What To Do With CO$_2$

CCTR Basic Facts File # 10

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Global Carbon Cycle

Total amount of CO$_2$ stored in the atmosphere is 750 Billion Tons

Storage & annual exchange of CO$_2$ in Billions Tons

Burning fossil fuels adds about 5.5 Billion Tons of CO$_2$/year into the atmosphere.

Oceans absorb about 2 Billion Tons & forests about 0.5 etc

Options for CO$_2$ Control

- CAPTURE & STORAGE
- CAPTURE & TRADE
- CAPTURE & REUSE

Various approaches are possible for each of the above but in all instances we need to first of all capture CO$_2$. The economics of capture and what to do with it are huge issues that are to be assessed in the early part of the 21$^{st}$ century.
On retrofitting of existing coal-fired power plants the capture costs per Ton of CO₂ are expected to slightly decrease as the percentage capture rate is increased.

- **90% capture** = $80/Ton CO₂
- **30% capture** = >$100/Ton CO₂
CO₂ Storage Site Selection

“Data will be required to demonstrate the injectivity, capacity, and effectiveness (ICE) of a given site. A firm characterization of ICE is needed to address questions regarding project life cycle, ability to certify and later close a site, site leakage risks, and economic and liability concerns.”

“Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005
CO₂ Storage Improves with Time

CO₂ becomes less mobile over time as a result of multiple trapping mechanisms, further lowering the prospect of leakage.

Storage security depends on a combination of physical & geochemical trapping. Over time, the physical process of residual CO₂ trapping & geochemical processes of solubility trapping & mineral trapping increase.

Sources: “Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005
CO₂ Storage Economics

Underground storage costs are very site specific

Capital Costs include: (1) Research for identifying suitable sites, (2) Drilling, (3) Oil and gas recovery may need additional facilities

Operating Costs include: (1) Labor, (2) Fuel for pumping CO₂ (3) Maintenance of the equipment

<table>
<thead>
<tr>
<th>Field Parameter</th>
<th>Net cost</th>
<th>Rate of CO₂ injection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeability</td>
<td></td>
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<tr>
<td>Reservoir thickness</td>
<td></td>
<td></td>
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<tr>
<td>Effective Radius</td>
<td></td>
<td></td>
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<tr>
<td>Availability of Oil and gas</td>
<td></td>
<td></td>
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<tr>
<td>Oil and gas prices (if oil or gas recovered from the site)</td>
<td></td>
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</tbody>
</table>

↑ Increases with an increase in the field Parameter

↓ Decreases with a increase in the field parameter
Location of some U.S. Natural Gas Storage Sites

Underground natural gas storage projects offer experience relevant to CO$_2$ storage (operated successfully for almost 100 years). These projects provide for peak loads & balance seasonal supply & demand fluctuations. Majority of gas storage projects are in depleted oil & gas reservoirs & saline formations.

Factors critical to the success of site: permeability, thickness, extent of storage reservoir, tightness of cap rock, geological structure, lithology.

Sources: “Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005
CO₂ Biological Surface Storage

Plants convert CO₂ in the atmosphere to carbon. Trees store carbon in above ground mass, litter, roots & soil.

Over time forests reach a dynamic equilibrium where the amount of CO₂ converted into carbon is equal to the amount of carbon converted back into CO₂.

Reducing the amount of tillage increases the soil organic content of the soil.

Conservative tillage results in an increase of equilibrium carbon storage in the soil. With careful selection of crops & tillage practices, the net equilibrium carbon content of a cropland can be increased.

CO$_2$ Forest Storage Costs

There are a diverse set of factors that affect the cost of forest carbon sequestration & so a broad range of estimates:

To sequester 300 MTons/year
$25-75 per short ton of carbon

To sequester 500 MTons/year
$30 - $90 per short ton of carbon


Indiana Center for Coal Technology Research
## Capture & Sequestration Economics

Carbon Capture & Sequestration, CCS  
Cost of Electricity, COE

### Percentage increases in COE with CCS:

<table>
<thead>
<tr>
<th></th>
<th>Pulverized Coal Power Plant</th>
<th>IGCC Power Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without CCS</strong></td>
<td>44-90%</td>
<td>24-52%</td>
</tr>
<tr>
<td><strong>With CCS</strong></td>
<td>62-99</td>
<td>51-93</td>
</tr>
</tbody>
</table>

### Cost of Electricity  
2005 Estimates  
US$/MWh

<table>
<thead>
<tr>
<th></th>
<th>Pulverized Coal Power Plant</th>
<th>Integrated Coal Gasification Combined Cycle Power Plant, IGCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Without CCS</strong></td>
<td>43-52</td>
<td>41-61</td>
</tr>
<tr>
<td><strong>With CCS</strong></td>
<td>62-99</td>
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</table>

Source: “Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

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Emissions Trading

**REGULATORY AUTHORITY**
- Sets the cap
- Issues allowances
- Monitors and enforces allowances

**EXCHANGE**
- Entity with emissions less than the allowance
- Facilitates trading of allowances, Price discovery
- Entity with emissions beyond the allowance

**CAPTURE & TRADE**
Emissions Trading

- Trading is seen by its proponents as a better alternative to “command-and-control” mechanism where regulatory body sets the limit and enforces it.

- Conventional trading approach is used to discover the market price of emissions for a given cap.

- Emissions trading approach recognizes that different polluters incur different cost of pollution abatement – if enforced properly, the one with the lowest cost of abatement ends up polluting the least.
Comparison of Strategies

Command-and-control

- No Option
  - Invest in new abatement technology

Emissions trading

- Option 1
  - Invest in new abatement technology
- Option 2
  - Buy Credits from other polluter

Depending on the relative costs, the firm is expected to choose the least-cost option.
Emissions Trading in the U.S.

- **Chicago Climate Exchange (CCX established 2000)**, first in North America to facilitate GHG trading
- **Voluntary participation**, commitments legally binding
- **Verification provided** through Financial Industry Regulatory Authority (formerly National Association of Securities Dealers, NASD)
- Commitments are standardized, **one Carbon Financial Instrument (CFM) represents 100 metric tons of CO₂**
- In 2006, nearly 10.3 Million tons of CO₂ was traded. Small amount compared with EU 1 Billion tons

SO₂ Emissions Trading

**Acid Rain Program** is a market-based initiative taken by the US EPA (Environmental Protection Agency) in an effort to reduce overall atmospheric levels of SOx and NOx, which cause acid rain.

**Title IV of the 1990 Clean Air Act** established the **allowance market system** we know today as the Acid Rain Program. Initially targeting only sulfur dioxide, Title IV set a decreasing cap on total SO₂ emissions for each of the following several years, aiming **to reduce overall emissions to 50% of 1980 levels.**

*The program did not begin immediately, but was implemented in two stages: Phase I beginning January 1, 1995, and Phase II starting January 1, 2000.*

http://www.environmentaldefense.org/page.cfm?tagID=1085
U.S. Cap & Trade

Cap & trade argues that **property rights are more effective than employing a tax.** One allowance (emission permit) gives the right to emit one unit of pollution/year.

First started in the US in the 1950s in the context of **fisheries management** to prevent overuse & collapse. Only quota holders could legally harvest fish – quotas were transferable in practice (**ITQs, Individual Transferable Quotas**) going to those who value them most.

Many environmentalists recognize a level of success in the 1990 **SO\(_2\)** program who originally were opposed to “**buying & selling the right to pollute**”
With Cap & Trade the emissions **level is established** & the **market determines the emissions price**. With a carbon tax the **tax is the emissions price** & the **market determines the emissions level** (so offers relative cost certainty)

Cap & Trade relied on giving emissions allowances away **for free** as in Acid Rain Program & more recently with the EU Emissions Trading system (ETS). Government foregoes potential revenues & so **there is increased talk about selling allowances through auctions** becoming more similar to the carbon tax approach

“A Primer on Market-Based Approaches to CO2 Emissions Reductions”, L.Raymond, G. Shively, Purdue Climate Change Research Center
CO₂ Kyoto Reduction Options

Creation of emission trading systems to provide incentives to firms & increase their efficiency or switch to lower GHG production processes

Purchase emission credits from investing in GHG reduction projects abroad

- Clean Development Mechanism (CDM): investing in emission reduction projects in non-Annex-I countries earn Certified Emission Reductions (CERs)

- Joint Implementation: investing in emission reduction projects in Annex-I countries generates Emission Reduction Units (ERUs)

- Each Annex-I country receives Assigned Amount Units (AAUs) & trading of these is allowed
EU CO$_2$ Trading Example

NORWAY (Annex I country)

A Norwegian firm earns CERs by investing on a GHG reducing project in China

CHINA (Non Annex I)

GERMANY (Annex I country)

The country Norway obtains AAUs from Germany

A Norwegian firm earns ERUs by investing on a GHG reducing project in Australia

AUSTRALIA (Annex I country)
CO₂ European Union Emission Trading Scheme, ETS

- The first phase, 2005-2007, of the European Union Emission Trading Scheme, ETS, was launched on January 1st, 2005
- The 25 member states have issued allowances to emitters located in their countries. The cap for each member state is defined in their National Allocation Plan
- The total cap was set at 6,600 MTons of CO₂ for 2005-07 with Germany accounting for a quarter of the allowances
- During 2005, 322 MTons of CO₂ was traded under ETS
- It has been criticized that the cap was too generous & that the initial allowances have been issued freely by the government instead of auctioning them

CO$_2$ Trading Lessons for the U.S.

- Credible regulatory authority is essential
- Centralized authority to set a cap at the national level
- Frequent appraisals on actual emissions to avoid extreme price fluctuations (as it was in Europe)
- Banking of contracts should be allowed to ensure continuity (EU-ETS, Phase II has this provision)
- Longer time horizon may provide greater incentive to invest in capital intensive long-term technologies
Midwest Geological Sequestration Consortium (MGSC)

New Albany Shale
Injection of CO₂ into the organic shale may result in CO₂ absorption & possibly the enhanced production of CH₄, (Shale Gas) just as in coal beds (Coal Bed Methane, CBM)

Source: “Carbon Sequestration of the United States and Canada”, NETL, DOE
Enhanced Coal Bed Methane

One ton of Coal may contain up to 25 m$^3$ of methane. CO$_2$ has higher affinity to coal than methane. This property is exploited to extract methane from coal seams by injecting CO$_2$.

Source: IPCC, 2005: Special Report on Carbon Dioxide Capture and Storage, Special Report of the Intergovernmental Panel on Climate Change [Metz, Bert, Davidson, Ogunlade, de Coninck, Heleen, Loos, Manuela, and Meyer, Leo (Eds.).]
Enhanced Coal Bed Methane Economics

**Methane Recovery:** It is estimated that 1.5-10.0 m³ of CO₂ is needed to extract 1 m³ of methane

**Cost:** The profitability depends on the price of gas

According to Schreurs, 2002, capital costs are:
- Production well: US$ 750,000 per well
- In seam drilling: US$ 1,500 per meter
- Injection well: US$ 430,000 per well


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CO₂ for Extracting Shale Gas

There are enormous amounts of shale gas in Indiana. How economically can CO₂ be used to extract shale gas?

Source: Baseline Oil & Gas, Inc.
**CO₂ Capture & Sequestration (CCS) & then used in Oil & Gas Reservoirs**

**Injecting CO₂** into a mature oil reservoir can enable incremental oil to be recovered. Typical oil recovery produces 30-40% of original oil in place (OOIP). 5-40% is usually recovered by conventional primary production & an additional 10-20% of OOIP is produced by secondary recovery that uses water flooding.

**A CO₂ flood allows recovery of an additional 10-15% of the OOIP. A price of $25 per ton of CO₂ is significant as this approaches levels that makes CCS economical**

Sources: “Carbon Sequestration” Atlas of the United States and Canada”, NETL, DOE
“Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005
CO$_2$ Sequestration & EOR

Small amounts of CO$_2$ dissolve in the oil, increasing the bulk volume & decreasing the viscosity, so facilitating flow

Average of 13% of the original oil in place, OOIP, is produced from **Enriched Oil Recovery, EOR**

Sources: “Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005
Possible Configuration of the Purdue Proposed Hydrogen Carbon H2CAR Process

Long-term potential process to recycle CO₂ emissions

Indiana’s Average CO$_2$ & Power Production from 1 Ton of Coal

- 1 Ton of Coal produces 2.26 Tons CO$_2$
- 1 Ton of Coal produces 2.25 MWh Electricity
- 1MWh of power $\approx$ 1 Ton of CO$_2$ produced

Source: CCTR Basic Facts File # 4
Indiana’s CO₂ Storage

“The majority of estimates support the contention that sufficient capacity exists to store many 100’s to many 1000’s of GTons CO₂, but this range is too large to inform sensible policy.” (MIT study)

Indiana produces nearly 0.32 Billion tons of CO₂ annually of which 0.15 BTons (47%) come from utilities. The U.S. produces about 6.0 Billion Tons of CO₂ annually of which 2.5 BTons (42%) comes from utilities

Initial estimates from the Indiana Geological Survey indicate that there are 38.0 BTons of CO₂ storage capacity under Indiana’s Mt Simon Sandstone & 7.8 BTons under the New Albany Shale

Summary

The future use or storage of CO$_2$ from coal-fired power plants will have a **major impact on the economy**

The Midwest Regional Carbon Sequestration Partnership, MRCSP is the **most comprehensive regional U.S. Midwest CO$_2$ study taking place**

Extensive debates on carbon capture and what to do with the captured carbon will be taking place during the next few years

This topic has **major impact on Indiana’s cost of electricity** with over 95% of the state’s power supply coming from coal

Source: “Carbon Sequestration of the United States and Canada”, NETL, DOE