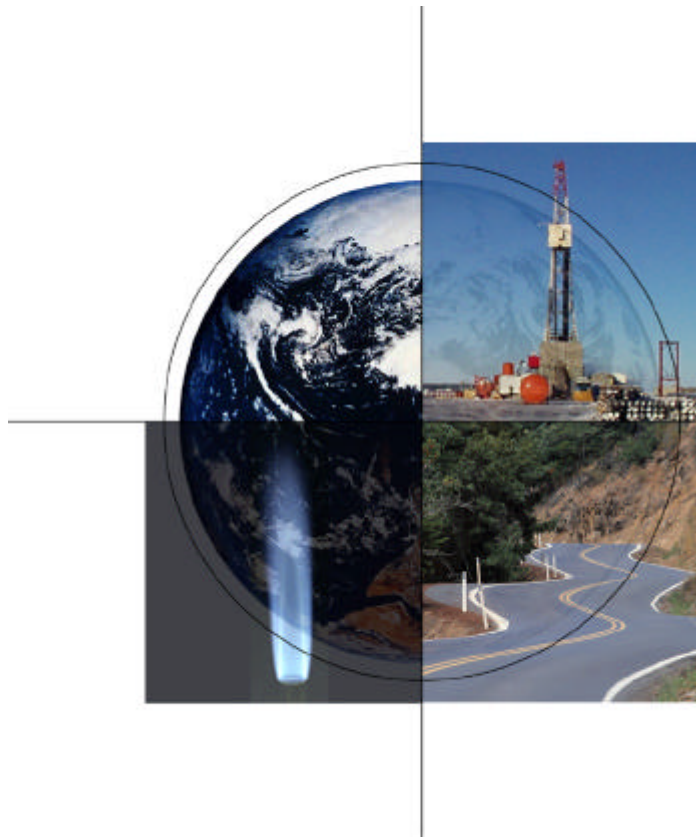


Sequestration of Carbon Dioxide in Geologic Formations



*Where We've Been -
Where We're Going*

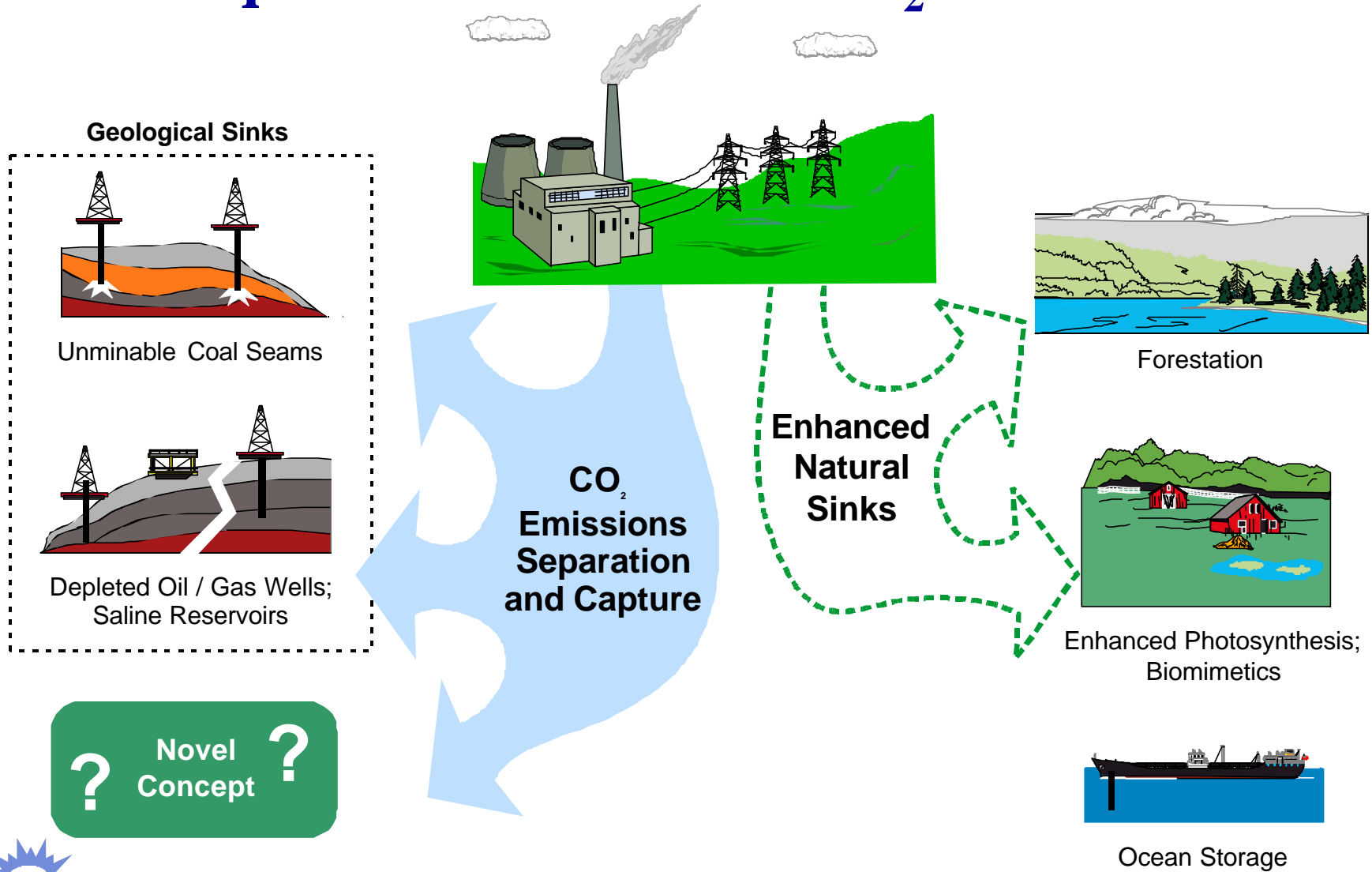
COAL - SEQ 1 Forum

*Houston, Texas
March 14, 2002*

Charles W. Byrer
National Energy Technology Laboratory



Sequestration Sinks for CO₂ Emissions



Range of Estimates for CO₂ Sequestration in U.S. Geologic Formations

Geologic Formation	Capacity Estimate (GtC)	Source
Deep saline reservoirs	1-130	Bergman and Winter 1995
Natural gas reservoirs in the United States	25 ^a 10 ^b	R.C. Burruss 1977
Active gas fields in the United States	0.3 / year ^c	Baes et al. 1980
Enhanced coal-bed methane production in the United States	10	Stevens, Kuuskraa, and Spector 1998

a. Assuming all gas capacity in the United States is used for sequestration

b. Assuming cumulative production of natural gas is replaced by CO₂

c. Assuming that produced natural gas is replaced by CO₂ at the original reservoir pressure



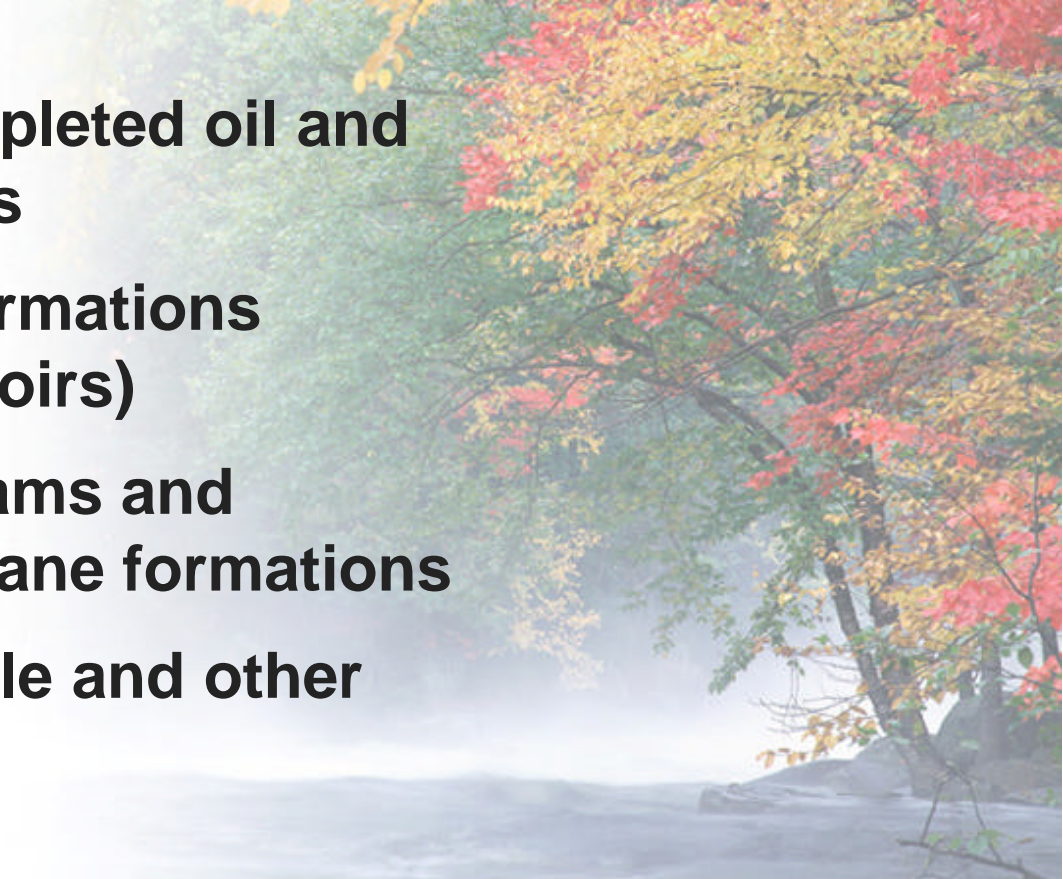
CO₂ Sequestration in Geologic Formations

- Related industrial experience
- Potential capacity ?
- Beneficial use of CO₂
- Natural analogues for sequestration
- Safety and cost analysis
- Performance assessment and prediction
- Monitoring



Sequestration in Geologic Formations Builds on a Strong Industry Experience Base

- Active and depleted oil and gas reservoirs
- Deep brine formations (saline reservoirs)
- Deep coal seams and coalbed methane formations
- Devonian shale and other formations



What the Gas Industry Knows Now

- **Dynamic flow properties of oil, gas, and coal formations**
- **Storage capacity of oil and gas formations**
- **Monitoring technologies for pressure, volume, water saturation**
- **Fairly complete geologic characterization of formations**



Drivers for Geologic Sequestration R&D

- **Monitoring-** developing reliable and cost effective systems for monitoring / tracking CO₂ in subsurface
- **Stability-** assessing and ensuring long term stability of sequestered CO₂ (>100 years)
- **Cost** reducing the cost and energy requirements of CO₂ sequestration in geologic formations
- **Public perception-** gaining public acceptance for geologic sequestration of CO₂



Ongoing Natural Gas Storage and Natural CO₂ Analogs in Geologic Formations

- Provides experience and demonstrates the feasibility of the geologic trapping mechanisms for use in sequestering CO₂ emissions
- Reservoir *Examples:*
 - *Mt. Simon Sandstone reservoir*
 - *Natural CO₂ reservoirs in the western and gulf coast regions of U.S.*



CO₂ Sequestration in Geological Formations Can Have Auxiliary Benefits

- **Injection of CO₂ into oil reservoirs can recover residual oil by two primary mechanisms:**
 - CO₂ displaces oil and brine
 - CO₂ dissolves in oil and reduces viscosity and swelling of oil
- **Injection of CO₂ into coalbeds could enhance coalbed methane (CBM) production:**
 - Pilot program of CO₂-assisted CBM in San Juan Basin has been underway since 1996:
 - Injects 4 million cubic feet / day of CO₂ in nine injection wells
 - Preliminary results: CBM recovery could be boosted to 75-90%
 - Over 2.5 Bcf of CO₂ injected - CO₂ breakthrough very slight



Prior DOE - NETL R&D Efforts Related To CO₂ Injection Into Geologic Formations

- 1960-70s - EOR and EGR in Appalachian Basins
- 1970s - CO₂ Laboratory R&D for ECBM Recovery
- 1990s - CO₂ R&D in saline reservoirs (Battelle)
- 1995 - Renewed interest in sweeping effects of CO₂ for ECBM
- 1996 - Visited AMOCO, CONOCO, Burlington, and others to ascertain knowledge base of CO₂-ECBM Field Efforts
- 1996 - Became a partner in ARC pilot CO₂-ECBM Project
- 1996 - Began discussions with STATOil on Sleipner CO₂ project
- 1996 - Became active in IEA GHG Programme
- 1997 - Site Visit to ECBM Project in San Juan Basin
- 1997 - Awarded contract to Oklahoma State - Penn State for CO₂-N₂-CH₄ affinity studies on targeted coal samples



DOE - NETL R&D Efforts for CO₂ Injection into Geologic Formations (Cont'd)

- **1998 - Awarded six Phase I Novel Concepts contracts for CO₂ R&D**
- **1998 - Down-selected to five Phase II Novel Concepts (BEG, Battelle, TDA, McDermott, and RTI).**
- **1999 - Issued a “Lab Call” for geologic sequestration of CO₂**
- **1999 - Awarded National Lab R&D funding for geological CO₂ sequestration (LBL, LLNL, ORNL, SNL, LANL)**
- **2000 - Awarded funding for industry / academia projects (ARI-BP, Texas Tech, Geol. Survey of Alabama, and MID-CARB)**
- **2001 - Awarded CBM-CO₂ field pilot project (CONSOL)**
- **2002 - Selected two Phase III Novel Concepts (UT-BEG and Battelle Laboratories) for pilot field demonstrations**



Geologic Sequestration

Coordination of Efforts with a Strategy

- DOE facilitated a 9 month roadmapping exercise focused on Carbon Sequestration R&D
- Collaborating on ongoing R & D strategy and priority efforts with stakeholders (industry, government agencies, academia, and environmental organizations (NGOs))
- DOE NETL is the lead National Laboratory for geologic CO₂ sequestration



Geological Sequestration

FY 2002 Participants and Activities

- **Oklahoma State - Penn State** – Adsorption assessments of CO₂, N₂, and CH₄ on targeted coal samples
- **Univ. Texas -Bureau of Economic Geology** – Coal characterization of coal samples
- **Battelle Columbus** – Assessment of characteristics of saline reservoirs in U.S.
- **Lawrence Berkeley National Lab** – **Geochemical Assessment of Mt. Simon Reservoir: Lab, modeling & economic effort**
 - Lawrence Livermore N.L.
 - Oak Ridge N.L.
 - ARC, academia partners
 - Industry partners
- **ORNL -** – Measuring kinetics, equilibrium densities, and sorption relations for CO₂ -CH modeling validation



Geological Sequestration:

FY 2002 Participants and Activities (Cont'd)

- Texas Tech – CO₂ injectivity and capacity studies / modeling
- Ala. Geological Survey – Geologic screening for coalbeds in Alabama
- ARI – Natural CO₂ Analogs for Geologic CO₂ Sequestration
- Sandia National Lab – Field demo for EOR-CO₂ monitoring/storage; Los Alamos and Industry partner
- ARI / BP – Field Demonstration: Enhanced coalbed methane recovery - CO₂ sequestration
- CONSOL – CO₂-CBM field demo associated with mining operations
- Battelle - AEP – Pilot field demonstration in Mt. Simon saline reservoir
- UT - BEG – Pilot field demonstration of CO₂ into Frio Formation



CO₂ Sequestration in Geologic Formations: R&D Priorities

2000-2005

Understand Geochemical Reactions on Reservoir and Caprock Integrity

Characterize Target Reservoir Spatial Properties Variations

Improve Horizontal Well Models for CO₂ Injection

Assess / Develop Abandoned Well Detection Methodologies

Establishing Site Screening Criteria

Match CO₂ Generators to Sequestration Sites

2005-2010

Assess Seismic CO₂ Invasion Monitoring Methods

Develop Sequestration Efficiency & Safety Simulators

Conduct Small-Scale Reservoir Field Pilot Test

Develop Verification / Monitoring Capabilities for Reservoir Applications

2010-2015

Obtain Full-Scale Demo Cost & Performance Data

Develop Low-Permeability & Deep Formation Injection Technologies

Increase Injection Efficiency From 10-20% (Pore Volume) to > 50%



CO₂ Sequestration in R&D Priorities

2000-2005

Understand Adsorption/
Desorption Processes

Assess Porosity/
Permeability & Expansion/
Contraction Effects

Increased Gas Production
Pilot Test

Develop Reservoir
Screening Criteria

Develop Injection
Engineering & Design
Techniques

Understand Seismic Wave
Propagation Responses

2005-2010

Develop Modeling Tools

Assess Flue Gas-Coal
Interactions

Flue Gas Injection
Pilot Tests

Test Drilling Technologies
versus
Injection/Production Dynamics

Develop Methods for
Monitoring CO₂ Migration

Understand
Microorganism-CO₂-Matrix
Interactions

2010-2015

Obtain Full-Scale Demo
Cost & Performance Data

Develop Low-Permeability
& Deep Formation
Injection Technologies

Evaluate Water-Saturated
versus
Dewatered CO₂ Injections

Test/Monitor Long-Term
CO₂ Sequestration on
Various Coal Seams



Coal Formations Near-term R&D (*<2005*)

- **Understand adsorption / desorption process**
- **Assess expansion / contraction effects of methane exchange by CO₂**
- **Conduct pilot tests on displacement of methane by CO₂ in coal beds**
- **Develop screening criteria for sequestration sites**
- **Develop engineering design techniques for sequestration and production in coal**



Coal Formations Mid-term R&D

(2005 – 2010)

- **Develop modeling tools for gas flow dynamics**
- **Assess flue gas interactions with coal**
- **Conduct a flue gas coal injection pilot test**
- **T & E dynamics of horizontal & vertical injection wells**
- **Develop methods to monitor CO₂ migration**
- **Understand effects of microorganisms on long term sequestration**



Coal Formations Long-term R&D *(2010 – 2015)*

- **Obtain cost and performance data from full scale demo**
- **Develop technologies for low permeability coals**
- **Determine necessity of dewatering before sequestration**
- **T & E sequestration time for coals**



Summary

- **Storage / disposal of fluids in deep formations is a widely accepted industry practice**
- **There is enormous potential capacity on a regional basis for CO₂ storage in coal deposits**
- **The key issues are local capacity, long term fate, engineering, cost, safety, public acceptance, and industry's level of interest in concept**
- **These issues are presently being explored using computer simulations and laboratory experiments
- then validate with pilot scale demonstrations**

