Development of real time geophysical data acquisition and processing toolbox to monitor flood performance

Quarterly Progress Report

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Disclaimer

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Executive Summary

The team of Sky Research and Pacific National Northwest Laboratory are engaged in a project funded by the National Energy Technology Laboratory, Strategic Center for Natural Gas and Oil in the U.S. Department of Energy to develop and validate novel non invasive methods to monitor and quantify CO2 EOR flood performance.

The project is divided into three research phases corresponding to the three budget periods. The emphasis in Phase I (Budget Period: February 1, 2011 through February 1, 2012) was on site selection, numerical modeling of CO2 EOR flooring and associated expected geophysical signatures for a number of different geophysical sensing modalities for selected sites, and on sensing modality selection. The emphasis in Phase II (Budget period: February 1, 2012 through February 1, 2013) is on refinement of the modeling scenarios, sensing system assembly and testing and on inverse method development. The emphasis in Phase III (Budget period: February 1, 2013 through February 1, 2014) will be on the system field deployment on a selected site and on the interpretation of the field data. This report covers the reporting period of January 1, 2012 through March 31, 2012 (last month of Phase I, first two months of Phase II)

The primary achievements in Phase I included

- A literature review was completed to assess the feasibility of using different sensing modalities to image CO2 EOR
- An agreement was put in place between the project team and Morgan Kinder under which Morgan Kinder will provide (under and NDA with Sky Research and PNNL) access to data for the Yates and Katz fields (two fields in which Kinder Morgan in performing CO2 EOR).
- Modeling using the PNNL developed code STOMP and the commercial code GEM was started to simulate different CO2 EOR scenarios
- Modeling efforts using several geophysical modeling codes were initiated to perform sensitivity studies for different geophysical
- Initial system design was started for both a TDEM (Time domain Electro Magnetic) and ERT (Electrical Resistivity Tomography) system which would be used in the monitoring phase

In February of 2012 the project team submitted a continuation application discussing the achievements under Phase I. On February 23 a presentation was given to DOE staff on Phase I, and following that DOE gave permission to proceed to Phase II of the project. Phase II is now underway

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1 Introduction

1.1 Background

The team consisting of Sky Research and Pacific National Northwest Laboratory is engaged in a project funded by the National Energy Technology Laboratory, Strategic Center for Natural Gas and Oil in the U.S. Department of Energy to develop and validate novel non invasive methods to monitor and quantify CO2 EOR flood performance.

The motivation for this project is the need for next generation imaging capabilities of CO2 EOR floods. Specifically, such imaging capabilities should allow companies involved in CO2 EOR the capability to obtain timely and actionable information about CO2 EOR floods which would allow for the optimization of such floods through injection parameter tuning. The ability to optimize floods is expected to increase the number of sites at which CO2 EOR can be economically applied, and thus result in increases in (and reduction in the cost of) tertiary oil production.

1.2 Scope of Work

The scope of the project is the design, development and validation of a real time, semi-autonomous, multisensory geophysical data acquisition and processing system to monitor CO_2-EOR flood performance. This system will consist of a combination of commercially available and recipient developed geophysical sensors which will collect continuous geophysical data. The acquisition system will be integrated with middleware to provide for automated transmission of data to a server for data management and near real time processing and inversion. The output of the data processing (changes in physical properties resulting from the geophysical inversion) will be coupled to reservoir models (specifically, the PNNL developed STOMP code) to provide for near real time estimates of CO_2 flooding performance. The detailed scope of work is provided in appendix A.

There are three phases of research in this project: Phase 1 (system design), Phase 2 (system construction) and Phase 3 (system field testing). These phases generally correspond to the three years of the project. The project started on February 1, 2011, and this report covers the fifth three month period of the project, which focused on the completion of Phase I and started work on Phase II.

2 Progress of work

2.1 Site commitment

Following the project award discussions were had with both DOE funded projects, academia and industry to explore the potential of monitoring at sites where CO2 EOR is either ongoing or planned. Sites included SACROC, the Citronella field in Alabama, Chaparral Energy's North Burbank Unit site (NE OK) and multiple sites in the Permian Basin. Several of these operators are interested in the technology.

An agreement was obtained with Morgan Kinder under which Morgan Kinder will provide data on two fields (Katz and Yates) where CO2 EOR is occurring. This data will be used by the project team in the modeling effort and the subsequent site ranking.

2.2 Literature review

A literature review on the feasibility of CO2 EOR monitoring using a range of different geophysical sensing modalities was completed and submitted to the DOE PM. A journal article based on this review is being prepared. The summary of the literature review are

1. Theoretical, numerical and field based evidence exists that CO2 EOR emplacement can be observed and monitored both with gravity, active seismic, electrical and electromagnetic methods. Surface deformation monitoring techniques (INSAR & tiltmeters) can also observe and monitor CO2 EOR emplacement. While passive seismic data can sometimes be used to locate the initial emplacement passive seismic data is not suitable for monitoring.
2. The magnitude of the changes in measurements is dependent on the combination of several factors, including
    a. volume of CO_2 injected
    b. host conditions of the reservoir
    c. distance between the geophysical sensors and the injection
    d. geometry of the geophysical sensors
    e. injection history
3. There is a good agreement between the actual magnitudes of changes observed in field data and the numerically and theoretically predicted values. This indicates that numerical methods can be used effectively to predict the efficiency of geophysical monitoring of CO2 EOR.

2.3 Modeling

2.3.1 CO2 Modeling

This task consisted of development and implementation of a forward model that allows the simulation of changes in physical properties (electrical, electromagnetic, density and acoustic properties) associated with the injection of CO_2 for typical EOR field applications.

The modeling effort in phase 1 has two parts. The first part is the modeling of specific CO2 EOR scenarios for a range of different systems using the PNNL Stomp code and a commercial reservoir simulation code. The second part is the modeling of the geophysical signal using a range of forward geophysical models. In phase 2 the geological modeling and geophysical inversion will be integrated in the PNNL developed Geological Sequestration Software Suite (GS^3) (Figure 1 which provides a process by which teams can accomplish the simulation process, while the system automatically manages the data, data translations, versions of conceptual and numerical models, captures provenance and user annotation, and in doing so, vastly reduce the burden on modelers for manually organizing and tracking information throughout the modeling process.

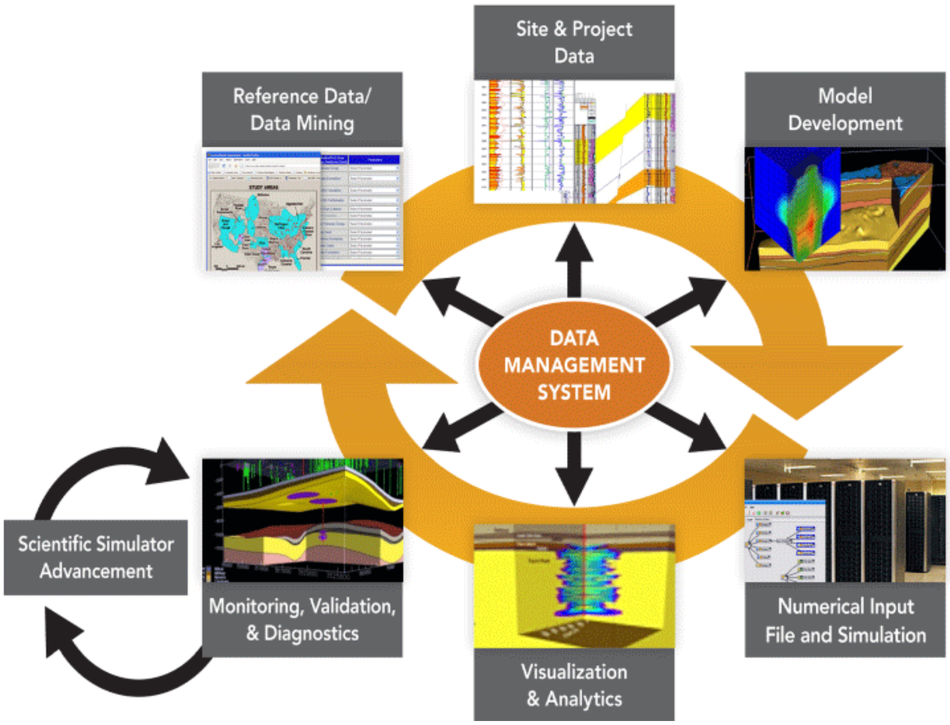
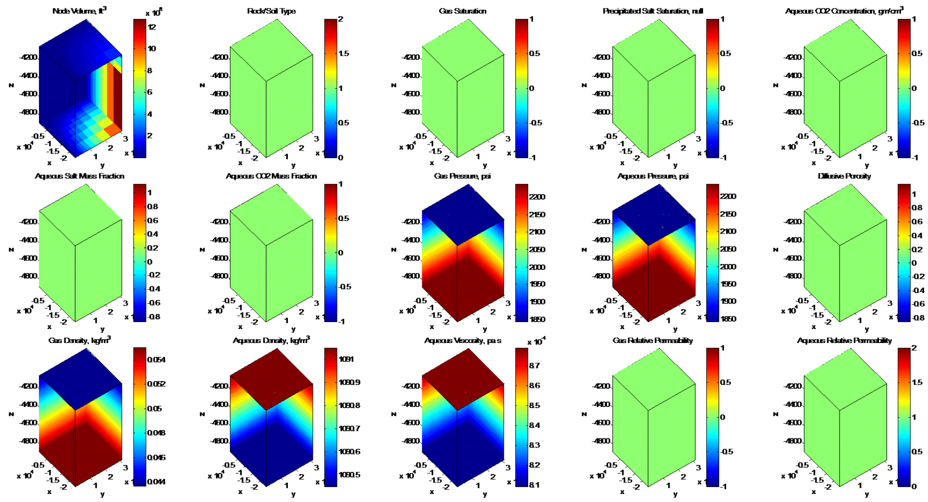


Figure 1 ***GS3 platform for modeling process and data management.***

Under this task the project team is using two different simulation engines. The first is the PNNL developed Stomp code, which has been used successfully for simulation of multiple CO2 sequestration scenarios (Figure 2). While it has been verified extensively and can model multiple different systems STOMP is primarily a research code, which originated as a reactive transport code for environmental applications. The second is the commercial GEM (**G**eneralized **E**quation-of-State **M**odel Reservoir Simulator) code. GEM is a full equation-of-state compositional reservoir simulator which has been widely applied to model the effect of CO2 injection in oil reservoirs. The project team decided to use both codes side by side, both to validate the STOMP performance and as the GEM code turned out to be currently better suited for rapid model evaluation and for the modeling of the behavior of the Yates Field. Code development on STOMP is ongoing outside of the current project which should allow us to use STOMP for the simulation of Yates in year 2, and both STOMP and GEM can be used in our inverse framework approach

Time step 0



Time step 359 (1 year)

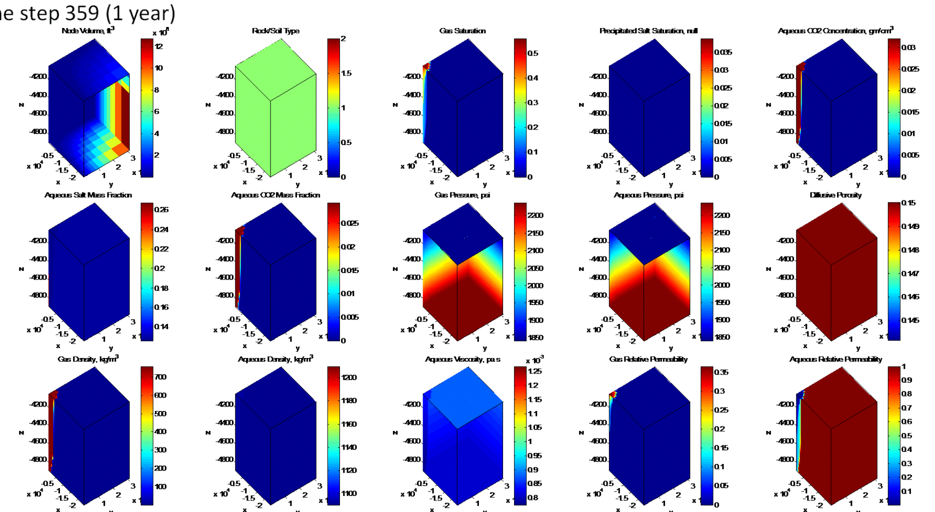


Figure 2 Output of the PNNL developed STOMP modeling code

The simulators provide spatial and temporal distributions of porosity, temperature, pressure, chemistry, and relative concentration and phase of oil, water/brine, gas and CO2. These concentrations will be input in a petrophysical model for transforming these values into changes in density and electrical conductivity. For this, an experimental relationship has been developed (modified Archie's law), which is based on theoretical, laboratory and field measurements of changes in density and electrical conductivity as a result of CO2 flooding. The coefficients for this relationship are site specific, and work is currently ongoing to determine these coefficients for the Katz and Yates field.

Data have been received from Kinder Morgan allowing for the construction of geocellular models of both the Katz and Yates field. These data were received in January of 2012. Forward models are currently being run and refined with interactions occurring between the program team and modelers from Kinder Morgan.

2.3.2 Geophysical modeling

Under this task forward geophysical modeling codes were developed allowing for the calculation of changes in geophysical measurements for a number of sensing modalities and instrument configurations. Codes were developed for forward modeling of gravity, resistivity and Time Domain Electromagnetic sensing modalities. These codes were developed in Fortran 90 (Time Domain EM), Matlab (resistivity) and Comsol Multiphysics (Time Domain EM, resistivity and gravity). These codes were validated for simple test scenarios, but await the full completion of task 2.3 to be able to simulate the changes in geophysical properties from CO2 injection for the Katz and Yates fields. As these forward models can be rapidly executed, we expect these efforts to be completed shortly after completion of task 2.3.

Sensitivity studies were done for a number of different geometries, both including surface transmitters and borehole receivers and borehole transmitters and borehole receivers (Figure 3)

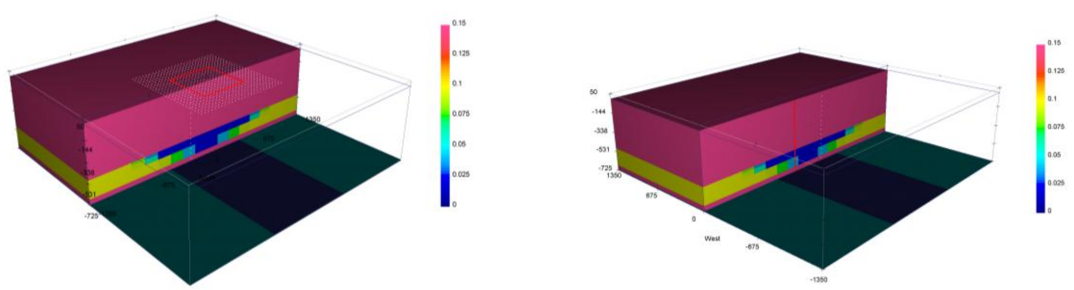


Figure 3 Configuration for sensitivity study: left surface transmitters and borehole receivers. Right: borehole transmitters and receivers.

The initial result of this is that a borehole to borehole system will provide superior visibility (Figure 4), and that frequency dependent data will improve detectability of changes

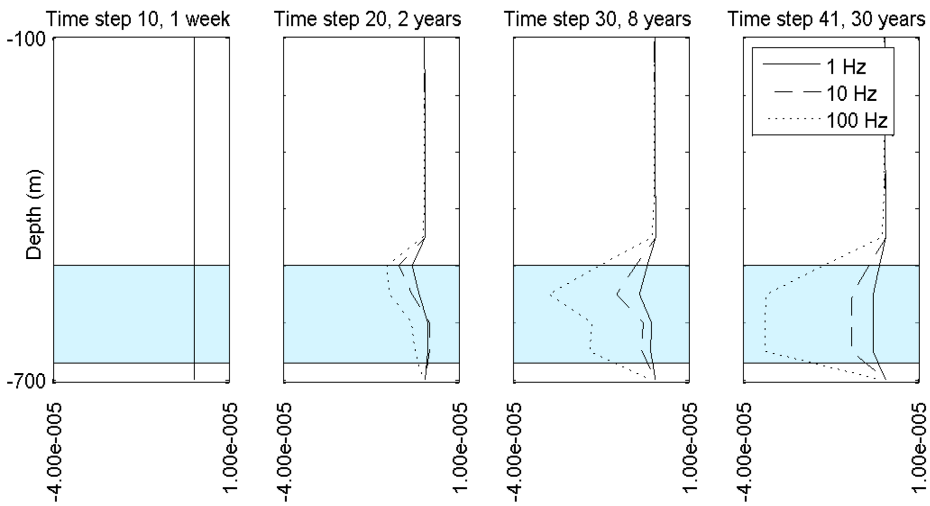


Figure 4 Changes over time in EM signal associated with CO2 injection

2.4 Sensor system design and layout

The sensor system design will predominantly occur in Phase 2. However, one of the questions was whether our system would need to be independently powered or whether it could use in field available power. Based on the discussions with Kinder Morgan for our two test sites we currently feel that our system will be able to use either the existing power infrastructure for both the geophysical sensors and the overall data acquisition infrastructure. In parallel with the geophysical modeling effort we are evaluating commercial and in house developed hardware for both resistivity, electromagnetic and gravity data acquisition. Specifically, we are examining the feasibility of integrating experimental gravity gradiometers and/or borehole resistivity and borehole em transmitters/receivers in our system. As part of this discussions are being held with different manufacturers as to the cost and availability of different hardware elements. We evaluated several possible vendors for such systems including MultiPhase Technologies, Zonge and AGI and purchased a multi channel, 64 electrode system from Multiphase technologies which is currently being configured for autonomous operation. For the TDEM system we anticipate using a combination of a surface transmitter (either a large loop or galvanic source), coupled with either surface or borehole receivers, either wideband B-field receivers or dB/dt sensors. Sky has experience with several of these sensors as well as the integration of these sensors in compact receiver packages (Figure 5), and we are currently working on the completion of the sensor package.

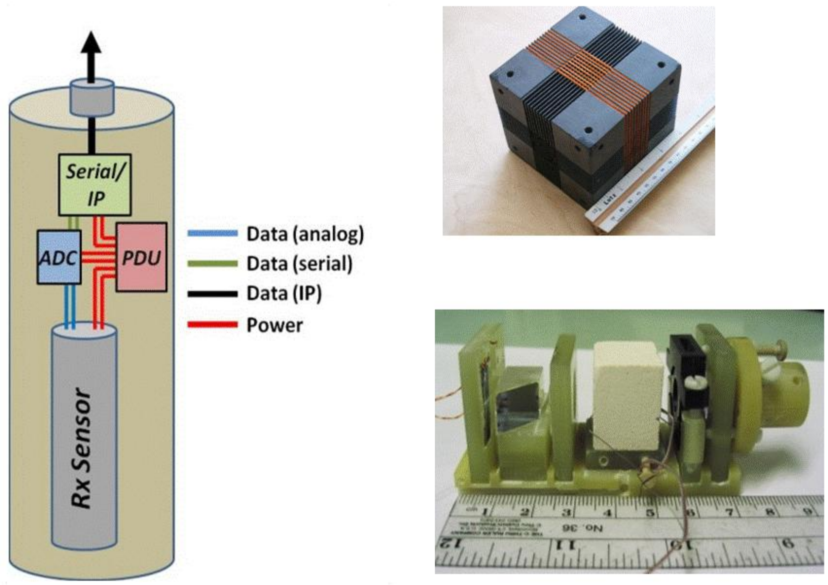


Figure 5 Left: general concept of borehole sensor. Top right: three component EM sensor. Bottom right: prototype SERF magnetometer.

3 Milestone status

3.1 Milestone description

The project is divided into three research phases corresponding to the three budget periods. The emphasis in Phase I (Budget Period: February 1, 2011 through February 1, 2012) is on site selection, numerical modeling of CO2 EOR flooring and associated expected geophysical signatures for a number of different geophysical sensing modalities for selected sites, and on sensing modality selection. The emphasis in Phase II (Budget period: February 1, 2012 through February 1, 2013) will be on sensing system assembly and testing and on inverse method development. The emphasis in Phase III (Budget period: February 1, 2013 through February 1, 2014) will be on the system field deployment on a selected site and on the interpretation of the field data.

The effort includes 9 milestones. Table 1 lists the name, planned start and complection date of each milestone, as well as the task or subtask with which each milestone is associated.

Task number	Task name	Project Milestone name	Planned start date	Planned end date	Phase
2.1	Test site commitment	Test site commitment	2/1/11	4/1/11	1
2.2	Literature Study	Literature study	2/1/11	5/1/11	1
2.4	Geophysical Forward Model coupling to CO2 induced changes in physical properties	Forward Model coupling	5/1/11	12/31/11	1
2.5	Sensing Modality and Geometry Selection	Modality selection	7/1/11	12/31/11	1
3.2	System Construction and Testing	Prototype completion	11/1/11	5/1/12	2
4.1	TDEM Processing Code Development	TDEM inverse code	11/1/11	8/1/12	2
4.3	CO_2-EOR Model Linking with Geophysical Framework Output	Model linking	2/1/12	5/1/13	3
5.2	System Deployment and Data Collection	System deployment	11/1/12	2/1/13	3
6	Data Analysis	Data analysis completion	2/1/13	2/1/14	3

As reported in the continuation application, the status of milestones 2.4 and 2.5 has been delayed. A meeting with DOE in July 2012 is planned to update DOE on interim project progress.

3.2 Milestone status

Milestone 1: Test site commitment
This milestone consists of obtaining commitment letters to allow for field deployment of the geophysical monitoring system from one or more sites where CO2 EOR is being done. Meeting of this milestone will be demonstrated by providing these letters to the DOE program office.

Milestone status: COMPLETED. An agreement was made with Morgan Kinder under which Morgan Kinder will provide data for two fields at which Morgan Kinder is performing CO2 EOR. These are the Yates fields and the Katz field. Morgan Kinder has indicated their willingness to allow monitoring (if several conditions on site safety and relevancy are met). A copy of the letter was provided to the DOE Program manager

Milestone 2: Literature study
This milestone consists of completion of a literature study about the use of geophysical characterization and monitoring of CO2 EOR. Meeting of this milestone will be demonstrated by providing this literature study to the DOE program office.

Milestone status: COMPLETED. The literature study was completed and provided to the Program Manager.

Milestone 3: Forward Model coupling
This milestone consists of the coupling of the PNNL developed GS 3 model for CO2 injection with Sky Research developed geophysical forward models such that the coupled models can predict the geophysical signal associated with CO2 EOR efforts. Meeting of this milestone will be demonstrated by performing a series of numerical simulations which the coupled models. The results of the simulations will be documented in a letter report which will be provided to the DOE program office

Milestone status: Ongoing.

Milestone 4: Modality selection
This milestone consists of selection of the sensors and configuration of these sensors which will be used in the field demonstration. This milestone will be demonstrated by a report describing the sensor selection and providing the theoretical, field and numerical data supporting the sensor selection. This report will be provided to the DOE program office.

Milestone status: Ongoing.

Milestone 5: Prototype completion
This milestone consists of the completion of the initial prototype sensor system (note that several of these will be constructed for deployment, but this milestone concerns the construction of the initial one). This milestone will be demonstrated by documenting the prototype design specifications, physical assembly (both component and system level) and test data resulting from the prototype. The documents will be provided to the DOE program office.

Milestone status: started

Milestone 6: TDEM (Time Domain Electro Magnetic) inverse code
This milestone consists of the completion of a TDEM inverse code which can estimate changes in subsurface conductivity from TDEM data. This milestone will be demonstrated by processing a number of synthetic (and possibly field) TDEM datasets and demonstrating that the code can obtain realistic estimated of changes in subsurface conductivity from this data.
Milestone status: started

Milestone 7: Model linking
This milestone consists of the linking of the GS3 model with the geophysical codes to allow for inverse property estimation. This milestone will be demonstrated by executing a number of scenarios on synthetic data to show the coupling and property estimation. A document summarizing the results of these scenarios will be provided to the DOE program office.

Milestone status: started

Milestone 8: System deployment
This milestone consists of the deployment to the field site of the monitoring hardware and the start of data collection. This milestone will be demonstrated by documenting field deployment activities and data collection progress (which will be accessible through a password protected interface). A document summarizing field site deployment and a password/username allowing access to the data portal will be provided to the DOE program office.

Milestone 9: Data analysis completion
This milestone consists of the completion of the data analysis and processing of the field data collected in the field demonstration. This milestone will be demonstrated by a data analysis report which will document field data and processing results. This document will be provided to the DOE program office.

3.3 Any changes in approach or aims and reasons for change.

No changes in approach or aims of this project occurred

3.4 Actual or anticipated problems or delays and actions taken or planned to resolve them.

As noted in the executive summary the site related modeling has been delayed due to the challenge of obtaining a site. This has impacts both on the progress and the expending of funds. We are working diligently to resolve this delay and anticipate being able to experience no further delay. We are working with Kinder Morgan towards a system deployment in Q4 of 2012

3.5 Any absences or changes of key personnel or changes in consortium/team arrangement.

No absences or changes of key personnel or changes in consortium/team agreement occurred

4 Appendix A. Statement of Project Objectives

4.1 PROJECT OBJECTIVE

The objective of the project is to design, develop and validate a real time, semi- autonomous geophysical data acquisition and processing system to monitor CO_2-EOR flood performance.

4.2 SCOPE OF WORK

The scope of the project is the design, development and validation of a real time, semi-autonomous, multisensory geophysical data acquisition and processing system to monitor CO_2-EOR flood performance. There are three phases of research to be conducted: Phase 1 (system design), Phase 2 (system construction) and Phase 3 (system field testing). This system shall consist of a combination of commercially available and recipient developed geophysical sensors which will collect continuous geophysical data. The acquisition system shall be integrated with middleware to provide for automated transmission of data to a server for data management and near real time processing and inversion. The output of the data processing (changes in physical properties resulting from the geophysical inversion) shall be coupled to reservoir models to provide for near real time estimates of CO_2 flooding performance.

4.3 TASKS TO BE PERFORMED

Phase I

Task 1.0 – Project Management and Planning

The Recipient shall execute the project in accordance with the approved Project Management Plan (PMP) covering the entire project period. The Recipient shall manage and control project activities in accordance with their established processes and procedures to ensure subtasks and tasks are completed within schedule and budget constraints defined by the Project Management Plan. This includes tracking and reporting progress and project risks to DOE and other stakeholders.

The Recipient shall work with the DOE Project Officer to modify and update the PMP submitted as part of the original application package, as necessary. The revised PMP shall be submitted within 30 days of the award. The DOE Project Officer shall have 20 calendar days from receipt of the Project Management Plan to review and provide comments to the Recipient. Within 15 calendar days after receipt of the DOE's comments, the Recipient shall submit a final Project Management Plan to the DOE Project Officer for review and approval.
This task shall include all work elements required to maintain and revise the Project Management Plan, and to manage and report on activities in accordance with the plan. The Recipient shall review, update, and amend the Project Management Plan (upon request of the DOE Project Officer) at key points in the program, notably at each Budget Period transition or GO/NO-GO decision point (if required) and upon schedule variances of more than three (3) months and cost variances of more than 15%.

It shall also include the necessary activities to ensure coordination and planning of the project with DOE/NETL and other project participants. These shall include, but are not limited to, the submission and approval of required National Environmental Policy Act (NEPA) documentation.

The Applicant is restricted from using Federal funds to take any action that would have an adverse affect on the environment or limit the choice of reasonable alternatives prior to DOE providing final NEPA decision regarding this project.

Task 2.0 – Test site selection, sensitivity and Cost/Benefit Studies and Sensing Modality Selection

The recipient shall secure commitments from CO_2 EOR site operators for the system deployment associated with task 5 (field testing). The recipient shall perform a literature study to identify potential sensing modalities. The recipient shall assess the sensitivity of each potential geophysical sensing modality to changes in physical properties associated with CO_2-EOR and the cost/benefit provided by each sensing modality in terms of information (both alone and in conjunction with other sensing data).

From the results of this sensitivity study the recipient shall select the specific sensing modalities for the system as well as the performance characteristics (e.g. acquisition lengths, sensitivities, number of units required, spacing between units). This task shall also include an analysis of the optimal deployment configuration of sensors. This task shall include a modeling study to determine the physical changes associated with EOR which will be coupled to geophysical forward modeling studies performed by the recipient (Subtask 2.3 – Geophysical forward model development).

Subtask 2.1 – Test site commitment

The recipient shall obtain commitment letters from at least one but preferably multiple CO_2 EOR site operators to serve as system testing sites for the effort to be performed under task 5 (field testing). The commitment letter shall include information on site location, required site access and resource needs (e.g. space required, power requirements and so on) and length of site access, as well as auxiliary data which will be required by the project and provided by the operator. The recipient shall provide the results of subtask 2.1 (including the sites considered, general site properties, and test site commitment letters) and a preliminary ranking of potential test sites to the DOE Project Officer.

Subtask 2.2 – Literature Study

The recipient shall evaluate the CO_2 Measurement, Monitoring and Validation (MMV) literature (including both reports from specialized workshops and meetings, as well as literature from SEG, SPE, AGU and EAEG and other relevant geophysical and geological societies) to evaluate all different potential sensing modalities and monitoring approaches. This study shall inform and guide the efforts under task 2.3 -2.5. A comprehensive topical report shall be submitted by the recipient at the end of this subtask. This shall have a bibliography and a description of the literature sources used for the report

Subtask 2.3 – CO2 EOR Model Development

The recipient shall develop and implement a forward model that allows the simulation of changes in physical properties (electrical, electromagnetic, density and acoustic properties) associated with the injection of CO_2 for typical EOR field applications. This model will be used as input into subtask 2.4

Subtask 2.4 – Geophysical Forward Model coupling to CO2 induced changes in physical properties

The recipient shall execute forward geophysical modeling tools to map the changes in physical properties provided by subtask 2.2 to calculate observable changes in geophysical measurements for a number of sensing modalities and instrument configurations, including electrical, electromagnetic, active and passive seismic and gravity measurements in surface, single borehole, borehole to borehole and borehole to surface configurations as well as other potentially possible modalities and configurations. This task shall include a detailed numerical sensitivity analysis listed under Task 2.0 which shall quantify the relative and absolute changes in each sensing modality and the expected noise signatures for each sensing modality, and from this the likely probability of detection by the sensing modality/configuration combination

Subtask 2.5 – Sensing Modality and Geometry Selection

The recipient shall select the final combination of sensing modalities, sensor specifications and deployment geometries for the system based on the results of subtask 2.2-2.4.

Phase 2

Task 3.0 – System Prototype Construction

The recipient shall construct a prototype acquisition system that includes both commercial sensors as well as a recipient developed Time domain Electromagnetic TDEM receiver (if selected as an appropriate sensing methodology in task 2). Data from these sensors shall be acquired by data acquisition software and hardware based on recipient-developed geophysical acquisition systems used for high quality geophysical surveys. This system shall be designed to be fully autonomous and environmentally rugged capable of collecting continuous data under expected testing field conditions (changes in temperature, rain, etcetera).

Subtask 3.1 – System Design

The recipient shall design the system (power requirements, form factor, auxiliary components, and sensor placements). This design shall be supported by field tests to minimize noise and component interference. It shall also include the selection of specific geophysical sensors for the sensing modalities selected under task 2 which meet or exceed the sensitivity requirements.

Subtask 3.1 – System Design

The recipient shall design the field data acquisition system which shall has as objective to collect the data as identified as a result of task 2. This system shall consist of an environmental enclosure (which will contain data acquisition hardware, power distribution system, a dedicated system control unit and internal geophysical sensors) and external geophysical sensors. The system components are described under the following subtasks

Subtask 3.1a: Environmental enclosure: The recipient shall design an environmental enclosure: this enclosure shall enclose all the data acquisition elements and be watertight against expected field conditions (including extreme events). The environmental enclosure shall provide industry standard, watertight connectors for system power (either DC or AC power) and wired ethernet connectivity and required connectors to the external geophysical sensors. The recipient shall provide for wireless internet connectivity which shall be integrated in the environmental enclosure. The environmental enclosure shall be designed so that the temperatures in the enclosure will be in the range provided by component manufacturers.

Subtask 3.1b: External geophysical sensors: The recipient shall decide on the number, placement and orientation of external geophysical sensors based on the results of task 2. Each external sensor shall be provided in an environmentally tight enclosure designed for the appropriate environment (e.g. surface mounting or placement in well) with appropriate mounting and orientation capabilities. Each external geophysical sensor shall be connected to the data acquisition hardware in the environmental enclosure through a wired connection which shall meet all applicable site safety requirements.

Subtask 3.1c: Internal geophysical sensors: The recipient shall decide on the number, placement and orientation of internal geophysical sensors based on the results of task 2. The internal geophysical sensors shall be permanently mounted in the environmental enclosure and be connected to the data acquisition hardware through a wired connection which shall meet all applicable site safety requirements. The internal sensor placement shall be optimized to minimize noise and cross sensor interference.

Subtask 3.1d: Power distribution system: The recipient shall decide on the power requirements of the field data acquisition system. Based on these, the recipient shall design a power distribution system which shall receive its power from the external source. The power distribution system shall be able to automatically accommodate a broad range of voltages and currents and fluctuations therein and shall provide clean power to all of the system components. The power distribution system shall be equipped with surge protection capabilities which shall be easily resettable from the outside of the environmental enclosure.

Subtask 3.1e: Data acquisition hardware: The recipient shall provide for data acquisition hardware which will record and store the data from the internal and external geophysical sensors. The data acquisition parameter shall be derived from task 2.

Subtask 3.1f: System control unit: The recipient shall provide for a system control unit which shall control and monitor overall system behavior. This system control unit shall control and monitor the data acquisition hardware, power output and environmental conditions in the environmental enclosure (temperature and humidity) and transmit data collected by the data acquisition hardware systems.

Subtask 3.2 – System Construction and Testing

The recipient shall construct and test the system. This shall include deployment of the prototype system for at least two weeks under field conditions representative of the planned field test site (task 5) to assess system stability and performance in agreement with the design specifications. During the test, geophysical data from each of the selected sensors as well as data describing system health and conditions (power, temperature and humidity) shall be acquired and saved and transmitted continuously. Data assessment shall include but not be limited to data quality, sensor drift, system noise, effect of environmental conditions and the ability to detect specific known changes in the subsurface. For this test the system shall be located at a well- instrumented site where such changes are known from auxiliary observations.

Task 4.0 – Processing Flow Development and Linking with CO_2-EOR Models

The recipient shall develop a processing flow for all geophysical data selected under task 2, which were integrated in the system developed under task 3. The result of the processing flow will be linked with the CO_2-EOR modeling framework. This processing flow shall map the geophysical field data to changes in physical properties which can be ingested by the CO2 EOR modeling framework. The recipient shall integrate the results of all these processing flows into a geophysical processing framework and link the results with a CO2 EOR model

Subtask 4.1: Geophysical Processing Flow Development

The recipient shall design, develop and implement a processing for all the selected geophysical and acquired sensing modalities. This processing flow shall exist of a number of well described data processing steps (data receiving from the field units, QA/QC, data storage in relational database, preprocessing, inversion and finally delivery of a spatiotemporal map of physical properties with associated resolution and confidence matrixes).

Subtask 4.2 – Geophysical Processing Framework Development and linking with CO_2-EOR Model

The recipient shall develop a geophysical processing framework which will utilize the individual processing flows developed under task 4.1 to provide the CO2 EOR model timelapse values of changes in physical properties. This data shall be used by the CO2 EOR model to provide estimates of flood performance.

Phase 3

Task 5.0 – Field Testing

The recipient shall test the system performance by deploying multiple units at a selected field site and collecting and processing data autonomously for a period of 3-6 months. The number and relative placement of units and length of data acquisition shall be based on a numerical modeling effort as well as on programmatic constraints.

Subtask 5.1 – Final Site Selection

The recipient shall select one appropriate site for the system test out of the sites which have committed to serve as potential test sites (task 2.1). Criteria for final test site selection shall include existing infrastructure, favorable conditions in terms of expected geophysical data, ability to collect base line data before and during CO_2-EOR, availability of auxiliary data and the ability to model the underlying system. The recipient shall provide information relative to the selected site, design criteria, and planned testing duration to the DOE Project Officer for approval prior to commencement of testing.

Subtask 5.2 System Deployment and Data Collection

The recipient shall deploy the data acquisition system at the selected site and collect data for approximately 3-6 months. Initial data acquisition length shall be based on the modeling effort. Actual data acquisition length and termination of the field test shall be based both on project constraints and the success full acquisition, processing and interpretation of timelapse geophysical data associated with CO2 EOR. During the field deployment the recipient shall frequently brief the DOE program manager on testing progress and results.

Subtask 5.3 Data Processing

The recipient shall apply the geophysical data processing described under Task 4 to the collected data.

Task 6. Data Analysis

The recipient shall analyze the overall system developed under this effort (both acquisition hardware and processing framework). The recipient shall evaluate the success and limitations of the developed methodology. This shall include both the predicted and actual performance of the data acquisition system, the performance of the data processing flow from both a numerical, computational and result perspective, the match between results obtained from this system and data provided by the site operator, as well as the merit of the resulting data as assessed by the site operator, and the potential benefits of such data to other sites.

Task 7: Technology Transfer

The Recipient shall disseminate the findings of this project, including advances in theory, modeling, processing, and imaging. The mechanisms for transferring these results shall include the development of a project website to report results, presentations at annual SEG and AGU meetings or at other appropriate conferences, at least 1 paper per year in relevant journals, and organization of a workshop or research forum at the appropriate annual meeting of a national organization (e.g., SEG, AAPG, SPE) or in conjunction with PTTC.

5 Cost/Plan Status

Budget status

As reported at the continuation application presentation the project is substantially under spent. This was primarily due to the delay of the start of the site specific modeling efforts which resulted from the delay in obtaining data from Morgan Kinder. This resulted in a delay in the completion of tasks 2.3, 2.4 and 2.5 and the associated Milestones 3 and 4, and an associated delay in expending of the funds set aside for the completion of these tasks (both for Sky Research and subcontractor PNNL). As of February 1, 2012 (end of budget year 1) there are $185 K in carryover funds. Carryover funds from Phase I will be used to complete tasks 2.3, 2.4 and 2.5 and associated milestones 3 and 4. Note that the cost plan below does not include Q1 costs which were incurred by PNNL (but have not been billed of approximately $50 K).

Baseline Reporting Quarter	YEAR 1 Start:	Jan-11	End:	Dec-11	YEAR 2 Start:	Jan-12	End:	Dec-12	YEAR 3 Start:	Jan-13	End:	Dec-13	YEAR 4 Start:
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Baseline Cost Plan													
Federal Share	41,193	61,790	61,790	61,790	61,790	61,790	61,790	61,790	61,790	61,790	61,790	61,790	20,597
Non-Federal Share	10,298	15,447	15,447	15,447	15,447	15,447	15,447	15,447	15,447	15,447	15,447	15,447	5,149
Total Planned (Federal and Non-Federal)	51,491	77,237	77,237	77,237	77,237	77,237	77,237	77,237	77,237	77,237	77,237	77,237	25,746
Cumulative Baseline Cost	51,491	128,728	205,964	283,201	360,438	437,674	514,911	592,147	669,384	746,620	823,857	901,094	926,840
Actual Incurred Costs													
Federal Share	24,201	15,741	13,402	9,478	30,887								
Non-Federal Share	5,034	2,837	2,247	2,401	53,365								
Total Planned (Federal and Non-Federal)	29,235	18,579	15,649	11,879	84,252	-	-	-	-	-	-	-	-
Cumulative Baseline Cost	29,235	47,814	63,462	75,342	159,594	159,594	159,594	159,594	159,594	159,594	159,594	159,594	159,594
Variance													
Federal Share	16,992	46,048	48,388	52,312	30,903								
Non-Federal Share	5,264	12,610	13,201	13,046	(37,918)								
Total Planned (Federal and Non-Federal)	22,256	58,658	61,588	65,357	(7,016)	-	-	-	-	-	-	-	-
Cumulative Baseline Cost	22,256	80,914	142,502	207,860	200,844	200,844	200,844	200,844	200,844	200,844	200,844	200,844	200,844

6 Publications

A brief article was provided for the DOE E&P quarterly publication. This should be published online in June 2012. A paper titled "Reservoir monitoring using electrical and electromagnetic methods" was submitted and accepted to the SEG/SPE/AAPG workshop titled "New advances in integrated reservoir surveillance". This workshop will be held in La Jolla from June 24-29 2012