On the Potential Large-Scale Commercial Deployment of Carbon Dioxide Capture and Storage Technologies:
Findings from Phase 2 of the Global Energy Technology Strategy Project

James J Dooley (dooleyj@battelle.org)
Joint Global Change Research Institute
Pacific Northwest National Laboratory
Battelle

PNWD-SA-7972

October 11, 2007
Carbon Management Problem Statement Summarized by Article 2 of the United Nations Framework Convention on Climate Change

- UNFCCC has nearly 200 member countries, including the United States, and establishes as its “ultimate objective”:
  - …the stabilization of greenhouse gas concentrations…
  - …at a level that would prevent dangerous…interference with the climate system…
  - …and to enable economic development to proceed in a sustainable manner.

Concentrations not Emissions

Don’t Know What is Dangerous

Economic Development Matters
Climate change is a long-term strategic problem with implications for today

• Stabilizing atmospheric concentrations of greenhouse gases and not their annual emissions levels should be the overarching strategic goal of climate policy.
  
  – We all share a planetary greenhouse gas emissions budget.
  
  – Every ton of emissions released to the atmosphere reduces the budget left for future generations.
  
  – As we move forward in time and this planetary emissions budget is drawn down, the remaining allowable emissions will become more valuable.
  
  – Emissions permit prices should steadily rise with time.
Stabilization of CO$_2$ concentrations means fundamental change to the global energy system.
The Challenge of Scale Grows with Time — the near term

**Annual Rates of Deep Geologic CO₂ Storage**

- **Monitored CO₂ Storage 2007**: 3 MtCO₂/year
- **2020 (550 ppm)**: 260 MtCO₂/year

**Future History**
- **Preindustrial**: 280 ppm
- **1900**: 300 ppm
- **1950**: 310 ppm
- **Today**: 380 ppm
- **2050**: 490 ppm
- **2100**: 550 ppm
The Challenge of Scale Grows with Time — the mid to long term

Annual Rates of Deep Geologic CO₂ Storage

- Monitored CO₂ Storage 2007
- 2020 (550 ppm) 2050 (550 ppm) 2095 (550 ppm)

MtCO₂/year

- Monitored CO₂ Storage 2007
- 2020 (550 ppm)
- 2050 (550 ppm) 2095 (550 ppm)

MtCO₂/year

- 3
- 260
- 2,100
- 22,000

Annual Rates of Deep Geologic CO₂ Storage

MtCO₂/year

- 2020 (550 ppm)
- 2050 (550 ppm) 2095 (550 ppm)
Stabilization of CO₂ concentrations means fundamental change to the global energy system...

- CO₂ capture and storage (CCS) plays a potentially large role assuming that the institutions make adequate provision for its use.

- Bioenergy crops have dramatic potential, but important land-use implications.

- Hydrogen could be a major new energy carrier, but requires important technology advances in fuel cells and storage.

- Nuclear energy could deploy extensively throughout the world but public acceptance, institutional constraints, waste, safety and proliferation issues remain.

- Wind & solar could accelerate their expansion particularly if energy storage improves.

- End-use energy technologies that improve efficiency and/or use energy carriers with low emissions can also play significant roles, e.g. continued electrification of the global economy.
The Macroeconomic Role of CCS Technologies in Addressing Climate Change

• When will CO\textsubscript{2} capture and storage deploy?
  – The potential deployment of CCS could be very large and the majority of CCS deployment and deep geologic CO\textsubscript{2} storage will occur in the second half of this century.
  – The large scale deployment of CCS will require the presence of a significant disincentive on the free venting of greenhouse gas emissions (e.g., >$25/tonCO\textsubscript{2}).
  – This is often misinterpreted as implying that CCS deployment – and perhaps significant deployment -- will not take place for many years to come.

• Where will CO\textsubscript{2} capture and storage technologies deploy?
  – Plenty of theoretical CO\textsubscript{2} storage capacity; however this natural resource is not evenly distributed around the world.
  – Knowing whether a country, region, or specific locale has suitable geologic CO\textsubscript{2} storage reservoirs provides a powerful insight into how that region’s energy infrastructure will evolve in a greenhouse gas constrained world.

• Who will use CO\textsubscript{2} capture and storage technologies?
  – The potential market for CCS technologies is and will remain very heterogeneous.
  – Baseload coal-fired power plants and potential coal-to-liquids facilities are the largest potential market for CCS technologies.
CO₂ Capture and Storage: Not Nearly this Simple
Overview of Carbon Dioxide Capture and Storage (CCS)

Geological Storage Options for CO₂:
1. Depleted oil and gas reservoirs
2. CO₂-driven enhanced oil recovery
3. Deep saline formations
4. Deep unmineable coal seams
5. CO₂-driven enhanced coal bed methane recovery
6. Deep saline filled basaltic formations and other formations

Produced oil or gas
 Injected CO₂
 Stored CO₂

Courtesy of CO2CRC
Global CO₂ Storage Capacity: Abundant, Valuable and Very Heterogeneous Natural Resource

• ~8100 Large CO₂ Point Sources

• 14.9 GtCO₂/year

• >60% of all global anthropogenic CO₂ emissions

• 11,000 GtCO₂ of potentially available storage capacity

• U.S., Canada and Australia likely have sufficient CO₂ storage capacity for this century

• Japan and Korea’s ability to continue using fossil fuels likely constrained by relatively small domestic storage reservoir capacity
Global CO₂ Storage Capacity:
**Abundant, Valuable and Very Heterogeneous Natural Resource**

- There appears to be sufficient global theoretical storage capacity to easily accommodate the demand for CO₂ storage for stabilization scenarios ranging from 450-750ppmv.

- However, geologic CO₂ storage reservoirs, like many other natural resources, are not homogenous in quality nor in their distribution:
  - Some regions will be able to use CCS for a very long time and likely with fairly constant and possibly declining costs.
  - In other regions, CCS appears to be more of a transition technology.
CCS Deployment Across the US Economy

Large CO₂ Storage Resource and Large Potential Demand for CO₂ Storage

3,900+ GtCO₂ Capacity within 230 Candidate Geologic CO₂ Storage Reservoirs
• 2,730 GtCO₂ in deep saline formations (DSF) with perhaps close to another 900 GtCO₂ in offshore DSFs
• 240 Gt CO₂ in on-shore saline filled basalt formations
• 35 GtCO₂ in depleted gas fields
• 30 GtCO₂ in deep unmineable coal seams with potential for enhanced coalbed methane (ECBM) recovery
• 12 GtCO₂ in depleted oil fields with potential for enhanced oil recovery (EOR)

1,715 Large Sources (100+ ktCO₂/yr) with Total Annual Emissions = 2.9 GtCO₂
• 1,053 electric power plants
• 259 natural gas processing facilities
• 126 petroleum refineries
• 44 iron & steel foundries
• 105 cement kilns
• 38 ethylene plants
• 30 hydrogen production
• 19 ammonia refineries
• 34 ethanol production plants
• 7 ethylene oxide plants
CCS Deployment Across the US Economy
Differentiated CCS Adoption Across Economic Sectors

The Net Cost of Employing CCS within the United States - Current Sources and Technology

(5) Large, coal-fired power plant / nearby (<25 miles) deep saline formation

(4) High purity hydrogen production facility / nearby (<25 miles) depleted gas field

(3) Large, coal-fired power plant / nearby (<10 miles) ECBM opportunity

(2) High purity natural gas processing facility / moderately distant (~50 miles) EOR opportunity

(1) High purity ammonia plant / nearby (<10 miles) EOR opportunity

(10) Gas-fired power plant / distant (>50 miles) deep saline formation

(9) Cement plant / distant (>50 miles) deep saline formation

(8) Smaller coal-fired power plant / nearby (<25 miles) deep saline basalt formation

(7) Iron & steel plant / nearby (<10 miles) deep saline formation

(6) Coal-fired power plant / moderately distant (<50 miles) depleted gas field

The graph shows the net cost of employing CCS within the United States, with different sources and technology costs. The x-axis represents CO2 captured and stored (MtCO2), and the y-axis shows the net CCS cost ($/tCO2). The bars in the inset graph illustrate the cost pairs for different applications.
It is important to realize that we are in the earliest stages of the deployment of CCS technologies.

- The potential deployment of CCS technologies could be truly massive. The potential deployment of CCS in the US could entail:
  - 1,000s of power plants and industrial facilities capturing CO$_2$, 24-7-365.
  - 1,000s of miles of dedicated CO$_2$ pipelines.
  - 100s of millions of tons of CO$_2$ being injected into the subsurface annually.

- The deployment across the rest of the world could be at least another order of magnitude.
Geologic CO₂ Storage: Selected Basic Engineering and Operational Issues

• The cost of capturing CO₂ is not the single biggest obstacle standing in the way of CCS deployment.

• No one has ever attempted to determine what it means to store 100% of a large power plant’s emissions for 50+ years.
  – How many injector wells will be needed? How close can they be to each other?
  – Can the same injector wells be used for 50+ years?
  – Are the operational characteristics that make a field a good candidate CO₂-driven enhanced oil recovery similar to the demands placed upon deep geologic formation that is being used to isolate large quantities of CO₂ from the atmosphere for the long term?
  – What measurement, monitoring and verification (MMV) “technology suites” should be used and does the suite vary across different classes of geologic reservoirs and/or with time?
  – How long should post injection monitoring last?
  – What are realistic, field deployable remediation options if leakage from the target storage formation is detected?
  – Who will regulate CO₂ storage on a day-to-day basis? What criteria and metrics will this regulator use?
Seven regional partnerships have been organized by DOE across the U.S. to address sequestration.
The MRCSP’s 8-state Midwest Region is a major part of the US Economy and a major user of coal.

Nearly 25% of the Nation’s:

- Citizens
- Economic Activity
- Manufacturing
- Electrical Generation Capacity
- CO₂ Emissions
The MRCSP’s mission is to be the premier resource for sequestration knowledge in its region

Defining Regional Characteristics
- 1/6 of the U.S. Economy
- 300 Large Point Sources, 800 Million tonnes CO₂/year

Developing a Regional Model of the Economics of Sequestration

Quantifying CO₂ Sinks in the Region
- Terrestrial: Potential for 20% annual offset for large point sources
- Geologic: 100s of years of capacity for large point sources in deep saline alone

Phase I, Oct 2003 – Sep 2005
- Defining Regional Characteristics

Phase II, Oct 2005 – Sep 2009
- Developing a Regional Model of the Economics of Sequestration

Reaching Out To and Educating Stakeholders

www.mrcsp.org

Implementation
- Phase I: Oct 2003 – Sep 2005
- Phase II: Oct 2005 – Sep 2009
- Other projects:
  - Geological
  - Terrestrial
The MRCSP serves a large part of the Midwest

U.S. Department of Energy/NETL
The Scope of the Scale-up Challenge

World CCS Projects
Projected Lifetime CO₂ Storage

- 0-10 MtCO₂
- 10-20 MtCO₂
- 20-30 MtCO₂
- 250 Million tons CO₂ (approximate amount CO₂ storage needs of one 1000MW IGCC operating for 50 years)

Stabilizing at 550 ppmv
Cumulative Global Carbon Stored Between 2005 and 2050:
33,000 MtCO₂

Stabilizing at 550 ppmv
Cumulative U.S. Carbon Stored Between 2005 and 2050:
8,000 MtCO₂

1: Big Sky Partnership*
2: CO₂SINK  13: Salt Creek / NPR-3
3: Frio
14: Sleipner
4: Gorgon   15: Snohvit
5: Illinois Basin Partnership* 16: Southeast Partnership*
6: In Salah
17: Southwest Partnership*
7: K12B
18: Surat
8: Midwest Partnership* 19: West Coast Partnership*
9: Minama-Nagaoka
20: Weyburn
10: Otway
21: Yubari
11: Plains Partnership*
GTSP Phase II Capstone Report on Carbon Dioxide Capture and Storage

- CCS technologies have tremendous potential value for society.

- CCS is, at its core, a climate-change mitigation technology and therefore the large-scale deployment of CCS is contingent upon the timing and nature of future GHG emission control policies.

- The next 5-10 years constitute a critical window in which to amass needed real-world operational experience with CCS systems.

- The electric power sector is the largest potential market for CCS technologies and its potential use of CCS has its own characteristics that need to be better understood.

- Much work needs to be done to ensure that the potential large and rapid scale-up in CCS deployment will be safe and successful.