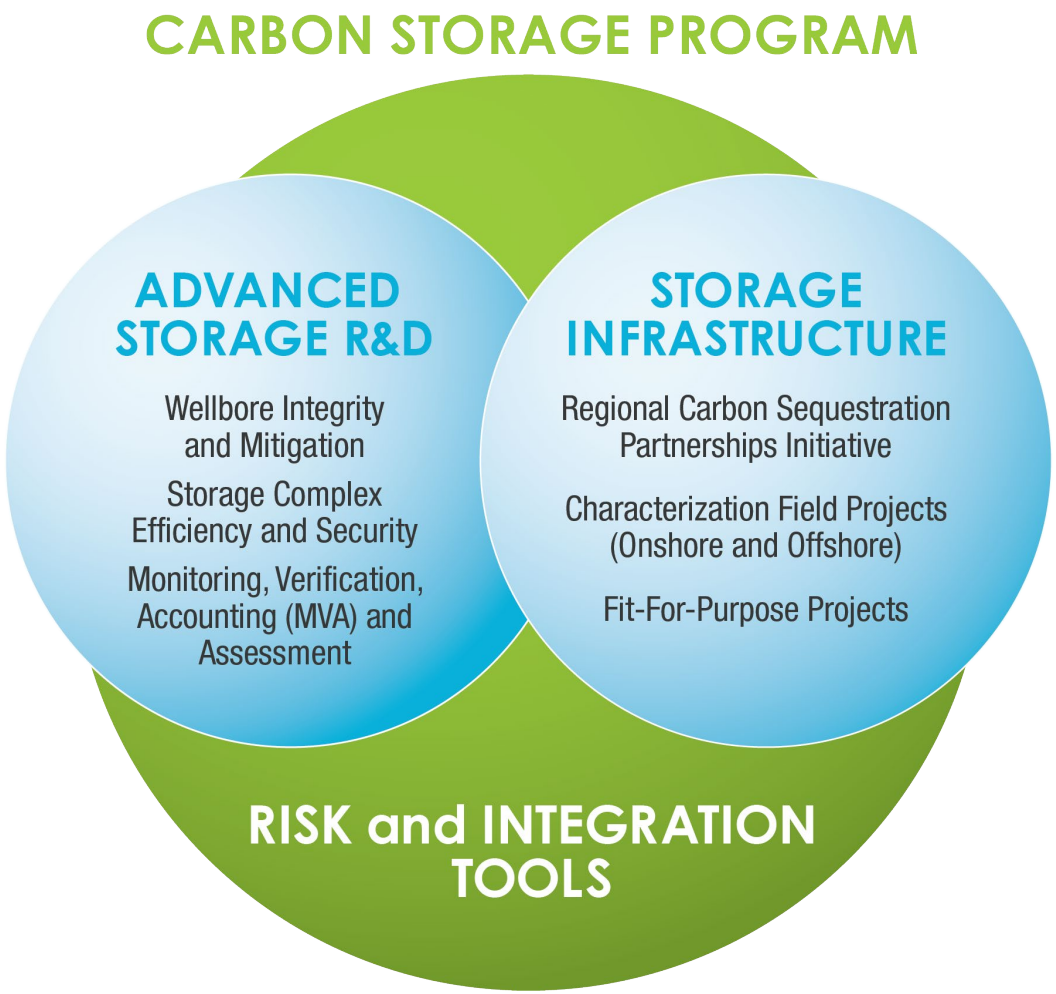
Carbon Storage Program Structure



Storage Infrastructure

- Field projects to validate storage technologies in different storage complexes in various geologic settings and address practical technical and non-technical issues of storage

Advanced Storage R&D

- Applied R&D to improve wellbore integrity, increase reservoir storage efficiency, improve management of reservoir pressure, confirm permanent storage, and identify and mitigate potential induced seismicity and CO_2 release risks

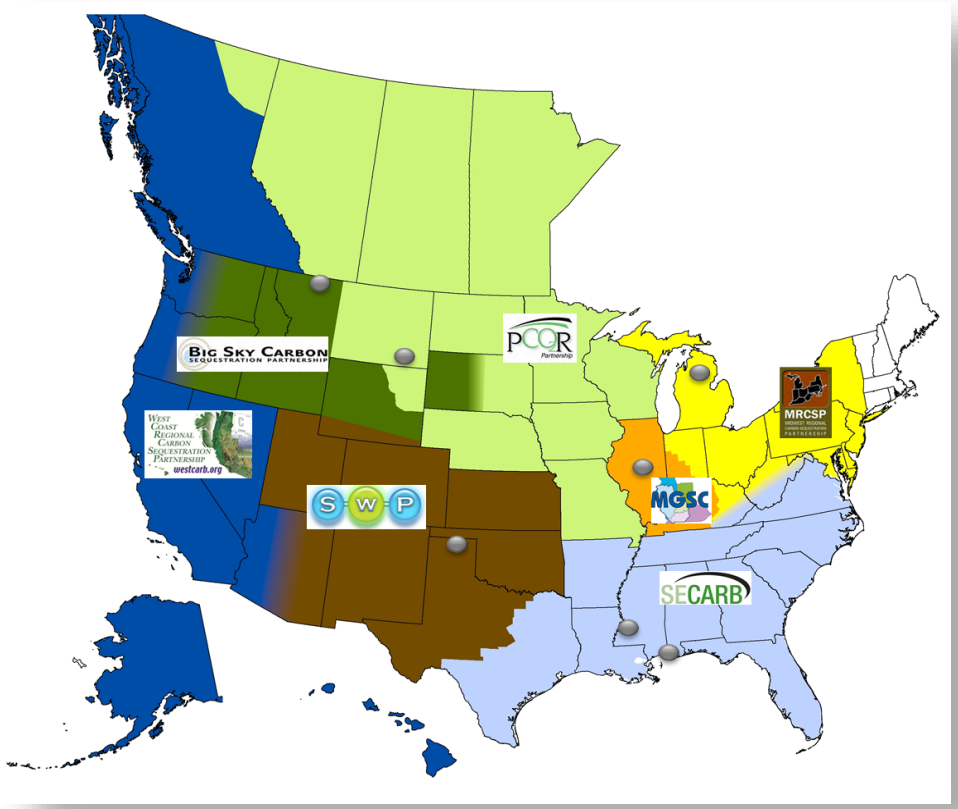
Risk and Integration Tools

- Development and validation of effective quantitative risk assessment tools and integration of knowledge and data

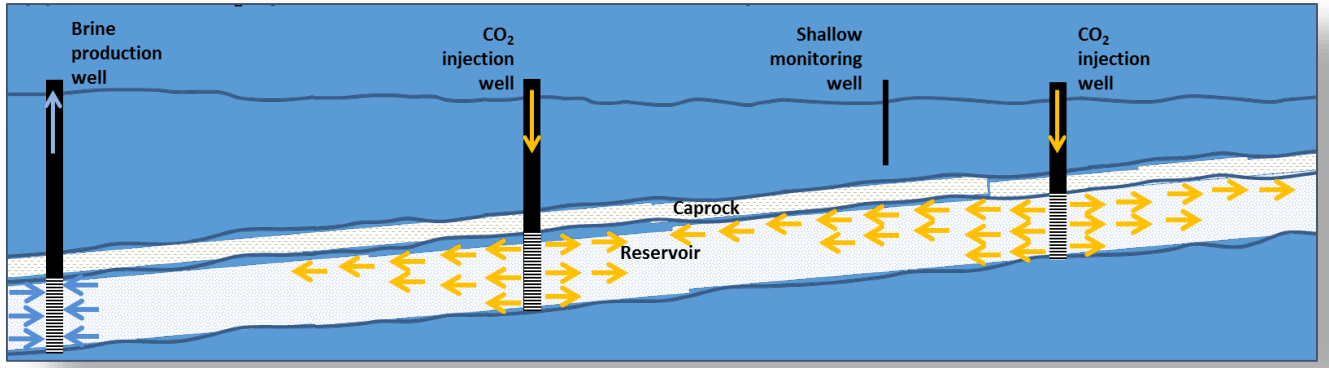
Carbon Storage Program
Addressing Larger-scale Challenges

NATIONAL ENERGY TECHNOLOGY LABORATORY

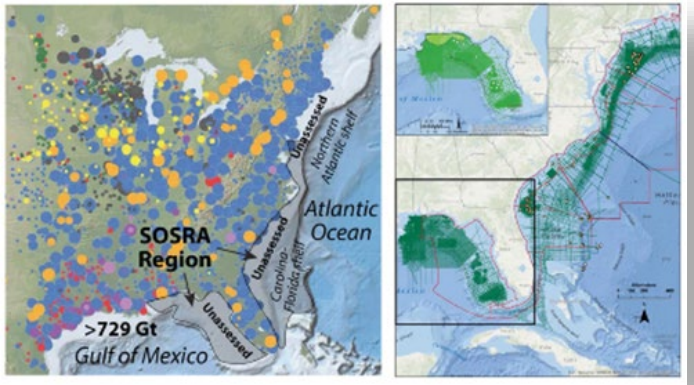
Regional Carbon Sequestration Partnerships (RCSPs)



Brine Extraction Storage Tests (BEST)

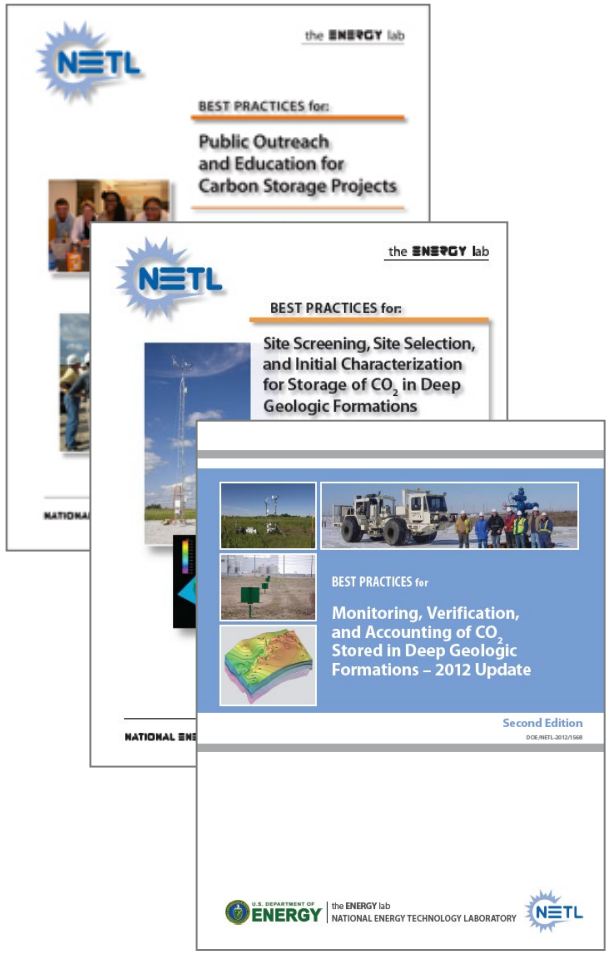


Offshore Storage



Carbon SAFE

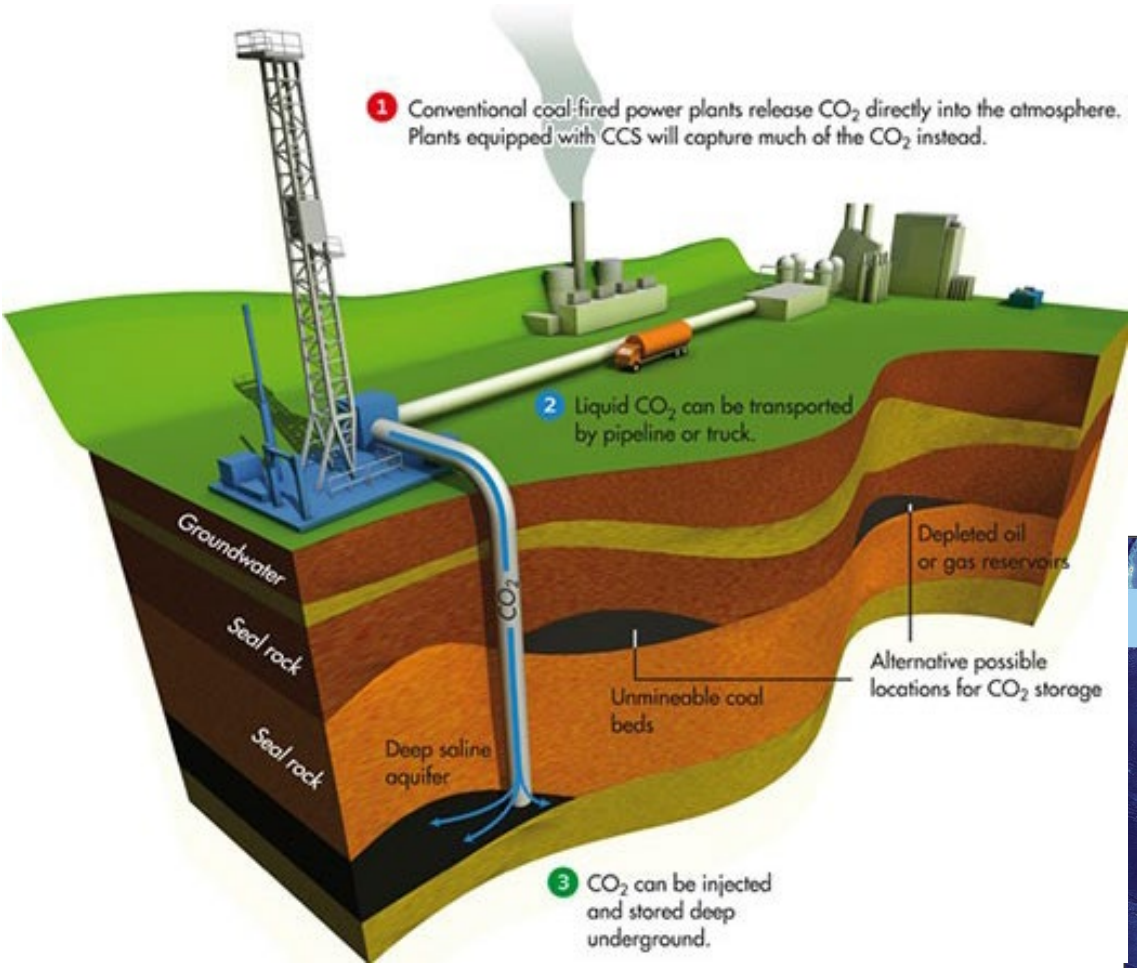
Knowledge Sharing Products
Carbon Storage Best Practices Manuals



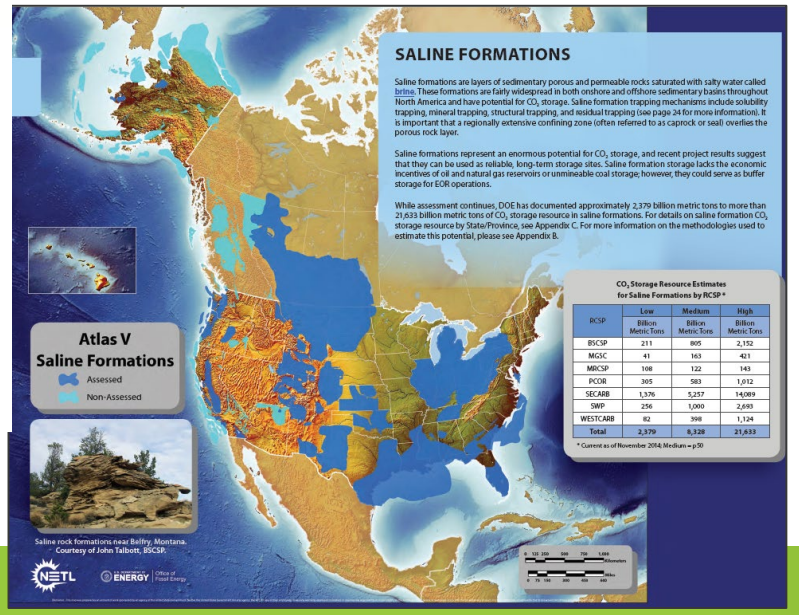
Critical Requirement for Significant Wide Scale Deployment-Capturing Lessons Learned

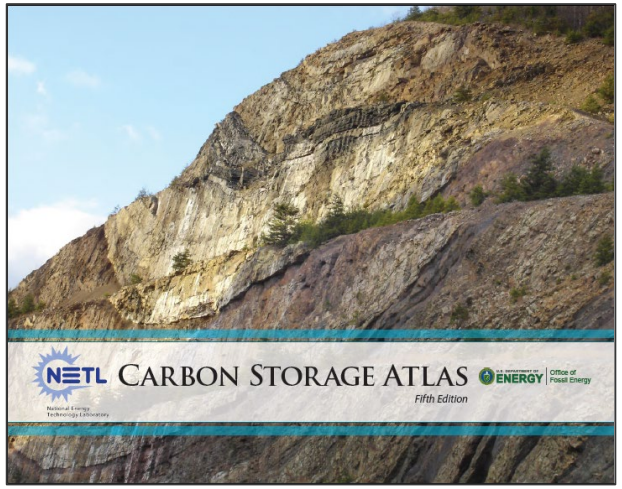
Best Practices Manual	Version 1 (Phase II)	Version 2 (Phase III)	Final Guidelines (Post Injection)
Monitoring, Verification and Accounting of CO_2 Stored in Deep Geologic Formations	2009/2012	2017	2020
Public Outreach and Education for Geological Storage of CO_2 Projects	2009	2017	2020
Site Screening, Site Selection and Site Characterization of CO_2 in Deep Geologic Formations	2010	2017	2020
Risk Management and Simulation for Geologic Storage of CO_2	2010	2017	2020
Operating Carbon Storage Projects*	2011	2017	2020

Resource Assessments – How Much CO_2 Can be Stored in the Subsurface?



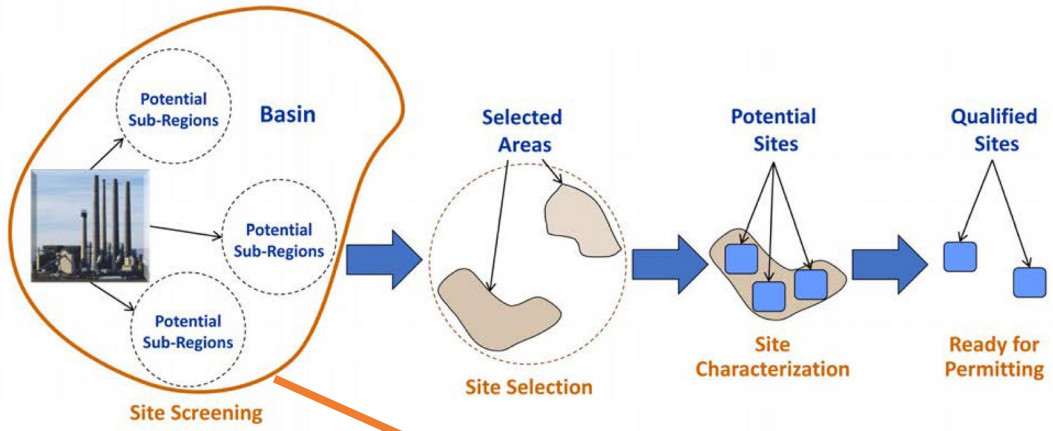
Prospective CO_2 Storage Resource for U.S. and parts of Canada		
Regonal Carbon Storage Partnerships	Billion Metric Tons	
	Low	High
Oil and Natural Gas Reservoirs	**186**	**232**
Unmineable Coal	**54**	**113**
Saline Onshore	**2,379**	**21,633**
Shale Formations		
Saline Offshore		
Residual Oil Zones		





Methods Based on NETL's Best Practice Manuals

"Project Site Maturation" through the Exploration Phase.



Subsurface Data Analysis

i. Injection Formation

- Oil and Natural Gas Reservoirs, Saline Formations, Unmineable Coal Seams, Shale, Basalt and Other Volcanic and Mafic Rocks, Salt Caverns

ii. Adequate Depth

- Sufficient depth to maintain injected CO_2 in the supercritical state

iii. Confining Zone

- Contain injected CO_2

iv. Prospective Storage Resources

- Sufficient pore volumes and can accept the change in pressure to accommodate planned injection volumes

CO_2 Classification Table

Petroleum Industry	CO_2 Geological Storage
Reserves	**Storage Capacity**
On Production	Active Injection
Approved for Development	Approved for Development
Justified for Development	Justified for Development
Contingent Resources	**Contingent Storage Resources**
Development Pending	Development Pending
Development Unclarified or On Hold	Development Unclarified or On Hold
Development Not Viable	Development Not Viable
Prospective Resources	**Prospective Storage Resources**
Prospect	Qualified Site(s)
Lead	Selected Areas
Play	Potential Sub-Regions

Prospective Storage Resources	
Project Sub-Class	**Evaluation Process**
Qualified Site(s)	Site Characterization
Selected Areas	Site Selection
Potential Sub-Regions	Site Screening

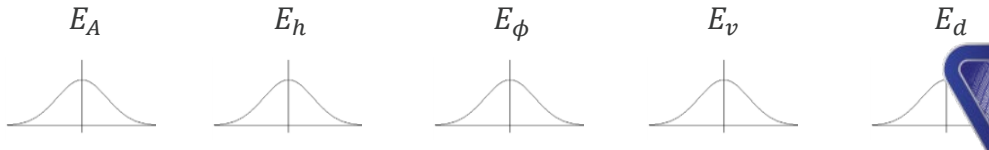
Social Data | Regional Site Data | Regional Geologic Data

https://www.netl.doe.gov/File%20Library/Research/Carbon-Storage/Project-Portfolio/BPM-SiteScreening.pdf

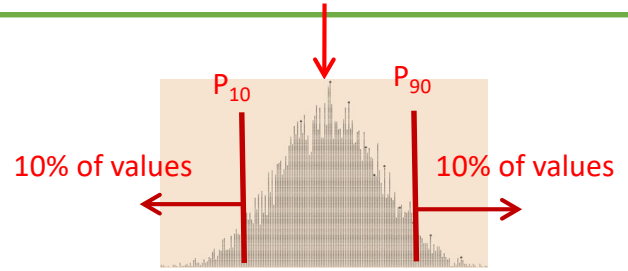
Saline Methodology Equation

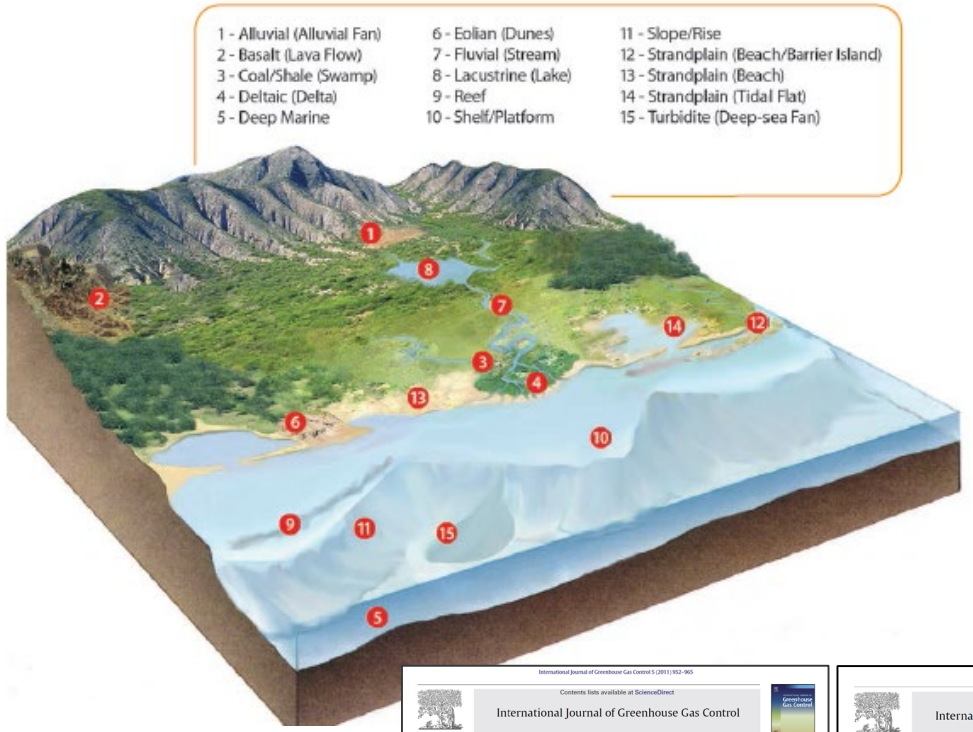
$$G_{CO_2} = A_t h_g \phi_t \rho E_{saline}$$

$$E_{saline} = E_A E_h E_\phi E_V E_d$$



$$\frac{1}{(1+e^{(-E_A)})} * \frac{1}{(1+e^{(-E_h)})} * \frac{1}{(1+e^{(-E_\phi)})} * \frac{1}{(1+e^{(-E_V)})} * \frac{1}{(1+e^{(-E_D)})}$$





CO2-SCREENv2.0 Tool

Saline Formation E… ncy Factors For Geologic and Displacement Terms

$E_{saline} = E_{An/At} E_{hn/hg} E_{\phi e/\square\phi tot} E_v E_d$

Lithology	P_{10}	P_{50}	P_{90}
Clastics	0.51%	2.0%	5.4%
Dolomite	0.64%	2.2%	5.5%
Limestone	0.40%	1.5%	4.1%

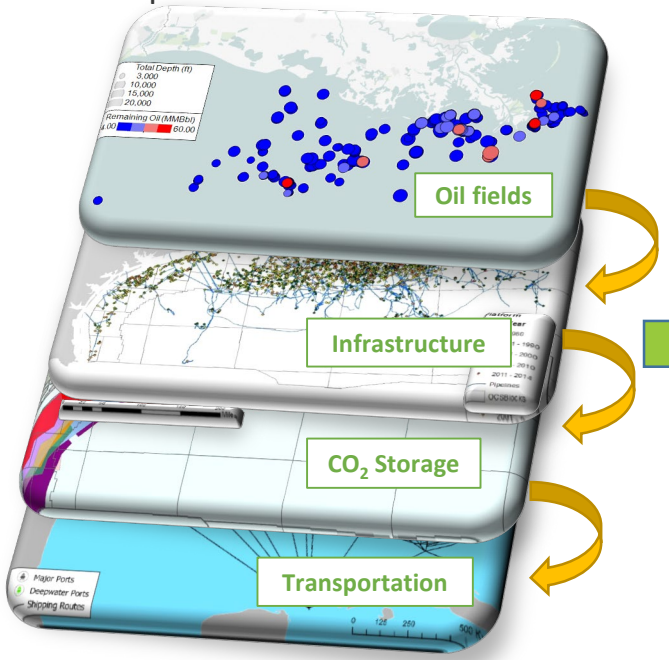
Complete Site Screening	Social Data		Regional Site Data				Regional Geologic Data				COMPONENT
	Social Context Analysis		Regional Proximity Analysis				Subsurface Data Analysis				
Selected	Land Use: Industrial and Environmental History	Demographic Trends	Pipeline ROWs	Existing Resource Development	Population Centers	Protected and Sensitive Areas	Prospective Storage Resources	Confining Zone	Adequate Depth	Injection Formation(s)	ELEMENT

https://edx.netl.doe.gov/dataset/co2-screen-version-2-0

Multi-criteria CCUS Screening Framework of GOM OCS

- Incorporate multiple and disparate CCUS decision making criteria into a systematic, quantitative analysis of OCS in the GOM to identify areas with potentially high suitability for CO_2 storage

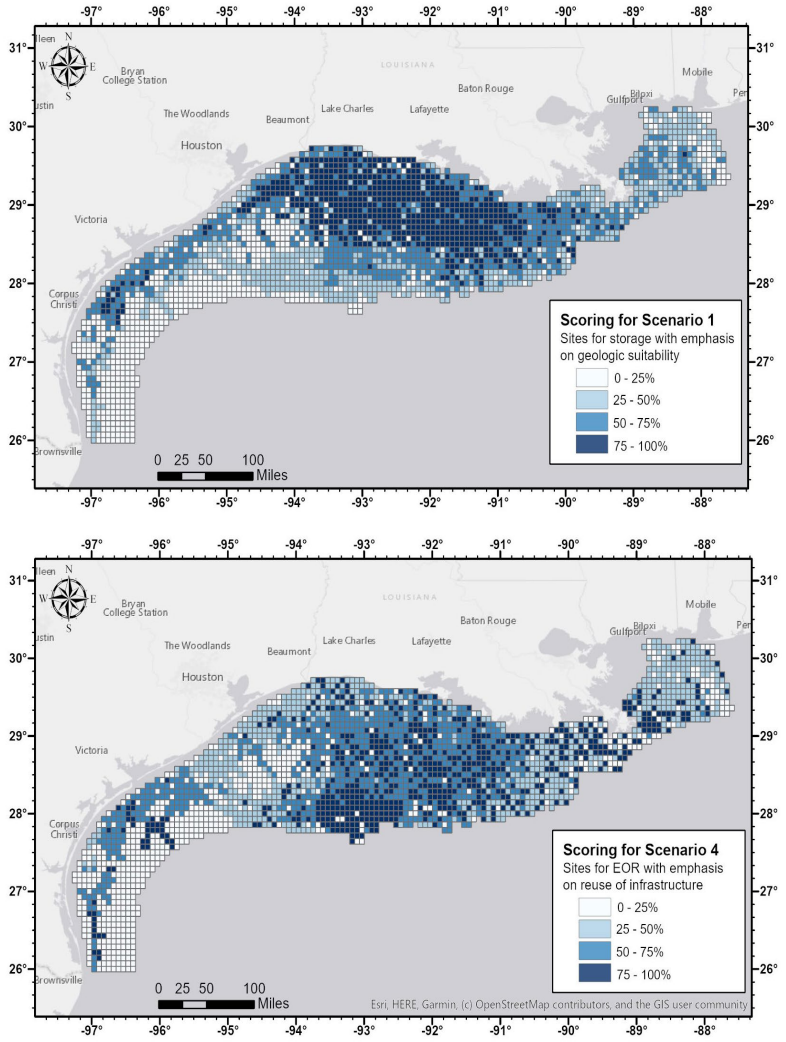
- Sites/regions best suited for offshore CO_2 storage would possess criteria and characteristics deemed appropriate for offshore CCUS applications; from both technical and logistical / feasibility-related standpoints



Incorporate criteria into a quantitative analysis to identify areas with potentially high suitability using NETL-developed (G&G team) Cumulative Spatial Impact Layer (CSIL) tool*

Number	Criteria
i = 1	Reservoir quality without depth ranked by quartile
i = 2	Sum of injectivity proxy
i = 3	Sum of oil in reserve (barrels)
i = 4	Number of active caissons
i = 5	Number of active well protectors
i = 6	Number of major active multi-purpose platforms
i = 7	Distance to closest onshore CO_2 source > 100,000 tonnes/year
i = 8	Pipeline right-of-way proxy
i = 9	Within major shipping route buffer area
i = 10	Water depth – saline reservoirs
i = 11	Water depth – oil reservoirs
i = 12	Above salt domes
i = 13	Plugged and abandoned wells
i = 14	Faults

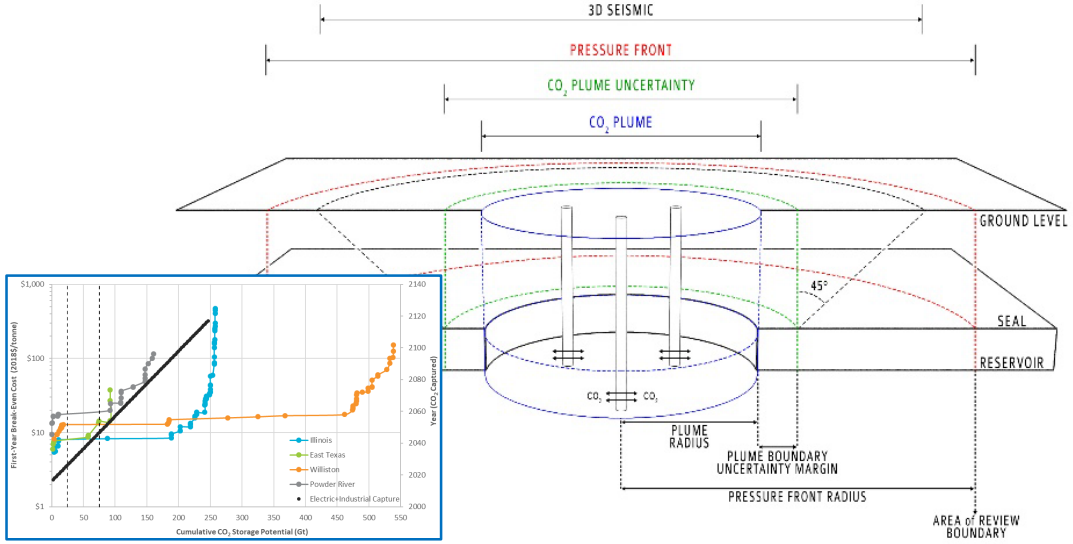
Qualitative input from experts to weigh the importance of each for 4 separate scenarios



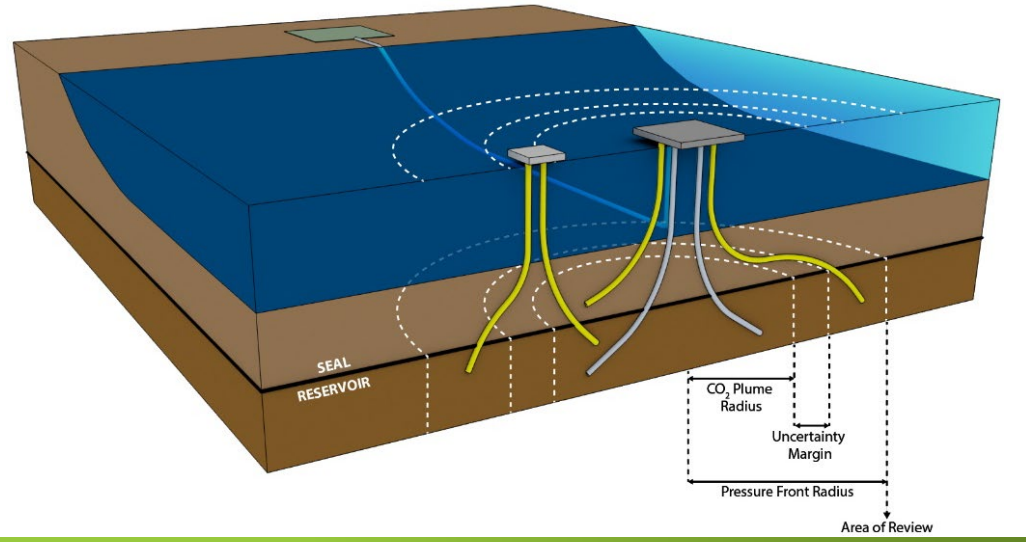
*Romeo, Lucy, Nelson, Jake, Wingo, Patrick, Bauer, Jennifer, Justman, Devin, and Rose, Kelly (In Press). *Cumulative Spatial Impact Layers: A Novel Multivariate Spatio-Temporal Analytical Summarization Tool*. Transactions in GIS.

CCUS Cost Models

- **FE/NETL CO_2 Storage Cost Model (Publicly Available)**
  - Designed to meet Class VI regulations, estimate cost of compliance
  - Can model storage costs for single reservoir or multiple reservoirs
  - Assumes successful operations
  - Contains geologic database representative of geologic section in numerous basins
  - Latest updates: new geologic database, changes to water module, new financial parameters, methodology updated to obtain costs in real dollars, and platform change to Python



- **FE/NETL Offshore CO_2 Saline Storage Cost Model (In Development)**
  - Extension of onshore CO_2 Storage Cost Model
  - Bureau of Ocean Energy Management (BOEM)/Bureau of Safety and Environmental Enforcement (BSEE) (Department of the Interior [DOI]); no Class VI in federal waters
  - Needed actions: discussion with offshore working group, relevant cost data and operational steps, and firm conceptual basis



National Risk Assessment Partnership

NRAP leverages DOE's capabilities to quantify storage risks amidst system uncertainties, to help remove barriers to full-scale CO_2 storage deployment.

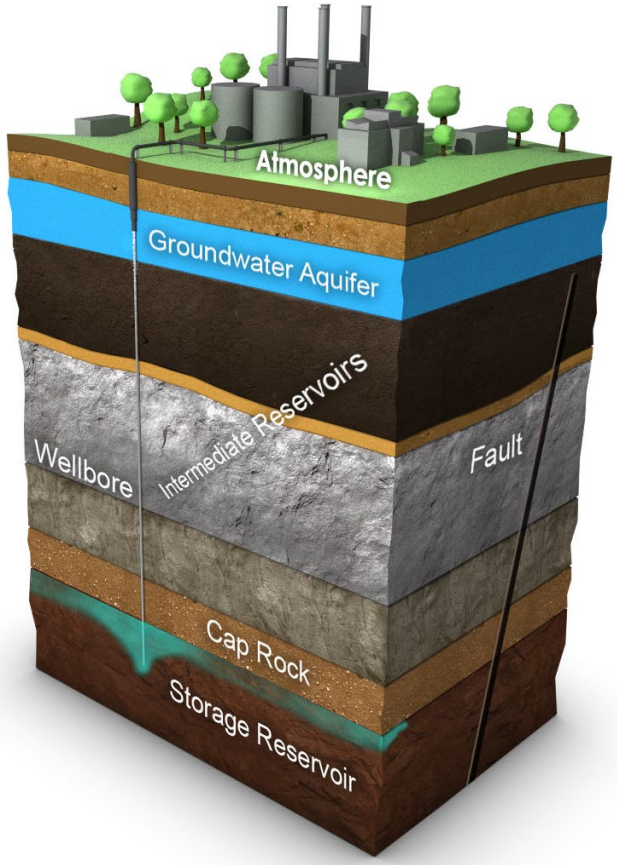
Technical Team

NATIONAL ENERGY TECHNOLOGY LABORATORY

BERKELEY LAB
Lawrence Berkeley National Laboratory

Los Alamos
NATIONAL LABORATORY
EST. 1943

Pacific Northwest
NATIONAL LABORATORY



Stakeholder Group

PRINCETON UNIVERSITY

THE UNIVERSITY OF UTAH

ILLINOIS

bp

BATTELLE

USGS
science for a changing world

GLOBAL CCS INSTITUTE

Southern Company

ieaghg

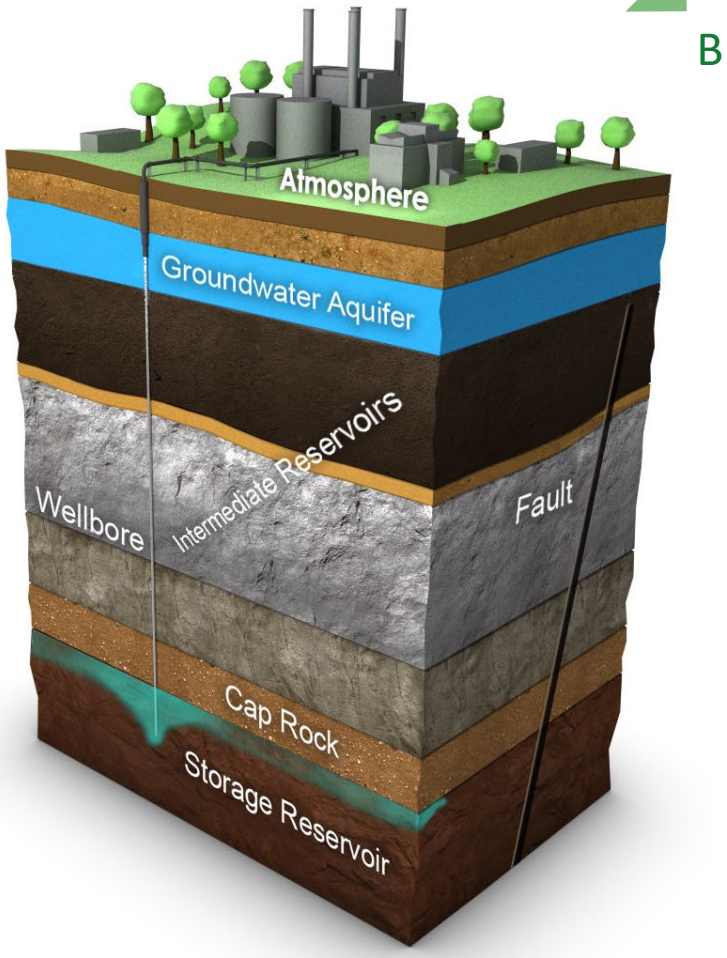
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NRDC

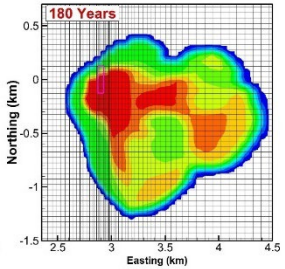
UNITED STATES Carbon Sequestration Council

NRAP's approach for rapid prediction of whole-system risk performance

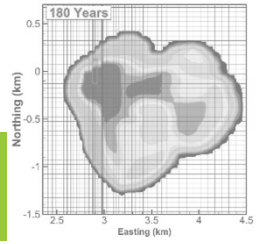
A. Divide system into discrete components



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



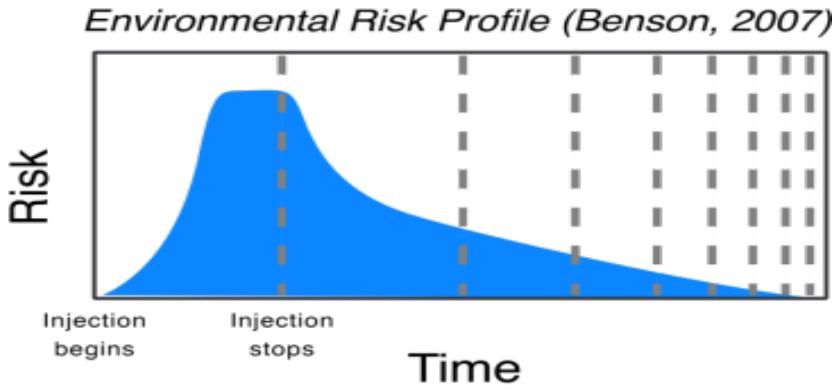
C. Develop reduced-order models (ROMs) that rapidly reproduce component model predictions

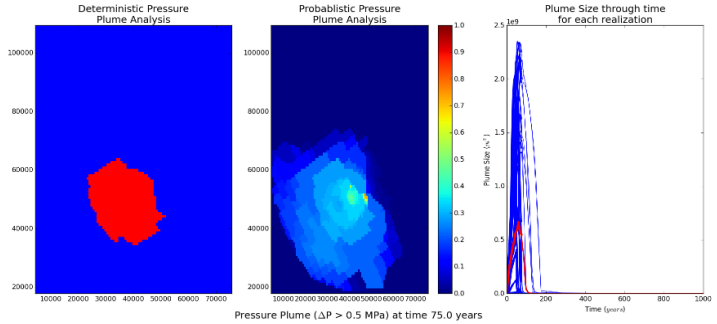


D. Link ROMs via integrated assessment models (IAMs) to predict system performance

E. Exercise whole system model to explore risk performance

Integrated Risk Assessment





NRAP helps to address key stakeholder questions about long-term GCS risks.

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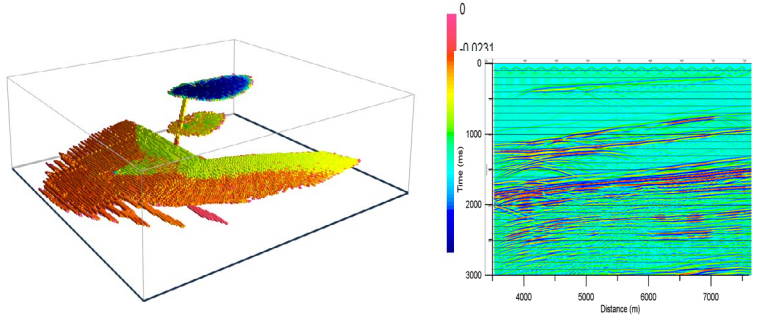
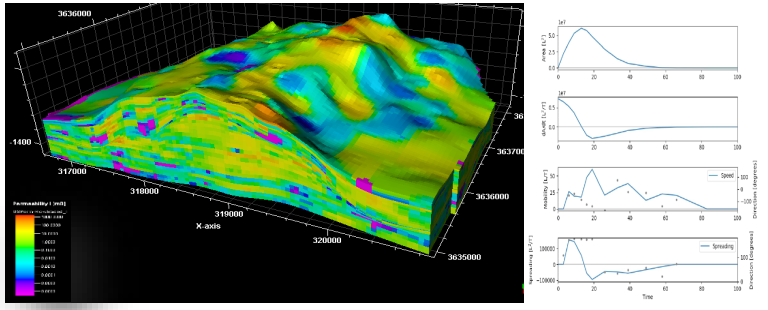
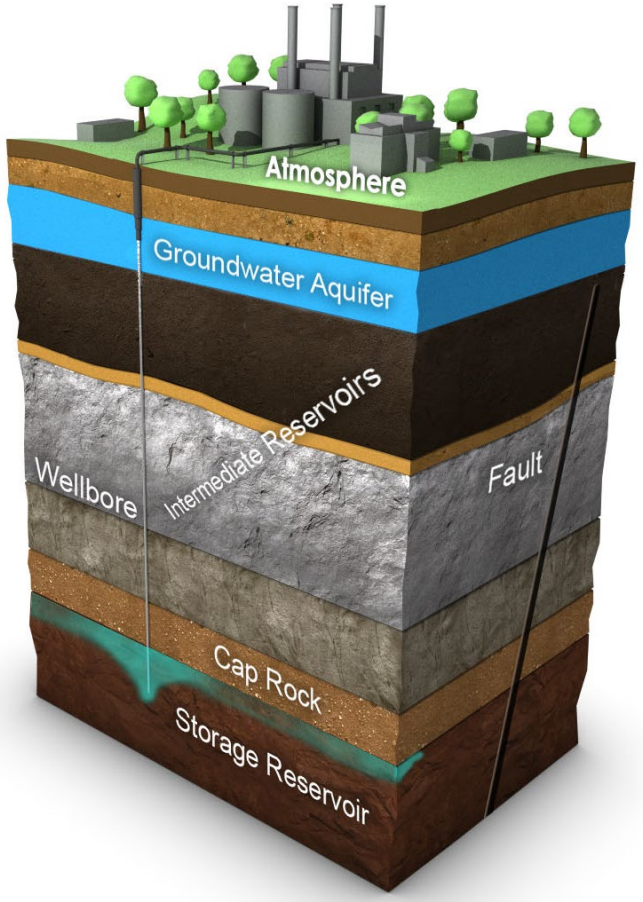
Characterize, detect, and manage potential leakage



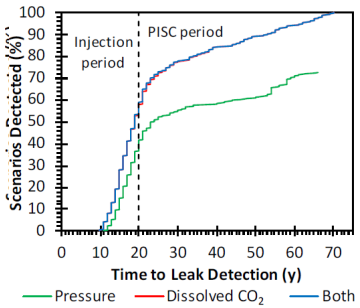
Rapidly predict storage reservoir behavior and long-term stability

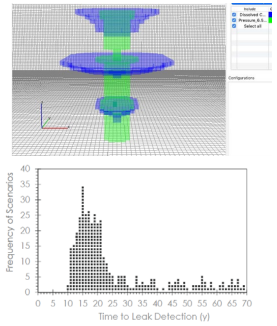


Build stakeholder confidence that GCS risks are small and manageable

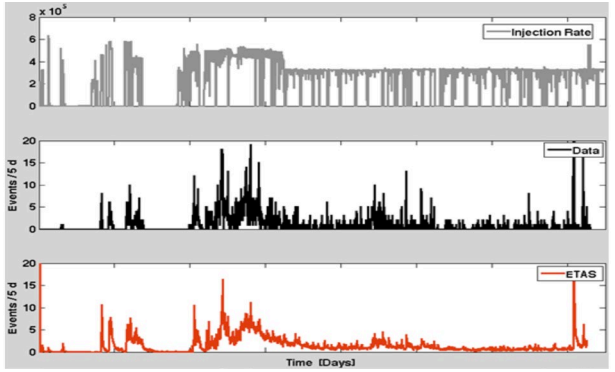


Design efficient & effective monitoring networks



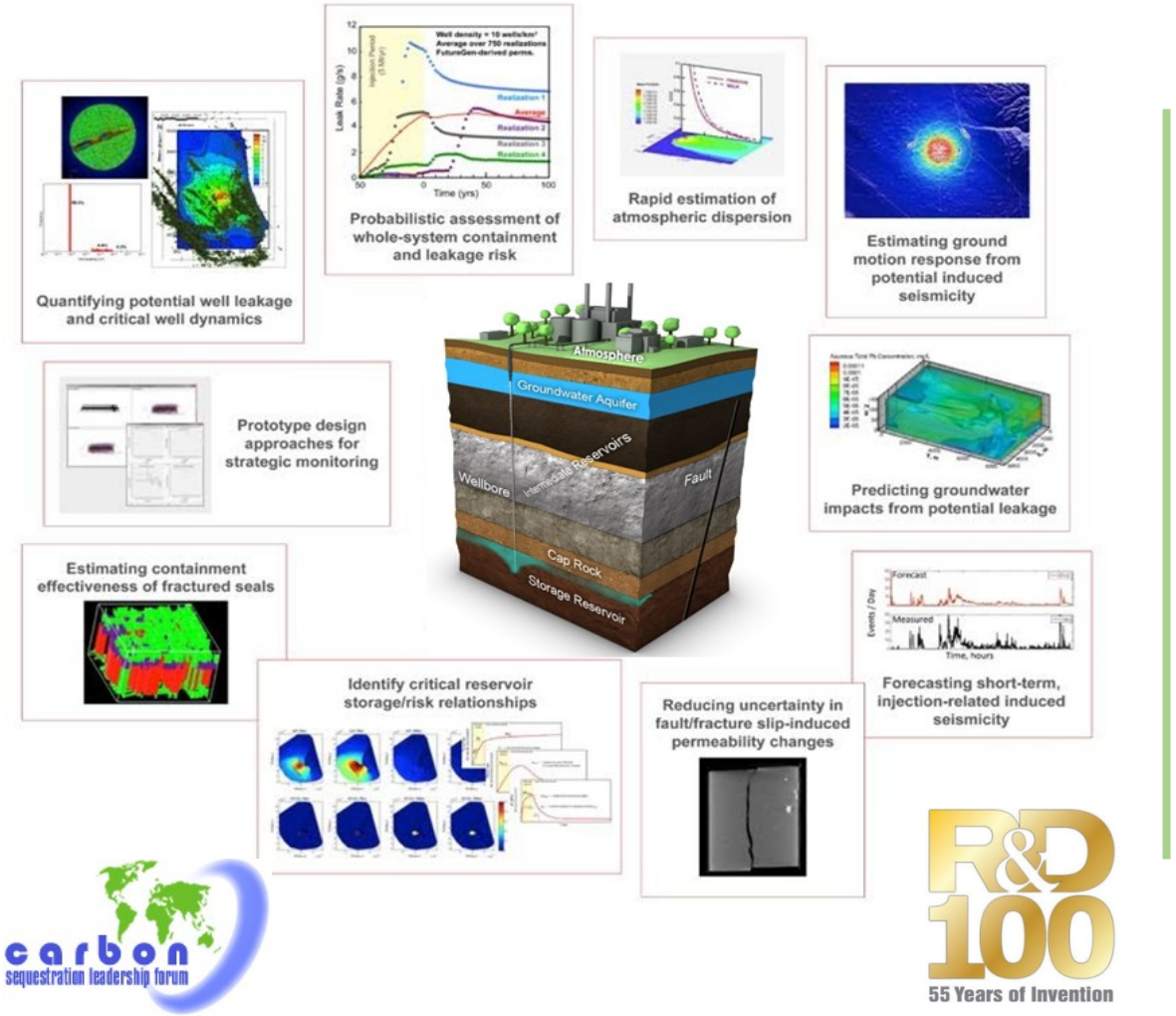


Forecast and manage potential induced seismicity



NRAP Risk Assessment Tools

Phase I Toolset (November 2016)



Phase II Tools

Leakage Risk/Containment Assurance

- NRAP Open-Source Integrated Assessment Model (NRAP-Open-IAM)

Induced Seismicity Risk

- Short-term Seismic Forecasting Tool (STSF)
- State of Stress Analysis Tool (SoSAT)
- Probabilistic Seismic Risk Assessment Tool (RiskCat)

Monitoring Design and Optimization

- Designs for Risk Evaluation and Management (DREAM 2.0)
- Microseismic monitoring design optimization tool (forthcoming)

NRAP Tools Available at:
www.edx.netl.doe.gov/nrap