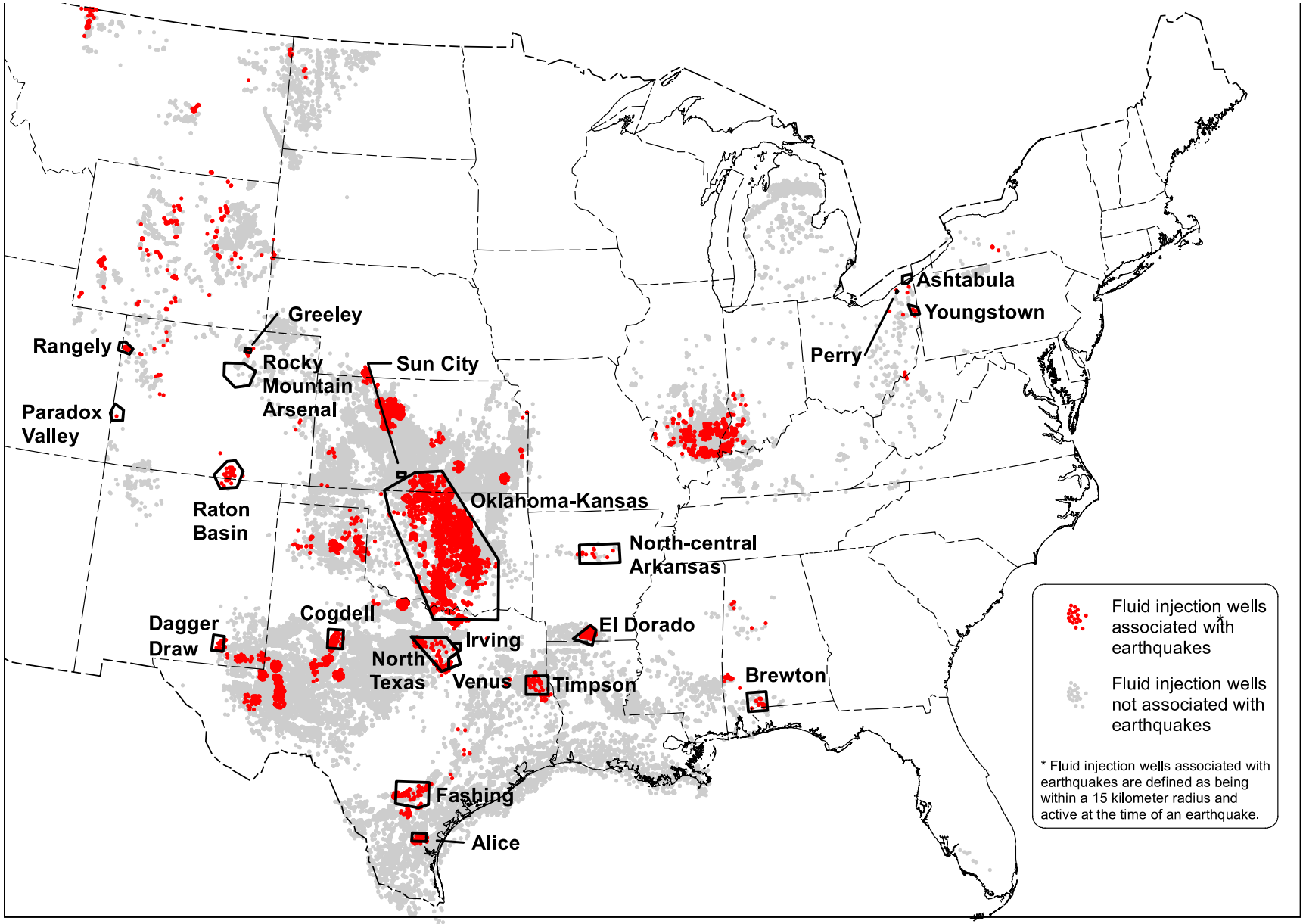
National Risk Assessment Partnership:

Induced Seismicity Working Group

Joshua White

Lawrence Livermore National Laboratory

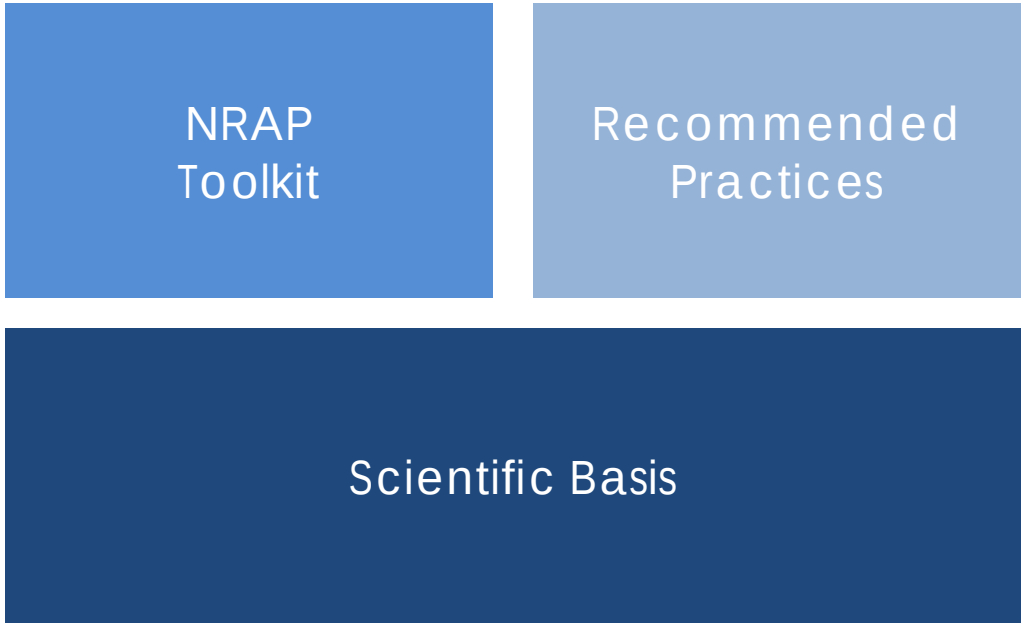


USGS map displaying 21 areas impacted by induced earthqu akes as well as the location of fluid injection wells that have and have not been associated with earthquakes.

[USGS 2016]

Working Group Goals

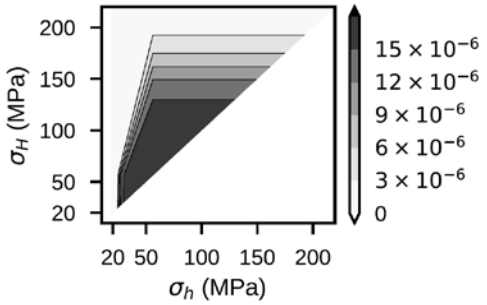
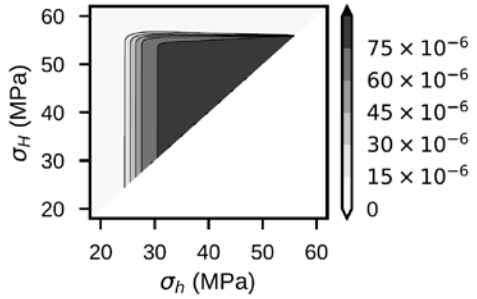
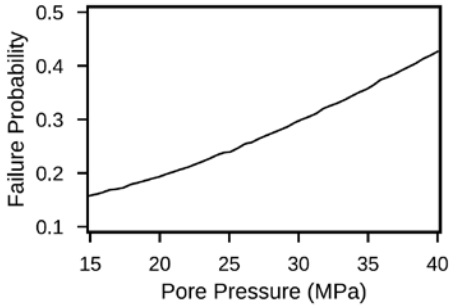
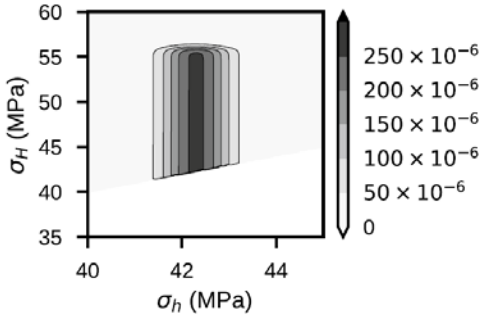
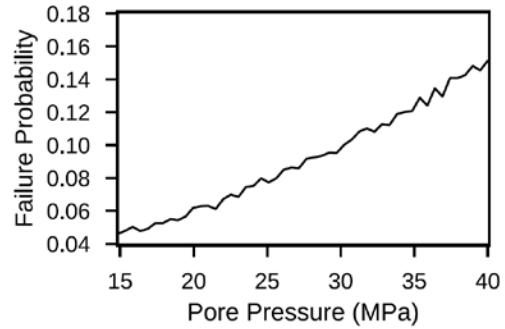
- Identify sites and operations that lead to low-risk—i.e. minimal hazard, minimal damage.
- Develop techniques to quickly identify and manage seismicity problems if they should appear.
- Share recommended practices with the CCS community



NRAP Tools, Products, and Capabilities - 2019

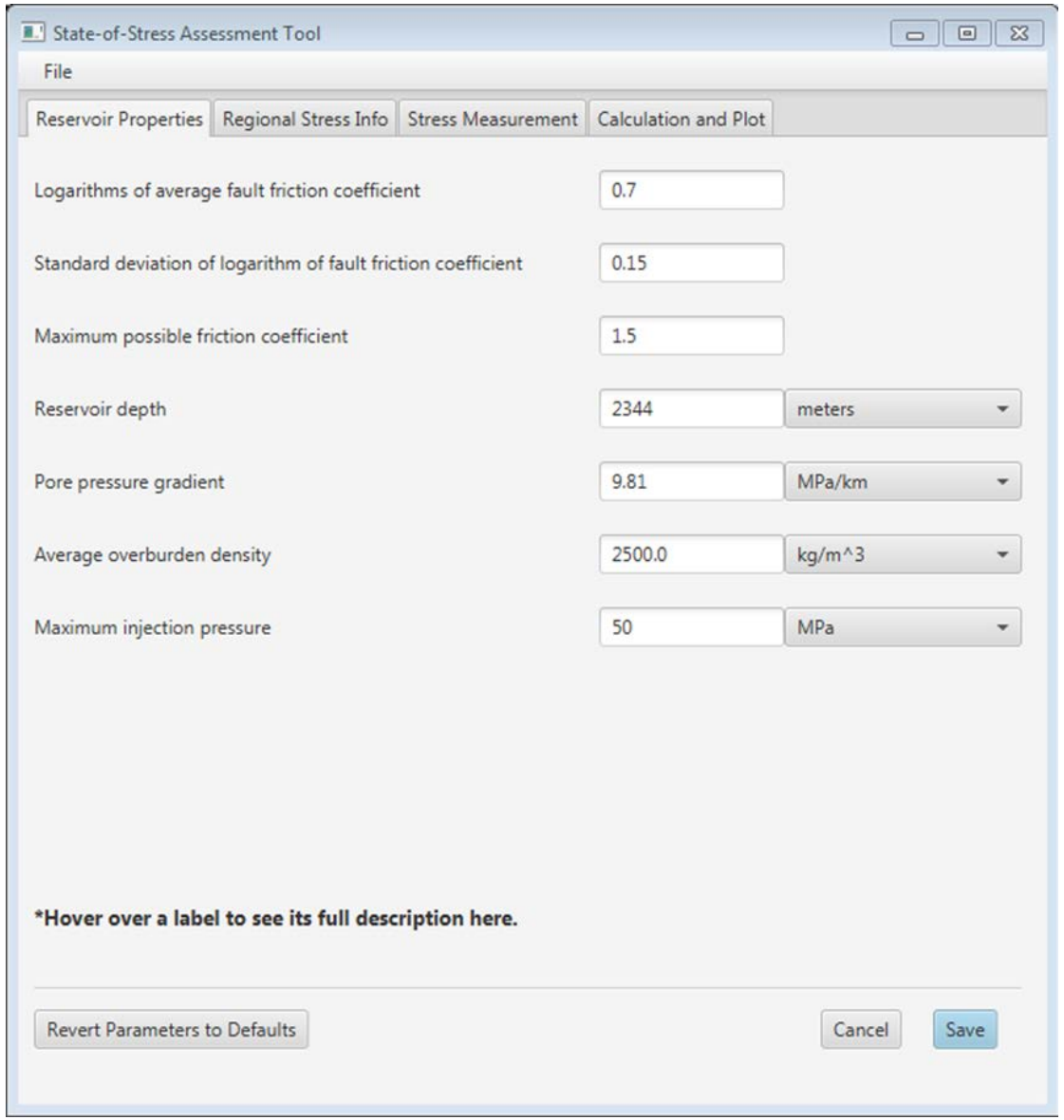
Tools	**Short-term seismic forecasting tool**	Available on EDX
	Ground motion prediction tool	Available on EDX
	** **State-of-stress assessment tool**	New / available on EDX
	** **Probabilistic seismic risk assessment (PSRA) tool**	New / in beta-testing
Reports	**CO_2 seismic risk assessment review**	IJGGC Special Issue
	Numerous technical papers	NRAP Publication List
	** **Seismicity recommended practices**	In progress
Capabilities	**Induced seismicity simulator (RSQSim)**	Mature
	Coupled hydromechanical reservoir simulators	Mature
People	**Broad discipline expertise**	Seismicity Working Group

State-of-Stress Assessment Tool (SOSAT)

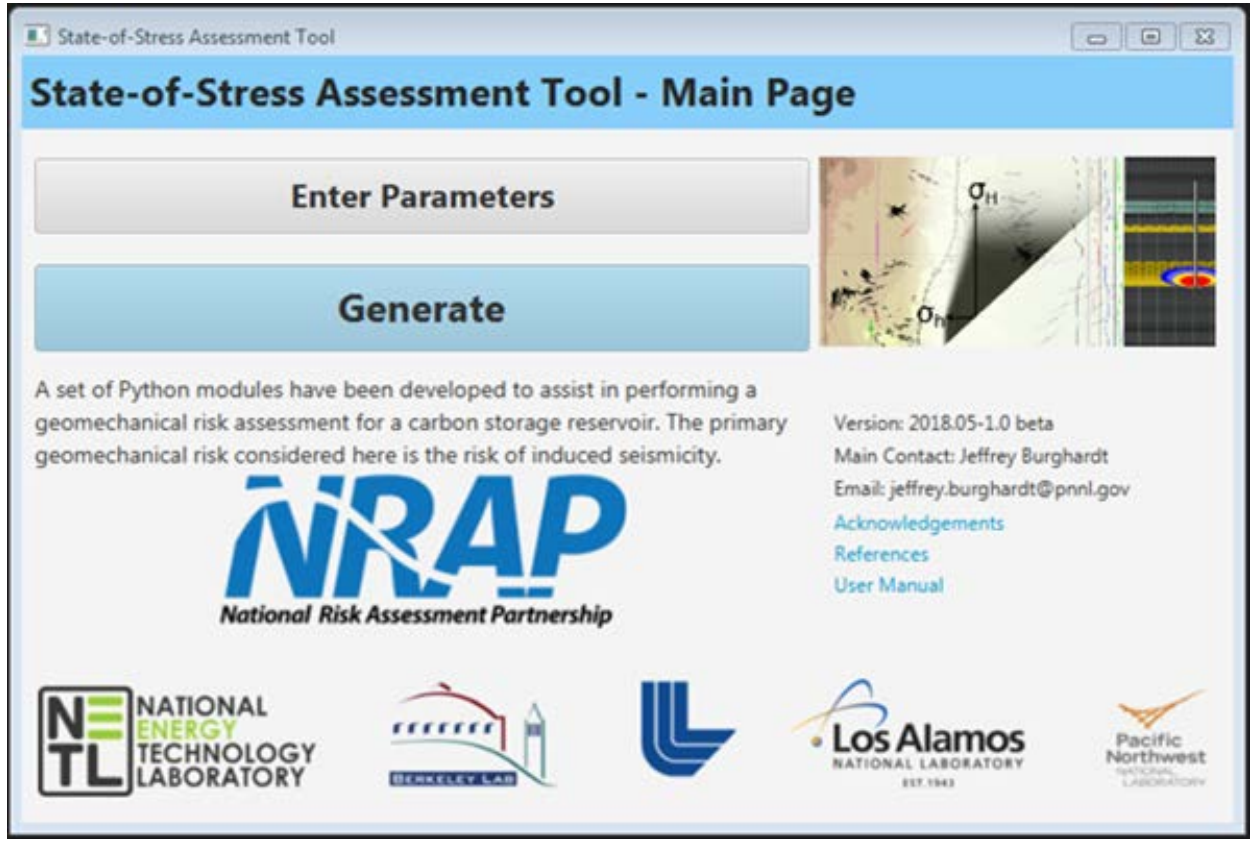
Input data available	Joint probability for σ_H and σ_h	Probability of activating critically-oriented fault
• Pore pressure • Overburden density		
• Regional stress indicators • Geodetic data		
• Local measurement of σ_h		

Reference: Jeff Burghardt (2018) SOSAT User's Manual.

State-of-Stress Assessment Tool (SOSAT)



- Available on EDX
- https://edx.netl.doe.gov/organization/nrap-tools



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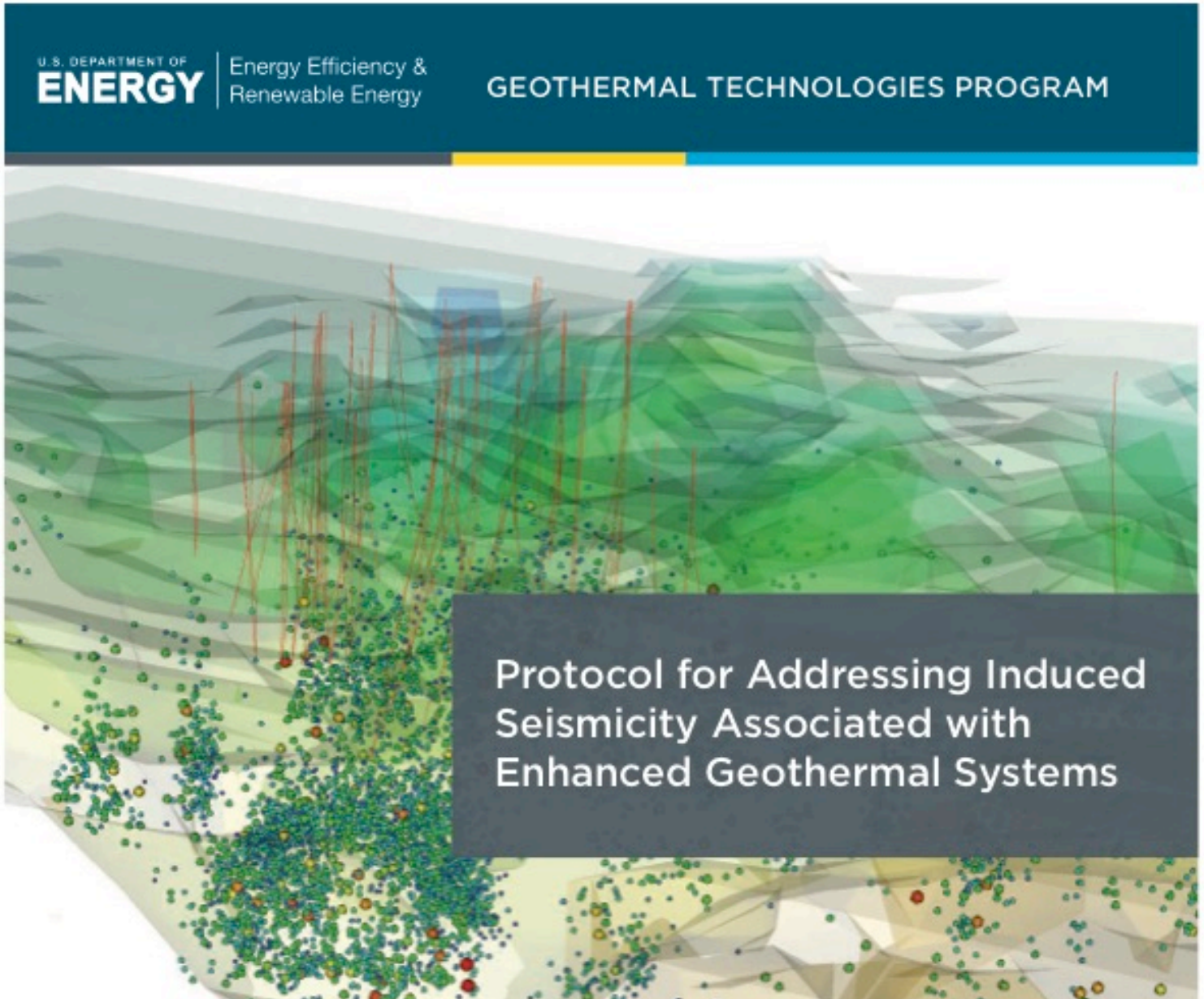
Carbon Storage Recommended Practices



- **Starting Point:** GTO Geothermal Seismicity Protocol (2012).
- **Goal:** Develop recommended practices guidelines relevant for carbon storage

Reference: E. Majer et al (2012).

Carbon Storage Recommended Practices

Seismicity Protocol: Primary Steps

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.

Four key drivers for update:

1) Update with lessons learned since 2012
2) Strengthen risk analysis components using NRAP insights
3) Ensure relevance for carbon storage operations
4) Add specificity

Carbon Storage Recommended Practices

Step 1: Preliminary Seismic Risk Screening Evaluation

Purpose

The purpose of this step is to broadly assess the probability of success of candidate site locations before investing substantial resources into the planning and construction of a project. The preliminary seismic risk screening evaluation is based on simple bounding methods and acceptability criteria with the goal of determining go/no-go decision points for future planning.

Recommendations

1.1) Preliminary Classification of Site-Specific Seismic Risk

1.1.1) A preliminary site-specific seismic risk assessment shall be completed which qualitatively classifies seismic risk into one of four general categories. This assessment shall include, but is not limited to:

1.1.1.1) A review of local, state, and federal laws and regulations;
1.1.1.2) An initial estimation of the *Radius of Influence* of potential seismic events;
1.1.1.3) A listing of the potential impacts to within the *Radius of Influence*;
1.1.1.4) Lower and upper bound estimates of the potential impacts;
1.1.1.5) An assessment of local stakeholder risk tolerance; and
1.1.1.6) A final assessment of the overall site risk, based on factors (1.1.1.1) – (1.1.1.5).

I. Very Low:	II. Low:	III. Medium:	IV. High:
Proceed with planning.	Can proceed with planning, but may require additional analysis to confirm.	Probably should not proceed at this site, but additional analysis might support proceeding.	Do not proceed.

Explanation and Commentary

[4 – 5 pages of technical content, including References]

Lessons Learned

- **We need to do a better job integrating our risk assessment methods into existing industry practice**
  - Essential for engagement and tech transfer
  - Recommended Practices should help here

- **We have a diverse set of stakeholders, with different but equally important needs**
  - Operators:
    - Writing permits
    - Day-to-day site management
  - Regulatory authority
    - Evaluating permits
    - Regional-scale management
  - Public
    - Context for evaluating risks and benefits

Synergy Opportunities

- **Always looking for partners with microseismic data**
  - CO_2 is most relevant, but other injection operations can be good analogs

- **Always valuable to hear about specific needs from stakeholders**
  - Allows us to maximize technical impact

- **NRAP is focused on a narrow component (risk assessment) of a very large problem (seismicity)**
  - Eager to engage with broader community, particular other DOE-funded initiatives

Thanks

Program Goal No. 4

- Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation.

Benefit Statement

- An understanding of induced seismicity is essential for effective risk management of storage sites.
- This project seeks to develop:
  - An open toolkit to support seismic characterization and management.
  - Support best-practices to minimize risk while supporting the growth of the CO_2 storage industry

Significant Accomplishments in FY19

1	Active pressure management study
2	State-of-stress assessment tool (SOSAT) Probabilistic seismic risk assessment tool (RiskCat)
3	Recommended practices document
4	Numerous journal publications / conference presentations

Phase II Workscope

- **Task 3.1 – Real-time Hazard Forecasting**
  - **Focus:** Improve Short-Term Seismic Forecasting (STSF) tool by testing new forecasting methods and improving tool usability.
- **Task 3.2 – Active Seismicity Management**
  - **Focus:** Study effectiveness of different techniques (e.g. pressure control) for managing seismicity at problematic sites.
- **Task 3.3 – Probabilistic Seismic Risk Assessment**
  - **Focus:** Transition NRAP workflow to a practical industrial workflow by partnering with stakeholders in the seismic risk consulting world.
- **Task 3.4 – Fault Leakage** **(Deferred to FY20+ due to resource limitations)**
  - **Focus:** Targeted monitoring and active mitigation of fault leakage (through, e.g., hydraulic barriers).
- **Task 3.5 – Seismicity Management Protocal** **(Re-prioritized for FY18-FY19)**
  - **Focus:** Best-practices protocol for CO_2 seismicity management, supported by a suite of tools to help stakeholders implement a practical workflow.