Coal Facilitation of Renewable Energy Alternatives

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Environmental Impacts

Comparison of Growth Areas and Emissions

- Gross Domestic Product
- Vehicle Miles Traveled
- Energy Consumption
- U.S. Population
- Aggregate Emissions (Six Principal Pollutants)
Coal Facilitates Renewable Energy

• Coal-biomass integrated systems (pcc, igcc, etc.) advantages relative to dedicated plants
  • Increased
    • Availability
    • Efficiency
    • Reliability
  • Decreased
    • Cost (capital, operating, and power production)
    • Risk (technical, financial, project)
    • Implementation time
Cofiring is a Cross Cutting Option

- Combustion
- Oxyfuel
- Gasification
- Liquefaction
- Fuel Cells
US CO₂ Emissions

Coal Facts and Figures:
- 1 Billion Tons of Coal Consumed
- Coal generates 54% of US Electricity
- ~1200 Coal-Fired Power Plants

15% of Coal Emissions
Potential Biomass Contribution

![Graph showing carbon emissions over years. The graph includes three lines representing Status Quo, Cofiring Scenario, and Kyoto Protocol. The y-axis represents carbon emissions in 10^6 metric tons, and the x-axis represents years from 1990 to 2010. The Status Quo line is a solid red line, the Cofiring Scenario line is a dashed blue line, and the Kyoto Protocol line is represented by a purple horizontal line at 450 million metric tons.]
Cofiring Reduces Net CO₂ Emissions

- **Efficiency Multiplier**
- **Effective Reduction in CO₂ Emissions**

- **100% Efficient**
- **Thermodynamic Limit**
- **Future Technology**

- Power Plant Efficiency

- Effective Reduction in CO₂ Emissions
Cofiring Effectively Reduces Net CO₂ Emissions

The graph illustrates the relationship between the effective reduction in CO₂ emissions and the efficiency multiplier. The solid line represents the best proven technology, while the dotted line shows existing facilities. The graph indicates that as the effective reduction in CO₂ emissions increases, the efficiency multiplier also increases. For example, at 10% effective reduction, the efficiency multiplier for existing facilities is 1.04, whereas for the best proven technology, it is significantly higher, demonstrating the potential for increased efficiency with co-firing technology.
Biomass Energy Economics

Typical Cost of Energy from Conventional Co-firing Combustion

Cost of Electricity compared to feedstock prices, with various conditions, incentives, or subsidies

Switchgrass COE Under Various Scenarios ($/kWh):

- COE w/ SO2 Credit and PTC
- COE w/ SO2 Credit, PTC, and Lost Ash Sales
- COE w/o Incentives
- COE w/o Incentives and Lost Ash Sales

Typical biomass Cost
(US$ per ton)

Acknowledgement: Graph provided by Antares Group Inc

PTC – proposed production tax credit incentive, e.g., Green Pricing Premium
Biomass Cofiring Best Uses Resource

- Cofired Units
  (demonstration and optimized)

- Dedicated Unit Increasing Size

Efficiency/Coal Efficiency

- 10 MWe
- 60 MWe

BYU
US Commercial Experience

- Over 40 commercial demonstrations (>100 world wide)
- Broad combination of fuel (residues, energy crops, herbaceous, woody), boiler (pc, stoker, cyclone), and amounts (1-20%).
- Good documentation on fuel handling, storage, preparation.
- Modest information on efficiency, emissions, economics.
- Almost no information on fireside behaviors, SCR impacts, etc.
Fuel Properties

H:C Molar Ratio vs. O:C Molar Ratio

- Black Liquor
- Cellulose
- Grass
- Average Biomass
- Lignin
- Wood
- Peat
- Lignite
- Subbituminous Coal
- Bituminous Coal
- Semianthracite
- Anthracite

Legend:
- □ anthracite
- △ semianthracite
- ○ bituminous coal
- ◇ subbituminous coal
- ◆ lignite
- ▼ peat
- ◊ biomass
- □ average values

 BYU
Typical Fuel Properties

- **Dry Heating Value:**
  - **Biomass:** \(~ 16\text{ MJ/kg}\)
  - **Coal:** \(~ 25\text{ MJ/kg}\)

- **Volatile Matter:**
  - **Biomass:** ~80%
  - **Coal:** ~40%

- **Particle Size:**
  - **Coal:** ~100 \(\mu\text{m}\)
  - **Biomass:** ~3 mm
Coal & Biomass Elemental Compositions Differ

**COAL:**
- Black Thunder
- Pittsburgh #8

**BIOMASS:**
- Imperial Wheat Straw
- Red Oak Wood Chips

Legend:
- C
- H
- N
- S
- Cl
- Ash
- O (diff)
Coal & Biomass Ash Compositions Differ

COAL:

- Black Thunder: 7.2% Ash
- Pittsburgh #8: 7.8% Ash

BIOMASS:

- Imperial Wheat Straw: 15.4% Ash
- Red Oak: 1.3% Ash

Coal & Biomass Ash Compositions Differ
Woodland Fuel Mix, Spring-Summer 1993

- Eucalyptus
- Almond
- Coffee
- Mich Cal
- Pit Mix
- Pits
- Sawdust
- Shells
- Prunings
- Pine Dust
- White Pine
- WEYCO
- UWW

Commercial Fuel Mix Varies
Major Technical Cofiring Issues

- Fireside Issues
  - Pollutant Formation
  - Carbon Conversion
  - Ash Management
  - Corrosion
  - SCR and other downstream impacts

- Balance of Process Issues
  - Fuel Supply and Storage
  - Fuel Preparation
  - Ash Utilization

Lab and field work indicate there are no irresolvable issues, but there are poor combinations of fuel, boiler, and operation.
**NO\textsubscript{x} Behavior Complex**

- **NO**
  - Straw ($\phi = 0.6$)
  - Coal ($\phi = 0.9$)
  - 70:30 Straw:Coal ($\phi = 0.9$)

- **NH\textsubscript{3}**
  - Straw ($\phi = 0.6$)
  - Coal ($\phi = 0.9$)
  - 70:30 Straw:Coal ($\phi = 0.9$)
Cofiring Deposition

1

2

3

4
Deposits Dissimilar to Fuel

![Bar graph showing mass percent of various elements in fuel and ceiling/corner deposits.](Image)
Composition Maps Support Corrosion Hypothesis

100% Imperial Wheat Straw

85% E. Kentucky  15% Wheat Straw
Fuel Properties Predict Corrosion

Increasing Time

Stoichiometric Sulfur:Alkali Vapor

Deposit Chlorine (% dry mass)

Corrosion Potential
High
Low

2*Fuel Sulfur/Max (Available Alkali, Chloride)
Vapor deposition flux [g/m$^2$/h]
Basic Compounds Poison Catalysts

Catalyst Activity vs. Na Poison Amount

- BYU wet
- BYU dry
- Chen et al.

Poison Ratio (Na:V)

Activity (k/k₀)

K, cm³/g·s

Temperature (°C)

NO Conversion

M1 Catalyst
- Fresh
- Fresh Fit
- Exposed 2063 hr
- Exposed 2063 hr Fit
- Exposed 3800 hr
- Exposed 3800 hr Fit

24-hour sulfated
A = 26527 ± 18400
Ea = 34737 ± 2920

Light sulfated
A = 27045 ± 7580
Ea = 34556 ± 1270

Fresh
A = 17736 ± 21500
Ea = 34640 ± 5720

UC_24HSK

UC lightly sulfated

UC_KF

Lightly sulfated

Exposed 2063 hr Fit

Exposed 3800 hr Fit

Exposed 3800 hr
Conclusions

• Major technical issues include fuel handling, storage, and preparation; $\text{NO}_x$ formation; deposition; corrosion; carbon conversion; striated flows; effects on ash; impacts on SCR and other downstream processes.

• Importance of these issues depends strongly on fuel, operating conditions, and boiler design.

• Proper choices of fuels (coal and biomass) and operating conditions can minimize or eliminate most impacts for most fuels.

• Ample short-term demonstrations illustrate fuel handling feasibility. Paucity of fireside and long-term data.

• Cofiring residuals is a no-regrets process in almost all implementations.
How does this talk grow corn?
Research Issues

• Fundamentals
  • Behavior of inorganics
  • Materials
  • Impurities/Emissions (N, S, Hg, etc.)

• Process Issues
  • Pressure
  • Matrix Effects

• Radical Changes
  • Processes that have stable, condensed-phase effluents under conditions accessible on earth.
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