CRITICAL SMV ISSUES FOR CO_2 STORAGE IN COAL

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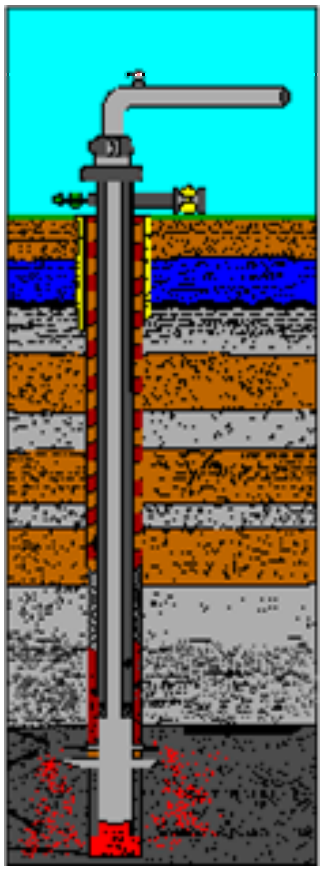
OUTLINE OF PRESENTATION

- Risks Associated with Geological Sequestration/Storage
- Basis for Monitoring and Verification Framework
- Monitoring and Verification Requirements to Address Risks
- Research Needs/Other Considerations

CHARACTERISTICS OF RISKS

- Risks are a function of ***both*** consequences and the probability of occurrence
- ***Consequences*** have, for the most part, been defined, primarily in terms of scenarios
- ***Probabilities*** have yet to be effectively characterized
  - Some work in this area is underway, though little to date has been targeted at coal seams.

CO_2 INJECTION IN OIL & GAS FIELDS IS A WELL UNDERSTOOD PROCESS



- CO_2 is generally injected into natural traps
  - More is known about the geology of oil & gas fields than any of the other CO_2 storage options under consideration
- Less is known about storage in coal seams
- Key issue: Will the CO_2 remain "permanently" sequestered?
  - Oil & gas have been there for millions of years
  - How will "permanence" be defined?

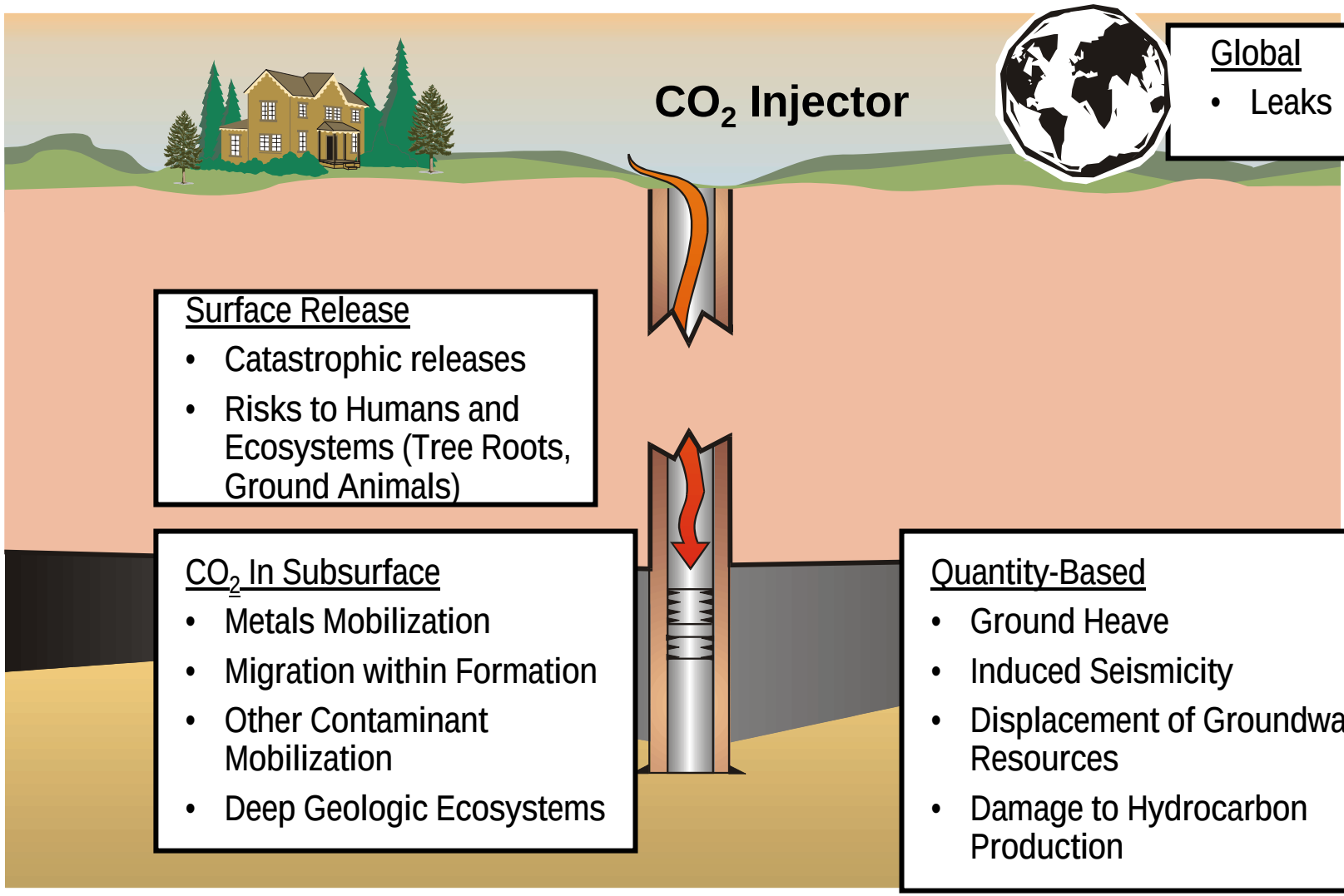
CONVERTING CO_2 INJECTION TO LONG-TERM STORAGE

- Need to distinguish three categories of risks:

  -- Global Risks -- Operational Risks -- Local Risks

- Better understanding of risks needed
  - Implications of significant "scale-up" of injection activity
- Risks relate to unique features of long-term storage
  - Assessing and configuring formation for long-term (~1,000 year) storage of CO_2
  - Ensuring the CO_2 remains in the formation
  - Establishing cost-effective, long-term monitoring and verification systems

POTENTIAL RISKS FROM CO_2 SEQUESTRATION



LARGEST IDENTIFIED RISK PATHWAYS

- Leakage up wellbores and similar conduits
  - Injectors
  - Producers
  - Abandoned wells
  - Water wells
  - Gob wells
  - Mine shafts
- Leakage due to inadequate caprock
- Leakage through faults, fractures, etc.
- Risks relate to the pathway and ultimate destination
  - Other formations and aquifers
  - Vadose zone
  - Land surface
  - Lakes, streams, oceans
  - Buildings

RISK PATHWAYS UNIQUE TO COAL SEAMS

- Leakage through abandoned gob wells or mine shafts
- Leakage through hydro fractures created by stimulation
- Leakage of methane displaced by injected CO_2 (20+ times the GWP)
- Impact of CO_2 injection on swelling
- May be mining target in future?
- Adsorption of CO_2 reduces probability and extent of CO_2 migration relative to sequestration in oil fields

LESSONS LEARNED TO DATE CONCERNING RISKS

1. CO_2 can be stored safely
2. Health effects are well understood
3. Hazards generally depend on nature of release, not size
4. Largest risks have been identified
5. CO_2 storage has unique attributes
   - Relative to other substances injected into the subsurface

FEW THOUGHTS ON A REGULATORY FRAMEWORK FOR CO_2 STORAGE

- Little or no existing policy, but some are/can be extended to apply to CO_2 storage:
  - Acid gas injection
  - Enhanced oil recovery
  - Natural gas storage
  - CO_2 transport and industrial use
  - Waste injection
- Can also apply knowledge from natural storage analogs
  - Oil and gas reservoirs
  - Natural CO_2 Reservoirs
- And natural CO_2 releases
  - Volcanic eruptions
  - Hydrothermal vents
  - Limnic releases
  - Diffuse venting
  - Ecosystem CO_2 recycling

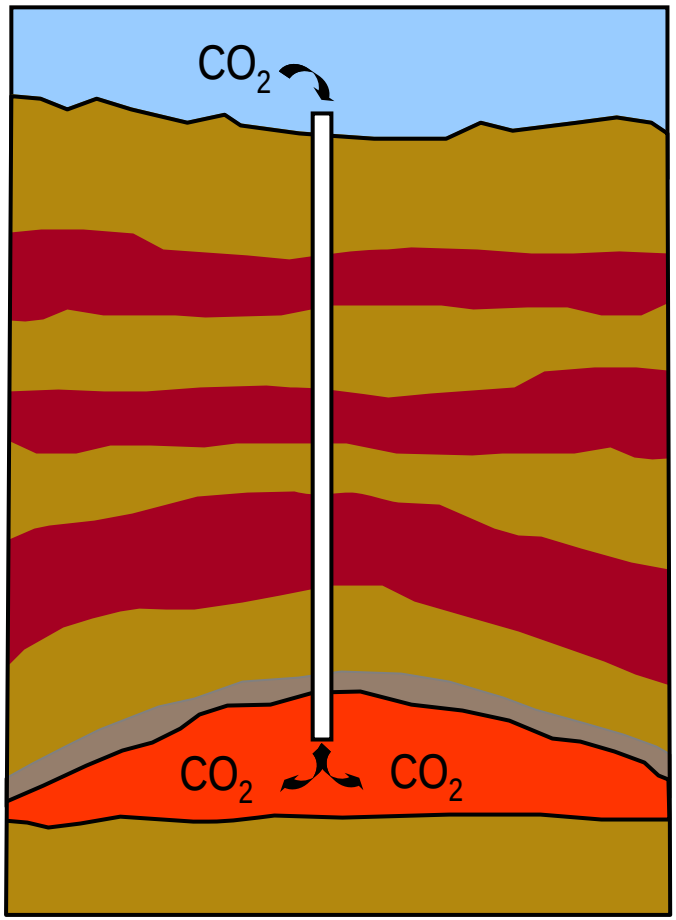
MONITORING AND VERIFICATION REQUIREMENTS

- ***Measurement*** **of the amount of CO_2 stored**
- ***Monitoring*** **for leaks or deterioration of storage integrity**
- ***Verification*** **that the CO_2 remains stored and causes no risks**

BASIS FOR MONITORING AND VERIFICATION FRAMEWORK

- Ensure public that geologic storage is safe and environmentally acceptable
- Obtain public acceptance of storage as viable option to reduce GHG emissions
- Establish accepted, verifiable methods for characterizing volumes of CO_2 stored
- While ensuring that geologic CO_2 storage is an economically viable GHG emission reduction alternative

RELIABLE AND EFFECTIVE MONITORING



- Essential to ensure geologic storage is safe, effective and acceptable
- Serves multiple purposes
  - Ensure worker safety
  - Ensure public health and safety of local environment
  - Verify CO_2 stored
- Additional purposes for monitoring
  - Track migration of stored CO_2
  - Confirm predictions of physical and geochemical storage/trapping efficiency
  - Provide early warning for storage failure
  - Diagnose cause of storage reservoir failure

MONITORING AND VERIFICATION TECHNOLOGY EXISTS FOR MANY APPLICATIONS

- Procedures for pipelines, shipping, handling and industrial storage
- Procedures for injection wells (water and gas)
  - Pre-injection characterization
  - Modeling
  - Mechanical integrity testing
  - Maximum allowable injection pressure
  - Well completion standards
  - Well abandonment standards
  - Area of review

WHAT'S NOT GENERALLY CONSIDERED UNDER CURRNT MONITORING AND VERIFICATION PROCESSES

- **Unique properties of CO_2**
  - **Buoyant in most subsurface settings**
  - **Denser than air in atmosphere**
  - **Non-toxic at <1% concentrations**
- **Long time frame**
  - **Leakage/impacts away from wellbore**
- **Future widespread application**
  - **More diverse settings geologically, geographically, and ecologically**

POTENTIALLY APPLICABLE MONITORING AND VERIFICATION TECHNOLOGIES

- Traditional reservoir management techniques
  - Wireline logs and subsurface fluid sampling
  - Reservoir pressure, temperature measurement
- Reservoir modeling
  - Will need to be verified by actual measurement to be accepted
- Atmospheric monitoring
  - Many options and tools; can be applied at different scales
  - Can be expensive
  - Complicated because of ambient CO_2
- Soil gas monitoring
  - Escaped CO_2 could concentrate in soil layer
  - Relatively low cost; currently being tested at several field sites
  - Also must address ambient CO_2

POTENTIALLY APPLICABLE MONITORING AND VERIFICATION TECHNOLOGIES (Cont'd)

- Groundwater monitoring
  - Expensive
  - Signal of leakage could be complex
  - Could be used in combination using multiple tracers
- Tracers and geologic inferences
  - CO_2 can be isotopically unique
  - Introduced constituents can provide unique "fingerprint"
- Subsurface geophysics
  - Alternative methods (2D, 3D, tiltmeters, etc.)
  - Time-lapse 3-D surveys successfully detected CO_2 plume at Sliepner
- Cross-well seismic and vertical seismic profiling
  - Not very sensitive to concentration
  - May not detect low leaks

STRATEGIES FOR MONITORING AND VERIFICATION

- **Intensive monitoring in early pilot projects**
  - **Need greater focus on M&V issues in coal seams**
- **Tailor later monitoring requirements based on relative risks**
  - **(probably x consequences)**
- **Still need to develop procedures and mechanisms for oversight**
  - **To address both long time frames and large-scale application**

RESEARCH AND DEVELOPMENT NEEDS

- Accepted risk assessment frameworks and methodology
- Appropriate regulatory/oversight framework based on risks posed
- Performance requirements for geologic storage in different settings
- Monitoring approaches and requirements appropriate for specific settings and/or storage targets
- Credible site-specific case studies
  - Adequate site characterization data
  - Modeling and risk assessment
  - Performance confirmation

GOOD SCIENCE IS NOT ENOUGH: PUBLIC PERCEPTIONS ARE ALSO KEY

- Public perception issues will need to be confronted early
  - Determined and organized local opposition could derail progress despite larger global benefits
  - Public will need to be involved early in process
  - Proactive information dissemination critical
- Public concerns
  - Technology performance
  - Risks/benefits of alternatives
  - Effectiveness of risk management mechanisms and institutional oversight
- Geologic sequestration divisive issue among environmentalists

CONCLUSIONS/ CLOSING REMARKS

- Most R&D performed to date on M&V has not focused on coal seams.
- Focuses primarily on:
  - Oil and gas reservoirs
  - Deep saline aquifers
- Many of the risk pathways are similar between coal seams and oil and gas reservoirs
  - But the actual risks (probably x consequences) may be quite different
  - Thus, M&V requirements for coal seams may be different than for oil and gas reservoirs.