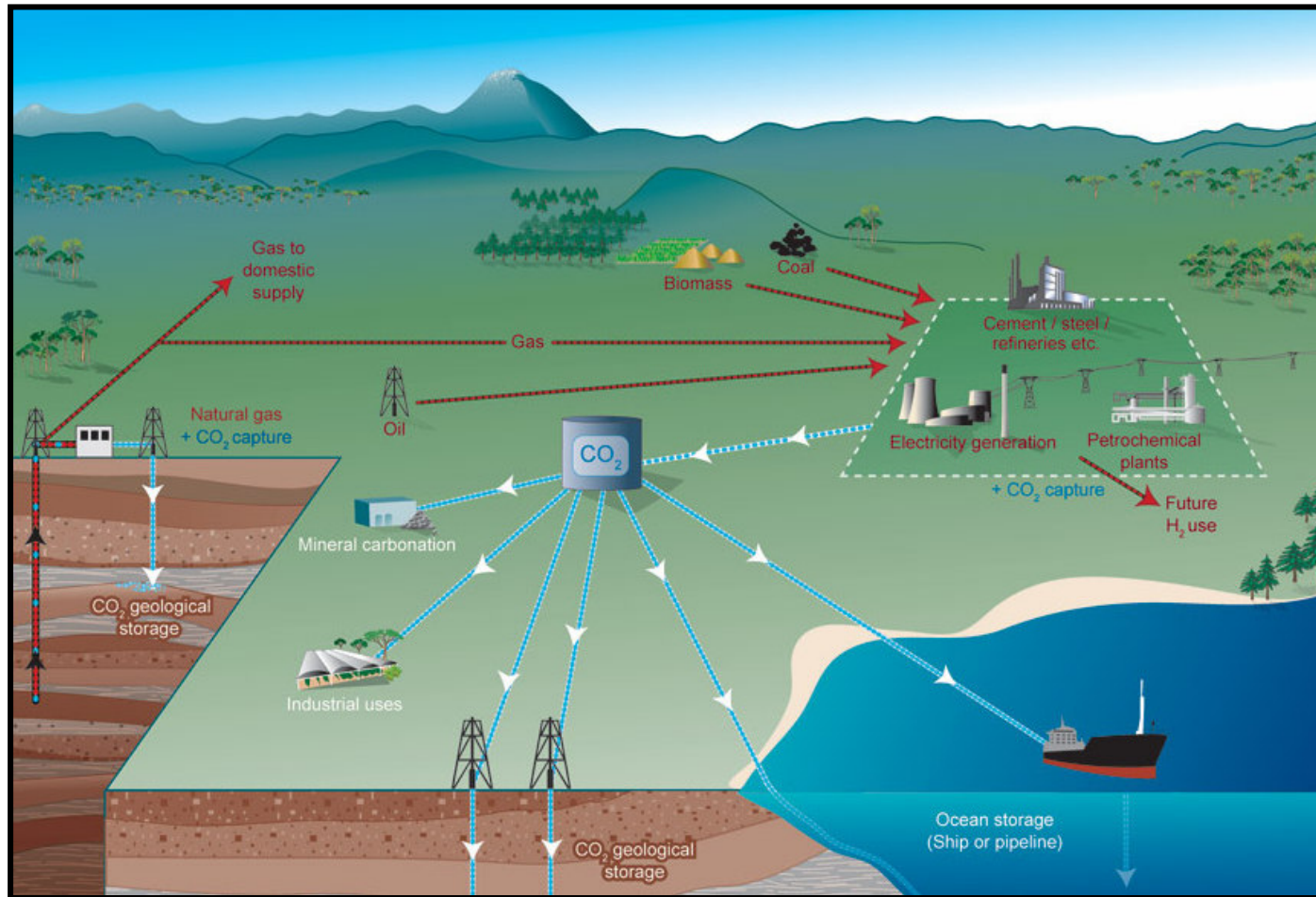


Liability Issues Related to Geological Storage of CO₂

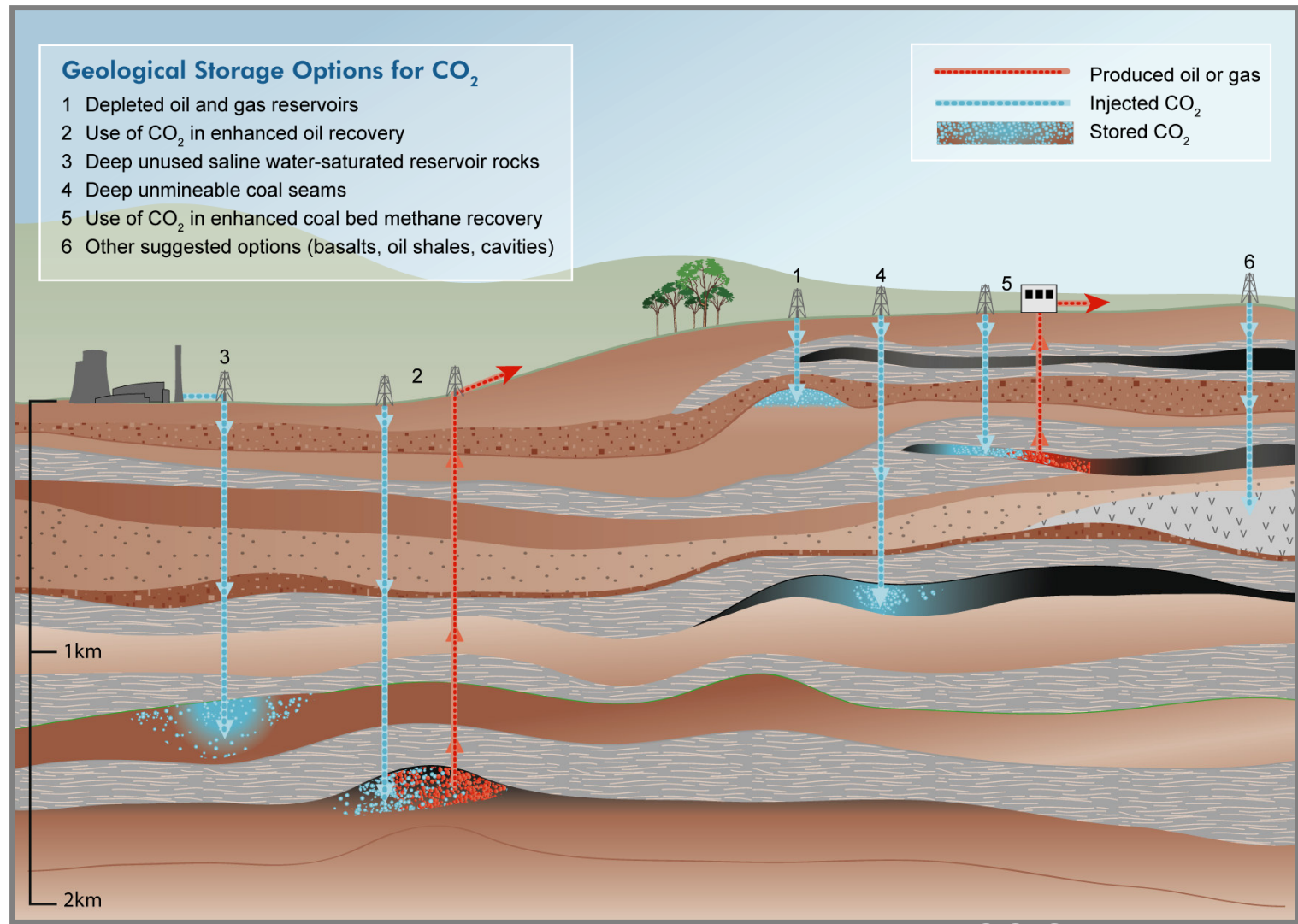
Sally M. Benson
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, California 94720
smbenson@lbl.gov

Carbon Dioxide Capture and Storage is Needed to Reduce Emissions From Fossil Fuels



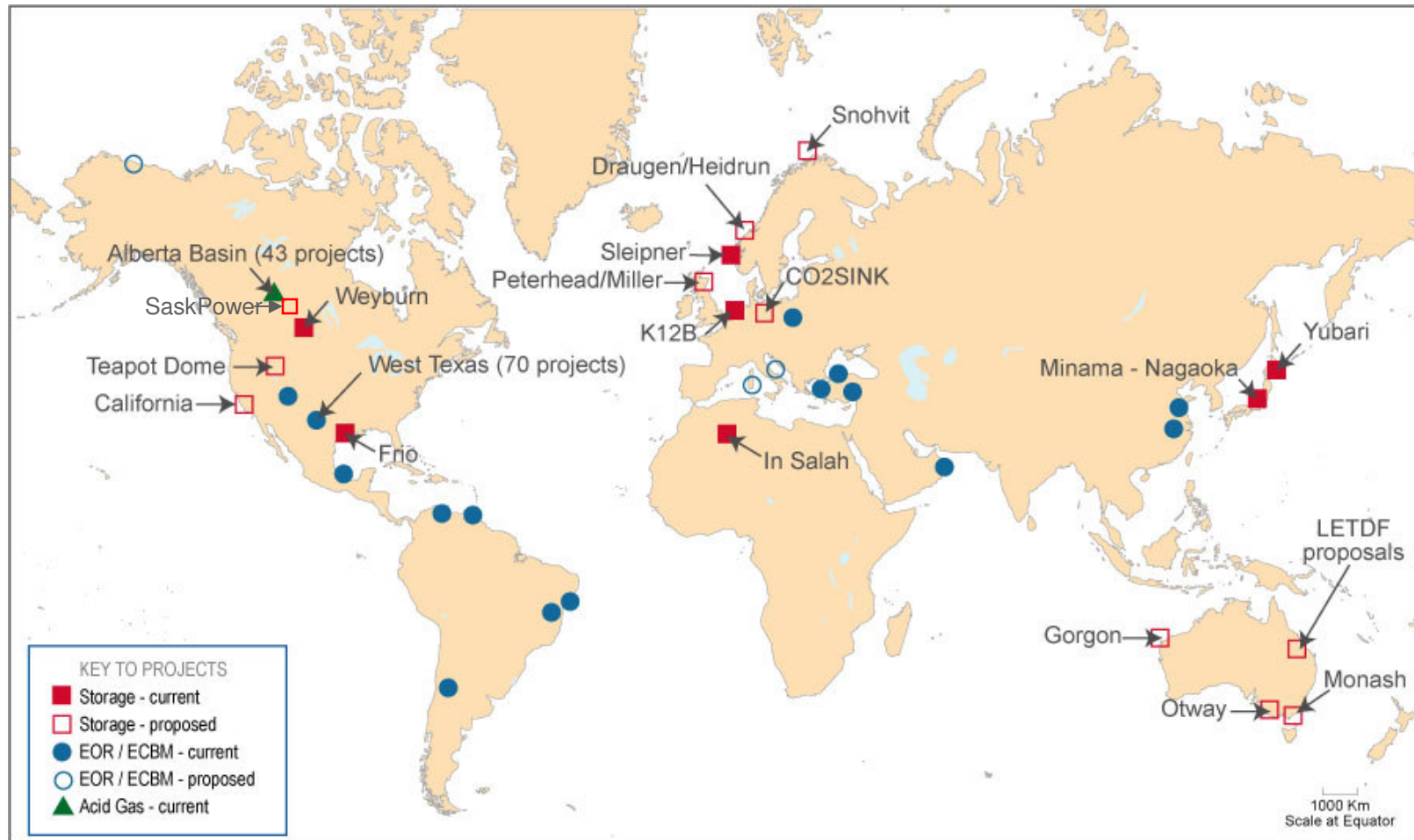
<http://www.ipcc.ch/activity/csspm.pdf>

Options for Geological Storage



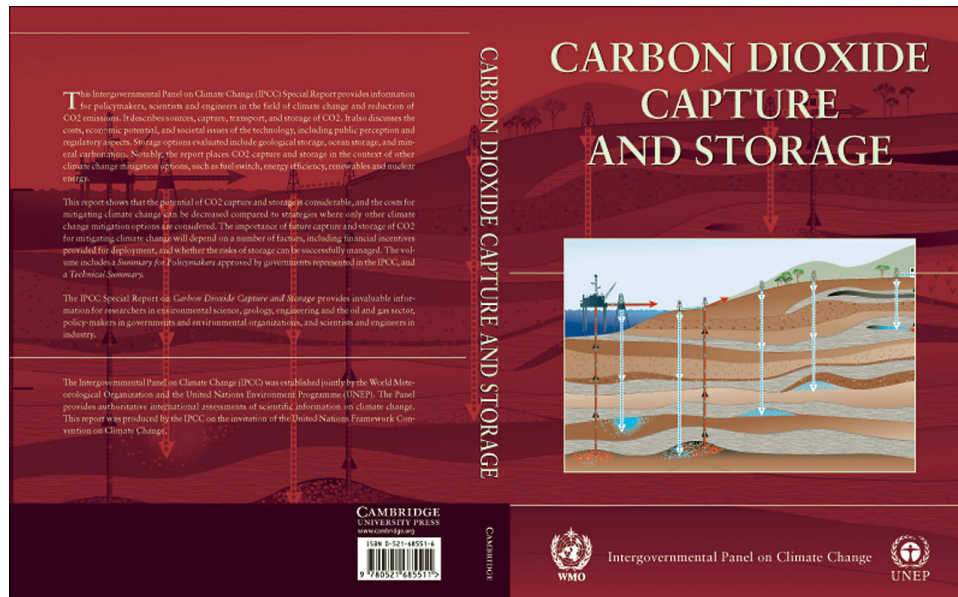
IPCC, 2005

Carbon Dioxide Capture and Storage is a Growing CO₂ Mitigation Option



From Peter Cook, CO2CRC, Australia

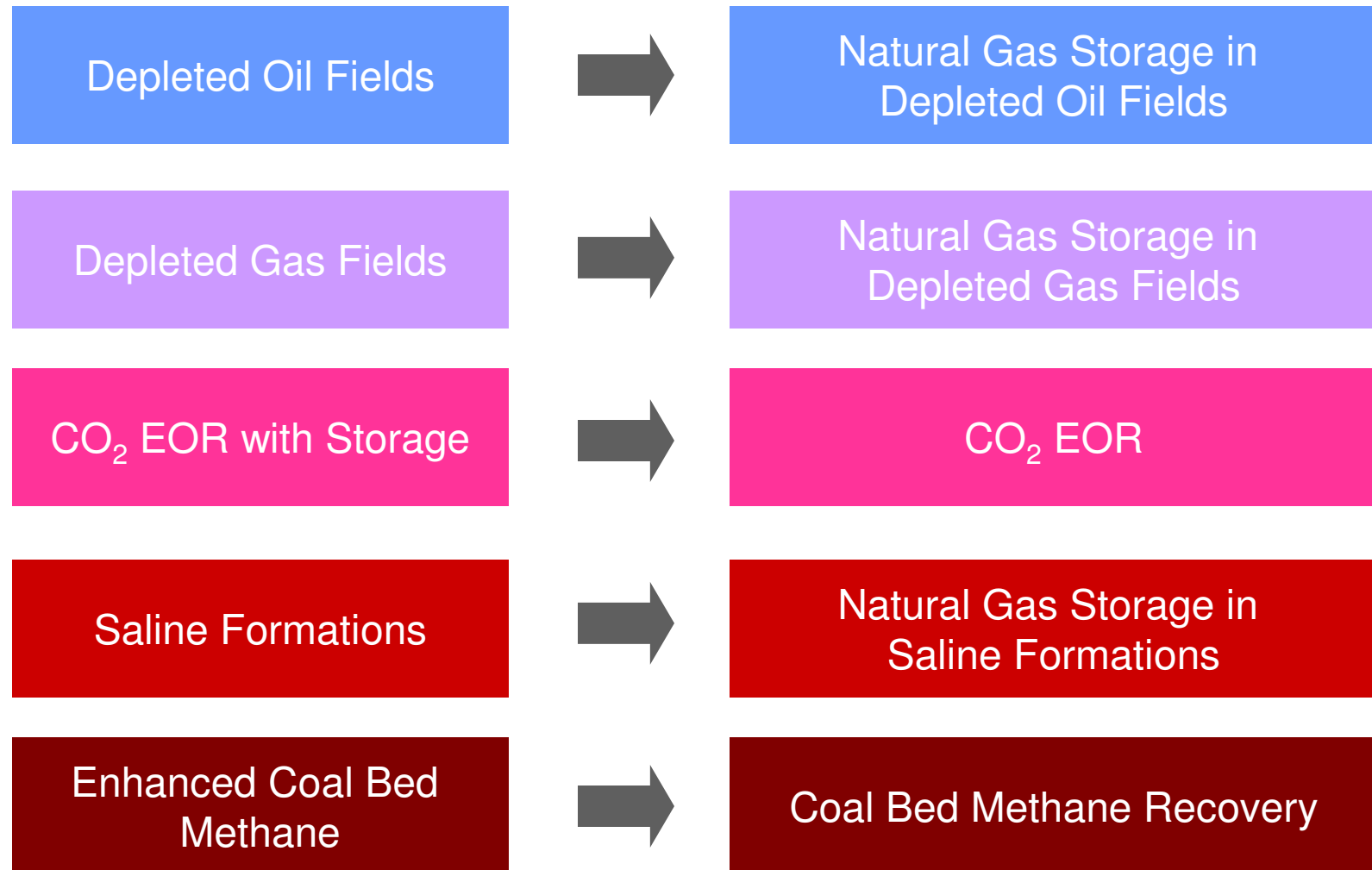
What Do We Know About the Risks of Geological Storage of CO₂?



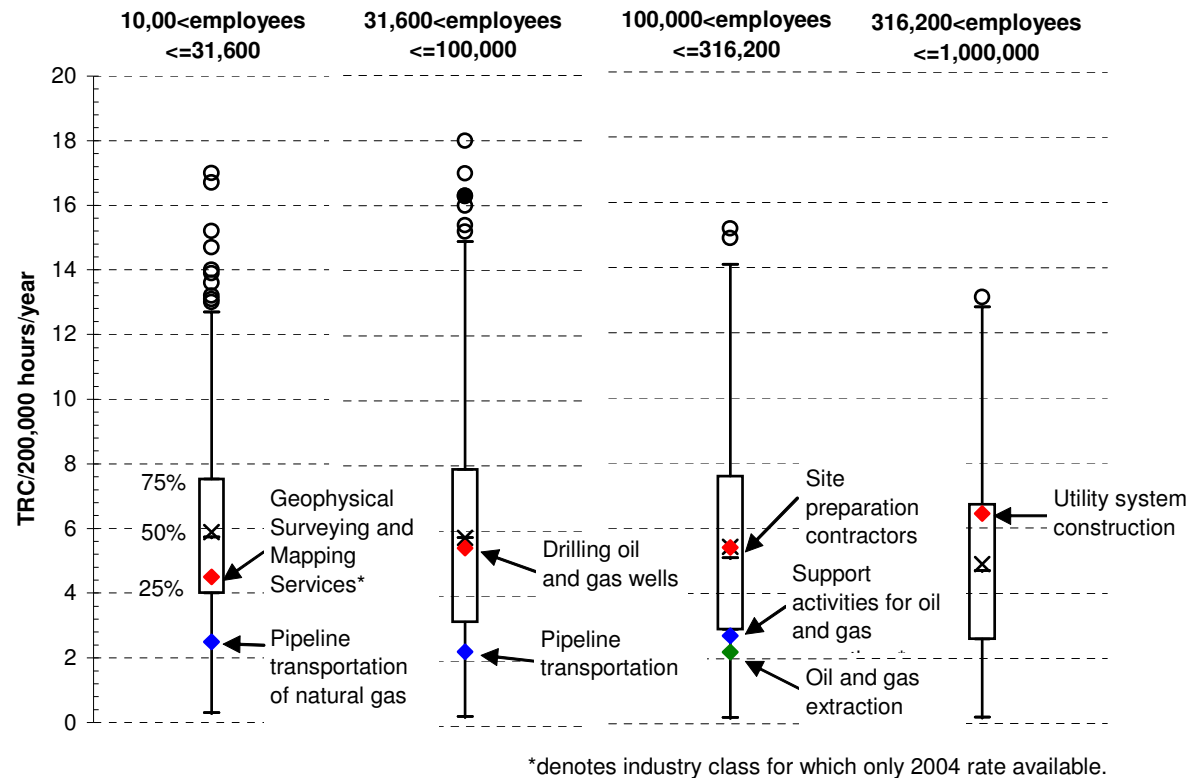
<http://www.ipcc.ch/activity/csspm.pdf>

*“ With **appropriate site selection** informed by available subsurface information, a **monitoring program** to detect problems, a **regulatory system**, and the **appropriate use of remediation methods** to stop or control CO₂ releases if they arise, the **local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas.** ”*

Storage Formation Specific Risks

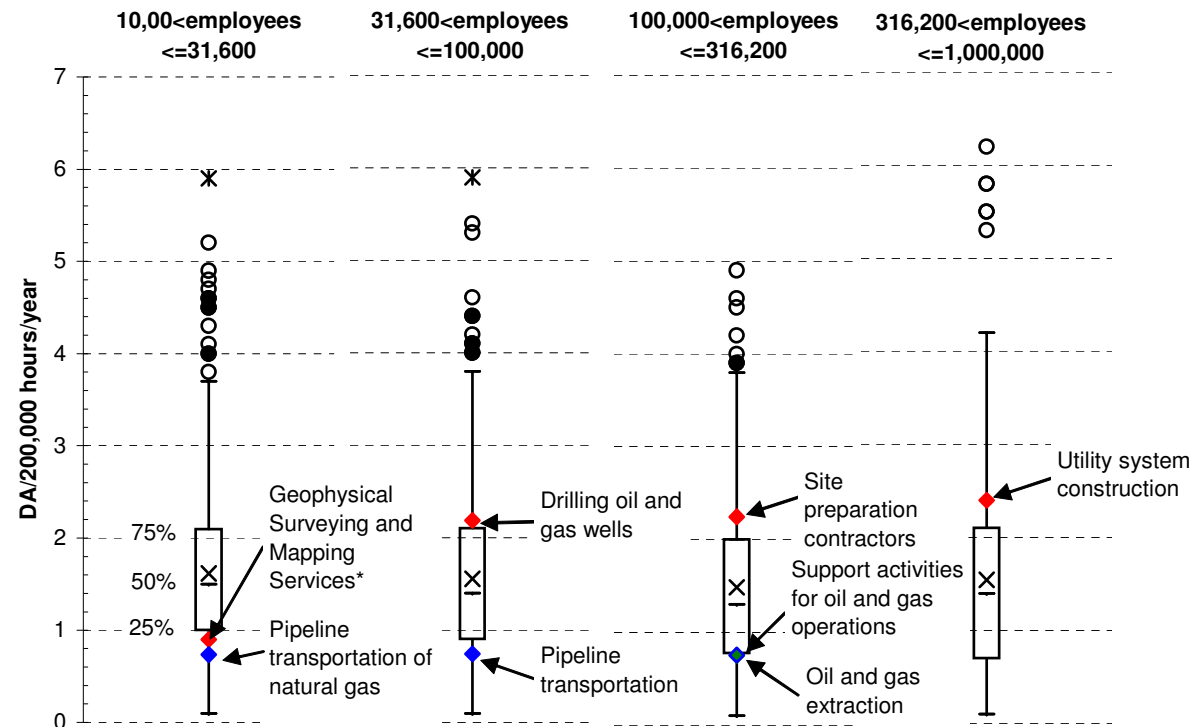


TRC Rate for Various Oil and Gas Related Activities



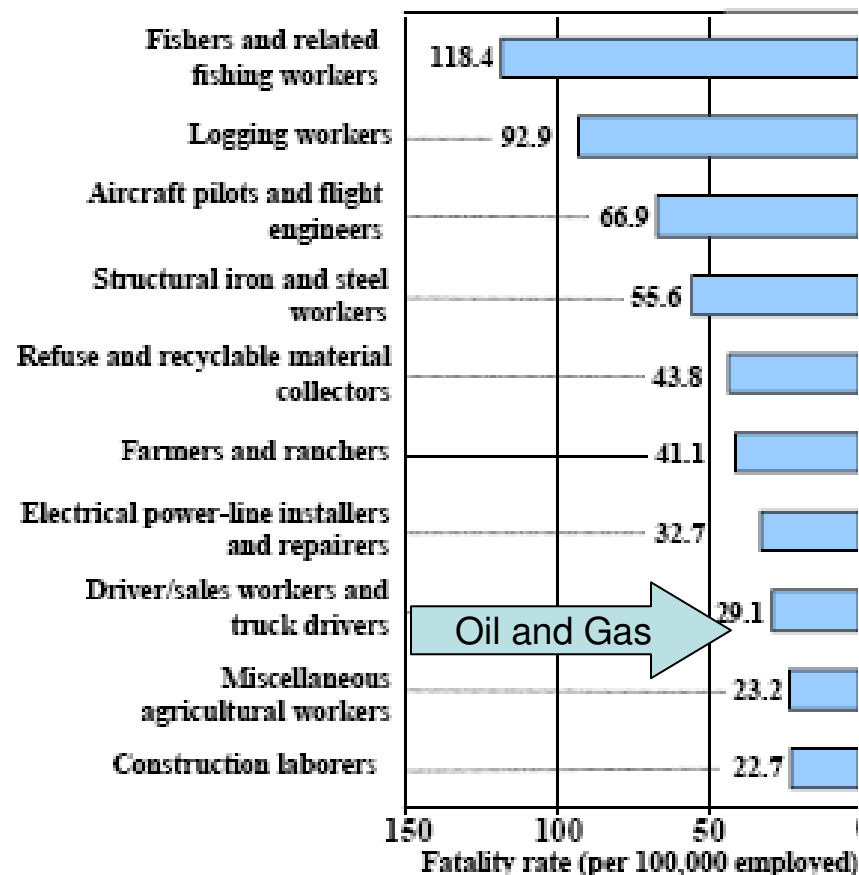
Total Recordable Case (TRC) rate box plots for NAICS industry classes within an employment size group. Size groups shown are in thousands of employees. TRC rates for industry classes participating in the oil and gas exploration and production industry are shown.

DA Case Rate for Various Oil and Gas Related Activities



Days Away case (DA) rate box plots for NAICS industry classes within an employment size group. Size groups shown are in thousands of employees. DA rates for industry classes participating in the oil and gas exploration and production industry are shown.

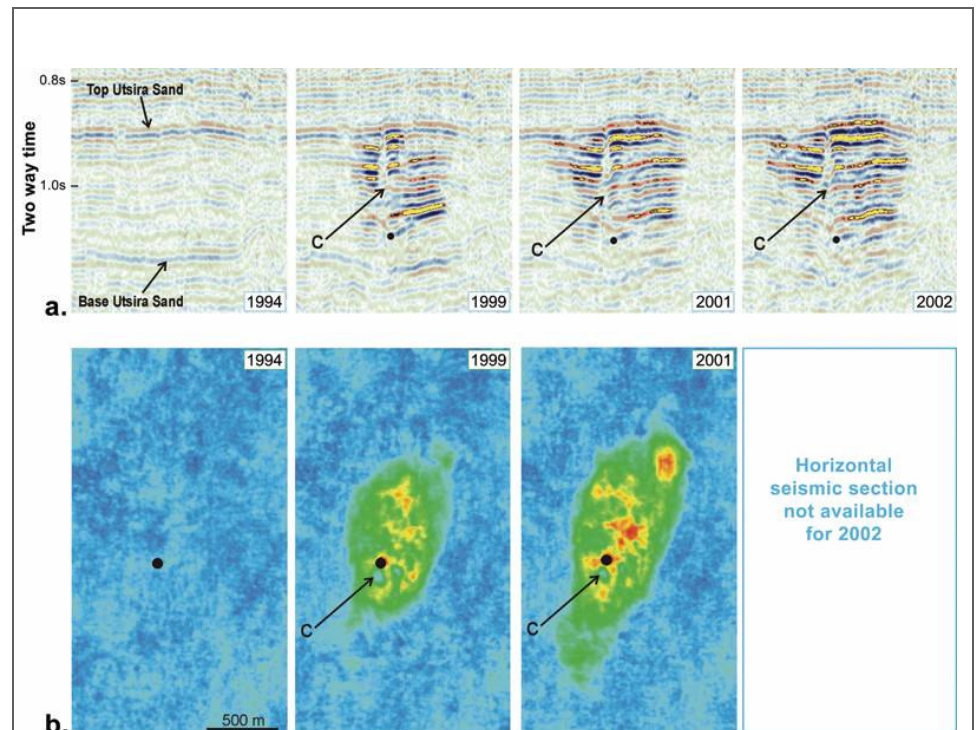
Estimated Fatality Rates*



* Preliminary assessment, subject to change

What Does a Good Storage Project Look Like?

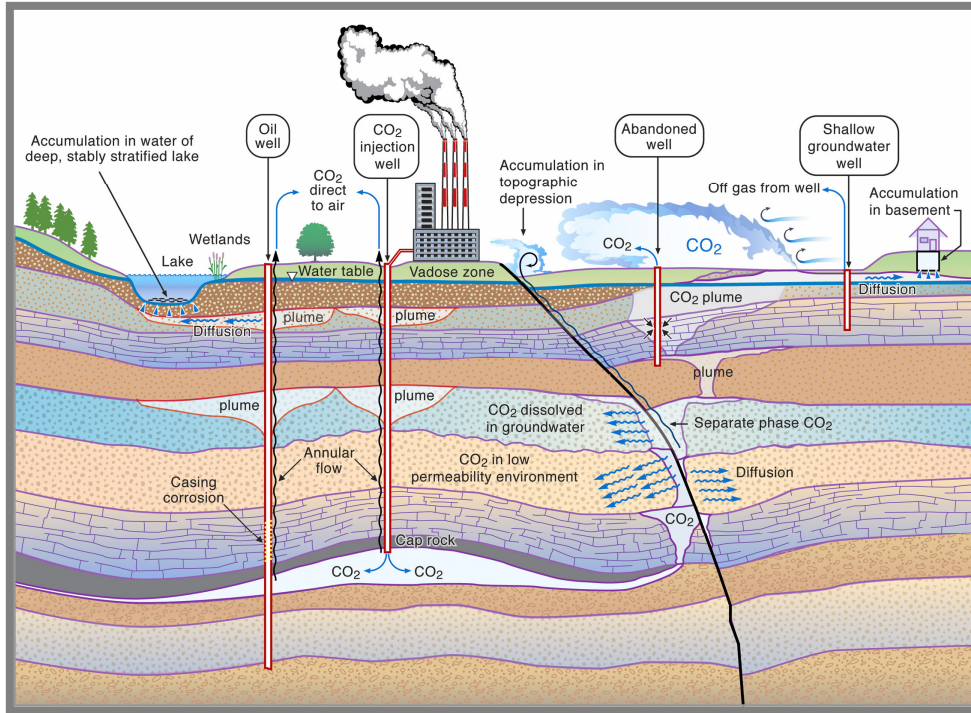
- Three examples
 - Sleipner, off-shore Norway
 - Weyburn, Canada
 - In Salah, Algeria
- CO₂ remains in the storage reservoir
- Formation pressures remain below the fracture gradient
- Wellbore integrity is maintained
- Monitoring demonstrates satisfactory performance
- No serious accidents



From Chadwich et al, 2004

Seismic data at Sleipner demonstrate CO₂ containment

What Could Go Wrong?



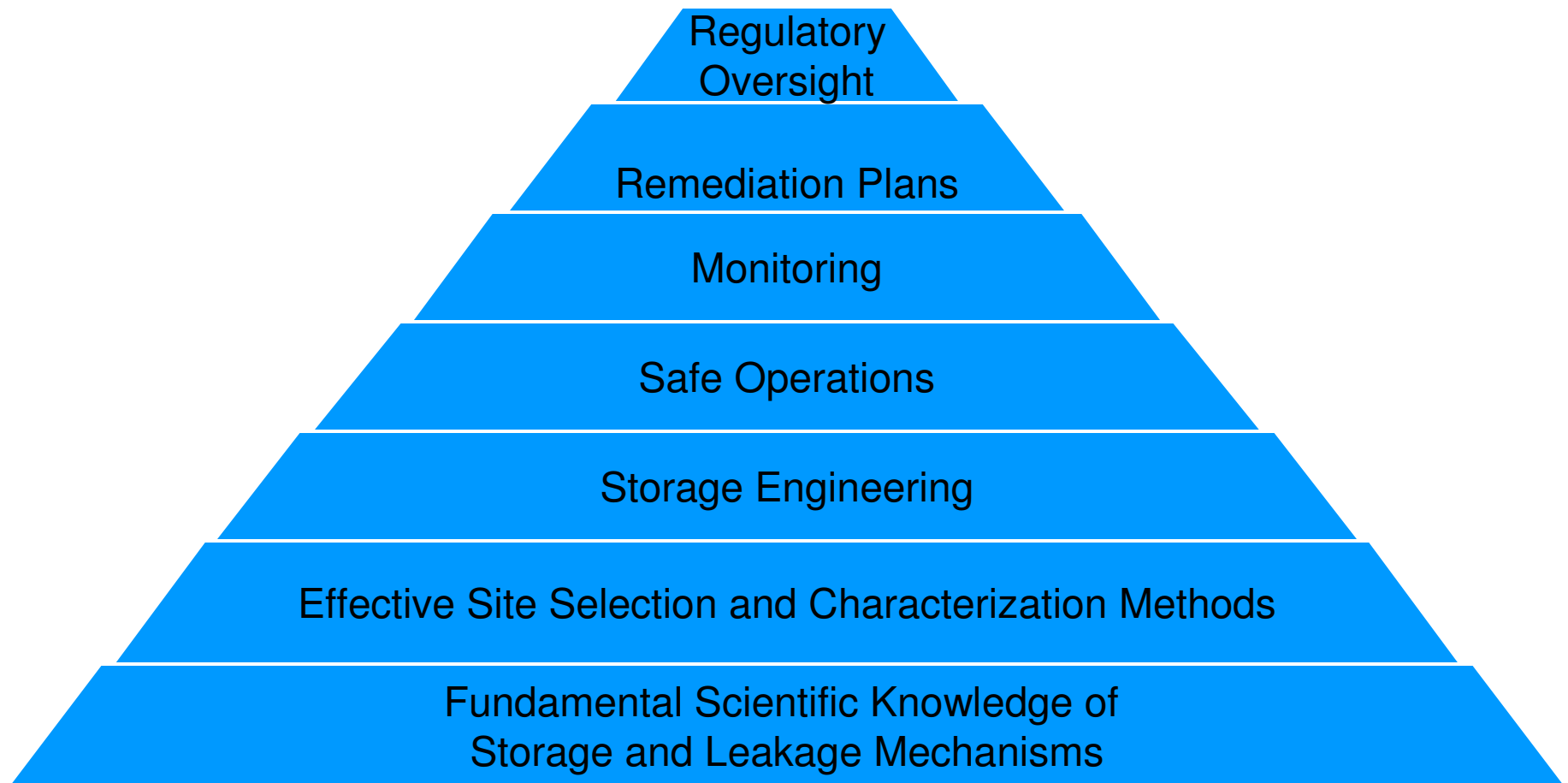
Potential failure pathways for a poorly conceived and executed storage project

- Well leakage (injection and abandoned)
- Poor site characterization (undetected faults)
- Excessive pressure buildup damages seal

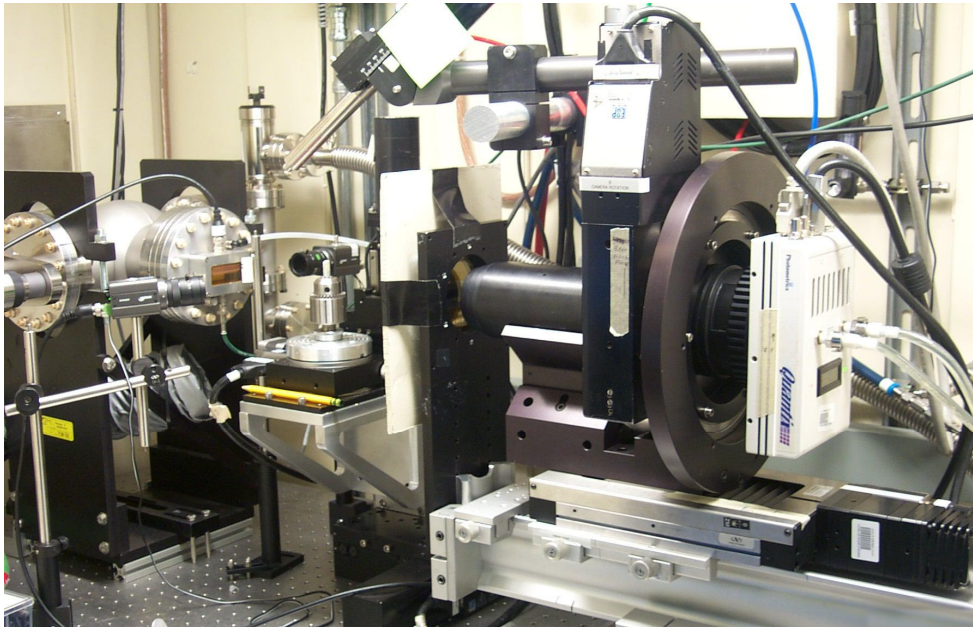
Potential Consequences

1. Worker safety
 - Industrial operations accidents
 - CO₂ exposure due to leakage from surface and subsurface facilities
2. Financial losses
 - Emissions to atmosphere
 - Pre-mature closure
 - Litigation expenses
3. Groundwater quality degradation
 - CO₂ and geochemical reaction products
 - Brine or gas displacement, including dissolved or separate phase hydrocarbons
4. Resource damage
 - Migration to oil and gas fields
 - Migration to minable coal
5. Ecosystem degradation
 - Terrestrial plants and animals
 - Aquatic plants and animals
6. Public safety
 - CO₂ exposure due to leakage from surface and subsurface facilities
7. Structural damage
 - Induced seismicity
 - Differential land surface subsidence or inflation

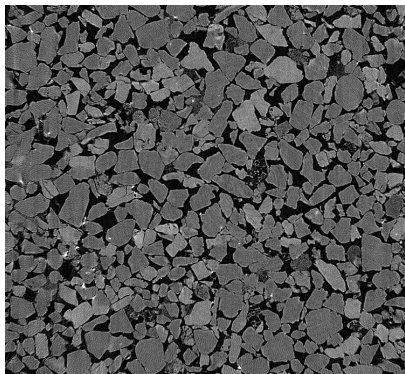
How Can These Problems Be Avoided?



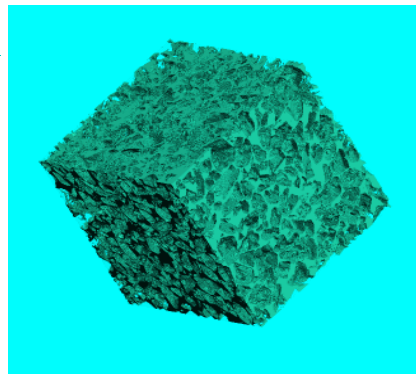
CO₂ is Contained in Tiny Pore Spaces



Microtomography at the Advanced Light Source

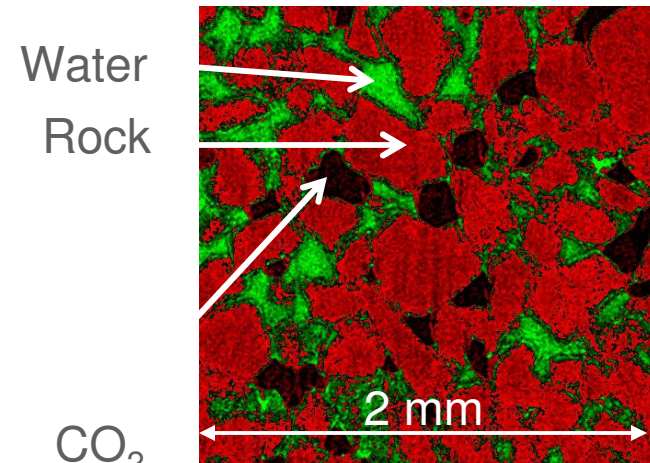


2-D pore space image

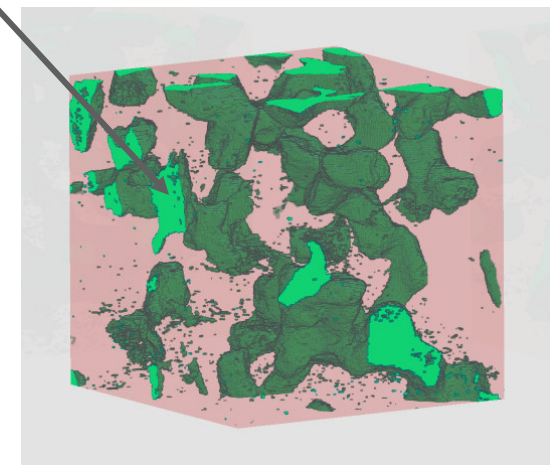


3-D pore space image

2-D image of CO₂ in pore space



CO₂



3-D image of CO₂ in pore space

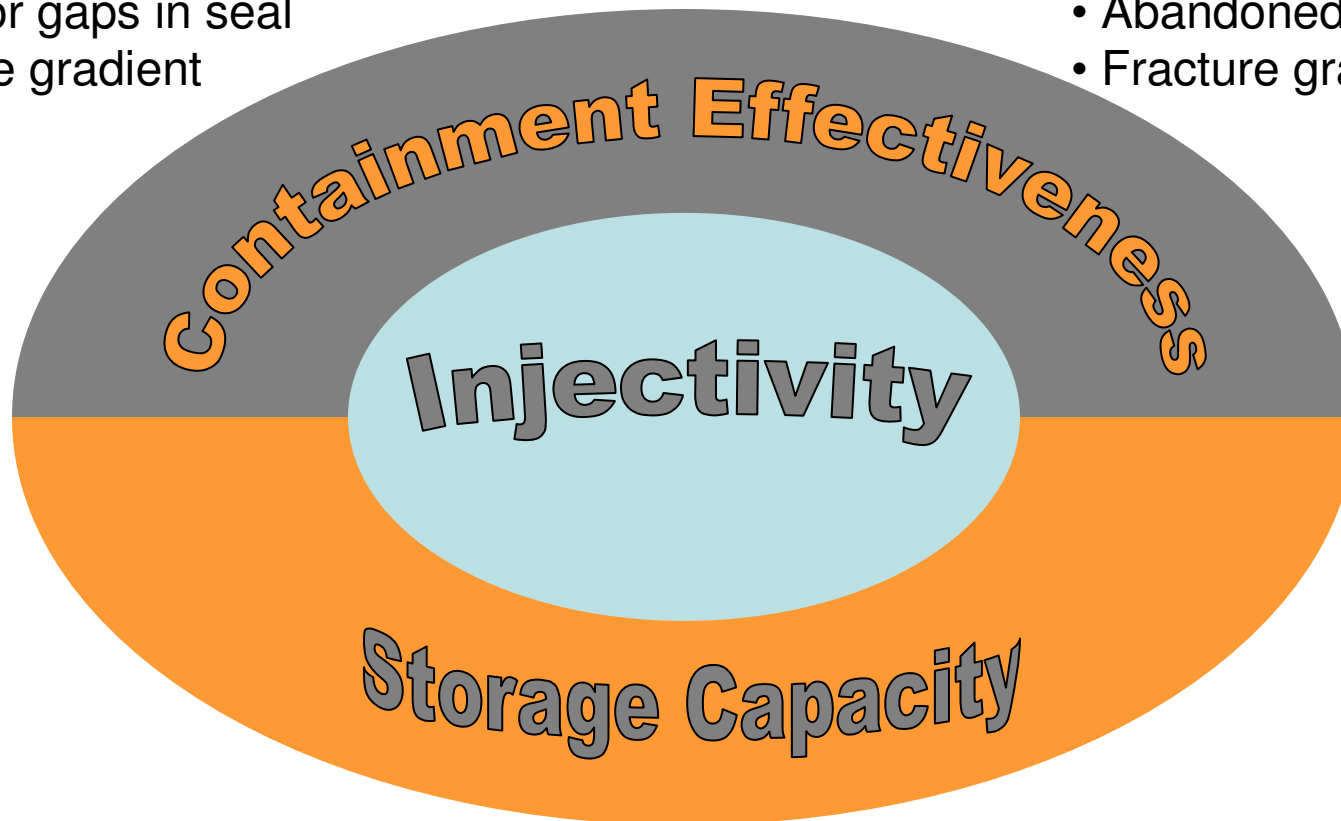
Site Characterization and Selection Are of Paramount Importance

Saline Formations

- Faults or gaps in seal
- Fracture gradient
- Wells

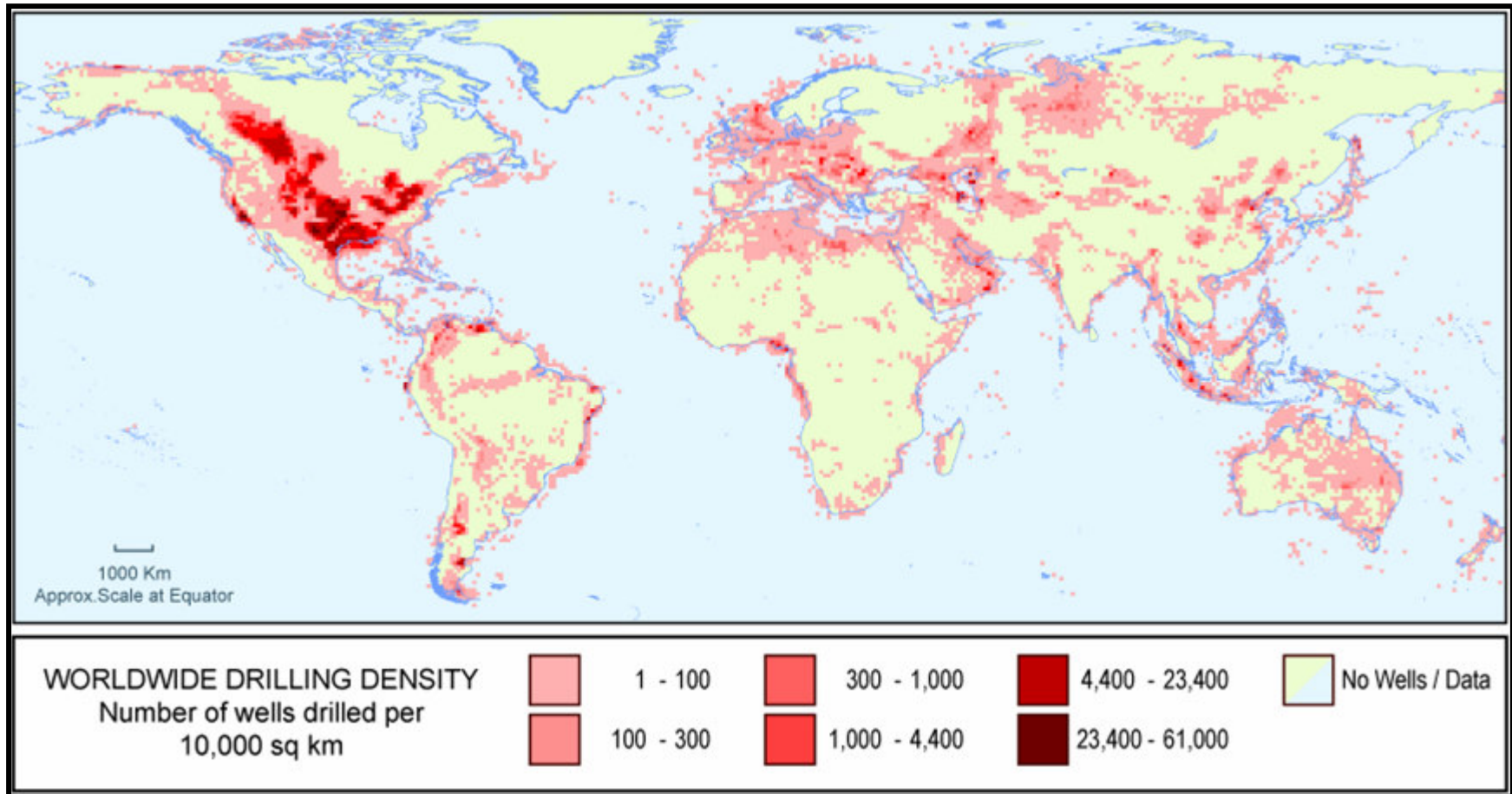
Oil and Gas Reservoirs

- Abandoned wells
- Fracture gradient



Modified from J. Freidman, 2006

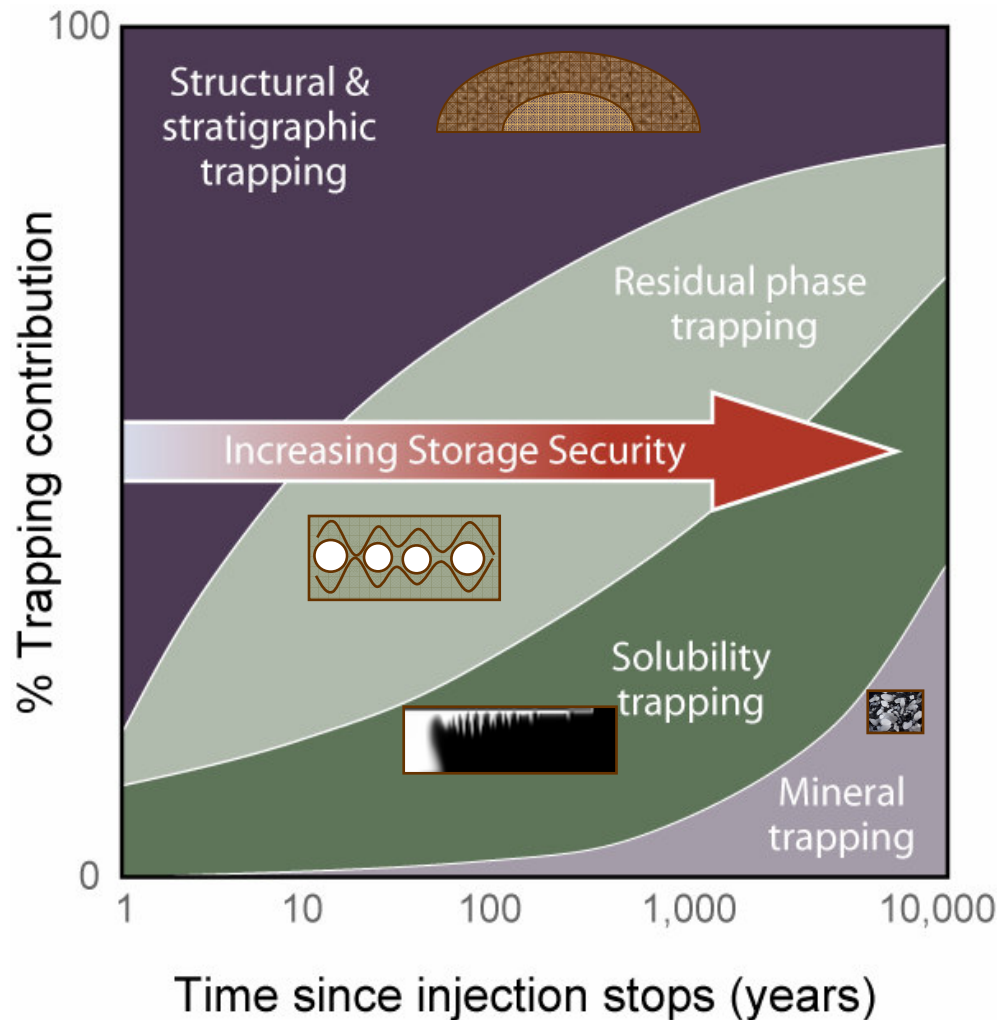
In North America Abandoned Wells Are A Significant Issue



Well density and risks from abandoned wells depends on location

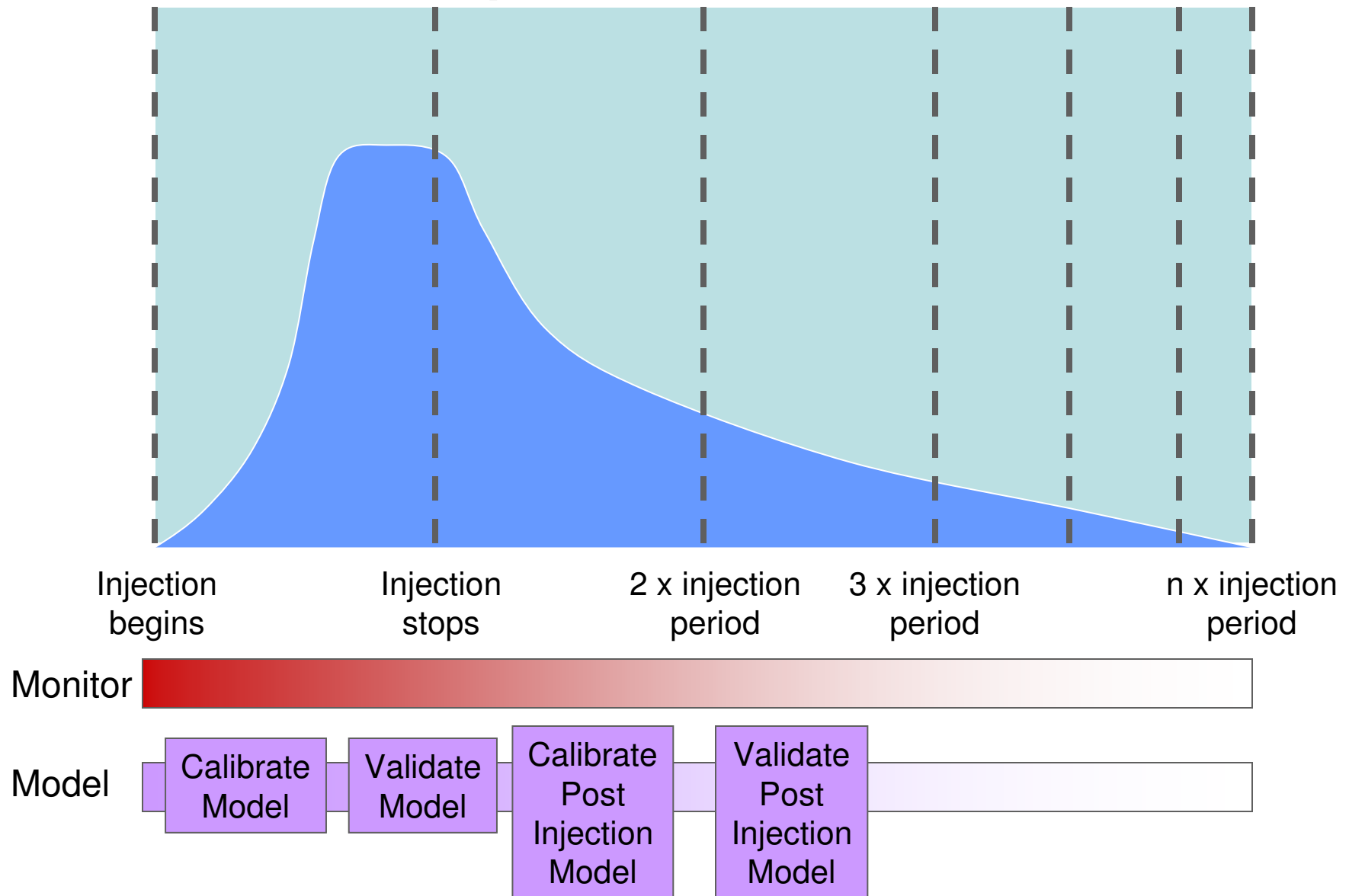
From IHS Energy

Longer Term Issues: Post Injection



- Storage security increases over time
 - Secondary trapping mechanisms
 - Pressure decline
- Time frames are site specific
- Projects can be engineered to enhance trapping
- Monitoring can demonstrate longer term performance
- Eventually, a high degree of assurance will be achieved

Conceptual Risk Profile



More Experience With Large Commercial Scale Projects is Needed

