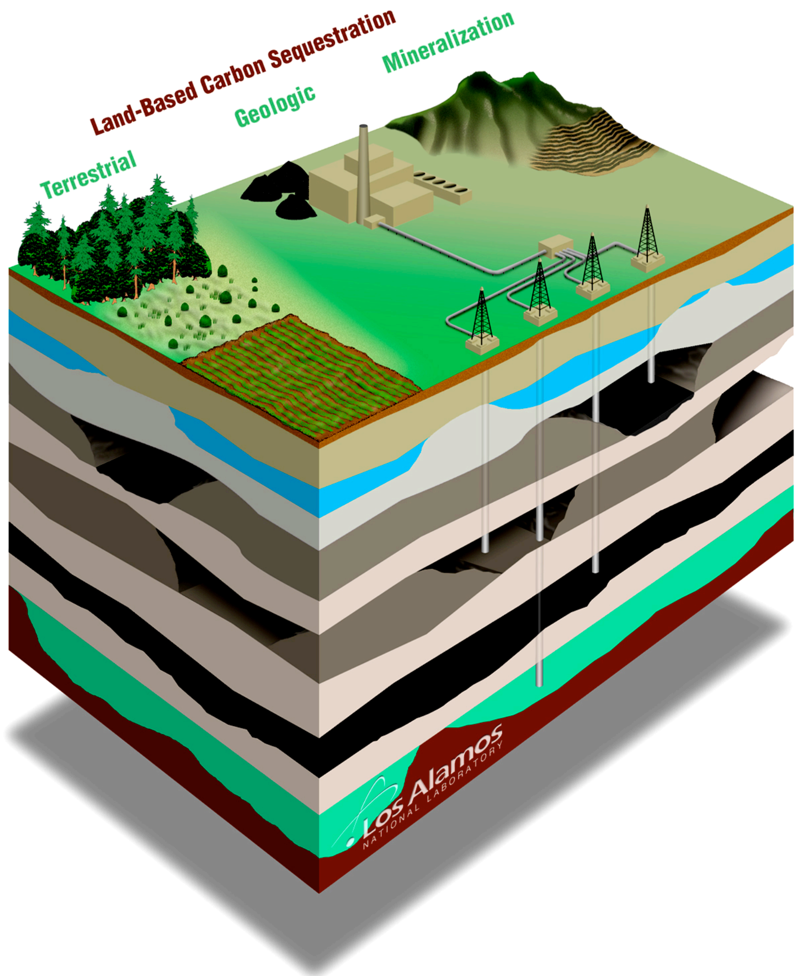
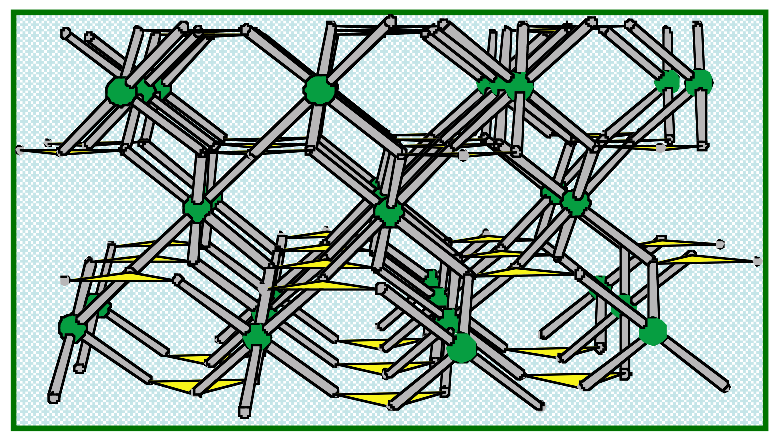
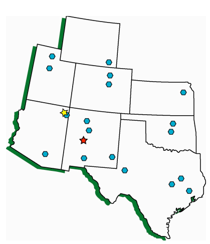
CO_2 Mineralization as an Option in the Carbon Storage Strategy for the U.S. Southwest Region



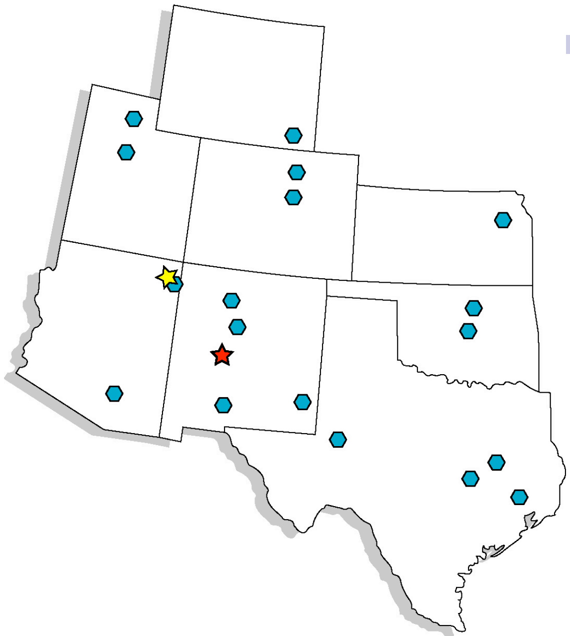
Gillian Bond—New Mexico Tech
Faruk Civan—Univ of Oklahoma
Jim Evans—Utah Geological Survey
Craig Forster—Utah Geological Survey
George Guthrie—Los Alamos National Lab
Dick Hughes—Univ of Oklahoma
Mike McKelvy—Arizona State Univ
Brian McPherson—New Mexico Tech
Beth Widmann—Colorado Geolical Survey
Hans Ziock—Los Alamos National Lab





Southwest Regional Partnership for Carbon Sequestration

Southwest Regional Partnership
southwestcarbonpartnership.org



CO_2 Mineralization Team

Arizona State University
Colorado Geological Survey
Los Alamos National Lab.
NM Inst. of Mining and Tech.
Oklahoma State University
Utah Geological Survey

40+ Partners

Arizona Universities & Government
Arizona Geological Survey
Arizona State University
Diné College (Navajo Nation)

Colorado Universities & Government
Colorado Geological Survey
Colorado State University

New Mexico Universities & Government
New Mexico Oil Cons. Division
New Mex. Bureau of Geology
New Mexico Envir. Department
NM Inst. of Mining and Technology
New Mexico State University
Diné College (Navajo Nation)

Oklahoma Universities & Government
Oklahoma Geological Survey
University of Oklahoma
Oklahoma State University
Sarkey's Energy Center

Texas
Texas Bureau of Economic Geology
Texas A&M

Utah Universities & Government
Utah Geological Survey
University of Utah
Utah State University
Utah AGRC
Utah Division of Air Quality
Utah Energy Office
Utah Division of Oil Gas & Mining

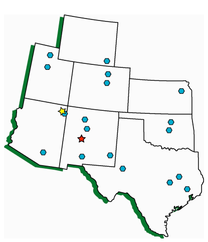
Power Utilities
Tucson Electric Power
Oklahoma Gas & Electric
Intermountain Power Agency
Pacificorp
Public Service Co. of New Mexico (PNM)

Oil, Gas, & Coal Producers
Yates Petroleum, ChevronTexaco
Marathon, Occidental Permian
ConocoPhillips, Burlington

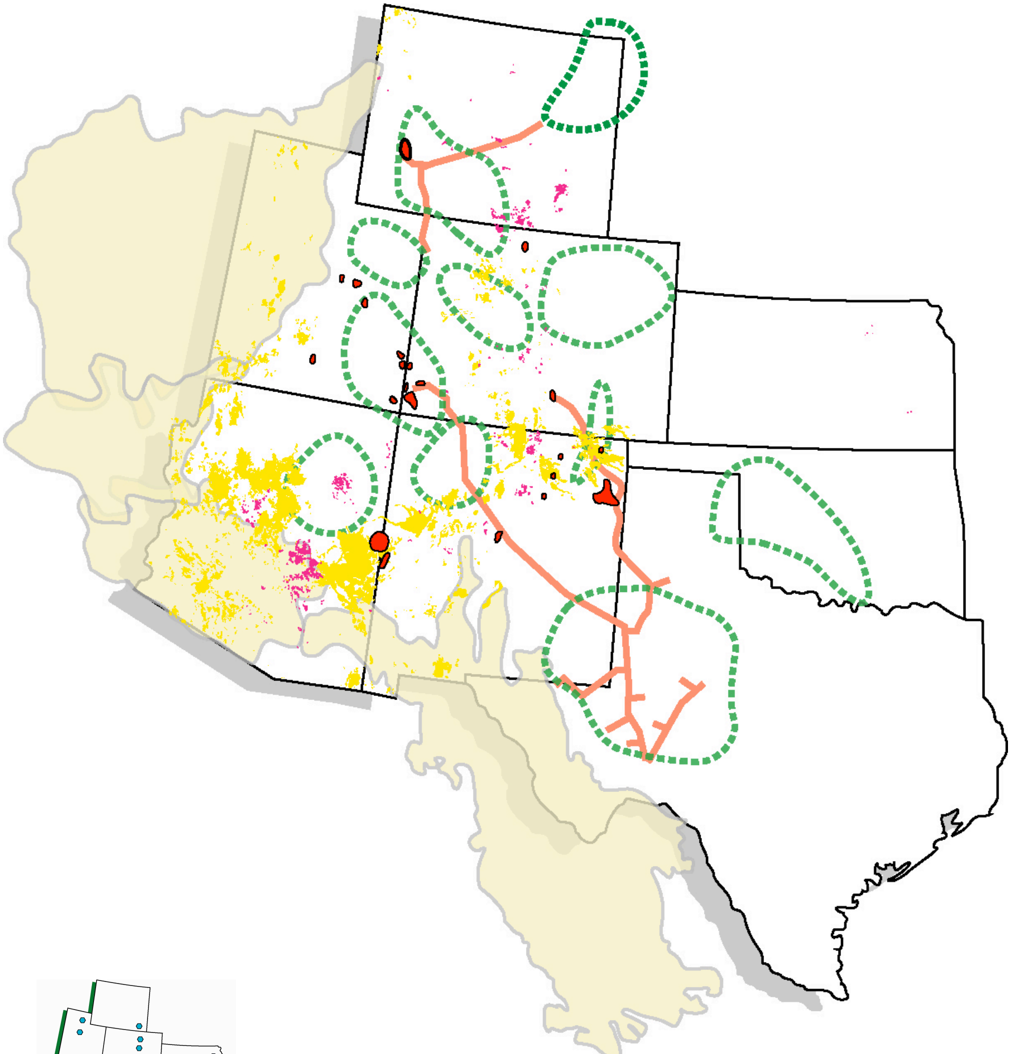
Gas Infrastructure
Kinder Morgan

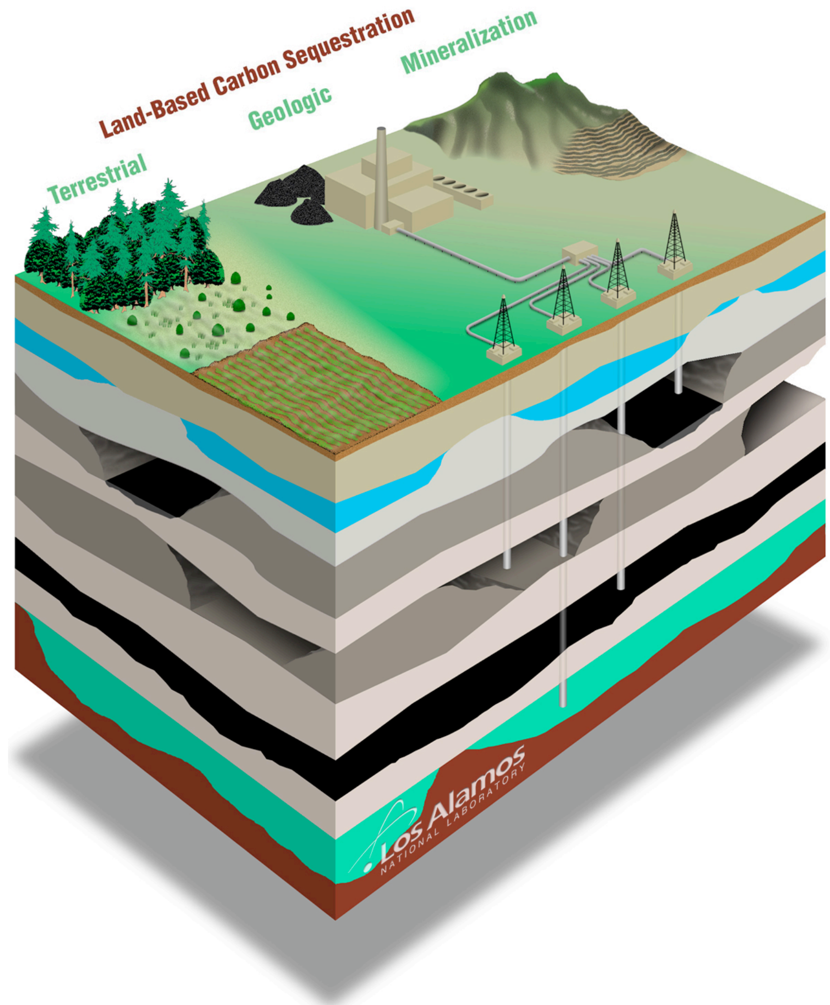
Federal Government Partners
Los Alamos National Laboratory
Sandia National Laboratory
U.S. Dept. of Agriculture

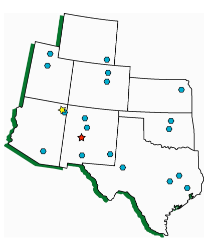
Various Additional Partners
Navajo Nation
New Mexico Oil and Gas Association
Gas Technology Institute (GTI)
Electric Power Research Institute (EPRI)
IOGCC
CEED
Advance Resources International (ARI)
Western Governors Association
Petroleum Recovery Research Center (PRRC)
Waste-management Educ. & Research Center (WERC)



Southwest's regional attributes offer the ability to consider multiple land-based options for CO_2 storage.





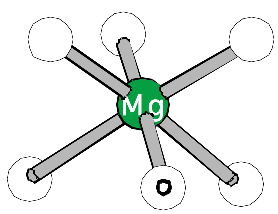


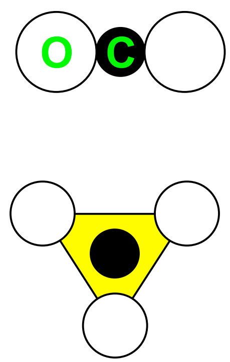
Southwest Regional Partnership for Carbon Sequestration

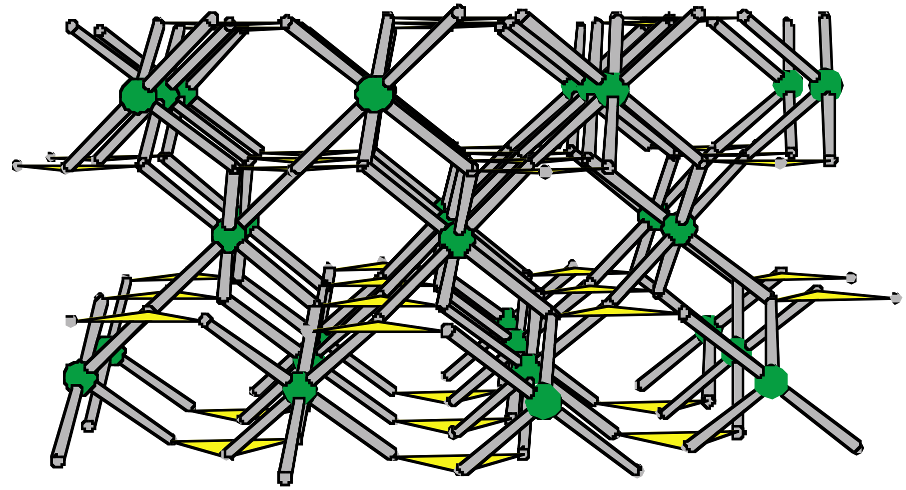
CO_2 Mineralization as an Advanced Storage Concept

Goal: To trap carbon dioxide in an alkali or alkaline-earth metal solid carbonate, rendering it benign and immobile.

metal oxide + carbon dioxide $\rightarrow$ metal carbonate







Ca- or Mg-carbonate
***e.g.*, calcite or magnesite**

- **Both thermodynamic and kinetic factors must be considered**

CO_2 Mineralization as an Advanced Storage Concept

Natural parallels…

- **weathering reactions**
- **water–CO_2–rock interactions in subsurface environments**
- **biomineralization**

Industrial mineralization…

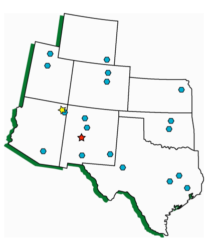
- **Metals (Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, K^{+}) derived from combination of sources—e.g., brines, mined ores (*e.g.*, serpentinites), wastes**

In situ mineralization…

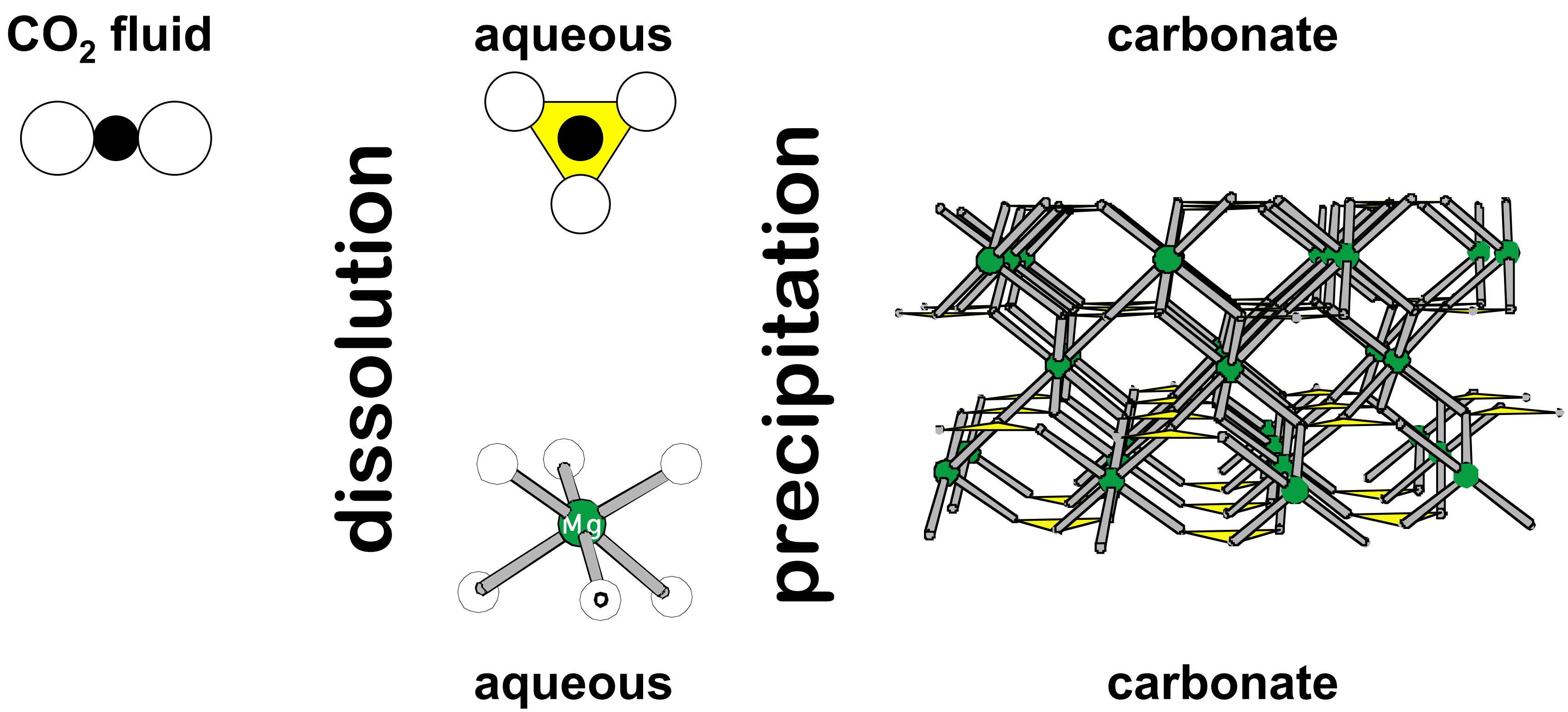
- **CO_2–water–rock interactions in geologic storage reservoirs, leading to complete mineralization or to reduced permeability**

CO_2 Mineralization Relative to NETL Storage Goals

- **Permanency**
  - \+ immobile; relatively low solubilities
- **Environmental acceptability**
  - \+ solid carbonates are typically benign
  - \+ waste conversion
  - – process could involve mining or production operation
- **Verification of amount of C stored**
  - \+ solids can be easily quantified
- **Value added benefit**
  - \+ by products (*e.g.*, Pt, …; water); construction materials
  - \+ waste utilization
- **Economic viability**
  - ? need to identify feasible conversion process(es)



CO_2 Mineralization via Dissolution–Precipitation



Brine Mineralization: Overview of the Process

- **precipitation of solid carbonate from aqueous solution**

  $M^{2+}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightarrow MCO_{3(s)}$ **(where M = Ca, Mg, Fe)**

- **hydration of carbon dioxide is rate limiting at lower T for Ca**

  $CO_{2(g)} \rightarrow CO_{2(aq)}$ ***interfacial diffusion***

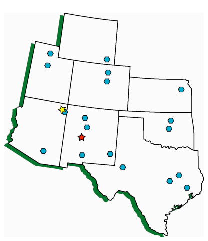
  $CO_{2(aq)} + H_2O \rightarrow H_2CO_3$ ***hydration***

  $H_2CO_3 \rightarrow HCO_3^- + H^+$

  $HCO_3^- \rightarrow CO_3^{2-} + H^+$

- **biomineralization uses catalysts to accelerate CO_2 hydration;**

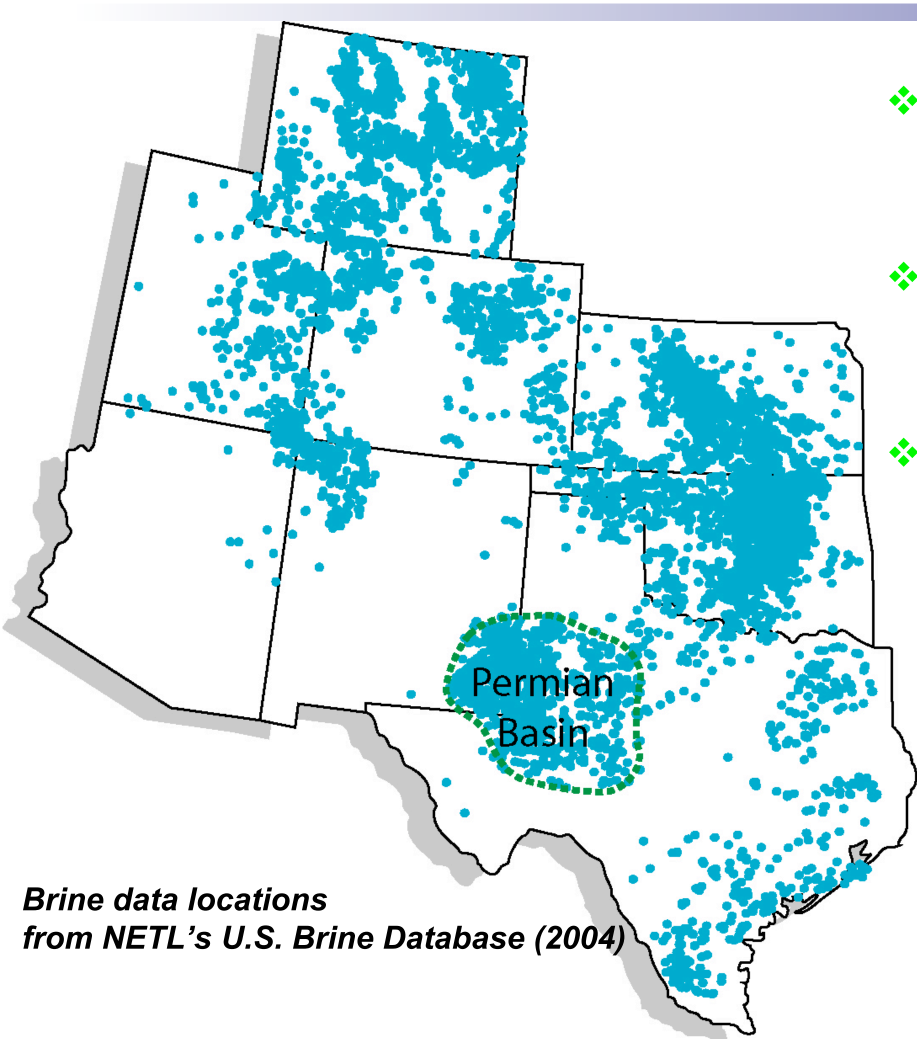
  Can biocatalysts enhance the rate of CO_2 mineralization?



Brine Mineralization: Status of Research

- **Feasibility demonstrated using HCA II and brine simulants**
  - **accelerated hydration of CO_2**
  - **accelerated precipitation of $CaCO_3$**
  - **flow-through demonstrated using immobilized HCA II**
  - **robust relative to industrial levels of SOx, NOx, As, Hg**
- **Economic source of enzyme identified**
  - **bacterial overexpression of HCA II**
  - **immobilized HCA II with good activity and low leakage**
- **Carbonate successfully precipitated from range of simulants**
  - **low cation concentration (~90% Ca ppt in single pass)**
  - **high cation concentration (~80% TIC ppt in single pass)**
- **Possible brine sources under evaluation**
  - **produced waters from oil/gas; various waste streams (including from desalination)**

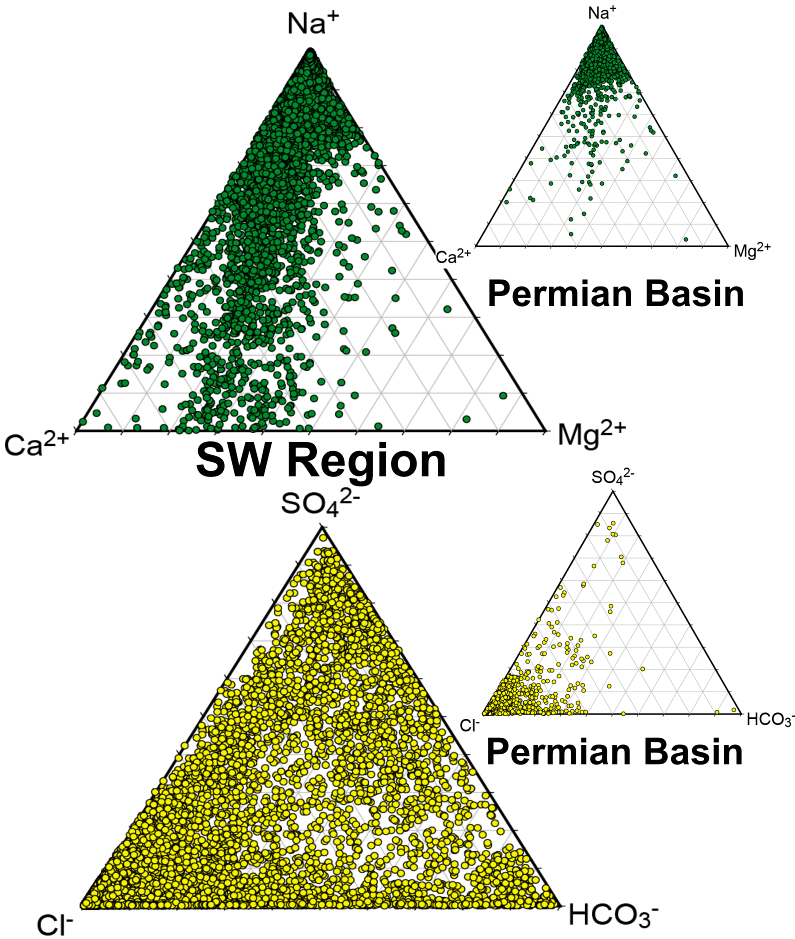
Brine Mineralization: Regional Resources

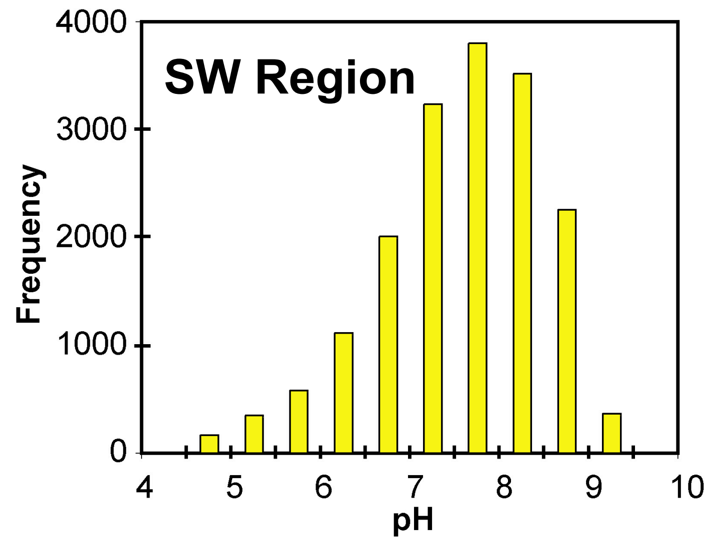


Brine data locations
from NETL's U.S. Brine Database (2004)

- Permian Basin produced waters for 2002 3x10^9 litres
- ~90% of Permian Basin produced waters currently reinjected
- ~3.5 MtCO_2/yr equivalent of Ca+Mg in Permian Basin produced waters

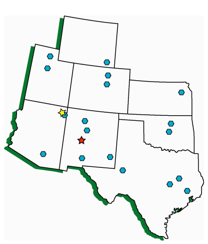
Brine Mineralization: Regional Resources



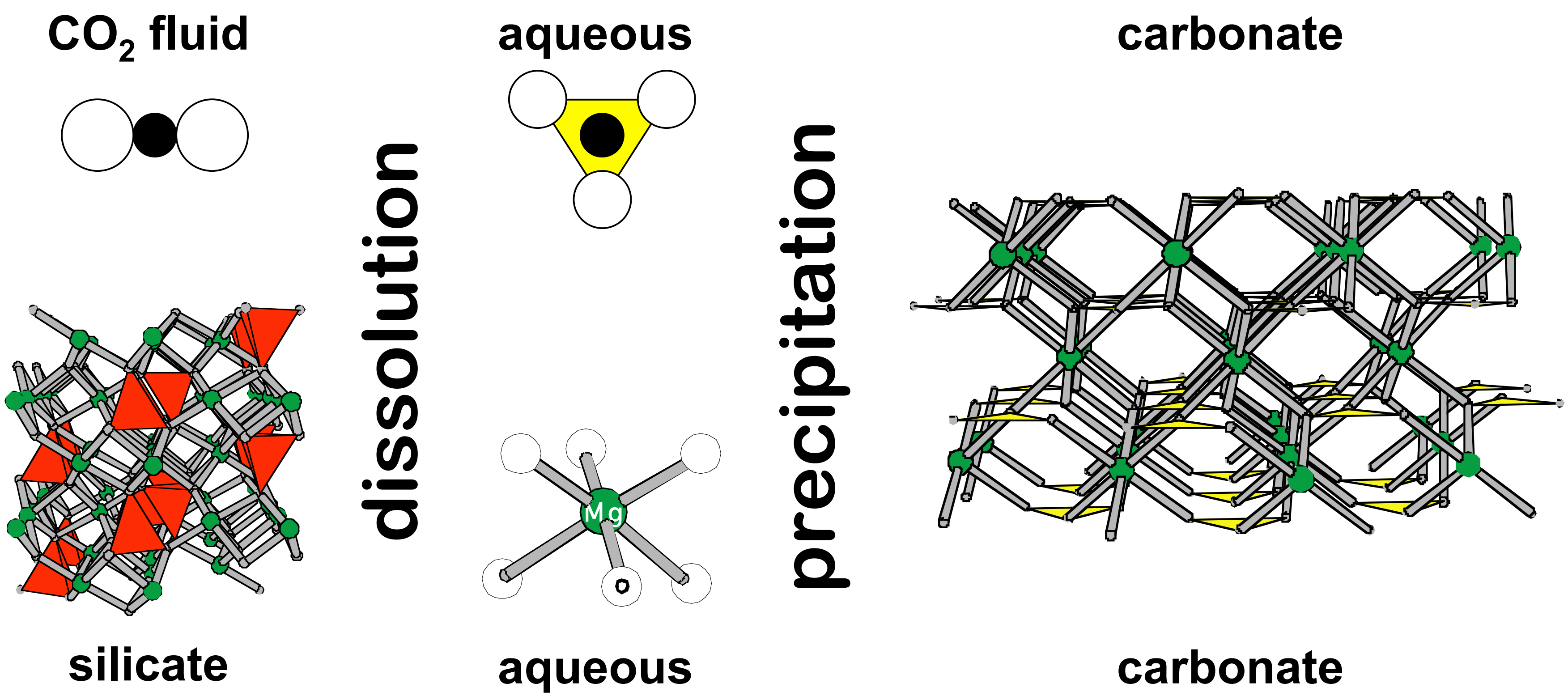


- **Variable regional brine chemistry will be used to evaluate potential target basins/brines**
- **Produced waters will be a particular target for above-ground process**

Data from NETL's U.S. Brine Database (2004)



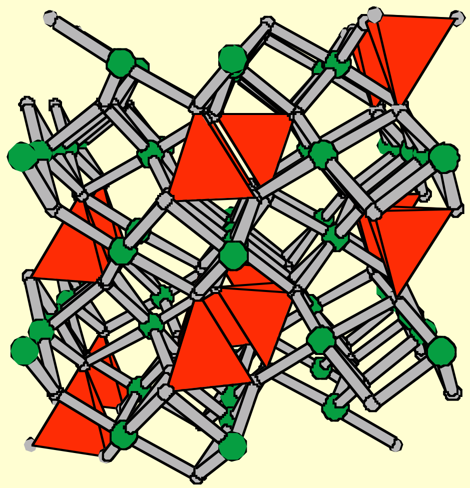
CO_2 Mineralization as an Advanced Storage Concept



Silicate Mineralization: Overview of the Process

- Exploits Mg/Ca-rich minerals, for which global deposits exceed known global coal reserves; selected solid wastes possible (*e.g.*, fly ash).
- Requires mining & milling; costs reasonable based on comparable large scale mining; reclamation is integral to process.
- Forms carbonate exothermically (*i.e.*, requires no energy input).
- Requires separation of metal from silicate; could involve 1 step or multi-step process; aqueous & molten-salt processes most studied.
- Example aqueous conditions:
  150°C, 2000 psi, 1M NaCl/0.64 M $NaHCO_3$
  (Albany Research Center)

Ca- or Mg-silicate



e.g., forsterite

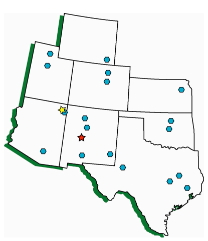
$$Mg_2SiO_4 + 2HCO_3^- + 4H^+$$

$\downarrow$ dissolution

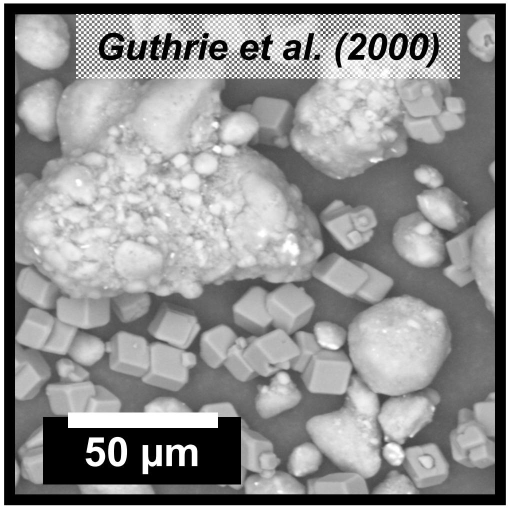
$$2Mg^{2+} + SiO_{2(aq)} + 2HCO_3^-$$

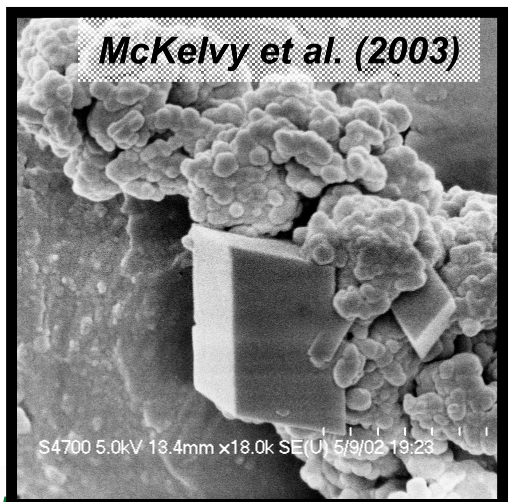
$\downarrow$ precipitation

$$2MgCO_3 + SiO_{2(s)} + 2H_2O + 2H^+$$



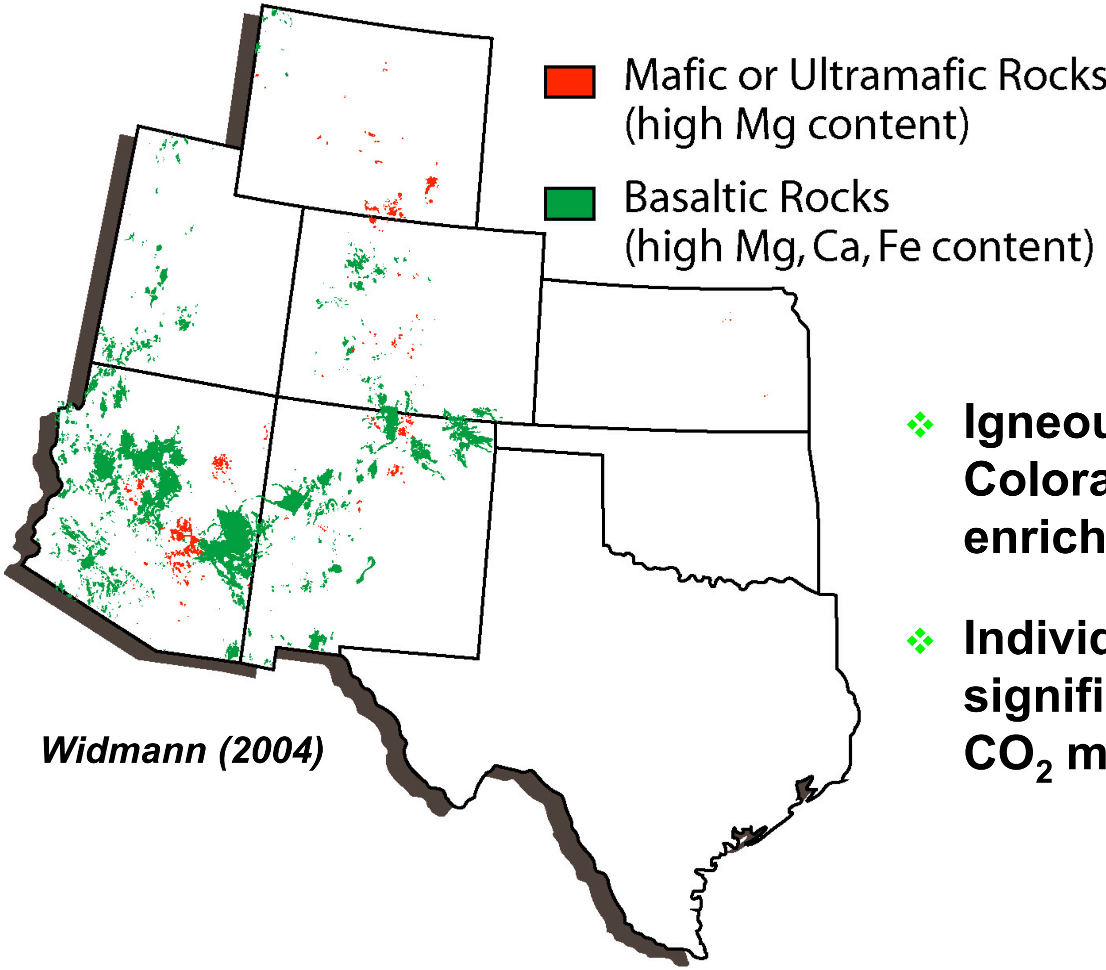
Silicate Mineralization: Status of Research





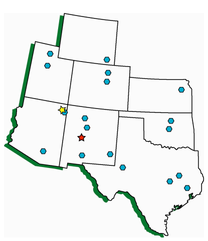
- **Carbonation in aqueous medium primary focus—rates have been accelerated to near completion in less than an hour for activated Mg/Ca silicate feedstocks (*e.g.*, serpentine, olivine, wollastonite)**
- **Elevated P&T (*e.g.*, 100–2200 psi; 150–185°C) used to increase kinetics**
- **Mechanical and/or thermal activation is currently needed to increase kinetics, but these processes are cost prohibitive**
- **Acid-base swing can achieve reasonable rates of dissolution-precipitation**
- **Chemical catalysts currently under investigation and show promise**

Silicate Mineralization: Regional Natural Resources

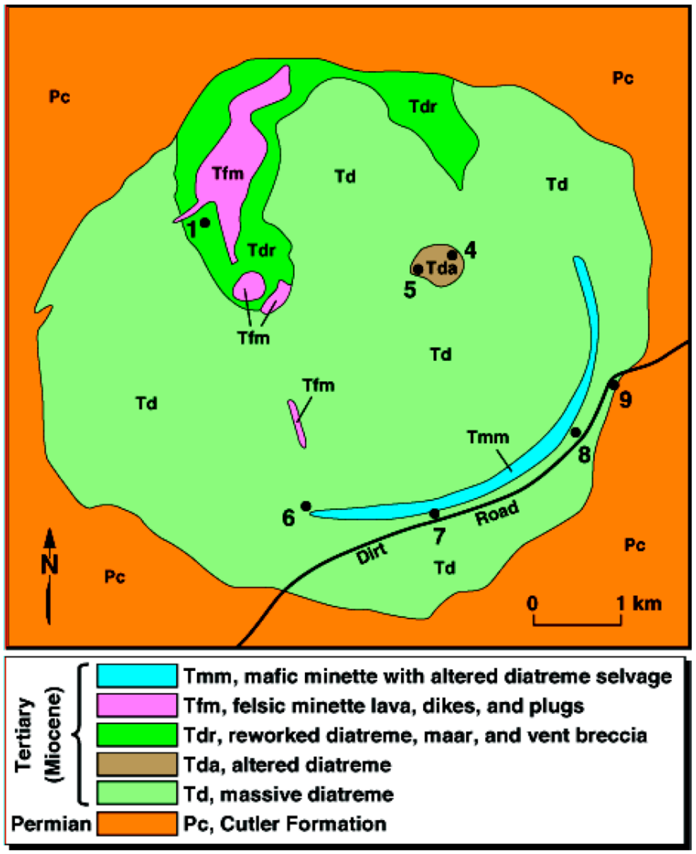


Widmann (2004)

- **Igneous activity associated with Colorado plateau produced rocks enriched in Mg, Ca, and Fe**
- **Individual deposits can be significant regional resources for CO_2 mineralization**



Silicate Mineralization: Resource Evaluation Case Study (Buell Park Diatreme)

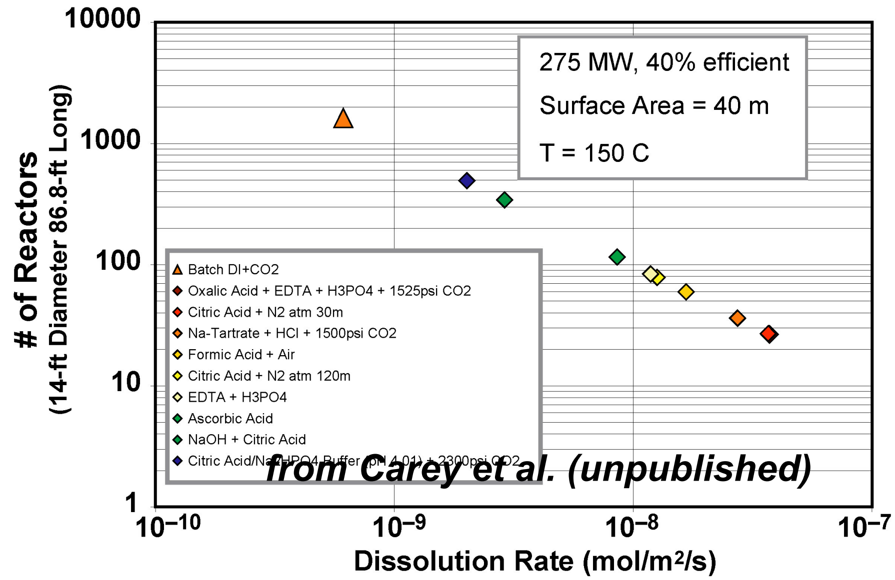


from Goff et al. (2002)

- **Serpentinized microbreccia diatreme (tuff) ~30 wt% MgO**
- **Volume of the deposit is sufficient to mineralize ~1.6 GtCO_2 (~5–10 yrs regional) or >200 GW-yrs**

Silicate Mineralization: Remaining Challenges

- **Identification and development of a feasible conversion process**



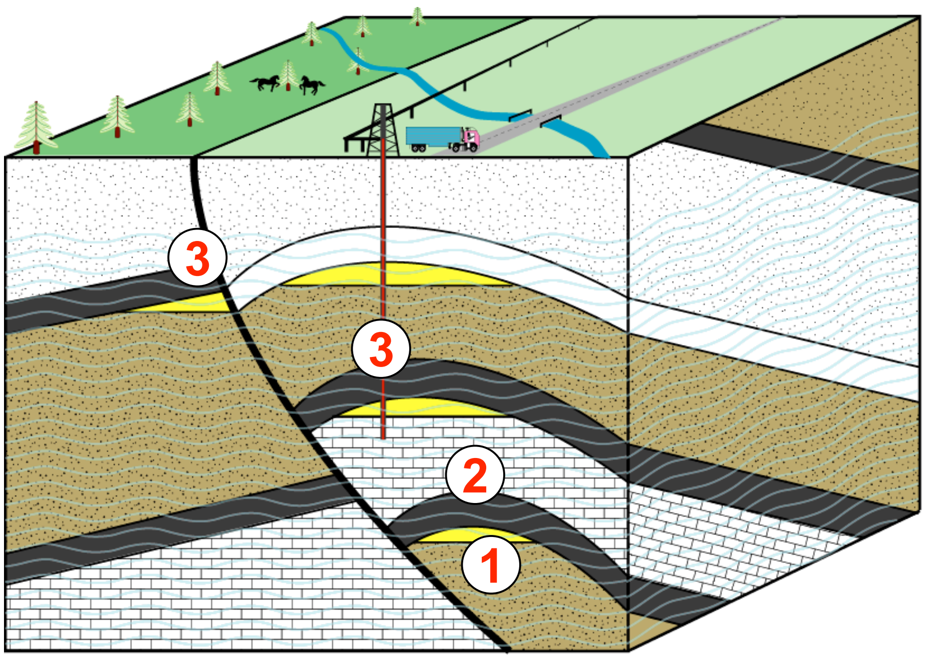
  - Economic and technical viability
  - Strong carbonation efficiency (to minimize materials handling)
  - Elimination of intense thermal/mechanical activation and possibly a reduction in P & T for current aqueous process
  - Catalysts and/or multi-step processes are encouraging possibilities

- **Total cost–benefit analysis relative to other storage options**

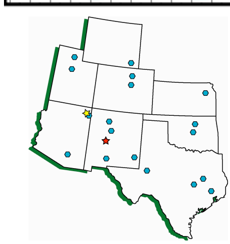
- **Public acceptance of large-scale mining**

Role of CO_2 Mineralization in Geologic Storage

- complete mineralization
- impact on permeability
- impact on seal integrity

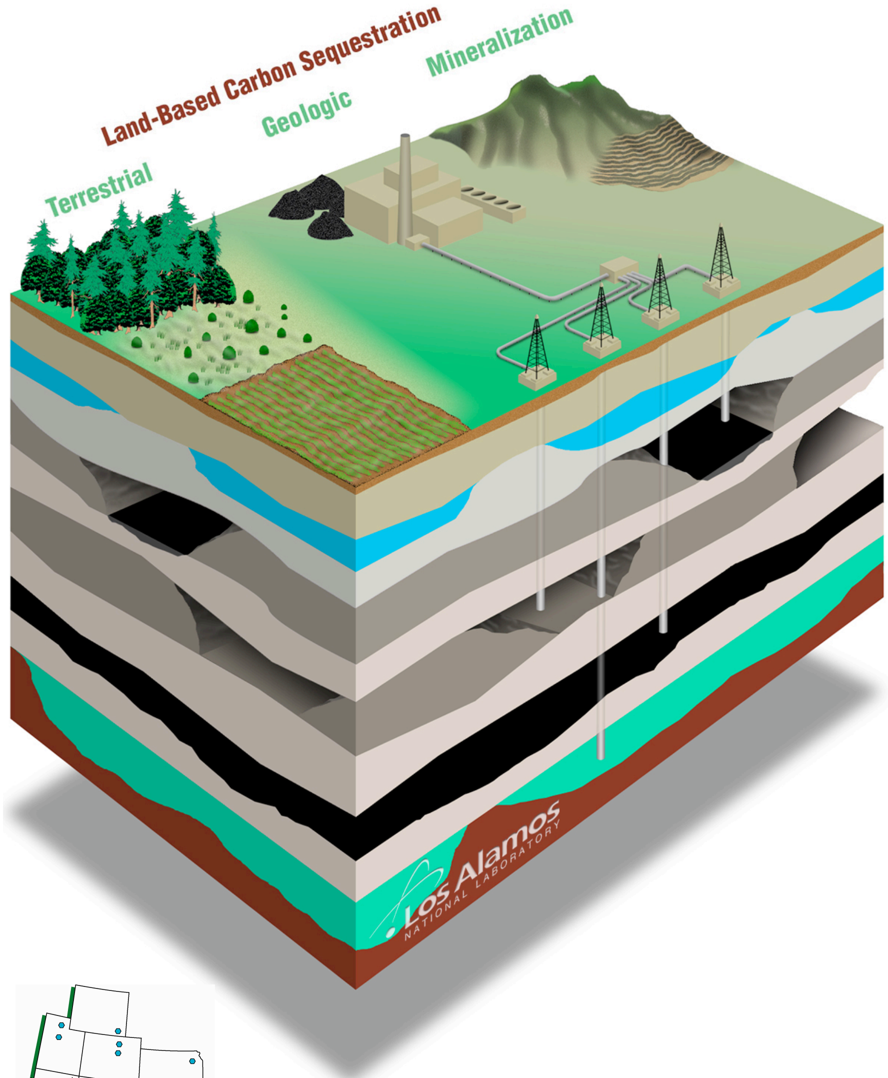


1. Fate/distribution of CO_2 plume
   complete mineralization
   vs.
   permeability changes
2. Primary seal integrity
3. Vulnerable points
   - fractures (clays)
   - grout (cement)



Southwest Regional Partnership for Carbon Sequestration

Southwest Regional Partnership's Strategy for Evaluating CO_2 Mineralization as a Storage Option



- Catalog potential regional resources
  - brines (chemistry, volume)
  - mafic/ultramafic ores (chemistry volume)
  - other (fly ash, etc.)
- Evaluate offsetting costs/benefits
  - water production
  - waste minimization
  - strategic metals (e.g., PGEs)
- Monitor research progress
- Develop model for evaluating options relative to changes in economics