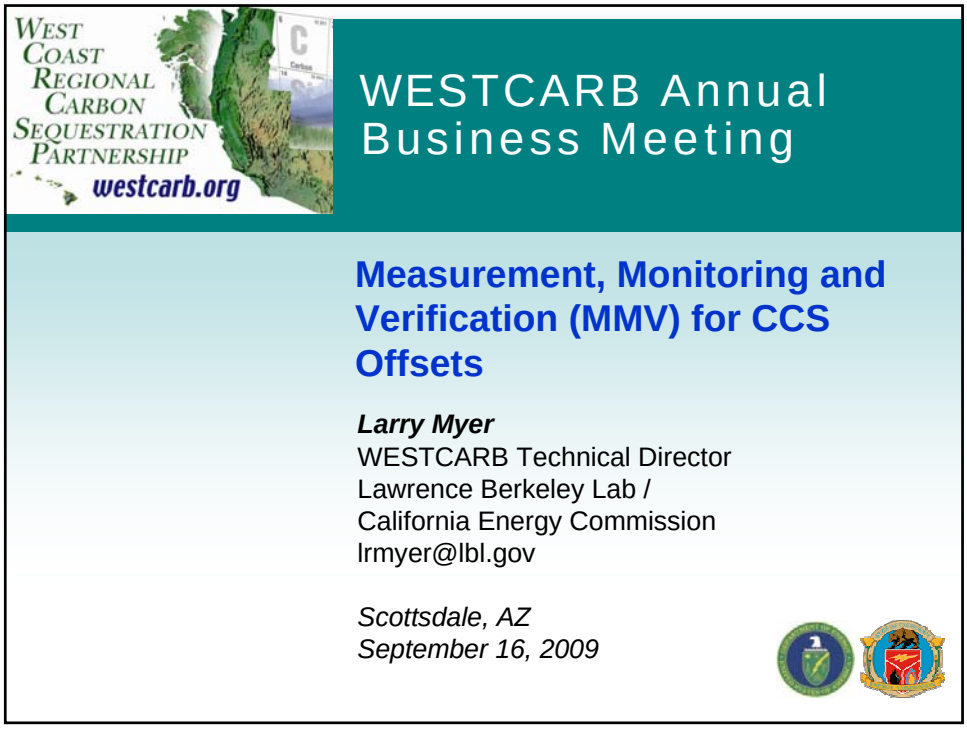
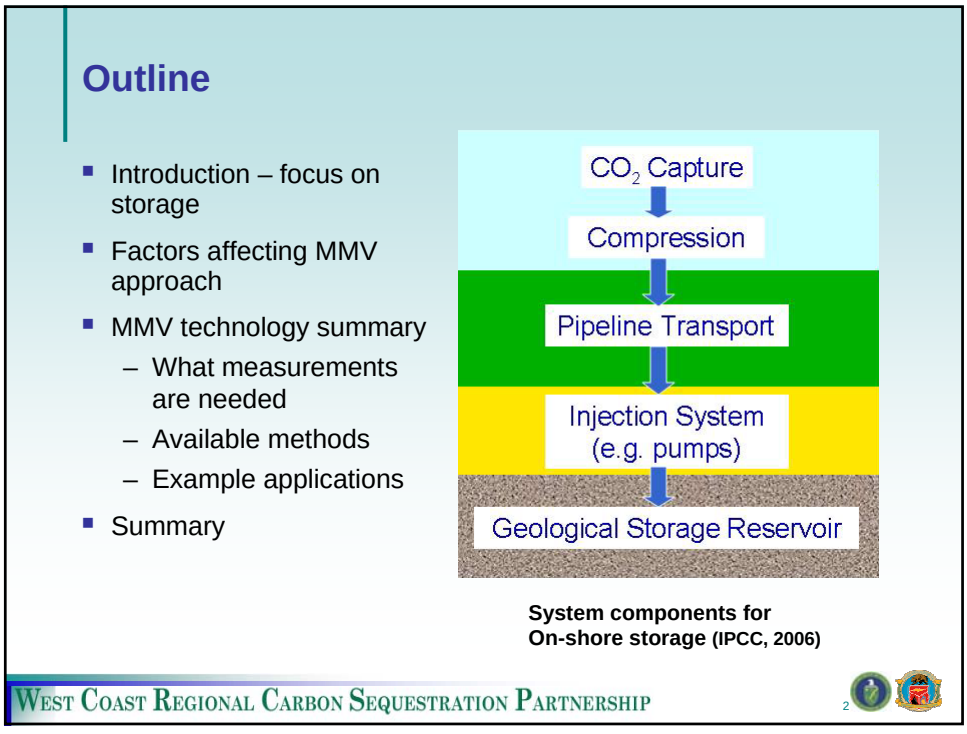

West Coast Regional Carbon Sequestration Partnership
westcarb.org
WESTCARB Annual Business Meeting
Measurement, Monitoring and Verification (MMV) for CCS Offsets
Larry Myer
WESTCARB Technical Director
Lawrence Berkeley Lab /
California Energy Commission
lrmyer@lbl.gov
Scottsdale, AZ
September 16, 2009

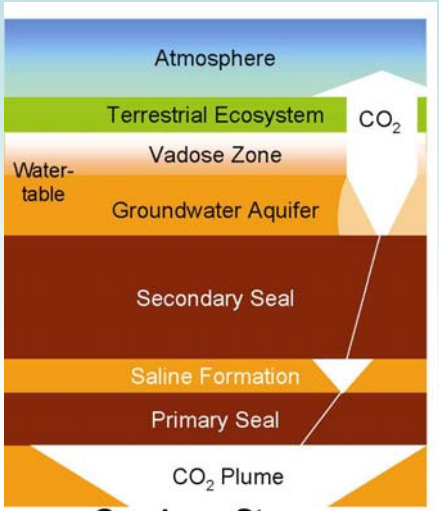

Outline
Introduction – focus on storage
Factors affecting MMV approach
MMV technology summary
What measurements are needed
Available methods
Example applications
Summary
CO2 Capture
Compression
Pipeline Transport
Injection System (e.g. pumps)
Geological Storage Reservoir
System components for On-shore storage (IPCC, 2006)
West Coast Regional Carbon Sequestration Partnership
2

Issues Affecting MMV Approach/Success

- Compliance point – surface or subsurface?
  - In subsurface, at reservoir or above?
  - Lateral compliance point?
- Time after injection at which payment is provided
  - Long term stabilization time
  - Liability and trespass issues
- Acceptable leakage amount?
  - Detectable leakage

A Substantial Portfolio of Monitoring Techniques are Available

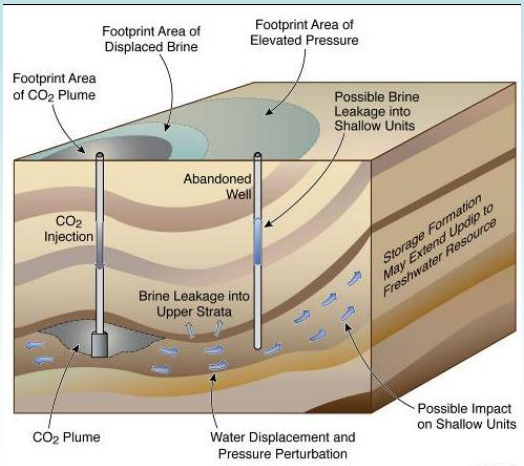
- Geophysics; seismic, electrical, gravity
- Well logging
- Hydrologic pressure and tracer measurements
- Geochemical sampling
- Remote sensing
- CO_2 sensors
- Surface measurements



(Figure courtesy of S. Benson)

Primary Subsurface Monitoring Information Needs

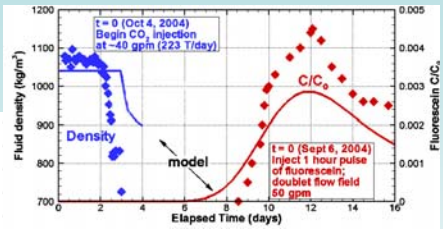
- CO_2 spatial distribution in the storage formation
- Storage capacity, effectiveness of trapping mechanisms/plume stabilization
- Caprock and wellbore integrity

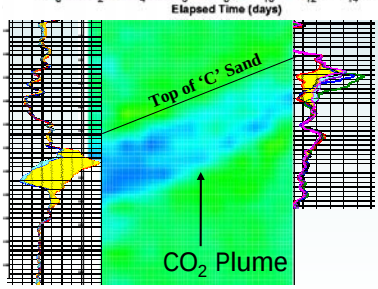


(Figure courtesy of J. Birkholzer)

Monitoring CO_2 Spatial Distribution

- Time lapse seismic
  - 3D, VSP, crosswell
- Well logs
- Fluid sampling in monitoring wells – CO_2 arrival, fluid chemistry
- Gravity
- Electrical geophysics
  - EM, MT, SP



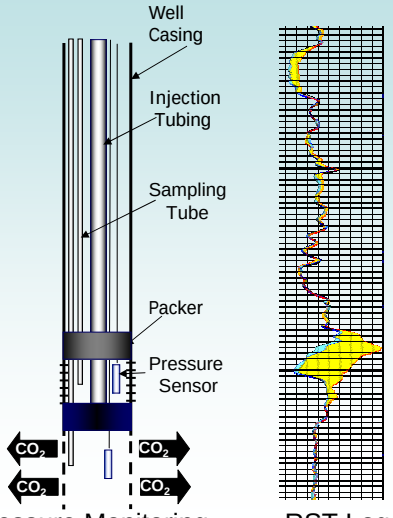


Monitoring to define the CO_2 plume at Frio

Injection Well — -1.0 -0.5 0.0 0.5 1.0 CHANGE IN VELOCITY (KM/S) — Monitoring Well

Assessing Seal Integrity

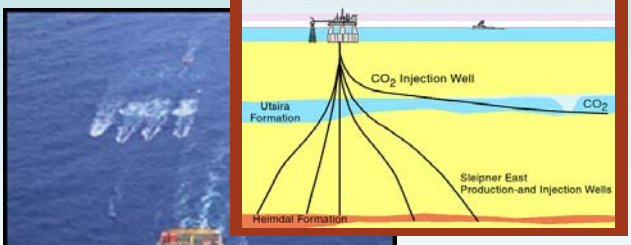
- 3D seismic, electrical geophysics
- Geomechanical analysis
  - Safe injection pressure
- Pressure and water quality in formation above seal
- Well logs; core



Pressure Monitoring

RST Log

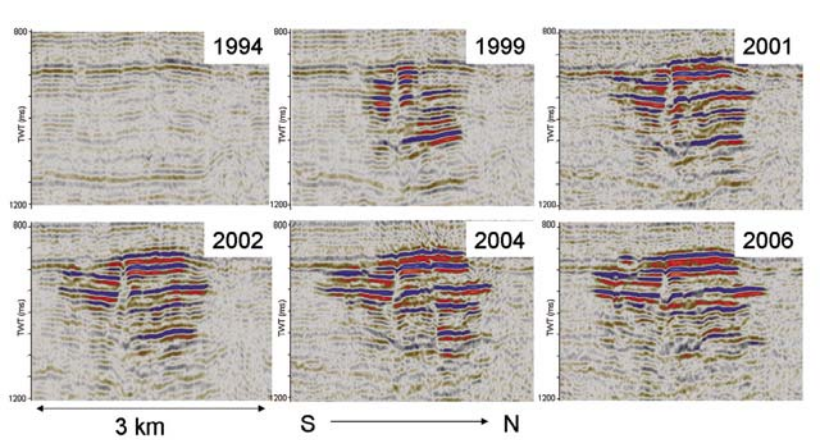
Integration of Time Lapse 3D Seismic and Gravity at Sleipner



Seismic acquisition ship
(http://www.ukooa.co.uk)

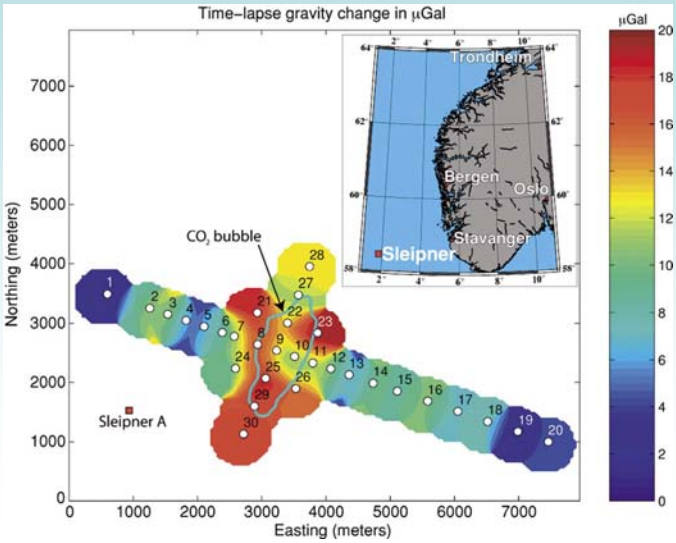
Right: Sub-sea gravity survey
(Arts et al., 2008)

Time Lapse Seismic Successfully Monitored Plume Development



Seismic reflection cross-section before injection and then after 2.3, 4.2, 5.0, 6.8, and 8.4 Mt CO_2 injected (Arts et al., 2008)

Uncertainties Constrained With Gravity



Time lapse gravity response from 2002 to 2005 (Arts et al, 2008)

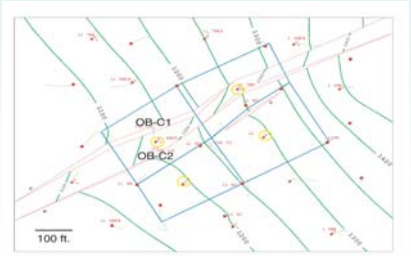
Frio Formation: Vertical Seismic Profile Data

1600 tonnes CO_2

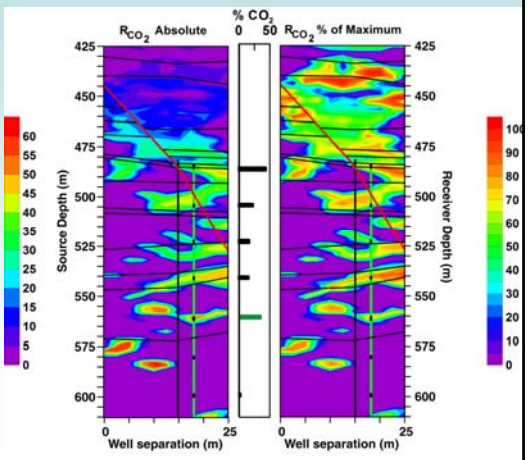
Data from Tom Daley, LBNL

Combining EM and Seismic to Better Quantify Fluid Distribution

- Crosswell seismic and electrical (EM) methods used to image CO_2 saturation in the reservoir
- Rock-physics models derived from wireline logs



Plan view of Lost Hills Pilot

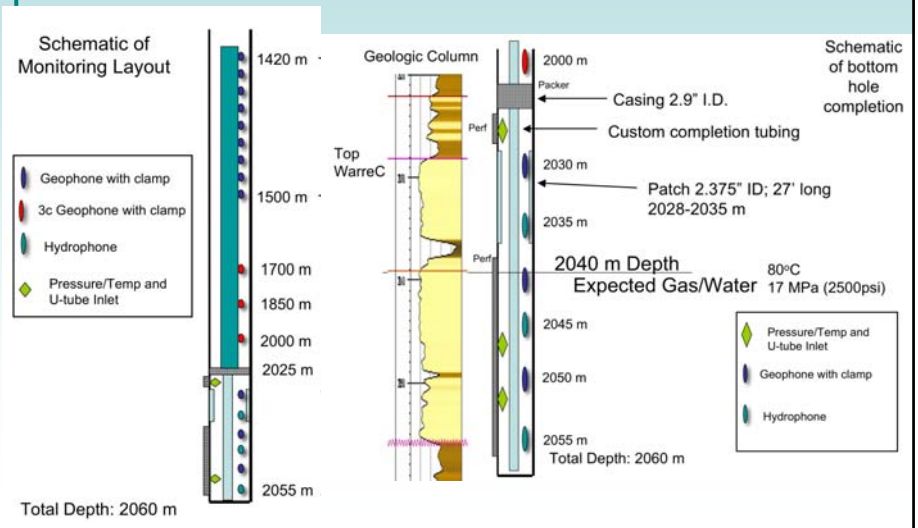


Time lapse image of CO_2/oil ratio between wells at Lost Hills pilot
(M Hoversten, LBNL)

Summary

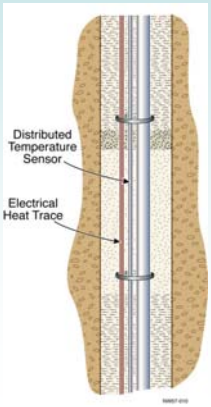
- Various decisions on accounting process will influence MMV approaches
- There is a large portfolio of measurement techniques available to meet accounting needs; program wiil be tailored to site conditions
- Monitoring of the plume and seal should provide sufficient information for accounting purposes
- Testing of new techniques and approaches will continue to improve MMV for CCS offset applications

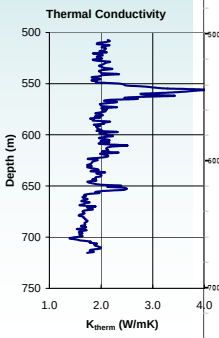
Pressure, Temperature, Fluid Sampling, Seismic System Deployed in Nylar 1 Well, Otway

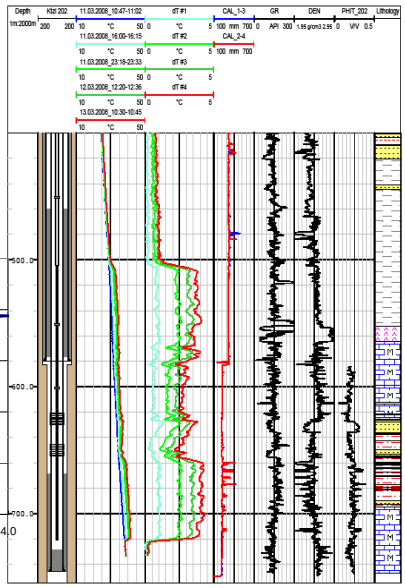


Using Thermal Properties to Derive CO_2 Saturation (CO2SINK)

DTS fiber-optic sensor monitors
Thermal transients







Monitoring Data Will Serve Multiple Purposes

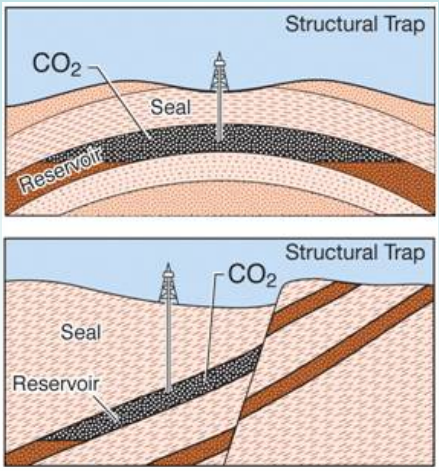
Requirements for Geologic Storage

- Worker and Public Safety
- Performance Confirmation
- Local Environmental Impacts to Groundwater and Ecosystems
- GHG Mitigation Effectiveness

Monitoring Information Needs

MMV Approaches Will be Tailored to Site Specific Geology

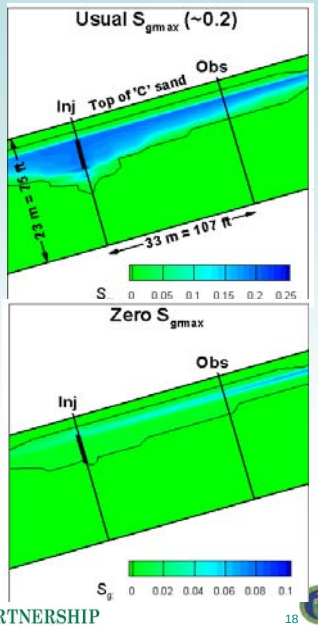
- Hydrocarbon reservoirs formed by structural, stratigraphic, and fault traps have demonstrated long-term containment
- Seal integrity can be established during operational phase
- Secondary trapping important if trap not present



Typical geological structures ideal for trapping CO_2 *(Source: W Gunter, ARC)*

Factors Affecting Stabilization by Residual Gas Trapping

- Intrinsic properties of the reservoir rock
  - Porosity, permeability, residual gas saturation
- Reservoir heterogeneity
- Amount of CO_2 injected (plume size)
  - Injection strategy



Right: Modeled effect of residual gas saturation value on immobilization of plume for Frio pilot test
(Doughty et al., 2007)