Reinhold Environmental Ltd.

2010 NOx-Combustion Round Table & Expo Presentation

February 8 & 9, 2010 Chattanooga, TN

Biomass Power Generation: Co-firing & Dedicated Firing Challenges

For Energy and
Environmental
Solutions

REACTION ENGINEERING INTERNATIONAL

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2010 NO_X – Combustion Round Table

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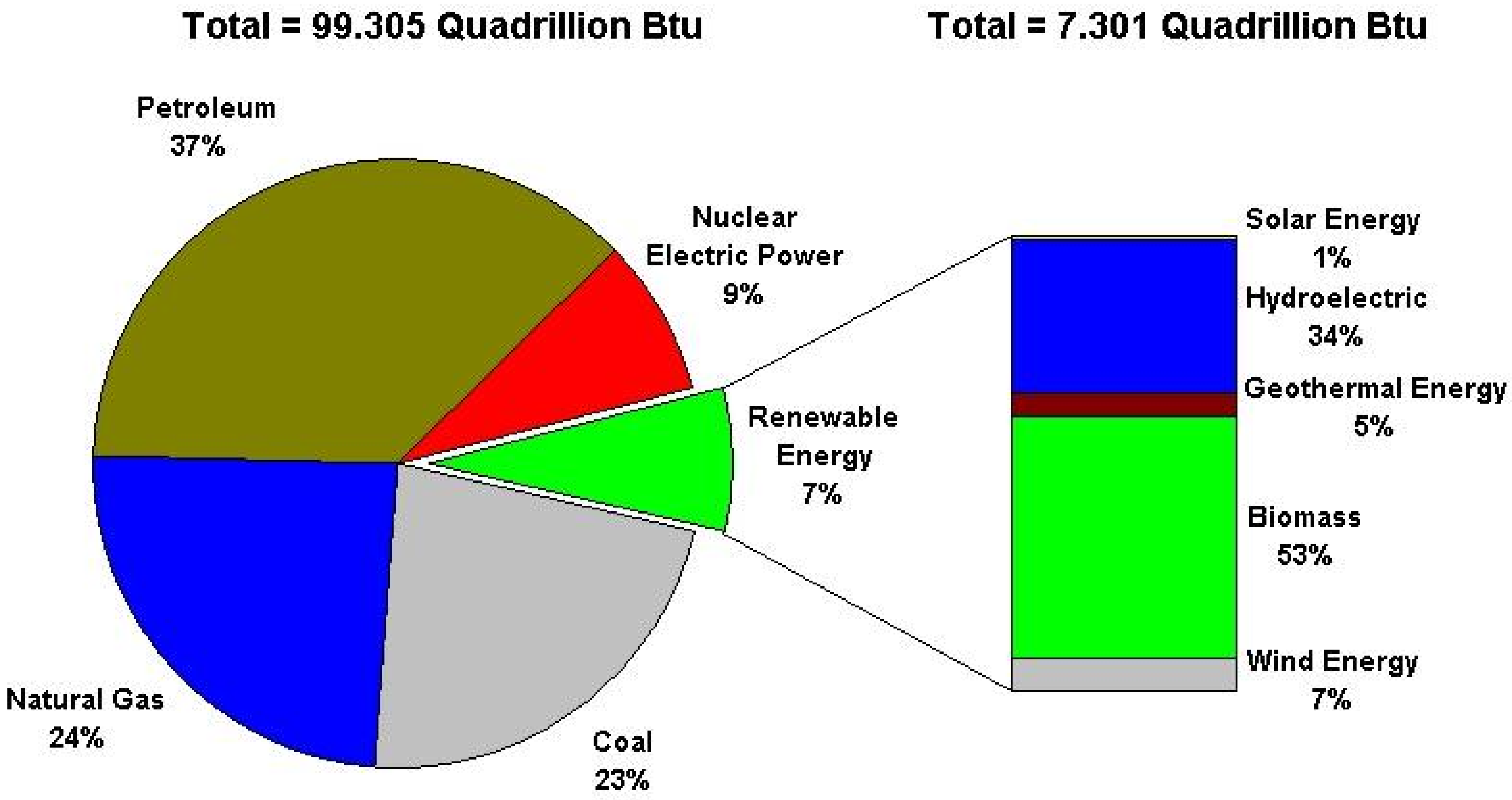
U.S. Energy Picture - 2008



Energy Information Administration

Official Energy Statistics from the U.S. Government

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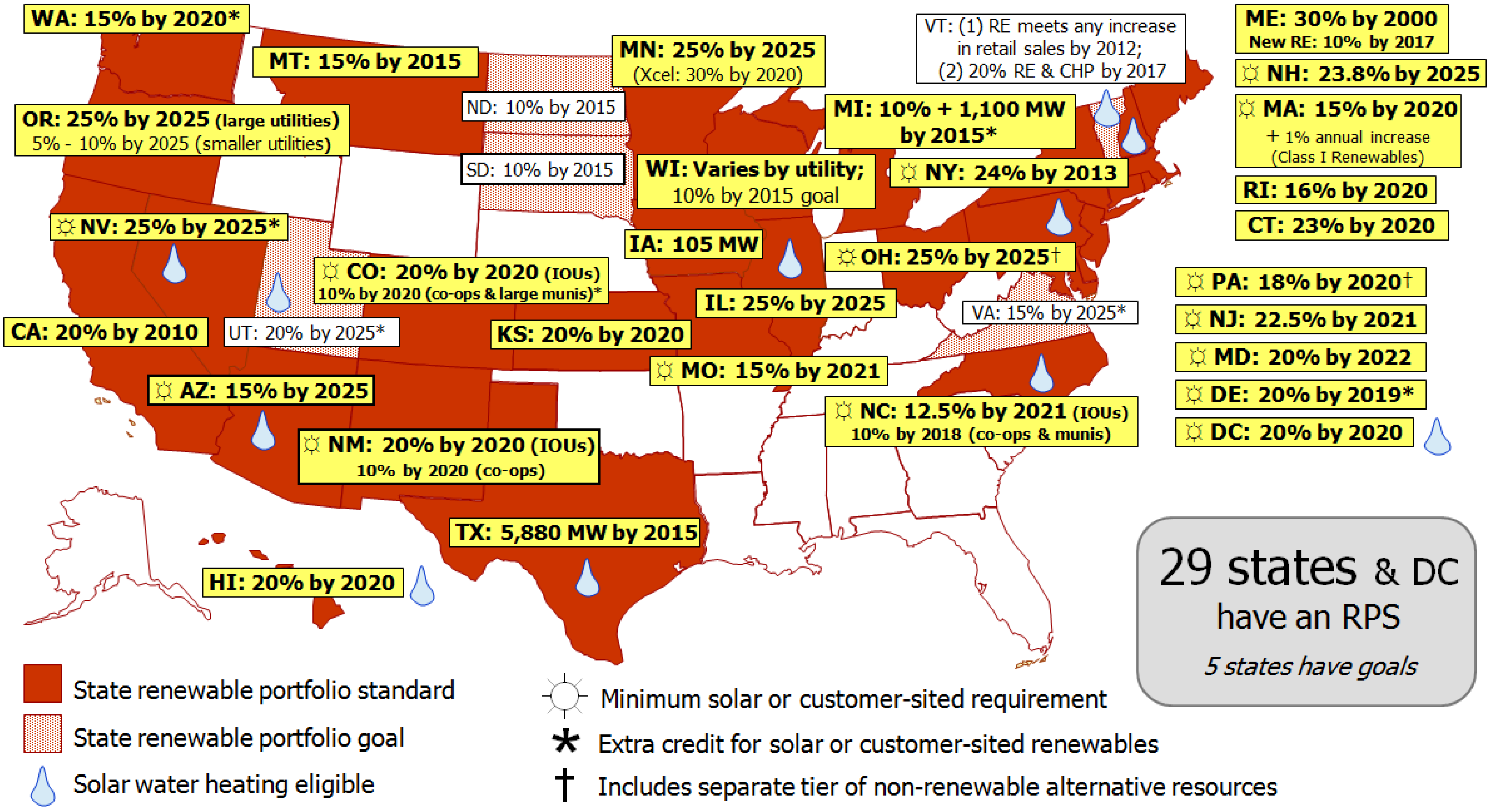
State Renewable Portfolio Standards

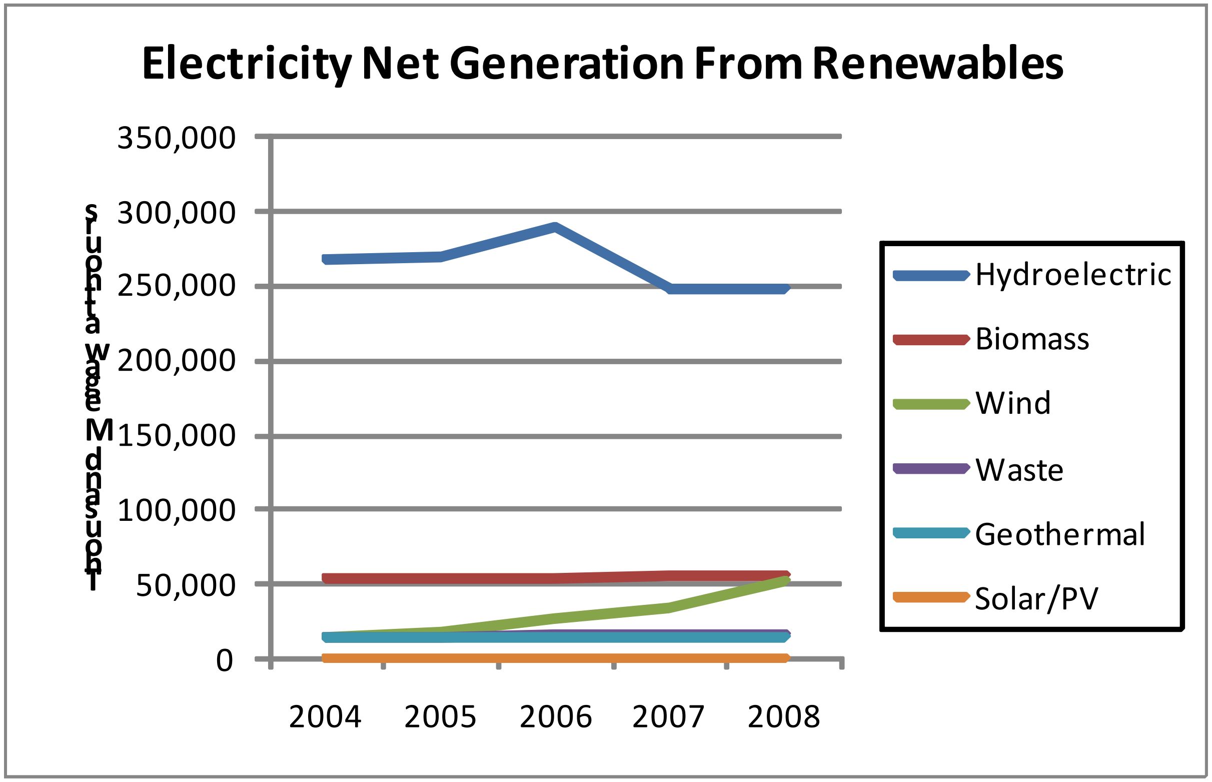
www.dsireusa.org / July 2009



29 states & DC have an RPS

5 states have goals

Renewable Power Generation



Energy Information Administration
Official Energy Statistics from the U.S. Government

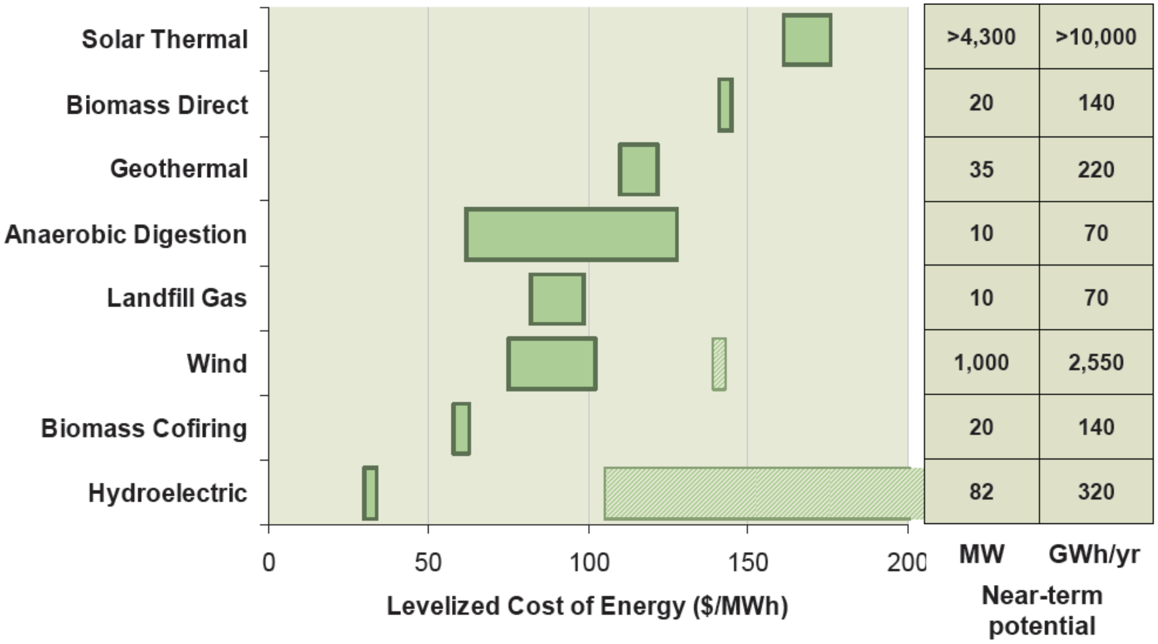
Biomass (2008)

- ➔ **55,875 GWhr total**
  - **38,789 wood and wood wastes**
  - **2,036 agricultural residues, sludge**
  - **8,460 MW MSW**
  - **6,590 landfill gas**
- ➔ **Classes:**
  - **Dedicated**
  - **Co-fired**
    - » **Co-mingled**
    - » **Separate injection**

Biomass Firing Experience

- **Dedicated Firing**
  - Usually smaller units such as stokers and CFBs, common in pulp & paper industry
  - Schiller – 50MW Fluidized Bed – wood

Black & Veatch, EUEC 2008.



	MW	GWh/yr
Solar Thermal	>4,300	>10,000
Biomass Direct	20	140
Geothermal	35	220
Anaerobic Digestion	10	70
Landfill Gas	10	70
Wind	1,000	2,550
Biomass Cofiring	20	140
Hydroelectric	82	320

Near-term potential

- **Co-firing (sample pc units)**

Unit	Size/ Type	Fuel
Bailley	475 MW Cyclone	wood
Willow Island	188 MW Cyclone	wood
Seward / Albright	150 MW T-fired	wood
Dunkirk	100 MW T-fired	wood (poplar)
Gadsden	70 MW T-fired	wood / switchgrass
Ottumwa	725 MW T-fired	switchgrass
Mitchell	150 MW T-fired	switchgrass
Polk	250 MW IGCC	wood
Greenidge	110 MW T-fired	wood

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Moving Forward

- ➔ **Given past demonstrations and current operations, how do we increase usage?**

1) **Identify issues that inhibit biomass usage**
2) **Improve understanding of how biomass firing differs from coal firing**
3) **Develop techniques to guide application and predict performance and operational impacts**

Issues to Consider

- **Fuel collection, storage, processing and handling**
- **Combustion**
  - Combustion stability
  - Burnout
  - Temperature / Heat transfer
  - Efficiency
- **Emissions**
  - Carbon Dioxide
  - Sulfur Oxides
  - Mercury
  - Fine Particles
  - Nitrogen Oxides

- **Operational Impacts**
  - Slagging / Fouling
  - Catalyst deactivation
  - Fly-ash properties
  - Corrosion
- **Economics**
- **Policy**

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Biomass Combustion

- ➔ **Combustion impacted by:**
  - Particle drying and heat-up
  - Volatile yield
  - Devolatilization rate
  - Char oxidation rate
- ➔ **Relative to coal, woody biomass has**
  - Larger and less spherical particles
  - More moisture
  - Less ash
  - More volatiles and less fixed carbon (char)
  - Lower heating value (due mostly to higher moisture)
  - Higher variability in ash content and composition

Combustion Impacts

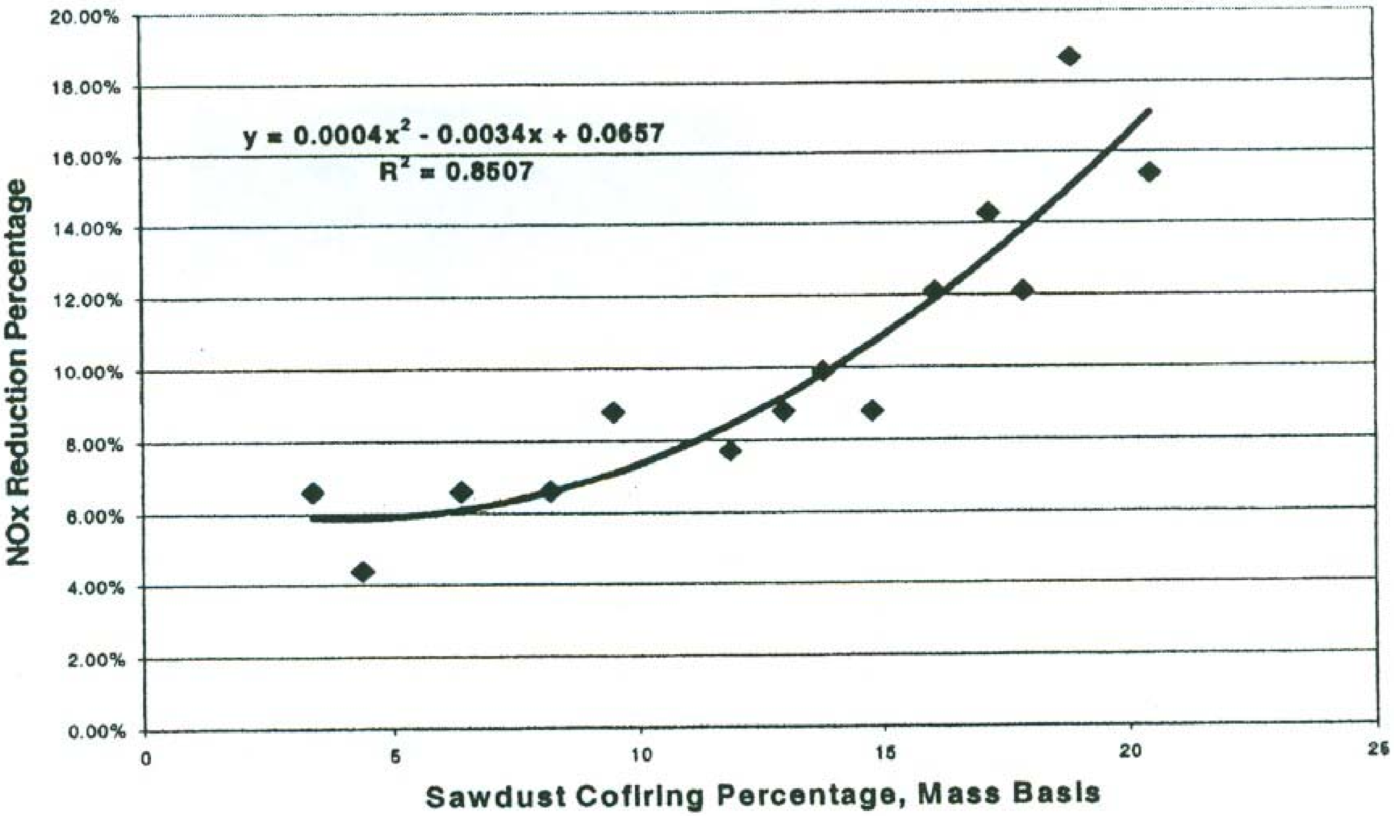
- **For suspension firing:**
  - **If mingled or burner injected, flame stability controlled by injection design**
  - **Burnout is a function of biomass particle size, shape and residence time; generally slower than coal**
  - **Lower adiabatic flame temperature than coal (not necessarily lower flue gas temperature)**
  - **Slightly lower boiler efficiency (~1% per 10 wt% co-fired)**
  - **Significance of impacts depends on amount fired**
- **Application should be addressed on case-by-case basis due variability of biomass and firing systems**

Biomass Emissions

- **Emission reductions are greatest benefit of biomass co-firing**
  - **CO_2 – consider net zero emissions**
  - **SO_2 – lower because biomass is a very low sulfur fuel**
  - **Hg – lower because biomass is a very low mercury fuel**
  - **Fine particulates – co-firing tests have shown minimal impact**
  - **NO_x – complex process, but reductions can be significant**

NOx Reduction: Seward Co-firing

Tillman and Harding (2004)



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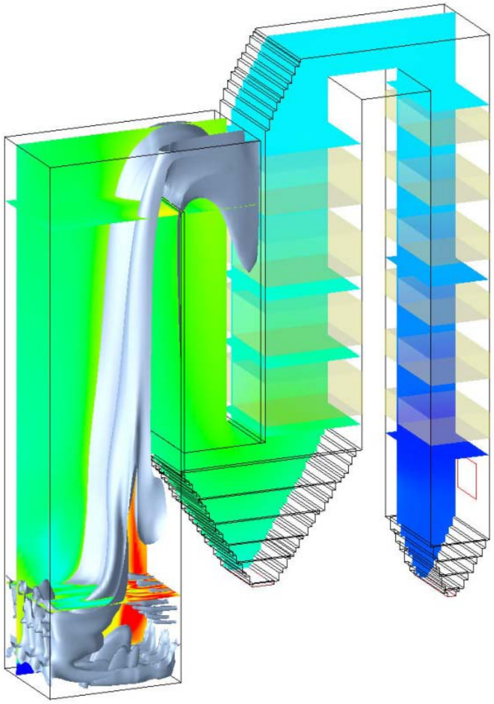
Operational Impacts

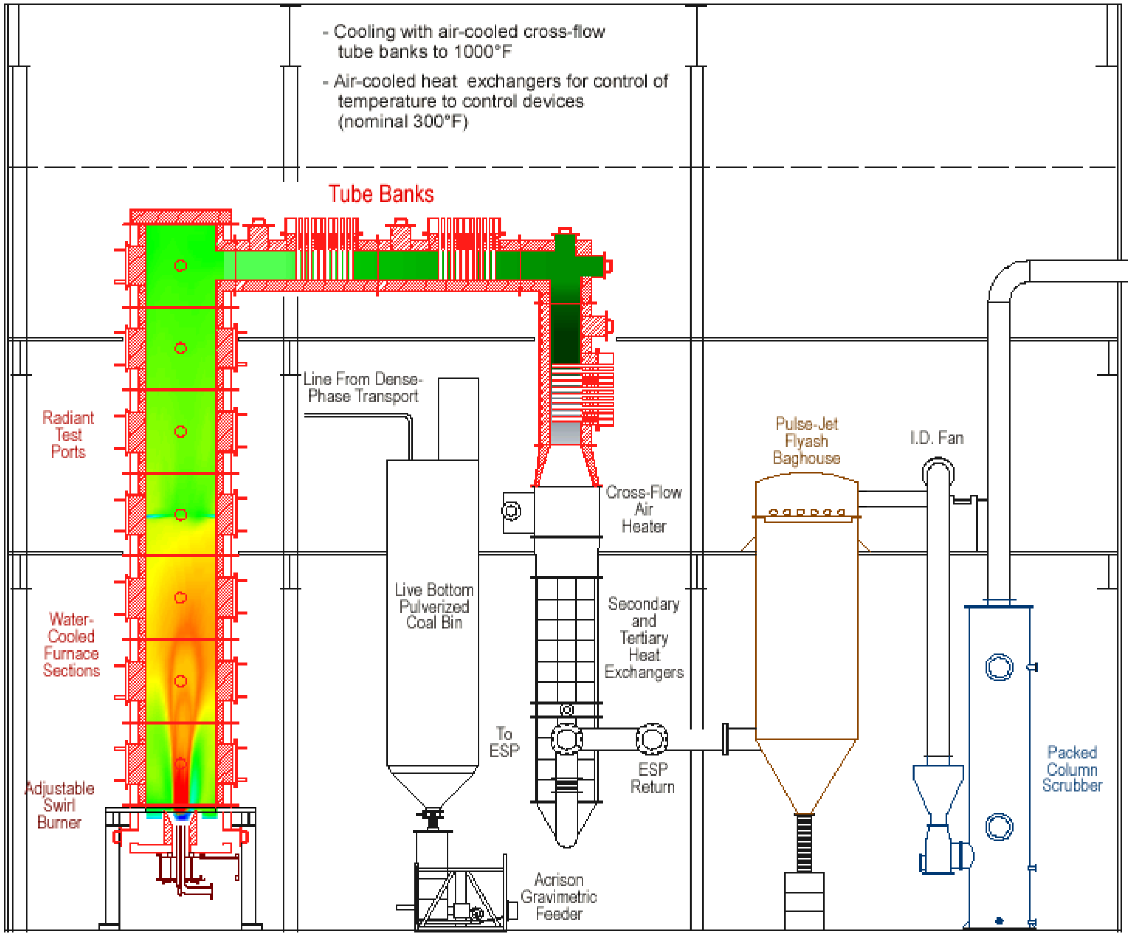
- **Slagging and Fouling**
  - **Depends on deposition rates and ash chemistry (CaO, K_2O, SiO_2)**
  - **100% biomass systems more susceptible**
  - **Co-firing less susceptible (minimal impacts with <10 wt%)**
  - **Urban wood waste has higher slagging/fouling potential than naturally grown or wood products**
- **Potential for corrosion and SCR catalyst impacts with 100% firing; lower ash with co-firing can mitigate impacts**

Predictive Technical Assessment



- Application of co-firing should be assessed on a case-by-case basis
  - Characterization of combustion system
  - Characterization of biomass fuel
  - Appropriate modeling of biomass firing
- Combustion (CFD) modeling can be used to:
  - Characterize current system
  - Assess different biomass injection strategies and fuels
  - Track dispersion, reaction, deposition of coal and biomass
  - Predict combustion, emissions, and slagging/fouling

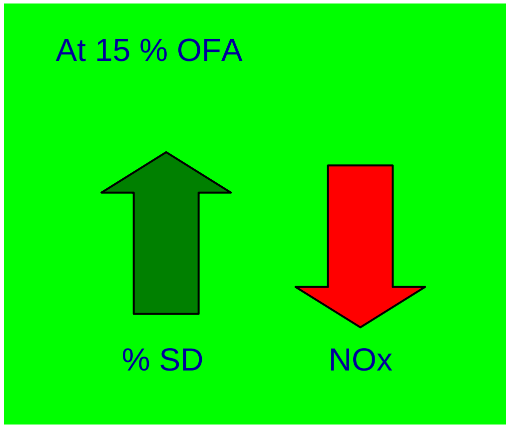
Biomass Injection Strategies



- ➔ **Southern Research Institute facility designed to reproduce pc boiler conditions**
- ➔ **Assess NOx impacts for different injection strategies**
  - ◆ **Co-milled**
  - ◆ **Separate center injection**
- ➔ **Detailed CFD modeling with biomass-specific sub-models**

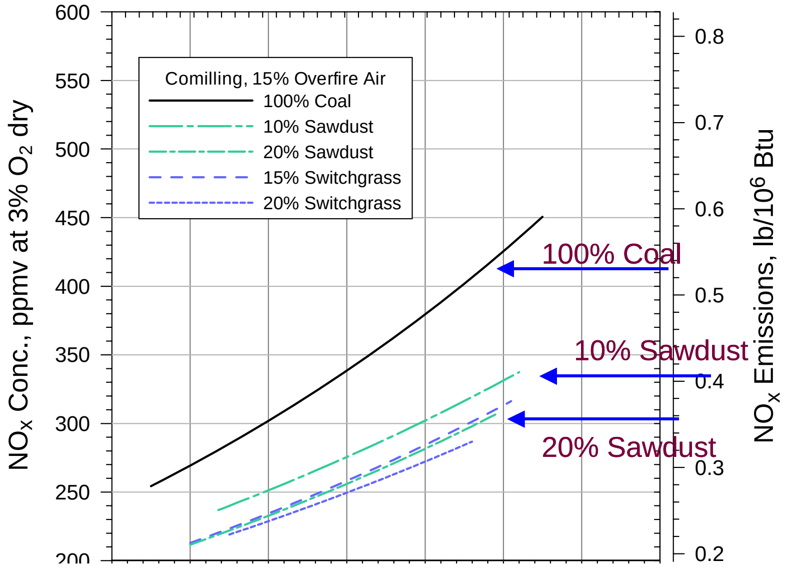
NOx Measurements During Testing

Co-milled


At 15 % OFA

% SD

NOx

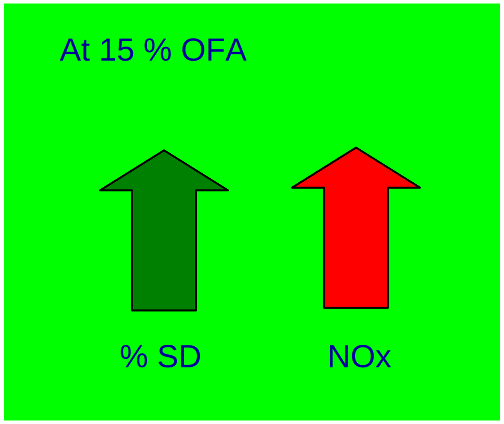


100% Coal

10% Sawdust

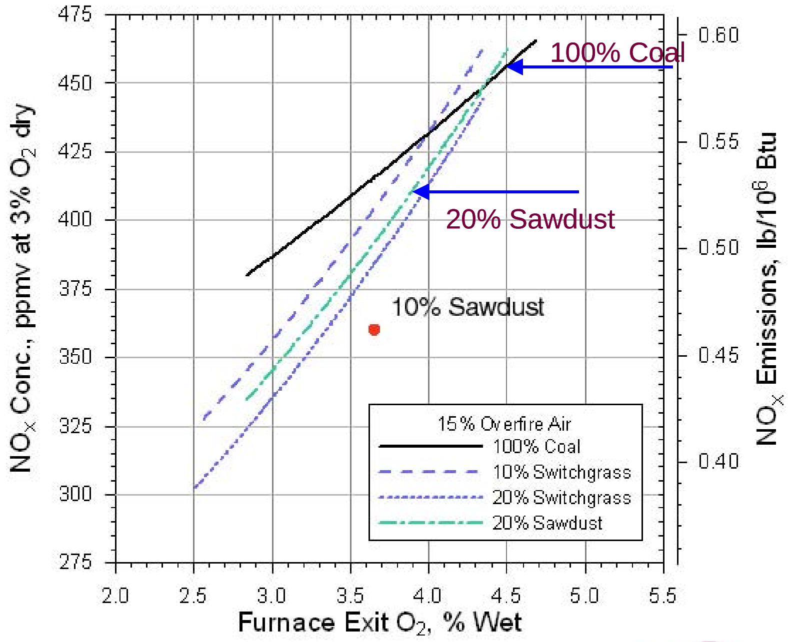
20% Sawdust

Center Injection


At 15 % OFA

% SD

NOx



100% Coal

20% Sawdust

10% Sawdust

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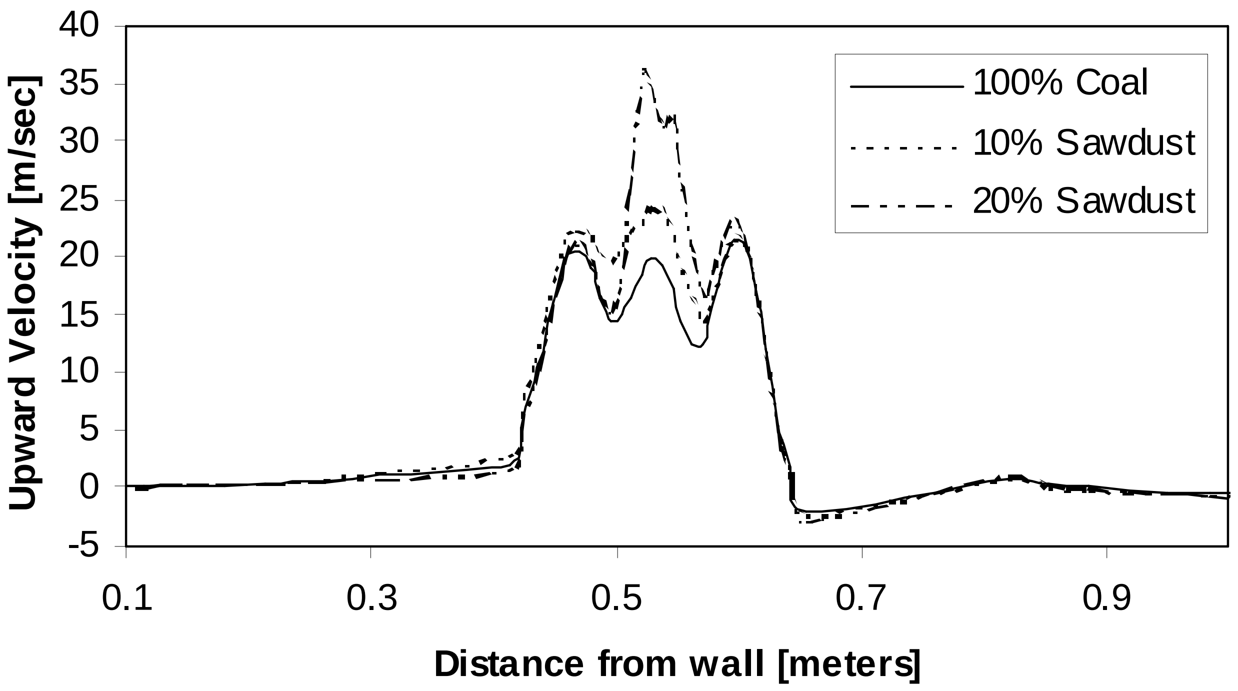
Near Burner Velocity Profile

- CFD showed change to flame shape led to higher NOx



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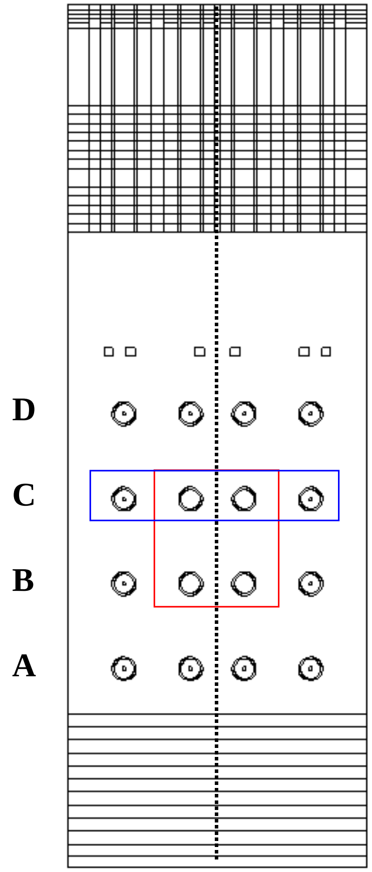
Full-scale NOx Application

- 150 MW front wall-fired boiler
- 16 Low NOx burners in 4 elevations and OFA
- Co-firing scenarios
  - 7% Green Wood Chips based on heat input
  - Separate center injection
    - Multi-fuel burners in “C” row.
    - Multi-fuel burners at center 2 locations in B & C rows
- Determine impacts on
  - NO_x reduction
  - Unburned carbon-in-flyash
  - CO



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Modeling Results

- ➔ **Results look favorable, but how transferable?**

Proximate Analysis	Coal	Biomass
Volatiles	35.70%	48.47%
Fixed Carbon	51.69%	7.68%
Moisture	6.04%	43.47%
Ash	6.57%	0.39%
HHV (Btu/lb)	132701	4667
Ultimate Analysis		
C	72.80%	28.12%
H	5.69%	3.52%
O	6.10%	24.37%
N	1.50%	0.07%
S	1.30%	0.06%
Moisture	6.04%	43.47%
Ash	6.57%	0.39%

	Location	Temp. (°F)	O2 (%)	CO (ppm)	%Carbon-in-flyash	NOx (ppm)
Plant Estimates	Nose	2300	n/a	1500	n/a	n/a
	Economizer Exit	n/a	3.5	n/a	n/a	300
Baseline	Nose	2250	3.9	2930		297
	Furnace Exit	1920	3.7	340	16	292
"C" Row Biomass	Nose	2240	4.0	3370		269
	Furnace Exit	1940	3.8	140	10	264
Center 4 Biomass	Nose	2260	3.9	2020		264
	Furnace Exit	1940	3.7	110	12	267

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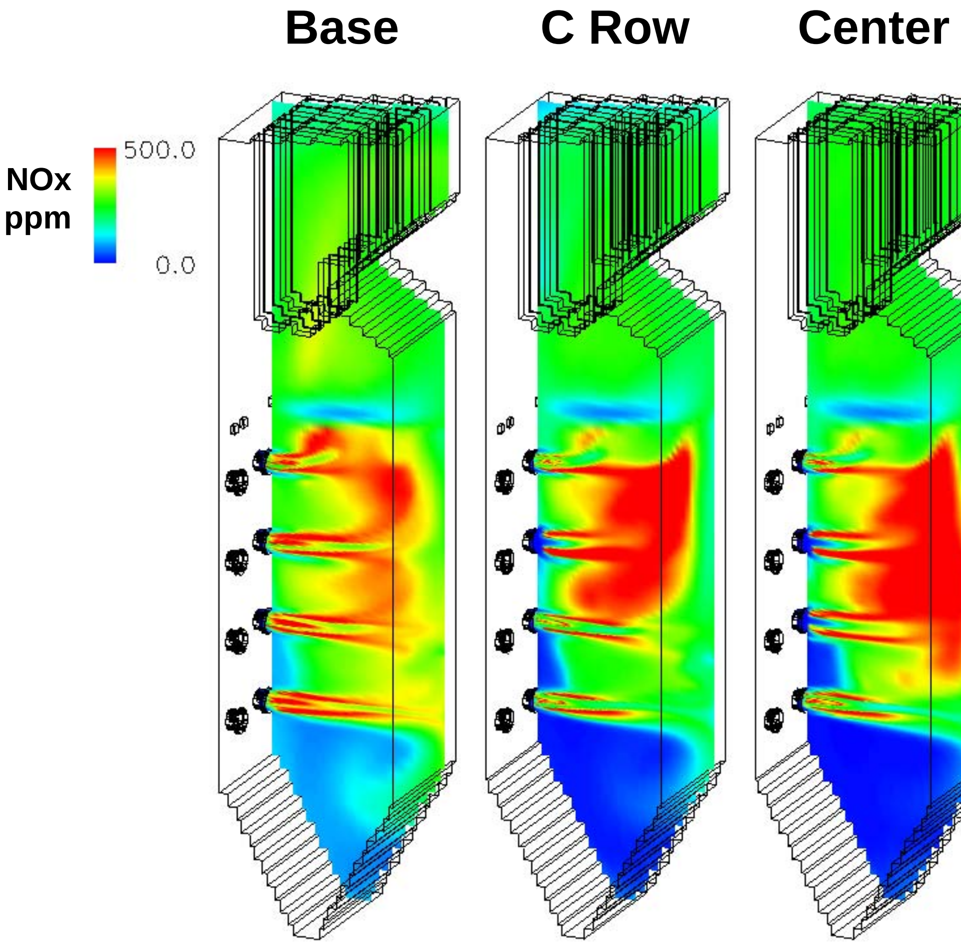
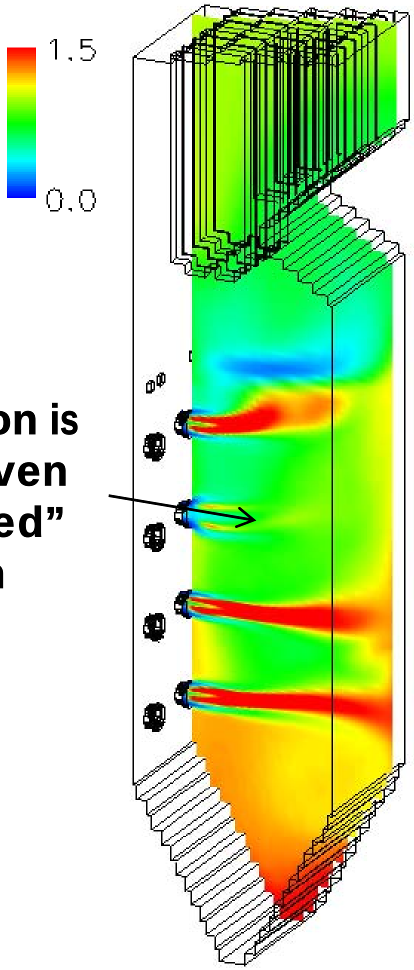
NOx Concentration



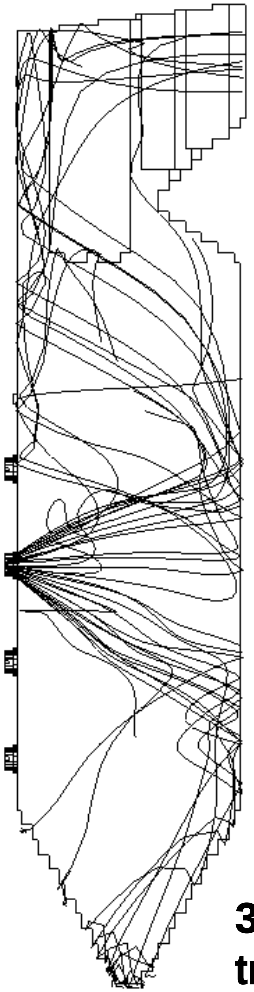
- ➔ **Co-fired burners actually produced more NOx**
- ➔ **Why did NOx go down?**

Wood Particle Paths



Equivalence Ratio

C Row region is fuel lean even though “fired” fuel-rich



3.85 mm particle trajectories

- ➔ **Large, green (wet) wood chips delayed volatile release, creating:**
  - **Fuel-lean upper burner zone which increased NOx**
  - **Fuel-rich lower furnace which reduced NOx from coal-fired burners**
- ➔ **Modeling non-spherical, wet particles with wood kinetics important**

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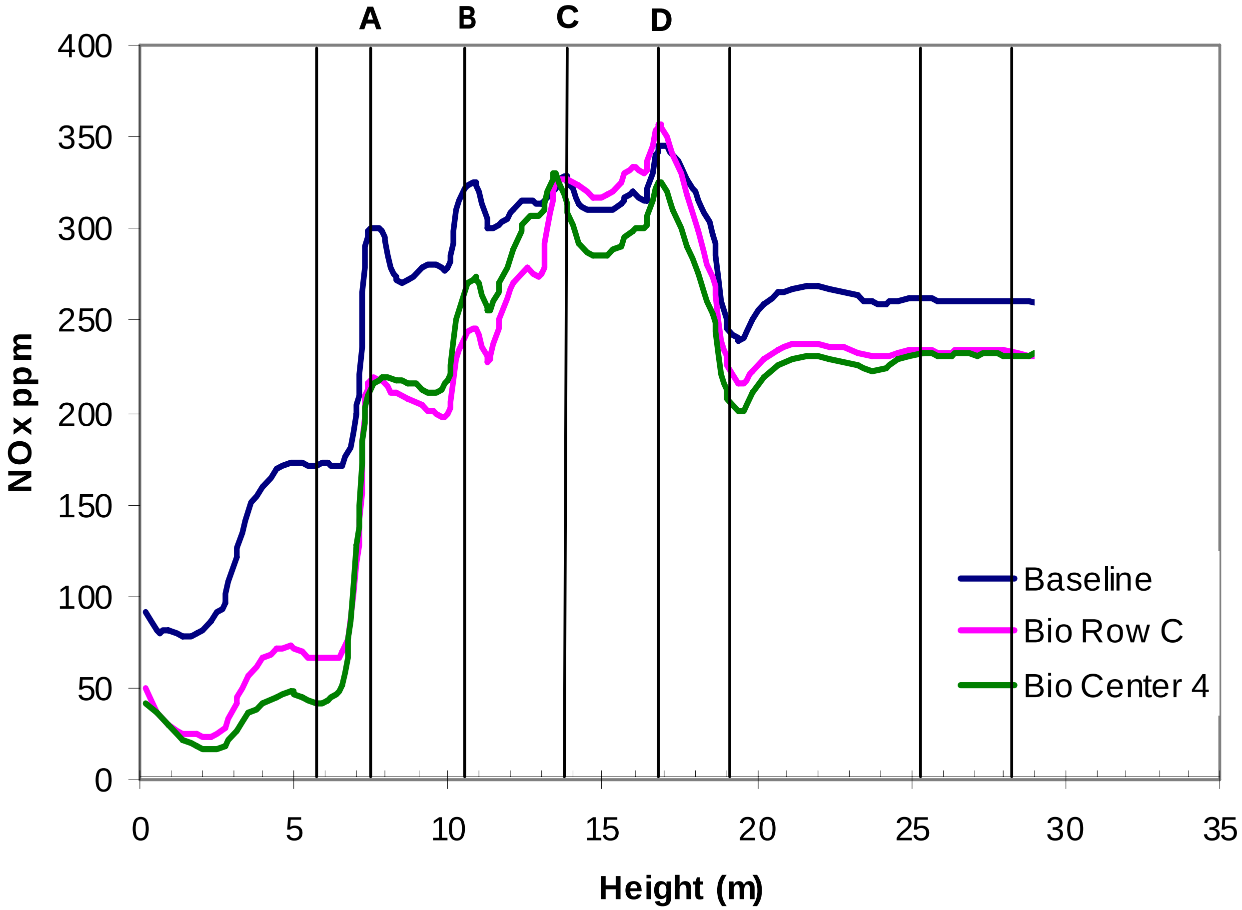
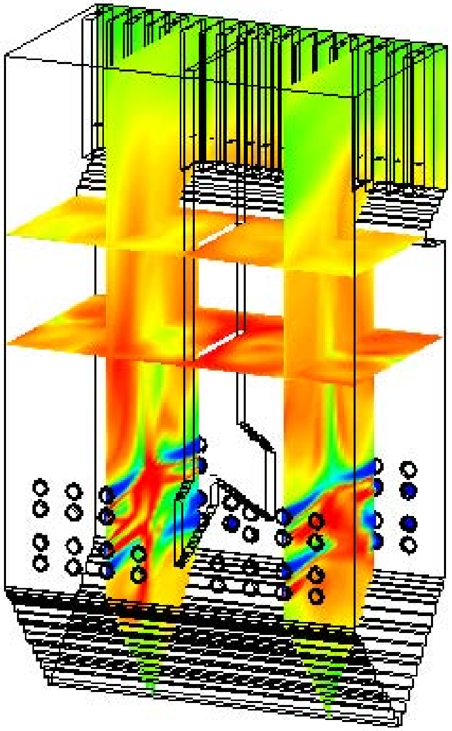
NOx Distribution



Furnace Deposition



- Predict deposition impacts w/ CFD
  - Deposition patterns and rates
  - Size, shape, composition of fly ash
  - Fly ash viscosity = *f*(composition, temperature, local stoichiometry)
  - Deposit sintering = *f*(deposit mass, composition, temperature)
- Unit Summary
  - 800 MW opposed wall-fired unit
  - 56 burners firing 55/45% PRB/MSB coal blend

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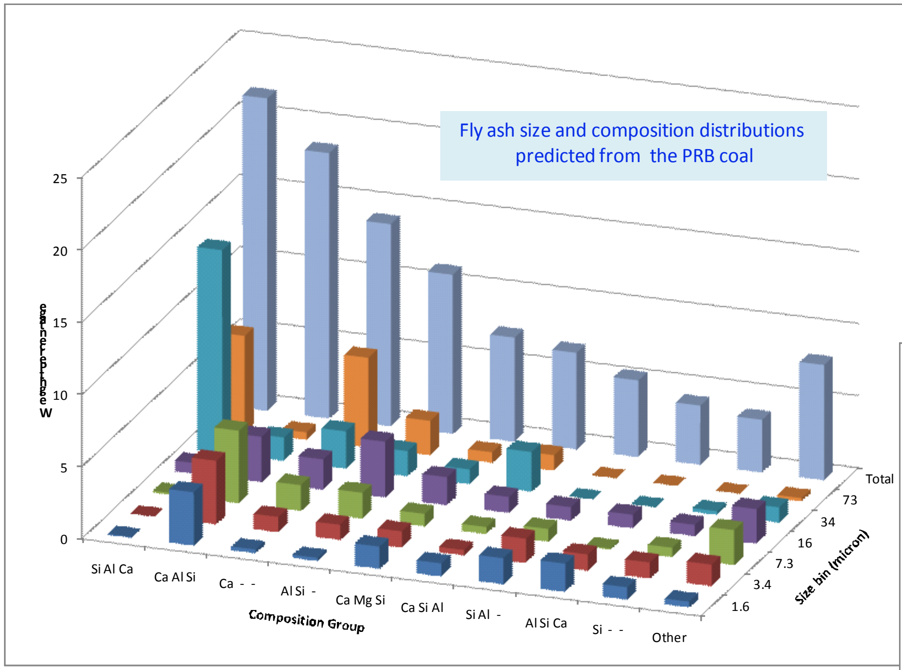
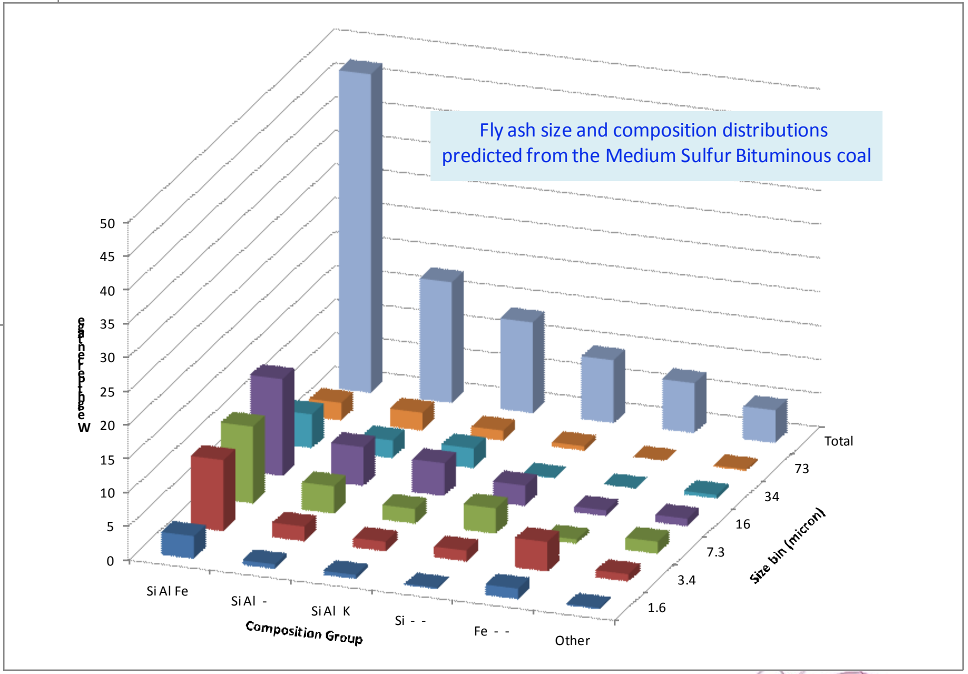
Fly Ash Size and Composition

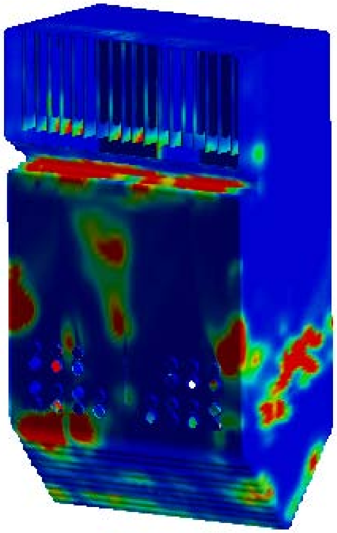
- ➔ **Track properties separately (size, composition, trajectory)**
  - ◆ **PRB has mostly Si-Al-Ca group**
  - ◆ **MSB has mostly Si-Al-Fe group**

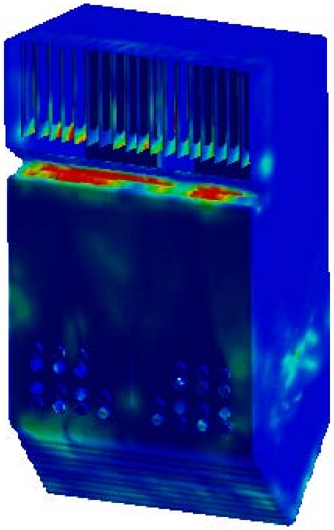

Fly ash size and composition distributions predicted from the PRB coal

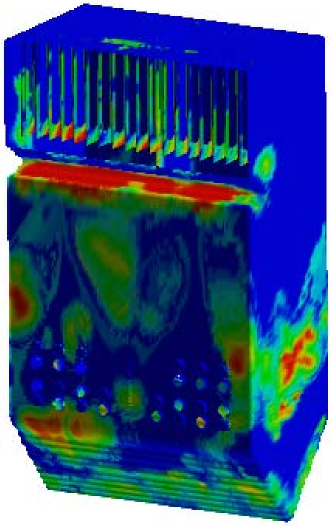

Fly ash size and composition distributions predicted from the Medium Sulfur Bituminous coal

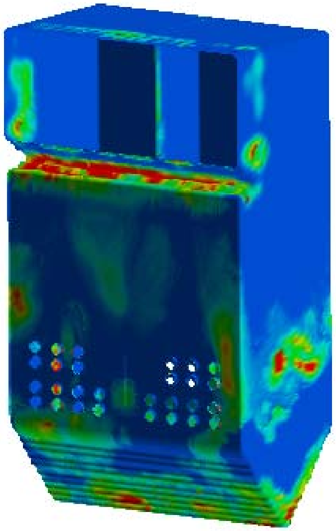
Predicted Deposition Impacts

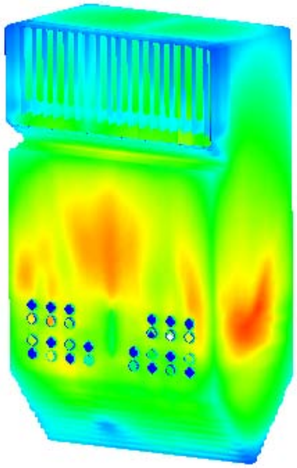
- ➔ **6-hours after build-up**
- ➔ **Deposits change performance**

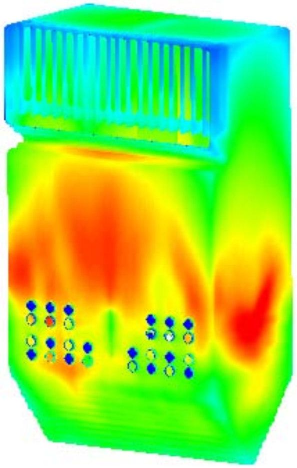

Deposition rate

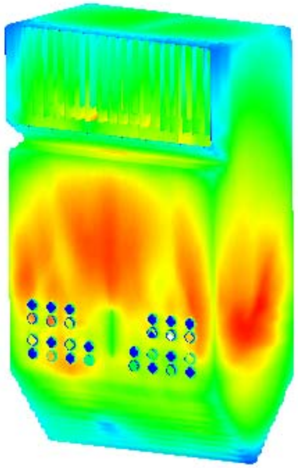

Deposit thickness

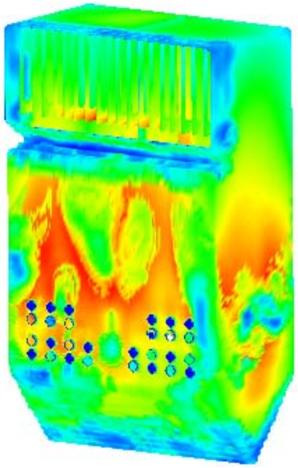

Deposit sintering


Deposit resistance


Initial incident heat flux


6-hr incident heat flux


Initial net heat flux


6-hr net heat flux

T_{exit} up 80 °F
NOx up 18%

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Summary

- ➔ Biomass has a role in future power generation, but current applications are limited
- ➔ Key technical issues for moving forward include
  - Fuel processing and handling
  - Combustion impacts
  - Emissions
  - Operational impacts
- ➔ Case-by-case characterization of system, fuel and injection strategies can help assess applicability
- ➔ Combustion modeling can provide assessment of combustion, emissions and operational impacts