Award Number: DE-FE0029474

# Integrated CCS for Kansas (ICKan)

DUNS NUMBER**:** 076248616

Research Performance Progress Report (Quarterly)

*Submitted to:*
The Department of Energy
National Energy Technology Laboratory

*Recipient:*
University of Kansas Center for Research &
Kansas Geological Survey
1930 Constant Avenue
Lawrence, KS 66047

*Submitted by:*

Joint Principal Investigators:

Tandis S. Bidgoli
785-864-3315
tbidgoli@kgs.ku.edu

& Martin Dubois
785-218-3012
mdubois@ihr-llc.com

Date of Report: 10-31-17

**Project Period: March 15, 2017 to September 15, 2018**

**Period Covered by the Report: July 1, 2017 to October 31, 2017**

Signature of submitting official:

Tandis S. Bidgoli, Assistant Scientist

# INTRODUCTION

## A. OBJECTIVES

This *Phase I- Integrated CCS Pre-Feasibility Study* activity under CarbonSAFE will evaluate and develop a plan and strategy to address the challenges and opportunities for commercial-scale Carbon Capture and Storage (CCS) in Kansas, *ICKan (Integrated CCS for Kansas)*. The objectives of *ICKan* include identifying and addressing the major technical and nontechnical challenges of implementing $CO_2$ capture and transport and establishing secure geologic storage for $CO_2$ in Kansas. The study will examine three of Kansas' largest $CO_2$ point sources and corresponding storage sites, each with an estimated 50+ million tons capacity (of saline aquifer storage), and a local transportation network to connect with nearby geologic storage. The project will also provide high level technical sub-basinal evaluation, building on previous characterization of the regional stacked storage complex.

## B. SCOPE OF WORK

ACCS Coordination Team will examine three of Kansas' largest $CO_2$ point sources and corresponding storage sites, each with an estimated 50+ million tons capacity, and a local transportation network to connect with nearby geologic storage. ICKan will evaluate and develop a plan and strategy to address the challenges and opportunities for commercial-scale CCS in Kansas. The *Team* will identify and address the major technical and nontechnical challenges of implementing capture, transportation, and secure geologic storage of $CO_2$ in Kansas.

The ICKan and CCS Coordination Team will generate information that will allow DOE to make a determination of the proposed storage complex's level of readiness for additional development under Phase II, by establishing and addressing the key challenges in commercial scale capture, transportation, and storage in this investigation.

## C. TASKS TO BE PERFORMED

**Task 1.0 – Project Management and Planning Integrated CCS for Kansas (ICKan)**
This Task includes the necessary activities to ensure coordination and planning of the project with DOE/NETL and other project participants. These activities include, but are not limited to, the monitoring and controlling of project scope, cost, schedule, and risk, and the submission and approval of required National Environmental Policy Act (NEPA) documentation

This Task includes all work elements required to maintain and revise the Project Management Plan, and to manage and report on activities in accordance with the plan.

Subtask 1.1 - Fulfill requirements for National Environmental Policy Act (NEPA) documentation
Phase I shall not involve work in the field, thus the activities shall have no adverse impact on the environment. Potential future activities that could have negative environmental impact in subsequent project phases will be documented in the Phase I reports.

Subtask 1.2 - Conduct a kick-off meeting to set expectations
The PIs shall layout expectations for adherence to scope, schedule, budget, risk management, and overall project plan in an "all-hands" meeting within the first four weeks of project initiation. The PIs shall provide protocols and reporting mechanisms for notice of modifications.

Subtask 1.3 - Conduct regularly scheduled meetings and update tracking

The team shall hold regularly scheduled monthly meetings including all personnel and subcontractors via conference calls or online videoconferences. The PIs shall update scope, tasks, schedule, costs, risks, and distribute to the DOE and the project team. Accountability shall be encouraged by the monthly review sessions. The PIs shall hold full CCS team meetings (including $CO_2$sources and field operators) quarterly.

Subtask 1.4 - Monitor and control project scope
PIs shall evaluate and analyze monthly reports from all team section leads ensuring compliance with the requirements of DOE.

Subtask 1.5- Monitor and control project schedule
PIs shall closely monitor adherence to the project schedule, facilitated by monthly project team meetings. Schedule tracking and modifications shall be provided to the team on a monthly basis. PI will monitor resources to ensure timely completion of tasks.

Subtask 1.6 - Monitor and control project risk
Project risks and mitigation protocol shall be discussed with the team at the beginning of the project to help limit risks being realized and help recognize patterns that could signal increased risk.

Subtask 1.7 - Finalize the DMP. The DMP and its components shall be finalized by the PI. Information acquired, during the project, will be shared via the NETL-EDX data portal including basic and derived information used to describe and interpret the data and supplementary information to a published document. Information will be protected in accordance with the usage agreements and licenses of those who contribute the data.

Subtask 1.8 - Revisions to the PMP after submission
The PMP shall be updated as needed, including:1) details from the negotiation process through consultation with the Federal Project Officer, 2) revisions in schedule, 3) modifications in the budget, 4) changes in scope and tasks, 5) additions or changes in personnel, and 5) other material changes in the project.

Subtask 1.9 - Develop an integrated strategy/business plan for commercial scale CCS
The PIs shall set goals and timelines in early meetings and the team shall develop and build on strategy that will be documented in a business plan.

**Task 2.0 – Establish a Carbon Capture and Storage (CCS) Coordination Team**
The PIs shall develop a multidisciplinary team capable of addressing technical and non-technical challenges specific to commercial-scale deployment of the $CO_2$storage project. The Phase I team will 1) determine if any additional expertise and manpower required for Phase II, 2) recommend individuals, groups or institutions to fill any additional needs that are identified, and 3) assist in the recruitment and gaining formal commitments by key individuals or institutions for Phase II.

Subtask 2.1 - Identify additional CCS team members
Identify additional team members required to evaluate; 1) geologic storage complex, 2) large-scale anthropogenic sources and approaches to capturing $CO_2$, 3) transportation/delivery systems from source to the geologic complexes and injection into the storage reservoir, 4)costs, economics and financial requirements, 5) legal and political challenges, and 6) public outreach for the Phase II effort. Future needs will also be evaluated and additional team members will be selected if there are additional gaps in technical or non-technical areas that would be advisable to fill.

Subtask 2.2 - Identify additional stakeholders that should be added to the CCS team
The team will identify possible additional stakeholders that could include environmental groups, business

groups, state legislators, state organizations (commerce), rate-payer organizations, land use and land owner groups.

Subtask 2.3 - Recruit and gain commitment of additional CCS team members identified
A comprehensive review of the gap analyses and develop recommendations of additional individuals, groups or institutions which should be filled before proceeding to Phase II. The CCS team shall identify primary and secondary choices, recruit, and gain commitments for possible participation in Phase II.

Subtask 2.4 - Conduct a formal meeting that includes the Phase I team and committed Phase II team members
A one-day working meeting will be conducted to1) review Phase I preliminary results, 2) present draft plans for Phase II, and3) gather input from recruited potential Phase II members. The meeting shall be held at the KGS or a mutually agreed upon alternate site with an option to participate by videoconferencing.

**Task 3.0 – Develop a plan to address challenges of a commercial-scale CCS Project**
This application presents three candidate sources and identifies three possible geologic complexes suitable for storage. Phase I work shall determine which are most feasible, and shall identify and develop a preliminary plan to address the unique challenges of each source/geologic complex that may be feasible for commercial-scale CCS (50+ million tonnes captured and stored in a saline aquifer). Reliable and tested approaches, such as Road mapping and related activities (Phaal, et al., 2004, Gonzales-Salavar, et al., 2016; IEA, 2013: DOE, 2003) shall be used to identify, select, and establish alternative technical and non-technical options based on sound, transparent analyses including monitoring for adjustment as the assessment matures.

Subtask 3.1 - Identify challenges and develop a plan to address challenges for $CO_2$ capture from anthropogenic sources
A plan will be developed that addresses $CO_2$ capture including use of plant configuration, current and anticipated operating conditions, product distribution (e.g. electrical power grid), and regulatory uncertainty.

Subtask 3.2 - Identify challenges and develop a plan to address challenges for $CO_2$ transportation and injection
A plan will be developed that describes challenges specific to Kansas to deliver $CO_2$to the injection well(s) including addressing regulations, right of way, pipeline configuration, maintenance, safety, and deliverability.

Subtask 3.3 - Identify challenges and develop a plan to address challenges for $CO_2$ storage in geologic complexes
The KGS shall evaluate candidate geological complexes for technical risks (capacity, seal, faults, seismicity, pressure, existing wellbores), economics (location/distance, injectivity, availability), and legal (pore space rights, liability) and document the results in a plan.

**Task 4.0 – Perform a high level technical sub-basinal evaluation using NRAP and related DOE tools**
Three candidate sources and two possible storage complexes were identified. Phase I work shall determine which are most feasible, and will identify and develop a plan to address the unique challenges of each storage complex that may be feasible for commercial-scale CCS (50+ Mt captured and stored in a saline aquifer).Each location will be evaluated using NRAP models and the results shall be submitted to DOE.

Subtask 4.1 - Review storage capacity of geologic complexes identified in this proposal and consider alternatives

Three possible sites in two complexes are in various stages of analysis and each appears to meet the50+Mt storage requirement. They shall be further evaluated and a survey of other potential geologic structures will undergo a rigorous site screening and selection process to determine suitability.

Subtask 4.2 - Conduct high-level technical analysis of suitable geologic complexes using NRAP- IAM-CS and other tools for integrated assessment
The KGS shall evaluate candidate storage complexes in terms of capacity, seal, faults, seismicity, pressure, existing wellbores, and injectivity.

Subtask 4.3 - Compare results using NRAP with methods used in prior DOE contracts including regional and sub-basin $CO_2$ storage
The CCS team shall use the results of the NRAP models obtained in this study with the regional simulation of $CO_2$ storage in southern Kansas to provide an assessment of risk to this greater area and compare with findings of project DE-FE0002056, including Pleasant Prairie Field and other potentially prospective storage sites (e.g., Eubank, Cutter, and Shuck fields).

Subtask 4.4 - Develop an implementation plan and strategy for commercial-scale, safe and effective $CO_2$ storage
A technology roadmap or similar methodology shall be used to convey a detailed realistic implementation plan and strategy that shall utilize the experience gained by the KGS in developing a US EPA Class VI permit. The result shall be based on a sound analysis that meets the goals of stakeholders, defines effective action, and is adaptable and open for review and updates as conditions change, e.g., new technology breakthroughs, incentivizing, and market conditions (McDowall, 2012).

**Task 5.0 – Perform a high level technical $CO_2$ source assessment for capture**
An assessment of the capture technologies best suited for efficiency, addressing the concerns of the electric utilities and their operating requirements and economic needs will be performed.

Subtask 5.1 - Review current technologies and $CO_2$ sources of team members and nearby sources using NATCARB, Global $CO_2$ Storage Portal, and KDM
The CCS team shall develop an organized electronic clearinghouse of vital information pertaining to the project, ranked by suitability, historical usage records, adaptability, scaling, and demonstration of success, and operations and maintenance requirements.

Subtask 5.2 - Determine novel technologies or approaches for $CO_2$ capture
$CO_2$ sources shall carefully be evaluated for suitability with new capture technologies. The evaluation will utilize private research including that sponsored by DOE and results of international efforts and projects such as DOE's Carbon Capture Simulation Initiative (CCSI) to determine the suitability and rational for making decisions to pursue or table the technology.

Subtask 5.3 - Develop an implementation plan and strategy for cost effective and reliable carbon capture
An optimal CCS plan and strategy that best represents the holistic operating environment and requirements of the $CO_2$ sources will be developed. The team shall develop a means to ensure a mechanism to update and adapt to new disruptive technologies and possibly accommodate them in the design document.

**Task 6.0 – Perform a high level technical assessment for $CO_2$ transportation**
The CCS team shall consider best practices in pipeline design to ensure safety, security, and compliance with regulations in force in Kansas and other states were the pipeline may extend.

Subtask 6.1 - Review current technologies for $CO_2$ transportation
The CCS team shall address the challenges in pipeline transportation and shall catalog and classify the

technologies best suited for use in Kansas.

Subtask 6.2 - Determine novel technologies or approaches for $CO_2$ transportation
The CCS team shall review the challenges and solutions conveyed by current research and development and using a SWOT analysis determine the suitability and rational for making a decision to pursue or table transportation technologies.

Subtask 6.3 - Develop a plan for cost-efficient and secure transportation infrastructure
The CCS team shall develop an optimal plan and strategy for a$CO_2$distribution system that aligns with the needs of the proposed $CO_2$ sources and the storage complex put forth by the team.

**Task 7.0 – Technology Transfer**

Subtask 7.1 - Maintain website on KGS server to facilitate effective and efficient interaction of the team
The KGS shall create and maintain a web site available to both the members of the CCS team and the public. A non-secured site portion of the site shall be dedicated to apprising the public on the status of the on-going project as well as publishing the acquired data. The format of the public site shall be directed toward both technical and non-technical audiences. The public site will contain all non- confidential reports, public presentations, and papers. All data developed by the project or interpretation of existing data, performed by the project, shall be uploaded to EDX (edx.netl.doe.gov).

Subtask 7.2 - Public presentations
Progress and information gained from the study shall be convey to the public when deemed appropriate to enable an understanding of issues, concerns, and solutions for Integrated CCS in Kansas, *ICKan*. A focused dialog with interested stakeholders shall be sought through informational meetings and workshops that correspond with formal reporting to DOE including intermediate results and the final report. Prior to the final report being released, the CCS team shall invite key stakeholders and interest groups to participate in addressing the general topics of CCS and to comment on the plan and strategy through a conference and workshop in order build public support for taking the next steps in ICKan.

Subtask 7.3 - Publications
The CCS team shall publish methodologies, findings, and recommendations.

## D. DELIVERABLES

Reports will be submitted in accordance with the attached “Federal Assistance Reporting Checklist” and the instructions accompanying the checklist.

In addition to the reports specified in the "Federal Assistance Reporting Checklist", the Recipient will provide the following to the DOE Project Officer.

**Data Submitted to NETL-EDX**
Data generated as a result of this project shall be submitted to NETL for inclusion in the NETL Energy Data eXchange (EDX), https://edx.netl.doe.gov/. The Recipient will work with the DOE Project Officer to assess if there is data that should be submitted to EDX and identify the proper file formats prior to submission. All final data generated by this project shall be submitted to EDX including, but not limited to: 1) datasets and files, 2) metadata, 3) software/tools, and 4) articles developed as part of this project.

Other key deliverable include:

- Task 1.0–Project Management Plan
- Task 1.10 – Technical report on *Integrated Strategy For Commercial-Scale CCS Project*
- Task 2.0 – Commitment letters from fully formed *CCS Coordination Team*
- Task 3.0 – Technical report on *Plan to Address Challenges of the Commercial-Scale CCS Project*
- Task 4.0 – Technical report on *High-Level Sub-Basinal Evaluations*
- Task 5.0 – Technical report on *High-Level $CO_2$ Source Assessment for Capture*
- Task 6.0 – Technical report on *High-Level Assessment for $CO_2$ Transportation*
- Initial Business Plan that describes the selected source, capture technology, transportation route, and injection site(s), in a saline aquifer, with anticipated surface and subsurface infrastructure requirements. Additionally, a data gap analysis should be performed and include a discussion on the missing data and how the identified data gaps will be filled. There should be a discussion on non-technical issues such as outreach, political aspects of the project, legal requirements such as pore space ownership, permitting requirements, and the ownership of the $CO_2$/liability throughout the process of capturing, transportation and injection. An economic analysis should be performed that includes anticipated costs for filling in data gaps, anticipated capital expenditures, construction costs, and future system operational expenditures for the proposed CCS system. There should be a list of anticipated sources of funding and strategies to pay for the installation and the operation of the CCS system. The business plan should also have discussions on how the costs of oil will affect the financing of the project and at what price point will it be economically feasible.

## E. BRIEFINGS/TECHNICAL PRESENTATIONS

The Recipient shall prepare detailed briefings for presentation to the Project Officer at a location(s) to be designated by the Project Officer, which may include the Project Officer's facility located in Pittsburgh, PA or Morgantown, WV. The Recipient shall make a presentation to the NETL Project Officer/Manager at a project kick-off meeting held within ninety (90) days of the project start date. At a minimum, annual briefings shall also be given by the Recipient to explain the plans, progress, and results of the technical effort and a final project briefing prior to the close of the project shall also be given.

The Recipient shall also provide monthly E-mail updates on the status of the project to the FPM.

# TABLE OF CONTENTS

# ACCOMPLISHMENTS

## Task 1.0 – Project Management and Planning Integrated CCS for Kansas

### Subtask1.1 - Fulfill requirements for National Environmental Policy Act documentation

Completed in prior quarter.

### Subtask 1.2 - Conduct a kick-off meeting to set expectations

Completed in prior quarter.

### Subtask 1.3 - Conduct regularly scheduled meetings and update tracking

**Full Team Meetings:**
A 'Carbon Capture, Utilization, and Storage in Kansas' workshop was held on September 21, 2017 in lieu of a full team meeting (see below and Task 3).

**KGS Team Meetings:**
Regular KGS team meetings are held on the third Thursday of each month, alternating with meetings scheduled with the full team. Goals of these meetings are to provide an overview of ongoing work and evaluate progress on deliverables. Frequent individual meetings are held on an as-needed basis throughout the course of the reporting period as well.

**Other:**
On September 20, 2017, KGS ((Bidgoli, Holubnyak) and Linde (Krishnamurthy, Byron) team members held a meeting with Westar representatives at their Jeffrey Energy Center facility in St. Marys, Kansas. During the meeting Linde presented some preliminary design plans for carbon capture and areas of optimation, utilizing waste heat from the plant.

On September 21, 2017, we held, jointly with the State CO2-EOR Deployment Work Group, a workshop and forum on Carbon Capture, Utilization, and Storage in Kansas. The meeting was held in Wichita, KS. The meeting brought ICKan team members and project partners together with individuals representing industry, policy makers, and regulators, to discuss the viability and steps needed for implementation of commercial-scale carbon capture and utilization in Kansas. The feedback from attendees was very positive. The outcomes of the meeting are being used by the team to frame an implementation plan for the project. The meeting is also enabling the recruitment of new team members and partners on the project.

On September 21, 2017, KGS ((Bidgoli, Holubnyak), IHR (Dubois) and Linde (Krishnamurthy, Byron) team members held a meeting with CHS representatives in Wichita, Kansas. During the meeting Linde presented some preliminary design plans for carbon capture and areas of optimation, utilizing waste heat from the CHS's refinery.

### Subtask 1.4 - Monitor and control project scope

The KGS held regular monthly and bimonthly meetings with the team to discuss the status of deliverables and evaluate tasks. Participants provided a brief overview of their work and discussed steps forward.

### Subtask 1.5 - Monitor and control project schedule

The project schedule was reviewed during monthly and bimonthly meetings with the team.

### Subtask 1.6 - Monitor and control project risk

Risks were evaluated in an ongoing basis within normal workflow. Larger concerns were presented in team meetings where in depth discussions could be held.

### Subtask 1.7 - Finalize the DMP.

Data will be delivered to DOE upon completion of models for efficiency. This is planned for completion by December 2017.

### Subtask 1.8 - Revisions to the PMP after submission

Nothing to report.

### Subtask 1.9 - Develop an integrated strategy/business plan for commercial scale CCS

Our September 21 2017 'Carbon Capture, Utilization, and Storage in Kansas' workshop and forum included a number of discussions on implementation of commercial-scale CCS. The outcomes of these discussions are being compiled and used for follow-up meetings with various entities and incorporated into our strategy/business plan.

## Task 2.0 – Establish a Carbon Capture and Storage (CCS) Coordination Team

The Integrated CCUS for Kansas project will join Battelle Memorial Institute's Integrated Mid-Continent Carbon Stacked Storage Hub (DE-FE0029264) in a CarbonSAFE Phase II proposal. We are currently in the final stage of developing a Memorandum of Understanding and plan a joint meeting of the two projects around December 1. ICKan has suspended the identification and recruitment of additional team members and stakeholders until we re-evaluate the possible gaps in a combined Phase II project.

### Subtask 2.1 - Identify additional CCS team members

Mostly completed in the prior quarter. This will be reviewed after our meeting with Battelle in December.

### Subtask 2.2 - Identify additional stakeholders that should be added to the CCS team

Mostly completed in the prior quarter. This will be reviewed after our meeting with Battelle in December.

### Subtask 2.3 - Recruit and gain commitment of additional CCS team members identified

Recruiting of additional industry partners and stakeholders has been initiated. The need for additional recruitment will be reviewed after our meeting with Battelle in December.

### Subtask 2.4 - Conduct a formal meeting that includes the Phase I team and committed Phase II team members

A meeting is being scheduled with Battelle for around December 1. We plan to have a full ICKan meeting in this quarter, after the Battelle meeting.

**Significant activities and accomplishments in the reporting period for Task 2 include the following:**

- Initiated the process of recruiting additional industry partners (oil, midstream, and ethanol industries) with a one-day workshop, CCUS for Kansas, held in Wichita, Kansas, on September 21, 2017.
- Initiated the process of recruiting additional stakeholders (regulatory, legislative, and NGOs) with the one-day workshop on September 21, 2017.

**Goals and objectives for the next Quarter:**
In light of the pending combining of the Battelle project with ICKan, the primary goals for the next quarter are to (1) in collaboration with Battelle, re-evaluate potential gaps in the combined team, including team members and stakeholders, (2) determine who ICKan will recruit, and (3) begin the recruitment process.

## Task 3.0 – Develop a plan to address challenges of a commercial-scale CCS Project

### Subtask 3.1 - Identify challenges and develop a plan to address challenges for CO2 capture from anthropogenic sources

A plan will be developed that addresses $CO_2$ capture, including use of plant configuration, current and anticipated operating conditions, product distribution (e.g. electrical power grid), and regulatory uncertainty.

The ICKan proposal presented three candidate sources for $CO_2$ capture. The objective of Phase I work is to determine which are most feasible, and to identify and develop a preliminary plan to address the unique challenges of each source that may be feasible for commercial-scale CCS (50+ million tonnes captured and stored in a saline aquifer). Although no time frame was defined by FOA15824 for the processing of 50 million tonnes, the ICKan project set 2.5 million tonnes/year over a 20-year period as a target.

**Summary of Activities:**
During the quarter, the team focused its efforts on performing a detailed engineering analysis of waste heat recovery options at Westar's Jeffrey Energy Center. The analysis focused on three potential locations for waste heat extraction that could be used to generate steam for regeneration of the solvent in the stripper. Figure 1 highlights the opportunities that were considered and investigated. These options are:

1. The flue gas upstream of the FGD (flue gas desulfurizer) which is around 350-400$^{o}$F
2. The flue gas leaving the selective catalytic reactor (SCR) for NOx removal at 832$^{o}$F
3. Fly ash leaving the boiler at a high temperature and collecting in an ash removal hopper.

The team approach for the engineering analysis was as follows:

- Determine low pressure steam requirement based on target $CO_2$ capture rate and estimate thermal energy required for LP steam generation
- Calculate waste heat recovery potential range and configuration options for an 800 $MW_e$ unit at Jeffrey Energy Center
    - for different assumed coal moistures, up to 30%
    - to prevent acid condensation of $SO_2$ and $SO_3$ in flue gas
- Determine thermal energy required for other uses within power plant
- Calculate the reduction in power production based on waste heat extraction
- Highlight other challenges for proposed heat recovery.

The results of this analysis are described in the next section.

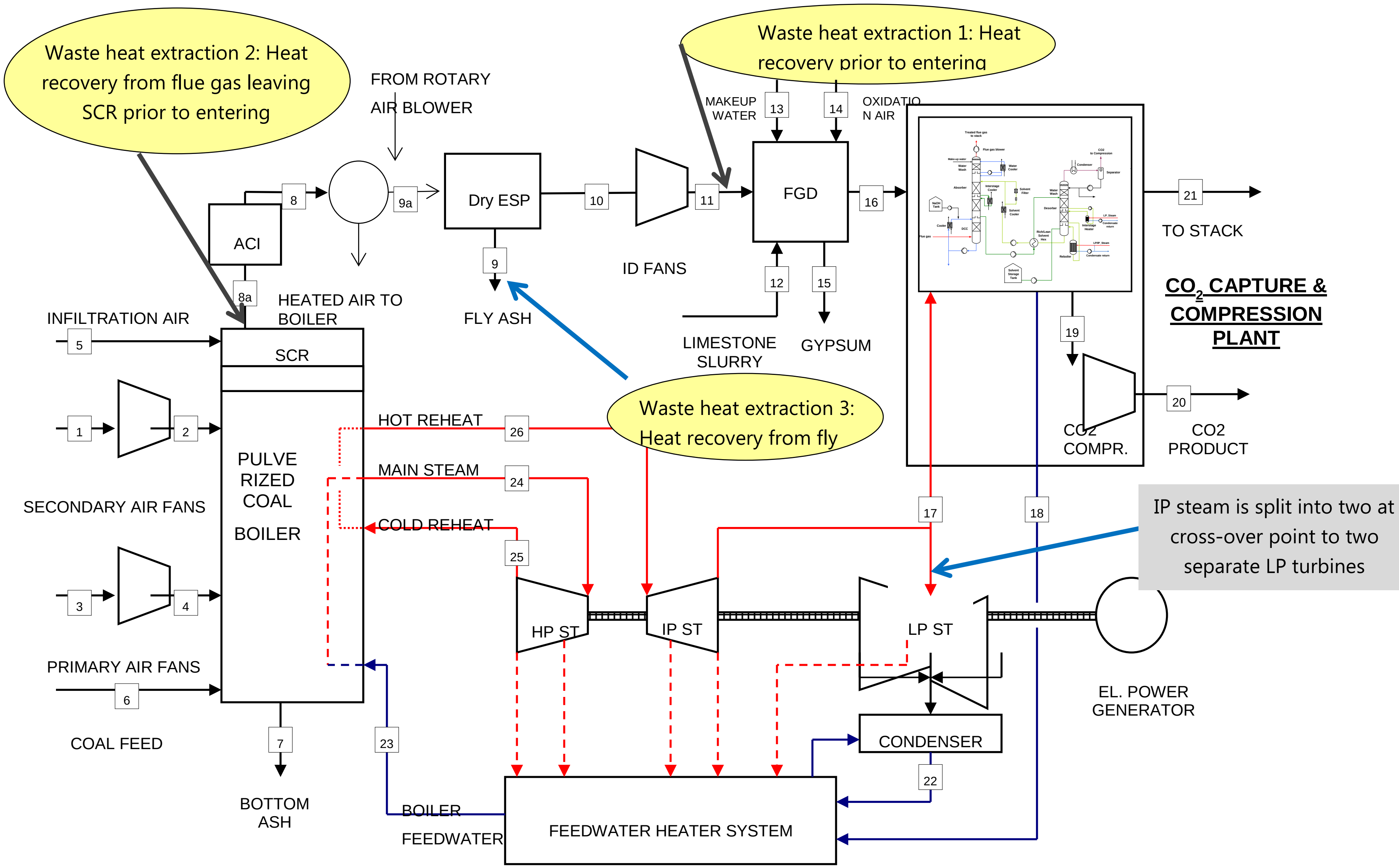


**Figure 1.** Block Flow Diagram of power plant showing potential sources of waste heat for extraction and use in PCC plant to generate low pressure steam

**Significant Results/Key Outcomes:**
Based on a target capture rate of 7,500 metric tonnes per day of captured $CO_2$ at Westar's Jeffrey Energy Center, 360 tonnes/hour of low pressure (LP) steam is required for solvent regeneration in the Linde-BASF post combustion carbon capture system using a novel amine solvent called OASE® blue. The available heat that could potentially be obtained from the three heat recovery options was used to calculate the amount of LP steam that could be generated under each scenario. This was then compared against the LP steam requirements of 360 tonnes/hour for the Jeffrey Energy Center case. The results are given in Table 1, along with the challenges that each option presents.

**Table 1.** Waste heat extraction and utilization options at Westar's Jeffrey Energy Center

| | Waste Heat Recovery Option | LP steam from waste heat (tonnes/hour) | Challenges for Heat Extraction |
|---|---|---|---|
| #1 | Flue Gas Upstream Flue Gas Desulfurizer | 42 | Low flue gas temperatures can cause acid condensation of SOx, which would require more expensive materials of construction |
| #2 | Downstream Selective Catalytic Reactor (SCR) but upstream Activated Carbon Filter (ACI) | 613 | Some of this thermal energy is required for preheating air for coal combustion |
| #3 | Fly Ash Waste Heat Recovery | < 1 | Solid/gas heat exchange is a technical challenge. Significant capex required for low thermal energy extraction. |

The results indicate that option 2 presents the most attractive option for the Jeffrey Energy Center. This opportunity has the potential to provide >100% of thermal energy required for the carbon capture plant's LP steam generation needs. The other two options, 1 and 3, are not able to meet the full LP steam load of the PCC. However, to fully understand the feasibility of these options, the total cost of heat recovery and utilization (CAPEX + OPEX) would need to be compared with the cost of utilizing steam from the existing IP-LP (intermediate pressure to low pressure) crossover at 700°F. This is the current method for obtaining LP steam for solvent generation in post-combustion capture (PCC) plants, although it affects the power plant efficiency and reduces the total power production.

**Goals and objectives for the next Quarter:**
During the next quarter, the team will evaluate the cost associated with each heat recovery option and compare this against the current practice for LP steam generation in PCC plants. The team will also perform an analysis of aerosol mitigation options that may be applicable to Westar's Jeffrey Energy Center to address the other identified possible challenge for $CO_2$ capture.

**Products for Subtask 3.1:**
Table illustrating challenges and possible mitigation plans for capture from two $CO_2$ source sites.

## Subtask 3.2 - Identify challenges and develop a plan to address challenges for CO2 transportation and injection (non-technical)

## Subtask 3.3 - Identify challenges and develop a plan to address challenges for $CO_2$ storage in geologic complexes (non-technical)

**Note** - The SOPO combined technical and non-technical aspects of the Phase I project in Task 3, in particular Subtasks 3.2 and 3.3. To simplify for reporting and for the reader, the technical and non-technical are discussed separately. Furthermore, the non-technical subject matter pertaining to Subtasks 3.2 and 3.3

have considerable overlap and will be combined for this and future reports.

**<u>Non-Technical Section:</u>**

**Overview:**

The ICKan Legal, Regulatory and Public Policy team (LRPP), is comprised of attorneys from Depew Gillen Rathbun & McInteer, public policy experts from Great Plains Institute and the Kansas Geological Survey outreach manager. In this quarter they (1) further identified key non-technical challenges for transportation, injection, and storage, (2) met with other legal and geology personnel on approach to get their ideas, (3) met with KDHE on project, and (4) presented initial ideas on possible strategies for implementation at a CO2 Capture, Utilization, and Storage (CCUS) for Kansas workshop and obtained feedback from regulators, policy makers, and stakeholders.

**Significant activities in the reporting period for Subtasks 3.2 and 3.3 include the following:**

- Stover met with KGS staff and consultants that worked to obtain a Class VI well permit under a current contract (DE-FE0006821). They explained their experience and ultimately, the barriers to their obtaining a permit.
- Steincamp discussed legal models for CO2 transport and storage with Professor David Pierce, Washburn Law School, and Dr. Kempton and Dr. Raef, Geology Dept, Kansas State University.
- Stover, Bidgoli, Holubnyak, and Dubois met with the Kansas Department of Health and Environment Division Director and others on August 10, 2017, to review study. Although KDHE does not regulate activities associated with oil and gas, they do administer the UIC program (all except Class II wells), and regulate air quality. Concern was expressed by KDHE that that how CO2 storage is characterized could have implications on how hazardous waste is characterized and permitted for disposal in underground saline aquifers.
- KGS co-hosted with Great Plains Institute the CCUS for Kansas workshop, held in Wichita, Kansas, September 21, 2017.
    - The workshop invitation list brought together a diverse group of about 50 representing utilities (coal-fired power), refineries, oil and gas producers, ethanol producers, mid-stream pipeline companies, NGOs, policy makers, regulators, engineers and scientists. This included State Representative Mark Schreiber, a former biologist and lobbyist for a public utility, that now serves on the House Energy Committee. Also staff for U.S. Congressman Ron Estes and Congressman Roger Marshal. Their two congressional districts cover the majority of Kansas areas that would utilize CO2 in enhanced oil recovery and potential reservoir sites. They also expressed interest in possibilities for a market use of CO2 from refineries and ethanol plants. The workshop agenda and attendee list are provided in Appendix XXX. Presentations from the meeting are also available on the ICKan project page (http://www.kgs.ku.edu/PRS/ICKan/presentations.html

    - Steincamp presented a proposed public utility model for transportation and geologic storage at the workshop. Good discussion followed with a variety of ideas and feedback. Follow up meetings were proposed with the Kansas Corporation Commission and Kansas Department of Health and Environment.

    - Several State Legislators that were unable to attend the CO2 Capture and Utilization in Kansas Workshop asked to be kept informed as the study progressed. One State Legislator that chairs the House Water and Environment Committee is open to introducing legislation to facilitate CCUS at the appropriate time.

**Goals and objectives for the next Quarter** (non-technical)**:**

- Continue discussions with the State regulatory agencies Kansas Corporation Commission and Kansas Department of Health and Environment on proposed statute and public utility model for transportation and/or geologic storage.
- Meet with a senior advisor to EPA Secretary Pruitt on the challenges with Class VI permitting process and monitoring requirement.
- Teleconference with Illinois State Geological Survey scientist on their experience with Class VI well permit, which was ultimately successful.
- Examine KSA 74-623 for Kansas Corporation Commission's authority to regulate oil and gas activities, as it might extend to CCUS, including enhanced oil recovery.

**Products for Subtasks 3.2 and 3.3** (non-technical)**:**

No new products in this past quarter.

**<u>Technical Section:</u>**

### Subtask 3.2 - Identify challenges and develop a plan to address challenges for $CO_2$ transportation and injection *(Technical)*

The likely mode of transportation for large-scale CCS is via pipelines. Because of the long history (40+ years) of CO2 transportation, and even a longer history of transporting high pressure natural gas, there are no significant technical challenges to transporting CO2 via pipelines. Non-technical challenges are covered separately.

**Summary of significant activities**: None to report
**Significant Results/Key Outcomes:** NA
**Goals and objectives for the next Quarter:** NA

### Subtask 3.3- Identify challenges and develop a plan to address challenges for $CO_2$ storage in geologic complexes *(Technical)*

**Summary of significant activities**:

- Key risks were defined for the Lakin Field, part of the Pleasant Prairie Complex during the process of the high-level technical evaluation.

**Significant Results/Key Outcomes:**

- The Lakin field portion of the Pleasant Prairie Complex is capable of storing in excess of 30 Mt CO2, based on a high-level technical evaluation and reservoir simulation. Optimization and additional simulations should demonstrate more storage capacity.

**Goals and objectives for the next Quarter:**

- Develop plans to address risks for geologic sites it is has been determined they have the capacity to store >50mT CO2.

## Task 4.0 – Perform a high level technical sub-basinal evaluation using NRAP and related DOE tools

### Subtask 4.1 - Review storage capacity of geologic complexes identified in this proposal and consider alternatives

In the proposal we identified three possible sites in two complexes that were in various stages of analysis and each appeared to meet the 50+Mt storage requirement. Post award, they were to be evaluated further and a survey of other potential geologic structures were to be screened and evaluated for suitability.

**Overview:**
Two geologic complexes identified in the proposal as potential sites for storing >50 million tonnes (Mt) are the Pleasant Prairie field geologic site in the Hugoton Embayment storage, considered the primary storage site, and the Davis Ranch and John Creek fields, in the Forest City Basin (FCB) storage complex, considered a secondary site (Figure 2). Prior to applying for funding for this project the Pleasant Prairie site was estimated to have a capacity of 170 Mt and, in combination, the Davis Ranch and John Creek, an estimated 50Mt capacity. In the last Quarterly Report we documented that the FCB geologic complex was probably not capable of storing 50Mt CO2. Reservoir simulations suggest the volume of CO2 capable of being stored is more on the order of 25Mt. Alternatives to the two geologic complexes selected for this project were sites identified by a recent regional characterization study under DE-FE0002056. The study completed in 2015, identified nine potential sites capable of storing >50 Mt.

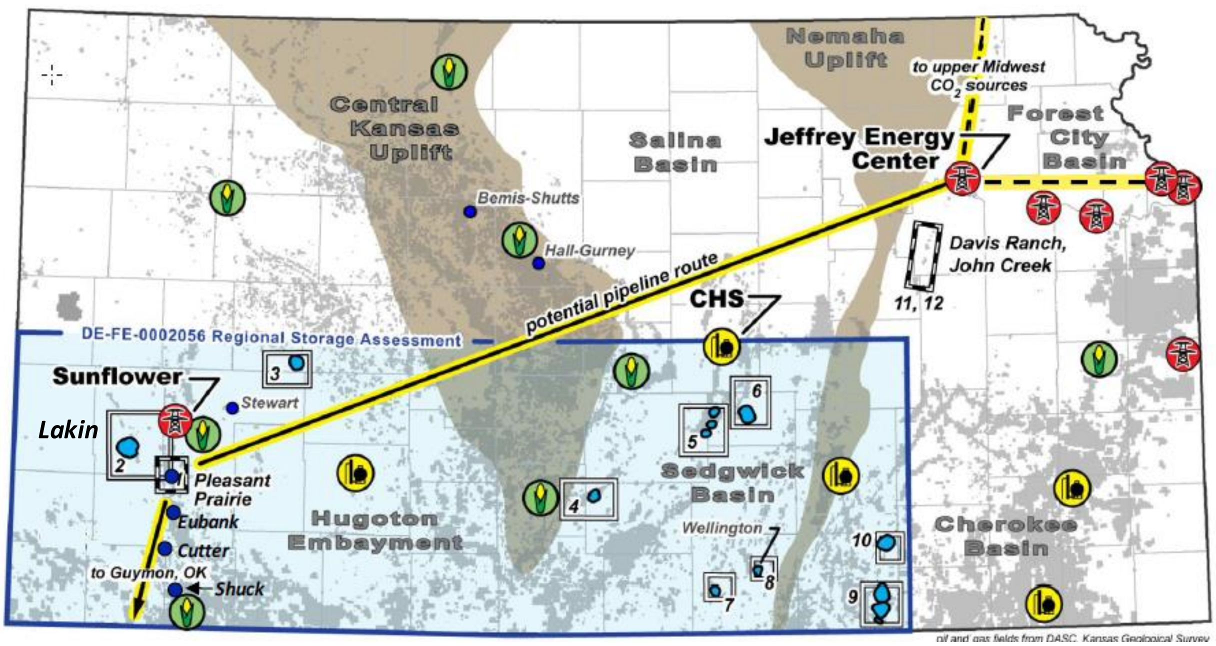


**Figure 2.** Kansas map showing possible $CO_2$ injections sites (numbered 1-12), $CO_2$ sources, possible CO2 pipeline routes, DE-FE0002056 study areas (blue), and oil fields. The Lakin Field is site 2 located inside a box in the southwest part of Kansas. (modified from ICKan proposal SF 424 R&R, 2016).

**Summary of significant activities:**

- The Lakin field structure, identified by the DE-FE0002056 regional study and considered as an alternative site was characterized, modeled and simulated for storage capacity and injectivity (Figure 3).
- Data gathering and 2D modeling of the Pleasant Prairie site was completed.
- Nine alternative sites identified in the completed DE-FE0002056 were reviewed and prioritized (Figure 3).

**Significant Results/Key Outcomes:**

- A high-level evaluation of the storage capacity and injectivity in saline aquifers beneath the Lakin Field structure revealed that the storage capacity is in excess of 30Mt. After optimization it is believed that the capacity could meet the 50Mt requirement by itself. The Lakin Field is located seven miles northwest of the larger Pleasant Prairie Field, and may be considered part of the Pleasant Prairie storage complex (Figure 4). Please see discussion of modeling and simulation results under Subtask 4.2.

- In the prior quarter, nine alternative sites capable of storing 50 Mt CO2 identified in the completed DE-FE0002056 were narrowed to four for further study, sites numbered 6, 7, 4, and 8 in Figure 3. Site number 7 was eliminated from serious consideration because, after 2D mapping and data review, it was determined that it would be difficult to demonstrate a high probability that the site could store 50Mt. Site number 6, the Lakin Field Site was evaluated for capacity and injectivity in the quarter being reported (see Subtask 4.2).

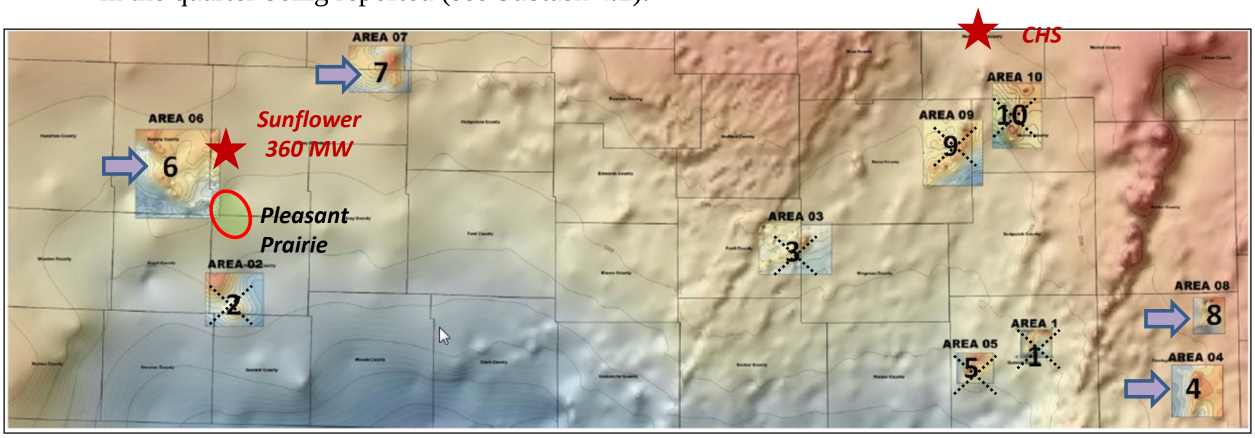


**Figure 3.** Location of alternate CO2 storage sites (arrows) being evaluated (modified from Watney et al., 2015).

**Goals and objectives for the next Quarter:**

- The primary goal for the next quarter is to confirm storage capacity of >50Mt in the Pleasant Prairie.

**Products for Subtask 4.1:**

- Preliminary characterization and modeling study of the Lakin Field structure outlined in this Quarterly report.

## Subtask 4.2 - Conduct high-level technical analysis of suitable geologic complexes using NRAP- IAM-CS and other tools for integrated assessment

The KGS shall evaluate candidate storage complexes in terms of capacity, seal, faults, seismicity, pressure, existing wellbores, and injectivity.

**Summary of significant activities**:
Table 2 summarizes activities and work completed by the ICKan technical team related to Subtasks 4.1 and 4.2.

- The Lakin Field geologic structure was characterized, modeled and simulated for storage capacity and injectivity. Technical risk work on water geochemistry was completed, and progress was made on seal petrophysics and fault leakage risks.
- Work progressed on the high-level technical analysis on the Pleasant Prairie site, including completion of data gathering, 2D modeling, brine geochemistry, seal Petrophysics, and fault leakage risks.

| | FCB - Davis Ranch and John Creek | Plesant Prairie | Lakin |
|---|---|---|---|
| **Volumetric capacity** | | | |
| Data gather and process | complete | complete | complete |
| Well log anslysis and tops | complete | complete | complete |
| Petrophysics | complete | complete | complete |
| 2D models | complete | complete | complete |
| 3D models | complete | Q3 | complete |
| Volumetric (capacity) | complete | Q3 | complete |
| Simulate for injectivity | complete | Q3 | complete |
| **Technical risks** | | | |
| Seals - geochemistry | complete | complete | complete |
| Seals - petrophysical | *NA* | partial (Q3) | partial (Q3) |
| Fault leakage | *NA* | partial (Q3) | partial (Q3) |
| Seismicity | *NA* | Q3 | Q3 |
| Wellbores | *NA* | Q3 | Q3 |
| **Implementation Plan** | | | |
| Injection plan | *NA* | Q4 | Q4 |
| Monitor plan | *NA* | Q4 | Q4 |

**Table 2**. Summary of technical analysis activities and work completed on potential geologic sites. Shaded entries are work in this reporting quarter (Project Q2) Partial indicates work was accomplished, but not completed in Q2. Q3 and Q4 indicates the project quarter when the work is to be completed. NA indicates analysis that will not be completed because the site was determined incapable of storing 50Mt $CO_2$.

## Significant Results/Key Outcomes:

### Lakin Field structure high-level technical analysis:

The high-level technical analysis of the Lakin Field structure helps to confirm that it is a site that could be considered individually or in combination with the nearby Pleasant Prairie geologic site. The simulation documented in this report indicates that at least 30 Mt could be injected in a relatively short period (25 years) and stored within the three target zones (Osage, Viola, and Arbuckle). With slight modifications and extending the injection period the stored CO2 volume could exceed the 50Mt target. The Lakin and the larger Pleasant Prairie Geologic site could be considered as part of the same Storage Complex and may be combined for Phase II.

***Setting***

The Lakin Field is situated in southwest Kansas, seven miles northwest of the Pleasant Prairie field (Figures 2). The two structures (Figure 4) could be considered part of the same storage complex as they are along a prominent northwest-southeast structural trend, have the same geologic history, and the same saline aquifer reservoirs beneath them. Three stratigraphic intervals are considered for CO2 storage, the Mississippian Osage, Middle-Ordovician Viola, and Cambro-Ordovician Arbuckle (Figure 5). All three have regional lateral extent and appear to be separated by vertical barriers to fluid migration (Spergen, Kinderhook, and Simpson dense carbonate and thin shales). The Morrow shale (Pennsylvanian) on top of the Meramec (Mississippian) is a regional top seal for the oil and gas accumulations in the Mississippian.

Saline aquifer reservoirs in the Osage and Viola consist of thick (>100ft), vertically continuous, laterally extensive porous carbonate, primarily medium-crystalline sucrosic dolomite with good intercrystalline porosity and varying amounts of chert. The Arbuckle storage reservoir consists of stacked thin intervals of porous dolomite separated by thin intervals of tight carbonate. Although they do not appear to be well-connected vertically, drill stem tests, albeit limited in number prove otherwise with fluid recoveries averaging over 2000 feet of saltwater in one-hour flow tests.

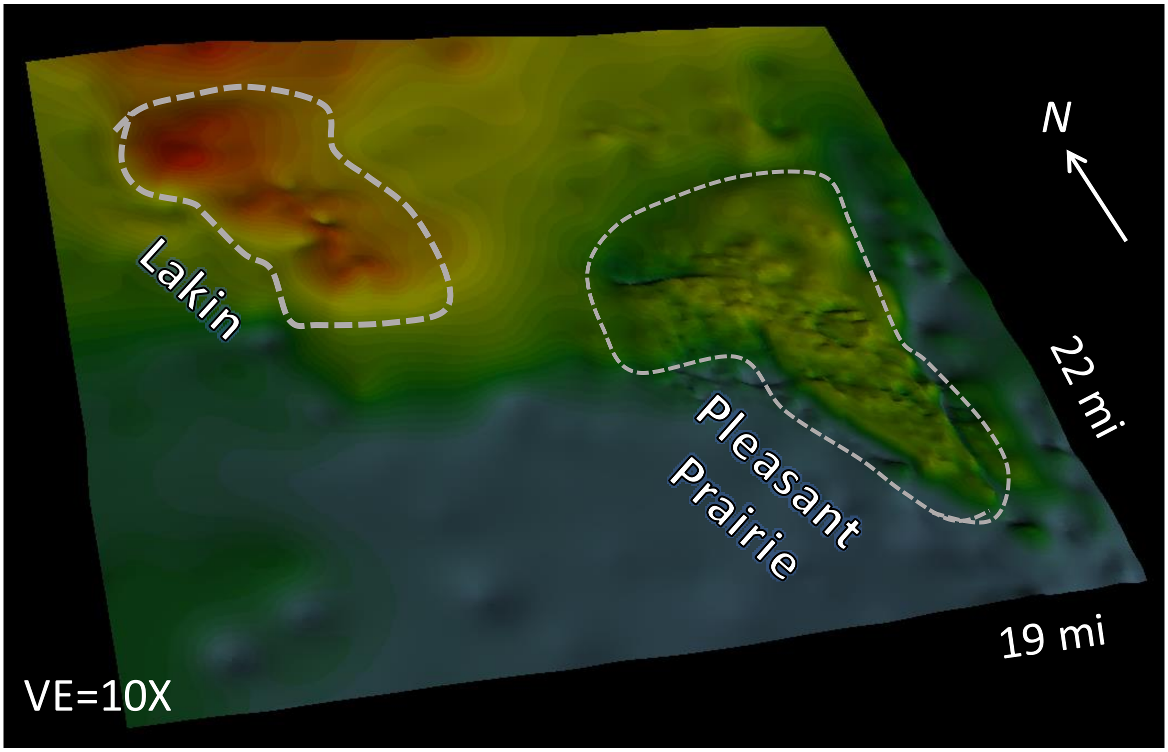


**Figure 4.** Structure map on top of the Meramec (Mississippian) covering parts of Kearny, Finney, and Haskell Counties, Kansas.

***Workflow***
A simple, un-faulted 3D static model was built for a 557 mi^2 (1442 km^2) area and then a smaller area was cut out of the model for simulation (Figure 6). A standard workflow (Figure 7) for building a 3D static model was deployed: 1) gather, prepare and analyze well-scale well data from public sources and operator-partner data, 2) build 2D structure and isopach maps with Geoplus Petra$^{TM}$, 3) develop petrophysical relationships to estimate permeability knowing porosity, 4) build a larger-area 3D static property model populated with porosity and permeability for the Osage, Viola and Simpson, 5) upscale the model to reduce cell counts for simulation, and 6) cut out and export smaller field-scale model for simulation.

There are 305 wells deeper than 4,500 ft in the model area (depth filtered to exclude shallow Hugoton gas wells) (Figure 8). Of these, 304 wells contain formation top data including manually picked tops from the depth-calibrated wireline log images at 164 wells. There are 211 wells with picked tops penetrating Mississippian strata, 60 wells penetrating the Spergen Limestone, 26 wells penetrating the Warsaw, 13 wells penetrating the Viola, and 8 wells penetrating the Arbuckle. Figures 7a through 7e identify well penetrations per formation in the modeling area and 7f identifies 18 wells with modern logs that penetrated at least the Osage and were the basis for the porosity and permeability models.

***Petrophysics***
Estimating permeability for in the Lakin and Pleasant Prairie is constrained by the lack of core data in the key saline aquifer reservoirs and sealing caprock intervals. The nearest set of core data for the key intervals

is from the Berexco KGS-Cutter 1 well, approximately 25 miles south of the Lakin Field (Watney, et al., 2015). In the KGS-Cutter well portions of the key intervals, Osage, Kinderhook, Viola, Simpson, and to a greater extent Arbuckle, have extensive core petrophysical data as well as an NMR log.

A fairly simple, straightforward approach was taken for obtaining porosity-permeability transforms for wells with modern digital well logs, triple-combo type logs, suitable for Techlog's multi-mineral analysis and porosity estimation.

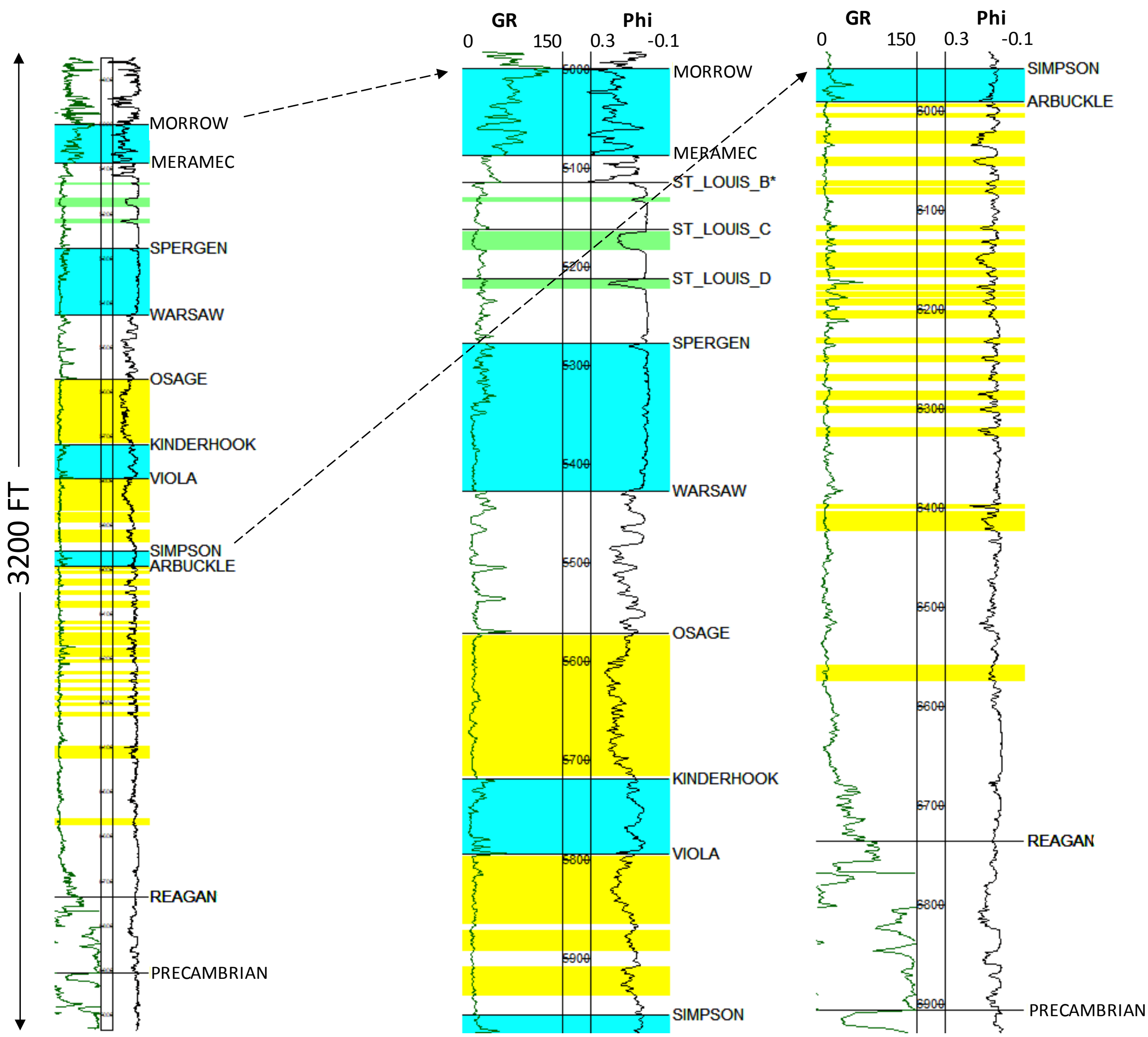


**Figure 5.** Generalized stratigraphic column for the Pleasant Prairie and Lakin Filed area. The wireline log is from the Helmerich & Payne Inc. USA A-16 well (PI 15-055-20536) in the Pleasant Prairie Field. The image on the left covers the entire 3200-ft interval of interest and the two on the right represent the same interval at a larger scale. Three possible storage intervals have porous intervals highlighted in yellow, the main seals are in blue, and the main oil pay zones are highlighted in green. Abbreviations included GR – natural gamma ray radiation in API counts, Phi – multi-mineral porosity expressed in decimal fraction.

1. Derive Coates permeability from NMR logs in the Cutter-KGS 1 well for intervals from the Spergen through the Arbuckle.
2. Compare Coates permeability with core permeability for calibration - satisfactory.
3. Develop porosity-permeability relationships by cross-plotting and fitting a mathematical curve (K-Phi transform) for the Osage, Viola, and Arbuckle.
4. Apply the K-Phi transform to 18 wells with digital curves in the Lakin-Pleasant Prairie area having appropriate digital well logs in at least the uppermost saline aquifer candidate, the Osage.

Several different approaches and transforms were evaluated before settling on the three shown in Figure 9.

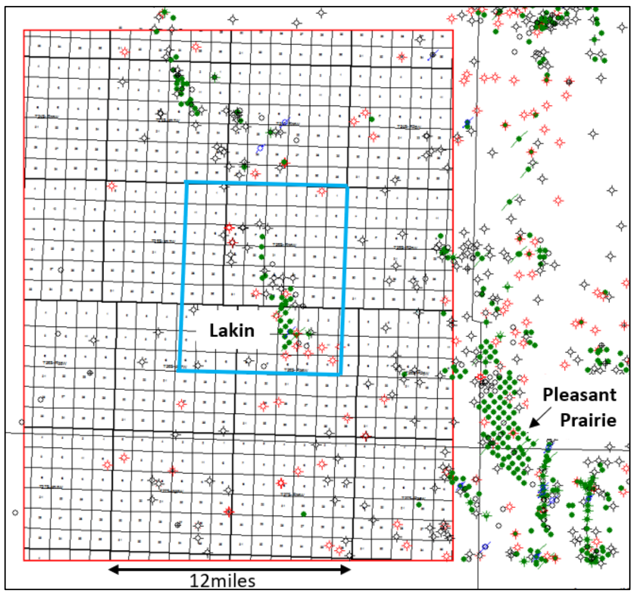


**Figure 6**. Lakin Field model area. Larger 3D modeled area is outlined in red. The cutout that was exported for simulation is outlined in blue.

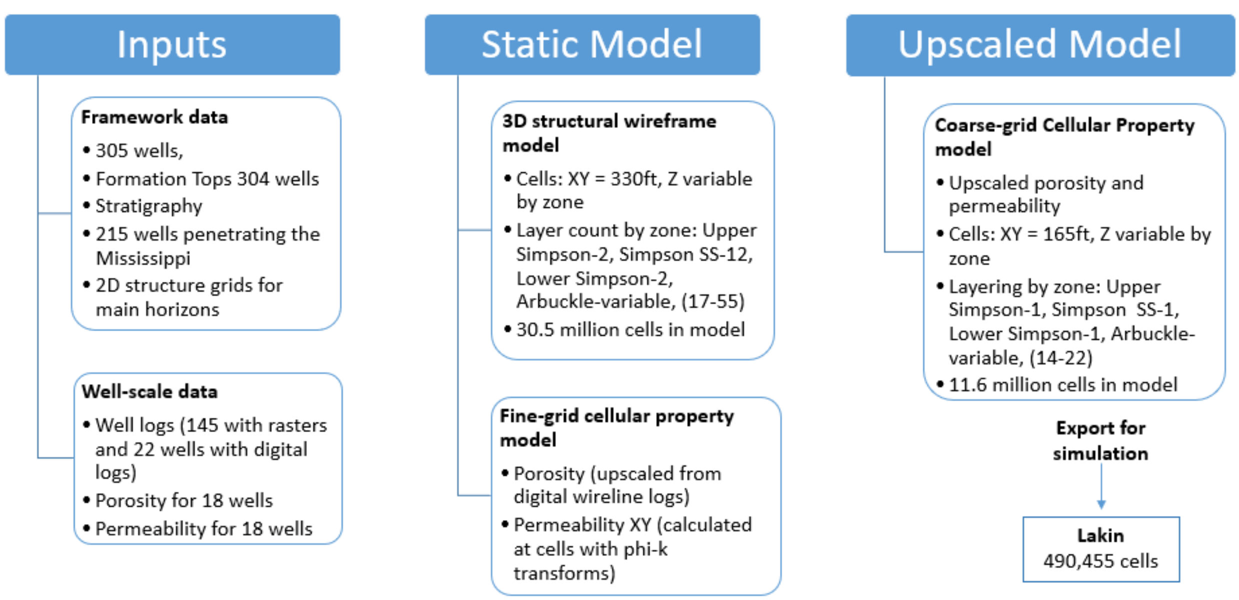


**Figure 7.** Workflow diagram

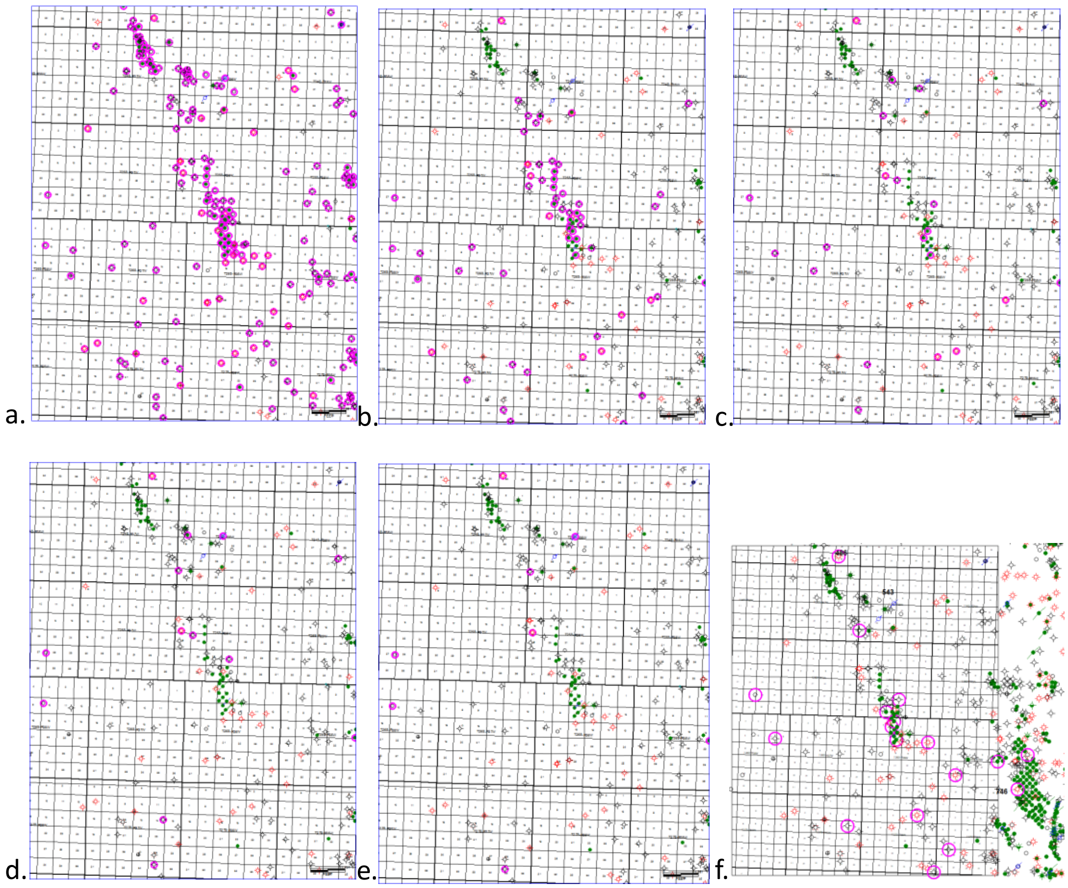

**Figure 8.** Well penetrations with tops by formation inside model area. Wells are highlighted with circles: a. 211 Meramec Tops, b. 60 Spergen Tops, c. 26 Warsaw Tops, d. 13 Viola tops, e. 8 Arbuckle tops, f. 18 wells with digital log curves in LAS format, 16 within the model area, two others in Pleasant Prairie.

***3D static model***

The three target $CO_2$ injection zones Osage, Viola and Arbuckle, were modeled for evaluating injectivity and capacity for storing $CO_2$. The caprock and sealing intervals above and between the injection zones were less rigorously modeled. Data was gathered and processed in Geoplus Petra$^{TM}$ and then imported into Petrel$^{TM}$ for 3D cellular modeling. Because of 1) the high density of the data in the Meramec and Spergen, 2) the conformance of the structure on the target zones below, and 3) the limited penetrations below the Spergen, a Meramec structure 2D grid was constructed and the structure of the horizons below were generated by grid-to-grid operations with isopachous grids. Well-scale porosity at the half-foot was upscaled to layer-scale in the fine grid model, and the cells between the wells were modeled using Gaussian random function simulation. Permeability was calculated at the cell scale using the transform functions in Figure 9. The large-area model was then upscaled for simulation (Figure 10) and the field-scale area was cut out and exported in a rescue format for simulation (Figure 11).

***Simulation model***

The key objectives of the dynamic modeling were to determine the volume of $CO_2$ stored, resulting rise in pore pressure and the extent of $CO_2$ plume migration in the Lakin filed structure. Simulations were conducted using the Computer Modeling Group (CMG) GEM simulator, a full equation of state compositional reservoir simulator with advanced features for modeling the flow of three-phase, multicomponent fluids that has been used to conduct numerous CO2 studies (Chang et al., 2009; Bui et al., 2010).

Initial reservoir conditions and simulation constraints

The initial conditions specified for the model are listed in Table 3. The simulations were conducted assuming isothermal conditions. Although isothermal conditions were assumed, a thermal gradient of 0.008 °C/ft was considered for petrophysical properties that vary with layer depth and temperature such as CO2 relative permeability and CO2 dissolution in formation water. The original static pressure in the injection zone was set to reported field test pressures and the Arbuckle pressure gradient of 0.48 psi/ft was assumed. The perforation zone was set at the top 35 ft in the three injection intervals: Osage, Viola, and Arbuckle. The injection rate was assigned according to maximum estimated from well tests and reservoir properties. Boundary conditions were selected as open Carter-Tracy aquafer with leakage allowed.

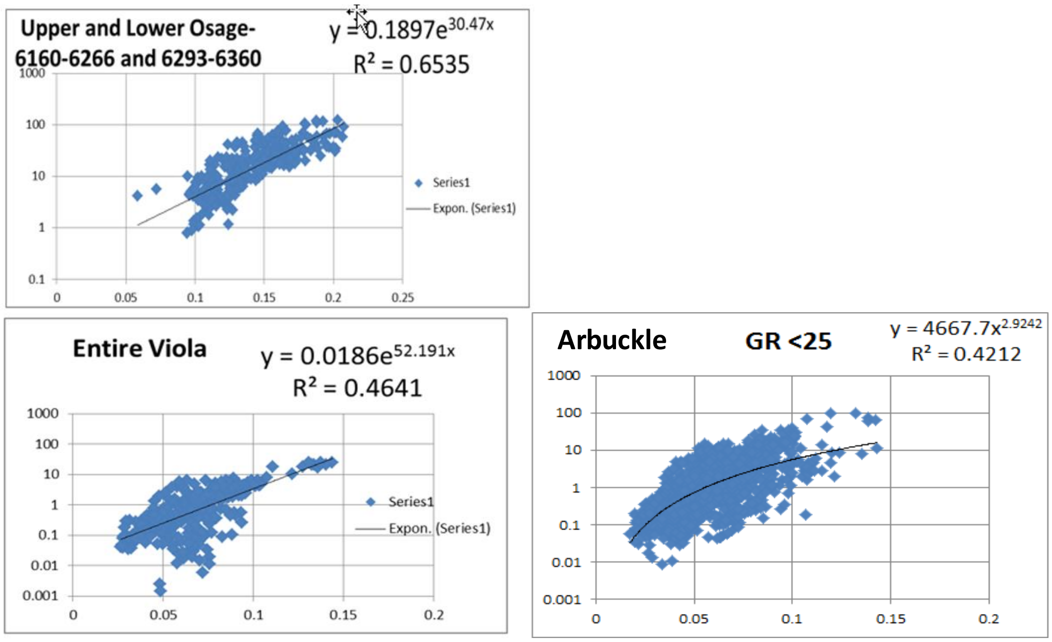


**Figure 9.** Cross plots of multi-mineral phi (x-axis) and Coates NMR permeability (y-axis); and porosity-permeability transform equations for the Osage, Viola, and Arbuckle.

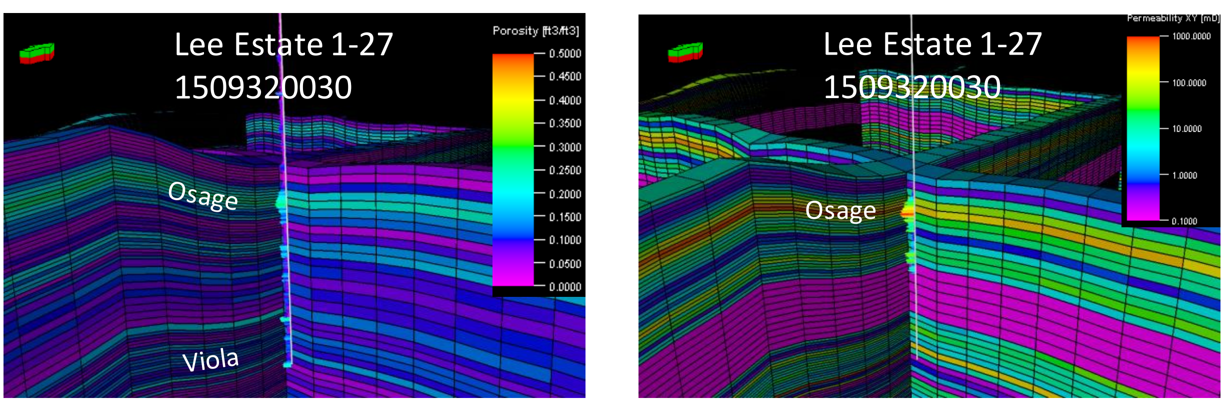


**Figure 10.** Fence diagrams illustrating model porosity (left) and permeability (right). Finley layered model is shown on the left in each panel and coarse grid (upscaled) on the right. Finer scaled, half-ft data is shown by the well log at the intersection of the lines. VE=10

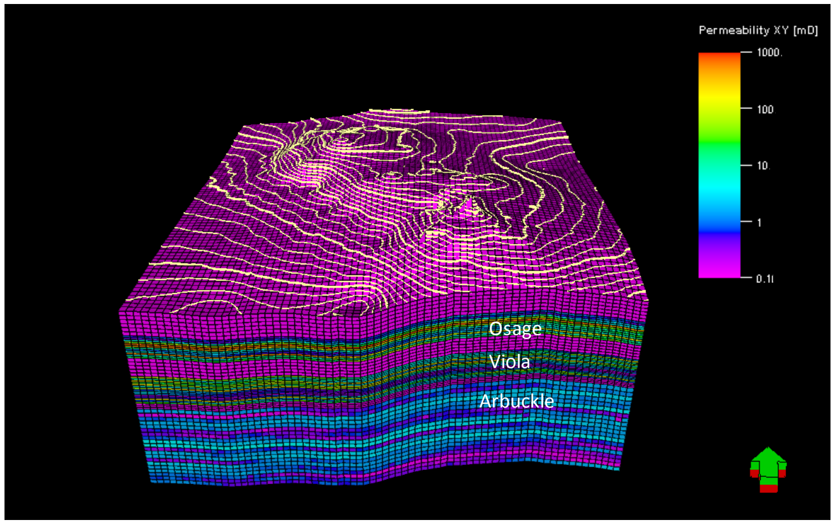


**Figure 11.** 3D view of the Lakin Field cellular model extracted from the larger model. (VE=15, CI=10).

**Table 3**. Model input specification and $CO_2$ injection rates

| Injection Interval | **Osage** | **Viola** | **Arbuckle** |
|---|---|---|---|
| Temperature | 60 °C (140 °F) | 61 °C (142 °F) | 62 °C (144 °F) |
| Pressure | 1,650 psi (11.38 MPa) | 1,670 psi (11.5 MPa) | 1,700 psi (11.72 MPa) |
| TDS | 100 g/l | 140 g/l | 180 g/l |
| Formation Top | 5,260 ft | 5,500 ft | 5,740 ft |
| Formation Base | 5,400 ft | 5,700 ft | 6,340 ft |
| Perforation Zone | | Top 35 ft | |
| Injection Period | | 25 years | |
| Injection Rate | 1500 T/day | 890 T/day | 1060 T/day |
| Total $CO_2$ injected | 13.7 MT | 7.4 MT | 9.7 MT |

Three wells were completed in the main part of the Lakin structure and were "perforated" in the Mississippi Osage, Viola, and Arbuckle. No flow boundary conditions were specified above and below the injection zones as indicated by brine chemistry. Additional work is underway to support these assumptions. CO2 was injected at rates determined by the petrophysical conditions at each injection site and within each perforated interval. The lateral boundary conditions were set as an infinite-acting Carter-Tracy aquifer (Dake, 1978; Carter and Tracy, 1960) with leakage.

Simulation results

Figure 12 shows the maximum lateral migration of the CO2 plume approximately 100 years after cessation of CO2 injection activities at Lakin Field. The plume grows rapidly during the injection phase and is largely stabilized by the end of injection period. CO2 travels throughout the reservoir for additional several years and enters stabilization phase after several years post injection commencement. Significant amount of CO2 (~30%) is dissolved in water over the period of 50 years past injection commencement.

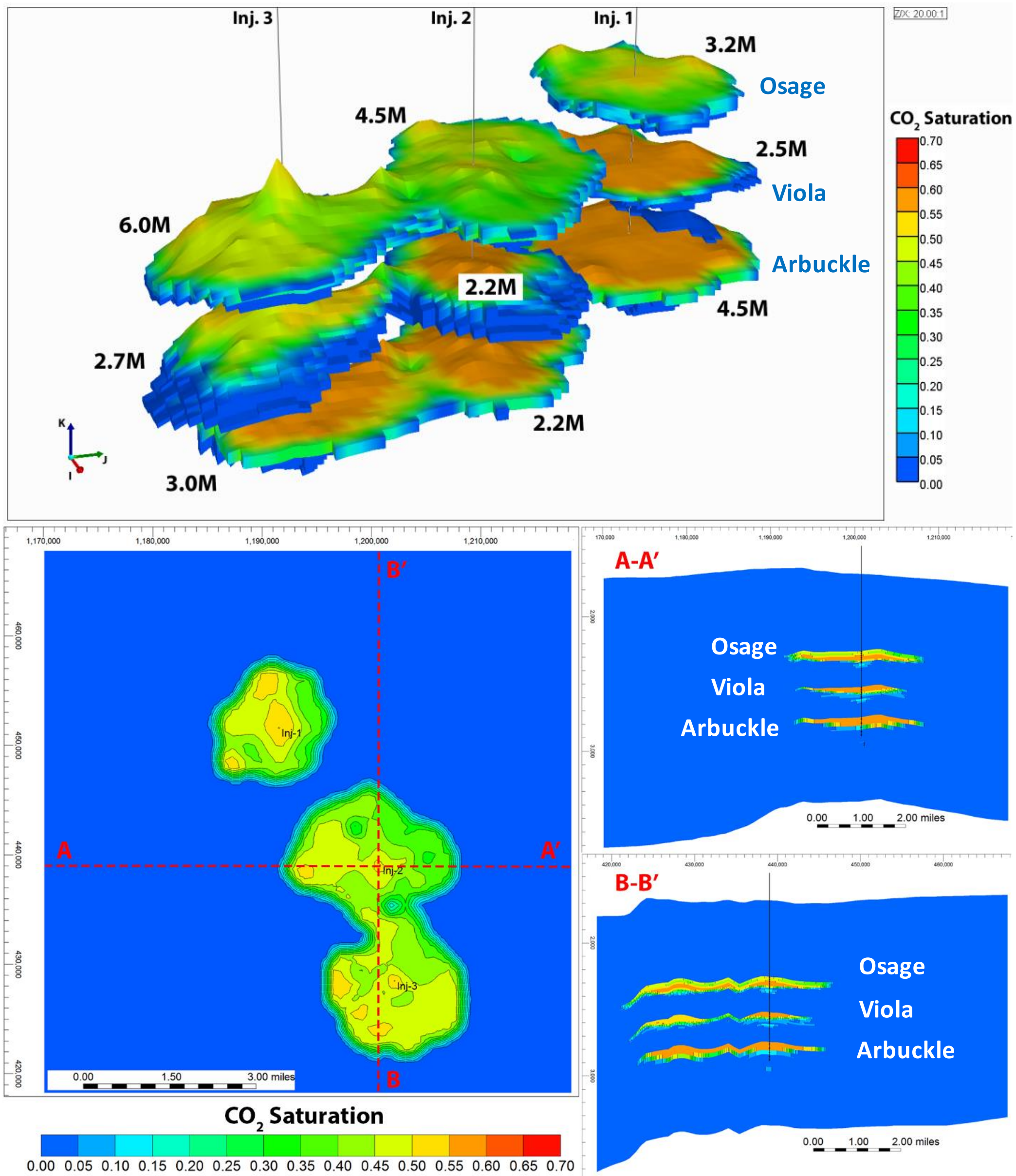


**Figure 12**. Maximum $CO_2$ plume distribution. Top: 3D view of CO2 distribution; bottom: aerial and vertical sections of CO2 plume distribution. Volumes in millions of tonnes (M) per injector and zone are shown in the top figure.

Figure 13 presents the distribution of reservoir pore-pressure at the maximum point of CO2 injection. The pressure increases are estimated to be below 400 psi on commencement of injection and then pressure gradually drops after the commencement of the injection as the capillary effects are overcome. The pressure decreases to almost pre-injection levels after approximately 15-20 years as illustrated in Figure 14.

Figure 15 illustrates modeled maximum injection rates and cumulative injection volumes obtained via injection by 3 injection wells completed at Osage, Viola, and Arbuckle intervals. Maximum combined injection rate for 3 wells modeled for Lakin Field is 3,450 metric tonnes/day. The cumulative injected CO2 estimate for Lakin Field is ~31 M metric tonnes; however, the injection strategy could be optimized to inject even higher amount of CO2 in this field.

Summary/Discussion

Work and results presented are to be considered preliminary. Minimal modifications were performed to optimize the model for maximum storage. Additional modifications would result in higher storage capacity than the 30Mt indicated in Table 2 and Figure 11 perhaps as much as the 50Mt target.

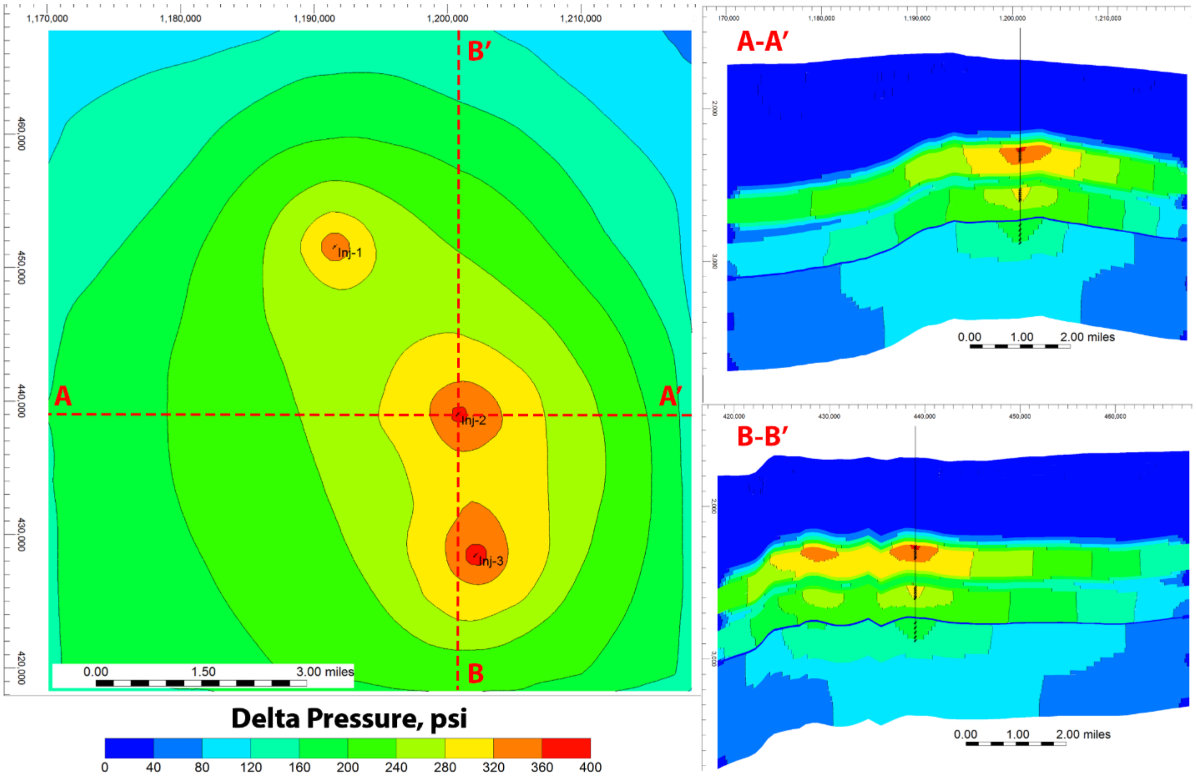


**Figure 13. Maximum reservoir pressure increased as a result of $CO_2$ injection**

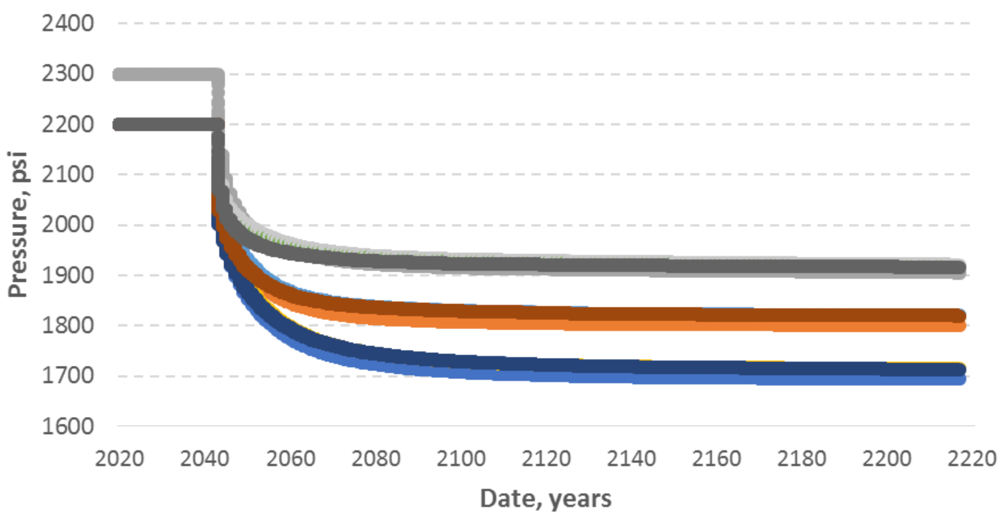


**Figure 14.** Bottom-hole pressure profiles for CO2 injection in three wells and three injection intervals**.**

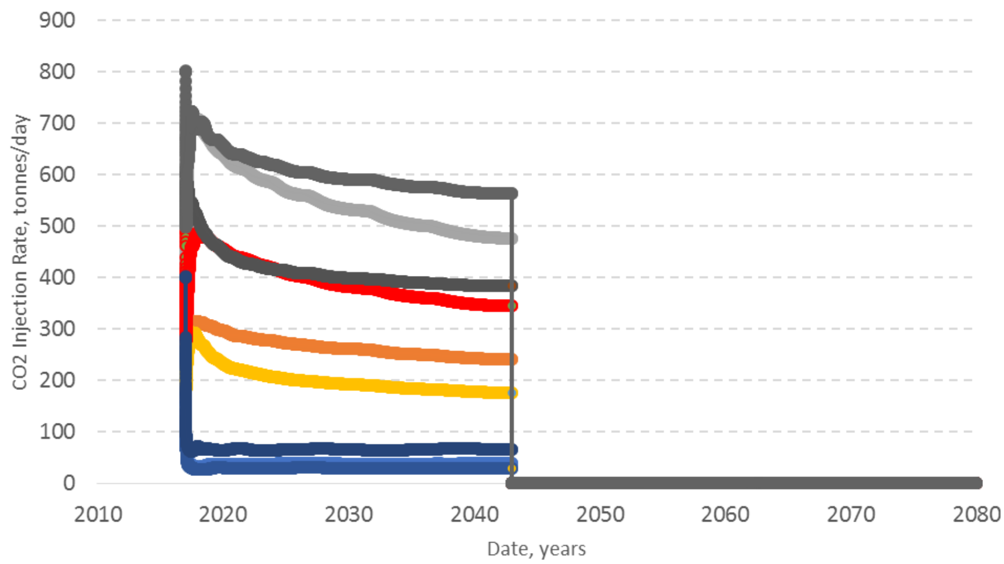


**Figure 15.** CO2 injection rates in three wells and three injection intervals.

***Geochemistry***

Comparison of salinities in the reservoirs at the Pleasant Prairie and Lakin Fields (Figure 16) has utility for inferring the potential for cross-stratigraphic flow, or *leakage*, between reservoirs. Gradually increasing or similar salinity with depth regardless of apparently separate reservoir may indicate communication between reservoirs. Conversely, contrasts in the salinity of the waters in the principal reservoirs of the fields may indicate that the reservoirs are isolated from each other, in that drastic salinity contrasts would not be expected for reservoirs in close hydraulic communication. Salinity contrasts thus may assure that each reservoir will not readily leak when they are separately charged with $CO_2$. Salinity data was therefore examined for the Chester Mississippian, underlying Mississippian carbonates, Viola, Simpson, and Arbuckle reservoirs.

There are four basic sources of information on salinity: the Kansas Geological Survey on-line brine database, chemical analyses of produced water donated by oilfield operators, salinity analyses reported for water recovered in drill-stem tests, and salinity determined from geophysical well logs. For the Pleasant Prairie area, no operator-donated analyses were available.

Sixteen (16) analyses (A though P in (Figure 16) were from DST chlorinity and salinity field measurements. Scans of DST test are available on-line at the Kansas Geological Survey website. Two (2) analyses (Q and R in (Figure 16) were available from the KGS on-line brine database. Salinity measurements from DSTs or swab tests from the KGS Cutter well, 22 miles to the south of Pleasant Prairie Field were available from DOE quarterly reports, via personal communication from Kansas Geological Survey Scientist Mina Fazelalavi. The Cutter #1 well represents the nearest locality where these is a spread of salinity measurements over several geologic formations. The well-log resistivity method (Doveton, 2004) was employed to generate most of the salinity data.

The well-log resistivity method utilizes a rearrangement of the Archie Equation to determine the resistivity of formation water (Rw). Rw is then converted to a salinity measurement (Doveton, 2004). Input into the formula includes a porosity and resistivity measurements, usually averaged over a two-ft vertical interval. The porosity used is an average of the neutron and density porosity measurements. The resistivity measurement is that of the deep induction log, so as to measure resistivity away from the vicinity of the well bore, which is subject to the effects of drilling mud and mud filtrate. Reservoir intervals with >50 API gamma ray units were not used in the analysis (so the effects of shaliness could be avoided), nor were tight zones measured where porosity is <8%. Oil-bearing zones were ignored, so that any resistivity measured in any given reservoir would be due principally to that of the formation water.

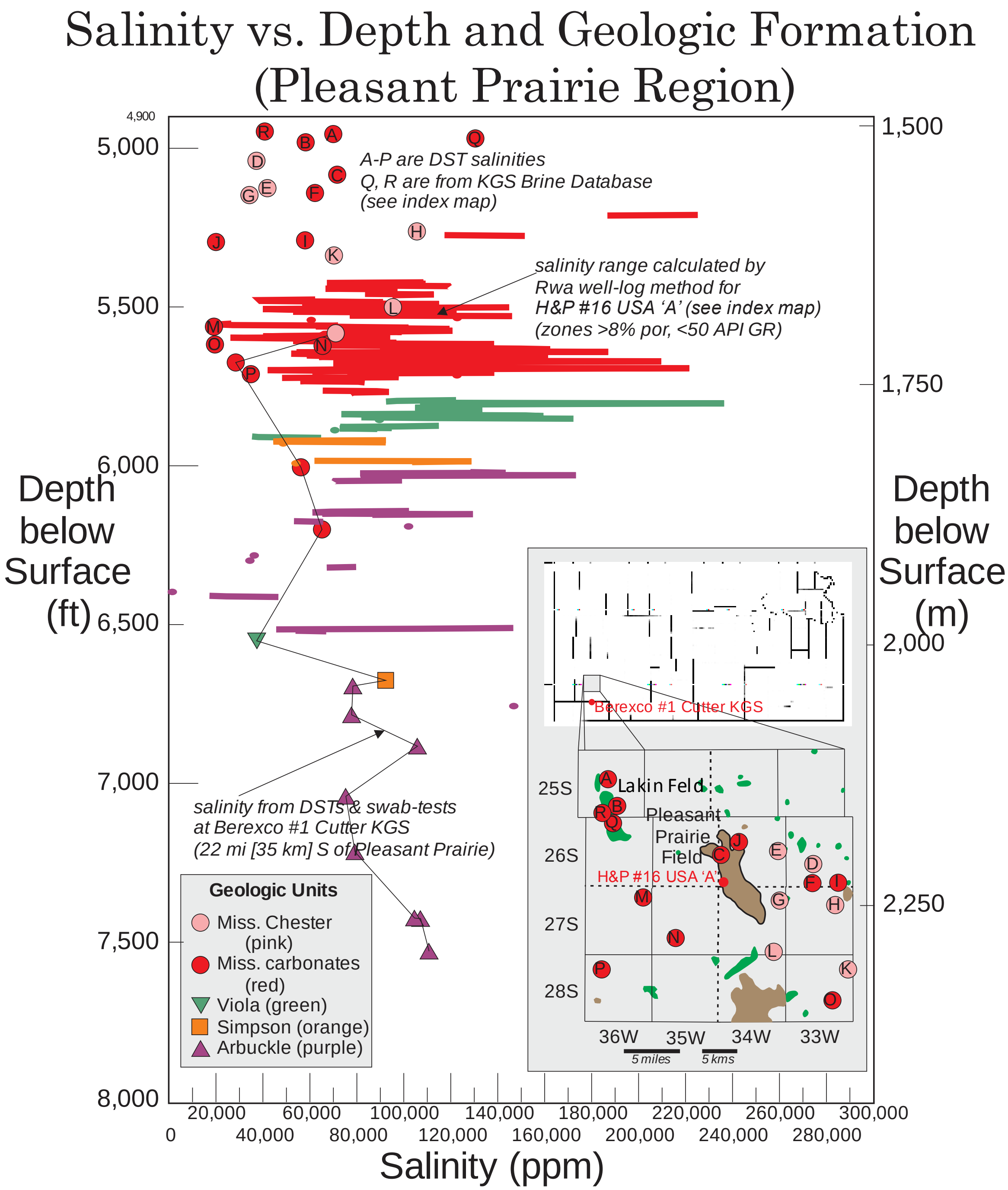


**Figure 16.** Salinity vs. depth of porous zones in the vicinity of Pleasant Prairie Field, southwestern Kansas. Measurements from swab tests and DSTs and production water are designated by geometric figures (circle, square, triangle) whereas calculated salinities from geophysical well logs are smaller dots and lines. Geologic formations are also color-coded.

The well-log salinity measurements at Pleasant Prairie were from the H&P #16 USA 'A' well. Porous carbonates in the Mississippian in this well show drastically varying salinity – from dense basinal brines approaching 200,000 ppm, to dilute brines with ~20,000 ppm salinity – over narrow depth ranges (< 100 ft). Although Upper Ordovician Viola water in the H&P #16 USA 'A' well is generally more saline than Mississippian water, water from the deeper Middle Ordovician Simpson sandstones is less saline than the Viola. The deepest geologic formation examined – the Cambrian-Ordovician Arbuckle - has varying salinity with depth. Several measurements in the Cutter well in the Arbuckle also show varying salinity.

The varying salinity with depth, both sharply within the Mississippian carbonates, and salinity varying between different formations at depth, indicates that there is likely no natural communication between waters in the various porous zones at Pleasant Prairie and Lakin. No susceptibility of natural leakage of sequestered $CO_2$ out of the Mississippian and deeper reservoirs is thus indicated, although impermeable beds between the porous units can be thin.

**Goals and objectives for the next Quarter:**

- Complete an initial draft of high-level technical evaluation for the Pleasant Prairie site. Complete technical risk assessments for the Lakin and Pleasant Prairie sites.

**Products for Subtask 4.2:**
Lakin Field structure high-level technical analysis (capacity, injectivity, seals) presented in this report.

## Subtask 4.3 - Compare results using NRAP with methods used in prior DOE contracts including regional and sub-basin $CO_2$ storage

**Significant accomplishments:** Nothing to report.

**References:**

Bui, L. H., Tsau, J. S., and Willhite, G. P., 2010, Laboratory investigations of CO2 near-miscible application in Arbuckle Reservoir: SPE Improved Oil Recovery Symposium held in Tulsa, Oklahoma, 24–28 April 2010, SPE Publication 129710.

Carter, R. D., and Tracy, G. W., 1960, An improved method for calculating water influx: Petroleum Transactions, AIME, vol. 219, p. 415–417.

Chang, K. W., Minkoff, S. E., and Bryant, S. L., 2009, Simplified model for CO2 leakage and its attenuation due to geological structures: Energy Procedia, v. 1, p. 3,453–3460.

Dake, L. P., 1978, Fundamentals of Reservoir Engineering," Chapter 9, Elsevier Scientific Publishing Co., 1978.

Doveton, J.H., 2004, Applications of estimated formation water resistivities to brine stratigraphy in the Kansas subsurface: Kansas Geological Survey, Open-File report 2004-22, 20 p.

Watney, W.L. et al., 2015, Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas, Final Report, Award Number: DE-FE0002056, submitted October 2, 2015, 4867 p.

Watney, W.L., 2016, Integrated CCS for Kansas (ICKan) SF 424 R&R, Application for Federal Assistance, Phase I - Integrated CCS Pre-Feasibility Study activity under CarbonSAFE, DOE-NETL FOA 1584.

Kansas Geological Survey, 2003, MidCarb CO2 online property calculator, http://www.kgs.ku.edu/Magellan/Midcarb/co2_prop.html. Accessed on July 12, 2017.

## Task 5.0 – Perform a high level technical CO2 source assessment for capture

An assessment of the capture technologies best suited for efficiency, addressing the concerns of the electric utilities and their operating requirements and economic needs will be performed.

### Subtask 5.1- Review current technologies and $CO_2$ sources of team members and nearby sources using NATCARB, Global $CO_2$ Storage Portal, and KDM

The CCS team shall develop an organized electronic clearinghouse of vital information pertaining to the project, ranked by suitability, historical usage records, adaptability, scaling, and demonstration of success, and operations and maintenance requirements.

**Summary of Activities**: None this quarter

**Significant Results/Key Outcomes:** None this quarter

### Subtask 5.2- Determine novel technologies or approaches for $CO_2$ capture

***Goals and Objectives***: $CO_2$ sources shall carefully be evaluated for suitability with new capture technologies. The evaluation will utilize private research including that sponsored by DOE and results of international efforts and projects such as DOE's Carbon Capture Simulation Initiative (CCSI) to determine the suitability and rational for making decisions to pursue or table the technology.

**Summary of Activities**: The Linde team reconsidered the technology options for $CO_2$ capture from both the Westar Jeffrey's Energy Center and the CHS refinery and selected the best fit option for the objectives of the project.

**Significant Results/Key Outcomes:**

Due to the large volumes of flue gas generated at the power plant, the team has determined that a solvent based technology would be the most appropriate candidate for large-scale capture at the Westar's Jeffrey Energy Center. Options for industrial $CO_2$ capture at the CHS Refinery SMR-based hydrogen reformers can be either solvent-based, sorbent-based or membrane applications. To best meet the objectives of the ICKan project to store 2.5 million tons of $CO_2$ per year, solvent based post-combustion capture from the reformer furnace flue gas, shown in Figure 17, presents the best option for maximum $CO_2$ emissions reduction. Thus, for both of these $CO_2$ sources, the Linde-BASF OASE® blue technology for post combustion capture may be the best fit technology for implementation.

However, as was mentioned in the last quarterly report, the refinery is short on steam and sources are distributed throughout the facility. If solvent-based PCC is selected, a new gas-fired boiler would need to be built to generate the low-pressure steam required for solvent regeneration. Additional work is therefore needed to assess the relative costs of the technology applications and determine the most economical choice for the **CHS refinery.** Adsorption-based technologies, although they do not require steam, do require electric power to drive the compressor or vacuum pumps. The ultimate choice of $CO_2$ capture technology for the CHS refinery will consider the availability of steam and power in the reformer as well as the economics of capture.

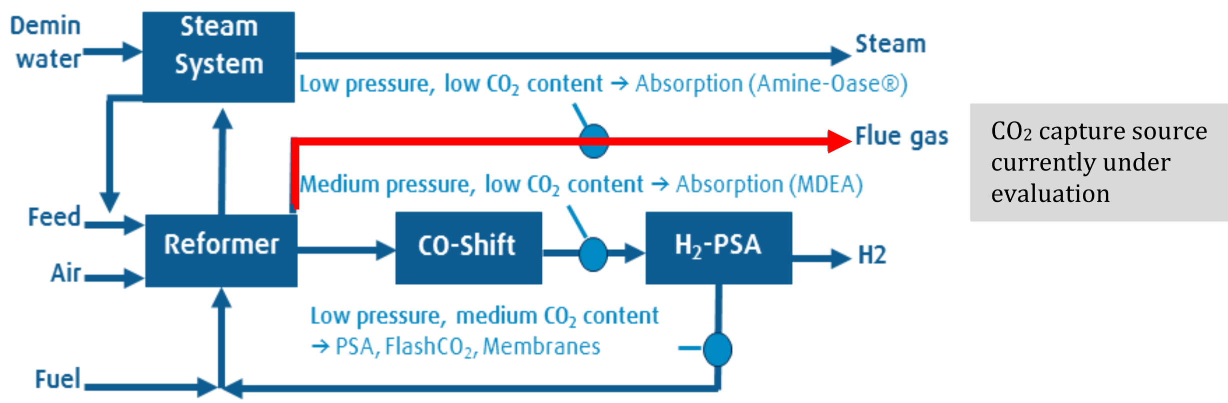


**Figure 17.** Selected $CO_2$ Capture in Steam-methane reformer (SMR) based H2 plants: Solvent, PSA/VSA & membrane applications.

### Subtask 5.3- Develop an implementation plan and strategy for cost effective and reliable carbon capture

**Goals and Objectives**: An optimal CCS plan and strategy that best represents the holistic operating environment and requirements of the $CO_2$ sources will be developed. The team shall develop a means to ensure a mechanism to update and adapt to new disruptive technologies and possibly accommodate them in the design document.

**Summary of Activities**: A preliminary $CO_2$ capture design and assessment was completed by the Linde engineering team for the two potential sources, based on the Linde-BASF novel amine-based technology for post combustion capture.

- Source 1: coal fired power plant, **<u>Westar Energy Company's Jeffrey Energy Center,</u>** St. Mary's, KS
- Source 2: flue gas from 2 SMR (combined PCC), **<u>CHS Inc.'s Refinery</u>**, McPherson, KS.

For both sources, the following deliverables are presented in this quarterly report:

- Overall material balance
- Utility consumption
- Plot space requirement
- 3D plot plan

Additional economic assessment is required to optimize the cost of capture based on the CAPEX and OPEX and these results will be presented in a future quarterly report.

**Significant Results/Key Outcomes:**

Table 4 presents a high-level overview of the results for the proposed $CO_2$ sources. Figure 18 also displays a 3D model plot plan of the proposed PCC plant at the **<u>Westar's Jeffrey Energy Center</u>**. The plant would have a similar design for the **CHS refinery**, although the equipment trains are smaller due to the reduced scale (approximately 1/5$^{th}$ of **Westar's JEC**).

**Table 4.** Overview and comparison of proposed CO2 sources

| | **Westar's Jeffrey Energy Center** | **CHS Inc.'s Refinery** |
|---|---|---|
| ***Flue Gas*** | | |
| Flow Rate, (MT/hr.) wet | 2,063 | 363 |
| Composition, (mol %) dry | $CO_2$ (13.2%)<br>O2 (6.3%) | $CO_2$ (19.1%)<br>O2(2.7%) |
| Capture plant Capacity, ($MW_e$) | 583 (~73% of Unit 1) | ~100 (100% available flue gas) |
| Flue Gas Pressure, (bar) | 1 | 1 |
| Flue Gas Temperature, (◦C) | 60 | 60 |
| ***Product Gas*** | | |
| Captured $CO_2$, (MTPD) | 7,500 | 1,872 |
| Capture Efficiency, (%) | 90 | 90 |
| Product Purity, (mol %) | 99.7+<br>(<100ppmv O2)<br>(<100ppmv H2O) | 99.7+<br>(<100ppmv O2)<br>(<100ppmv H2O) |
| Product Pressure, (bar) | 150 | 150 |
| Product Temperature, (◦C) | <40 | <40 |
| ***Utility Requirements*** | | |
| Regenerator LP Steam, (MTPD) | 8,640 | 2,184 |
| Electrical Power, (MW) | 40.4 | 9.6 |
| Cooling Water, (m3/hr) x 1000 | 36 | 9 |
| ***Plant Configuration*** | | |
| Plot Size, m x m<br>(PCC + compression/drying) | 130 x 150 | 60 x 90 |
| Absorber Height, (m) | 60-75 | 60-75 |
| Stripper Height, (m) | 30-40 | 30-40 |

**Goals and objectives for the next Quarter:**
During the next quarter, the team will perform an economic analysis to optimize the cost of capture based on the CAPEX and OPEX of the Linde-BASF PCC technology. Additional economic evaluation will also be performed to determine the best fit option for industrial $CO_2$ capture at the **CHS refinery**.

**Products for Subtask 5:**

1. Table illustrating results of preliminary engineering and $CO_2$ capture assessment of solvent-based $CO_2$ capture at both potential sites using the Linde-BASF OASE® blue post-combustion capture technology.
2. Figure showing a snapshot of the 3D model of the PCC plant at **Westar's Jeffrey Energy** completed as part of the engineering study.

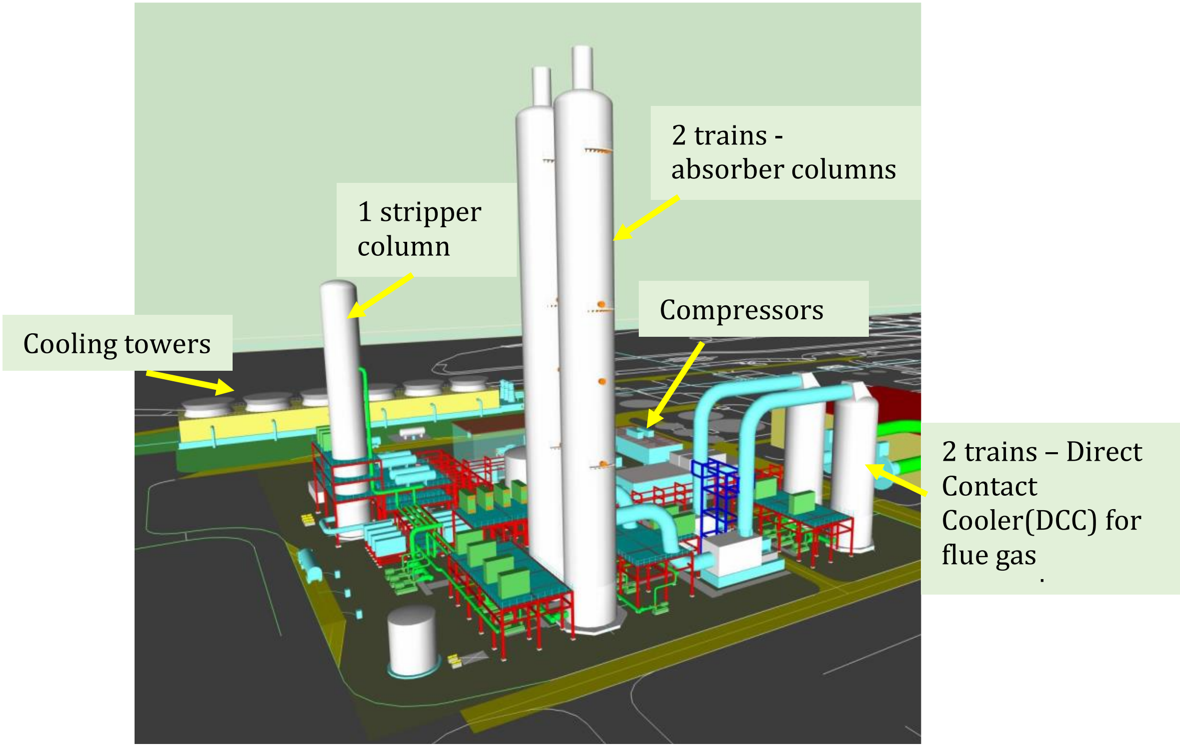


**Figure 18.** 3D model of Linde-BASF post combustion capture plant designed for Westar's Jeffrey's Energy Center

## Task 6.0 – Perform a high level technical assessment for $CO_2$ transportation

### Subtask 6.1 - Review current technologies for $CO_2$ transportation

Nothing to report.

### Subtask 6.2- Determine novel technologies or approaches for $CO_2$ transportation

Nothing to report.

### Subtask 6.3 - Develop a plan for cost-efficient and secure transportation infrastructure

**Overview:**
Understanding the economics of and exploring options and strategies for transportation of CO2 from large-scale anthropogenic sources, in particular coal-fired power plants, in the most optimal manner is a key component of the ICKan project. Estimating costs for variety of pipeline scenarios is the first step in the process. Because large-scale coal-fired power plants (e.g., Jeffrey Energy Center) are distant to potential storage sites, pipelines are the only option for transporting large volumes of CO2. However, pipelines have extremely high capital costs that negatively impact the overall costs and feasibility for CCS projects. The ICKan project considers the option of reducing the net costs for CO2 transported for CCS by combining CO2 captured from power plants and/or a refinery with CO2 destined for EOR operations. One case would include a very large-scale system, where CO2 is captured from 34 ethanol plants in the Upper Midwest and

joined with CO2 captured from a power plant (Westar's Jeffrey Energy Center). CO2 would then be transported to a saline aquifer storage site as well as to EOR markets. Both sides would benefit by the economies of scale for the pipeline system.

**Summary of significant activities:**

- Established communications and collaborated with David Morgan, co-author of the DOE/NETL Cost model (Grant et al., 2013, and Grant and Morgan, 2014) on corrections to the published model.
- Performed economic analyses for several transportation infrastructure scenarios outlined in the past quarterly report.
- Presented a paper, High-level Economic Analysis for CO2 Capture, Compression and Transportation (McFarlaned and Dubois, 2017) to an industry group at the ICKan co-sponsored workshop, CCS for Kansas, Wichita, September 21, 2017. Expanded the interest in large-scale CO2 transportation infrastructure and gained feedback from the the top four Kansas oil producers, ethanol producers and midstream pipeline companies.
- Presented a poster, CO2 Pipeline Cost Analysis Utilizing and Modified FE/NETL Cost Model Tool, poster presented Dubois et al, 2017) at the Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh PA, August 3, 2017. https://www.netl.doe.gov/File%20Library/Events/2017/carbon-storage-oil-and-natural-gas/posters/Martin-Dubois-CO2-pipeline-cost-analysis-utilizing-a-modified-FENETL-CO2-Transport-Cost-Model-tool.pdf

**Significant Results/Key Outcomes:**

**Economic analysis of pipeline transportation networks**

***Introduction***

In the last quarterly report (ICKan Q1), we described estimated costs for CO2 transportation in Appendix C: Modifications to FE/NETL CO2 Transport Cost Model and preliminary CO2 pipeline cost estimates (http://www.kgs.ku.edu/PRS/ICKan/2017/Aug/Q1_7-31-2017.pdf). Estimated capital and operating costs for several pipeline infrastructure scenarios were presented, but the financing costs were not part of that analysis. In this past quarter we performed a high level economic analysis of pipeline scenarios at varying scales, taking into account the cost of capital to build the infrastructure and operate the pipeline networks over a 20-year period.

A simple economic analysis was performed using the following set of assumptions.

- Two-year construction period, followed by two years of operations
- All CO2 sources come on line at the beginning of year one and continue for 20 years
- Construction costs and operating expenses derived from the modified FE/NETL cost model (Dubois and McFarlane, 2017)
- Zero inflation
- Two simple financing scenarios including both equity and bond financing

The CO2 transportation pipelines were modeled as 22-year long projects with a two-year construction phase and 20 years of operation and amortization. Two financing scenarios were modeled: first, a weighted average return of 10% comprised of a BBB- rated taxable bond (5% return) for half of the capital required and a regular LLC investment (15% return) for the other half of capital required; and second, a weighted average return of 6.7% comprised of a BBB rated tax-exempt private activity bond (PAB) (4% return) for 55% of the capital required and a publicly traded master limited partnership (MLP) (10% return) for the remaining 45% of capital.

***Pipeline network scenarios***
The pipeline infrastructure scenarios analyzed were mostly for capture from ethanol plants in the Upper Midwest and transportation to Enhanced Oil Recovery (EOR) markets and geologic storage sites. ICKan has been evaluating the possibilities for dual use pipeline infrastructure (EOR and storage) as a means to reach sufficient scale to reduce cost$/tonne delivery. Many pipeline network scenarios were analyzed; three representative examples (ethanol CO2) as well as connecting branches to a refinery and coal-fired power plant are presented in this report:

1. Simple point to point: one ethanol plant (0.15 million tonnes/year (Mt/yr) to one oil field for EOR (no map)
2. Moderate-sized: 15 ethanol plants (14.3 Mt/yr) in Nebraska and Kansas to EOR and storage sites in Kansas (Figure 19).
3. Large-Scale: 34 ethanol plants (9.85 Mt/yr) throughout Upper Midwest through Kansas and terminating at a Permian Basin access point in Texas. Connector lines from Jeffery Energy Center and CHS refinery shown in Scenario 3 (Figure 20).

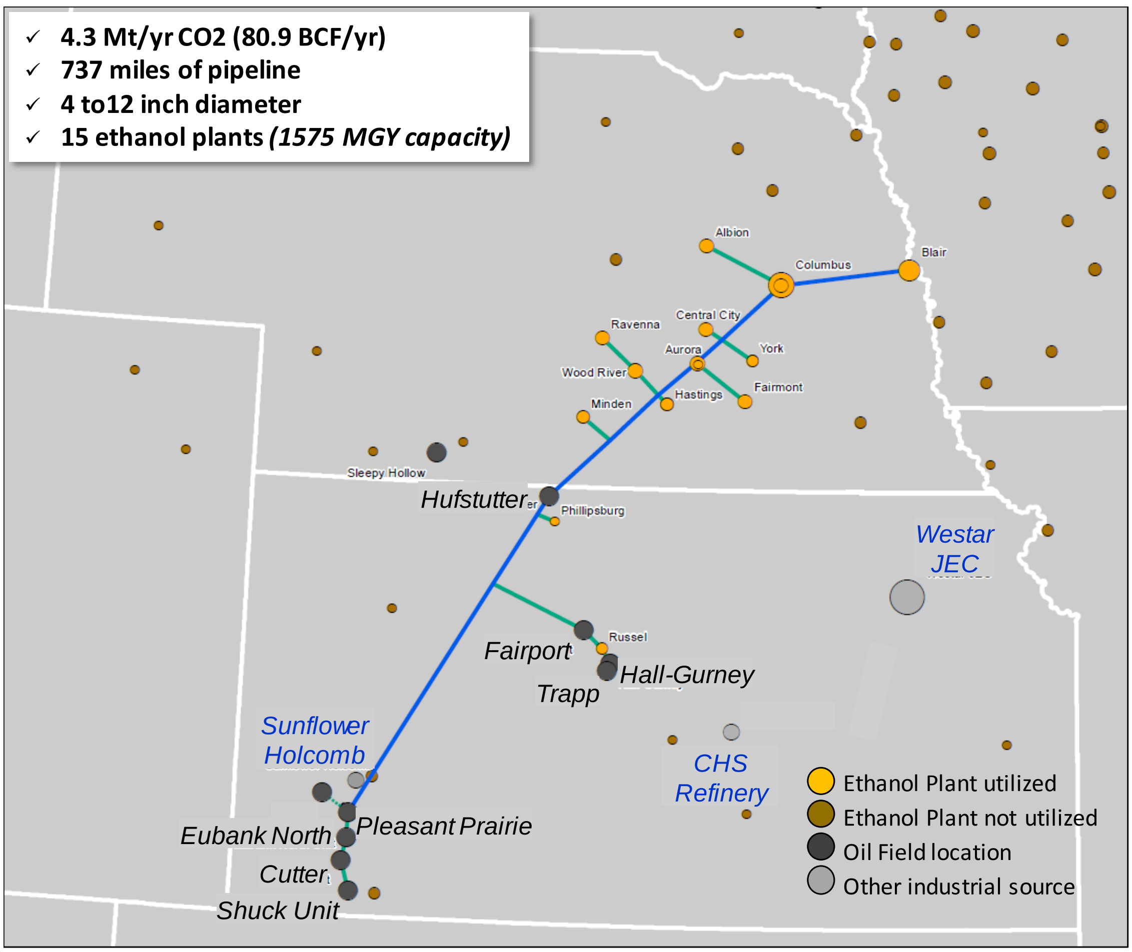


**Figure 19.** Scenario 2. Pipeline network (blue and turquoise lines) would gather CO2 from the largest ethanol plants in Nebraska and two in Kansas, and deliver 4.3 Mt/yr to CO2-ready oil fields and geologic storage sites (green lines) in Kansas. Abbreviations include Mt/yr - million tonnes/year, BCF – billion cubic feet, MGY – million gallons/year.

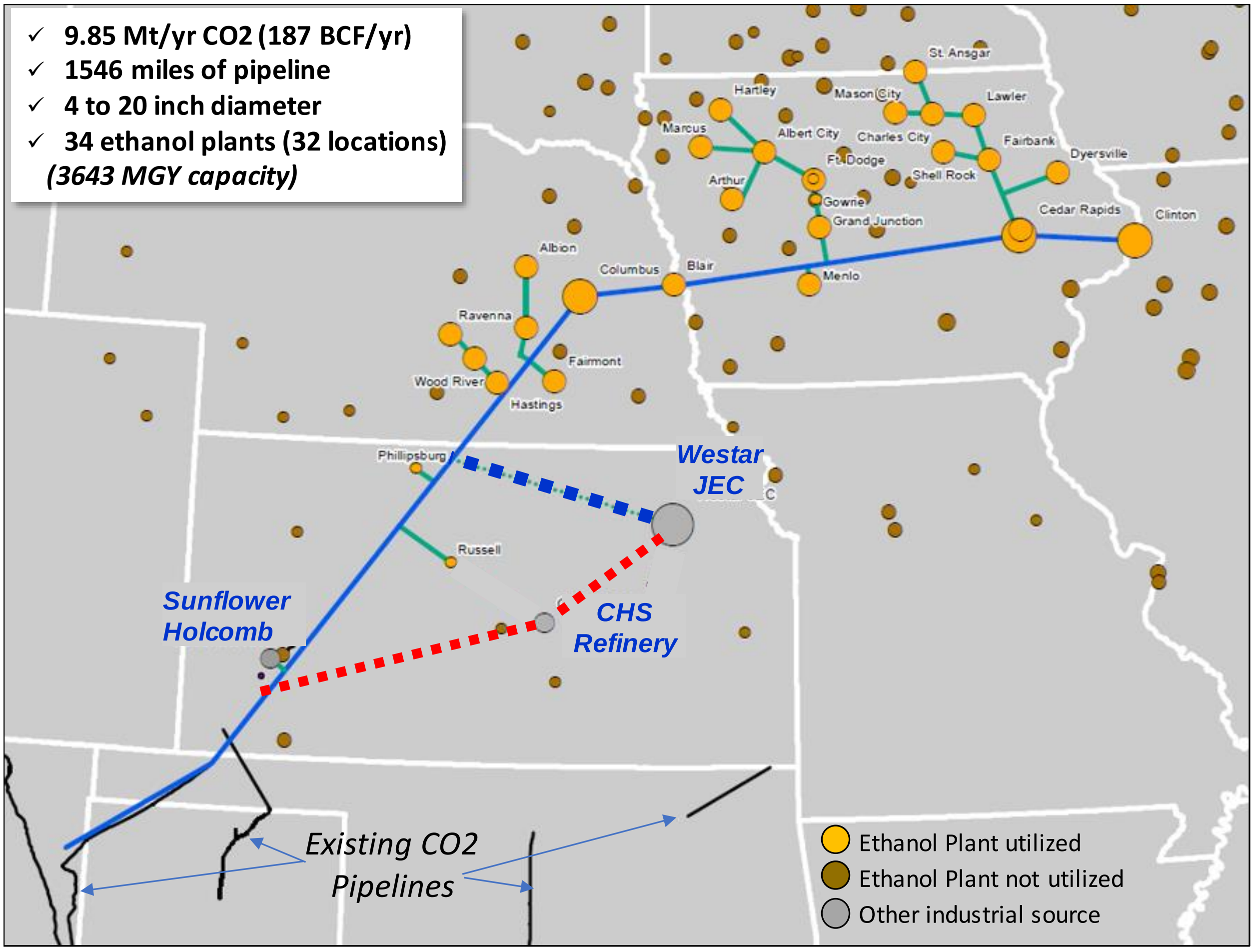


**Figure 20.** Scenario 3. Pipeline network (blue and turquoise lines) would gather CO2 from the ethanol plants in Iowa, Nebraska, and Kansas, and deliver 9.8 Mt/yr to CO2 through Kansas to CO2 pipeline access for the Permian Basin. Alternative connecting branches (dashed lines) could deliver CO2 from Other large industrial sources that are industry partners in ICKan. Abbreviations include Mt/yr - million tonnes/year, BCF – billion cubic feet, MGY – million gallons/year.

***Summary of Economic Analysis***

Estimated capital and annual operating costs for the several pipeline infrastructure scenarios were generated using the modified FE/NETL Cost Model (Dubois et al, 2017; McFarlane and Dubois, 2017). Table 5 summarizes capital and operating cost estimates from the Cost Model, and the calculated cost/tonne ($US), excluding the cost of capital (required rate of return). Also presented for comparison are capital cost estimates using a common "rule of thumb" factor, $100 per inch-mile, where the pipeline diameter (inches) is multiplied by $100 and the length of the pipeline (miles) (Melzer, 2017; Tracy, 2017, personal communication). The rule of thumb is generally used for long-distance large diameter pipelines, so it is not surprising that the variance between the two methods is for the very short, small-diameter line in Case 1. The variance is rather small for longer, multi-segment systems.

| Scenario | Pipeline Miles | CO2 (Mt/yr) | CapX ($Million) Cost Model | CapX ($Million) $100/inch-mile | Variance (%) | Annual OpX ($M) | Cost/ tonne |
|---|---|---|---|---|---|---|---|
| 1 | 16 | 0.15 | 11 | 6 | 41.8% | 0.22 | $5.18 |
| 2 | 737 | 4.26 | 642 | 613 | 4.5% | 16.20 | $11.34 |
| 3 | 1546 | 9.85 | 1,857 | 1,821 | 2.0% | 46.98 | $14.20 |
| JEC & CHS | 323 | 3.25 | 327 | 351 | -7.3% | 6.34 | $6.97 |
| JEC | 167 | 2.50 | 166 | 199 | -20.0% | 2.83 | $4.45 |

**Table 5.** Estimated nominal cost for three pipeline configurations and two alternative connecting lines, JEC & CHS and JEC. Abbreviations include JEC – Jeffrey Energy Center, CHS – CHS Refinery, Mt/yr - million tonnes/year, CapX – capital expense, OpX -operating expense.

The simple methodology described in the introduction section, above, was used to estimate the cost per tonne of CO2 delivered to the market for EOR or geologic storage, taking into account the cost of capital over a 20-year project operating life. Table 6 summarizes the revenues required for two required rates of return (ROR), or costs of capital, 10% and 6.7%. The values in the table are the CO2 price that would be required for the two RORs, in dollars/tonne.

| | | | 10% Rate of Return | | | 6.7% Rate of Return | | |
|---|---|---|---|---|---|---|---|---|
| Scenario | Pipeline Miles | CO2 (Mt/yr) | CapX | OpX | Total | CapX | OpX | Total |
| 1 | 16 | 0.15 | $9.12 | $1.48 | $10.60 | $7.05 | $1.48 | $8.53 |
| 2 | 737 | 4.26 | $18.60 | $3.80 | $22.40 | $14.37 | $3.80 | $18.17 |
| 3 | 1546 | 9.85 | $23.26 | $4.77 | $28.03 | $17.97 | $4.77 | $22.74 |
| JEC & CHS | 323 | 3.25 | $12.39 | $1.95 | $14.34 | $9.58 | $1.95 | $11.53 |
| JEC | 167 | 2.50 | $8.17 | $1.13 | $9.31 | $6.31 | $1.13 | $7.45 |

*Costs are in $US/tonne*

**Table 6.** Estimated cost/tonne ($US) for three pipeline configurations and two alternative connecting lines. JEC & CHS and JEC I a line connecting Jeffrey Energy Center and CHS Refinery to the system in Scenario 3, and JEC is the shorter line connecting only Jeffrey Energy Center to the system. Abbreviations are the same as in Table 1.

***Discussion***

For evaluating economics of CO2 transportation, the analysis must include the cost of capital to construct and operate the pipeline system. Compared to nominal costs for a 20-year project, the delivered cost for CO2 is approximately 1.6 times for the 6.7% weighted-average ROR case and double the actual capital expense for the 10% ROR case when taking the cost of capital into account

One metric for evaluating the costs in Table 6 is to compare then with CO2 costs in the commercial market for in the Permian Basin. The price for CO2 sold for EOR in the Permian is generally tied directly to the West Texas Intermediate oil price (WTI) where the $cost/mcf is approximately 0.02 X $WTI (Melzer, 2017, personal communication). At today's oil price ($50/barrel of oil), the CO2 price would be approximately $1.00/mcf, or $19/tonne, delivered. When oil reached $100/barrel in 2014, the price for CO2 was about $38/tonne. Table 2 costs do not include capture and compression.

Scenarios 2 and 3 illustrate the cost for transporting large volumes of CO2 from 15 and 34 ethanol plants, respectively. Because individual ethanol plants are relatively small volume sources and they are spread over a large area, the transportation infrastructure costs per tonne are relatively high, $18 to $28/tonne, depending on the system and the ROR. On the other hand, the transportation costs for large industrial source CO2 (Jeffrey Energy Center and/or CHS Refinery) on a per-tonne basis is much lower ($7 to $14/tonne). Adding large-source CO2 to an expanded network could reduce overall transportation costs on a per-tonne basis.

The overall economics must also take into account the cost of capture and compression. McFarland and Dubois (2017) estimated the cost for capture and compression for Scenarios 2 and 3 would range from $16 to $23/tonne over the 20-year-life projects, depending on the system and the ROR. The Linde Group is working with Westar Energy (Jeffrey Energy Center, a coal-fired) and CHS refinery to estimate capture and compression costs for those facilities. After those costs are determined the full economics can be evaluated and blended source and transportation scenarios evaluated.

**Goals and objectives for the next Quarter:**

- Respond to modifications in overall plans for transportation infrastructure after discussions with Battelle in December when we discuss how ICKan will be combined with the Battelle project for the Phase II application.
- After capture and compression costs for Jeffrey Energy Center and CHS Refinery, evaluate a multi-source CO2 integrated capture and transportation system.
- Consider other optimization opportunities, such as shared ROW to reduce costs.

**Products for Subtask 6.3:**

- High-level Economic Analysis for CO2 Capture, Compression and Transportation, a presentation at the ICKan co-sponsored workshop, CCS for Kansas, Wichita, September 21, 2017.

**References:**


Grant, T., D. Morgan, and K. Gerdes, 2013, Carbon Dioxide Transport and Storage Costs in NETL Studies: Quality Guidelines for Energy Systems Studies: DOE/NETL-2013/1614, 22 p.

Grant, T. and D. Morgan, 2014, FE/NETL CO2 Transport Cost Model. National Energy Technology Laboratory. DOE/NETL-2014/1667. https://www.netl.doe.gov/research/energy-analysis/analytical-tools-and-data/co2-transport. Accessed 6/28/2017.

Dubois, M.K., D. McFarlane, and T, Bidgoli, 2017, CO2 Pipeline Cost Analysis Utilizing and Modified FE/NETL Cost Model Tool, poster presented at the Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh PA, August 3, 2017, Pittsburgh PA, August 3, 2017. https://www.netl.doe.gov/File%20Library/Events/2017/carbon-storage-oil-and-natural-gas/posters/Martin-Dubois-CO2-pipeline-cost-analysis-utilizing-a-modified-FENETL-CO2-Transport-Cost-Model-tool.pdf

McFarlane, D. and M.K. Dubois, 2017, High-level Economic Analysis for CO2 Capture, Compression and Transportation, presented at CCUS for Kansas, Wichita, September 21, 2017.

Melzer, Steve, 2017, personal communication, Melzer Consulting, Midland, TX.

Tracy, Keith, 2017, personal communication, Cornerpost CO2 LLC, Oklahoma City, OK.

## Task 7.0 – Technology Transfer

The ICKan project decided on 2 areas for consideration for the $CO_2$ sequestration, the Forest City Basin which includes the John Creek & Davis Ranch Fields and the Pleasant Prairie Field. A search area was created to search for wells and the available data in the Kansas Geological Survey Database. A web page was created so the project members could get direct access to the wells in the study areas. The web page URL is http://www.kgs.ku.edu/PRS/ICKan/Summary/ and is illustrated in the following sections.

### Subtask 7.1- Maintain website on KGS server to facilitate effective and efficient interaction of the team

The ICKan Project Well Data Summary Web Page provides a publicly available database for users to view and download data collected from the ICKan project. This paged is updated on a regular basis and maintained by John Victorine with contributions from others. A screenshot of the well data summary page is provided below in figure 20.

### Subtask 7.2 - Public presentations

Two presentations were made at the DOE-NETL Annual Review Meeting - 2017 Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration, held on August 1-3, 2017 in Pittsburgh, Pennsylvania.

Bidgoli, T.S., 2017, Integrated CCS for Kansas (ICKan): Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage, Oil and Natural Gas Technologies Review Meeting, DOE-NETL Annual meeting, August 1-3, 2017, Pittsburgh, PA (Talk)

Dubois, M., McFarlane, D., and Bidgoli, T.S., 2017, $CO_2$ Pipeline Cost Analysis Utilizing a Modified FE/NETL $CO_2$ Transport Cost Model Tool: Carbon Storage, Oil and Natural Gas Technologies Review Meeting, DOE-NETL Annual meeting, August 1-3, 2017, Pittsburgh, PA (Poster)

Several presentations were made at the American Association of Petroleum Geologists Midcontinent Section Meeting held on October 1-3, 2017, in Oklahoma City, Oklahoma.

Bidgoli, T.S., Dubois, M., Watney, W.L., Stover, S., Holubnyak, Y., *Hollenbach, A., *Jennings, J.C., and Victorine, J., 2017, Is commercial-scale CO2 capture and geologic storage a viable enterprise for Kansas?: AAPG Midcontinent Section Meeting 2017, Oklahoma City, OK.

Hollenbach, A., Bidgoli, T.S., and Dubois, M., 2017, Evaluating the Feasibility of CO2 Storage through Reservoir Characterization and Geologic Modeling of the Viola Formation and Arbuckle Group in Kansas: AAPG Midcontinent Section Meeting 2017, Oklahoma City, OK.

Jennings, J. and Bidgoli, T.S., 2017, Identifying Areas at Risk for Injection-Induced Seismicity through Subsurface Analysis: An Example from Southern Kansas: AAPG Midcontinent Section Meeting 2017, Oklahoma City, OK.

### Subtask 7.3 - Publications

Nothing to report.

## Organizational Chart

| Organizational Chart<br>"Integrated CCS for Kansas (ICKan)" |
|---|
| **Project Management & Coordination, Geological Characterization** |
| **Kansas Geological Survey** |
| **University of Kansas** |
| **Lawrence, KS** |
| Tandis Bidgoli, Joint-PI - structural geology, fault reactivation/leakage risks |
| W. Lynn Watney, Co-PI - project leader, carbonate sedimentology/stratigraphy |
| Yvehen 'Eugene' Holubnyak, Co-PI - lead engineer, dynamic modeling |
| K. David Newell - Co-PI, site characterization |
| John Doveton, Co-PI - log petrophysics |
| Susan Stover, Key Personnel - public outreach, stakeholder alignment, policy analysis |
| Mina FazelAlavi, Key Personnel - petrophysical and well test analyses |
| John Victorine, Key Personnel - data management; website; web-based tools |
| Jennifer Hollenbach - project coordinator |
| **Improved Hydrocarbon Recovery, LLC** |
| **Lawrence, KS** |
| Martin Dubois, Joint-PI, project manager, reservoir modeling, economic feasibility |
| **CO2 Source Assessments, Capture & Transportation, Economic Feasibility** |
| **Linde Group (Americas Division)** |
| **Houston, TX** |
| Krish Krishnamurthy, Head of Group R&D - CO2 sources, capture tech., and economics |
| Kevin Watts, Dir. O&G Business Development - CO2 sources, transport., and economics |
| **Policy Analysis, Public Outreach & Acceptance** |
| **Great Plains Institute** |
| **Minneapolis, MN** |
| Brendan Jordan, Vice President - policy & strategic initiatives, stakeholder facilitation |
| Brad Crabtree, V.P. Fossil Energy - policy and project development, strategic initiatives |
| Jennifer Christensen, Senior Associate - statutory and regulatory policy analysis |
| Dane McFarlane, Senior Research Analysist - analytics for policy research & development |

| Energy, Environmental, Regulatory, & Business Law & Contracts |
|---|
| **Depew Gillen Rathbun & McInteer, LC** |
| **Wichita, KS** |
| Christopher Steincamp, Attorney at Law - legal, regulatory, & policy analysis |
| Joseph Schremmer - Attorney at Law - legal, regulatory, & policy analysis |

| Committed Project Partners |
|---|
| **CO2 Sources** |
| **Westar Energy** |
| Brad Loveless, Executive Director of Environmental Services |
| **Kansas City Board of Public Utilities** |
| Ingrid Seltzer, Director of Environmental Services |
| **Sunflower Electric Power Corporation** |
| Clare Gustin, Vice President of Member Services & External Affairs |
| **CHS, Inc. (McPherson Refinery)** |
| Rick Johnson, Process Engineering and Development Manager |
| Richard K. Leicht, Vice President of Refining |
| **Kansas Oil & Gas Operators** |
| **Blake Production Company, Inc. (Davis Ranch and John Creek fields)** |
| Austin Vernon, Vice President |
| **Knighton Oil Company, Inc. (John Creek field)** |
| Earl M. Knighton, Jr., President |
| **Casillas Petroleum Corp (Pleasant Prairie field)** |
| Chris K. Carson, Vice President of Geology & Exploration |
| **Berexco, LLC (Wellington, Cutter, and other O&G fields)** |
| Dana Wreath, Vice President |
| **Stroke of Luck Energy & Exploration, LLC (Leach & Newberry fields)** |
| Ken Walker, Operator |
| **Regulatory** |
| **Kansas Department of Health & Environment** |
| Division of Environment |
| John W. Mitchell, Director |

# Gantt Chart and Accomplishments

| | | | 2017 | | | | | | | | | | 2018 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Task** | **Task Name** | **Deadline** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **Task 1.0** | **Project Management and Planning Integrated CCS for Kansas (ICKan)** | | | | | | | | | | | | | | | | | | | |
| Subtask 1.1 | Fulfill requirements for National Environmental Policy Act (NEPA | **complete** | | | | | | | | | | | | | | | | | | |
| Subtask 1.2 | Conduct a kick-off meeting to set expectations | **complete** | | | | | | | | | | | | | | | | | | |
| Subtask 1.3 | Conduct regularly scheduled meetings and update tracking | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.4 | Monitor and control project scope | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.5 | Monitor and control project schedule | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.6 | Monitor and control project risk | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.7 | Maintain and revise the Data Management Plan including submital of data to NETL-EDX | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.8 | Revisions to the Project Management Plan after submission | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.9 | Submit reports as prescribed | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 1.10 | Develop a integrated strategy for commercial scale CCS | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| **Task 2.0** | **Establish a Carbon Capture and Storage (CCS) Coordination Team** | | | | | | | | | | | | | | | | | | | |
| Subtask 2.1 | Identify additional CCS team members | **Aug 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 2.2 | Identify additional stakeholders that should be added to the CCS team | **Aug 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 2.3 | Recruit and gain commitment of additional CCS team members identified | **Sept 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 2.4 | Conduct a formal meeting that includes Phase I team and committed Phase II team members | **Oct 2017** | | | | | | | | | | | | | | | | | | |
| **Task 3.0** | **Develop a plan to address challenges of a commercial-scale CCS Project** | | | | | | | | | | | | | | | | | | | |
| Subtask 3.1 | Identify challenges and develop a plan to address challenges for CO2 capture | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| Subtask 3.2 | Identify challenges and develop a plan to address challenges for CO2 transportation and injectio | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| Subtask 3.3 | Identify challenges and develop a plan to address challenges for CO2 storage in geologic compl | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| **Task 4.0** | **Perform a high level technical sub-basinal evaluation using NRAP and related DOE tools** | | | | | | | | | | | | | | | | | | | |
| Subtask 4.1 | Review storage capacity of geologic complexes identified in this proposal and consider alternati | **complete** | | | | | | | | | | | | | | | | | | |
| Subtask 4.2 | High-level technical analysis using NRAP-IAM-CS and other tools | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| Subtask 4.3 | Compare results using NRAP with previous methods | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| Subtask 4.4 | Develop an implementation plan and strategy for commercial-scale, safe and effective CO2 stor | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| **Task 5.0** | **Perform a high level technical CO2 source assessment for capture** | | | | | | | | | | | | | | | | | | | |
| Subtask 5.1 | Review current technologies using NATCARB, Global CO2 Storage Portal, and KDM | **Dec 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 5.2. | Determine novel technologies or approaches for CO2 capture | **Dec 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 5.3 | Develop an implementation plan and strategy for cost effective and reliable carbon capture | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| **Task 6.0** | **Perform a high level technical assessment for CO2 transportation** | | | | | | | | | | | | | | | | | | | |
| Subtask 6.1 | Review current technologies or CO2 transportation | **Dec 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 6.2 | Determine novel technologies or approaches for CO2 capture | **Dec 2017** | | | | | | | | | | | | | | | | | | |
| Subtask 6.3 | Develop a plan for cost-efficient and secure transportation infrastructure | **Jan 2018** | | | | | | | | | | | | | | | | | | |
| **Task 7.0** | **Technology Transfer** | | | | | | | | | | | | | | | | | | | |
| Subtask 7.1 | Maintain website on KGS server to facilitate effective and efficient interaction of the team | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 7.2 | Public presentations | **ongoing** | | | | | | | | | | | | | | | | | | |
| Subtask 7.3 | Publications | **ongoing** | | | | | | | | | | | | | | | | | | |

# Budgetary Information

## Cost Plan

| COST PLAN/STATUS DE-FE0029474 (KUCR FED0076651) | | | | | | |
|---|---|---|---|---|---|---|
| BP1 Starts: 3/15/17 through 9/15/18 - one budget period | | | | | | |
| | 3/15/17 - 6/15/17 | 6/16/17 - 9/15/17 | 9/16/17 - 12/15/17 | 12/16/17 - 3/15/18 | 3/16/18 - 6/15/18 | 6/16/18 - 9/15/18 |
| Baseline Reporting Quarter | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** | **Q6** |
| **Baseline Cost Plan (from SF-424A)** | (from 424A, Sec. D) | | | | | |
| Federal Share | $197,247.00 | $197,247.00 | $197,247.00 | $197,247.00 | $197,254.00 | $197,255.00 |
| Non-Federal Share | $49,598.00 | $49,598.00 | $49,598.00 | $49,601.00 | $49,599.00 | $49,599.00 |
| Total Planned (Federal and Non-Federal) | $246,845.00 | $246,845.00 | $246,845.00 | $246,848.00 | $246,853.00 | $246,854.00 |
| Cumulative Baseline Cost | $246,845.00 | $493,690.00 | $740,535.00 | $987,383.00 | $1,234,236.00 | $1,481,090.00 |
| **Actual Incurred Costs** | | | | | | |
| Federal Share | $98,249.07 | $97,884.85 | $0.00 | $0.00 | $0.00 | $0.00 |
| Non-Federal Share | $4,923.39 | $22,234.59 | $0.00 | $0.00 | $0.00 | $0.00 |
| Total Incurred Costs-Quarterly (Federal and Non-Federal) | $103,172.46 | $120,119.44 | $0.00 | $0.00 | $0.00 | $0.00 |
| Cumulative Incurred Costs | $103,172.46 | $223,291.90 | $223,291.90 | $223,291.90 | $223,291.90 | $223,291.90 |
| **Variance** | | | | | | |
| Federal Share | $98,997.93 | $99,362.15 | $197,247.00 | $197,247.00 | $197,254.00 | $197,255.00 |
| Non-Federal Share | $44,674.61 | $27,363.41 | $49,598.00 | $49,601.00 | $49,599.00 | $49,599.00 |
| Total Variance-Quarterly (Federal and Non-Federal) | $143,672.54 | $126,725.56 | $246,845.00 | $246,848.00 | $246,853.00 | $246,854.00 |
| Cumulative Variance | **$143,672.54** | **$270,398.10** | **$517,243.10** | **$764,091.10** | **$1,010,944.10** | **$1,257,798.10** |

# Appendix A

## Workshop Agenda

**Carbon Capture, Utilization, and Storage in Kansas**
**Sept 21, 2017**
**Double Tree Hotel**
**2098 Eisenhower Airport Pkwy**
**Wichita, KS 67209**

Hosted by:

- State $CO_2$-EOR Deployment Work Group
- Kansas Geological Survey

Objectives:

- Share rationale for increased carbon capture and enhanced oil recovery in Kansas
- Engage potential project partners for a collaborative carbon capture and enhanced oil recovery initiative in Kansas
- Share information on supportive national and state policies, and policy initiatives
- Expand awareness of economic opportunity for carbon capture and utilization in KS

8:30 a.m. Participants arrive and register, coffee and light breakfast available

9:00 a.m. Welcome and introductions

- Matt Fry, Policy Advisor to Governor Matt Mead, Wyoming
- Rolfe Mandel, Director, Kansas Geological Survey
- Introductions – name and organization

9:15 a.m. Background on carbon capture and utilization

- Steve Melzer, Melzer Consulting: primer on $CO_2$-EOR, history of the industry, scale of the opportunity, economics and benefits.

9:50 a.m. Kansas $CO_2$-EOR history and potential

- Martin Dubois, Improved Hydrocarbon Recovery, LLC, Kansas $CO_2$-EOR history and potential

10:10 a.m. Federal and state policy update

- Brad Crabtree, National Enhanced Oil Recovery Initiative, 45Q, LCFS, other state and federal policies
- Matt Fry, Overview on State $CO_2$-EOR Deployment Working Group history and major deliverables

10:45 a.m. Break (possible media availability)

11:00 a.m. Overview on Integrated CCS for Kansas, and other DOE-funded projects

- Tandis Bidgoli, Kansas Geological Survey

11:20 a.m. Environmental rationale for carbon capture, $CO_2$-EOR and other geologic storage

- John Thompson, Clean Air Task Force

11:40 a.m. Legal and regulatory hurdles and remedies for geologic storage in Kansas

- Chris Steincamp or Joseph Schremmer, Depew Gillen Rathbun & McInteer, LC

12:00 p.m. Lunch

12:30 p.m. Economic and business case for $CO_2$ capture

- Krish Krishnamurthy, Linde, Preliminary design for capture from fossil fuel sources
- Keith Tracy, Cornerpost $CO_2$ LLC, Practical considerations for ethanol carbon capture

1:00 p.m. High-level economic analysis for capture, compression and transportation systems (including Kansas examples)

- Dane McFarlane, Great Plains Institute
- Martin Dubois, Improved Hydrocarbon Recovery LLC

1:30 p.m. Pulling the pieces together: the economic opportunity

- Eric Mork, EBR Development LLC

1:45 p.m. Break

2:00 p.m. Discussion:

- What practical steps should be taken to move carbon capture, $CO_2$ transport, and EOR projects forward in Kansas?
- What barriers exist that can be addressed?
- What policy and regulatory issues can be addressed?
- What partners must be involved to make this a success?

2:45 p.m. Closing remarks

3:00 p.m. Adjourn

## Attendee List

| First Name | Last Name | Organization/Agency/Business (no abbreviations, please) | Title |
|---|---|---|---|
| Chris | Steincamp | Depew Gillen Rathbun & McInteer LC | Managing Pertner |
| Fatima | Ahmad | Center for Climate and Energy Solutions | Solutions Fellow |
| Sarah | Bennett | Merit Energy Company | MidCon Exploitation Manager |
| Tandis | Bidgoli | Kansas Geological Survey | Assistant Scientist |
| Dan | Blankenau | Great Plains Energy Inc. | President |
| Chuck | Brewer | GSI Engineering | President |
| Makini | Byron | Linde LLC | Innovation Project Manager |
| Mike | Cochran | Kansas Department of Health & Environment | Chief of the Geology & Well Technology Section |
| Al | Collins | Occidental Petroleum Corporation | Senior Director Regulatory Affairs |
| Edward | Cross | Kansas Independent Oil & Gas Association | President |
| Jessica | Crossman | KDHE | Professional Geologist |
| Brandy | DeArmond | KDHE | PG, Chief, Underground Injection Control |
| Kim | Do | White Energy | Finance Manager |
| Martin | Dubois | Improved Hydrocarbon Recovry, LLC | Owner |
| Andrew | Duguid | Battelle | Principal Engineer |
| ROGER | ERICKSON | CONGRESSMAN ESTES KS 4TH DISTRICT | FIELD REPRESENTATIVE |
| Frank | Farmer | Mississippi Public Service Commission | General Counsel |

| | | | |
|---|---|---|---|
| Sarah | Forbes | United States Department of Energy | Scientist |
| Matt | Fry | Wyoming Governor's Office | Policy Advisor |
| Justin | Grady | Kansas Corporation Commission | Chief of Accounting and Financial Analysis |
| Kevin | Gray | Flint Hills Resources | Director, Innovation |
| Yevhen | Holubnyak | Kansas Geological Survey | Petroleum Engineer |
| Ryan | Huddleston | Merit Energy Company | |
| Rick | Johnson | CHS McPherson Refinery | Process Engineering & Development Manager |
| Krish R. | Krishnamurthy | Linde LLC | Head of Group R&D - Americas, Technology & Innovation |
| Martin | Lange | Merit Energy Company | |
| Rolfe | Mandel | Kansas Geological Survey | Director |
| Jeff | McClanahan | Kansas Corporation Commission | Director, Utilities Division |
| Dane | McFarlane | Great Plains Institute | Senior Research Analyst |
| Christian | McIlvain | Poet Ethanol Products | Vice President, Denaturant and Carbon Dioxide |
| Steve | Melzer | Melzer Consulting | Owner |
| Deepika | Nagabhushan | Clean Air Task Force | Energy Policy Associate |
| Leon | Rodak | Murfin Drilling Company | VP PRODUCTION |
| Joe | Schremmer | Depew Gillen Rathbun & McInteer LC | Attorney |
| Doug | Scott | Great Plains Institute | Vice President |
| Susan | Stover | Kansas Geological Survey | Outreach Manager, Geologist |
| Keith | Tracy | Cornerpost CO2 LLC | President |
| Scott | Wehner | Wehner CO2nsulting, LLC | Owner |
| Dan | Wilkus | Westar Energy, Inc. | Director, Air Programs |
| Dana | Wreath | Berexco | VP |
| Scott | Ball | BOE Midstream | VP{ |
| Jeffrey | Brown | Stanford Business School/Steyer Taylor Center | Research Fellow |
| PAUL | RAMONDETTA | VESS OIL CORP. | MANAGER of EXPLORATION and EXPLOITATION |
| Gary | Gensch | Gary F. Gensch Consulting | Consultant |