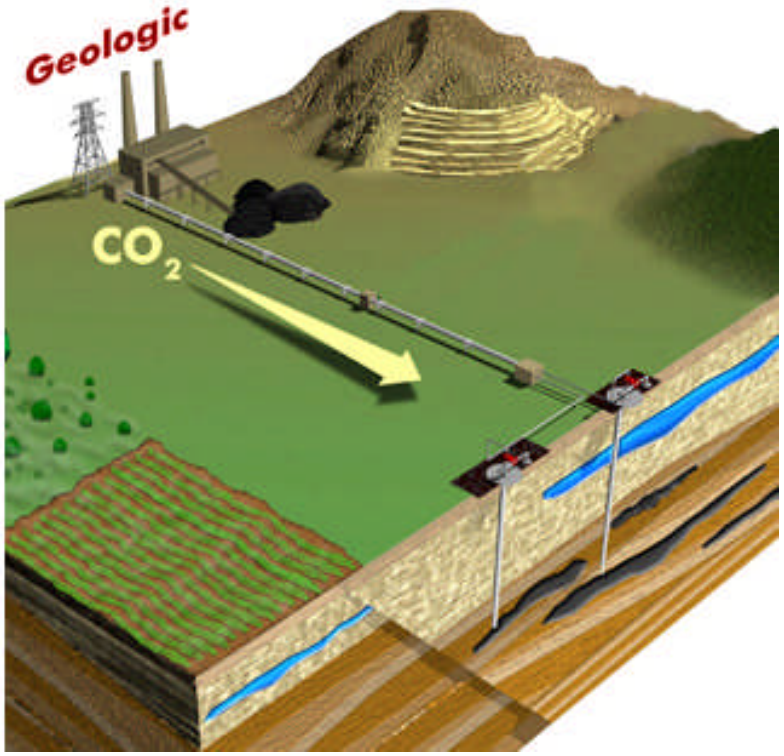
Large-scale deployment of geologic storage will require making predictions of each site's behavior over time.



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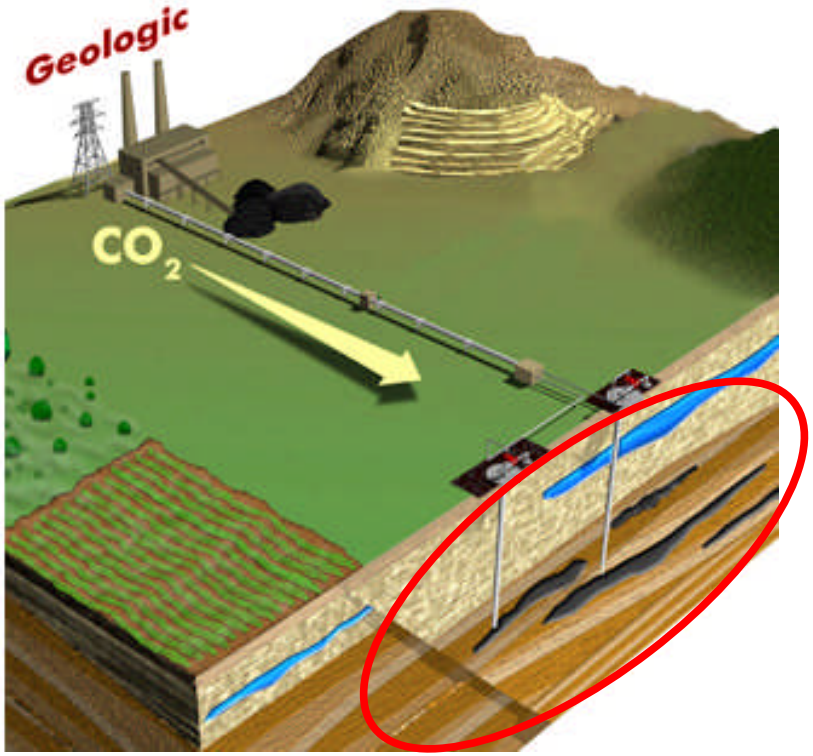
Fossil Energy & Environment Programs
Los Alamos National Laboratory

- **Will the site have sufficient capacity & injectivity over time?**
  - distribution/connectivity of reservoir pore space
  - fluid movement (CO_2 & brine)
- **What will the impacts be from introducing CO_2 into the reservoir?**
  - pressure distribution; chemical reactions
  - fluid movement (CO_2 & brine)
- **What is the chance that all of the CO_2 will remain in the reservoir?**
  - distribution/connectivity of non-reservoir pore space (wellbores; faults/fractures; fastpaths)
  - fluid movement (CO_2 & brine)
- **What might the impacts be of CO_2 release from the reservoir?**
  - CO_2 & brine fate; CO_2 & brine impact
  - fluid movement (CO_2 & brine)

Take-Home Points

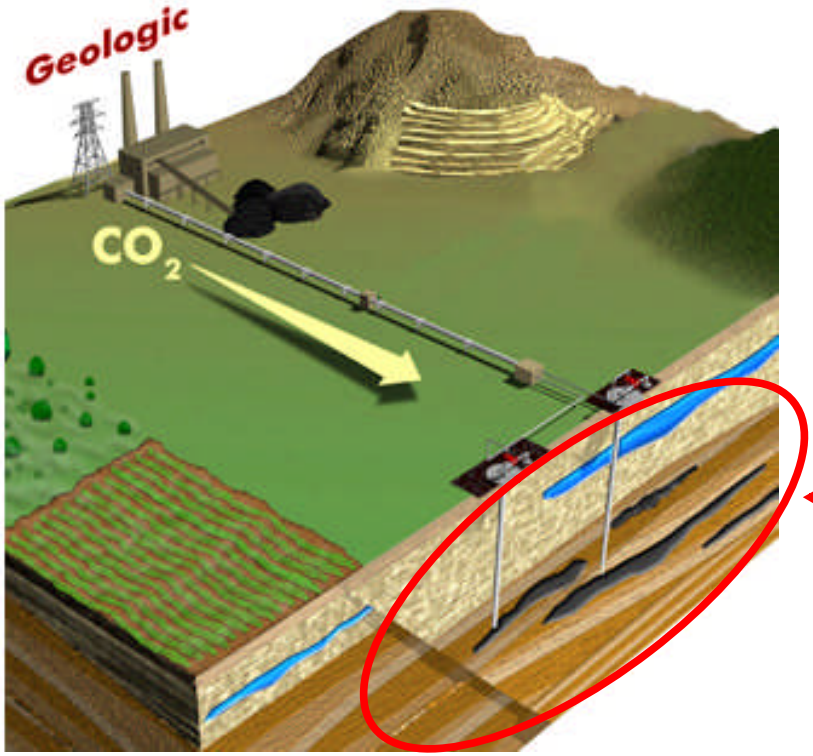
- **Risk assessment for CO_2 storage differs from reservoir modeling**
  - long-term processes (geochemistry of fluid-rock interactions)
  - coupling with mechanical processes
  - must address release mechanisms
  - must address “out of reservoir” factors
- **Strong science base improves predictions (e.g., well bores)**
- **Need for quantitative assessments of analogs**
  - Some EOR operations are analogs to power plant storage

Risk assessment for CO_2 storage involves predicting the behavior of engineered geologic systems.



- **Risk assessment can address multiple factors related to CCS projects**
  - health/safety/environment concerns
  - storage project economics
  - long-term effectiveness (e.g., C credits)
- **Risk assessment can span from qualitative to quantitative**
  - FEP analysis (Features, Events, Processes)
  - process models (detailed physics/chemistry)
  - system models
- **Natural systems are inherently heterogeneous and complex**
  - Predictions, therefore, contain uncertainty
- **A strong science base is essential**
  - projections must be over long time periods
  - sites will have wide variation in conditions

To achieve a strong science base, why can't we apply process models to the entire site?



- **computational challenge**
  - **large range in scale**
- **limitations on site data**
  - **uncertainty will always remain**

- **Risk assessment can address multiple factors related to CCS projects**
  - health/safety/environment concerns
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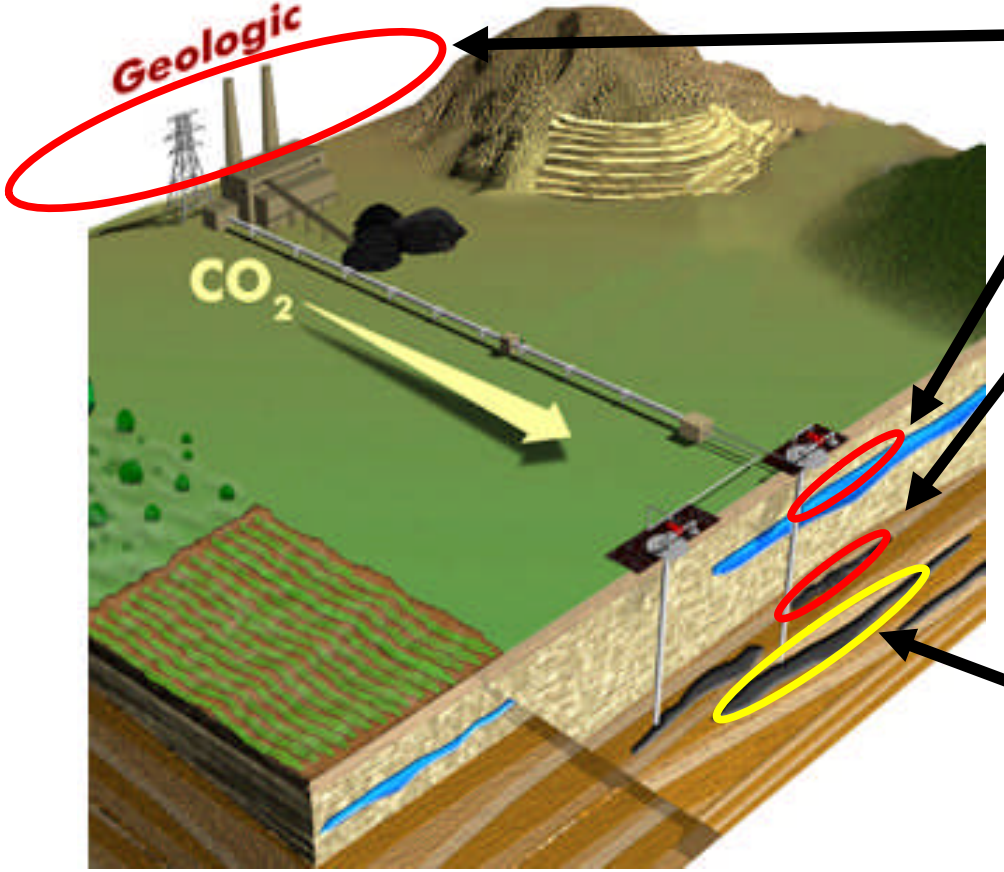
Risk assessment typically treats a storage site as a set of coupled natural & engineered subsystems (compartments).



Potential Receptors
(other reservoirs; groundwater; anthropogenic structures; ecosystems, oceans, atmospheres)

Transport Processes

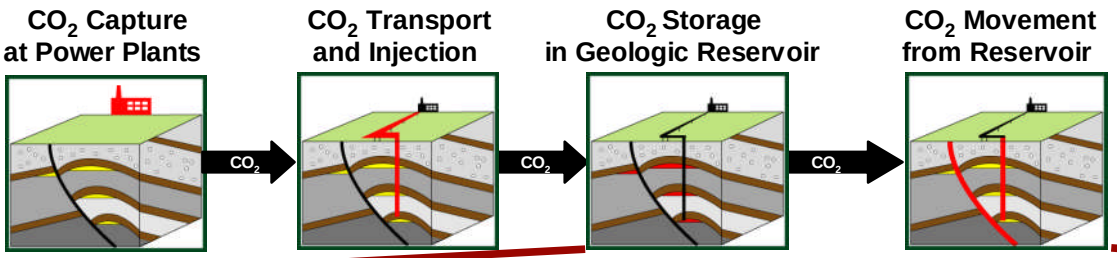
Release Mechanisms

CO_2 Storage Reservoir

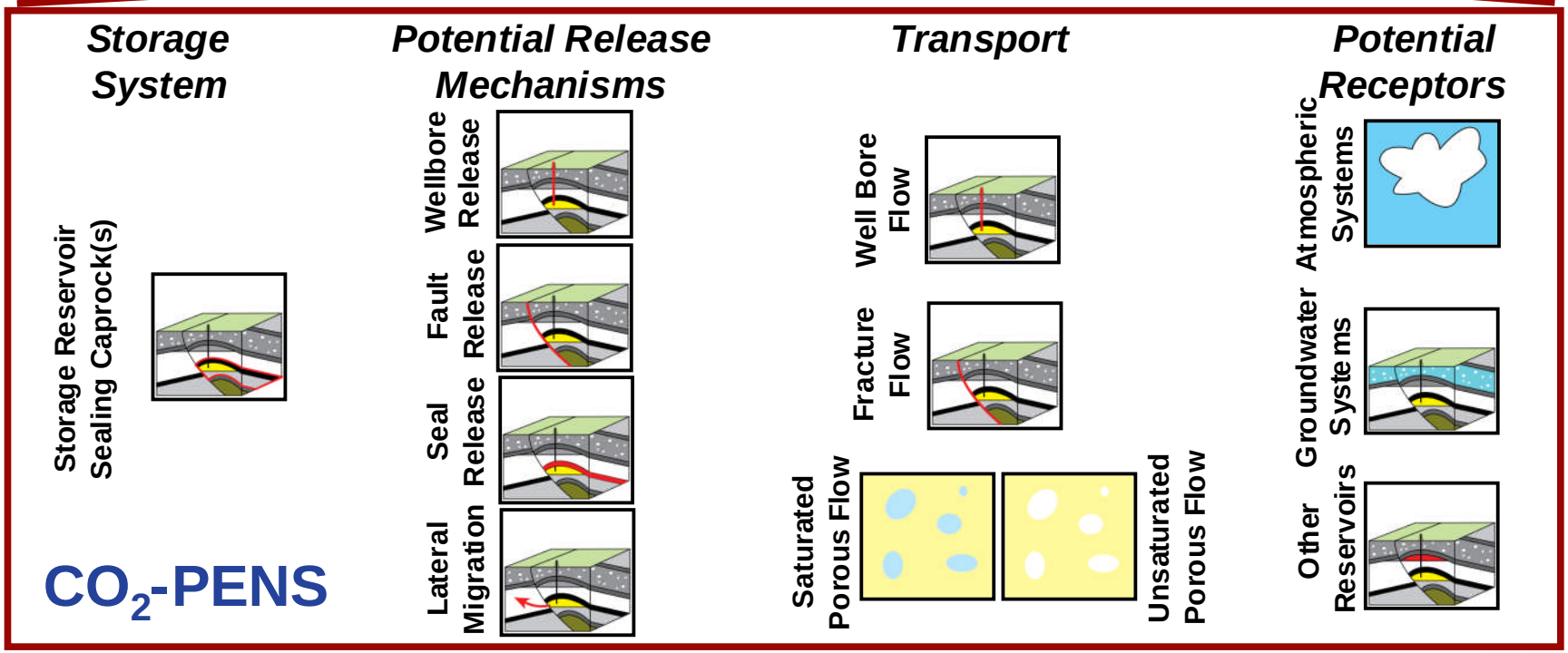
Impact Assessment (HSE risks; economics)

Impacts must be assessed with respect to each of the compartments within the overall storage site (from reservoir to receptors).

Several modular, probabilistic, system models are being develop to assess potential risks at a CCS sites.

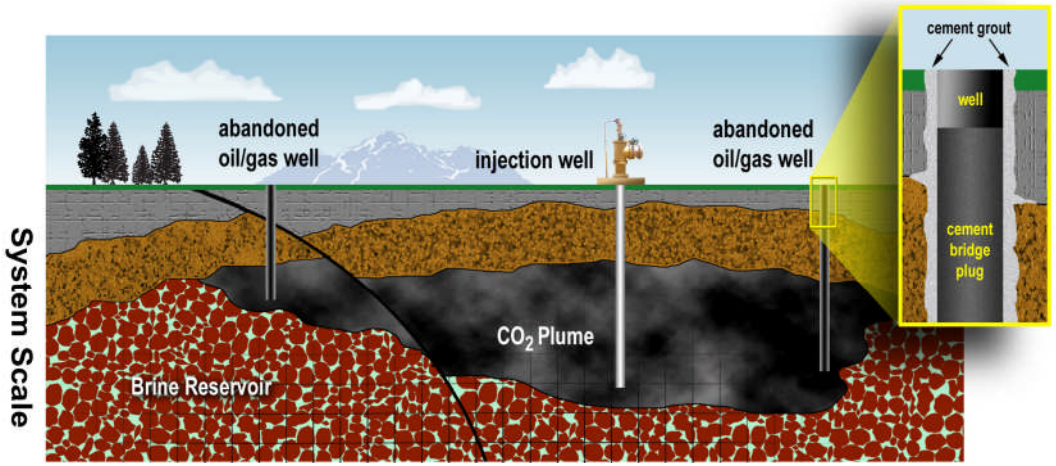


Integrated Assessment/System Model



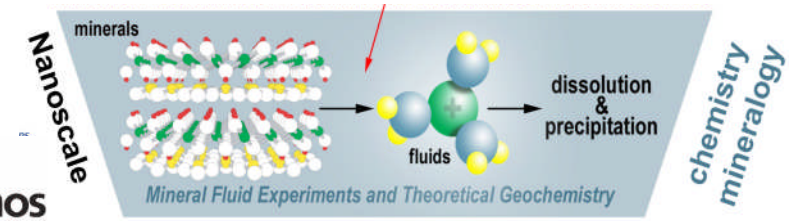
Pawar *et al.*, 2006, Proc. GHGT-8

Science-based system models tie system-level descriptions to process-level phenomena.



- probability distribution functions (PDFs)
- simplified analytical expressions

- **System models—(semi-)analytical & probabilistic**
  - allow the treatment of heterogeneity and uncertainty
  - can be too general or limited in site-specific applicability
- **Process models—deterministic (e.g., reservoir simulators)**
  - allow explicit treatment of physics and chemistry
  - can be too detailed and/or difficult to apply at large scale



- detailed physical & chemical processes

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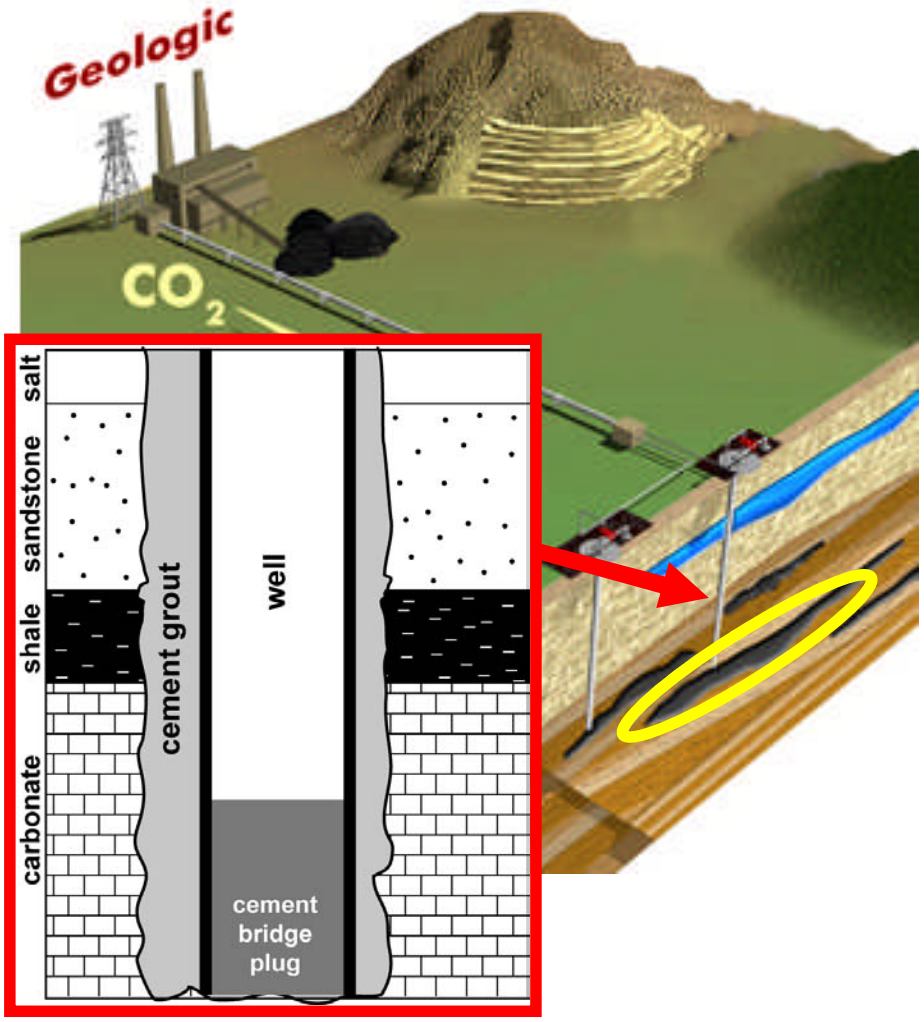
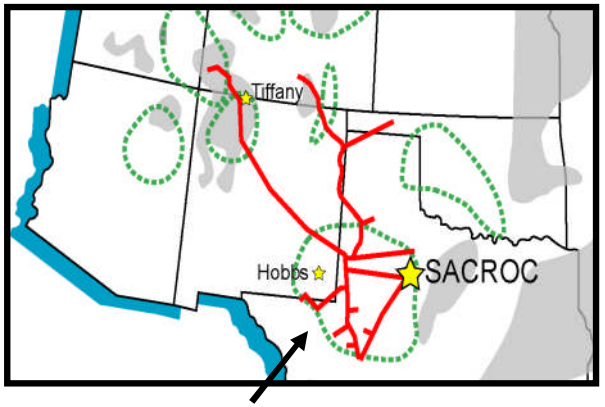
Well-bore integrity is important in long-term CO_2 storage.

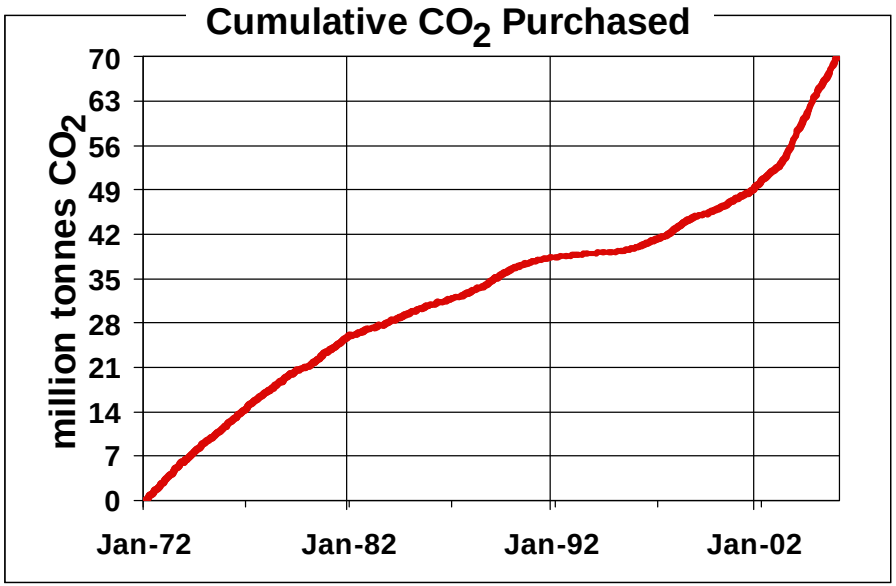


- **Well bores are key components of a storage system and impact CO_2 fate**
  - Required for placement of CO_2
  - Potential release pathway from reservoir (penetration through seals)
    - poor completion or abandonment
    - mechanical and/or chemical damage
  - Potential conduits/fastpaths for CO_2 movement within the geologic site
- **Well bores are typically completed & plugged with portland-based cement**
  - calcium-silicate, calcium aluminate, and calcium hydroxide (a base)
- **Portland cements can degrade in the presence of CO_2 & water**
  - CO_2 + water => carbonic acid
  - batch experiments suggest rapid degradation by carbonic acid

SACROC—an industrial-scale storage analog in W. Texas—began CO_2 flooding in the early 1970s.



Permian Basin



SACROC in 2006

- **~2.8 billion barrels original oil in place (~300 million t CO_2eq)**
- **~13.5 million tonnes of CO_2/yr injected (~6-7 million t/yr of new CO_2)**

1 GW Coal-Fired Power Plant

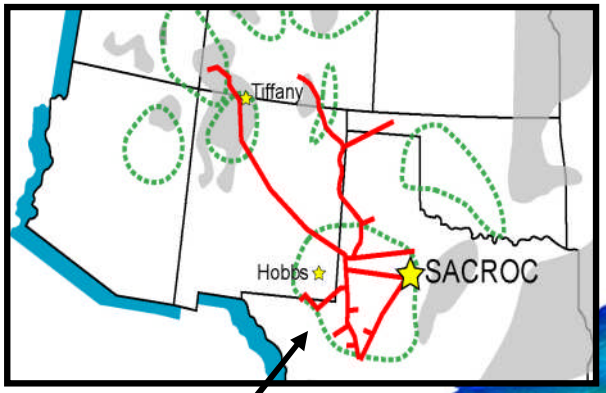
- **~350 million t CO_2 over 50 yrs**
- **~7 million t CO_2/yr**

billion-barrel reservoir → coal-fired power plant

LA-UR-07-7795

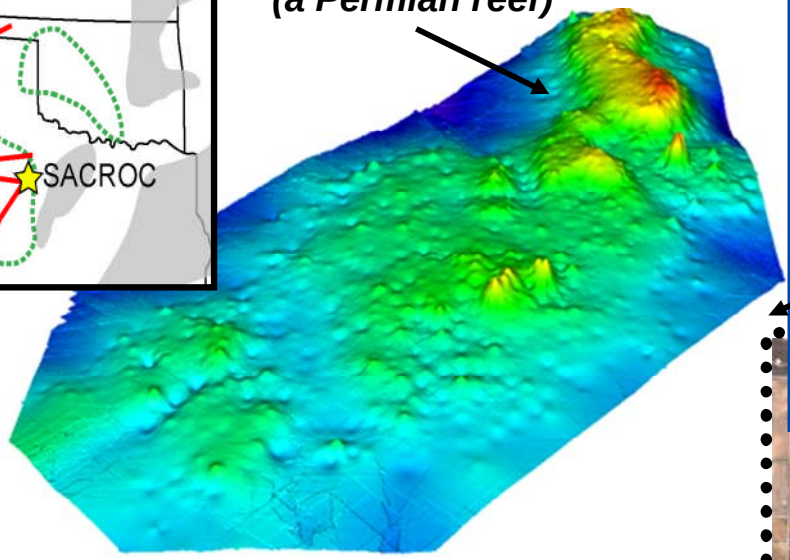
Carey et al., 2007

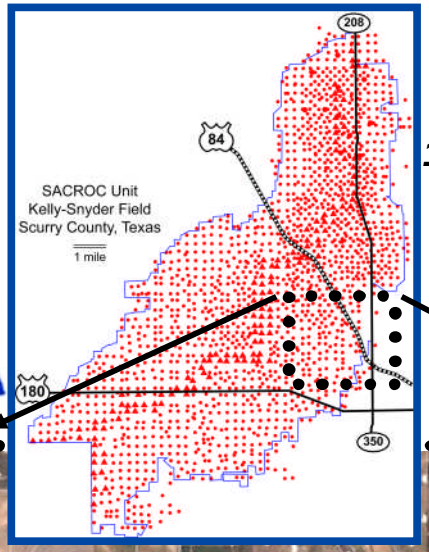
CO_2-EOR operations routinely utilize well-bore technology to place (and to contain) fluids within the reservoir.



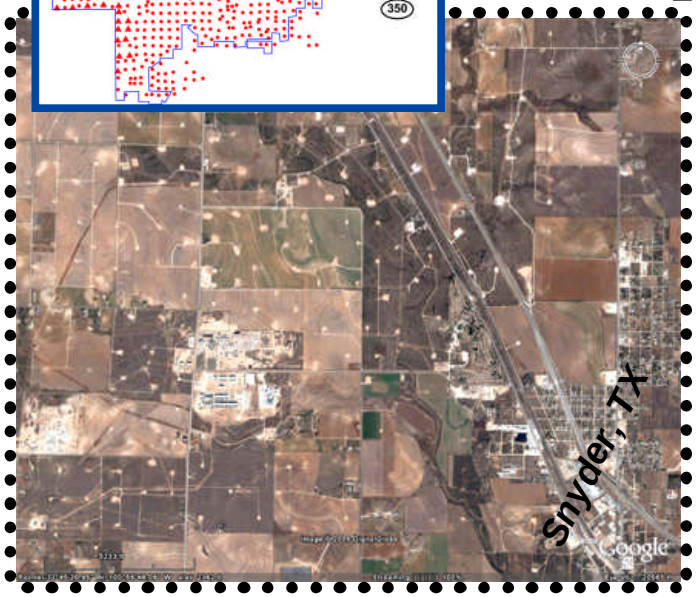
Permian Basin

Top of SACROC unit (a Permian reef)





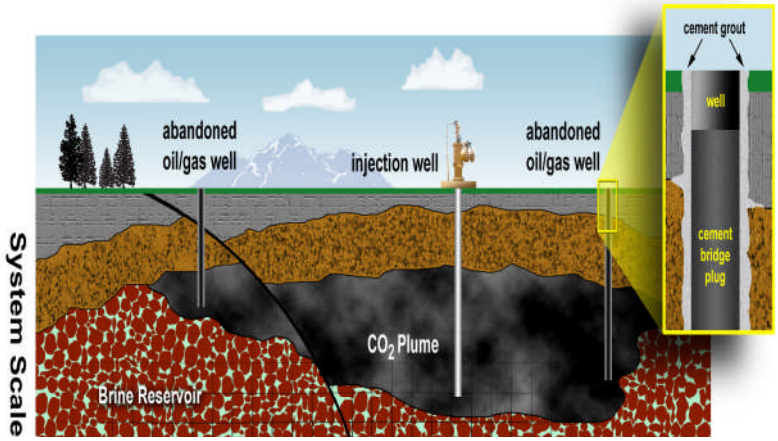
There are over 1800 well bores in the SACROC unit



Carey et al., 2007

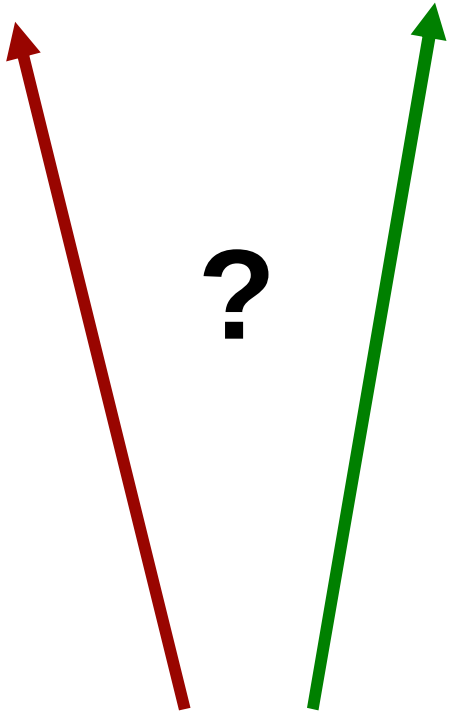
How can we scale fundamental processes to system-level behavior?

Example: Developing a science base in selection between two scenarios for upscaling of fundamental cement chemistry (acid dissolves cement).



well bores will corrode and release CO_2

well bores will not corrode nor release CO_2

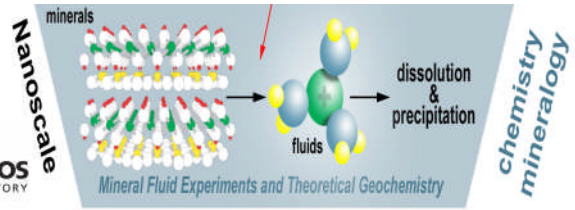


Based on conservative assumptions…

- **Avoid areas with well bores**
  - avoid depleted oil and gas reservoirs
- **Require use of CO_2-resistant cement**
  - higher costs & limited field-use experience

Based on limited experience base…

- **Potentially underestimate long-term costs**
  - liability; well-bore maintenance; etc.



CO_2+brine dissolves hydrated cement

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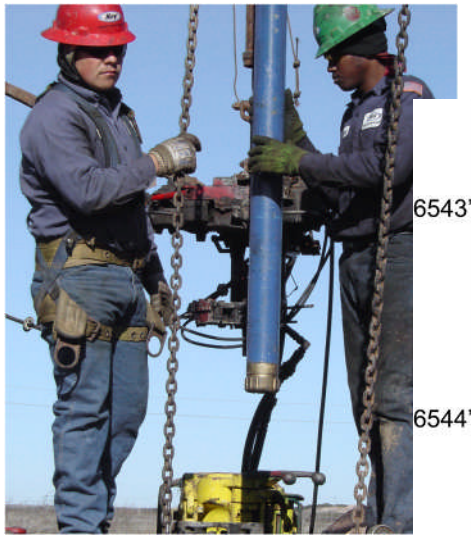
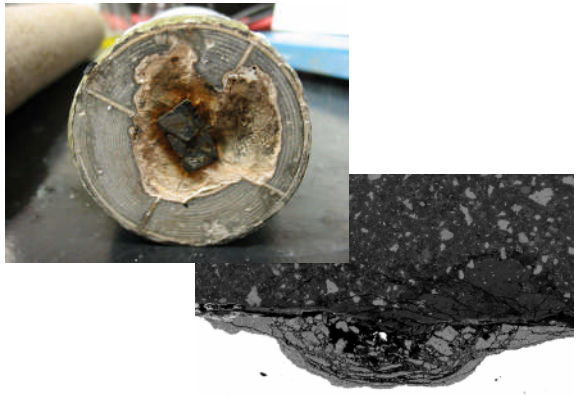
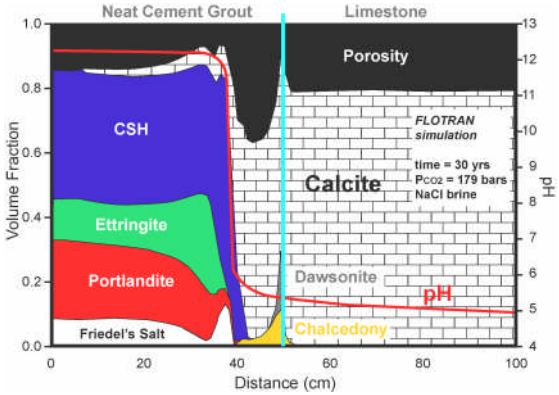
Studies of cement from SACROC CO_2-EOR site begun to develop a science base for predicting cement integrity.



1. field sampling

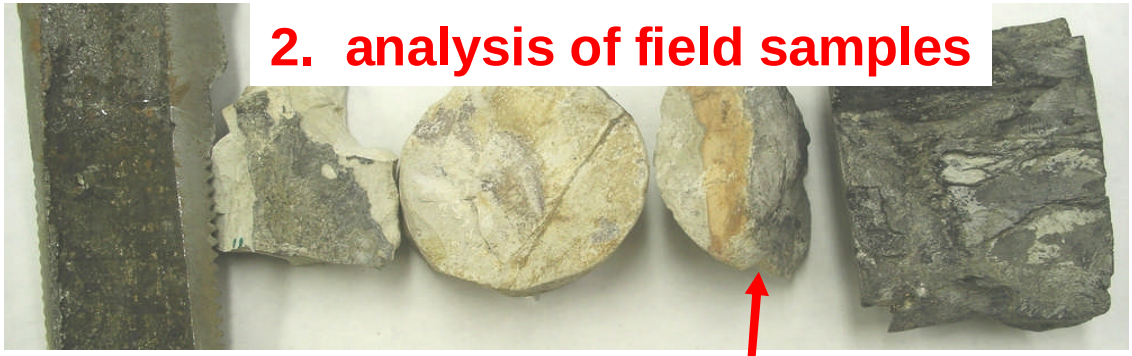


3. accurate experimental models



4. better predictive models

2. analysis of field samples



well bore | casing | "pristine" cement | carbonated cement | shale caprock

LA-UR-07-7795

Guthrie et al., 2005, Midland CO_2 Conf.; Carey et al., 2007, Int. J. GHG Cont.

Some of the Challenges Faced in Risk Assessment

- **Incompletely understood aspects of the storage site**
  - heterogeneity
  - imperfect site data arising from sampling limitations and/or limitations in resolution of measurement & monitoring technology
  - incompletely understood physics and chemistry

  ➢ ***Leads to uncertainty in the predictions***

- **Computationally challenging**
  - large scale-up from molecular (chemistry) to field (performance)

  ➢ ***Leads to assumptions in the predictions***

- **Lack of detailed assessments of analog sites**
  - long-term impact of CO_2 storage must be understood through quantitative assessments of natural CO_2 reservoirs, mature CO_2-EOR sites, etc.

  ➢ ***Leads to less-certain predictions for long-time frames***

Some of the Ongoing Efforts in Risk Assessment

- **CSLF Task Force on Risk Assessment**
  - Phase I underway; anticipated completion summer 2008
  - Coordinated with IEA-GHG effort
  - ➢ ***Summary of existing literature and activities; highlight of critical issues***
- **IEA GHG International Risk-Assessment Network**
  - Initiated August 2005
  - ➢ ***Coordination of research community in risk assessment; identification of research needs, opportunities, and information***
- **Industrial and governmental efforts to develop RA tools and to apply RA to field efforts**
  - Numerous efforts
  - ➢ ***Development of methodologies; data collection for model development and validation***

Take-Home Points

- **Risk assessment for CO_2 storage differs from reservoir modeling**
  - long-term processes (geochemistry of fluid-rock interactions)
  - coupling with mechanical processes
  - must address release mechanisms
  - must address “out of reservoir” factors
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  - Some EOR operations are analogs to power plant storage