# Permitting Greenhouse Gases: Carbon Capture and Sequestration – A Perspective from California

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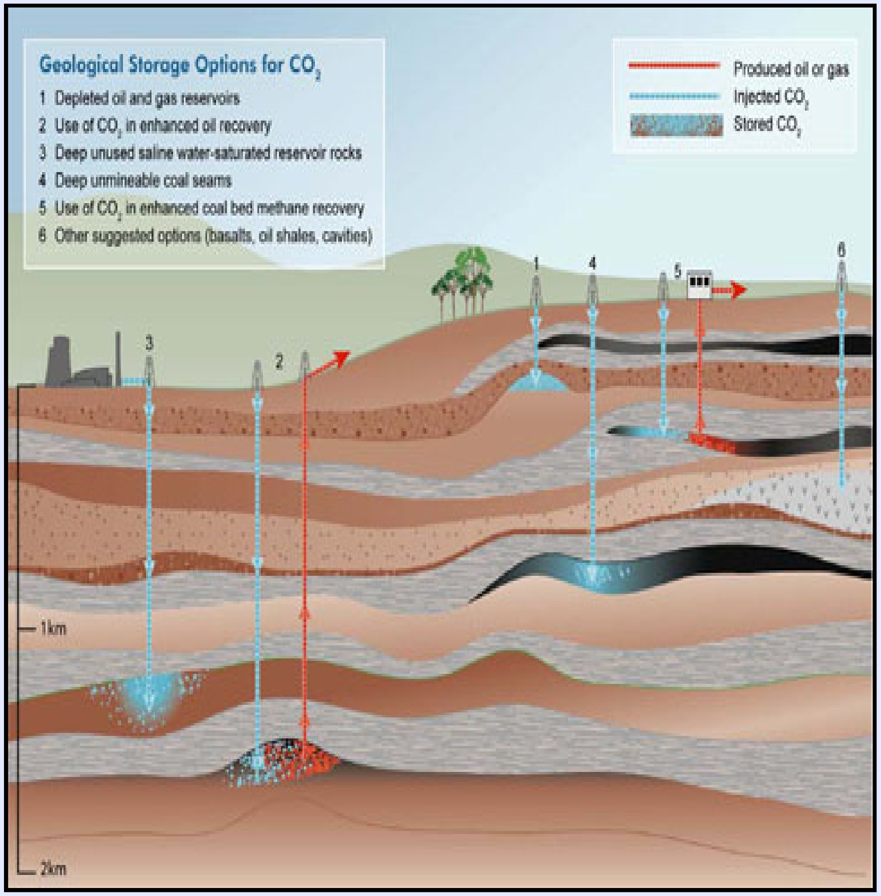
# What are the components of Carbon Capture and Storage (CCS)?

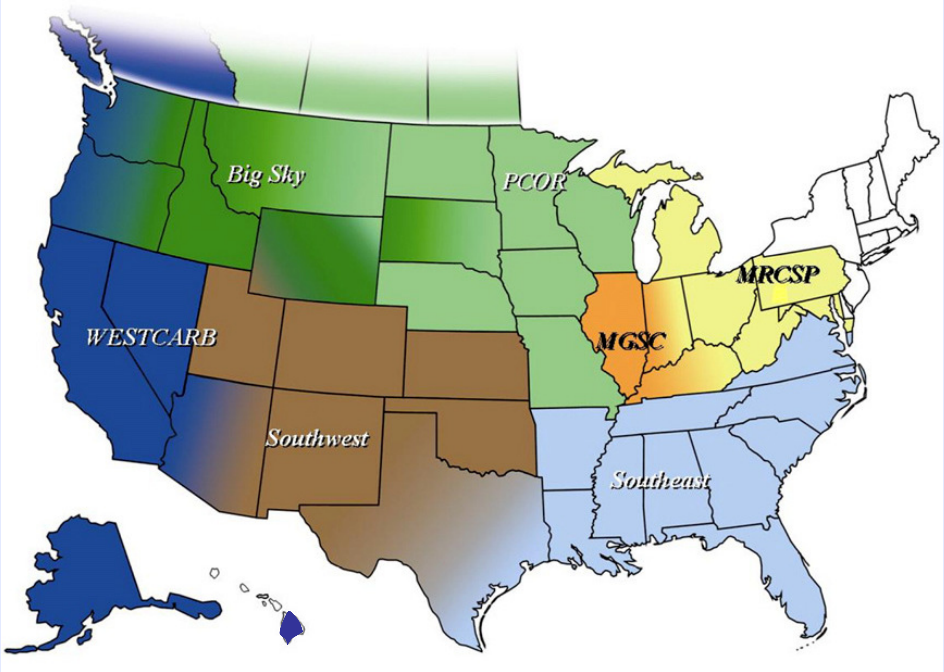



"Special Report on CCS", IPCC 2005

- $CO_2$ is "captured" out of emissions from a power plant or industrial facility (a point source)
- The separated $CO_2$ is transported to a storage site
- $CO_2$ is injected as a supercritical (liquid-like) fluid for storage in deep geological formations:
  - Saline Formations
  - Depleted Oil & Gas fields
  - Unmineable Coal Seams

# DOE “Regional Partnerships” Program Addresses Technical and Institutional Issues

- Launched in 2003, the 7 “regional carbon sequestration partnerships” now represent 42 states and more than 350 partner organization
- Terrestrial and geologic carbon sequestration opportunities are being evaluated/validated, but emphasis is on long-term geologic storage
- Public education and broad stakeholder engagement (industry, regulators, insurers, NGOs, K-12 educators, etc.) are key program elements
- Phase I ( (complete)—focus was on regional capacity assessments, source-sink mapping, and costs
- Phase II (under way): focus is on pilot-scale technology validation tests
- Phase III (just starting): focus is on large-volume geologic storage tests



# Over $2.3 Billion in American Reinvestment and Recovery Act 2009 funds will accelerate adoption of CCS

| Funding Opportunity | Total Amount |
|---|---|
| Regional Sequestration Technology Training | $6.97 M |
| Site Characterization of Promising Geologic Formations for CO2 Storage | $49.75 M |
| Carbon Capture and Sequestration from Industrial Sources and Innovative Concepts for Beneficial CO2 Use | $1420.3 M |
| Geologic Sequestration Training and Research | $80 M |
| Clean Coal Power Initiative—Round 3 | $800 M |

# California's greenhouse gas emissions approach

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- **Executive Order S-3-05**: in 2005, established 3 target reduction levels for GHG emissions in California
  - 2000 levels by 2010
  - 1990 levels by 2020
  - 80% below 1990 levels by 2050
- **AB 32**: requires the CA Air Board to adopt regulations to report and verify GHG emissions and to adopt limits at 1990 levels by 2020
- **SB1368**: sets an emission standard (1100 lbs $CO_2$ MWh) and prohibits long term power purchase agreements for baseload power with emissions above the standard
- **AB1925**: report to the Legislature on "recommendations for how the state can develop parameters to accelerate the adoption of cost-effective geologic sequestration strategies for the long-term management of industrial carbon dioxide"

# The AB 1925 report addresses economic, geological, technical, statutory and regulatory issues

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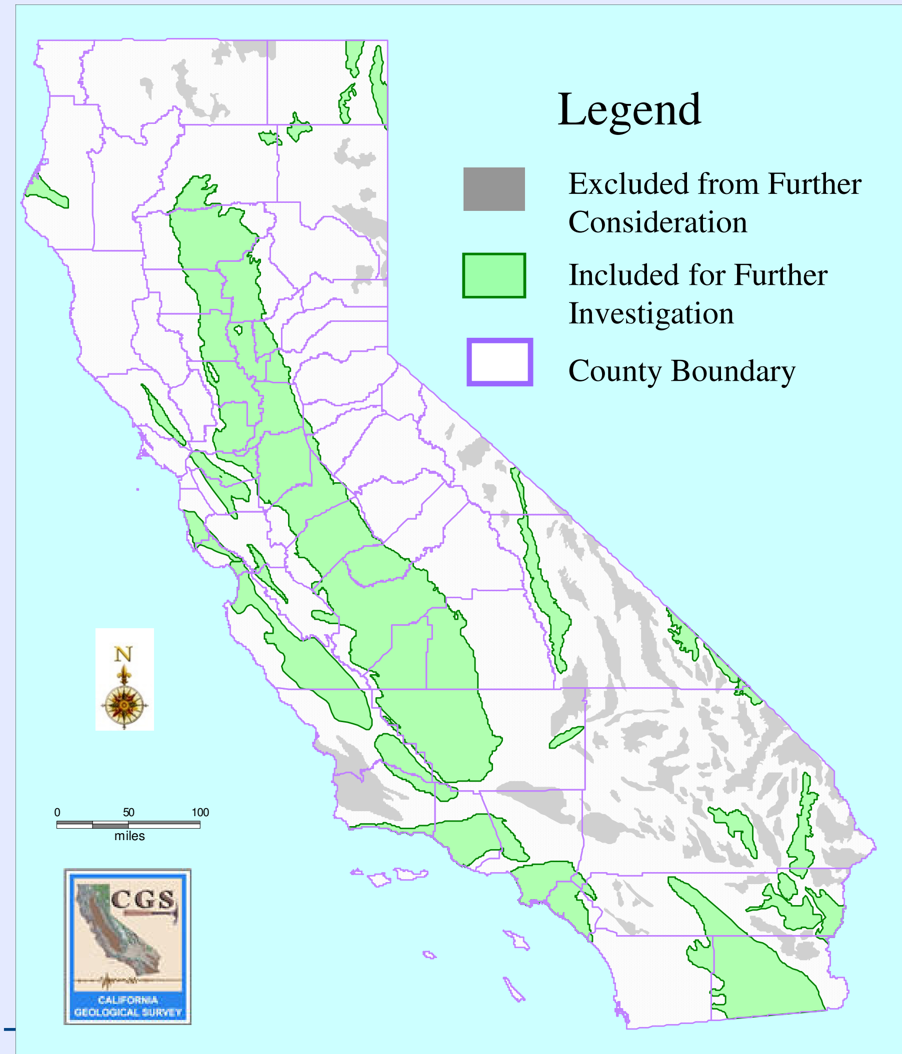
## The first report was an assessment of the issues:

- How much geological potential for CCS does California have and the types and locations of major $CO_2$ point sources?
  - Imported electricity from coal plants provides 20-30% of electricity and accounts for about half of inventoried GHG emissions from the power sector
  - Largest point sources in-state are natural gas power plants, cement plants, and oil refineries
- How well is California positioned to move forward?
  - Technical readiness
  - Regulatory and statutory readiness
  - Risks and risk management
  - Economic considerations
  - Potentially favorable early opportunities
  - Further work

## The second report is due in 2010

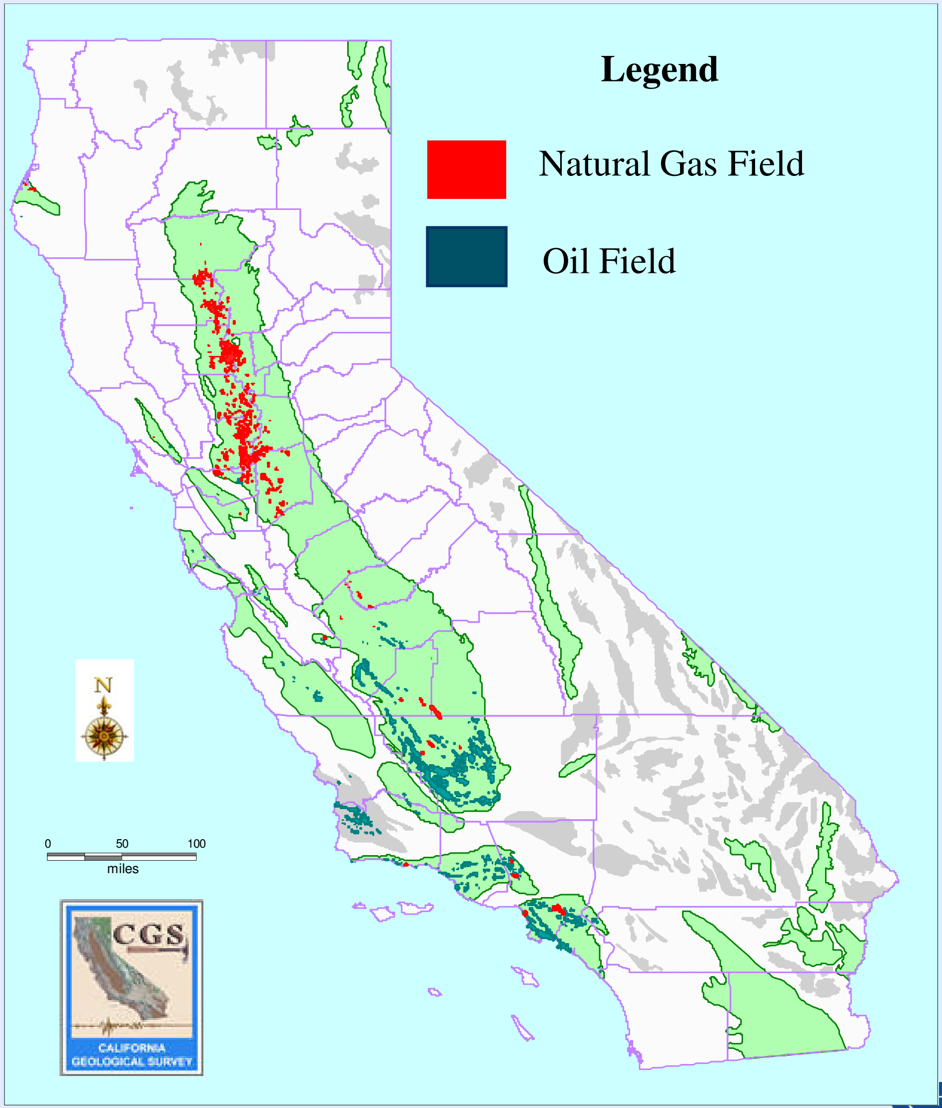
# Screening of sedimentary basins in California

- 104 basins were screened
- 77 basins were eliminated from further consideration due to:
  - Lack of porous and permeable formations
  - Lack of suitable seals
  - Sediment thickness <800 meters
  - Being within parklands, tribal lands, or military installations
- 27 basins met the initial screening criteria (>38,000 square miles)
  - Most promising are Sacramento, San Joaquin, Ventura, Los Angeles, and Eel River basins
  - Storage estimates using NETL (2007) methodology for 10 largest basins = 75-300 Gt $CO_2$

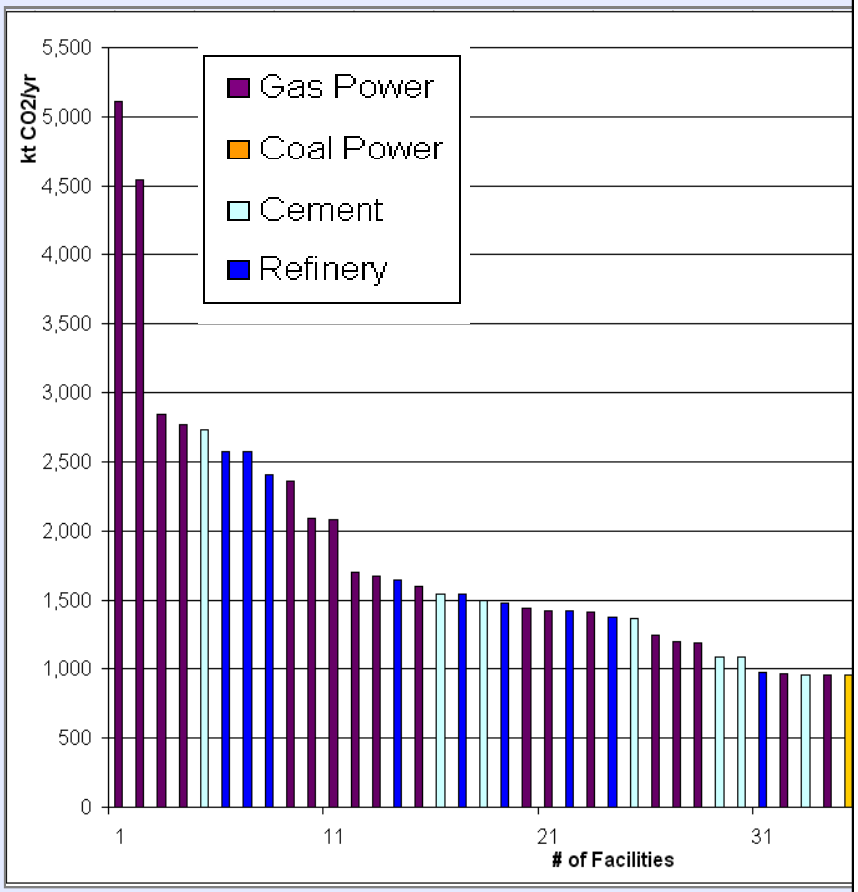


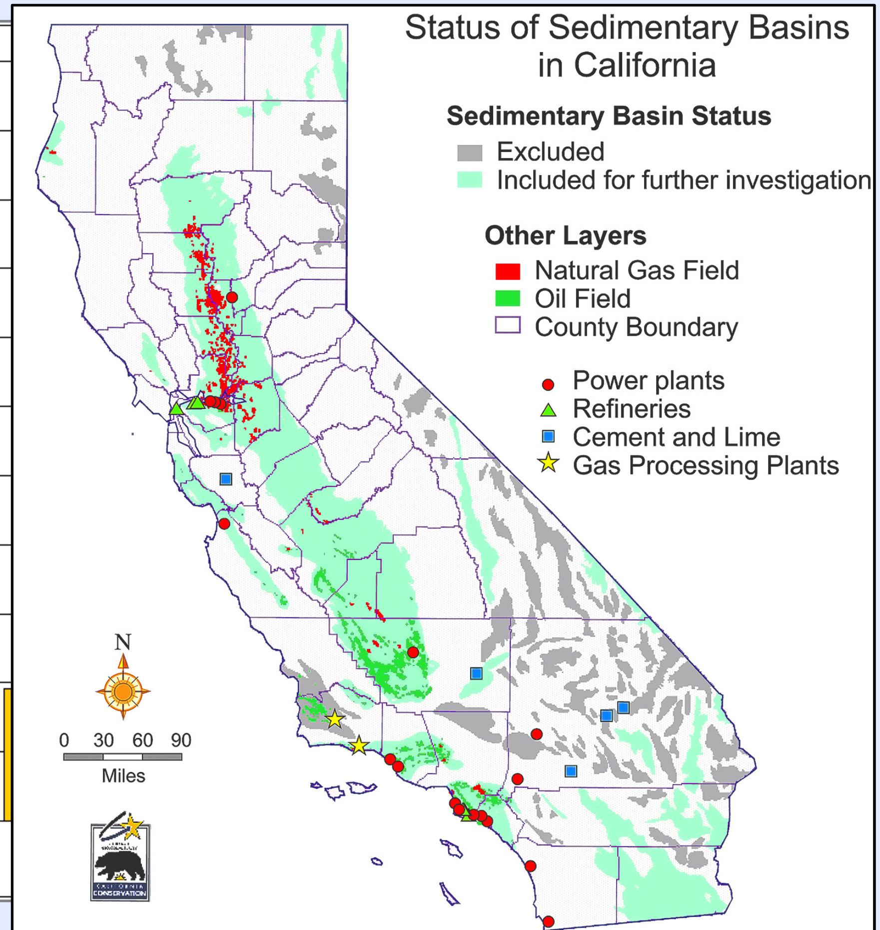
# Oil and gas fields are common in basins passing the screening criteria

- Depleted oil and gas fields are potentially good sequestration sites
- Capacity estimates are about 5000 $MMTCO_2$
- Presence of oil and gas demonstrates the capability of structures in these basins to sequester buoyant fluids over geologic time scales (millions of years)



# The largest in-state point sources are natural gas power plants, cement plants, and refineries




**90% are within 50 km of a potential sequestration site**

# However, how to best implement CCS for California is a regional issue

- Electricity imports into California
  - 22-32 % of electricity used
  - 39-57 % of GHG emissions
- Transportation fuels are exported to neighboring states—
  - 100% of Nevada's
  - 60% of Arizona's
  - 35% of Oregon's
- Does the carbon flow with the energy?
  - Inventory
  - Credits; cap-and-trade
  - Actual
- How does each state meet its individual carbon emissions goals in this context?

# SB 1368 and economics suggested a CCS focus on imported coal-generated power

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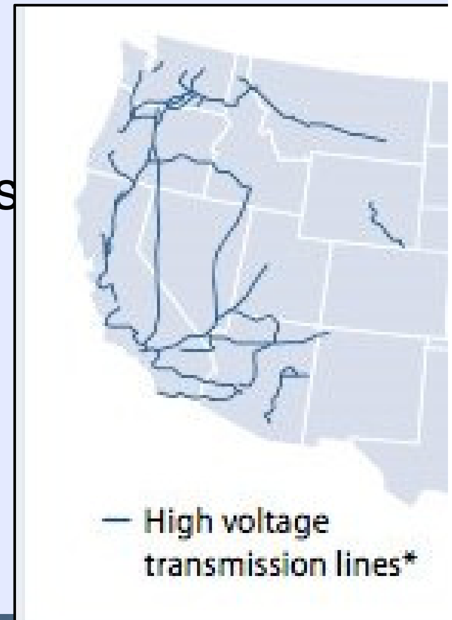
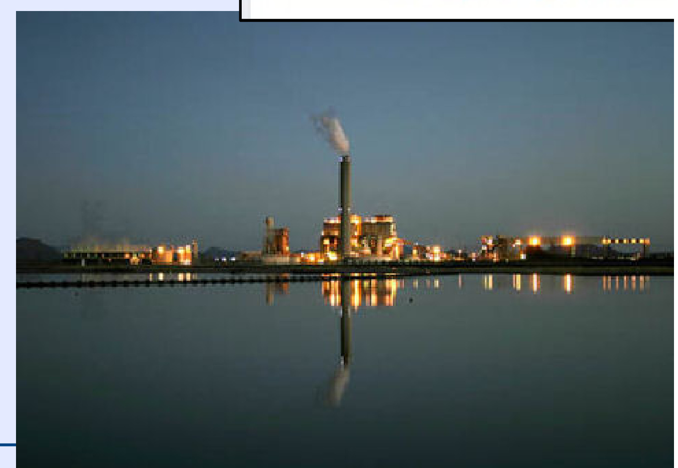
- Imported power generates more than half of power sector emissions (60 out of about 107 MMT $CO_2$/yr)
- SB 1368 sets an emission standard (defined at 1100 lbs $CO_2$/MWh) and prohibits long-term baseload power purchase agreements emissions above the standard
  - Addition of CCS is the most likely way to meet SB 1368 standard, but IEPR (2007) concluded that commercial-scale demonstration is key to developing investor confidence, and CCS on out-of-state coal plants is unlikely to be available to meet 2020 AB 32 goals.




However, that opinion is now being re-examined given recent federal policy momentum and in-state petroleum coke-fueled commercial projects, such as that of Hydrogen Energy



# Early economic opportunities in alternative fuels and chemicals

- Ethanol/biorefineries
  - Only a few large plants currently in California, but more are planned
  - About 2500 metric tons $CO_2$/million gallons of ethanol produced
  - Emissions are essentially pure $CO_2$ so separation costs are avoided
  - Provides net-negative GHG emissions reductions
- Syngas/pet-coke hydrogen
  - $CO_2$ capture integrates into pre-combustion process

# Opportunities for enhanced oil recovery using captured $CO_2$

- 80% of emissions sources are within 50 km of a potential EOR site
- EOR operations recycle $CO_2$, but result in 30-60% of injected volumes left underground
- EOR improves CCS project economics by valuing carbon
- $CO_2$-EOR has potential to recover up to 5 billion barrels of additional oil*
- $CO_2$ demand potential for EOR could result in storage of up to 1 billion tons*

*U.S. Department of Energy/Advanced Resources International (2005) Basin Oriented Strategies for $CO_2$ Enhanced Oil Recovery: Onshore California Oil Basins

# Deploying CCS projects depends on economics and technical and statutory readiness

Components of technical readiness

- Capture technologies and transportation
- Surface issues for plant and well siting
- Subsurface elements
  - Risk management
  - Site characterization and certification
  - Monitoring and verification
  - Remediation and mitigation

# $CO_2$ pipelines are a mature technology; California lacks infrastructure

- Regulatory framework exists – Office of the State Fire Marshal
- Over 3000 miles of $CO_2$ pipeline in the U.S. delivering over 10 Tcf of gas
- Experienced workforce exists
- No serious injuries or deaths associated with $CO_2$ pipelines
- Mature safety technology (automatic block valve closure, spacing regulated by USDOT, telemetry for 24-hour real-time monitoring)
- FutureGen environmental risk assessment identified most significant hazard as pipeline leakage, not subsurface leakage

# Subsurface technical readiness relies on mature technologies and experience with analogs

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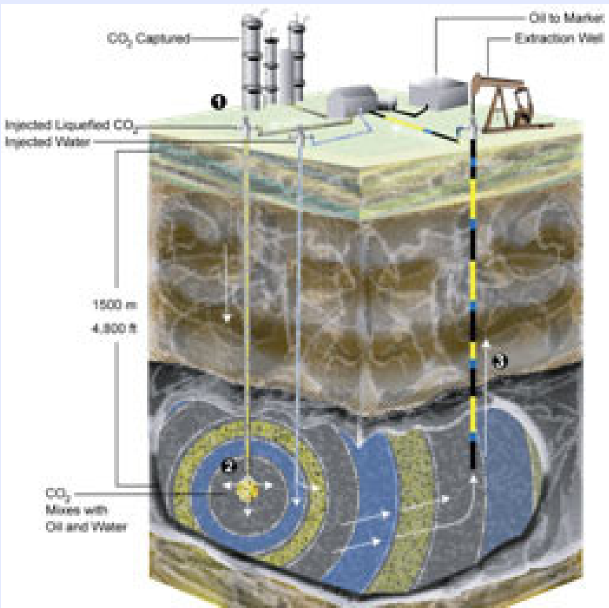
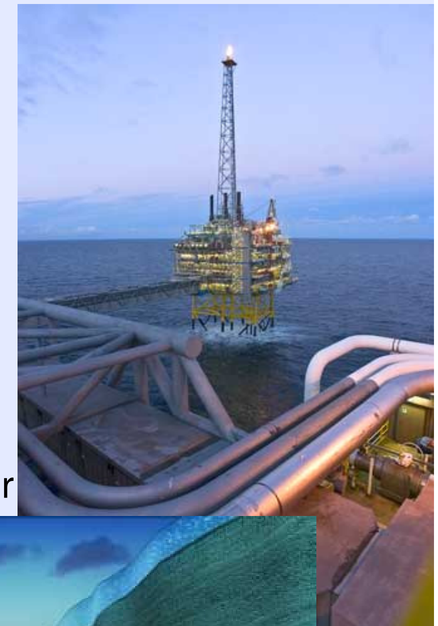


Weyburn

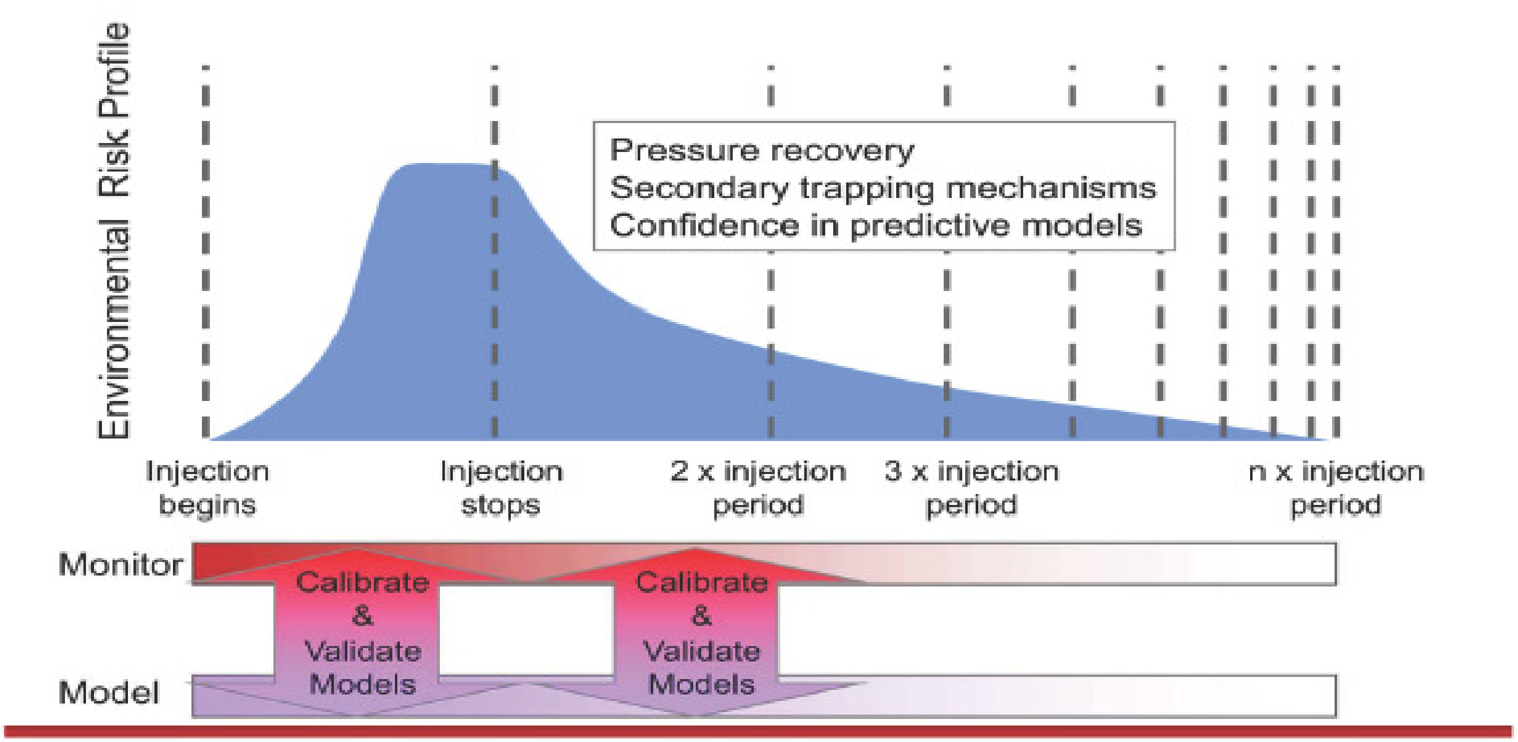
## Many analogs

– Natural $CO_2$ reservoirs
– $CO_2$ storage through EOR
– Natural gas storage
– CCS pilots and early commercial projects


Sleipner

Oil and gas industry has highly developed subsurface characterization technologies and provides relevant knowledge and experience

# Technical risk levels out during injection and then declines over time

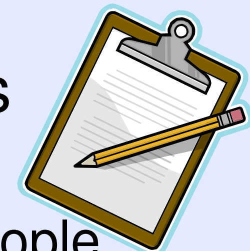



From Patton, Zurich, 2008.

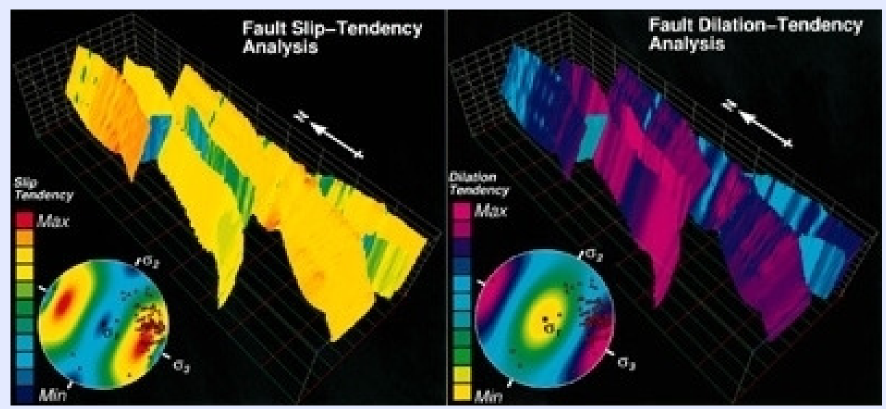
The key to risk management is assuring that site characterization and monitoring data give confidence in predictive modeling of reservoir performance

# Risk perception and awareness of CCS technology can affect rates of adoption

- Surveys show public's greatest concerns are
  - Harm or damage to people, the environment, or property by leakage of $CO_2$
  - Accountability/stewardship over long time scales



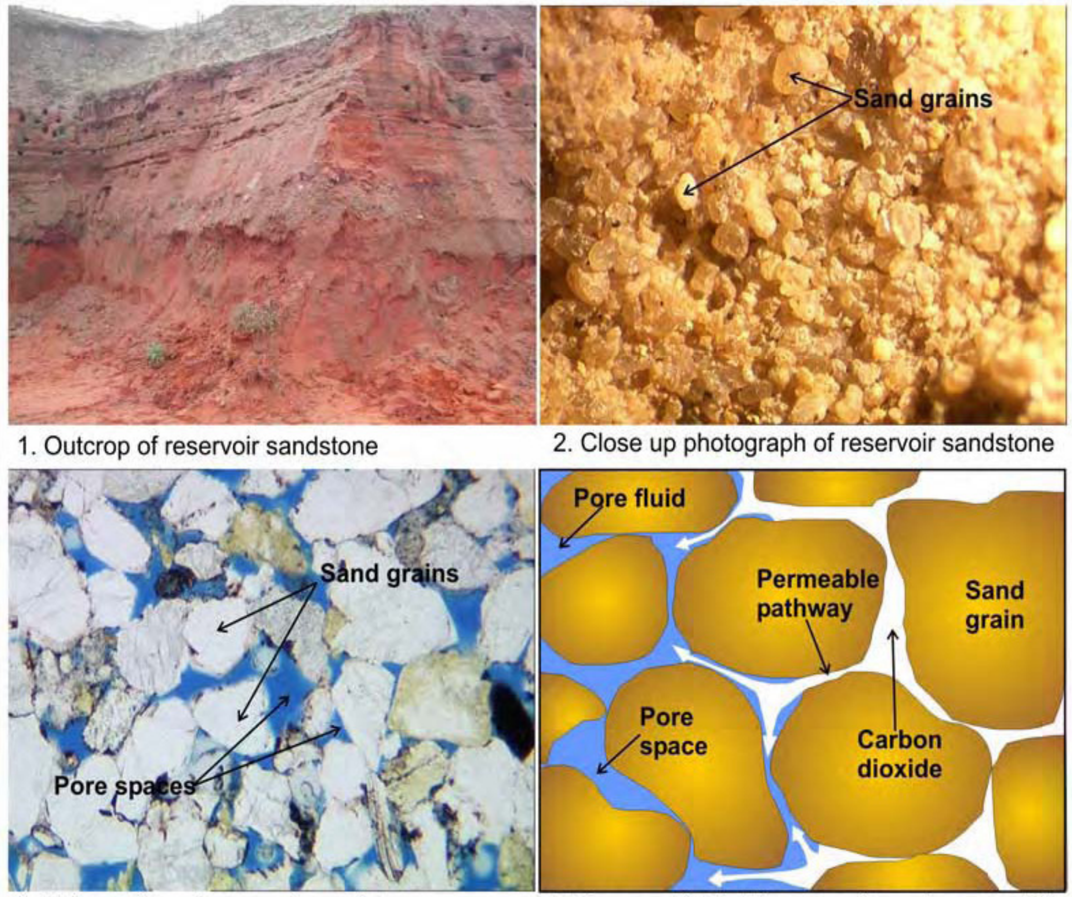
- Other risks
  - Damage from induced seismic or brine migration from saline formations
  - Climate-change risk from cumulative slow leakage of $CO_2$ to the atmosphere




http://www.swri.org/4org/d20/home/what/subsurf.htm

# $CO_2$ is stored in tiny pockets between rock grains, not in “pools” or “bubbles”

- Reservoir rocks commonly are sandstones with high permeability
- Saline water or brine (from one-third to four times seawater) occupies pore spaces
- $CO_2$ displaces brine between grains but also dissolves in it and reacts with sand grains



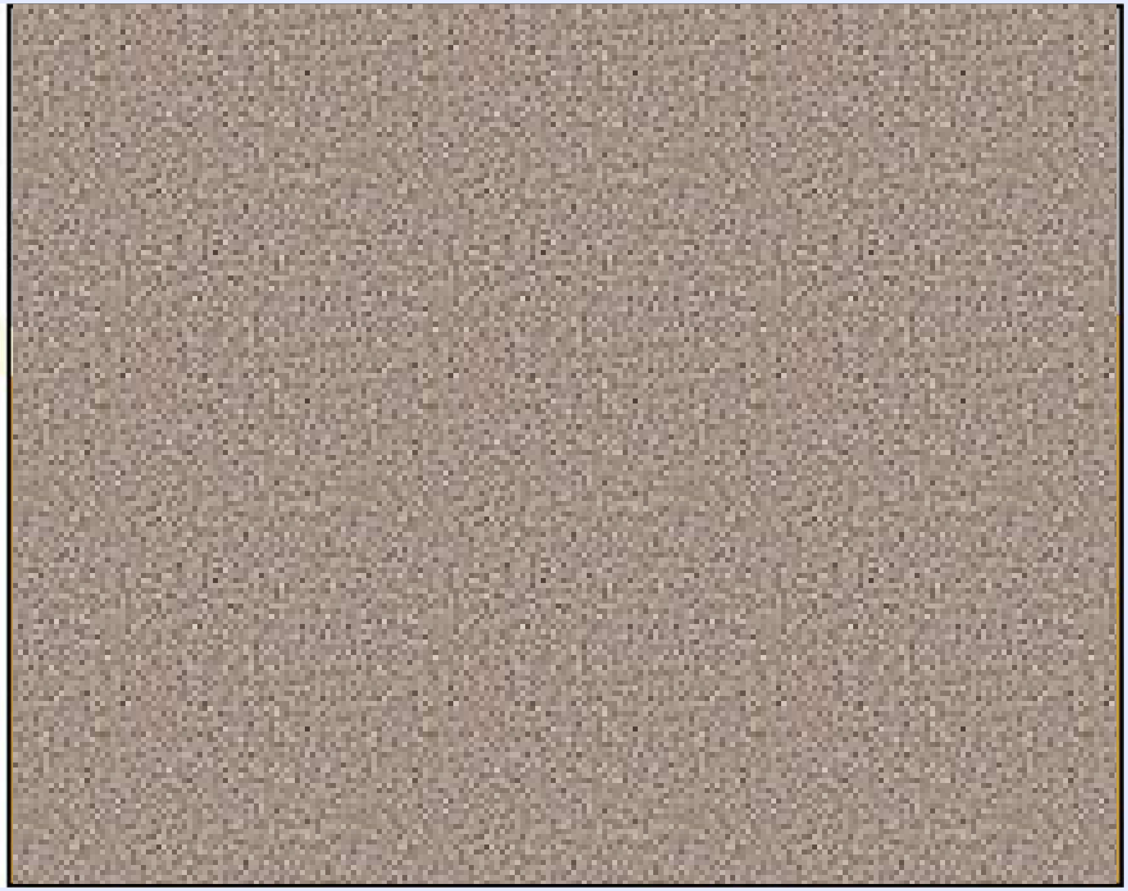

1. Outcrop of reservoir sandstone
2. Close up photograph of reservoir sandstone
3. Thin section of reservoir sandstone viewed through a microscope
4. Diagram highlighting porosity and permeability

M Bentham © British Geological Survey

# A good sequestration reservoir has specific subsurface attributes

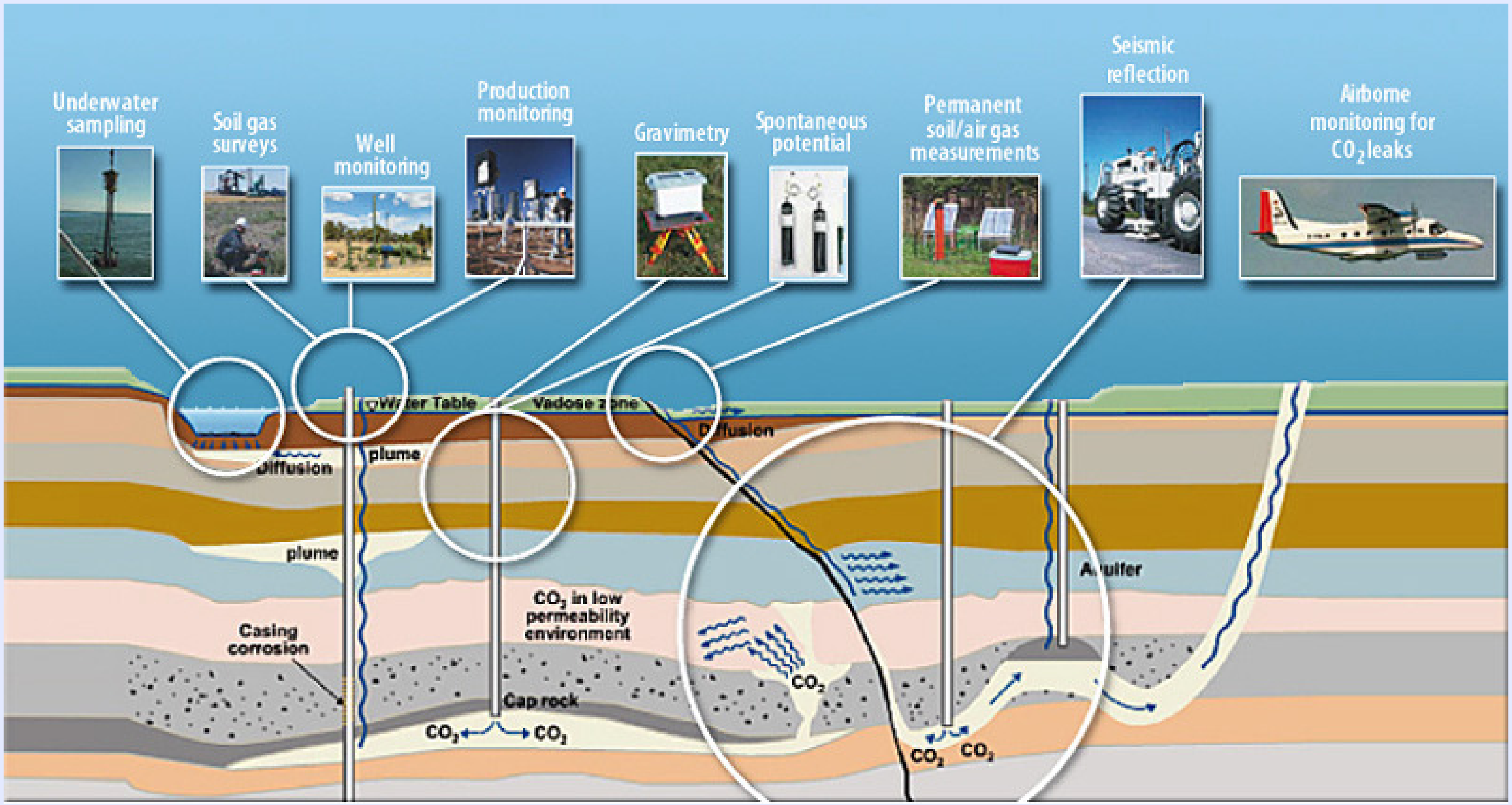


- Injectivity: ability of $CO_2$ to displace existing subsurface fluids
- Capacity: ability of rock to hold $CO_2$ as gas, dissolved ions or mineral phases
- Integrity: ability of overlying nonporous rocks to seal reservoir, and no “leaky” orphaned wells or faults



**Data collected in site characterization and by monitoring throughout the life of the project must verify reservoir performance.**

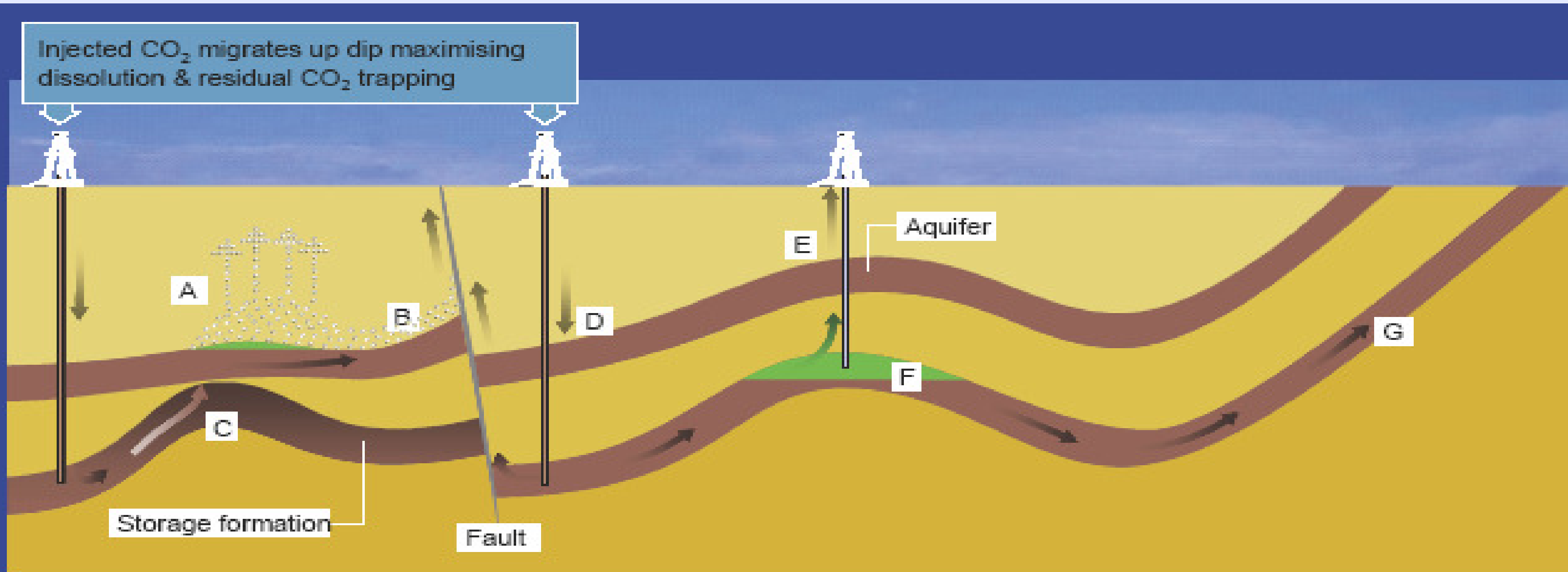
# Monitoring must track $CO_2$ migration, detect leaks, and verify storage




http://www.co2captureproject.org/images/monitoring_diag1.jpg

**Density and frequency of monitoring surveys are designed to confidently predict reservoir performance, and may decrease as confidence increases over time**

# Remediation and mitigation addresses what to do in case of a leak




Potential escape mechanisms

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 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 | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| A. Extract & purify ground water | B. Extract & purify ground water | C. Remove CO2 & re-inject elsware | D. Lower injection rates or pressures | E. Re-plug well with cement | F. Intercept & re-inject CO2 | G. Intercept re-inject CO2 |

**Proper site characterization and monitoring to provide early detection are key to avoiding large acute or chronic leakage**

# Analogs demonstrate that, if a large acute leak occurs and reaches the surface, $CO_2$ must build to high concentrations to cause harm


Mammoth Mt., CA

magmatic emissions into soils can become fatal to trees and also to humans and animals in low places with stagnant atmospheric conditions

Crystal Geyser, UT

Abandoned exploration well penetrates natural $CO_2$ reservoir, which geysers $CO_2$ and water without creating harm

# Regulatory needs for CCS

Must accommodate opportunities to reuse $CO_2$, safeguard people and the environment, and verify effective GHG emissions mitigation

- The necessary technology and knowledge exist to inform regulations
- Demonstration and early projects are needed to provide test cases
- Given the differences in emissions sources and sequestration reservoirs, any CCS regulatory framework needs:
  - Flexibility
  - Consistency
  - Predictability

# Statutory needs for CCS

Given the long-term nature of geologic sequestration, statutory frameworks must:

- Assure long-term stewardship to protect people and the environment (including climate change mitigation)
- Address ambiguities in ownership
- Define liability limits (and how these follow ownership)
- Address issues arising from carbon credits—e.g., when there is value for $CO_2$

# Summary and Conclusions

- Large geologic potential and large point sources in reasonable proximity with several potential options:
  - Out-of-state power suppliers with coal plants
  - CCS with EOR
  - CCS with ethanol (double carbon reductions)
- CCS is technically ready and similar technical risks have been managed in other industries

- Needs/Next steps
  - Demonstrations and early commercial projects ASAP
  - Enabling regulatory and statutory frameworks for early projects
  - Improving economics of capture
  - Understanding how to develop pipeline infrastructure
  - Understanding effects of CCS on power costs and future energy portfolios for California
  - Identifying ramifications of various regulatory and statutory options
  - Developing appropriate protocols for CCS site selection, operations, and closure