Monitoring, Mitigation, and Verification (MMV) in Geological Sequestration Scenarios, Technical Advances and Economic Constraints

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Where MMV is Needed

Power Plants

• Separate CO$_2$ - S, NOx, Metal
  Scrubbers, Membranes

• Leak Testing – Pipes
  Monitors (CO$_2$, S, N, T)
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Pipelines

- Leak Testing Monitors (gas, biology)
- Pipe Integrity Sensors inside pipe (nanotechnology, acoustics)
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Reservoirs
- Leak Testing Monitors (gas, H$_2$O, biology)
- Reservoir Integrity CO$_2$ movement Faulting, cementing

IAEE  USAEE

Unclassified
Purpose of Monitoring in Geological Reservoirs

- **Determine effectiveness of CO₂ storage**
  - safety (public, environment)
  - economics (carbon credits, infrastructure)

- **Determine impacts on reservoir**
  - chemical/physical changes
  - CO₂ movements, calibrate models
  - remediation

- **Settle legal disputes**
  - storage/seepage scenarios
  - impacts to other reservoirs
Reservoirs – EOR, coal beds, aquifers

• Spatial set-up of MMV - subsurface, surface, local, satellite

• Timeline of measurements - Baseline, operation, closure

• Safety/regulations set-up – workers/public, environment, mitigation

• Economic constraints – tech costs and sampling designs
Spatial Analyses and Technologies

• **Satellite** = Vegetation (NDVI), [CO₂], geology

• **Regional** = [CO₂], H₂S, Rn, EM

• **Local** = Eddy Flux, LIDAR, Tracers

• **Surface** = Chamber, Tracers, LIBS, Vegetation, microbes, soil gas/water composition

• **Wells** = injection/production rate, temperature, pressure (wellhead, formation, casing, annulus) wire line (gamma, neutron, resistivity)

• **Subsurface** = Groundwater, Ground Deformation, Seismics (Passive, 4D, X-well, Micro), gravity, Tracers, tilt, EM

*Unclassified*
Temporal Scales Needed to be Monitored

Daily
- Injection well monitor (T, P, CO₂, flow)

Weekly
- Eddy Covariance (T, flow, CO₂)

Year-Multiyear
- Satellite-15 m resolution (CO₂, vegetation index)
- Rock/cement weathering

Groundwater (DIC)
Timeline for Monitoring at Varying Sites

• **Baseline Measurements** = seismic, groundwater, atmospheric CO\textsubscript{2}, tracers, vegetation type, microbes, soil gas/water composition

• **Operation** = well logs, seismics (4D-frequency below), groundwater (comp., pH), [CO\textsubscript{2}] and isotopes (regional, local, surface), vegetation

• **Closure** = periodic checks of seismics, groundwater, [CO\textsubscript{2}], pressure

**Proposed frequency of geophysical measurement (Larry Myer LBNL)**
Safety and Regulations in Place

- **Worker/public**: EPA standards, controls, safety locks, emergency response
- **Risk assessment/mitigation**: Potential hazards (geologic, public), emergency response
- **Outreach efforts**: townships, company, local/state governments
Economic Issues in Geological MMV

- **Technological costs**
  - geophysics, geochemical, satellite
- **Sampling designs** (network arrays)
  - temporal and spatial
  - regulatory constraints

Costs taken from contractors, universities, labs, web
Geophysical Costs - Technologies

- Costs = equipment, collection, analyses
  1 time costs for 40 acres
  No drilling of new wells

Costs taken from contractors, universities, labs, web

Unclassified
Geophysical Costs - Technologies

- Cost = Drilling (1 hole)
Geochemical Costs - Technologies

- Costs = analyses (lab) analyses + equipment (field)

Costs taken from contractors, universities, labs, web
Tailored Approach to Monitoring Site

- **Reservoir type and history** – Geology, well location, data archives, Land ownership (permitting), Infrastructure, risks/safety

- **Economics** – Dictate MMV technologies, sampling strategies

- **Technology Overlap** – Geophysics, couple tests with similar equipment
Conclusions & Future Directions

Conclusions:

- MMV – Power plants, pipelines, reservoirs
- MMV – Spatial and temporal scales
- Economics – Dictate technology & sampling
- Tailored approach used per reservoir

Future Directions

- Economic modeling: Needed for MMV
  - Help with sampling designs
  - Help with risk/safety evaluations