# Assessing Combustion and Emission Impacts of Firing Biomass for Power Generation

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*For Energy and*
*Environmental*
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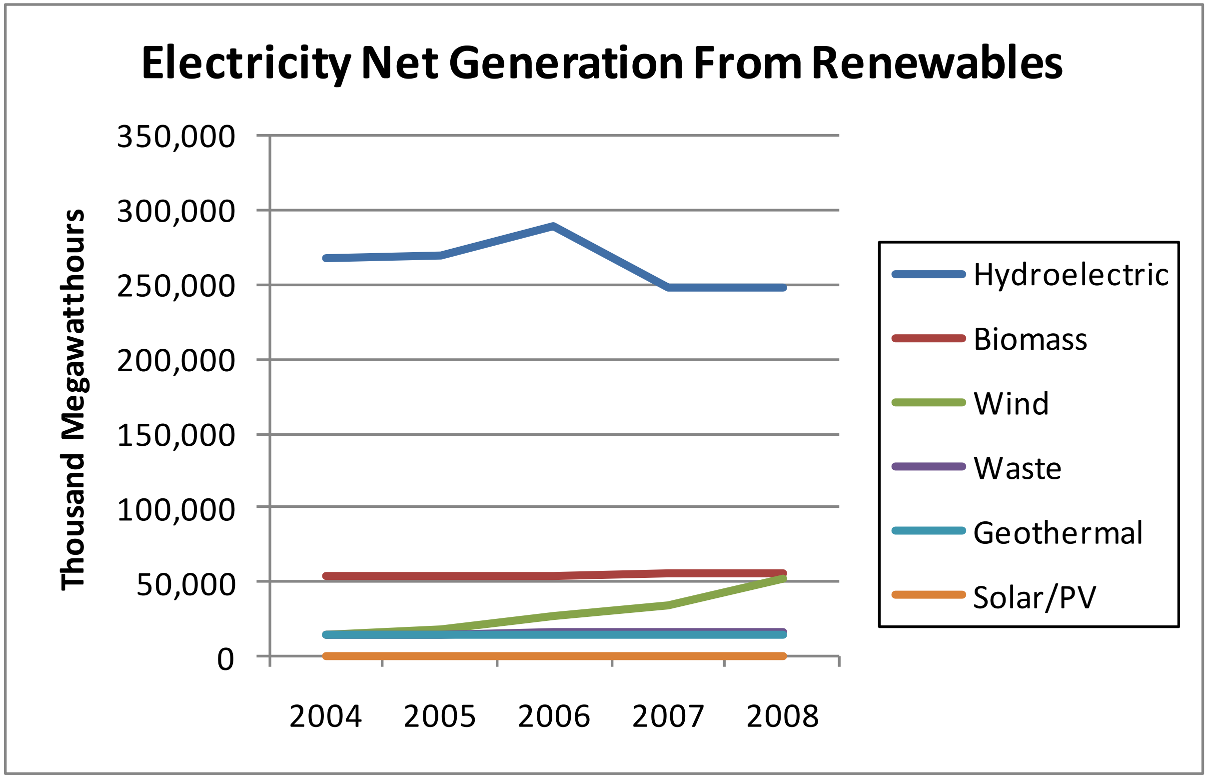
**Hot Topic Hour** THE McILVAINE COMPANY

***Co-Firing Biomass, Sewage Sludge, Municipal Waste***

**August 5, 2010**

# Renewable Power Generation



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

**<u>Biomass (2008)</u>**

- **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**

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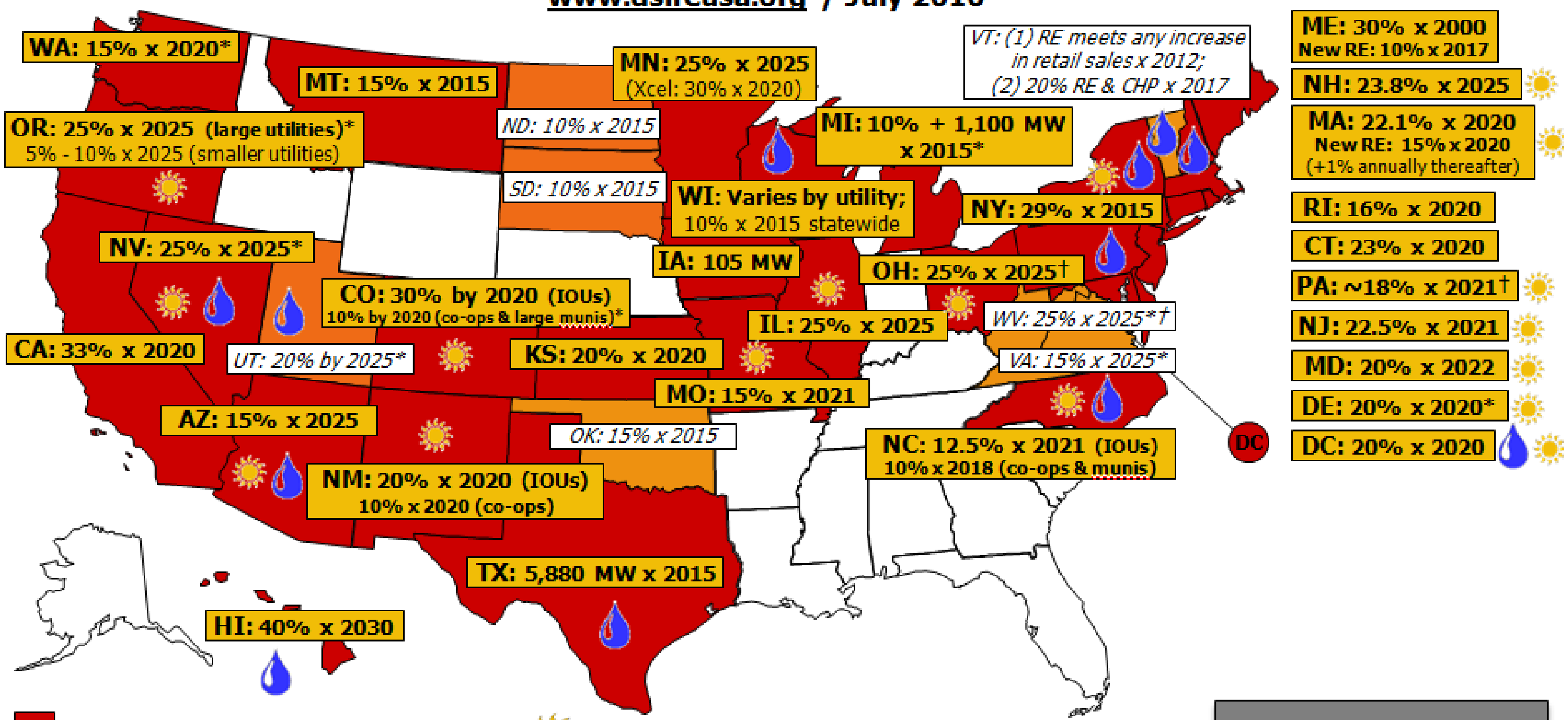
# Legislative Driving Force

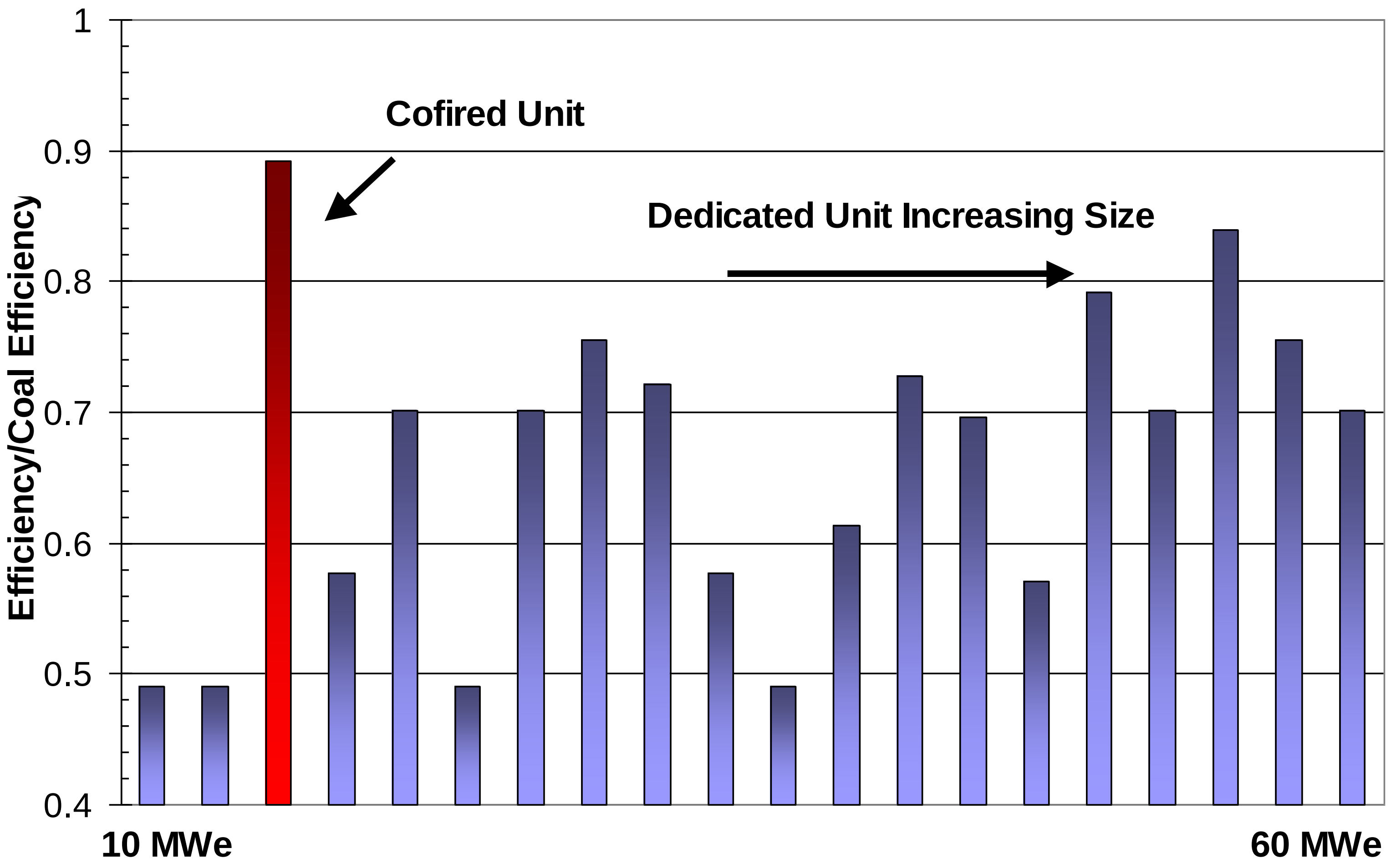
**www.dsireusa.org / July 2010**



- 🟥 State renewable portfolio standard
- 🟧 State renewable portfolio goal
- 💧 Solar water heating eligible
- ☀ Minimum solar or customer-sited requirement
- * Extra credit for solar or customer-sited renewables
- † Includes non-renewable alternative resources

**29 states + DC have an RPS**
*(7 states have goals)*

# Efficiency of Biomass-fired Boilers



# 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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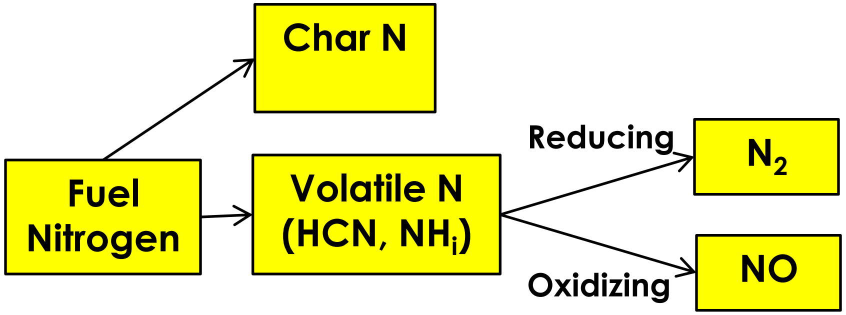
# Biomass Combustion

- 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

# 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**

# Biomass NOx



Char N

Fuel Nitrogen

Volatile N (HCN, $NH_i$)

Reducing

$N_2$

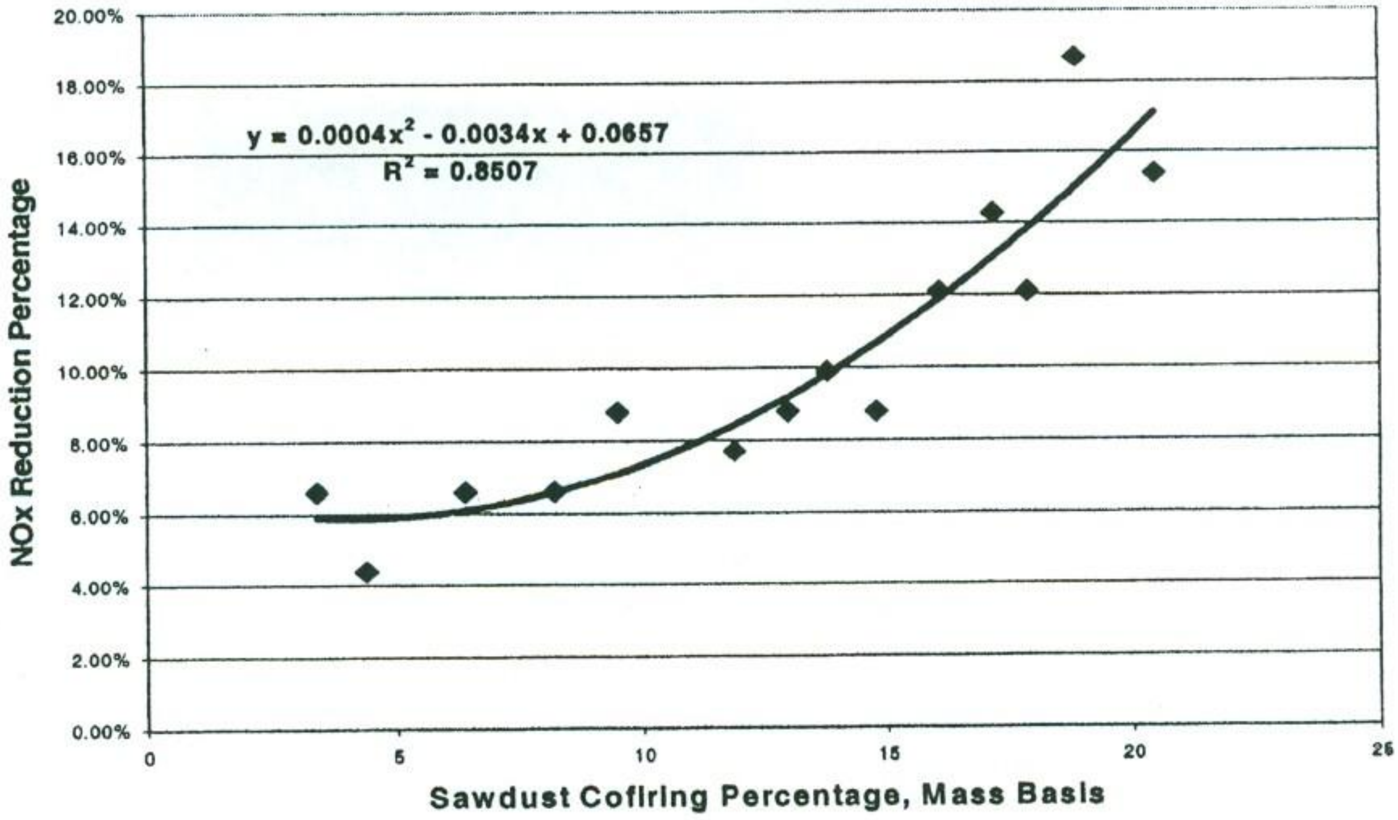
Oxidizing

NO

- **Fuel NOx from volatile products**
  - Based on fuel nitrogen content, pyrolysis yield, and rate of volatile nitrogen release (relative to fuel)
  - Biomass volatile content higher than coal, can produce early fuel-rich zone in flame and reduce subsequent fuel NOx
  - Biomass volatile nitrogen evolves more rapidly than total volatiles and tends to form $NH_i$ instead of HCN
- **Fuel NOx from char oxidation**
  - Based on char yield and NOx in gas-phase
  - Biomass impact low due to low char N
- **Thermal NOx**
  - Based on gas temperature
  - Biomass higher moisture produces lower flame temperature

# NOx Reduction: Seward Co-firing

Tillman and Harding (2004)



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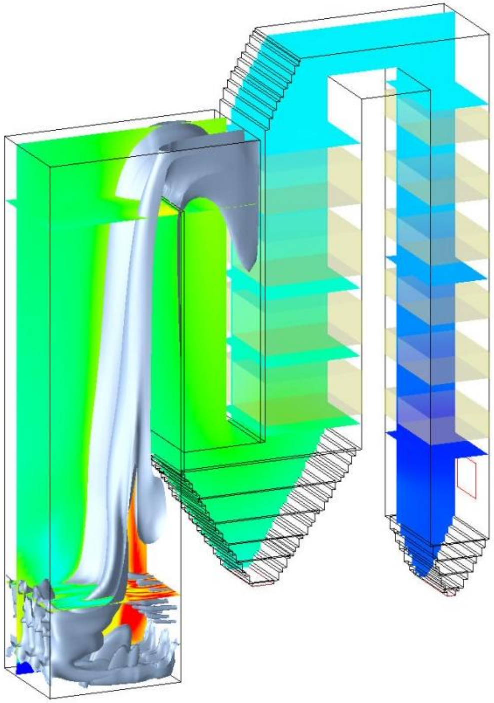
# Operational Impacts

- **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; low ash with co-firing mitigates impacts**

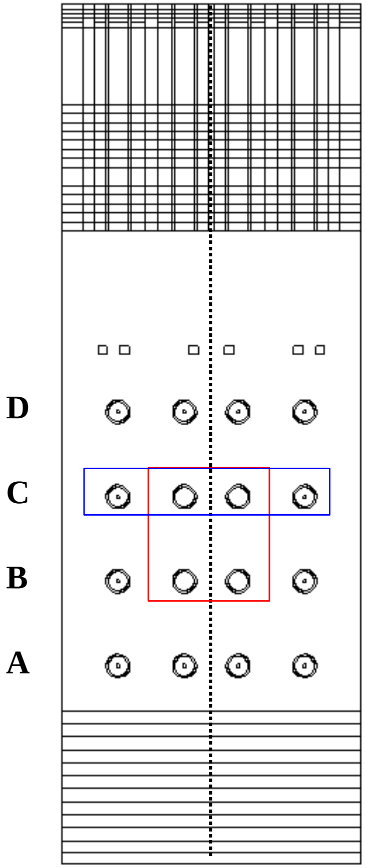
# Predictive Technical Assessment



- **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**

# 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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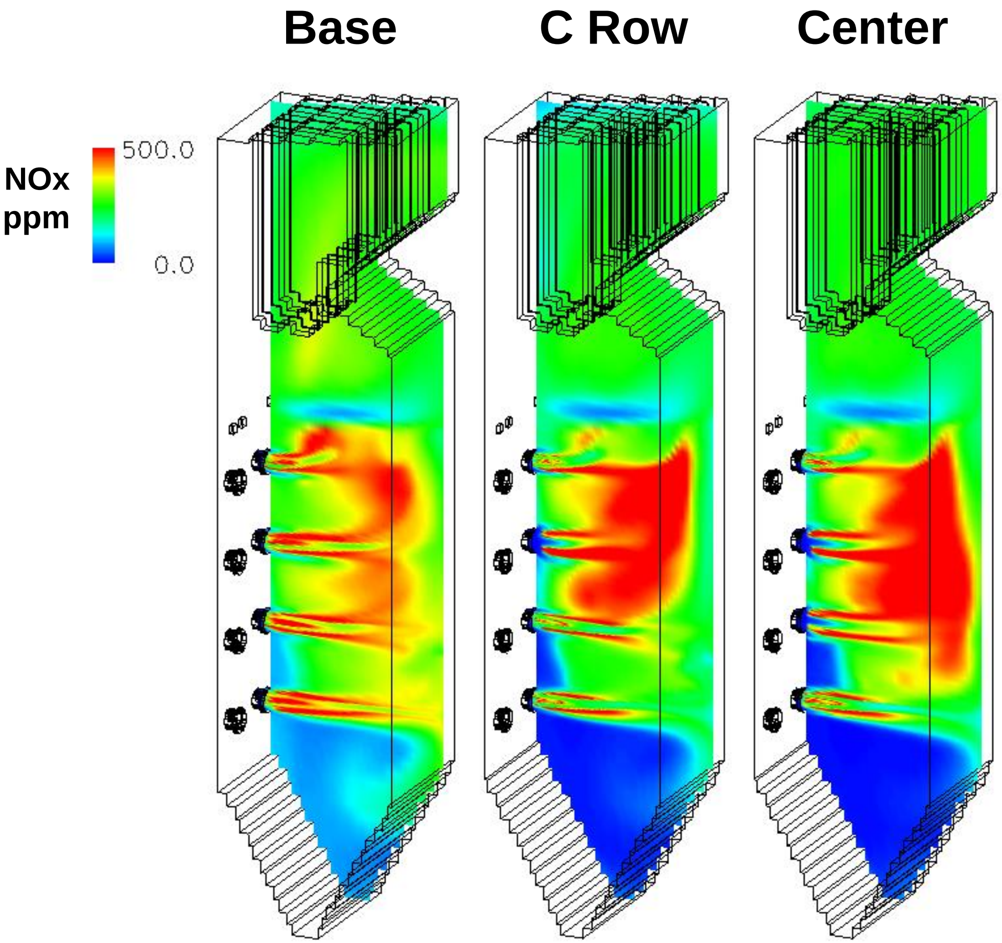
# Modeling Results

| 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% |

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

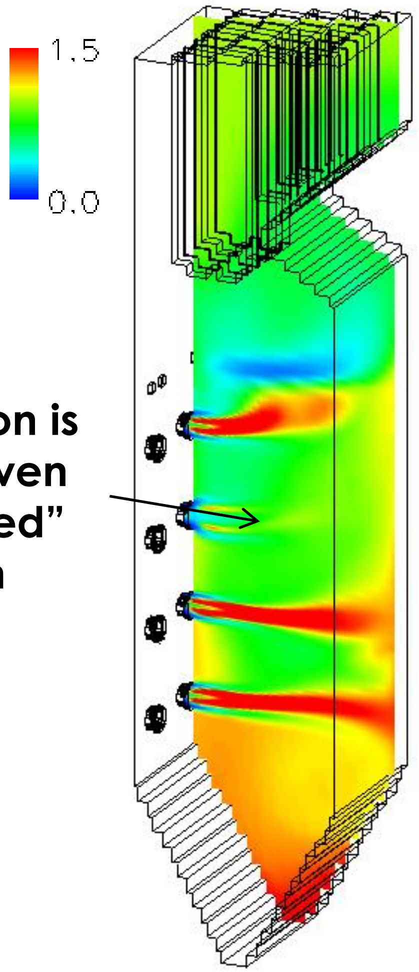
| | Location | Temp. (°F) | O2 (%) | CO (ppm) | %Carbon-in-flyash | NOx (ppm) |
|---|---|---|---|---|---|---|
| Plant Estimates | Nose | 2300 | n/a | 1500 | n/a | n/a |
| | Economizer Exit | n/a | 3.5 | n/a | n/a | 300 |
| Baseline | Nose | 2250 | 3.9 | 2930 | | 297 |
| | Furnace Exit | 1920 | 3.7 | 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 |

# NOx Concentration

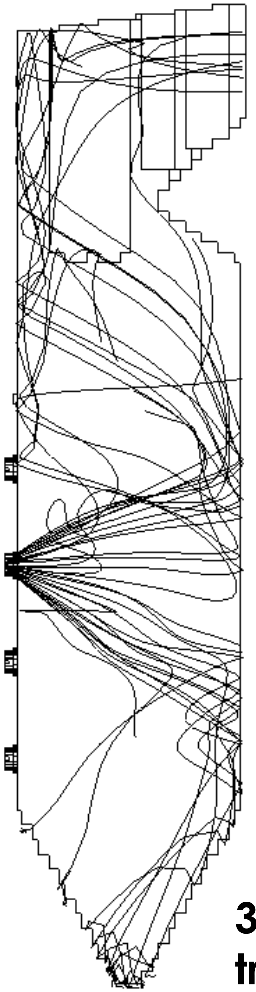


- Co-fired burners actually produced more NOx
- Why did NOx go down?

# Wood Particle Paths



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

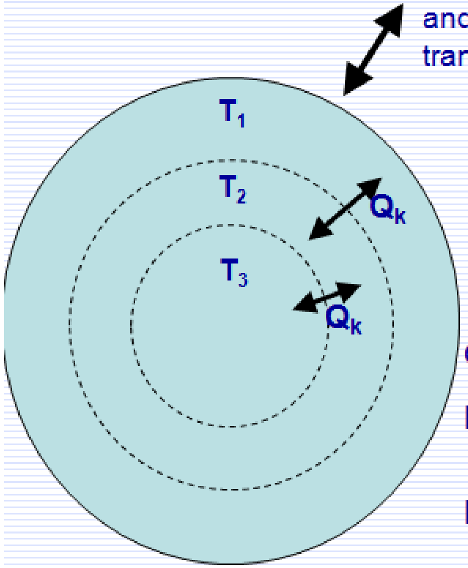


3.85 mm particle trajectories

- ➔ **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**

# Biomass Particle Combustion (Cyclones & Stokers)

- Large particles are modeled as a series of concentric spherical shells of equal mass
- The number of shells is dependent on the particle diameter
- External radiative and convective heat transfer are only to the outermost shell
- Conductive heat transfer occurs between each shell and the shells immediately adjacent



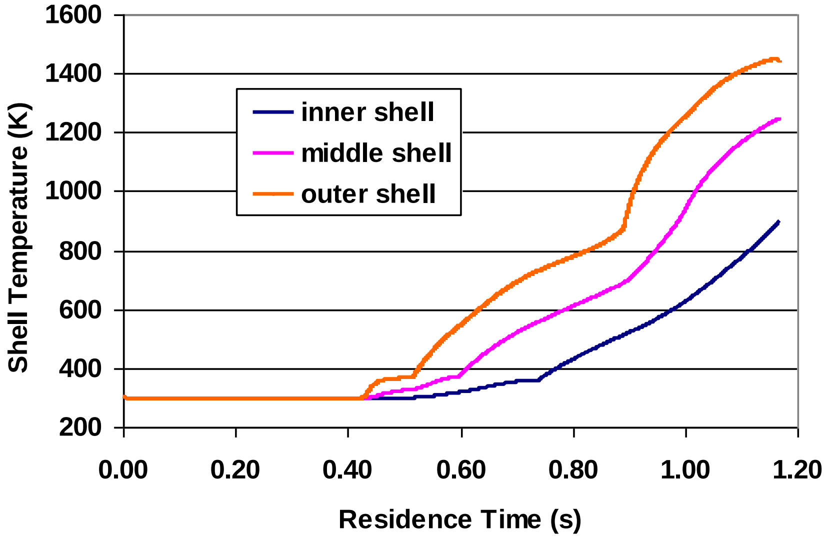
$Q_k = - K\, A_{surf} \, {}^{dT}/_{dx}$

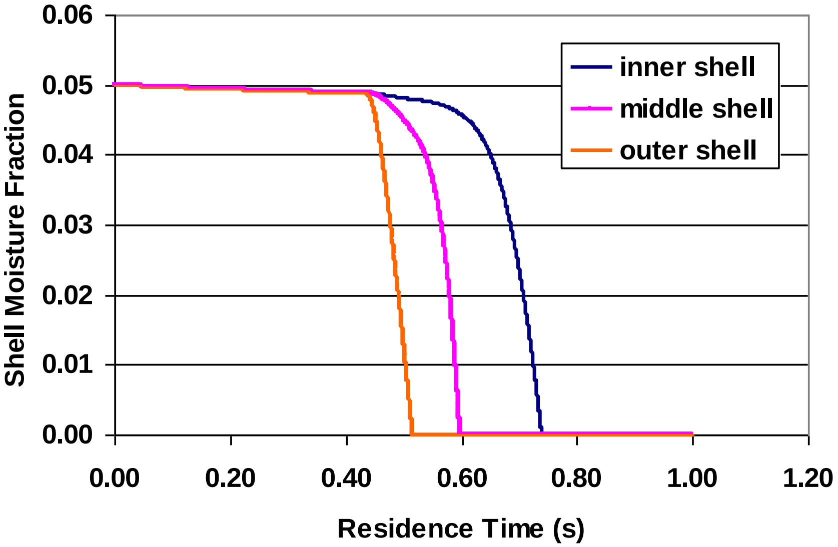
For coal:
K = 1.5 W/m/K

For wood:
K = 0.12 W/m/K

Three Shell Example

# Drop Tube Shell Model Example





- ➔ **Temperature increase and drying of outer shell occurs most rapidly; inner shell most slowly**
- ➔ **While moisture is present in a shell, the temperature of that shell is limited to boiling temperature (373 K)**
- ➔ **The temperature of the outer shell is well above the boiling temperature while moisture is still present in the inner shell**

Three shell example
with K = 0.12 W/m/K
(wood conductivity)

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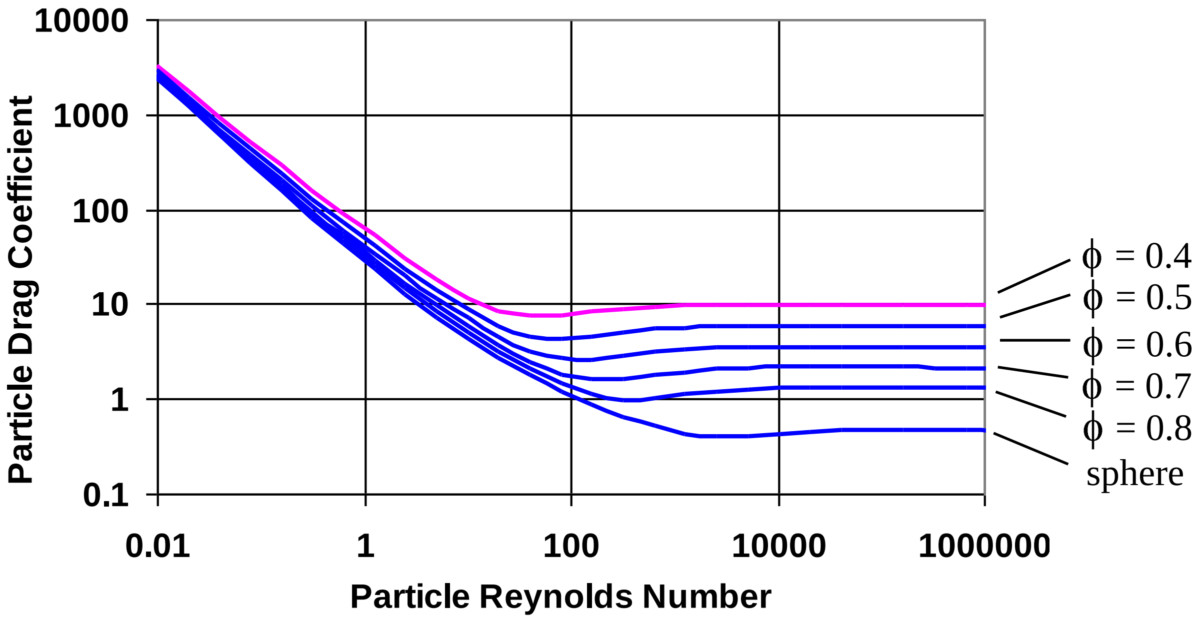
# Drag on Non-Spherical Particles

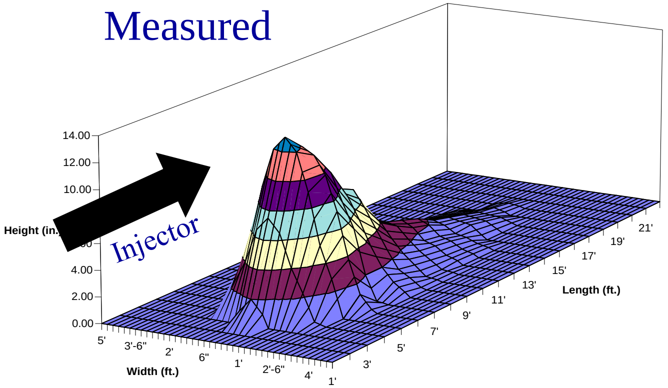
Particle drag is calculated in terms of a shape factor $\phi$ (Haider and Levenspiel, *Powder Technology*, 58 (1989), pp63-70.

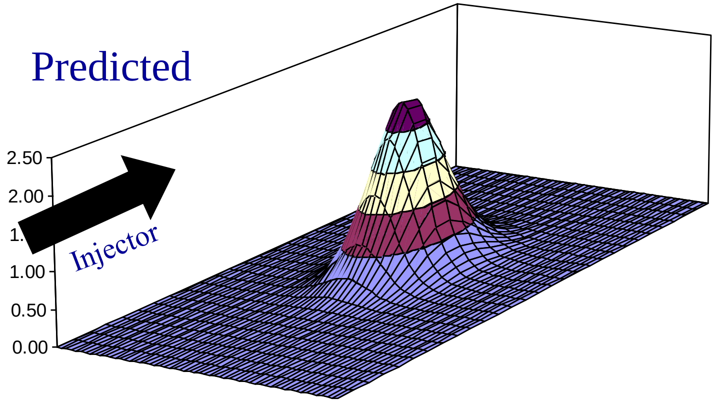
$$\phi = \frac{\text{Surface area of sphere of same volume}}{\text{Surface area of particle}}$$



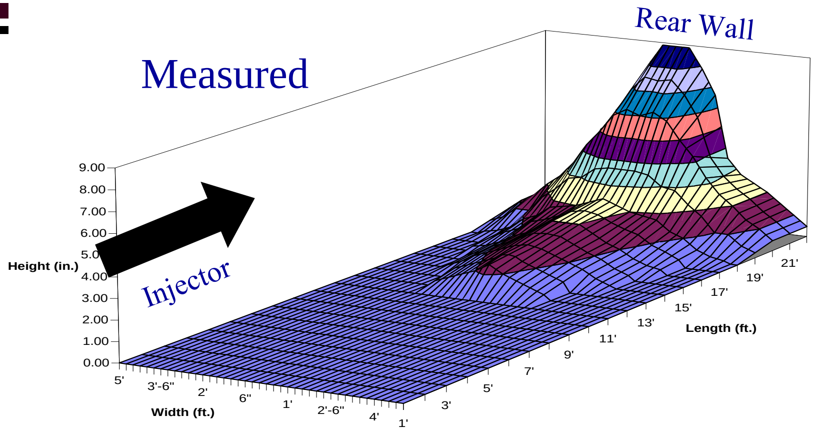
Particle drag increases with increasing deviation from spherical shape

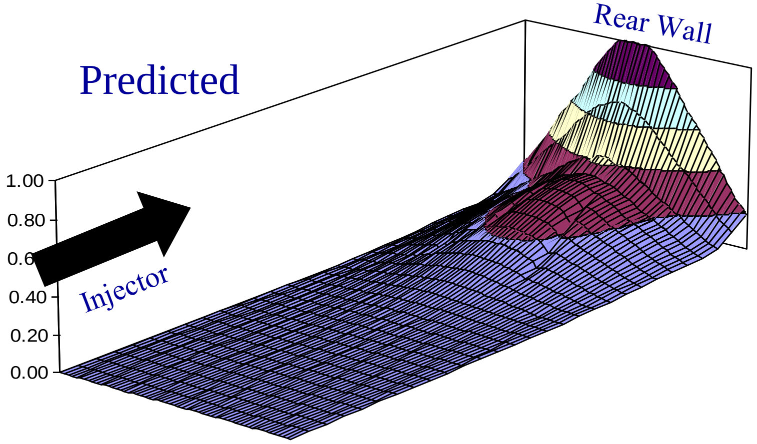
# Non-Spherical Drag Model Verification


Measured


Predicted

Low air velocity


Measured


Predicted

High air velocity

Wood chip spread from an air blast spreader

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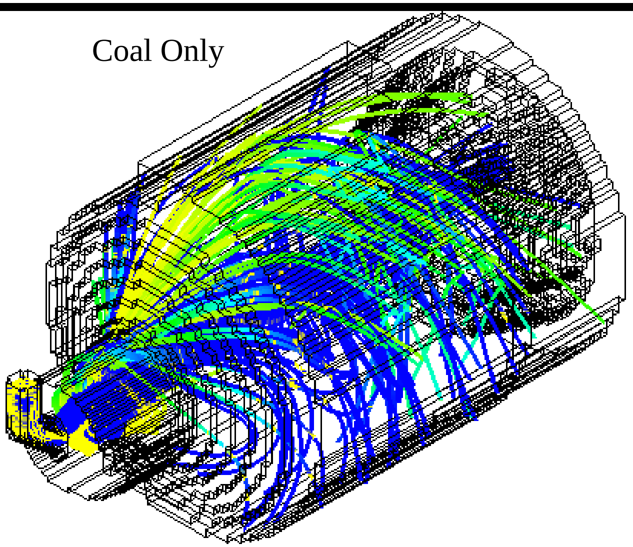
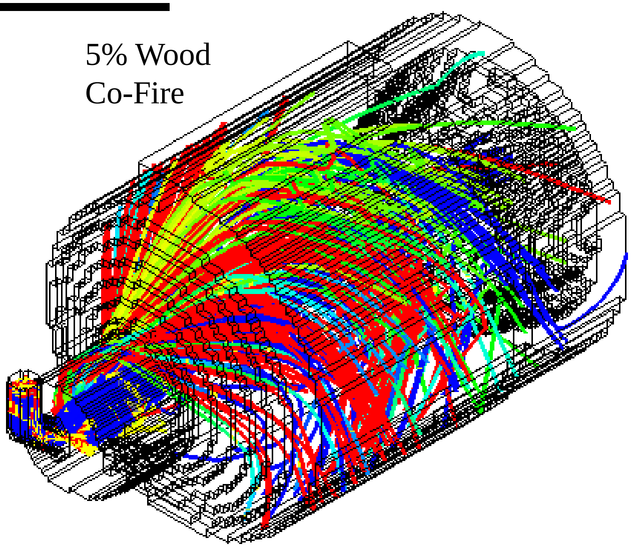
# Cyclone Boiler Application

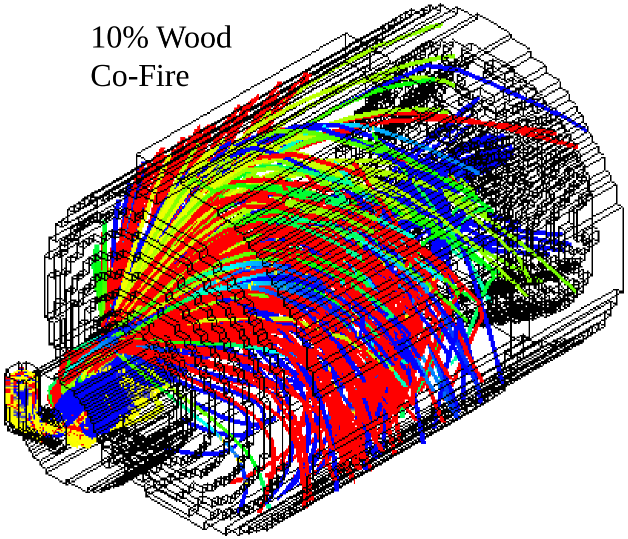
Coal Only



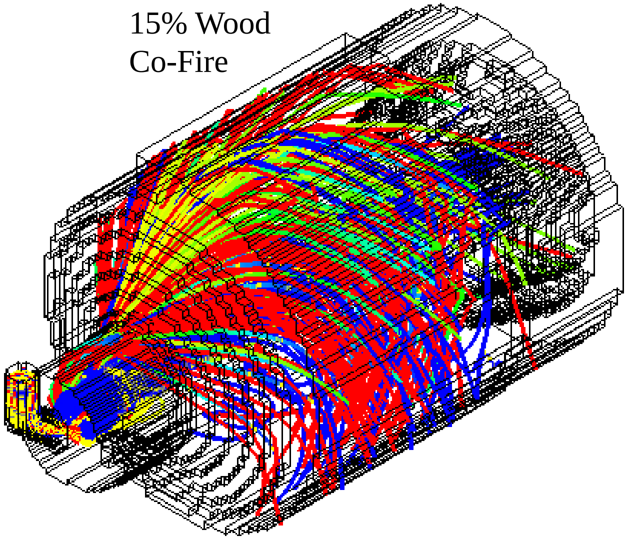
5% Wood Co-Fire



10% Wood Co-Fire



15% Wood Co-Fire



> 10%

Particle Moisture

0%

Mass Weighted Average of All Shell Moisture Contents

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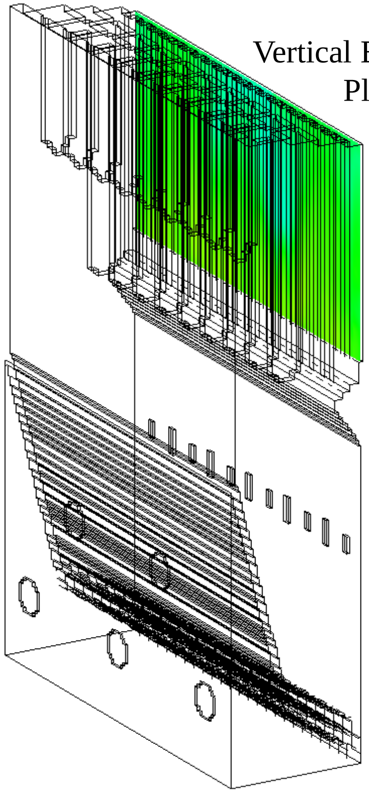
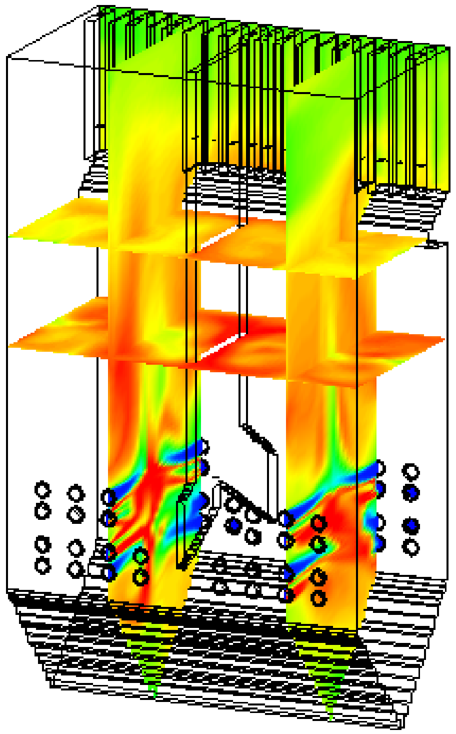
# Furnace Exit Predictions



| | Coal Only | 5% Wood Co-Fire | 10% Wood Co-Fire | 15% Wood Co-Fire |
|---|---|---|---|---|
| Temperature | 2332° F. | 2355° F. | 2354° F. | 2363° F. |
| CO Concentration | 3761 ppm | 4876 ppm | 4951 ppm | 5373 ppm |
| O2 Concentration | 3.48% | 3.41% | 3.48% | 3.40% |
| NOx | 0.41 MBtu/hr | 0.41 MBtu/hr | 0.40 MBtu/hr | 0.38 MBtu/hr |
| Carbon in Fly Ash | 69% | 62% | 58% | 56% |
| Fraction Ash Escaping | 15% | 17% | 20% | 20% |
| Total Wall Heat Transfer | 694,741 Btu/hr | 694,659 Btu/hr | 669,966 Btu/hr | 639,127 Btu/hr |

- Predicted furnace exit NOx and carbon in fly ash decrease with wood co-firing
- The fraction of ash escaping the furnace, CO concentration, and temperature increase with wood co-firing
- Wall heat transfer decreases with increasing fraction of wood co-firing (the decreased sooting propensity of wood vs. coal results in less radiative heat transfer to the walls)

# 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/Bit.  coal blend

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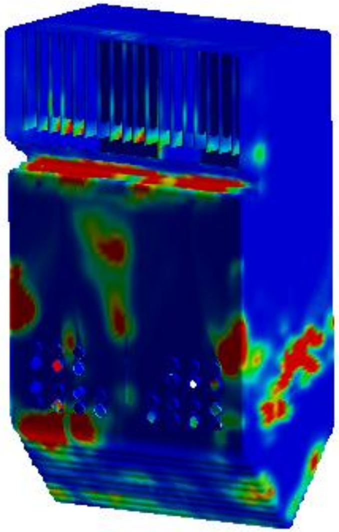
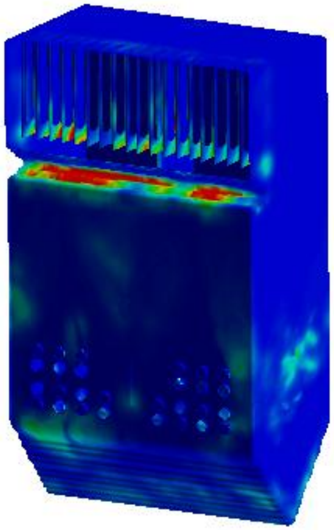
# Predicted Deposition Impacts

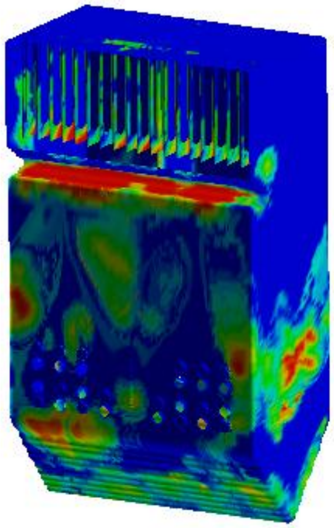
- 6-hours after build-up
- Deposits change performance



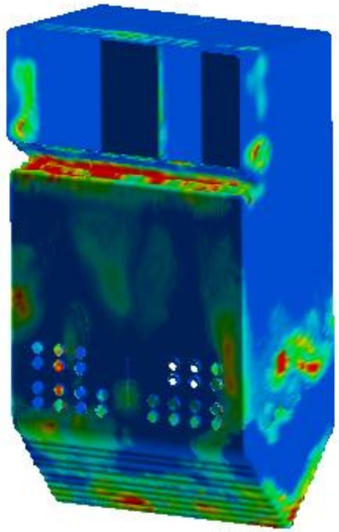
**Deposition rate**



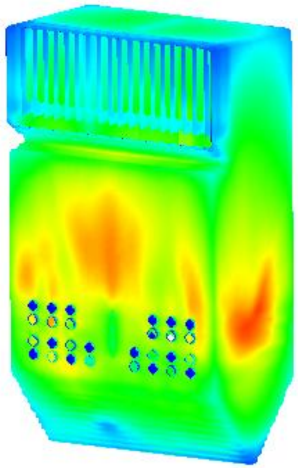
**Deposit thickness**



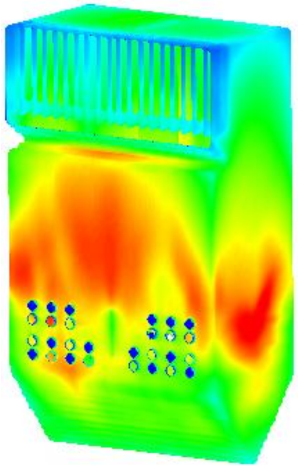
**Deposit sintering**



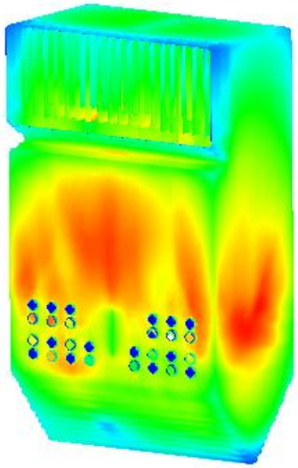
**Deposit resistance**



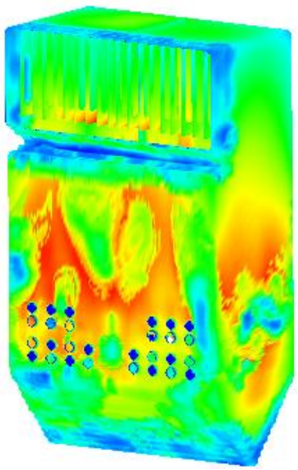
**Initial incident heat flux**



**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