National Risk Assessment Partnership:

Leveraging DOE's Science-Based Prediction Capability to Build Confidence in Engineered–Natural Systems

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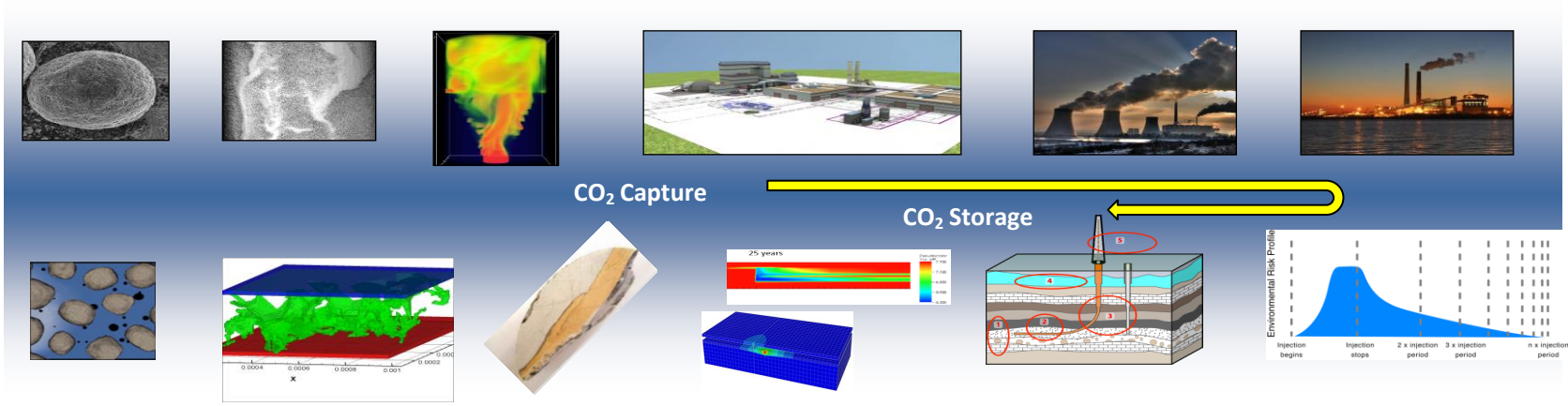
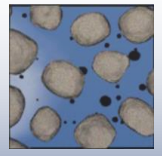
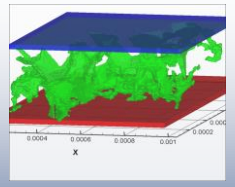
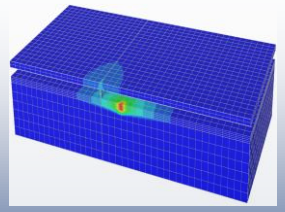
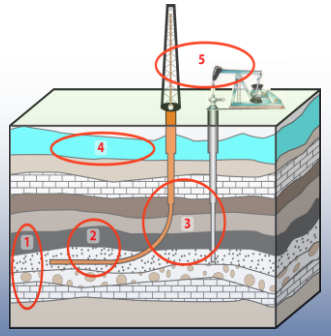
Carbon Capture Simulation Initiative (CCSI)

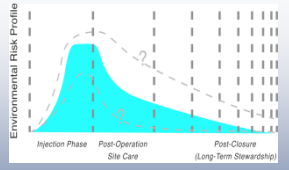
To accelerate the path from concept (bench) to deployment (commercial power plant) by lowering the technical risk in scale up.



National Risk Assessment Partnership (NRAP)

To accelerate the path to CCUS deployment through the use of science-based prediction to quantify storage-security relationships, thereby building confidence in key decisions.



National Risk Assessment Partnership

Leveraging DOE's competency in science-based prediction for engineered–natural systems to build confidence in the business case for CO_2 storage.

Building toolsets and the calibration & validation data to resolve questions like…

• How should a site be monitored post injection? • What are appropriate operational envelops relative to injection pressures? • What are the potential long-term costs associated with monitoring?

• What is the potential long-term liability? • Will stored CO_2 leak, impact groundwater, or induce seismic events?

Technical Team

NETL-RUA Regional University Alliance

Carnegie Mellon · 1855 · West Virginia

URS

Berkeley Lab

Los Alamos National Laboratory EST.1943

Pacific Northwest National Laboratory

Stakeholder Group

AEP American Electric Power · Blue Source · bp · EPA United States Environmental Protection Agency

ExxonMobil · leaghg · IEc

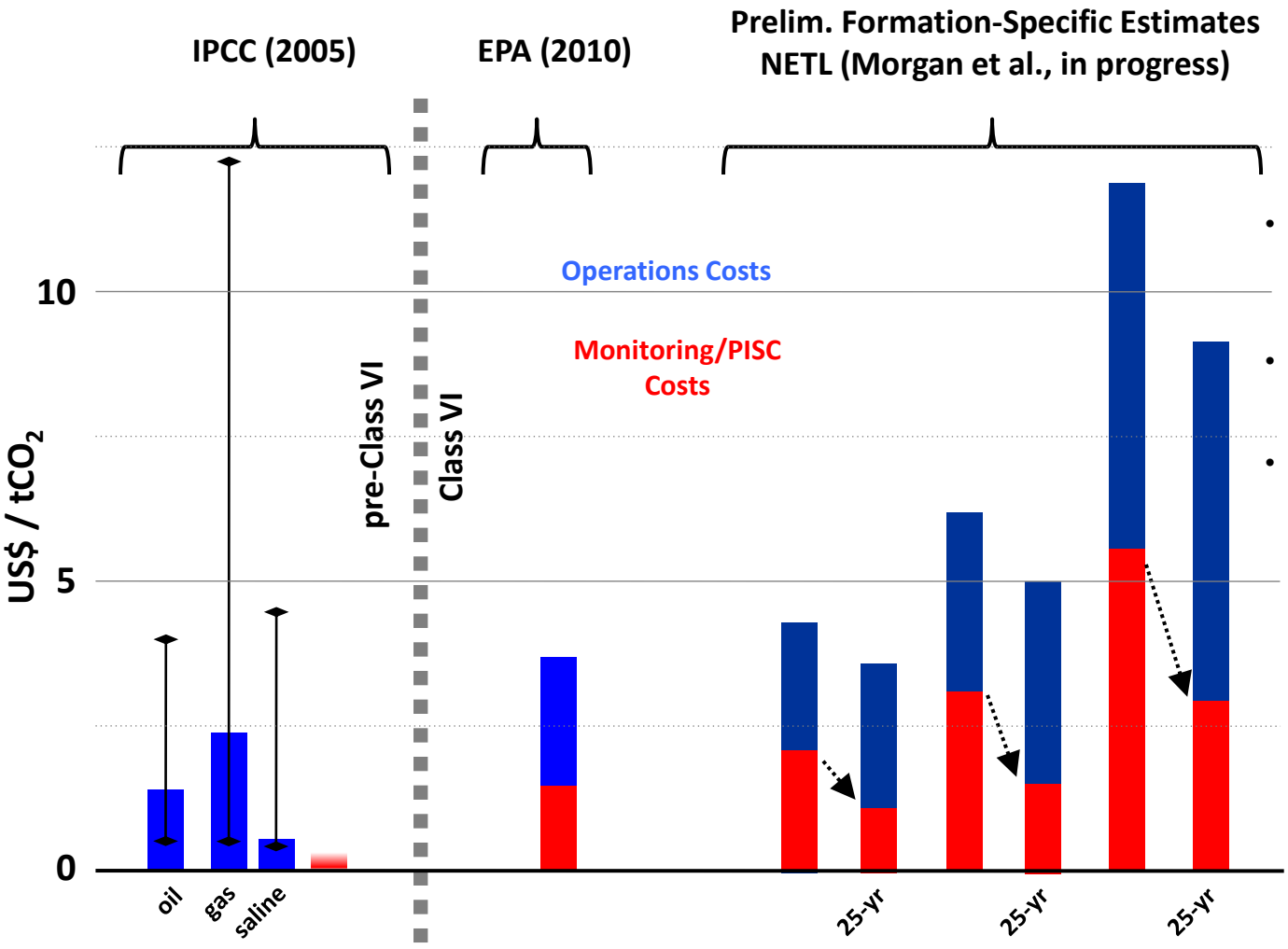
MIT · NRDC · Schlumberger · Southern States Energy Board

Stanford University · Texas Railroad Commission · Whiting · Zurich (Because change happens)

The University of Utah

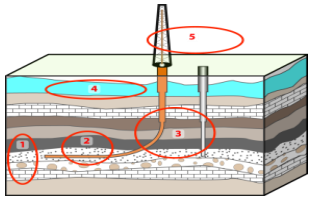
Wade, LLC

What information is needed to provide the confidence necessary to consider an alternative approach to PISC monitoring needs?



- **IPCC (2005) estimated post-injection monitoring costs to be <10% of project costs.**
- **Post Class VI estimates range from 35–50% of total costs.**
- **Primary drivers for costs include:**
  - long time frame (50 yrs)
  - large area-of-review
  - large battery of techniques

A reduction of 1-2 $/ton CO_2 would mean a savings of $50-250 million per project.



NRAP Tasks and Toolsets

Toolsets and Science Base (Data for Calibration/Validation)

Targeted Assessments through Application

Risk-Based Monitoring Protocols

Basin-Scale Effects?

EPA Class VI Review?

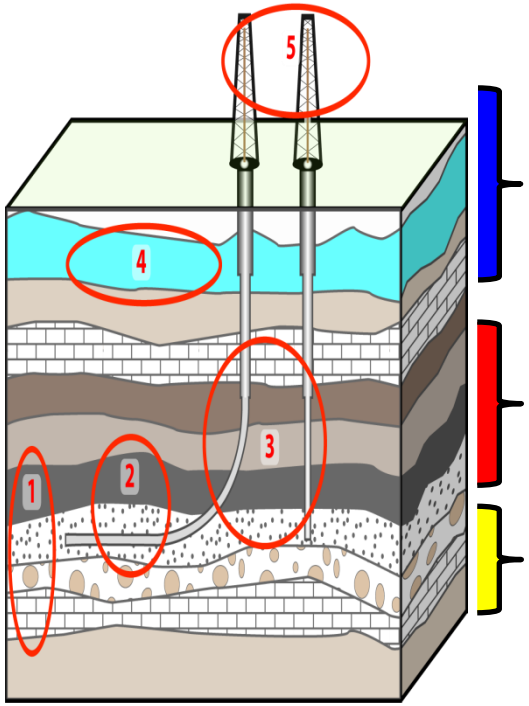
FY2011	FY2012	FY2013	FY2014	FY2015	…	FY2020

Develop Toolsets

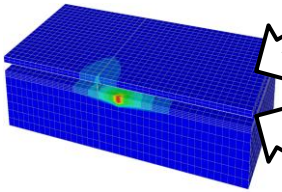
Components	Generation 1	Generation 2	Generation 3
Reservoir	flow only 2 reservoir classes multiple reservoir simulators stochastic permeability	flow & geomechanics 3 reservoir classes (EOR) quantified trapping mechanisms ΔP due to semi-permeable caprock	4 reservoir classes
Release & Transport	wellbores (flow + phase change) faults (flow + phase change) 1D flow into thief zones	wells (flow+chemistry w/ varying permeability; field-based initial state, wellbore failure faults/fractures/caprock (flow+geomechanics; fault-zone complexity) porous flow through overburden	wellbores/fractures (flow, chemistry, geomechanics) coupling of flow in wells, faults, & porous media heterogeneous overburden
Groundwater	TDS, pH equilibrium geochemistry 2 endmember aquifers CO_2 & brine flux	TDS, pH, metals multiple leakage sources	TDS, pH, metals, organics kinetic geochemistry co-constituents redox geochemistry
Induced Seismicity	hazard assessment	hazard and damage risk	hazard, damage and nuisance risk
Atmosphere	total flux only		atmospheric dispersion

NRAP's approach to quantifying performance relies on reduced-order models to probe uncertainty in the system.

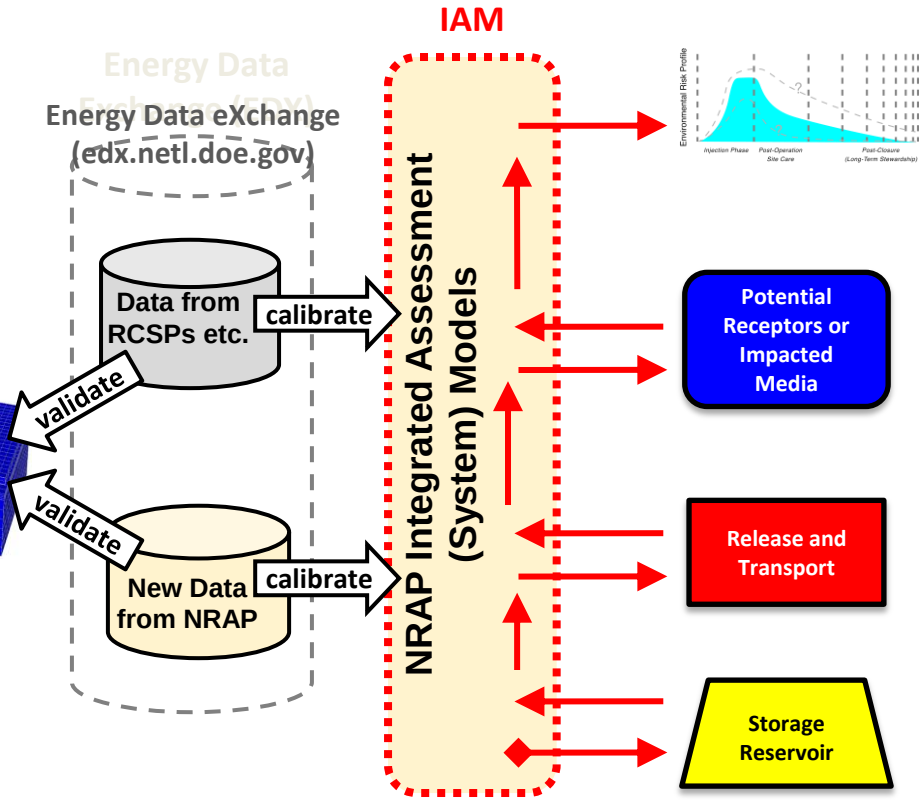
A. Divide system into discrete components



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 & risk; calibrate using lab/field data from NRAP and other sources**

E. Develop strategic monitoring protocols that allow verification of predicted system performance

Approach to Development of Reduced-Order Models (ROMs): Case Study at a Candidate Field Site

Sensitivity analysis
Identify key variables that control component behavior

Detailed Simulations
Multiple simulations of detailed component models (reservoir, wellbores, faults, aquifer)

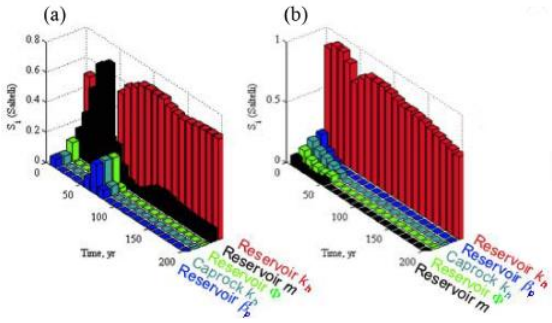
ROM Development
- Look-up tables (LUTs)
- Response surfaces (e.g. via PSUADE)
- Artificial intelligence approaches
- Analytical relationships (e.g., polynomial chaos expansion)

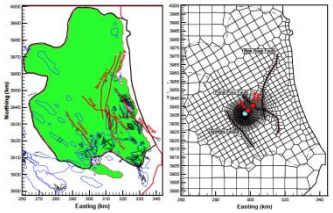
Define Key Parameters for ROM

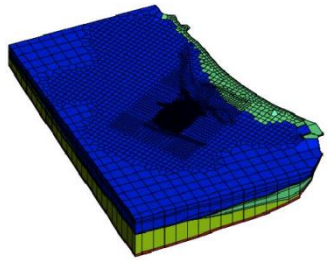
Validate ROM against simulations

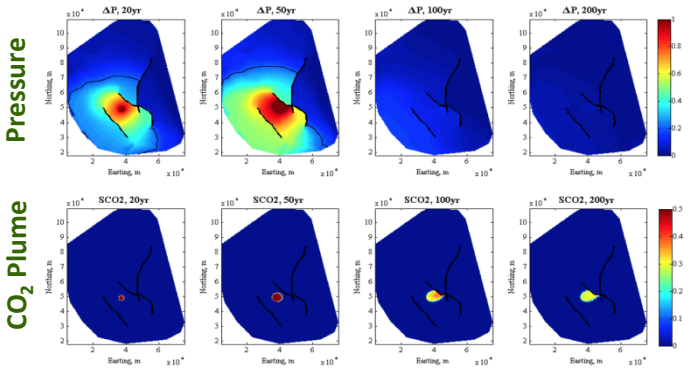
CO_2 Plume

Pressure





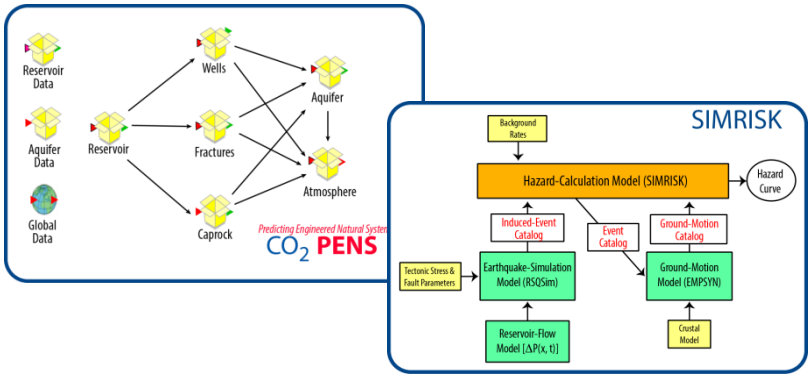




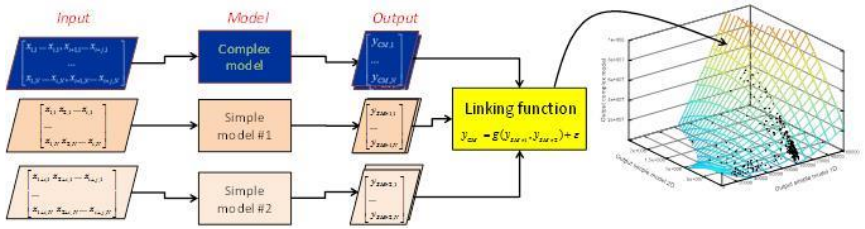
from Wainwright et al. (2012) NRAP-TRS-III-002-2012

Building the Toolsets

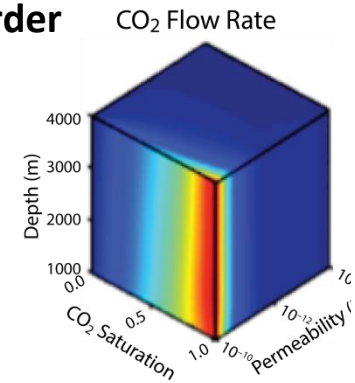
- **First-of-a-kind toolsets for science-based, quantitative evaluation of risks and uncertainties**
  - Leakage risks (reservoirs to receptors)
  - Induced seismic events

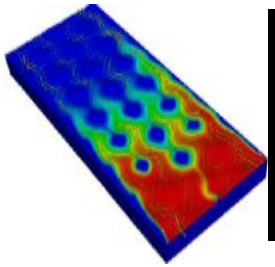


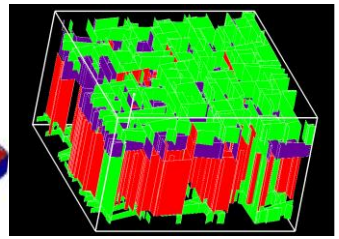
- **Site-specific and adaptable ROMs**
  - Reservoirs (3 classes; 3 injection scenarios)
  - Wellbores (open and cemented)
  - Fractures (discrete and networks)
  - Aquifers (two major types)

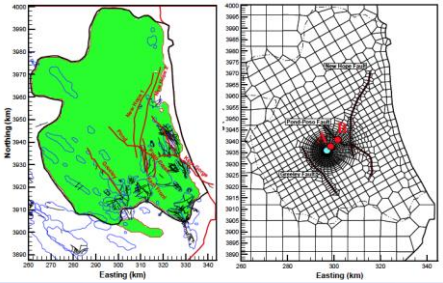


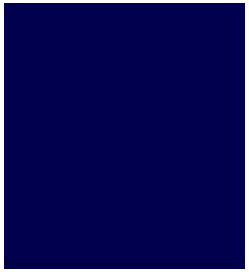
- **Evaluated numerous approaches to reduced-order models (lookup table to artificial intelligence)**
  - Achieve balance between fidelity and speed





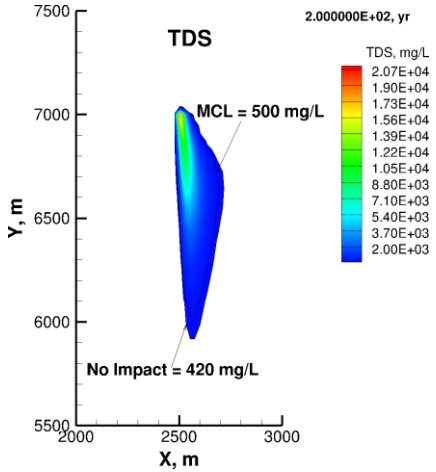




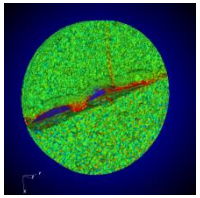


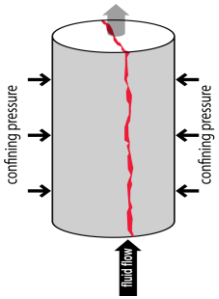
Building the Science Base

- **Developed underpinning, physics-based models for wellbores and fractures**
- **Demonstrated validity and limitations of de-coupling assumption in integrated assessment models**
- **Established "no-impact" threshold values for two major classes of aquifers**
- **Expanded science base and data needed for model calibration**
  - Lab studies on cement, shale, aquifers
  - Geostatistical studies on wellbore characteristics
  - Natural analog studies on reservoirs/aquifers

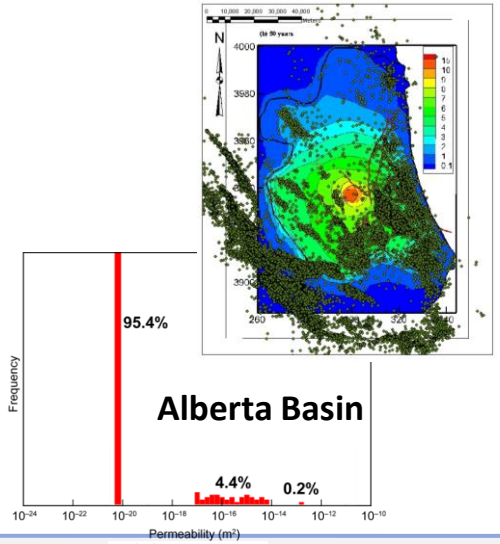


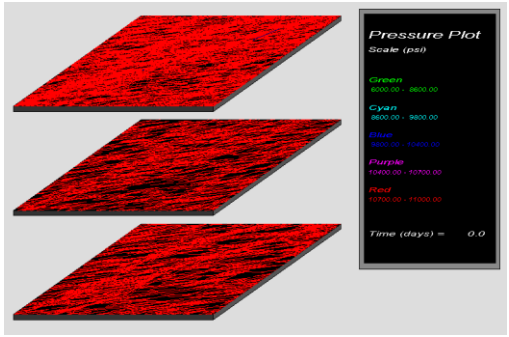
groundwater





wellbores



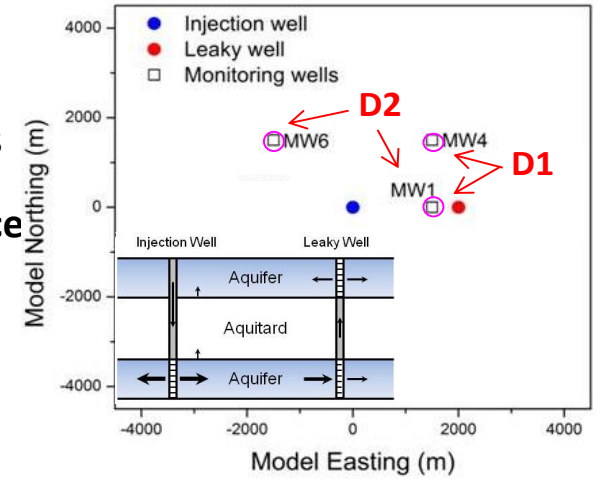


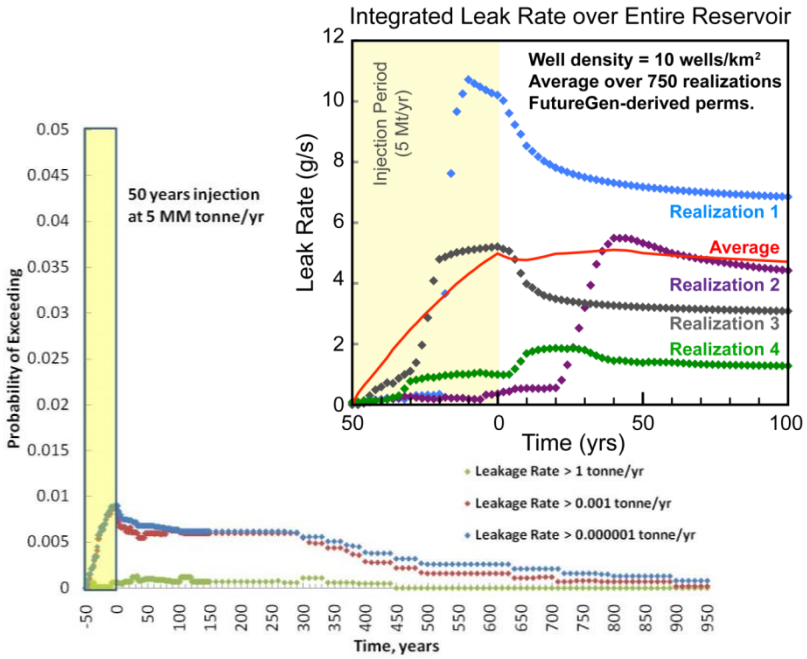
fractures

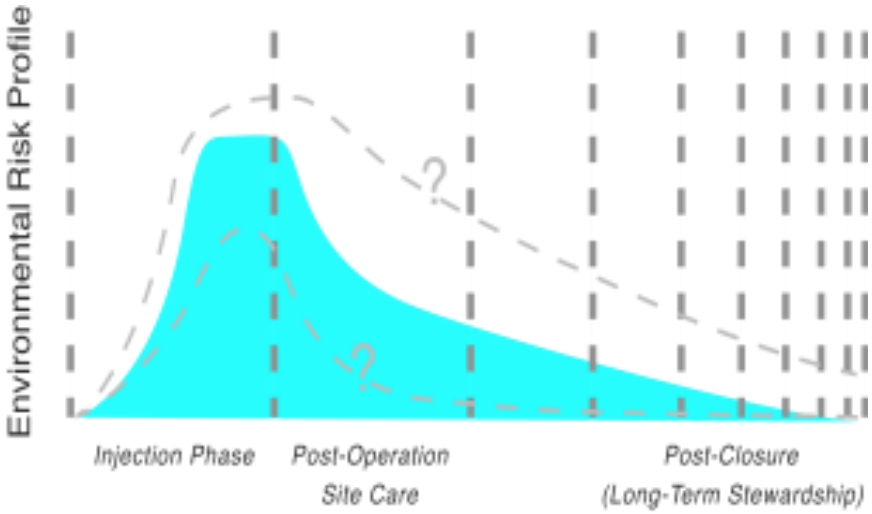
Applying the Toolsets

- **Generated first quantitative risk profiles for long-term behavior**
  - Route to quantifying probability of meeting containment goals
- **Demonstrated use of IAMs to quantitatively identify key subsurface parameters that impact risk at a site**
- **Developed a preliminary technique for risk-based monitoring network design of CO_2 storage sites**

Leaky Storage Cases







a la Benson (2007)

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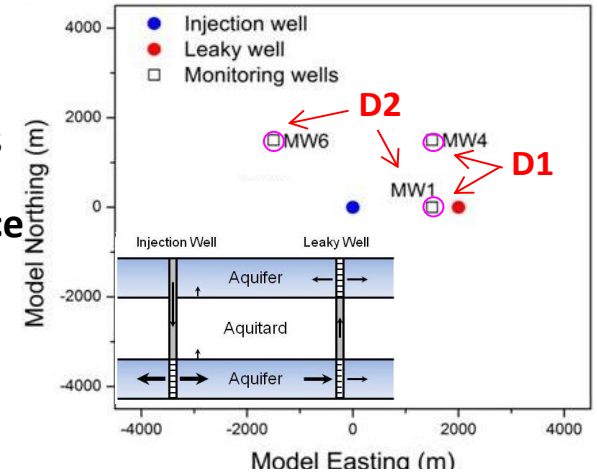
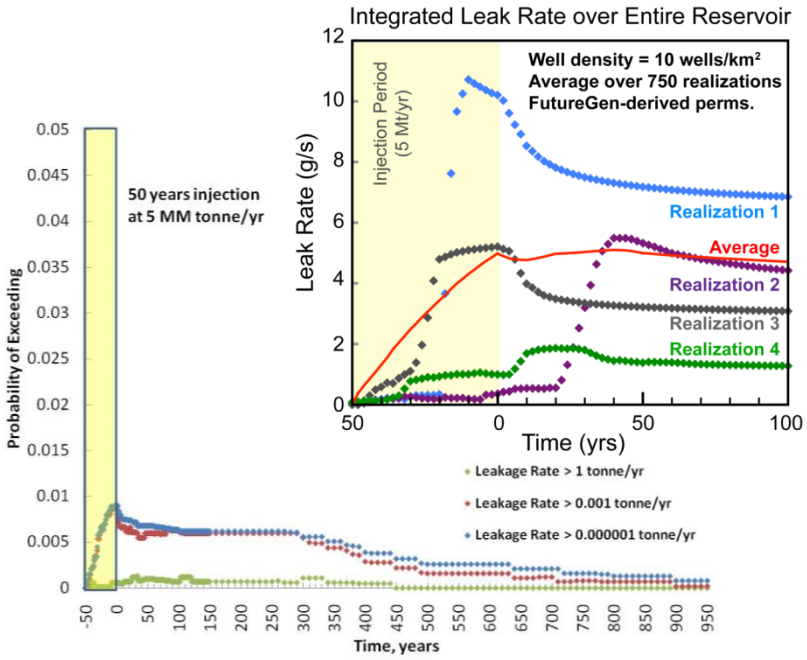
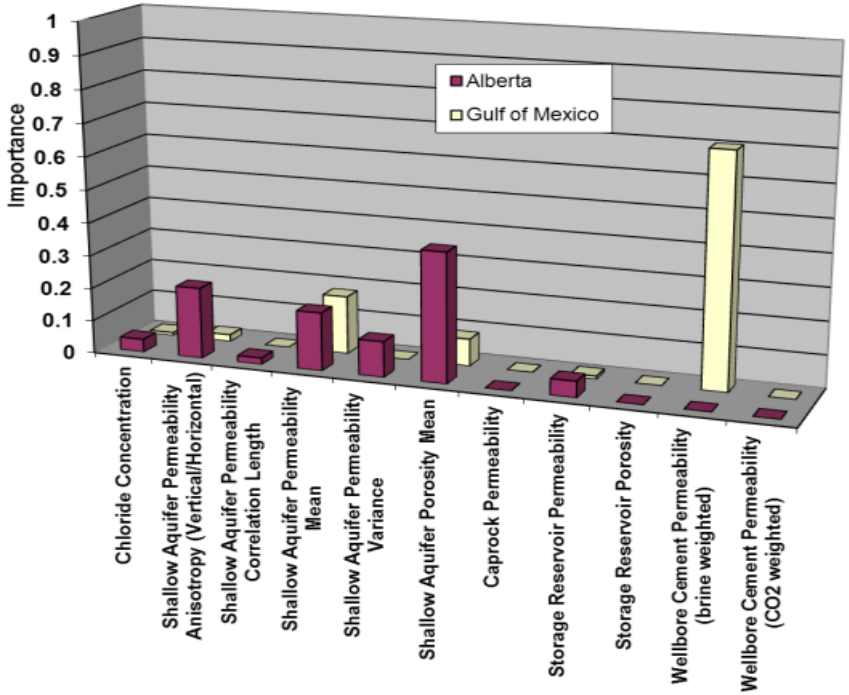
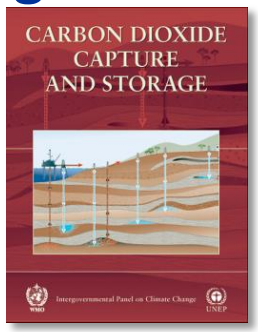


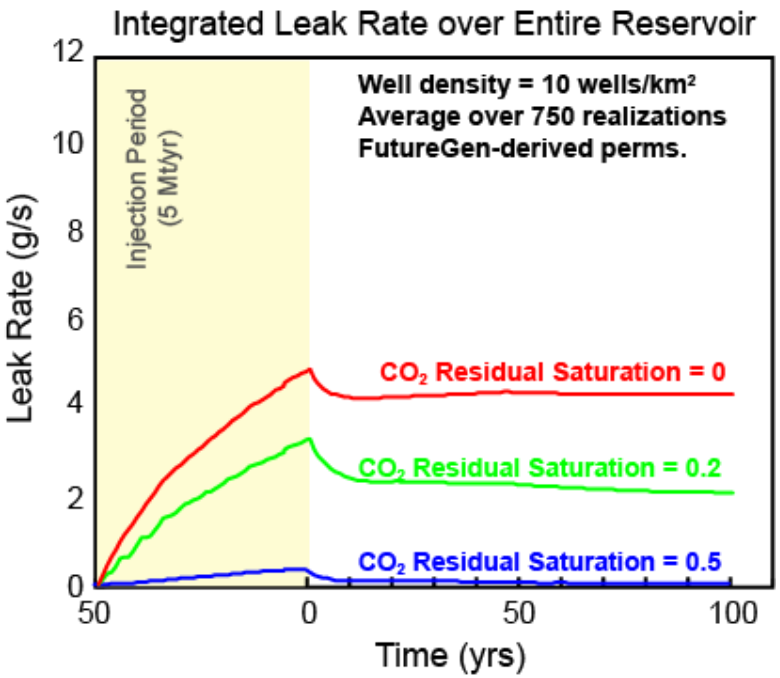


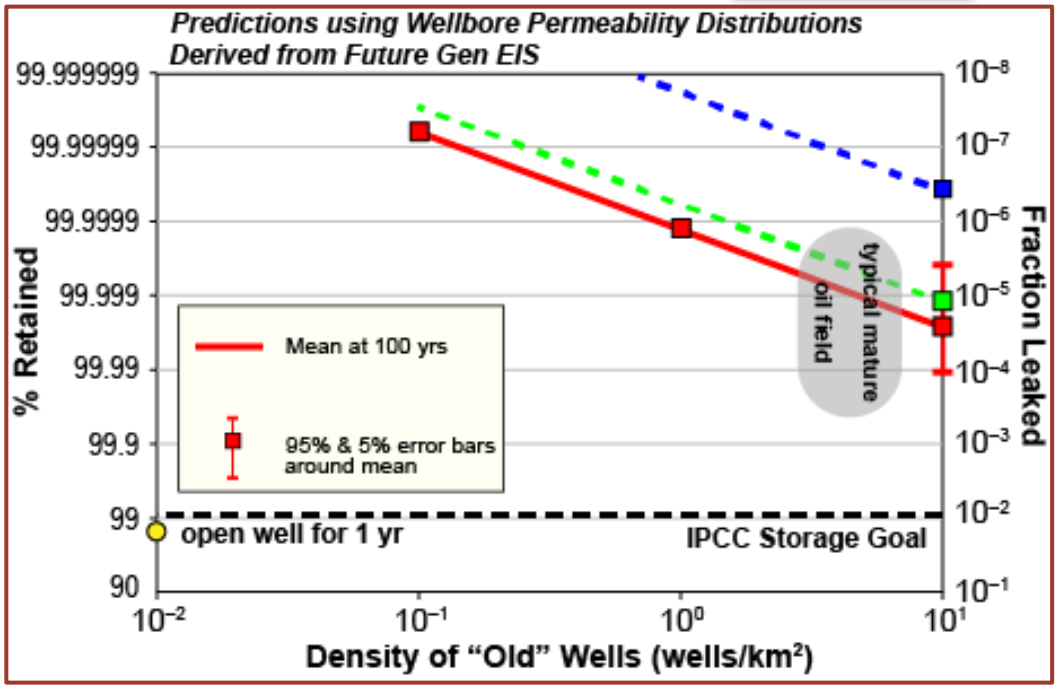


2nd generation risk profiles for atmospheric release can be used to assess retention goal (>99%) relative to pre-existing wells.



- Inclusion of residual trapping lowers release (i.e., raises the "% Retained")
- System dynamics are dominated by individual leaky wells





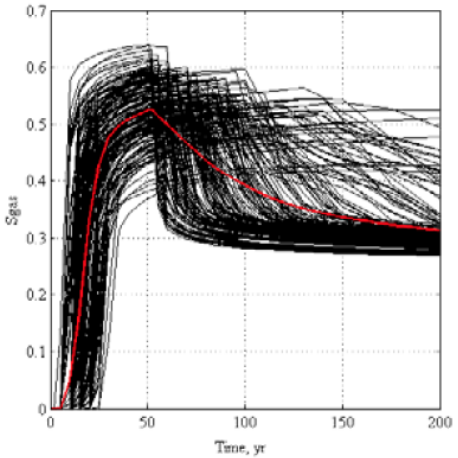
In all 24 cemented well scenarios evaluated, cumulative CO_2 leakage remained well within IPCC storage permanence scenario of 99% retention after 1000 years.

Applying NRAP's Work in EPA's UIC Program
(for example)

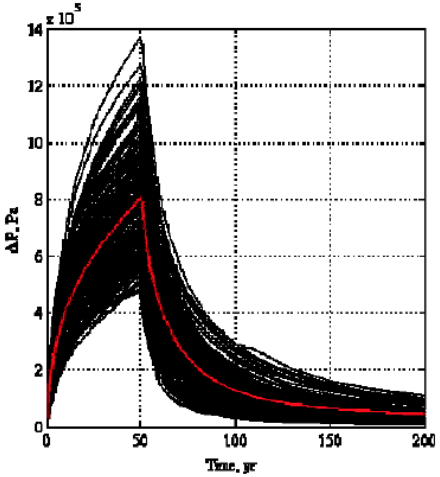
- **Allow development of site-specific risk profiles for different project phases to support science-based decision-making**
- **Improve permitting efficiency**
- **Transitioning from Class II to Class VI**
- **Inform the Adaptive Approach to the Class VI Rule**
- **Facilitate consistent information-sharing among stakeholders**

NRAP Tools can help address uncertainty in AoR quantitatively.

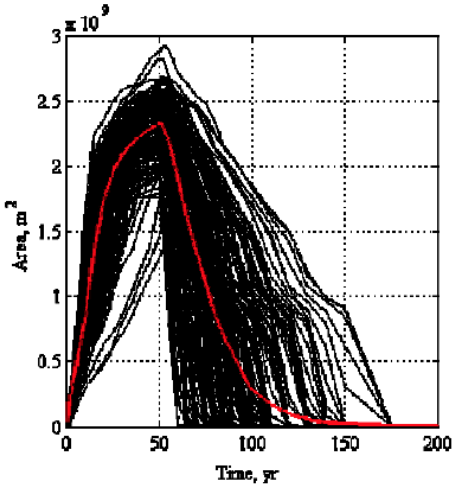
Saturation



Pressure Buildup



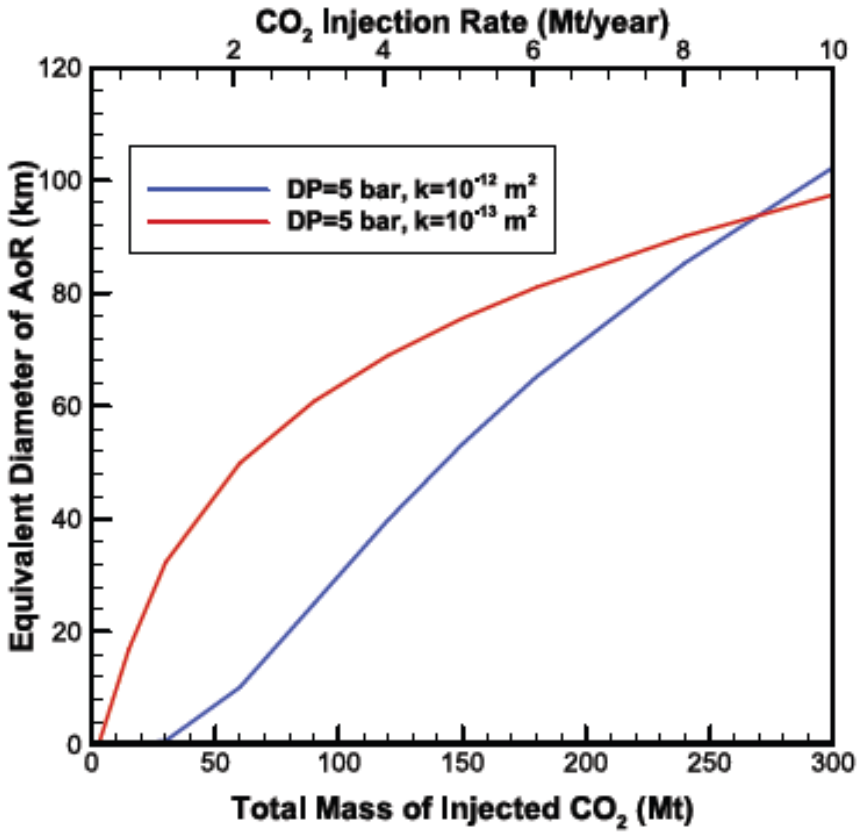
Area of Pressure Buildup

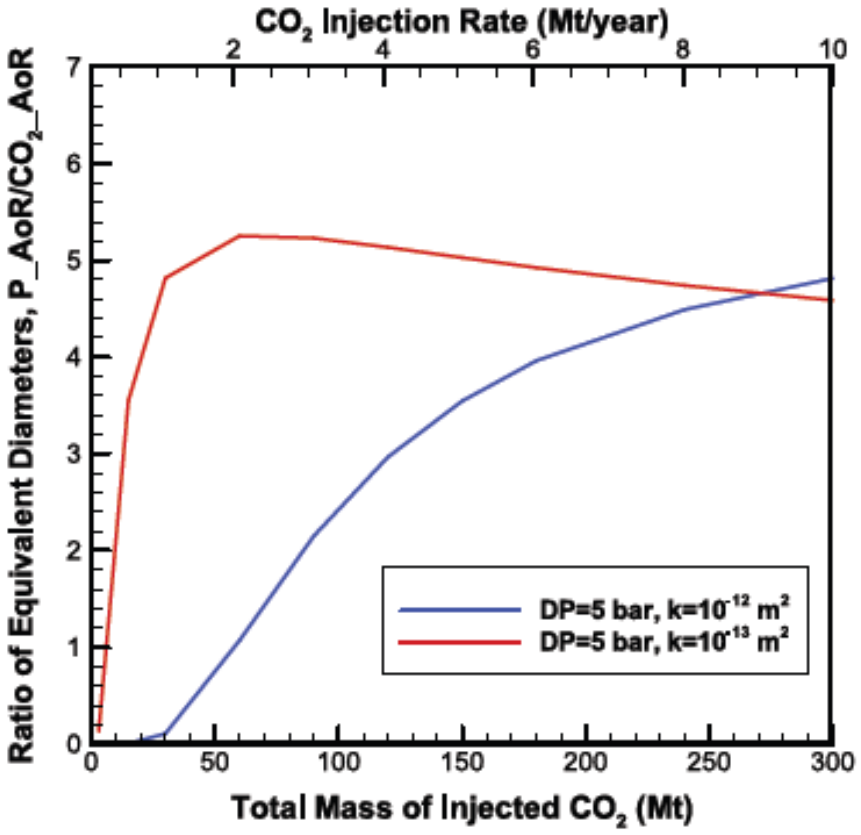


from Wainwright et al. (2012) NRAP-TRS-III-002-2012

AoR Results for 30-Year Injection Period

- AoR based on 0.5 Mpa pressure threshold can be much larger than CO_2 plume
- Ratios depend on injection rate, permeability, and threshold pressure





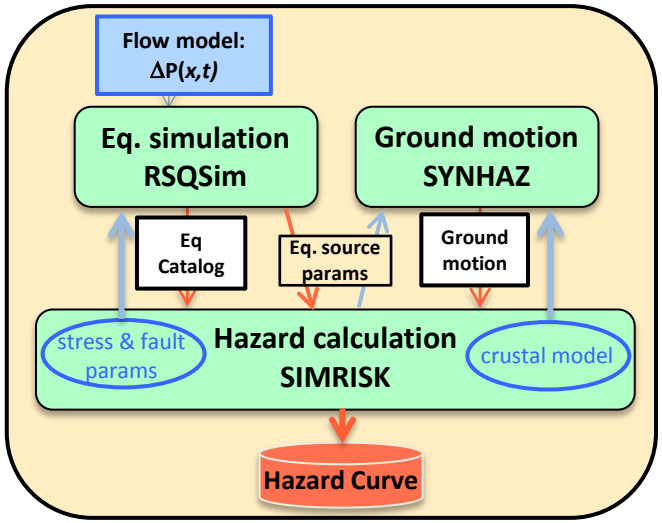
Induced Seismicity

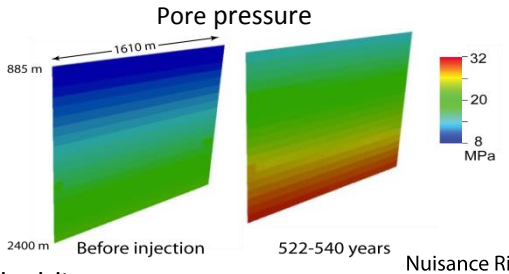
Tool & Method Development

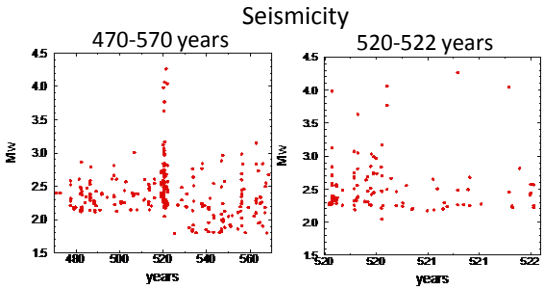
- Developed a probabilistic seismic hazard assessment (PSHA) tool for induced seismicity
  - adapted widely accepted conventional PSHA approach
- Extending development to assess damage and nuisance (felt event) risks
  - demonstration application to realistic CO_2 injection scenarios based on In Salah (Algeria)

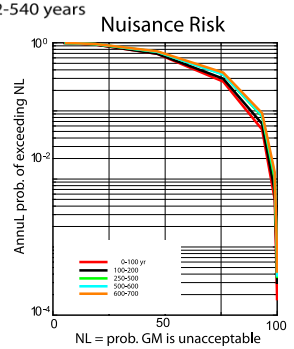
General Trends & Relationships

- Rates of occurrence and sizes of earthquakes are determined by tectonic stress and reservoir pressure
  - sensitive to fault permeability and a few key parameters in the law governing the evolution of fault frictional strength
- Risk of CO_2 leakage may be coupled to slip on faults during earthquakes









High costs and large uncertainties suggest a phased approach to seismicity management

Phase	Characterization & Monitoring	Modelling	Risk Assessment
• Site-screening	• Regional stress estimates • Fault density estimates	• Back-of-the-envelope	• Red-flags • Atlas
• Pre-injection	• 3D seismic • XLOTs • FMI • Limited microseismic	• Simple models	• Qualitative Assessments • PSHA
• Injection & PISC	• 4D seismic • Full microseismic	• Sophisticated models	• Traffic-light • PSRA

-- Cost/benefit of additional methods assessed based on evolving project conditions.

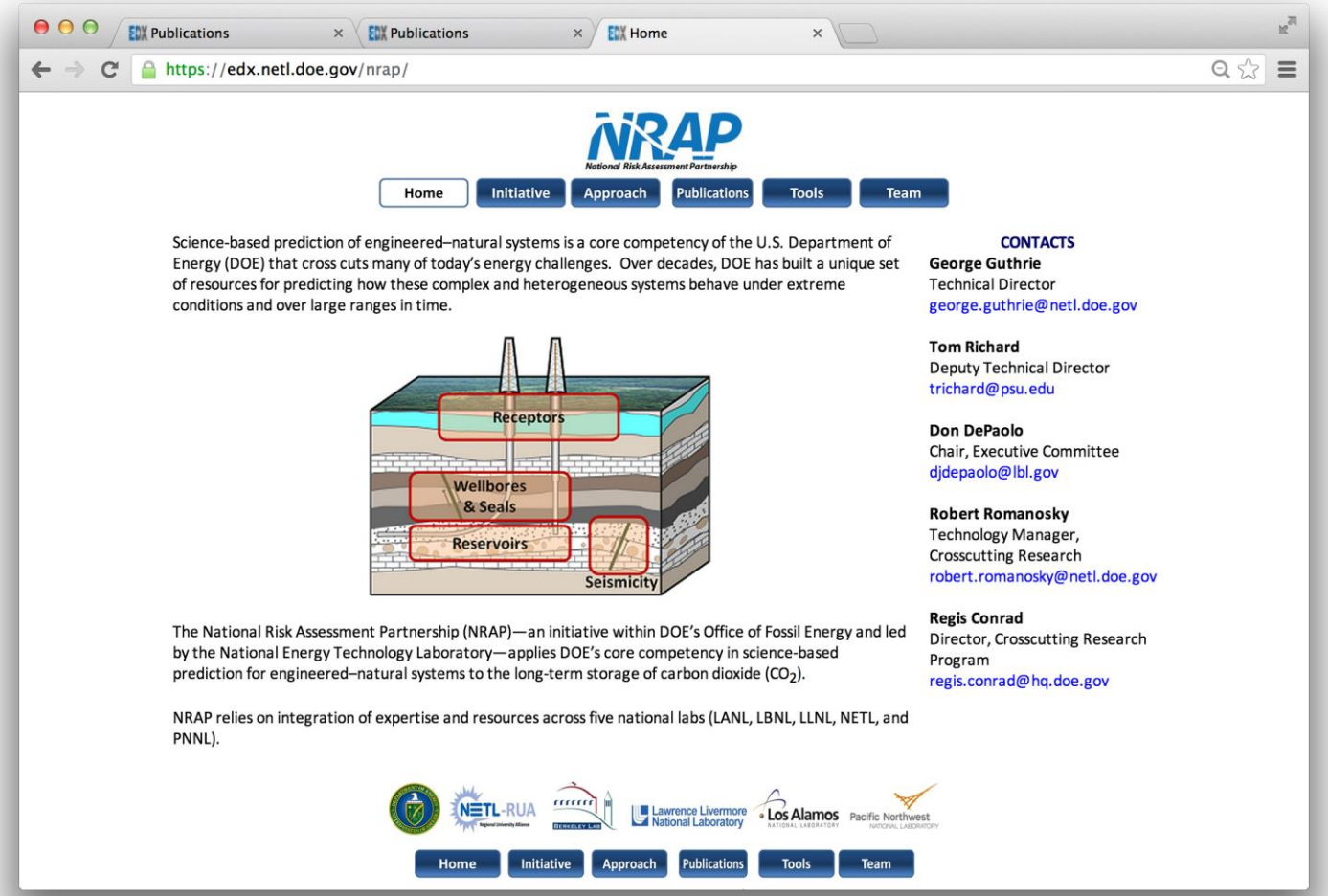
-- Baselines are important.

-- Timely processing and interpretation of data are important.

Planned Future Products

- AoR & PISC tools for facilitating dialog during the permitting process
- Complete third generation toolsets for quantifying long-term performance
    - ROMs, IAMs
    - Investigation of key influence parameters
- IAMs that integrate monitoring and mitigation strategies
- Risk-based monitoring protocols for verification (operators, regulators, …)
- Field-calibrated toolset for forecasting induced seismic risk to aid operators and regulators (e.g., confidence in injection envelops)
- Induced seismicity protocol document
- Synthetic datasets for validation of risk methods (within & outside NRAP)?

Thank You!



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