The National Risk Assessment Partnership: Phase II Accomplishments and Phase III Introduction

Robert Dilmore, PhD, P.E.
NRAP Technical Director

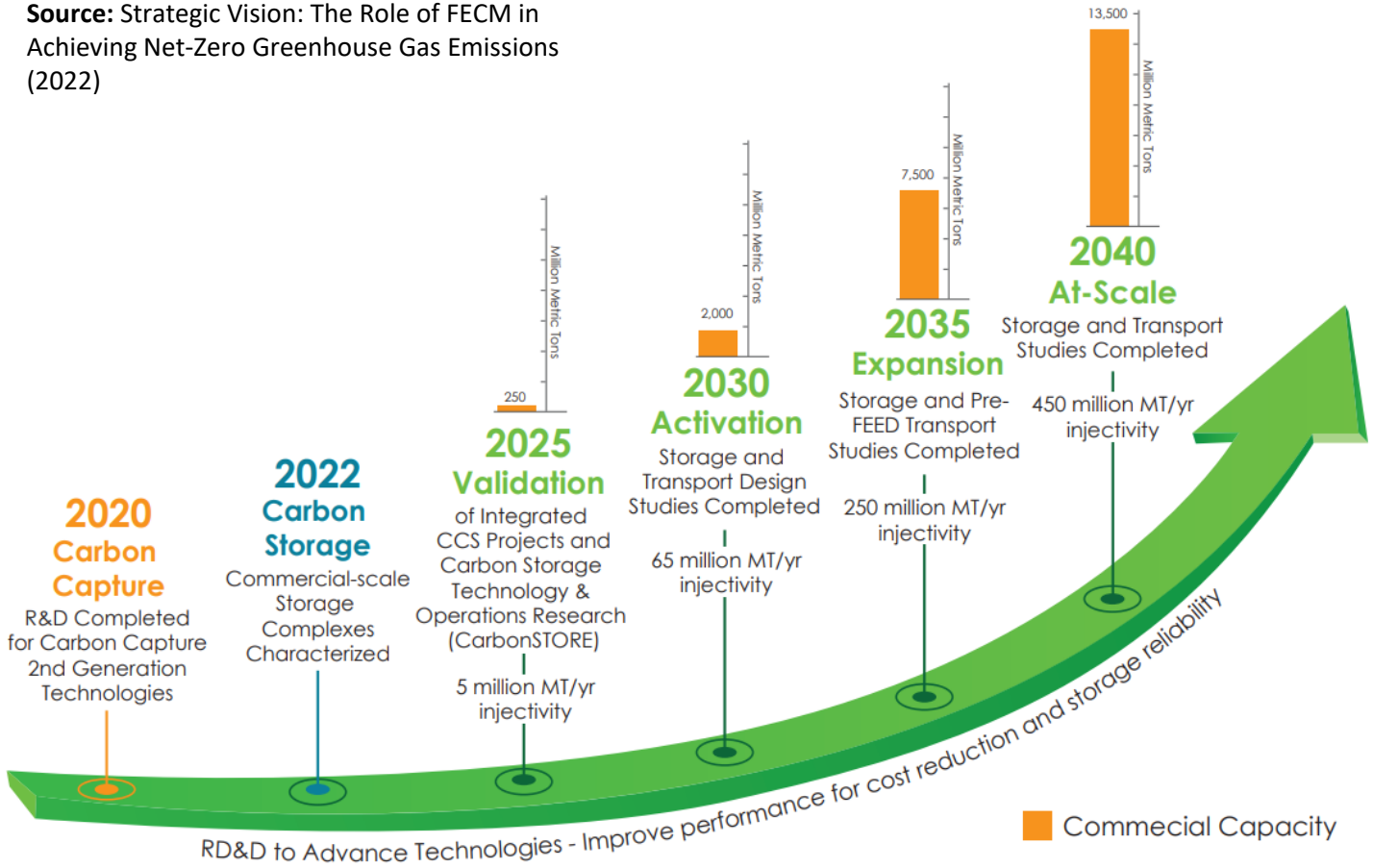
August 18, 2022

Meeting the CCS Challenge

"Given the urgency and the scale on the climate change front, and the huge opportunity and need for [carbon capture, utilization and storage], we all need to do more… **This is really a make-it-or-break-it opportunity and window on the CCUS front**."

David Turk,
Deputy Secretary,
US DOE
April 2021

Source: Strategic Vision: The Role of FECM in Achieving Net-Zero Greenhouse Gas Emissions (2022)



U.S. DOE's National Risk Assessment Partnership

NRAP leverages DOE's capabilities to quantitatively assess and manage long-term environmental risks of geologic carbon storage amidst uncertainty.

NRAP
National Risk Assessment Partnership

Technical Team

BERKELEY LAB
Lawrence Berkeley National Laboratory

Los Alamos
NATIONAL LABORATORY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Pacific Northwest
NATIONAL LABORATORY

NRAP leverages DOE's capabilities to quantitatively assess and manage long-term environmental risks amidst geologic uncertainty and variability.

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EST. 1943

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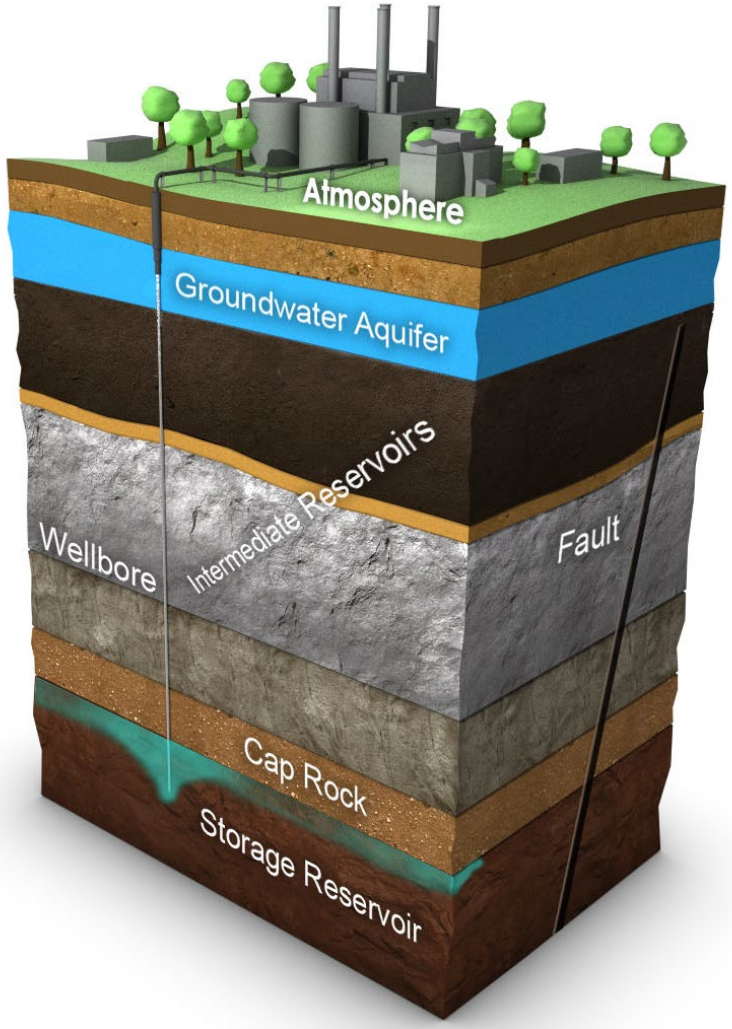
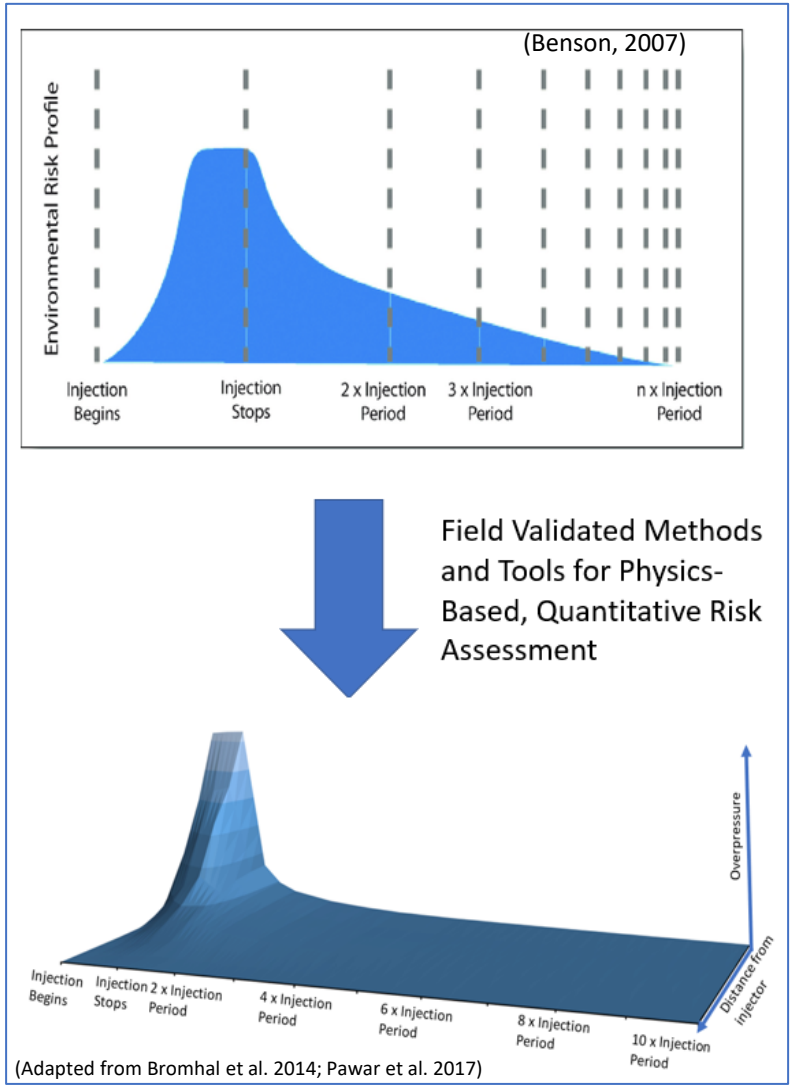
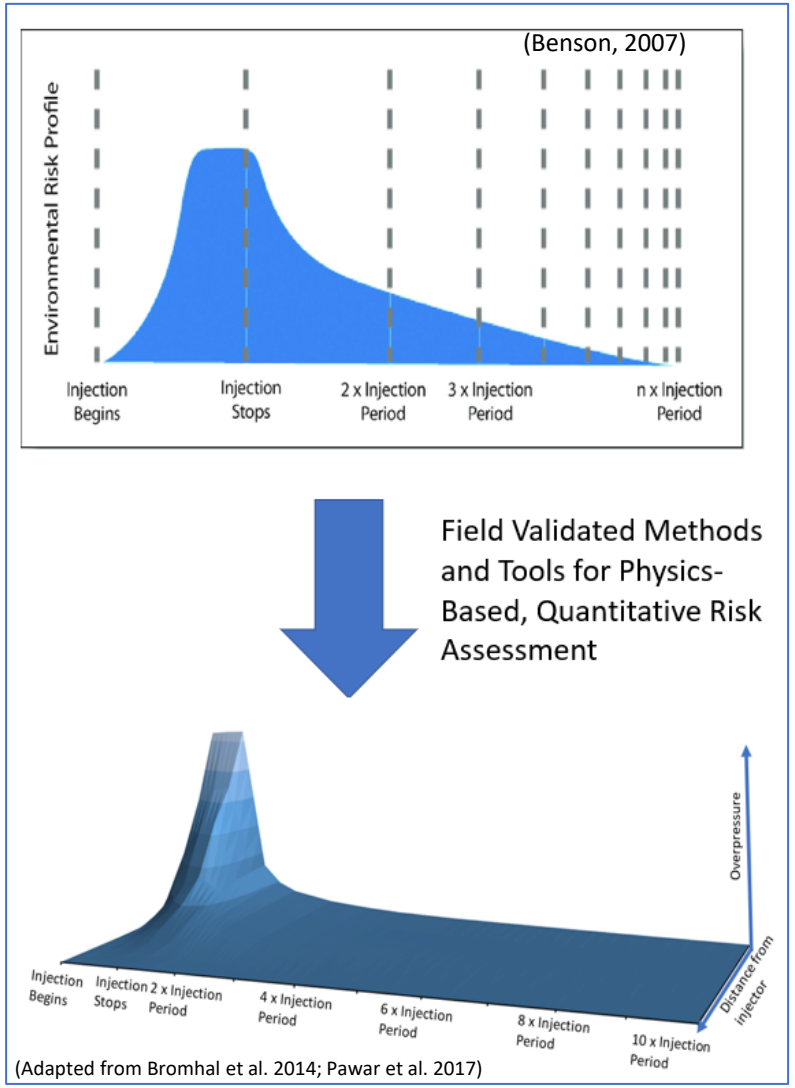
NATIONAL LABORATORY





Evolving Focus of NRAP

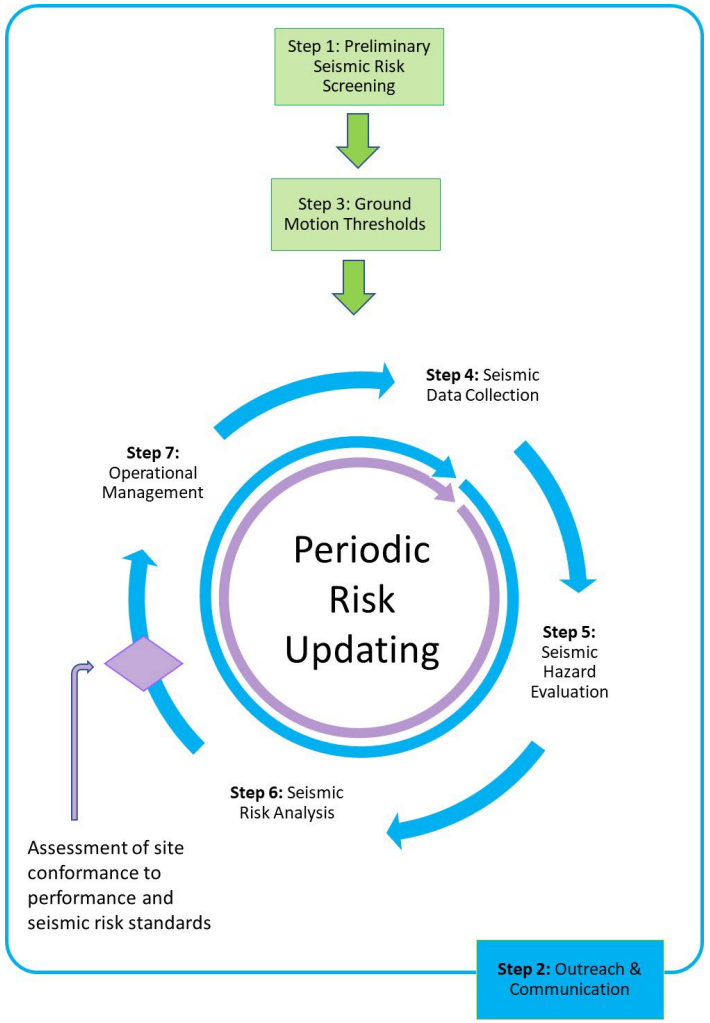
- Phase I (2010–2016) - Risk Assessment and Uncertainty Quantification
- Phase II (2017–2022) - Risk Management and Uncertainty Reduction
- Phase III (2022 – 2027) –Supporting CCS deployment.



Delivering methods and computational tools to assess and manage risk

Computational tools and workflows to:

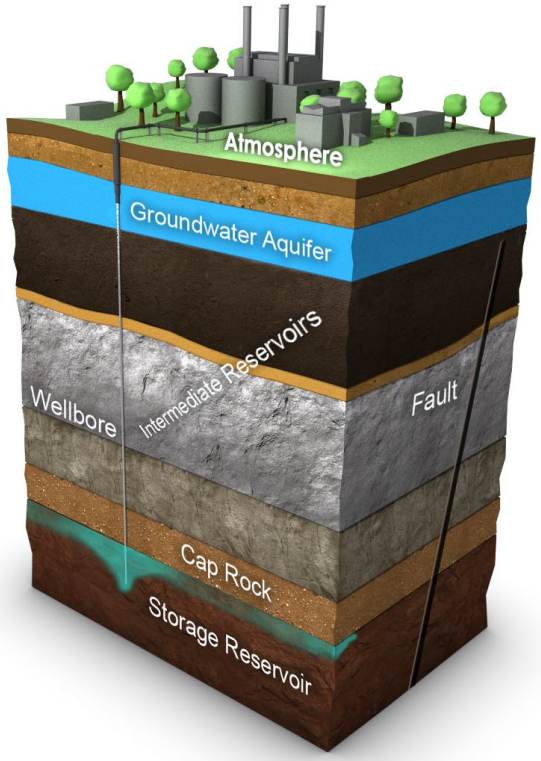
- Quantify leakage risk
- Assess and manage induced seismicity risk
- Design risk-based monitoring networks
- Inform site selection and permitting



Source: Templeton et al., (2021) Recommended Practices for Managing Induced Seismicity Risk Associated with Geologic Carbon Storgae

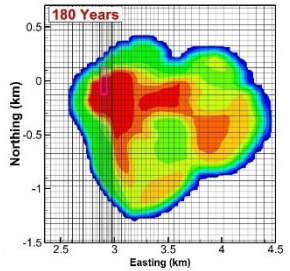
An approach for rapid prediction of whole-system risk performance

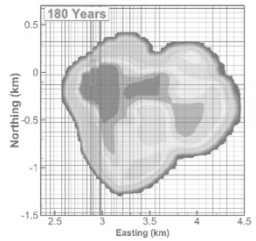
A. Divide system into discrete components

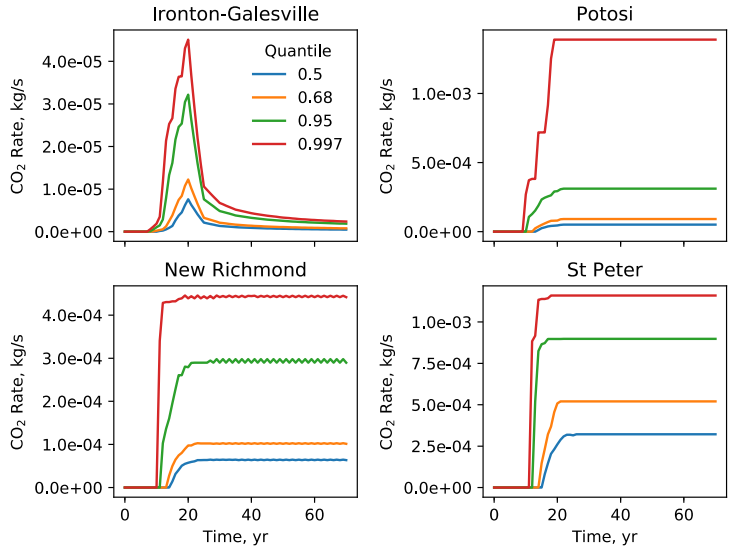


B. Develop detailed component models that are validated against lab/field data

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



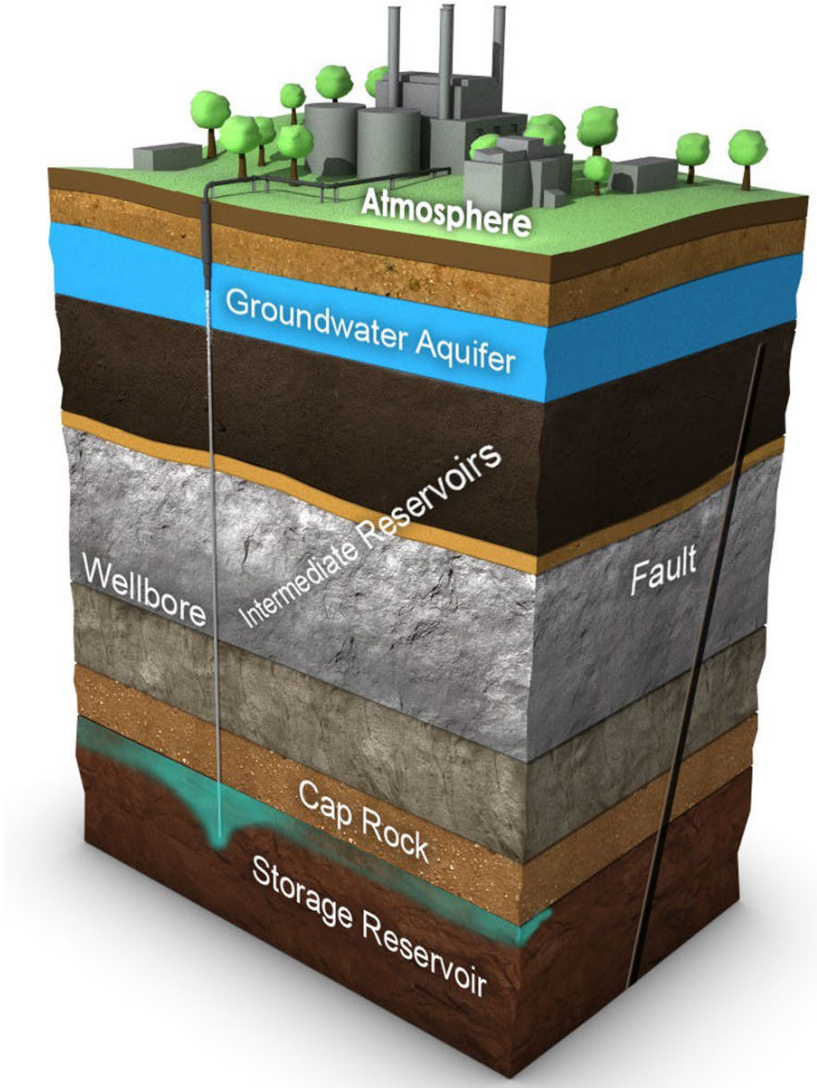




D. Link ROMs via integrated assessment models (IAMs) to predict system performance

E. Exercise whole system model to explore risk performance

A framework and computational tool to quantify leakage risks and containment

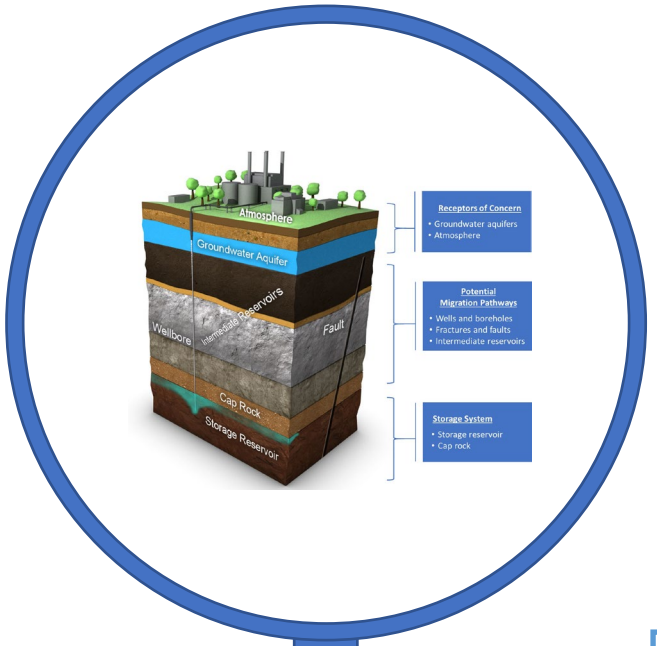


Receptors of Concern
- Groundwater aquifers
- Atmosphere

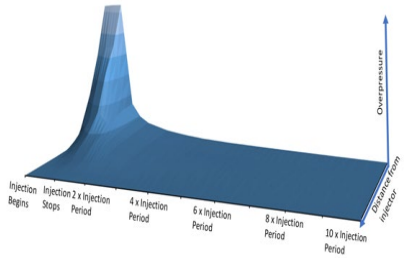
Potential Migration Pathways
- Wells and boreholes
- Fractures and faults
- Intermediate reservoirs

Storage System
- Storage reservoir
- Cap rock

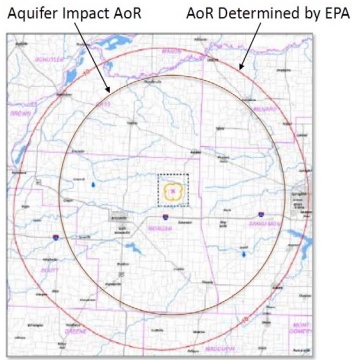
Fit-for-purpose applications to address stakeholder questions



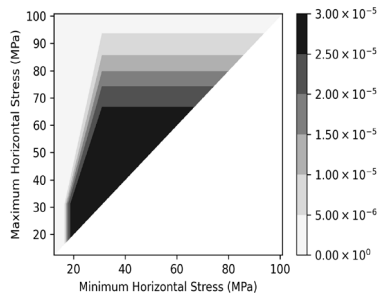
Quantitative, Site-Specific Risk Profiles



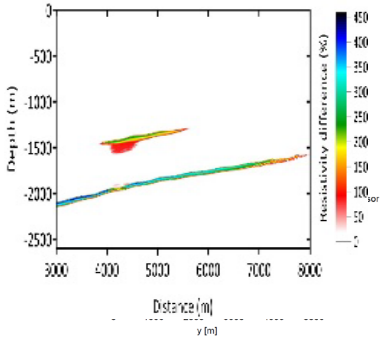
Risk-based AoR



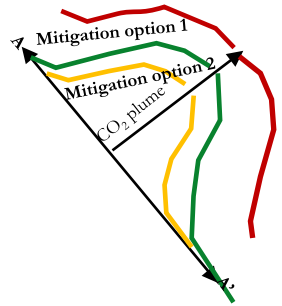
State-of-Stress Assessment



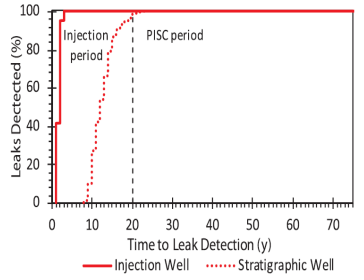
Monitoring Design Evaluation



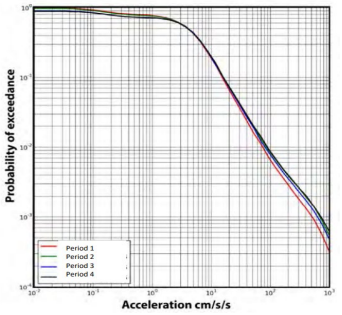
Risk Management and Site Closure Evaluation



Performance-based Closure Assessment

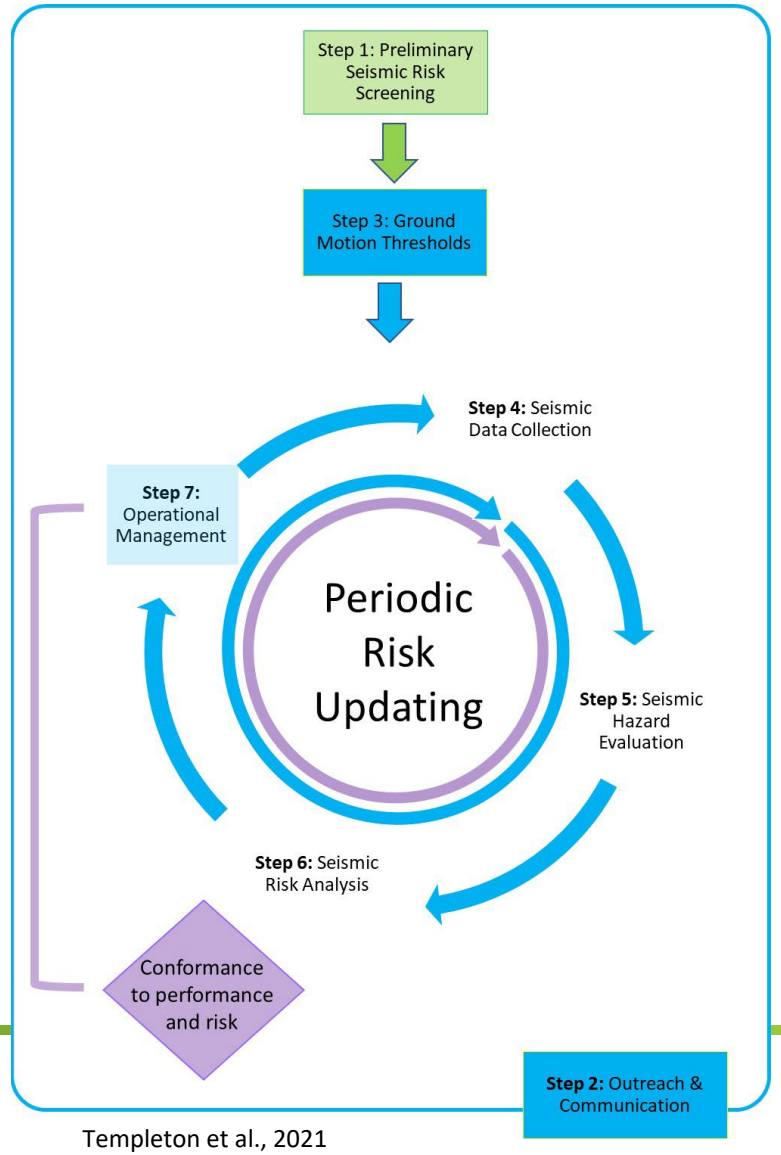


Probabilistic Seismic Risk Analysis



Savy and Foxall (2018)

Risk management incorporates updating and uncertainty reduction



Templeton et al., 2021

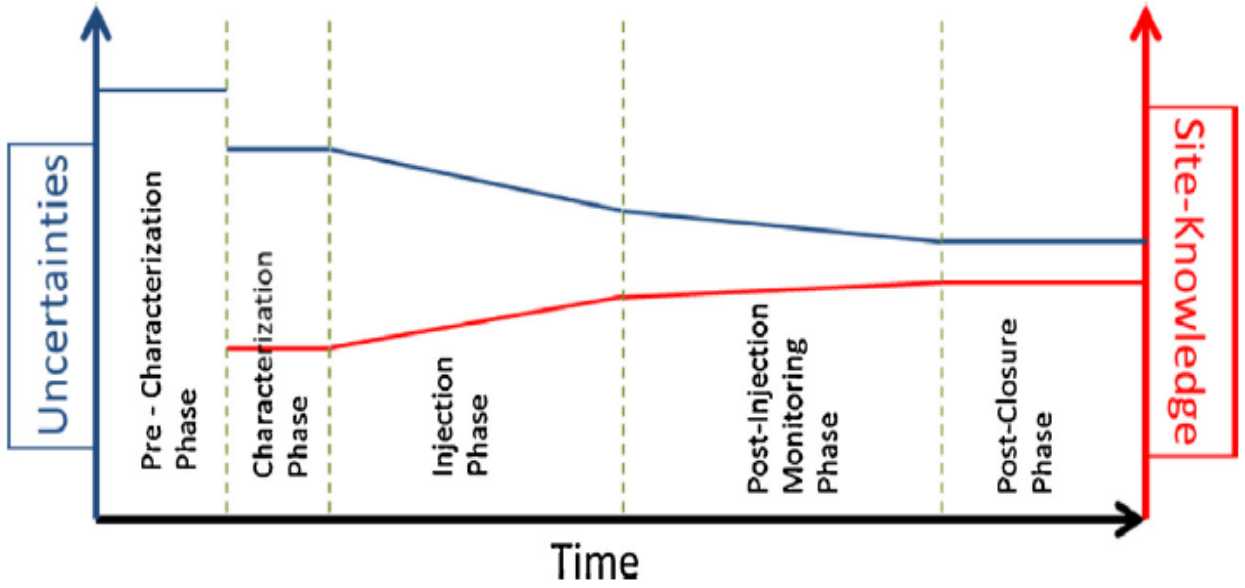


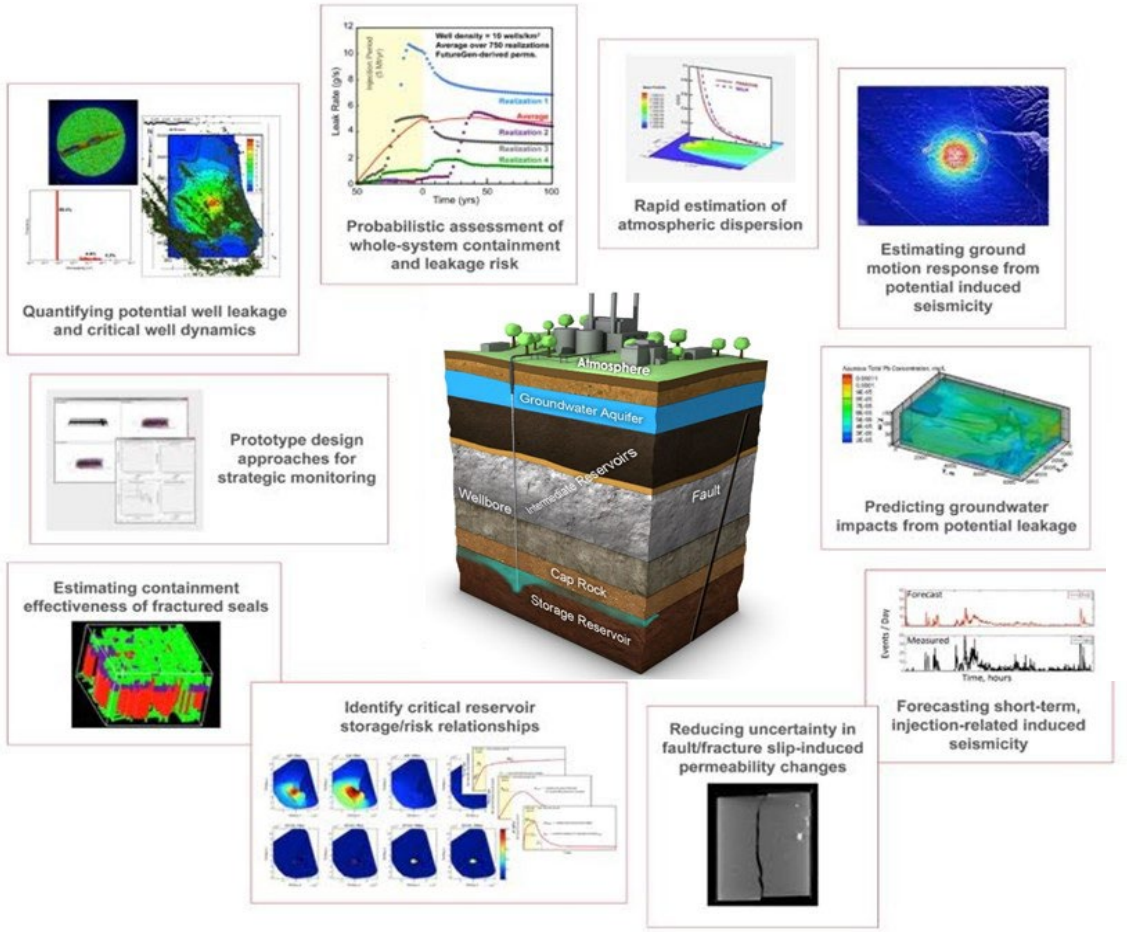
Fig. 3. Qualitative illustration of the level of uncertainties over time at GCS sites.

Pawar et al., 2015

NRAP Phase I (2010 – 2016)

How big might the risks from a GCS operation be?

- Pioneered hybrid methods for quantifying complex systems (integrated risk assessment)
- Developed computational tools for quantifying risks amidst uncertainty
- Developed foundation for strategic (risk-based) monitoring (e.g., no-impact thresholds, optimization approaches)



carbon sequestration leadership forum

R&D 100 55 Years of Invention

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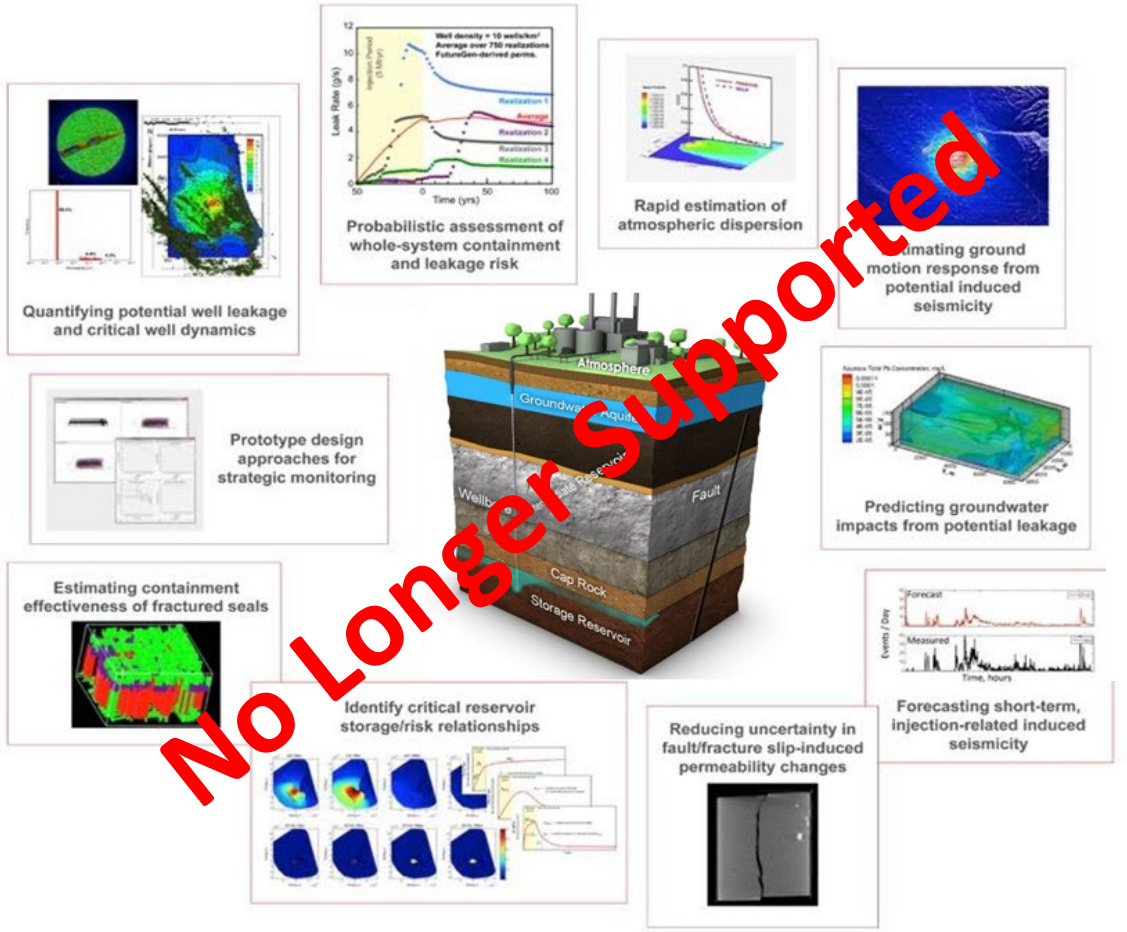


carbon sequestration leadership forum

R&D 100 55 Years of Invention

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB

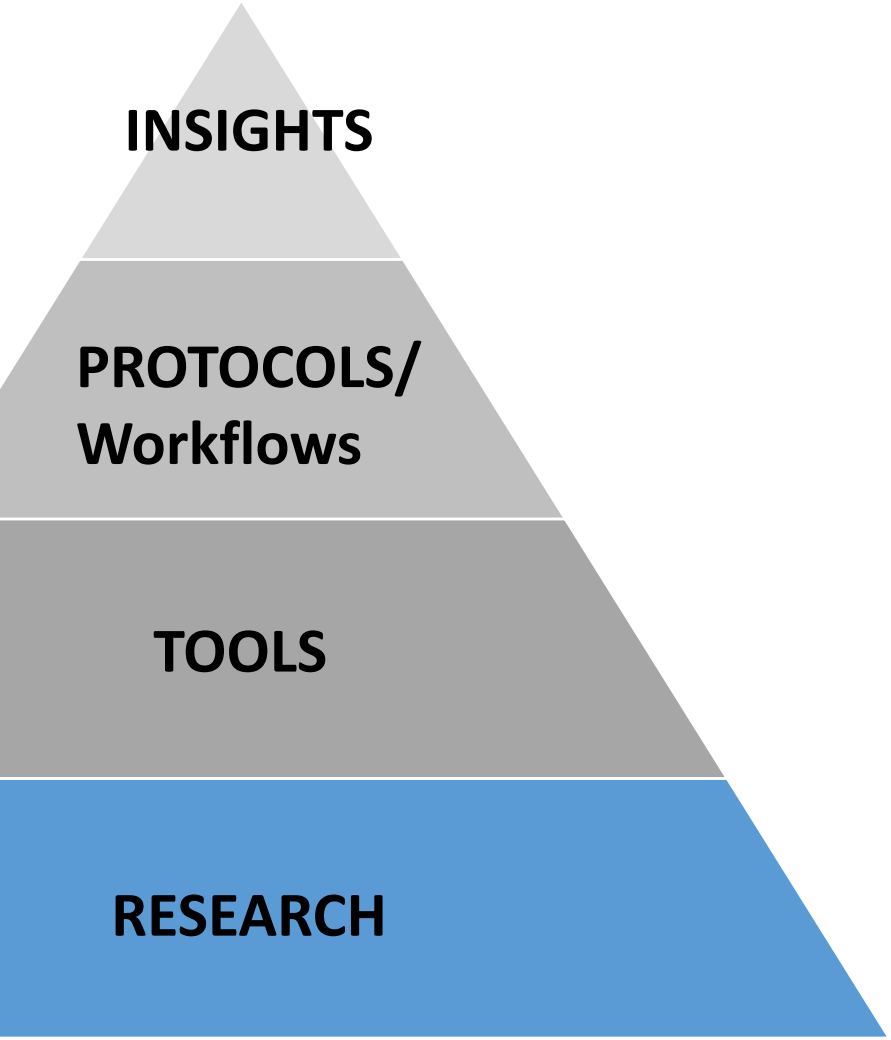
Los Alamos NATIONAL LABORATORY

Pacific Northwest NATIONAL LABORATORY

NRAP Phase II (2017 – 2022)

How can risk assessment approach be used to manage risk and inform GCS site decisions?

NRAP Foundational Research and Community Data



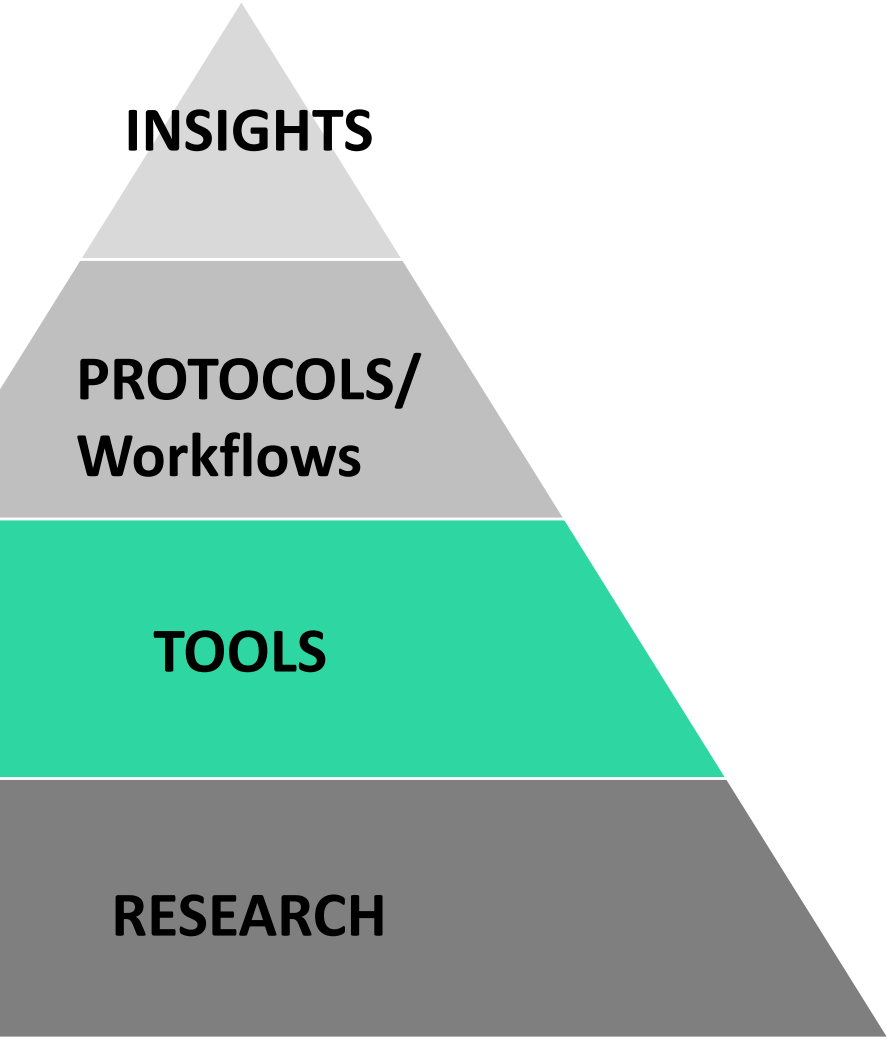
- **NRAP Phase II - Virtual Special Issue *International Journal of Greenhouse Gas Control* - (September 2020)**

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

- **https://www.osti.gov/**

~450 publications, 16,000 citations; h-index 72

NRAP Risk Assessment Tools



Leakage Risk/Containment Assurance

- **NRAP Open-Source Integrated Assessment Model (NRAP-Open-IAM)** - New beta release August 2022

Induced Seismicity Risk

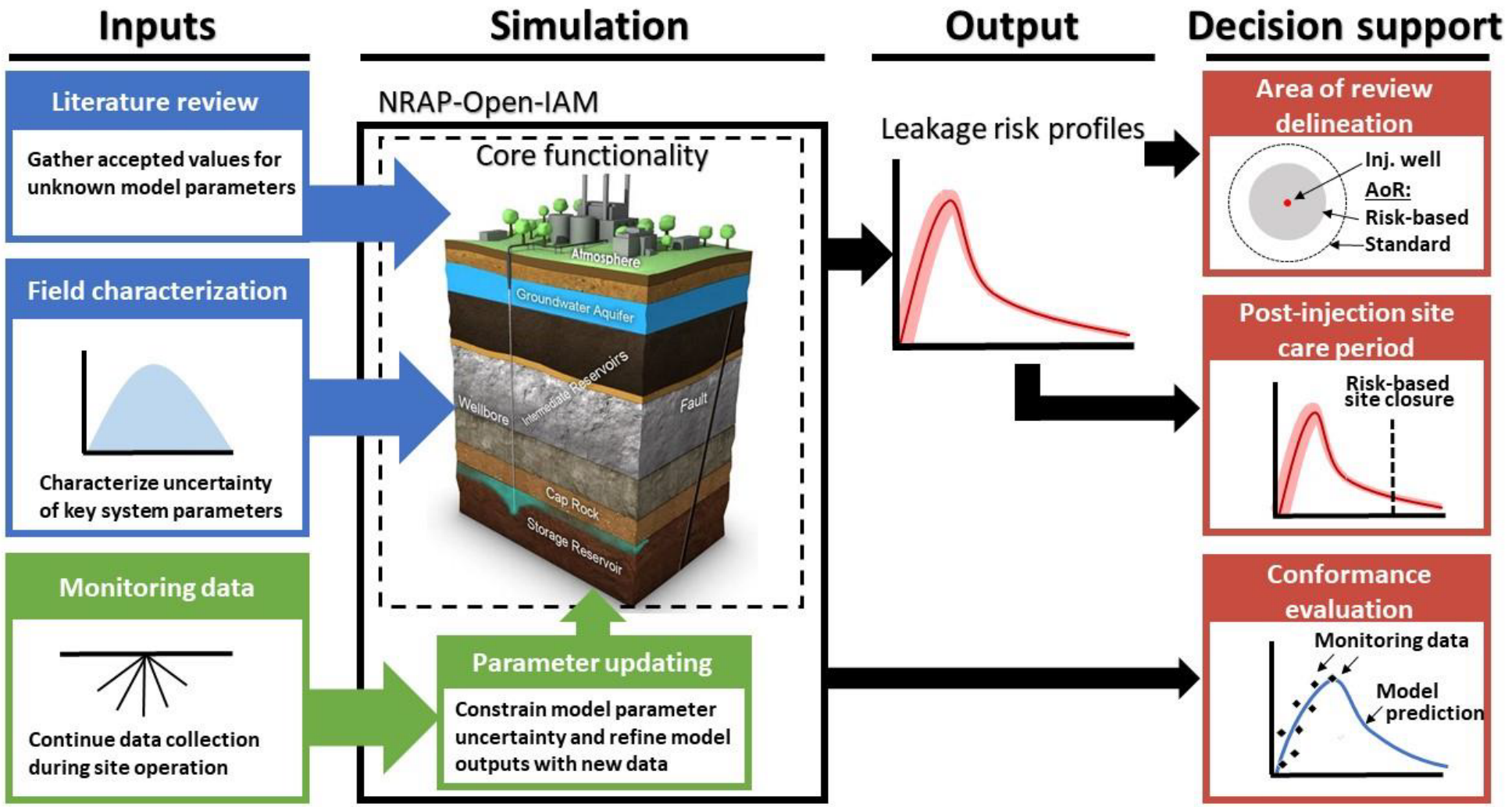
- **State of Stress Analysis Tool (SoSAT)** – Beta release October 2018
- **Operational Forecasting of Induced Seismicity (ORION) -** prototype forthcoming

Monitoring Design and Optimization

- **Designs for Risk Evaluation and Management (DREAM 3.0) –** Release expected fall 2022
- **Microseismic monitoring design optimization tool** – Released October 2020

NRAP Tools Available at:
https://edx.netl.doe.gov/nrap/tools-main/

NRAP-Open-Source Integrated Assessment Model

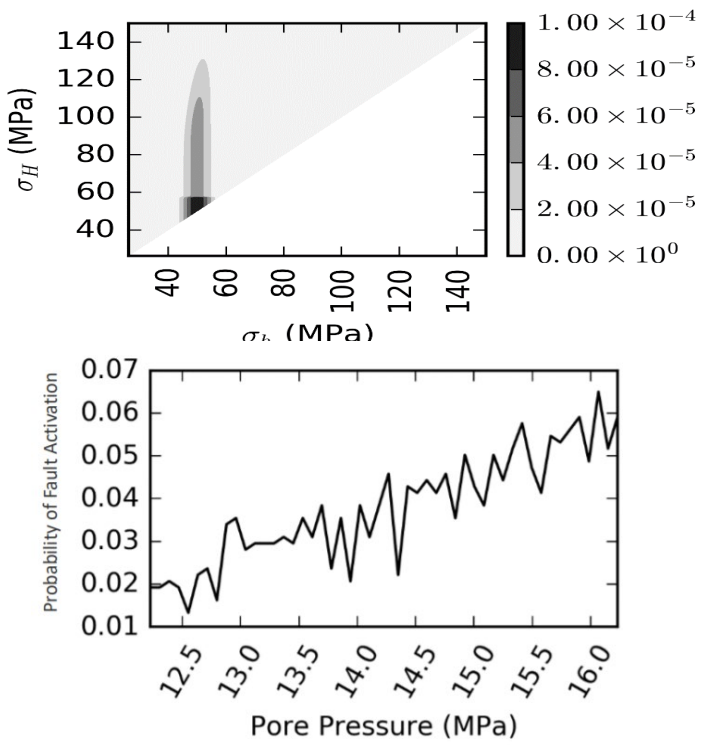


Download at: https://gitlab.com/NRAP/OpenIAM

Vasylkivska, VR Dilmore, G Lackey, Y Zhang, S King, D Bacon, B Chen, K Mansoor and D Harp (2021). "NRAP-open-IAM: A flexible open-source integrated-assessment-model for geologic carbon storage risk assessment and management." Environmental Modelling & Software **143**.

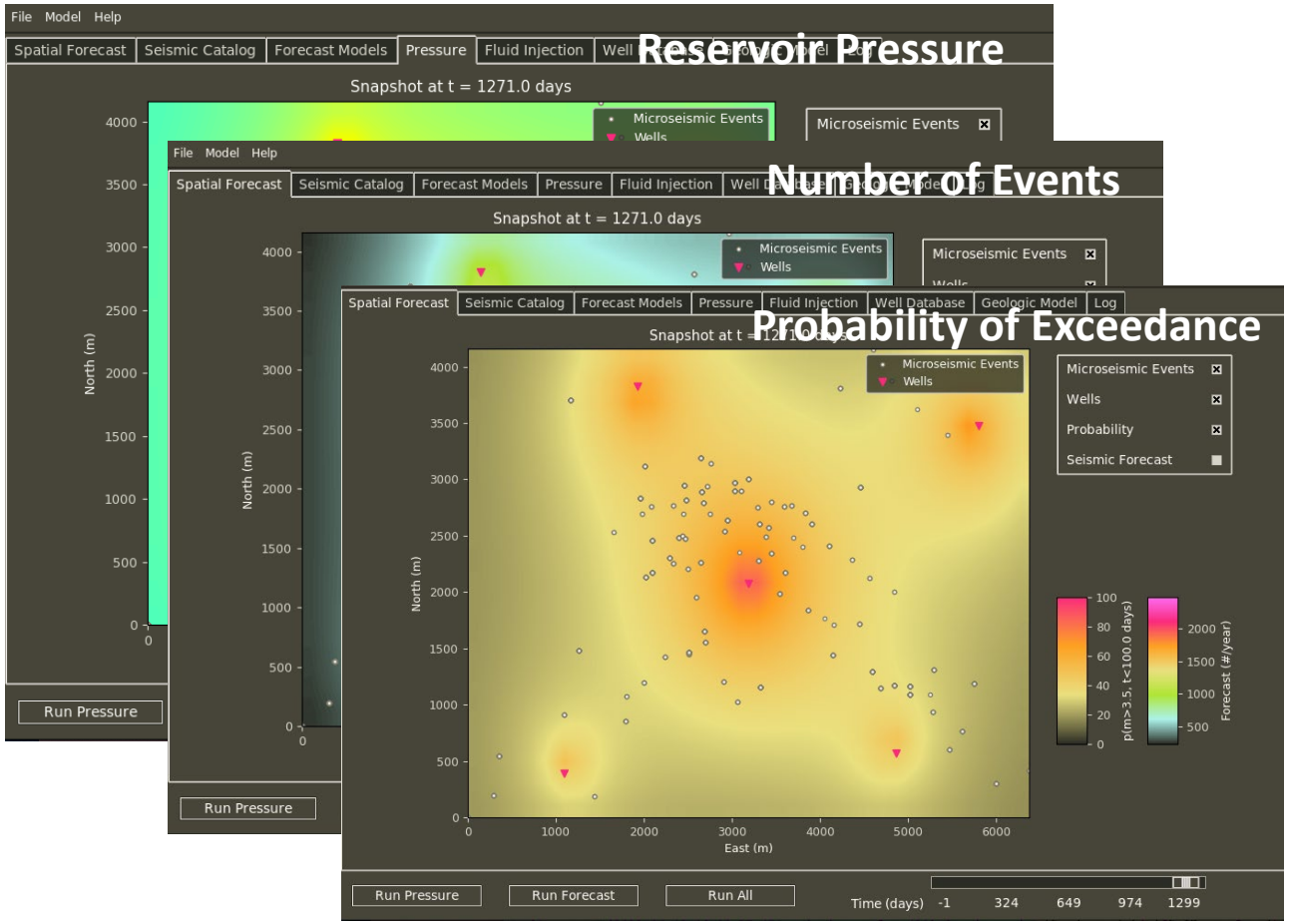
Tools and methods to manage induced seismicity risk

State of Stress Analysis Tool (SOSAT)



(Burghardt, 2018)

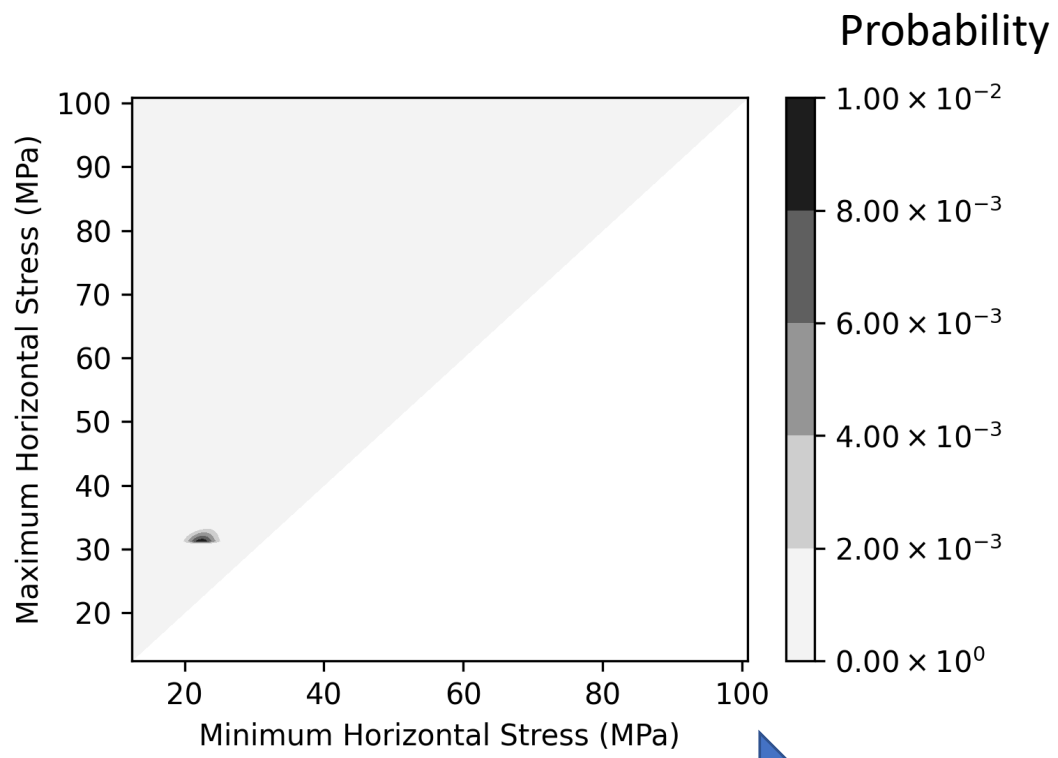
Prototype ORION toolkit for IS Risk Management



Source: Kroll et al. (prototype forthcoming) Operational Forecasting of Induced Seismicity

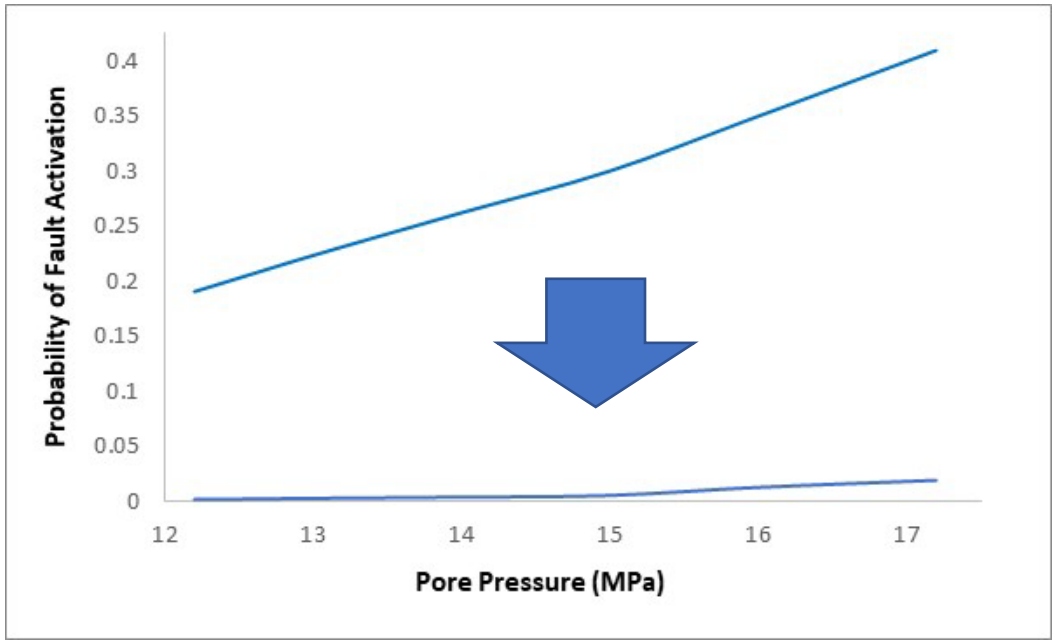
Constraining Parameter Uncertainty: Updating State-of-Stress Estimates

Updating state-of-stress



More Information w/ Time

Update assessed geomechanical risk



U.S. DEPARTMENT OF ENERGY

Modified from: Burghardt (PNNL)
Delphine Appriou (2021)

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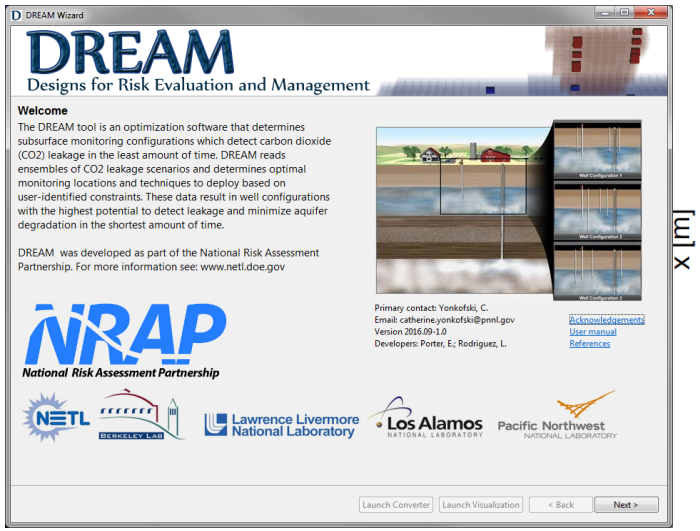
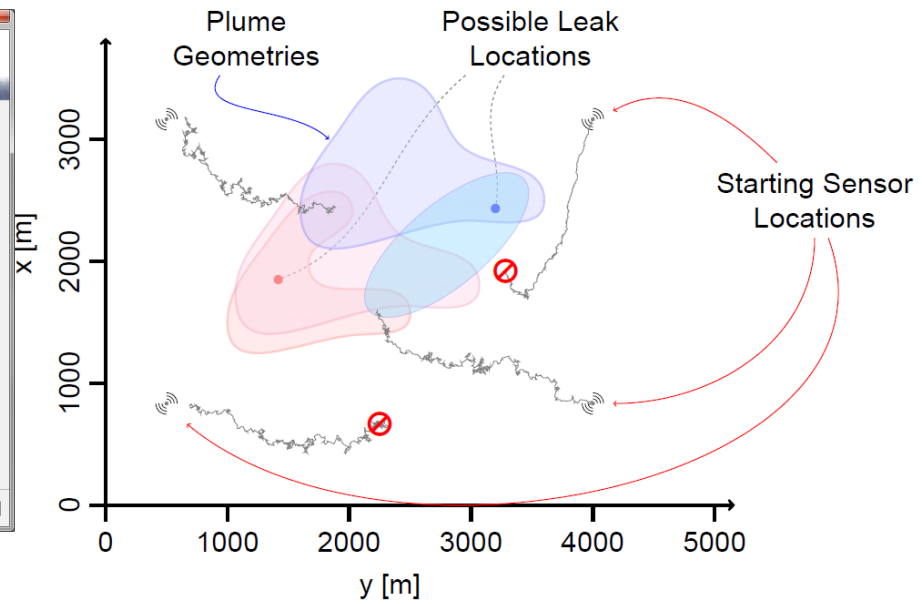
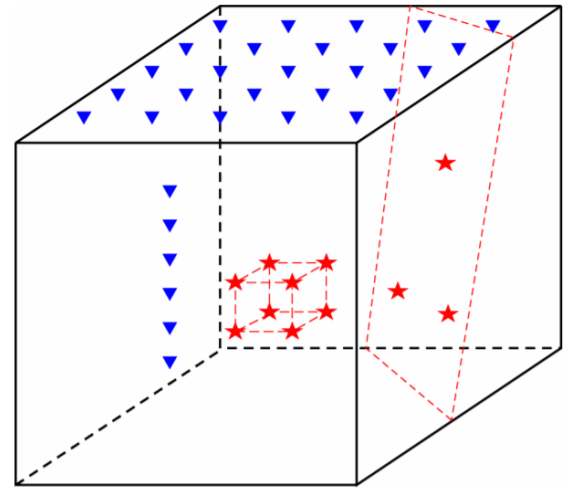
NRAP Monitoring Design Optimization Tools

Design for Risk Evaluation and Management (DREAM)





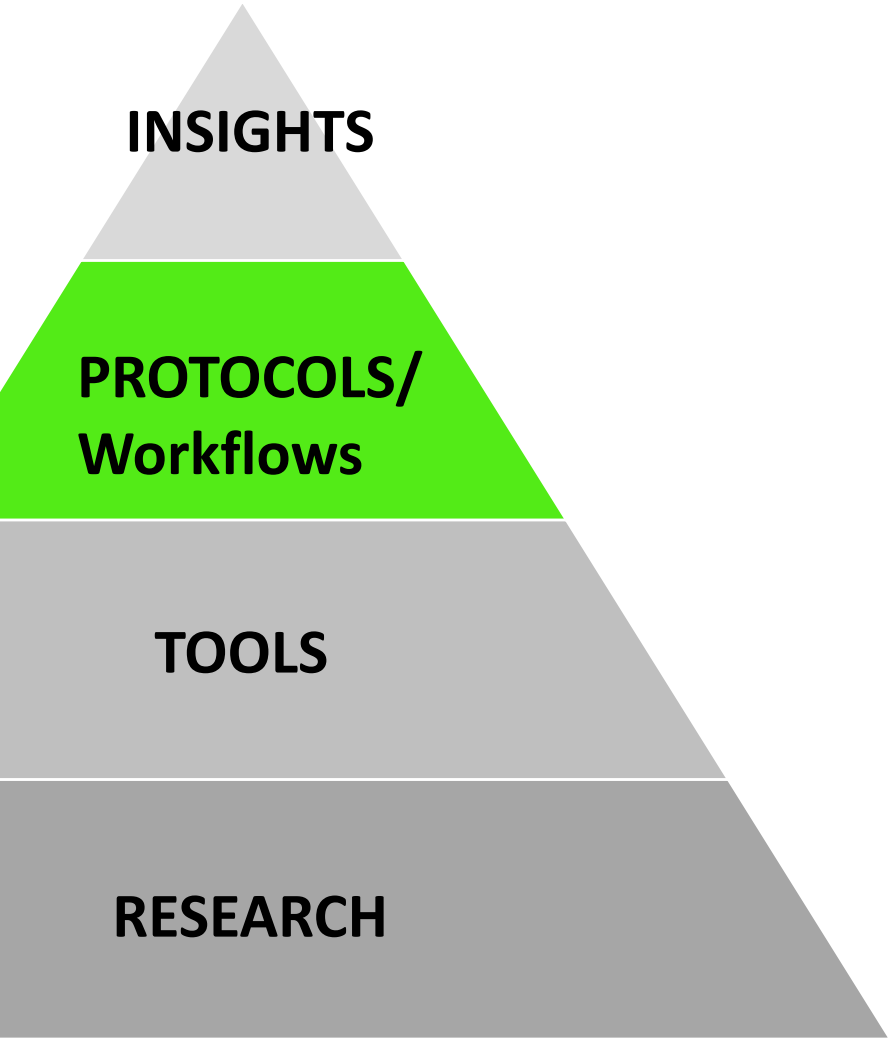
Passive Seismic Monitorina Tool



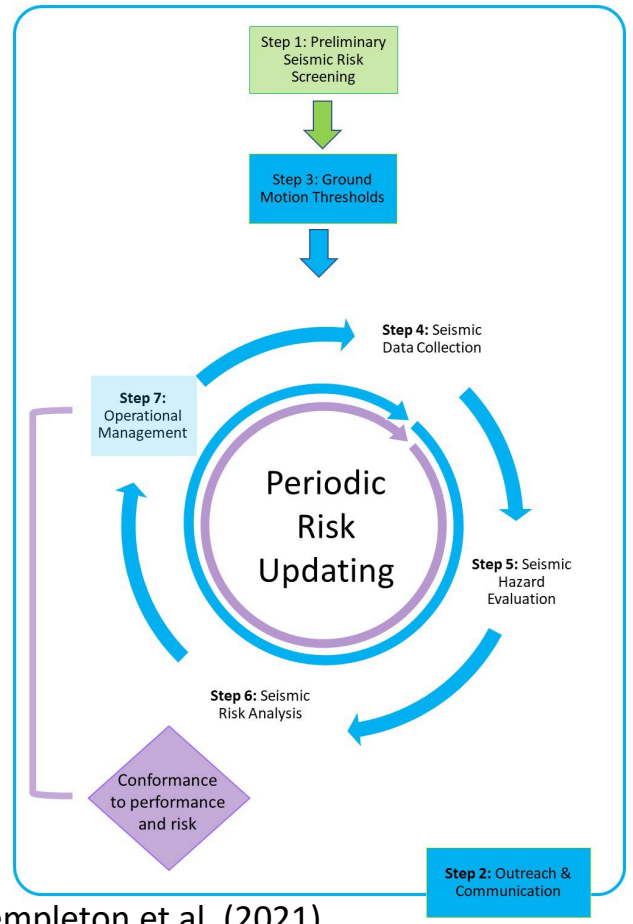
Microseismic events
Target monitoring region
Geophone distribution

- Yonkofski, C. M. R; Porter, E. A.; Rodriguez, L. R.; Brown, C. F. Designs for Risk Evaluation and Management (DREAM) Tool User's Manual, Version: 2016.11-1.0; NRAP-TRS-III-019-2016; NRAP Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2016; p 40. DOI: 10.18141/1592100.
- Chen, T.; Huang, L. Optimal design of microseismic monitoring network: Synthetic study for the Kimberlina CO2 storage demonstration site. International Journal of Greenhouse Gas Control 95, 102981. https://doi.org/10.1016/j.ijggc.2020.102981.

Recommended Practices for Risk Management

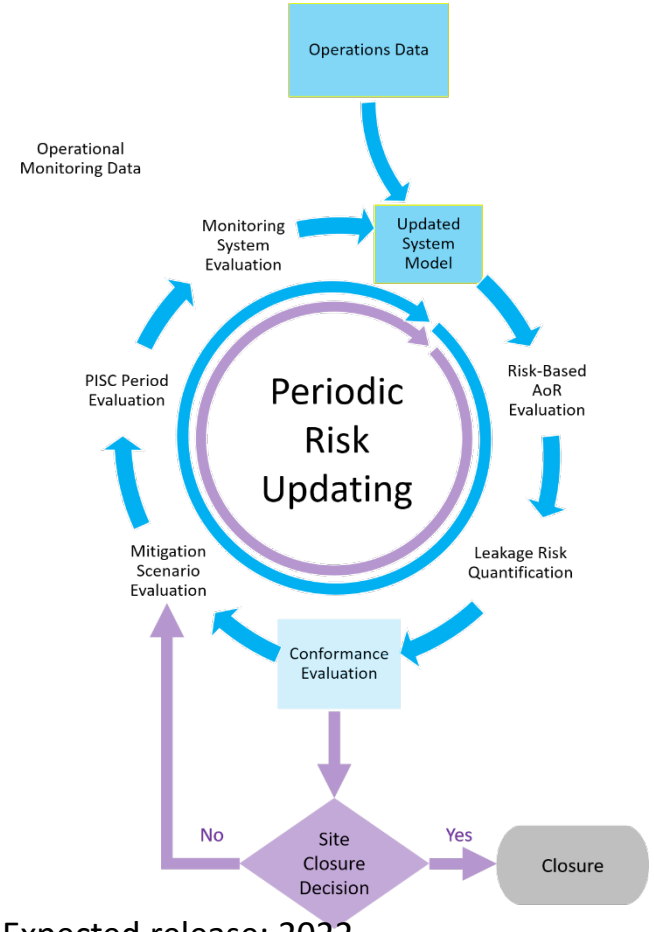


Induced Seismicity Risk Management



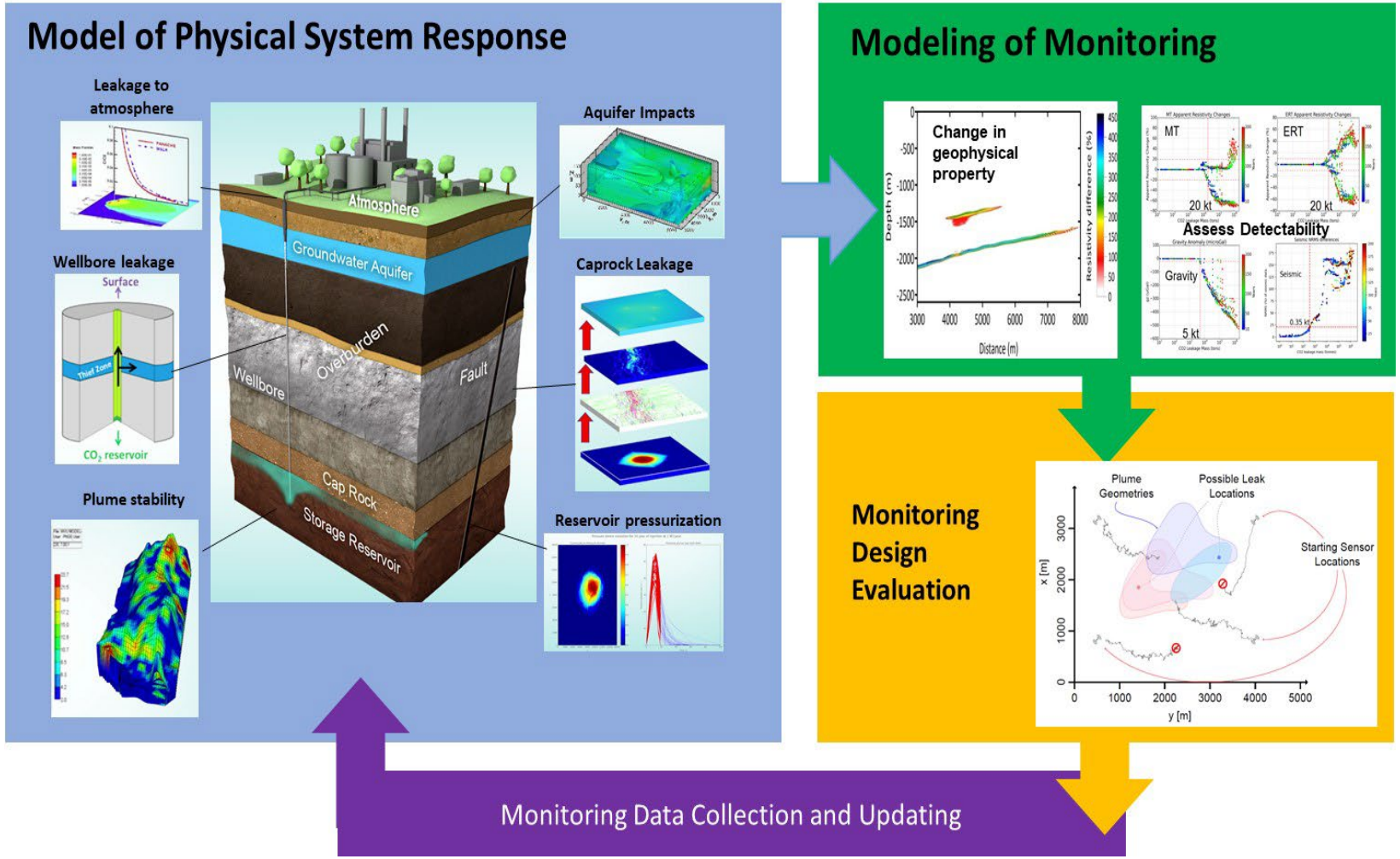
Templeton et al. (2021)

Leakage Risk Management and Containment Assurance



Expected release: 2022

Develop adaptive, risk-based monitoring designs that are efficient and effective.

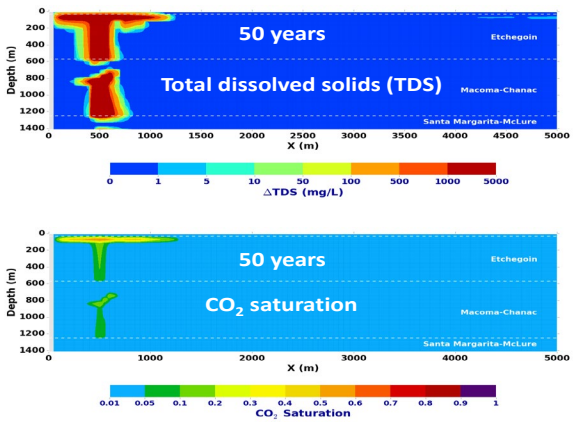


Adapted from: Yang, Y.; Dilmore, R.; Mansoor, K.; Carroll, S.; Bromhal, G.; Small, M. Toward an adaptive monitoring design for leakage risk - closing the loop of monitoring and modeling. *International Journal of Greenhouse Gas Control*. V. 76, September 2018, Pages 125-141.

Modeling of Geophysical Monitoring

Estimating Leak Detection Thresholds of Monitoring Techniques

Stochastic Leakage Simulations



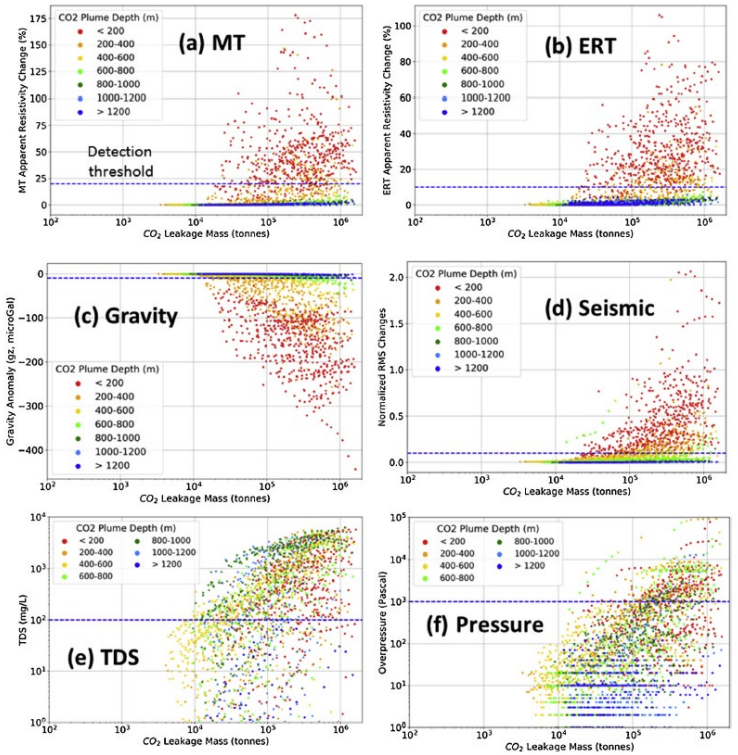
Monitoring Technology

- MT (Magnetotellurics)
- ERT (Electrical Resistivity Tomography)
- Gravity
- Seismic
- TDS (Total Dissolved Solids)
- Pressure

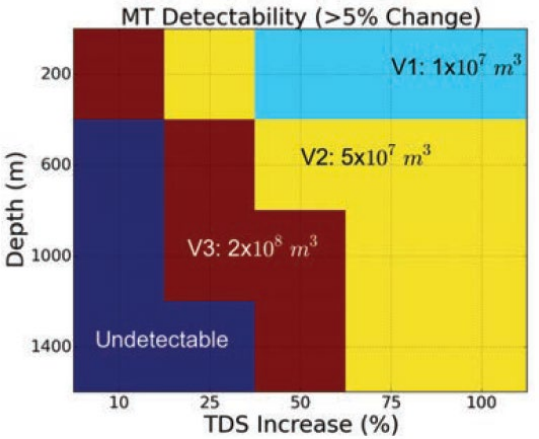
SURFACE

DOWNHOLE

Model Geophysical Monitoring



Estimate Leak Detectability



Gasperikova, E.; Appriou, D.; Bonneville, A.; Feng, Z.; Huang, L.; Gao, K.; Yang, X.; Daley, T. Sensitivity of geophysical techniques for monitoring secondary CO_2 storage plumes, *International Journal of Greenhouse Gas Control* 2022, 114, Article 103585. https://doi.org/10.1016/j.ijggc.2022.103585.

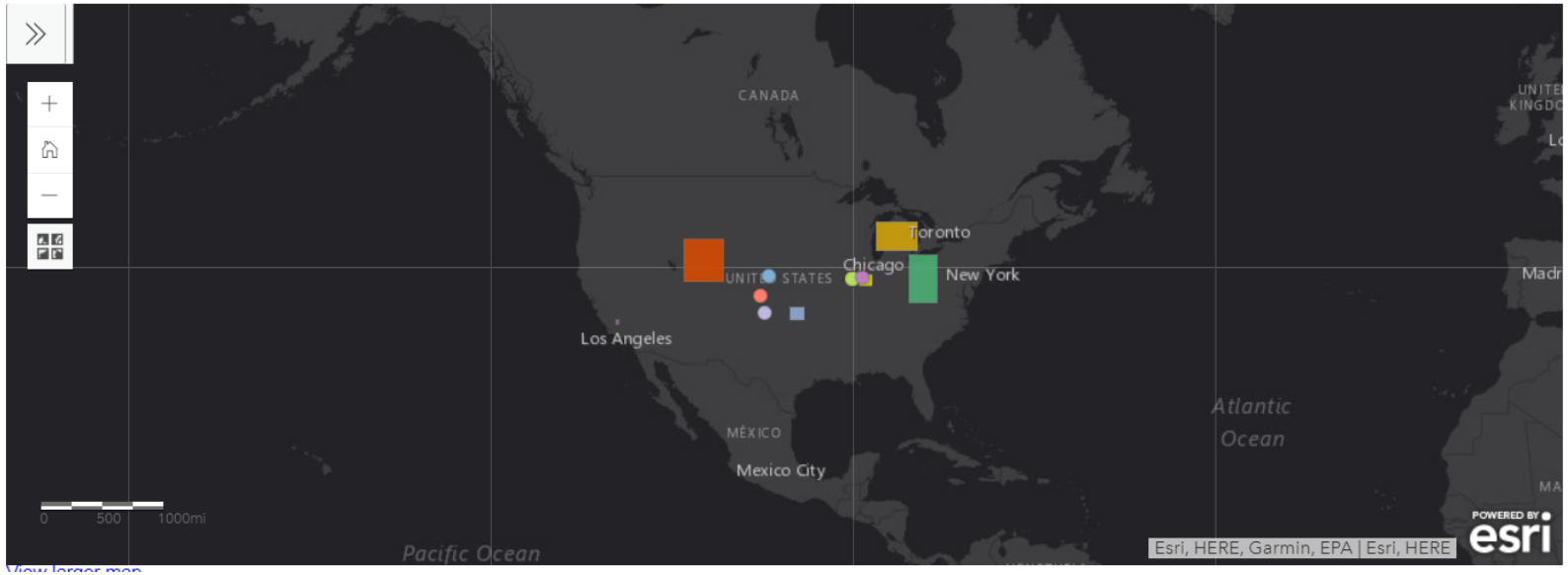
NRAP Application Catalog on EDX

N. Huerta, et al. (2021)

- **Summary of 16 studies including**
  - Prototype tool testing/method development
  - Site characterization
  - Analog studies
- **Link to relevant publications**

NRAP released a set of open-source computational tools designed to help evaluate the performance of geological carbon storage sites and to assess risks across a project's life cycle. The NRAP tools enable stakeholders and operators to rapidly explore the behavior of the storage complex and to evaluate containment effectiveness and quantify leakage risk, assess geomechanical risks and manage induced seismicity, and develop risk-based monitoring strategy for uncertainty reduction.

More...



Huerta, Nicolas; Bacon, D.; **Dilmore, R.**; Morkner, P. The NRAP Applications Catalog, 6/2/2021, https://edx.netl.doe.gov/dataset/the-nrap-applications-catalog. DOI: 10.18141/1785536

Rules and Tools Crosswalk

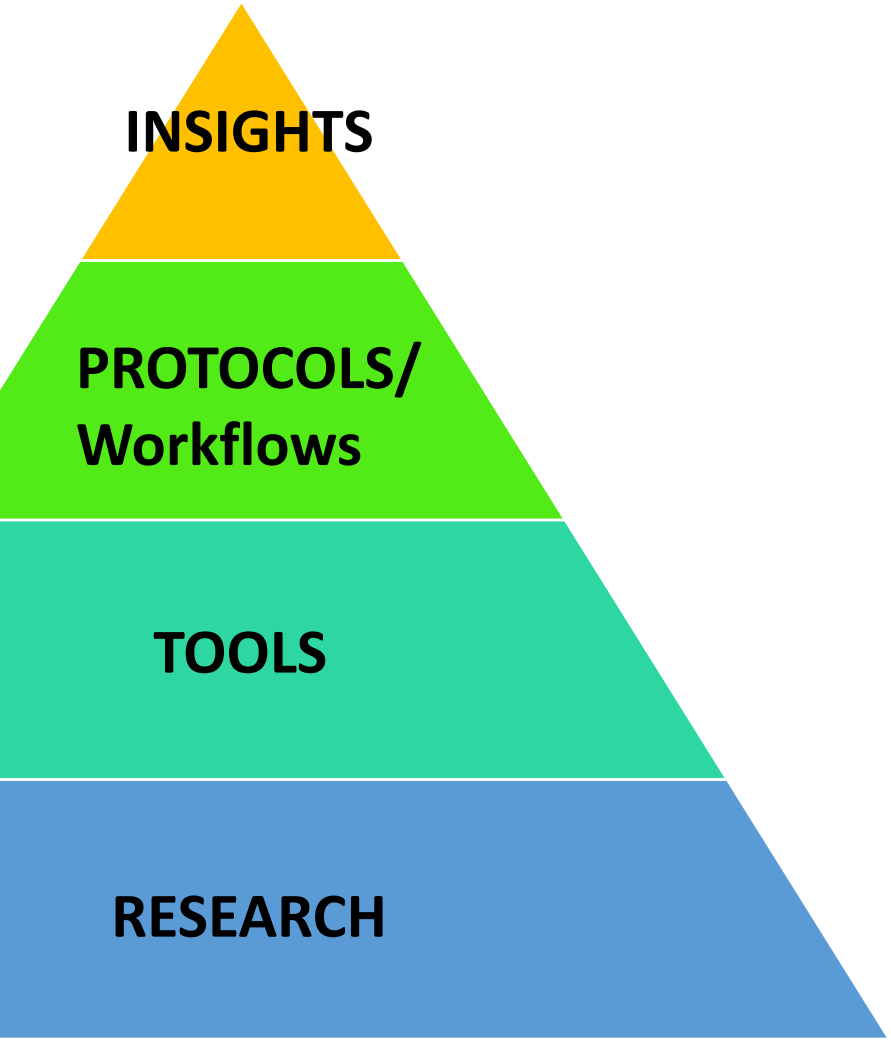
Objective: Collect information and report on computational subsurface performance/risk assessment tools that are potentially relevant to EPA UIC Class VI regulations (Rules and Tools Crosswalk) – to support stakeholders and accelerate CCS deployment.

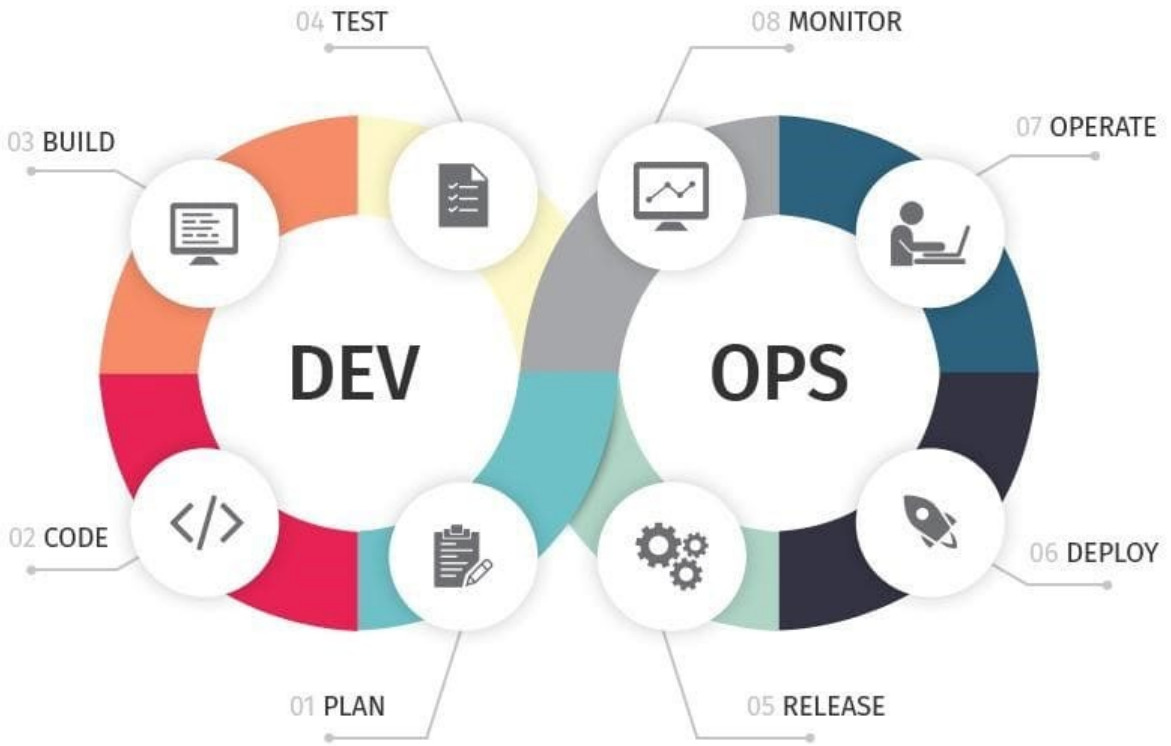
Outcome: Compendium of 59 computational tools to support GCS environmentally protective UIC Class VI permitting

Contributors: US EPA, Regional Initiatives, LANL, LBNL, LLNL, PNNL, and NETL

Lackey, G.; Strazisar, B. R.; Kobelski, B.; McEvoy, M.; Bacon, D. H.; Cihan, A.; Iyer, J.; Livers-Douglas, A.; Pawar, R.; Sminchak, J.; Wernette, B.; Dilmore, R. M. Rules and Tools Crosswalk: A Compendium of Computational Tools to Support Geologic Carbon Storage Environmentally Protective UIC Class VI Permitting; NRAP-TRS-I-001-2022; DOE.NETL-2022.3731; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA, 2022; p 120. DOI: https://doi.org/10.2172/1870412

NRAP Products and Stakeholder Engagement





DEV-OPS Image SOURCE: https://res.cloudinary.com/practicaldev/image/fetch/s---dbI8WY9--/c_limit%2Cf_auto%2Cfl_progressive%2Cq_auto%2Cw_880/http://aisaac.io/content/images/2018/11/DevOps.jpg

NRAP Phase III (2022 – 2027)

Supporting CCS deployment.

NRAP Phase III is one of three planned DOE FECM complementary applied research projects to enable and accelerate CCS deployment

Real-time Visualization, Forecasting and Virtual Learning for Decision Makers

Risk-based decision support for geologic carbon storage

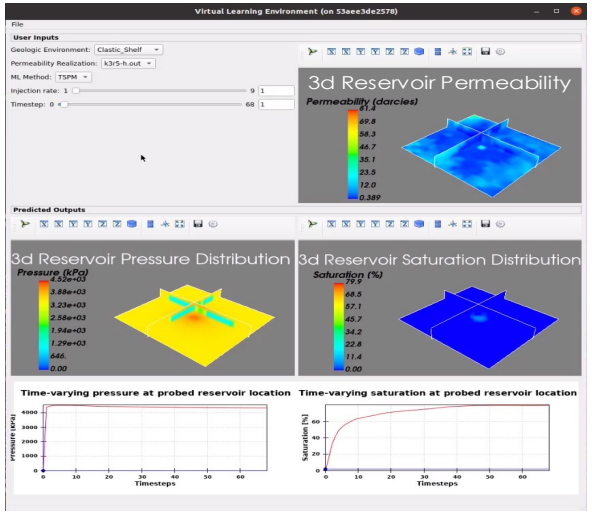
Putting CCS data resources to work - virtual data infrastructure to enable CCS

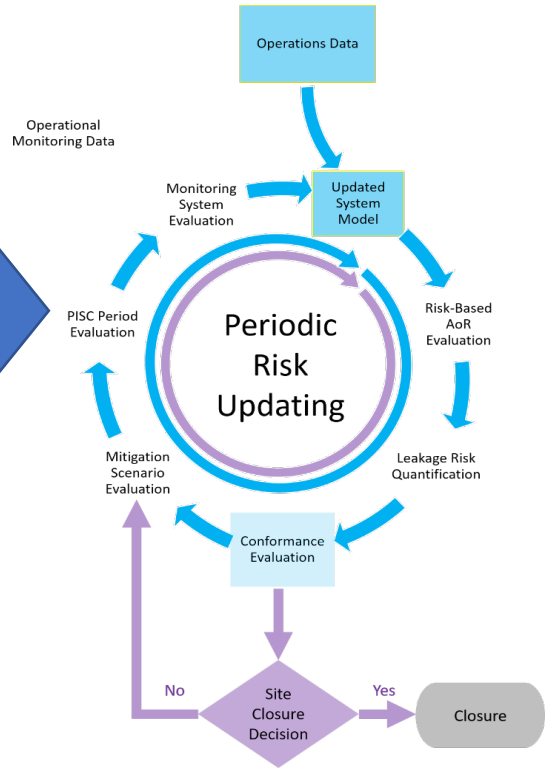
Refining and operationalizing workflows to support environmentally protective and efficient permitting (Task 2)

SMART

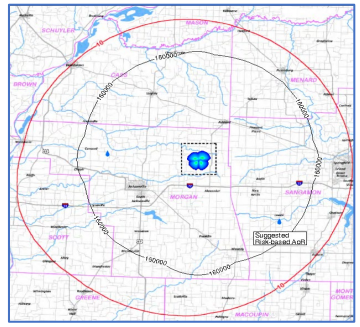
NRAP
National Risk Assessment Partnership

Rapid Prediction
Virtual Learning

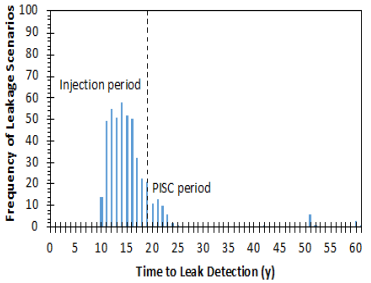




Expedited site risk and performance evaluation



Risk-Based AoR



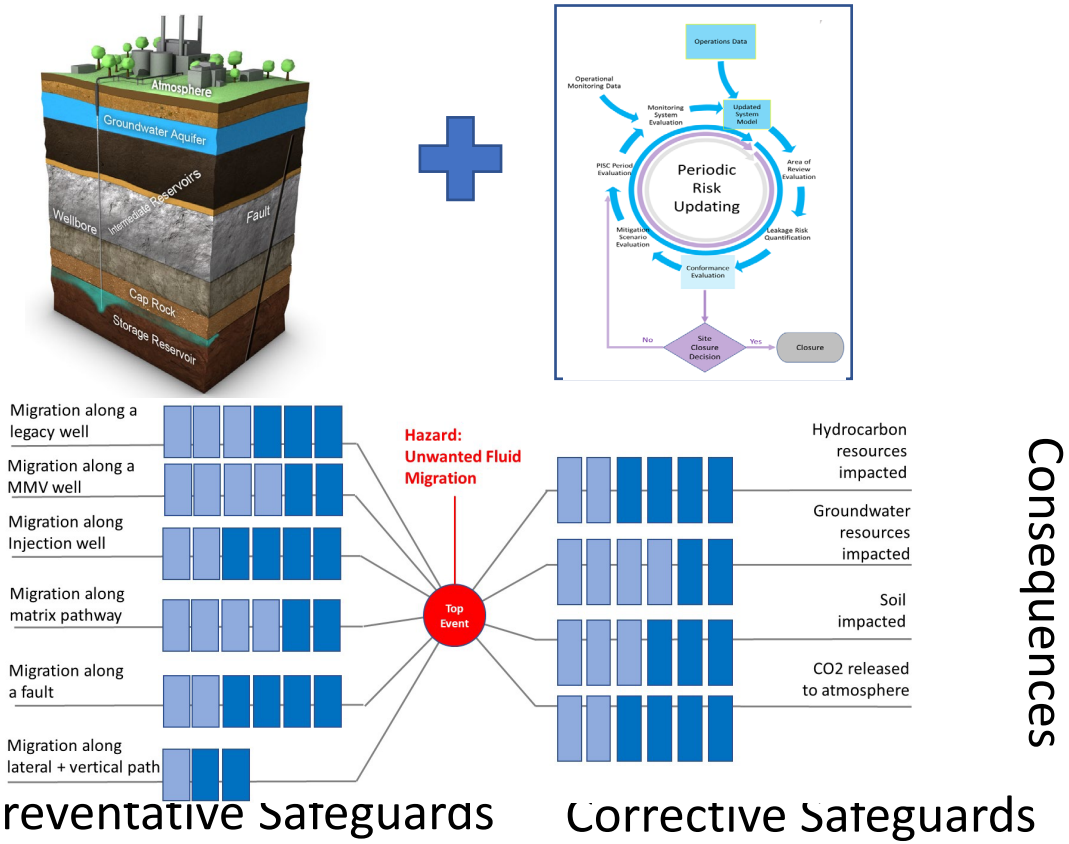
Risk-Based PISC

etc.

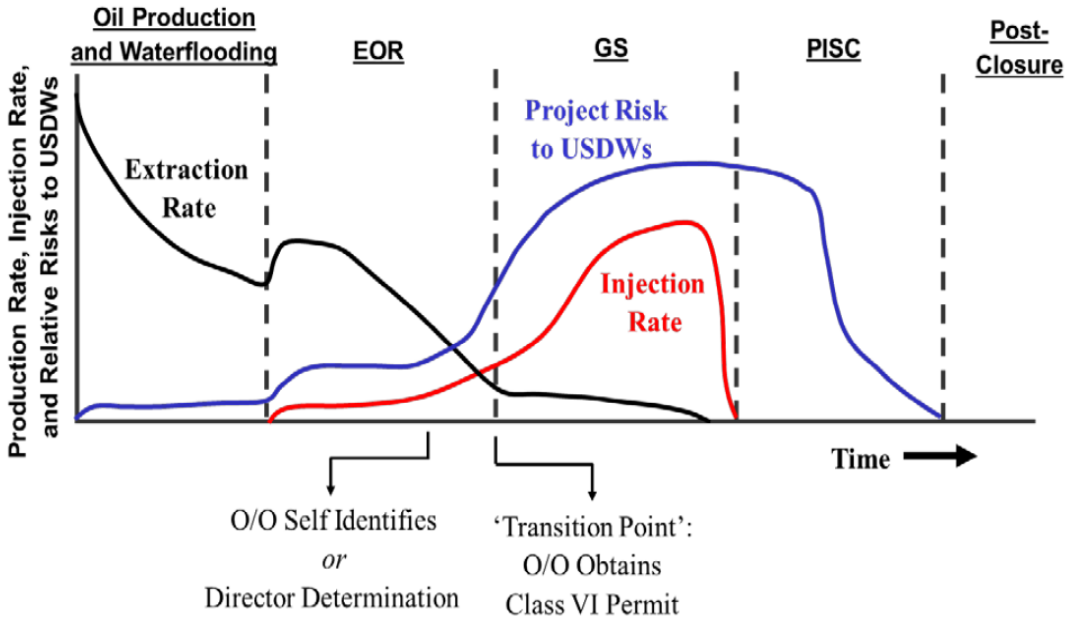
U.S. DEPARTMENT OF ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY
BERKELEY LAB
Los Alamos NATIONAL LABORATORY
Pacific Northwest NATIONAL LABORATORY

Task 2. Manage Site-Scale Risks

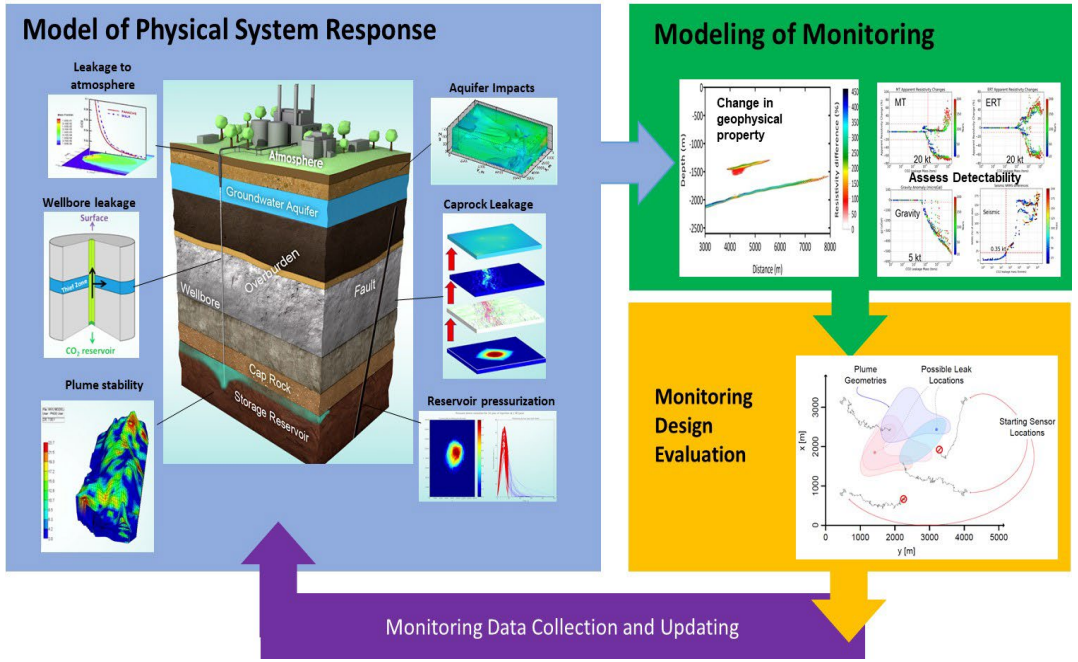
Mapping NRAP QRA to Bowtie Framework

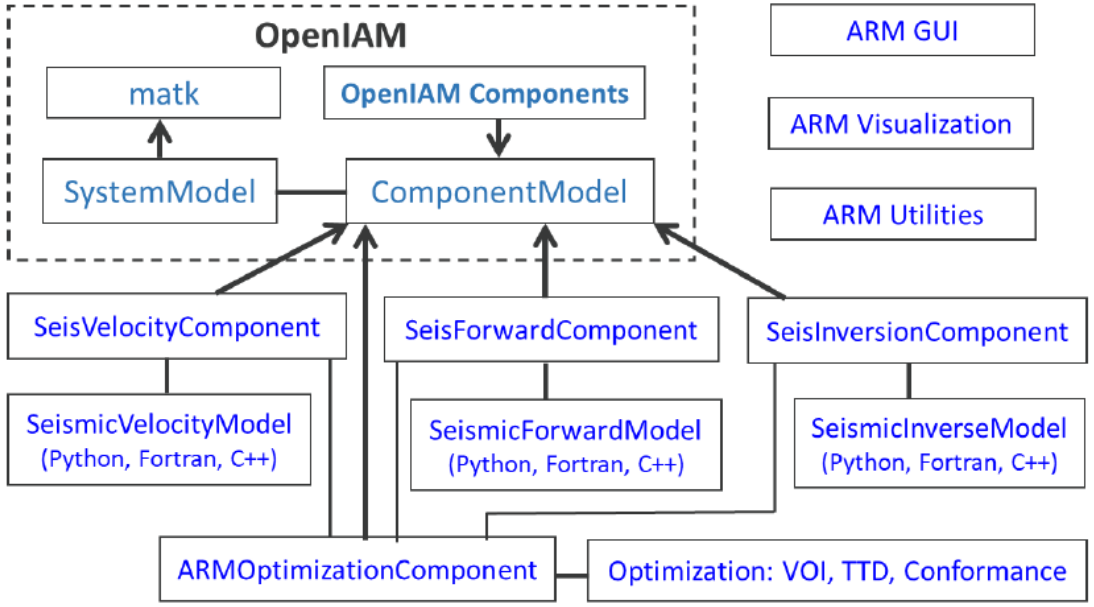


Assessing Risks of Class II to Class VI transition



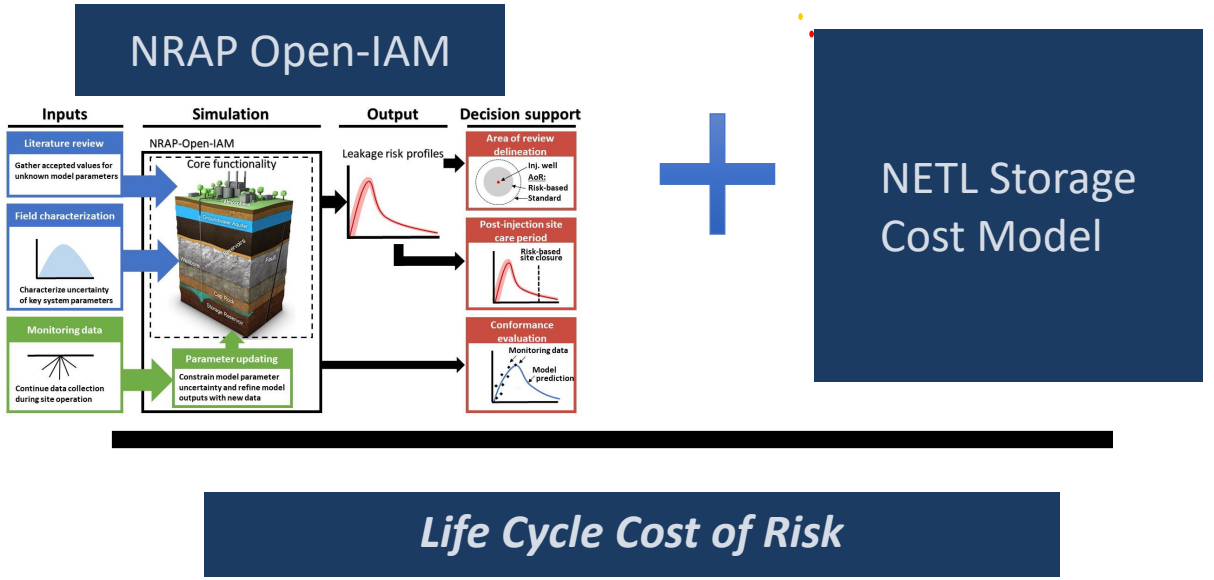
Task 4: Maturing an integrated risk-based monitoring design



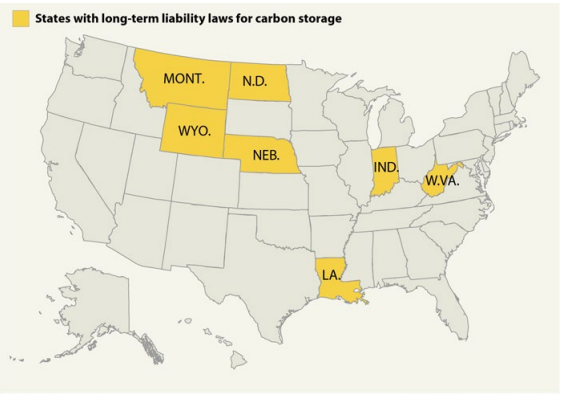


Task 5. Quantifying Long-Term Risk and Liability

What is the cost of long-term liability assumed by geologic carbon storage project stakeholders?



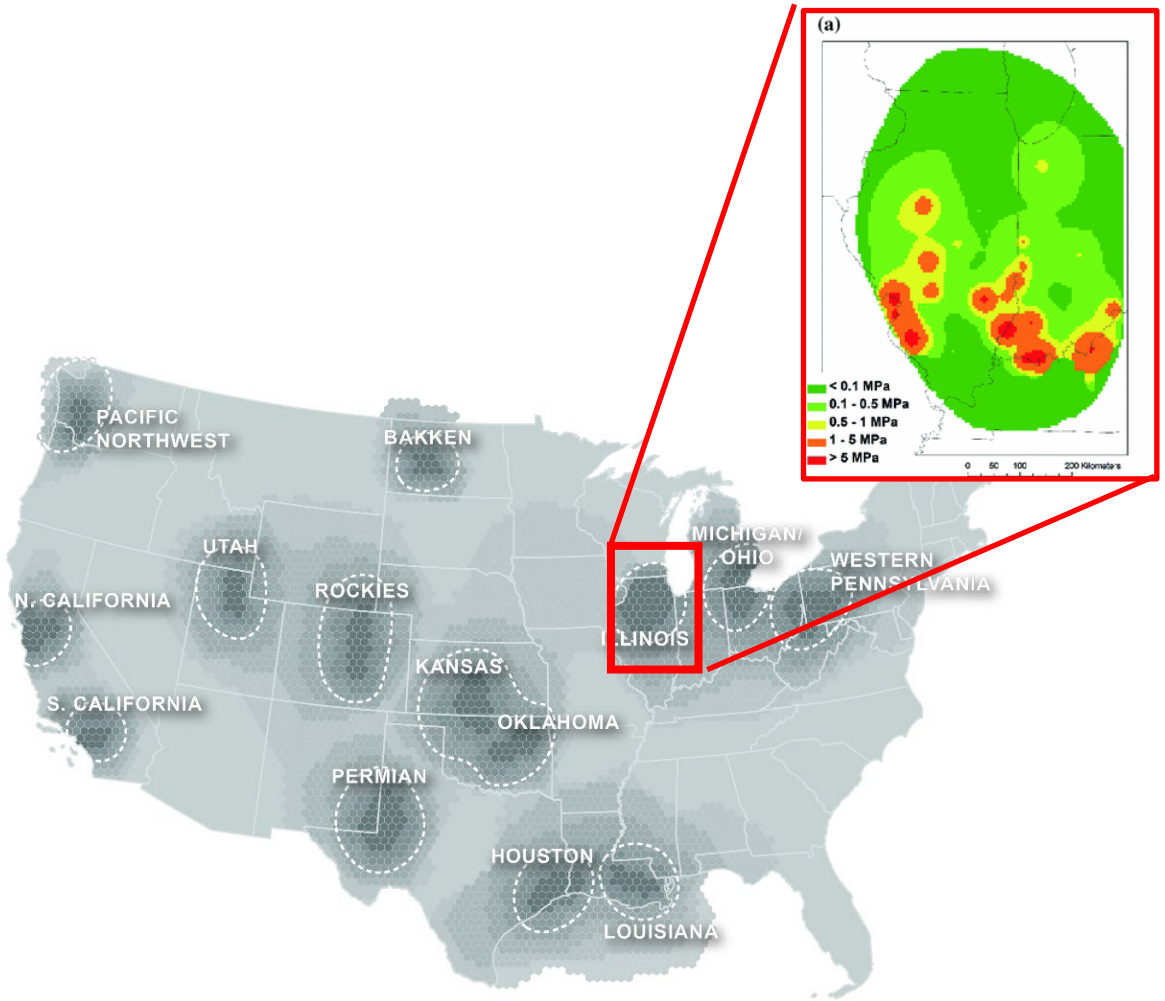
States assuming post-injection liability.



Task 6. Assessing risks of rapid basin-scale deployment

What are basin-scale risks associated with rapid deployment of many commercial projects?

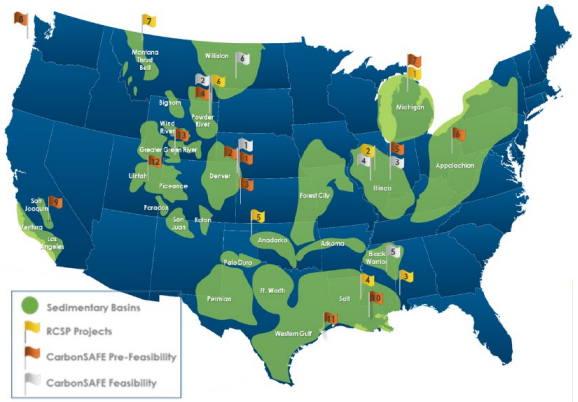
How are they best managed?



Source: An Atlas of Carbon and Hydrogen Hubs, GPI, 2022

Part of an integrated strategy to enable CCS deployment

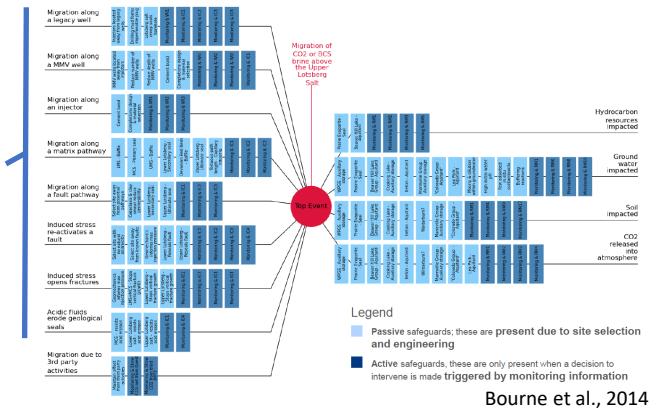
DOE CarbonSAFE



NETL Research Carbon Storage Program

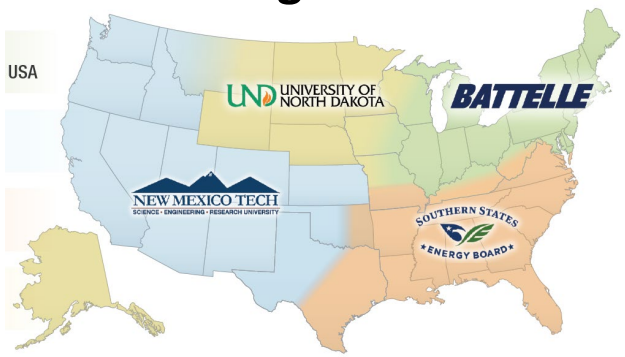
EDX 4CCS Energy Data eXchange

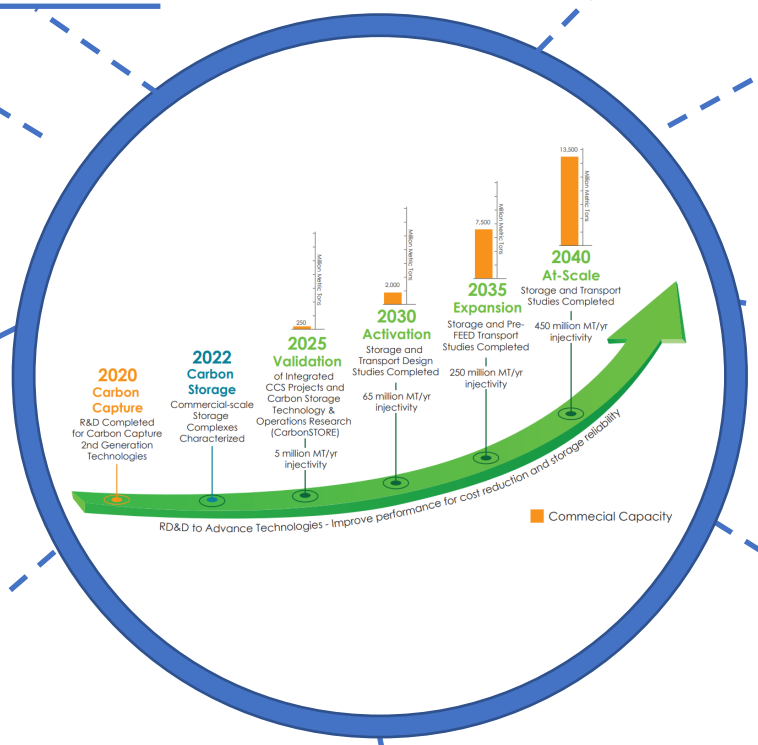
Industry Best Practices



Bourne et al., 2014

DOE-FE Regional Initiatives





International CCUS RD&D Community

ieaghg

Regulatory Context

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NORTH DAKOTA OIL AND GAS DIVISION

DEQ

SMART

NRAP National Risk Assessment Partnership

Thank you!

Comments and Questions:

NRAP@NETL.doe.gov

NRAP Website: https://edx.netl.doe.gov/nrap/

Selected NRAP References:

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For a full list of NRAP publications, visit here.

NRAP Phase III Tools

- **NRAP-Open-IAM (NRAP Open-Source Integrated Assessment Model)**
  - Leakage risk assessment and fit-for-purpose workflows for decision support
- **DREAM (Designs for Risk Evaluation and Monitoring)**
  - Monitoring design optimization to minimize time to first detection and cost
- **ORION Toolkit (Operational Forecasting of Induced Seismicity)**
  - Rapid seismic hazard assessment that uses field data (microseismic, well pressure, flow rate) calibrate field or basin models and identify conditions requiring operator intervention.
- **SOSAT (State of Stress Analysis Tool)**
  - Estimate of the stress tensor to evaluate the geomechanical risks of unintentional fracturing and induced seismicity, with Bayesian updating
- **Long-term risk and liability tool (tentative title: Carbon Storage – Financial Integrated Risk Model, CS-FIRM)**
  - Using quantified risks, estimation of remedial response and liability to monetize CS project lifecycle risk
- **NRAP-Open-IAM Basin-Scale**
  - Assess basin-scale risks from rapid-scale CCS deployment, and evaluate various deployment, monitoring, and mitigation scenarios

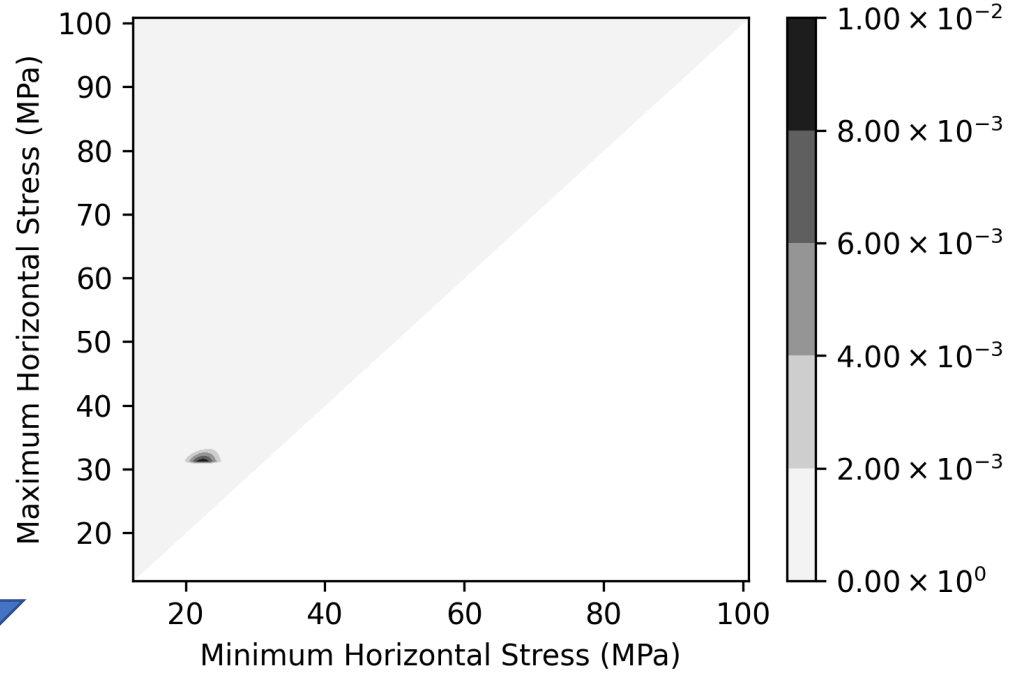
NRAP Phase III Outcomes

- **Commercial Project Risk-Based Decision Support**
  - Class II to Class VI well risk assessment – Safe reuse of existing subsurface infrastructure
  - Integrated analysis of long-term risk and liability /financial risk – GCS investment decisions
  - Demonstrate NRAP tools with industry-standard risk management (bowtie method) – Integration with industry risk management workflows
  - Integrated assessment and risk-based monitoring design tools – Maturing tools for industry uptake
- **Basin-scale risk assessment for rapid commercial deployment – Informing deployment decisions**
- **Tech transfer:**
  - Open-source NRAP tools – freely deployed to CCS stakeholders
  - Support risk assessment for DOE's Carbon Storage Validation and Testing program (CarbonSAFE) and early entry commercial projects
  - Regulator and industry engagement

Constraining Parameter Uncertainty

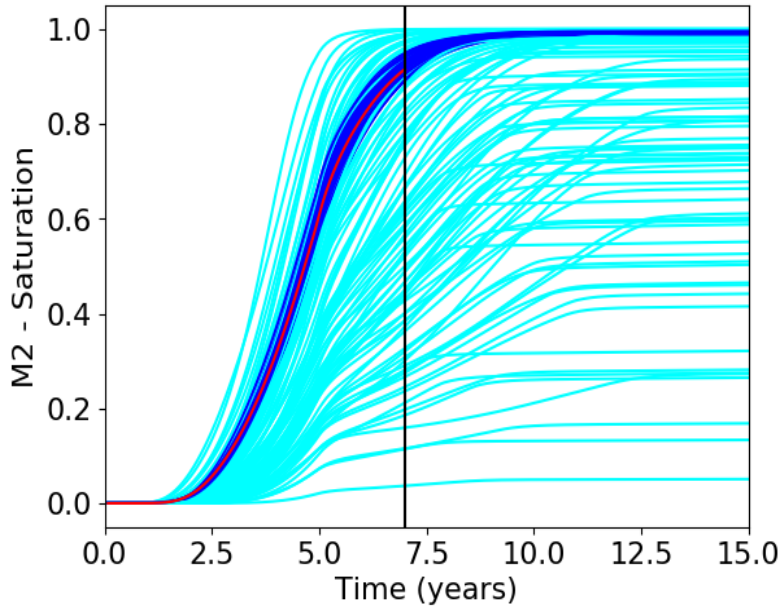
Site characterization data to update estimates of stress state

More Information



Monitoring observations used to update uncertain parameters

7 yrs



Cyan: prior models

Blue: posterior models

Chen, B. et al., 2020, Int. J. Greenh. Gas Control

Chen, B. et al., 2020, Int. J. Greenh. Gas Control

NRAP Phase III Technical Tasks and Org. Structure