CO2 Sequestration in Saline Reservoirs

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Wyoming DEQ Meeting

Schlumberger

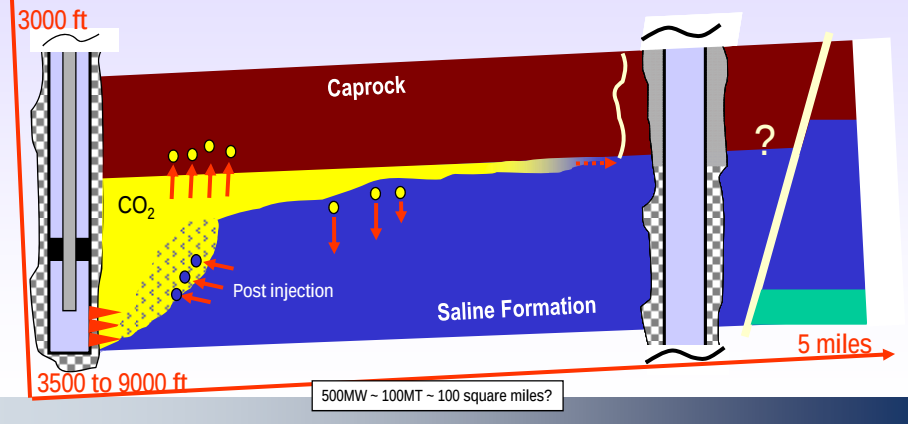
Comparative Scope

- Inject 41 MtCO2/yr for enhanced oil recovery
  - Output of six 1000-Mw coal-fired plants
  - Moved safely hundreds of miles via pipeline
- 50 U.S. oilfields that produce >150,000 bbl fluid per day
  - Output of a 1000-Mw coal-fired plant
- No huge technical barriers to geologic storage of CO2
  - But…EOR experience has been focused on the oil, not the CO2.
- Non-technical challenges, on the other hand, are huge

Storage Fundamentals

3

- **Capacity**: (match to source, estimate plume shape)
- **Injectivity** (how many wells, reservoirs)
- **Containment** (caprock integrity, fractures, wellbore integrity, faults)



Capacity

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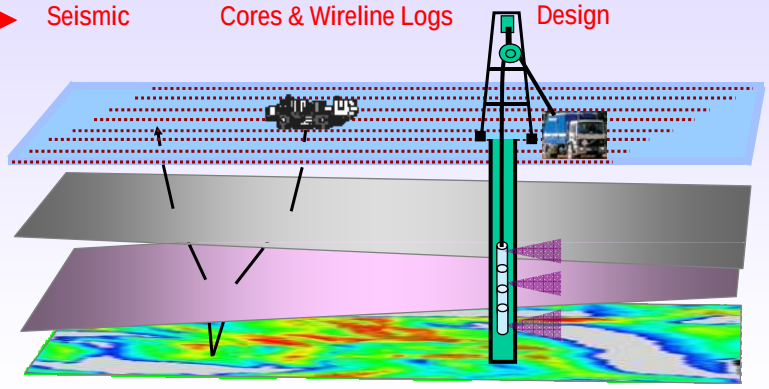
Bulk Volume X Porosity X Storage Factor

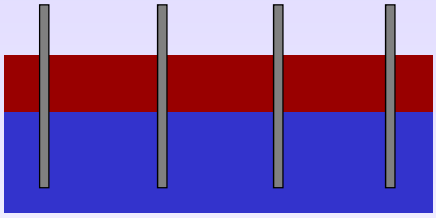
Seismic Cores & Wireline Logs Design

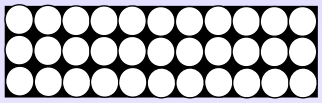


Injectivity

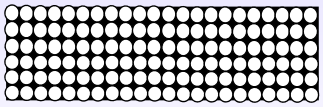
5

How many wells needed?





Big Grains = high permeability



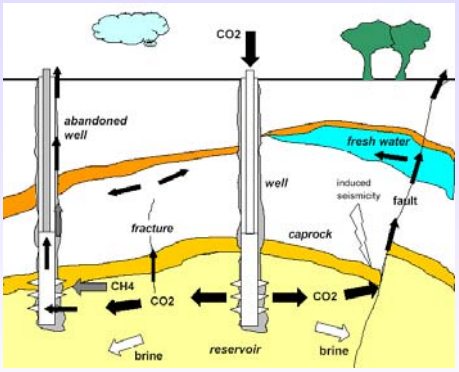
Small Grains = low permeability

➔ Cores, Wireline Logs, Well Tests

Containment

6

- Caprock & Overburden
  - Hydrostratigraphy
  - Composition
  - Mechanical properties
  - Flow properties
- Faults
  - Transmissibility
  - Mechanical Properties
- Wells
  - Completions state
  - Degradation mechanisms



➔ Wellbore Integrity, Geomechanics, Geochemistry & Modeling

Similarities / Differences with Oilfield

7

- Capacity
- Injectivity
- Containment
- Reservoir
- Seal
- Closure
- Source
- Timing
- Access

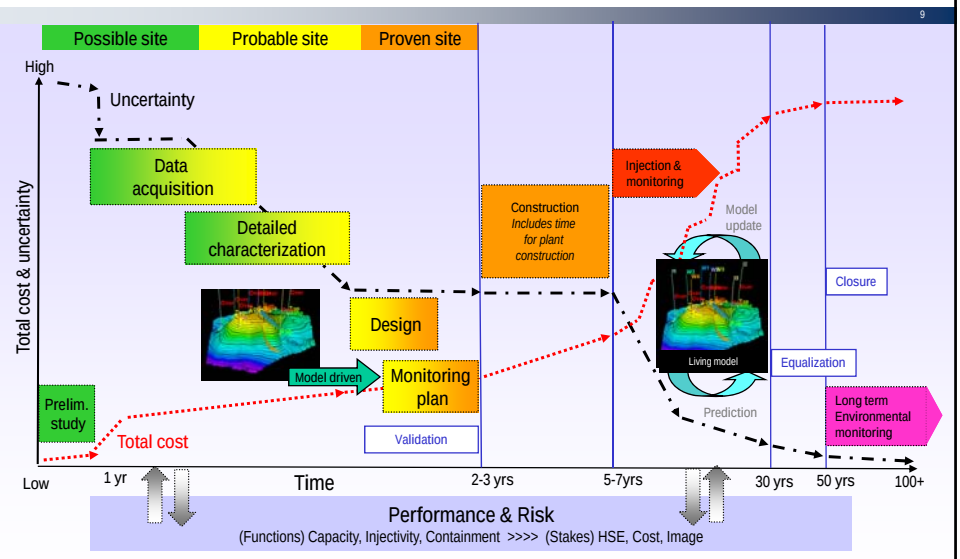
Other Similar Settings

8

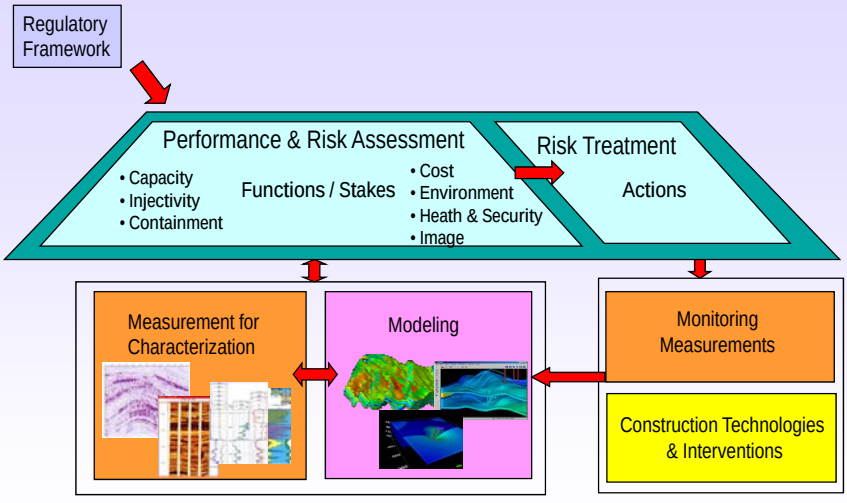
Natural gas storage
- Smaller volumes
- Shorter term focus
- Losses accepted
- Use eminent domain

UIC / Acid Gas
- Regulation built to protect potable water
- Regulated by EPA, not O&G
- No verification required
- Limited “area of influence”

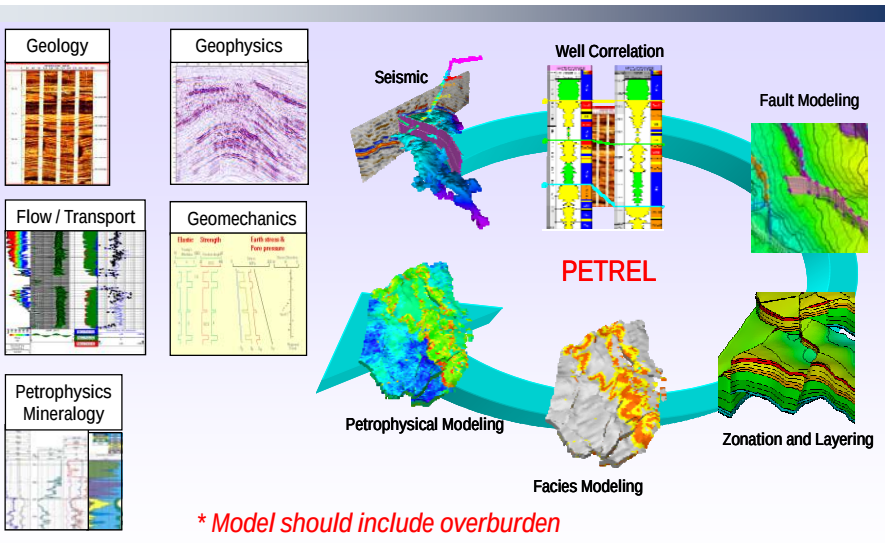
Commercial Scale Storage Timeline



Performance and Risk Management

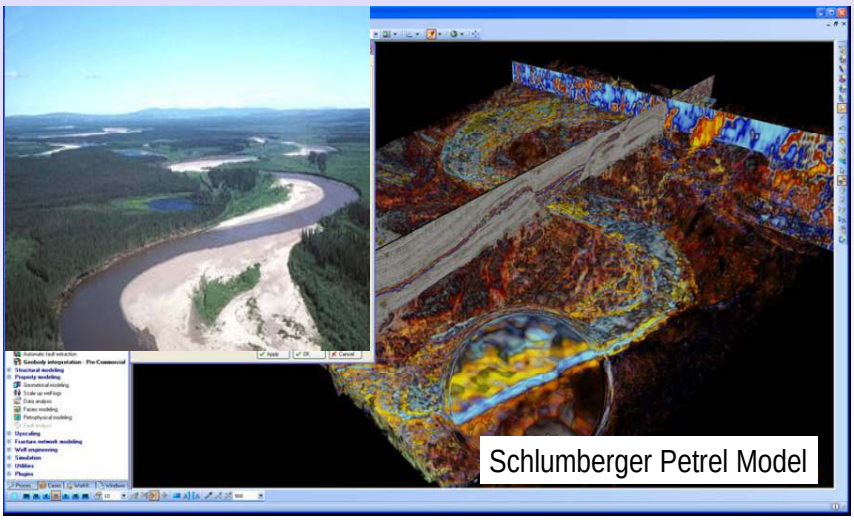


Building a Static Shared Earth Model

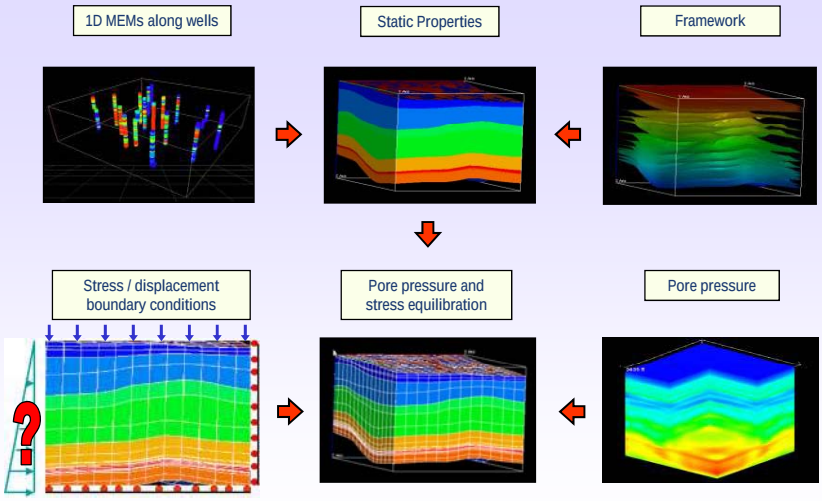


** Model should include overburden*

Detailed Modeling

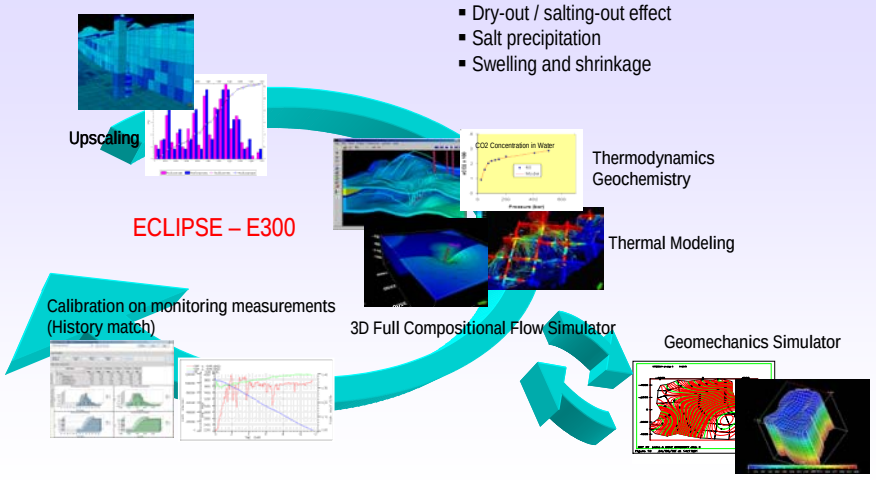


Building a 3D Mechanical Model – Initial State

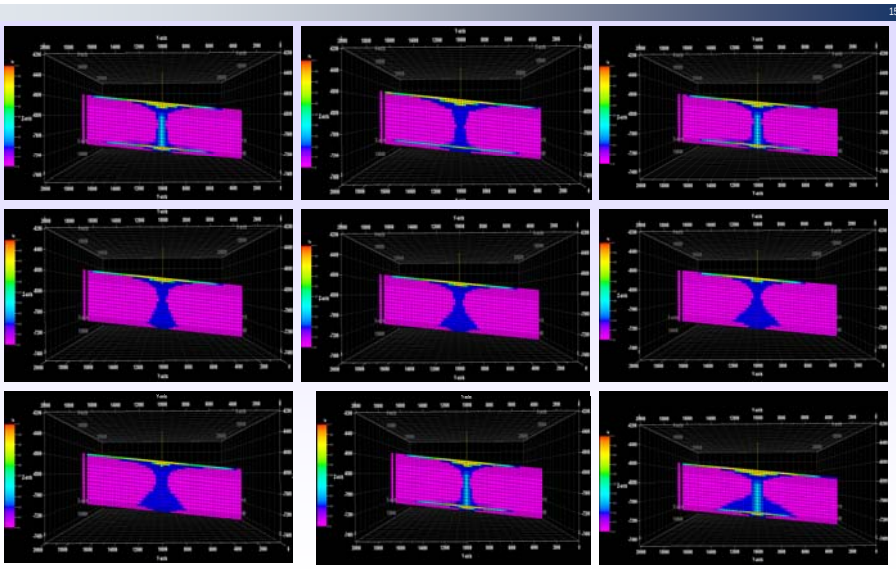


CO2 Injection Dynamic Modeling

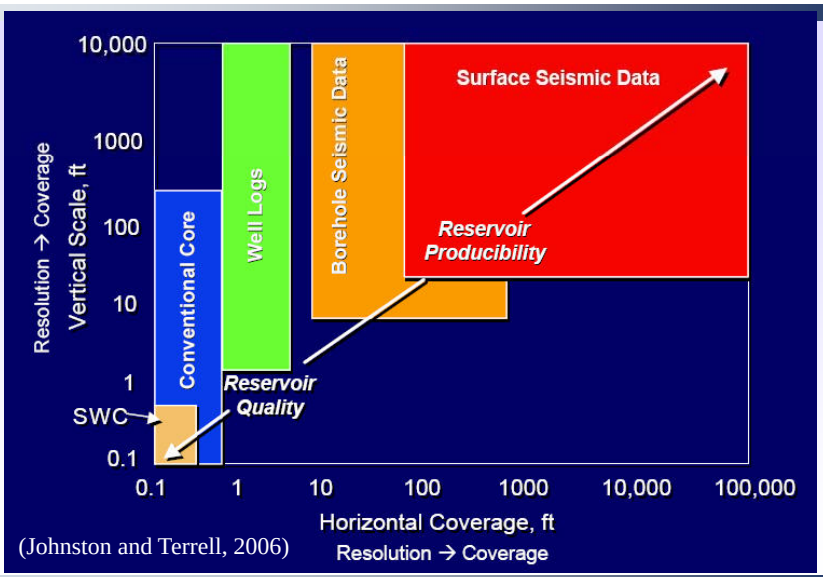
- Improved fluid-fluid / fluid-rock interactions
- Accurate description of mutual solubilities
- Dry-out / salting-out effect
- Salt precipitation
- Swelling and shrinkage



Plume Uncertainty Example



Data and Reservoir Scales

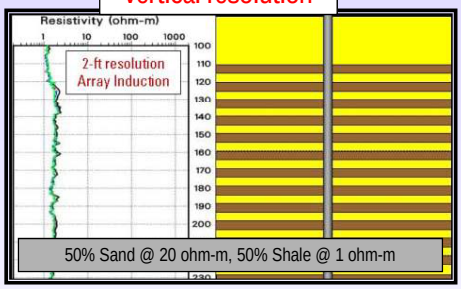


(Johnston and Terrell, 2006)

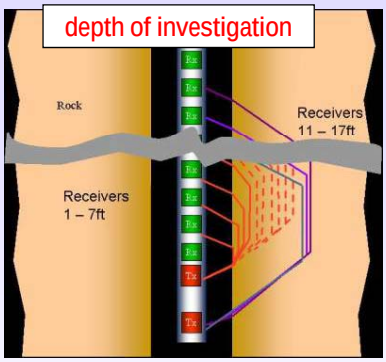
Data is Key, All Measurements Have Limitations

17

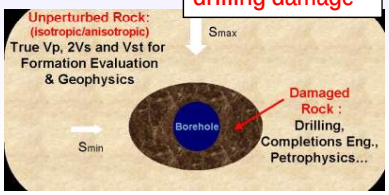
vertical resolution



depth of investigation



drilling damage

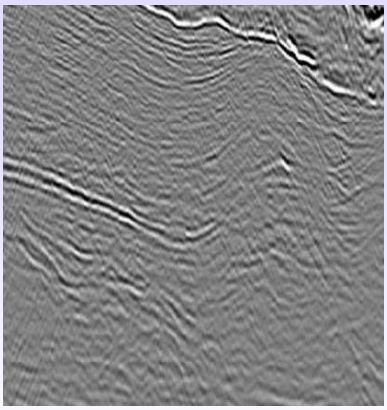


not in-situ

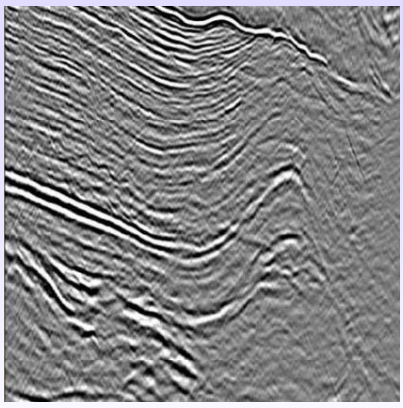
Cores & Fluids brought back to surface

Seismic Example

18



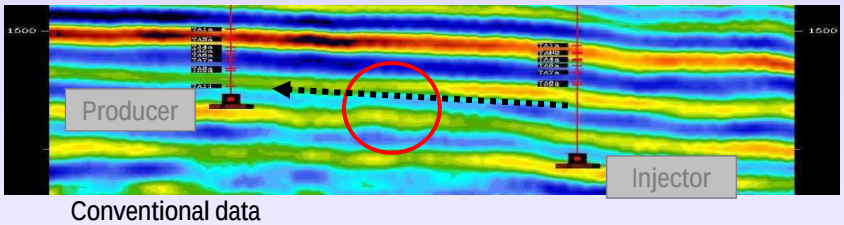
Low resolution 3D



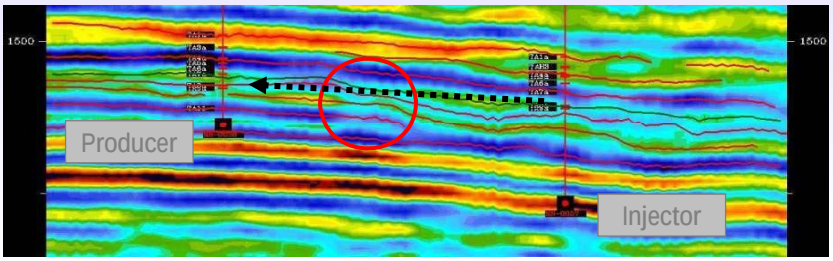
High resolution “Q” 3D

Data courtesy of BHP Billiton, Hess Corporation and Repsol YPF

Conventional Data vs Hi-Resolution Data

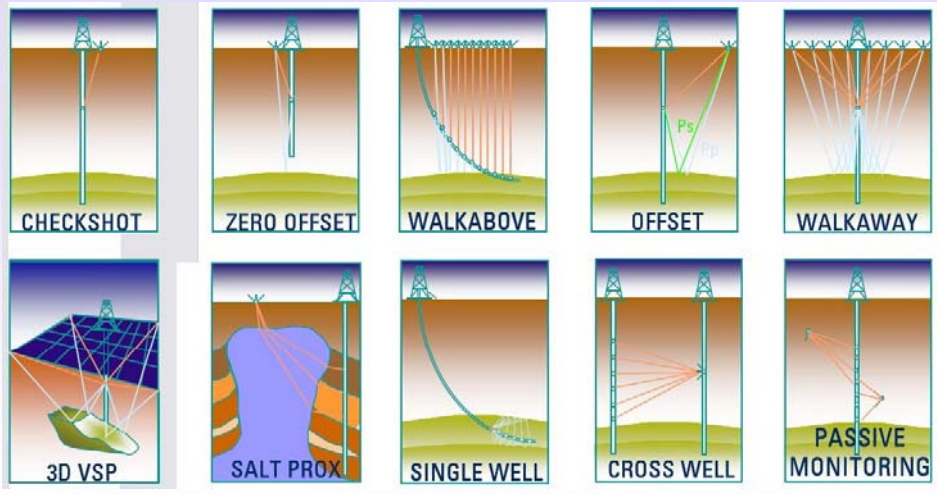


Conventional data

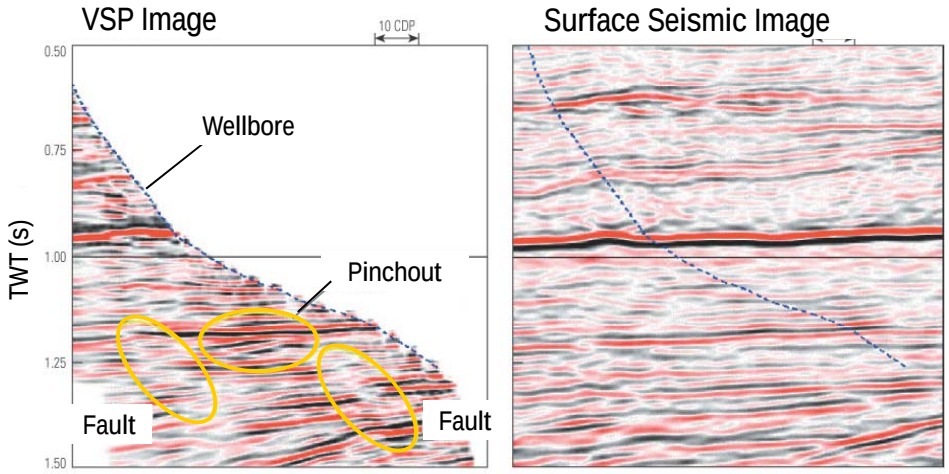


Q-Land single-sensor data

Well-Based Seismic Monitoring

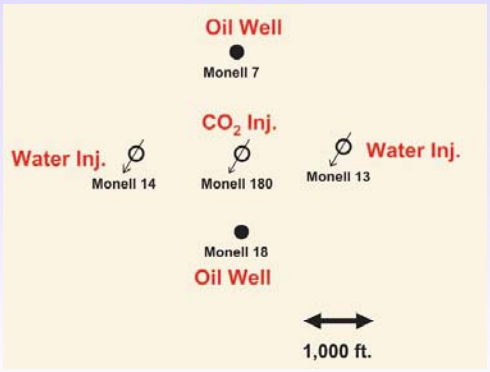


VSP Surveys: Improvements in Resolution



Examples: Anadarko Time-lapse 3D VSP

- CO_2 EOR Pilot in a homogeneous sandstone unit
- Pilot used a 5 spot pattern
- Injected 430 million ft^3 of CO_2 over 18 months
- Used 80 geophone levels & 1007 source points in 3D VSP

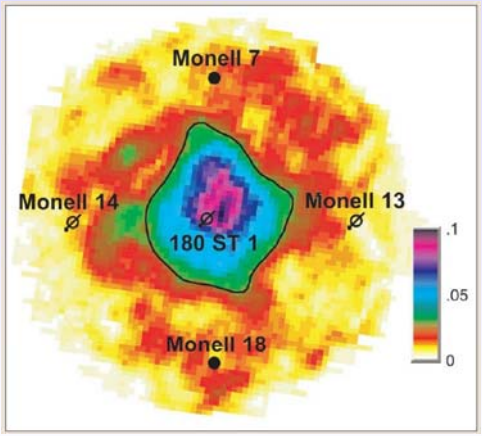


(O'Brien et al., 2004)

Examples: Anadarko Time-lapse 3D VSP

23

- Clear amplitude anomaly associated with the CO_2 flood
  - Indicates that the CO_2 has migrated 700 – 900 ft away from the injector well
- Decrease in P-wave velocity was between 14-19%
  - Uncertainties in pore fluid properties or short comings in modeling equations

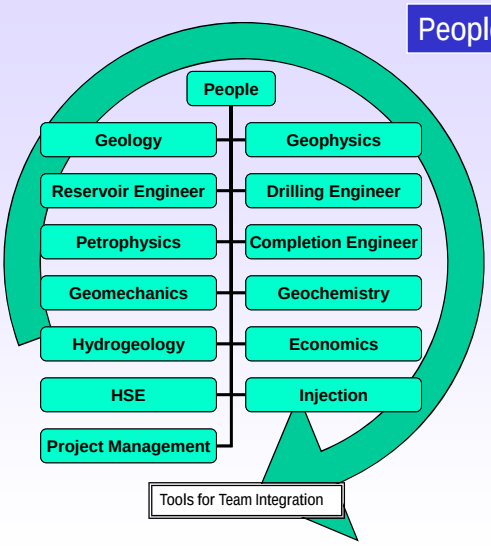


(O'Brien et al., 2004)

What Resources Will Be Needed?

24

People & Technology



+

CO2 Technology
Seismic Services
Wellbore Integrity Evaluation
Drilling & Completion
Cementing
Logging, Testing & Sampling
Lab Analysis
Data Processing
Modeling & Prediction
Data Management
Monitoring

Non-technical Needs

25

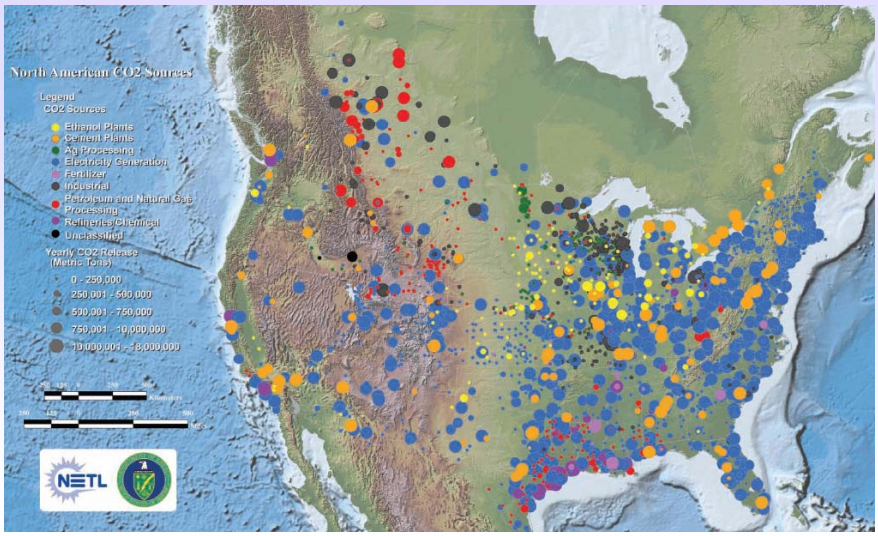
- Carbon value
- Pore ownership ruling
- Regulatory environment
  - Defined area of review, area of influence
- Long-term liability
  - Insurance framework

Education Needs

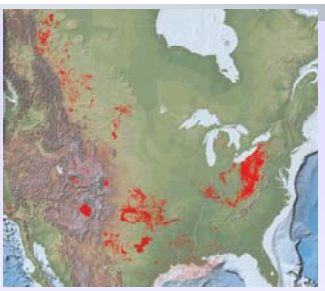
26

- Sources
  - Comfort with the “risk” element
  - Coordinated timing on siting decisions
  - Dealing with the PUC
  - Parasitic load
- Public
  - What happens to the water?
  - Other long-term dangers
  - Value to them vs. cost
  - Communication methodology

North American CO2 Sources



Potential Storage Reservoirs

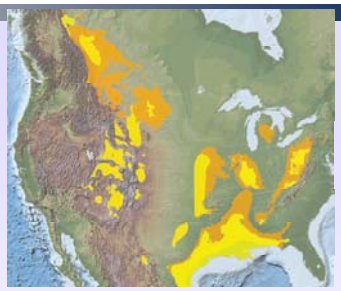


Depleted oil & gas

84 Gt

Unmineable coal

156-184 Gt



Basalts

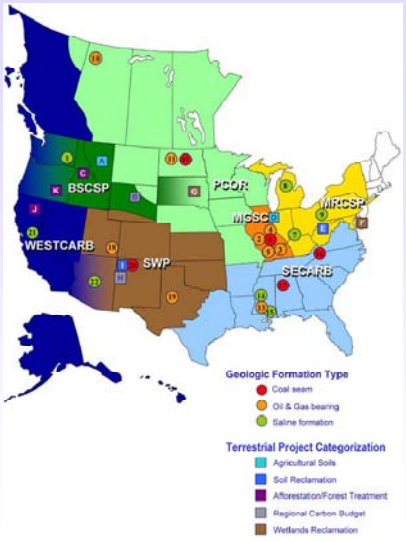
?? Gt

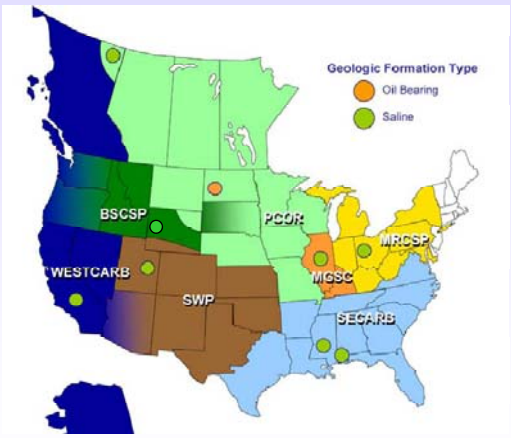
Saline aquifers

919-3378 Gt

Demonstration Projects

29





Conclusion

30

- We must get some smaller-scale demonstration projects done quickly
- Good technology is available today
- Technology choices can impact risk
- High-quality modern data sets need to be gathered prior to injection
- The integration of technologies with modeling tools is a skill
- Modeling tool selection is an important consideration

Keys to Success

31

- Pick the Right Site
  - Non-complex, depth, porosity, perm, extent, structure, caprock…
  - Some existing wells, but not too many
  - Access and capability for: 3-D seismic acquisition, logs, core, fluids, background
- Use the Right Technology
  - Proper density, resolution, noise limits, area of review
  - Value equivalent uncertainty reduction
  - Has impact on performance and risk
- Properly Integrate the Data
  - Requires an experienced, skilled, multi-disciplinary team.
  - Unified modeling environment
  - Shared earth model, easily updatable - “Living”

Going Forward

32

- Non-technical factors are the key to progress
- Clear regulatory guidelines and and long-term liability protection are needed for commercial involvement.
- Resource requirements will be large
- Uncertainties can be managed with technology, people, and process
- Expertise and technology must be valued and respected
- Thorough assessment and baseline characterization is key
  - Number of wells
  - Frequency of monitoring
  - Public acceptance
  - Overall cost