Future of Coal-Fired Power and CO$_2$ Sequestration

Dr. James C. Cobb
State Geologist and Director
University of Kentucky
Kentucky Geological Survey

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Outline for the talk

I. IPCC and climate change
II. Fossil fuels the driver in climate change
III. CO₂ Sequestration, the answer or an answer, or no answer?
The understanding (science) of anthropogenic (human) warming and cooling influences on climate has improved leading to very high confidence that the global average net effect of human activities since 1750 has been one of warming,” UN IPCC, 2008
According to the IPCC

- Carbon dioxide is the most important anthropogenic greenhouse gas
- Concentration of carbon dioxide in the atmosphere exceeds the natural range over the last 650,000 years
- Fossil fuel use was the primary source of carbon dioxide with deforestation a significant but smaller contributor
- Annual carbon dioxide emissions increased from 23.5 GtCO2 per year in 1990 to 26.4 GtCO2 per year in 2005
Global Temperature

Sea Level Rise

Snow Cover Decline

IPCC, 2008
Human Climate Effects and Responses

EARTH SYSTEMS

HUMAN SYSTEMS

IPCC, 2008
### Accounting for Warming

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W/m²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Long-lived greenhouse gases</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
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<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td></td>
<td></td>
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<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
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<tr>
<td><strong>Ozone</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Stratospheric</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>0.35 [0.25 to 0.65]</td>
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<tr>
<td><strong>Stratospheric water vapour from CH₄</strong></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
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<tr>
<td><strong>Surface albedo</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Land use</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med-Low</td>
</tr>
<tr>
<td>Black carbon on snow</td>
<td>0.1 [0.0 to 0.2]</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Aerosol</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Direct effect</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med-Low</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Linear contrails</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
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<tr>
<td><strong>Solar irradiance</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Total net anthropogenic</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>1.6 [0.6 to 2.4]</td>
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</tbody>
</table>

IPCC, 2008
If Fossil Fuels are Bad Why Pick on Coal

<table>
<thead>
<tr>
<th></th>
<th>Carbon Intensity (g C/unit energy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>15</td>
</tr>
<tr>
<td>Oil</td>
<td>20</td>
</tr>
<tr>
<td>Coal</td>
<td>26</td>
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</tbody>
</table>

Modified from Masters, G.M., 1998
Loss of overall power plant efficiency as a consequence of CO2 capture

About 20% penalty in theory
NRC Report on Future of Coal in U.S.

- Coal production could increase 70% by 2030
- U.S. has more than adequate reserves to accommodate this increase but R & D is needed

NRC, 2007
Projected U.S. Electric Power by Fuel Type

Annual Energy Outlook 2007 (Report #: DOE/EIA-0383-1)
U.S. Projected CO$_2$ Emissions

CO$_2$

U.S. CO$_2$ Emissions from Stationary Sources by Category

Electric Power

DOE, 2007
Stationary Sources of CO$_2$ in the U.S.

4,500 sources and 8.0 billion tons CO$_2$/yr

DOE Atlas, 2007
Energy in the World
Global Energy Use by Region

Energy Use (Quadrillion Btu)

Data: EIA, October 2007

87% Fossil Fuels
Energy in Kentucky
KyHB-1 Funding Research for Economic Development

- In passing HB-1 (2007), Kentucky legislators signaled that the need for domestic energy and controls on CO₂ had penetrated into the state political scene, a bellwether event!
- Leveraged nearly $6.0 million in private industry funding and technical input.
- Motivated the creation of the Western Kentucky Carbon Storage Foundation [501 (c) (3)] foundation to match HB-1 funding.
<table>
<thead>
<tr>
<th></th>
<th>Western KY Seq.</th>
<th>Eastern KY Seq.</th>
<th>EOR</th>
<th>EGR</th>
<th>TOTALS</th>
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</thead>
<tbody>
<tr>
<td>State*</td>
<td>$1.35</td>
<td>1.35</td>
<td>0.85</td>
<td>0.85</td>
<td>$4.40</td>
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<tr>
<td>Industry</td>
<td></td>
<td>1.35</td>
<td>0.85</td>
<td>0.85</td>
<td>$8.74</td>
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<tr>
<td>Other</td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>$1.75</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$14.89</td>
</tr>
</tbody>
</table>

*UK is contributing $1.0 million
Oil and Gas Fields of Kentucky

- OOIP: 2.4 billion barrels*
- Gas resource: 125 Tcf
- Production
  - 780 MMbo produced
  - 5.6 Tcf produced

*Does not include 3.4 billion barrels tar sand in W. Ky.*
Coal-fired Electric Generation in and near Kentucky

Coal Power Plants (Kentucky and surrounding states)
- Operating
- Proposed
- Proposed Gasified Coal

- Eastern Coal Field
- Western Coal Field
Kentucky’s Carbon Numbers

- Kentucky ranks 3rd nationally in annual coal production
- 10-15 billion short tons of recoverable coal reserves
- 92% of electrical generation is from coal-fired power plants
- 155 million metric tons CO₂/annually (all sources)
- Kentucky produces coal, natural gas, oil, tar sand, ethanol, and processes uranium at Paducah
CO$_2$ Sequestration
“the Basics”
What is carbon sequestration?

- **Carbon** is short for CO$_2$ or carbon dioxide
- **Sequestration** means removed or isolated from the atmosphere and stored away for a long time
- Sequestration is by injection into **deeply buried rock formations, oil or gas fields, or coal seams**
- CO$_2$ is to be confined for **thousands of years**
- This is **experimental evolving technology**
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
DOE Sequestration Regional Partnerships

DOE Atlas, 2007
U.S. CO₂ Emissions by Region

* Northeast category includes states not covered by the RCSPs

DOE, 2007
Why Sequester CO$_2$?

- Political consensus manmade CO$_2$ is changing the climate, storing CO$_2$ away from the atmosphere will help moderate climate change

- CO$_2$ emissions are rising

- Concern about CO$_2$ emissions is high
Carbon Capture and Sequestration

- CCS is a three part process
  1) Capturing the CO$_2$ at the power plant
  2) Compressing and transporting CO$_2$ to storage site
  3) Injecting CO$_2$ into a deep geologic formation
Challenges to CCS Deployment

- EPA forming news regulations on deep well injection under UIC program
- No cap and trade or CO$_2$ credit system in place
- No state regulations on pore space management
- No private or public (state or federal) indemnification
Challenges to CCS Deployment

- Scale of deployment is massive
- Public acceptance questionable
- Potential Benefits – Actual Costs = True Value
- Ultimate value – Will it make a difference in moderating climate change?
North Sea Sleipner Project

The Sleipner CO2-injection into the Utsira Formation at 1000 Meters Below Sea Bottom
- About 1 million tons/yr -
Sequestration Research in Kentucky
HB 1 Research Projects Planned or Proposed

Kentucky Counties with Active and Proposed HB-1 Projects with the Kentucky Geological Survey

- EOR proposals
- Henderson: Enhanced Oil Recovery Test
- Western Kentucky: Deep Sequestration Test
- Clark County: Trianon Sequestration Test
- Lee County: Dig Andy Enhanced Oil Test
- Pike/Johnson: Devonian Shale Test
- Perry: Teco Sequestration Test
- Leslie: Enhanced Oil Recovery Test
- Duke Energy: CO2 test

Western Coalfield
Eastern Coalfield
North-South Seismic Line Hancock County showing sequestration research in deep saline reservoirs

KGS #1 Sequestration Well

New Albany Shale

TD 8350 ft
Project Goals

- Demonstrate CO₂ storage in deep saline reservoirs
- Demonstrate reservoir sealing strata for long-term CO₂ storage
- Demonstrate technologies for evaluation of CO₂ storage in Kentucky
- Publish the results
- Accomplish this project with consideration of the interests and concerns of landowners, industry, government agencies, and the citizens
Potential Reservoirs for CO2

Regional saline reservoirs:
- Mt. Simon Sandstone
- Knox Group dolomites
- St. Peter Sandstone

Rock units:
- Maquoketa Gp
- Black River Gp (High Bridge Gp)
- Pecatonica Fm
- Wells Creek-Dutchtown Fm
- Joachim Dol
- St. Peter Ss
- Beekmantown Fm
- Gunter Ss
- Eau Claire Fm
- Mount Simon Ss
- Copper Ridge Dol.
- Granite-Rhyolite Complex

System:
- Ordovician
- Cambrian
- Proterozoic

Series:
- Upper
- Middle
- Lower

Potential CO2 sinks/reservoirs

Sealing interval

Missing section

Sink or seal (depends on location)

Metamorphic and igneous rocks (mostly seal)
Testing Program

- Testing from the deepest formation up to casing
- Test intervals will be isolated by packers
- Units will be tested with brine injection
- Favorable units tested by injection of CO₂
- Well will be plugged and abandoned
KGS #1 Wellsite Construction Program

Proposed Wellsite
(1.75 Ac)

- culverts for drainage
- slage
- pond
- hill

Total of 0.75 km (0.47 mile) gravel road needed:
- first 1/3 needs slight upgrade
- second 1/3 needs simple blading, compacting & gravel
- last 1/3 is new through woods with elevation changes

Barns

- existing hard packed dirt road
- culvert for drainage
- wide turn
- wide cattle guard w/ gate

Historic Cemetery

- cemetery

Landowner Residence

- paved road
Partners in Kentucky Sequestration Research

Energy and Environment Cabinet
University of Kentucky
Kentucky Geological Survey
Western Kentucky Carbon Storage Foundation
E.ON U.S.
Peabody Energy
ConocoPhillips
TVA
Big Rivers
Smith Management
Illinois Office Coal Development
GeoConsultants LLC
Chesapeake Energy, Pike County, Pine Mountain Dev. Corp.
Wyatt, Tarrant, and Combs
Hancock Co
Take away Message

I. Global climate change is a political reality

II. Legislation requiring CCS is likely

III. Affects on Kentucky will be large

IV. Geological sequestration is a possibility but unproven

V. Costs for electric generation will go up

VI. Research is being done at CAER, KGS, etc.

VII. More should be done
The Kentucky Association of Rural Electric Cooperatives and its members might want to join in this effort and become more involved.

Please let me know.
Thank You