CO₂ Capture Project

Risk Assessment and Remediation Options for Geologic Storage of CO_2

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Outline

- Lessons learned from natural and industrial analogues
- Scenarios for assessing consequences of leaking storage projects
- Probabilistic risk assessment methodology
- Risk management, mitigation and remediation options

Analogues for Geologic Storage of CO_2

Industrial Analogues

- Deep injection of liquid and hazardous wastes
- Natural gas storage
- CO_2 enhanced oil recovery
- Occupational health and safety regulations
- Nuclear waste storage*

Natural Analogues

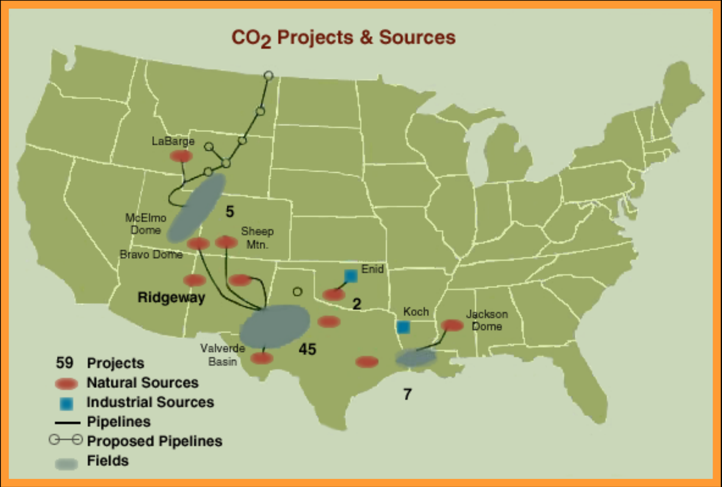
- Oil and gas reservoirs
- Natural CO_2 reservoirs
- Natural CO_2 releases
  - Volcanic eruptions
  - Hydrothermal vents
  - Limnic releases
  - Diffuse venting
  - Ecosystem CO_2 cycling

Limited relevance but some important lessons

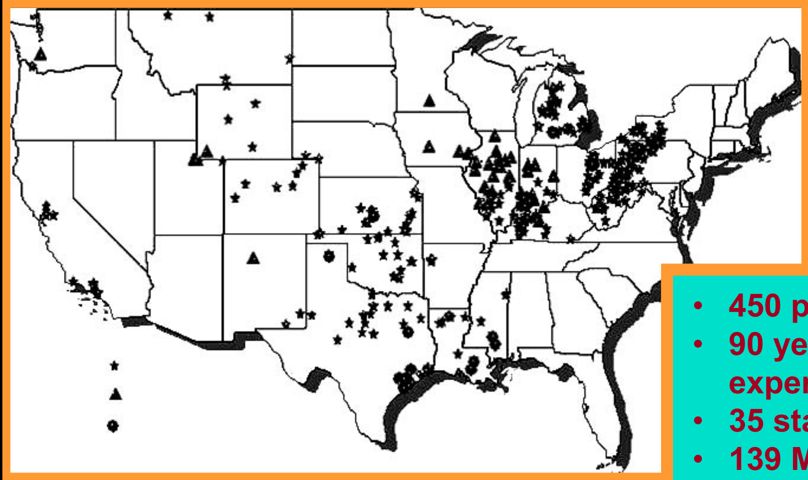
Lesson 1: CO_2 Can be Stored Safely

- Enhanced oil recovery
- Natural gas storage
- Deep injection of liquid and hazardous wastes

CO_2 Enhanced Oil Recovery



Natural Gas Storage



- 450 projects
- 90 years experience
- 35 states
- 139 MMT stored annually

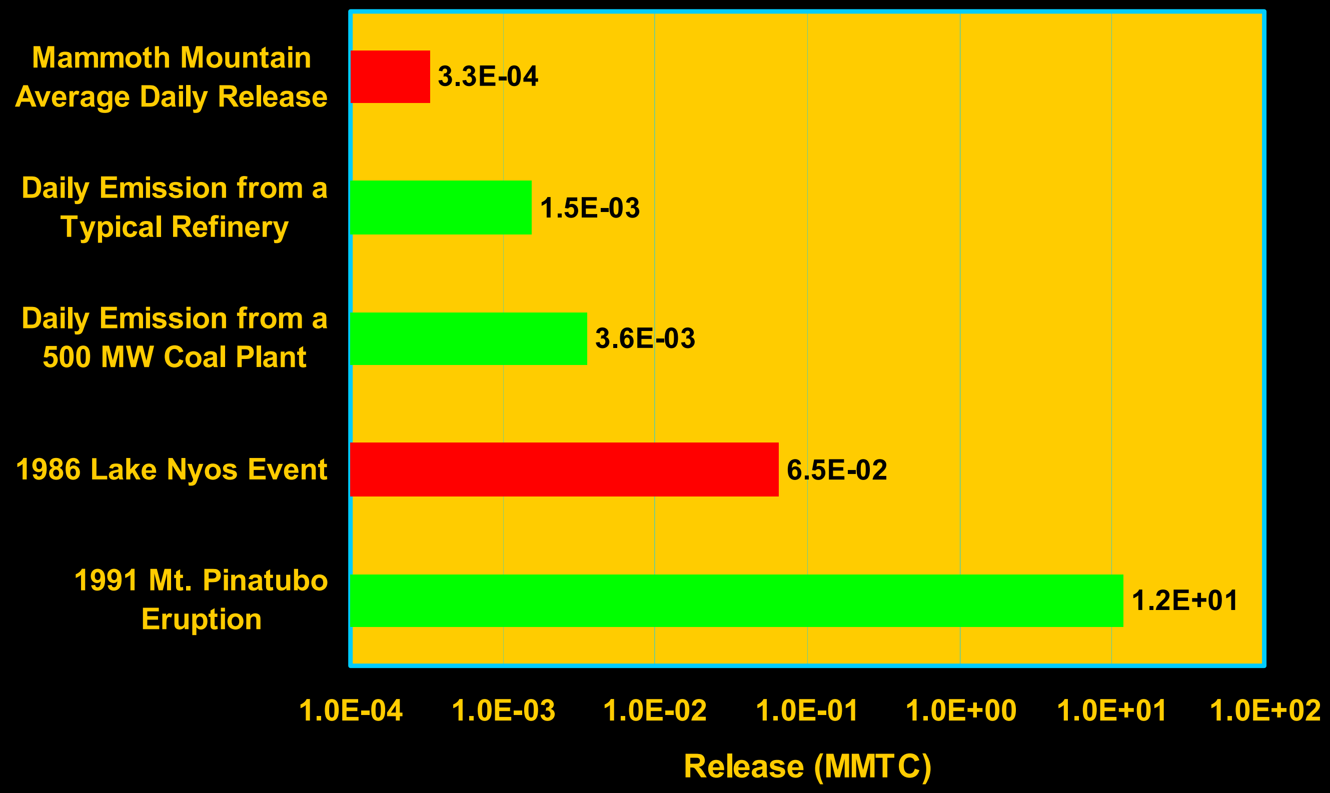
Lesson 2: Health Effects are Well Understood

- Atmospheric CO_2 370ppm
- Humans tolerate up to 1% with no adverse effects
- Significant effect on respiratory rate and physical discomfort at 3-5%
- Death imminent at >30% for several minutes

Federal occupational safety and health regulations set standards:

- 0.5% for 8-hour, 40 hr work week
- 3% for short term, 15 minute exposure
- 4% for maximum instantaneous exposure

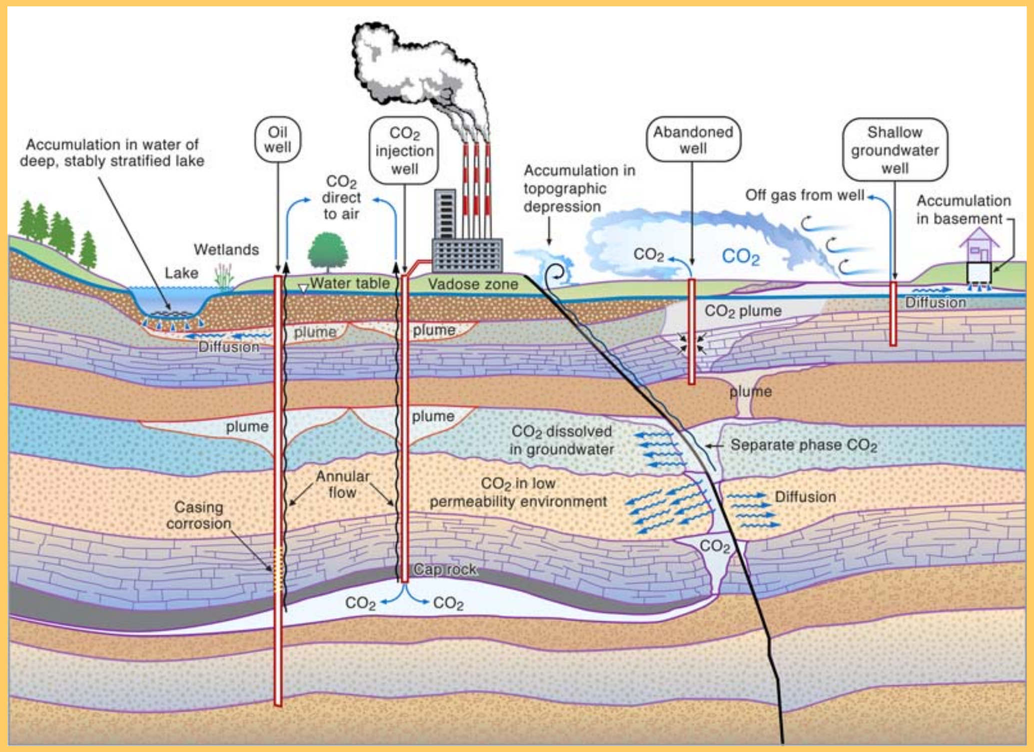
Lesson 3: Hazard Depends on Nature of Release, not Size



Releases that are quickly dispersed in the atmosphere provide little hazard

Lesson 4: Biggest Risks Have Been Identified

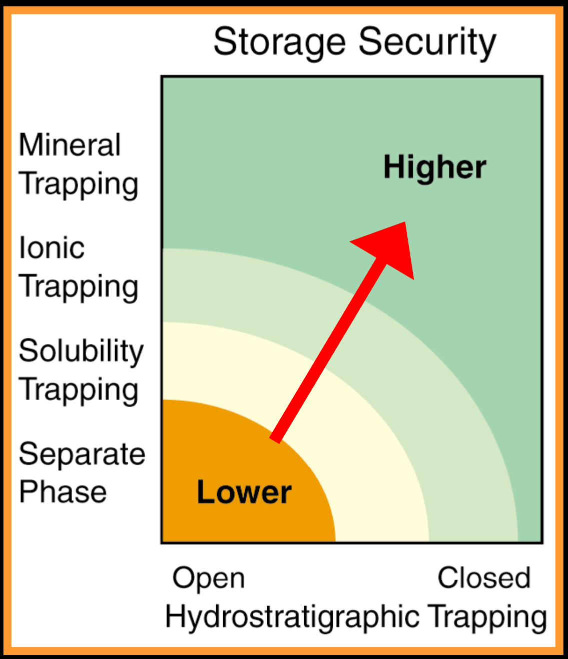
- Leakage through poor quality or aging injection well completions
- Leakage up abandoned wells
- Leakage due to inadequate caprock characterization
- Inconsistent or inadequate monitoring

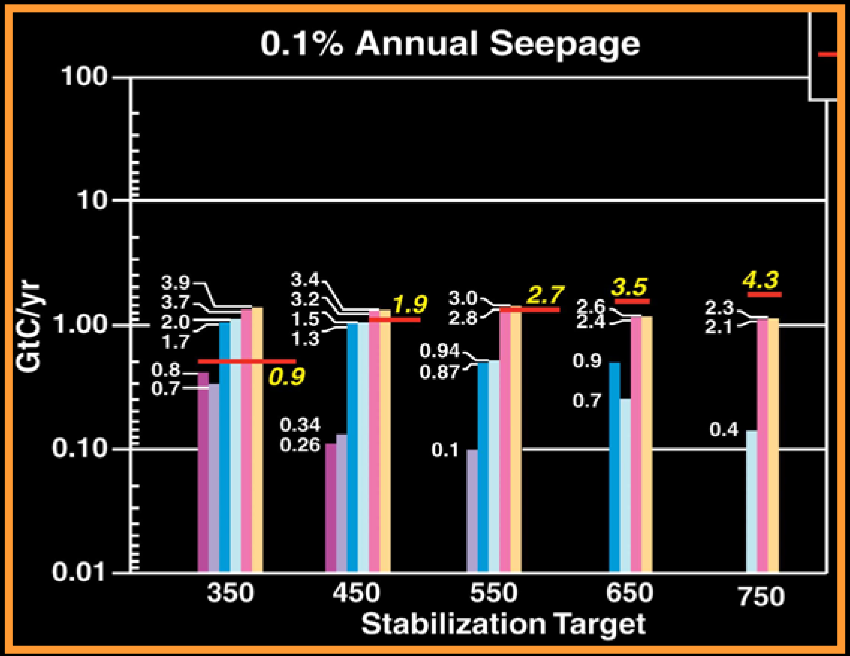


Maturation of the technology and improved regulations have mitigated most of these problems for the industrial analogues

Lesson 5: CO_2 Storage has Some Unique Attributes

- Buoyancy driven migration and trapping
- Solubility and mineral trapping
- Long time frame (1000s of years)
- Non-hazardous at low concentrations

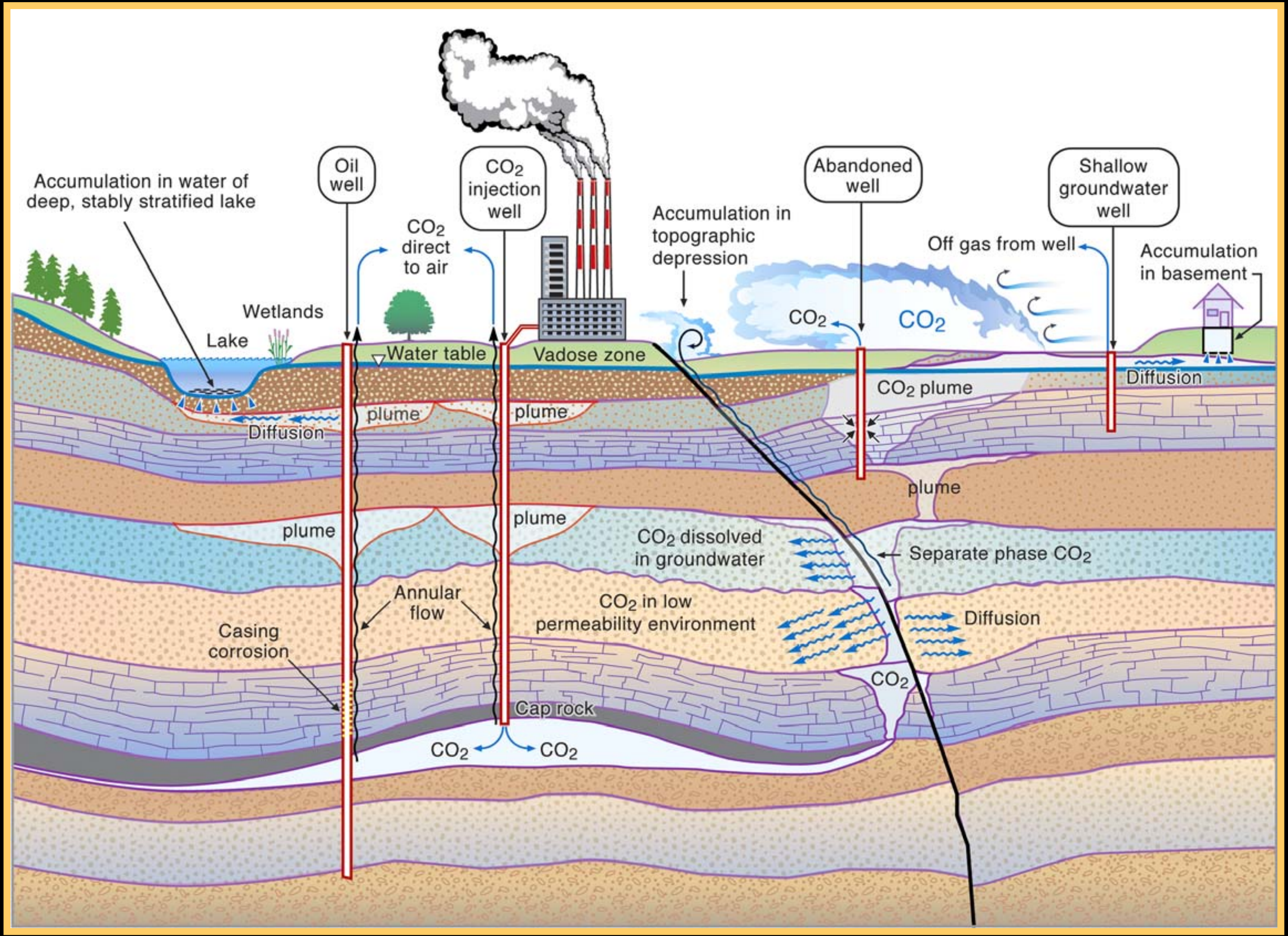




Risk Assessment

- Risk = Probability x Consequences
- Probability = Likelihood of an event occurring
- Consequences = Effects of the event occurring

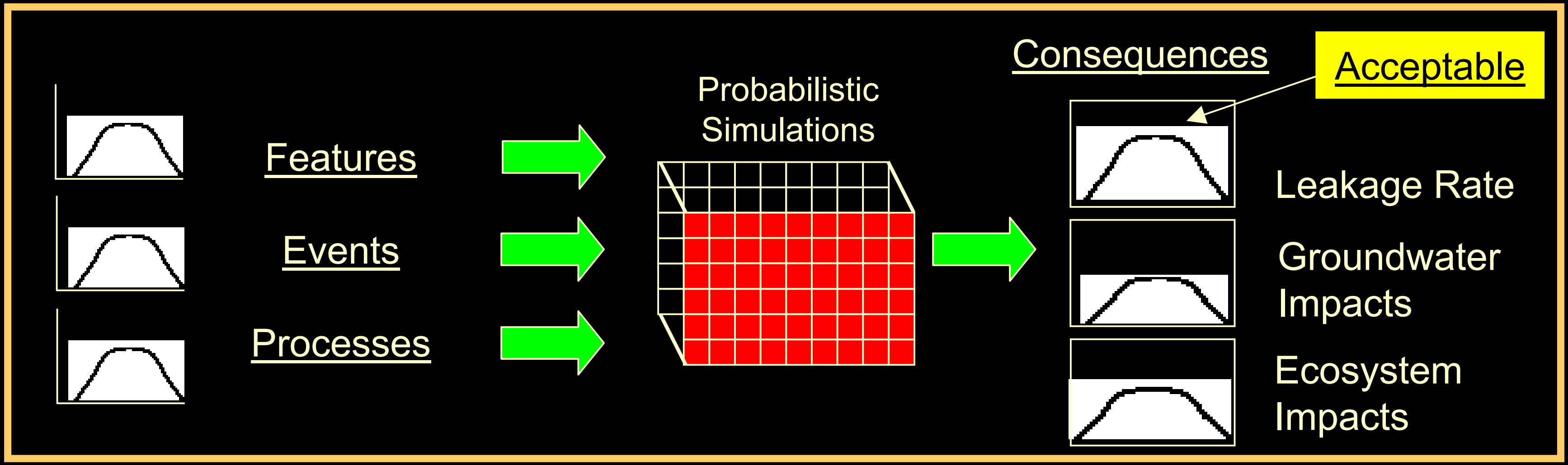
Scenarios and Consequences



Probability: Features-Events-Processes-Methodology

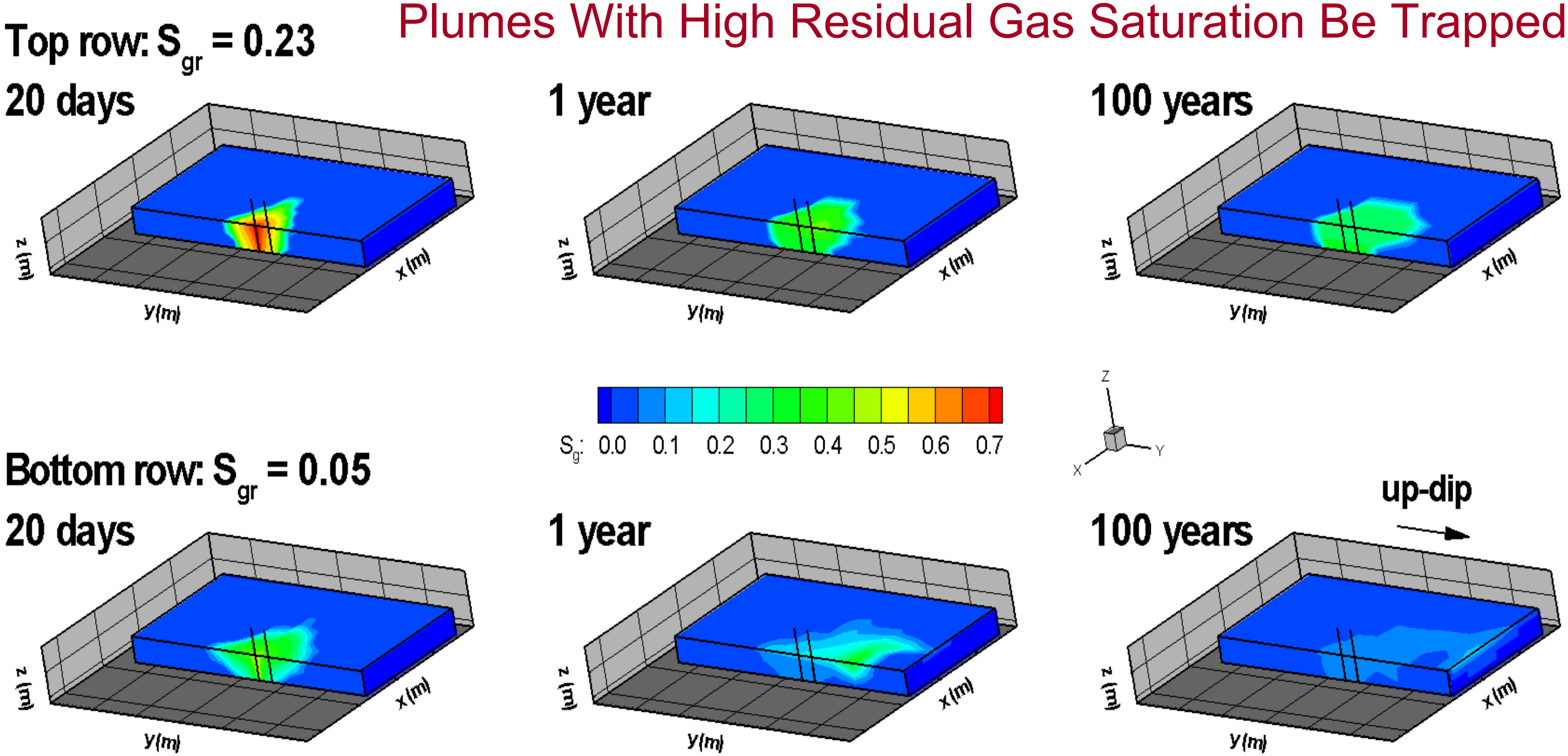
Features	Events	Processes
• Caprock thickness and permeability • Mineralogy of the storage zone • Faults and abandoned wells	• Earthquakes • New exploration wells • Changes in groundwater use • Well blowout	• Buoyancy-driven flow • Mineral trapping • Solubility trapping • Geomechanical changes in the caprock

FEP Risk Assessment Framework



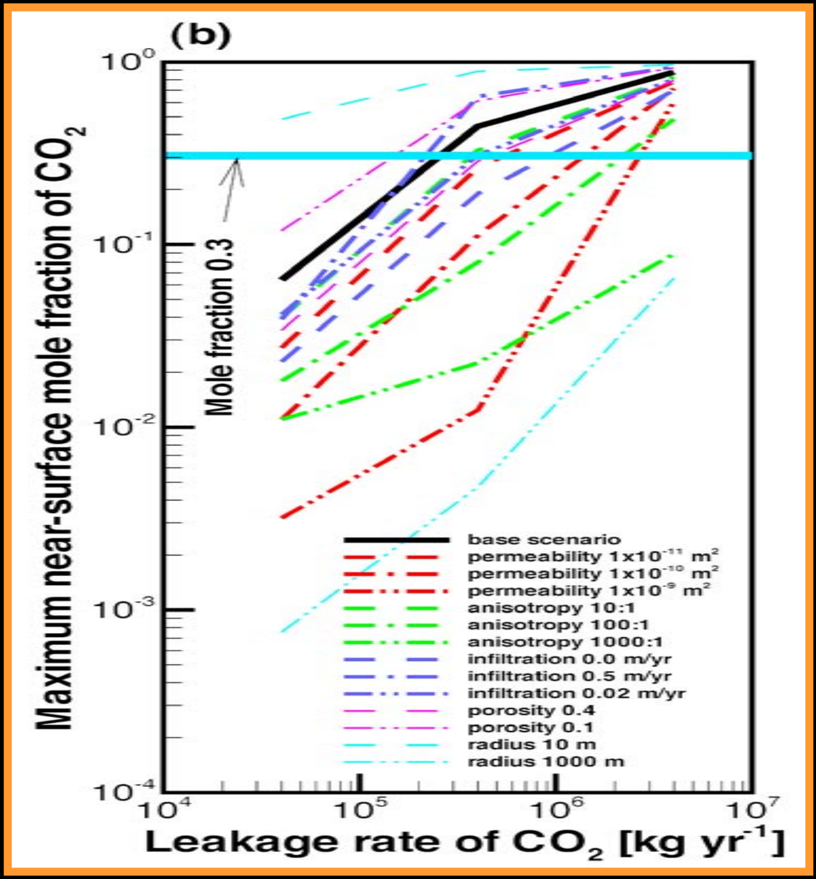
Long Term Fate of Injected CO_2: Slippery vs. Sticky Plumes

Plumes With High Residual Gas Saturation Be Trapped

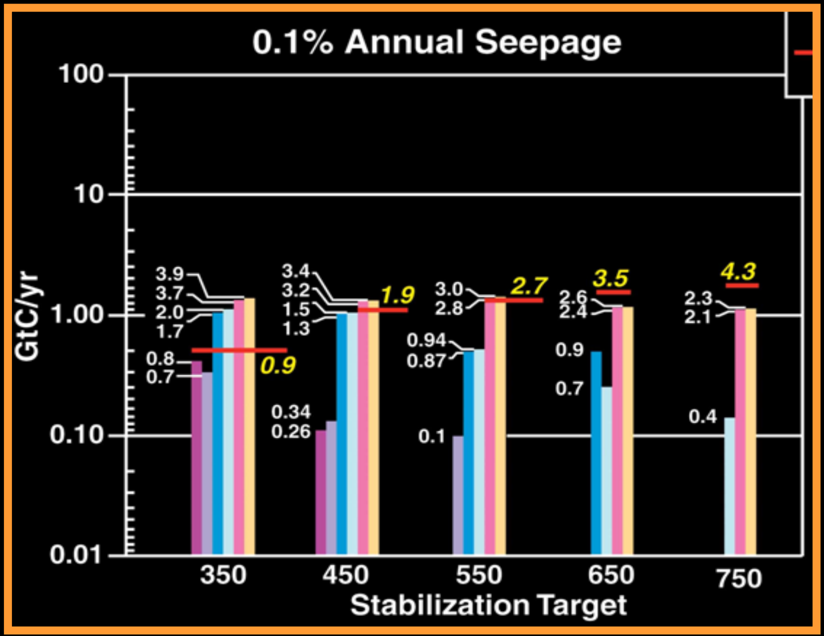


Plumes With Low Residual Gas Saturation Will Migrate and Dissolve

Acceptable Leakage Rates



Sensitivity of CO_2 Seepage and Soil Gas Concentration to Various UZ Properties

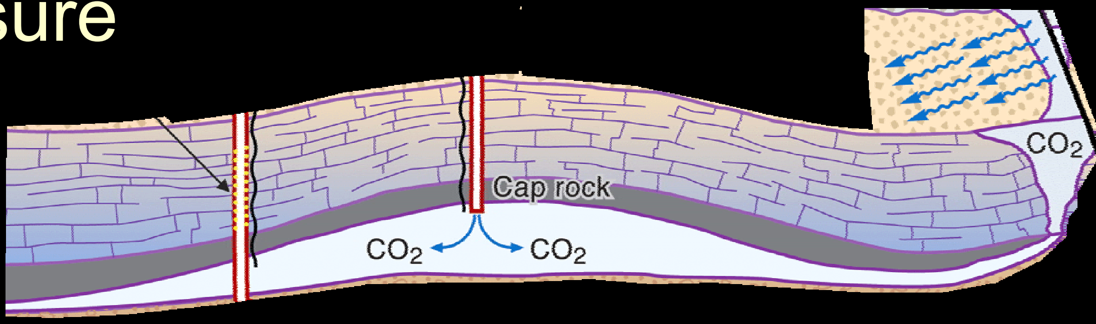


Effectiveness for Greenhouse Gas Control

Ecosystem impacts may decrease acceptable leakage rates to less than 0. 1% per year

Remediation of Leaks within the Storage Reservoir

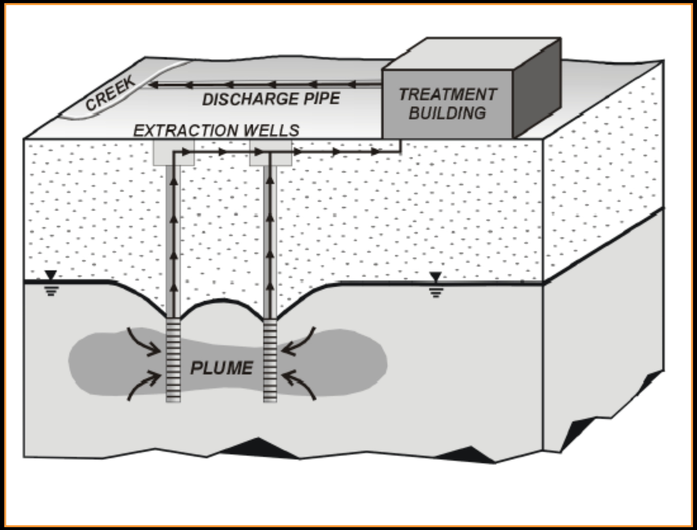
- Lower reservoir pressure
  - Inject at lower rate
  - Stop injection
  - Begin CO_2 extraction
  - Pump out groundwater peripherally to lower pressure



- Extract CO_2 before it reaches the leakage path
  - Pump from reservoir before leakage point
- Hydrofracture to access new areas of the reservoir away from areas of leakage

Groundwater Remediation

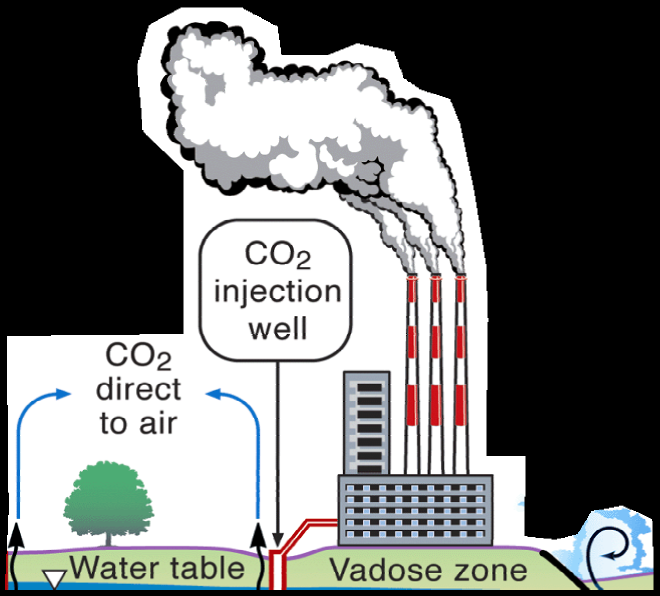
- Passive methods
  - Natural attentuation by dissolution, migration, and mineralization
- Active methods
  - Gas phase pumping
  - Groundwater extraction to dissolve plume
  - Single well dissolution system: inject and produce water
- Methods to deal with other contamination due to dissolution of minerals by CO_2
  - Pump and treat with wells
    - Vertical
    - Horizontal
    - Deep gravel trenches/drainage
  - Containment by managing hydraulic heads
- Sealing faults in limited areas
  - Foam injection
  - Grout injection



Picture taken from *http://www.clu-in.org/download/remed/542r01021b.pdf*

Vadose Zone Remediation

- Passive methods
  - Diffusive flux to surface
  - Baroballs
- Active methods
  - Soil gas extraction
    - Vertical wells
    - Horizontal wells
    - Drainage systems
    - Trenches
  - Covers
    - Landfill cover—low permeability material
    - Collection system below cover
  - Sprinkling/irrigation to dissolve CO_2 and move it downward



Conclusions

- CO_2 storage can be safe and effective
- Impacts of leaking storage projects are well understood
- Methodology for probabilistic risk assessment is available
- Remediation of leaking storage projects is possible
- Credible site-specific risks assessments are the biggest challenge
  - Adequate site characterization data
  - Performance confirmation