

# National Risk Assessment Partnership Task 5 – Application of Risk Assessment Tools and Methodologies to Synthetic and Field Data

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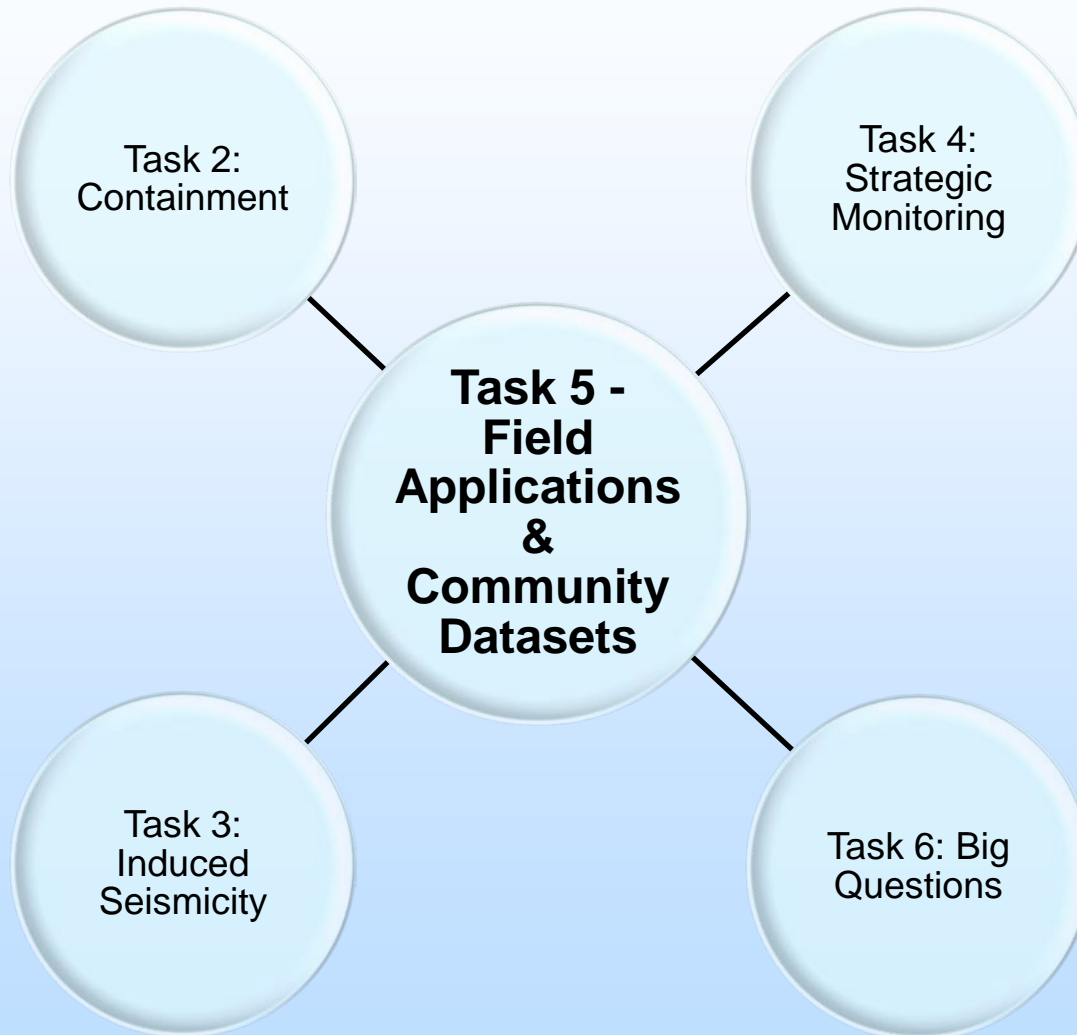
U.S. Department of Energy

National Energy Technology Laboratory

Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture,  
Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting

August 26-30, 2019

# NRAP Phase II Tasks



# Presentation Outline

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- **Containment Tools and Methodologies Field Demonstration**
- **Induced Seismicity Tools and Methodologies Demonstration**
- **Strategic Monitoring Tools and Methodologies Demonstration**
- **Identify Field Sites for Large Scale Leveraged Activities**
- **Development of Community Data Sets**
- **Synergy: Application of NRAP Tools to CarbonSAFE projects**

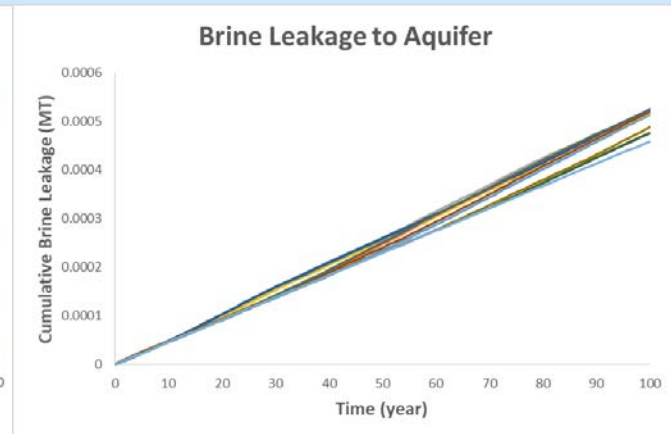
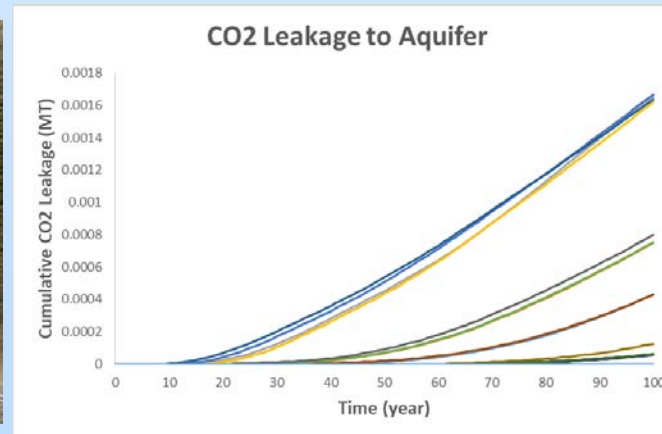
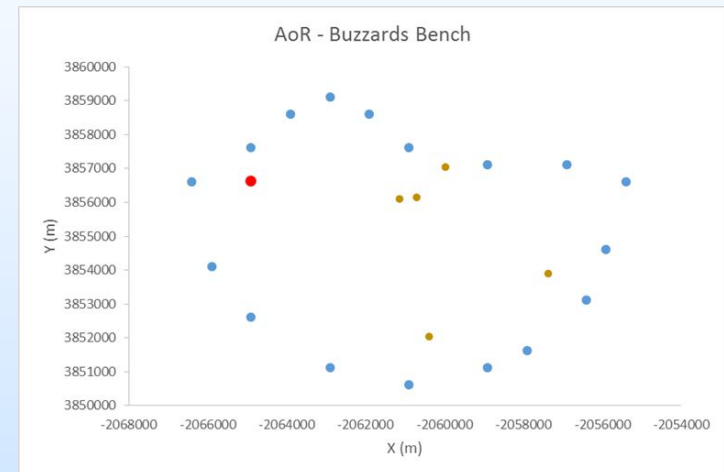
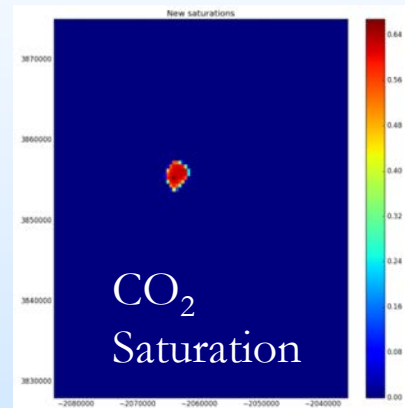
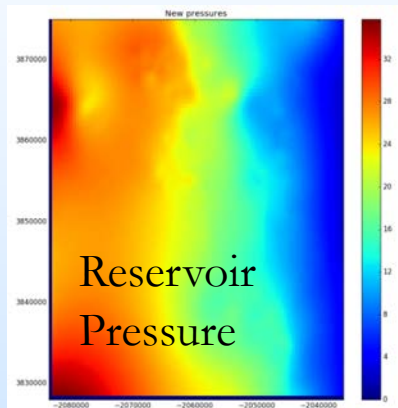


# Containment Tools and Methodologies Field Demonstration

Application of NRAP-IAM-CS at Rock Springs Uplift (Shaoping Chu, LANL)

## Risk Analysis: Buzzards Bench

Potential leakage wells inside AoR were used in the risk analysis CO<sub>2</sub> and brine leakage calculations

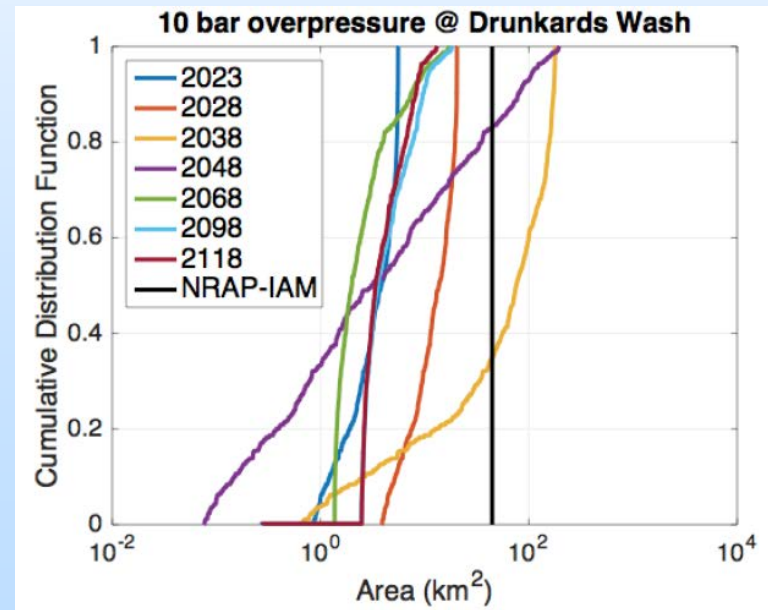
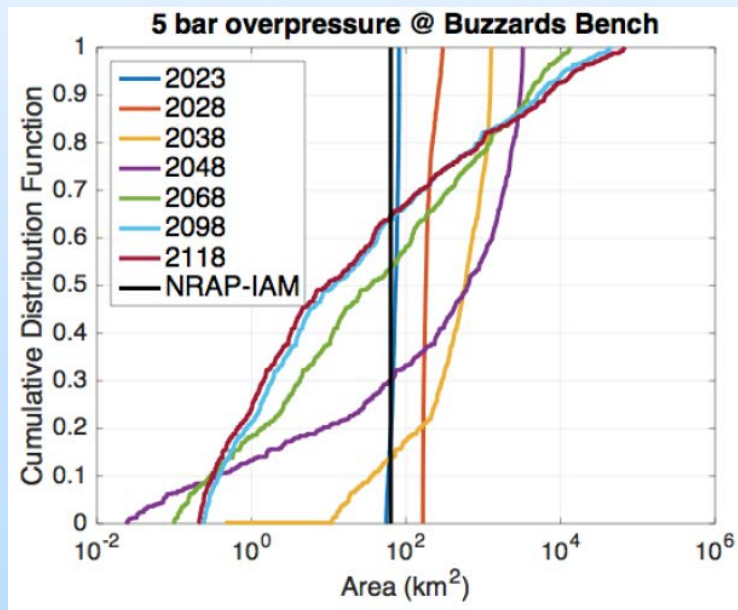


# Containment Tools and Methodologies Field Demonstration

Application of NRAP-IAM-CS at Rock Springs Uplift (Shaoping Chu, LANL)

## AoR comparison: LANL risk-based delineated vs. University of Utah geological model forecast

- Navajo Sandstone in the study area is likely at hydrostatic to slightly overpressurized state, therefore a numerical modeling approach is required per the EPA class VI guidance documents.
- Following figures show risk-based AoR prediction fall in the uncertain range of 5-bar and 10-bar overpressure areas forecasted by Univ. of Utah's geological model.

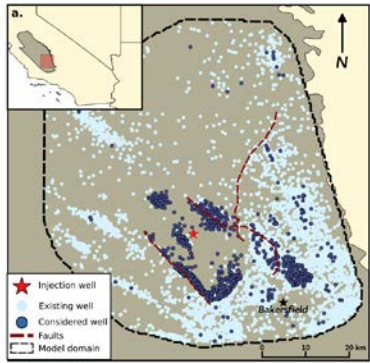


(Figure courtesy of “Final Report on CARBONSAFE ROCKY MOUNTAIN PHASE I: ENSURING SAFE SUBSURFACE STORAGE OF CARBON DIOXIDE IN THE INTERMOUNTAIN WEST (DE-FE0029280)”) 5

# Containment Tools and Methodologies Field Demonstration

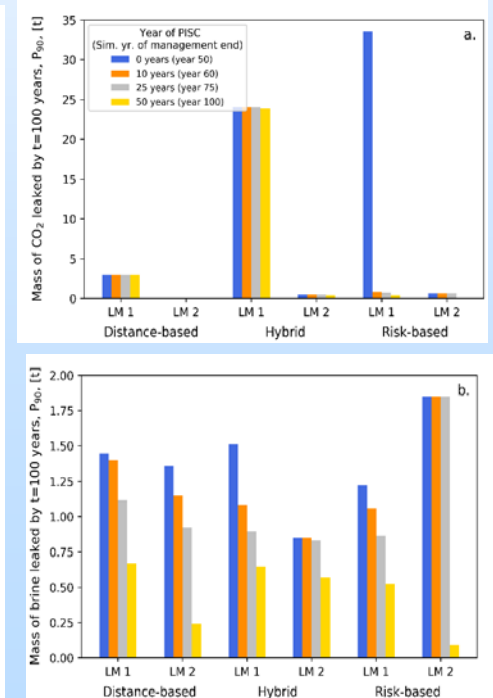
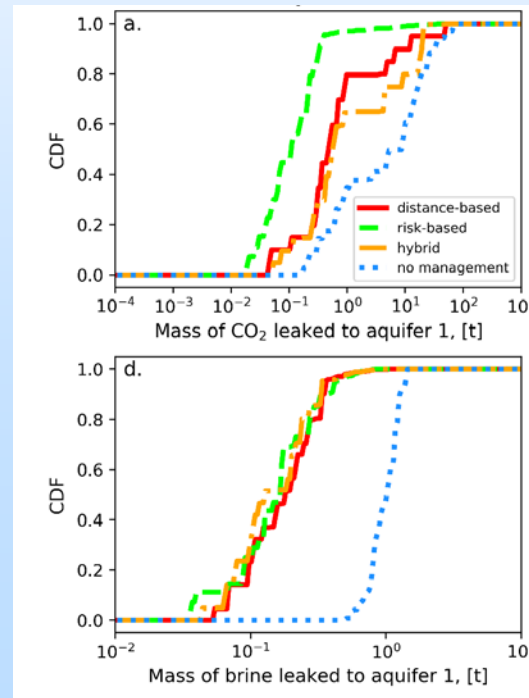
Managing Well Leakage at a GCS Site with Many Wells (Greg Lackey<sup>1,2</sup>, Veronika Vasylykivska<sup>1,3</sup>, Nicolas Huerta<sup>4</sup>, Seth King<sup>1,3</sup>, Robert Dilmore<sup>1</sup>

<sup>1</sup>NETL, <sup>2</sup>ORISE, <sup>3</sup>Leidos Research Support Team, <sup>4</sup>PNNL)



- NRAP-Open-IAM model of a brownfield GCS site with 1,000 legacy wells based on Kimberlina.
- Built well inspection and remediation functionality into NRAP-Open-IAM to simulate leakage risk management.
- Used real well data from the San Joaquin basin to characterize leakage risks for legacy wells at the site.
- Considered three leakage risk management strategies: (1) risk-based, (2) distance-based, (3) hybrid risk & distance.

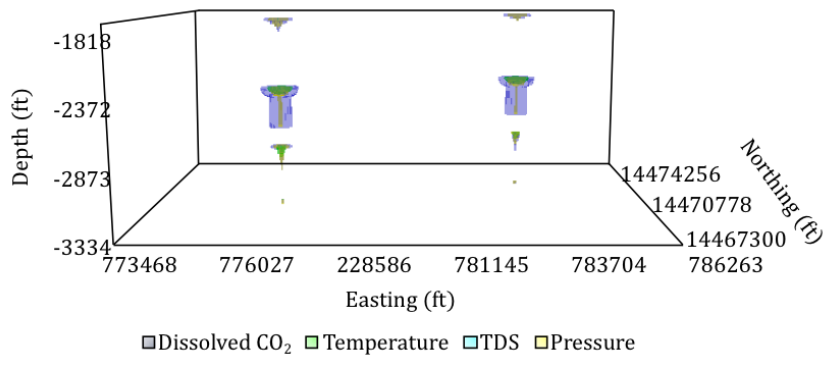
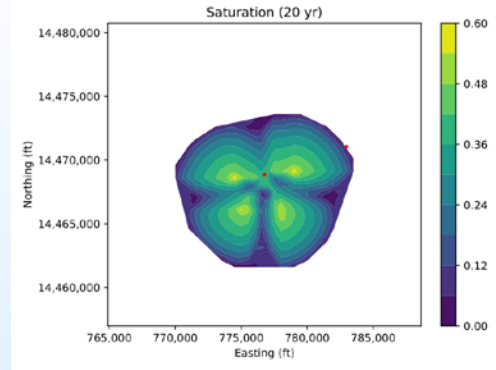
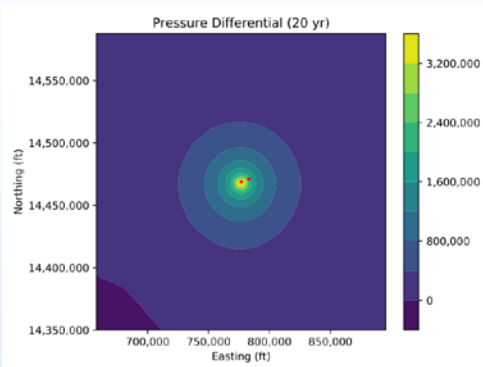
- Leakage risks at brownfield sites can be mitigated through the implementation of effective leak management strategies
- While both distance-based and risk-based management strategies were effective, risk-based strategies were more robust to changes in reservoir behavior.



# Strategic Monitoring Tools and Methodologies

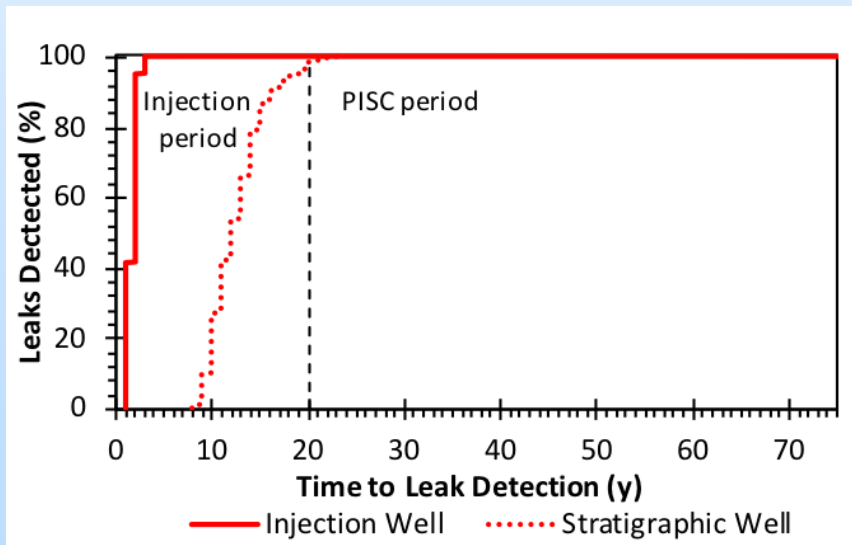
## Demonstration

Coupling of NRAP-Open-IAM and DREAM for risk-based PISC period determination at the FutureGen 2.0 site (Diana Bacon & Catherine Yonkofski, PNNL)



DREAM generated solution space showing all locations where the leakage threshold of the respective monitoring parameter was exceeded

Percentage of leakage scenarios detected vs. time (after start of injection) for the best performing monitoring configuration

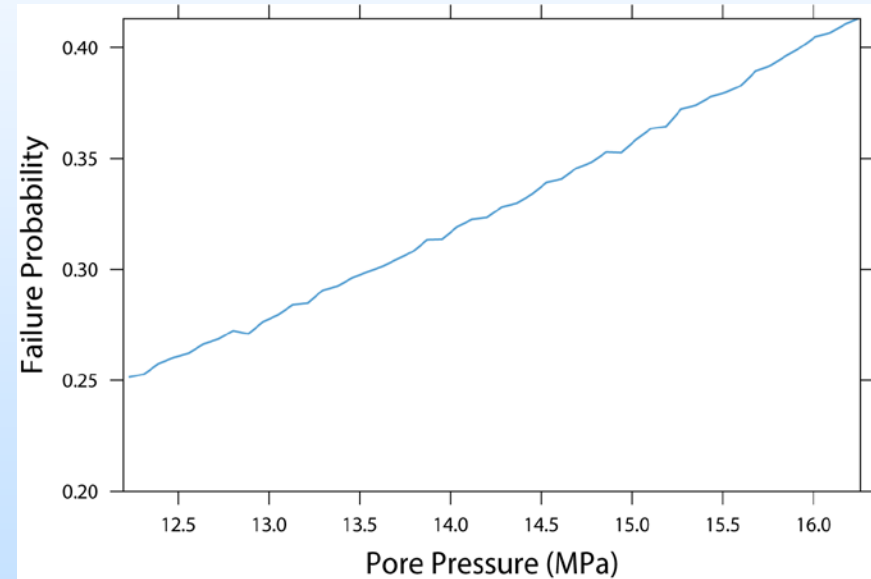
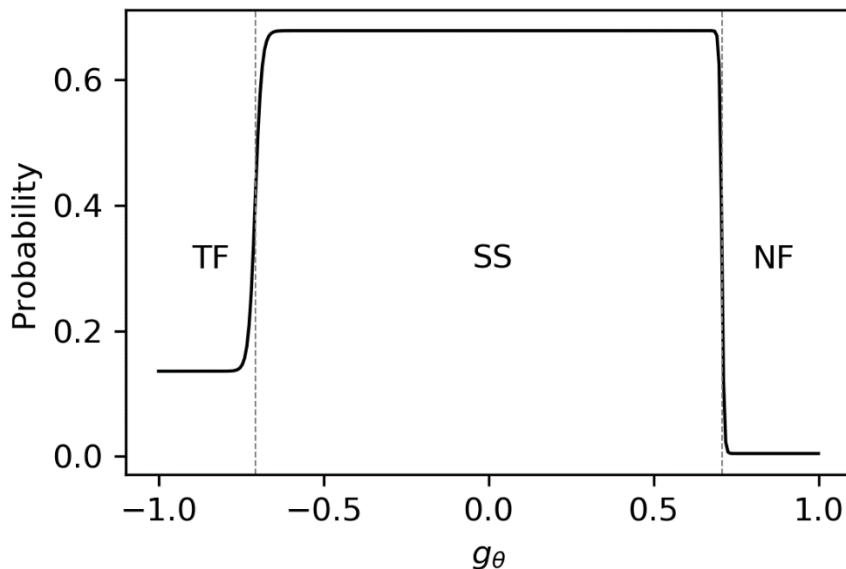


# Induced Seismicity Tools and Methodologies Demonstration

Application of SOSAT for state-of-stress analysis at the FutureGen 2.0 site  
(Delphine Appriou, PNNL)

SOSAT is a tool to help the operator reducing the geomechanical risks at a given site and at different phases of the project

**Probability distribution  
expressing the regional stress  
state**

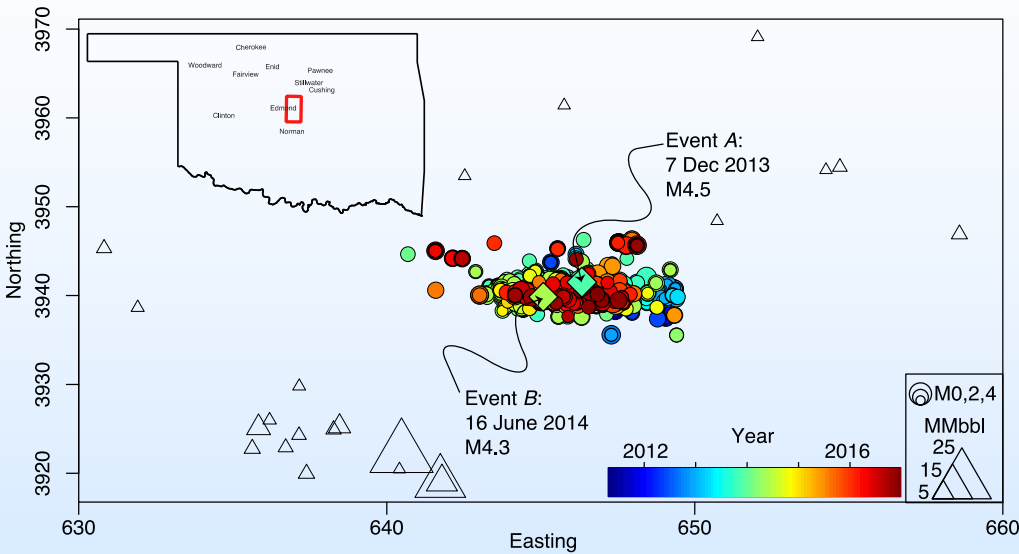


**Probability of inducing shear  
failure on a critically oriented fault  
for a given pore pressure**



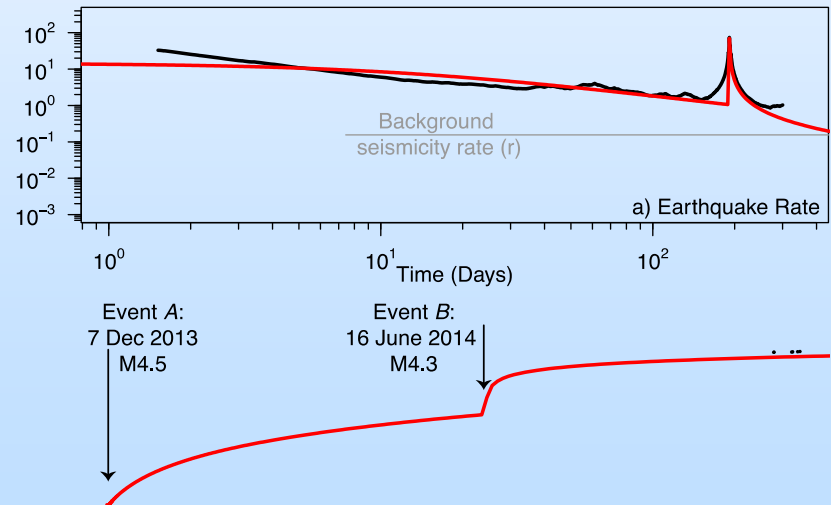
# Induced Seismicity Tools and Methodologies Demonstration

## Analysis of Aftershock Durations in Oklahoma (Kayla Kroll, LANL)



- ~3500 events between 2011 & 2016 (Skoumal & Brudzinski, 2019)
- Events occur before nearby injection begins
- M4.5 and M4.3 ~180 days apart each generate aftershock sequences

- Use coupled Coulomb/Rate-State approach to model seismic sequence (method of Kroll et al., 2017)
- Recover stressing rates, aftershock duration, product of normal stress and rate-coefficient
- Preliminary results suggest aftershock durations of induced events may be 6-100 times shorter than tectonic aftershock durations

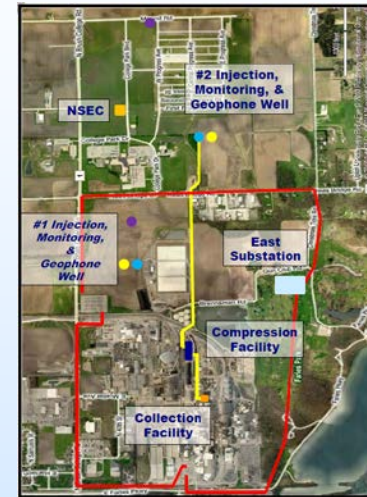


# Identify Field Site for Large Scale Leveraged Activities

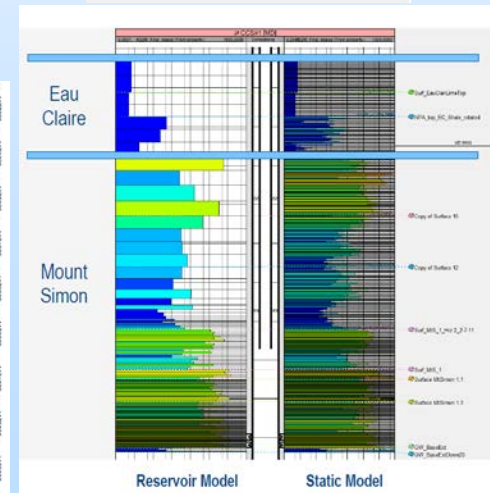
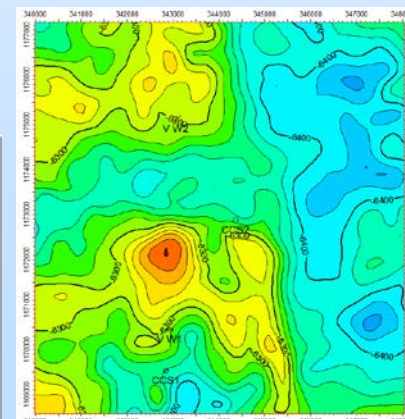
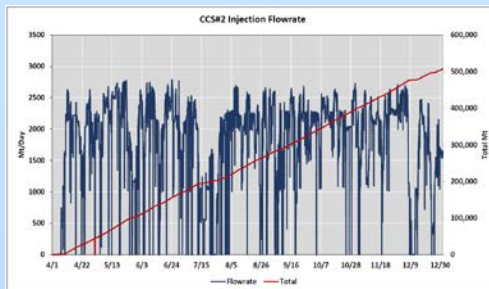
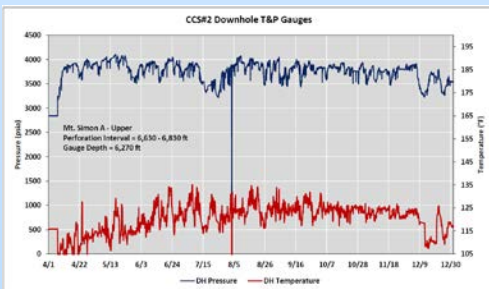
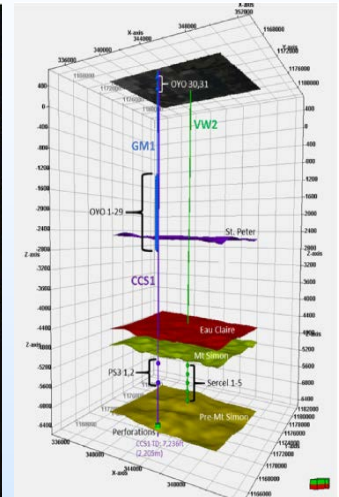
ADM Sites (Quanlin Zhou, LBNL)

- Established a collaboration with Archer Daniels Midland Company (ADM) on IBDP and the IL-ICCS project that is **ongoing with injection of 1 Mt/year**
- Identified field data available from the Decatur site
  - In Situ P/T/X/conditions
  - Core and well logs data for CCS1, CCS2, VW1, VW2
  - Geological model calibrated using the IBDP and IL-ICCS data
  - CO2 injection and monitoring data for the IBDP project
  - CO2 injection and monitoring data for the IL-ICCS project
  - All data (106 GB) for triggered events for induced seismicity acquired
  - 2-D and 3-D seismic surveys and 3-D VSP data
- The data transfer is ongoing from ADM to LBNL
- The models and data will be used for NRAP tool validation and development

Site with Wells



Borehole IS Sensors



IL-ICCS Project Data

Basement Highs

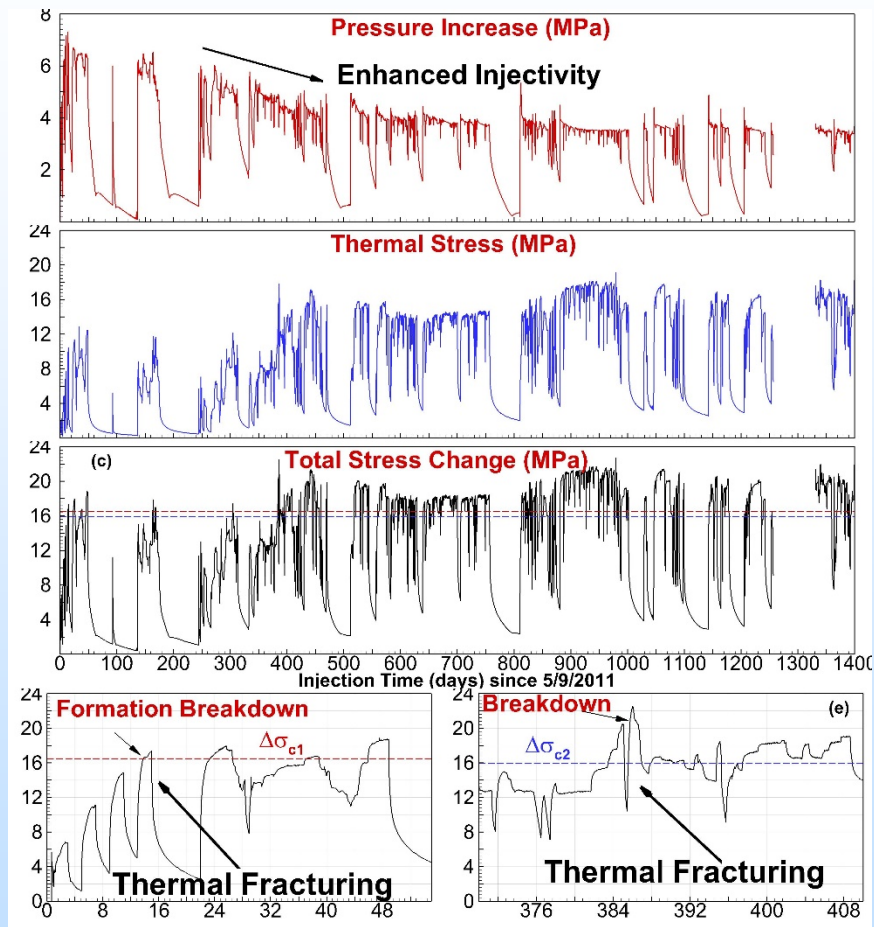
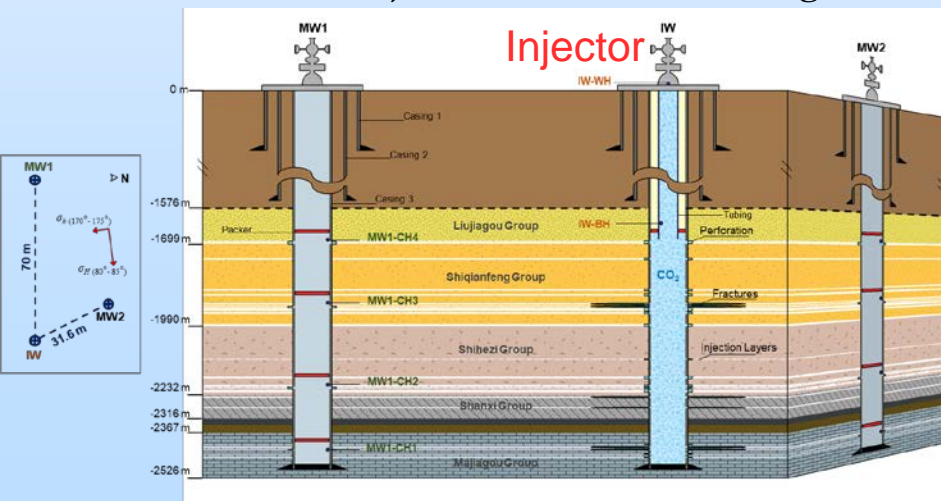
Geological Model

# Development of Community Data Sets

## Thermal Fracturing (Quanlin Zhou, LBNL)

- Completed data integration and analysis by collecting all characterization and field-monitoring data for the **Ordos, China CCS site**;
- Identified field evidence of **thermal fracturing**: enhanced injectivity, formation breakdown, and dynamic CO<sub>2</sub> feed-zone changes at different depths as fracturing occurs (Zhou et al., 2019c);
- Developed a conceptual model to better understand thermal fracturing of and fracture propagation in multiple storage formations/layers.

**800 m thick multi-formation storage complex with one injection and two monitoring wells**



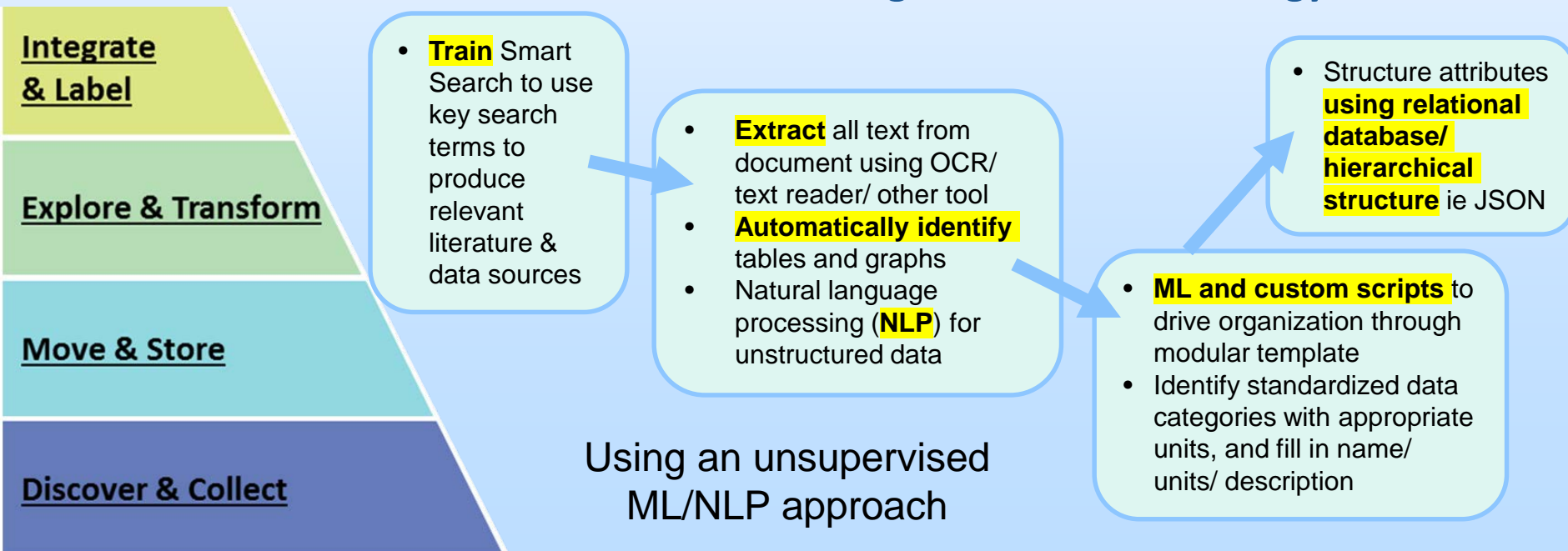
- Thermal fracturing was initiated at 14 days in the second uppermost injection layer and at 386 days in the uppermost injection layer;
- Fractures gradually propagate into the formations

# Development of Community Data Sets

## Data Catalog & ML (Kelly Rose, Gabe Creason, NETL)

- Data Catalog, Phase I Tool Matrix, and Task 4 reservoir monitoring literature on EDX
- **Developing and applying ML/NLP tools for a smarter approach to discovering, collecting, organizing, and labeling CS knowledge and data**
- Synchronizing ML/NLP Data Discovery effort with other FE resources
  - RCSP, Oil/Gas, Coal, REE, Geothermal, etc., under EDX virtual subsurface data framework

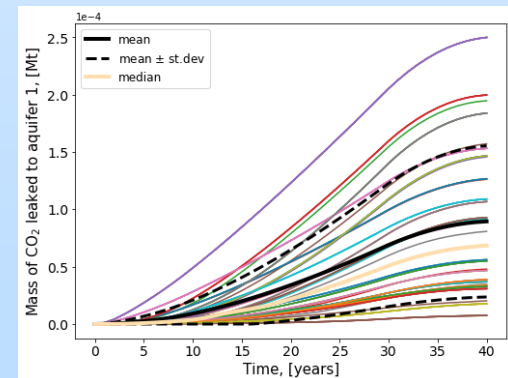
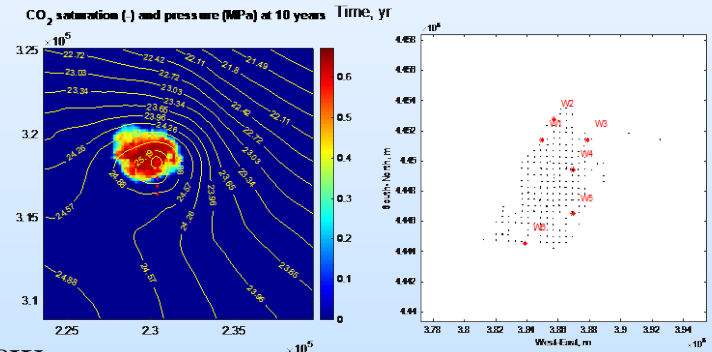
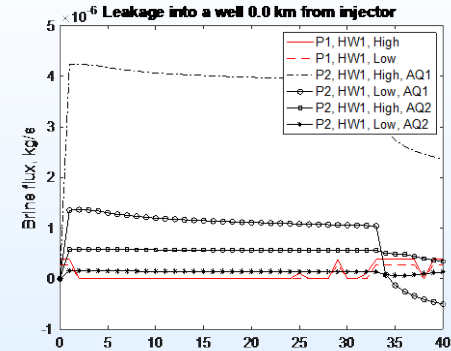
### “Smart” Data & Knowledge Generator for Energy Geoscience



# Synergy Opportunities

(Application of NRAP Tools to CarbonSAFE Projects, Nicholas Huerta, PNNL)

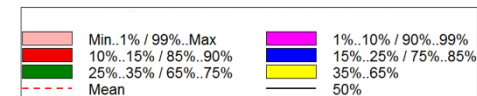
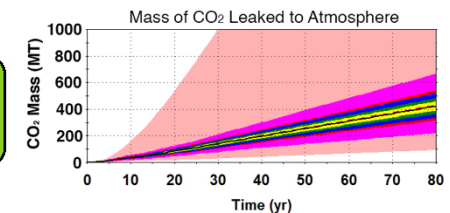
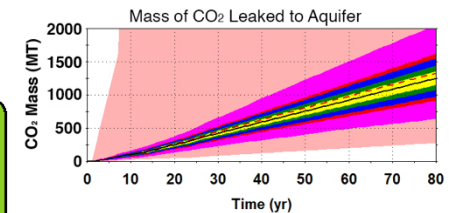
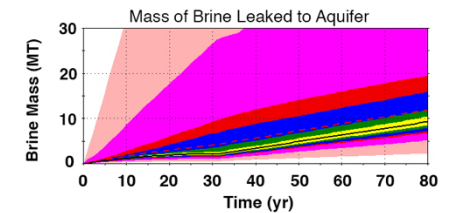
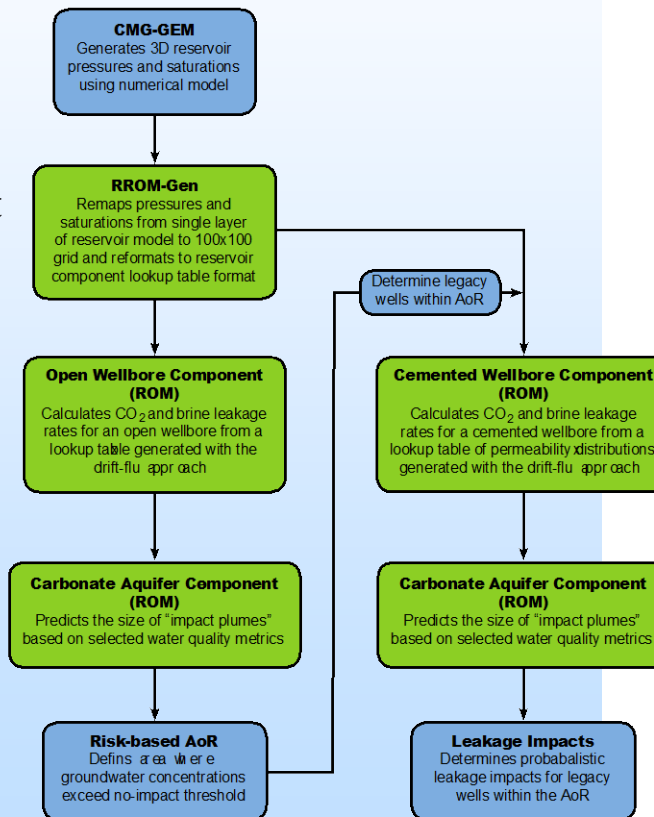
- CarbonSAFE East Sub-basin [DE-FE0029445]
  - Compared Phase I and Phase II of NRAP's Integrated Assessment Model (IAM)
  - Study confirmed leakage behavior is comparable but more realistic in the new version
- CarbonSAFE Illinois Macon County (Christian Co.) [DE-FE0029381]
  - Work will focus on possible leakage impact to groundwater
- Wabash CarbonSAFE [DE-FE0031626]
  - Work will focus on leakage impact, Area of Review delineation, and State of Stress estimation
- Integrated Midcontinent Stacked Carbon Storage Hub [DE-FE0031623]
  - Preliminary results show low probability for an impactful leak, despite many wells



# Synergy Opportunities

(A Risk-Based Approach to Evaluating the Area of Review and Leakage Risks at CO<sub>2</sub> Storage Sites,  
Signe White, PNNL, Susan Carroll, LLNL, Shaoping Chu, LANL, et al.)

- NRAP IAM CS was used to estimate the project risk area that could represent the AoR and the impact of leakage through legacy wells to overlying drinking waters at these candidate CO<sub>2</sub> storage sites.
- Study shows that risk to USDWs is minimal despite
  - the presence of multiple legacy wells at these sites where the AoR approximates the maximum extent of injected CO<sub>2</sub> or
  - the presence of a much larger AoR approximating the pressure front caused by the injection of CO<sub>2</sub>.

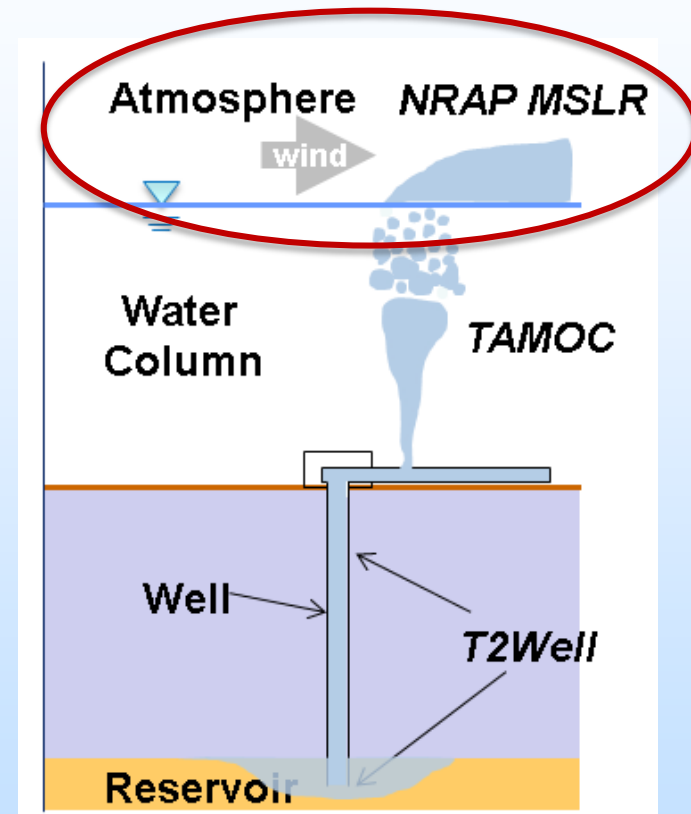


# Synergy Opportunities

Risk Assessment of Offshore CO<sub>2</sub> Wells and Pipelines

(Curtis M. Oldenburg, Lehua Pan, Yingqi Zhang, Quanlin Zhou, LBNL)

- Offshore GCS needs sub-sea risk assessment
- For the GoMCarb project, we are coupling three existing models to understand consequences of offshore CO<sub>2</sub> leaks and blowouts
  - T2Well for reservoir-well flow
  - TAMOC for jet and buoyant plume flow in the water column
  - **NRAP MSLR** for atmospheric dispersion



# Project Summary

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- Field applications and user feedback are driving enhancements to NRAP-IAM-CS, NRAP-Open-IAM, SOSAT, DREAM and MSLR tools
- Characterization data and modeling results for the Kimberlina, FutureGen 2.0, ADM, Oklahoma and CarbonSAFE sites are contributing to development and testing of NRAP containment, monitoring and induced seismicity tools and methodologies
- The list of field applications is growing and will be highlighted in a catalog made available on EDX



# Appendix

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- These slides will not be discussed during the presentation, **but are mandatory.**

# Accomplishments to Date

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- **Containment Tools and Methodologies Field Demonstration**
  - Aquifer Impact Model applied at Illinois Basin – Decatur site
  - At CaMI site, unique field site for testing CO<sub>2</sub> leakage monitoring technologies, predictive models were developed and hypothetical leakage scenarios were simulated
  - Risk-based AoR using NRAP-Open-IAM demonstrated at FutureGen 2.0 greenfield site
  - NRAP-IAM-CS applied to a 50Mt injection scenario for preliminary risk assessment at YHS site
  - NRAP-Open-IAM applied for wellbore leakage risk determination at a brownfield site
  - Good comparison between risk-based AoR and overpressure area model forecast at Rock Springs Uplift sites

# Accomplishments to Date

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- **Strategic Monitoring Tools and Methodologies Demonstration**
  - WLAT and DREAM applied for risk-based monitoring design for CO<sub>2</sub> Leakage through Abandoned Wellbores using BCO's wellbore database
  - DREAM/NRAP-Open-IAM coupling demonstrated for risk-based monitoring and PISC period determination for the FutureGen 2.0 site
- **Induced Seismicity Tools and Methodologies Demonstration**
  - Poroelastic properties of the Arbuckle Group in Oklahoma derived from well fluid level response to the Mw5.8 Pawnee and Mw5.0 Cushing Earthquakes
  - Conducted study on feasibility of using coupled Coulomb/Rate-State model to understand aftershock durations of induced seismicity with goal of informing PISC period
  - SOSAT tool applied at the Farnsworth and FutureGen 2.0 sites

# Accomplishments to Date

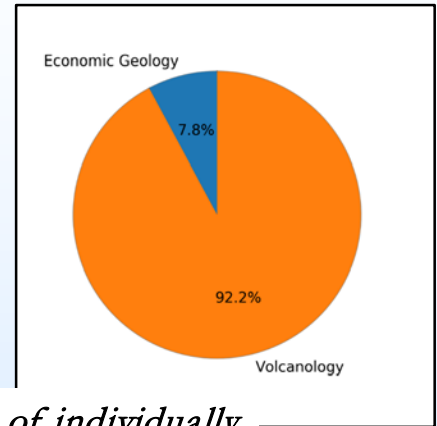
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- **Identify Field Sites for Large Scale Leveraged Activities**
  - Curated characterization data and model results from FutureGen 2.0 UIC License Application available on EDX
  - Established a collaboration with Archer Daniels Midland Company (ADM), identified field data from Decatur site
- **Development of Community Data Sets**
  - Total of 610 data resources cataloged that align to NRAP tool and user needs
  - Incorporated Kimberlina modeling scenarios into online data catalog
  - Documented field evidence of thermal fracturing and associated flow focusing at Ordos, China, Cranfield, USA, and In Salah, Algeria.

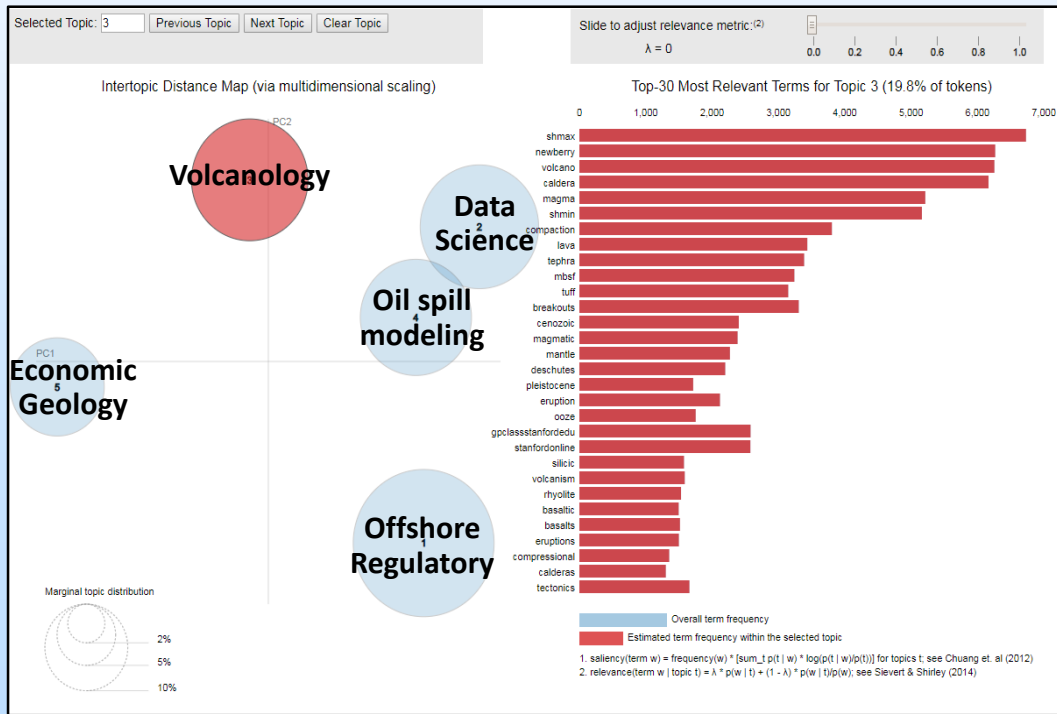
# Accomplishments to Date

## Development of Community Datasets

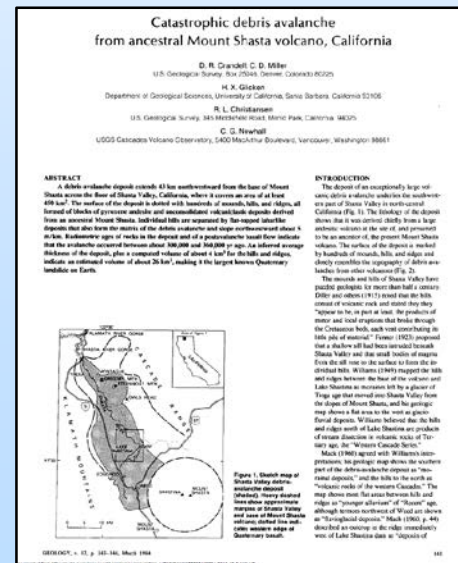
- Developed and demonstrated an unsupervised ML work-flow that labels and classifies textual knowledge
  - This tool gives meaning with programing context
- Next step → deploy for NRAP models & tools!



*Example of individually classified paper*



Documents = 2,738, Unique words = 113,264



*Feeding models thru document mining*

# Lessons Learned

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- **Containment Tools and Methodologies Field Demonstration**
  - Current aquifer ROMs are being trained on a wider range of leakage rates than the original carbonate aquifer ROM
  - While both distance-based and risk-based management strategies were effective, risk-based strategies were more robust to changes in reservoir behavior.
- **Strategic Monitoring Tools and Methodologies Demonstration**
  - Predicted leakage rates for wellbore permeabilities  $< 10^{-14} \text{ m}^2$  are small and difficult to detect; larger leaks must be assumed for effective monitoring design

# Lessons Learned

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- **Induced Seismicity Tools and Methodologies Demonstration**
  - Analysis of aftershock durations in regions where regulations required reduced injection volumes after a large earthquake will be more complicated by non-linear stressing rates (spatial and temporal), related to pressure diffusion and changes in poroelastic stresses
  - Risk of unintentional hydraulic fracturing should be incorporated in the release version of SOSAT
- **Identify Field Sites for Large Scale Leveraged Activities**
  - Although characterization efforts were significant at the FutureGen 2.0 site, data were missing to build a comprehensive geomechanical model and reduce uncertainties

# Lessons Learned

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- **Development of Community Data Sets**
  - Cooling-induced thermal fracturing during cold CO<sub>2</sub> injection found at several storage sites has not been considered as a risk of CO<sub>2</sub> storage;
  - The effect of natural heterogeneity on CO<sub>2</sub> migration and trapping has not been well understood because of the lack of detailed field monitoring data and data integration
  - Training data must be tailored specific to disciplines
  - Useful at paper, paragraph, sentence, and word scale
  - Big Data problem
    - At least 30,000 unique words
    - Computationally intensive (time =  $n^2$ )



# Benefit to the Program

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- The motivating goal of NRAP is to develop science-based methodologies and tools for calculating risks at any CO<sub>2</sub> storage site while providing necessary scientific and technological advances to support that methodology. Phase II is focusing on management of risk associated with large-scale CO<sub>2</sub> storage, and with reducing associated uncertainties.
- Objectives of efforts under Phase II will focus on applying and extending that predictive capability to actively manage risks related to CO<sub>2</sub> storage to quantitatively assess improvements in environmental risk performance afforded by select mitigation strategies, and to reduce uncertainties in system performance through iterative conformance assessment and prediction improvement.

# Project Overview

## Goals and Objectives

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- This task focuses on the validation of various components of the NRAP toolset, and the NRAP-IAM-CS. A primary goal of this task is to compare the predictive capability of the tools with data from real field observations.
- However, since field data are limited, and since there are no comprehensive field data sets where a large scale CO<sub>2</sub> leak has occurred, a synthetic data set based on simulated CO<sub>2</sub> storage with hypothetical leakage and stress effects at the Kimberlina site is being developed and used as a community dataset.

# Organization Chart

- **Containment Tools and Methodologies Field Demonstration**
  - Diana Bacon, PNNL; Greg Lackey, NETL; Shaoping Chu, LANL; Curtis M. Oldenburg, Liange Zheng, LBNL, Nicholas Huerta, PNNL
- **Strategic Monitoring Tools and Methodologies Demonstration**
  - Diana Bacon, Catherine Yonkofski, PNNL
- **Induced Seismicity Tools and Methodologies Demonstrations**
  - Jeff Burghardt, Delphine Appriou, PNNL; Kayla Kroll, LANL
- **Identify Field Sites for Large Scale Leveraged Activities**
  - Inci Demirkanli, Delphine Appriou, Signe White PNNL; Quanlin Zhou, LBNL
- **Development of Community Data Sets**
  - Kelly Rose, Gabe Creason NETL; Quanlin Zhou, LBNL

# Task Milestones

|          |   |
|----------|---|
| 9/30/17  | Publish application of NRAP tool to large GCS field site. Method of Verification: Article entitled “Applicability of the Aquifer Impact Model to Support Decisions at a CO <sub>2</sub> Sequestration Site.” Published in journal <i>Greenhouse Gases: Science and Technology</i> . |
| 6/30/18  | Select site for detailed geo-data model development.<br>Action: Proceed with geo-data model development for selected community dataset.   |
| 12/31/18 | Develop a prototype geo-data model for one U.S. carbon storage community data system (for internal NRAP use).   |
| 12/31/18 | Complete one or more draft manuscripts describing the application of NRAP tool(s) to field sites.<br>Method of Verification: Draft manuscript for submission to peer-reviewed journal or technical report uploaded to the NRAP workspace on the NETL Energy Data Exchange.          |
| 12/31/19 | <b>Develop catalog of studies testing and demonstrating NRAP tools/methods.</b><br><b>Method of Verification: Slide presentation describing applications of NRAP tools/methods uploaded to the NETL Energy Data Exchange.</b>   |
| 9/30/20  | <b>Decide if the NRAP community dataset and geodatabase are ready for external release.</b><br><b>Action: Proceed with plan to finalize/publish community dataset.</b>  |
| 12/31/20 | <b>Complete NRAP community dataset and geodatabase development. Method of Verification: Upload draft-final NRAP community dataset for internal review and final QA/QC to the NRAP workspace on the NETL Energy Data Exchange.</b>   |
| 9/30/21  | <b>Complete draft final report on NRAP tools field validation. Method of Verification: Upload draft-final report to the NRAP workspace on the NETL Energy Data Exchange.</b>  |

# Bibliography

- Journal articles:

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