COGA
Denver, CO
Aug, 2007

CO$_2$ and Climate: Assessing the Options

What to do About CO$_2$

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Acknowledgments

• BEG Researchers
• GCCC Member Companies
• DOE Frio and Regional Partnerships
• BEG Global Collaborators
• FutureGen Texas Team
• NRC BEES
Introductory Thoughts

• Electricity demand is growing globally

• All power options have a cost/benefit
  - Some are clean(er), costlier and intermittent
  - Some are dirtier, cheap(er), and more reliable

• The Three E Waltz — Energy, Economy, Environment — is resulting in a transition from carbon-intensive energy to less carbon-intensive energy

• Decarbonization has been happening predictably for over 100 years for many reasons, independent of climate concerns
We depend upon fossil fuels.
Electricity will play an ever greater role in the energy end use mix.
Harvesting CO₂

IEA GHG, 2002
Praxair unpublished data
Gary Rochelle, UT, unpublished data

CO₂ content of “flue” gas (%)

Capture costs ($/ton)

- Natural gas combined cycle (NGCC)
- Natural gas boiler (NGB)
- Coal boiler (PC)
- Integrated gasification combined cycle (IGCC)
# Generating Power

## Average Power Emissions (lbs/MWh)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CO₂</th>
<th>SOₓ</th>
<th>NOₓ</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>1,135</td>
<td>0.1</td>
<td>1.7</td>
<td>Negligible</td>
</tr>
<tr>
<td>Coal</td>
<td>2,249</td>
<td>13</td>
<td>6</td>
<td>Yes, highest</td>
</tr>
<tr>
<td>Oil</td>
<td>1,672</td>
<td>12</td>
<td>4</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Other
Biomass contributes gases. Nuclear, hydroelectric, wind, solar, geothermal do not produce emissions through fuel combustion. Emissions are produced for all power generation facilities as part of full cycle accounting.

Source: USEPA, eGRID, 2006
Comparative CO$_2$ Emissions (T/gWh)

After Gerald L. Kulcinski, 2004

- Pulverized Coal: 974 T/gWh
- Natural Gas: 469 T/gWh
- Photo-Voltaic: 39 T/gWh
- Fission: 15 T/gWh
- Wind: 14 T/gWh
The wind doesn’t always blow, the sun doesn’t always shine, and “storage” technologies are still not adequate.

As a result, the capacity factor of intermittent power sources (solar, wind) is low when compared to base load fuels (coal, natural gas, uranium).

Capacity matters greatly in the overall economic and policy considerations of carbon.

After Gerald L. Kulcinski, 2004
CO₂ Emissions w/Storage

Tonnes CO₂e./GWh

Wind: 14
Wind/PHS: 20
Wind/CAES: 109
PV: 39
PV/VRB: 136+

PHS: Pumped Hydro Storage
CAES: Compressed Air Energy Storage
VRB: Vanadium

After Gerald L. Kulcinski, 2004
CO$_2$ Emissions w/Storage

- **Dirti(er)**
- **Reliable**
- **Clean(er)**
- **Intermittent**
- **Cheap(er)**
- **Costli(er)**

<table>
<thead>
<tr>
<th>Source</th>
<th>Tonnage of CO$_2$/GWh</th>
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<tr>
<td>Coal</td>
<td>974</td>
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<td>Nat. Gas</td>
<td>469</td>
</tr>
<tr>
<td>Fission</td>
<td>15</td>
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<tr>
<td>Wind w/o storage</td>
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<td>Wind-PHS</td>
<td>20</td>
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<td>Wind/CAES</td>
<td>109</td>
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<tr>
<td>PV w/o storage</td>
<td>39</td>
</tr>
<tr>
<td>PV/Pb-acid</td>
<td>152</td>
</tr>
<tr>
<td>PV/V</td>
<td>136</td>
</tr>
</tbody>
</table>

After Gerald L. Kulcinski, 2004
Life-Cycle Analysis

- Energy for Raw Material Mining, Milling and Fabrication
- Energy for Plant Construction
- Energy for Fuel Procurement and Transport
- Fuel Cycle
- Energy Content of Fuel
- Operation
- Decommissioning
- Energy to Decommission Plant and Reclaim Land
- Energy To Operate and Maintain Plant Equipment
- Electrical Output

After Gerald L. Kulcinski, 2004
What Can We Do With CO₂
Sources and Sinks

- Global ~ 25.6 Gt of CO2 annually
- U.S. ~ 5.7 Gt of CO2 annually
- Texas ~ 700 MMt of CO2 annually

Source: Gulf Coast Carbon Center
Field Demonstration Projects and Experiments

Frio II

$1 million funding from DOE
USGS, 3 Nat’l labs contributing
Schlumberger, Praxair

Objective:

Improve quantification of two-phase and dissolution-trapping mechanisms leading to permanent CO$_2$ storage
Inventory of Large-Volume GOM Sinks (Brine-Bearing Formations)

Source: Gulf Coast Carbon Center

~ 220 Gt

- Offshore GOM
- Upper Tertiary ss
- Middle Tertiary ss
- Lower Tertiary ss
- Cretaceous ss
- Lower Potomac Fm.
- Cape Fear Fm.
Sinks with Economic Offset (EOR)

Source: Gulf Coast Carbon Center
What Might We Do With CO₂
<table>
<thead>
<tr>
<th>Sector</th>
<th>Key mitigation technologies and practices currently commercially available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Supply [4.3, 4.4]</td>
<td>Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bio-energy); combined heat and power; early applications of CCS (e.g. storage of removed CO2 from natural gas)</td>
</tr>
<tr>
<td>Transport</td>
<td>More fuel efficient vehicles; hybrid vehicles; cleaner diesel vehicles;</td>
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- Improved supply and distribution efficiency
- Fuel switching from coal to gas
- Nuclear power
- Renewable heat and power (hydropower, solar, wind, geothermal and bio-energy)
- Co-mingled heat and power
- Early applications of CCS (storage of removed CO2 from natural gas)
### 2030

<table>
<thead>
<tr>
<th>Sector</th>
<th>Key mitigation technologies and practices projected to be commercialized before 2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Supply [4.3, 4.4]</td>
<td>Carbon Capture and Storage (CCS) for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and waves energy, concentrating solar, and solar PV.</td>
</tr>
<tr>
<td>Transport</td>
<td>Second generation biofuels; higher efficiency aircraft; advanced</td>
</tr>
</tbody>
</table>

- CCS for gas, biomass and coal-fired electricity
- Advanced nuclear power
- Advanced renewable energy, including tidal and waves, energy, concentrating solar and solar PV

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<td>Industry [7.5]</td>
<td>Advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture</td>
</tr>
<tr>
<td>Agriculture [8.4]</td>
<td>Improvements of crops yields</td>
</tr>
<tr>
<td>Forestry/forests [9.4]</td>
<td>Tree species improvement to increase biomass productivity and carbon sequestration. Improved remote sensing technologies for analysis of vegetation/ soil carbon sequestration potential and mapping land use change</td>
</tr>
<tr>
<td>Waste [10.4]</td>
<td>Biocovers and biofilters to optimize CH₄ oxidation</td>
</tr>
</tbody>
</table>

IPCC, 2007
Stern Report: Three Elements of Policy

**Carbon pricing**, through taxation, emissions trading or regulation... to build a common global carbon price across countries and sectors.

**Technology policy**, to drive the development and deployment at scale of a range of low-carbon and high-efficiency products.

**Remove barriers** to energy efficiency and inform, educate and persuade individuals about what they can do to respond to climate change.

Stern Report, 2006
“We do not have the kind of information that would enable attaching numbers to all consequences, weighting them, and adding them up with any plausibility.

Thus, economists attempt aggregations of impacts and costs using very simplified aggregate modeling and, in the process, throw away much that is of fundamental importance to a balanced judgment.”

• Energy efficiency and demand-reduction measures
• Shifts to lower-carbon or zero-carbon fuels
• Inclusion of non-carbon power (nuclear, wind, solar, ocean, and geothermal)
• Use of carbon-neutral sources (biomass)
• Extensive carbon capture and sequestration (CCS)
• Provide effective global framework for carbon management
• Establish transparent, predictable, economy-wide cost for \( \text{CO}_2 \) emissions
Cap and Trade

Cap and trade is wasteful

- Constraints on the economy
- Unnecessary volatility of energy prices
- Create a source of wealth to lobby for and to distribute politically (wasteful activity)
  - that is why it is so popular!
- Requires an international monitoring system

Feels voluntary approaches are working

If must do something, carbon tax is better

Carbon Tax

Who pays?

- Producers of carbon?
- Transporters of carbon?
- Industrial users of carbon?
- Small businesses?
- Everyone who uses energy?

There is a reason CEOs around the country are standing in the “debate is over” line and it has little to do with climate science...
Lessons from the Field

FutureGen has taught us a few things already
- Site matters
- CCS is not for everyone
  - NUMBY: Not Under My Back Yard (new acronym!)
  - but CO$_2$ will be under many yards...
- Liability concerns are real and uninsurable at this early stage
- Permitting and regulatory requirements are extensive and must be streamlined
- Compression is expensive
- The cost of capture “ready” power is much less than capture “really” power
Government Roles

- Incentivize and reward
- Assume ownership/liability
- Streamline regulatory and permitting
- Share infrastructure costs
- Property rights and IP
- Political boundary issues
Industry Roles

- Seek “Fit-for-purpose” sites
- Innovate and invent
- Invest in infrastructure and talent
- Commercialize and compete
- Less talk, more walk!
Public Roles

- Public opinion begets government policy, for better or worse.
- Dear public, keep Hollywood panic in perspective
- Plan to adapt *and* mitigate. Both cost money.
The “Stick”

- Climate is changing
- Negative impacts exceed positive
- CO₂ is “bad”
- Time to “do something” about it
- Regulate, tax and trade!
- Industry and economy (and environment)… deal with it

Government/Industry > 1
The “Carrot”

- Climate is changing, and has been, for hundreds of millions of years
- Anthropogenic CO$_2$: background noise
- BAU: pump out the GHGs!
- Public and Environment... adapt!

Government/Industry < 1
The “Cabbage”
(Hurts if it hits you, but you can still eat it...)

- Climate changing
- Anthropogenic CO₂ partially responsible
- CO₂ is a commodity
- Government “incentivize” change
- Commerce take over
- Adapt and Mitigate
- Energy/ Environment/ Economy compromise

Government/ Industry ~ 1
Summary Thoughts

• Electricity demand is growing and for a while natural gas, coal and uranium are the major fuels

• Policy will likely cause CO₂ CCS to happen
  – Dear public, it won’t be cheap
  – Everyone in the world might not play

• Research funding and new talent are needed

• Government, private, academic partnerships make sense

• Everyone must play. There can be no free passes.
Thanks!