Evaluating the Feasibility of CO_2 Storage through Reservoir Characterization and Geologic Modeling of the Viola Formation and Arbuckle Group in Kansas

KANSAS GEOLOGICAL SURVEY
The University of Kansas

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Abstract

The Cambro-Ordivician Arbuckle Group consists of laterally extensive shelf carbonates that uncomformably overly Proterozoic basement or Cambrian strata. In Kansas, the Arbuckle is a long-standing target for wastewater fluid injection due to properties such as thickness, high permeability, depth, and naturally low pressure. Integrated Carbon Capture and Storage for Kansas (ICKan), a U.S. DOE-funded project, evaluates CO_2 storage capacity and injectivity in the Arbuckle, Simpson, and Viola saline aquifers beneath oil producing strata at several potential storage sites including the Pleasant Prairie, John Creek, Davis Ranch, Patterson, Lakin, and Rupp fields. The study is being conducted to evaluate the feasibility of commercial scale CO_2 capture and storage (50+ million tonnes stored). The ICKan project evaluates risks related to disposal of CO_2, including impacts on seal integrity, pore-fluid pressure, and potential for induced seismicity. Here, we present 3-D cellular geologic models populated with reservoir characteristics such as porosity, permeability, and fluid saturations. The models are upscaled for numerical simulation of CO_2 injection and storage predictions using a full compositional simulator under varying scenarios.

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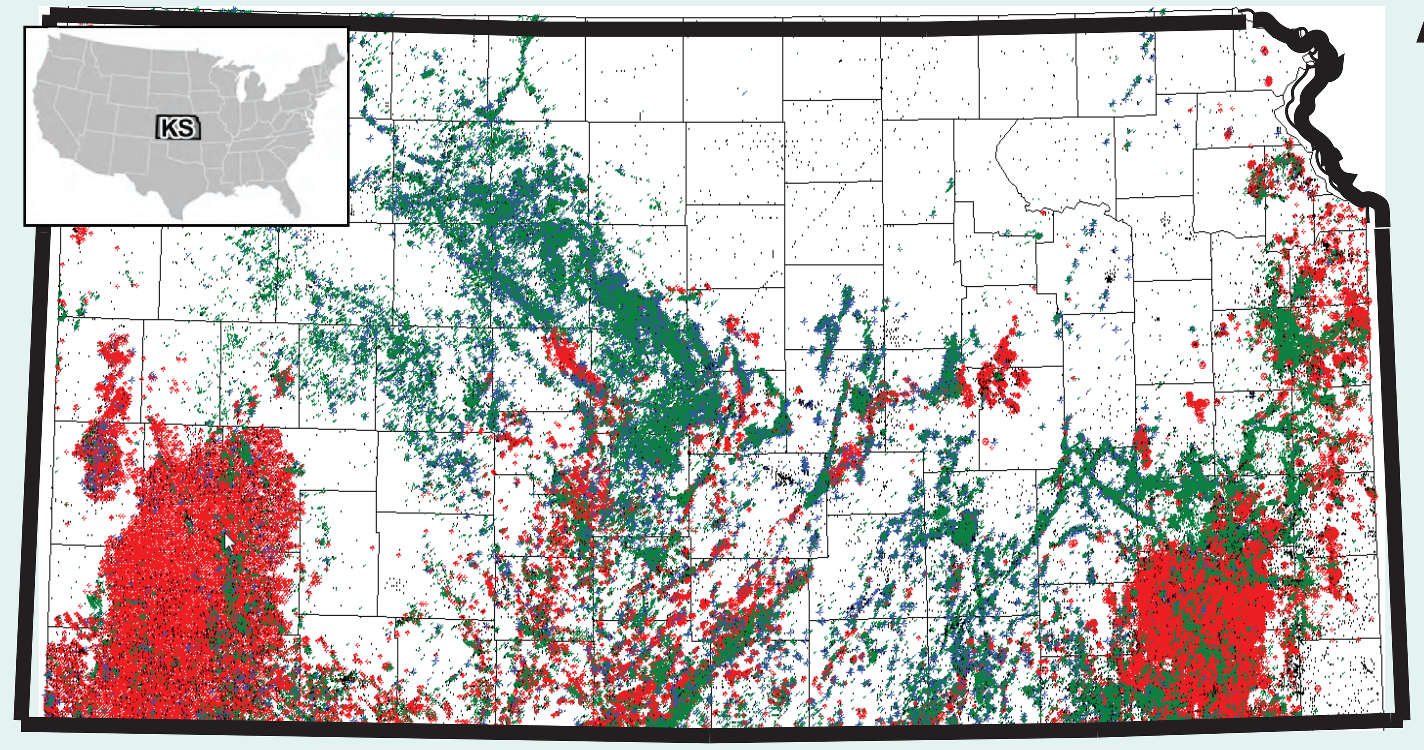

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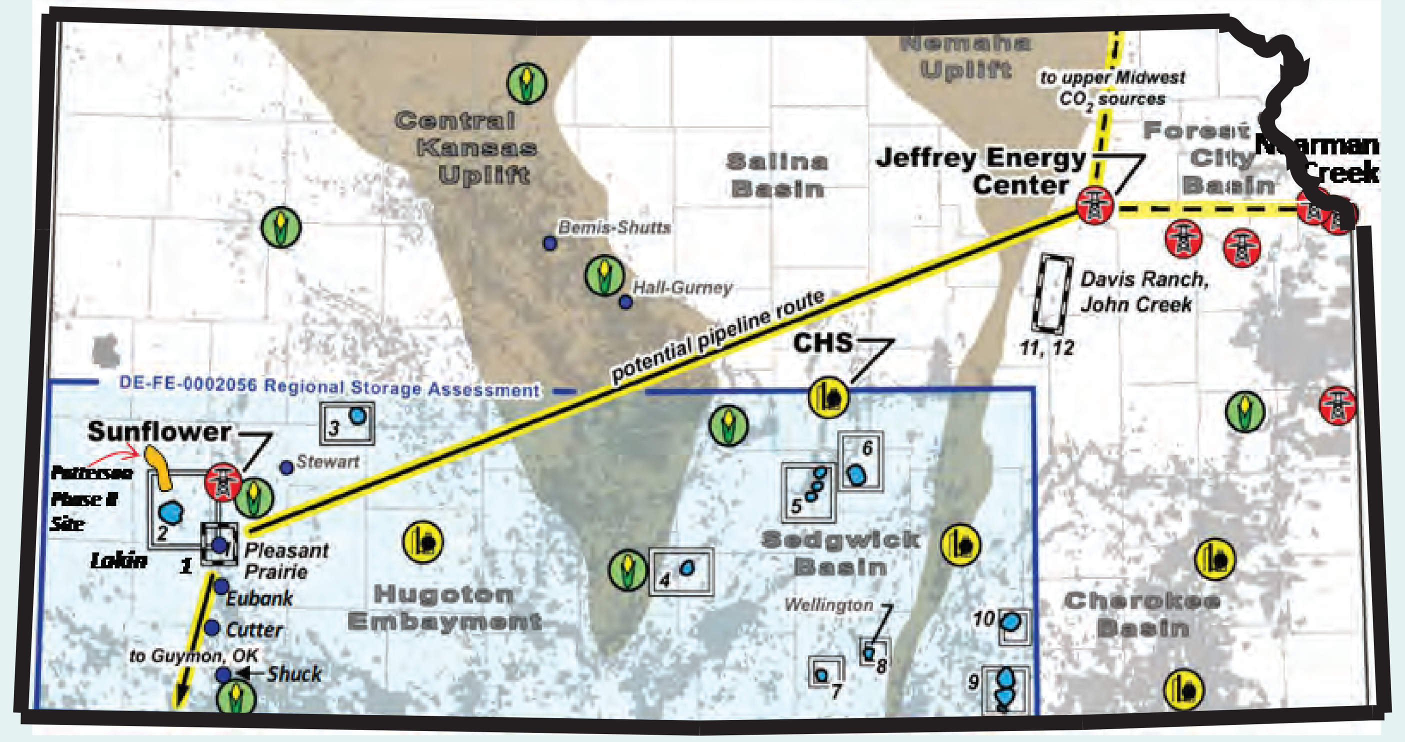

A. Kansas map displaying 475k+ oil (green), gas (red), and disposal (blue) wells. The [1]KGS is home to a unique and publically available database used to develop high resolution geologic models.
B. Kansas map diplaying potential pipeline route near possible CO_2 injections sites (numbered 1-12), and CO_2 sources (red, green,yellow). Key components of a commercial-scale capture and storage system.

Introduction

The project goal is to identify potential saline aquifer reservoir sites for storage of >50 million tonnes (Mt) CO_2 as part of the Integrated Carbon Capture and Storage (CCS) for Kansas (ICKan). An efficient commercially viable CO_2 market will utilize a pipeline connecting CO_2 capture/production to CO_2 storage/purchase.

Accurate storage volume estimates are needed to ascertain if CCS is viable for Kansas. Storage estimates are conducted through reservoir characterization and geologic modeling of sub-oil-reservoir saline aquifers of the Viola Formation and Arbuckle Group (target aquifers selected for long-term storage).

Targetted Kansas storage sites are evaluated at a high resolution due to the KGS publically avalaible database of well headers, formation tops, completion cards, scout cards, core information, and wireline logs; and, thanks to help from the DOE and numerous industry partners.

The data is used to develop 3-D cellular geologic models of potentially ideal storage sites. The cellular model is populated with the petorphysical properties porosity and permeability using wireline log analysis and up-scaling digital logs to the cellular model. The injection of CO_2 into the model is simulated to determine storage , gas saturation, and change in pressure through time.

Initial targets identified include the Davis Ranch and John Creek, two of the largest oil fields of the northeastern Kansas' Forest City Basin (the hypothetically upstream portion of the potential pipeline route depicted in the adjacent Figure, left). Model development and simulation results of the initial Forest City Basin targets (Figure, right) indicate that the Forest City Basin is likely not capable of storing >50Mt of CO_2.

Subsequent study targets were identified in the southwestern Kansas Hugoton complex (the hypothetically downstream portion of the aforementinoned pipeline). Model development of the sub-oil-reservoir saline aquifers and simulation results at the Rupp, Lakin, and Pleasant Prairie oil fields indicates that >50 Mt of CO_2 can likely be stored at each of the three targets, provided optimal injection conditions. The Patterson field is currently under development, but structural modelling suggests the field will also be capable of storing >50 Mt.

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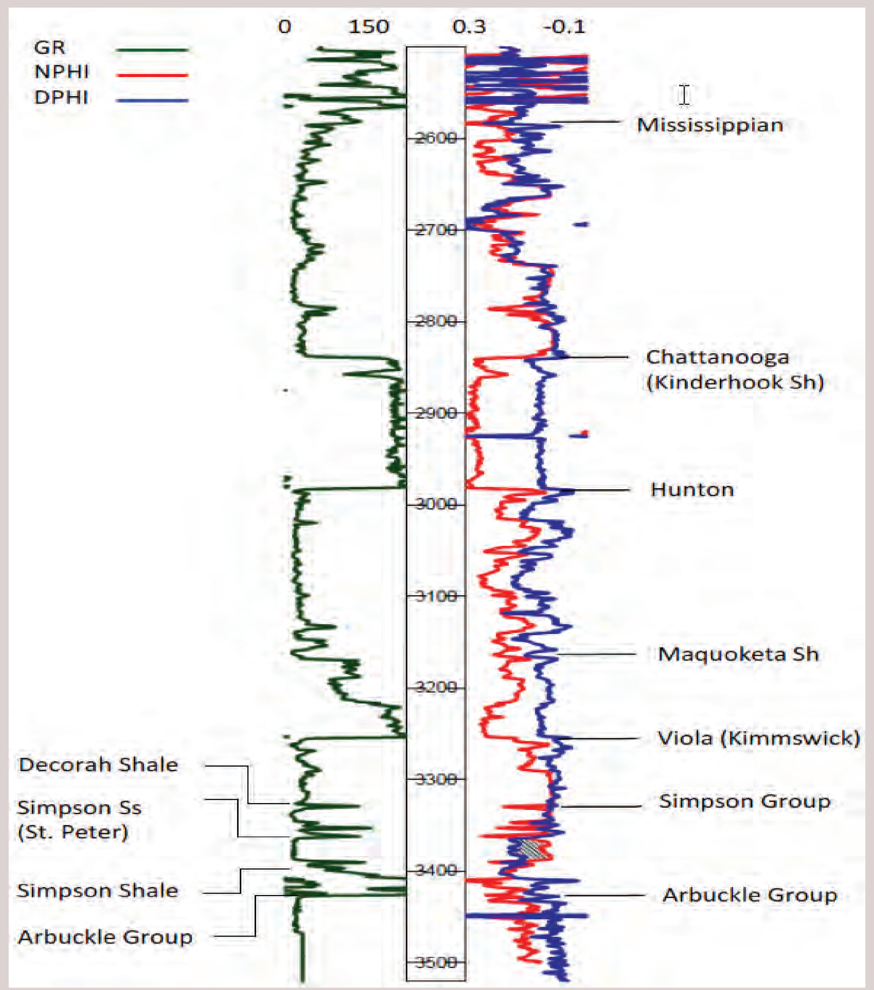

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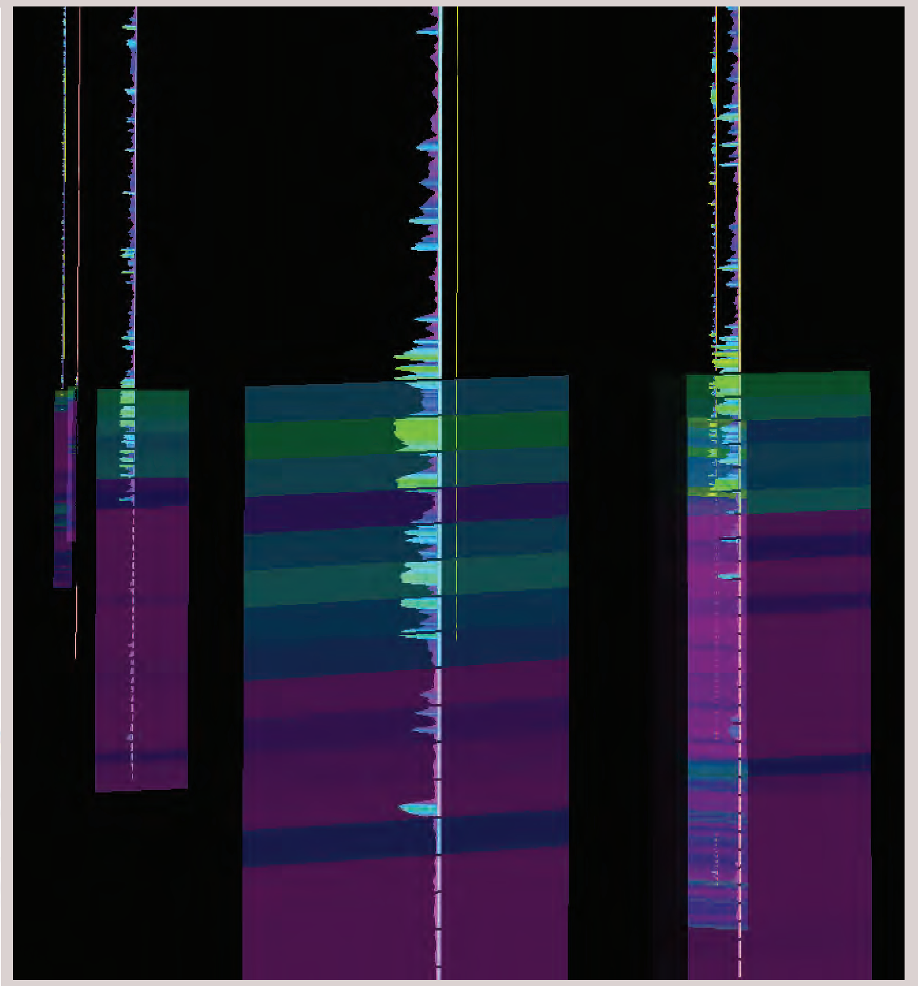

C. Gamma and porosity wireline logs with picked stratigraphic formation tops. These formation tops are correlated between wells, from log-to-log to ultimately produce a structure map of the stacked reservoir system, seals, and sub-reservoir target aquifers.
D. Porosity from wireline logs are averaged into a 3D cellular model at the Davis Ranch field of the Forest City Basin.
E. Large-scale 3D cellular porosity model of a selected segment of the Forest City Basin (Figure B), prior to extraction of the Davis Ranch and John Creek Field for simulation.
F. The John Creek and Davis Ranch 3D cellular porosity models are extracted and upscaled for simulation.
G. An example of results from simulating the injection of CO_2 into the Davis Ranch 3D cellular model.
H. A visualization of the distirbution of CO_2 in the subsurface following a simulation of CO_2 injection into the Davis Ranch 3D cellular model.

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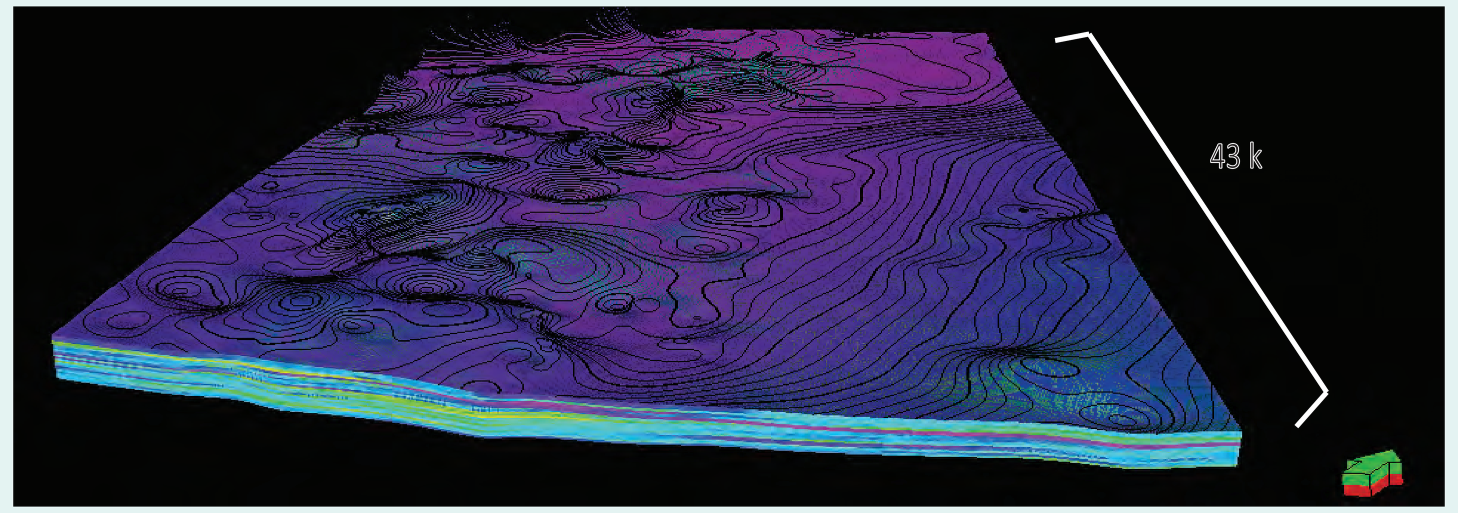

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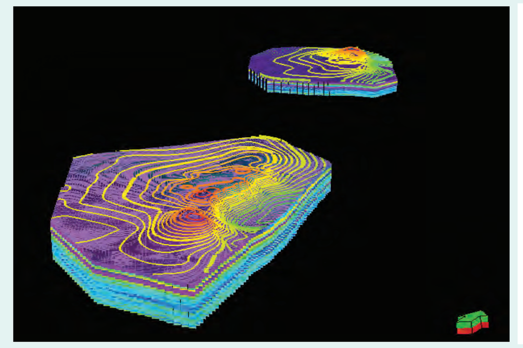

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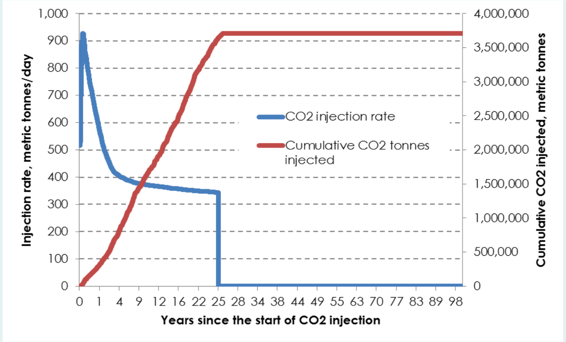

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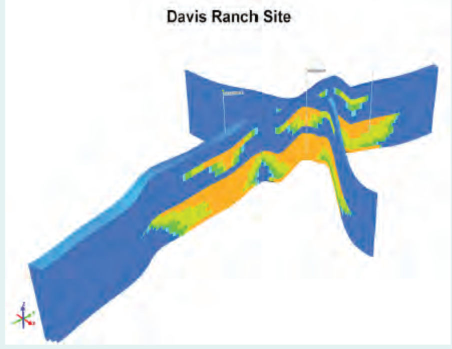

Workflow

Background -- A technical evaluation of the saline aquifer beneath the oil producing fields is conducted by building a sub-basin fine-grid static cellular 3D model in Petrel. The cells are then populated with porosity and permeability based well-scale wireline log data. The model is then vertically upscaled for reservoir simulation in CMG.

Data Collection -- The data for the model was collected from the KGS and Robert F. Walters Digital Libraries. Model framework and well-scale data was gathered from well header information, locations, formation tops, and wireline logs in the form of image files. The data is collected and analyzed in Petra™ .

Modeling -- Geologic structure and ispoach maps were generated in Petra™ and then exported to Petrel™ for 3D layering.

Structure Mapping -- A formation structure map (grid) for the formation with most tops control (oil-producing formation), was gridded from the tops data. These grids and isopach maps were modified to reflect inferred geologic structure and from correlating wireline logs to stratigraphic intervals of interest.

3D Cellular Structural Model -- A 3D cell size is selected for the xy-directional coordinates and layering between formation structures stacked in the z-direction resulting in a 3D cellular model. This cellular model is then populated with petrophysical properties via upscaling of digitized wireline logs and statistical modeling. The model is vertically upscaled and exported for simulation.

Simulation of CO2 subsurface injection -- 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 Pleasant Prairie 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, multi-component fluids that has been used to conduct numerous CO_2 studies

ACKNOWLEDGEMENTS

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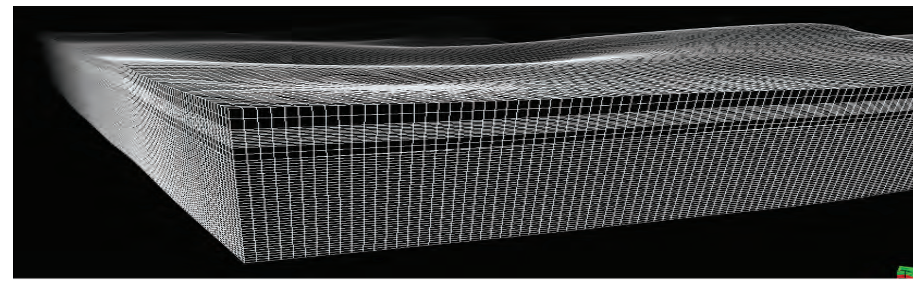
CarbonSAFE

Carbon Storage Assurance Facility Enterprise
DOE's, Office of Fossil Energy recognizes need for carbon capture and storage (CCS) to operate on massive scale in order achieve U.S. and global clean energy goals, but commerciality has been hindered by a lack of economic incentives for the private sector.

A major goal of CarbonSAFE is to address knowledge gaps associated with the development of a 50+ million metric tons CO_2 storage site. The 4-phase program will identify and certify sites for commercial-scale CCS that will be constructed & permitted for operation by 2025.



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The Southwestern Kansas 'North Hugoton' Storage Complex

I

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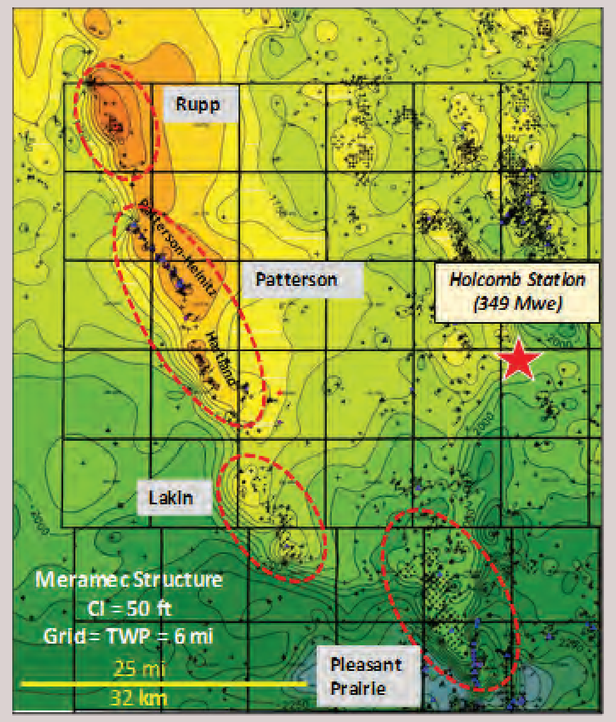
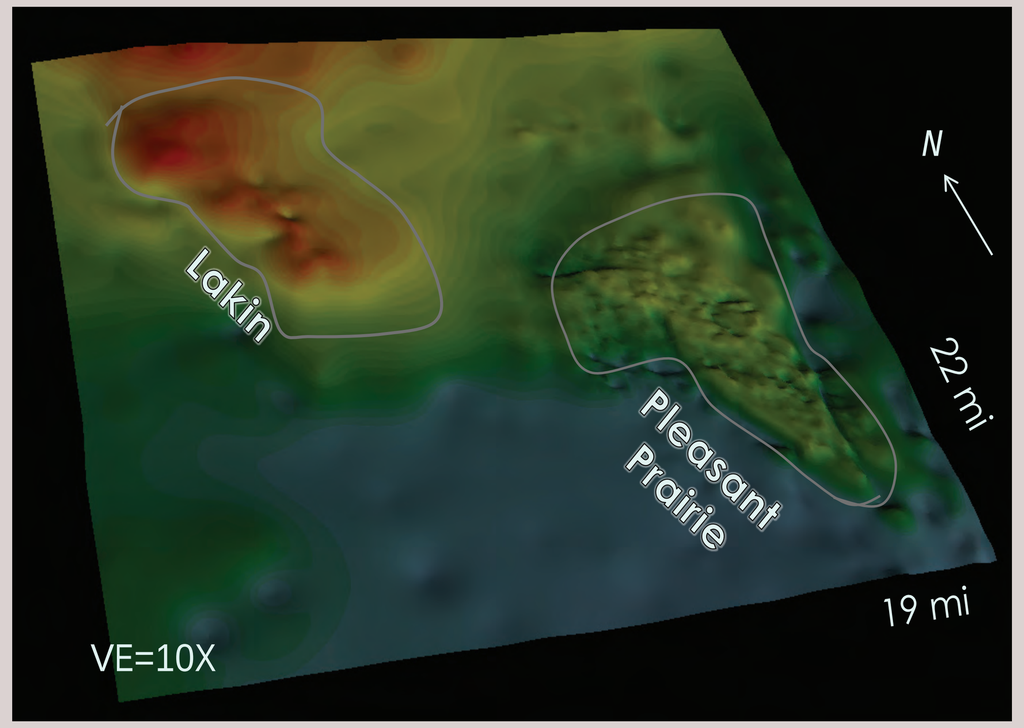




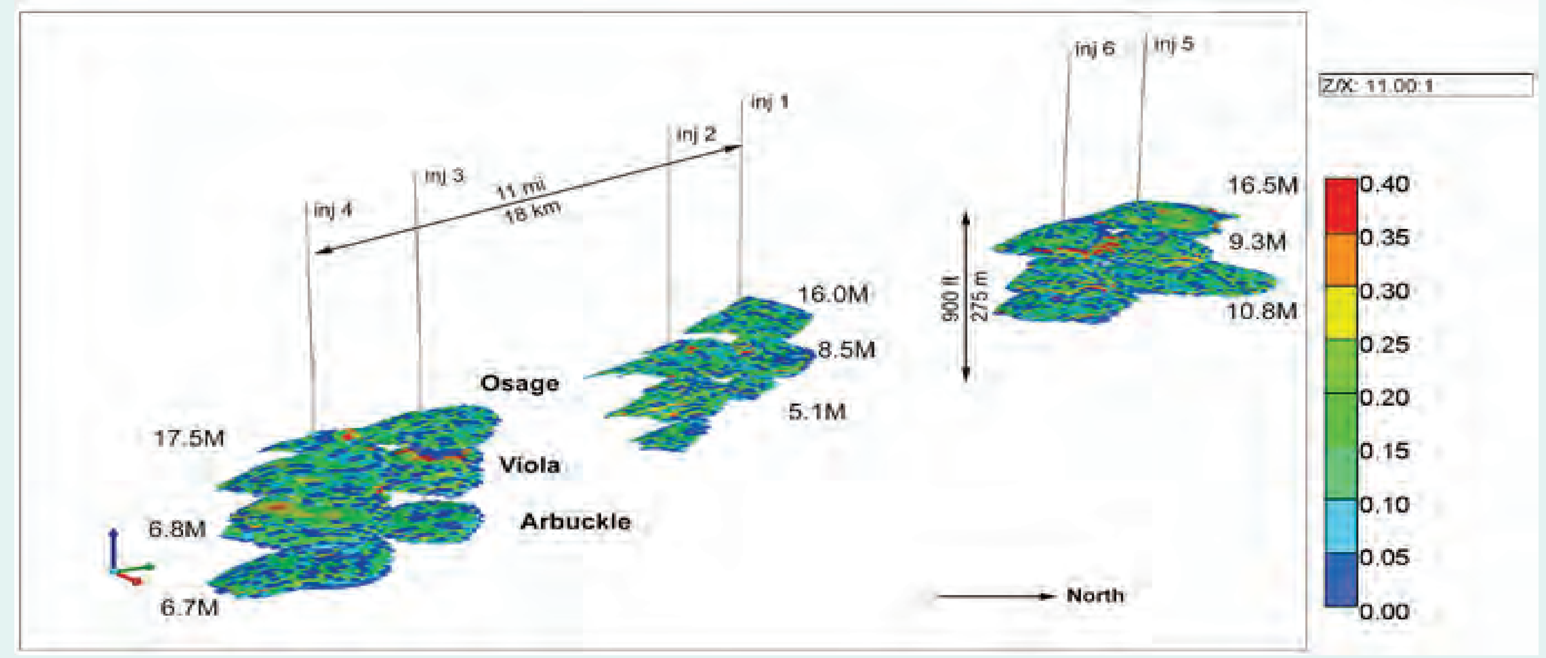
Zone	Permeability from Porosity (and GR for Arbuckle)
Meramec	Kxy=87.768*Porosity**2.0923
Spergen	Kxy=212571*Porosity**4.377
Warsaw	Kxy=452218* Porosity **5.0603
Osage	Kxy=331.31* Porosity **2.9257
Kinderhook	Kxy=157.2* Porosity **2.1019
Viola	Kxy=4160* Porosity **3.2036
Simpson	Kxy=40647* Porosity **3.7804
Arbuckle	Kxy=1000000000*GR**(-4.84)*(Porosity**(9.37*(GR**(-0.486))))

Porosity-permeability transforms derived from empirical data utilized in the Pleasant Prairie geomodel.

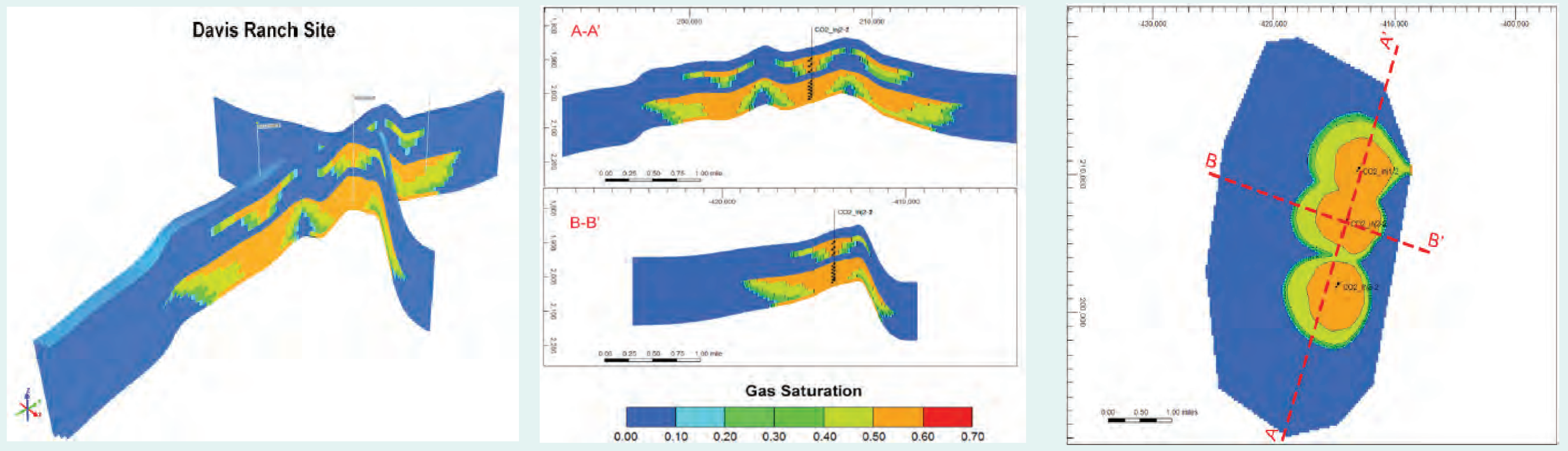
Injection Interval	Osage	Viola	Arbuckle
Temperature	60 °C (140 °F)	61 °C (142 °F)	62 °C (144 °F)
Pressure	1,650 psi (11.38 MPa)	1,700 psi (11.5 MPa)	1,800 psi (11.72 MPa)
Max. BHP	2250 psi ()	2300 psi	2400 psi
TDS	100 g/l	140 g/l	180 g/l
Formation Top	5,580 ft	5,790 ft	6,000 ft
Formation Base	5,620 ft	5,960 ft	6,730 ft
Perforation Zone	110 ft	140 ft	150 ft
Injection Period		25 years	
Number of wells		3	
Injection Rate	4,220 T/day	960 T/day	2,015 T/day
Total CO_2 injected	38.5 MT	10.5 MT	18.4 MT

Model input specification and CO_2 injection rates for dynamic simulation at the Pleasant Prairie Storage target.

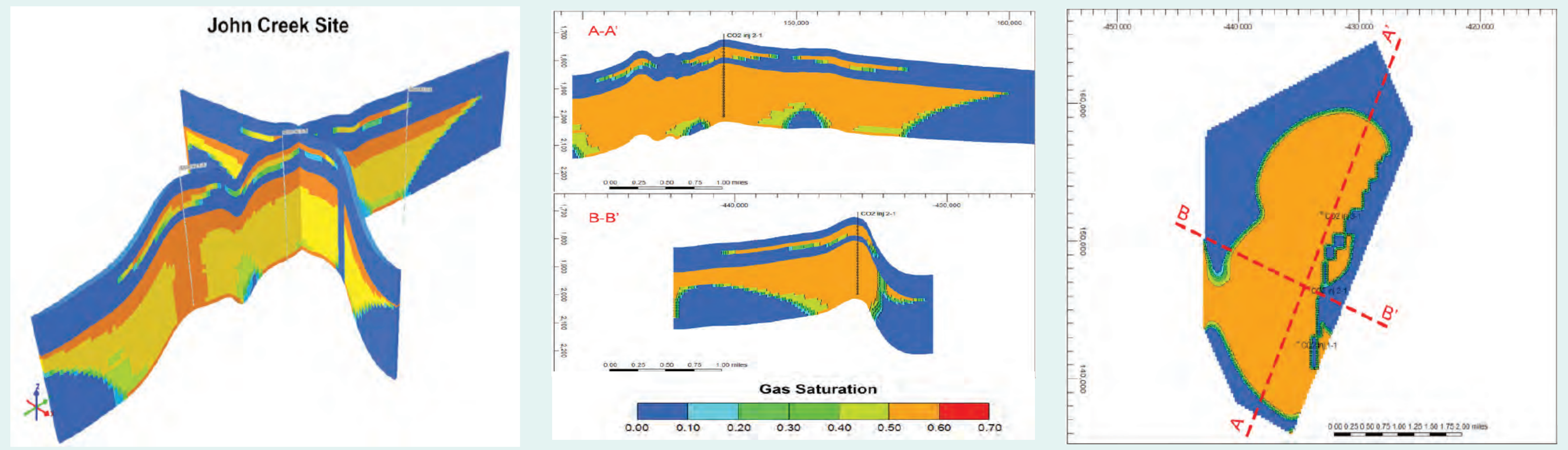
Rupp Simulation



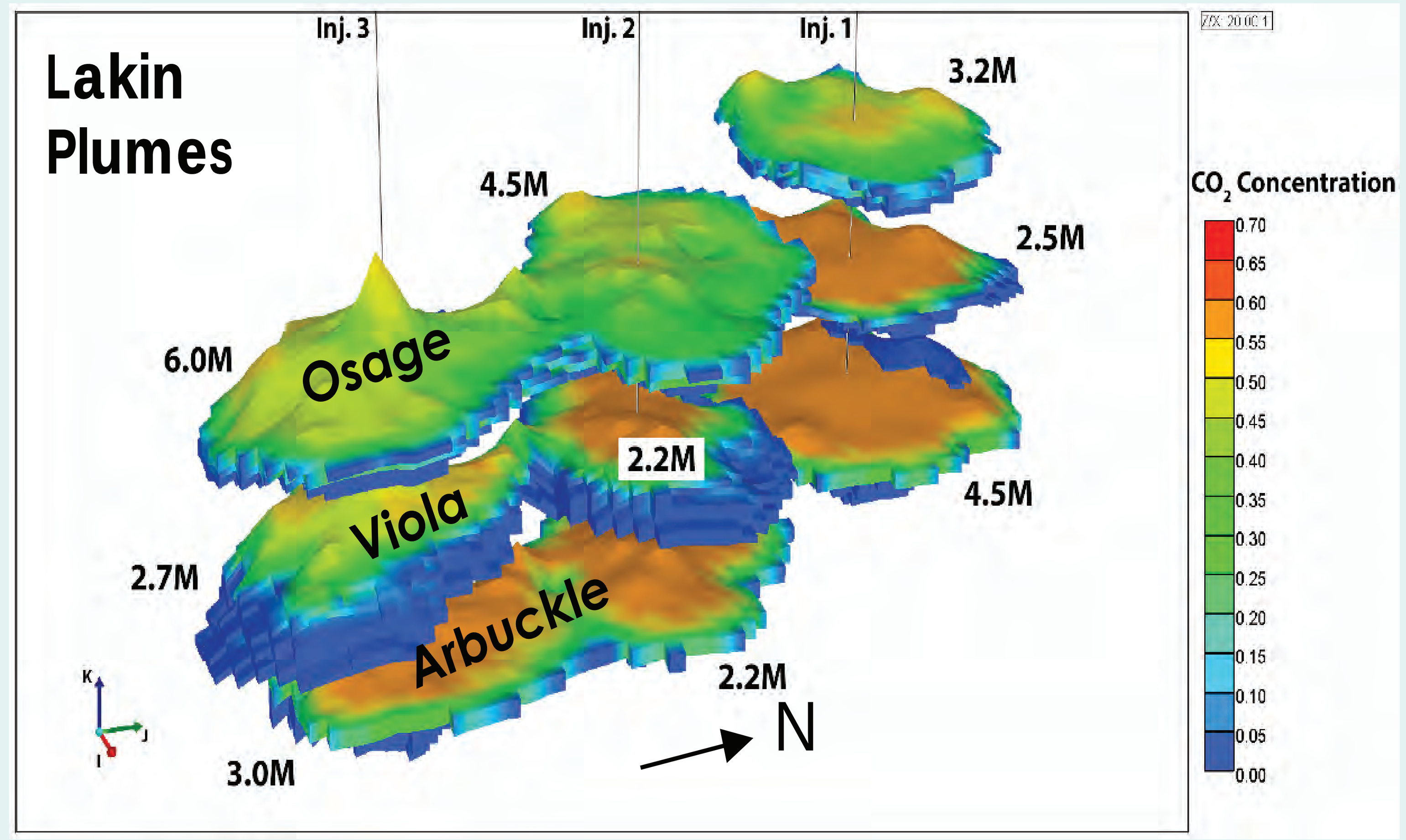
Davis Ranch Simulation



John Creek Simulation

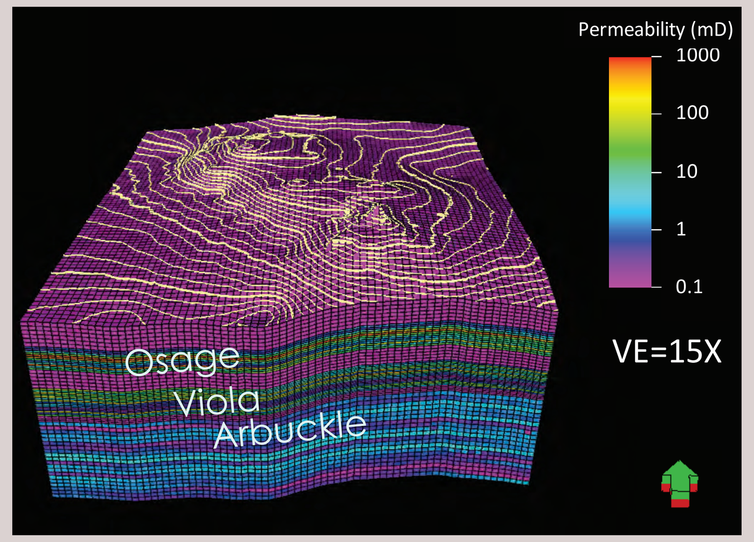


Lakin Simulation



Lakin Model

K



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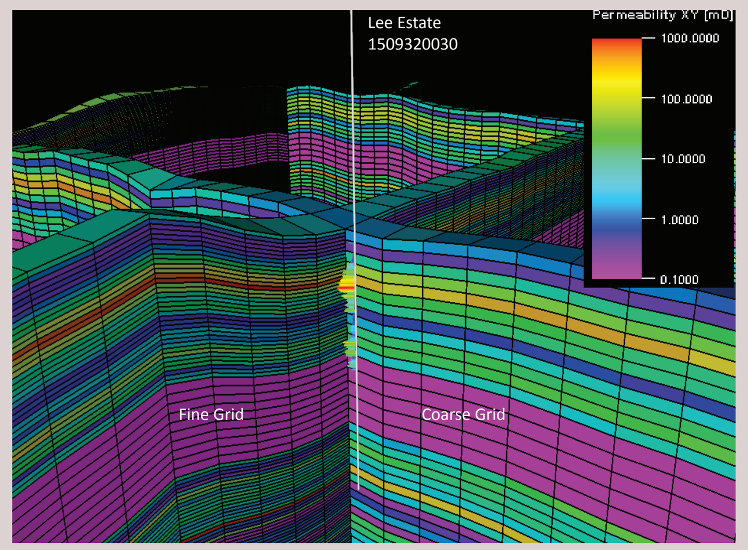
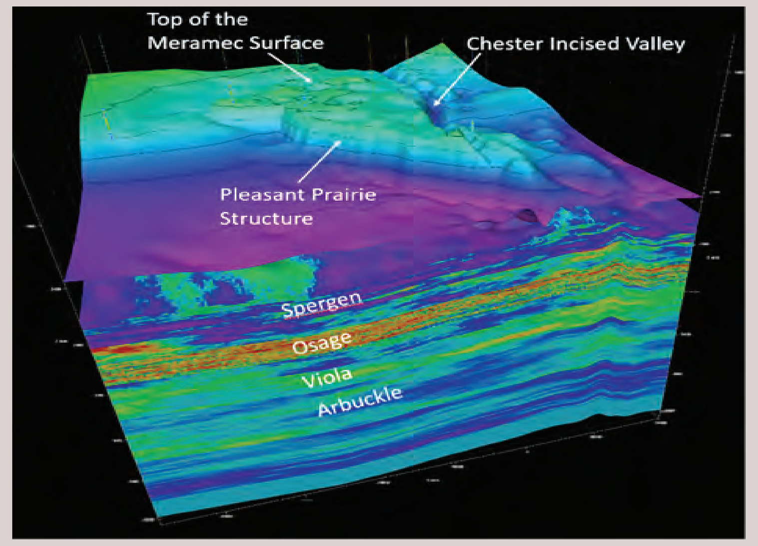


Pleasant Prairie Model

L



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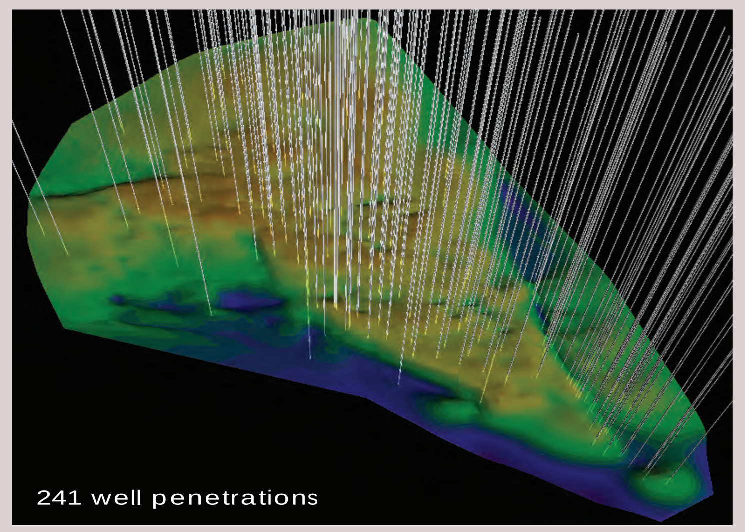
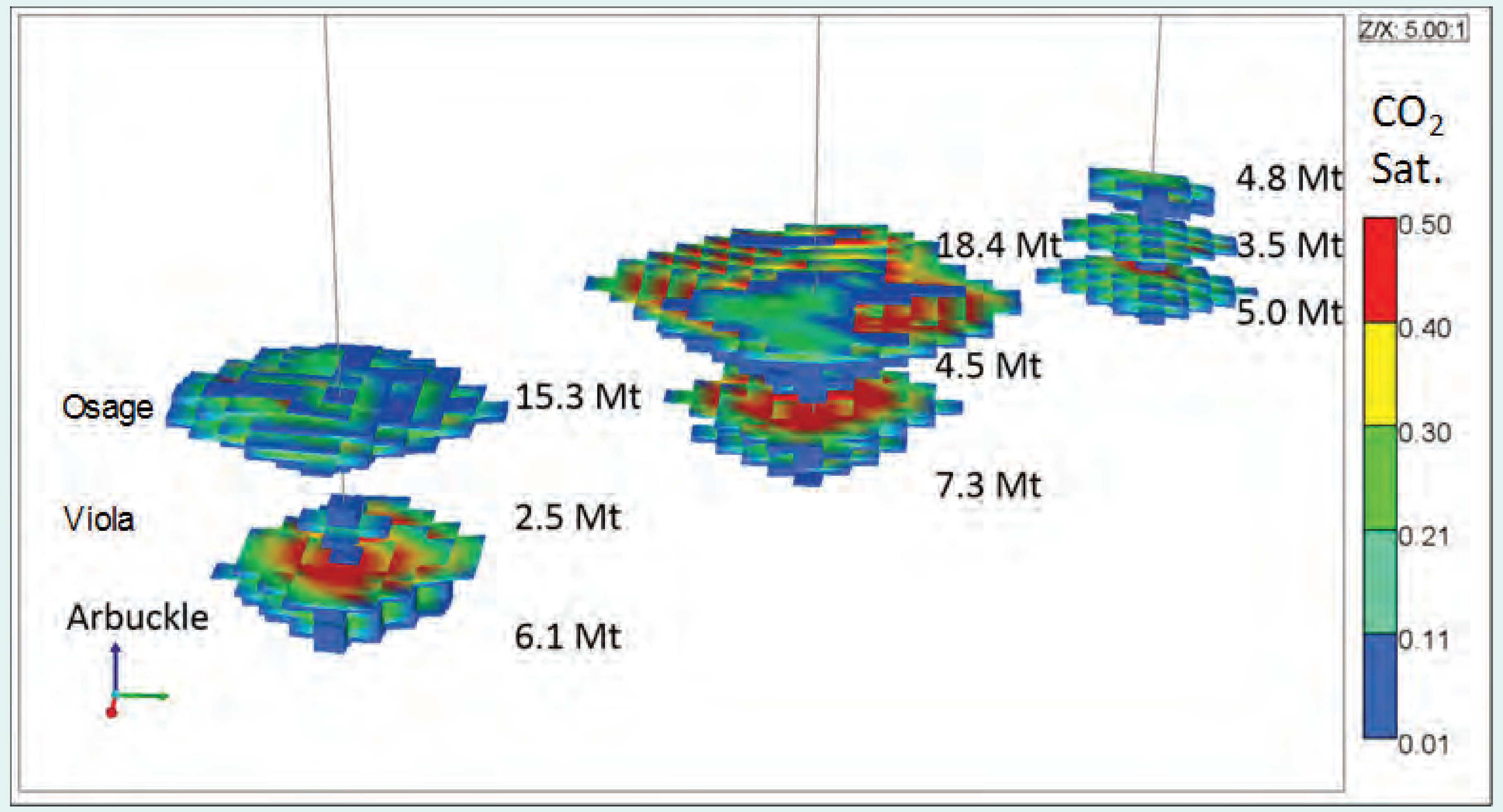


Pleasant Prairie Simulation



Summary of Results:

Storage Complex	Geologic Site	Volume Stored (Mt)	Injection Wells	Years of Injection	Comments
North Hugoton	Rupp	36.6	4	30	Likely to exceed 50 Mt
	Patterson	60.7	4	30	> 50 Mt minimum
	Lakin	30.8	3	25	Likely to exceed 50 Mt
	Pleasant Prairie	67.4	3	25	> 50 Mt minimum
Forest City Basin	Davis Ranch - John Creek	24.6	6	25	Cannot meet 50Mt minimum

I. Location of four plausible storage sites within the North Hugoton Storage Complex. Map is the structure on the top of the Meramec (Mississippian). Patterson is the primary site and the others are alternative sites.

J. The Lakin and Pleasant Prairie top of Meramac (Mississippian) structure.

K. 3D cellular permeability model of the Lakin Field identifying key horizons.

L. 3D cellular permeability model of the Pleasant Prairie field identifying key structure and horizons.

M. A fence diagram of the Lakin Model centered at a key well. The well log is upscaled to the 'fine grid' which is upscaled to the 'course grid' prior to simulation

N. A visualization of the well penetrations into the Pleasant Prairie model.

Future Work:

This is an exciting time for CO2 storage reseach. Our team is set to complete the technical evaluations at all five of the geologic sites. The upcoming steps including conducting a high-level technical analysis of the geologc storage complexes using NRAP-IAM-CS and other tools for an integrated assessment. The geology and petrophysical properties of the sub-oil-reservoir saline aquifers will be evaluated in terms of capacity, seal, faults, seismicity, pressure, and examination of existing wellbore integrity and injectivity. The fields in the North Hugoton Storage Complex have been designated as primary and alternative candidates for Phase II Storage. A recent CCS conference hosted by the KGS and the Great Plains Institute was held at the University of Kansas. Present at the meeting were representatives from many diverse backgrounds including regulartory, political, oil and gas producters, CO_2 producers, lawyers, geologic and engineering consultants, and researching academics. Kansas has assembled an excellent team to tackle the challenges ahead.