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Safety and Monitoring of CO_2 Storage Projects

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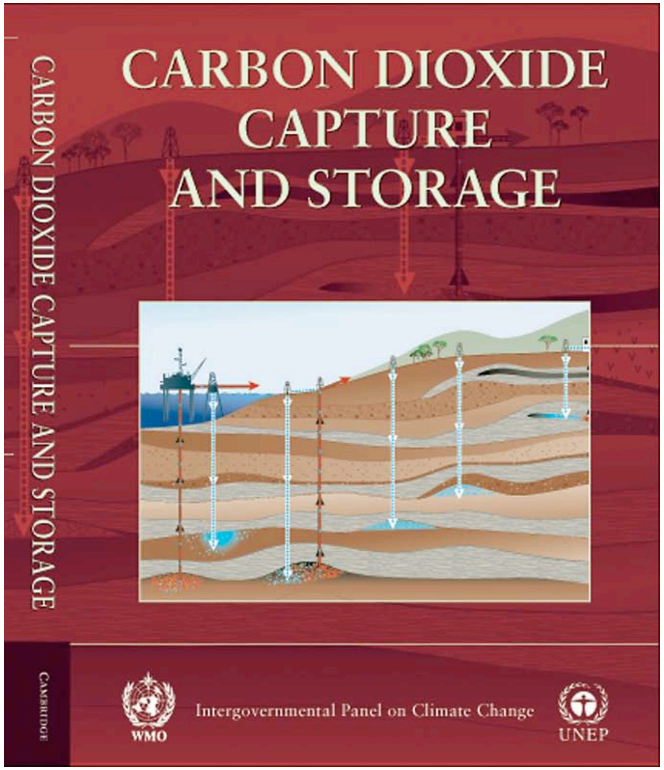
Outline

- Fundamentals of storage safety and security
  - Natural analogs
    - Oil and gas reservoirs
    - CO_2 reservoirs
  - Industrial analogues
    - Natural gas storage
    - CO_2 enhanced oil recovery
  - Existing projects
- Environmental risks of geological storage
- Risk management and mitigation
  - Storage security pyramid
  - Monitoring
- CCS development pathway

Expert Opinion about Storage Security from the IPCC Special Report on CO_2 Capture and Storage

"… the fraction retained in appropriately selected and managed geological reservoirs is likely to exceed 99% over 1,000 years."

" 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 CO_2 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."

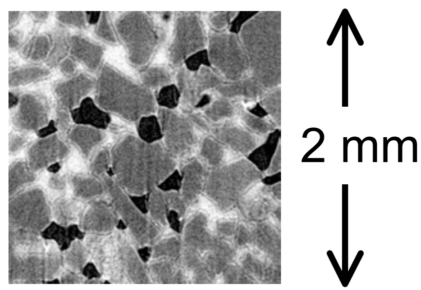


IPCC Special Report on CO_2 Capture and Storage, 2005

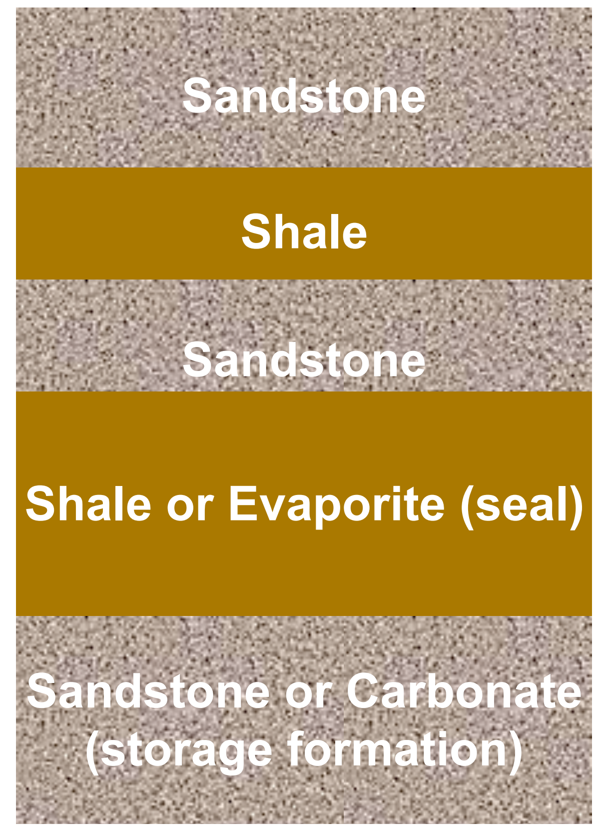
What Keeps the CO_2 Underground?

GCEP

- Injected at depths of 1 km or deeper into rocks with tiny pore spaces

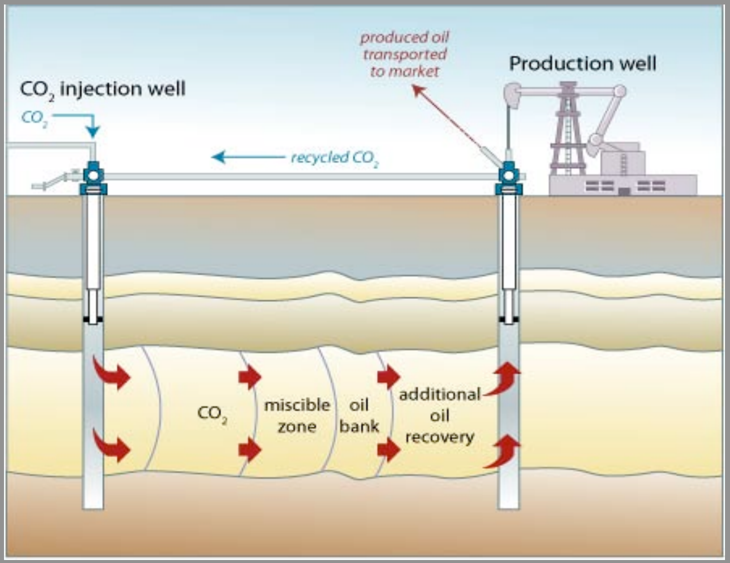


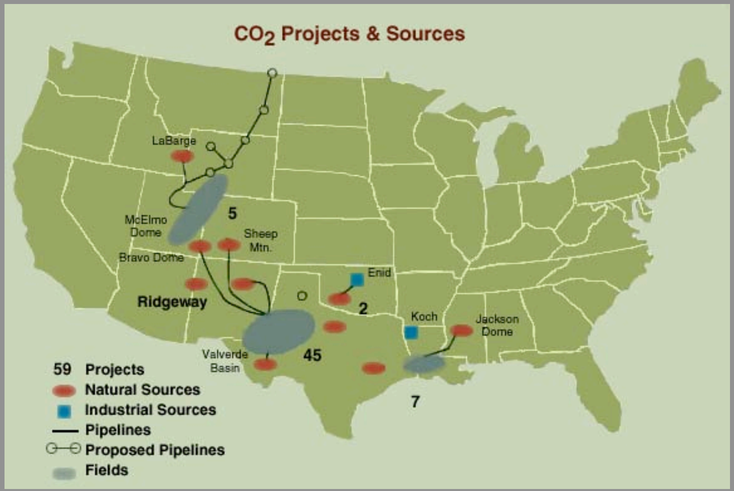
- Primary trapping
  - Beneath seals made of fine textured rocks that provide a membrane and permeability barrier
- Secondary trapping
  - CO_2 dissolves in water
  - CO_2 is trapped by capillary forces
  - CO_2 converts to solid minerals



Evidence to Support these Conclusions

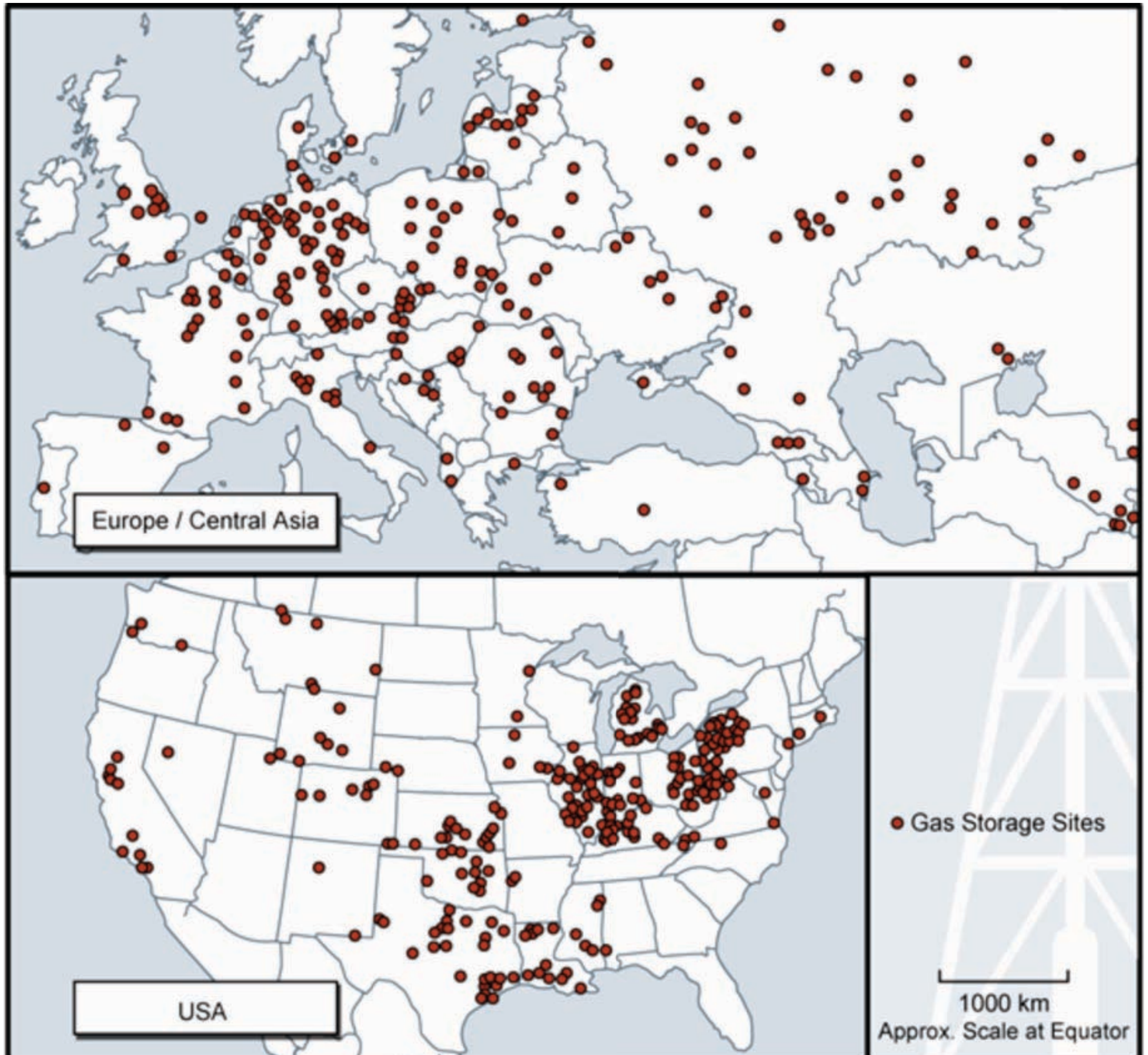
- Natural analogs
  - Oil and gas reservoirs
  - CO_2 reservoirs
- Performance of industrial analogs
  - 30+ years experience with CO_2 EOR
  - 100 years experience with natural gas storage
  - Acid gas disposal
- 20+ years of cumulative performance of actual CO_2 storage projects
  - Sleipner, off-shore Norway, 1996
  - Weyburn, Canada, 2000
  - In Salah, Algeria, 2004





~35 Mt/yr are injected for CO_2-EOR

Natural Gas Storage



- Seasonal storage to meet winter loads
- Storage formations
  - Depleted oil and gas reservoirs
  - Aquifers
  - Caverns

Role of Natural and Industrial Analogs

- Natural analogues
  - Proof that long term storage of buoyant fluids is possible
  - Identification of geological formations that can store CO_2
  - Understanding of geochemical interactions between CO_2 and rocks
  - Identification of features that cause leakage
- Industrial analogues
  - Demonstrated ability to extract and inject fluids
  - Health, safety and environmental performance
  - Injection technology
  - Modeling and monitoring technology

→ Proof that storage is possible.

→ Demonstration of how to do it.

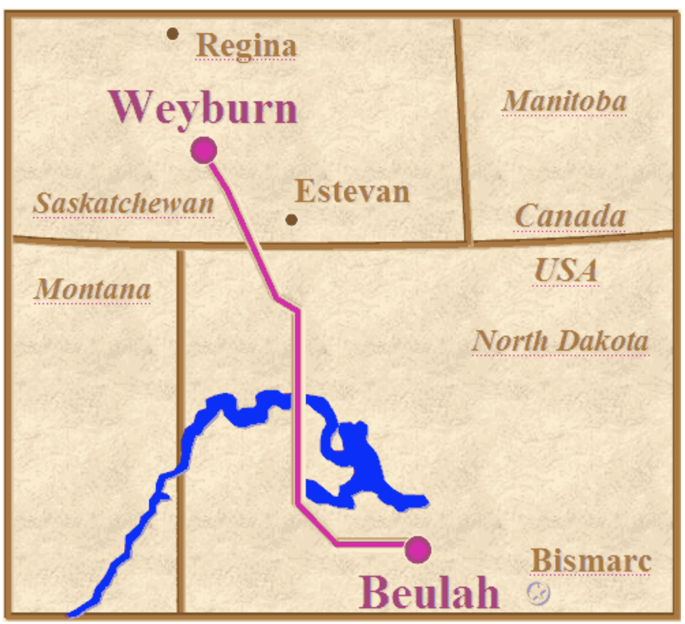
What Does a Good Storage Project Look Like?

- Three examples
  - Sleipner, off-shore Norway
  - Weyburn, Canada
  - In Salah, Algeria
- CO_2 remains in the storage reservoir
- Formation pressures remain below the fracture gradient
- Wellbore integrity is maintained
- Monitoring demonstrates satisfactory performance
- No serious accidents

Sleipner Saline Aquifer Storage Project

Weyburn CO_2-EOR and Storage Project

- 2000 to present
- 1-2 Mt/year CO_2 injection
- CO_2 from the Dakota Gasification Plant in the U.S.



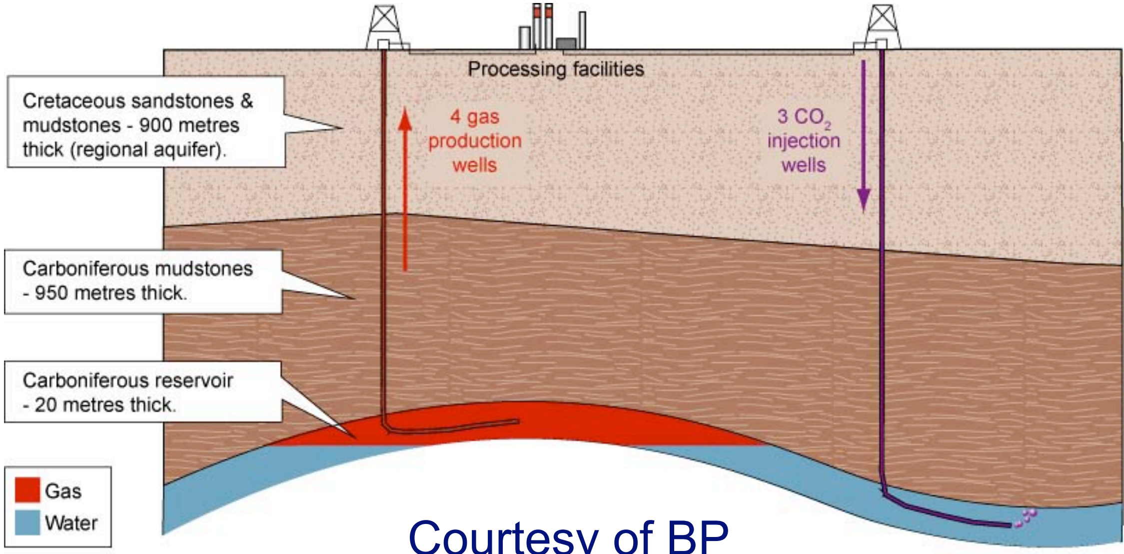
In Salah Gas Project

In Salah Gas Project
- Krechba, Algeria

Gas Purification
- Amine Extraction

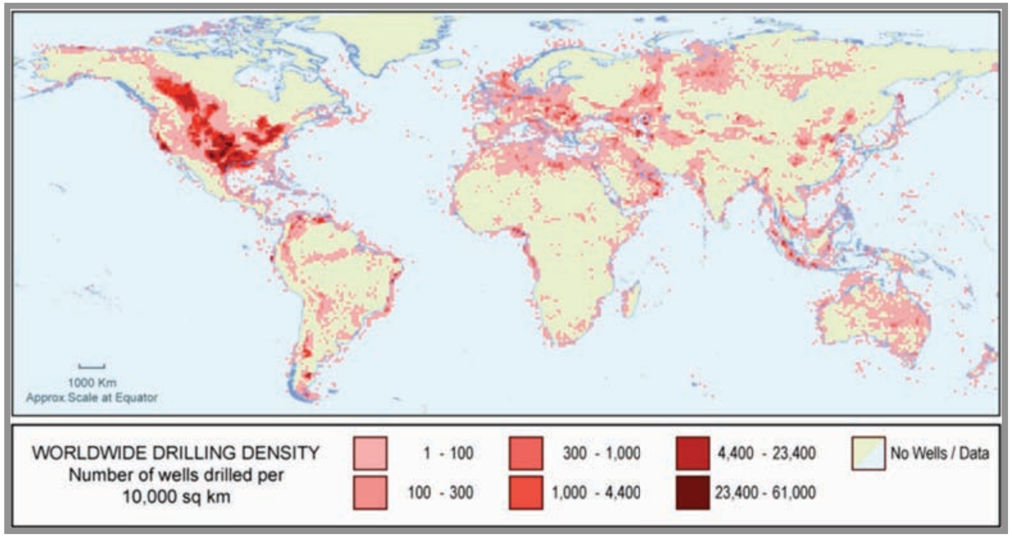
1 Mt/year CO_2 Injection

Operations Commence
- June, 2004



Courtesy of BP

What Could Go Wrong?



Potential Release Pathways

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

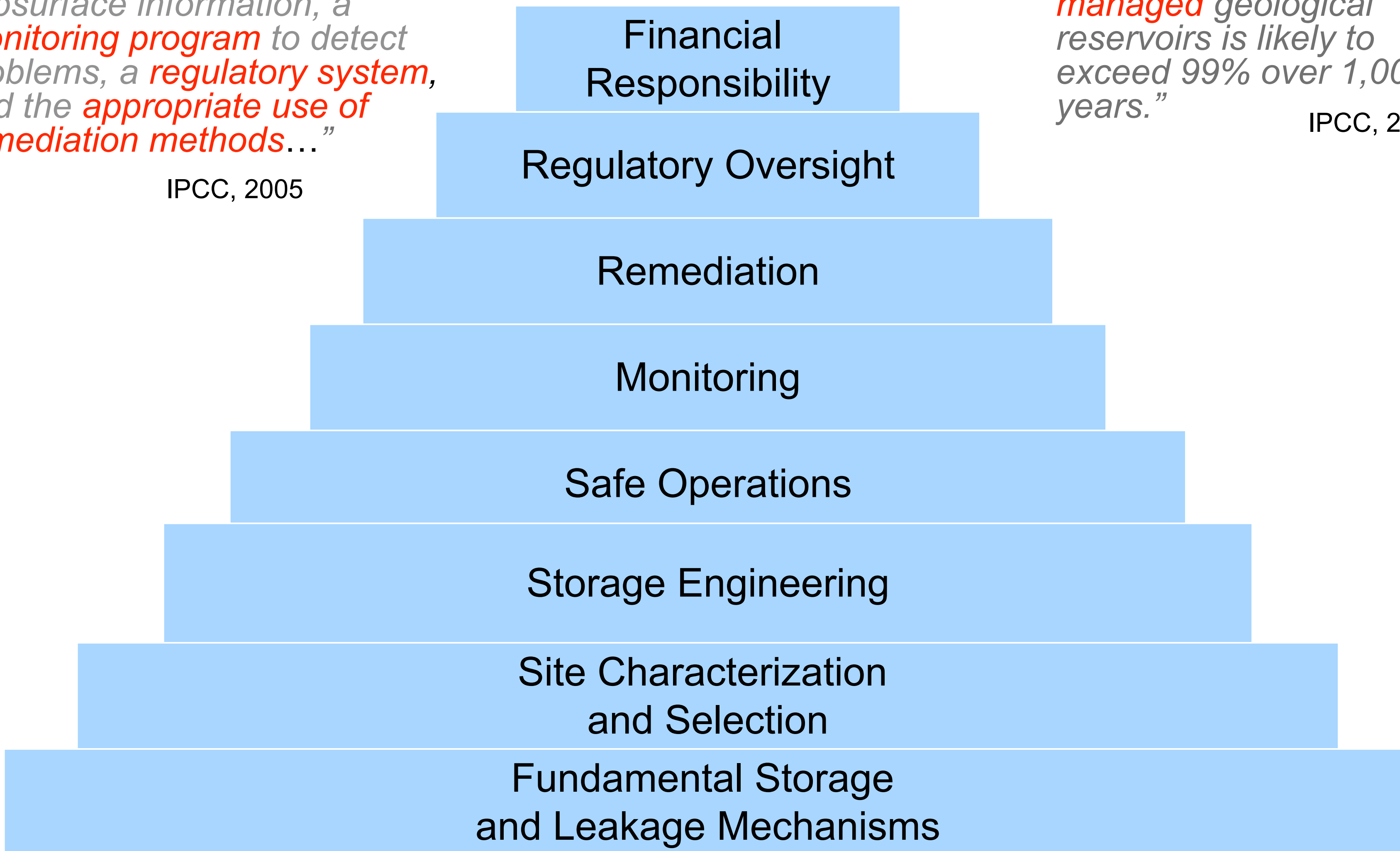
Potential Consequences

1. Worker safety
   - Industrial operations accidents
   - CO_2 exposure due to leakage from surface and subsurface facilities
2. Groundwater quality degradation
   - CO_2 and geochemical reaction products
   - Brine or gas displacement, including dissolved or separate phase hydrocarbons
3. Resource damage
   - Migration to oil and gas fields
   - Migration to minable coal
4. Ecosystem degradation
   - Terrestrial plants and animals
   - Aquatic plants and animals
5. Public safety
   - CO_2 exposure due to leakage from surface and subsurface facilities
6. Structural damage
   - Induced seismicity
   - Differential land surface subsidence or inflation
7. Release to atmosphere

Geological Storage Safety and Security Pyramid

" 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



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Financial Responsibility

Regulatory Oversight

Remediation

Monitoring

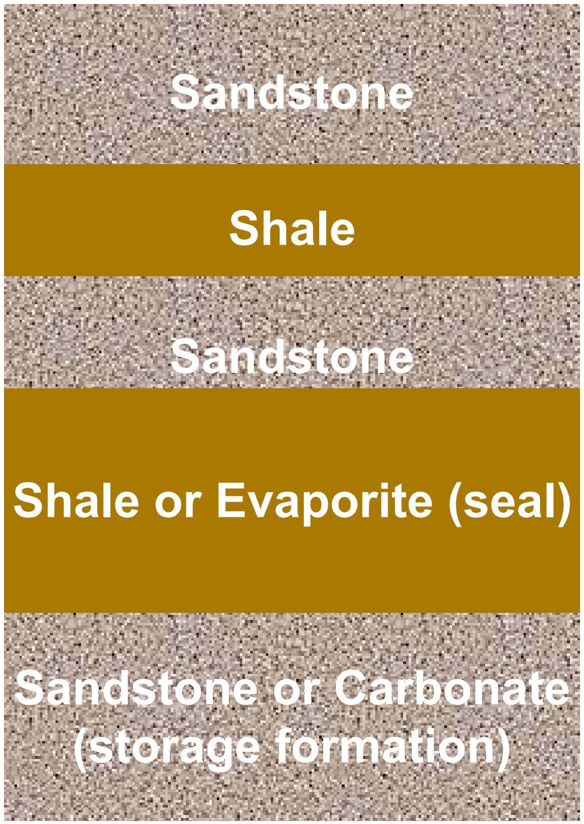
Safe Operations

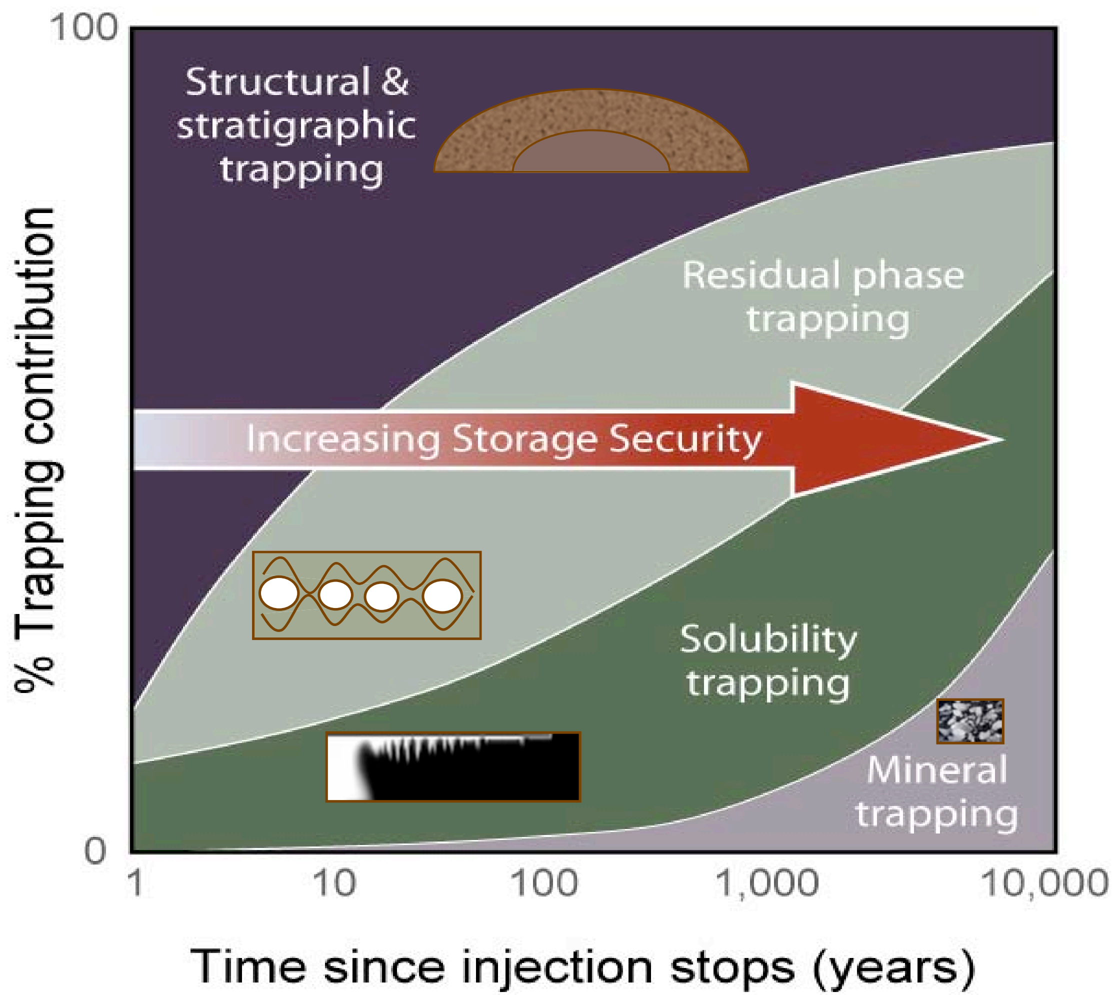
Storage Engineering

Site Characterization and Selection

Fundamental Storage and Leakage Mechanisms

Primary and Secondary Trapping Mechanisms





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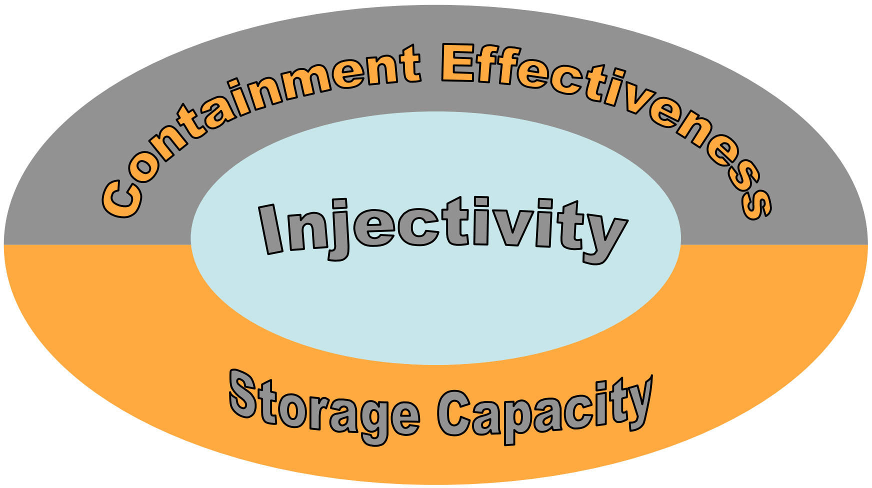
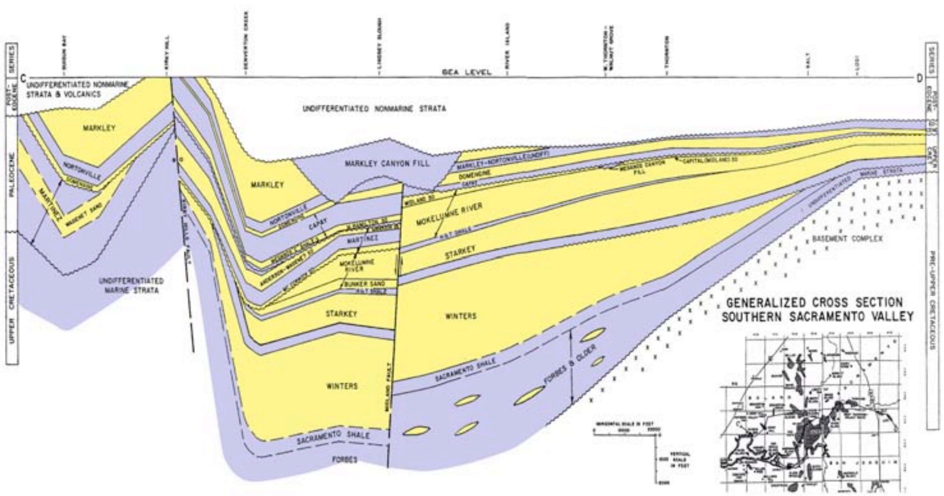
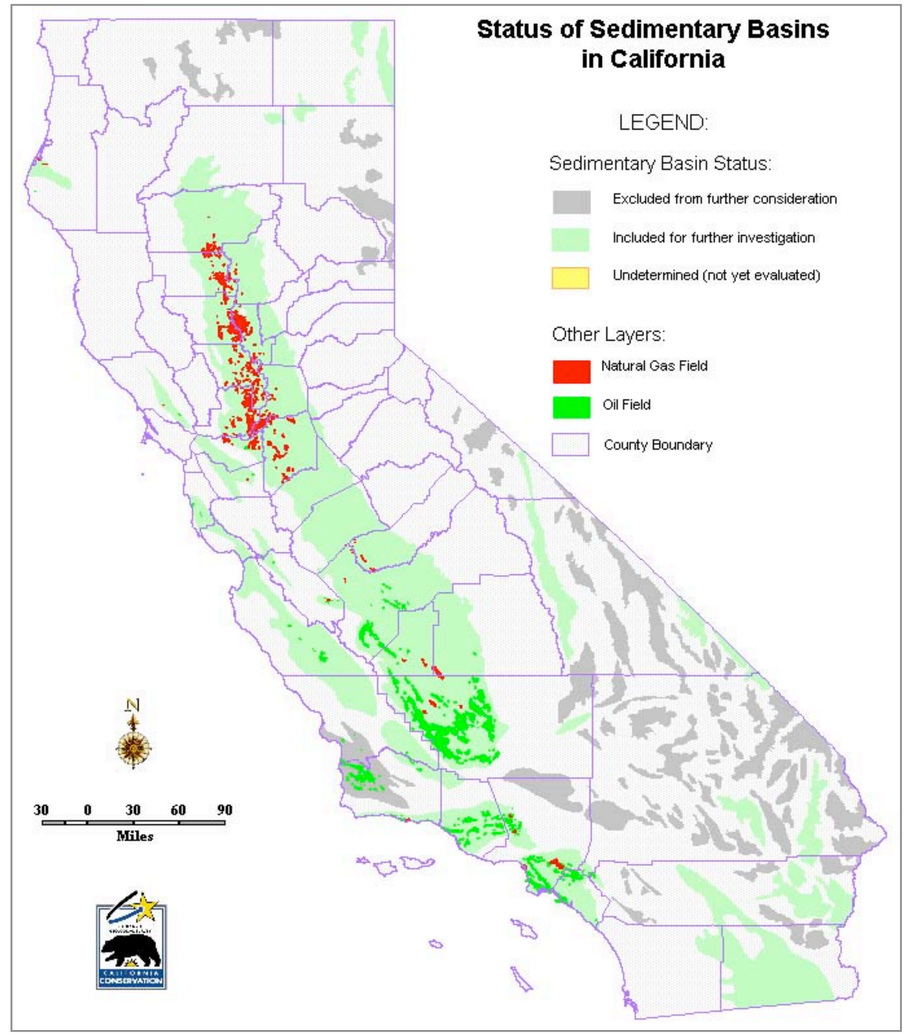
Site Characterization and Site Selection







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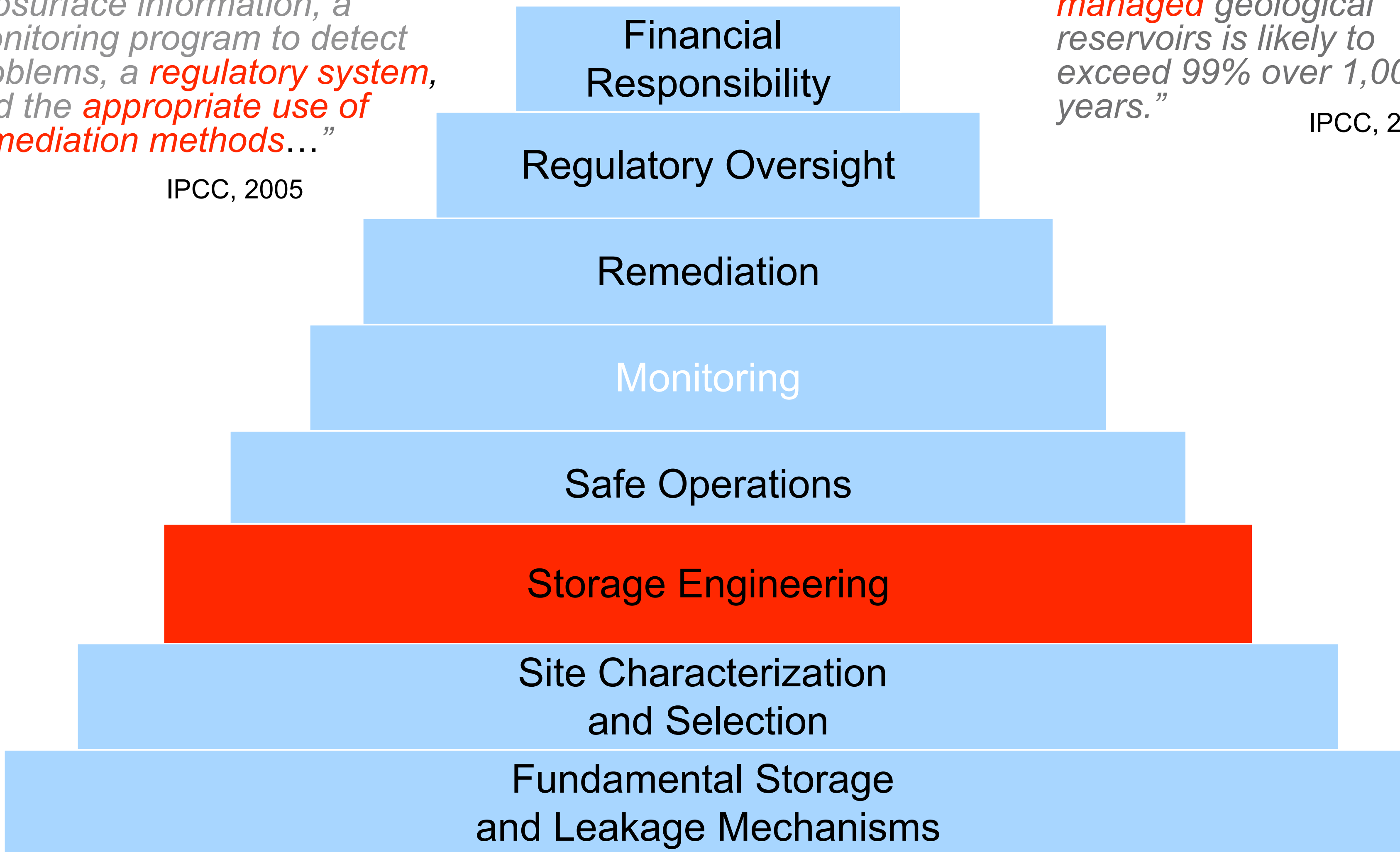

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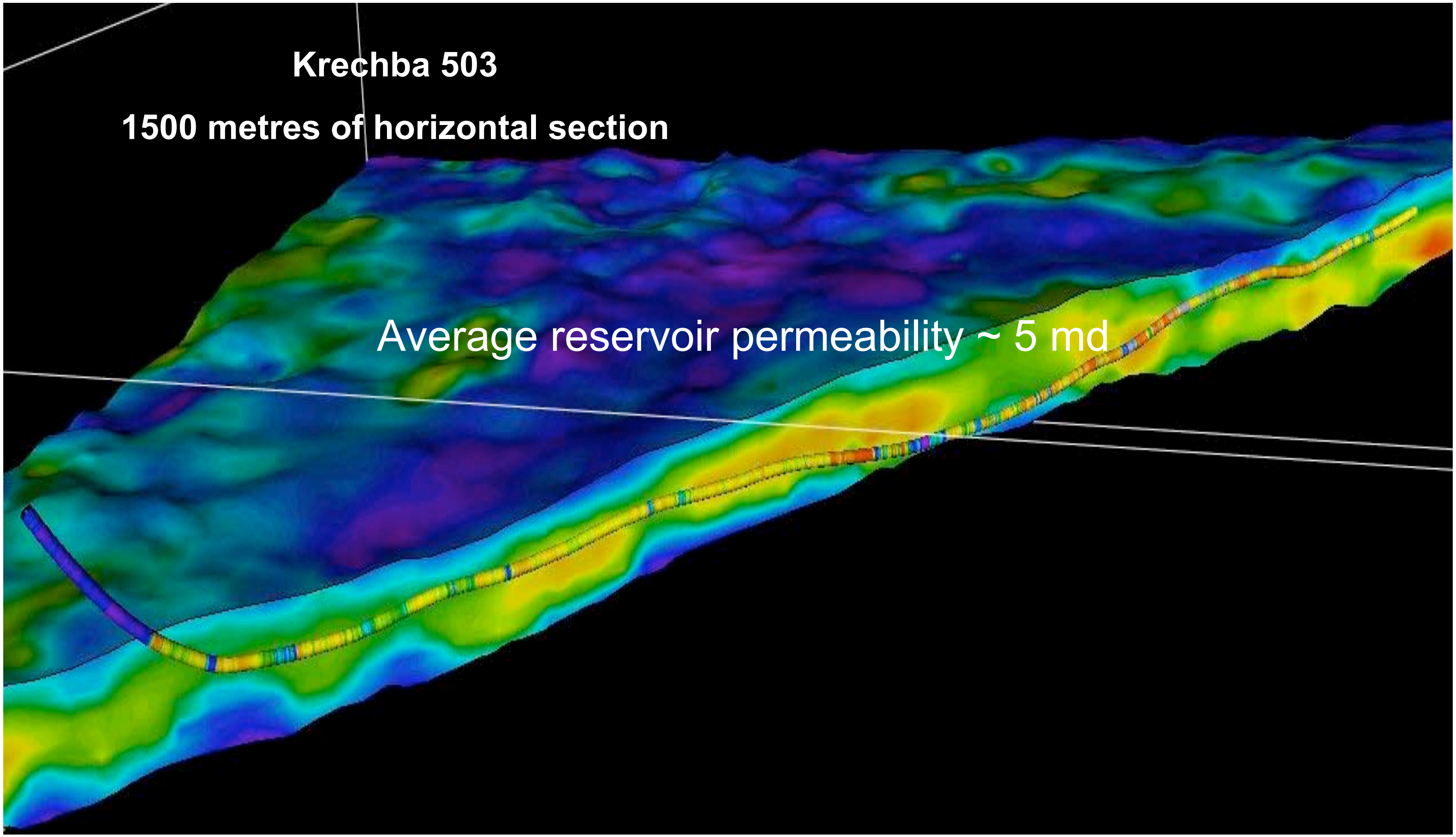
Increasing Injectivity with Long Reach Horizontal Wells



Courtesy of BP

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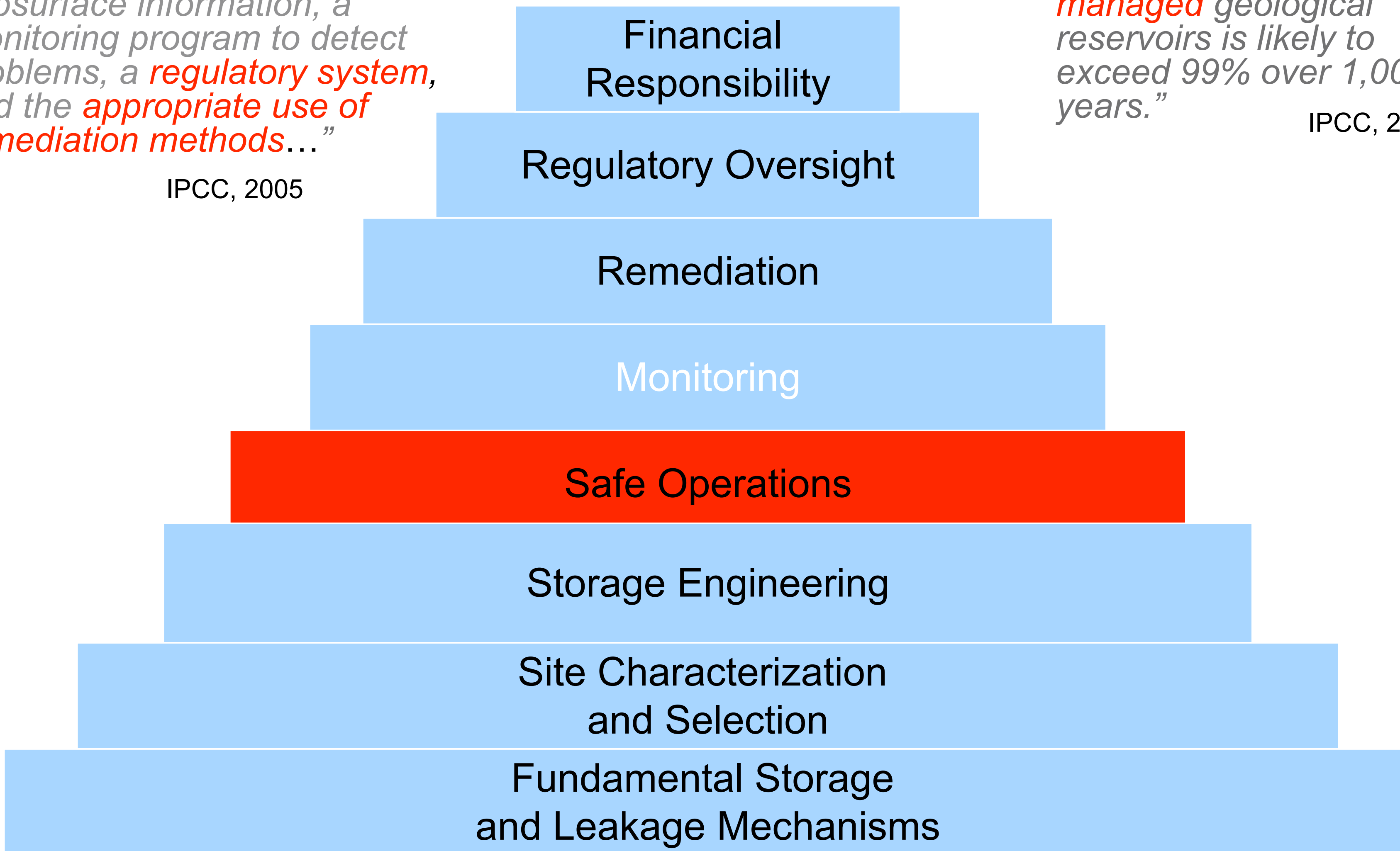

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Conclusions from Safety Analysis

- Industrial analogues suggest that CCS activities will have
  - Accident rates less than overall industry average
  - When accidents occur, they are more likely to result in days away from work than the industry average
  - Fatality rates typical of heavy industry
  - Well blowouts are rare events

Risks of CCS will be comparable to many workplace activities taking place today.

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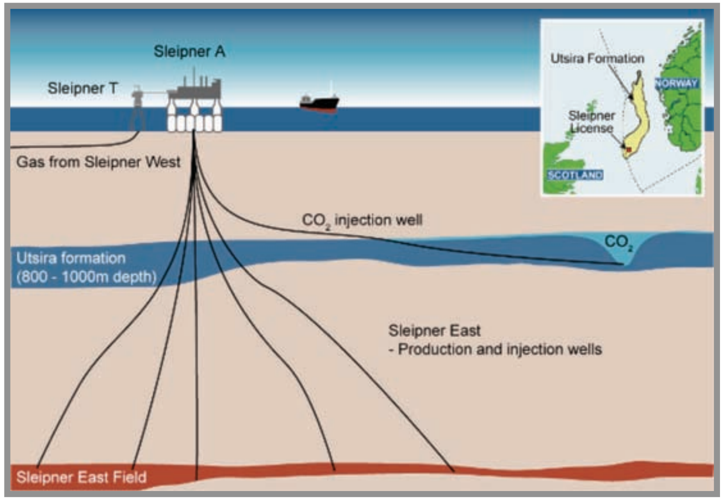
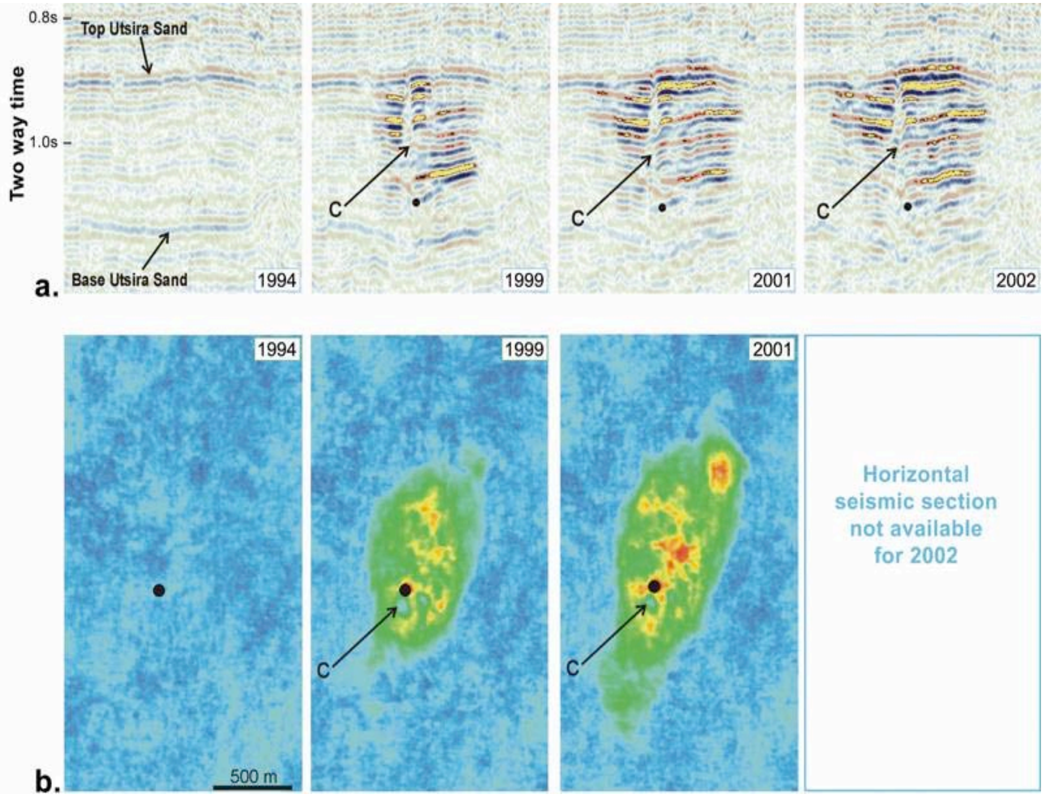
Seismic Monitoring Data from Sleipner



Sleipner Aquifer Storage Project



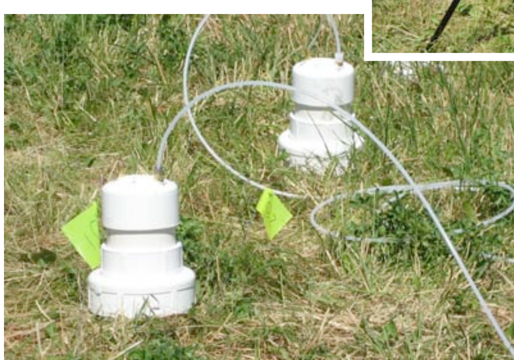
From Andy Chadwick, 2004

Photo and image, courtesy of Statoil

Surface Monitoring

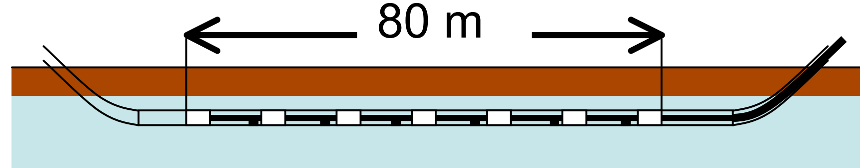
Flux Tower

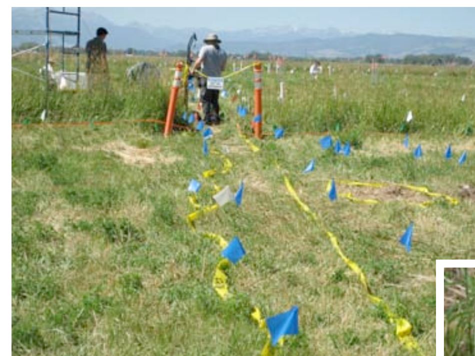
Hyperspectral Imaging of Vegetation



Soil Gas

Detection Verification Facility (Montana State University)



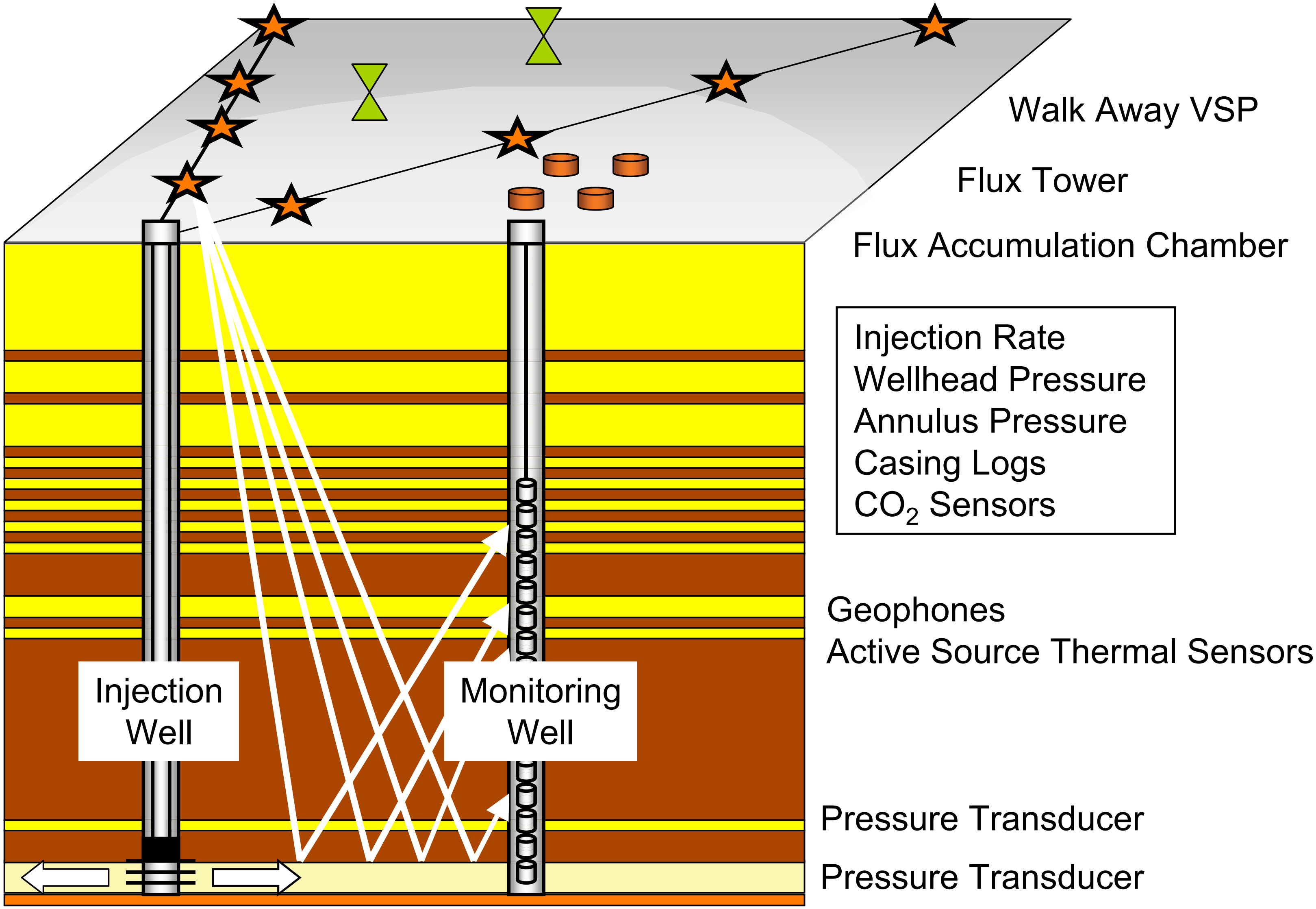


Field Site

Horizontal Injection Well

Flow Controllers

Monitoring Methods



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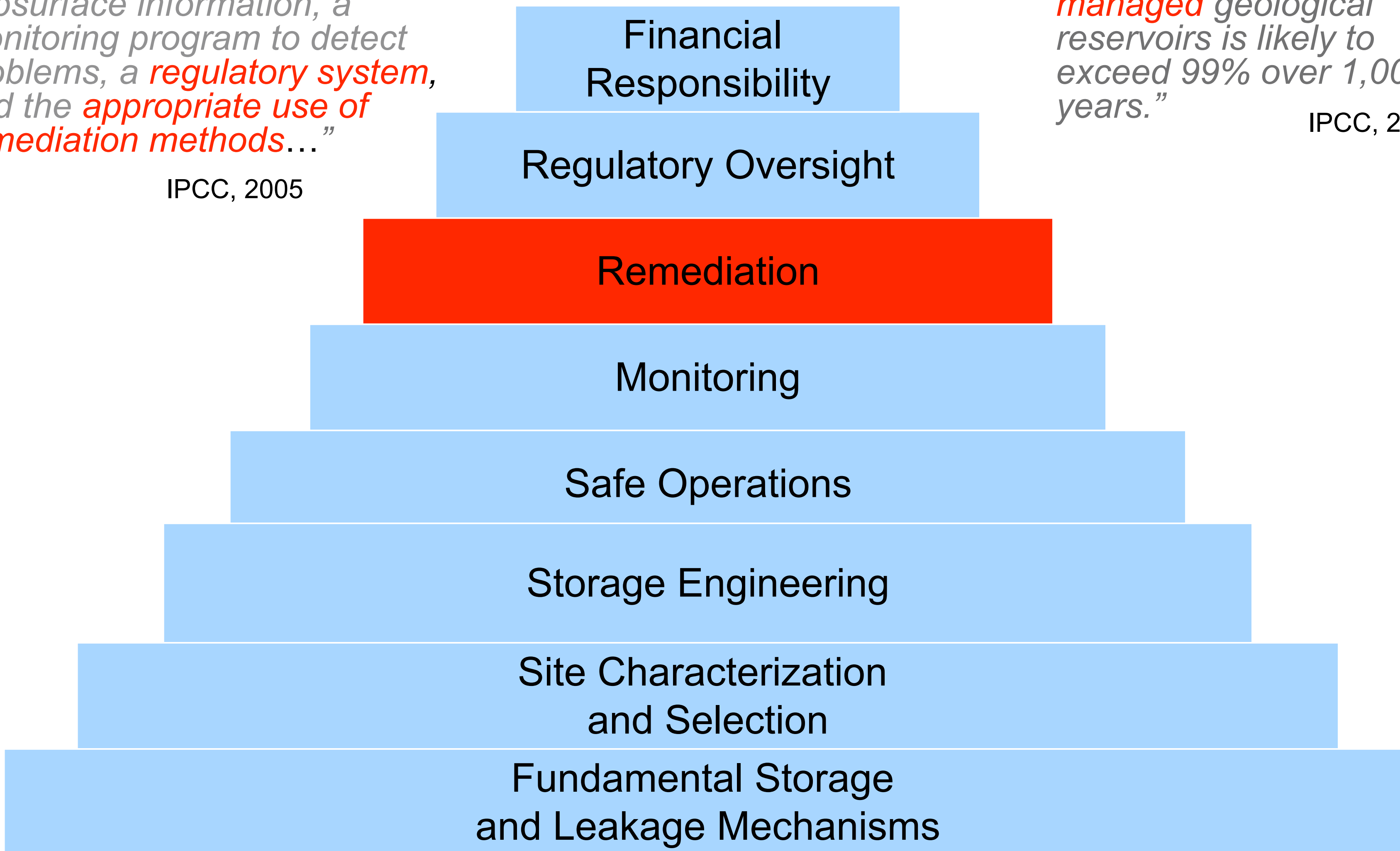

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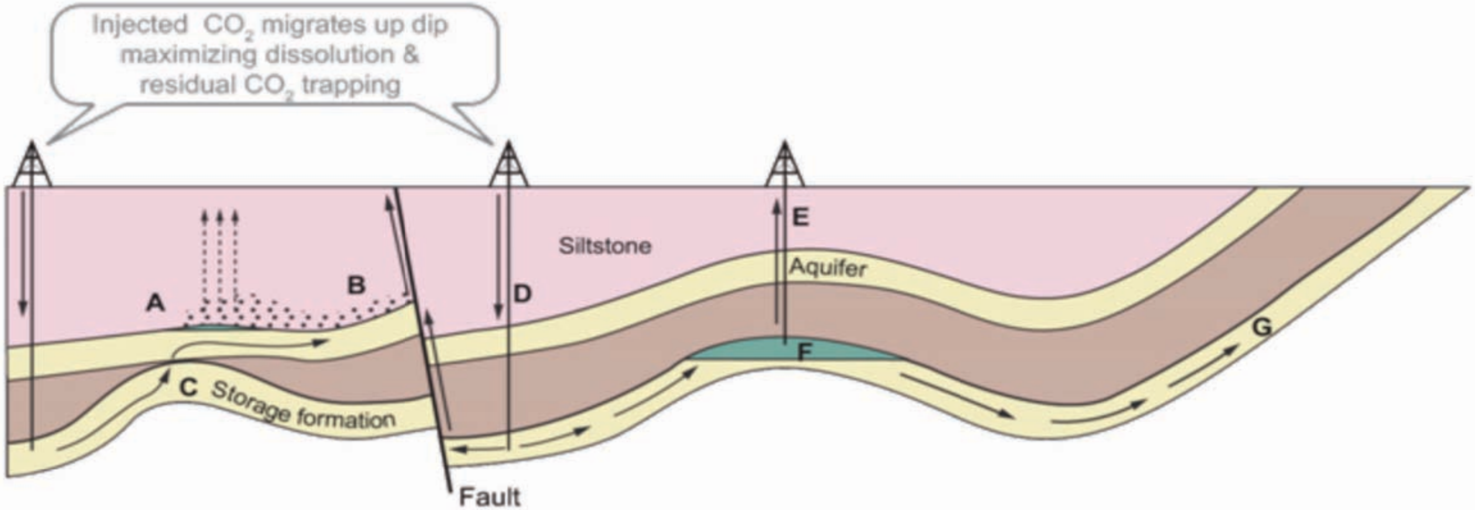
Reliable Remediation Methods Needed for Each Leakage Scenario



Potential Escape Mechanisms

A. CO_2 gas pressure exceeds capillary pressure & passes through siltstone	**B.** Free CO_2 leaks from A into upper aquifer up fault	**C.** CO_2 escapes through 'gap' in cap rock into higher aquifer	**D.** Injected CO_2 migrates up dip, increases reservoir pressure & permeability of fault	**E.** CO_2 escapes via poorly plugged old abandoned well	**F.** Natural flow dissolves CO_2 at CO_2 / water interface & transports it out of closure	**G.** Dissolved CO_2 escapes to atmosphere or ocean

Remedial Measures

***A.** Extract & purify ground-water*	***B.** Extract & purify ground-water*	***C.** Remove CO_2 & reinject elsewhere*	***D.** Lower injection rates or pressures*	***E.** Re-plug well with cement*	***F.** Intercept & reinject CO_2*	***G.** Intercept & reinject CO_2*

Source: IPCC, 2005

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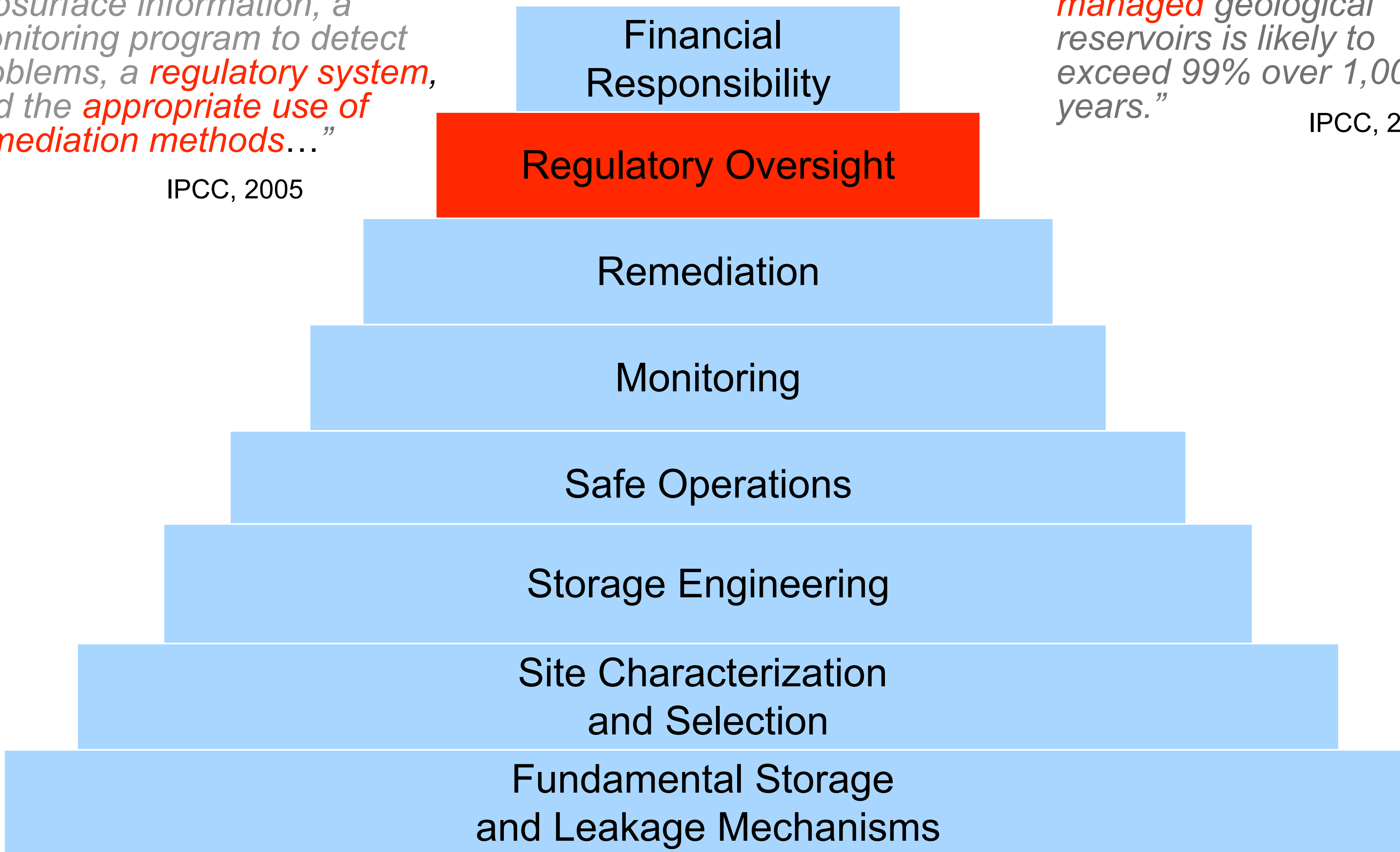

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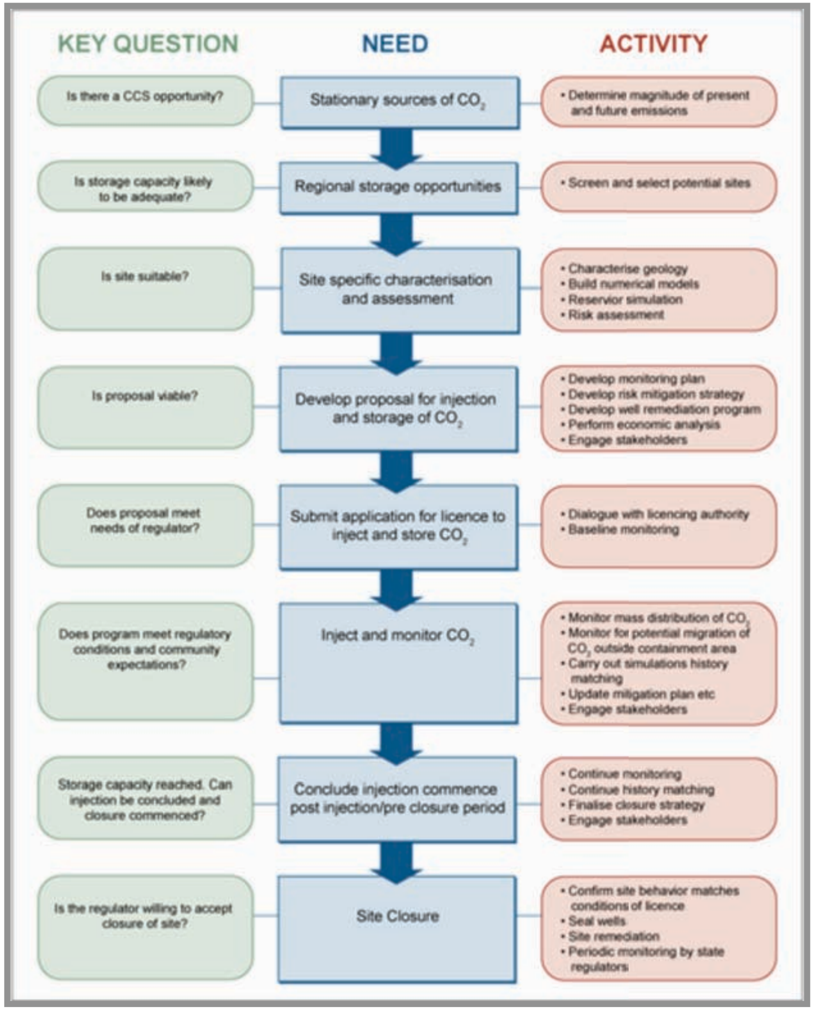
Regulatory Oversight

- Oversight of due diligence
  - Site selection
  - Operational parameters
  - Monitoring
  - Remediation plans
  - Site closure
- Transparency
- Confidence building

The regulatory regime for CCS is being considered. Long term stewardship needs to be resolved



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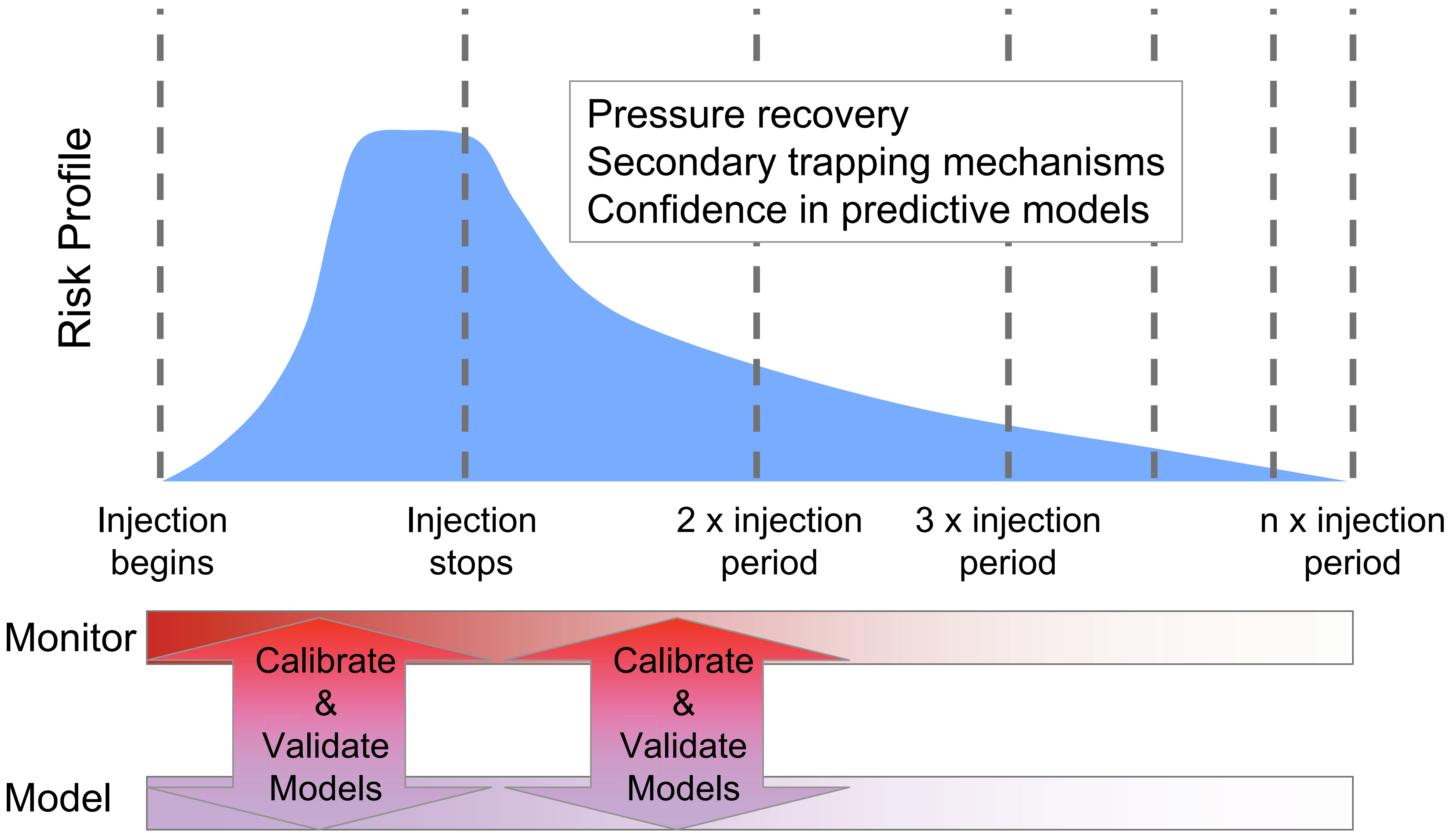
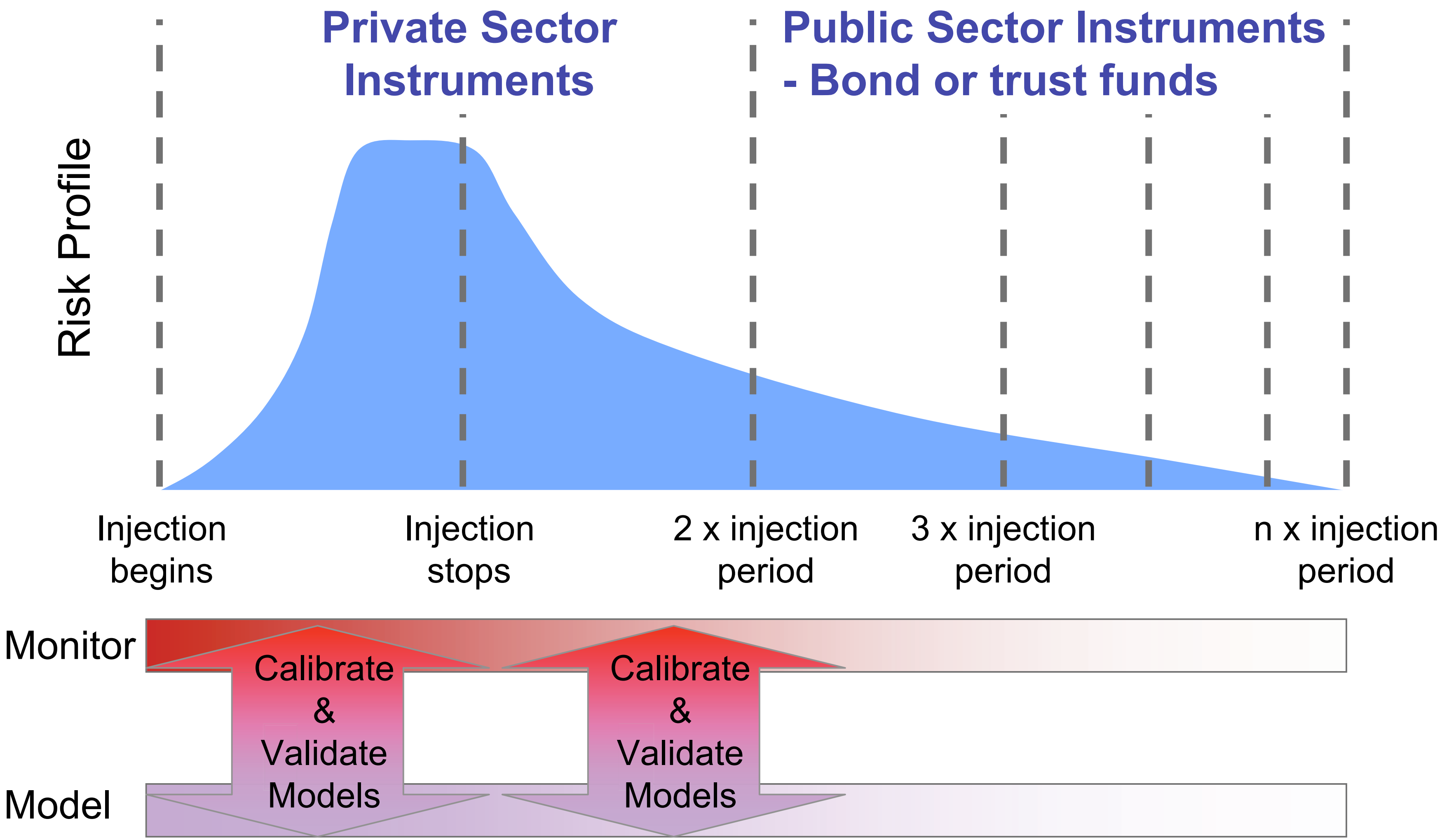
Risk Profile of a Storage Project



Phased Approach to Financial Responsibility



Integrated Technology Development Pathway