NRAP Phase II: Managing Risks and Reducing Uncertainties

An Overview of Research Objectives and Accomplishments

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U.S. DOE’s National Risk Assessment Partnership

NRAP leverages DOE’s capabilities to quantitatively assess and manage long-term environmental risks amidst significant geologic uncertainty and variability.
Integrated R&D Approach for Commercial-Scale Deployment

**2017**
- Large Capture Pilots Initiated
- Initiate Storage Feasibility for Integrated CCS

**2020**
- R&D Completed for Carbon Capture
- 2nd Generation Technologies

**2022**
- Commercial-scale storage complexes characterized

**2025**
- Integrated CCS Projects initiated

**2030**
- Advanced technologies available for broad commercial-scale deployment

“New target for the United States to achieve a 50-52 percent reduction from 2005 levels in economy-wide net greenhouse gas pollution in 2030”

~ Biden Administration, 4/2021
The NRAP Team (2021)
NRAP Phase II Technical Tasks and Org. Structure

- Task 2: Containment assurance / leakage risk management
- Task 3: Induced seismicity risk management
- Task 4: Strategic monitoring for Uncertainty Reduction
- Task 5: Validating NRAP tools and approaches
- Task 6: Addressing critical risk-related questions
Today’s Presentations

- Task 2: Containment assurance / leakage risk management
- Task 3: Induced seismicity risk management
- Task 4: Strategic monitoring for Uncertainty Reduction
- Task 5: Validating NRAP tools and approaches
- Task 6: Addressing critical risk-related questions

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How big might the risks be from a GCS operation?

NRAP Phase I (2010 – 2016)
Risk Assessment & Uncertainty Quantification

- Pioneered hybrid methods for quantifying complex systems (physics coupled to empirical, e.g., machine learning)
- Developed computational tools for quantifying storage post injection
- Developed foundation for strategic (risk-based) monitoring (e.g., DREAM tool; no-impact thresholds)

(Benson, 2007)
NRAP’s approach for rapid prediction of whole-system risk performance

A. Divide system into discrete components

B. Develop detailed component models that are validated against lab/field data

C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

D. Link ROMs via integrated assessment models (IAMs) to predict system performance

E. Exercise whole system model to explore risk performance

Adapted from Bromhal et al. 2014; Pawar et al. 2017

(Benson, 2007)
NRAP Phase I Accomplishments

NRAP Tools Available at: www.edx.netl.doe.gov/nrap
NRAP Phase II (2017–2021)

Risk Management and Uncertainty Reduction

• How can risks be managed at a GCS site?

• How can a risk-based approach help inform stakeholder decision making?

Supporting risk-based decisions at GCS sites

Leakage Risk Management and Containment Assurance

Induced Seismicity Risk Management

Risk-Based Monitoring Network Design
Site-specific, Physics-Based Risk Assessment

**Receptors of Concern**
- Groundwater aquifers
- Atmosphere

**Potential Migration Pathways**
- Wells and boreholes
- Fractures and faults
- Intermediate reservoirs

**Storage System**
- Storage reservoir
- Cap rock

Qualitative, Generalized Representation of Geologic Storage Risks (Benson, 2007)

Field Validated Methods and Tools for Physics-Based, Quantitative Risk Assessment

Decay rate for leakage risk at CO₂ storage sites is strongly correlated to reservoir pressure and decreases much more rapidly than previously thought (modified from Bromhal et al. 2014 and Pawar et al., 2017)
Integrated Decision Support for GCS Site Risk Mgmt

Quantitative, Site-Specific Risk Profiles

Metrics for Plume Stability

Plume Stability and Conformance, and Uncertainty Reduction

Risk Management and Site Closure Evaluation

Prob. of impacted USDW volume $> V_{\text{threshold}}$

https://gitlab.com/NRAP/OpenIAM
NRAP Products and Stakeholder Engagement

NRAP Foundational Research and Community Data

- NRAP Phase II - Virtual Special Issue *International Journal of Greenhouse Gas Control* - *(September 2020)*

- Community Datasets
  - Kimberlina *(initial release March 2020)*
  - FutureGen 2.0 *(initial release October 2020)*

- [https://www.osti.gov/](https://www.osti.gov/)

~450 publications, 13,650 citations; h-index 65
NRAP Phase II Tools

**Leakage Risk/Containment Assurance**
- NRAP Open-Source Integrated Assessment Model (NRAP-Open-IAM) - Beta Release May 2020

**Induced Seismicity Risk**
- Short-term Seismic Forecasting Tool (STSF) – Revision Expected 12/2021
- State of Stress Analysis Tool (SoSAT) – Beta release October 2018
- Probabilistic Seismic Risk Assessment Tool (RiskCat) - Beta release April 2020

**Monitoring Design and Optimization**
- Designs for Risk Evaluation and Management (DREAM 2.0) - Beta Release March 2020
- Microseismic monitoring design optimization tool – Beta release October 2020

NRAP Tools Available at: https://edx.netl.doe.gov/nrap/tools-main/
NRAP Open-Source Integrated Assessment Model (NRAP-Open-IAM)

Risk-based AoR
- Aquifer Impact AoR
- AoR Determined by EPA

Quantitative, Site-Specific Risk Profiles

Metrics for Plume Stability

Monitoring Design Evaluation

Conformance assessment and uncertainty reduction

Performance-based Closure Assessment

Risk Management and Site Closure Evaluation

(Vasylkivska et al., forthcoming)
https://gitlab.com/NRAP/OpenIAM
NRAP Induced Seismicity Risk Assessment and Management Tools

State of Stress Analysis Tool (SOSAT)

Stress probability distribution

$\sigma_1$ (MPa)

$\sigma_3$ (MPa)

$P(\text{fault activation})$

Probability of Fault Activation

(Burghardt, 2018)  Pore Pressure (MPa)

Short-term seismicity forecasting (STSF)

(Bachmann et al., 2014)

Probabilistic seismic risk analysis (RiskCat)

(Burghardt, 2018)

Beta tool available at: [www.edx.netl.doe.gov/nrap](http://www.edx.netl.doe.gov/nrap)

Beta tool available at: [www.edx.netl.doe.gov/nrap](http://www.edx.netl.doe.gov/nrap)

Beta tool available at: [https://gitlab.com/NRAP/RiskCat](https://gitlab.com/NRAP/RiskCat)
Design for Risk Evaluation and Management (DREAM)

(Yonkofski et al., 2016)

https://edx.netl.doe.gov/workspace/resources/nrap-tools

Passive Seismic Monitoring Tool

Microseismic events

Target monitoring region

Geophone distribution

(Chen and Huang, 2020)

New NRAP Phase II Tools User Forum on EDX

https://edx.netl.doe.gov/workspace/forum/nrap-tools

Requires EDX account and permission to access NRAP tools workspace
Recommended Practices for Risk Management

**Induced Seismicity Risk Management**

- **Step 1**: Perform a preliminary screening evaluation.
- **Step 2**: Implement an outreach and communication program.
- **Step 3**: Review and select criteria for ground vibration and noise.
- **Step 4**: Establish seismic monitoring.
- **Step 5**: Quantify the hazard from natural and induced seismic events.
- **Step 6**: Characterize the risk of induced seismic events.
- **Step 7**: Develop risk-based mitigation plan.

**Drafts Released March 8, 2021**

**Feedback still being accepted**

**Comments to:** NRAP@netl.doe.gov
## NRAP Tasks 4 and 6 Contributors

### Task 4 – Strategic Monitoring for Uncertainty Reduction
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### Task 6 – Addressing critical risk-related questions
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Task 4. Strategic Monitoring for Uncertainty Reduction

Estimating Leak Detection Thresholds of Monitoring Techniques

Stochastic Leakage Simulations

Monitoring Technology
- MT (Magnetotellurics)
- ERT (Electrical Resistivity Tomography)
- Gravity
- Seismic

Model Geophysical Monitoring

- TDS (Total Dissolved Solids)
- Pressure

Estimate Leak Detectability

Seismic imaging of CO₂ plumes using Kimberlina 2 models with realistic seismic noise

Zongcai Feng, Lianjie Huang, Kai Gao, Erika Gasperikova

**Baseline:** t₀

**Deep plume:** t₁

**Deep plume:** t₁+2yr

**Deep plume:** t₁+7yr

**Deep plume:** t₁+12yr

**Deep plume:** t₁+17yr

**Deep plume:** t₁+22yr

**Deep plumes:** t₁+47yr

1.5 km

1.5 km
Seismic imaging of CO₂ plumes using Kimberlina 2 models with realistic seismic noise

Zongcai Feng, Lianjie Huang, Kai Gao, Erika Gasperikova

Baseline: \(t_0\)

Deep plume: \(t_1\)

Deep plume: \(t_1+2\)yr

Deep plume: \(t_1+7\)yr

Deep plume: \(t_1+12\)yr

Deep plume: \(t_1+17\)yr

Deep plume: \(t_1+22\)yr

Deep plumes: \(t_1+47\)yr

Noise free data
Seismic imaging of CO$_2$ plumes using Kimberlina 2 models with realistic seismic noise

Zongcai Feng, Lianjie Huang, Kai Gao, Erika Gasperikova

Seismic data with SNR = 2

Seismic noise was extracted from field seismic data recorded at Kevin Dome, MT
CO2Grav – reduced complexity gravity modeling of \( \text{CO}_2 \) migration

Delphine Appriou, Alain Bonneville

**INPUT**

**Site-specific properties:**
- Geothermal Gradient
  - Surface Temp.
  - Gradient
- Hydrostatic pressure gradient.

**CO\(_2\) Plume properties:**
- \( \text{CO}_2 \) Sat.
- Matrix Porosity

**CO\(_2\) Plume Dimensions**
- xmin/xmax/stepx0
- ymin/ymax/zstepy0
- zmin/zmax/stepz0

**OUTPUT**

**Observation point**
- obsxmin/obsxmax/stepx
- obsymin/obsymax/stepy

**Gravity response**

**CO\(_2\) plume**

**Site specific properties**

**Model parameters and results**

(forthcoming)
Deep learning inversion of gravity data for detection of CO$_2$ plumes in overlying aquifers (1)

Xianjin Yang, Xiao Chen, Megan Smith

- Deep learning inversion can resolve single plume model accurately
- Undetected single plumes correspond to small gravity anomalies
- Detecting one of two plumes is possible, but detecting both plumes in the two-plume scenario is challenging
Deep learning inversion of gravity data for detection of CO$_2$ plumes in overlying aquifers (2)

Xianjin Yang, Xiao Chen, Megan Smith

The deep learning inversion accurately detects >80% of single plumes, but more noise in the data lowers detection fraction.

NRAP-Open-IAM simulations of Storage and Leakage

Optimization of monitoring design using DREAM

Decision support for monitoring design and PISC

Supports a net PISC period reduction of 40-years and a total cost reduction of ~ $50M
Task 6: Addressing critical risk-related questions

Recommended Practices Containment Assurance and Leakage Risk Management (Thomas et al., DRAFT)

- Planning and Execution of Risk-based GCS Site Characterization
- Characterization of State of Stress and Geomechanical Conditions
- Developing a Risk-based AOR
- Risk-based Strategic Monitoring
- Assessing GCS System Conformance
- Evaluating Mitigation Scenarios to Inform Risk Management Decisions (under development)
- Defining a Risk-based Period of Post-injection Site Care in Support of Site-Closure Decision-making

Draft Released March 8, 2021
Feedback still being accepted
Comments to: NRAP@netl.doe.gov

Engaging with Key Stakeholders

DOE CarbonSAFE

DOE-FE Regional Initiatives

DOE-FE SMART Initiative

Industry Best Practices

International CCUS RD&D Community

Regulatory Context

Bourne et al., 2014
Thank you!

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Sign up for NETL EDX: https://edx.netl.doe.gov/user/register
NRAP Timeline and Milestones for Phase II Completion

• NRAP Phase II Completion by March 2022
  – Release of final NRAP Phase II toolset
  – Release of final recommended practices documents
  – Release of final NRAP applications catalog
  – Finalize NRAP community datasets
  – Accomplishments and key insights reporting