PENNSTATE

IN-SITU STUDY OF CARBON DIOXIDE SEQUESTRATION IN SALINE BRINE FORMATIONS

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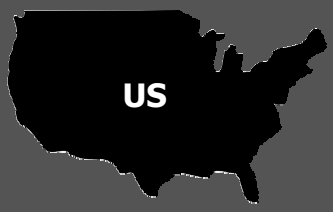
CO_2 Emissions from Fossil Fuels in 2001

(Giga Tons Carbon Equivalent)



6.568

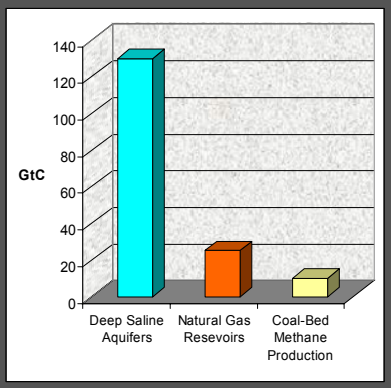
1.565

24% of the World's total CO2 fossil fuel emissions

Source: eia.doe.gov

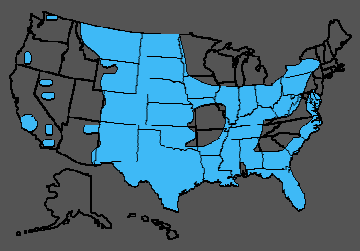
Geologic Sequestration Options

- Saline Aquifers - hydrodynamic trapping
  - Also solubility trapping & mineral trapping
- Hydrocarbon Reservoirs - geologic trapping
  - Effective confining layer already determined
- Coal Beds – absorption



Source: Carbon Sequestration Research and Development

Deep Saline Aquifers in the US



Source: US Geological Survey

- Depths greater than ~600 m
- Close to nearly all major CO_2 generators
- Greatest capacity of the geologic sequestration options (~130 GtC)
- Most technically challenging

Site Selection & Criteria

Soft Criteria – Change on a human timescale

- Economic
- Political
- Societal
- Identify point sources of CO_2
  - Output
  - Purity
  - Proximity

Hard Criteria – Change on a geologic timescale

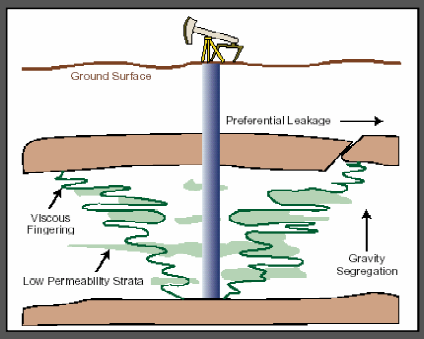
- Geology: Identify confining formations
- Hydrodynamics: Identify flow systems suitable for hydrodynamic trapping
- Geothermal and hydrostatic gradients

Injection Well Requirements

- Underground Injection Control (UIC) Program – Safe Water Drinking Act of 1974
- Class I Injection – municipal or industrial waste (including hazardous) below the deepest USDW
- Monitoring requirements:
  - Monitoring wells only required after an identified potential leak
  - Continuous monitoring of injection pressure and flow rate
  - Additional tests at one and five year intervals

CO_2 Properties affect Migration

- Density difference from that of brine leads to a buoyancy force.
- Low viscosity leads to viscous fingering.
- Dissolved CO_2 may dissolve minerals leading to a increase in permeability and porosity.



Source: Carbon Sequestration Research and Development

Storage Mechanisms

- Dissolved state in pore water
  - 1M salinity: 41-48 kg CO_2/m^3
  - 4M salinity: 24-29 kg CO_2/m^3
- Residual gas trapped by capillary forces
- Dense supercritical state
- Permanent state in a carbonate mineral

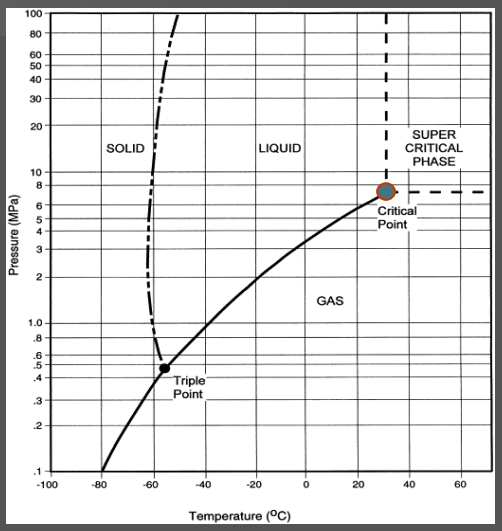
Source: Ennis-King, 2000

CO_2 Phase Diagram

Critical Point:

T = 31.1 °C

P = 7.38 MPa
(1070 psi)



Source: Bachu, 2000

The Major Challenge…

is discovering ways to optimize hydrodynamic trapping, while increasing the rate of carbonate formation.

Favoring Conditions			
	Temperature	Pressure	pH
Dense Supercritical State To maximize mass transfer and storage	Low	High	N/A
Carbonate Precipitation To immobilize and permanently store CO_2	High	High	High

Chemical Reactions

$CO_{2(g)} \leftrightarrow CO_{2(aq)}$	*CO_2 dissolves in water*
$CO_{2(aq)} + H_20 \leftrightarrow H_2CO_3$	*Carbonic acid is formed (low pH, <5)*
$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$	*Bicarbonate is formed (mid pH, ~7)*
$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$	*Carbonate is formed (high pH, >9)*

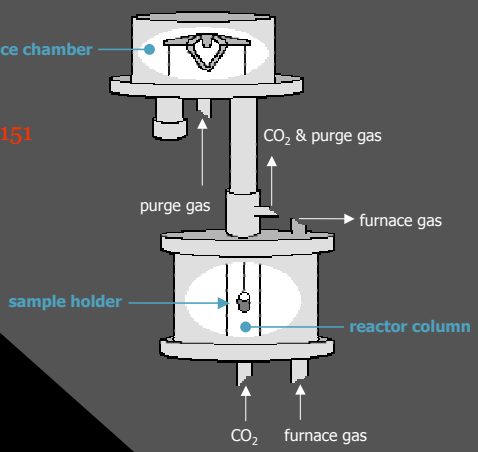
$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3$	→ *Calcite*
$Mg^{2+} + CO_3^{2-} \leftrightarrow MgCO_3$	→ *Magnesite*
$Ca^{2+} + Mg^{2+} + 2CO_3^{2-} \leftrightarrow CaMg(CO_3)_2$	→ *Dolomite*
$Fe^{2+} + CO_3^{2-} \leftrightarrow FeCO_3$	→ Siderite

Source: Soong, 2002

High Pressure Thermo-Gravimetric Analyzer

CAHN TGA-151

The Energy Institute



HP-TGA Specifications

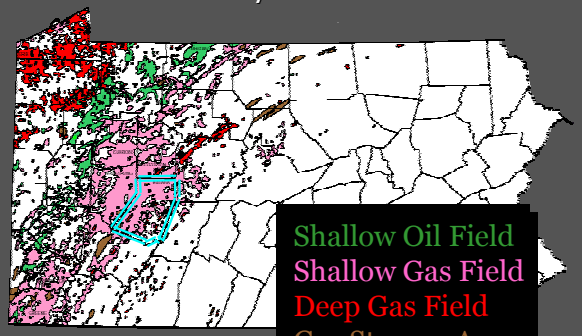
- Maximum pressure:
  - 1500 psi @ 25°C
  - 1000 psi @ 1000°C
- Temperature range:
  - 1100°C at ambient pressure
  - 1000°C at 1000 psi
- 1/8" Chromel-Alumel thermocouple
- Internal volume = 0.3 liters
- Maximum weight: 10g
  - Sensitivity: 1µg
  - Sensitivity decreases with high pressures

Research Objectives

- Explore the solution kinetics of reactions of CO_2 and field brine
  - Pressure range: 200 – 1200 psi
  - Temperature range: 25 – 200 °C
  - pH range: 3 – 11
- To verify the efficiency and accuracy of thermo-gravimetric analysis
- Scale-up experimentation to a 500 ml CSTR to corroborate optimum conditions

Experimental Field Brine

- Indiana County Gas Well
- Depth: 2,800 m
- Oriskany sandstone



Source: dcnr.state.pa.us

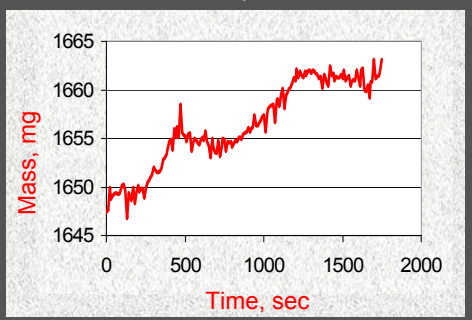
Metal	mg/l
Al	6.84
Ba	789
Ca	**23,600**
Fe	**223**
K	1,170
Mg	**1,440**
Mn	5.26
Na	44,900
P	< 2
S	13.1
Si	< 10
Sr	8,910

Metals of greatest concern for carbonate formation

HP-TGA Data

Conditions represent those attainable at a depth of approximately 500 m, typical of a shallow gas well.

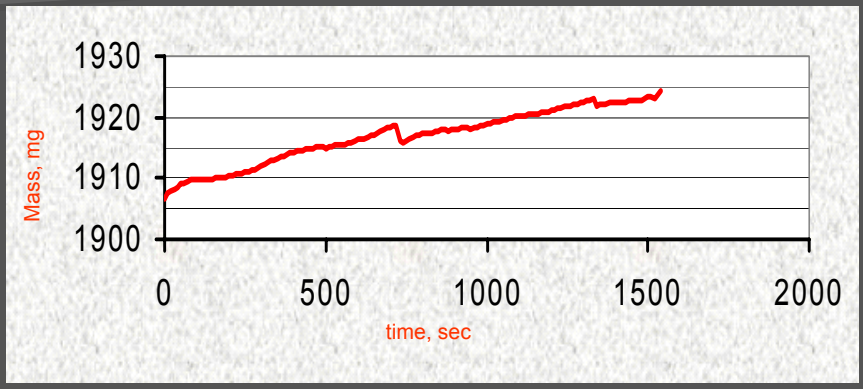
Conditions: 600 psi, 35°C, 30 min



Carbonate formation accounts for a 1.0% increase by weight

HP-TGA Data

Conditions: 300 psi, 55°C, 25 min



Carbonate formation accounts for a 0.9% increase by weight

HP-TGA Data

Weight Uptake of the Brine

Uptake observed through direct measurement		Uptake observed through HP-TGA measurement	
Overall increase wt%	Increase to solids wt%	Overall Increase wt%	Increase to solids wt%
1.1	6.5	0.9	5.3

Conclusions

- The large estimated storage capacity for CO_2 in geologic formations, namely deep brine formations, warrants an investigation into the kinetics of the carbonate forming reactions.
- The uptake of CO_2 into a Pennsylvanian gas well brine can be monitored using high pressure thermo-gravimetric analysis.
- A process for determining a better understanding of the kinetics of formation of mineral carbonates through the sequestration of CO_2 exists through the use of high-pressure thermo-gravimetric analysis.

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