Overview of Talk

- Coal and its environmental issues
- What exactly is “clean coal technology”? 
- Coal and global climate change 
- The potential role of CCS 
- The importance of technology innovation 
- Future options and outlook
Historically, coal has been a major source of low-cost energy

<table>
<thead>
<tr>
<th>Sector</th>
<th>U.S.</th>
<th>China</th>
<th>World</th>
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<tr>
<td>Electricity</td>
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<td>Industrial</td>
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<tr>
<td>Others</td>
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</table>
Air Pollution from coal burning has been a major public health issue

- Particulate matter (including smoke, dust, ash)
- Sulfur dioxide
- Nitrogen oxides
- Trace metals

Historically, Coal Got Little Love

- “Be it known to all within the sound of my voice, whosoever shall be found guilty of burning coal shall suffer the loss of his head.”

  — Proclamation of King Edward I of England, 1306, to provide a smoke-free environment in London during sessions of Parliament
Coal Use in Pittsburgh, ca. 1970

- Colfax Power Station, Springdale, 1970
- Brunt Island Power Station, 1970
- Clairton Coke Works, 1970
- Carnegie Mellon University, 1974

Number of Federal U.S. Environmental Laws, 1870-1990

![Graph showing the number of Federal U.S. Environmental Laws from 1870 to 1990.](image)

Source: EPRI
Air Pollutant Emissions from New Coal-Fired Power Plants

Particulate Matter
- Pre-NSPS
- 1971
- 1979
- 1999
- TSP

Sulfur Dioxide
- Pre-NSPS
- 1971
- 1979
- 1999
- FGD

Nitrogen Oxides
- Pre-NSPS
- 1971
- 1979
- 1999

U.S. Air Pollutant Emission Trends
(1940 – 1997)

Particulate emissions

Sulfur dioxide emissions
So What’s the Problem?

- Many existing coal-burning plants are not covered by stringent federal standards for new sources
- Regional emissions still exceed levels needed to achieve air quality standards for some health-related pollutants (especially PM$_{2.5}$ and O$_3$)
- Hazardous air pollutants (especially mercury) and solid wastes from coal plants are additional concerns
- Greenhouse gas emissions (mainly CO$_2$) from fossil fuel combustion are not presently controlled
- Coal mining and transportation add to environmental impacts on a life-cycle basis

What is “Clean Coal”?

“Clean coal refers to technologies that improve the environmental performance of coal-based electricity plants.”
– American Coalition for Clean Coal Electricity, September 2012

“Clean coal is a term pollsters came up with because it polls higher than regular coal. What we want are real cleaner-burning fuels . . . “
– President Jeb Bartlet, The West Wing (TV series), March 27, 2002

“[part of a] strategy to take control of our energy future …invested substantially in [cost-effective] carbon capture and sequestration”
– President Barack Obama (website), September 2012
Current Trends in Coal Use

- Global coal use is increasing, both as a percentage of total energy and in annual tonnage.
- Driven mainly by demand from non-OECD countries, primarily China and India.
- “Coal use in America has tripled over the last four decades while key emissions have been reduced more than 80%, thanks to advanced clean coal technologies.”

What Are These Advanced Clean Coal Technologies?

- Pollutant emissions have been reduced mainly by deploying efficient flue gas cleaning devices in response to regulatory requirements, including:
  - Low-NO\textsubscript{x} burners (LNB) and selective catalytic reduction (SCR) systems for NO\textsubscript{x} reduction
  - Electrostatic precipitator (ESP) or fabric filter (FF) collectors for particulate emissions;
  - Flue gas desulfurization (FGD) systems for SO\textsubscript{2} reduction
Other Clean Coal Technologies

- More efficient coal combustion plants have been developed and are in use in some parts of the world.

- Integrated gasification combined cycle (IGCC) power plants also have been developed and demonstrated, but are not currently in widespread commercial use.

_These plants reduce natural resource requirements and emissions per unit of delivered energy._

Baseline Projections of World Energy Consumption
(assuming no new policy initiatives)

Source: EIA, 2013
Global Climate Change and Sustainability

Global CO₂ Emissions and Atmospheric Concentrations are Increasing

Continued increases are projected in the absence of policy interventions

Source: ORNL, 2011
Source: NOAA, 2011
More extreme events are expected as atmospheric concentration rises.

In contrast to other air pollutants, CO₂ has a very long lifetime in the atmosphere (centuries).

Serious impacts are projected for >2°C rise in average global temperature.

**Stabilizing the Atmosphere Requires Large Emission Reductions, Soon**

CO₂ from energy use is the dominant greenhouse gas; Large CO₂ reductions are needed.

Required change in global CO₂, equiv emissions from 2000 to 2050

–85% to –50%

Source: IPCC, 2007
Enter: Carbon Capture and Storage (CCS)

- Fossil fuels will continue to be used for many decades — alternatives are not able to substitute quickly
- CCS is the ONLY way to get large (≥ 90%) CO₂ reductions from fossil fuel use—a potential bridging strategy to a sustainable energy future
- CCS also is needed decarbonize the transportation sector (via low-carbon electricity and hydrogen from fossil fuels)
- Models show CCS is a key component of cost-effective strategies; without CCS, the global cost of achieving a low-carbon energy future will be much higher

Schematic of a CCS Process
Current Applications of CO₂ Capture

- Gas-fired power plant
- Coal-fired power plant
- H₂ production plant

CCS Technology

- Is real
- Is effective
- Is commercially available

*but . . .*

- It is currently expensive
- It still must be demonstrated at full power plant scale
- It must gain public acceptance
Key Barriers to CCS Deployment

- Policy
- Policy
- Policy

While other factors also are important, without a policy requirement or incentive there is little or no reason to deploy CCS

First Commercial-Scale Demo of CCS on a Coal-Fired Power Plant will be in Canada

- Sask Power Boundary Dam project
- 110 MW coal-fired unit
- Post-combustion capture + EOR (storage)
- ~ 1 Mt CO$_2$/yr
- On-line early 2014
### USDOE-Supported Demonstrations

<table>
<thead>
<tr>
<th>Performer</th>
<th>Location</th>
<th>Capture Technology</th>
<th>Capture Rate (m tons/y)</th>
<th>Target Formation</th>
<th>Start Date</th>
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<td><strong>PC Power Plants</strong></td>
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<td>Saline</td>
<td>2015</td>
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<td>Oxy</td>
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<td>EOR/Saline</td>
<td>2015</td>
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<td><strong>IGCC Power Plants</strong></td>
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<td>Summit Texas Clean Energy</td>
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<td>Southern Company</td>
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<td><strong>Industrial Processes</strong></td>
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**The Importance of Technology Innovation**

Carnegie Mellon University
R&D Programs are Seeking Lower-Cost CCS Technologies

The Common (Linear) Model of Technological Change
A More Realistic Model of Technological Change

Policy options that can foster technology innovations

<table>
<thead>
<tr>
<th>&quot;Technology Policy&quot; Options</th>
<th>Regulatory Policy Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct Gov’t Funding of Knowledge Generation</strong></td>
<td><strong>Economy-wide, Sector-wide, or Technology-Specific Regs and Standards</strong></td>
</tr>
<tr>
<td>• R&amp;D contracts with private firms (fully funded or cost-shared)</td>
<td>• Emissions tax</td>
</tr>
<tr>
<td>• Intramural R&amp;D in government laboratories</td>
<td>• Cap-and-trade program</td>
</tr>
<tr>
<td>• R&amp;D contracts with consortia or collaborations</td>
<td>• Performance standards (for emission rates, efficiency, or other measures of performance)</td>
</tr>
<tr>
<td><strong>Direct or Indirect Support for Commercialization and Production</strong></td>
<td>• Fuels tax</td>
</tr>
<tr>
<td>• R&amp;D tax credits</td>
<td>• Portfolio standards</td>
</tr>
<tr>
<td>• Patents</td>
<td>• Education and training</td>
</tr>
<tr>
<td>• Production subsidies or tax credit for firms bringing new technologies to market</td>
<td>• Codification and diffusion of technical knowledge (e.g., via interpretation and validation of R&amp;D results; screening; support for databases)</td>
</tr>
<tr>
<td>• Tax credits, rebates, or payments for purchasers/users of new technologies</td>
<td>• Technical standards</td>
</tr>
<tr>
<td>• Gov’t procurement of new or advanced technologies</td>
<td>• Technology/Industry extension program</td>
</tr>
<tr>
<td>• Demonstration projects</td>
<td>• Publicity, persuasion and consumer information</td>
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<tr>
<td>• Loan guarantees</td>
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</table>
Value of Sustained RD&D

Projected price of CO₂ emissions under two technology scenarios:

REFERENCE CASE: continue historical rates of technology improvement

ADVANCED TECH: more rapid technological change

The availability of advanced technologies can greatly reduce the cost of emission reductions

So What Lies Ahead?
The Big Question

- Given our current reliance on fossil fuels, what are the potential roles of CCS and “clean coal technologies” in moving to a sustainable, low-carbon energy system?

Current Fossil Fuel Economy

Sustainable Energy System

How do we get there from here?

Forecasts often suggest perfect foresight

... even 100 years out!
But the Future is Uncertain

A carbon-constrained world could look very different than the past

Insights from Energy Models

- **Coal with CCS** is a critical component of cost-effective strategies for sustainable low-carbon energy systems
- **CCS on gas-fired plants** also is important, especially as natural gas gains a larger share of power generation markets

Source: NRC, 2010
Clean Coal / Clean Gas: A Potential Bridge to a Sustainable Energy Future

Thank You

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