



Stanford University  
**Global Climate & Energy Project**

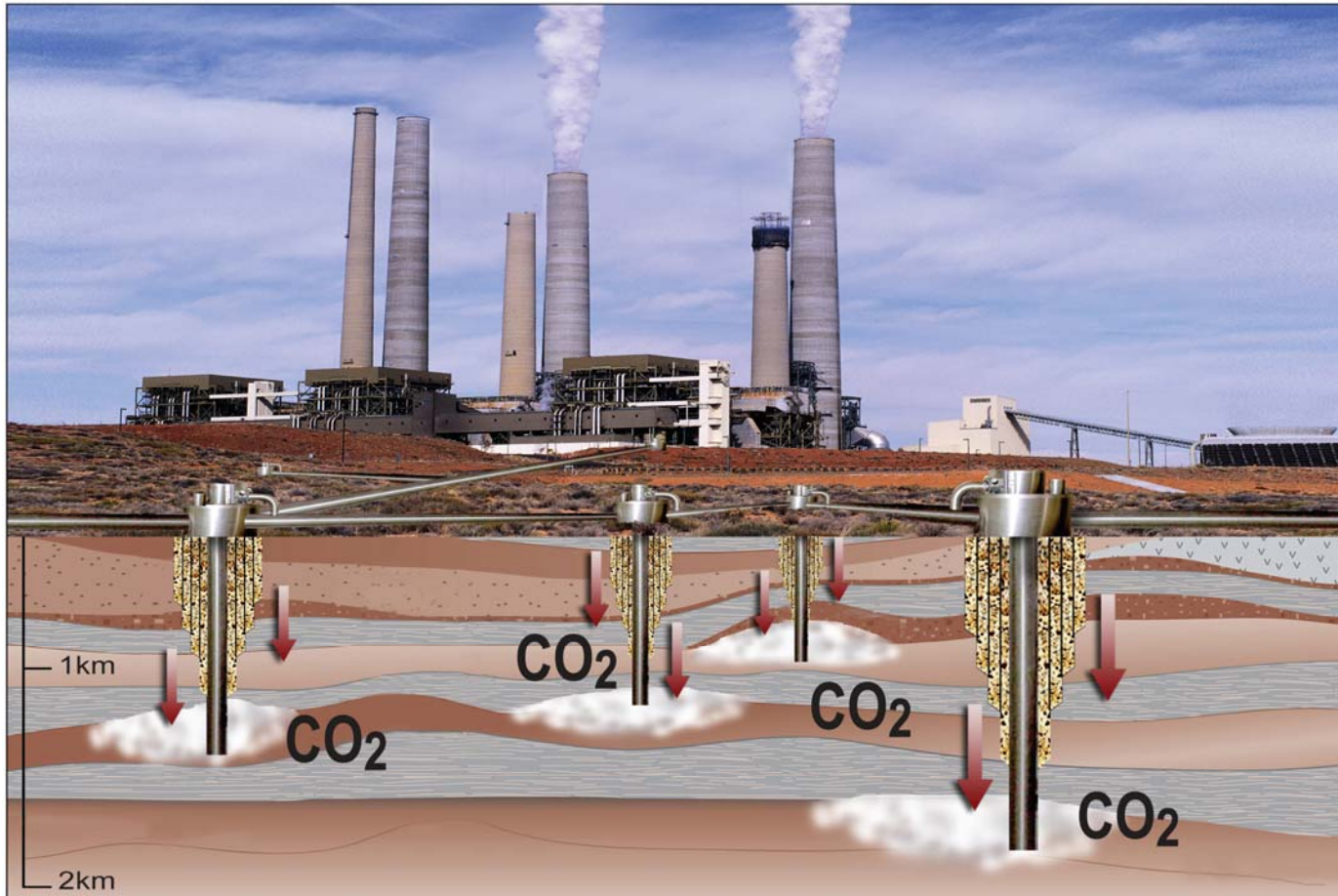
MIT Carbon Sequestration Forum VIII  
Stanford, November 11, 2007

# Is CCS (Geological Storage) Ready for Prime Time?

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Executive Director, Global Climate and Energy Project



# Carbon Dioxide Capture and Geologic Storage



Capture



Compression



Pipeline  
Transport



Underground  
Injection

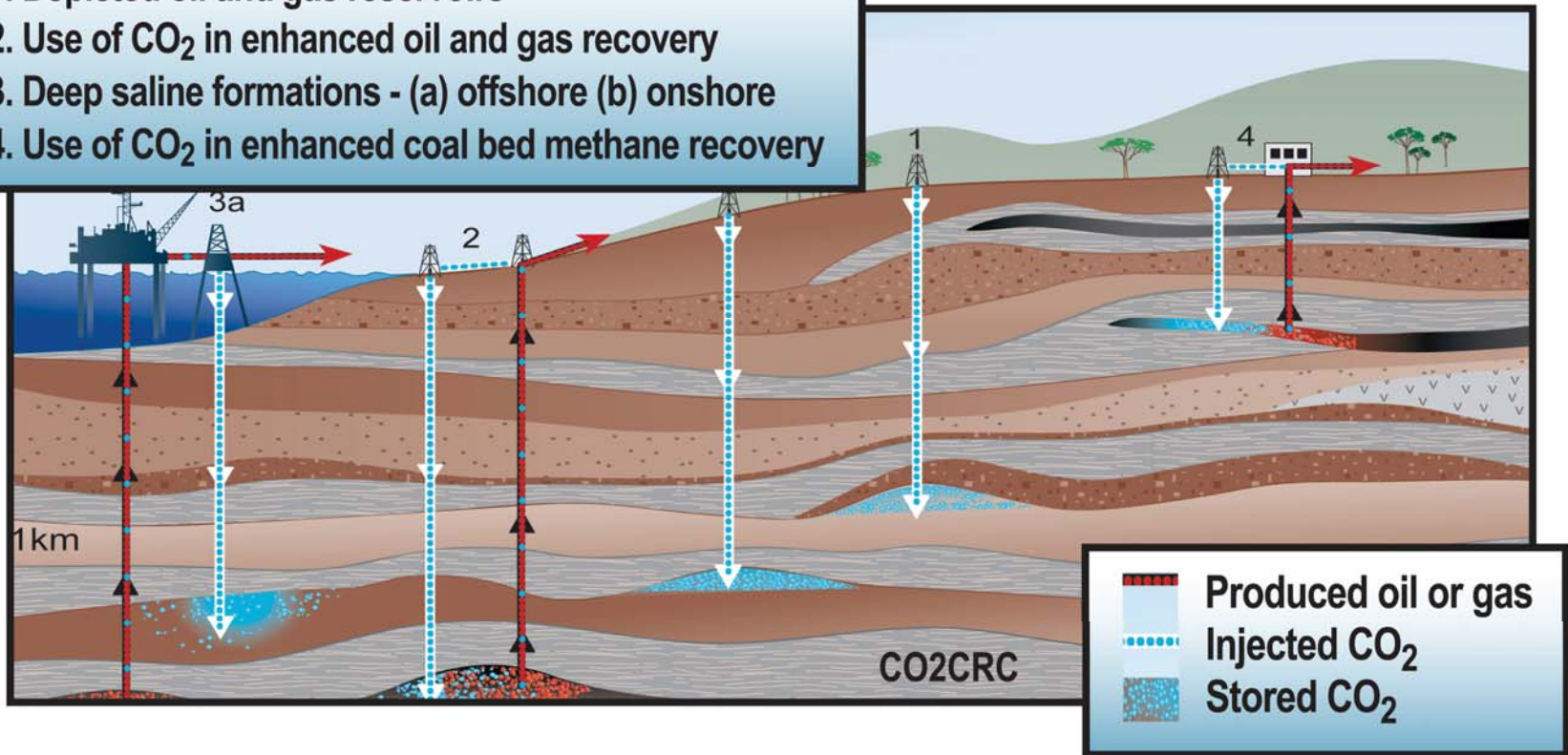


# Options for Geological Storage



## Overview of Geological Storage Options

1. Depleted oil and gas reservoirs
2. Use of CO<sub>2</sub> in enhanced oil and gas recovery
3. Deep saline formations - (a) offshore (b) onshore
4. Use of CO<sub>2</sub> in enhanced coal bed methane recovery



*Different types of formations have different states of readiness.*



# Key Elements of a Geological Storage Safety and Security Strategy



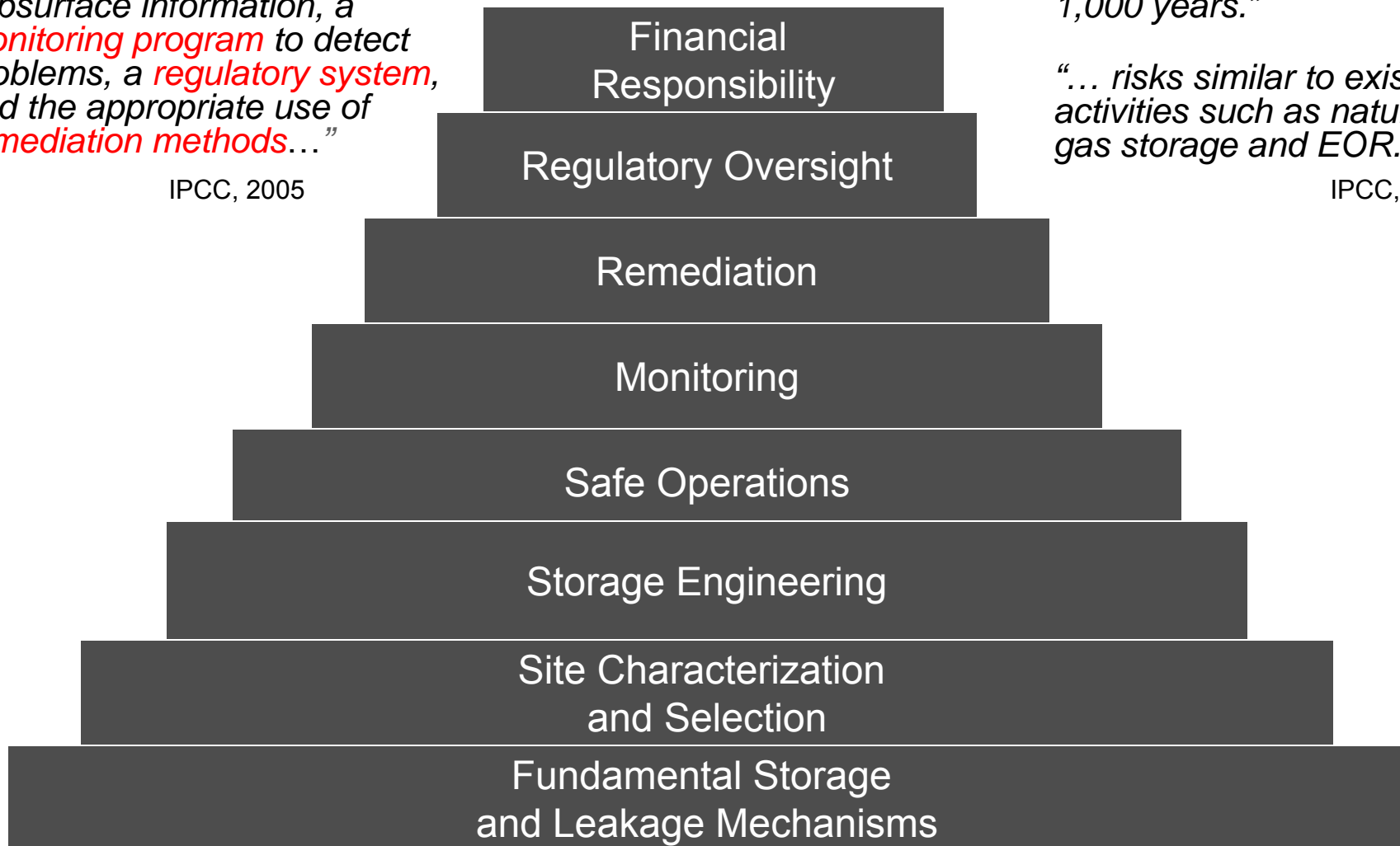
*“ With **appropriate site selection** informed by available subsurface information, a **monitoring program** to detect problems, a **regulatory system**, and the appropriate use of **remediation methods**...”*

IPCC, 2005

*“... the fraction retained is likely to exceed 99% over 1,000 years.”*

*“... risks similar to existing activities such as natural gas storage and EOR.”*

IPCC, 2005





# What Do We Need to Know?



|  |   |
|--|---|
| Financial Responsibility                   | Financial mechanisms and institutional approaches for long term stewardship (e.g. monitoring and remediation if needed)     |
| Regulatory Oversight                       | Oversight for site characterization and selection, storage system operation, safety, monitoring and contingency plans       |
| Remediation                                | Active and abandoned well repair, groundwater cleanup, and ecosystem restoration  |
| Monitoring                                 | Monitoring plume migration, pressure monitoring in the storage reservoir and above the seal, and surface releases           |
| Safe Operations                            | Well maintenance, conduct of operations, well-field monitoring and controls   |
| Storage Engineering                        | Number and location of injection wells, strategies to maximize capacity and accelerate trapping, and well completion design |
| Site Characterization and Selection        | Site specific assessment of storage capacity, seal integrity, injectivity and brine migration                               |
| Fundamental Storage and Leakage Mechanisms | Multi-phase flow, trapping mechanisms, geochemical interactions, geomechanics, and basin-scale hydrology                    |



# Is Geological Storage Ready for Prime Time?



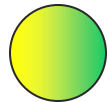
|  | Oil and Gas | Saline Aquifers | Coalbeds |
|--|-------------|-----------------|----------|
| Financial Responsibility                   | ○           | ○               | ○        |
| Regulatory Oversight                       | ○           | ○               | ○        |
| Remediation                                | ○           | ○               | ○        |
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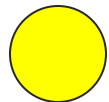
# Are We Ready?



State-of-the-art is well developed, scientific understanding is excellent and engineering methods are mature



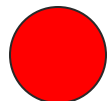
Sufficient knowledge is available but practical experience is lacking, economics may be sub-optimal, scientific understanding is good



Demonstration projects are needed to advance the state-of-the art for commercial scale projects, scientific understanding is limited



Pilot projects are needed to provide proof-of-concept, scientific understanding is immature



New ideas and approaches are needed



# Is Geological Storage Ready for Prime Time?



|  | Oil and Gas | Saline Aquifers | Coalbeds |
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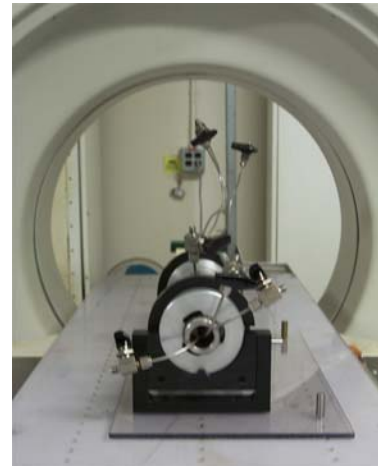




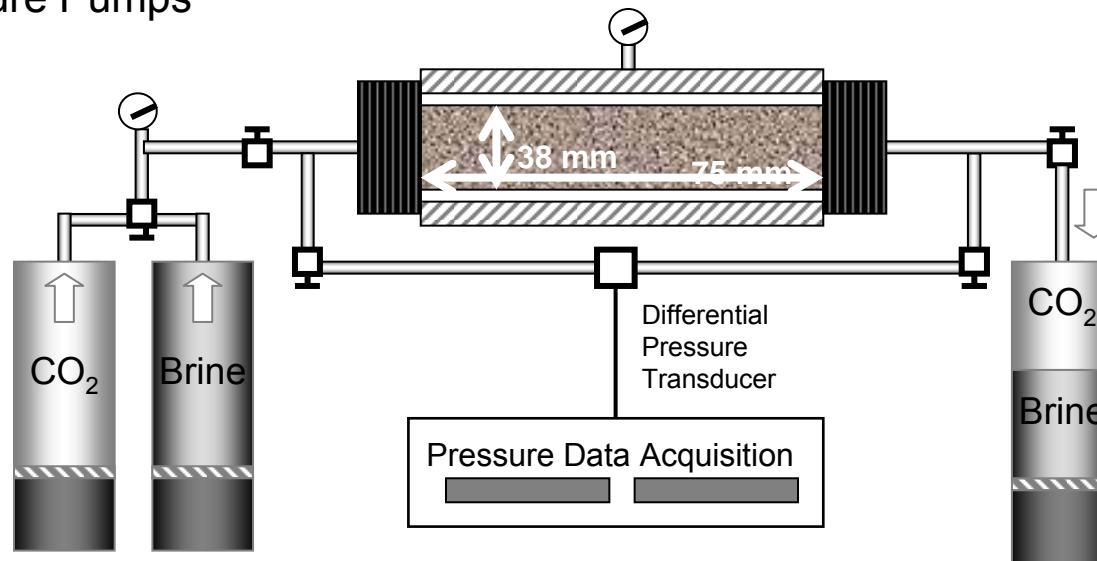
# Multi-phase Flow and Capillary Trapping



High Pressure Pumps



Core Holder In Scanner

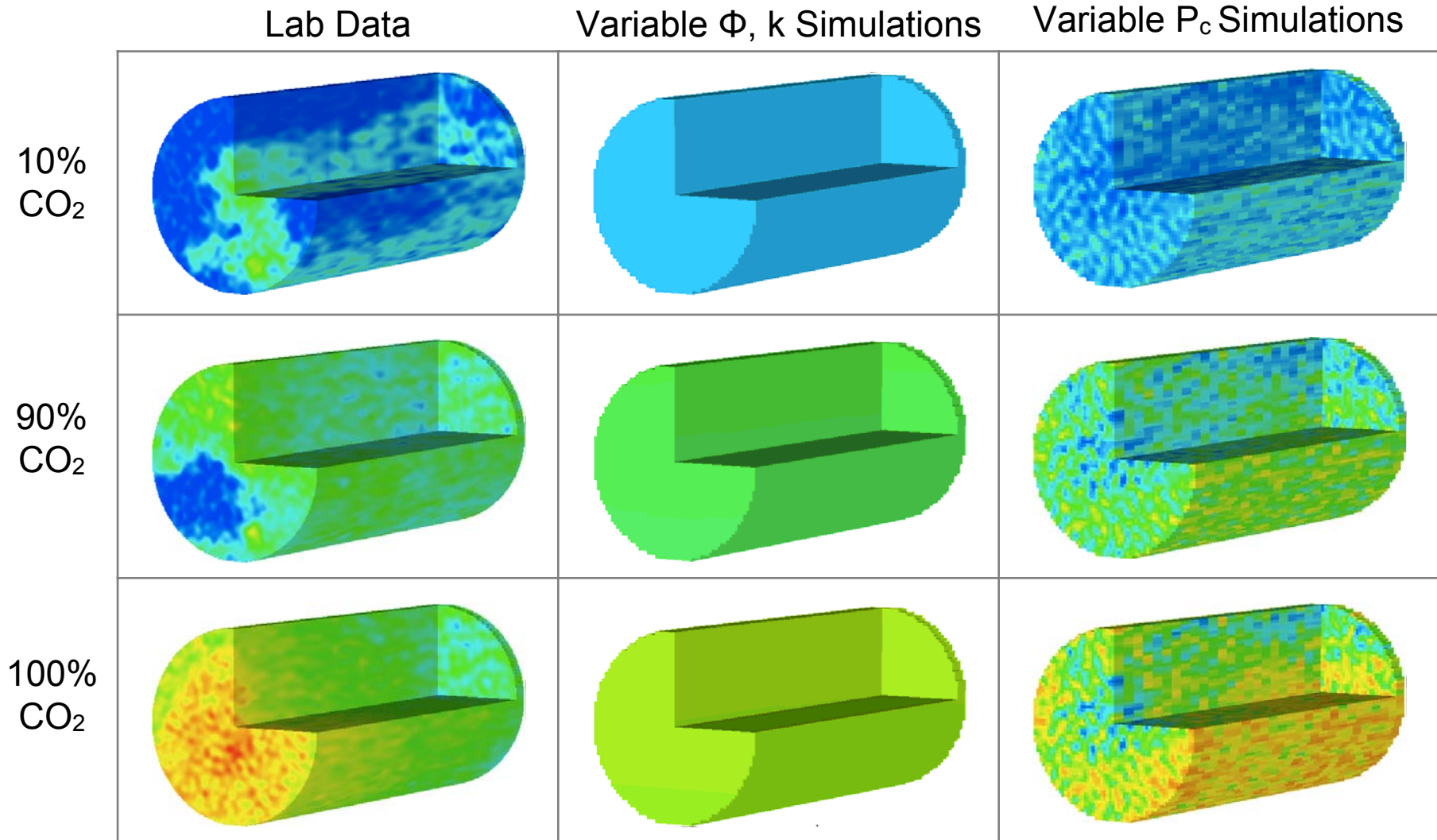




# Simulated CO<sub>2</sub> Saturations



Variable P<sub>c</sub> Produces Small-scale CO<sub>2</sub> Saturation Variations



CO<sub>2</sub> Saturation: 0% 70%

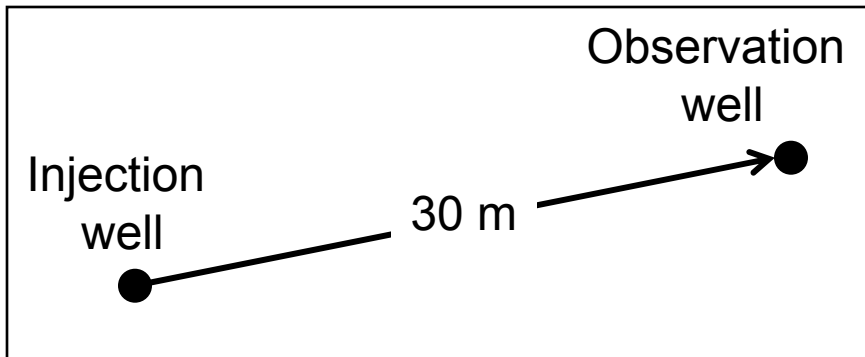


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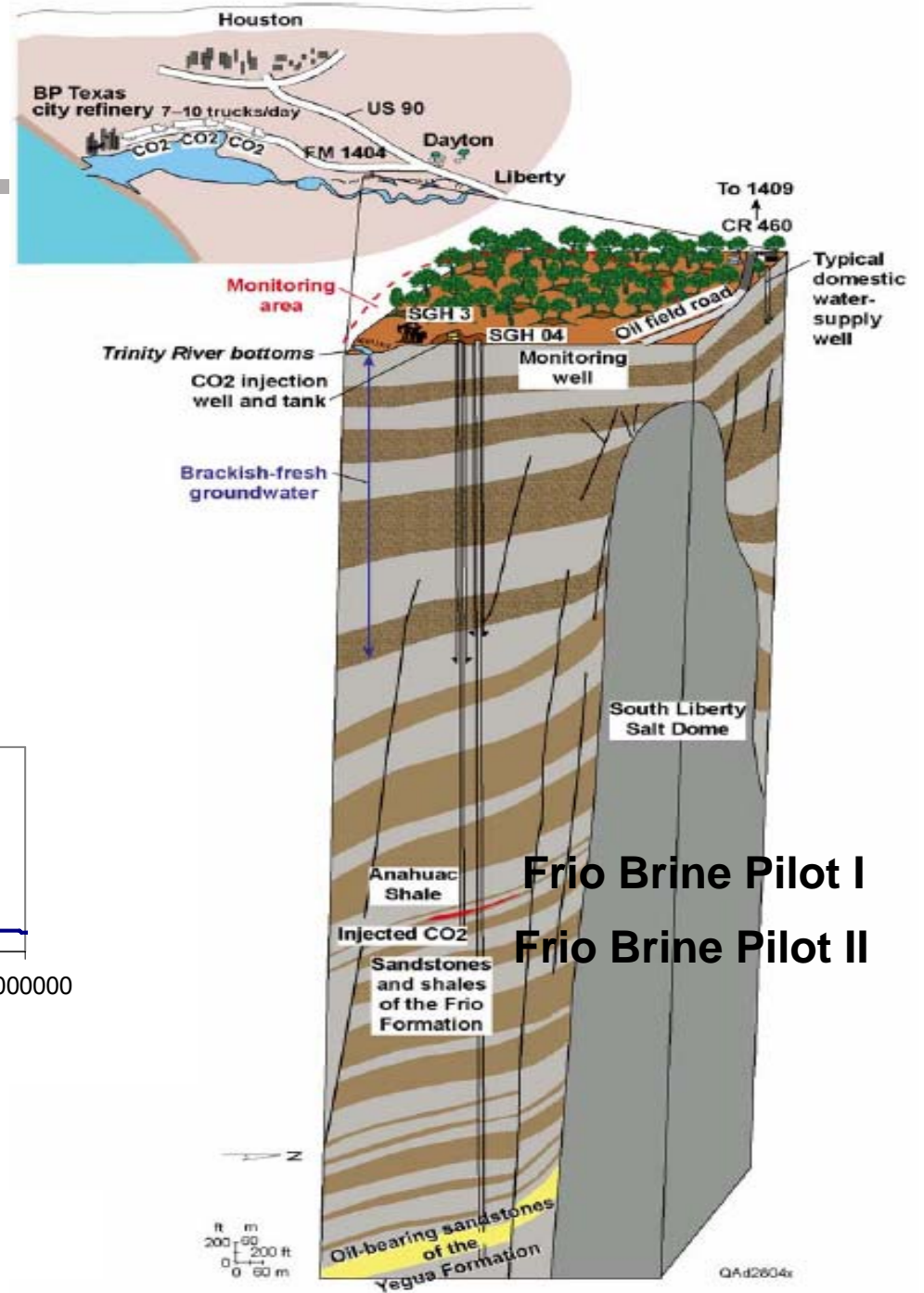
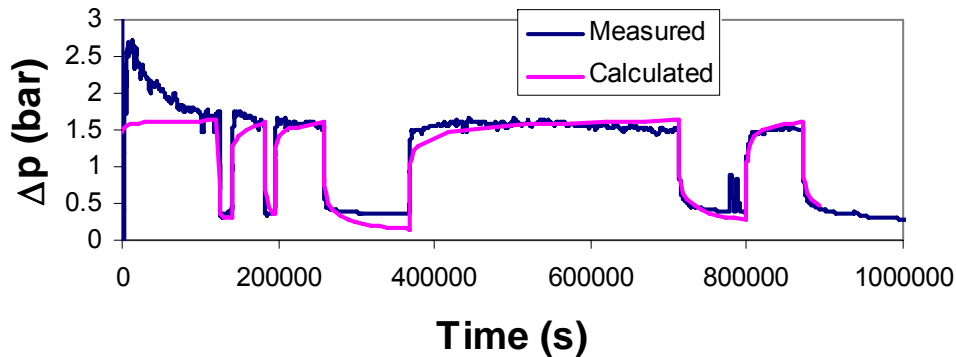


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# Characterization: Frio I and Frio II Pilot Tests



**Injection Well**





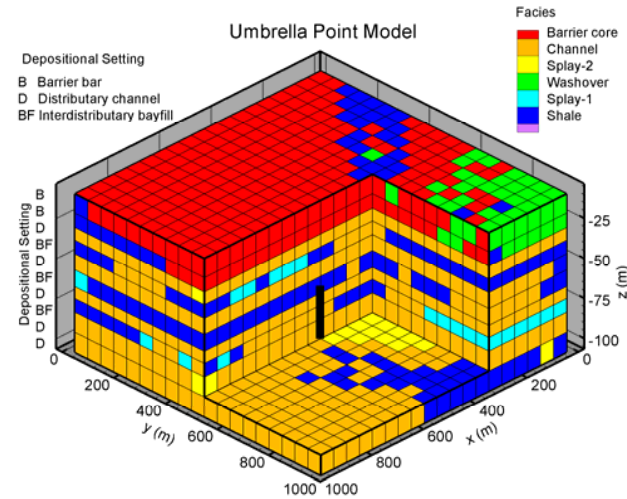
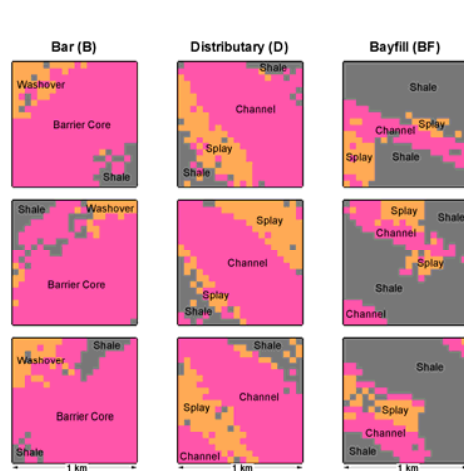
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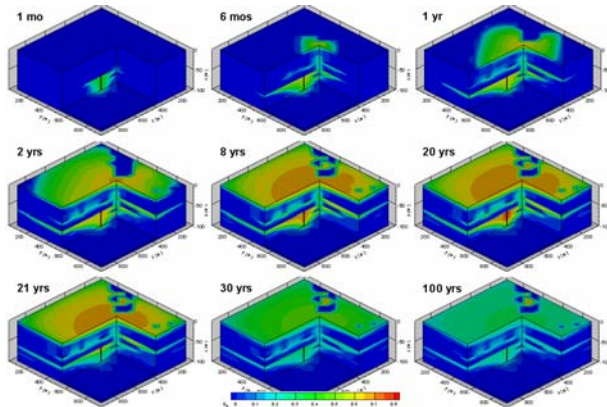
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# Storage Engineering: Storage Capacity and Trapping Mechanisms

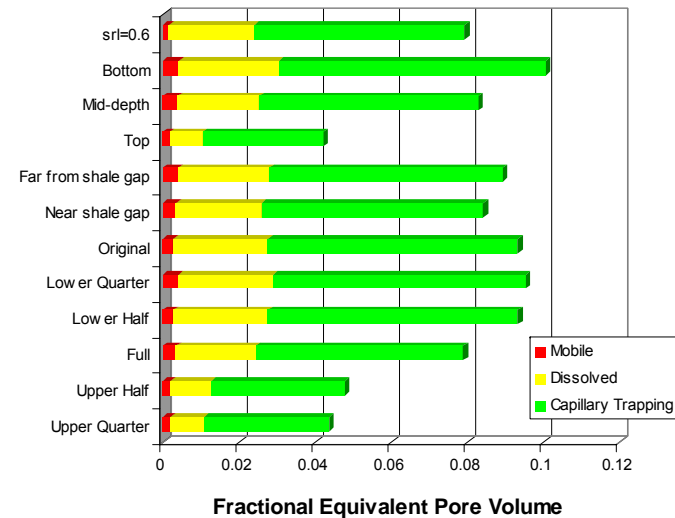


## Geological Model



## Reservoir Simulation

## Computational Grid



## Storage Capacity and Trapping



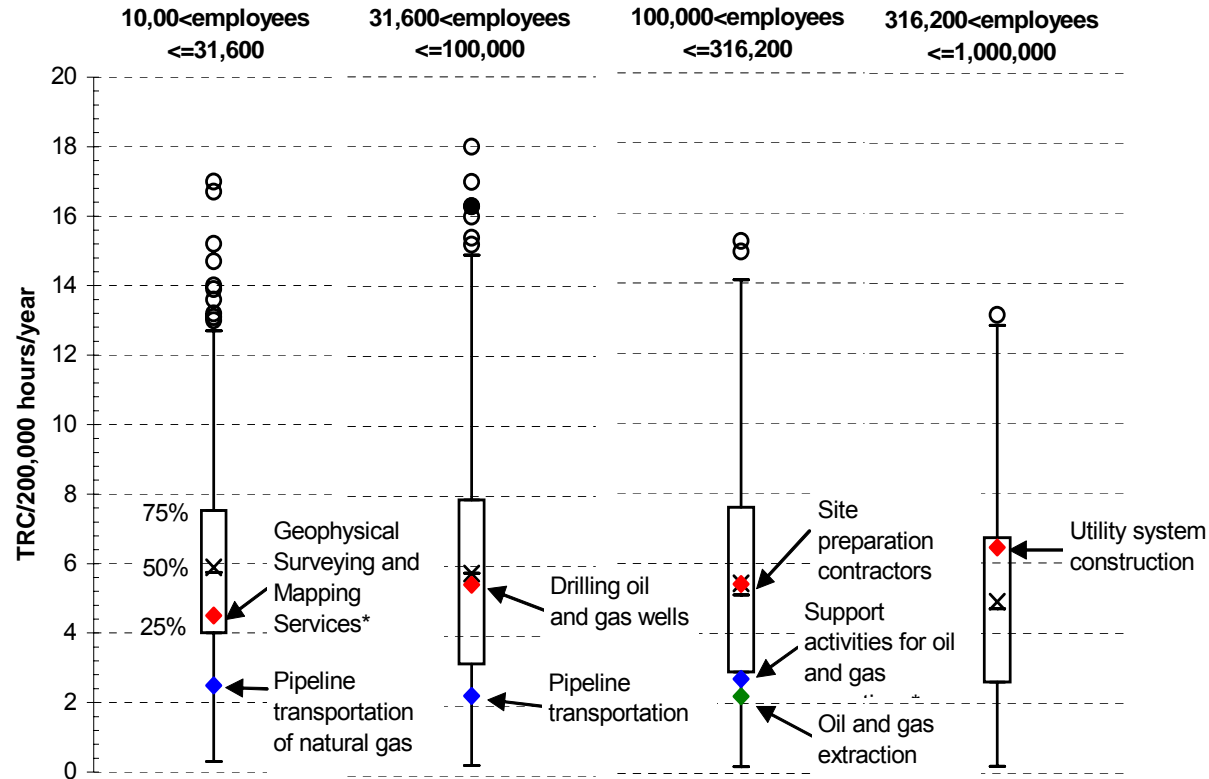
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# Safety: TRC Rate for Oil and Gas Related Activities



\*denotes industry class for which only 2004 rate available.

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.





# Is Geological Storage Ready for Prime Time?



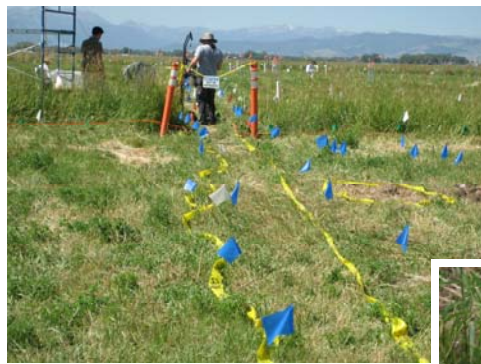
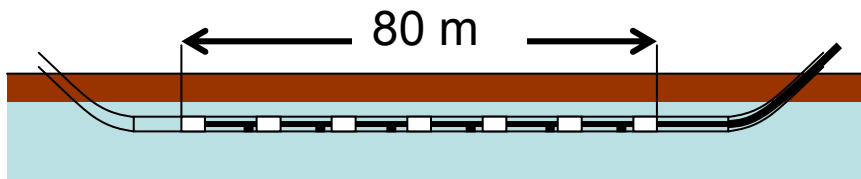
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# Monitoring: ZERT Detection Verification Facility



Detection Verification Facility  
(Montana State University)



Field Site

Horizontal  
Injection Well



Flow Controllers



Flux  
Tower

Hyperspectral  
Imaging of  
Vegetation



Soil Gas



Flux accumulation chamber

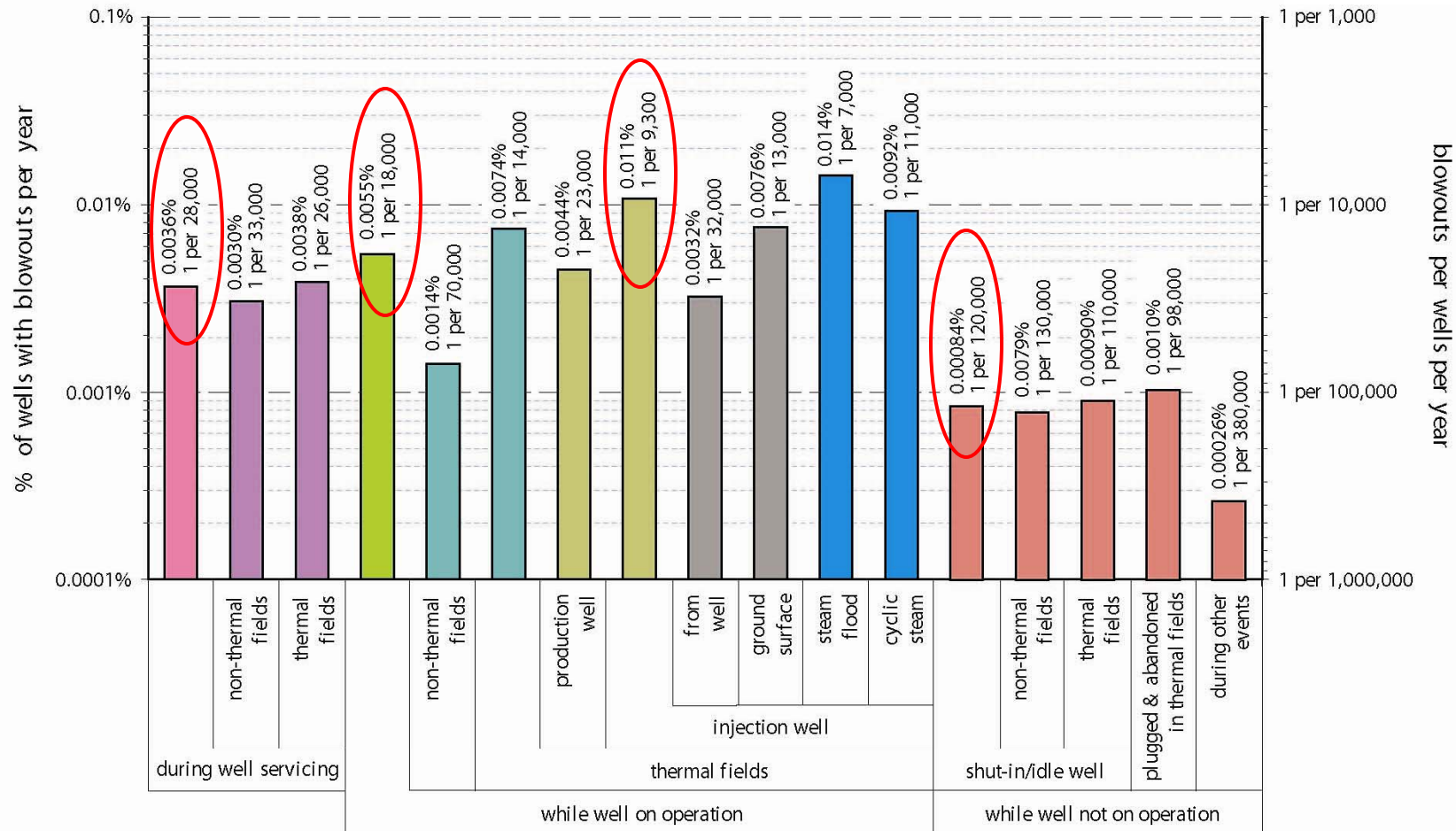


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# Blowout Frequency and Management in District 4, California



## District 4, California

- 50,277 active wells
- 18,660 shut-in wells
- 36,940 abandoned wells

Jordan and Benson, 2007, in preparation.



# Is Geological Storage Ready for Prime Time?



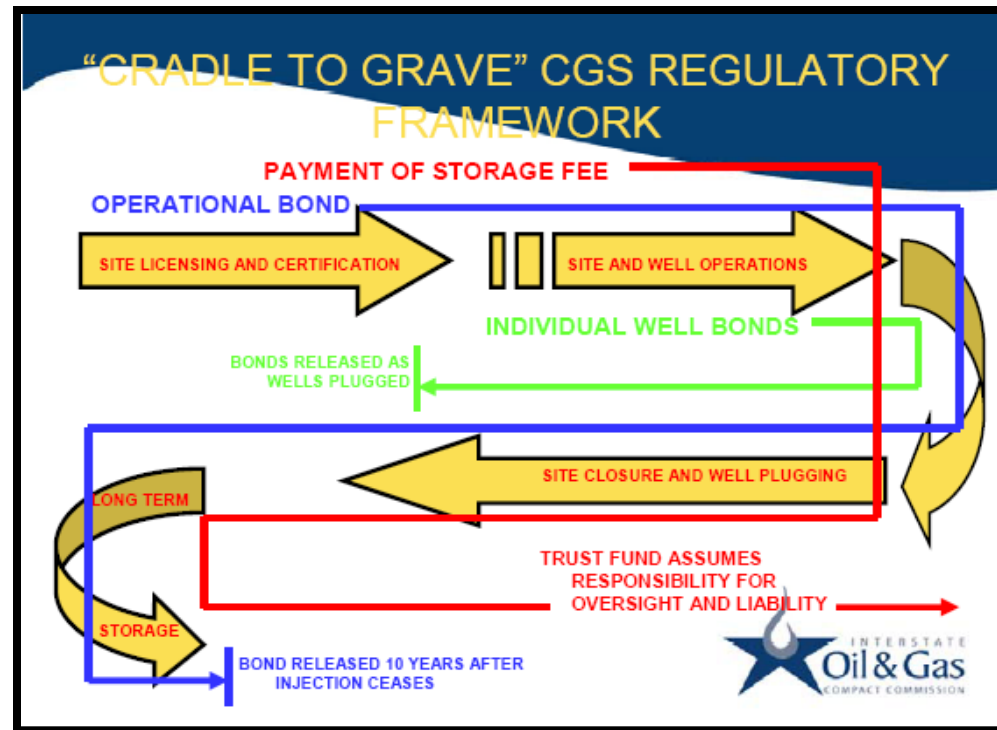
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# Regulations: “Cradle to Grave Regulatory Framework”



- Interstate Oil and Gas Regulatory Commission
- Seamless
- Simple
- Flexible and responsive
- Doable



*Storage of Carbon Dioxide in Geological Structures: A Legal and Regulatory Guide for States and Provinces. September, 2007.*

[http://www.iogcc.state.ok.us/docs/MeetingDocs/Master-Document-September-252007-FINAL-\(2\).pdf](http://www.iogcc.state.ok.us/docs/MeetingDocs/Master-Document-September-252007-FINAL-(2).pdf)



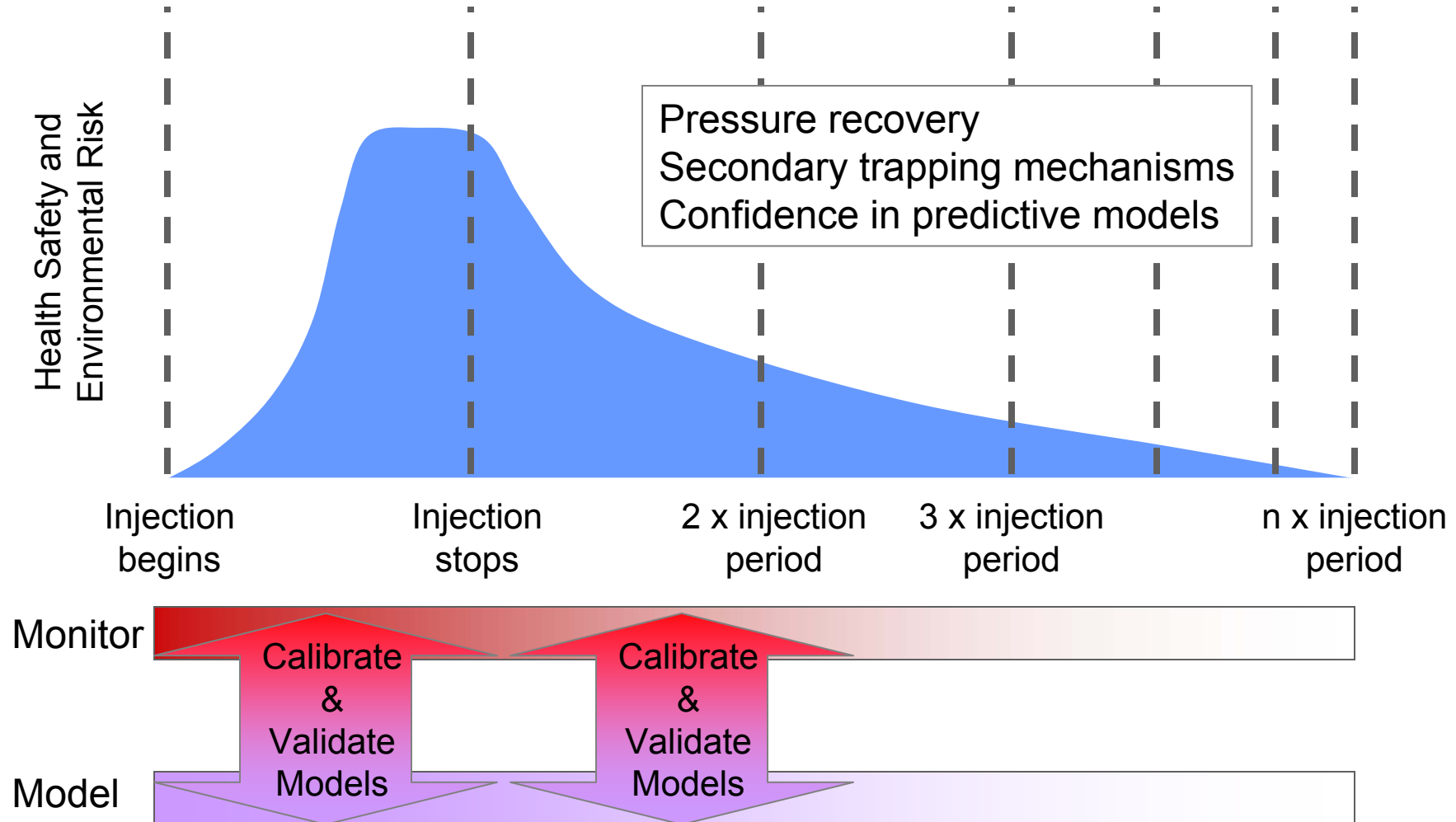
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# Quantitative Assessment of Long Term Liability and Risk Management Strategies







# Conclusions



- Is CCS Ready for Prime Time?
  - Oil and gas reservoirs: Yes
  - Saline aquifers: Ready for commercial scale demonstration projects
  - Coalbeds: Ready for pilot scale tests
- Readiness of storage safety and security strategy
  - Operational safety
  - Monitoring
  - Fundamental science, remediation, and site selection
  - Storage engineering, regulatory oversight
  - Long term financial responsibility



# Conclusions



- One persons opinion—mine
  - Engage scientific, engineering and regulatory community to assess state-of-the-art
  - Support deployment of demonstration projects now
  - Identify high impact areas
    - Fundamental and applied research
    - Pilot projects
-