Global Warming and Carbon Management – Timing, Costs, Priorities

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Key Issues for Geologic Carbon Sequestration

• Motivation
  – Carbon capture and storage (CCS) is necessary for stabilization of CO₂ levels in atmosphere
  – CCS alone is not sufficient for stabilization
  – Time is of the essence
    • Geologic carbon storage (GCS) technology available now
Anthropogenic $\text{CO}_2$ emissions comparable to net fluxes in Earth’s carbon cycle

CCS necessary – but not sufficient

Wedges of CO₂ emissions

Pacala and Socolow, *Science* **305**:968, 2004
CCS necessary – but not sufficient
Key Issues for Geologic Carbon Sequestration

• Feasibility
  – GCS must be implemented at scale of existing oil & gas industry
  – Storage capacity estimates are not time-weighted
  – Two prerequisites for CCS industry
    • Price for carbon
    • Regulatory framework
Storing 1 Gt/y carbon is same magnitude as current global oil and gas business

- One wedge of CO₂ sequestration
  - Injection rate at deep aquifer conditions
    - 17 million m³/d
    - 100 MMBD
  - Transportation from sources to sinks
    - 190 BCFD

- Global upstream business, 2007
  - Oil consumption
    - 13 million m³/d
    - 85 MMBD
  - Gas production
    - 285 BCFD
  - Permian Basin CO₂ pipeline capacity for enhanced oil recovery
    - 4 BCFD
Key Issues for Geologic Carbon Sequestration

• Hurdles
  – Single biggest gap
    • Lack of human capital: subsurface engineers
  – Single biggest environmental risk
    • Avoid displacing brine into groundwater
  – Single biggest legal difficulty
    • Acquiring rights to vast volume of pore space
  – Single biggest political/economic risk
    • Getting public to pay
  – Single biggest technical risk
    • Low-cost assurance of secure storage
Demand for Subsurface Engineers by Oil & Gas (US) will Strain Education Capacity for Next 20 Years

Demographics of US oil & gas industry

OVER HALF OF THE WORKFORCE ELIGIBLE TO RETIRE IN NEXT 10 YEARS

Source: U.S. Dept of Labor

Global Oil and Gas Study
Subsurface Engineering Educational Capacity in the US is Already Full

U.S. Petroleum Engineering Enrollment

- PhD
- MS
- Senior
- Junior
- Sophomore
- Freshman

2.5 times growth in 4 years
GCS and Brine Displacement

- Conventional CO$_2$ storage
  - Displaces equal volume of brine
  - Pressure elevation extends farther than CO$_2$

- Unconventional CO$_2$ storage
  - Deep ocean sediment
  - Deep ocean basalt
  - Surface dissolution
    - Inject saturated brine
Natural gas storage industry as analogue to GCS industry

• Natural gas storage
  – 8 TCF (in US)
  – Typical project 75 BCF

• CO₂ storage
  – Cumulative (in US to 2050) ~100 Gt CO₂
    • Need pore space equivalent to 750 TCF natural gas
  – Typical project ~100 Mt CO₂
    • 700 BCF natural gas pore space equivalent
Curry et al., GHGT7, paper 137. Will citizens pay for solutions to GHG emissions?

Figure 4. Response to: If it solved global warming, would you be willing to pay ___ more per month on your electricity bill? Percentage of respondents who answered “yes” to each dollar amount is shown.
Substantive Carbon Storage Will Require Regulation Comparable to Oil & Gas, USDW
GCS and Leakage Risk

- Conventional CO\(_2\) storage
  - Density CO\(_2\) less than density of brine

- Unconventional CO\(_2\) storage
  - Deep ocean sediment
  - Deep ocean basalt
  - Surface dissolution
    - Inject saturated brine
    - No bulk phase CO\(_2\) in subsurface