REINHOLD ENVIRONMENTAL Ltd.

2013 NOx-Combustion Round Table & Expo Presentations

February 18 & 19, 2013, in Salt Lake City, UT / Hosted by PacifiCorp

Flow Modeling and Ash Deposition

NOx-Combustion Round Table
February 19, 2013

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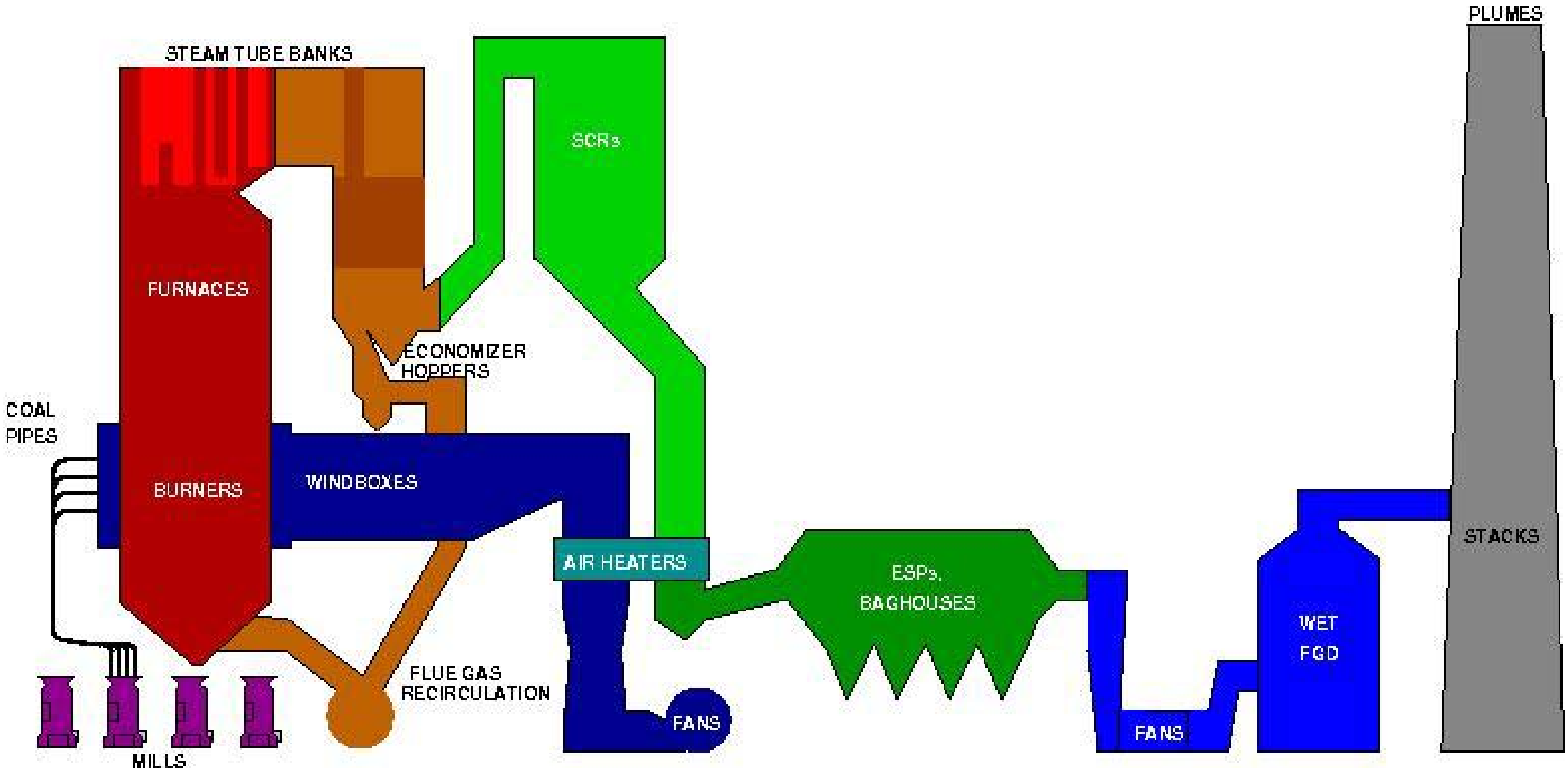
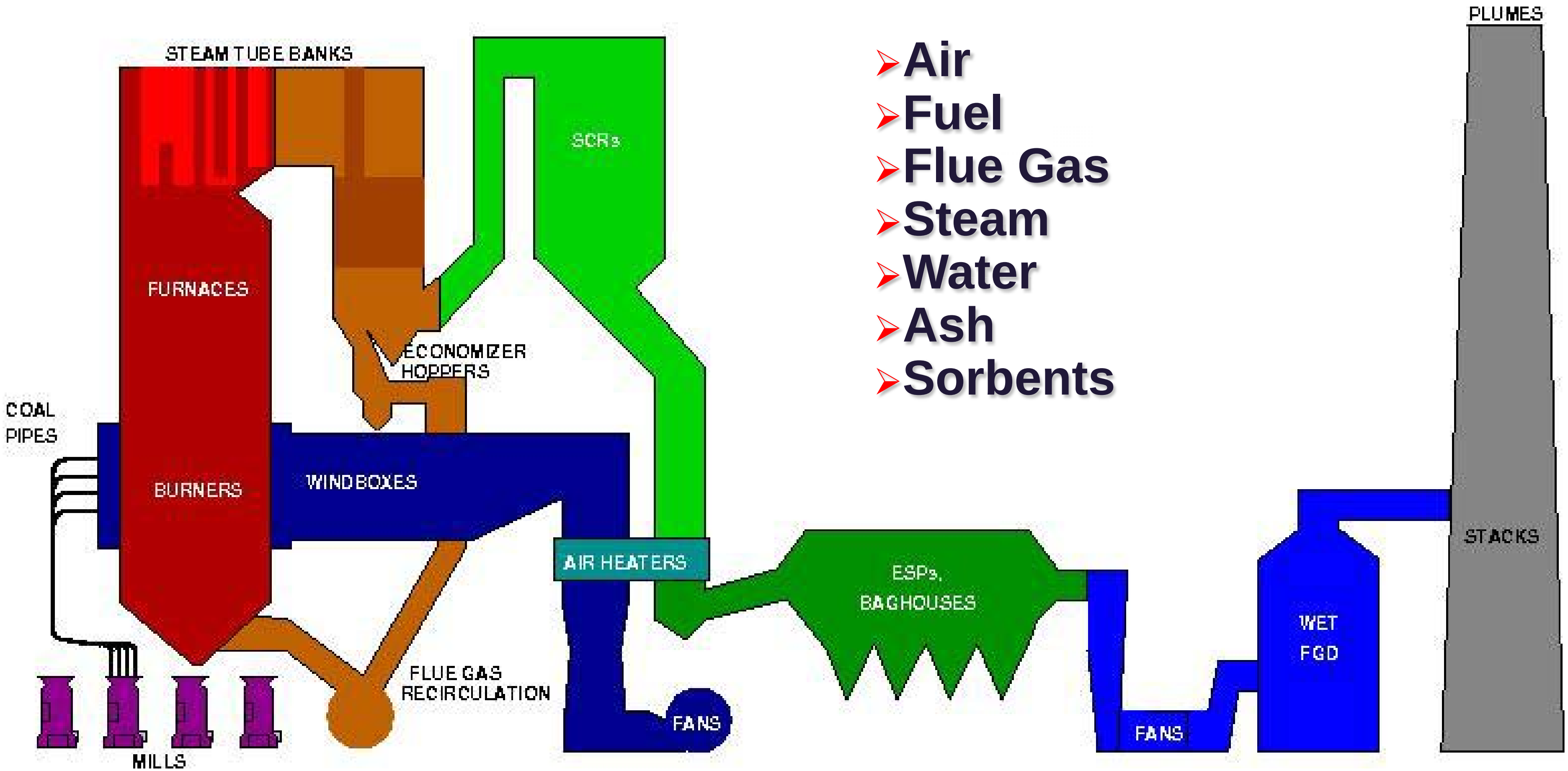
Why Do You Care About Flow?



Why Do You Care About Flow?

- Flow is Everywhere



- Air
- Fuel
- Flue Gas
- Steam
- Water
- Ash
- Sorbents

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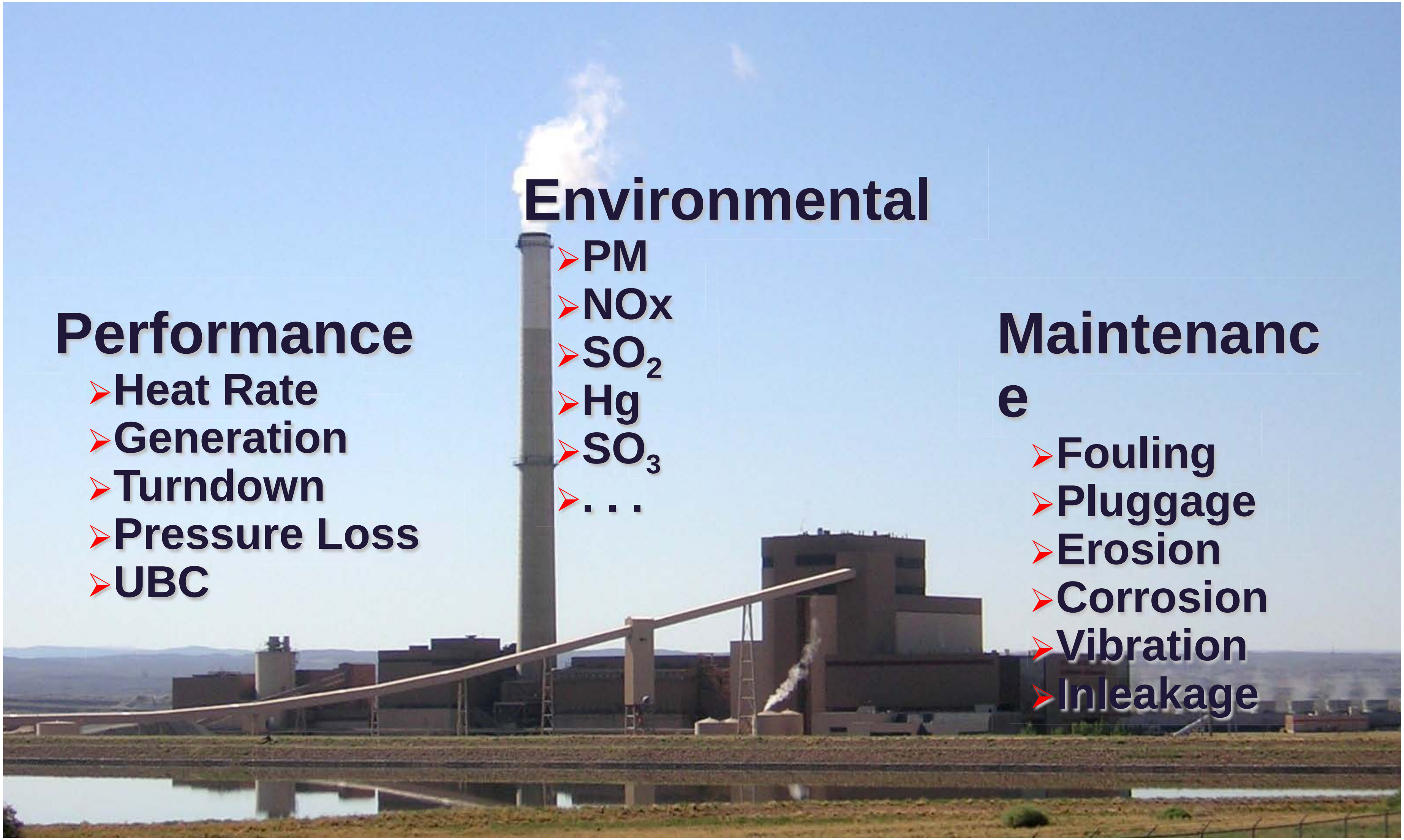
The Focus of Flow Optimization



Performance

- Heat Rate
- Generation
- Turndown
- Pressure Loss
- UBC

Environmental

- PM
- NOx
- SO_2
- Hg
- SO_3
- . . .

Maintenance

- Fouling
- Pluggage
- Erosion
- Corrosion
- Vibration
- Inleakage

Flow Analysis and Optimization Tools

- Field Testing
- Flow Modeling
  - Computational Fluid Dynamics (CFD)
  - Physical Flow Modeling

Field Testing

- Often used to support flow modeling efforts
  - Provide model boundary conditions
  - Collect correlation data

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Field Testing

- Velocity
- Temperature
- Pressure
- Particulate
- Chemical species
- Video inspection

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Flow Modeling

- ❖ Why perform flow modeling?
- ❖ Trial and error design optimization without modeling can work but…
  - Fixes can be costly
  - Results not as expected
  - New problems could develop
  - Modeling can save time and $$ in the long run
- ❖ Modeling is required for initial design of most new APC equipment
- ❖ Useful for troubleshooting / optimization of existing equipment

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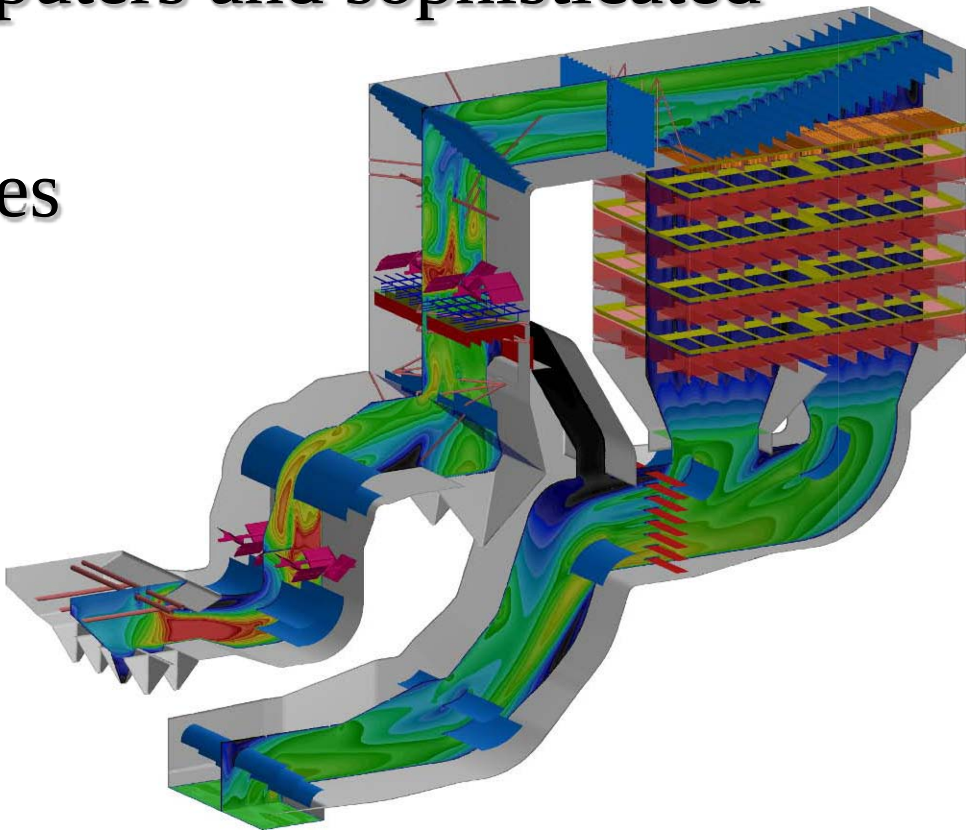
Computational Fluid Dynamics (CFD)

- Numerical simulation of flow
- Utilize high speed computers and sophisticated software
- Calculate flow properties
  - Velocity
  - Pressure
  - Temperature
  - Chemical species
  - Particle streamlines



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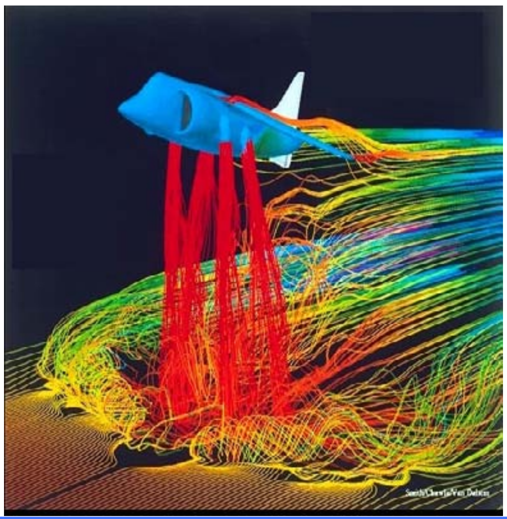
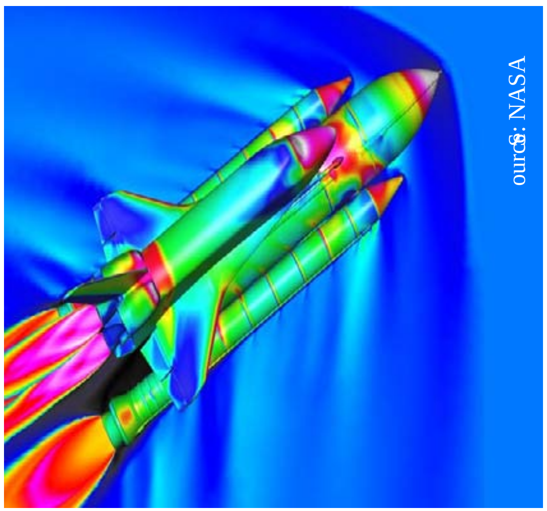
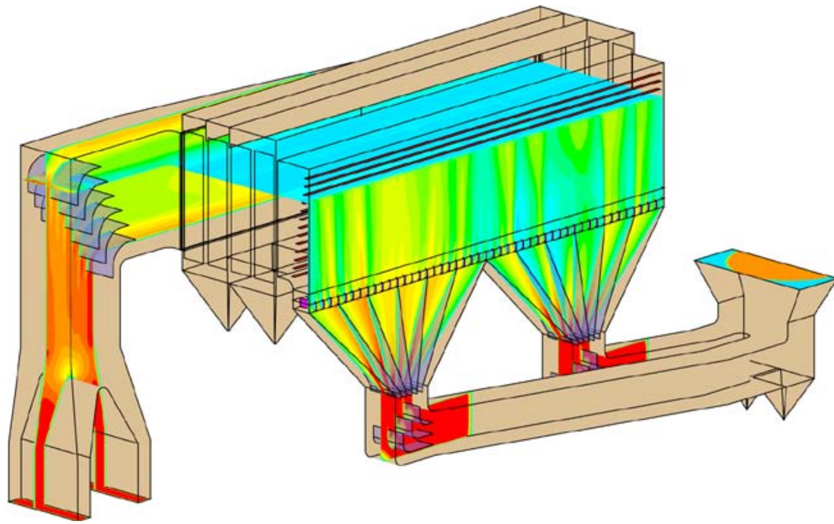
CFD History

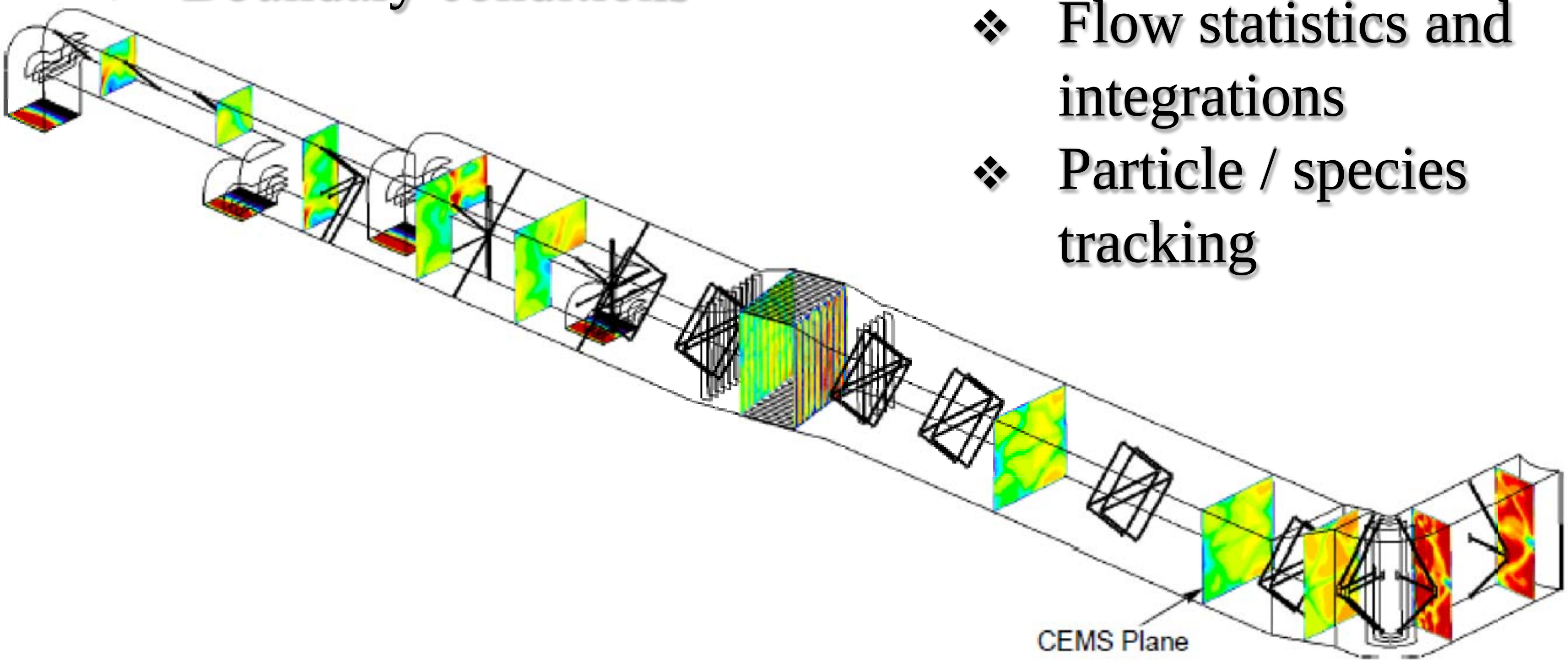
- Developed in the aerospace industry c.1970 (with the advent of “high speed” computers)
- Applied to power plant equipment for 25+ years
- Underlying principle is to solve the first-principles equations governing fluid flow behavior



CFD Methodology

1. Set up
   - ❖ Geometry (3D CAD)
   - ❖ Computational mesh
   - ❖ Boundary conditions
2. Solve
3. Analyze
   - ❖ Contour Plots
   - ❖ Flow statistics and integrations
   - ❖ Particle / species tracking



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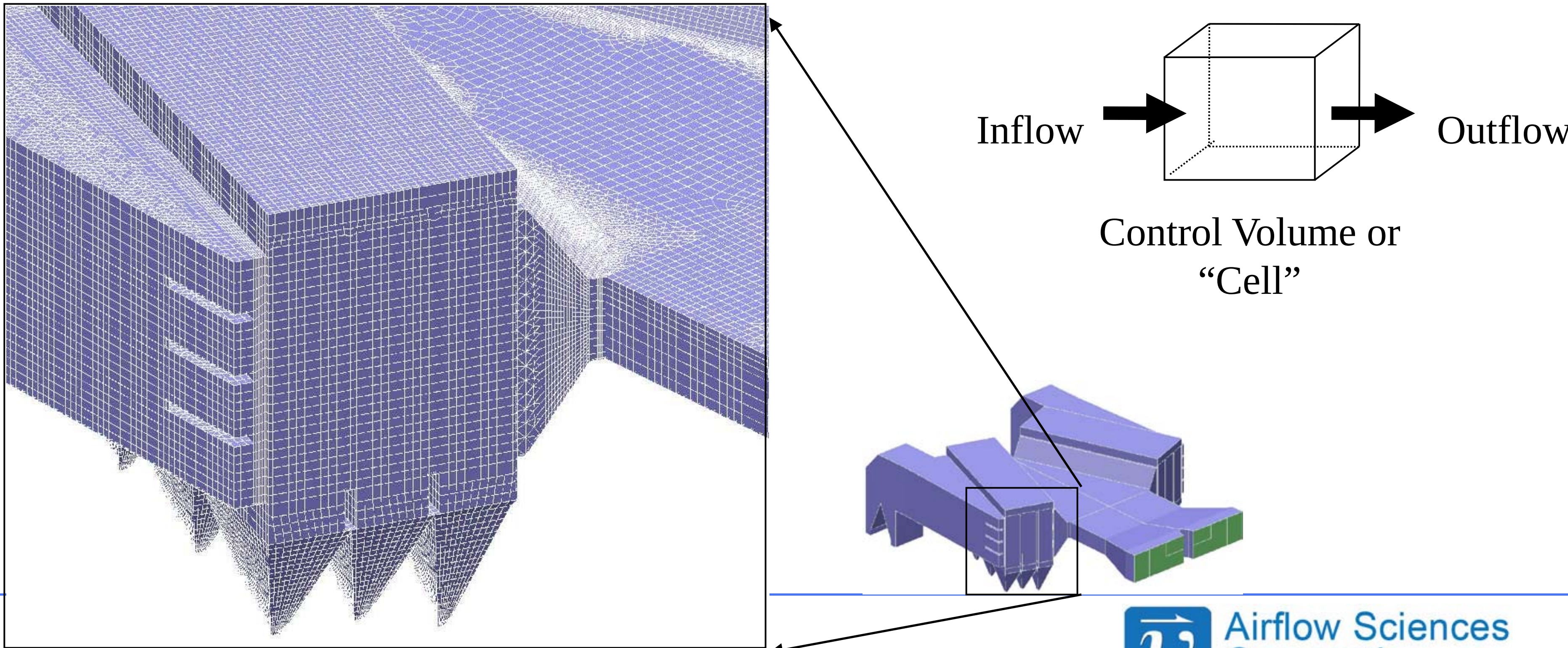
CFD Mesh

- Control Volume Approach
  - Divide the flow domain into distinct control volumes
  - Solve the Navier-Stokes equations (Conservation of Mass, Momentum, Energy) in each control volume



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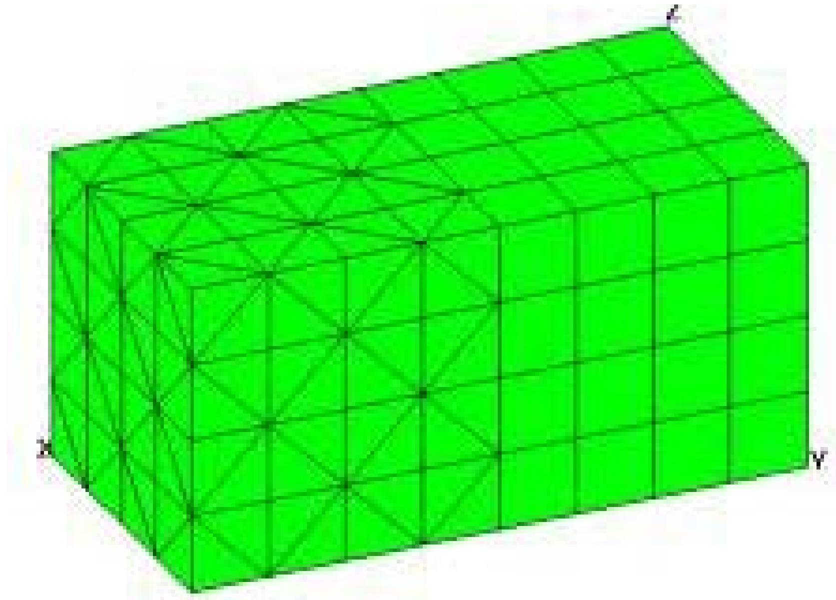
CFD Mesh Quality – It is Important!

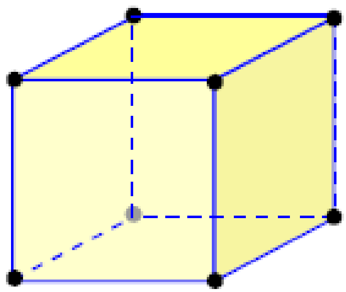
- Important mesh properties
  - Number of cells
  - Length scale of cells
  - Distribution of cells
  - Shape / topology of cells
  - Flow alignment



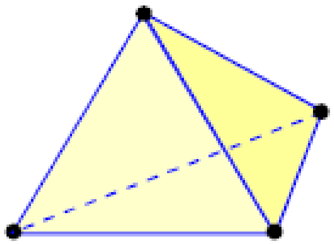
- Why?
  - Finer resolution = more accurate results
  - Numerical calculation scheme accuracy is influenced by cell arrangement

CFD Mesh Quality – Cell Topology

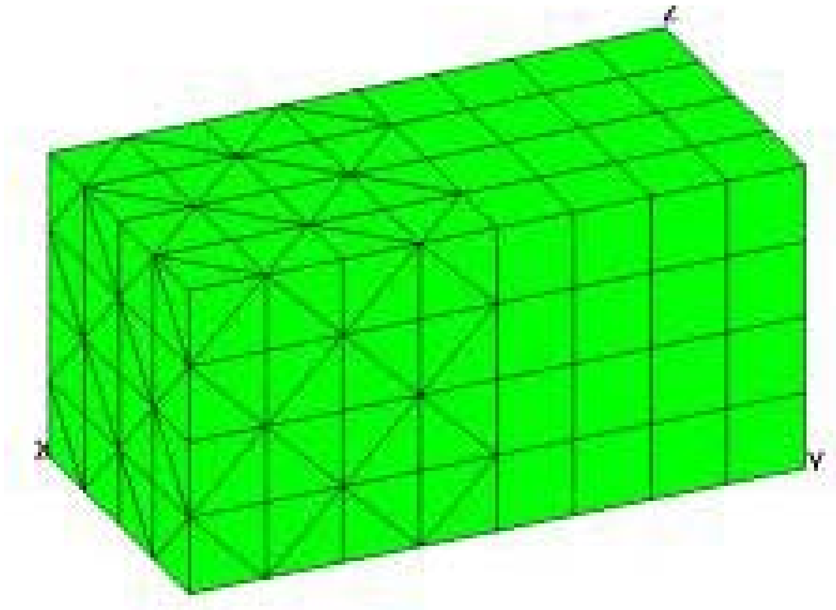
- Not all CFD cells are created equal
  - 5 million Hex cells = 20 million Tet cells



Hexahedral cell
(6 faces)

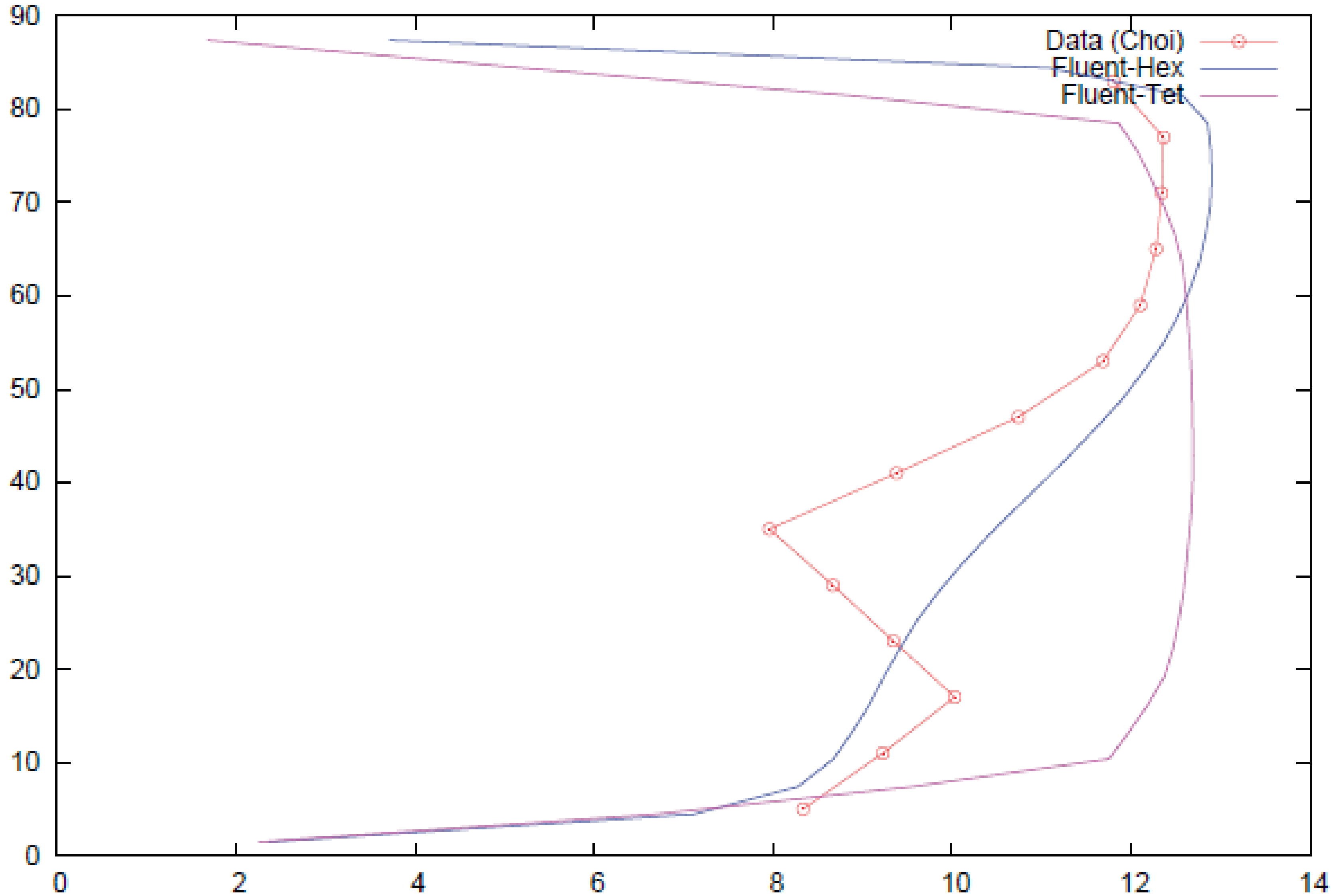


Tetrahedral cell
(4 faces)



Why? 4 Tet cells fit into 1 Hex cell of the same length scale

CFD Mesh Quality – Tet vs. Hex



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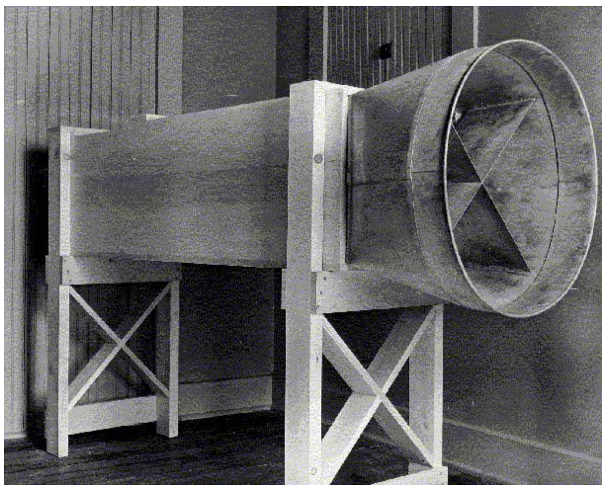
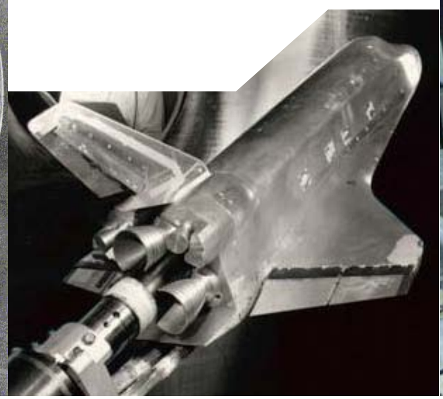
Physical Flow Modeling

- Lab representation of geometry
- Typical scale 1:8 to 1:16
- "Cold flow" modeling
- Visualize flow with smoke
- Simulate ash re-entrainment
- Measure flow properties
  - Velocity
  - Pressure
  - Tracer gas

Physical Modeling History

- Utilized for fluid flow analysis for a century … or more?
- Applied to power plant equipment for decades
- Underlying principle is to reproduce fluid flow behavior in a controlled, laboratory environment





Typical 1/12 scale physical model - SCR

- Turning vanes
- AIG w/static mixers
- Economizer bypass
- Economizer outlet
- LPA screen

- Vanes
- Rectifier
- Catalyst layers
- Air heater
- Dampers

Physical Model Methodology

- Key criteria is to generate "Similarity" between the scale model and the real-world object
  - Geometric similarity
    - Accurate scale representation of geometry
    - Inclusion of all influencing geometry elements
    - Selection of scale can be important
  - Fluid dynamic similarity
    - Precise Reynolds Number (Re) matching is not feasible
    - General practice is to match full scale velocity but ensure that Re remains in the turbulent range throughout the model

$$Re = \frac{\rho \, v \, D_h}{\mu}$$

Physical Model Methodology

1. Set up
   - ❖ Fabricate (from CAD)
   - ❖ Boundary conditions
   - ❖ Similarity calculations

2. Test
3. Analyze
   - ❖ Contour plots
   - ❖ Flow statistics and integrations
   - ❖ Flow visualization

Flow Modeling Pros and Cons

- Physical Modeling - Pros
  - Proven technique
  - Can "touch and feel"
  - Complex flow simulations and solutions
  - NH_3 distribution modeling
  - Ash dropout / re-entrainment
  - Flow visualization
- Physical Modeling - Cons
  - Iterations can be time consuming (no parallelization)
  - Thermal mixing difficult
  - Measurement points limited
  - Cannot simulate complex physics (reactions, density variation)
  - Model storage can take up significant space

Flow Modeling Pros and Cons

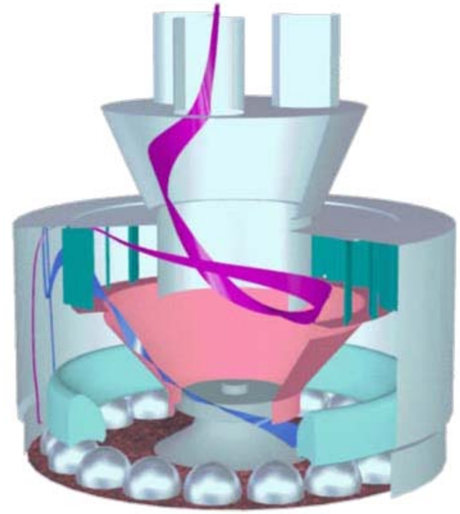
- CFD Modeling - Pros
  - Iterations can be done in parallel
  - Detailed representation of flow and mixing patterns
  - Data available at millions of traverse points
  - Output can be customized to maximize information
  - Can track particulate in flight
  - Model storage is simple
- CFD Modeling - Cons
  - Model is virtual, no “touch and feel” comfort
  - Accuracy of results relies on mesh quality and size
  - Particulate dropout/re-entrainment modeling is limited
  - NH_3 distribution modeling requires detailed mesh
  - Some physics and geometries are difficult to resolve in mesh

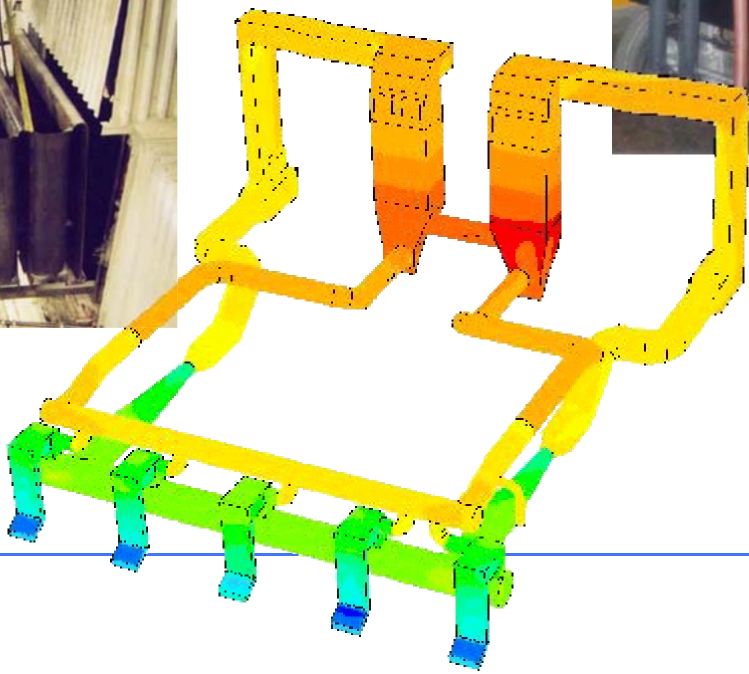
Flow Model Applications

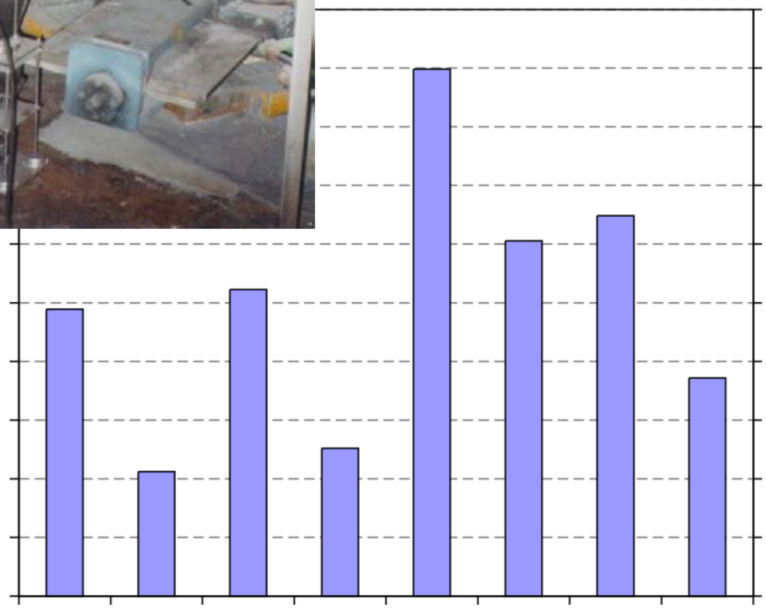
- Primary Air / Coal Flow
- Windboxes / Secondary Air
- Furnaces
- ESPs
- Fabric Filters
- FGD
- Sorbent Injection
- SCRs

Primary Air / Coal Flow Balancing

- Optimize combustion
  - Balance PA flows
  - Equal coal flow per burner
  - Adequate fineness
- Modeling and testing







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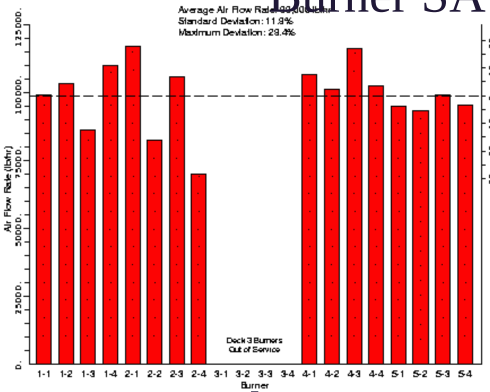
Windbox Flow Balancing

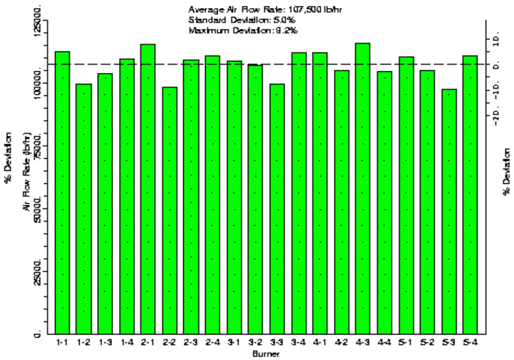
- ❖ Optimize combustion
  - Balance secondary air
  - Control flow entering burner (ram air effect)
- ❖ Modeling and testing

Burner SA flow balance



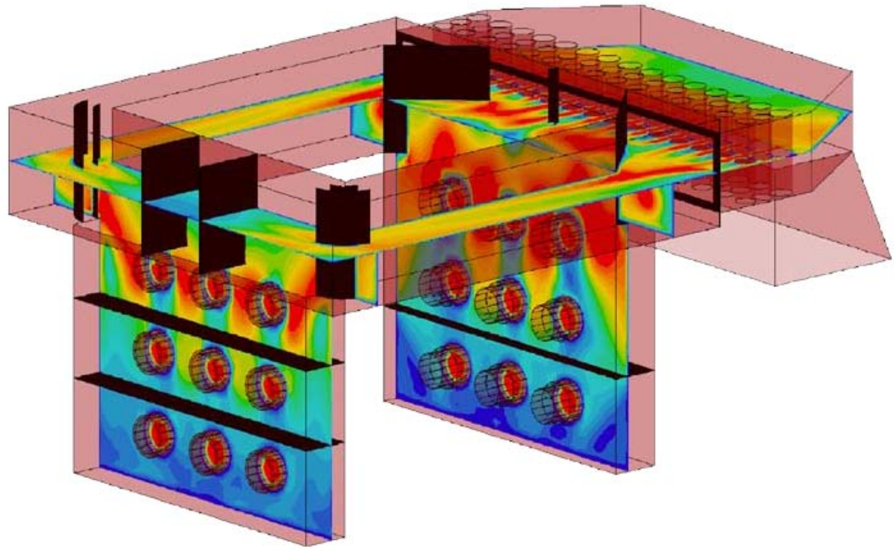
Baseline

Max deviation 29.4%



Design

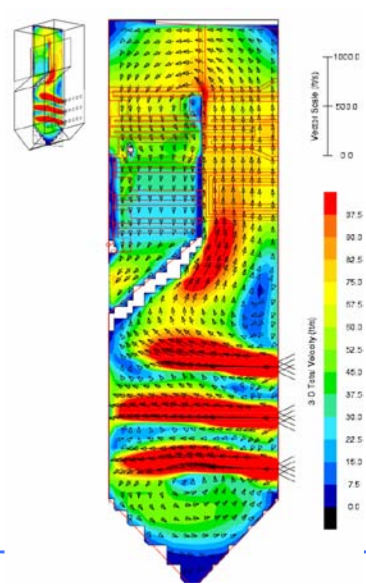
Max deviation 9.2%

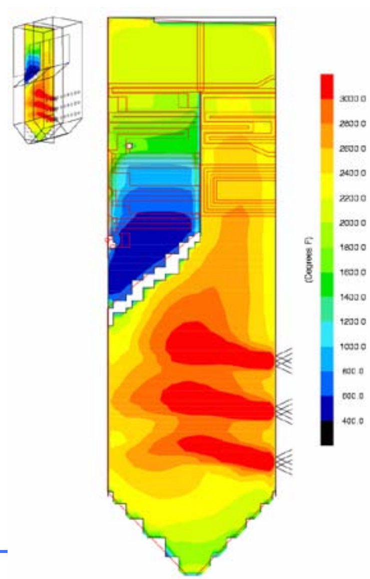


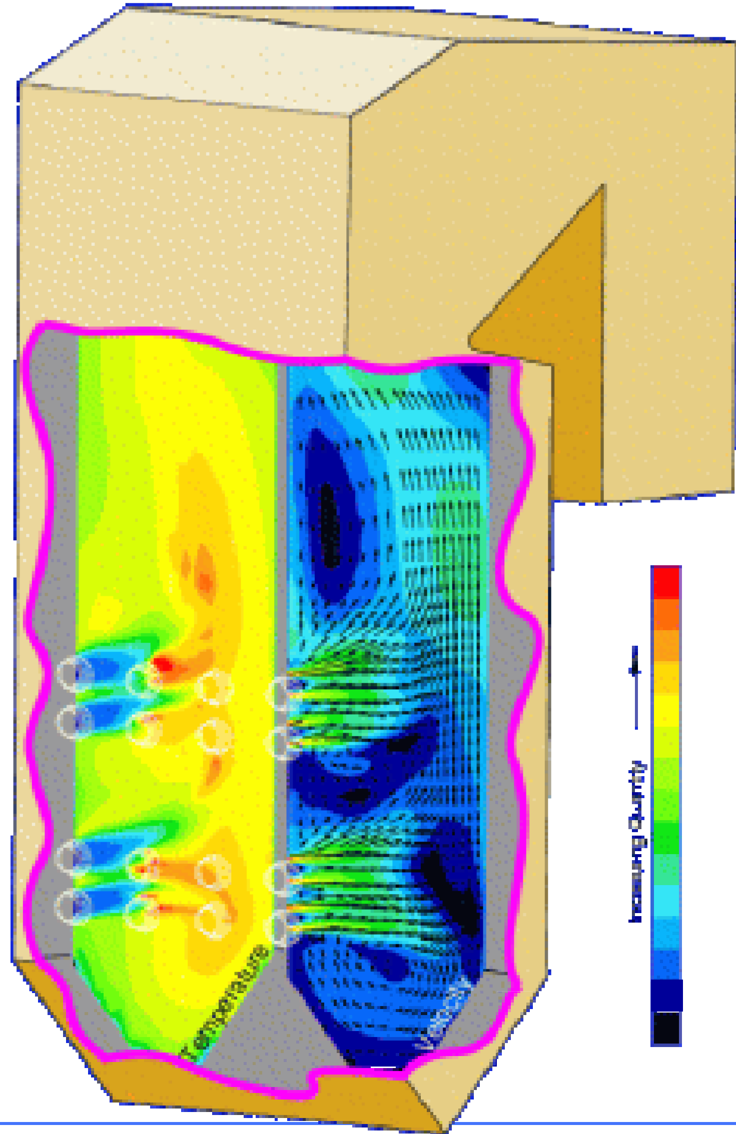
Furnace Combustion Optimization

❖ Typical goals

- Reduce NOx
- Minimize UBC
- Improve heat transfer
- Avoid corrosion
- Decrease slagging







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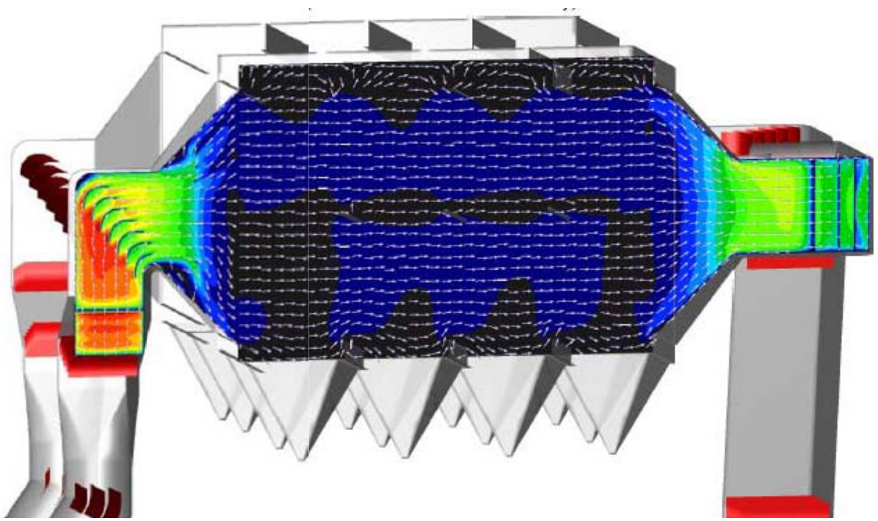
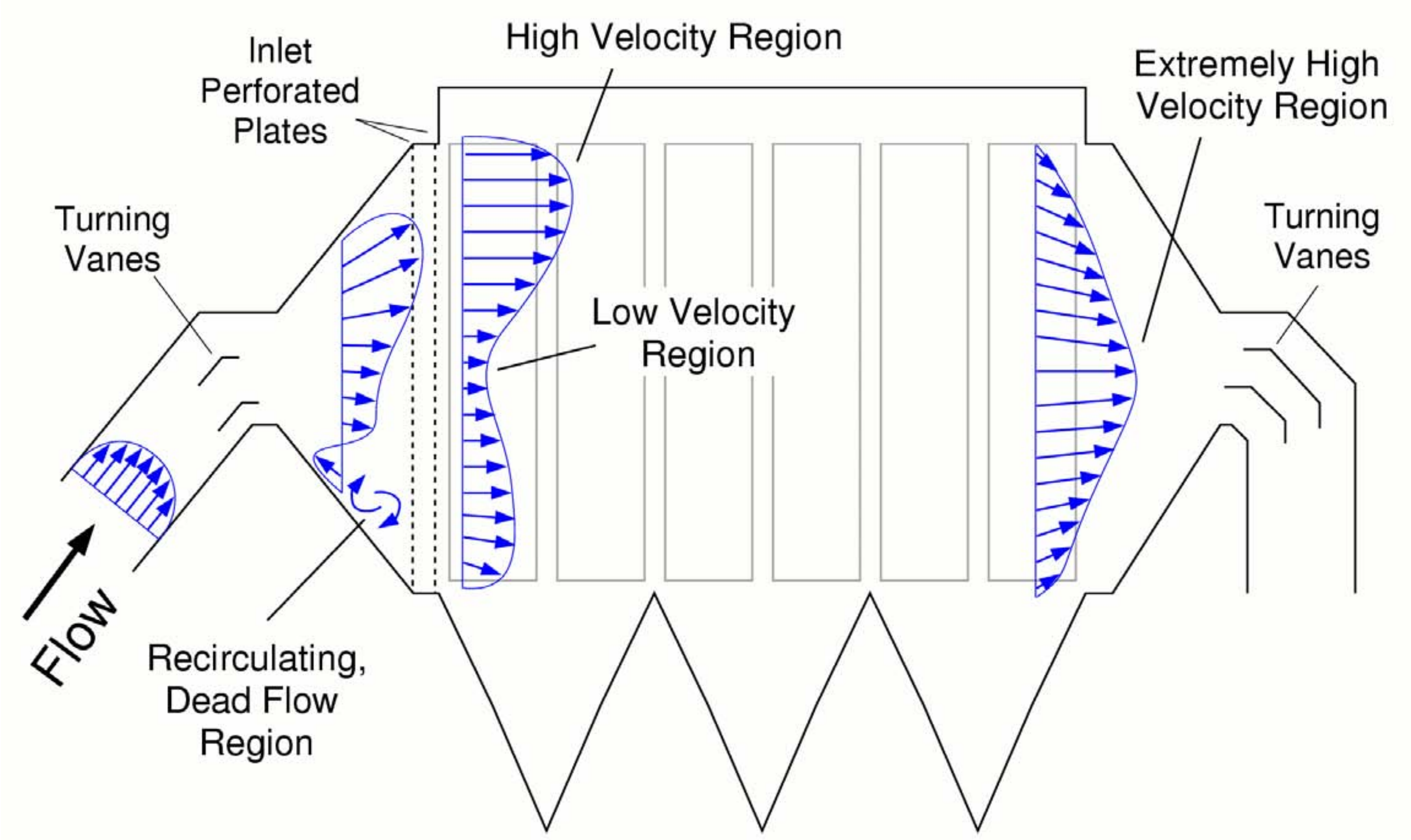
ESP Flow Optimization

- Flow distribution
- Flow balance between cells
- Pressure loss
- Thermal mixing
- Gas conditioning
- Ash deposition



ESP Velocity Distribution

- Uniform velocity within collection region
- Industry standards
  - ICAC
  - % RMS deviation



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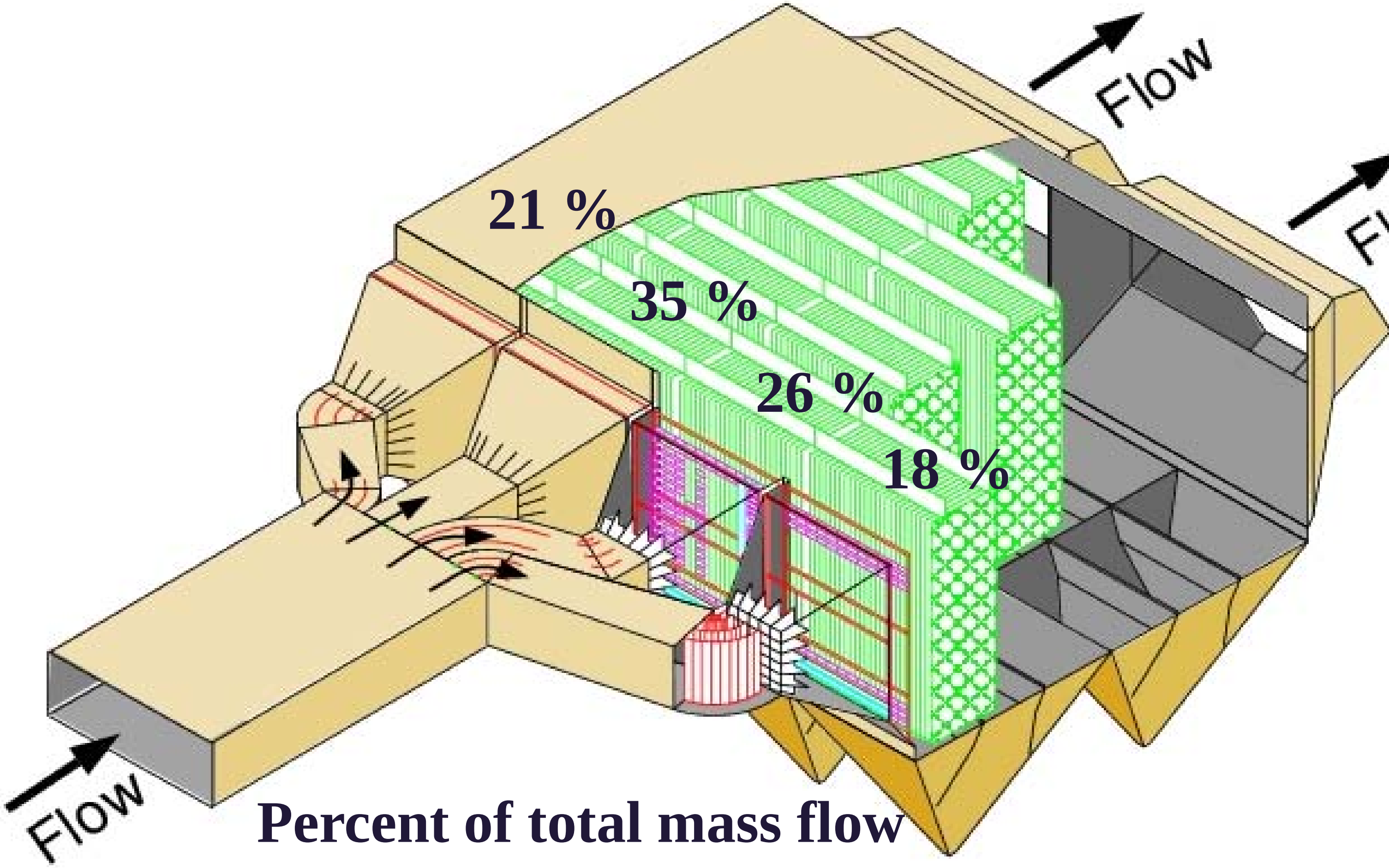
Gas Flow Balance

❖ Industry standard +/- 10% deviation



Percent of total mass flow through each chamber

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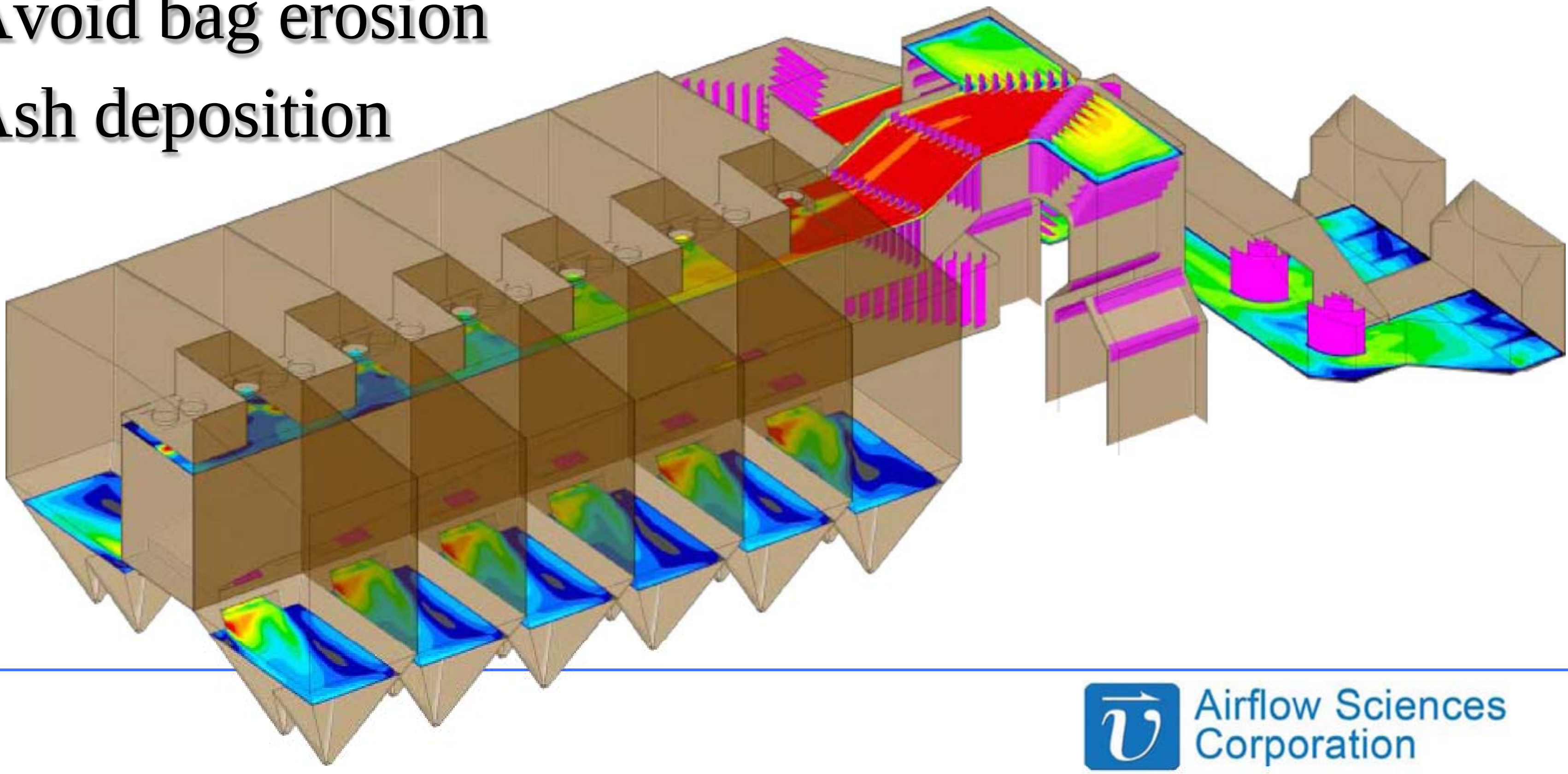
Fabric Filter Flow Modeling

- Uniform velocity distribution and equal balance between compartments
- Compartments out-of-service
- Avoid bag erosion
- Ash deposition



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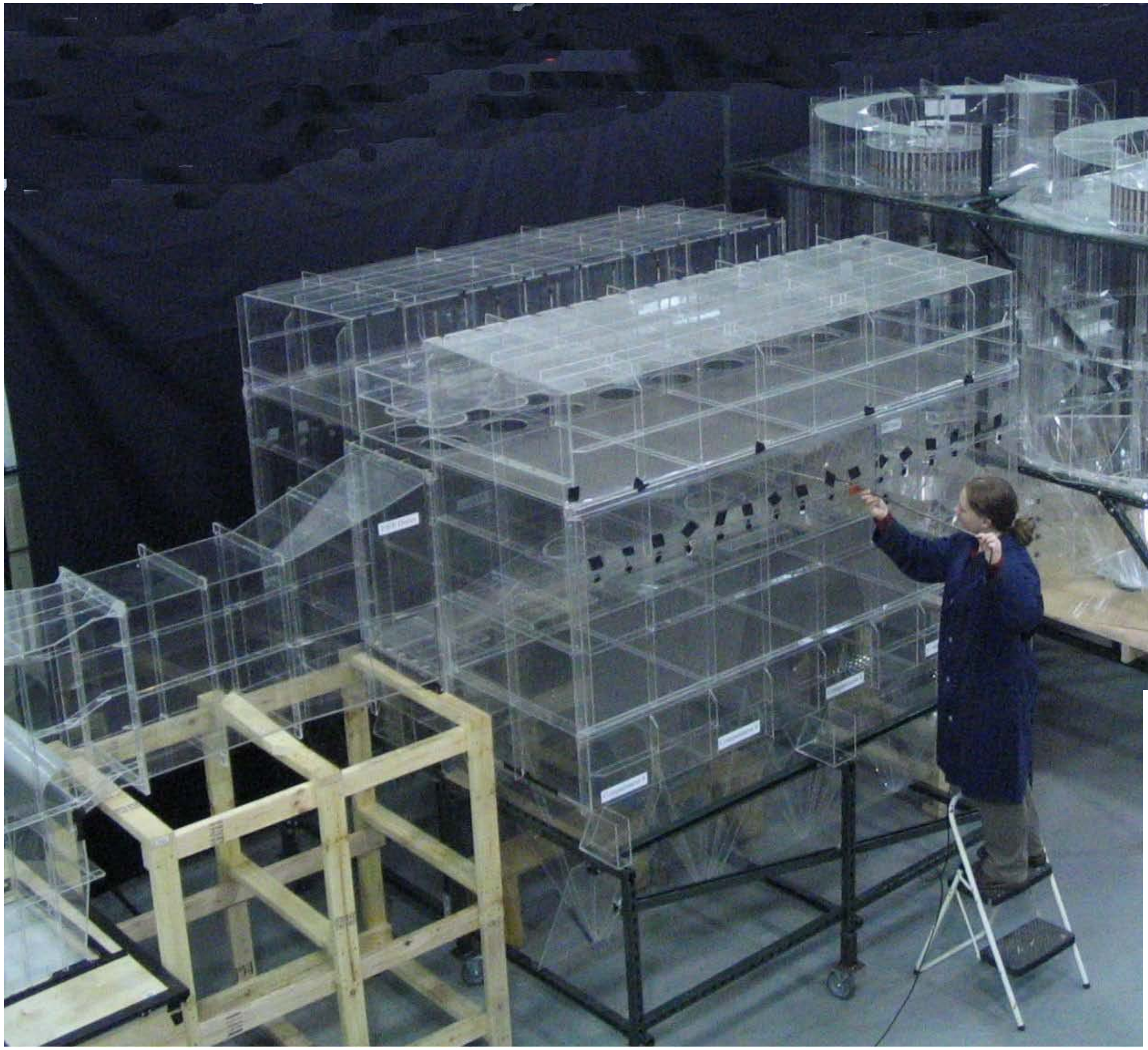
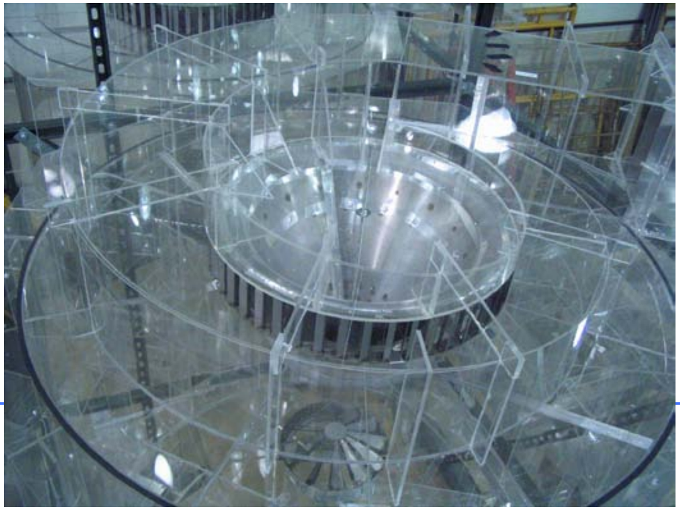
Fabric Filter Flow Modeling

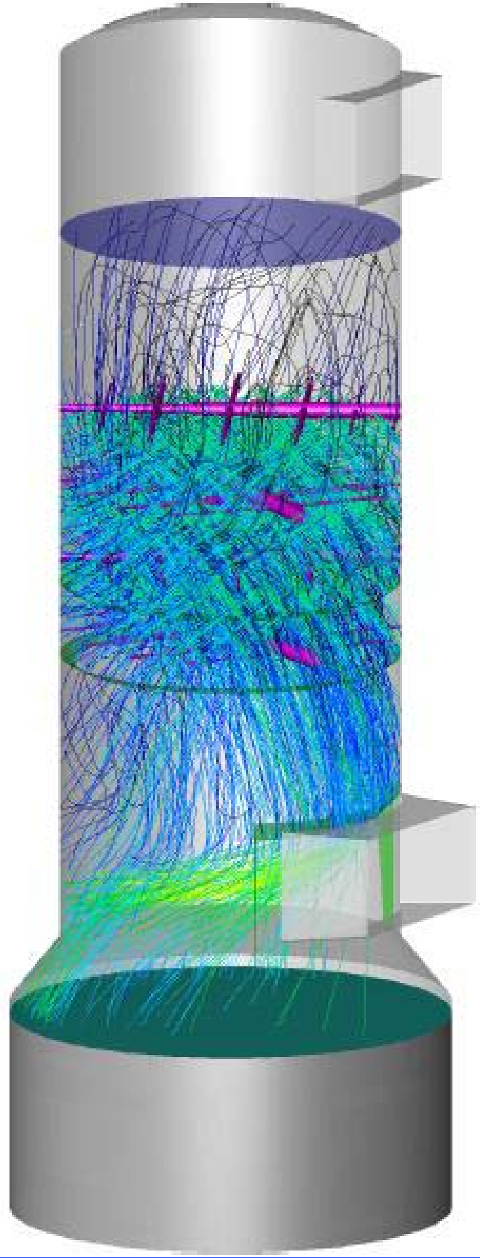


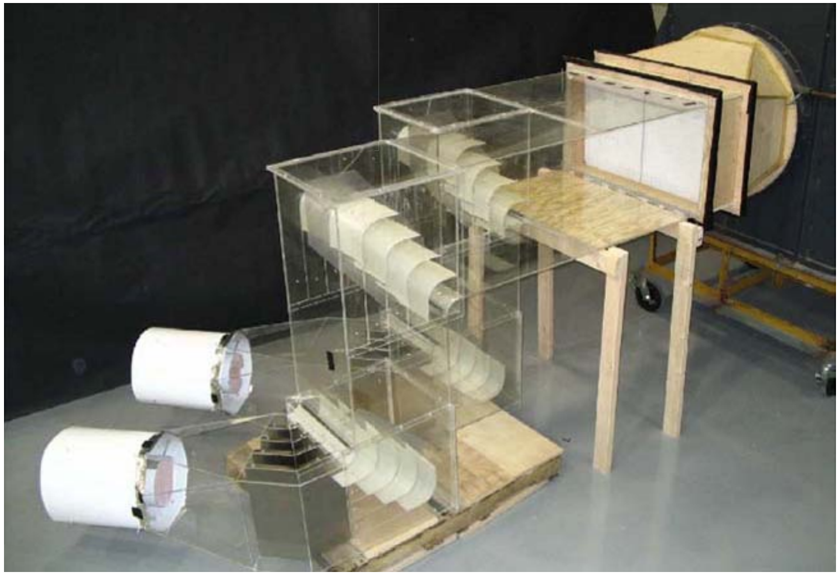


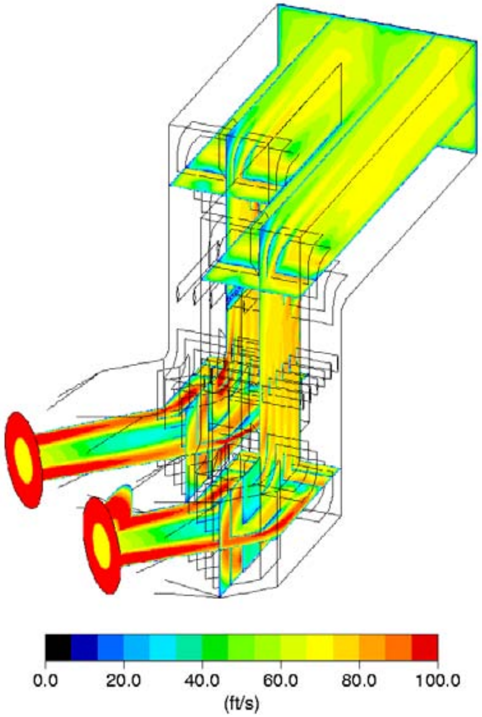
FF with SDA

Wet FGD Flow Modeling

- Flow distribution
- Water droplet behavior
- Pressure loss
- Solids deposition







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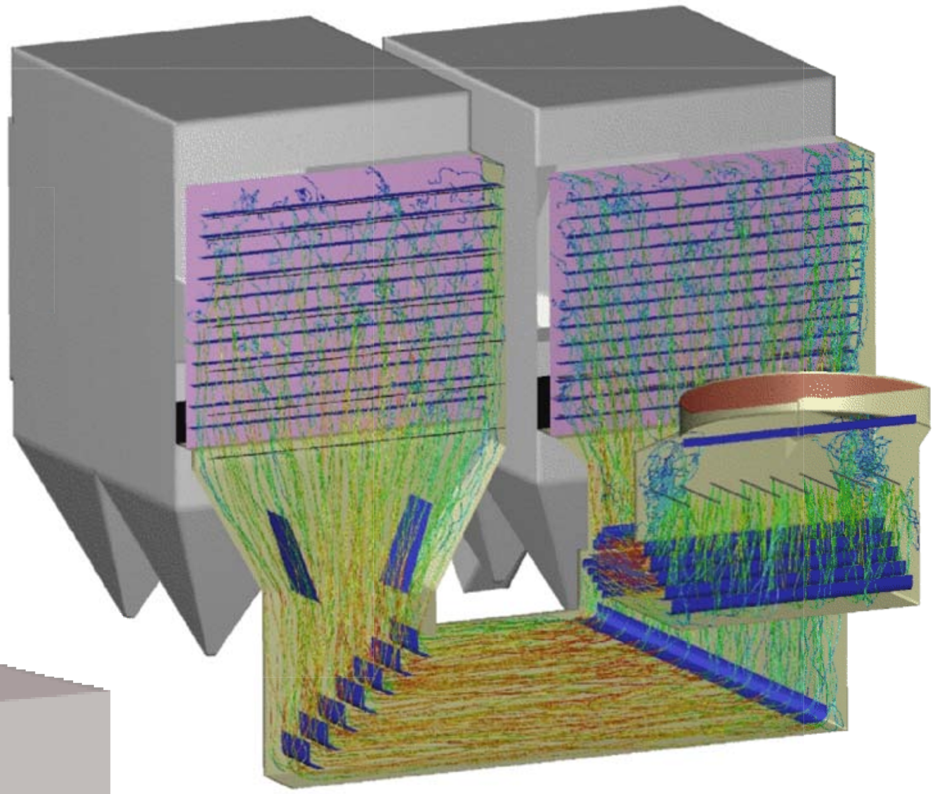
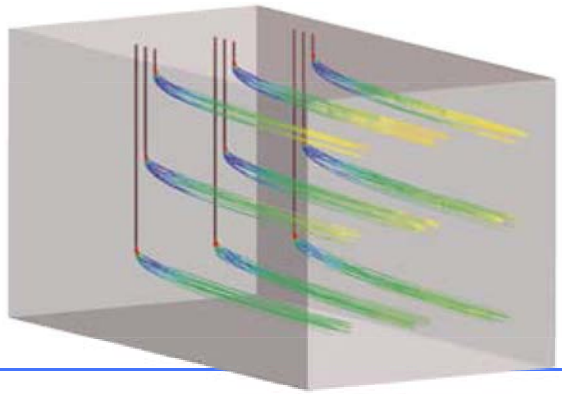
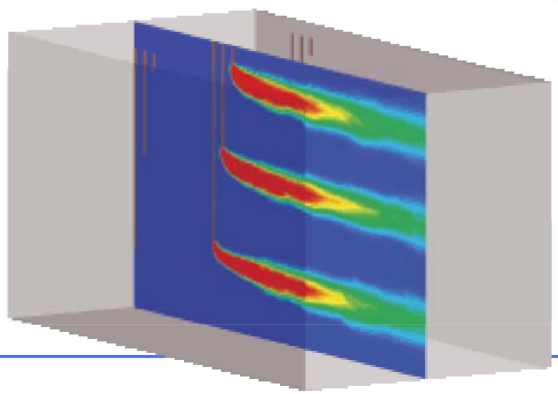
Mercury / SO_3 Reduction

- Injection upstream of baghouse or ESP
  - Activated carbon
  - Lime, Trona, SBS, etc.
- Uniform sorbent distribution
- Maximize residence time







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SCR Flow Optimization

- Velocity distribution
- Thermal mixing
- NOx profile / mixing
- Ammonia injection
- Pressure loss
- Large particle ash (LPA) capture
- Ash deposition

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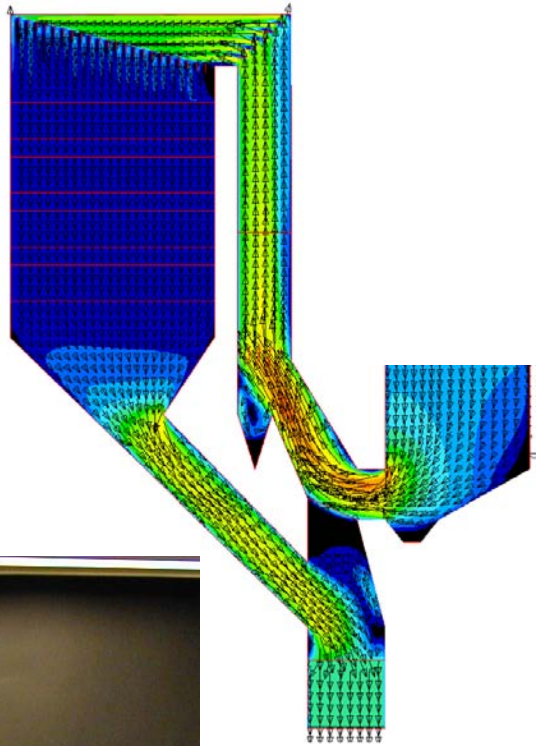
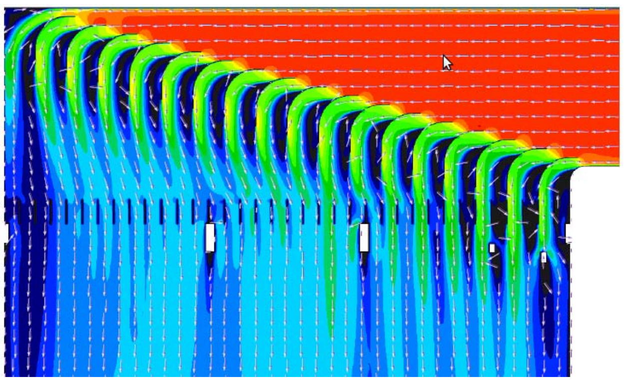
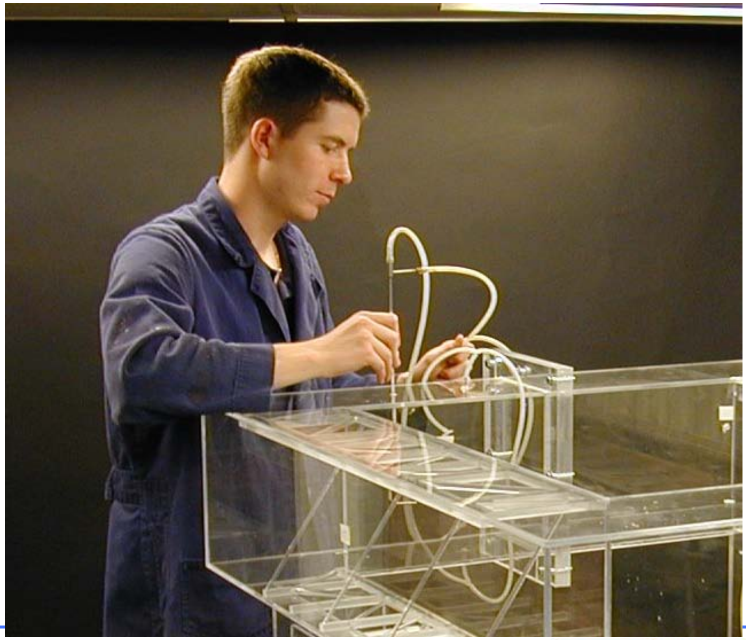
SCR Velocity Distribution



- Uniform velocity profile
  - At ammonia injection grid
  - At catalyst inlet
  - At air heater inlet
- Minimal angularity
  - At catalyst inlet





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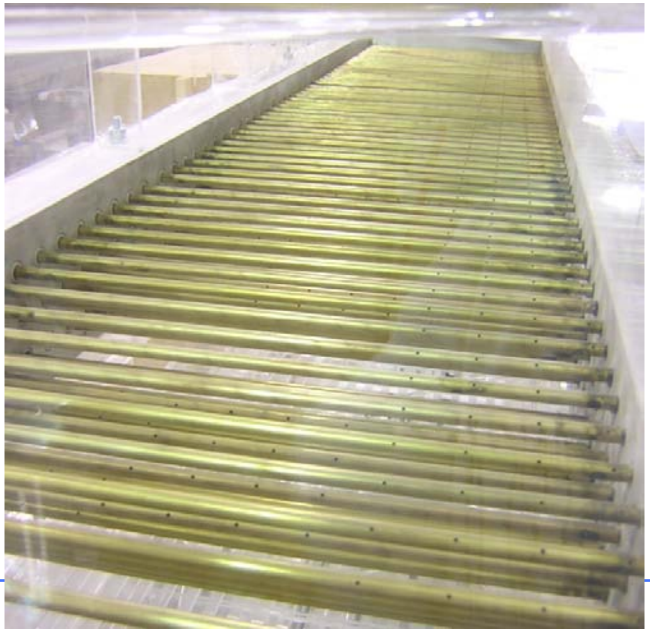
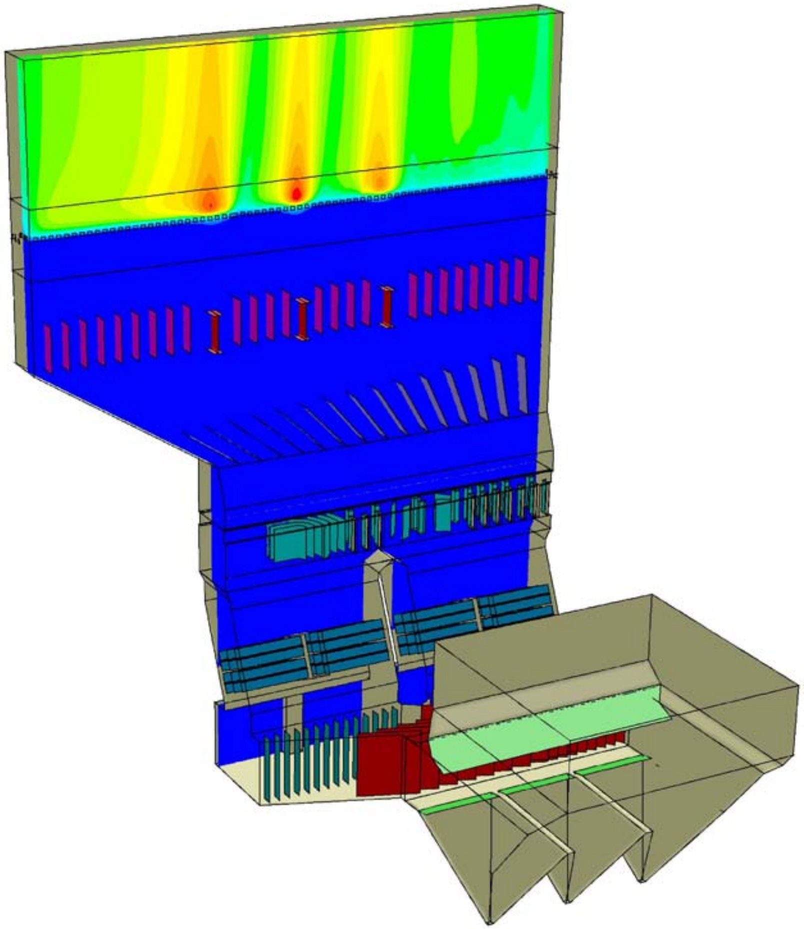
SCR Ammonia Injection

- Desire uniform NH3-to-NOx ratio at catalyst
- Tracer gas used to represent flows in physical model
- Track gas species in CFD





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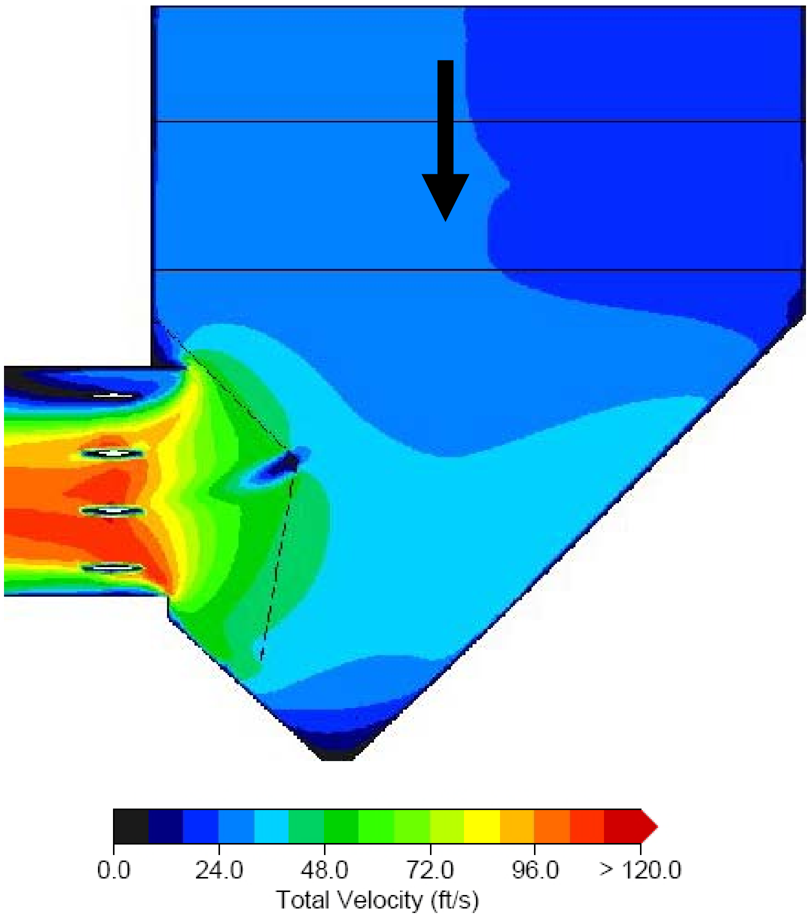
LPA Modeling via CFD

- Examine gas flow patterns and peak velocities through the system
- Track ash particles in flight through the ductwork and hopper regions
- Use model to evaluate wide range of design options



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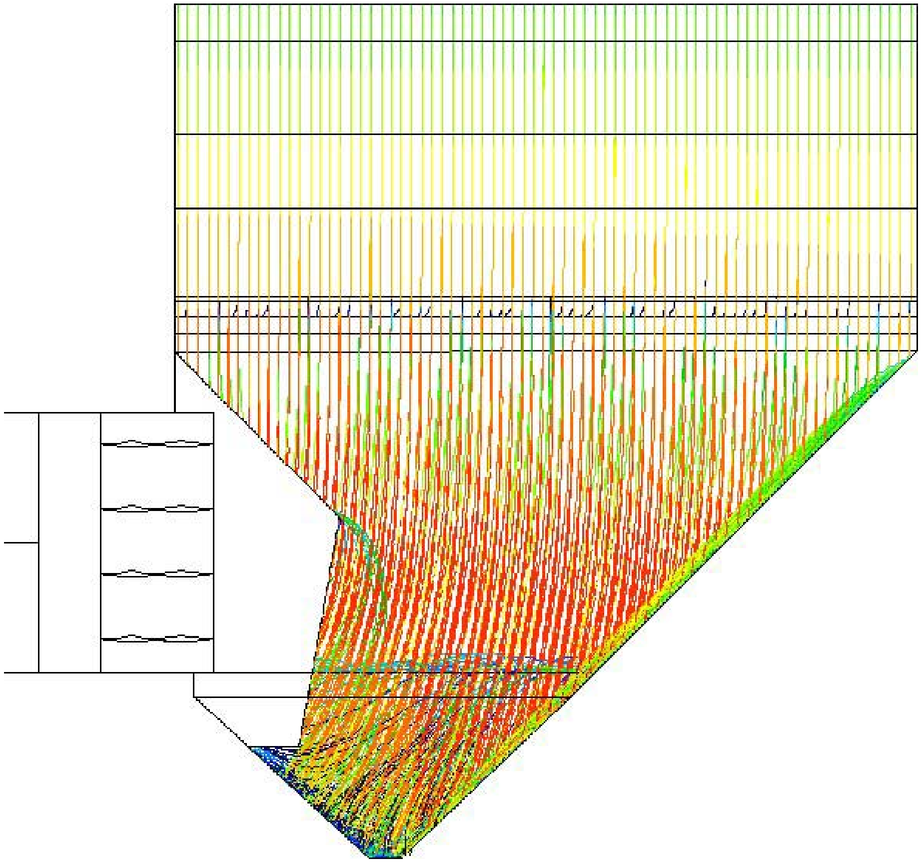
LPA Tracking in CFD

- ❖ Examine numerous particle sizes (3-7mm typical)
- ❖ Calculate particle paths
  - Rebound off surfaces
  - Impact on screen
  - Capture in hopper



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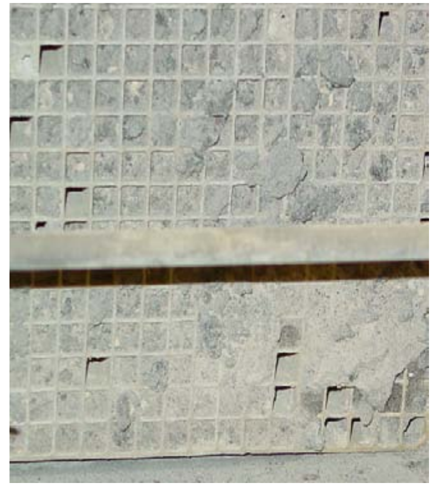
SCR Large Particle Ash Capture

- Catalyst openings for coal-fired plants are smaller than LPA particles
- Once LPA becomes "wedged" into the catalyst, fine ash builds up as well
  - Hard to clean
  - Get dunes of ash on top layer catalyst



LPA System Design – Key Points

- Capture LPA in hoppers of adequate size
- LPA screens have become standard practice
- Ash deflection baffles also useful
- Screen erosion and pluggage remain issues

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Model Accuracy

❖ Do physical and CFD models match field test data?
- Field data is unfortunately limited
- Tend to go by industry experience and whether catalyst performance goals are met

❖ Do CFD and physical models match each other?
- For velocity and pressure drop predictions, correlation is quite good
- For NH_3 injection correlation has improved steadily over time
  - ➢ Better CFD meshes (= mesh quality and level of detail)
  - ➢ Faster computers (= larger CFD meshes)
- Models can even predict transient behavior

Flow Visualization

- Physical models – smoke flow, string tufts, dust injection/re-entrainment
- CFD models –animations of gas streamlines and particle pathlines

Conclusions – Flow Modeling

- CFD and physical modeling are applied to a wide range of equipment "from the fan to the stack"
- Modeling is an excellent tool for design optimization versus trial and error in the field
- There are a number of flow-related objectives when designing or optimizing equipment
- Often trade-offs exist, as objectives can be competing
- Accuracy of model results is quite good, as has comparison of results between model types, as long as proper attention is paid to mesh quality and laboratory test techniques

Ash Deposition

- Flues
- Turning vanes
- Catalyst

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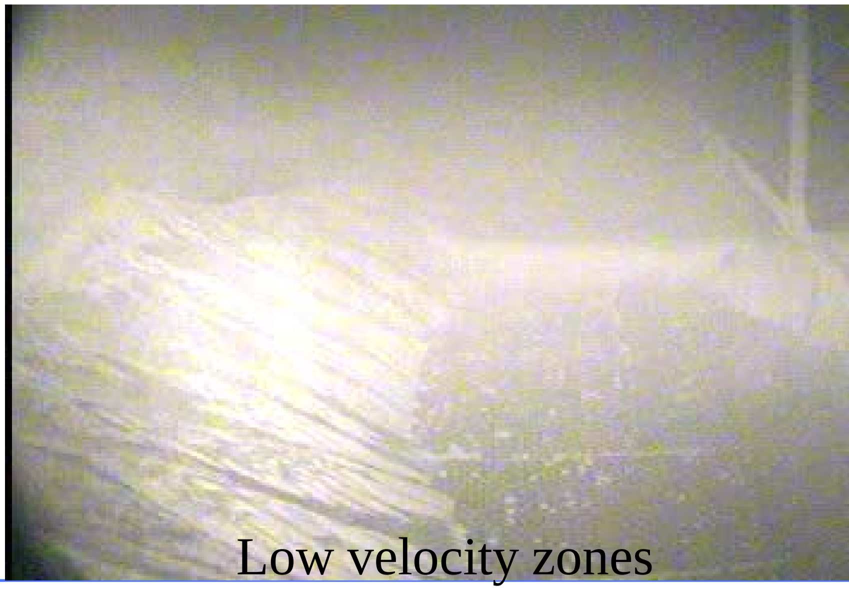
Ash Deposition – What Causes It?

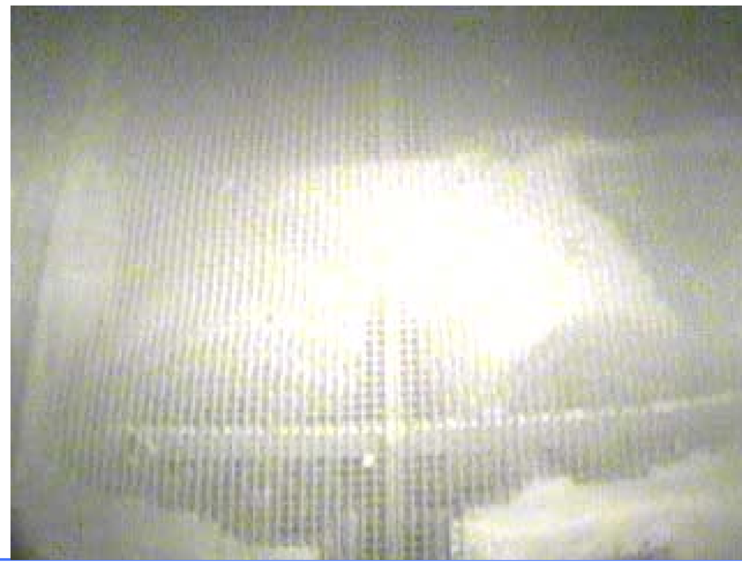
- Low velocity regions
  - Due to non-uniform velocity distribution
  - Due to prolonged lower load operation
- Dead, recirculation zones
  - Sticky ash agglomerates, especially PRB and blends
  - Due to internal structure, flow separation, poor flow control
  - Due to flow angularity, causing local flow separation (particularly at catalyst inlet)
- Horizontal surfaces, beams, trusses
  - In SCR, can result in avalanche of accumulated ash, plugging catalyst
- Inleakage, moisture infiltration
- Sticky ash

Ash Deposition – What Causes It?


Accumulation on beams

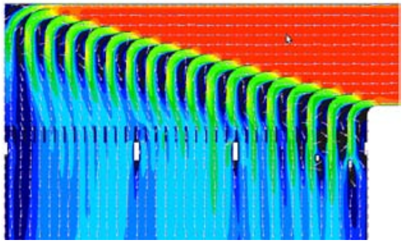

Ash avalanche

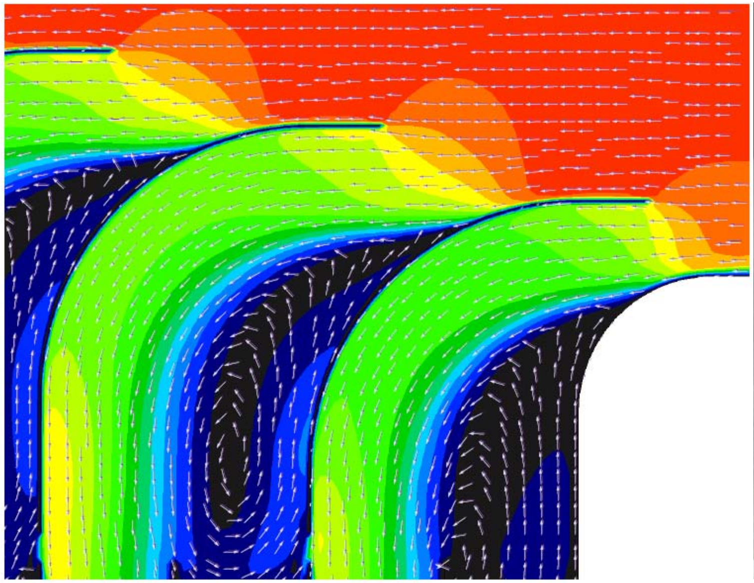

Low velocity zones



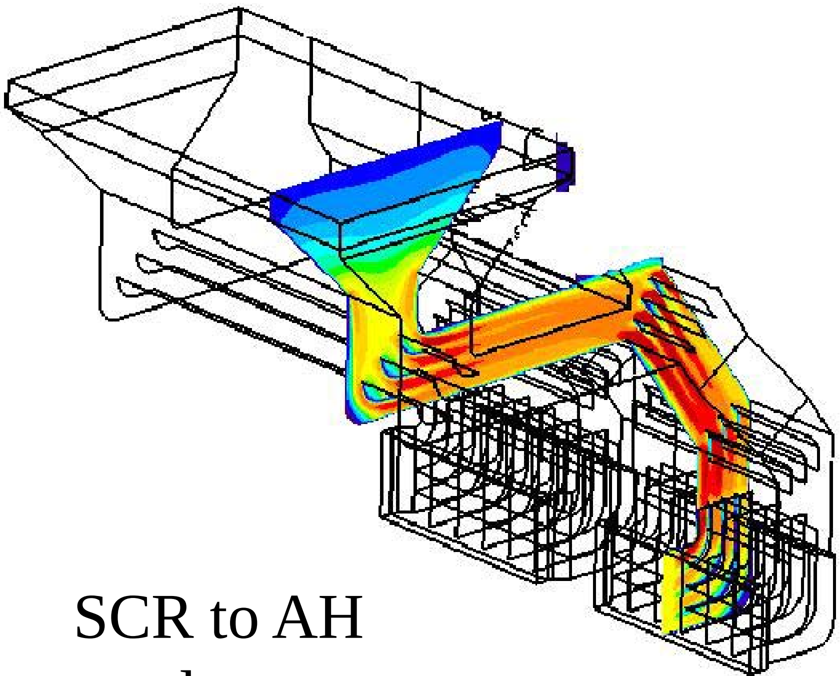
Ash Deposition – CFD Modeling

❖ CFD Model
- Observe low velocity, recirculation flow zones
- Assess velocity patterns over the load range
- Can examine all locations throughout model (i.e., millions of data points)

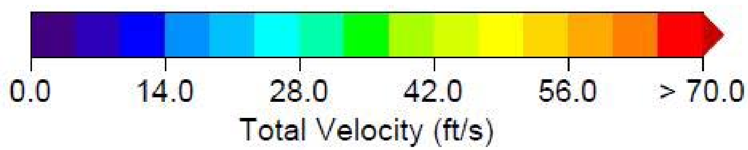


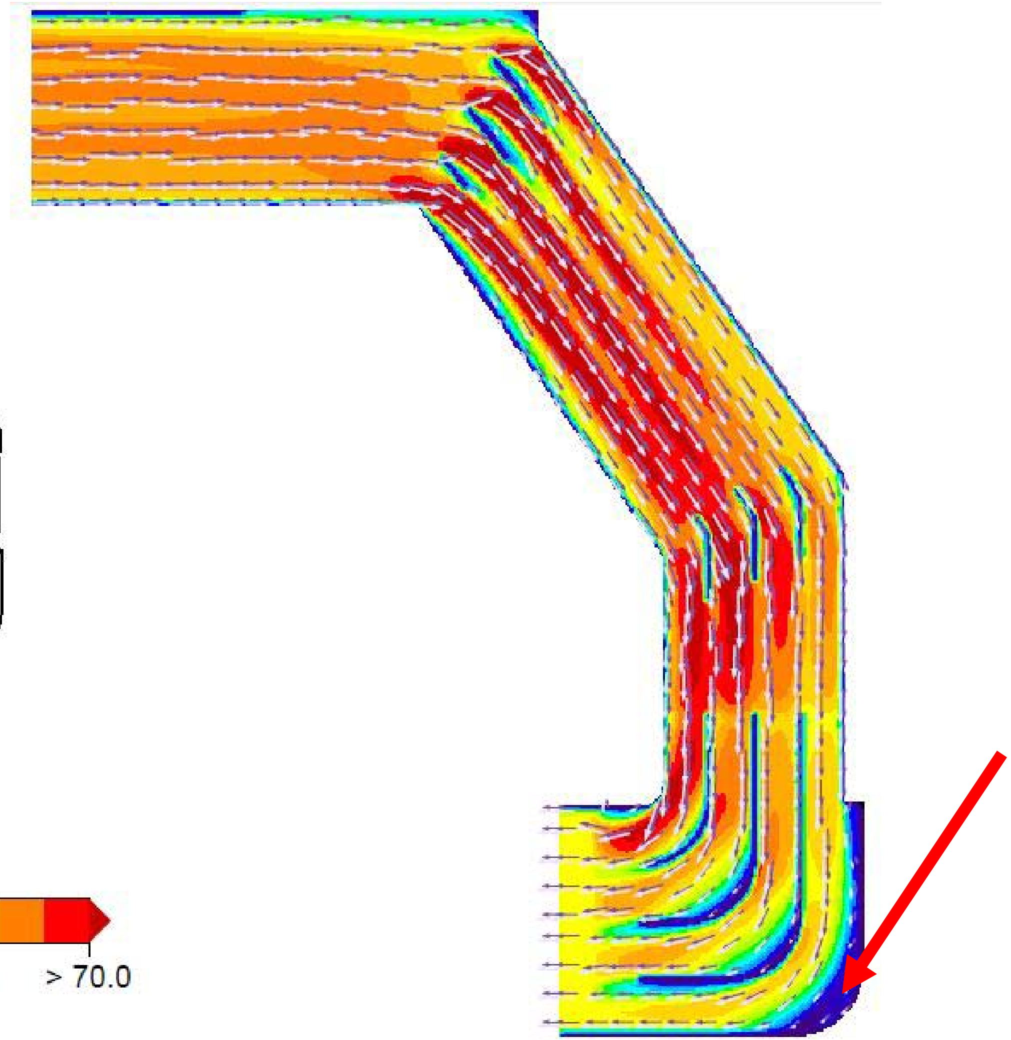


Ash Deposition – CFD Modeling



SCR to AH duct





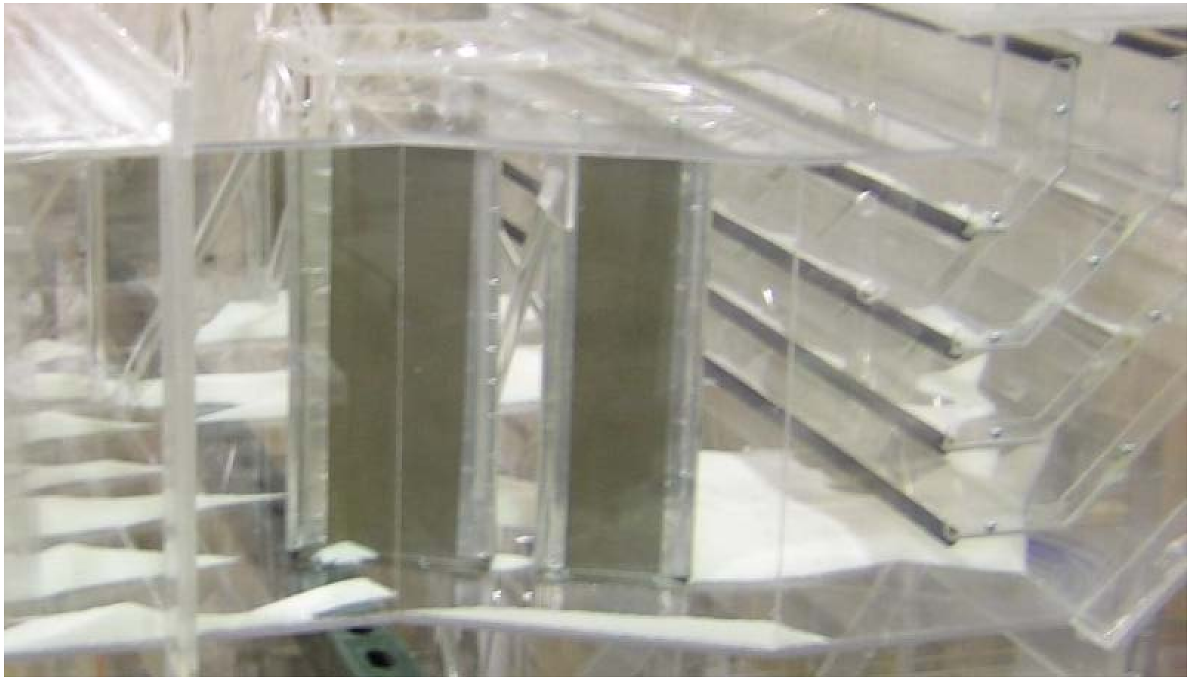
Ash Deposition – CFD Modeling

A-side AH inlet

B-side AH inlet

Ash Deposition – Cold Flow Modeling

- Cold Flow Physical Model
  - Perform “dust testing” to evaluate drop out and re-entrainment
  - Use simulated ash (laboratory dust) under ambient conditions
  - Match aerodynamics of dust to that of actual ash



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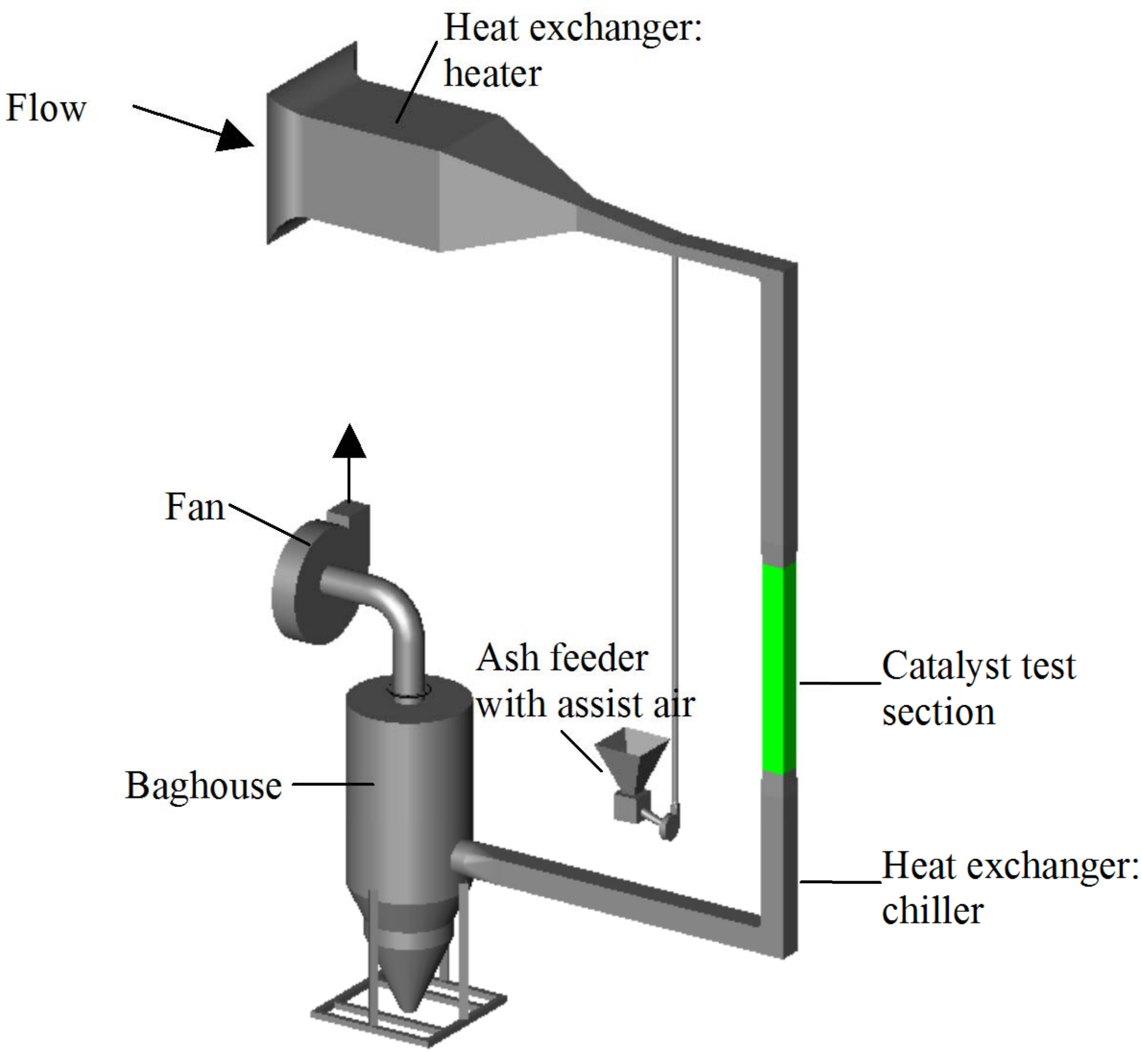
Ash Deposition – Hot Flow Modeling

- Hot Flow Model
  - Testing under actual temperature conditions
  - Real ash, not laboratory dust
  - Downside is smaller scale, lack of flue gas constituents
  - Recent research, not completed yet
  - Flues and SCR pluggage

Ash Deposition – Hot Flow Modeling



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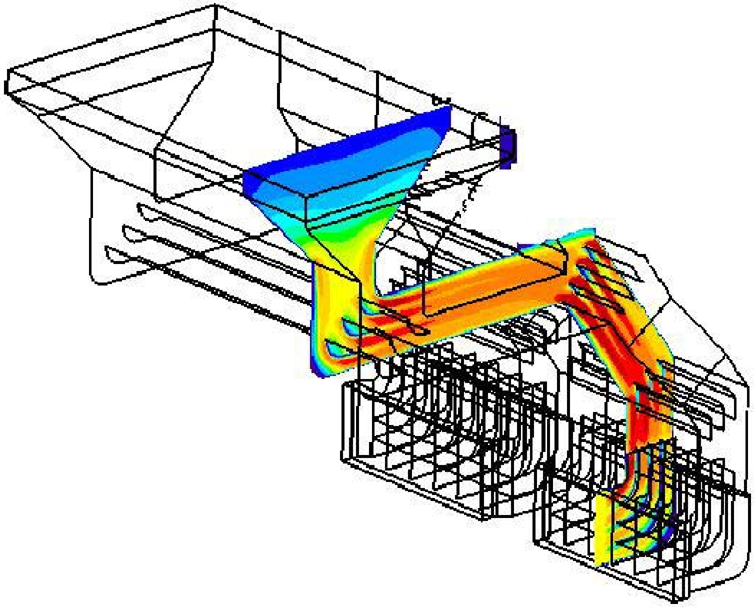
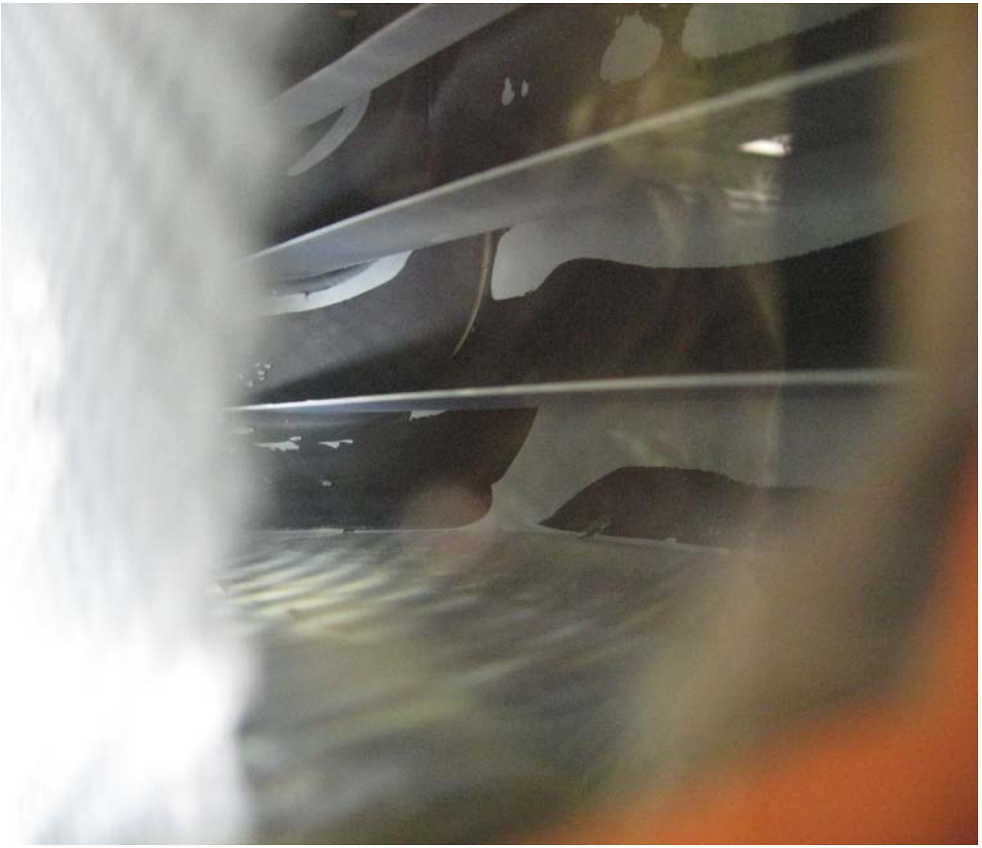
Ash Deposition – Hot Flow Modeling

Ash Deposition – Hot Flow Modeling



Ash Deposition – Hot Flow Modeling



Vanes in corner

Near AH

Conclusions – Ash Deposition

- Ash deposition and pluggage continue to be problems for plant equipment
- Modeling is used to minimize deposition potential
  - Standard modeling methods (CFD and cold flow modeling) are generally used
  - Hot flow modeling method is being evaluated
- Key elements to minimizing deposits include
  - Control and optimize velocity distribution (over the load range)
  - Avoid dead, recirculation zones
  - Minimize flow angularity / ash impingement angle at catalyst inlet
  - Address inleakage, moisture infiltration
  - Minimize horizontal surfaces / accumulation zones

Questions?