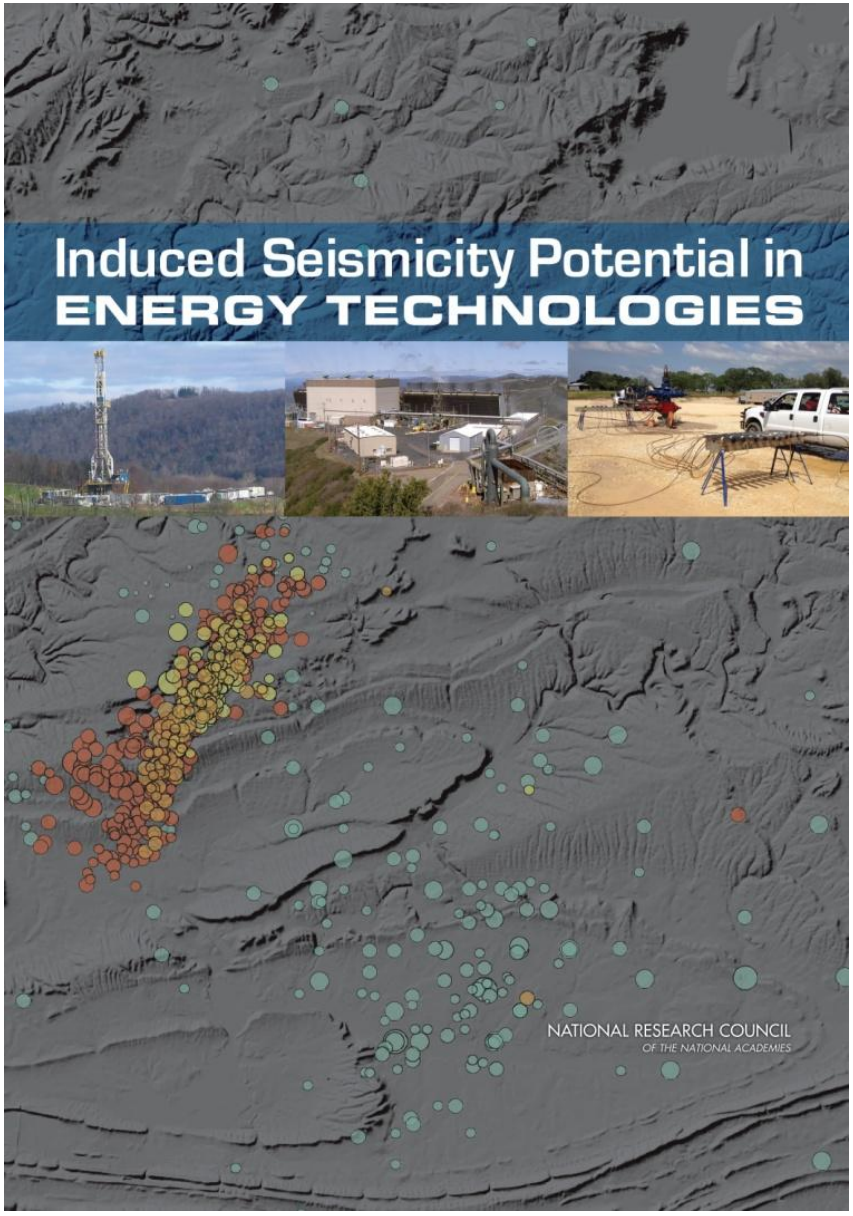


Induced Seismicity Potential in Energy Technologies

Conducted by the National Research Council's Committee on Induced Seismicity Potential in Energy Technologies

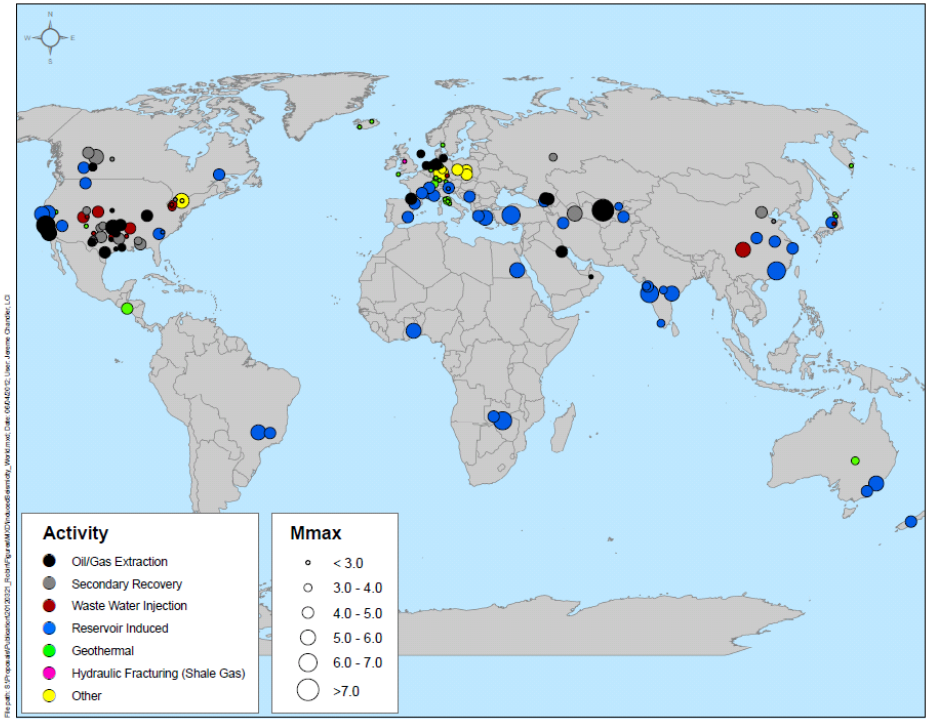
Sponsor
Department of Energy

Overseen by the Board on Earth Sciences and Resources and its standing Committees on Earth Resources; Geological and Geotechnical Engineering; & Seismology and Geodynamics

Released June 2012
Published 2013

Presentation for SDR
by M. Hitzman (committee chair)
December 5, 2013

Background



Source: NRC, 2013

- A number of seismic events apparently related to fluid injection for energy development have occurred in the recent past:

  - Basel, Switzerland, 2006, Enhanced geothermal system (M 3.4)

  - Dallas-Ft. Worth airport area, 2008-09, Waste water disposal from shale gas development (M 3.3)

  - Blackpool, England, 2011, Hydraulic fracturing (shale gas) (M 2.3)

- Public concern about these kinds of events prompted Senator Bingaman to ask Secretary Chu in 2010 to request a study by the National Research Council on "Induced Seismicity in Energy Technologies."

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Report Overview

- Introduction to induced seismicity and its history
- Types and causes of induced seismicity
- Induced seismicity of energy technologies
  - Geothermal
  - Oil and gas (including EOR and shale gas recovery)
  - Waste water injection
  - Carbon capture and storage (CCS)
- Government roles and responsibilities
- Understanding hazard and risk assessment to manage induced seismicity
- Steps toward best practices
- Findings, gaps, proposed actions, and research recommendations

Types and Causes of Induced Seismicity in Fluid Injection/Withdrawal for Energy Development

- The general mechanisms that create induced seismic events are well understood.

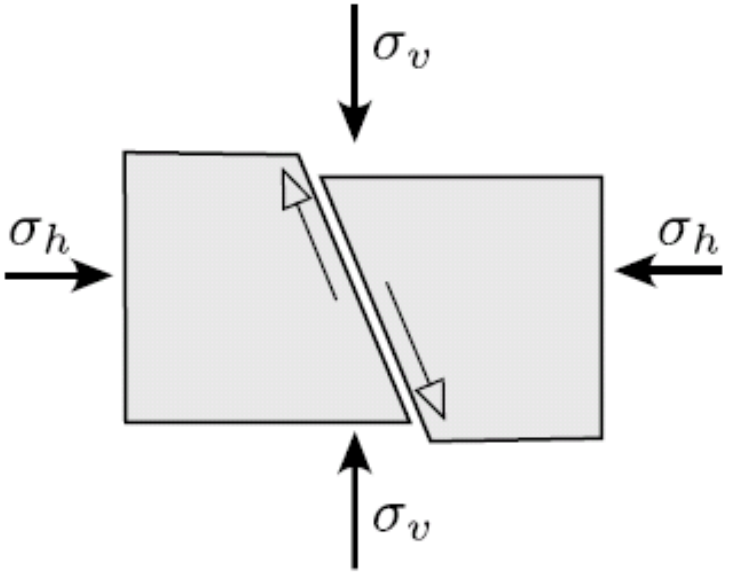
- However, we are currently unable to accurately predict the occurrence or magnitude of such events due to the lack of comprehensive data on complex natural rock systems and the lack of validated predictive models.

Types and Causes of Induced Seismicity in Fluid Injection/Withdrawal for Energy Development

- Induced seismicity is caused in most cases by change in pore fluid pressure and/or change in stress in the subsurface in the presence of:
  - faults with specific properties and orientations;
  - a critical state of stress in the crust.

- The factor that appears to have the most direct correlation in regard to induced seismicity is the net fluid balance — *the total balance of fluid introduced into or removed from the subsurface*.

- Energy technology projects that maintain balance between fluid being injected and withdrawn (e.g., geothermal and most oil and gas development) may produce fewer induced seismic events than technologies that do not maintain fluid balance.



Normal fault

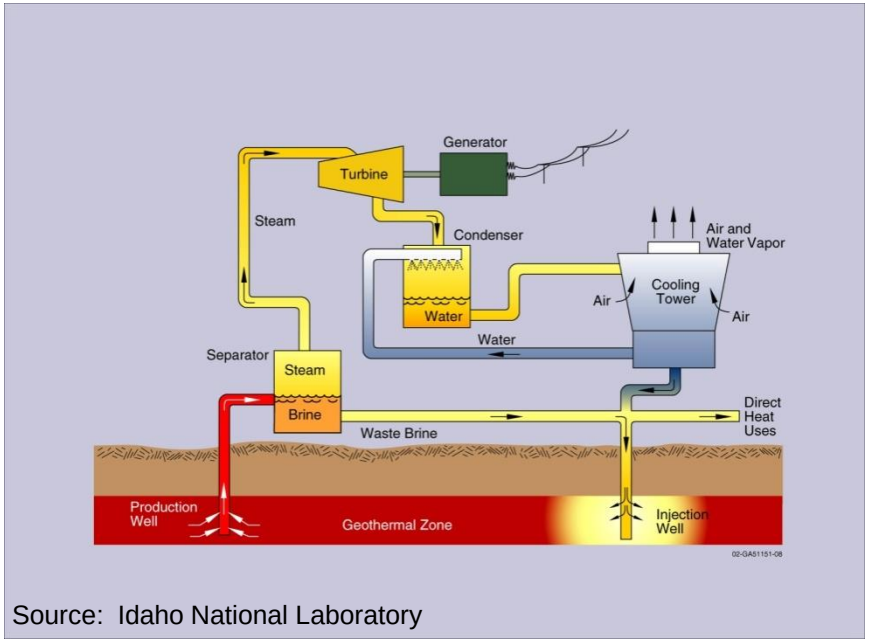
$\sigma_v > \sigma_H > \sigma_h$

Source: NRC, 2012

Historical Felt Seismic Events Caused by or Likely Related to Energy Technologies in U.S. *(as of Jan. 2012)*

Energy Technology	Number of **Current** Projects	Number of **Historical** Felt Events	**Historical** Number of Events M≥4.0	Locations of Events M≥2.0
Geothermal				
Vapor-dominated (The Geysers)	1	300-400 per year since 2005	1 to 3	CA
Liquid-dominated	23	10-40 per year	Possibly one	CA
EGS	~8 pilot	2-5 per year	0	CA
Oil and gas				
Withdrawal	~6,000 fields	20 sites	5	CA, IL, NB, OK, TX
Secondary recovery (water flooding)	~108,000 wells today	18 sites	3	AL, CA, CO, MS, OK, TX
EOR	~13,000 wells today	None known	None known	None known
Hydraulic fracturing for shale gas recovery	~35,000 wells today	1	0	OK
Waste water disposal wells (Class II)	~30,000 wells today	9	7	AR, CO, OH,TX
Carbon capture and storage (small scale)	2	None known	None known	None known

Energy Technologies—Geothermal Energy



Source: Idaho National Laboratory

Flash Steam Power Cycle for liquid-dominated systems

- Operators attempt to keep balance between fluid volumes produced and fluids replaced by injection to maintain reservoir pressure.

- Different forms of geothermal resource development have differing potential for producing felt seismic events:

  - High-pressure hydraulic fracturing in some geothermal projects (EGS) has caused seismic events that are large enough to be felt (e.g., Basel)

  - Temperature changes associated with geothermal development of hydrothermal resources has also induced felt seismicity (The Geysers)

Energy Technologies — Oil and Gas (conventional)

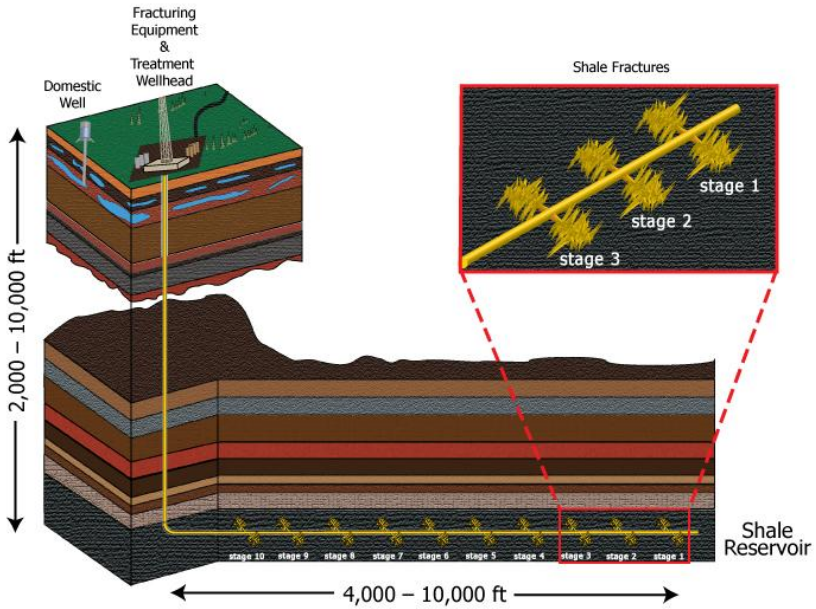
- Oil and gas operators attempt to balance the fluid volumes produced with fluid injection to maintain reservoir pressure.

- Withdrawal associated with conventional oil and gas recovery has not generally caused significant seismic events; however, several major earthquakes have been associated with this technology.

- Relative to the large number of waterflood projects for secondary recovery, the small number of documented instances of felt seismicity suggests small risk for events that would be of concern to the public.

- The potential for induced seismicity is low with regard to EOR.

Energy Technologies — Oil and Gas (unconventional)



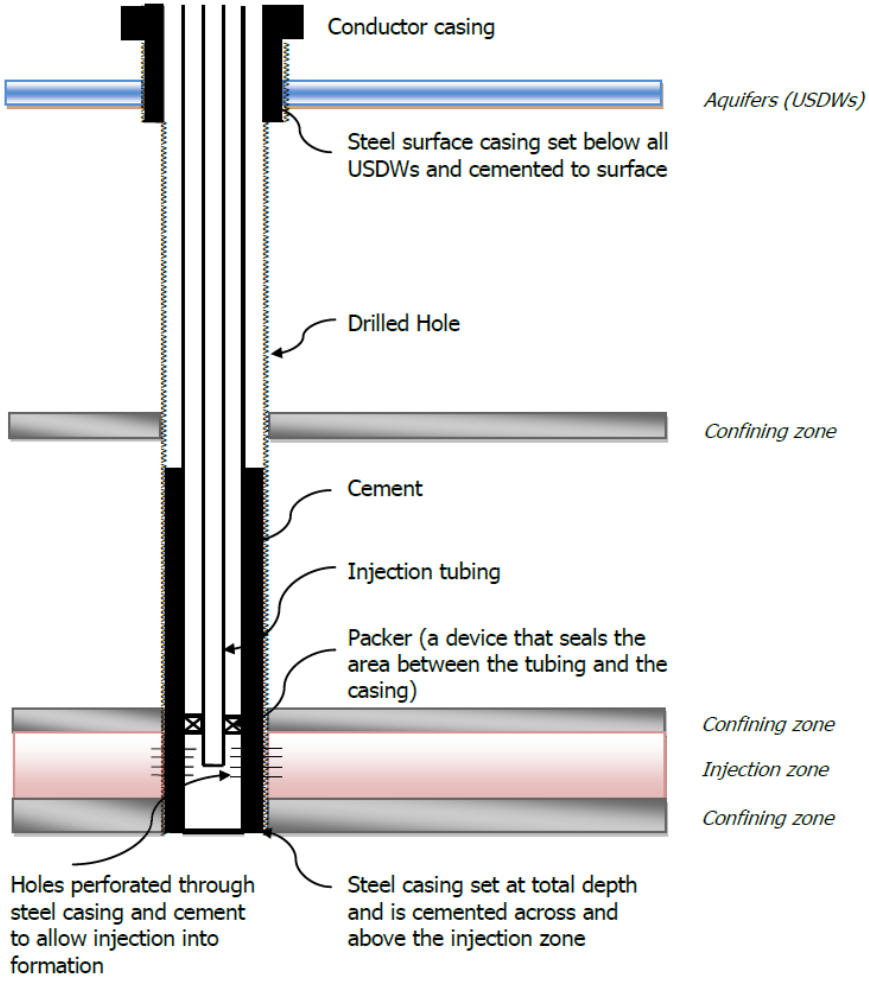
Adapted after Southwestern Energy, used with permission

Shale gas development

- The process of hydraulic fracturing a well as presently implemented for shale gas recovery does not pose a high risk for inducing felt seismic events.
- ~35,000 wells have been hydraulically fractured for shale gas development to date in the United States.*
- Only one case of demonstrated induced seismicity from hydraulic fracturing for shale gas has been documented worldwide (Blackpool, England – 2011).*

* As of the time of publication of the report in 2012

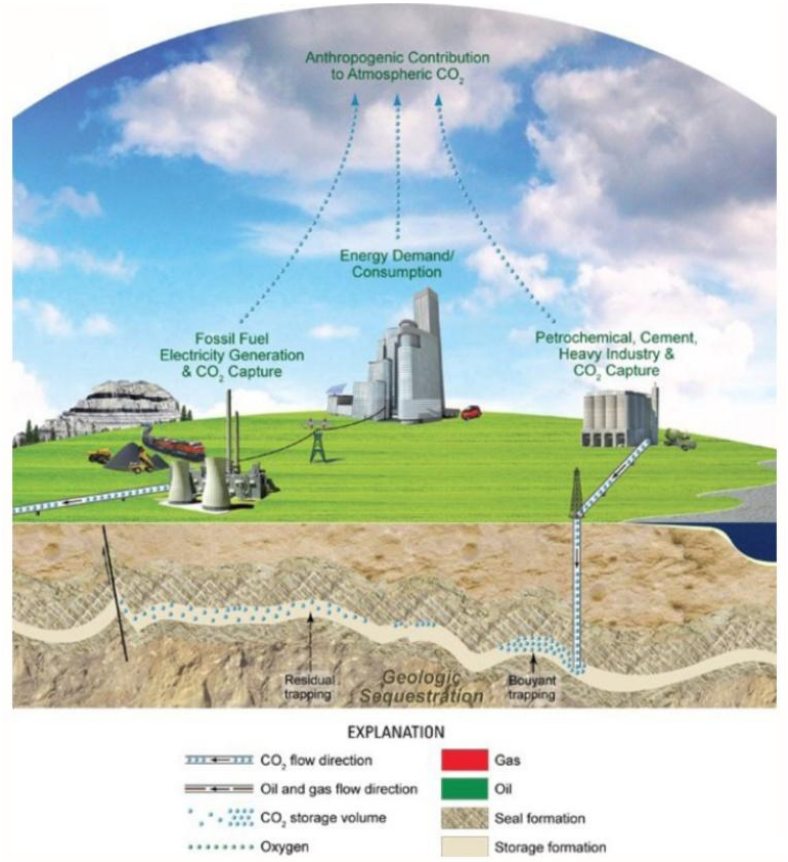
Energy Technologies — Waste Water Disposal Wells



Source: NRC, 2013

- >1/3 of the fluid waste volume from conventional and unconventional oil and gas production is managed through underground injection for permanent disposal in “Class II” wells.
- Very few felt induced seismic events reported among the ~30,000 Class II wastewater disposal wells currently in operation. Rare cases of seismic events were typically less than **M** 5.0.
- High injection volumes may increase pore pressure and in proximity to existing faults could lead to an induced seismic event.
- Induced seismicity may continue for months to years after injection ceases.

Energy Technologies—CCS



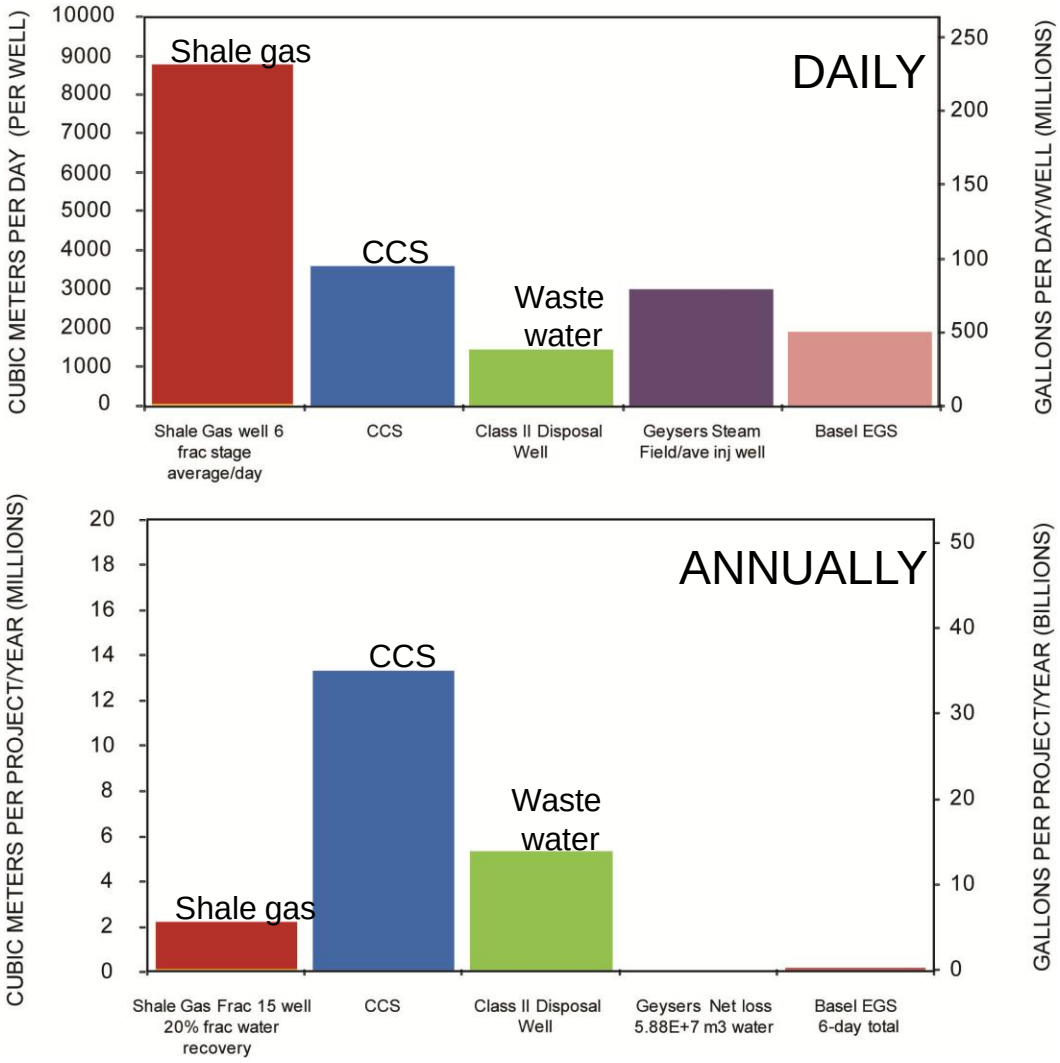
Source: USGS; Duncan et al. (2011)

- Small-scale commercial projects in operation (offshore Norway, onshore Algeria) inject about 1 million metric tonnes of CO_2 per year without significant induced seismicity.

- Regional partnerships in U.S. to test technologies and small-scale injection (Illinois)— plan to inject ~1 million metric tonnes of CO_2 per year.

- Future projects expect to inject much greater than 1 million metric tonnes for permanent storage. Such large volumes have the potential to increase the pore pressure over large areas and cause significant seismic events.

Comparative Estimated Fluid Volumes for Energy Technologies



Source: NRC, 2012

- Daily fluid volumes injected are highest for hydraulic fracturing: 8,500 m^3.
- Annual fluid volumes injected are highest for proposed CCS projects (13,000,000 m^3) and then Class II waste water disposal wells (4,000,000 m^3).
- Geysers geothermal field records net fluid loss annually.

Main Findings, Conclusions, and Recommendations

- Government roles and responsibilities
- Hazard and risk management
- Best practices
- Research recommendations

Government Roles and Responsibilities

1. Oversight is dispersed among federal and state agencies.

2. EPA has primary regulatory responsibility for fluid injection under the Safe Drinking Water Act; this act does not explicitly address induced seismicity.

3. USGS has capability and expertise to address monitoring and research associated with induced seismicity. Significant new resources would be required if their mission is expanded to include comprehensive monitoring and research.

Gap: Mechanisms are lacking for efficient coordination of governmental agency response to induced seismic events.

Proposed Actions:
- Relevant federal and state agencies, should consider developing coordination mechanisms to address induced seismic events that correlate to established best practices.

- Appropriating authorities and agencies with potential responsibility for induced seismicity should consider resource allocations for responding to future induced seismic events.

Hazard and Risk Management

No methods currently exist to implement assessments of hazards upon which risk assessments depend. Information and data for robust hazard assessment include:

- Net pore pressures, in situ stresses, information on faults
- Background seismicity
- Gross statistics of induced seismicity and fluid injection for proposed site activity

Proposed Actions:

- A detailed methodology should be developed for quantitative, probabilistic hazard assessments of induced seismicity risk.

- Data related to fluid injection (well locations; injection depths, volumes, pressures; time frames) should be collected by state and federal authorities in a common format and made accessible to the public (through a coordinating body such as the USGS).

- In areas of high-density of structures and population, regulatory agencies should consider requiring that data for fault identification for hazard and risk assessments be collected and analyzed before energy operations begin.

Steps Toward Best Practices

Findings

1. The DOE Protocol for EGS provides a reasonable initial model for dealing with induced seismicity that can serve as a template for other energy technologies.

2. Based on this model, two matrix-style protocols illustrate the manner in which activities can ideally be undertaken concurrently (rather than only sequentially), while also illustrating how these activities should be adjusted as a project progresses from early planning through operations to completion.

Gap

No best practices protocol for addressing induced seismicity is in place for each of these technologies, with the exception of the EGS protocol. The committee suggests that best practices protocols be adapted and tailored to each technology.

Research Recommendations–1 of 2

1. **Field and laboratory data collection and research:**
   - Active seismic events possibly caused by energy development; identify key data and data collection protocol
   - Non-destructive in situ stress measurements; microseisms in natural fracture systems
   - Effects of temperature variations on stressed jointed rock systems
   - In situ links among injection rates, pressure, and event size

2. **Develop instrumentation** to measure rock and fluid properties before and during energy development projects

3. **Hazard and risk assessment** for individual energy projects

4. **Modeling**
   - Scaling (from laboratory to field situations)
   - Link geomechanical and earthquake simulation models to identify critical geological characteristics controlling induced seismicity
   - Develop simulation capabilities integrating reservoir and earthquake simulation modeling for hazard and risk assessment
   - Develop coupled reservoir fluid flow and geomechanical simulation codes to understand occurrence of seismicity after wells have been shut in

Research Recommendations–2 of 2

5. Carbon capture and sequestration

- Use some of the many active fields where CO_2 flooding for EOR is conducted to understand more about the apparent lack of felt induced seismic events in these fields
- Develop models to estimate the potential earthquake magnitude that could be induced by large-scale CCS
- Develop detailed physicochemical and fluid mechanical models for injection of supercritical CO_2 into potential storage aquifers

Briefings and Dissemination of Report

Briefings preceding public release:
DOE-Fossil Energy and Geothermal Technologies Offices (sponsor), DOI, EPA
OSTP
Senate Committee on Energy and Natural Resources
Senate Committee on Environment and Public Works
House Committee on Science, Space, and Technology
House Committee on Natural Resources
House Committee on Energy and Commerce
Senate Committee on Energy and Natural Resources hearing (after release)

Press coverage:
~25 members of the press on the press conference call (release day)
-AP story was picked up by 250 news outlets worldwide
-14 local TV news stations across the country carried the story
-Interview on National Public Radio—All Things Considered; interview by 'The Economist'

Other briefings: 14 in 2012; 12 to date in 2013 (range of groups such as AAPG, IOGCC, AIPG, APS, GSW, GSA, GWPC, NAIC, local community groups and societies, etc.)

Video: http://www.youtube.com/watch?v=Uuh9lHavdvc&feature=youtu.be. (1,800 views)

Report: (PDF): ~6,000 downloads http://www.nap.edu/catalog.php?record_id=13355

Articles (2): written by the committee for trade journals, scientific society newsletters