engineering Department at Louisiana State University in 2002 as part of preparation for a second waterflood. The modeling effort summarized in this report took place between 2009 and 2012 as part of Blackhorse Energy's preparations for a CO_2 flood planned in the Livingston reservoir.

1.1 Reservoir Description:

Livingston Parish and the town of Livingston are located 26 miles east of Baton Rouge, Louisiana. The location of the reservoir is shown in Figure 1.1.

The reservoir was discovered in 1983 and produces from approximately 40 feet of Wilcox sand that is 10,000 feet deep. The reservoir covers 2,200 acres and contains 28-30 million barrels of 39 API oil with a MMP with CO_2 of 2,400 psig. Approximately 8.2 million barrels has been produced by primary and waterflood since 1983. Blackhorse Energy believes that the CO_2 EOR project will produce approximately the same volume in the 30 year life of the CO_2 project.

Figure 1.1 Location of the Livingston Oil Reservoir



1.2 Depositional Environment:

As shown in Figure 1.2, the reservoir and its analog to the west, Lockhart Crossing were deposited as a as an Eocene barrier island sandbar or near shore marine bar. The structural trap is a fault on the northern side of the reservoir.

1.3 Reservoir Structure:

The earliest study that we are aware of was by David Johnston and Randy Johnson[4]. According to their report the field is bounded on the north by a down-to-the-basin fault (Fault A in Figure 1.3) that places the Wilcox against marine shale. To the east the sand is cut by a tidal channel consisting of alternating sandstone and shale.

Figure 1.2 – Depositional Model for Wilcox Sandstone Barrier Island[3]

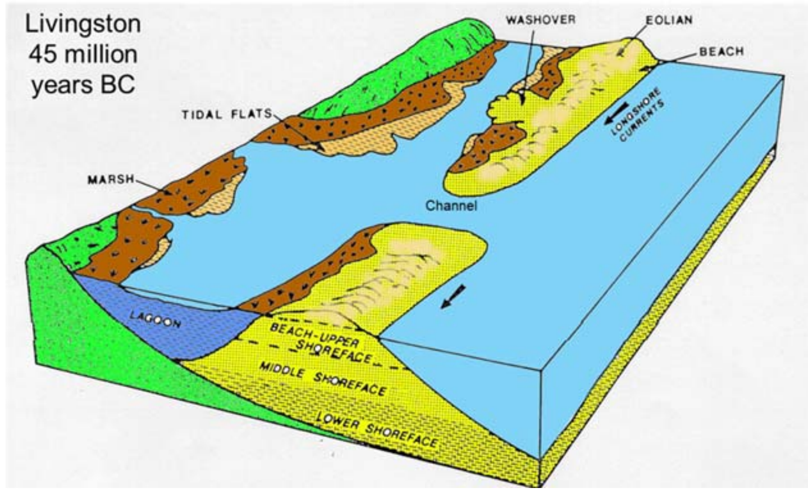
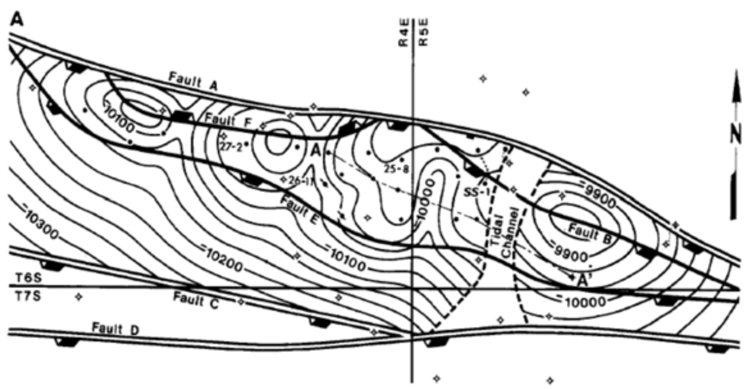
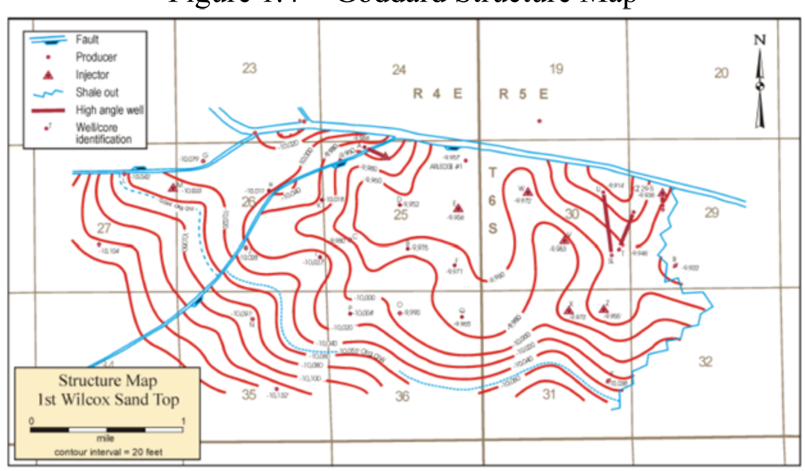


Figure 1.3 - Johnston and Johnson Structure Map



Within the Livingston field there are several post-depositional faults. Fault B has a throw of about 25 ft which is thought to not be sealing. Fault F has a throw of about 5 ft isolating a segment of the sand from the rest of the field. Fault E with a throw of about 25 ft approximates the southern boundary of the field. No production has been achieved south of this fault.

Figure 1.4 - Goddard Structure Map



The second study was by Donald Goddard, et al, at LSU.[5] (See Figure 1.4) Their structure map is similar to that of Johnston and Johnson. J&J's Fault A is shown to the north. Fault B is not shown. Fault F is as north-west boundary. Fault E is not shown but is presumably off the map to the south. Another fault is identified which cuts off the western third of the field. Their shale-out to the east matches the tidal channel. In their map, the sand dips gently to water levels to the west and south of the field found in both directions.

Figure 1.5 - TMR Structure Map

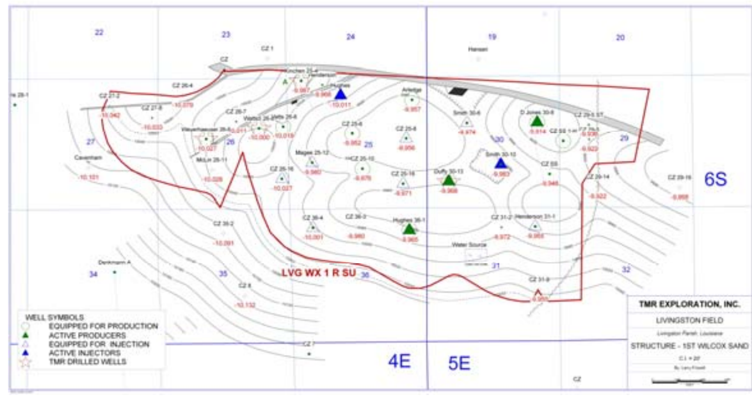
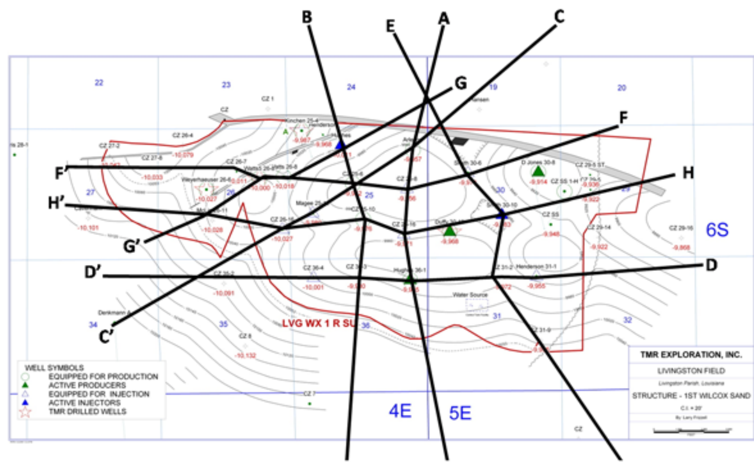


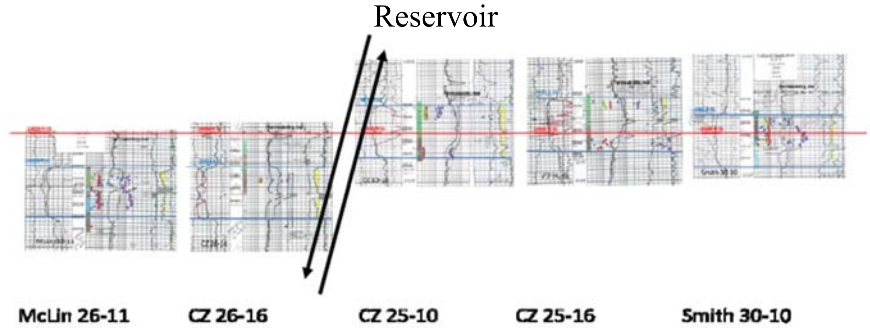
Figure 1.6 - TMR Structure Map with Cross-Sections



TMR created still another structure map (Figure 1.5), resembling the Goddard map including a splinter fault in the north-west which was thought to be sealing.

In our study, we carefully re-evaluated all logs to determine the tops of the Wilcox sand throughout the reservoir. In the process we created a number of cross-sections through the field. (See Figure 1.6.) The east-west cross-sections indicated a sharp change in elevation around the western third of the

Figure 1.7 – Correlation of Calcite Layers E-W across the Reservoir



field, which was posed as a new fault. Simulation studies, which will be described later, suggested the change in elevation is a non-sealing fold, rather than a fault. However this remains a key question to monitor during the CO_2 flood. Cross-section H-H’ is shown in Figure 1.7. In Figure 1.7 the red line is at -10,000 ft subsea. The blue lines show the tops and bottoms of the Wilcox sand. Both log and core data are shown.

The resulting structure map from our work is shown in Figure 1.8. This map does not include the potential fault identified in cross-section H-H’ in keeping with simulation results.

<u>1.4 Continuity</u>: The First Wilcox appears to be a well-consolidated shaly sand that contains 40-90% quartz with minor amounts of feldspar, calcite, ferro-dolomite, and pyrite. Clay content as high as 20% is also found and consists primarily of kaolinite, illite, and chlorite. Due to the high clay content, the rock has been shown to be sensitive to fresh water.

Figure 1.8 – Blackhorse Energy Structure Map

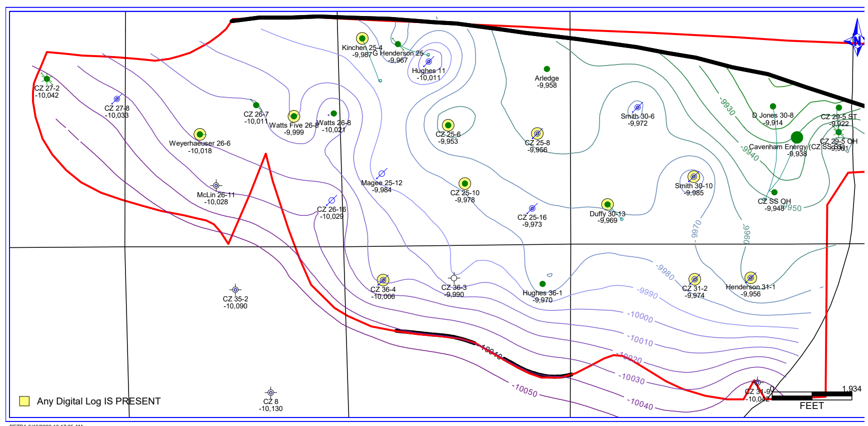
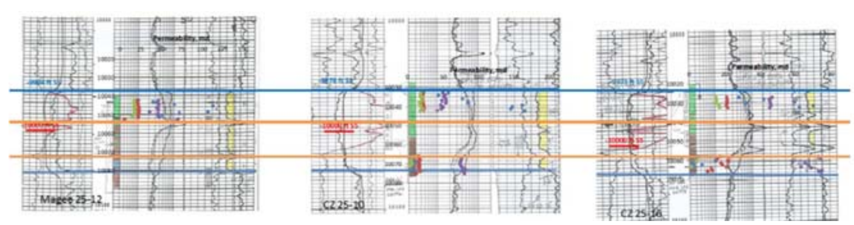


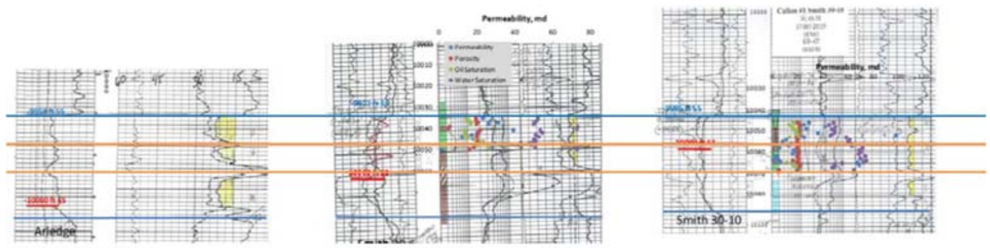
Figure 1.9 – Correlation of Calcite Layers E-W across the Reservoir



Although the sand is uniformly 40-50 feet thick without shale breaks; calcite intervals, or concretions, are found in several wells which are composed of carbonate cement in the pore space. These calcite intervals are from one to eighteen feet thick with low porosity and no permeability. The thickest occurrence is found in the CZ 36-3 well, which was plugged with only 3 feet of pay and 18 feet of calcite. The calcite intervals are weakly correlatable from well to well only in limited areas of the field, a conclusion reached by Gillham (1988) and confirmed by our analysis.

An example of the ability to correlate the concretions from well to well is shown in Figures 1.9 and 1.10. The blue lines show the top and bottom of the Wilcox interval. Orange lines identify calcite intervals in the left most well. Although the center and right most wells are nearby, correlation is difficult at best.

Figure 1.10 – Correlation of Calcite Layers E-W across the Reservoir



A key question is are the concretions randomly distributed through the reservoir or are they more or less horizontal and barriers to vertical flow? Goddard (2002) felt they served as "permeability and porosity restriction to vertical flow within several areas of the reservoir." Simulation results, which will be described later, suggest they are primarily barriers to vertical flow. However this remains a key question to monitor during the CO_2 flood.

1.5 Oil-water Contact.

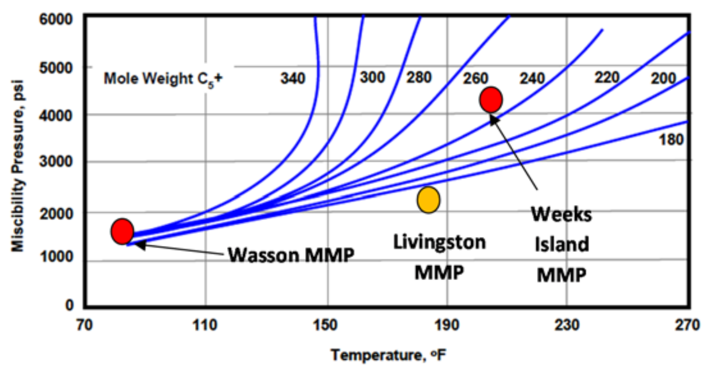
Amoco placed the oil-water contact at around -10,053 feet subsea (Gillham, 1988[1]). In this study, we concluded that the oil-water contact was closer to -10,040 ft subsea based on very limited log data.

2.0 CO_2 EOR

2.1 Mechanisms:

Enhanced Oil Recovery is primarily a method to improve the mobility of oil and push it from a reservoir by raising the pressure gradient between the injector and producer. CO_2 is useful for EOR because it is the most soluble of the inexpensive gases. This means that 60 to 70 mole percent can dissolve in the oil at reasonable pressures. This increases the oil volume substantially and reduces its viscosity. The combination of increased volume and reduced viscosity makes it easier to push the oil from the reservoir. The fluid that replaces the oil is generally a mixture of CO_2 and water.

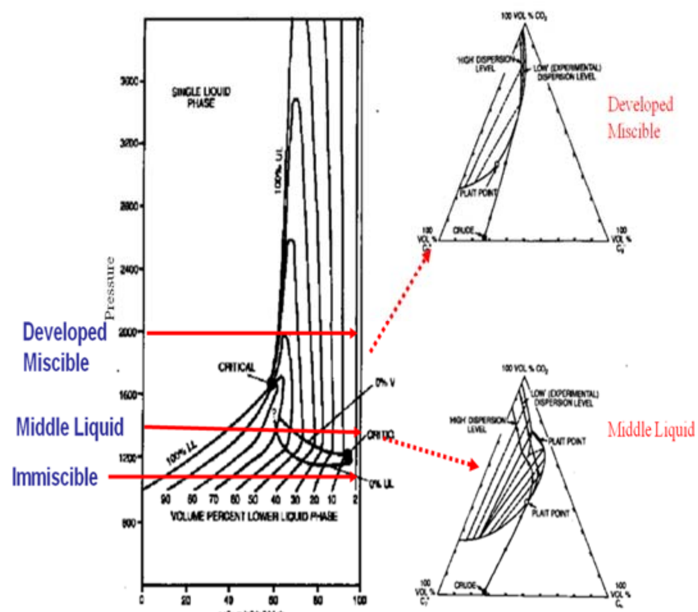
Figure 2.1 – Correlation for CO_2 MMP as a Function of Temperature



CO_2 can also vaporize more volatile components of the oil. These are extracted from the oil and carried forward by gas until they condense again. Eventually the oil has enough condensed components that CO_2 becomes at least temporarily miscible with lighter oils.

Often, this is interpreted with a Minimum Miscibility Pressure (MMP) test. The test is to displace an oil from a long tube packed with sand. The tube is saturated with oil, which is displaced at several pressures. The pressure at which 90 percent of the oil is displaced with 1.2 PV of gas is called the MMP. The next section demonstrates that passing a MMP test does not mean that the oil and CO_2 are miscible (soluble in all proportions). It only means that oil recovery is high in a zone swept by CO_2.

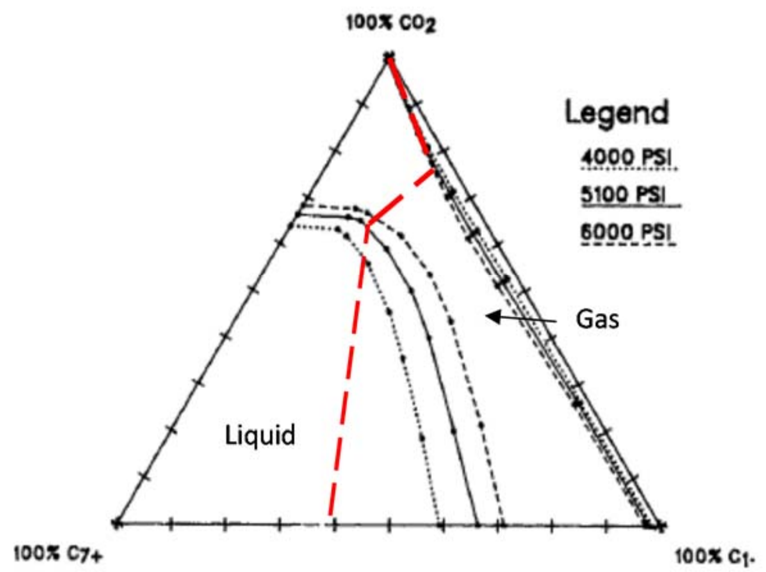
Figure 2.2 - Closed Ternary Diagram Low Methane Wasson Crude Oil



2.2 What does MMP mean?

As just described, CO_2 can develop miscibility with lighter oils. The results of MMP tests have been extensively studied and correlated. One of the more popular correlations is shown in Figure 2.1.[6] The figure is a plot of the MMP for oils with several molecular weight versus temperature. The figure tells us that lighter oils have lower MMP's and the MMP increases with temperature. The effect of temperature is primarily that CO_2 becomes less dense and a poorer solvent for oil at higher temperature. For example the density of CO_2 is about the same at 1,500 psi and 105°F at Wasson as for Weeks Island at 5,000 psi and 225°F, ~ 0.65 g/cc. However, the density of CO_2 at Livingston (210°F) is 0.4 g/cc

Figure 2.3 - Banded Ternary Diagram Calculated for Livingston from MMP Simulations



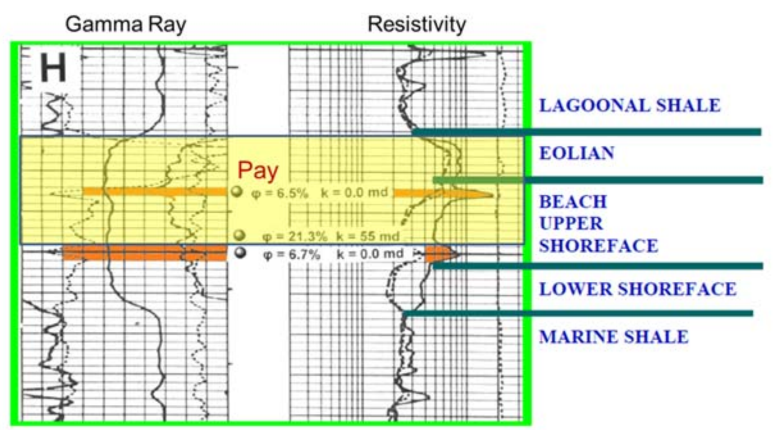
Figures 2.2 and 2.3 illustrate another important point about miscibility. Wasson PVT is described in Figure 2.2.[9] The MMP at Wasson is approximately 1,200 psi (blue line). The composition path at that pressure passes into the two phase region at 20 mole percent CO_2 and is technically immiscible but passes the MMP test because a low IFT middle liquid forms. At reservoir pressure (2.500 psi – upper red line) miscibility has developed. This means that enough volatile components of the oil have vaporized that the gas becomes miscible with the oil. The ternary diagram for the process at 2,500 psi is in the upper right hand corner of Figure 2.2. It shows that the mixture remains in the single phase region until the CO_2 concentration reaches 70 %. Then a lower liquid begins to condense. The transition from miscible to immiscible phase behavior will be discussed in section 5.1.1 (Miscible residual).

The phase behavior at Weeks Island and Livingston is shown in Figure 2.3. This type of ternary is found in reservoirs with a significant amount of methane. The composition path (red line) starts at the reservoir oil composition (bottom of the ternary) and remains in the single phase region up to 65 mole percent CO_2 (at the bottom hole injection pressure of 5000 psig), then the path crosses the two phase region to the gas side of the ternary and continues to extract hydrocarbons from the oil. This means that neither process just described is truly miscible, and that the MMP just means that oil recovery is high in a zone that is swept by CO_2.

3.0 Model Development

The general description of the reservoir developed by Goddard and Johnson is shown in Figure 3.1. As shown previously in section 1.3 (Figure 1.2) Livingston was a beach in the Eocene 45 million years ago. Thus Figure 3.1 shows that there were windblown (eolian) sand dunes, a water washed beach (the upper shoreface), a lower shoreface in shallow water deposited on mud which became a marine shale. There were also several intermittent layers of beach rock (described later) on the original beach. Eventually the beach was covered with a shore side (lagoonal shale) as the coast progressed to the south and is now buried beneath 10,000 feet of sediments. The digenesis that converted a relatively high porosity and permeability beach into a lower permeability and porosity oil reservoir is described in section 3.2.

Figure 3.1 - Vertical Structure of Livingston Reservoir



3.1 Core Data: Figure 3.2 summarizes porosity and permeability measurements from whole cores taken from Livingston wells. The first figure (a) shows that the permeability is high in the upper 20 feet of the reservoir. The zone below that is has very low permeability. It is a mixture of sand and calcite called beach rock. Its thickness can be as much as 18 feet but the average thickness is close to one feet. The lower shore face is the deepest zone. Since its permeability is low and the zone is deeper, the lower shoreface contains much less oil, is not considered pay and has not ever been perforated.

Figure 3.2 – Porosity (a) and Permeability (b) of Livingston Cores

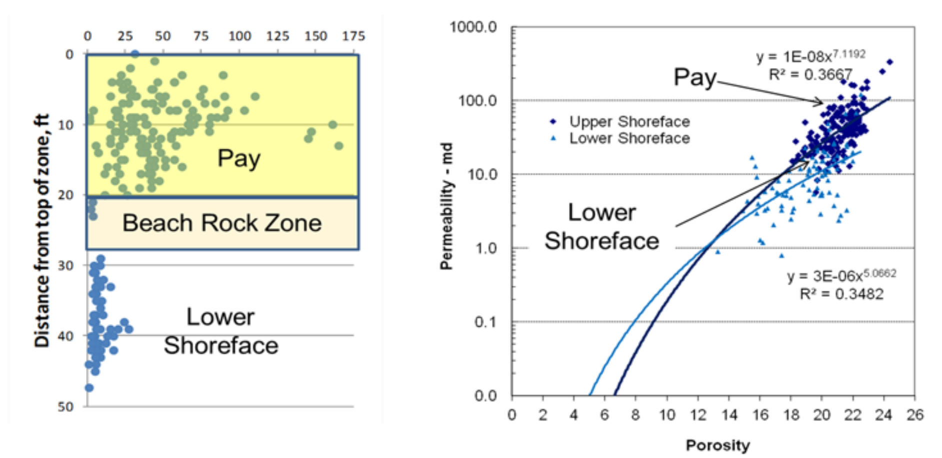


Table 1 summarizes the median permeability and Dykstra Parsons coefficient for the whole core permeability measurements. The table shows that the permeability of the upper shoreface is over five times the permeability of the lower shoreface. In addition the Dykstra Parsons coefficient of the upper zone is 0.487. This is very good. The coefficient for the lower shoreface is also relatively low, but the coefficient for the whole reservoir is high since the Dykstra Parsons coefficient is a measurement of permeability contrast.

Table 1 – Median Permeability and Dykstra Parsons Coefficient for First Wilcox Sands

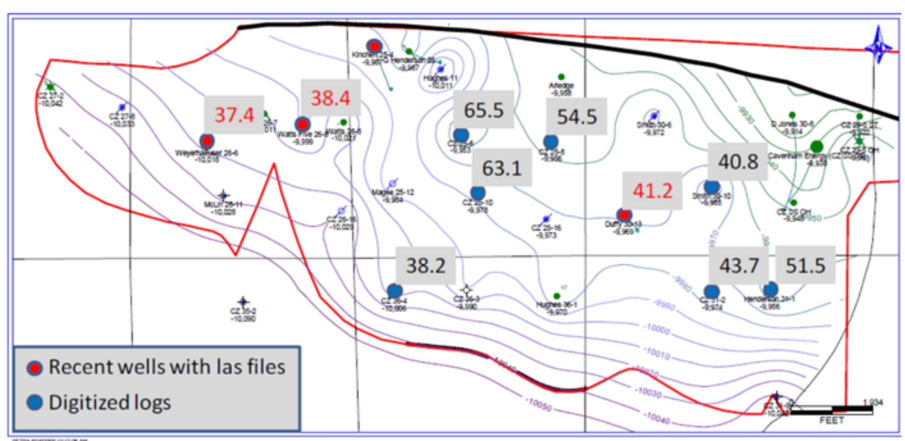
	Median Permeability md	Dykstra-Parson Coefficient
All Sand	25.5	0.776
Upper Shoreface	39	0.487
Lower Shoreface	8.4	0.607

<u>3.2 – Log Analysis</u>:

Figure 3.3 shows the wells whose logs had been digitized in 2011.

Twenty wells of the 36 wells in the field had digitized logs in 2011. The rest of the wells had paper logs. Twenty one wells had been cored. The following procedure was analyze the logs and develop effective porosity to be used in the static model of the reservoir

Figure 3.3 – Wells with Digitized Logs in 2011



First, Vshale was calculated from the measured gamma ray curve using the expression

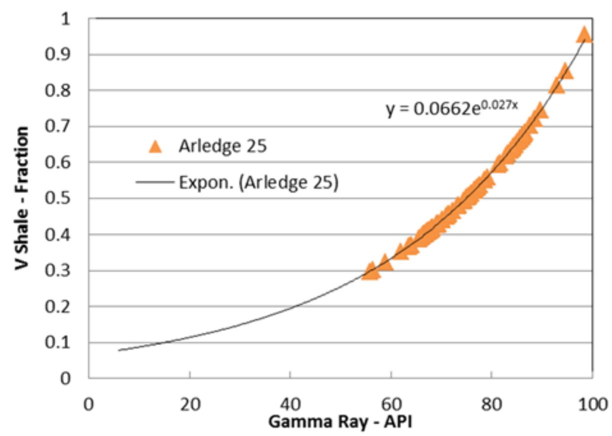
$$IF[\ GR<100,\ VSH = 0.0662 \cdot \exp(0.027 \cdot GR),\ VSH = 1]$$ [8]

This V Shale calculated from this equation for the well Arledge 25 is shown in Figure 3.4. It should be noted that the minimum V shale that was calculated for this well is 0.3. This means that a significant fraction of the porosity is filled with clays. Fair[7] noted that he saw no clean sand and Johnson[4] states that:

"The presence and quality of the reservoir are the direct result of diagenetic events that were strongly influenced by depositional facies. Early primary porosity was reduced by clay and quartz overgrowths and by carbonate cements.

Dissolution of the carbonate cement and leaching of feldspars and other unstable grains restored porosity to 65-75% of original values. The highest degree of secondary porosity was created in the facies of highest primary porosity - the eolian, beach, and upper shoreface - while the initially less porous middle and lower shoreface developed little or no secondary porosity."

Figure 3.4 – V-shale calculated from Gamma Ray Data for Well Arledge 25

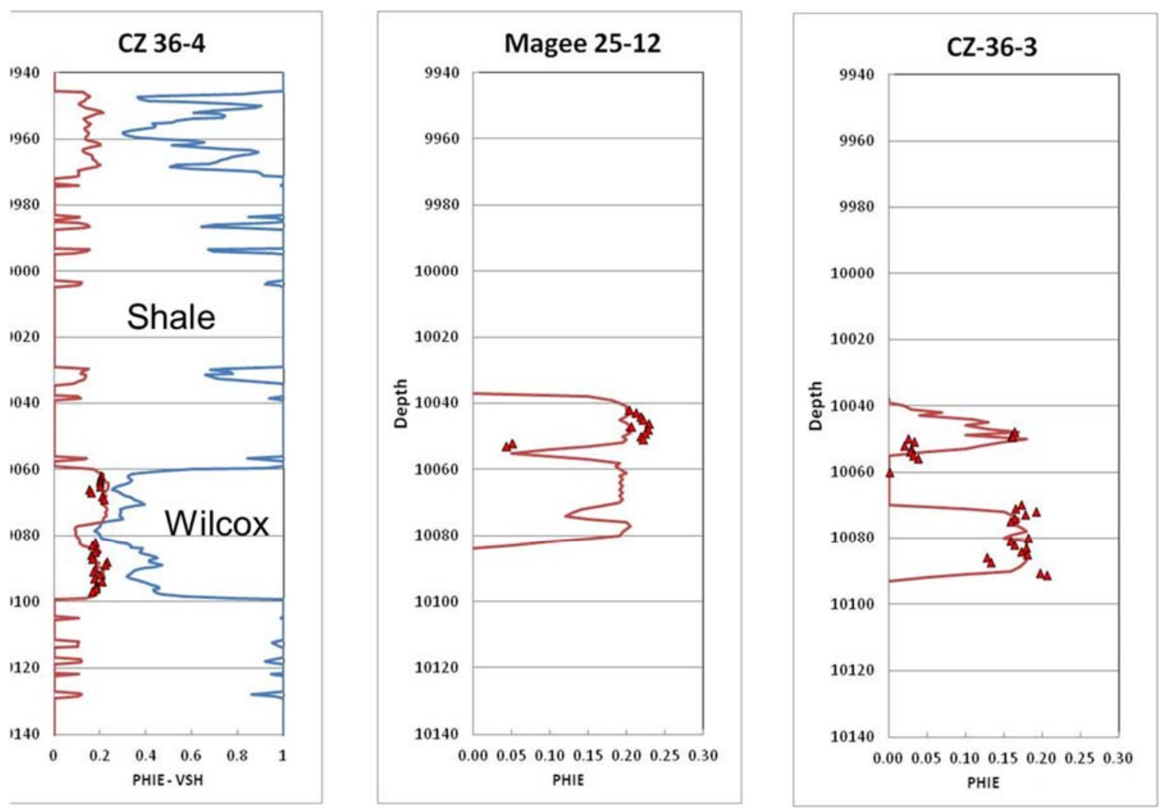


The effective porosity was then calculated from the density porosity curve using the equation[7]

$$IF[VSH<1,\ PHIE = 0.01 \cdot DPHI*(1-0.65 \cdot VSH),\ PHIE = 0]$$ [8]

This yields the effective porosity (PHIE) presented as the curve next to the left hand axis in Figure 3.5 for well CZ 36-4. Since that plot was generated from log curves. The sandy layers in the shale above the Wilcox sand can be displayed. The figure

Figure 3.5 – Examples of Effective Porosity and V-Shale from Logs and Cores



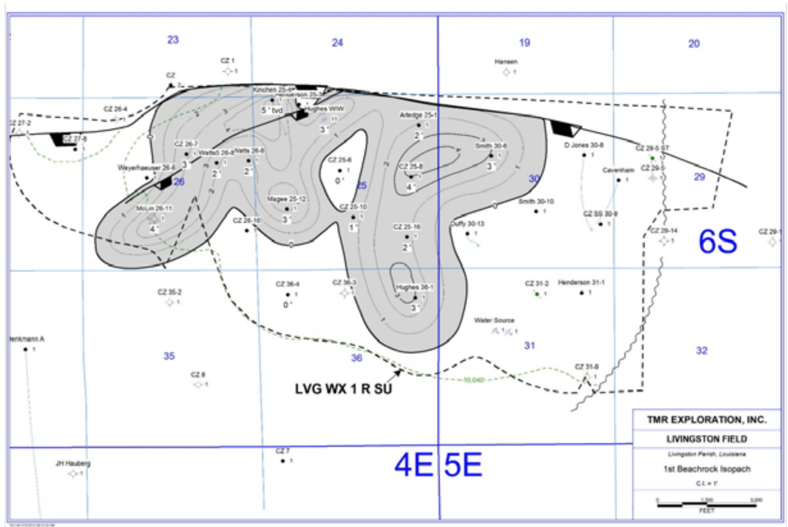
shows that the shale above the Wilcox is at least 70 feet thick. The porosity in the Magee 24-12 and CZ 36-3 plots are the DPHI data points manually digitized from paper curves. The data points in each curve are the porosity measured from cores.

The final point that can be made from Figure 3.5 is that most wells have a low porosity layer between the upper and lower shore face. This has been characterized by Goddard[4] as a carbonate beach rock layer which is present in the central area of the field.

3.3 Facies Mapping:

The upper shore face, beach rock and lower shore face have been mapped by Frizell.[8] Maps showing the beach rock isopach, upper-shoreface isopach and the thickness of sands with more than 10 md permeability are shown in Figures 2.6 to 2.8. The figures show that:

Figure 3.6 – Thickness of Beach Rock Layer in Livingston Reservoir



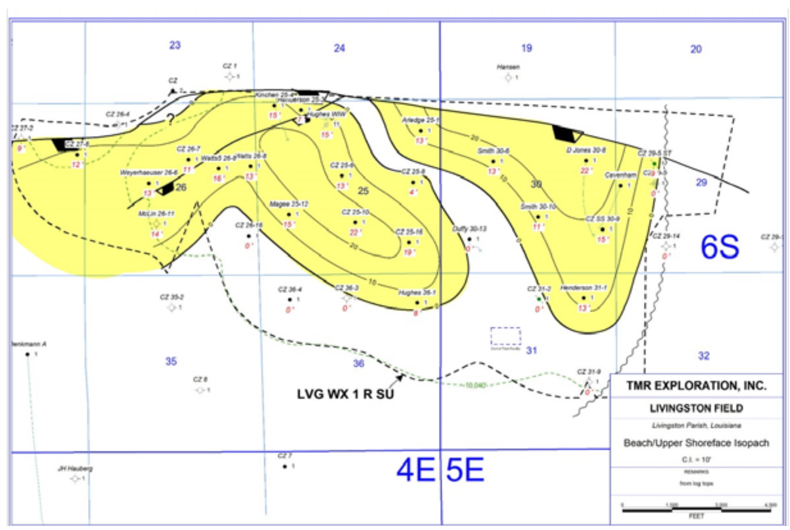
- The average thickness of beach rock is approximately 2 feet and that it is mostly in sections 25, 26 and 30 (Figure 3.6)
- The upper shoreface (Figure 3.7) is an average of 15 feet thick. Thus, most of the productive sand is in the upper shoreface.
- The most permeable sands are at the northern side of the reservoir.

The details in these three figures are important in the next step of model development.

2.4 – Creating a Static Model:

The geostatistical (Static) model was created using Builder (CMG's software for making input decks). The steps are:

Figure 3.7 – Thickness of Upper Shoreface in Livingston Reservoir



1) Create contour maps of the top of the shale, top of the First Wilcox Sand and bottom of the lower shoreface from TVD calculated from the logs.

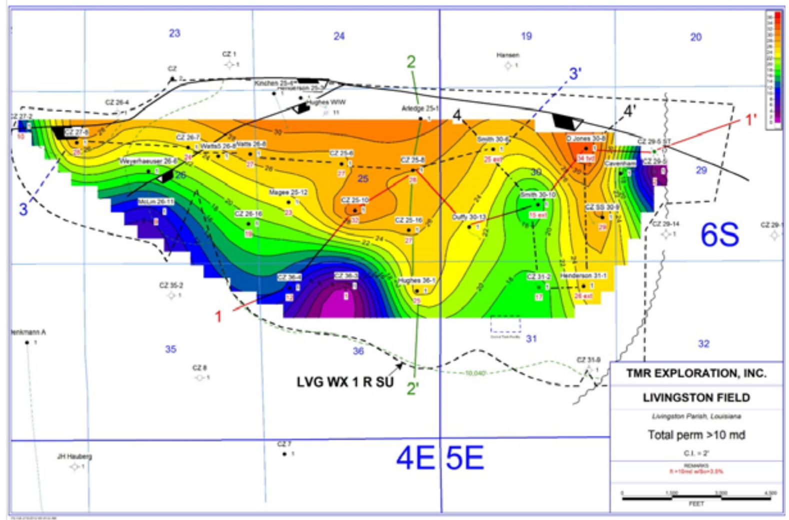
2) Use these contours to shape a grid

containing 20 layers with 92x39 (3588) 264 foot square cells in each layer. The grid contained approximately 90 feet of shale above the reservoir and 45-50 feet of First Wilcox sand.

3) Divide all logs into twenty lumped layers – five represent the upper shale while fifteen represent the upper and lower Wilcox sand.

4) Use the logs to build a static model of porosity for each layer using Gaussian Simulation. The allowed range of prediction was the upper and lower porosity of each lumped layers.

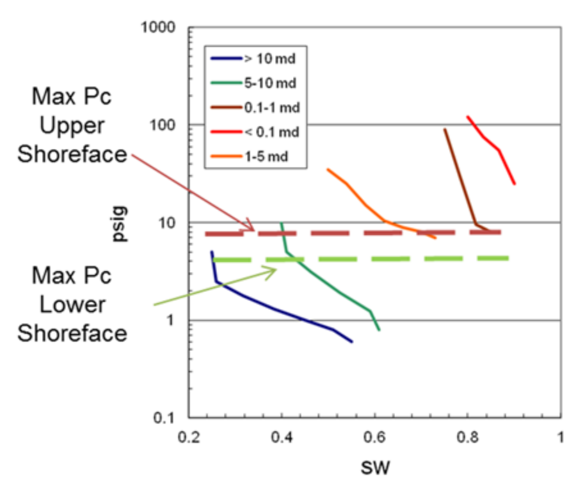
Figure 3.8 – Thickness of Sand with More Than 10 md Permeability



5) Calculate permeability for each cell using the power law equations in Figure 3.2b. These are power law correlations rather than the usual semi-log correlations so that the permeability would be lower at low porosity. Separate correlations were used for the upper shore face (layers 6 to 13) and lower shore face (layer 14 to 20). The lower shoreface correlation was used for the shale.

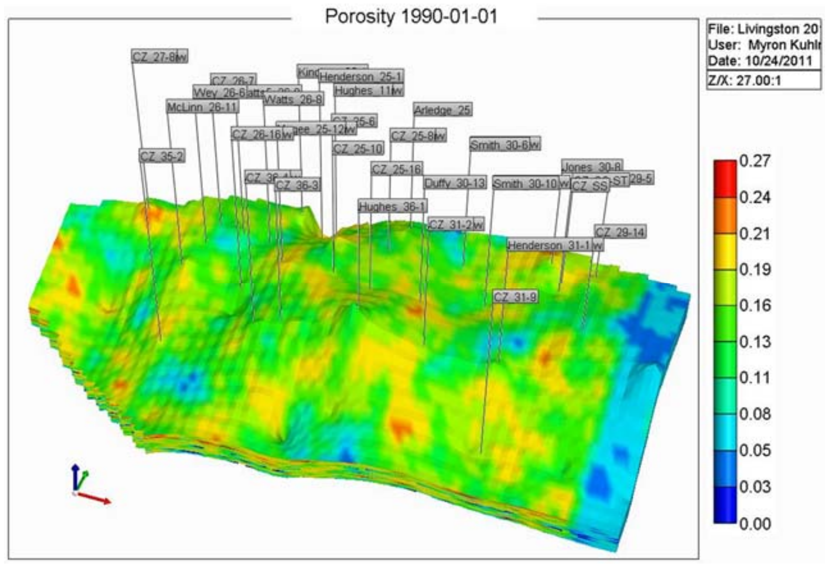
6) Saturate the model with capillary gravity equilibrium using the capillary pressure shown in Figure 3.9. These capillary pressures were assigned according to the permeability calculated for the cell. The entry pressures limit the oil saturation in the low permeability rock while the oil saturation in the upper and lower shoreface are limited by the capillary pressure at a saturation on the lower two curves in Figure 3.9.

Figure 3.9 – Capillary Pressure Assigned for Different Quality Rock



The median permeabilities listed in Table 1 for the upper and lower shoreface sands, respectfully, are 39 and 8.4 md. So, the better rock in the upper and lower shorefaces are represented by the lower two curves in Figure 3.9. These are called rock types 1 and 2. The maximum calculated capillary pressures in the upper and lower shorefaces are also shown in Figure 3.9. The maximum capillary pressures are low, because the oil column is small with a WOC of 1040 feet, yet the logs suggest that the initial oil saturation can be as high as 75 % in upper shoreface sand. The maximum saturation in the lower shoreface is close to 55 %.

Figure 3.10 – Porosity Distribution in the First Wilcox Sand



The results of this procedure are shown in Figures 3.10 to 3.12.

Figure 3.11 – Permeability Distribution in the First Wilcox Sand

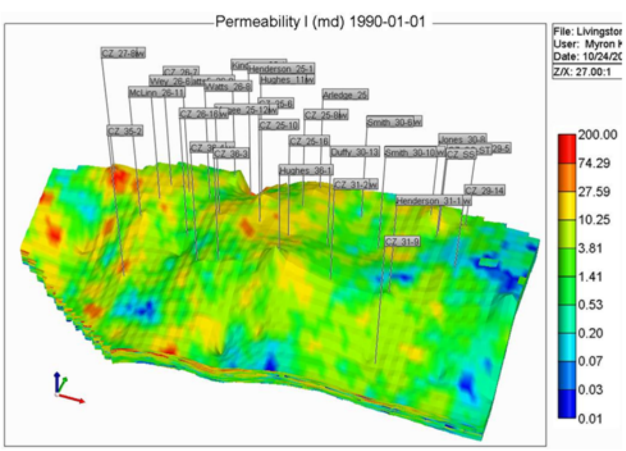
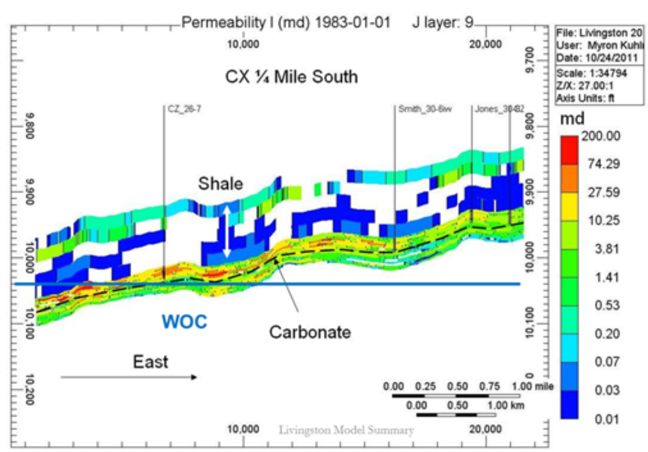


Figure 3.12 – Permeability Distribution in Cross Section of the Model



4.0 Modeling Primary and Waterflood

4.1 PVT:

The reservoir fluid is a black oil with an average API gravity of 39. There is no gas cap. The oil properties vary across the field. From east to west the fluid becomes lighter and contains more natural gas. The average solution GOR is around 400 scf/bbl, while the average producing GOR is 490 scf/bbl. The oil formation volume factor is 1.23.

While Blackhorse Energy has not located Amoco's PVT data for CO_2, they[1] report that the MMP was 2,400 psig with CO_2. The MMP with N_2 and mixture of 85 % N_2 and 15 % CO_2 (flue gas) exceed 4,500 psig. They also report that the MMP of a mixture of 60 % separator gas and CO_2 was miscible at 4,000 psi.

Since the PVT data for CO_2 with the oil was missing, the composition of an existing caliibrated equation of state model for a similar high API gravity oil was modified using the pseudo components C6-C8, C9-C12, C13-C16 and C17+ that were developed from a True Boiling Point GLC for Livingston stock tank oil. The parameters and composition are listed of the model are listed in Table 2. This model was used in WINPROP with a Peng Robinson Equation of State (EOS) to match the known bubble point, density, formation volume factor and differential liberation data for the reservoir oil and predtict the likely constant composition expenaion data for the oil mixed with 50 and 70 mole percent CO_2.

Figure 3.13 – Initial Oil Saturation Distribution in the First Wilcox Sand

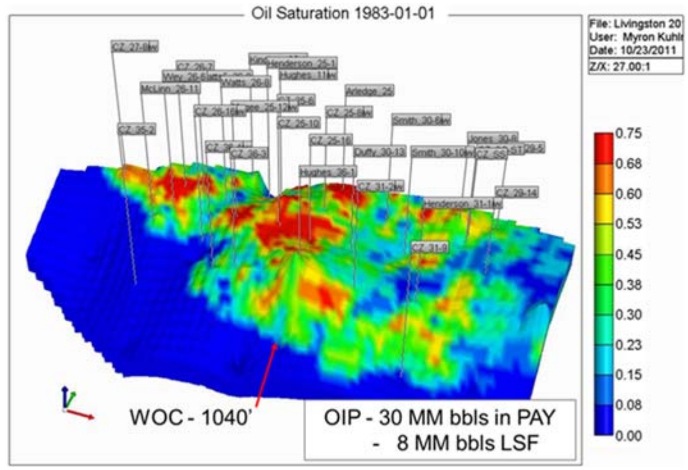


Table 2 – Parameters and Composition for WINPROP EOS of Livingston Oil

	'CO2'	'C1'	'C2'	'C3-C5'	'C6-C8'	'C9-C12'	'C13-C16'	'C17+'
S. G.	0.8180	0.3000	0.3560	0.5679	0.7293	0.8656	0.8977	0.9245
True BPT	-109.2	-258.6	-127.6	21.8	234.9	382.0	502.2	683.3
PCRIT	72.8	45.4	48.2	37.1	27.5	27.9	25.2	14.3
VCRIT	0.094	0.099	0.148	0.251	0.438	0.505	0.641	0.920
TCRIT	304.2	190.6	305.4	415.6	565.1	676.6	785.9	790.6
MW	44.0	16.0	30.1	58.3	104.9	155.4	205.1	312.1
X	0.0004	0.4019	0.0174	0.0070	0.0207	0.1265	0.2447	0.1814

Then, the model was used in GEM to match MMP (minimum miscibility pressure) experiments with CO_2. Now a oil and gas are considered miscible when recovery exceeds 90% at 1.2 PV.

4.2 Relative Permeability:

Table 3 and Figure 4.1 summarize the oil and water relative permeabilities used to model primary production and the waterfloods of the reservoir. These relative permeabilities are pseudo perms based loosely on core data and on Holtz's study of Sorw for Gulf Coast reservoirs. The term "pseudo perm" means that the relative permeabilities are transfer functions which describe performance of the reservoir. They are commonly developed by history matching oil, water and sometimes gas production from a model. Thus, the shape of the curves probably don't resemble relative permeabilities measured in the laboratories.

S_{WR} (irreducible water) in Table 3 is based on oil saturations measured from logs while S_{ORW}, which represents bypassing as well as the actual residual oil saturation, will be higher than that measured in the laboratory. Five types of relative permeability are listed in Table 1. They were assigned to each cell in the model according to the permeability in that cell.

Table 3: Characteristics of Krow and Krw Used in Waterflood Model

Rock Type	Permeability - md	S_{WR} - %	S_{ORW} - %
1	Greater than 10 md	25	40
2	5-10 md	40	37
3	1-5 md	50	23
4	0.1 0 1 md	75	14
5	Shale < 0.1 md	85	6.5

4.3 Primary - 1983 to 1987 and Waterflood - 1987 to 1994, 2005 to 2009

Continuous oil production began at Livingston in 1983. Since the reservoir had a low GOR and little water influx, production peaked and declined rapidly. The reservoir was unitized for a waterflood which started in 1987 and ended when AMOCO sold the field in 1994. TMR started the waterflood again in 2005 and continued until just before the field was sold to Blackhorse Energy in 2010.

Figure 4.1 - Characteristics of Krow and Krw Used in Waterflood Model

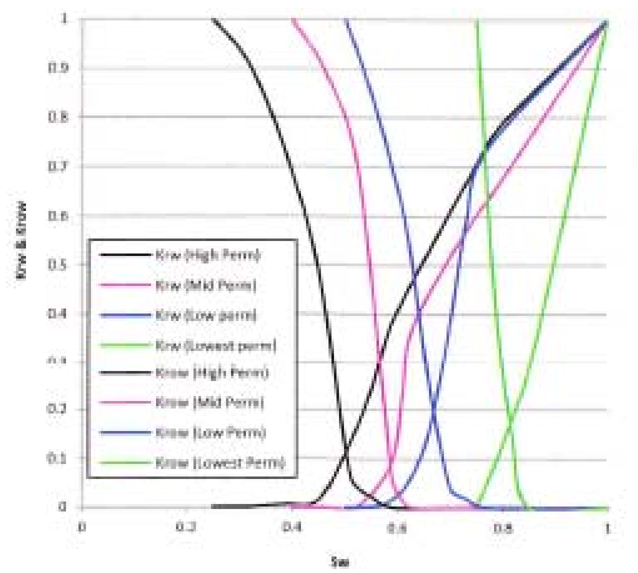


Figure 4.2 shows the location of the waterflood injectors during the first waterflood. They could roughly be described as two line drives with a central and flank injector. Blackhorse Energy modeled Livingston for the first time in 2009. One central result of that model was to answer the question; "Are any of the faults identified by in the geological models of the reservoir sealing?"

Figure 4.2 – Waterflood Injectors

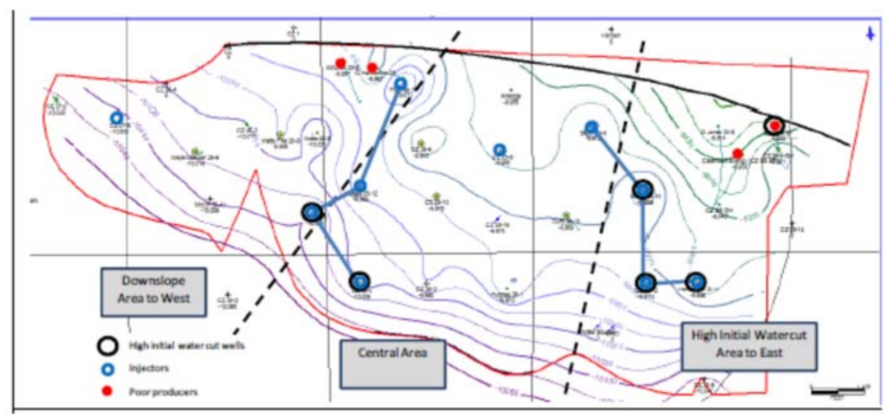


Figure 4.3 – Reservoir Pressure with (a) and Without (b) Sealing Fault

a b

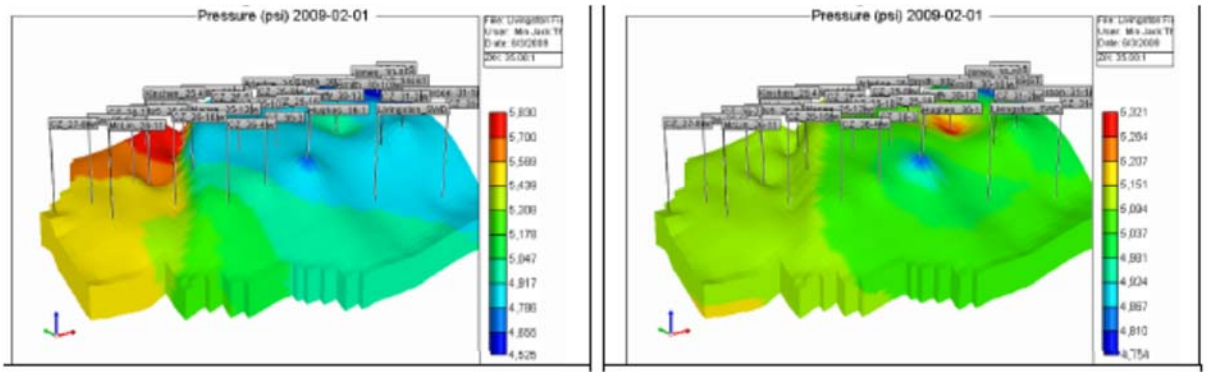


Figure 4.3 shows that the fault in the south west portion of the reservoir (Figure 1.4 and 1.5) is not a sealing fault. That fault is between the western injector in Figure 4.2 and the next north-south line of injectors. If the fault had stopped flow, the pressure on the western side the fault would have been much higher than reported (4.3a). The pressure was not high, so the fault is not sealing but still could be a barrier to flow.

Figures 4.4 and 4.5 show the matches to oil and water production that were reported and predicted by the models. These curves have the characteristic that production during primary is matched very well. Some differences between reported and predicted performance begin after the waterflood starts in 1987. However, the history match during the first waterflood which ended in 1994 is reasonable. Then the reservoir had a period that ended in 2005 with no waterflood.

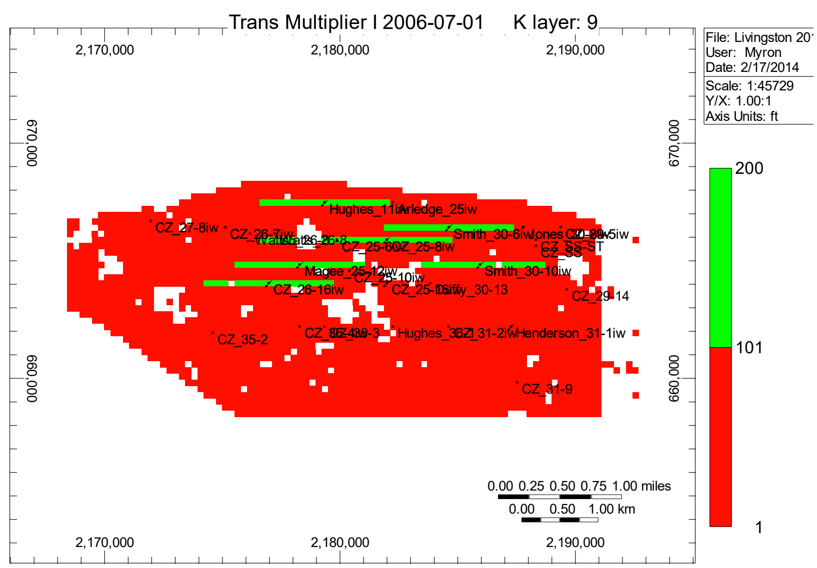
Figure 4.4 – Reported and Predicted Oil and Water Production	Figure 4.5 – Reported and Predicted Cumulative Liquid Production

TMR became the operator of the field in 2002 and commisioned the Goddard and LSU studies referenced above. Several new producers were drilled and a waterflood began in 2005. Figure 4.4 shows that the performance of the waterflood was very poor. Ninety five percent of the effort in modeling Livingston was exerted to match the low oil production in this period. The techniques used to match production after 2002 include;

- Adjusting relative permeabilities,
- Reducing oil saturation,
- Raising SORW and
- Modeling injector to producer fracture growth in both phases of the waterflood but especially in the 2005 to 2009 period.

<u>4.4 - Potential Fracture Growth in Waterflood</u>: Figure 4.6 shows the injection fractures that appeared to have grown after 2005 at Livingston. East -West Transmissibility between water injectors and producers was raised 200x to match post 2005 results.

Figure 4.6 – Transmissibility Modifiers Used in 2005 to 2009 Waterflood



This happened because all producers and injectors at Livingston had been intentionally hydraulically fractured by AMOCO in order the increase production and injection rates. The effective length of the fracture was measured at 50 feet in pressure fall off tests. The fractures were also preferentially orientated in an east west direction since the sealing fault at the up-dip side of the reservoir is an east west fault and the principal stress in the reservoir would be parallel to the fault. Hydraulic fractures are likely to grow when the pressure at the tip of the fracture exceeds 0.6 psi/foot of depth, i.e., approximately 6,000 psi.

Fracture extension appears to have begun during the AMOCO waterflood when well-head pressures exceeded 2,500 psig. This practice continued between 2005 and 2009. Pattern water injection ceased in late 2009 and BHE will reinject its produced water downdip.

<u>4.5 Reservoir Pressure</u>

There is very little reservoir pressure data for Livingston. The available data taken after 2000 is shown in Figure 4.7. A top and bottom aquifer was used in 2011 since the reservoir appears to be surrounded by faults (see figure 1.3) and there is clearly very little water influx to support the reservoir pressure. The pressure in a model with edge aquifers was ~ 1,000 psig greater than in models where water influx could come from shales.

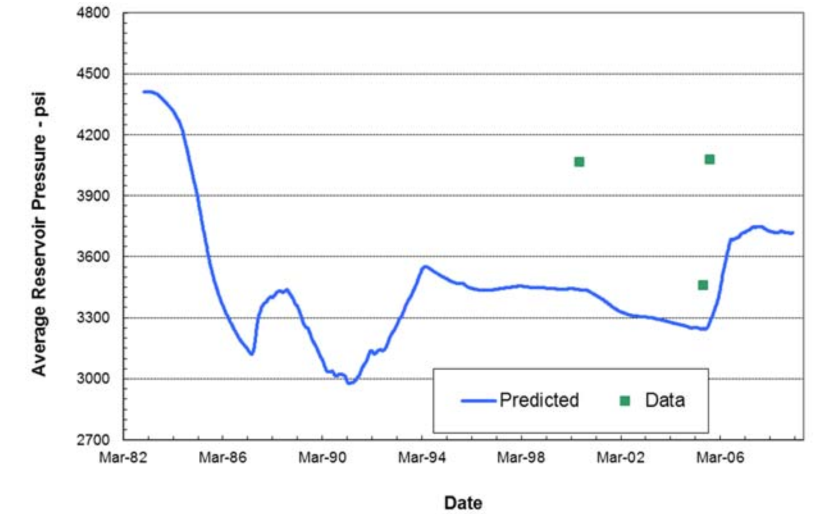


Figure 4.7 – Reported and Predicted Reservoir Pressure

5.0 CO_2 EOR Project

5.1 CO_2 injection and Recycle with Two Injectors:

The initial models of Livingston had two CO_2 injectors shown in Figure 5.1. The main reason for this was that there were no suitable up-dip injector locations near the northern fault (other than the most northeastern well CZ-29-5 which is a good producer in a CO_2 flood. So, models created in 2009 and 2010 had two injectors. These were Hughes 11 and Arledge 25. While CO_2 produced a significant amount of oil with just two injectors, oil production was limited by the delay of 15 years for CO_2 to rise from Arledge 25 to CZ-29-5. Much of the information summarized in

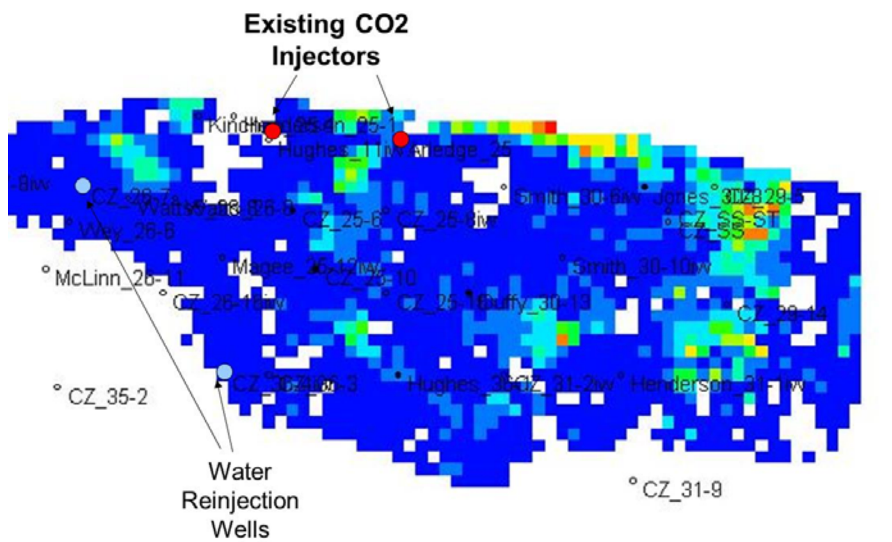


Figure 5.1 – Location of Existing CO_2 Injectors

this report are for two injectors because some of the most important EOR mechanisms are illustrated with two injectors.

5.1.1 Effect of Miscible Residual (SORM):

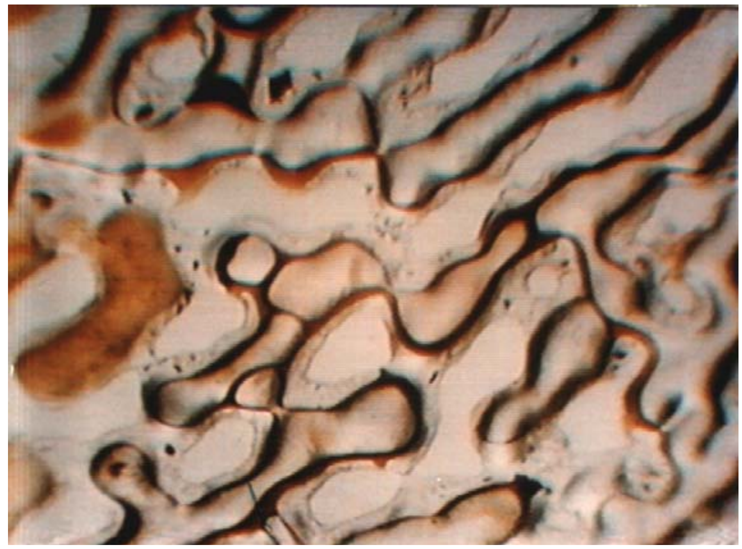
Figure 5.2 – Developed Miscible Displacement in Micro-visual Cell

The most important limitation of miscible flooding is the miscible residual. As noted in Chapter 2, one cause of the miscible residual is phase behavior, i.e., the injected gas is only miscible with the oil when the CO_2 concentration is modest and the oil contains a significant concentration of volatile hydrocarbons. The other factor contributing to the miscible residual is fingering and bypassing due to reservoir heterogeneity.

Figures 5.2 and 5.3 illustrate how a miscible residual (SORM) forms. The images were produced in a micro-visual apparatus at Shell Development Company, Houston, TX in 1984 by displacing waterflooded, live Wasson oil from an etched glass visual cell at 2,500 psig and 105°F, i.e., the upper line in Figure 5.2. Figure 5.2 shows bypassing in the miscible portion of the experiment. The highest concentration of CO_2 is fingering across the model in the light colored channel. The darker channels to the right and left are oil bypassed due to fingering and heterogeneity.

The fluid in the channel has less color because it is oil that is enriched and diluted by a mixture of CO_2 and extracted volatile hydrocarbons like natural gas liquids and colorless C_6-C_{15} saturates and aromatic hydrocarbons. The high molecular weight, non-volatile chromophores remain in the bypassed pores.

Figure 5.3 – Miscible Displacement in Micro-visual Cell with Lower Liquid



Eventually the volatile hydrocarbons are extracted from the zone and a viscous lower liquid precipitates. This means that the composition has entered the two phase region in the ternary diagram in the upper right corner of Figure 5.2.

The bypassed oil is primarily bitumen-like, heavy oil which would be a solid if it did not contain 25 to 30 mole percent CO_2. This oil is immobile under any practical circumstances, so it is called the miscible residual and represented by a parameter called SORM in a simulator.

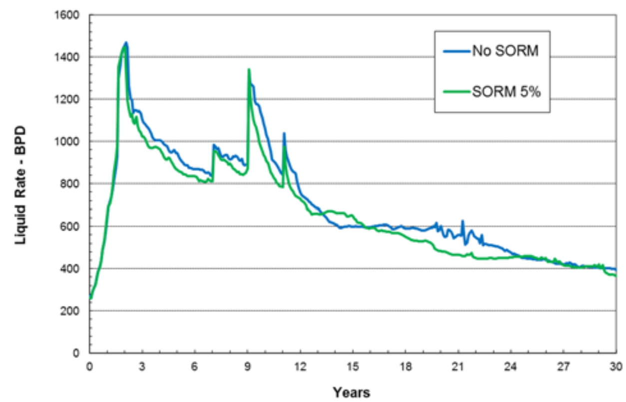
Table 4 and Figure 5.4 summarize the effect of SORM on production and injection in a model with two injectors. The table shows that increasing SORM from zero to five percent decreases oil production by about the same amount. Gas production decreases slightly, so, net utilization of CO_2 increases slightly.

Table 4 – Effect of Miscible Residual (SORM) on Fluid Production with Two Injectors

	Oil	Water	Inj'd W	Gas Prd	Gas Inj	WOR	GOR	Net GOR
SORM 0%	7.63	15.25	16.42	44.02	64.49	2.00	5.77	2.68
SORM 2%	7.46	15.10	16.42	44.12	64.49	2.02	5.91	2.73
SORM 4%	7.32	14.93	16.42	44.28	64.49	2.04	6.05	2.76
SORM 5%	7.32	14.32	16.42	43.05	64.15	1.96	5.88	2.88

The effect of 5 % residual on oil production in a Livingston miscible flood is shown in Figure 5.4. As shown in Table 4 oil production with is clearly lower for the first 24 years of the simulation.

Figure 5.4 – Effect of Miscible Residual (SORM) on Oil Production Rate



5.1.2 – CO_2 Solubility in Water:

Several mole percent CO_2 can dissolve in water. This forms carbonic acid which lowers the pH, may alter wettability and does react with or dissolve reservoir minerals. All of those effects are beyond this stage of the model of Livingston. However, the additional storage of CO_2 and its effect on production and utilization can be modeled. Figure 5.5 illustrates where CO_2 has dissolved in water after 32 years of injection.

Figure 5.5 – Distribution of CO_2 Dissolved in Water at End of CO_2 Project

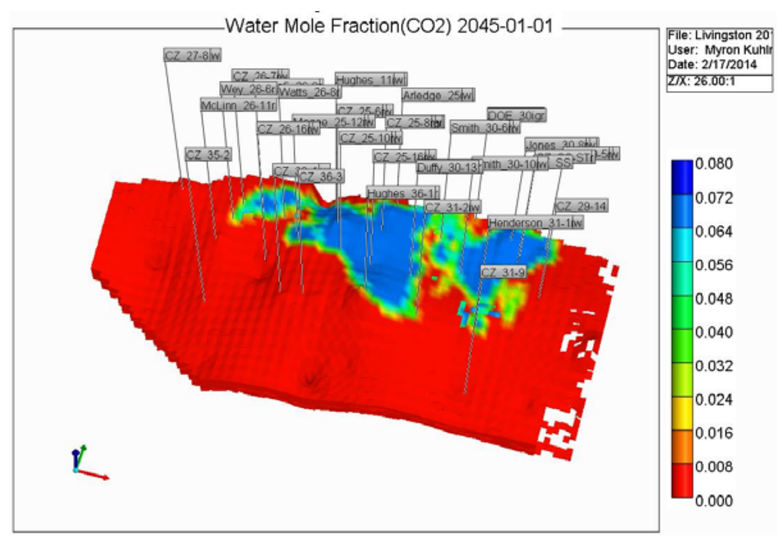


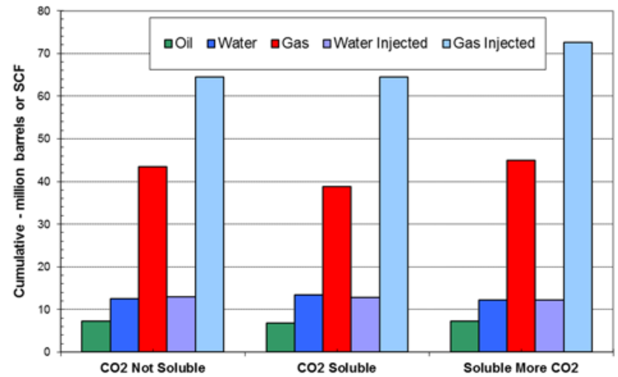
Table 5 and Figure 5.6 present examples of CO_2 solubility in water on production and injection with two injectors. The table and Figure show that oil and gas production decrease when CO_2 can dissolve in water but reduced oil production can be overcome by injecting more CO_2. The net GOR (utilization) of CO_2 rises 0.86 mcf/bbl when CO_2 is allowed to dissolve in water.

Table 5 – Effect of CO_2 Dissolved in Water on Fluid Production and Injection

	Oil MM bbls	Water MM bbls	Inj'd W MM bbls	Gas Prd BCF	Gas Inj BCF	WOR	GOR mcf/bbl	Net GOR mcf/bbl
Not Soluble	7.23	12.51	13.02	43.5	64.5	1.73	6.01	2.91
Soluble 6MM CO_2	6.79	13.40	12.83	38.9	64.5	1.97	5.72	3.77
Soluble 7MM CO_2	7.30	12.27	12.24	45.0	72.5	1.68	6.16	3.77

5.2 - Performance with Horizontal Injector:

Figure 5.6 – Effect of CO_2 Dissolved in Water on Fluid Production and Injection



As pointed out at the start of this chapter, there should be more than two injectors at Livingston to accelerate sweep of the reservoir by CO_2 and to increase production of oil and sequestration of CO_2. Figure 5.7 illustrates the currently proposed location of a 500 foot long horizontal injector at Livingston. The figure shows that a likely location would be near the bounding fault between Smith 30-6 and Jones 30-8. Figures 3.6 to 3.8 show that the beach rock layer is thin or absent, the upper shoreface is thick and the volume of higher permeability sand is high in that area.

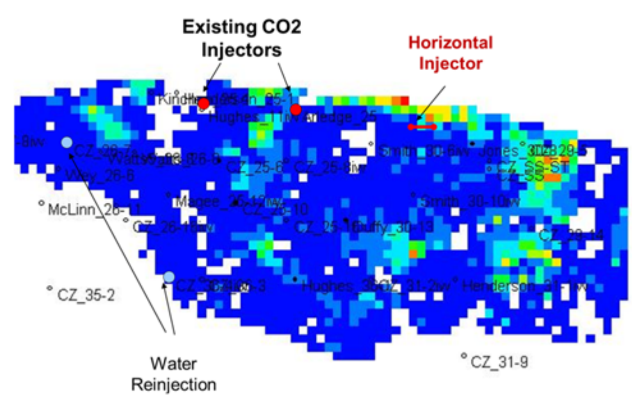
The effect of the horizontal injector there is shown in Table 6 and Figure 5.8.

Table 6 – Effect of Horizontal Injector on Fluid Production

	Oil	Water	Inj'd W	Gas Prd	Gas Inj	WOR	GOR	Net GOR
2 Injectors	7.30	12.27	12.24	45.0	72.5	1.68	6.16	3.77
3 Injectors	7.90	13.84	12.46	42.7	73.7	1.75	5.40	3.93
3 Inj - uneq rates	8.04	13.79	12.42	47.2	78.5	1.71	5.87	3.89
Accelerate Prod	8.35	17.01	15.30	43.1	76.1	2.04	5.16	3.95

The table and figure show that oil production can be increased a million barrels, while net water production increased by 2.7 million barrels if production is accelerated, i.e., produce more liquids. This means that the volume of CO_2 stored in the reservoir increases from 27.5 to 34 BCF (1.38 milion metric tons to 1.71 million metric tons) while the net utilization increases from 3.77 mcf/bbl to 3.95 mcf/bbl.

Figure 5.7 – Possible Location of Horizontal Injector



The effect of increasing SORM from 5% to 8% is presented in Table 7 and Figures 5.9 to 5.11 for 3 injectors. As with two injectors increasing SORM reduces both oil and gas production. However, gas injection is also decreased so the volume of CO_2 stored (Figure 5.11) decreases slightly (32.2 to 31.7 BCF, i.e., 25,000 metric tons).

Table 7 – Effect of Miscible Residual on Production and Injection with 3 Injectors

	Oil	Water	Inj'd W	Gas Prd	Gas Inj	WOR	GOR	Net GOR
SORM 5%	8.36	18.56	16.96	45.9	78.1	2.22	5.49	3.85
SORM 6.5%	8.11	18.58	16.99	45.4	77.4	2.29	5.59	3.95
SORM 8%	7.86	18.59	17.02	44.7	76.4	2.36	5.69	4.03