The Life Cycle Private and External Costs of Increased Coal Use in the United States

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Policy Questions

- What would a high coal use future look like?
- What are the life cycle impacts associated with this use?
- Do upstream choices affect the impact associated with this use?
U.S. Coal Supply
Why build more Coal Plants?

- >50% current power generation in the U.S.
- Large Reserves
- Technological Advances
  - Reduce Envt’l Impacts
- Baseload Alternatives Unclear
  - Natural gas (expensive and volatile)
  - Nuclear (uncertain)
  - Renewables (limited)
  - Conservation (?)
- Energy Policy Act 2005 - provides incentives for large scale commercial deployment of IGCC systems (some advanced PC as well)
Analytical Tools & Frameworks

- Future Energy Scenario Analysis
- Environmental Life Cycle Assessment
  - EPA/SETAC Process
    - Layout all stages, assess all energy and material inputs and outputs
    - Other models available to help model important parameters (IECM)
  - Input-Output
    - Accounts for supply chain impacts
    - Quick and easy
- Externality Valuation
14 Future Coal Scenarios

- **Electricity Demand Supplied by coal**
  - "BAU" – 1.5% annual growth, 50% from coal - 4 trillion kWh
  - High Growth -2% annual growth, 80% from coal - 8 trillion kWh

- **Generation Technology**
  - Pulverized Coal Plant
  - Coal Gasification Combined Cycle
  - Natural Gas Combined Cycle

- **CO₂ Control**

- **Proportion of Coal Type Used**
  - 51% Bituminous, 41% Subbituminous, 8% Lignite
  - 80% Bituminous (eastern), 20% Subbituminous (western)
  - 20% Bituminous (eastern), 80% Subbituminous (western)

- **Current policies are maintained**
  - NSPS, Title IV, Clean Air Interstate Rule
Extraction and Processing of Coal

- Total GWP (CO$_2$ eq) from this stage: 10 – 70 ton/GWh

- Methane emissions from mining
  - Surface – 0.0162 tons of CO$_2$ eq/ton of coal
  - Underground – 0.144 tons of CO$_2$ eq/ton of coal

- Methane emissions are ~77% of GWP for total GWP from “coal mining” sector

- Variability
  - Coal type (amount, age, rank)
Transport of Coal

- Total GWP (CO₂ eq) from transport: \(3 - 80\) ton/GWh

- CO₂ emissions from rail transport are \(\sim 84\%\) of total GWP emissions from “rail transportation” sector

- Variability
  - Rail, Barge, Truck
  - Emission Factors (based on fuel type and efficiency)
  - Distance shipped
Generation Phase

- Total GWP (CO$_2$ eq) from this stage (w/o CCS): $900-1100$ ton/GWh

- Variability
  - Technology (efficiency)
  - Control Technologies
  - Coal Type
  - Carbon Capture and Sequestration
Annualized System Costs

Scenarios

- PC Coal
- PC Coal w/ CCS
- PC Eastern Coal
- PC Eastern Coal w/ CCS
- PC Western Coal
- PC Western Coal w/ CCS
- IGCC Eastern Coal
- IGCC Eastern Coal w/ CCS
- IGCC Western Coal
- IGCC Western Coal w/ CCS
- Natural Gas
- Natural Gas w/ CCS

8 Trillion kWh from Coal

- Annualized Capital
- O&M
- Fuel
- $ for SO2
- $ for NOx
- $ for PM
- $ for Fatalities
Annualized System Costs

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total Annualized System Costs ($/kWh)</th>
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</thead>
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<td>Natural Gas</td>
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<tr>
<td>Natural Gas w/ CSS</td>
<td>$0.00</td>
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8 Trillion kWh from Coal

- **Annualized Capital**
- **O&M**
- **Fuel**
- **$ for SO2**
- **$ for NOx**
- **$ for PM**
- **$ for Fatalities**
Annual Emissions of $\text{SO}_2$, $\text{CO}_2$, NOx

- Annual SO$_2$ eq and NOx Emissions (million tons/yr)
- CO$_2$ eq Emissions (billion tons/yr)

2010 SO$_2$ Emissions Cap

2001 Total U.S. GHG Emissions (CO$_2$ eq)

Total Current Emissions from Electricity: 2 Trillion kWh from Coal

"BAU" Emissions: 4 Trillion kWh from Coal

"BAU" w/ CSS Emissions: 4 Trillion kWh from Coal

PC Western Coal Emissions: 8 Trillion kWh from Coal

PC Western Coal w/ CCS Emissions: 8 Trillion kWh from Coal

IGCC Western Coal Emissions: 8 Trillion kWh from Coal

IGCC Western Coal w/ CCS Emissions: 8 Trillion kWh from Coal

Natural Gas Emissions: 8 Trillion kWh from Coal

Natural Gas w/ CSS Emissions: 8 Trillion kWh from Coal

Scenarios

- SO2 Emissions
- CO2 Emissions
- NOx Emissions
Comparison of GHG Emissions (w/100% CO₂ Removal from Generation)

Annual GHG Emissions (tons CO₂ eq) Billions

- Electricity
- Transportation
- Industry
- 5b
- 3b
- 2b
- Agriculture
- Commercial
- 4b
- 0b
- Residential
- 7b
- 1b

Direct
Comparison of GHG Emissions (w/100% CO₂ Removal from Generation)

![Annual GHG Emissions (tons CO₂ eq) Bar Chart]

- **Electricity**: 2.5 Billion
- **Transportation**: 2 Billion
- **Industry**: 1.5 Billion
- **Agriculture**: 1 Billion
- **Commercial**: 0.7 Billion
- **Residential**: 0.5 Billion
- **Residential**: 0.3 Billion
- **Residential**: 0.2 Billion

**Billions**

- **Direct**
- **Extraction**
- **Transport**
Local Impacts – Western Scenarios

- Currently 350 million tons/year produced
- 80% of 8 trillion kWh from PRB coal requires 3.5 billion tons/year production
  - Requires a 5% annual production increase (average increase in Subbituminous coal since 1969 is 11%)
  - Exceeds current demonstrated reserve from producing surface mines in Wyoming
  - However, if 3.5 billion tons/yr it would take until the end of the century to exceed the resources identified for the Northern Rocky Mountains and Great Plains
- If shipped by rail, this would require significant upgrades for congestion management
Local Impacts cont’d…

- **Water**
  - If 80% of 8 trillion kWh were from gasification in PRB
  - Dry cooling towers would be required
    - Significantly increasing cost of plants
  - Water consumed in the gasification process
    - ~ 800 billion gallons/year
    - 1.4 times the total flow of the Big Horn River
    - Or up to 3% of the flow of the Columbia River

- **Local Air emissions**
  - Potential hot spots?
Long-Term Implications

- A high coal future could pose considerable environmental challenges.
- Advanced technologies for generation and control of pollution and greenhouse gases can offset these impacts and leave us better off than we are today.
- Even with 100% CO$_2$ removal from the generation phase, the CO$_2$ emissions from the rest of life cycle are comparable to the other major sources of CO$_2$ in the economy today.
Future Work

- Expand upstream impacts
  - Localized generation
  - Potential for upstream reductions of CO$_2$
- Other Generation Options
  - Renewables
- Potential for integration of life cycle assessment with large system level models?
Contact Information

- Carnegie Mellon University Electricity Industry Center
  www.cmu.edu/electricity

- Economic Input-Output Life Cycle Assessment
  www.eiolca.net

- Integrated Environmental Control Model
  www.iecm-online.com

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