Climate Change, Carbon Sequestration and the Future of Your Business

Edward S. Rubin
Department of Engineering and Public Policy
Carnegie Mellon University
Pittsburgh, Pennsylvania

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Outline of Talk

• Climate change and the electric power industry
• Options to reduce power sector GHG emissions
• A closer look at CO₂ capture and storage (CCS)
• The importance of technology innovation
• Policy options and outlook
Climate change and the electric power industry

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The concentration of greenhouse gases in the atmosphere has been increasing steadily as a result of emissions from human activities.

Continued increases are projected to raise Earth’s average temperature by 2.5 °F to 10.4 °F by the end of this century. Significant impacts would result.

Source: IPCC, 2001
The Major Greenhouse Gases

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Common Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
<td>Fossil fuel combustion, forest clearing, cement production, etc.</td>
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<tr>
<td>CH₄</td>
<td>Methane</td>
<td>Landfills, production and distribution of natural gas &amp; petroleum, fermentation from the digestive system of livestock, rice cultivation, fossil fuel combustion, etc.</td>
</tr>
<tr>
<td>N₂O</td>
<td>Nitrous Oxide</td>
<td>Fossil fuel combustion, fertilizers, nylon production, manure, etc.</td>
</tr>
<tr>
<td>HFC's</td>
<td>Hydrofluorocarbons</td>
<td>Refrigeration gases, aluminum smelting, semiconductor manufacturing, etc.</td>
</tr>
<tr>
<td>PFC's</td>
<td>Perflourocarbons</td>
<td>Aluminum production, semiconductor industry, etc.</td>
</tr>
<tr>
<td>SF₆</td>
<td>Sulfur Hexafluoride</td>
<td>Electrical transmissions and distribution systems, circuit breakers, magnesium production, etc.</td>
</tr>
</tbody>
</table>

Unlike conventional air pollutants, whose atmospheric lifetime is days to months, GHGs remain in the atmosphere for decades to centuries.
CO\textsubscript{2} from Fuel Combustion is the Dominant Greenhouse Gas

U.S. Greenhouse Gas Emissions, 2004
weighted by 100-yr Global Warming Potential (GWP)

- CO\textsubscript{2}: 84.6%
- CH\textsubscript{4}: 7.9%
- N\textsubscript{2}O: 5.5%
- Others: 2.0%

Source: USEPA, 2006

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Electric Power Plants are the Largest Source of CO$_2$ Emissions

U.S. Sources of CO$_2$ Emissions

- **Residential**: 20.1%
- **Commercial**: 17.1%
- **Industrial**: 29.8%
- **Transportation**: 33.0%

(b) Electric Power Sector

- **Coal**: 41.9%

*Source: Based on USDOE, 2002*

**Power plants and transportation together account for 75% of U.S. carbon dioxide emissions**

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Most U.S. Electricity Comes from Coal
(1950–2004 fuel share with EIA Reference Case projections to 2030)

EIA Reference Case projects 65% more coal use over next 25 years

Source: USEIA/DOE, 2006
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U.S. Power Sector CO$_2$ Emissions
(1950–2004 trend with EIA Reference Case projections to 2030)

EIA Reference Case projects a 45% increase in CO$_2$ emissions by 2030

Reference case scenario assumes no new policies

Source: USEIA/DOE, 2006
The Climate Change Policy Driver

• 1992 U.N. Framework Convention on Climate Change called for “stabilization of greenhouse gas concentrations in the atmospheric at a level that would prevent dangerous anthropogenic interference with the climate system”

• Because of their long atmospheric lifetimes, stabilizing emissions of GHGs is not sufficient to stabilize atmospheric concentrations

• This implies a long-term need to drastically reduce CO₂ emissions, no matter what target is selected for stabilization!
What it Takes to Stabilize Atmospheric CO$_2$ Concentration

(a) Atmospheric Stabilization Scenarios          (b) Required CO$_2$ Emissions

Source: IPCC, 2001

Long-term emissions must be reduced by roughly 80–90% in order to stabilize atmosphere concentrations

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What options are available to reduce CO$_2$ emissions from the electric power sector?
General Approaches to Reduce Power Sector CO$_2$ Emissions

- Technologies that reduce demand for electricity (e.g., improved end-use efficiency, building designs, DSM, etc.)

- **More efficient technologies** for power generation, transmission and distribution (e.g., NGCC, IGCC, SCPC; DG, co-generation; micro-grids, power electronics, etc.)

- Power generation technologies using **alternative energy sources** with lower or no GHG emissions (e.g., natural gas, nuclear; wind, biomass, geothermal, etc.)

- Technologies to capture and store (sequester) CO$_2$ produced at power plants
All of the options above have issues and limitations that must be considered.

- Several of my Carnegie Mellon colleagues recently produced a report for the Pew Center on Climate Change that addresses the full range of issues and options related to climate change mitigation and the U.S. electric power sector.

- Available at: www.pewclimate.org
A closer look at

$CO_2$ Capture and Storage

(CCS)
Why the Interest in CCS?

- Fossil fuels will continue to be used extensively for many decades to come—alternatives are not likely to achieve large CO₂ reductions in time frames of policy interest

- CCS offers a way to allow fossil fuels (especially coal) to be used with little or no CO₂ emissions—a potential bridging strategy

- Energy models indicate that the availability of CCS in a portfolio of options can significantly lower the cost of mitigating climate change
Can We Have Our Cake and Eat it Too?

Can We Have Our Coal Without CO$_2$?
The Intergovernmental Panel on Climate Change (IPCC) Web Site (www.ipcc.ch) has:

- Summary for Policymakers
- Technical Summary
- Full Technical Report

(available from Cambridge University Press, 2005)
CO₂ Capture and Storage Systems

Carbonaceous Fuels

Capture Processes

Transport and Storage Options

(Source: CO₂CRC)

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# Maturity of CCS Technologies

<table>
<thead>
<tr>
<th>Research Phase</th>
<th>Demonstration Phase</th>
<th>Econ. Feasible (specific conditions)</th>
<th>Mature Market</th>
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</thead>
<tbody>
<tr>
<td>Ocean storage</td>
<td>Enhanced coal bed methane</td>
<td>Post-combustion capture</td>
<td>Industrial separation</td>
</tr>
<tr>
<td>Mineral carbonation</td>
<td>Gas and oil fields</td>
<td>Pre-combustion capture</td>
<td>Pipeline transport</td>
</tr>
<tr>
<td>Enhanced oil recovery</td>
<td>Saline aquifers</td>
<td>Tanker transport</td>
<td>Enhanced oil recovery</td>
</tr>
<tr>
<td>Industrial utilization</td>
<td>Industrial utilization</td>
<td>Enhanced oil recovery</td>
<td>Mature Market</td>
</tr>
</tbody>
</table>
Leading Candidates for CCS

- Fossil fuel power plants
  - Integrated coal gasification combined cycle (IGCC)
  - Supercritical pulverized coal combustion (SCPC)
  - Natural gas combined cycle (NGCC)

- Other large industrial sources of CO₂

- Pipeline transport with geological sequestration

*Focus on power plants as the largest source of CO₂*
Status of Capture Technology

• CO₂ capture technologies are in commercial use today, mainly in the petroleum and petrochemical industries

• Capture also applied to several gas-fired and coal-fired boilers, but at scales small compared to a large modern power plant

• Net capture efficiencies typically 80-90%

• Integration of capture, transport and storage has been demonstrated in several industrial applications, but not yet at an electric power plant (which is the focus of DOE’s FutureGen project)
PC Plant with CO$_2$ Capture

Combustion Controls
- Fuel Type: Coal
- NOx Control: None

Post-Combustion Controls
- NOx Control: Hot-Side SCR
- Particulates: Cold-Side ESP
- SO$_2$ Control: Wet FGD
- Mercury: None
- CO$_2$ Capture: Amine System

Solids Management
- Disposal: mixed w/ Landfill

Plant Diagram

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Examples of Post-Combustion CO$_2$ Capture Systems

Coal-Fired Power Plant Flue Gas
(Oklahoma, USA)

Gas-Fired Process Flue Gas
(Keda, Malaysia)

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IGCC Plant with CO$_2$ Capture

**Gasification Options**
- **Gasifier:** Texaco (Oxygen-blown)
- **Gas Cleanup:** Cold-gas
- **CO2 Control:** Sour Shift + Selexol

**Combustion Controls**
- **NOx Control:** None

**Solids Management**
- **Slag:** Landfill
- **Sulfur:** Sulfur Recovery
Polk Power Station
Integrated Coal Gasification
Combined Cycle (IGCC) Plant
Tampa, Florida (250 MW)

Source: TECO, 2004
Examples of Pre-Combustion CO$_2$ Capture Systems

- Coal Gasification to Produce SNG  
  *(North Dakota, USA)*

- Petcoke Gasification to Produce H$_2$  
  *(Kansas, USA)*

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CO₂ Pipelines for Enhanced Oil Recovery

Source: USDOE/Battelle

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Existing/Proposed CO₂ Storage Sites

Source: S. Benson, LBNL
Geological Storage Options

Overview of Geological Storage Options:
1. Depleted oil and gas reservoirs
2. Use of CO₂ in enhanced oil and gas recovery
3. Deep saline formations — (a) offshore (b) onshore
4. Use of CO₂ in enhanced coal bed methane recovery

Source: IPCC, 2005
CO₂ Capture from Natural Gas Treatment with Deep Saline Aquifer Storage

Sleipner (Norway)

In Salah /Krechba (Algeria)

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Geological Storage of Captured CO$_2$ with Enhanced Oil Recovery (EOR)

Sources: USDOE; NRDC

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Large sources are clustered in four geographical regions. Fossil fuel power plants account for 78% of emissions; industrial processes (including biomass) emit 22%.
Potential Geological Storage Areas

(Prospective areas in sedimentary basins where suitable saline formations, oil or gas fields, or coal beds may be found)

Storage prospectivity
- Highly prospective sedimentary basins
- Prospective sedimentary basins
- Non-prospective sedimentary basins, metamorphic and igneous rock

Data quality and availability vary among regions

(Source: Geoscience Australia; IPCC, 2005).

Good correlation between major sources and areas with potential for geological storage. More detailed regional analyses required to confirm or assess actual suitability for storage.

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Trapping Mechanisms Provide Increasing Storage Security with Time

- Storage security depends on a combination of physical and geochemical trapping.
- Over time, residual CO$_2$ trapping, solubility trapping and mineral trapping increase.
- Appropriate site selection and management are the key to secure storage.

Source: S. Benson, LBNL
Current U.S. fluid injections exceed mass of all CO₂ from U.S. power plants


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Estimated CCS Cost for New Power Plants Using Current Technology

Levelized cost of electricity production in 2002 US$/MWh

<table>
<thead>
<tr>
<th>Power Plant System</th>
<th>Natural Gas Combined Cycle Plant</th>
<th>Supercritical Pulverized Coal Plant</th>
<th>Integrated Gasification Combined Cycle Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Plant Cost (without capture) ($/MWh)</td>
<td>30–50</td>
<td>40–50</td>
<td>40–60</td>
</tr>
<tr>
<td>Added cost of CCS with deep aquifer storage</td>
<td>10–30</td>
<td>20–50</td>
<td>10–30</td>
</tr>
<tr>
<td>Added cost of CCS with EOR storage</td>
<td>10–20</td>
<td>10–30</td>
<td>0–10</td>
</tr>
</tbody>
</table>

Source: IPCC, 2005

Variability is due mainly to differences in site-specific factors. Added cost to consumers will depend on extent of CCS plants in the overall power generation mix

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Cost of CO$_2$ Avoided (Based on Current Technology)

Levelized cost in 2002 US$ per tonne CO$_2$ avoided

<table>
<thead>
<tr>
<th>Power Plant System</th>
<th>Natural Gas Combined Cycle Plant</th>
<th>Pulverized Coal Plant</th>
<th>Integrated Gasification Combined Cycle Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same plant with CCS (deep aquifer storage)</td>
<td>40–90</td>
<td>30–70</td>
<td>15–55</td>
</tr>
<tr>
<td>Same plant with CCS (EOR storage)</td>
<td>20–70</td>
<td>10–45</td>
<td>(-5)–30</td>
</tr>
</tbody>
</table>

Source: IPCC, 2005

Different mixes of plants with and without CCS will have other avoidance costs; site-specific context is important

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Approximate Cost of Options

Coal plants based on bituminous coals; gas price ≈ $3–6/GJ; Costs in $ 2002.
The Importance of Technology Innovation

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Technology Innovation Tends to Lower Costs with Increasing Deployment

Source: IIASA, 1996

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“Technology Policies” are often used to spur innovation

**Direct Government Funding of Research and Development (R&D)**
- R&D contracts with private firms
- R&D grants and contracts with universities
- Intramural R&D conducted at gov’t laboratories
- R&D contracts with consortia (2 or more of the actors above)

**Direct or Indirect Support for Commercialization and Production; Indirect Support for Development**
- Patent protection
- R&D tax credits
- Production subsidies or tax credits to firms bringing new technologies to market
- Tax credits or rebates for new technology buyers
- Government procurement
- Demonstration projects

**Support for Learning and Diffusion of Knowledge and Technology**
- Education and training
- Codification and transfer of knowledge
- Technical standard-setting (non-regulatory)
- Technology and/or industrial extension services
- Publicity and consumer information

- *These policies influence different phases of the innovation process*
- *Provide incentives for technological change & innovation*
Regulatory policies also can stimulate innovations that reduce emissions …

U.S. Patenting Activity in SO$_2$ Control Technology

- No Federal R&D
- Some Federal R&D
- CAA Regs + R&D

**U.S. Clean Air Act of 1970**

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...with significant declines in cost as technologies are deployed

Experience Curve for Flue Gas Desulfurization Cost

Cost reduction = 11% per doubling of installed capacity; 50% reduction over 20 years

(Based on 90% $SO_2$ removal, 500 MW plant, 3.5%S coal)
Future technology innovations can reduce climate change mitigation costs

Use of CCS in Climate Policy Scenarios
(IPCC scenario A2 with and without stabilization at 550 ppm CO₂ by 2100)
Conclusions from Case Studies of Environmental Technologies

• The stringency of emission reduction requirements is a major factor in both *stimulating* and *directing* innovations and deployment of cleaner technologies.

• The cost of achieving a given level of emissions reduction tends to fall with increasing technology deployment and sustained R&D.

• The firms that innovate tend to capture large market share of environmental technology.
Policy Options and Outlook
Things are Heating Up

• Over the past 15 years, the Intergovernmental Panel on Climate Change (IPCC) has conducted three major assessments of global climate change; the fourth assessment is currently underway (expected in 2007)

• Over this time, the scientific evidence has shown more convincingly that climate change is real, and that greenhouse gas emissions from human activities are inducing climatic changes with potentially large impacts

• Assessments of climate change impacts increasingly are focused at the national and regional levels, and raising levels of concern (e.g., see: www.ipcc.ch and www.usgcrp.gov)
The amount of energy dissipated in tropical cyclones had doubled in the past 30 years, according to a recent report in *Nature*.

The destructive power of the storm is proportional to $V^3$.

Some claim natural cycles, but the author has since concluded this is largely due to sea surface warming due to climate change.

Antarctic Ice Sheet Losing Mass

“The melting of the West Antarctic ice sheet alone ...would raise global sea levels by more than 20 feet, according to researchers from the British Antarctic Survey.” (Source: www.usgcrp.gov)

*Photo courtesy CU-Boulder National Snow and Ice Data Center (Source: usgcrp.gov, 2006)*
Some Congressional skeptics are beginning to convert, and some power industry leaders are advocating carbon regulations.
Can we take the carbon out of carbon-based energy?

**Carbon Challenge** It is increasingly accepted that rising levels of greenhouse gases are contributing to changes in the world's climate. One of the main culprits is carbon dioxide. We exhale carbon dioxide when we breathe. Our cars, homes, factories, and the power plants that light our streets all release carbon dioxide into the air. It's also emitted when fossil fuels are burned for energy. But that's about to change.

**Less Pollution** BP is pioneering the world's first comprehensive industrial-scale project to help eliminate carbon dioxide released during electricity production. At a power station in Scotland, we are combining a number of proven technologies to allow the facility to produce electricity using hydrogen derived from natural gas. Carbon dioxide removed in the process will be captured and sent to an oil field about 190 miles offshore, where it will be safely returned to the natural environment where it came from—a reservoir 2.5 miles below the seabed—and stored safely and indefinitely. Carbon dioxide emissions are expected to fall by 90% as a result of the project.

**More Energy** But the project won't just have environmental benefits. It will actually enhance the recoverability of oil. In fact, returning carbon dioxide to the reservoir could increase the amount of oil extracted from the field by up to 40 million additional barrels. This particular North Sea oil field is scheduled to cease production within the next two years. The carbon capture process could extend that life span by 15 or even 20 years, which in turn would provide a boost for jobs and the economy. BP and partners plan to invest $600 million to make this facility a reality. When fully operational, the project is expected to capture and store around 1.3 million tons of carbon dioxide each year, while providing "carbon-free" electricity to the equivalent of 350,000 homes. If applied to just 5% of the new electricity-generating capacity the world is projected to need by 2030, we could reduce global carbon dioxide emissions by around 1 billion tons a year. We expect to complete front-end engineering design by the second half of 2006. If an economic review is successful, the facility could begin operation in 2009. This facility will be the first of its kind. But the ability to create electricity at scale with virtually no carbon dioxide emissions holds great potential as a solution to the challenge of climate change.

It's a start.

bp.com

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Many U.S. States are Developing Climate Action Plans …
... and GHG Reporting and Registries

Source: Pew Climate Center, 2006
U.S. Mayors Adopting Kyoto Targets

Source: Pew Climate Center, 2006; Map courtesy of the Seattle Mayor’s Office

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Current Climate Policies Include:

- European Union Emission Trading System \((C/T)\)
- Kyoto Protocol \((C/T, JI, CDM)\)
- Northeast Regional Greenhouse Gas Initiative \((C/T)\)
- California Climate Action Policy Proposals \((C/T)\)
- California GHG Performance Standard for Power Plants
California PUC/CEC Policy on Greenhouse Gas Performance Standard

• “The PUC directs Staff and its General Counsel to investigate adoption by the PUC of a greenhouse gas emissions performance standard for IOU [Investor Owned Utilities] procurement that is no higher than the GHG emissions levels of a combined-cycle natural gas turbine for all procurement contracts that exceed three years in length and for all new IOU owned generation. In the case of coal-fired generation, the capacity to capture and store carbon dioxide safely and inexpensively is necessary to meeting the standard;”

  – California Public Utilities Commission, October 6, 2005

• Proposed BP–Edison Mission Group IGCC- CCS 500 MW power plant may be first large project under this policy
## Recent Congressional Bills

<table>
<thead>
<tr>
<th>Bill, Sponsor and Title</th>
<th>Climate Research</th>
<th>Technology Deployment</th>
<th>Reporting &amp; Registry</th>
<th>Multi-Pollutant</th>
<th>GHG Caps &amp; Trading</th>
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</thead>
<tbody>
<tr>
<td>S. 150 (Jeffords) <em>The Clean Power Act of 2005</em></td>
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<tr>
<td>S. 245 (Collins) <em>Abrupt Climate Change Research Act of 2005</em></td>
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<tr>
<td>S. 883 (Hagel) <em>Climate Change Technology Deployment in Developing Countries Act of 2005</em></td>
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<tr>
<td>S. 887 (Hagel) <em>Climate Change Technology Deployment and Infrastructure Credit Act of 2005</em></td>
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<tr>
<td>S. 1151 (McCain) <em>Climate Stewardship and Innovation Act of 2005</em></td>
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<tr>
<td>S. 1203 (Hagel) <em>Climate Change Technology Tax Incentives Act of 2005</em></td>
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<td>H.R. 759 (Gilchrest) <em>Climate Stewardship Act of 2005</em></td>
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<tr>
<td>H.R. 1451 (Waxman) <em>Clean Smokestacks Act of 2005</em></td>
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Source: CRS, 2006
The Future is Uncertain

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Some Potential Policy Options to Reduce Power Sector GHG Emissions

- Incentives to Reduce GHG Emissions
- Cap and Trade System
- Carbon Tax
- Performance Standards for CO$_2$ Sources
- Portfolio Standards for Power Retailers
- “Capture Ready” Design Requirements
- “Feebate” System for Existing Power Plants
- Combinations of the Above
Toward a National Policy to Mitigate Climate Change

• Global climate change is an environmental problem that cannot be addressed by voluntary technology policies alone — *regulatory policies that limit GHG emissions* also are needed

• *Energy policies* can further help—or impede—progress and innovations that reduce GHG emissions; coordination and consistency are essential

• A *combination* of traditional *technology policies* and *regulatory policies* that limit GHG emissions can most effectively achieve multiple national goals, and foster innovations favored or required by markets in a carbon-constrained world
Thank You

rubin@cmu.edu

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