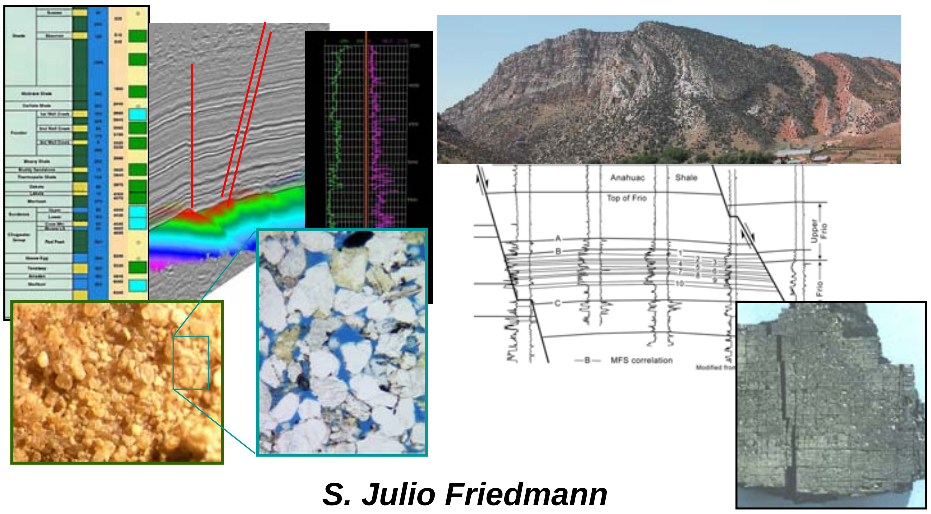
GCS Site Characterization and Certification

Technical issues and potential due diligence requirements



S. Julio Friedmann

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Conclusions

Site selection should proceed around three primary characterizations: Integrity, Capacity, and Effectiveness (ICE)

Effectiveness is the most difficult to characterize, but there are many standard, commercial approaches and tools. Wells present the greatest risk but appear manageable.

What constitutes due diligence will change, but is likely to defined initially around repeatable, defensible, readily obtained measurements

> **The map is not the territory**
> ***Alfred Korzbyski***

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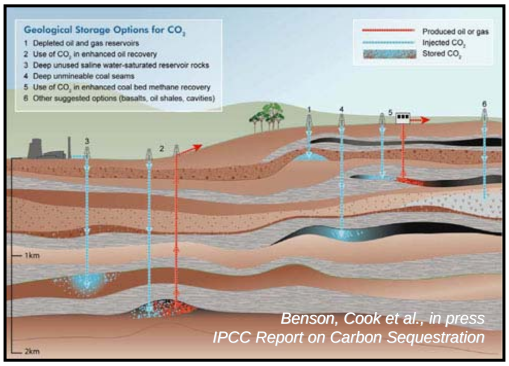
CO_2 can be stored in several geological targets, usually as a supercritical phase



Benson, Cook et al., in press
IPCC Report on Carbon Sequestration

Saline Aquifers
Depleted Oil & Gas fields
(w/ or w/o EOR and EGR)
Unmineable Coal Seams
(w/ or w/o ECBM)
Other options
(e.g., oil shales, basalts)

The storage mechanisms vary by reservoir type

EOR/Depleted Oil & Gas fields are early actors
Saline aquifers hold the largest storage capacity
California has an abundance of both

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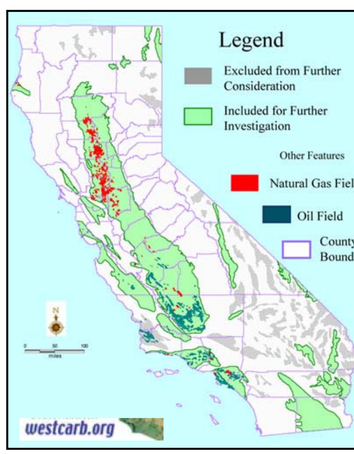
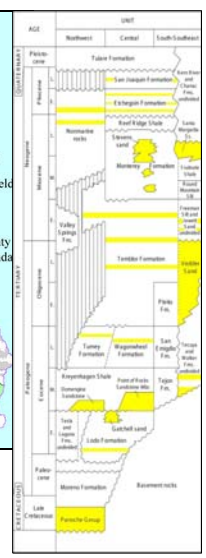
Preliminary estimates suggest California has an abundance of sequestration resource

- **Current WESTCARB estimates at 300 Gt capacity, mostly in Central Valley.**
- ***This is 10,000 times more than CA's point source emissions***
- **These estimates are preliminary, conservative and likely underestimates.**
- **Similar resource in WY, UT, NM, CO, MT each**





Site characterization is needed to turn resource into reserves

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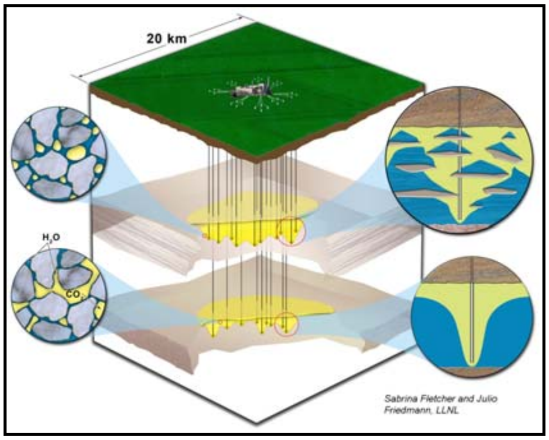
The discussion should focus on a real power plant capture case

Let's suggest that by 2020, all new coal plants will be fitted for CO_2 capture and storage. The scope and scale of injection from a single plant must be considered.



One 1000 MW p.c. plant, 85% c.f., 90% capture:

- **6 MM t CO_2/yr**
- **100,000 bbl/d (as supercritical phase)**
- **After 50 year, 2 G bbls**
- **CO_2 plume at 10y, ~10 km radius: at 50 yrs, ~30 km**
- **Many hundreds of wells**
- **Likely injection into many stacked targets**

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

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Empirical evidence suggests that transport & geological storage of CO_2 can be done safely

- **Nature has stored oil and natural gas in underground formations over geologic timeframes, i.e. millions of years**
- **Gas and pipeline companies are today storing natural gas in underground formations (>10,000 facility-years experience)**
- **Nature has also stored CO_2 underground for millions of years in naturally occurring CO_2 reservoirs, some of which are now being "mined" for EOR purposes**
- **Almost 3,000 miles of CO_2 pipelines are now in operation in N. America, carrying over 30 million tons of CO_2 annually**
- **Roughly 15 million tons of CO2 have been injected into saline aquifers and monitored over 12 years in many countries and reservoirs, including two large projects**
- **Well over 100 million tons of CO_2 have already been injected into oil reservoirs for EOR**

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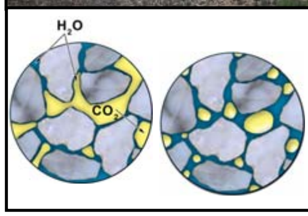
Storage mechanisms are sufficiently well understood to be confident of effectiveness

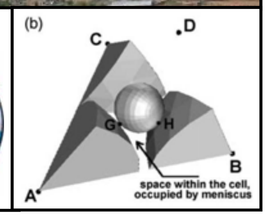
Physical trapping
- Impermeable cap rock
- Either geometric or hydrodynamic stability

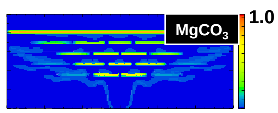
Residual phase trapping
- Capillary forces immobilized fluids
- Sensitive to pore geometry (<25% pore vol.)

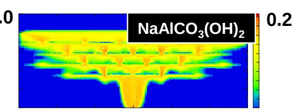
Solution/Mineral Trapping
- Slow kinetics
- High permanence

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









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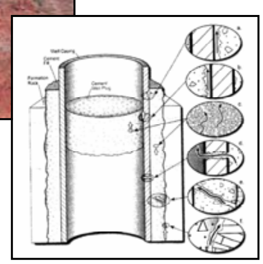
Site selection due diligence requires characterization & validation of ICE

Injectivity ***Capacity*** ***Effectiveness***

Injectivity
- Rate of volume injection
- Must be sustainable (months – years)

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

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



Gasda et. al, 2005

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The goal of site characterization is NOT to ensure storage integrity

That's a key goal of a successful CO_2 storage project, which requires site characterization

It is to provide a technical basis for decision making for secure storage, including financing & insurance

It is to provide data for planning, including operations, MMV deployment, and risk management

It is to select sites of low overall risk and high chance of success, short- and long-term

Injectivity & Capacity: Operators, insurers, financiers
Effectiveness: Insurers, regulators, public stakeholders

Injectivity | ***Capacity*** | ***Effectiveness***

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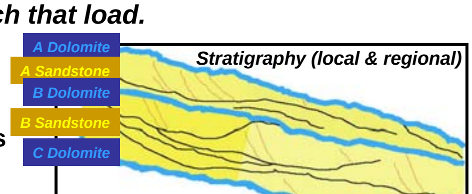
Site selection requires *Injectivity*

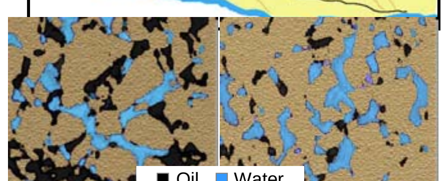
A 500 megawatt NGCC plant will produce 1.5 MM tons of CO_2 each year. Injectivity must match that load.

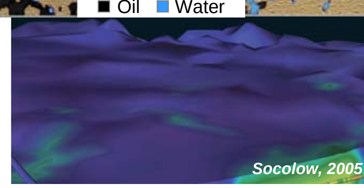
Estimated in many ways
- **Permeability tests of core**
- **Stem, injection, production tests**
- **Stratigraphic connectivity**

Ultimately a function of difficult to predict or measure key terms
- **Pore throat diameter (local)**
- **Cap rock yield strength**
- **Relative permeability**

Ultimately, can be engineered
- **Increased injection length (deviated wells)**
- **Stimulation (hydrofracture)**







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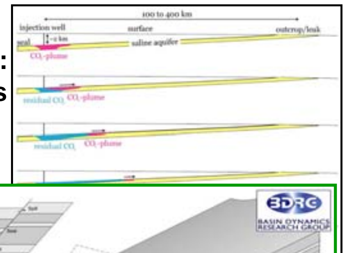
Site selection requires **Capacity**

A 500 megawatt NGCC plant will produce 90 MM tons of CO_2 in 60 years. Capacity must match that volume.

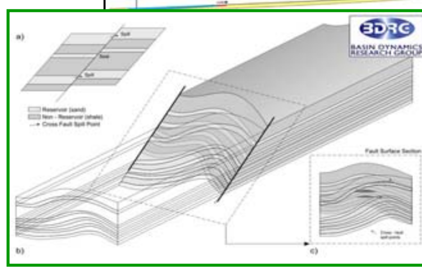
Estimation requires pore volume estimates: conventional mapping & conventional tools

- **Unit thickness and extent (rock volume)**
- **Net:gross (sand percent)**
- **Porosity/effective porosity**



Ultimately a function of pore-scale process *over functional injection duration and area*

- **Physical trapping; saturation**
- **Conventional simulation to define extent of plume relative to rock volume**
- **The rest (residual, dissolved, mineralized fractions)**



While "the rest" may be difficult to estimate precisely, reasonable estimation can be done with conventional tools

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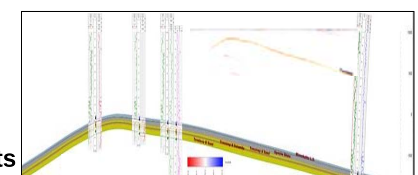
Site selection requires **Effectiveness**

Emissions from a 500 megawatt NGCC plant should reside in the crust a long time for CO_2 storage to be effective

Initial characterization is simple

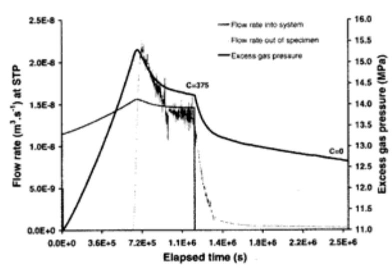
- **Does it close? (structurally, stratigraphically, hydrodynamically?**
- **Is there one of more good seals?**
- **Are there high permeability conduits out that will leak**



Friedmann & Stamp, in press

Multiple initial screening tools, multiple supporting tools

- **Geological mapping, characterization and correlation**
- **Capillary entry pressure**
- **Stress tensor estimation**



Harrington & Horseman, 1999

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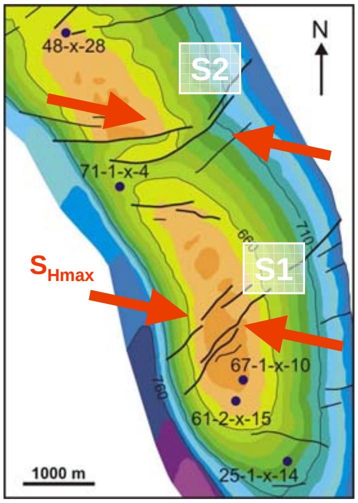
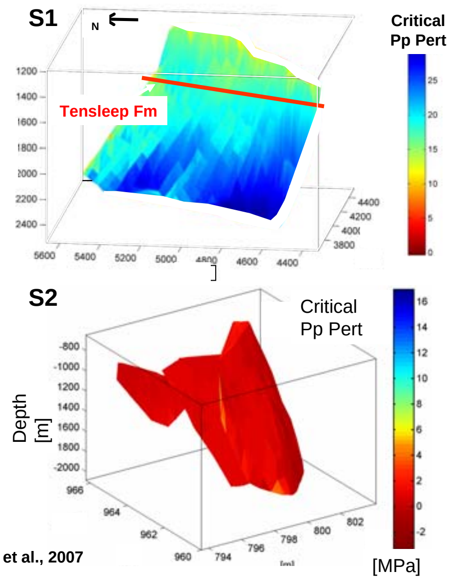
Some faults seal, and some faults leak: There are established means of determining this



Time structure map 2nd Wall Creek Fm
(after McCutcheon, 2003)



Chiaramonte et al., 2007

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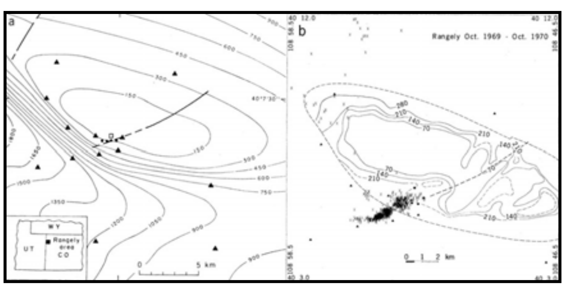
Faults, even seismically active faults, need not exclude site selection/effectiveness



An experiment at Rangely field, CO, attempted to induce earthquakes in 1969-1970. It did so, but only after enormous volumes injected over long times on a weak fault

- ***Mean permeability: 1 mD***
- ***Pressure increase: >12 MPa (1750 psi) above original***
- ***Largest earthquake: M3.1***

There were no large earthquakes
The seal worked, even after 35 years of water and CO_2 injection
This site holds over 28 million tons of CO_2.

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Raleigh et al., 1976

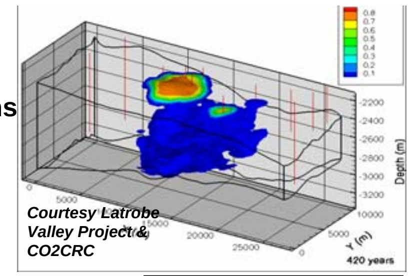
Due diligence will evolve around practical approaches, operations, and measurements

State agencies (e.g., Cal DOGGR; Cal EPA) must set protocols and permitting standards that can be met using conventional technologies

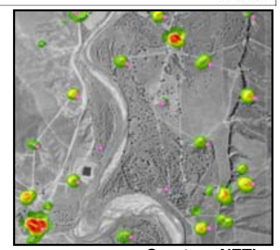
Injectivity
- **Core permeability**
- **Conventional reservoir simulations**
- **Injection/production test**

Capacity
- **Static reservoir models**
- **Conv. pore volume estimation**
- **Conventional stratigraphic mapping**

Effectiveness
- **Conventional stratigraphic mapping**
- **Conventional structural analysese**
- **Reactive transport simulation**
- **Capillary Entry Pressure**
- **Well accounting, monitoring**



Courtesy Latrobe Valley Project & CO2CRC


Courtesy NETL

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Monitoring is important to demonstrate effectiveness once injection begins

A monitoring plan is likely to be required for any site permit application.

The level of monitoring needed should reflect the geological knowledge of the site and the ability to recognize key hazard elements (e.g., faults, wells)

Baseline and operational monitoring during injection may be required

Monitoring for site characterization programs should (1) be minimal (2) define and improve understanding of local geology and geography (3) aimed at constraining effectiveness


Socolow, 2005

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Open issues in CA site selection

Regulatory agency jurisdiction:
- **Which agencies in which capacities?**
- **How flexible should the initial framework be?**

Technical constraints:
- **Consideration of preferred sites or regions?**
- **Technical basis for operational protocols?**
- **Minimal level of due diligence to constrain ICE?**

The threshold for validation should be different for each site and reservoir class.

Policy based on science is needed to establish a regulatory framework aimed at appropriate validation of selected sites for certification

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Conclusions

Site selection should proceed around three primary characterizations: Integrity, Capacity, and Effectiveness (ICE)

Effectiveness is the most difficult to characterize, but there are many standard, commercial approaches and tools. Wells present the greatest risk but appear manageable.

What constitutes due diligence will change, but is likely to defined initially around repeatable, defensible, readily obtained measurements

The threshold for validation differs for each site & reservoir class.

Policy is needed to establish a regulatory framework aimed at appropriate validation and certification of selected sites.

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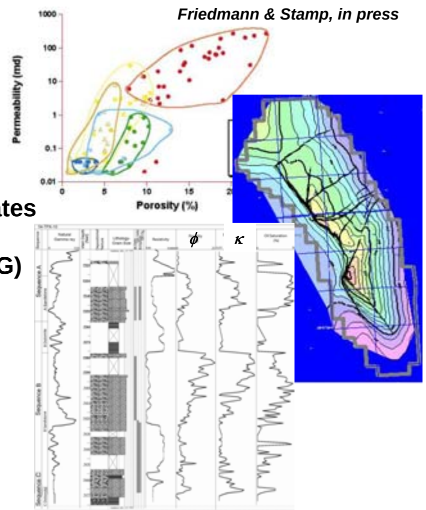
Possible due diligence: *Depleted Oil/Gas Field*

Multiple penetrations, production records, cores from the field or neighboring fields, saturation data, HC composition and gravity.

Injectivity
- **Equal to producibility (bbl/day/psi/ft)**
- **Limited by perf length and maximum injectiton pressure**

Capacity
- **Defined by spill point/column height**
- **Reserves come from pore vol. estimates**
- **HC composition, P, T define process (miscibility vs. displacement; EOR/EOG)**

Effectiveness
- **Cap rock is effective, prob. multiple**
- **Wells require review of locations & drilling records; some remediation & monitoring**
- **Structure maps inform fault leakage risk; some stress data & analysis may be required**



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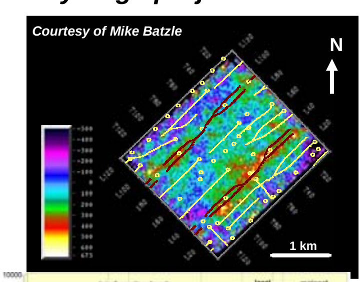
More odious due diligence: *Depleted Oil/Gas Field*

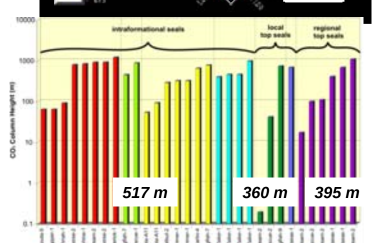
This kind of analysis may be needed to satisfy state regulators, stakeholders, nervous financiers; esp. for early large projects

Injectivity
- **Limited CO_2 injection test with operational monitoring**
- **One new well possible w/ analysis**

Capacity
- **New geological analysis (well correlation)**
- **Possible additional tests**
- **Conventional simulation**

Effectiveness
- **Capillary entry pressure measurements**
- **Recompletion of any old wells, perhaps all wells (Salt Creek)**
- **Limited monitoring program (may or may not require seismic)**
- **Stress characterization & risk analysis**





Courtesy Latrobe Valley Project & CO2CRC

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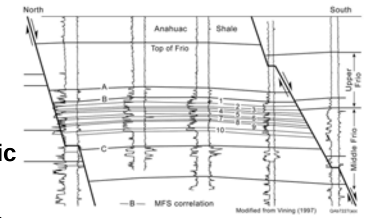
Possible due diligence: Saline Formation

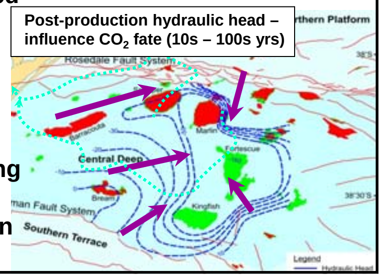
Limited well logs and cores; poor rock-volume and porosity estimation; limited brine composition or hydrological data



Injectivity: New well required
- Injection test, possible extra special core analyses
- Decent local/regional reservoir maps
- Credible drilling strategy; poss. 3D seismic

Capacity
- Pore volume may have large uncertainties to be represented; superabundance required
- Brine composition; special core analysis
- Conventional simulation

Effectiveness
- Credible caprock maps; if no secondary seals, petrol./mech. study may be needed
- Wells requires review of locations & drilling records; some remediation & MMV
- Closure mechanisms must be defended; in hydrol. case; some regional data required



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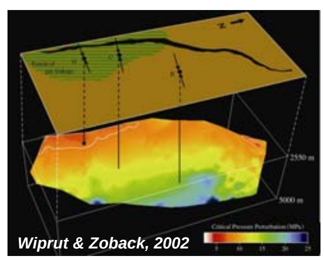
More odious due diligence: Saline Formation

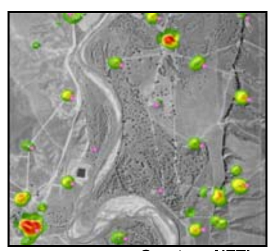
This kind of analysis may be needed to satisfy state regulators, stakeholders, nervous financiers; esp. for early large projects

Injectivity: More than one new well required
- Injection test, possible extra special core analyses
- Decent local/regional reservoir maps
- Credible drilling strategy; possible 3D seismic

Capacity
- Pore volume may have large uncertainties to be represented; superabundance required
- Brine composition; special core analysis
- Conventional simulation; ~20yr post-injection

Effectiveness
- Petrological/mechanical study may be needed
- Aeromagnetic well survey; recompletion of all wells (not many); other shallow geophysics (GPR)
- 3D survey required for structural risk analysis
- Commitment to short term monitoring; ~5yr review


Wiprut & Zoback, 2002


Courtesy NETL

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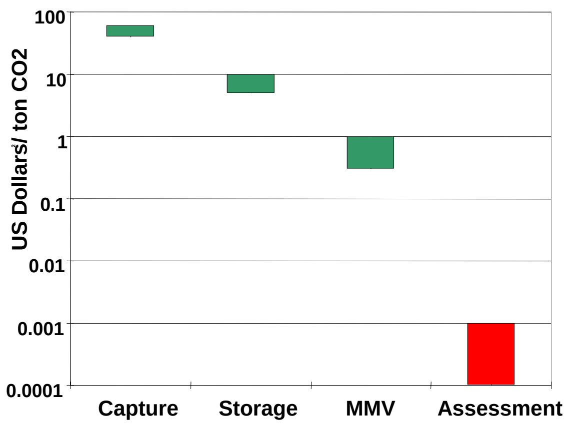
Assessments represent the lowest cost, highest impact step in CCS

For any large injection volume, local assessment is extremely low in cost and can be executed with conventional technology

Projected Costs of CCS Technology Elements



Friedmann et al., in press

On a national level, assessments should proceed through geological surveys or in partnerships with the oil and gas industry

Site assessments may be paid for by the site operator, the CO_2 owner, or through bonds.

This step is vital, and should be supported fully.

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