Carbon Capture and Geologic Storage

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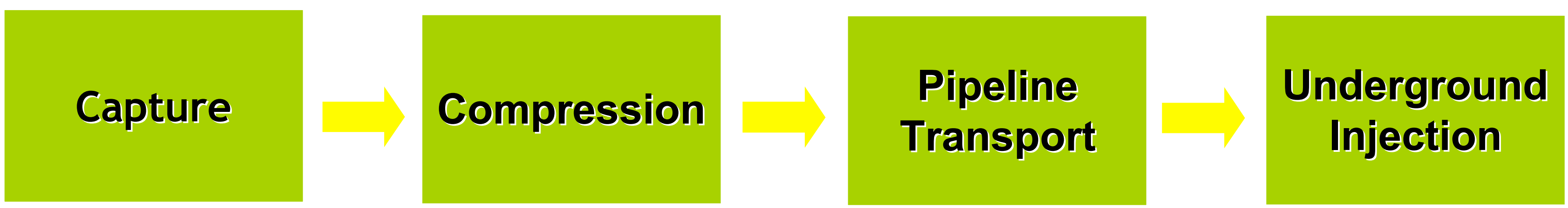
Topics

- Introduction
- Capture options
- CCS costs
- Storage options/mechanisms
- Storage capacity
- Geologic storage risks
- Need for monitoring
- Field studies
- Beyond coal

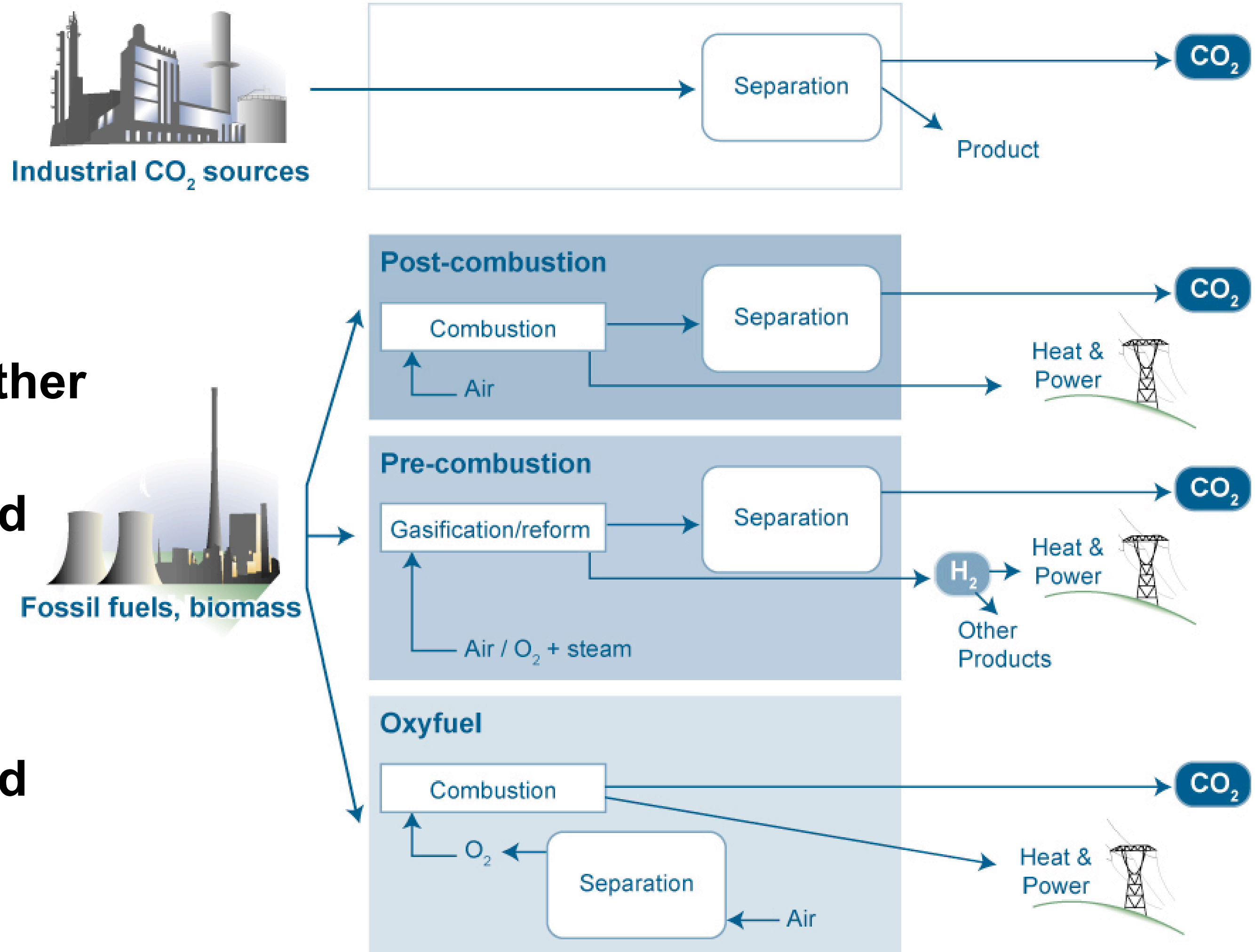
CO_2 Capture and Storage Technology

- **CCS is a four-step process**
  - **Pure stream of CO_2 captured from flue gas or other process stream**
  - **Compressed to ~100 bars**
  - **Transported to injection site**
  - **Injected deep underground into geological formation and stored safely for thousands of years**



Options for CO_2 Capture

- **Post-combustion**
  - **Established technology**
- **Pre-combustion**
  - **Established technology for other applications**
  - **Not demonstrated for power production**
- **Oxygen combustion**
  - **Not demonstrated for power production**



Source: S Benson, Stanford

CCS Costs

- Power generation from coal
  - —Additional $35 - 45/ MWh
  - —$50 – 60/tonne CO_2 avoided
- Power generation from natural gas
  - —Additional $30/MWh
  - —$80/tonne CO_2 avoided
- Industrial processes producing pure CO_2 stream
  - — $20 – 30/tonne CO_2 avoided
- EOR credit can offset ~$20/tonne

Source: H Herzog, MIT

Elements of Cost Estimates

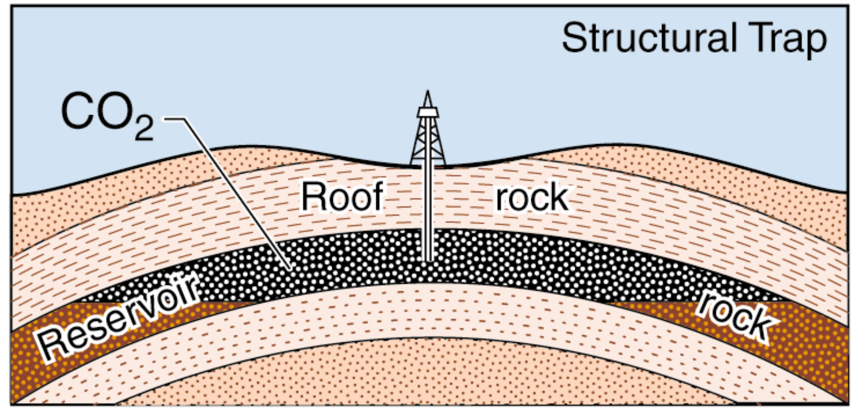
- Region specific (CA conditions for given costs)
- 90% of CO_2 is captured
- Transport and storage included ($10/tonne)
  - —Monitoring costs estimated as $.10 - .50/tonne
- Current technology
- Operations at scale

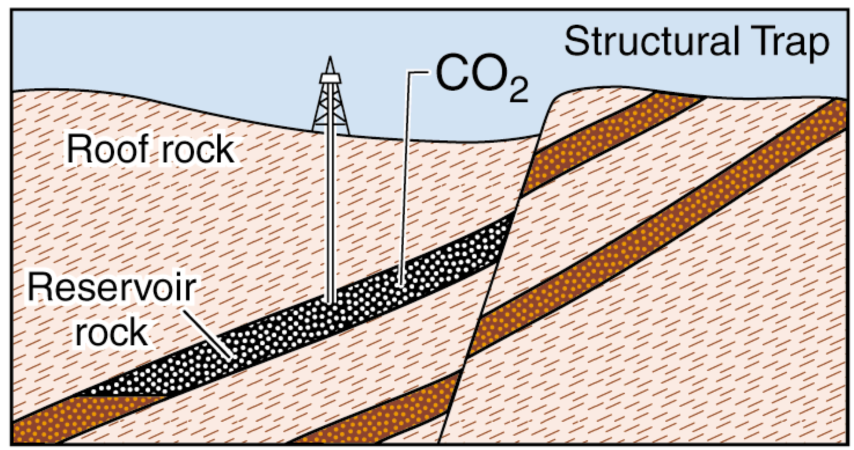
Primary Storage Options

- Oil and gas reservoirs
  - Storage with Enhanced Oil Recovery (EOR), Enhanced Gas Recovery (EGR)
  - Storage only
- Deep, unminable coal beds
  - Storage with Enhanced Coal Bed Methane (ECBM) recovery
- Saline formations
  - Storage only

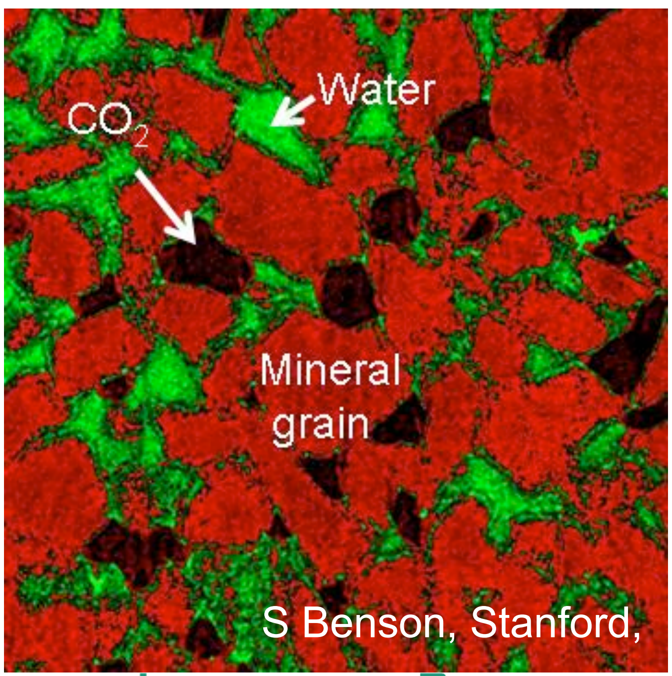
Geologic Storage Mechanisms

- **Physical/structural trapping**
- **Dissolution**
- **Phase trapping**
- **Mineralization**
- **Surface adsorption**

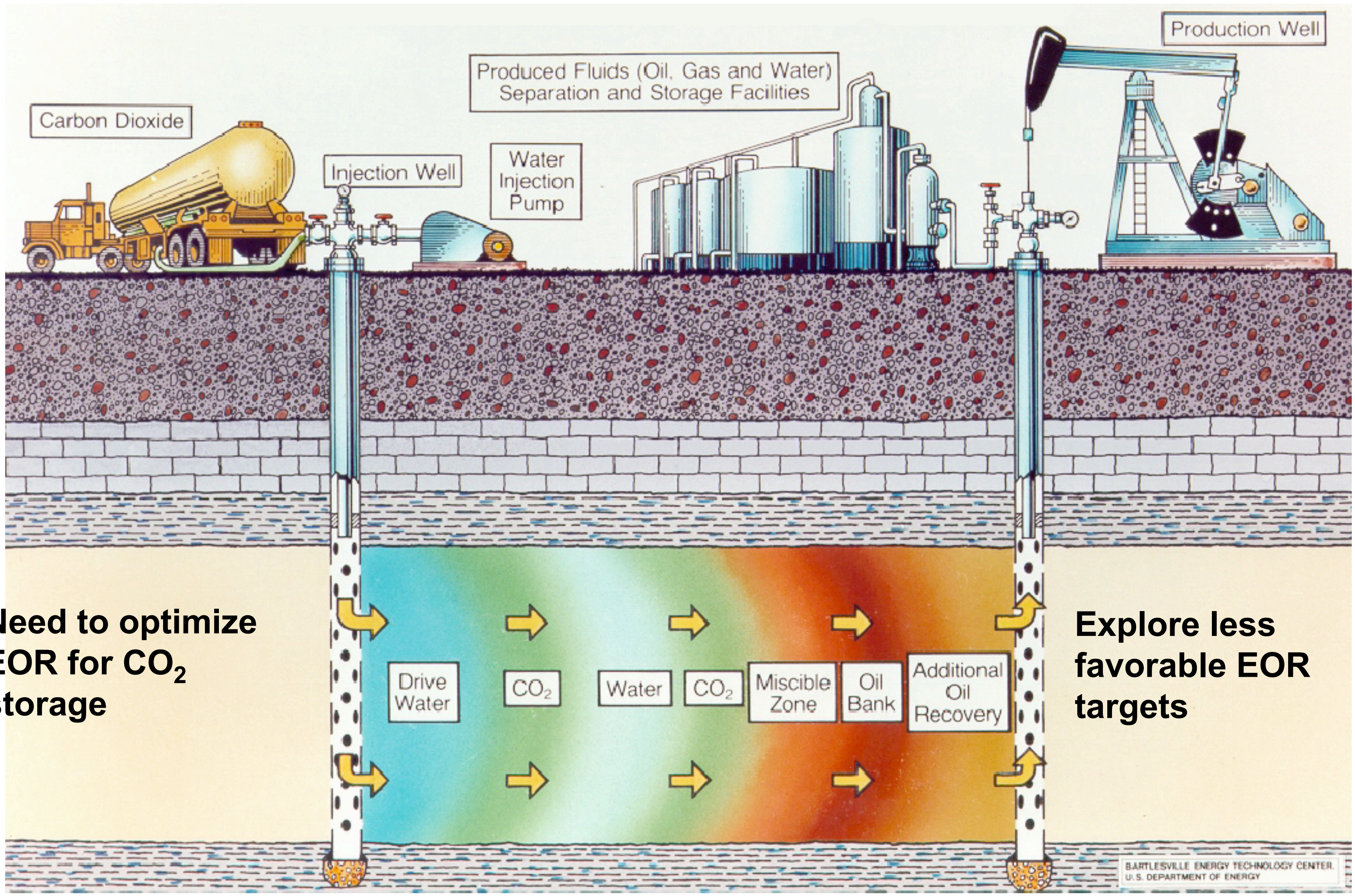




W Gunter, ARC



CO_2 EOR is a Commercial Technology

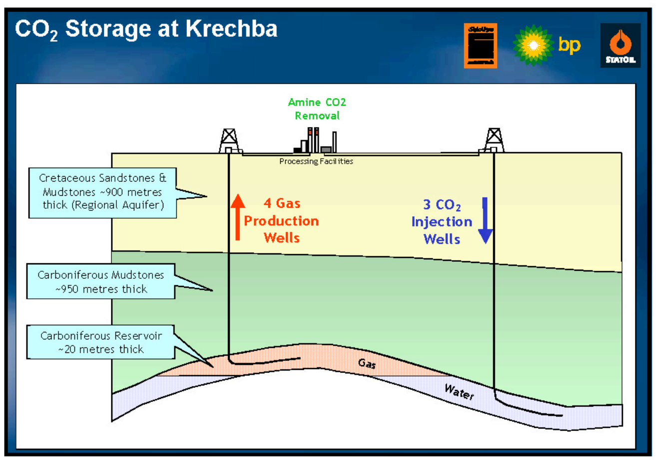


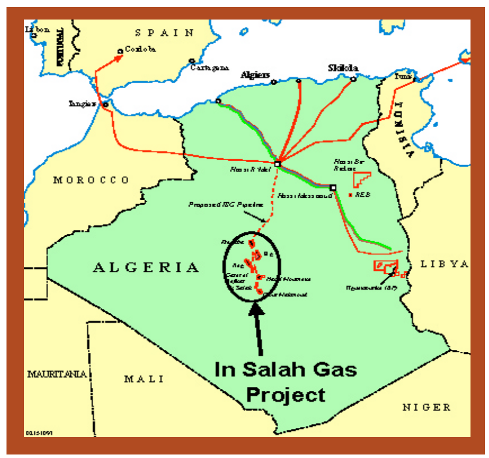
Need to optimize EOR for CO_2 storage

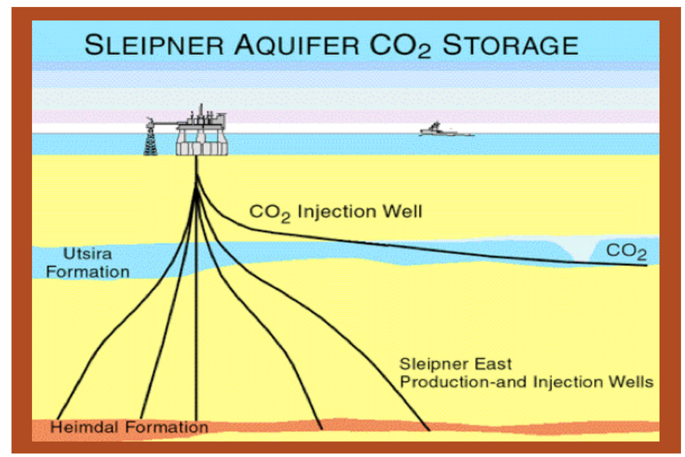
Explore less favorable EOR targets

Saline Formation Storage Is Already Under Way

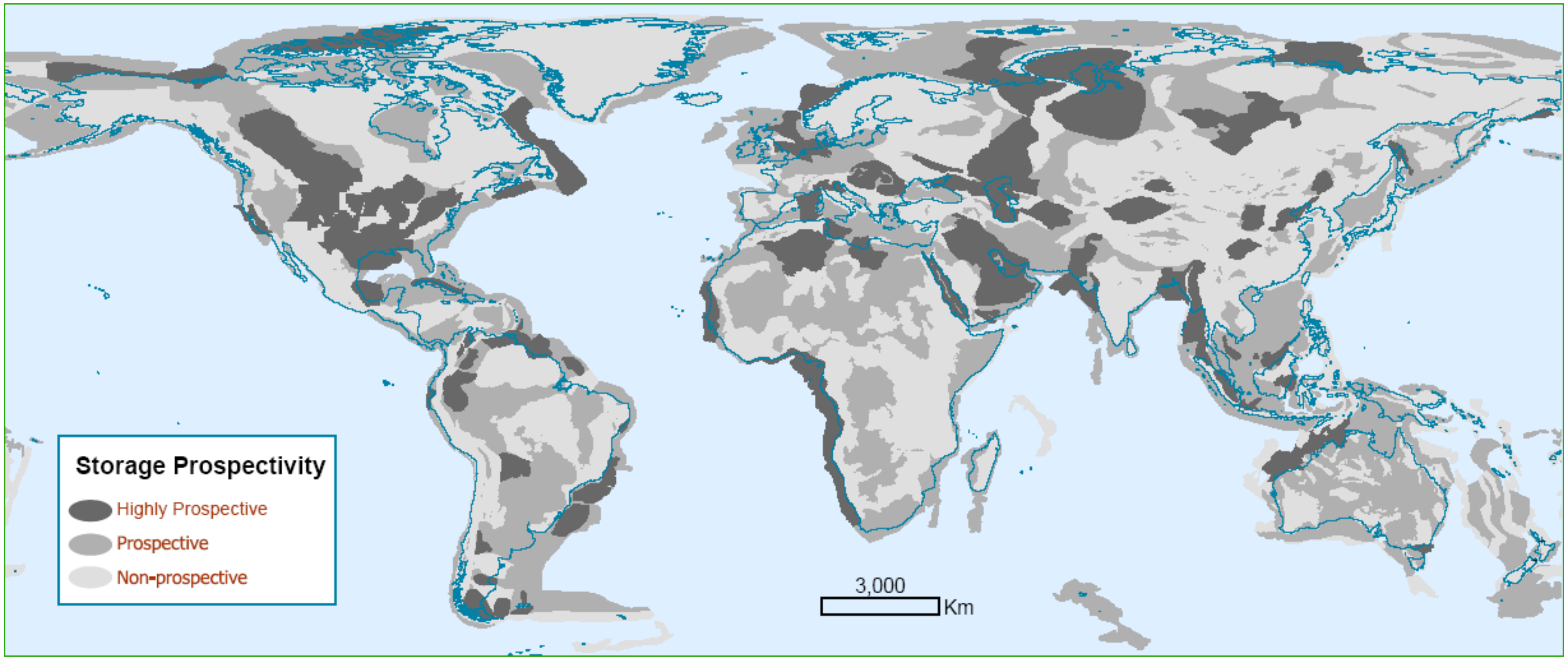
- Statoil injects 1x10^6 tons per year at Sleipner
- BP to inject 0.8x10^6 tons per year at In Salah







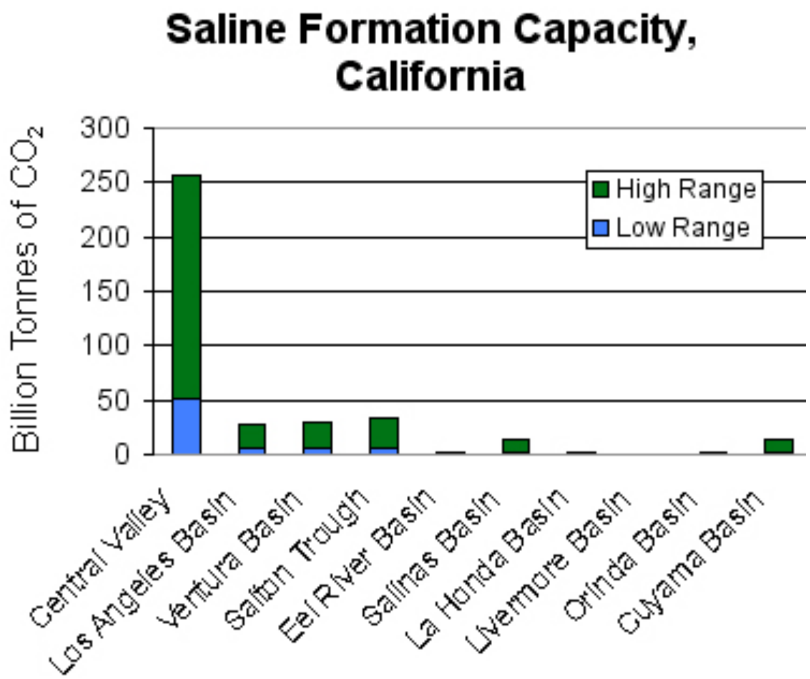
Prospective Saline Formation Storage Broadly Distributed

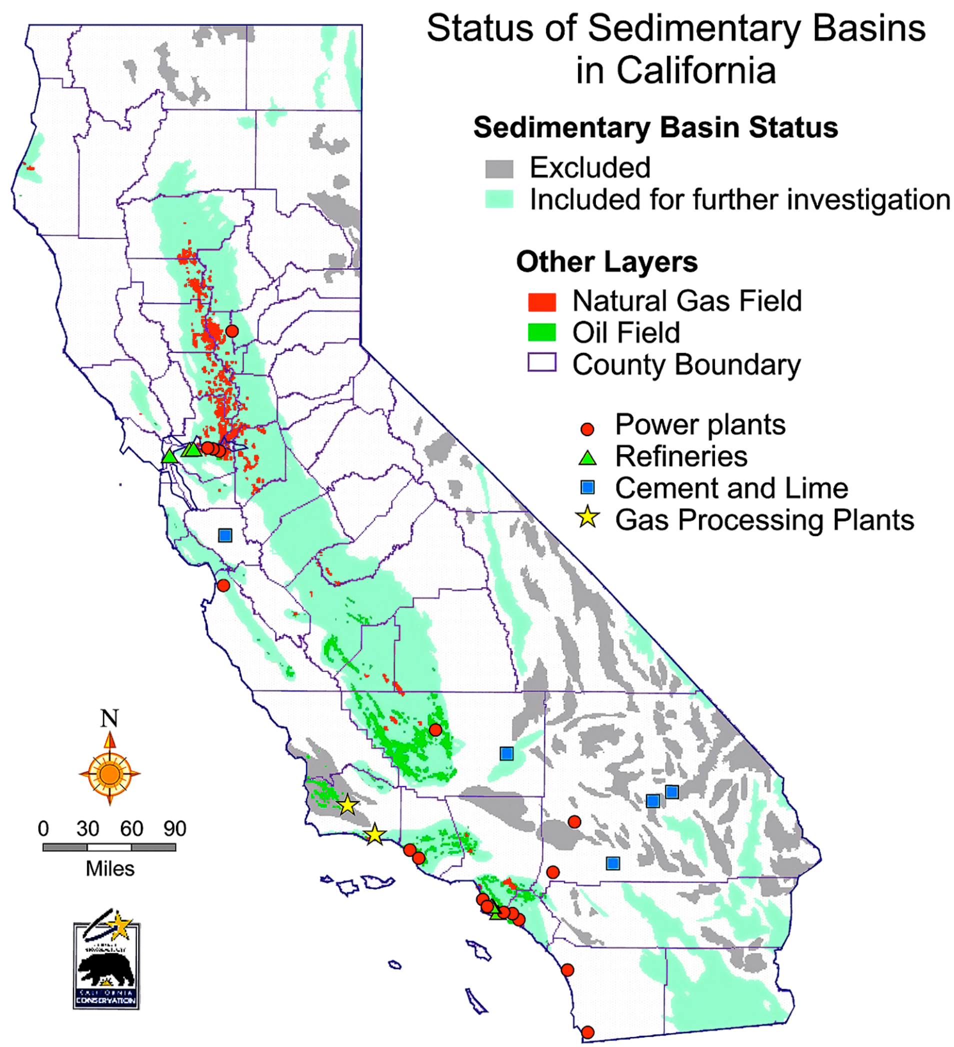


From Bradshaw and Dance 2005

"It is likely that the technical potential for geological storage is sufficient to cover the high end of the economic potential range (2200 GtCO_2), but for specific regions, this may not be true." *IPCC, 2005*

Regional Studies Provide Capacity Estimates and Source-Sink Matches





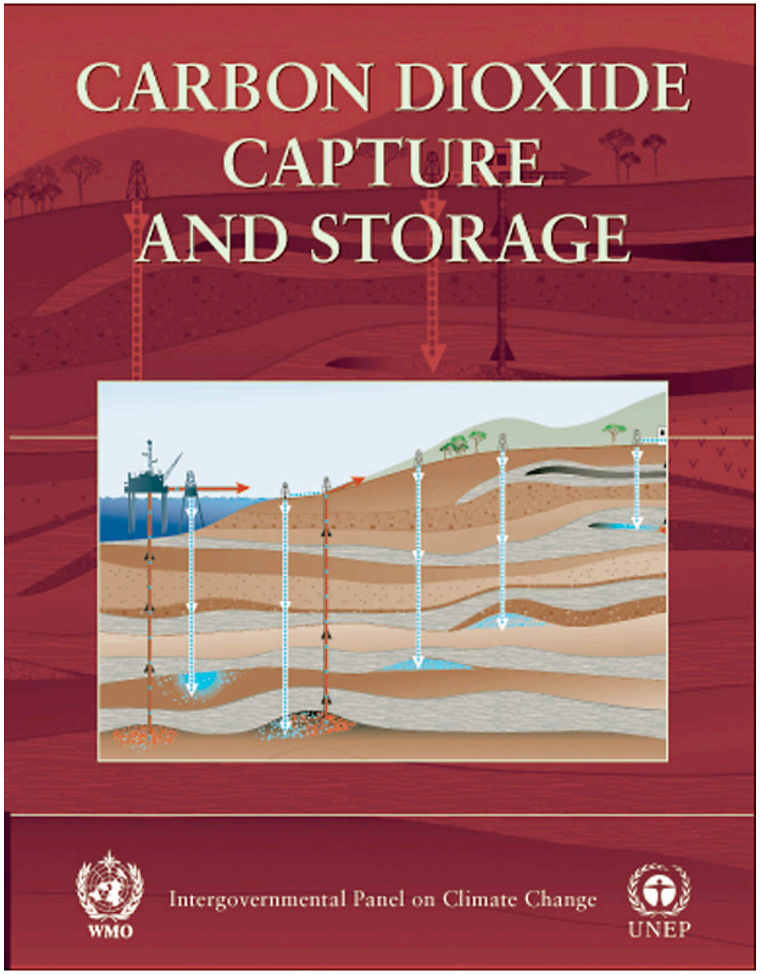
Gas reservoir capacity: 1.7Gt
Oil reservoir capacity: 3.6Gt

HSE Risks of Geologic Storage

- **Impacts of unintended leakage**
  - **Health and safety of workers and general population**
  - **Environmental impacts**
  - **Unwanted intrusion into drinking water**
- **Earthquakes**
- **Unwanted intrusion of saline fluids**

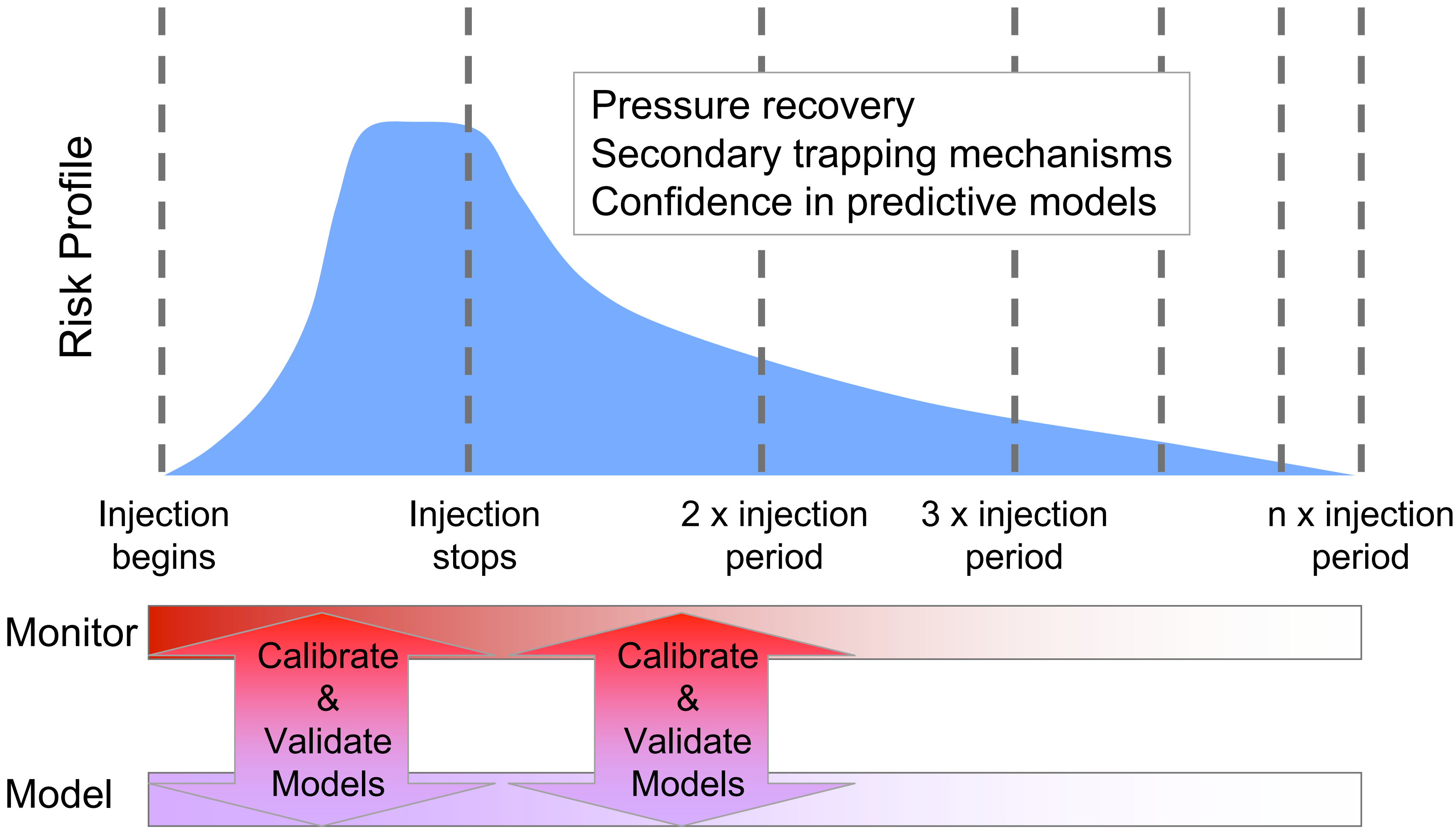
Tree kill at Mammoth Mountain, CA
http://quake.wr.usgs.gov/prepare/factsheets/CO2/

International Consensus on Geologic Storage Issues Provided by IPCC Report



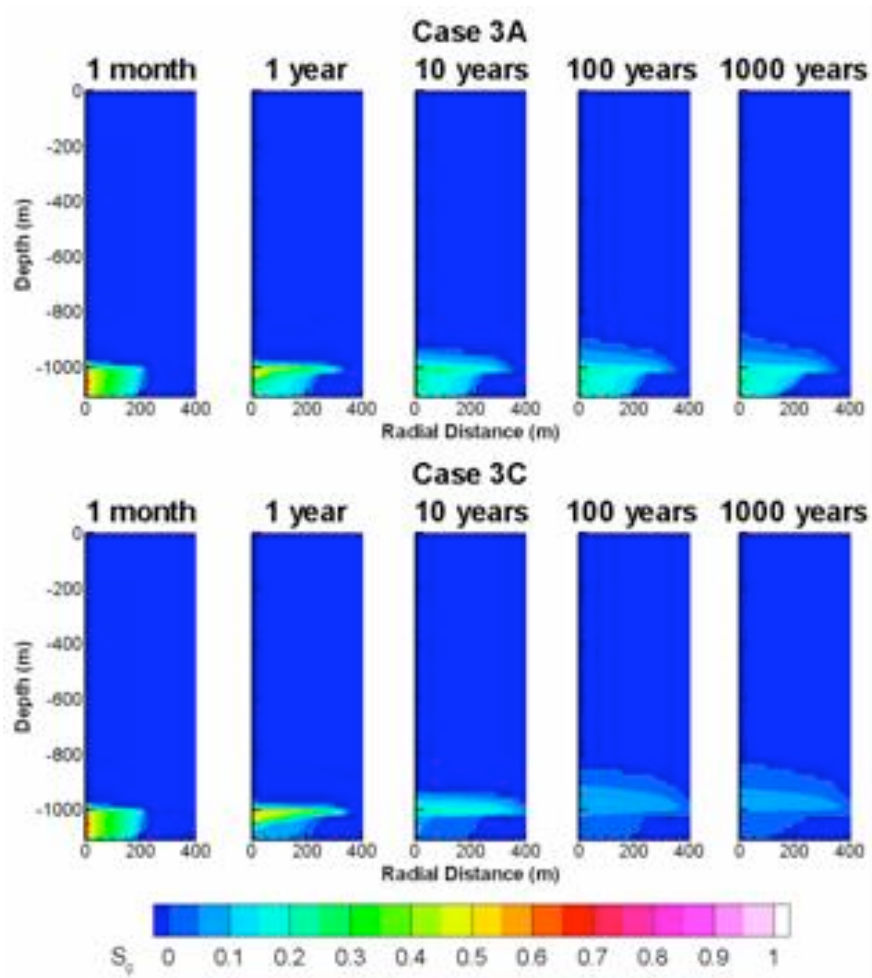
" With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety, and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas." IPCC, 2005

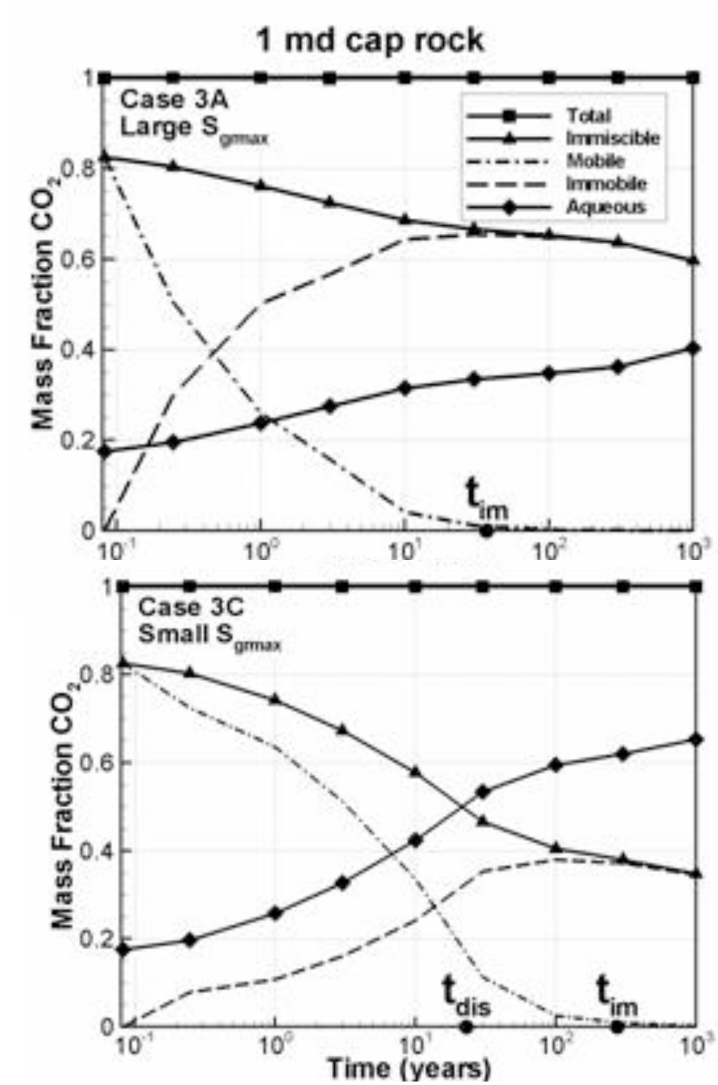
Risk Decreases Rapidly After Operational Phase



Source: S Benson, Stanford

Plume Mobility Decreases with Time

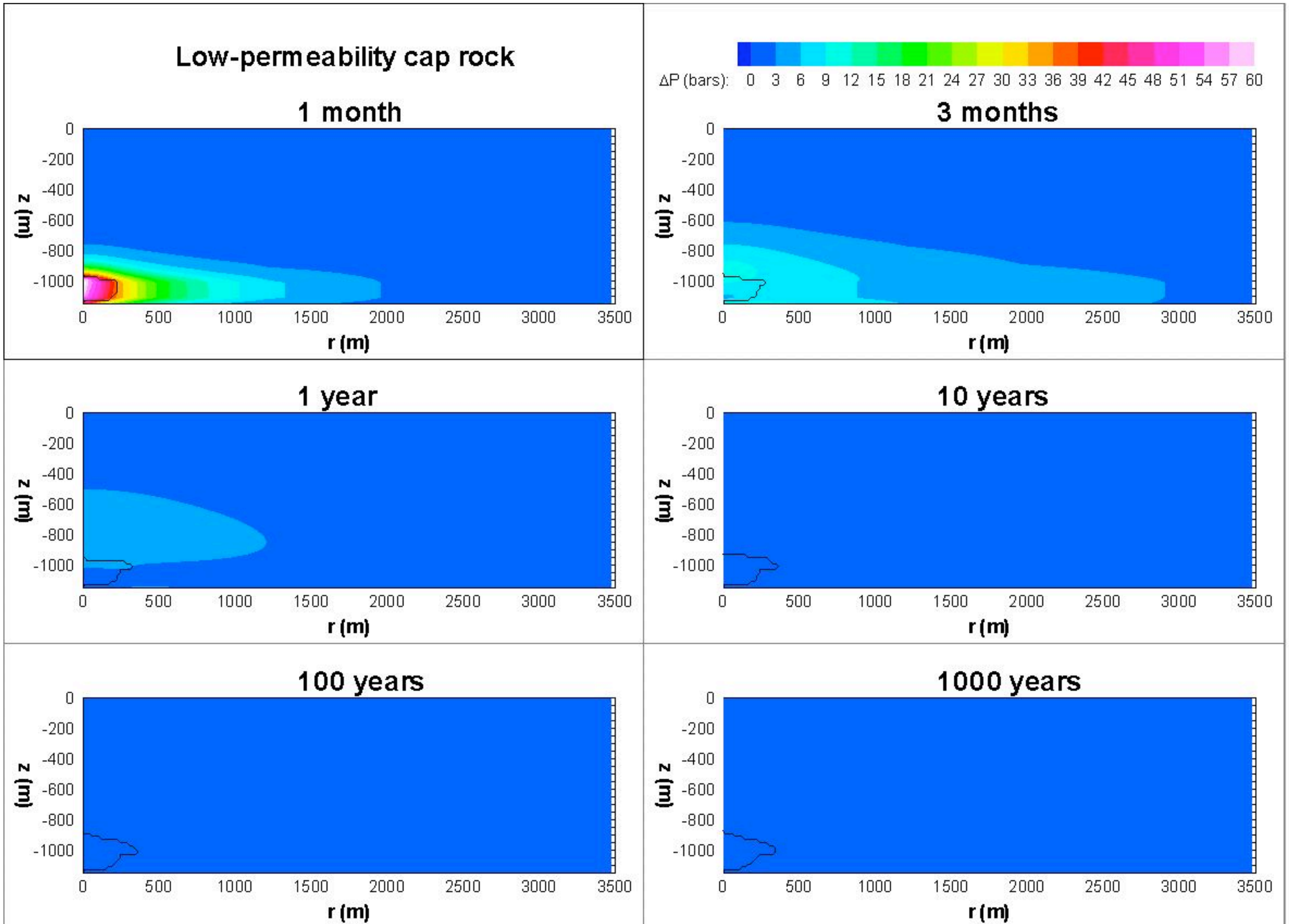




Reservoir simulation of CO_2 plume

(C Doughty, LBNL)

Pressure Decays Rapidly in Large Reservoirs



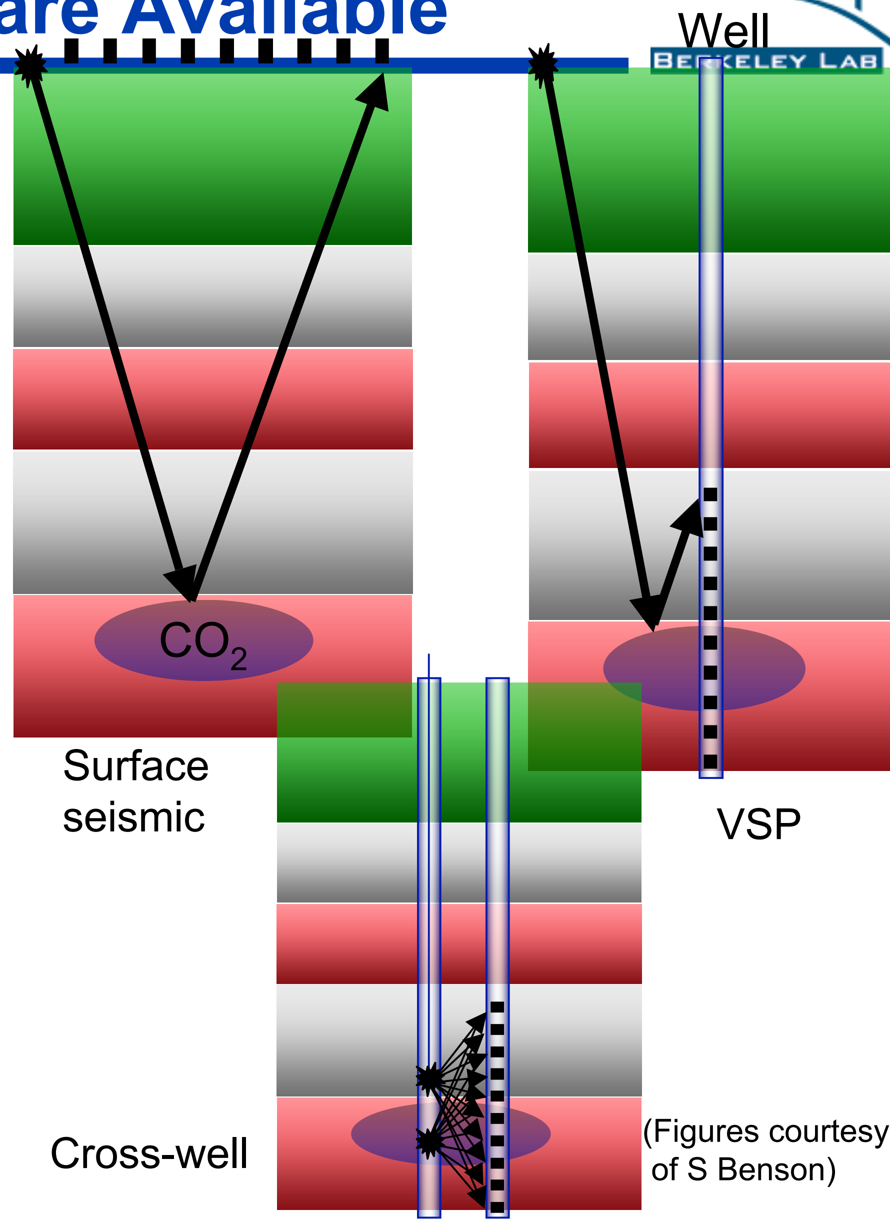
Reservoir simulation of pressure change (C Doughty, LBNL)

Why Monitor?

- Confirm storage efficiency and processes
- Ensure effective injection controls
- Detect plume location and leakage from storage formation
- Ensure worker and public safety
- Design and evaluate remediation efforts
- Detect and quantify surface leakage
- Provide assurance and accounting for monetary transactions
- Settle legal disputes

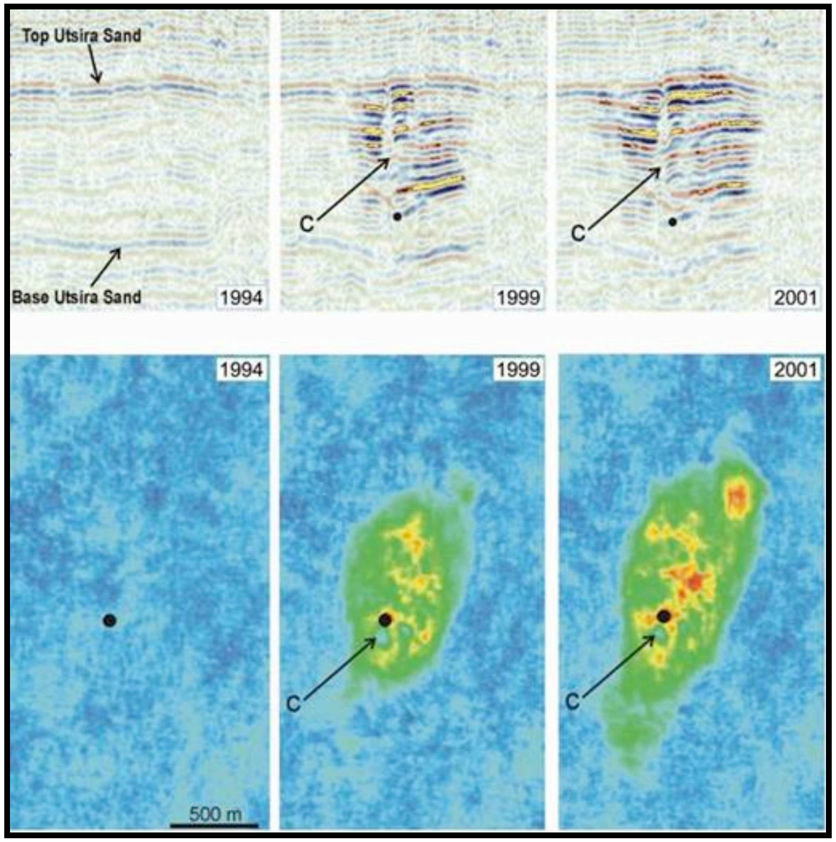
A Substantial Portfolio of Monitoring Techniques are Available

- **Seismic and electrical geophysics**
- **Well logging**
- **Hydrologic pressure and tracer measurements**
- **Geochemical sampling**
- **Remote sensing**
- **CO_2 sensors**
- **Surface measurements**

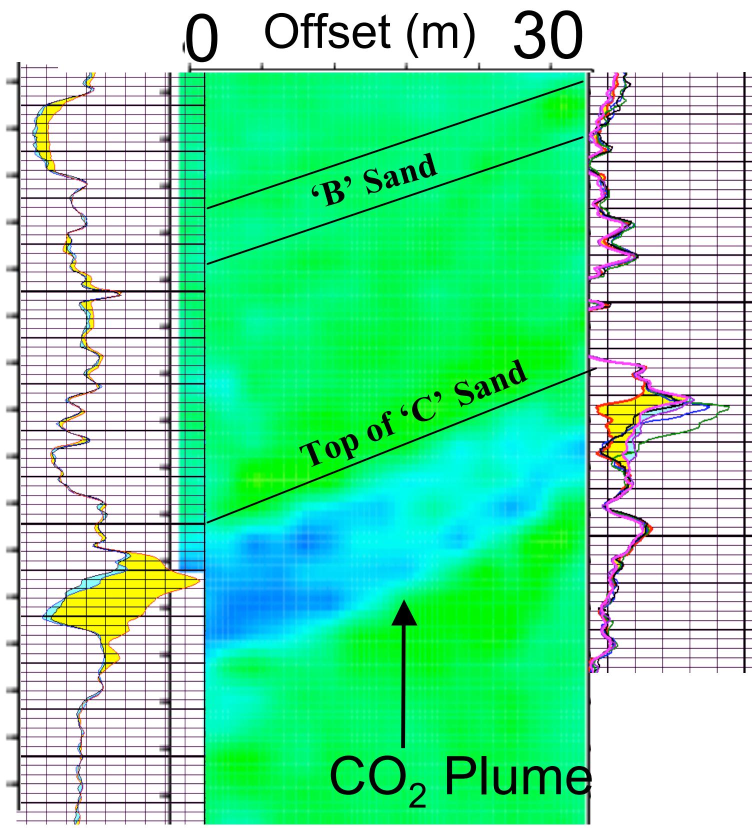


(Figures courtesy of S Benson)

Monitoring of CO_2 Using Seismic Methods



Time-lapse seismic monitoring results from Sleipner, after Chadwick et al., 2005



Cross-well imaging and RST logs from Frio saline injection test (Daley et al 2006)

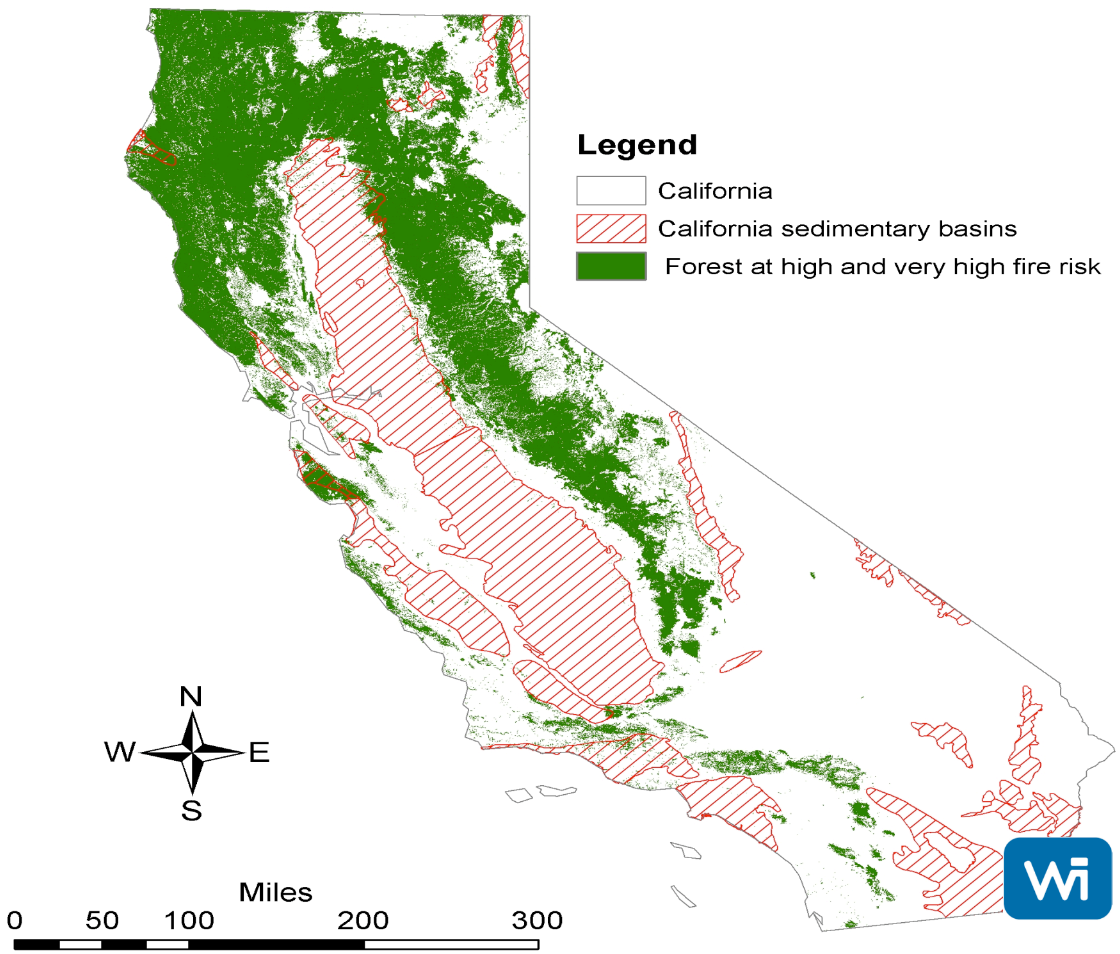
Pilots Provide Regional Knowledge Base Essential for Large Scale Implementation

- **Pilots demonstrate best sequestration options, unique technologies and approaches, in region**
- **Pilots involve site-specific focus for**
  - **Testing technologies**
  - **Defining costs**
  - **Assessing leakage risks**
  - **Gauging public acceptance**
  - **Exercising regulatory requirements**
  - **Validating monitoring methods**

Photos from Frio saline formation CO_2 injection test

CCS Beyond Coal

- Natural gas
- Industrial processes
  - —Cement
  - —Refineries (hydrogen plants)
  - —Ammonia
- Fermentation processes (eg. biofuels)
- Linking with terrestrial (forest management)

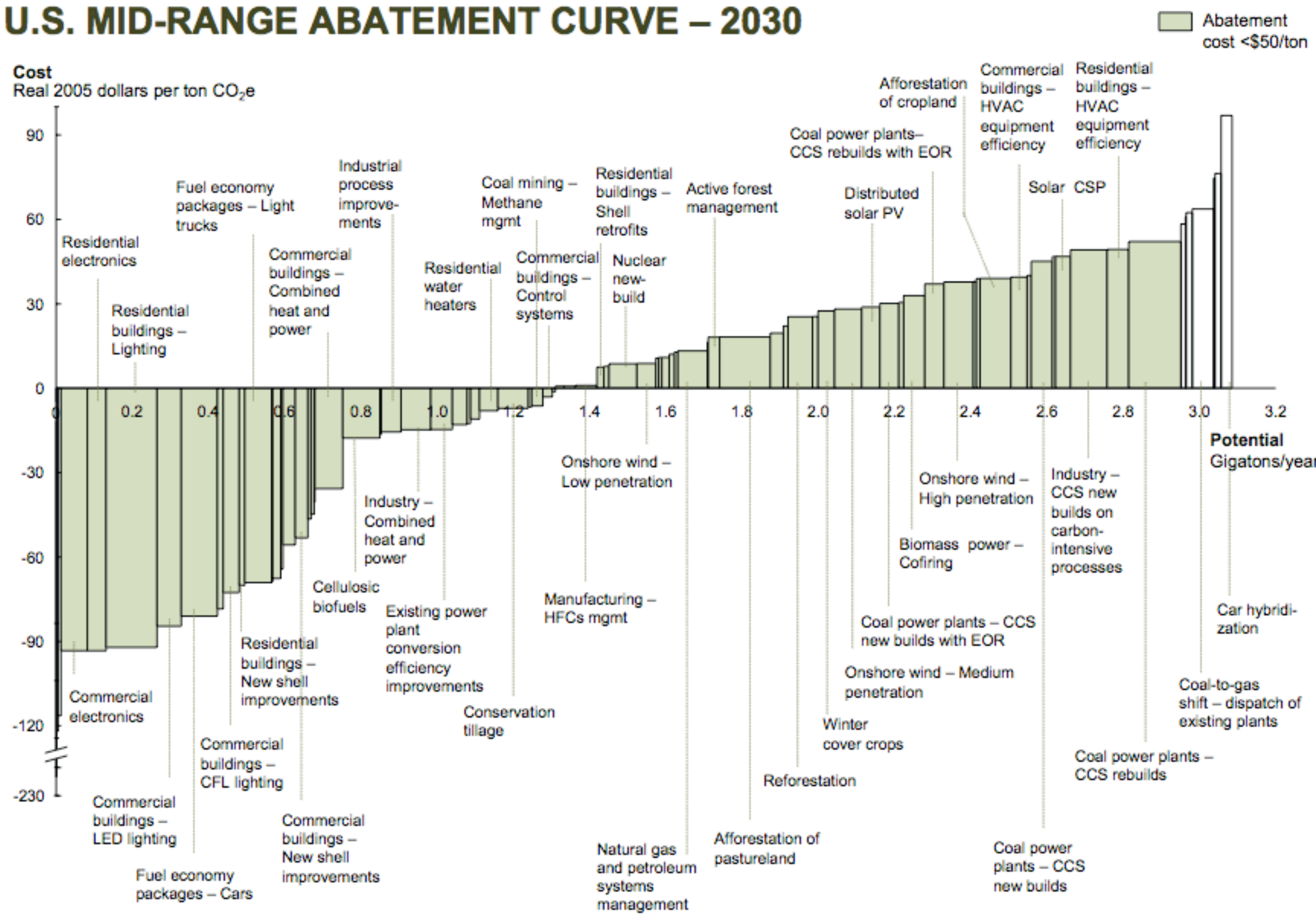


Current Status

- IPCC Special Report on CCS; CCS included in IPCC 4th Assessment as mitigation option
- Small number of commercial projects underway world-wide
- US DOE research effort focused on field testing (~$125M/yr and increasing)
- Numerous legislative actions at state and federal level

Exhibit B

U.S. MID-RANGE ABATEMENT CURVE – 2030



Source: McKinsey analysis

Summary

- The technology necessary to undertake CCS is available today
- Cost-effectiveness is driven mostly by capture costs
- Risks can be managed
- Field testing is essential to gain experience
- Plenty of opportunities for innovation
  - Fossil power generation optimized for CCS
  - Basic physics of storage mechanisms
  - New monitoring approaches, increased resolution
  - Thinking beyond coal