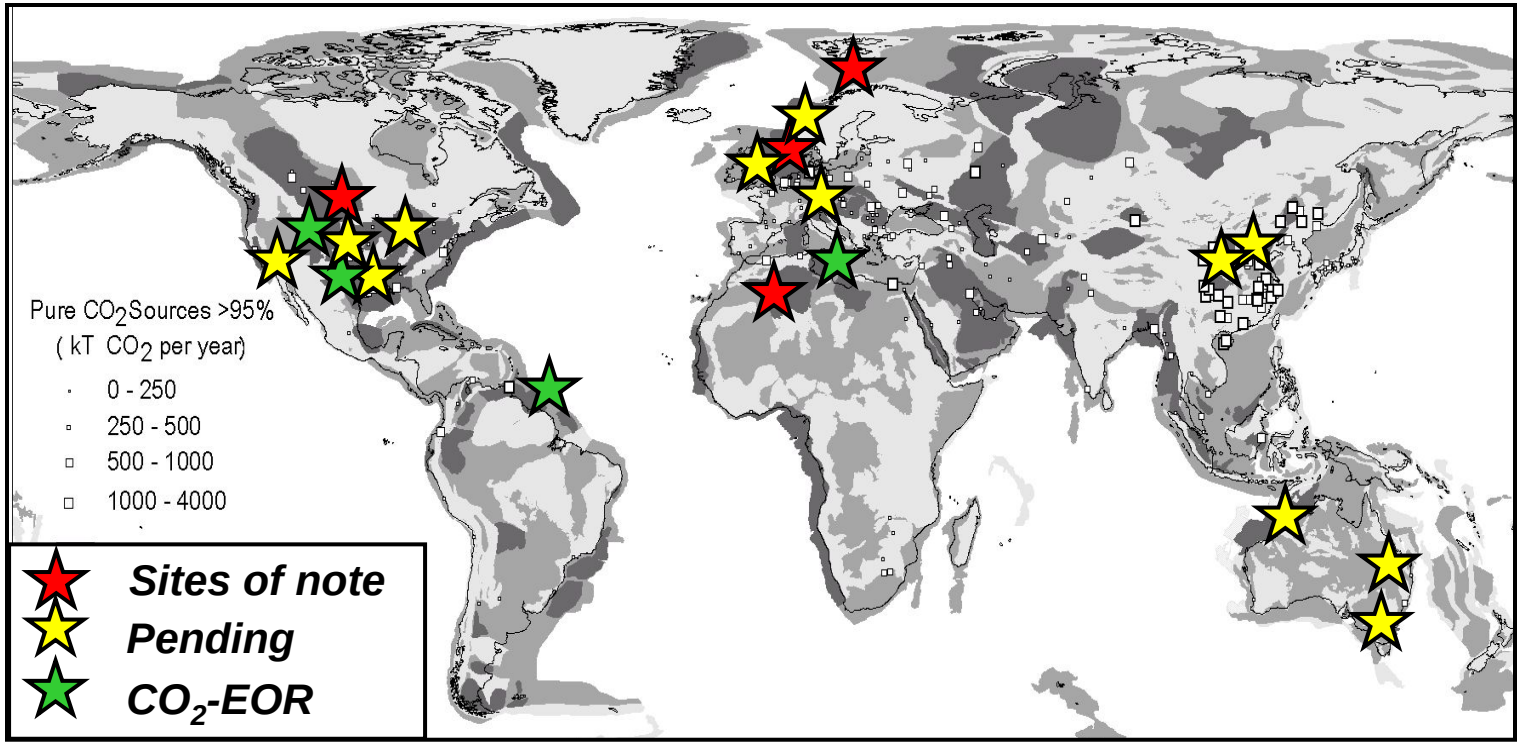
Requirements for Geological Storage

Science, deployment, and risks`



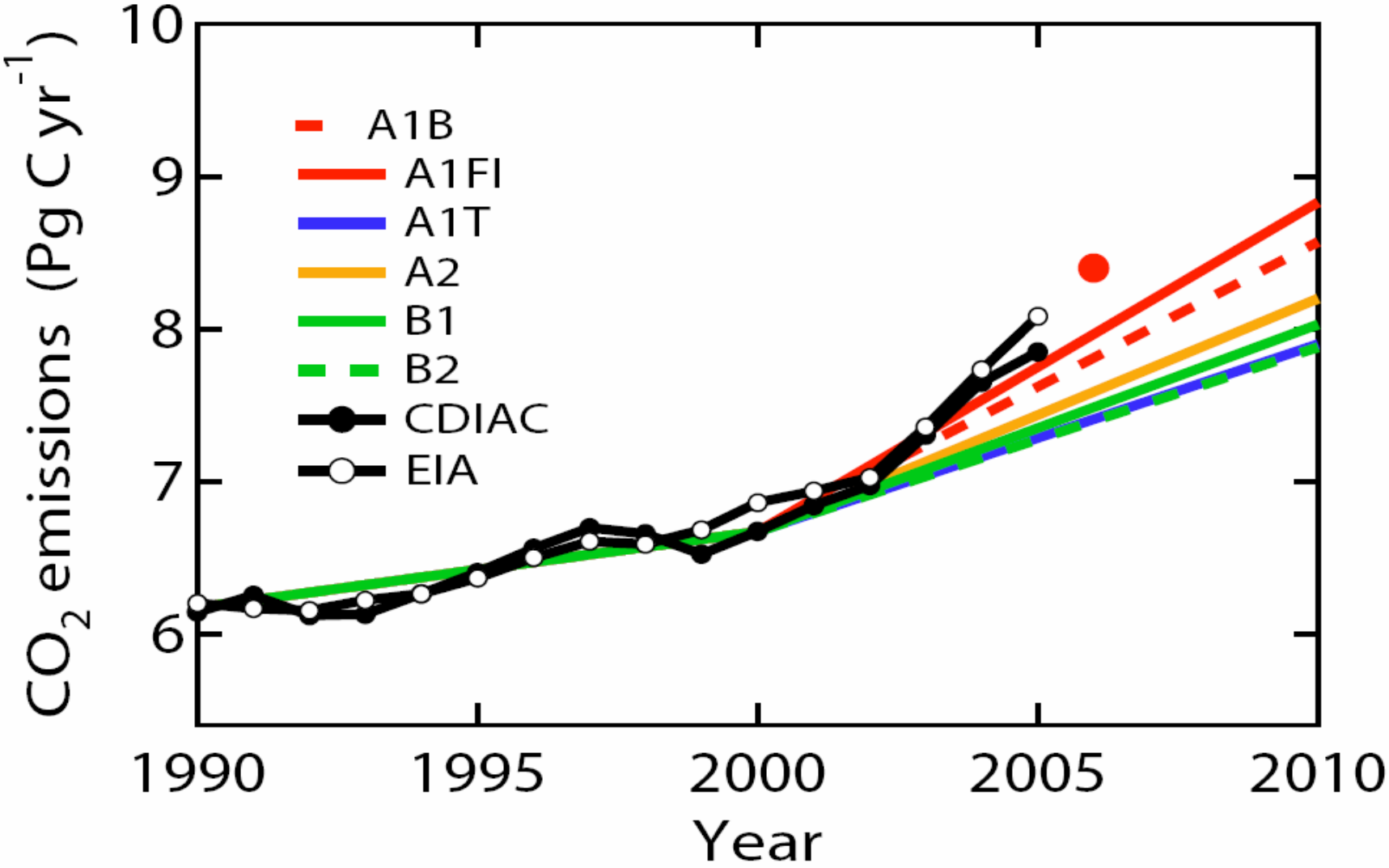
S. Julio Friedmann

Carbon Management Program APL

Energy & Environment Directorate, LLNL

http://co2.llnl.gov/ ***friedmann2@llnl.gov***

There is urgency to act on atmospheric stabilization



(Slide from Dr. Chris Field)

Scientific American, 2005

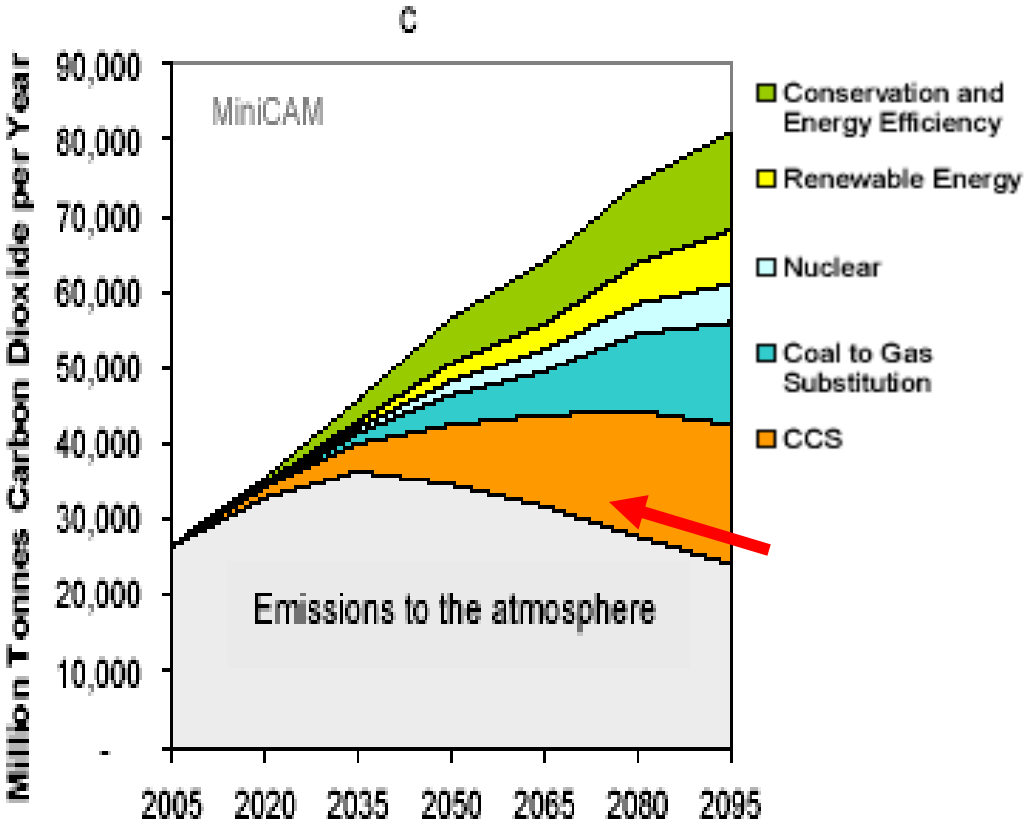
Carbon capture & storage (CCS) is central to world climate hopes: 15-50% of the solution

IPCC sees CCS as providing largest single portion of CO_2 reductions this century

Others seem to agree (e.g., IEA, EIA, WEC, JGCRI, EPRI, IIASA)

CCS is a bridging technology, not a long-term solution to decarbonized energy

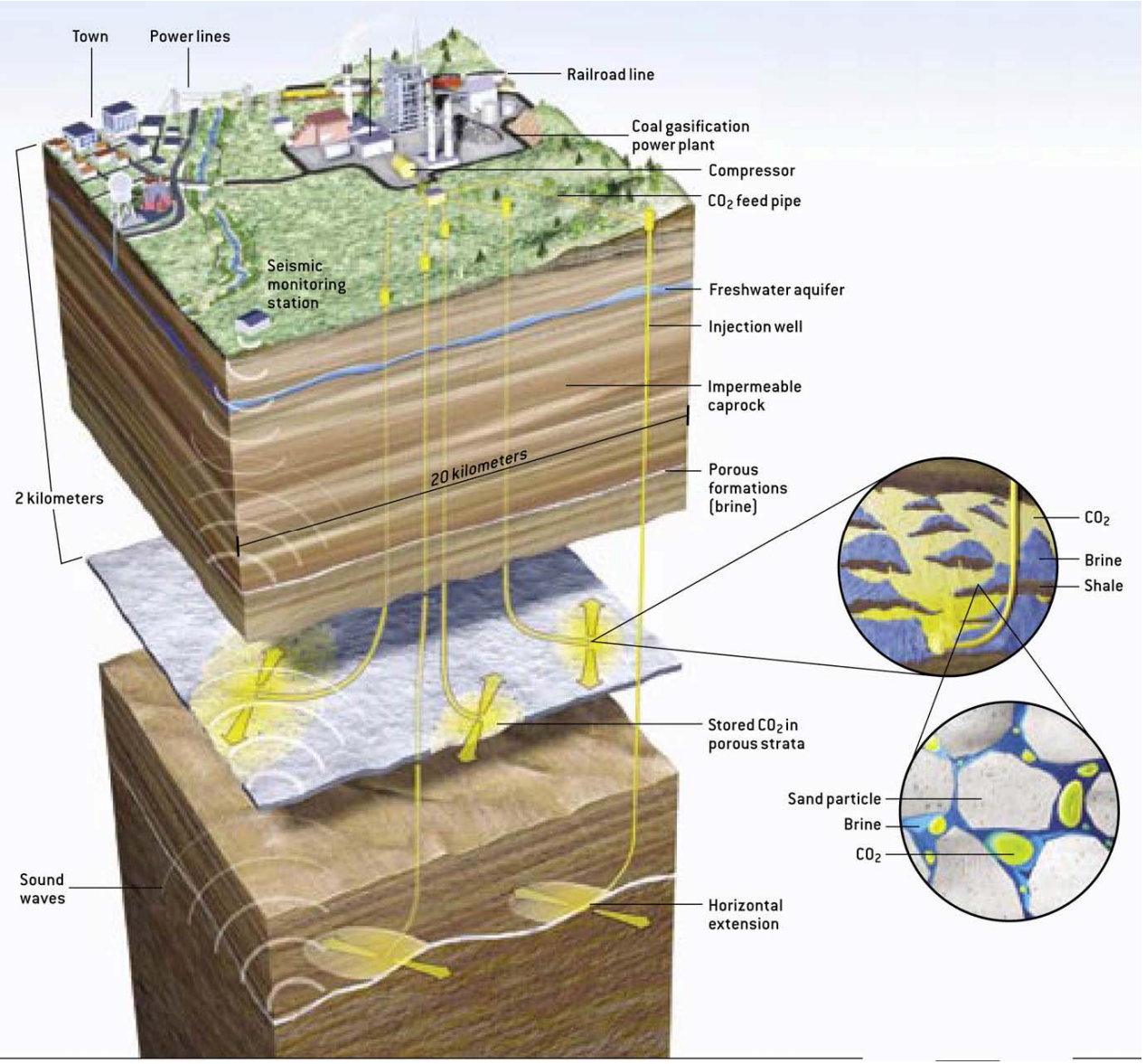
CCS is a key part of a portfolio (nuclear, solar, wind, conservation, efficiency)



IPCC Special Report on Carbon Dioxide Capture and Storage Summary for Policymakers as approved by the 8th Session of IPCC Working Group III, September 25th, 2005, Montreal, Canada

- ***ACTIONABLE***
- ***SCALEABLE***
- ***COST-EFFECTIVE***

Carbon dioxide can be stored in deep geological formations as a dense, pore-filling fluid



- **Saline Formations:** ***largest capacity (>2200 Gt)***
- **Depleted Oil & Gas fields:** ***potential for enhanced oil and natural gas recovery***

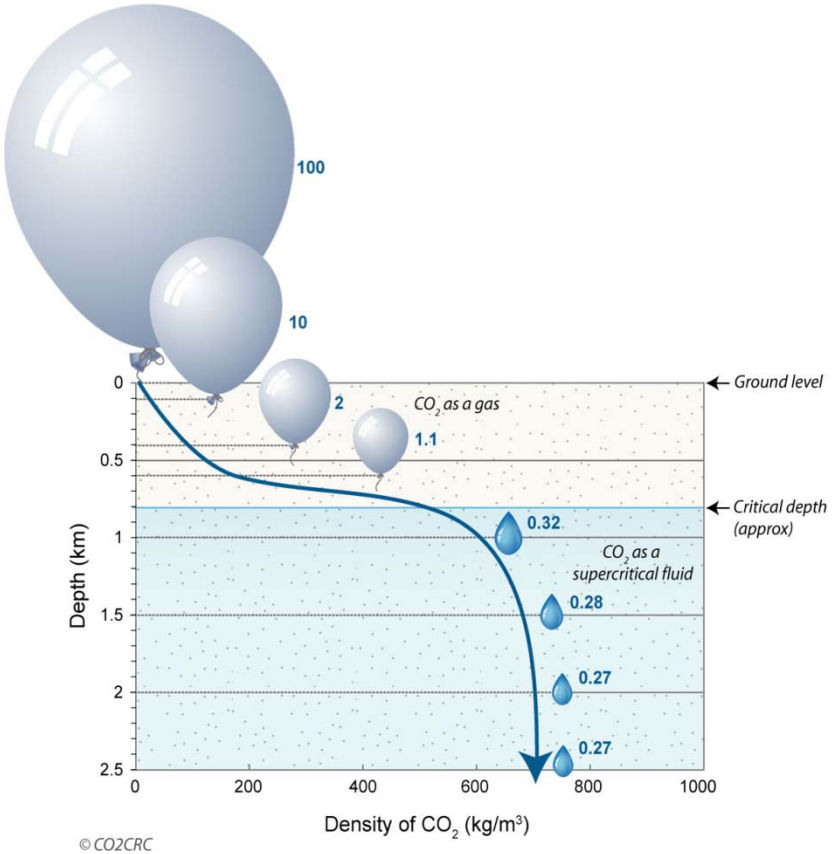
Scientific American, 2005

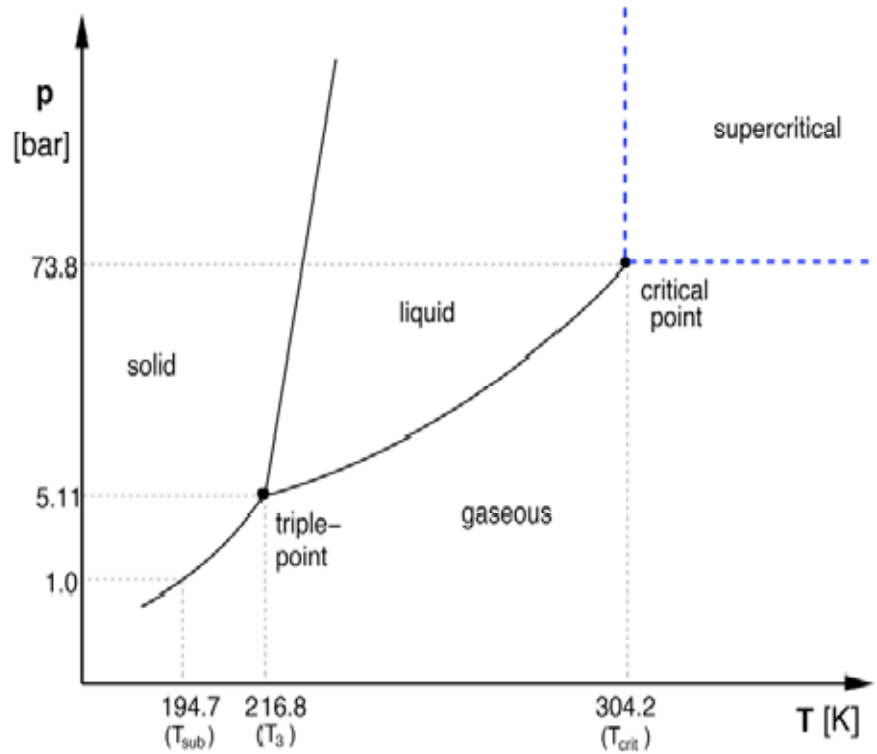
Can CO_2 be transported & stored safely?

- **Nature has stored oil & gas underground for millions of years**
- **Gas & pipeline companies store natural gas in underground formations (>10,000 facility-years experience)**
- **Nature has stored CO_2 in natural reservoirs – some now being "mined" for EOR (including 2 in Colorado)**
- **Almost 3,000 miles of CO_2 pipelines now operate in No. America, carrying more than 30 million tons of CO_2 annually**
- **Hundreds of millions of tons of CO_2 already injected for EOR; some fields receiving ~4 million tons/year**
- **Leakage is not a non-issue! But it's manageable, esp. compared with climate change**

(Slide thanks to Julio Friedmann)

CO_2 becomes a dense fluid in deep geological formations





It has the density of oil, is less viscous, and has ~400x less volume than at surface

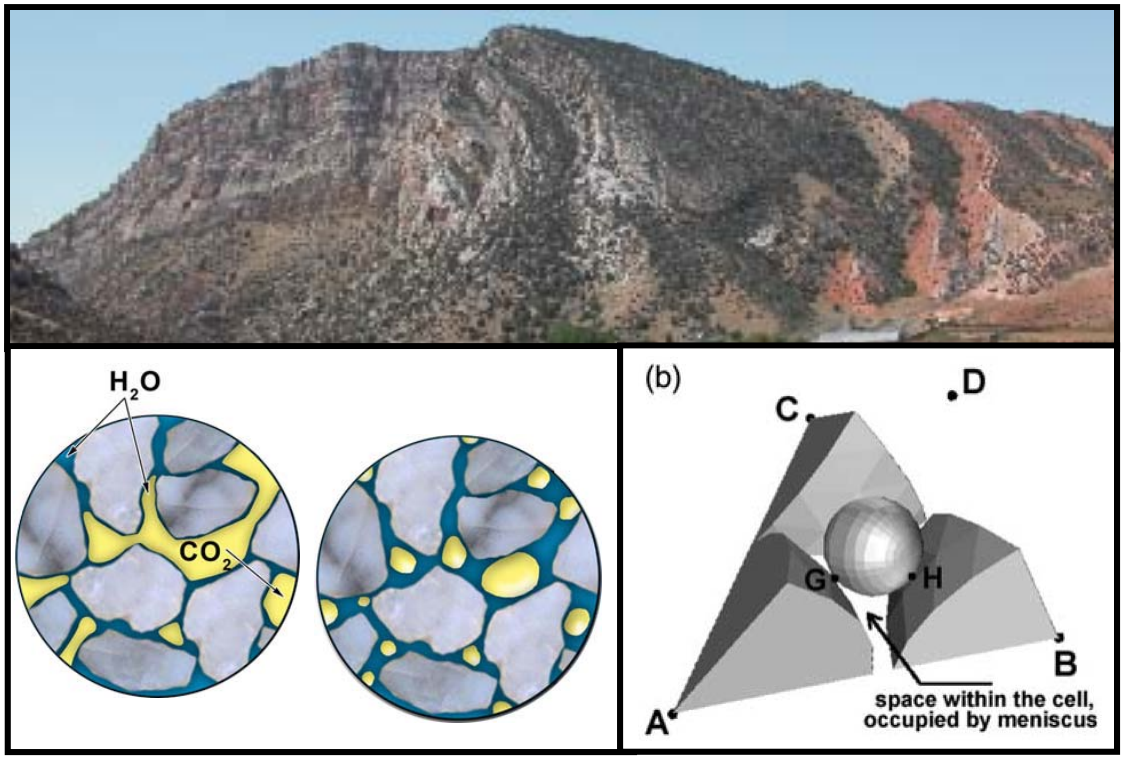
Storage mechanisms are sufficiently well understood to be confident of effectiveness

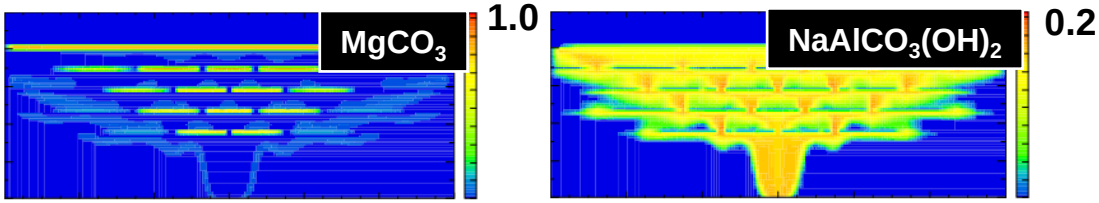
Physical trapping
- **Impermeable cap rock**
- **Either geometric or hydrodynamic stability**

Residual phase trapping
- **Capillary forces immobilized fluids**
- **Sensitive to pore geometry (<25% pore vol.)**

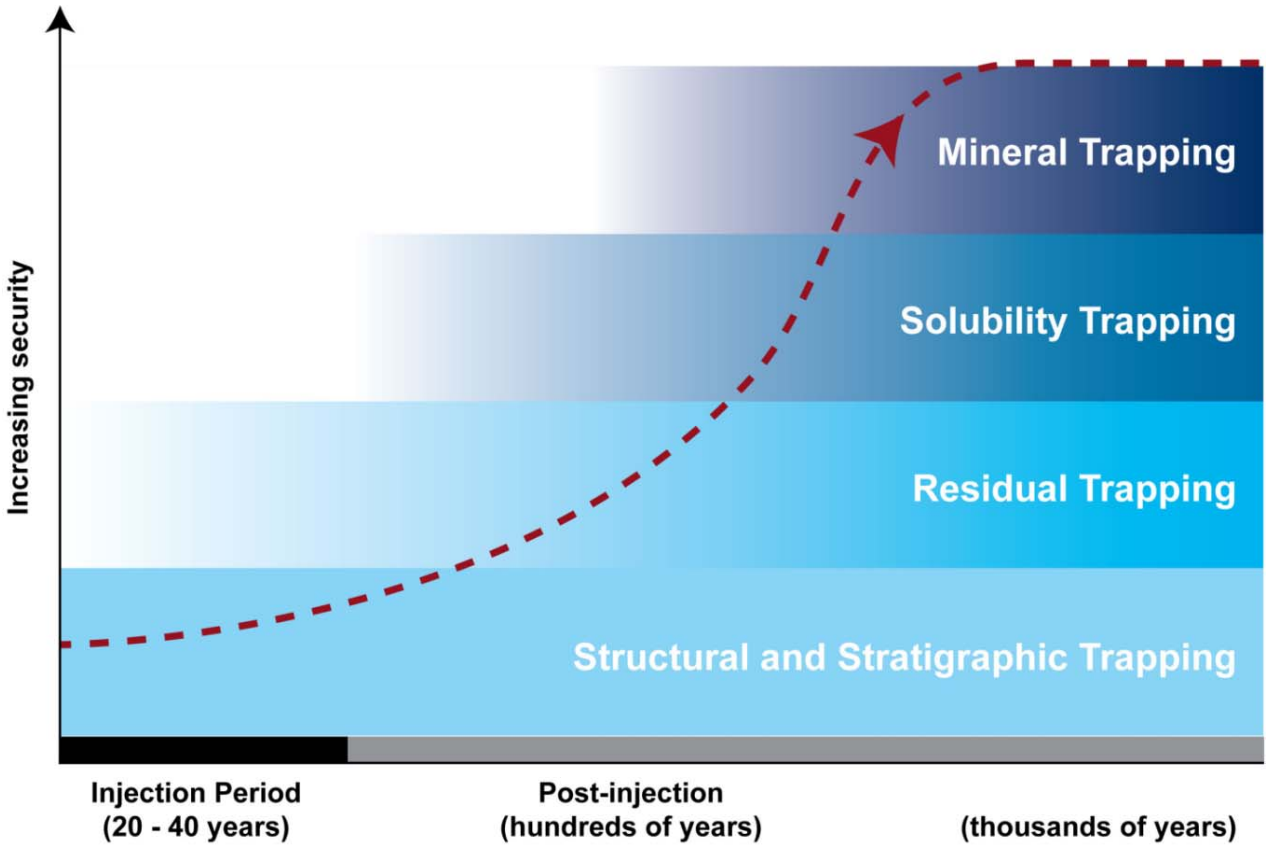
Solution/Mineral Trapping
- **Slow kinetics**
- **High permanence**

Gas adsorption
- **For organic minerals only (coals, oil shales)**





The crust is well configured to trap large CO_2 volumes indefinitely

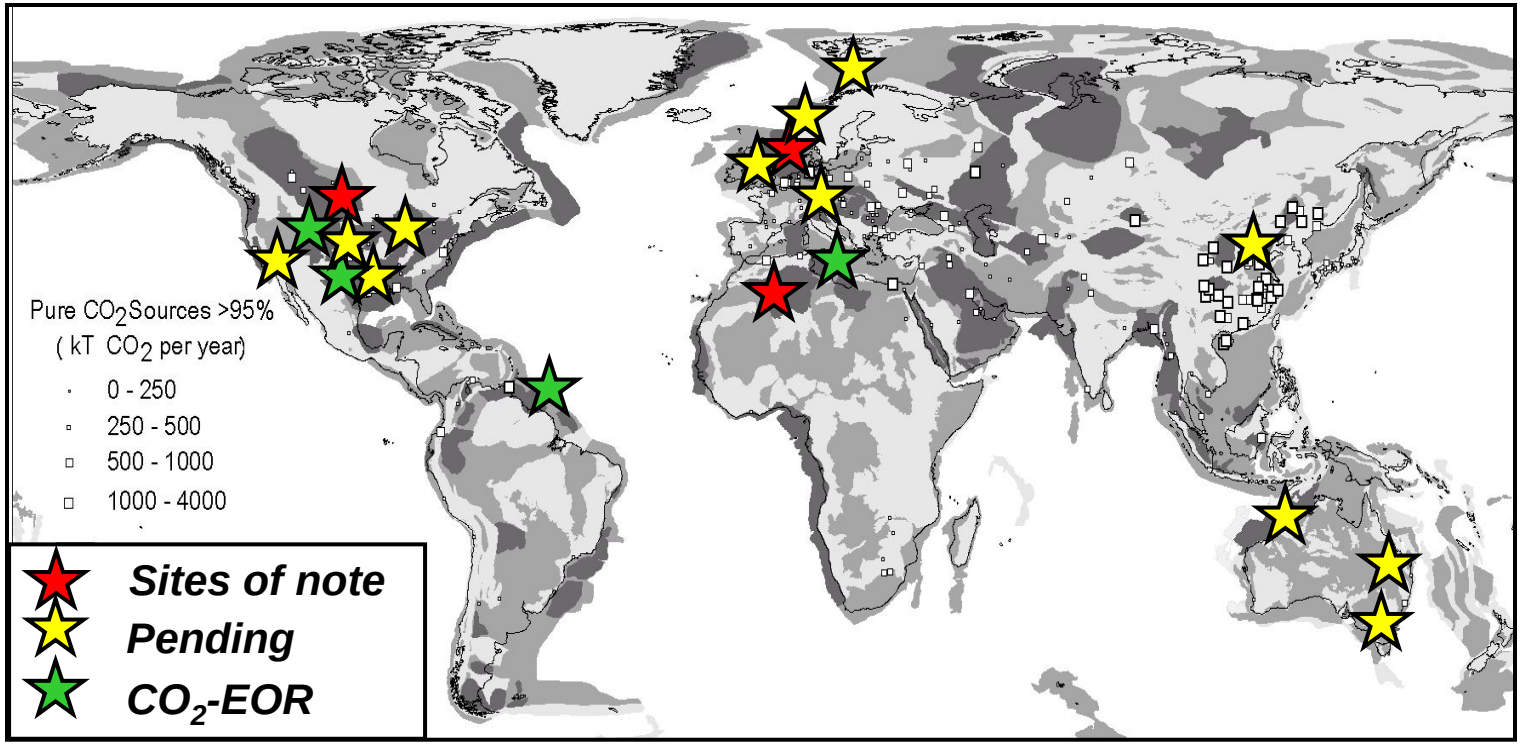


Because of multiple storage mechanisms working at multiple length and time scale, the shallow crust should attenuate mobile free-phase CO_2 plumes, trap them residually, & ultimately dissolve them

This means that over time risk decreases and permanence increases

We need large projects to give the technical basis regulation and legal frameworks

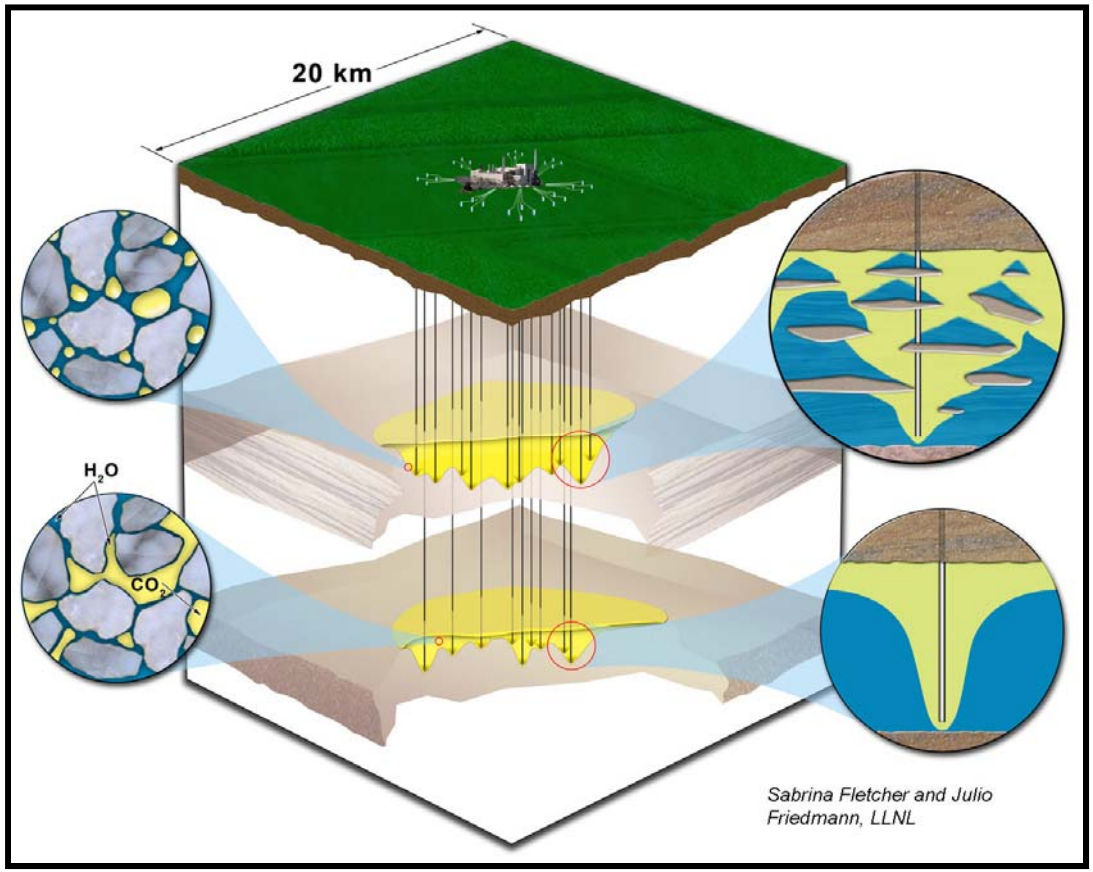
The projects demonstrate the high chance of success for CCS



Large projects must be the CCS engines of discovery

The true scope of large-scale CCS deployment is the primary challenge

Let's say that by 2020, all new coal plants must have CCS *(watch this space)*. The scope & scale of injection from a single plant must be considered.



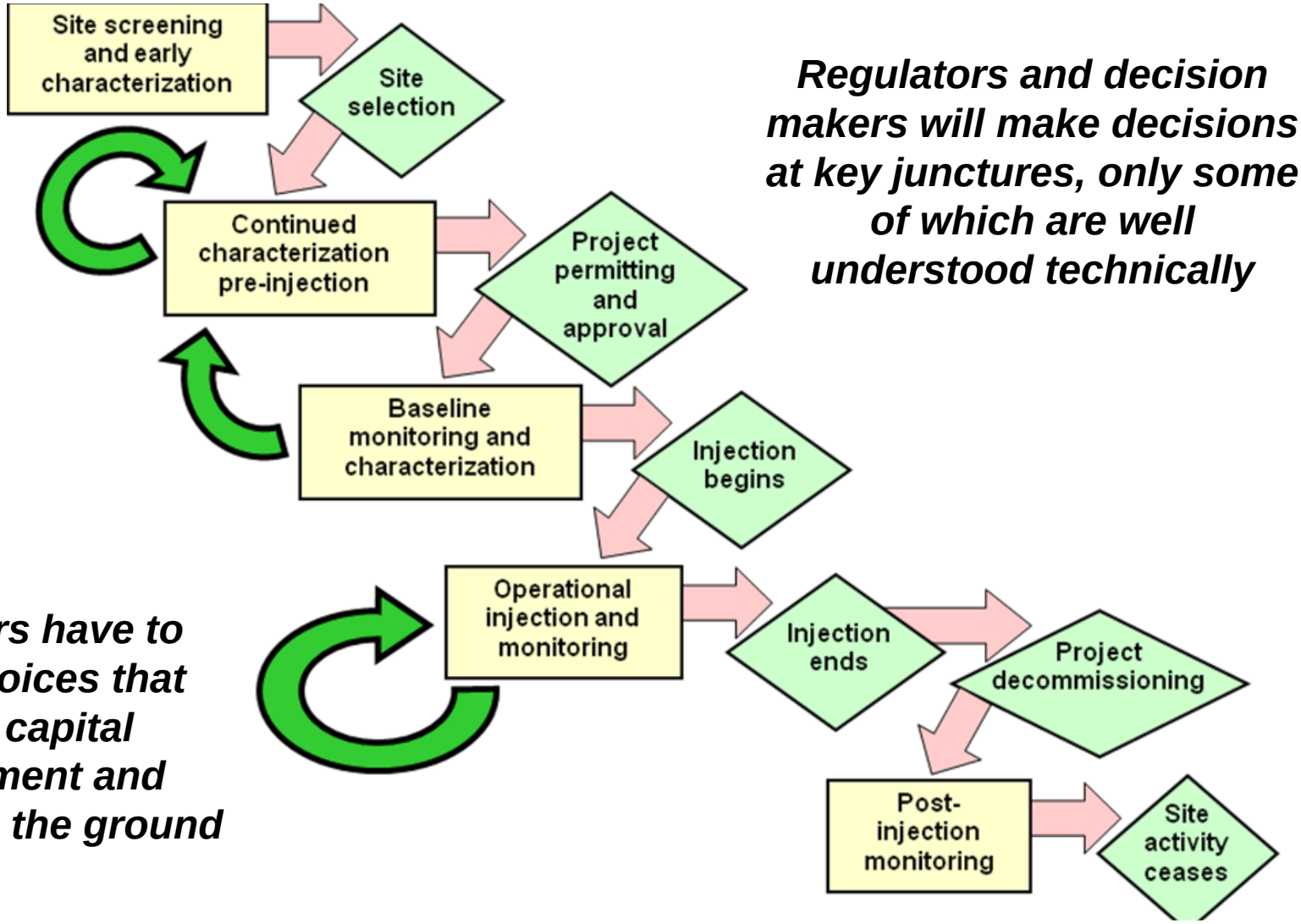
One 600 MW coal plant, 85% c.f., 90% capture:

- **4-5 MM t CO_2/yr**
- **70,000-120,000 bbl/d (as supercritical phase)**
- **After 60 year, 1.8-3 G bbls**
- **CO_2 plume at 10y, ~4 mi radius: at 50 yrs, ~12 mi**
- **Hundreds of wells**

50% capture, ~2.5 MMt/y
20% capture, ~1 MMt/y

Sites must receive large volumes of CO_2 at a high rate and contain them for long periods

The drive to deployment has brought focus on the life-cycle of CCS operations and its key issues



Regulators and decision makers will make decisions at key junctures, only some of which are well understood technically

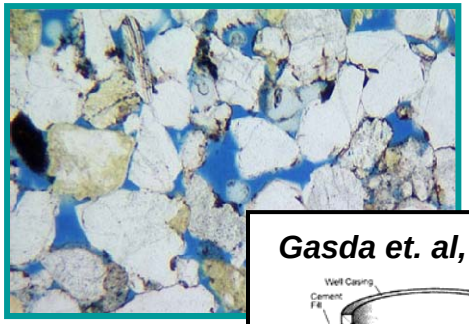
Operators have to make choices that affect capital deployment and actions on the ground

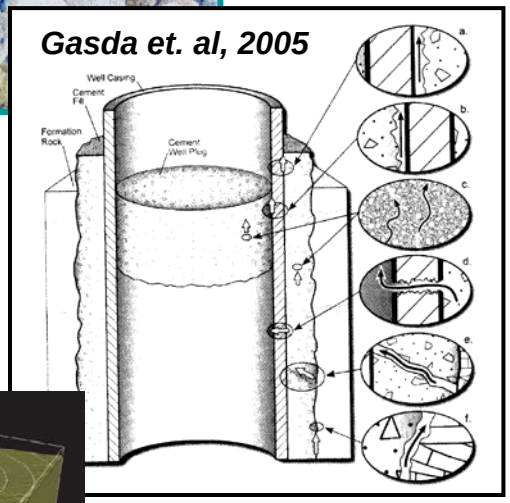
Site selection due diligence requires characterization & validation of IRC

Injectivity

Retention

Capacity





Injectivity

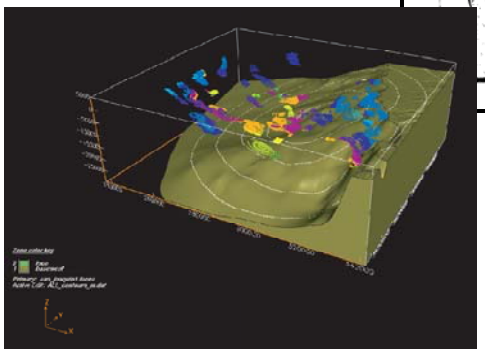
- **Rate of volume injection**
- **Must be sustainable (months – yrs)**

Retention

- **Ability for a site to store CO_2**
- **Long beyond the lifetime of the project**
- **Most difficult to define or defend**

Capacity

- **Bulk (integrated) property**
- **Total volume estimate**
- **Sensitive to process**



A lot of conventional (and new) technology exists to characterize ICE

Injectivity

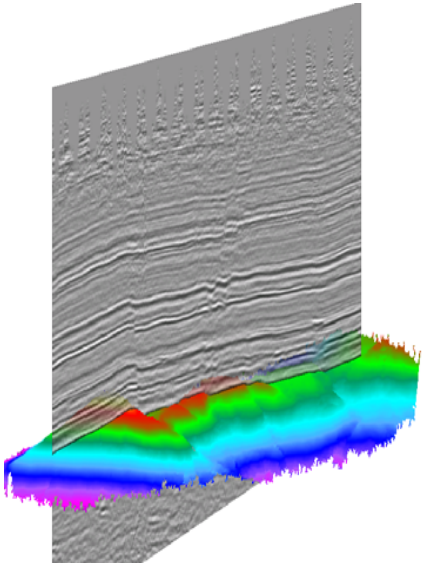
- Pump/injection tests
- Conventional P&P analyses
- Conventional reservoir mapping
- Fm. parting pressure tests

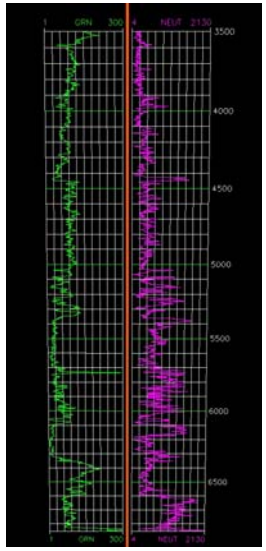
Retention

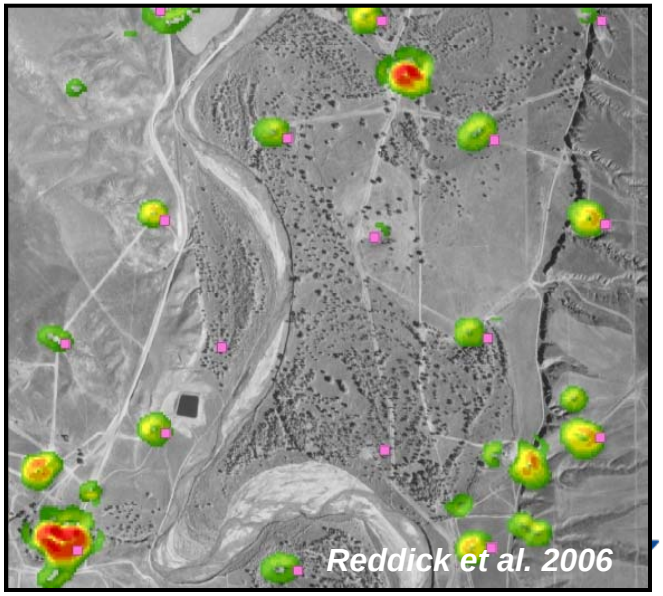
- Orphaned/abandoned well detection
- Conventional geological mapping
- Geomechanical analyses
- Capillary entry pressure tests

Capacity

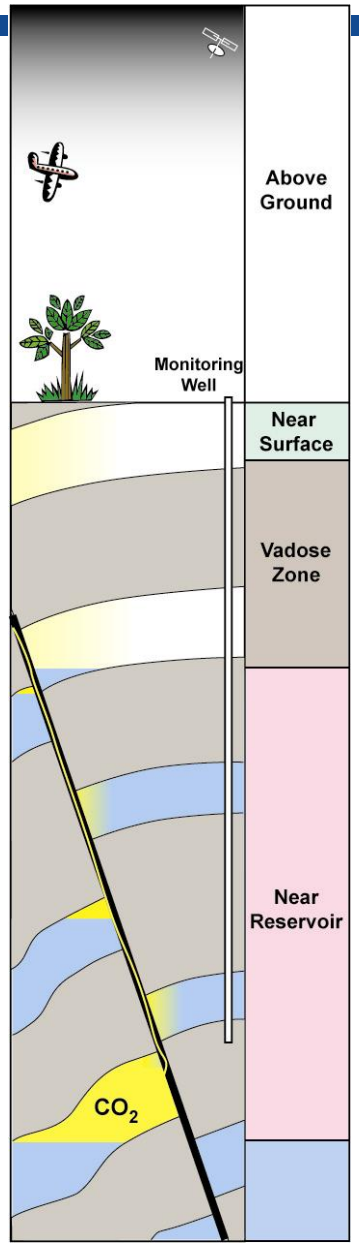
- Conventional reservoir mapping
- Residual phase core measurement
- Conventional simulation or RTM







Once injection begins, monitoring and verification (M&V) is required



M&V serves these key roles:

- **Understand key features, effects, & processes**
- **Injection management**
- **Delineate and identify leakage risk and leakage**
- **Provide early warnings of failure**
- **Verify storage for accounting and crediting**

Currently, there are abundant viable tools and methods; however, only a handful of parameters are key

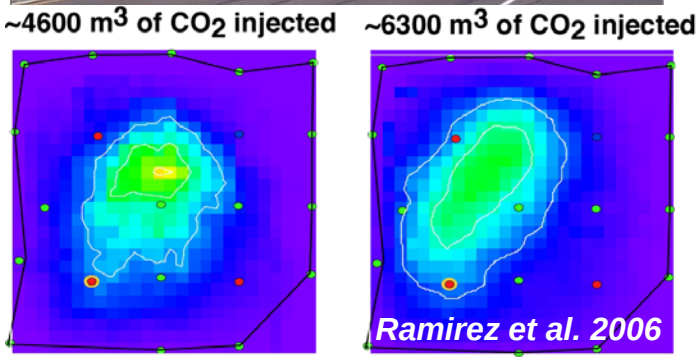
Without monitoring and verification, it is not possible to obtain offset credits and payment for sequestration effort

With monitoring and verification, carbon accounting is simpler and more robust than for most other offsets

Many tools exist to monitor & verify CO_2 plumes

These tools mostly come from oil and gas exploration & production

Parameter	Best tool	Other tools
Fluid composition	Direct sample	(Surface sampling + simulation)
T, P fieldwide	Thermocouples & pres. sensors	Fiberoptic Bragg grating
Subsurface pH monitoring	pH sensors	
CO_2 distribution	Time-lapse seismic	(microseismic, tilt, VSP, electrical methods)
CO_2 saturation	Electrical methods (ERT)	(advanced seismic)
Surface detection	Soil gas, PFC tracing	(Atmos. eddy towers, FTIRS, LIDAR, hyperspectral)
Stress/strain changes	(Tri-axial tensiometers)	Bragg grating, tilt, InSAR

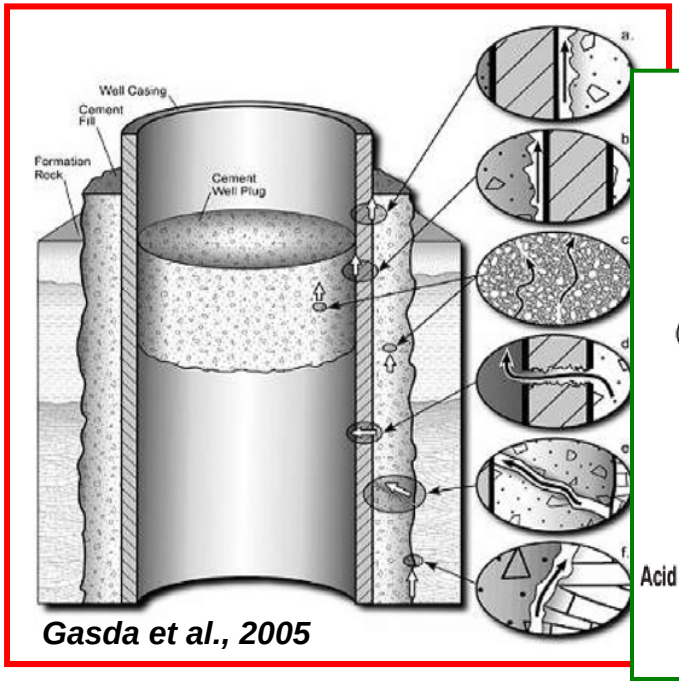


The nature & magnitude of CO_2-related risks appears small and manageable

- **CO_2 is not flammable or explosive (used to put out fires)**
- **CO_2 is not dangerous except in extremely high concentrations (> 15,000 ppm) – people frolic in Crystal Geyser, Utah**
  - **Not to be confused with carbon <u>mon</u>oxide (CO)**
  - **We inhale and exhale CO_2 with every breath**
  - **We drink carbonated (CO_2 containing) beverages**
  - **We buy "frozen" CO_2 for cooling (dry ice)**
- **Large-scale CO_2 injections have not produced large earthquakes (most << M2)**
- **Human, animal & plant mortality attributed to CO_2 has been from volcanic releases, either in large volumes (Cameroon) or pooled in depressions or pits (Mammoth Mountain, California)**

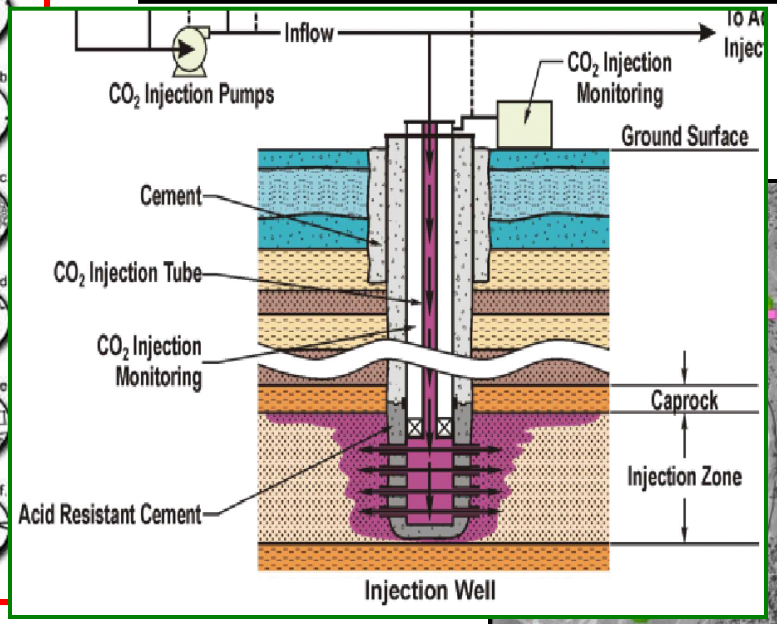
Wells represent the main hazard to GCS site integrity

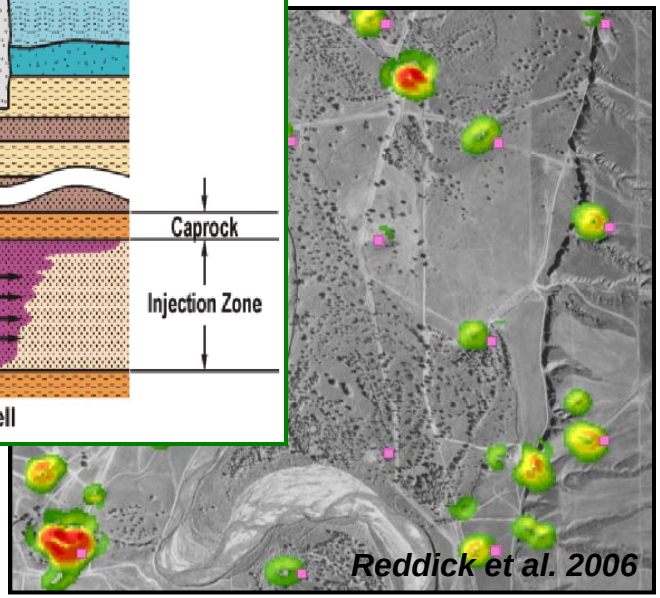
We have some understanding of well failure modes



Gasda et al., 2005

We can properly design CO_2 wells and plug failed wells





Reddick et al. 2006

We can identify and recomplete lost wells

Managing and maintaining well integrity is important to avoiding failure and risk minimization

Because of local nature of hazards, prioritization (triage) is possible for any case

Hypothetical Case: Illinois basin

Atmospheric release hazards	Groundwater degradation hazard	Crustal deformation hazards
Well leakage	Well leakage	Well failure
Fault leakage	Fault leakage	Fault slip/leakage
Caprock leakage	Caprock leakage	Caprock failure
Pipeline/ops leakage		
		Induced seismicity
		Subsidence/tilt

Pink = high priority
Orange = medium priority
Yellow = low priority

Part of protocol design is to provide a basis for this kind of local prioritization for a small number of classes/cases

Four propositions re CCS (plus one implication)

- CCS is necessary (not sufficient) for climate
- Much is already known – but not everything
- Questions & concerns (technical & legal) should be dealt with
- The existence of questions & concerns does not diminish the climate necessity of CCS

(Thanks to E. Redman, HellerEhrman)

What actions can a state take?

- Provide incentives for early actors (permitting, financial support, indemnification, pipelines)
- Create infrastructure (pipelines, regulatory & legal framework)
- Settle key questions (ownership of pore-volume, well class permitting, due diligence)
- ***START LARGE PROJECTS***

Conclusions

- **CCS is an important option**
- **Geological sequestration is likely to be effective at well selected sites**
- **Three important tasks underlie successful deployment:**
  - **Detailed site characterization**
  - **Monitoring and verification**
  - **Hazard and risk assessments**
- **Large projects are central to learning and advancing CCS as commercial ventures in any state**

(Thanks to Eric Redman, HellerEhrman)