Improving Effectiveness of SO_3 Mitigation Systems with CFD Modeling

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Presentation Outline

- SO_3 Mitigation & Impacts
- SO_3 Behavior in Power Plants
- SO_3 Control Technologies
- Example 1 – $Mg(OH)_2$ Furnace Injection
- Example 2 – Post-APH Sorbent Injection
- Conclusions

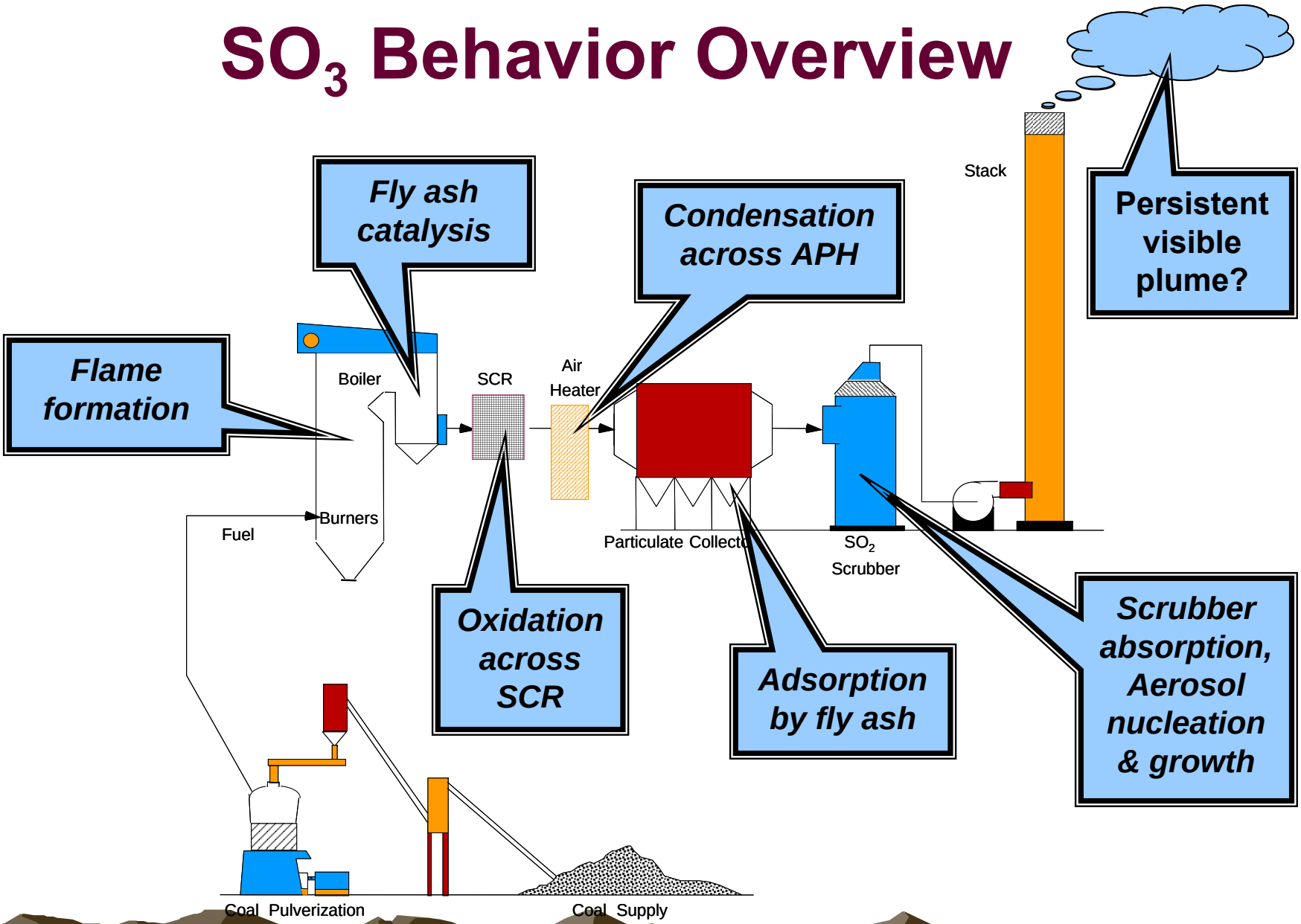
Key Elements of SO_3 Mitigation

- **Assessment *(where you are)***
  - **Understand SO_3 behavior in plants**
  - **Identify key plant components (current & future)**
  - **Assess plant SO_3 behavior**
- **Define emissions target *(where you're going)***
- **Select control options *(how to get there)***
  - **Assess design and performance**
  - **Assess balance-of-plant impacts**
  - **Consider mitigation costs**

SO_3 Impacts

- Visible plumes aren't the only concerns
- Process impacts:
  - Cold-end corrosion in air heaters, ductwork and APCDs
  - Air heater plugging (in combination with SNCR/SCR systems)
  - Negative impact on mercury sorbents

SO_3 Behavior Overview



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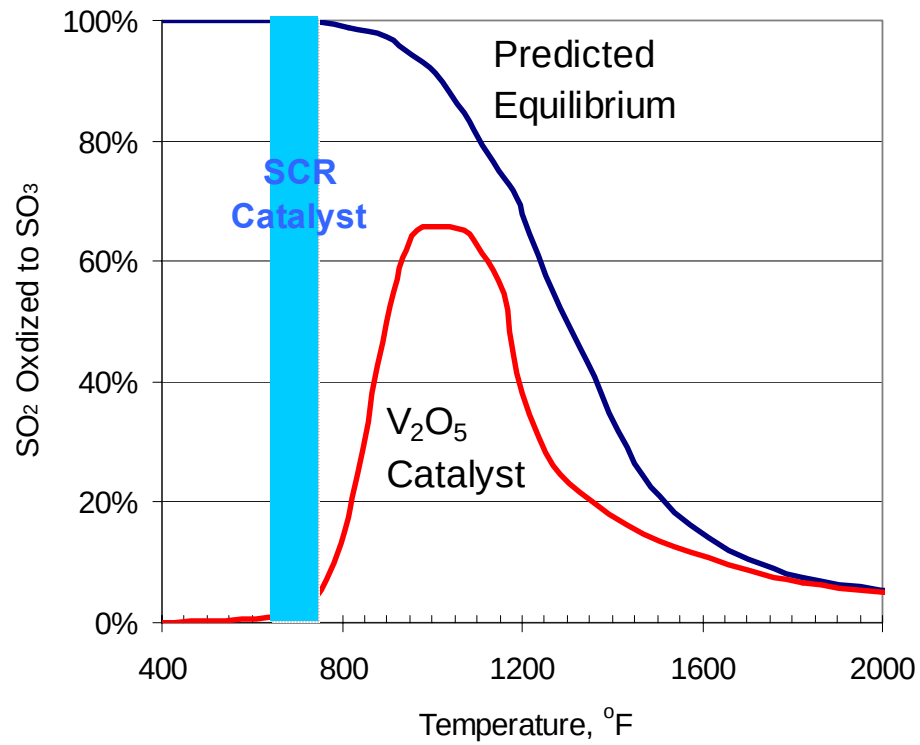
SO_3 Behavior - SCR

- SO_3 is formed in SCR by conversion from SO_2
- Extent of conversion depends on:
  - SO_2 levels
  - Catalyst type
  - Flue gas temperature (higher temp = more conversion)
- Conversion is typically 0.5-1.5%

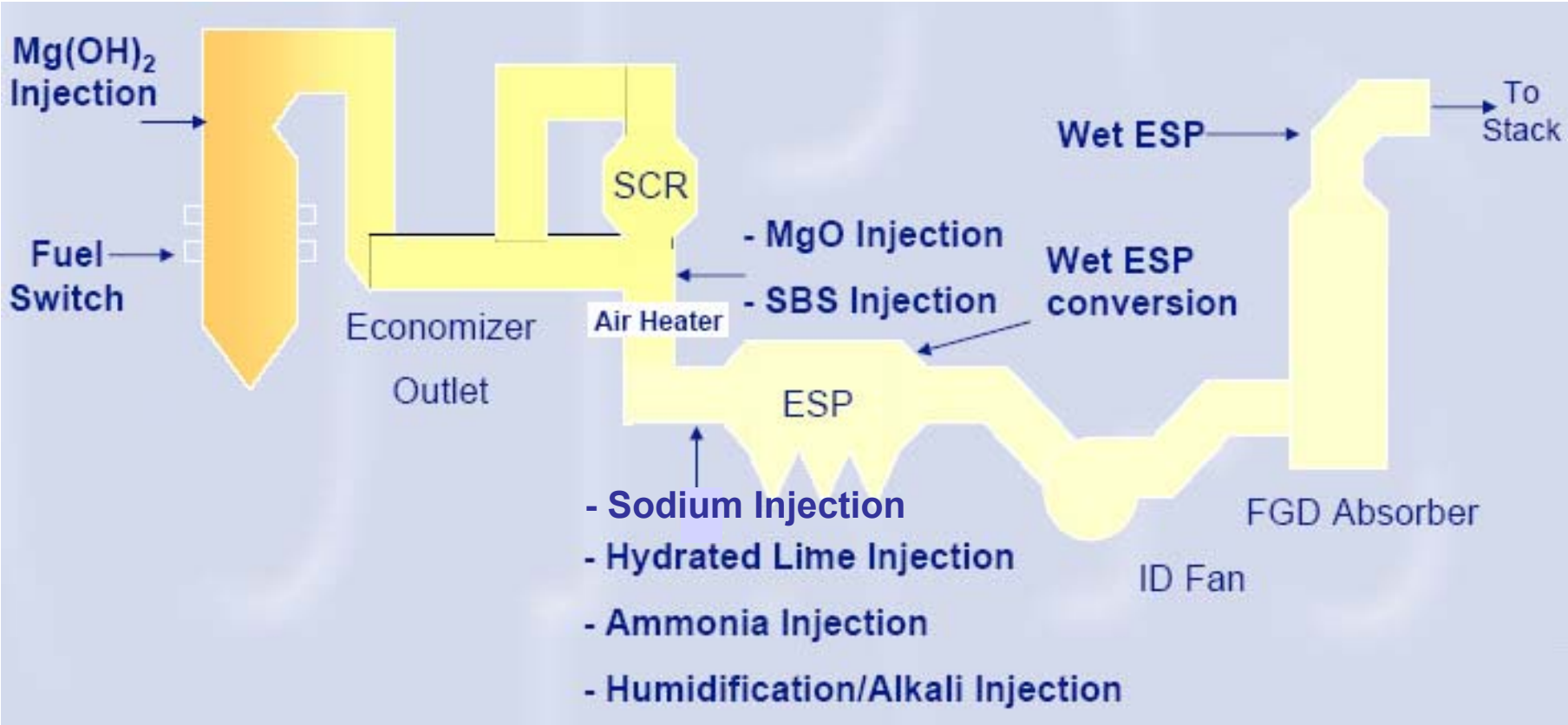


- Active catalyst in SCR is V_2O_5
- Catalysts operate at 650˚F - 750˚F
- Potential for conversion of ≤ 2%

SO_3 Plant Behavior

Component	Factors	Impact
Furnace & back pass	Fuel sulfur, furnace O_2, fly ash composition, gas temperature	0.75% to 1.5% SO_2 oxidation
SCR	SO_2 level, catalyst type, gas temperature	0.5 to 1.5% SO_2 oxidation
Air Preheater	AH type, cold-end temperature, quench rate, ammonia level	20 to 65% SO_3 removal
ESP	Gas temperature, fly-ash composition	25% to 50% removal
Baghouse	Effective, but not used with high SO_3	~90% removal
Spray Dryer	Effective (lime injection)	>90% removal
Wet FGD (scrubber)	Flue gas temperature, conversion to H_2SO_4	20% to 60% removal (average ~50%)
Wet ESP	Effective H_2SO_4 capture	>90% removal

SO_3 Control Technology Overview

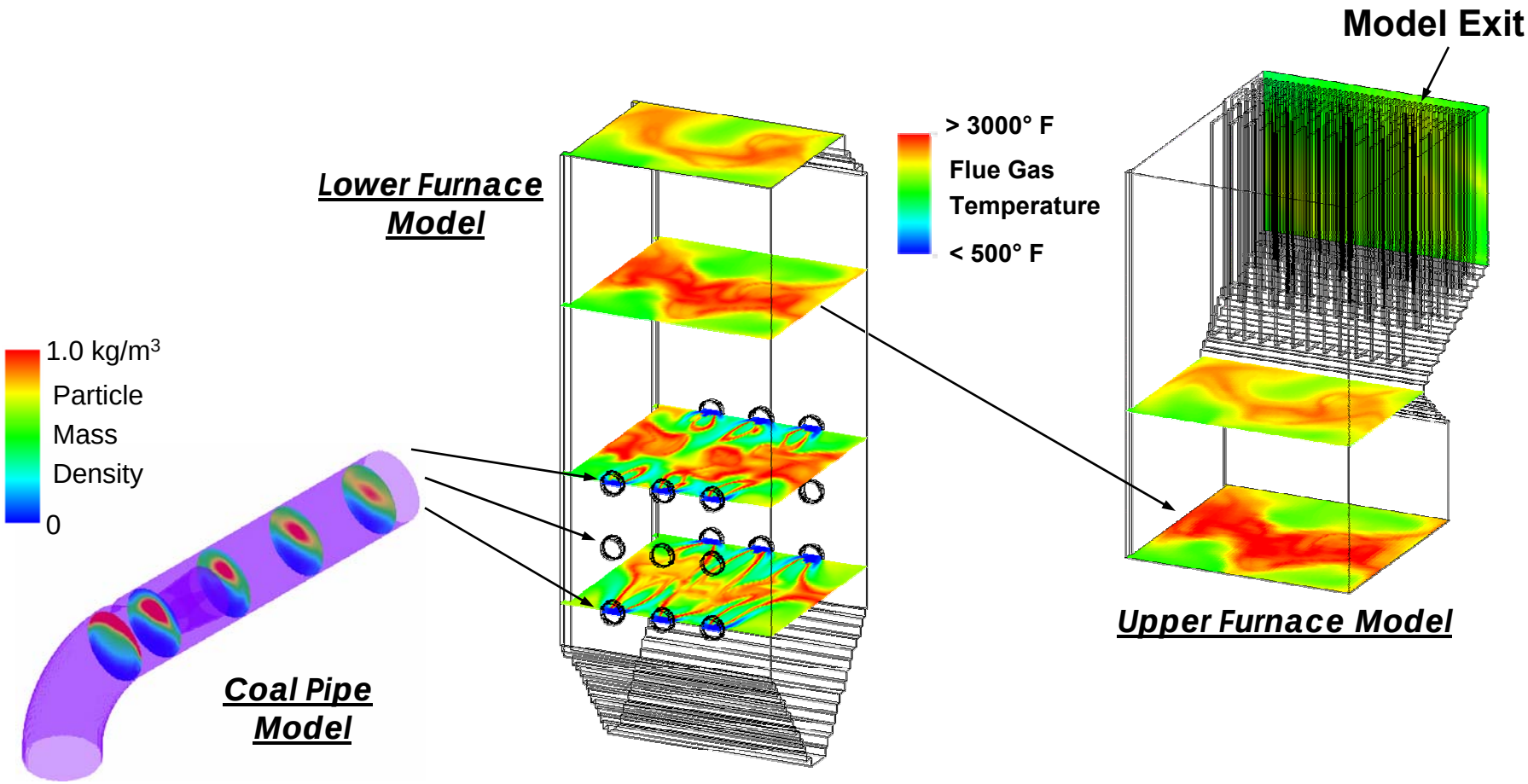


Source: Blythe, et. al, 2004

Example 1: $Mg(OH)_2$ Furnace Injection

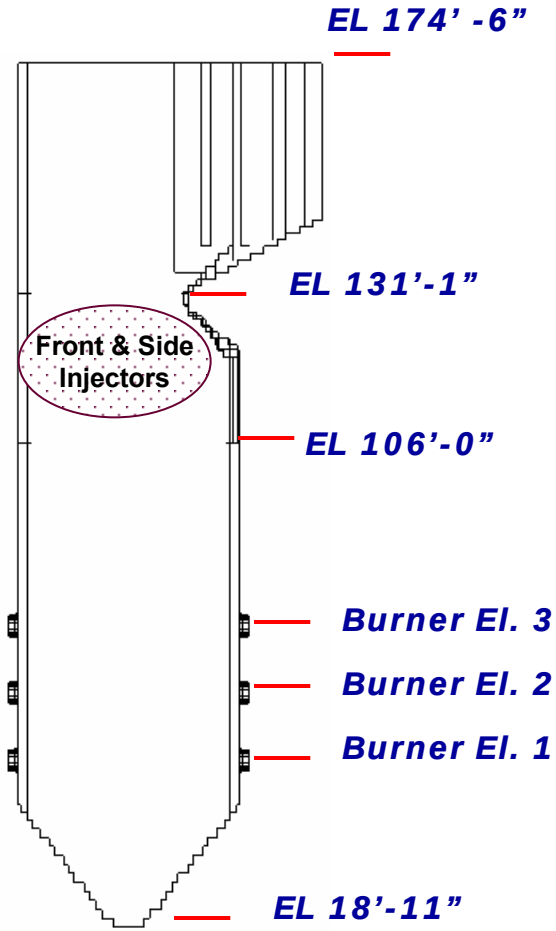
- **Use CFD Modeling to**
  - **Determine furnace temperature, flow, and species profiles including sulfur speciation**
  - **Determine design constraints**
  - **Quantify and optimize slurry injection efficiency**
    - **Nozzle quantity and locations**
    - **Droplet size distribution and slurry flow rate**
- **Assume that extent of MgO distribution is indicative of effectiveness of SO_3 capture through plant**

Modeling Approach

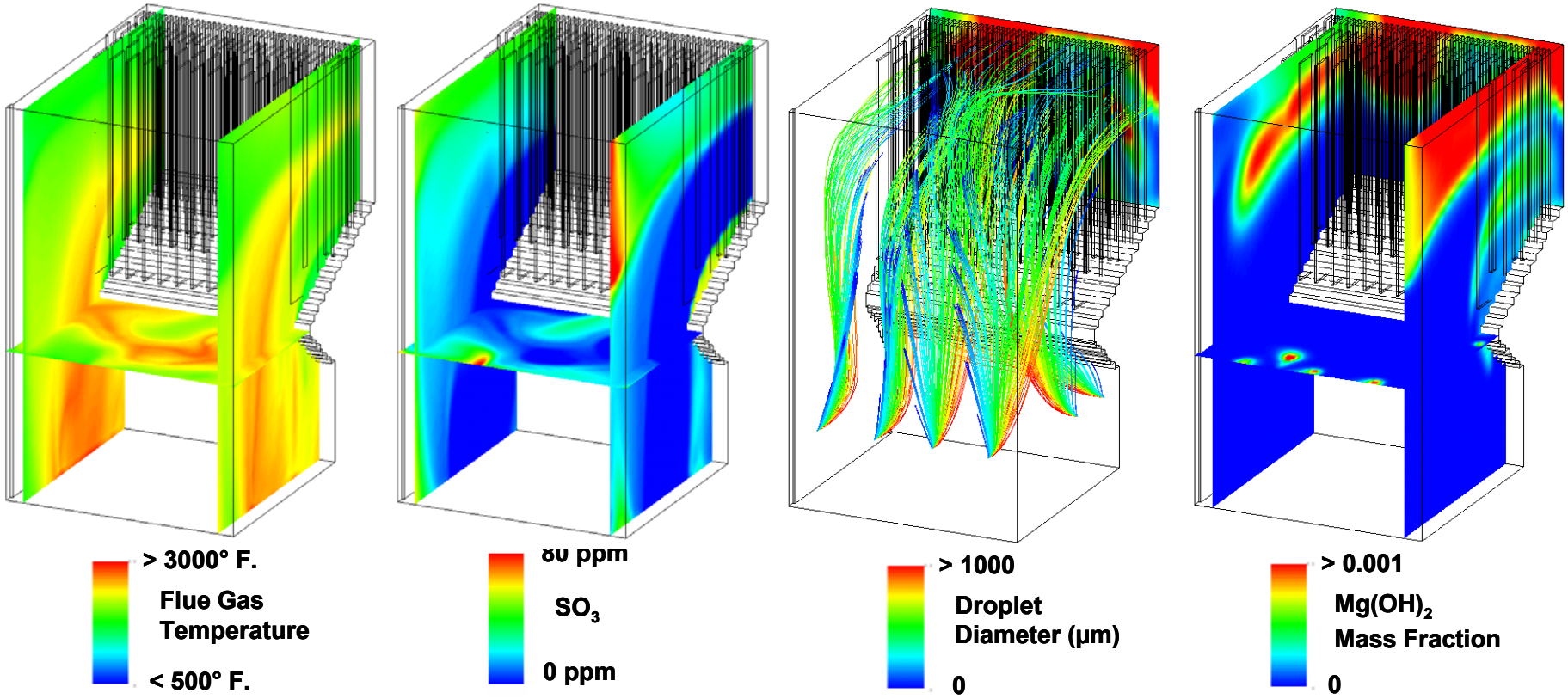


Injection Design Constraints

- **Furnace Wall Accessibility**
  - Rear wall not accessible above elevation 106’-0” (enclosure)
  - Front wall and sidewalls not accessible from El. 102’-0” to El. 115’-0” (headers); platforms at El. 116’-0” and 125’-0”
- **High flue gas temperatures below El. 106’ may inhibit MgO reactivity through sintering (> 2500° F)**
- **Slurry flow rate is load dependent**
- **Use commercially available nozzles**



Conceptual Design Performance

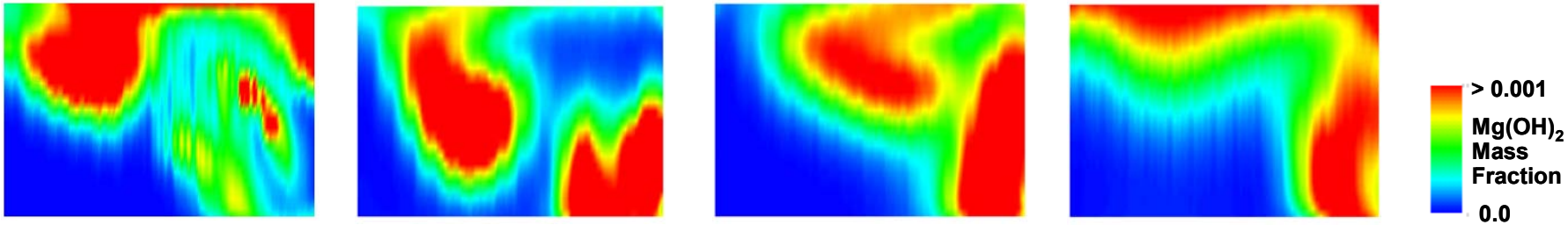


Average temperature of 2400 ºF at injection plane; MgO released higher in furnace at lower temperatures so low chance of sintering

Injection Sensitivities

(injection design, load range)

Full Load Cases | **75% Load Cases** | **50% Load Cases** | **Minimum (37.5%) Load Cases**

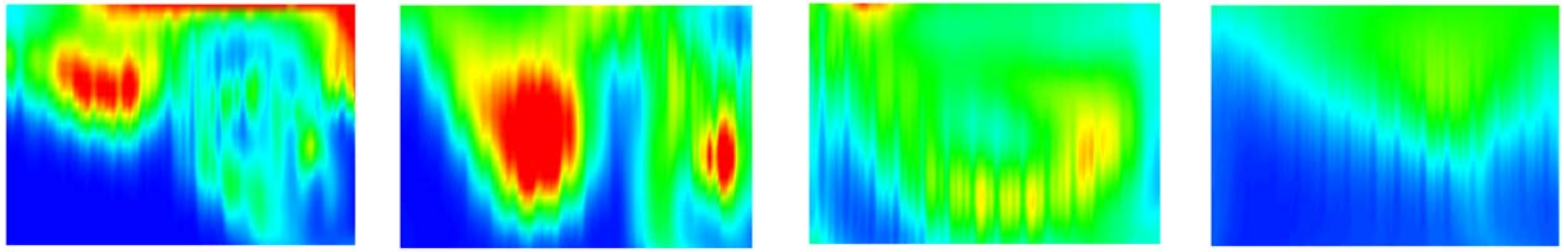


Design 1: 60 gpm, 400 μm SMD
Mixing Number = 0.65

45 gpm, 200 μm SMD
Mixing Number = 0.63

30 gpm, 200 μm SMD
Mixing Number = 0.66

22.5 gpm, 200 μm SMD
Mixing Number = 0.71



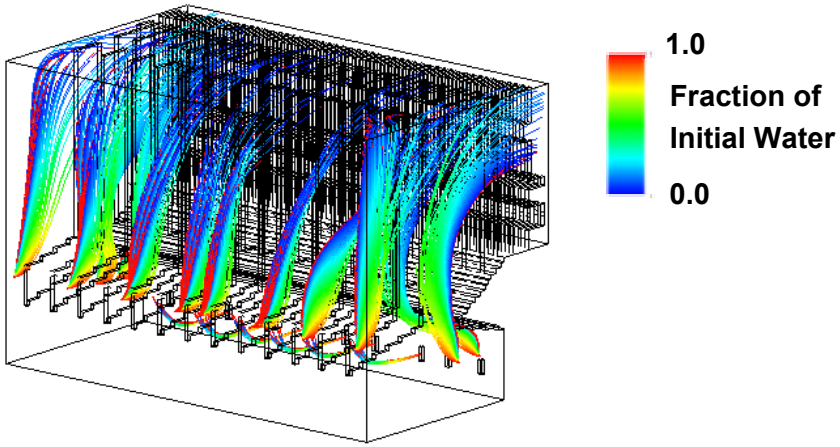
45 gpm, 475 μm SMD
Mixing Number = 0.65

45 gpm, 475 μm SMD
Mixing Number = 0.73

30 gpm, 600 μm SMD
Mixing Number = 0.87

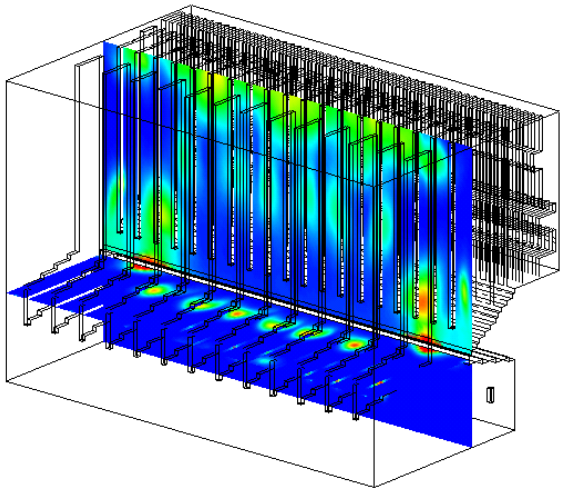
22.5 gpm, 800 μm SMD
Mixing Number = 0.75

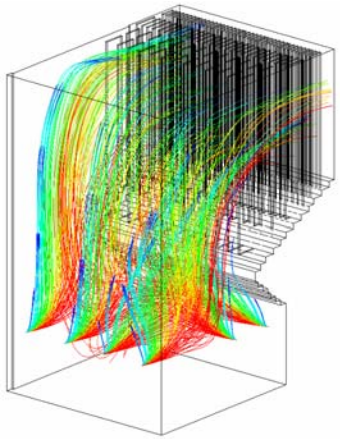
Droplet Trajectories Analysis



1.0
Fraction of
Initial Water
0.0

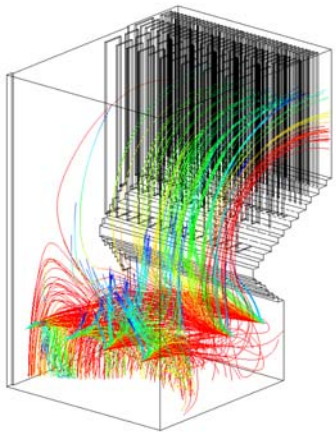
> 0.002
MgO
Mass Fraction
0.0





> 1000 μm
Droplet
Diameter
0 μm

50% Load
600 μm SMD Spray



Minimum (37.5%) Load
800 μm SMD Spray

- Larger droplets require greater gas momentum for upward motion
- At minimum (37.5%) load, 800 SMD droplets drop into the lower furnace

Summary of CFD Results

- **CFD modeling helps guide injection design and provides evaluations of injection performance**
  - **Sidewall injectors greatly improved reagent coverage**
  - **Lower elevation injection improved mixing**
  - **Marginal mixing improvement with increased nozzles**
  - **300-400 μm SMD droplet distributions yielded best results**
- **Successful SO_3 reduction at unit test correlated well with predicted results**

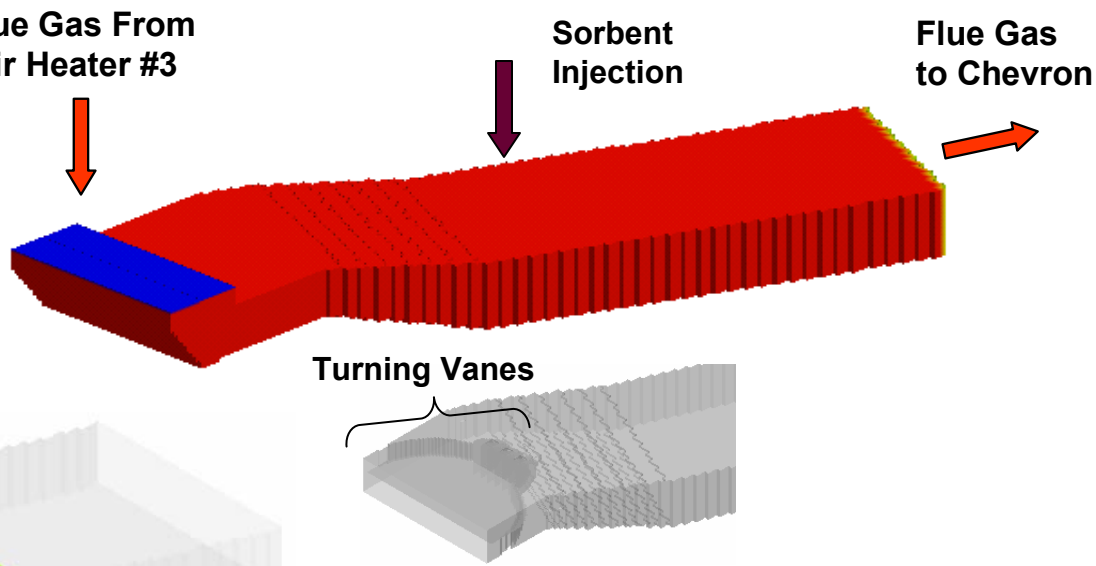
Example 2: Post-APH Sorbent Injection

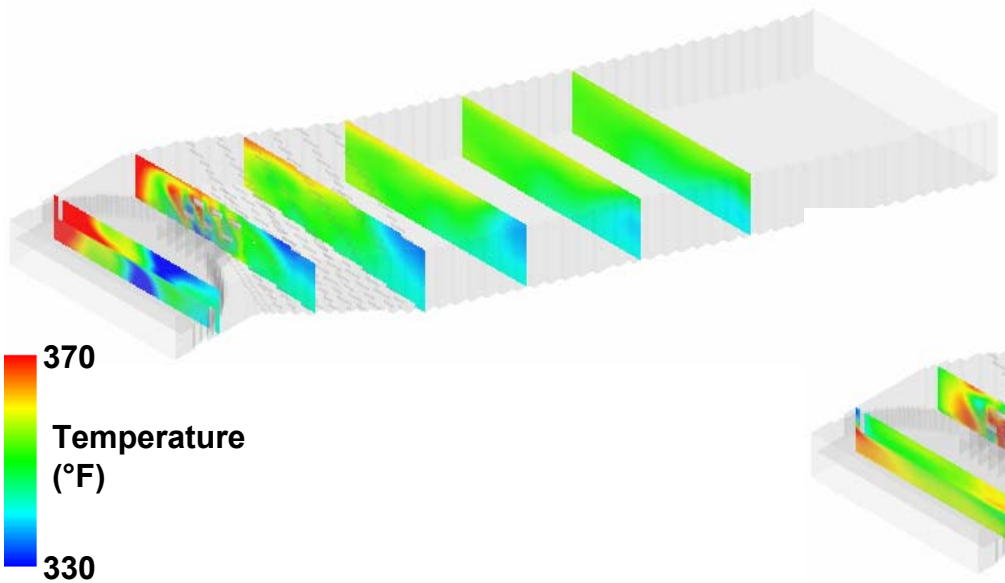
Use CFD to guide APH-ESP ductwork and sorbent injector design

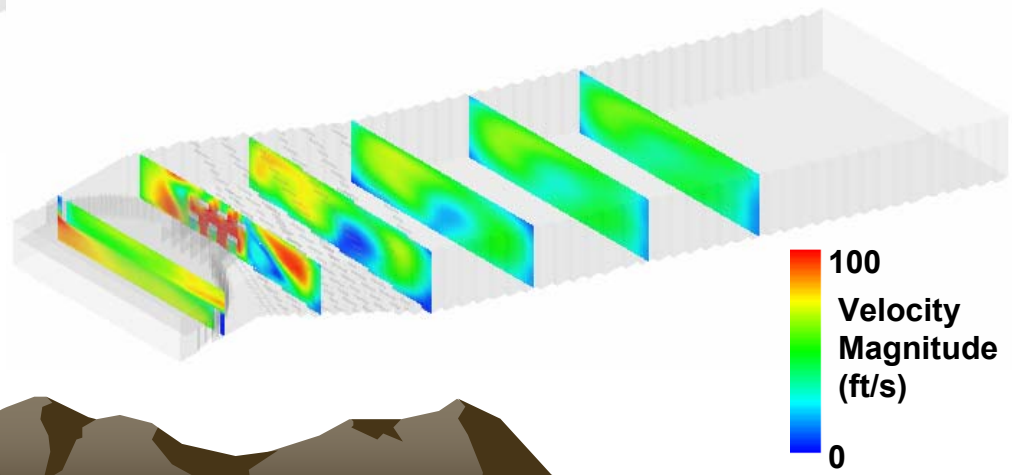
- Improve uniformity of temperature field
  - Turning vanes
  - Quench air lances
- Assess sorbent injection distribution
  - Optimize lance design and location for fixed conditions (# of lances, flue gas flow rate, sorbent injection rate, particle sizes)

Turning Vane Design

- Design mixing device to minimize temperature variation at sorbent injection plane (~350°F)

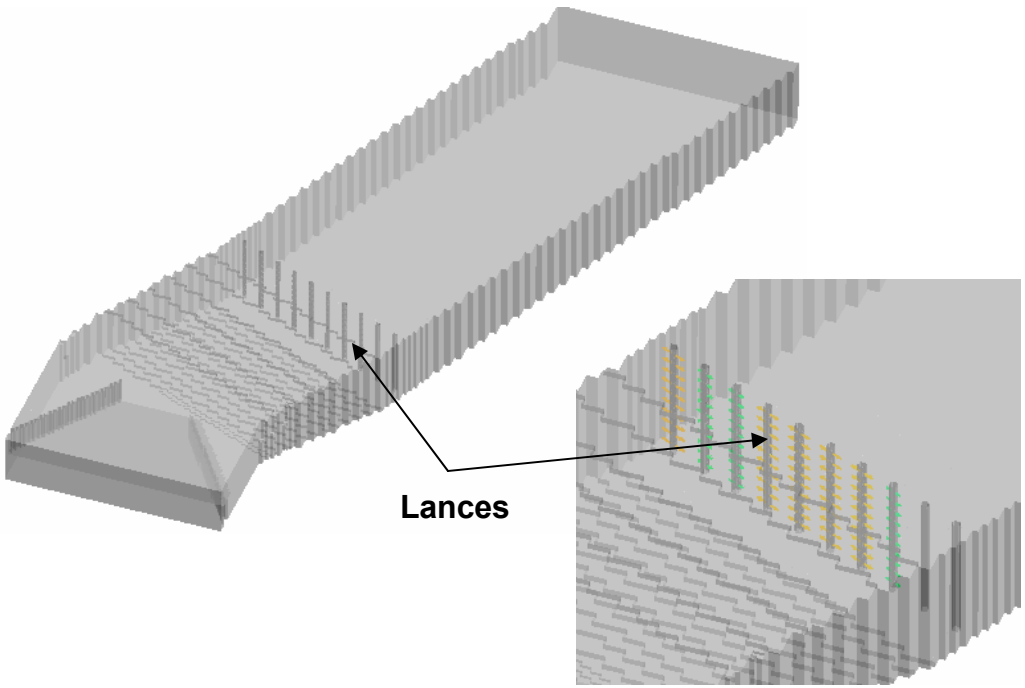


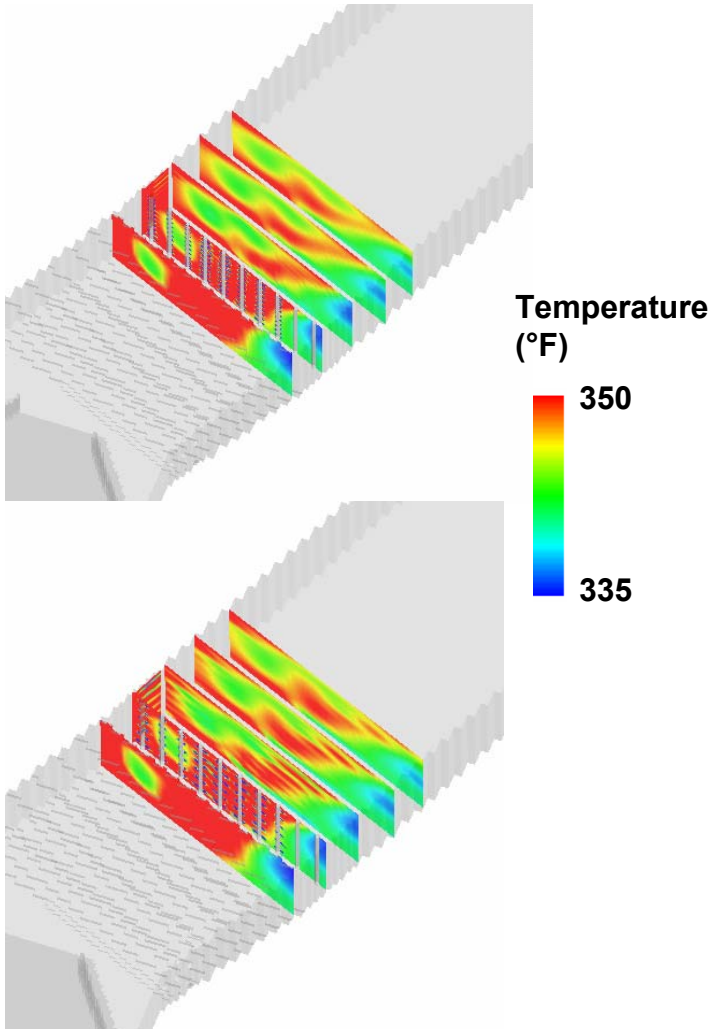




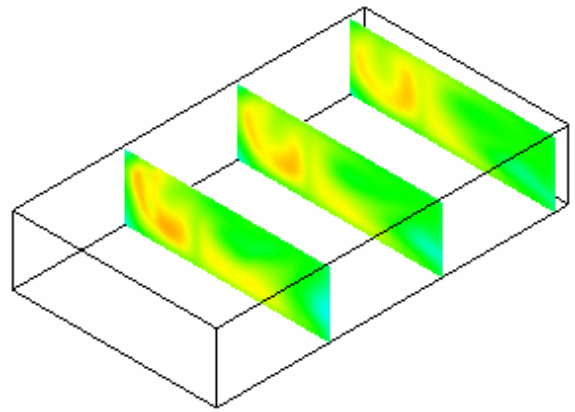
Quench Air Design

- **Design quench air system such that the maximum temperature <350°F at sorbent injection plane**
  - **Lance design & location**

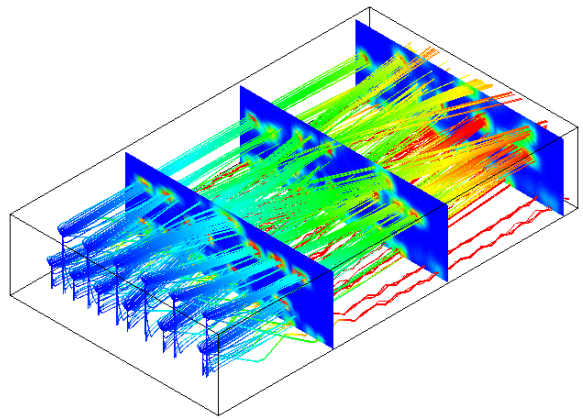




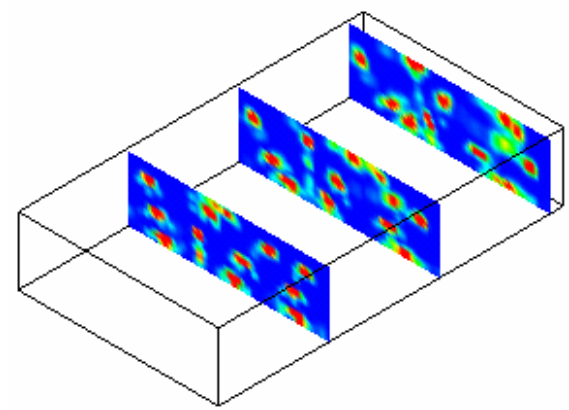
Sorbent Injection Summary



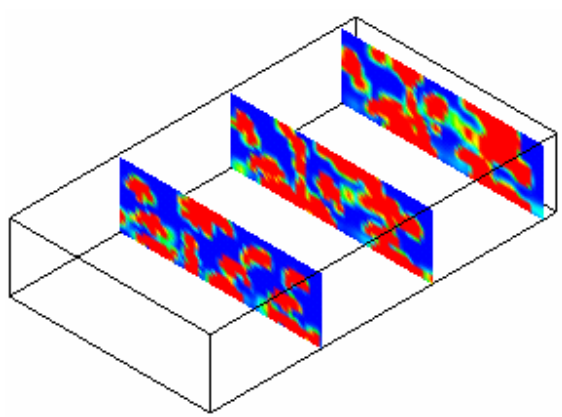
SO_3 Mole Flux (mol/m^2-s)



Sorbent Residence Time



Na Mole Flux (mol/m^2-s)



Na/SO_3 Flux Mole Ratio

- Turning vanes help temperature uniformity, but still not completely uniform
- Quench air lances do not reduce all temperatures below 350 °F
- Sorbent injection constraints cause “spotty” distribution, suggesting non-optimal coverage/mixing (but maybe enough)

Summary

- SO_3 impacts plant operation as well as plume
- SO_3 behavior highly plant specific
- Control options should be tailored to plant needs
  - Assess status, emission goals, appropriate technologies
- CFD tools useful in designing SO_3 mitigation systems
  - Capture unique plant geometry and operating conditions
  - Describe and assess changes to flue gas environment
  - Design sorbent injection system and evaluate performance

Thank You

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