REINHOLD ENVIRONMENTAL Ltd.

2013 APC Round Table
& Expo Presentation

July 8-9, 2013, in St. Louis, MO / Hosted by Ameren

Reducing ESP Hopper Re-entrainment for ACI Operation

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Rob Mudry and Brian Dumont, Airflow Sciences

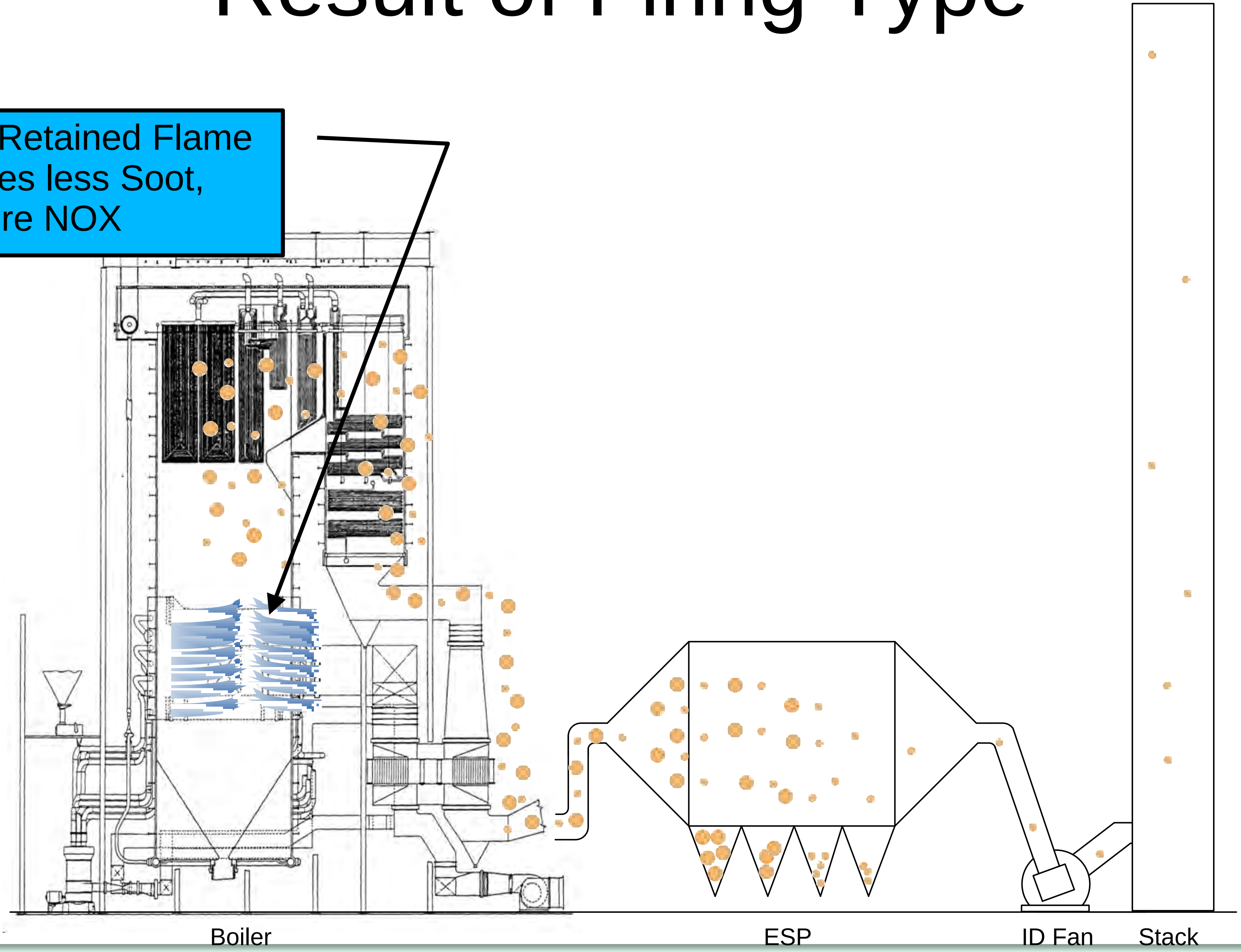
2013 APC Round Table

Introduction

- The need to manage the effects of carbon in ESPs comes from prior experience:
  - From high Loss on Ignition (LOI) particulate as a result of:
    - Low NOX burner / over fire air conversions
    - Low volatility coal
    - Wall-fired furnaces

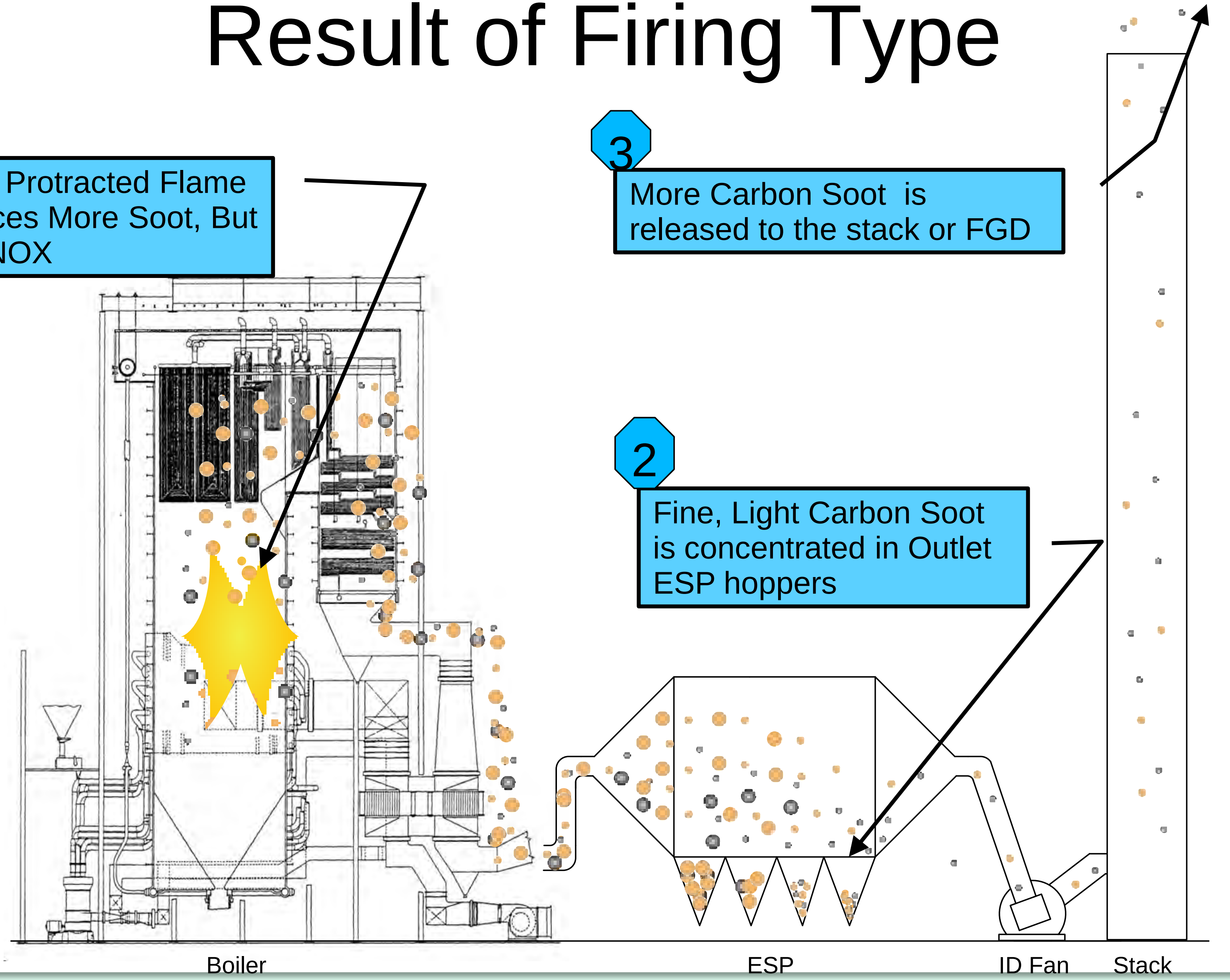
High Carbon carryover results in high opacity

Carbon Soot (LOI) Production as a Result of Firing Type



Highly Retained Flame produces less Soot, But More NOX

Carbon Soot (LOI) Production as a Result of Firing Type



1

Highly Protracted Flame produces More Soot, But Less NOX

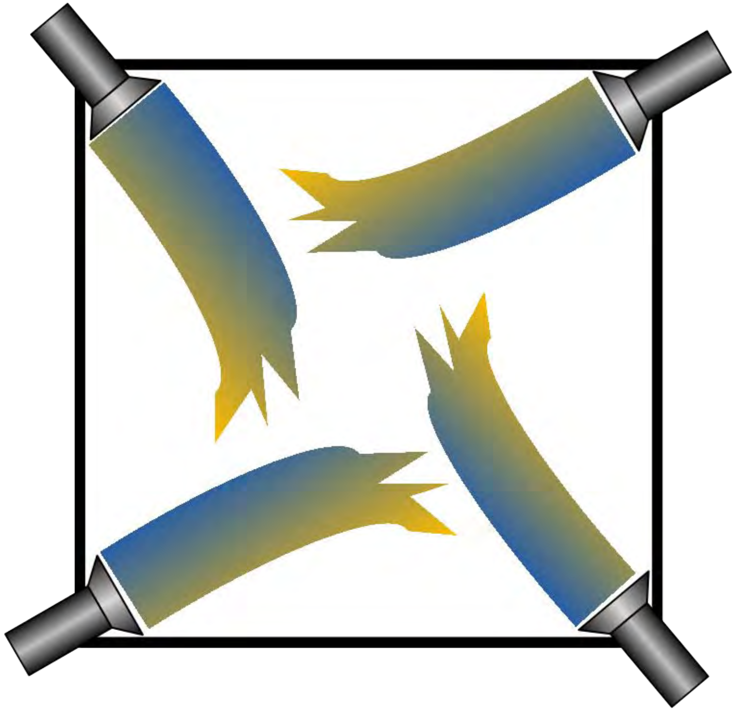
3

More Carbon Soot is released to the stack or FGD

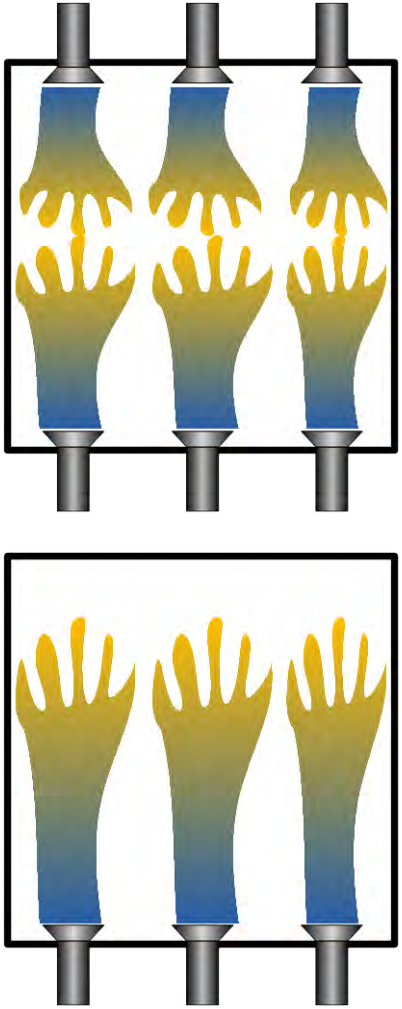
2

Fine, Light Carbon Soot is concentrated in Outlet ESP hoppers

Carbon Soot (LOI) Production as a Result of Firing Type



Tangential-Fired Furnace
Less LOI



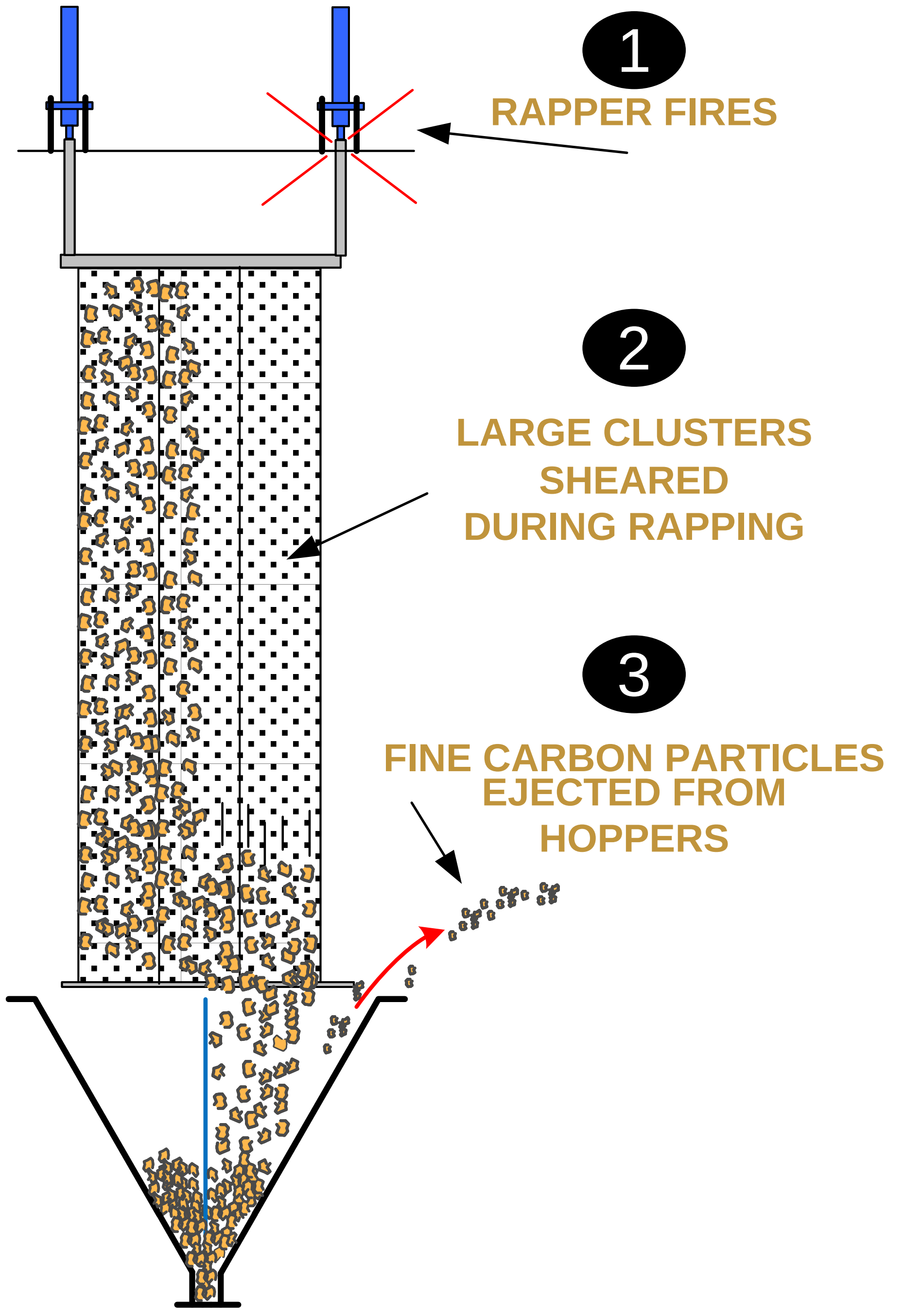
Wall -Fired Furnaces - More LOI

Investigation - Physical

- Self-performed physical modeling
  - Tested 1:4.5 scale model of Watson 5 ESP (partial)
    - Studied steady state as well as transient conditions during rapping
    - Developed hopper baffling concepts

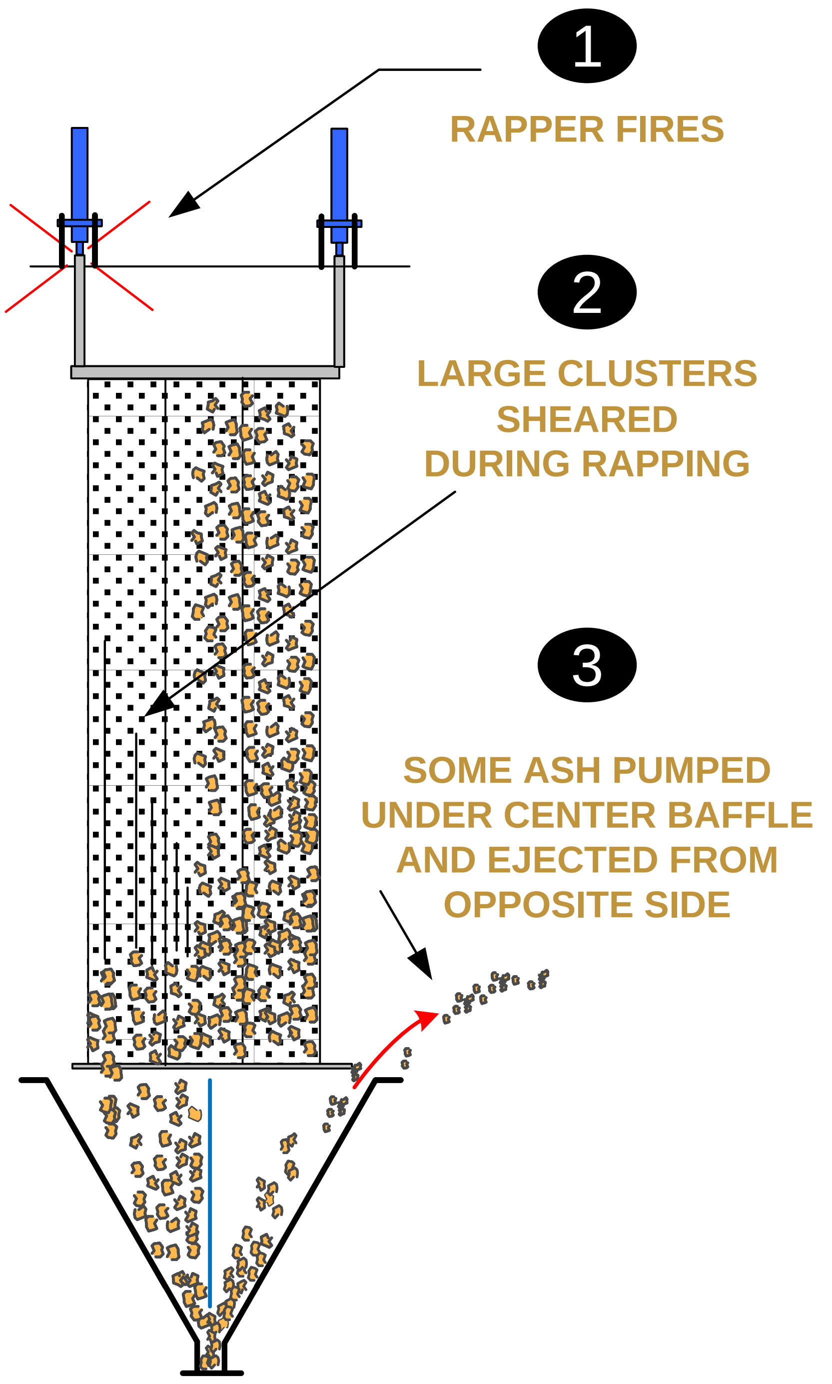
Lessons Learned from Physical Model

- Carbon particulate can separate from a falling plume during rapping
- Carbon particulate can be ejected from hopper during "splashdown"

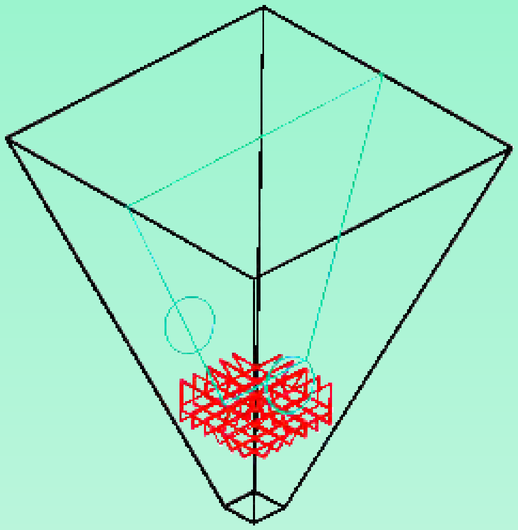


Lessons Learned from Physical Model

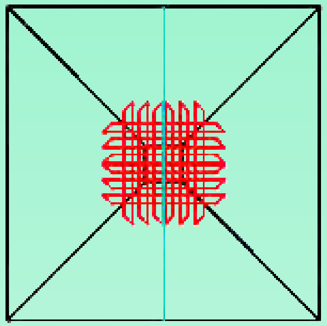
- Carbon particulate can be ejected from an otherwise empty hopper from the opposite side of center baffle



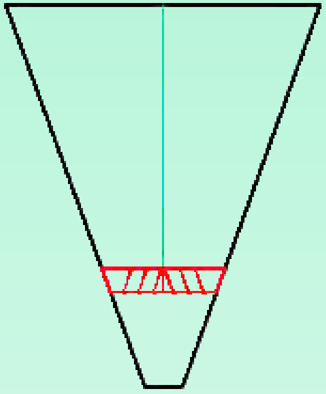
Devices from Physical Modeling



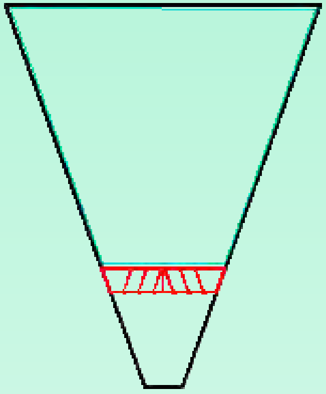
ISO VIEW



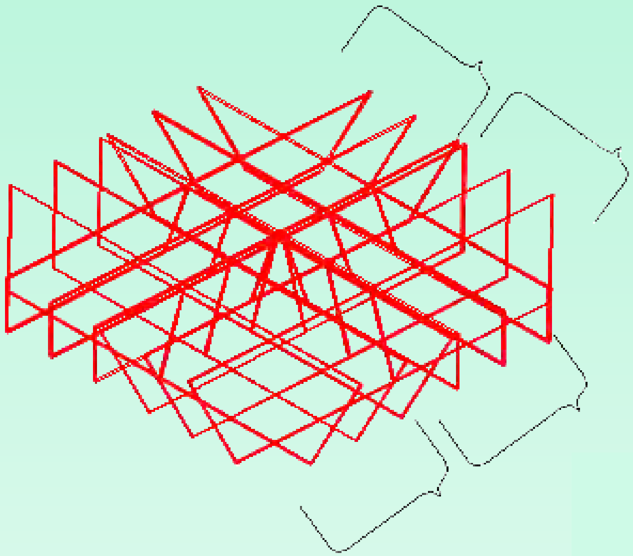
TOP VIEW



SIDE VIEW



END VIEW



DETAIL VIEW

Investigation - CFD

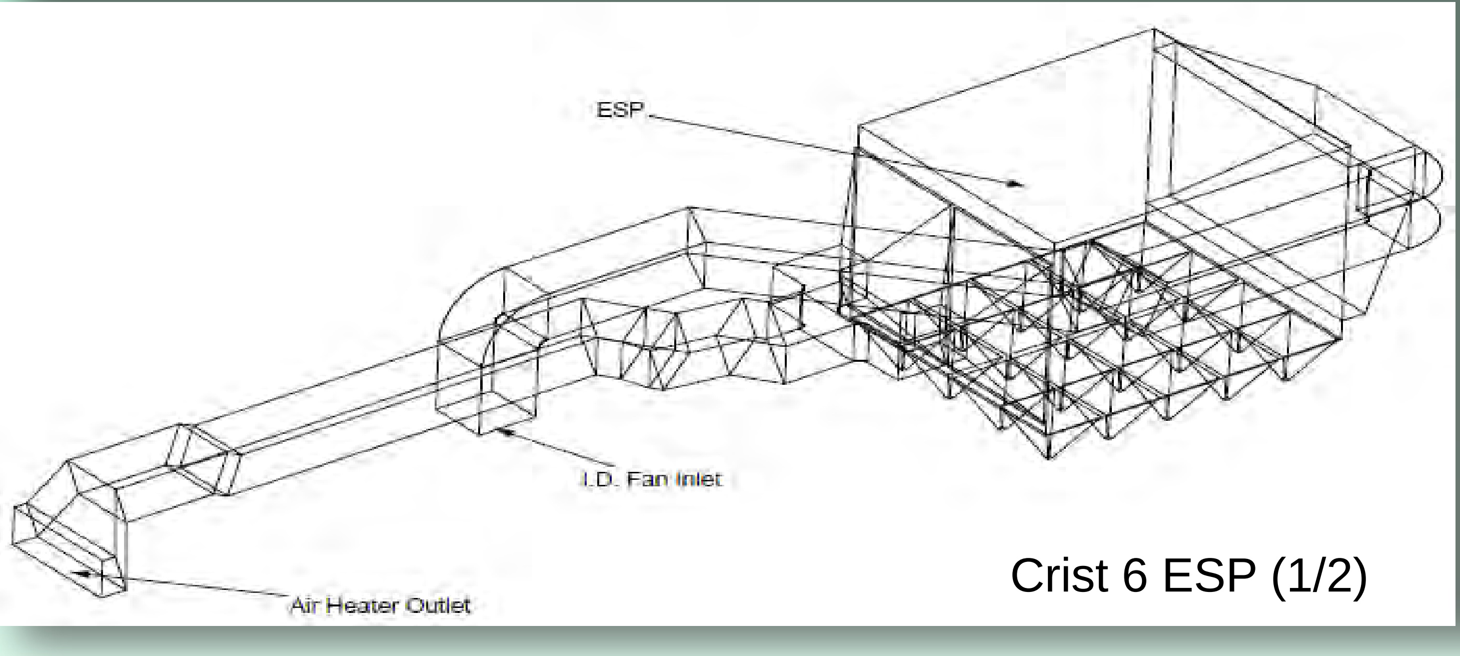
- Needed to know more about the dynamics of lessons learned in the physical model
- Next opportunity was ESP rebuild at Gulf Power, Plant Crist Unit, 6
  - Commissioned study by Airflow Sciences through H/R-C
  - Approach had a "typical" focus and included modeling of:
    - Duct System
    - Electrode region gas flow
    - Support Insulator purge air flow
  - CFD software AZORE® used
    - 14,500,000 computational cells
    - 92.5% hexagonal cell topology

Investigation – CFD (Cont.)

- An expanded design effort was also initiated to improve the capture of very fine, carbonaceous particles
  - Plant was dealing with high LOI ash – difficult for ESP to capture due to small particle size and elevated carbon content
  - Design effort concentrated on flow patterns in the hoppers, minimizing the potential for fine particle re-entrainment
- We feel that lessons learned will directly apply to MATS compliance
  - Activated Carbon Injection (ACI) will be used extensively for MATS compliance
  - Powdered Activated Carbon (PAC) has similar traits to high LOI flyash

Investigation – CFD (Cont.)

- Modeled both Steady state and Transient conditions
  - Steady State defined as normal operation at a constant gas flow with no disturbances
  - Transient defined as the localized behavior of ash and flue gas under rapping



Crist 6 ESP (1/2)

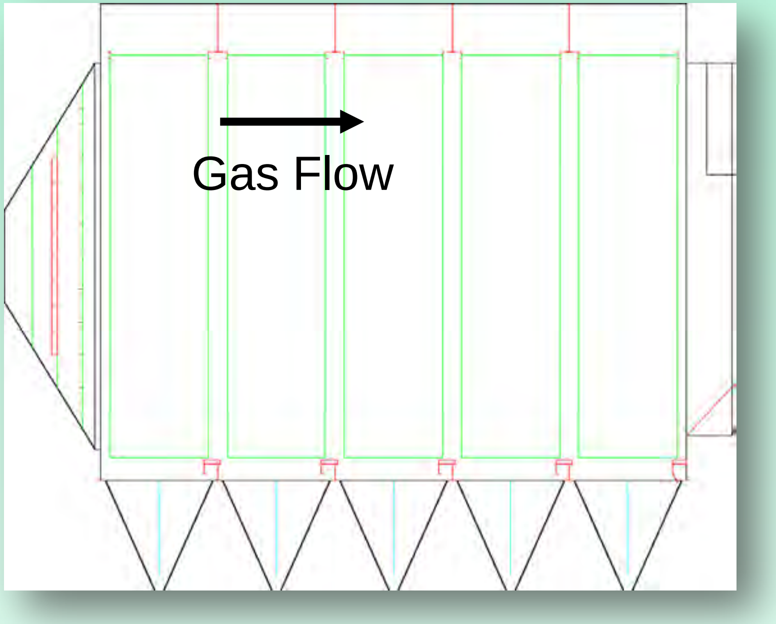
Plant Crist Unit 6 ESP

- Manufactured by Wheelabrator
- In service date 1994 (Retrofit from Buell)
- Rebuild with HRC internals 2012
- Necessary due to low temperature operation and rapping fatigue

Crist Unit 6 ESP

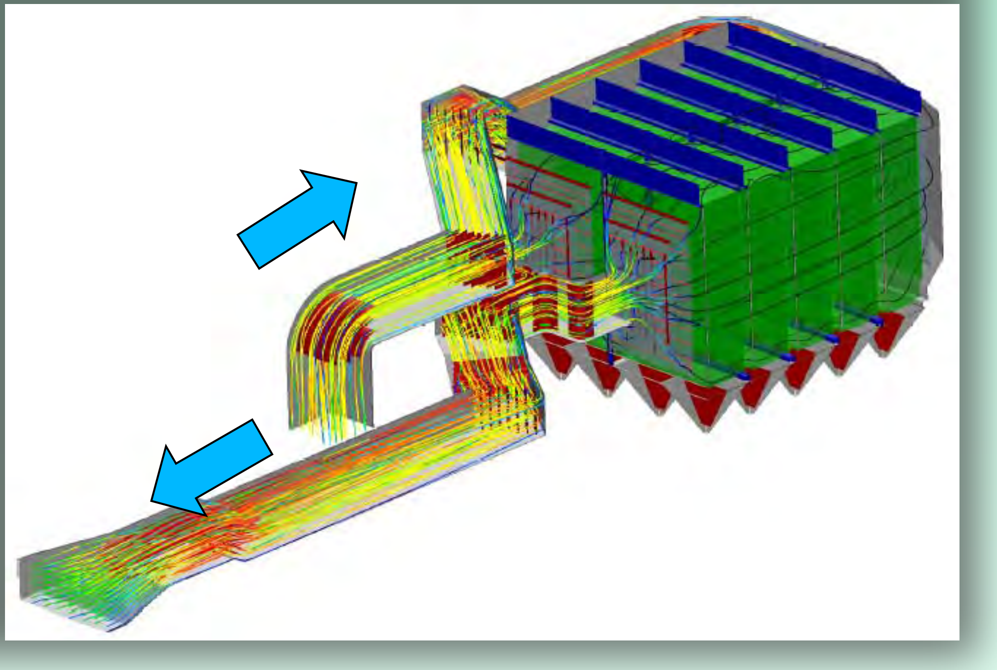
ESP Geometry

- Five mechanical fields
- Inlet perf plates and vanes
- Outlet perf plate
- Hopper baffles
- SCA = 378 @16” (672 @9”)
- Low sulfur fuel
- Avg velocity = 3.8 ft/s



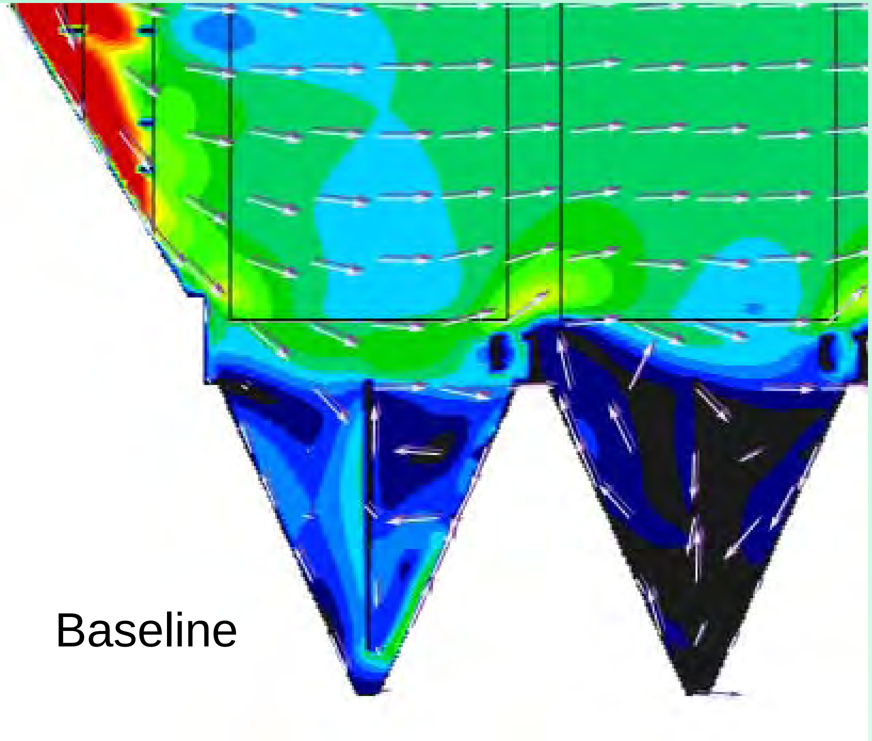
CFD Gas Flow Optimization

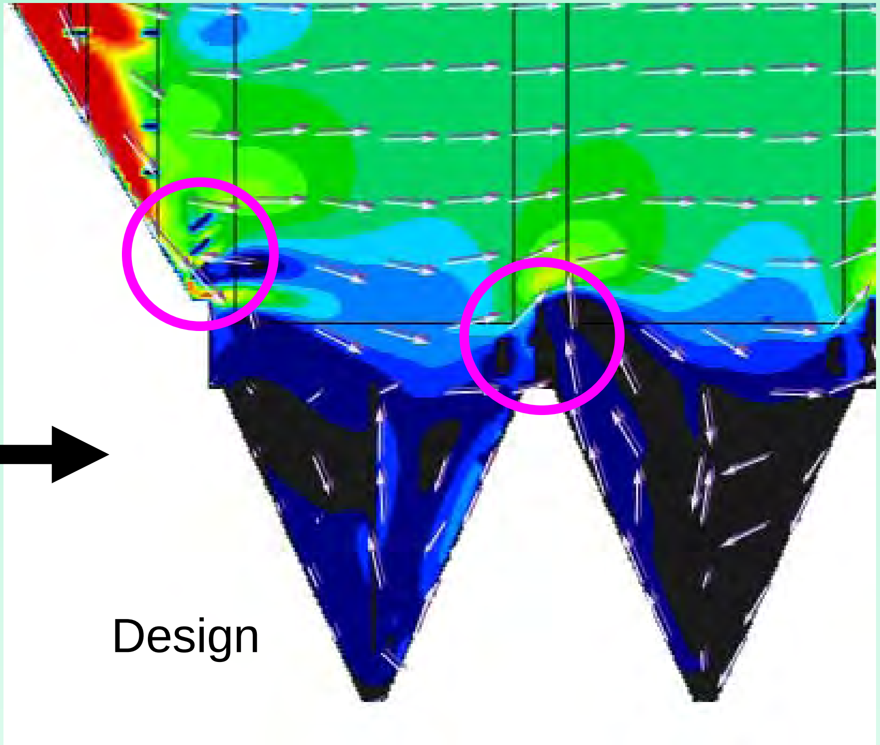
- CFD model study for overall flow improvements
  - ICAC flow uniformity at inlet/outlet planes
  - Balanced flow to compartments
  - Minimize sneakage
- Baseline model
- Design optimization
  - ESP gas flow
  - Basic hopper flows



Basic Hopper Flow Optimization

- Baffles added to reduce gas velocities and recirculation, in and above the hoppers
  - Added to inlet perforated plate
  - Added to walkways





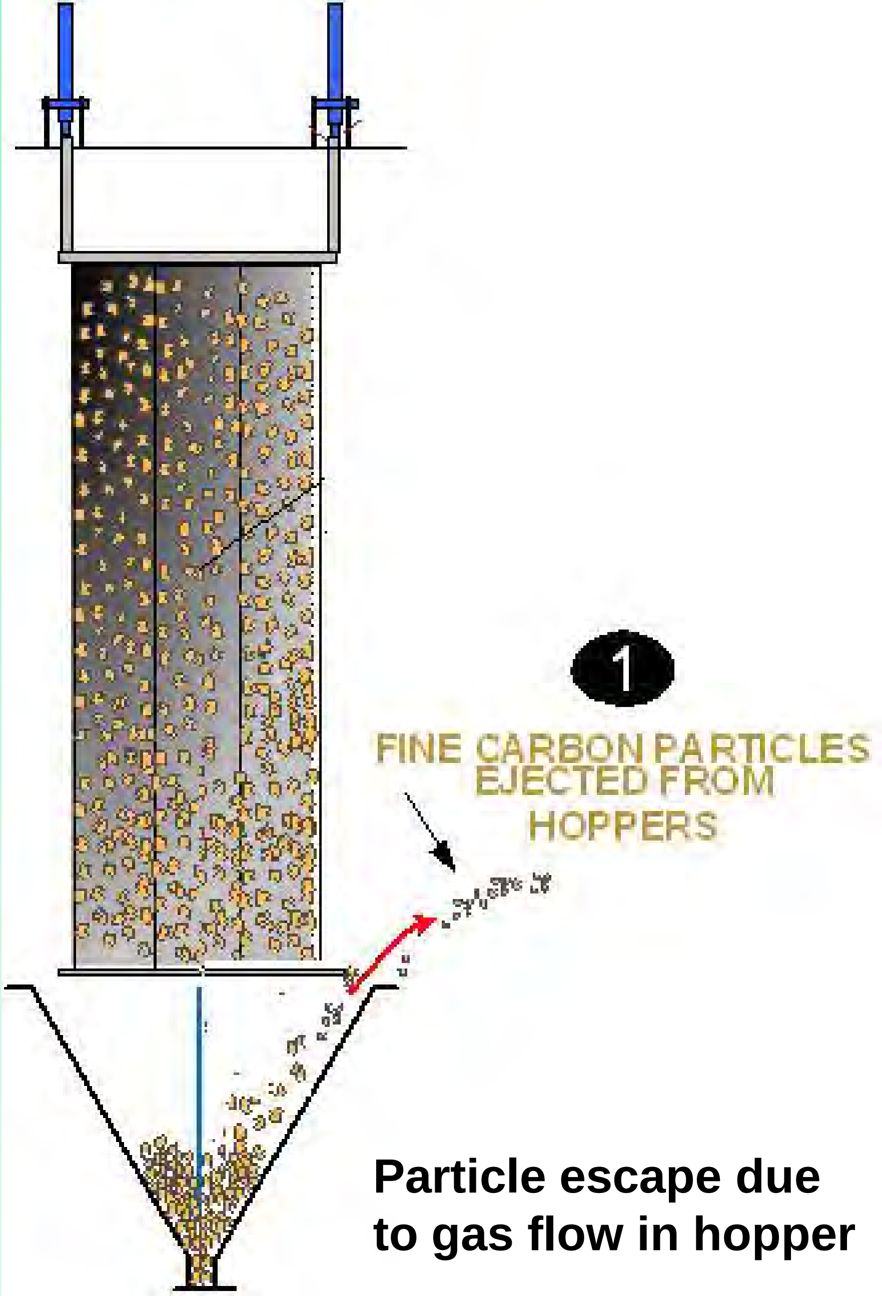
Expanded Modeling Effort

- Improve capture of very fine, high carbon flyash
- These are more difficult to capture in ESP because
  - Carbon content adversely affects resistivity
  - Fine particles migrate more slowly to collection plates
  - Fine particles are more likely to be re-entrained during rapping before they reach the hoppers
  - Fine particles are more likely to escape the hoppers
    - Due to subtle velocity patterns and recirculation, allowing fine ash to be re-entrained out of hoppers
    - Due to ash particle interaction and gas flow transient pressures caused by rapping of collection plates

Steady State Analysis

- Focus on hopper gas flow and particle behavior
  - Very fine, light weight particles, especially with a higher carbon content (LOI, PAC), are influenced less by gravity and more by subtle gas velocities
  - These particles are susceptible to re-entrainment if they waft upwards regardless of hopper fill level
  - During rapping, falling mass of ash impacts existing ash in hopper and causes “splash” effect, resulting in fine particles being pushed upwards, to be re-entrained in the main gas flow

Steady State Analysis



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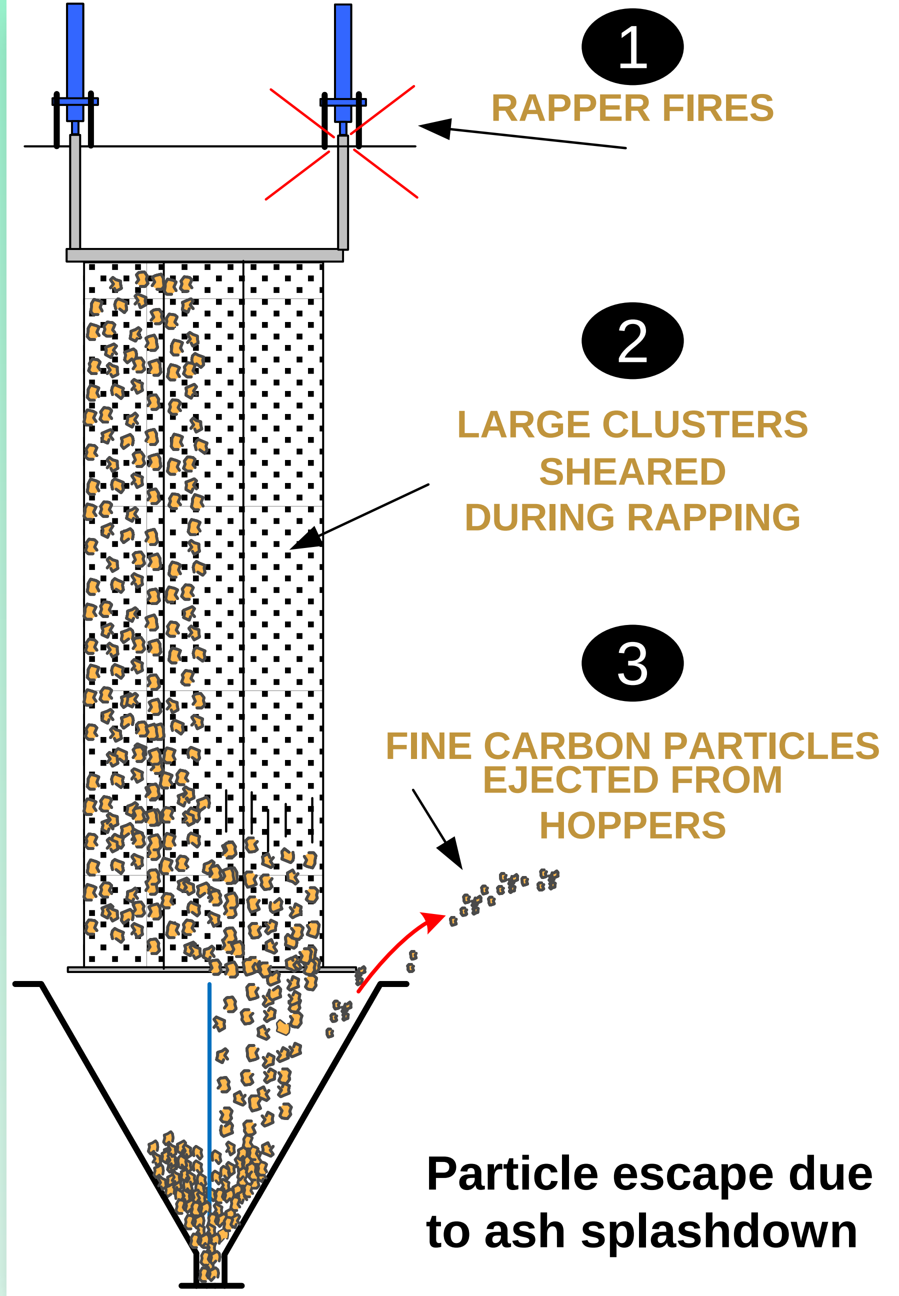
FINE CARBON PARTICLES EJECTED FROM HOPPERS

Particle escape due to gas flow in hopper



1

RAPPER FIRES

2

LARGE CLUSTERS SHEARED DURING RAPPING

3

FINE CARBON PARTICLES EJECTED FROM HOPPERS

Particle escape due to ash splashdown

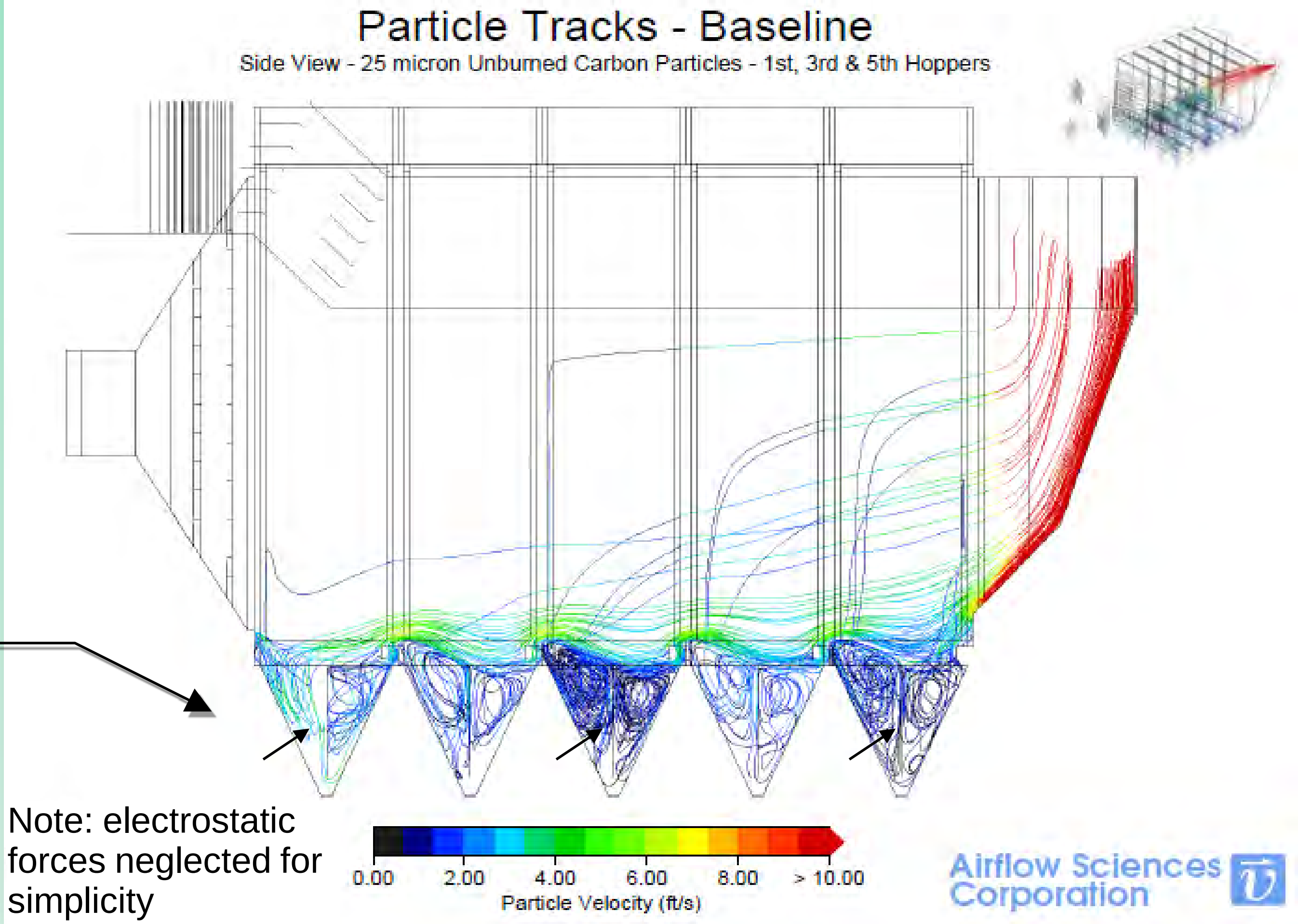
Steady State Analysis

- Performed ash tracking from the hoppers to predict behavior of ash when there is flow under the hopper baffle, subtle recirculation, or “ash splashdown”
- CFD model tracks the particle path of very fine, light weight particles (25 micron, 0.65 SG), “freely-released” in the hoppers, to see where they go
  - Captured if they hit a wall
  - Escape if they leave the hopper
- Metrics used to assess performance
  - Amount of flue gas flow going under the hopper baffle
  - Percent of particles captured versus escaping a hopper
  - Residence time of particles in hopper

Steady State Model Findings

- Baseline
  - Tracked particles from 1st, 3rd, and last hoppers
    - Thousands of individual particles tracked
    - Found measureable recirculation and re-entrainment from hoppers

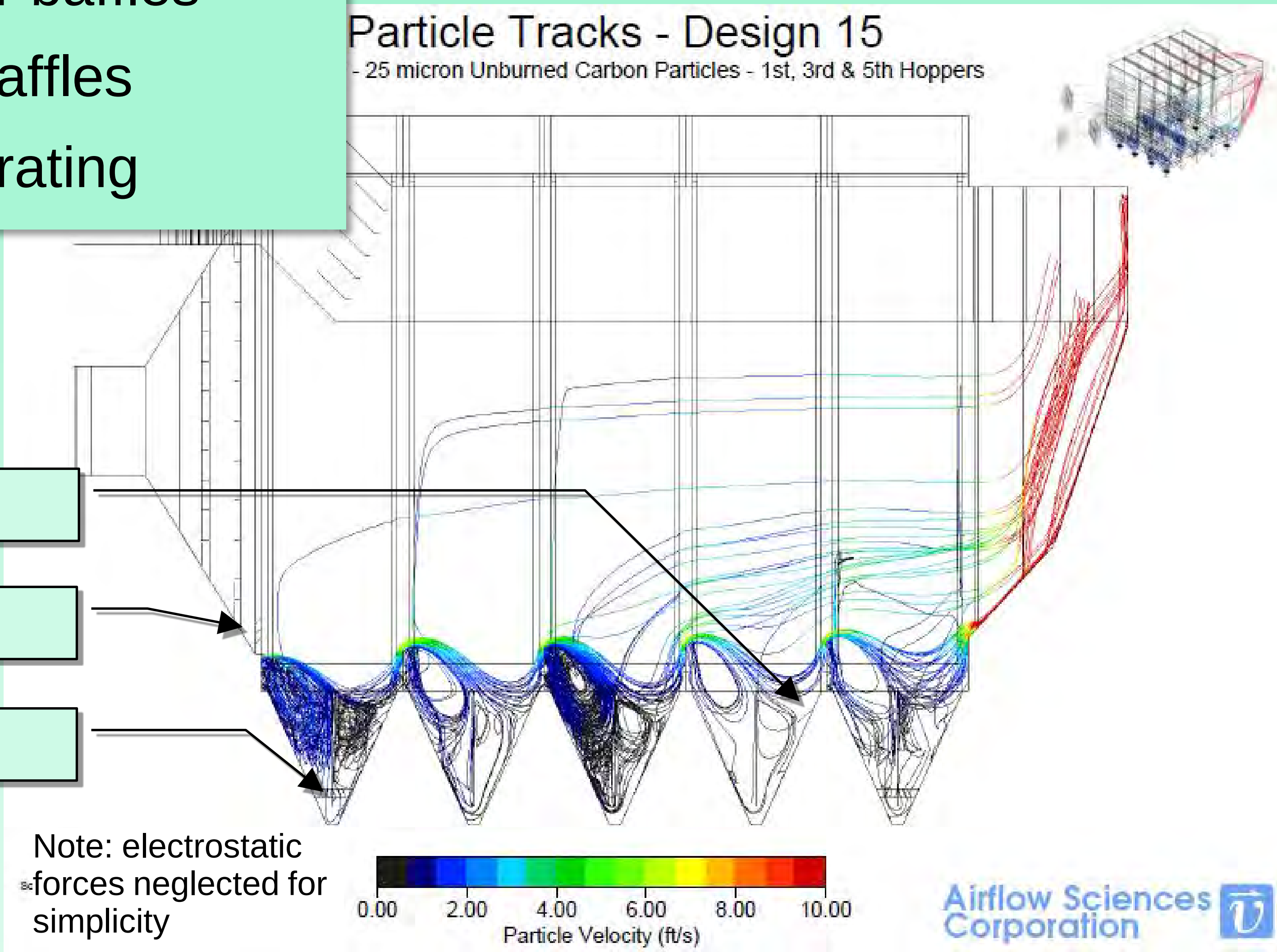
Particle release points for tracking



Note: electrostatic forces neglected for simplicity

Steady State Model Fixes

- Final design:
  - ASC inlet kicker baffles
  - SoCo hopper baffles
  - SoCo hopper grating



Hopper Baffles (Typ all)

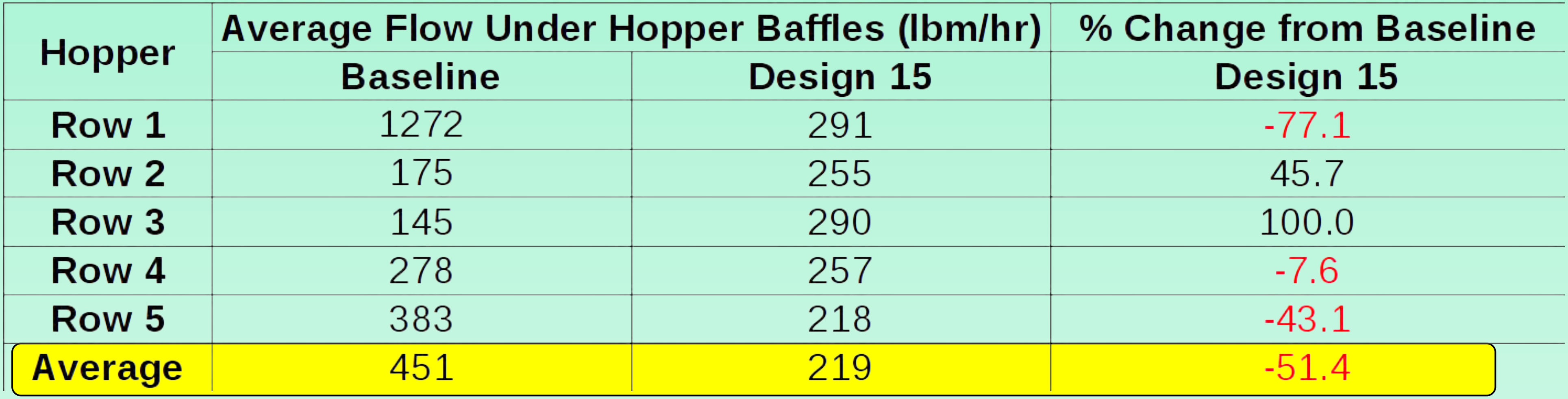
Kicker Baffles

Hopper Grating (Typ all)

Note: electrostatic forces neglected for simplicity

Improvements Seen

- Reduced gas flow under the hopper baffle

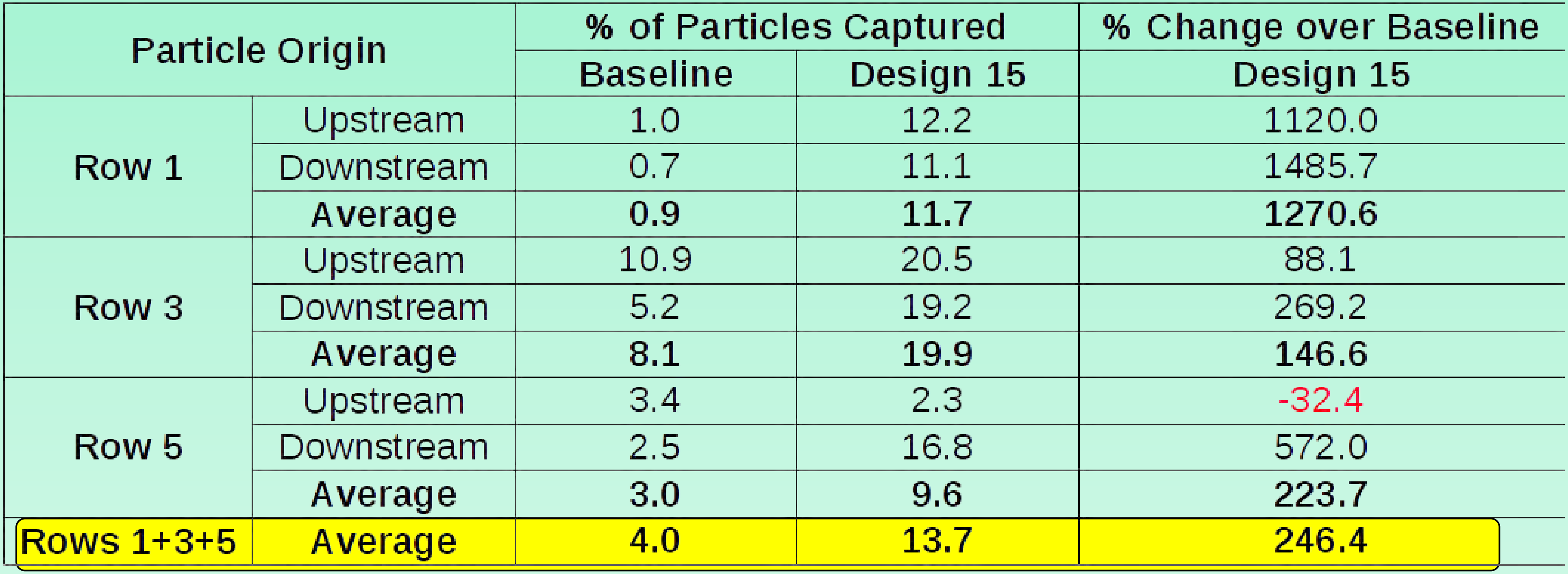


Hopper	Average Flow Under Hopper Baffles (lbm/hr)		% Change from Baseline
	Baseline	Design 15	Design 15
Row 1	1272	291	-77.1
Row 2	175	255	45.7
Row 3	145	290	100.0
Row 4	278	257	-7.6
Row 5	383	218	-43.1
Average	451	219	-51.4

- On average, 50% reduction in gas flow under hopper baffle

Improvements Seen

- Increased capture of “freely-released” particles

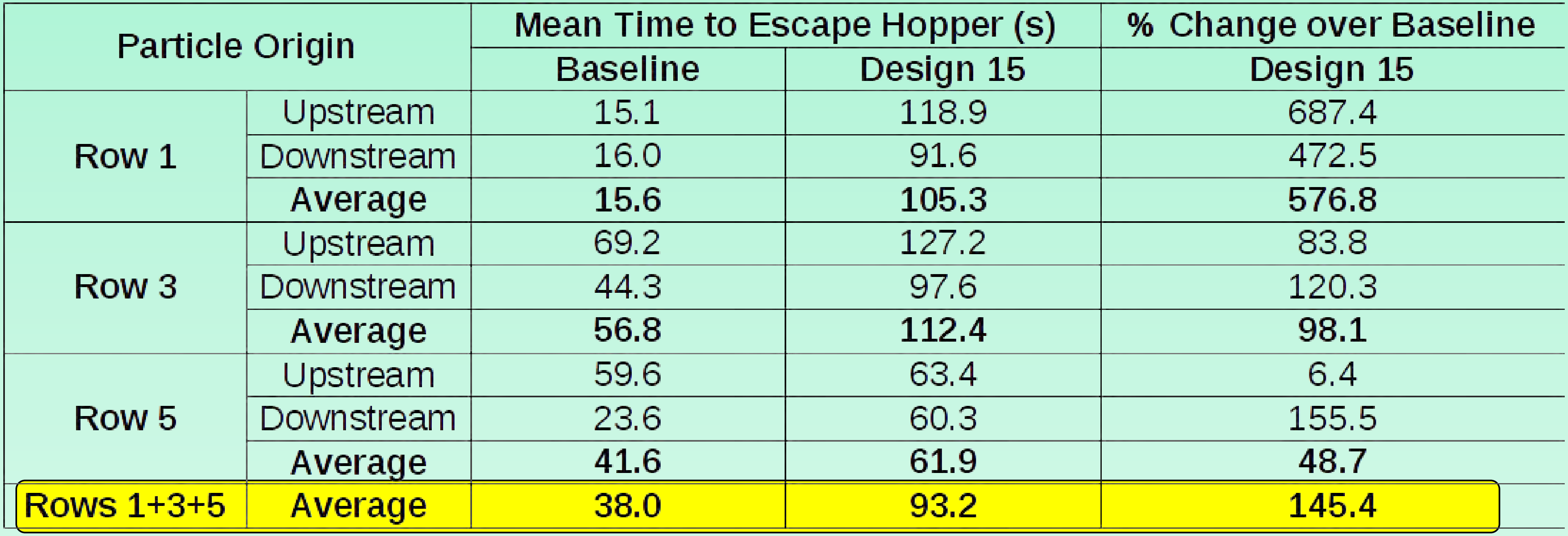


Particle Origin		% of Particles Captured		% Change over Baseline
		Baseline	Design 15	Design 15
Row 1	Upstream	1.0	12.2	1120.0
	Downstream	0.7	11.1	1485.7
	Average	**0.9**	**11.7**	**1270.6**
Row 3	Upstream	10.9	20.5	88.1
	Downstream	5.2	19.2	269.2
	Average	**8.1**	**19.9**	**146.6**
Row 5	Upstream	3.4	2.3	-32.4
	Downstream	2.5	16.8	572.0
	Average	**3.0**	**9.6**	**223.7**
Rows 1+3+5	**Average**	**4.0**	**13.7**	**246.4**

Note: Percentage of unburned carbon particles released from upstream or downstream side of hopper baffle that remain in that hopper.

Improvements Seen

- Increased residence time of particles in the hoppers



Particle Origin		Mean Time to Escape Hopper (s)		% Change over Baseline
		Baseline	**Design 15**	**Design 15**
Row 1	Upstream	15.1	118.9	687.4
	Downstream	16.0	91.6	472.5
	Average	**15.6**	**105.3**	**576.8**
Row 3	Upstream	69.2	127.2	83.8
	Downstream	44.3	97.6	120.3
	Average	**56.8**	**112.4**	**98.1**
Row 5	Upstream	59.6	63.4	6.4
	Downstream	23.6	60.3	155.5
	Average	**41.6**	**61.9**	**48.7**
Rows 1+3+5	**Average**	**38.0**	**93.2**	**145.4**

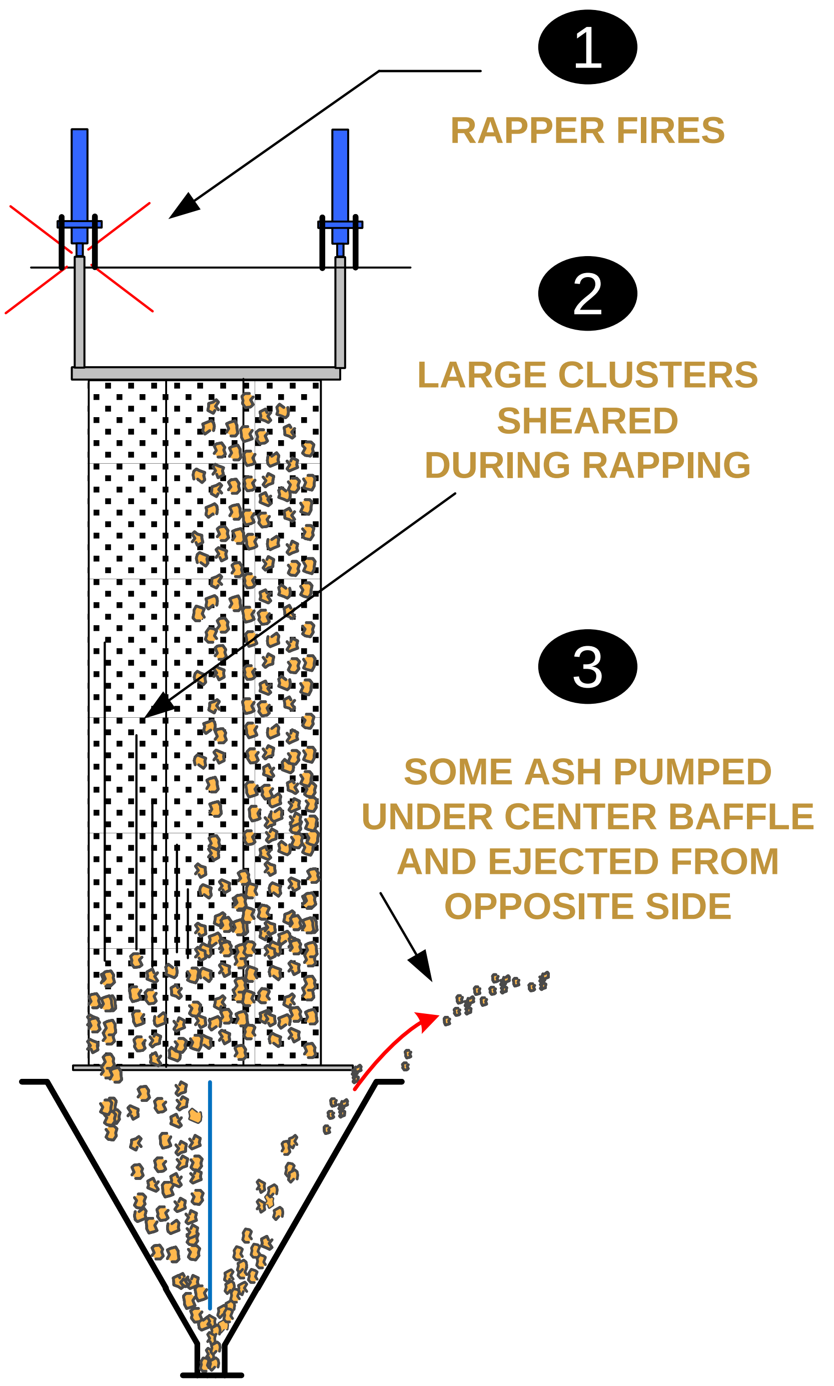
Note: Mean time taken by unburned carbon particles released from upstream or downstream side of hopper baffle to escape from hopper.

Steady State Model - Summary

- Ash tracking model trends match with engineering judgement and expectations
- A number of designs were evaluated to determine how best to reduce particulate escape from hoppers
- Main objectives are
  - Reduce gas flow under the hopper baffles
  - Inhibit recirculating, wafting flow in hoppers
  - Increase residence time of “freely-released” particles in the hoppers

Transient Analysis

- Focus on hopper gas velocities and pressure pulses caused by rapping of collection plates
- The falling mass of ash from the plates causes an increase in flue gas pressure that pushes gas and particulate under the center baffle and up the opposite side of the hopper
- Highly time dependent and highly complex to model

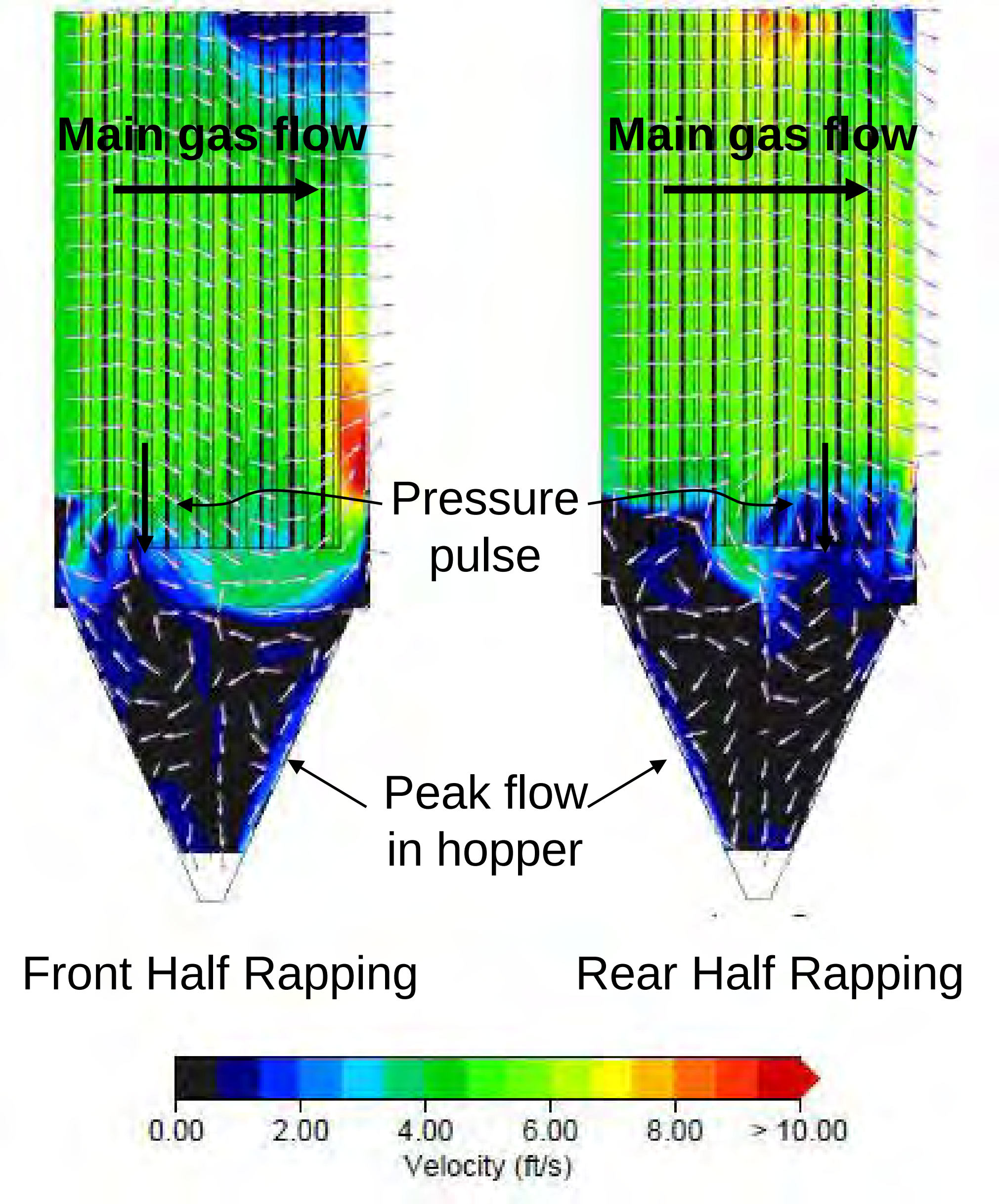


Transient Modeling

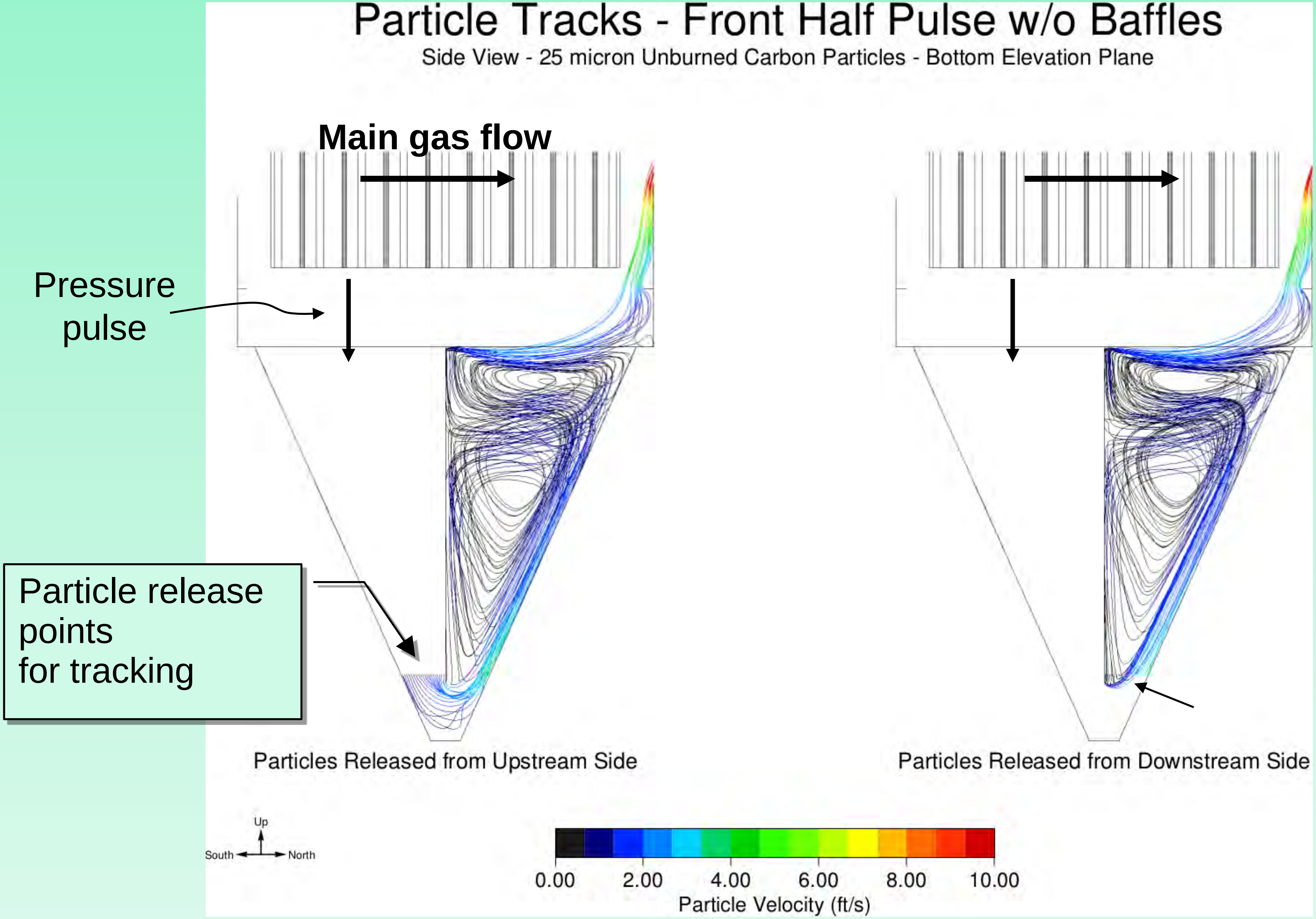
- Reduced model domain with fine geometric details of collection plates, electrodes, and hopper
- Simulate the transient motion of the falling ash sheet and downward momentum of the gas flow
  - Simulates impact of a select volume of ash falling
  - Front and back halves of hopper rapped separately
- What happens in and near the hoppers?
  - Flue gas velocity patterns change with time
  - Velocity and recirculation increase locally, and the amount of flow under the hopper baffle increases
  - To quantify impact on ash, freely-release particles in the hoppers per the Ash Tracking Method

Transient Model Findings

- Baseline
  - Modeled two cases: Front Half and Rear Half rapping scenarios
  - Determined velocity magnitude and direction in hopper
  - Results show expected behavior of gas flowing under center baffle and up opposite side



Transient Model Findings



Particle Tracks - Front Half Pulse w/o Baffles

Side View - 25 micron Unburned Carbon Particles - Bottom Elevation Plane

Main gas flow

Pressure pulse

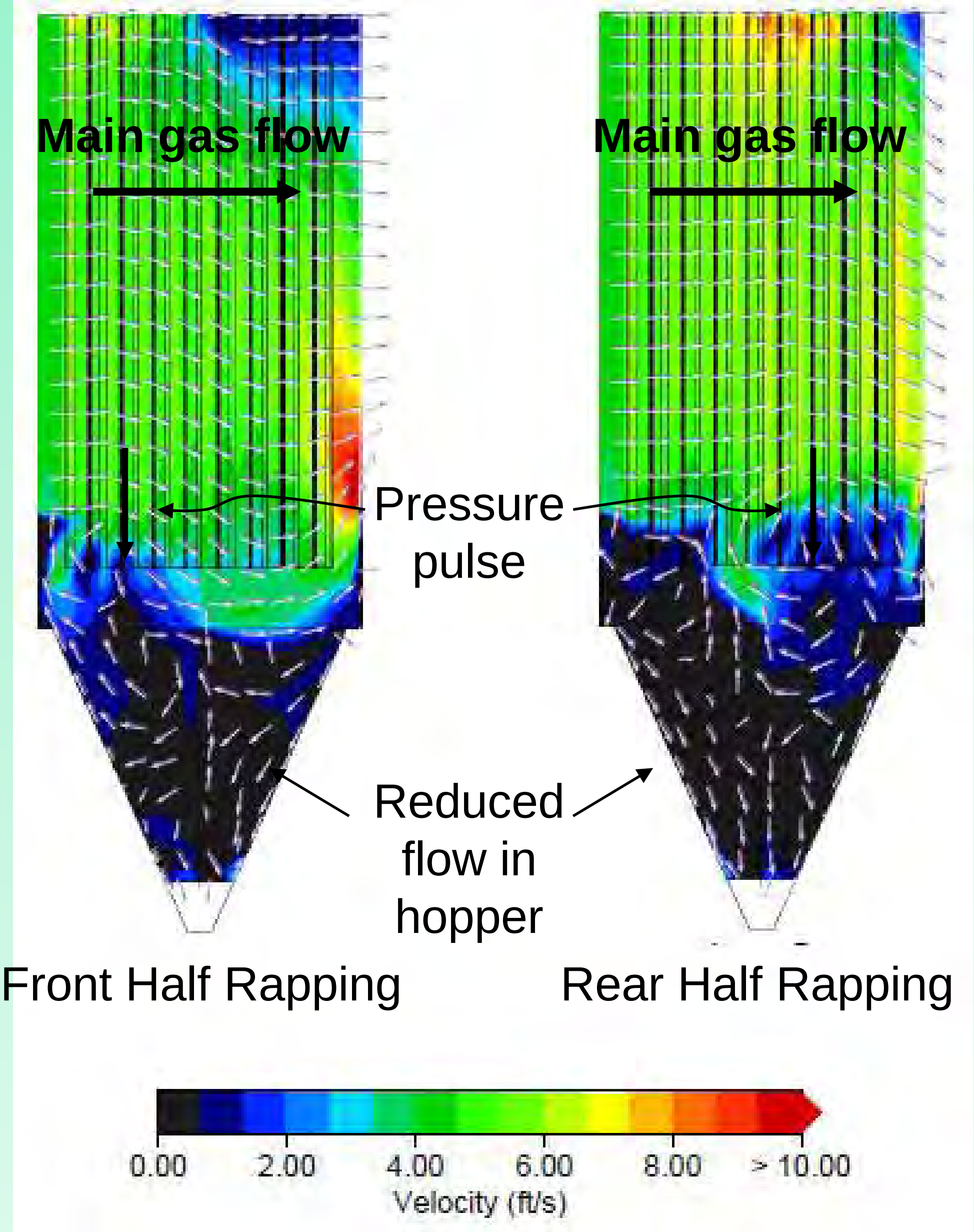
Particle release points for tracking

Particles Released from Upstream Side

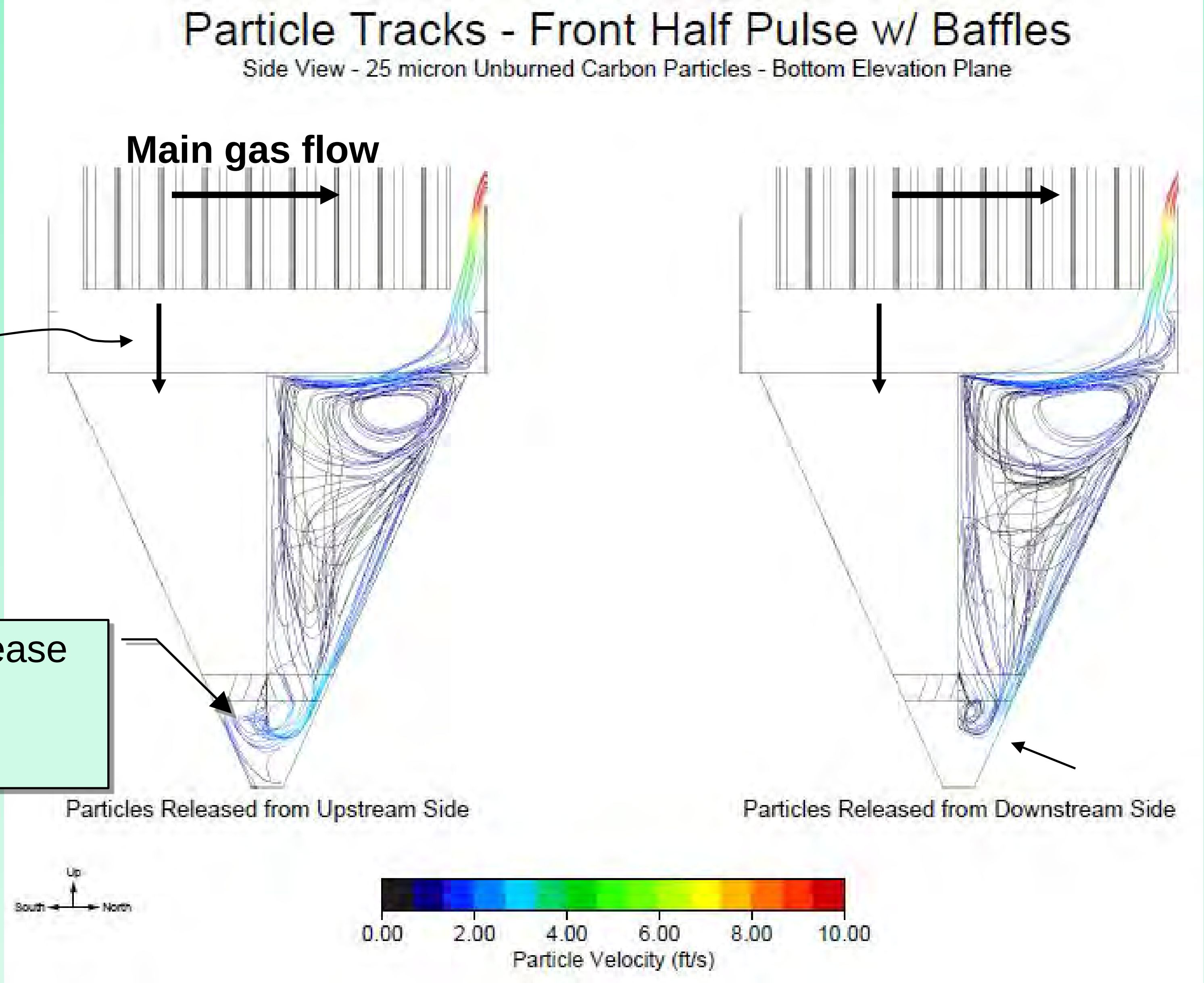
Particles Released from Downstream Side

Transient Model Fixes

- Design
  - Included hopper baffles and grating
  - Peak velocities along hopper slope greatly reduced
  - Fewer particles escape hopper



Transient Model Fixes



Pressure pulse

Particle release points
for tracking

Improvements Seen

Particles Captured

	Front half rapping		
Particle release location	**w/o Baffles**	**w/ Baffles**	**% Change**
Front half	13.0	29.7	128.5
Rear half	11.2	39.4	251.8

	Rear half rapping		
Particle release location	**w/o Baffles**	**w/ Baffles**	**% Change**
Front half	12.4	51.9	318.5
Rear half	18.1	31.5	74.0

Modeling Conclusions

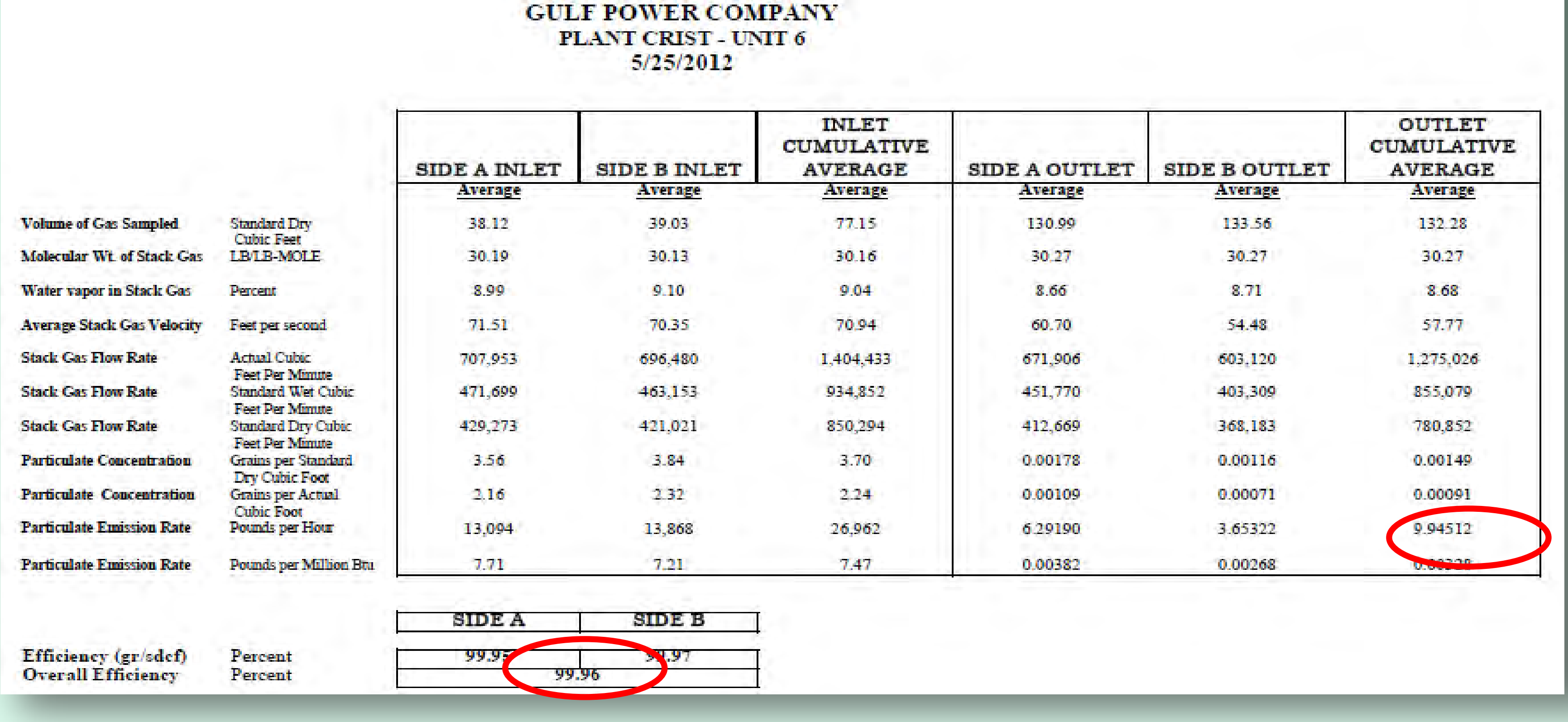
- CFD best practices used to model and optimize gas flow per ICAC standards
- New methods of CFD modeling and analysis developed to scrutinize fine ash behavior and design devices to improve capture and inhibit re-entrainment
  - Tracking and statistical analysis of freely-released particles
  - Assessment of gas flow under hopper baffles
  - Pressure pulse model to simulate transient effects during rapping
- Method applicable to flyash capture, especially light, fine, carbonaceous ash
- Method also believed applicable to fine, light injected species such as PAC

Design Implementation

- Installation
  - Installed grating in 1st and last hopper
  - Installed baffles in all hoppers
  - Installed kicker baffles and all other devices recommended by Airflow Sciences

Post Start Up Testing

- Method 17 testing was performed 5 weeks after start up.
  - Results showed 0.00328 #/mmBTU @ 99.96% eff.



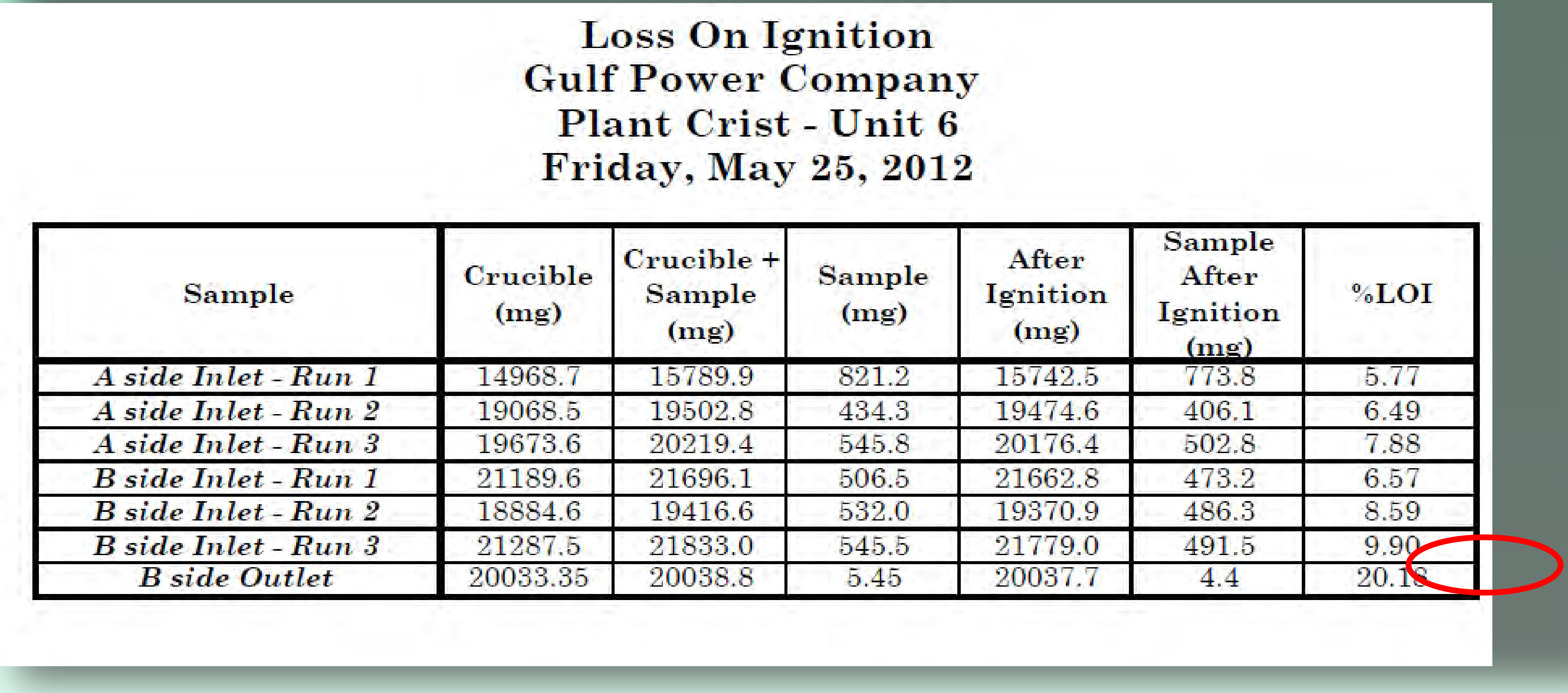
GULF POWER COMPANY
PLANT CRIST - UNIT 6
5/25/2012

		SIDE A INLET Average	SIDE B INLET Average	INLET CUMULATIVE AVERAGE Average	SIDE A OUTLET Average	SIDE B OUTLET Average	OUTLET CUMULATIVE AVERAGE Average
Volume of Gas Sampled	Standard Dry Cubic Feet	38.12	39.03	77.15	130.99	133.56	132.28
Molecular Wt. of Stack Gas	LB/LB-MOLE	30.19	30.13	30.16	30.27	30.27	30.27
Water vapor in Stack Gas	Percent	8.99	9.10	9.04	8.66	8.71	8.68
Average Stack Gas Velocity	Feet per second	71.51	70.35	70.94	60.70	54.48	57.77
Stack Gas Flow Rate	Actual Cubic Feet Per Minute	707,953	696,480	1,404,433	671,906	603,120	1,275,026
Stack Gas Flow Rate	Standard Wet Cubic Feet Per Minute	471,699	463,153	934,852	451,770	403,309	855,079
Stack Gas Flow Rate	Standard Dry Cubic Feet Per Minute	429,273	421,021	850,294	412,669	368,183	780,852
Particulate Concentration	Grains per Standard Dry Cubic Foot	3.56	3.84	3.70	0.00178	0.00116	0.00149
Particulate Concentration	Grains per Actual Cubic Foot	2.16	2.32	2.24	0.00109	0.00071	0.00091
Particulate Emission Rate	Pounds per Hour	13,094	13,868	26,962	6.29190	3.65322	9.94512
Particulate Emission Rate	Pounds per Million Btu	7.71	7.21	7.47	0.00382	0.00268	0.00328

		SIDE A	SIDE B
Efficiency (gr/sdcf)	Percent	99.95	99.97
Overall Efficiency	Percent	99.96	

Post Start Up Testing

- Percent carbon test was performed on inlets and outlet of B side
  - Results showed a low 20%, ~75% below typical



Loss On Ignition
Gulf Power Company
Plant Crist - Unit 6
Friday, May 25, 2012

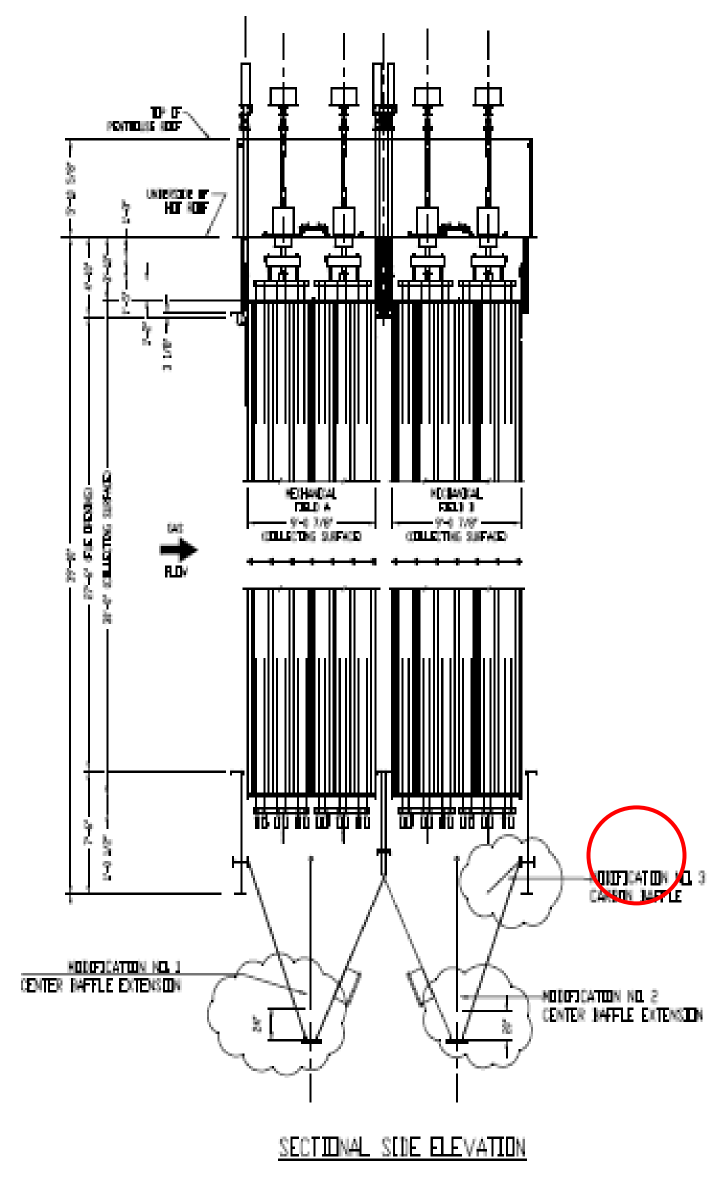
Sample	**Crucible (mg)**	**Crucible + Sample (mg)**	**Sample (mg)**	**After Ignition (mg)**	**Sample After Ignition (mg)**	**%LOI**
A side Inlet - Run 1	14968.7	15789.9	821.2	15742.5	773.8	5.77
A side Inlet - Run 2	19068.5	19502.8	434.3	19474.6	406.1	6.49
A side Inlet - Run 3	19673.6	20219.4	545.8	20176.4	502.8	7.88
B side Inlet - Run 1	21189.6	21696.1	506.5	21662.8	473.2	6.57
B side Inlet - Run 2	18884.6	19416.6	532.0	19370.9	486.3	8.59
B side Inlet - Run 3	21287.5	21833.0	545.5	21779.0	491.5	9.90
B side Outlet	20033.35	20038.8	5.45	20037.7	4.4	20.18

MATS Program

- Bowen 1&2 A&B
  - Rebuild to 16 spacing
  - CFD & Physical Model
  - Normal flow correction
  - Carbon PM capture devices

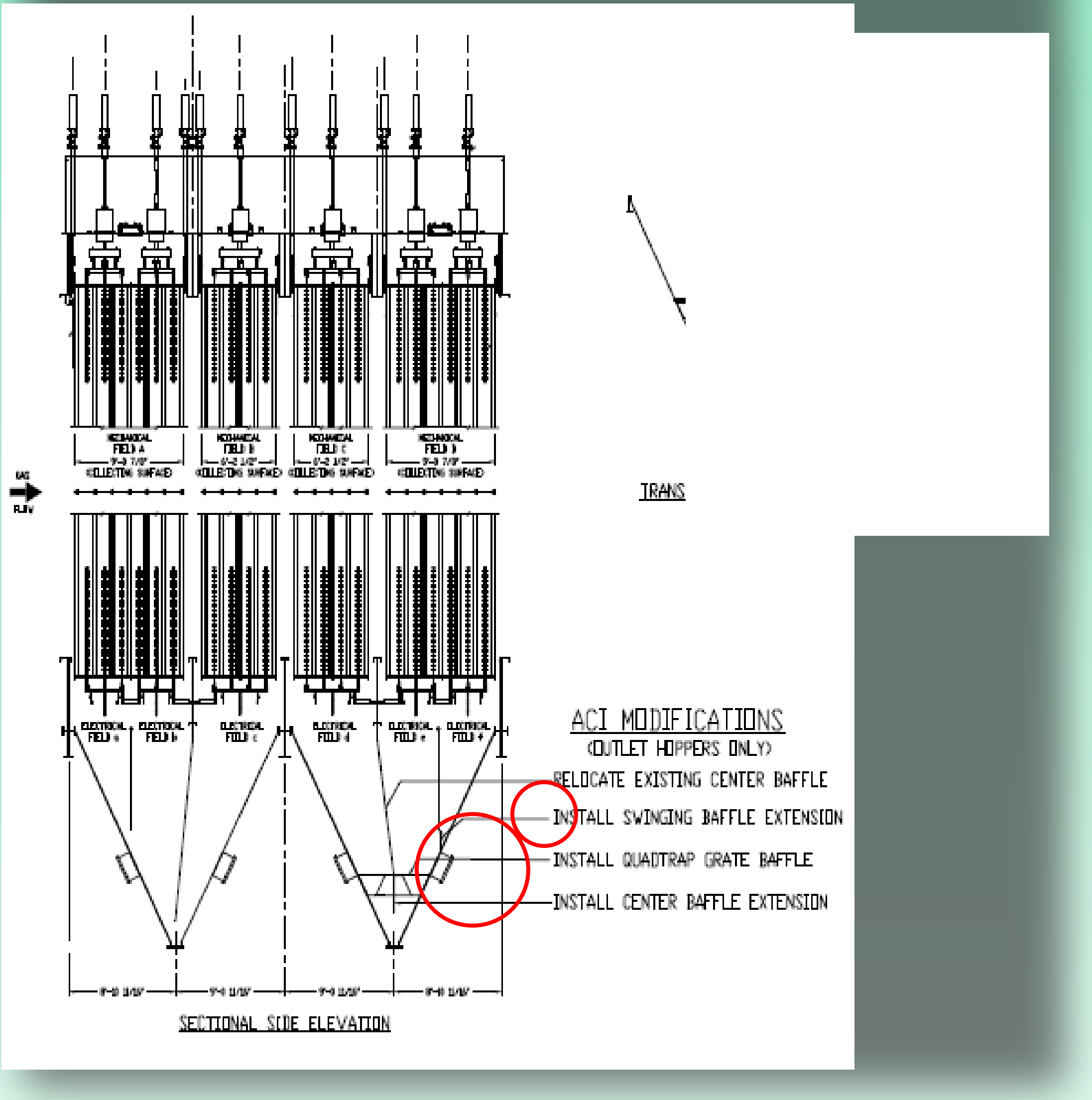
<u>CONFIGURATION</u>

- 750MW
- 4 ESPs in parallel
- 284 SCA @ 9” (16” act)
- 70 Kv



MATS Program

- Bowen 1&2 C&D
  - SMPS Addition to Inlets
  - CFD & Physical Model
  - Normal flow correction
  - Carbon PM capture devices

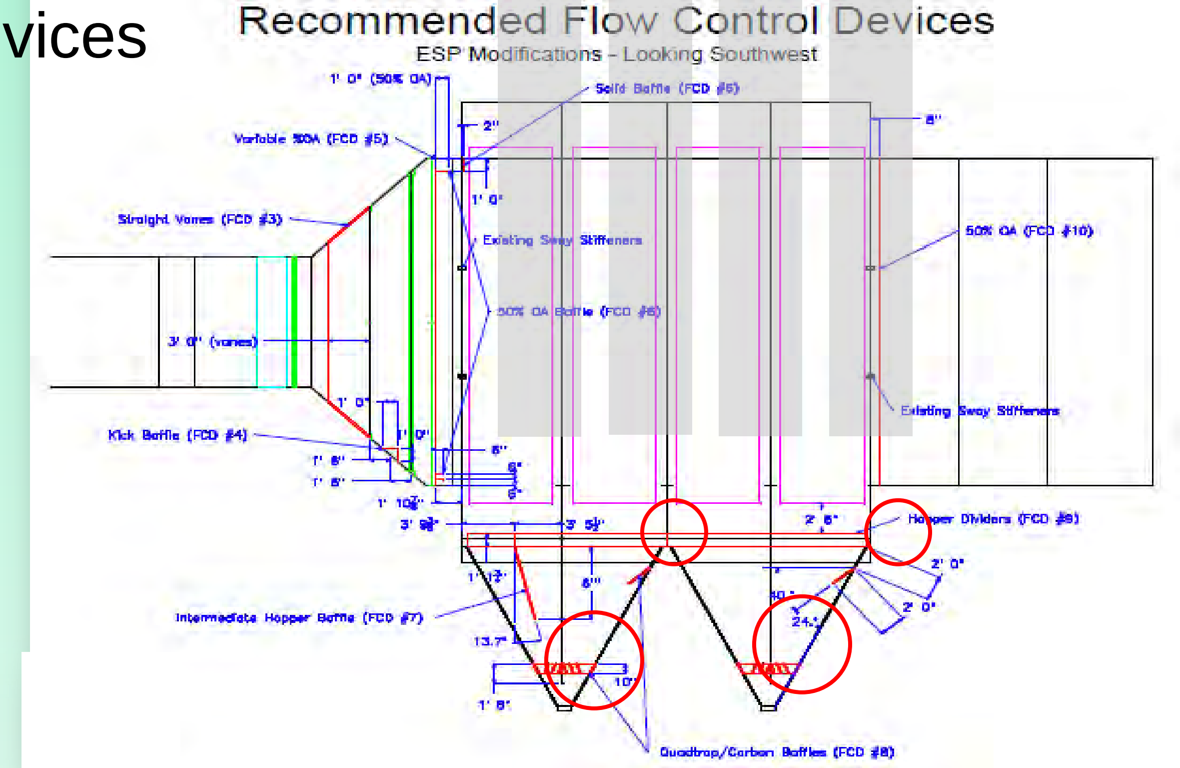


<u>CONFIGURATION</u>

- 750MW
- 4 ESPs in parallel
- 284 SCA @ 9” (11” act)

MATS Program

- Wansley 1&2
  - Unit 2 Rebuild to 16” spacing, Unit 1 prev. 11” spacing
  - CFD & Physical Model
  - Normal flow correction
  - Carbon PM capture devices
  - Outlet rudder vanes



CONFIGURATION

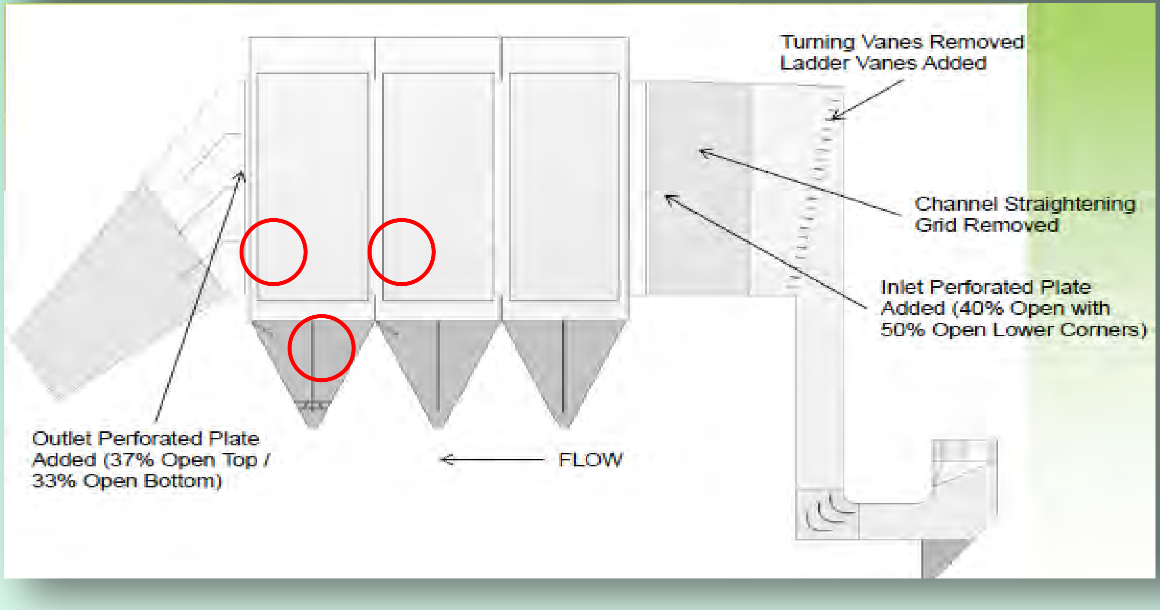
- 900MW
- 2 ESPs in chevron
- 214 SCA @ 9”

MATS Program

- Hammond 1-3
  - SMPS in inlet fields
  - CFD & Physical Model
  - Normal flow correction
  - Carbon PM capture devices

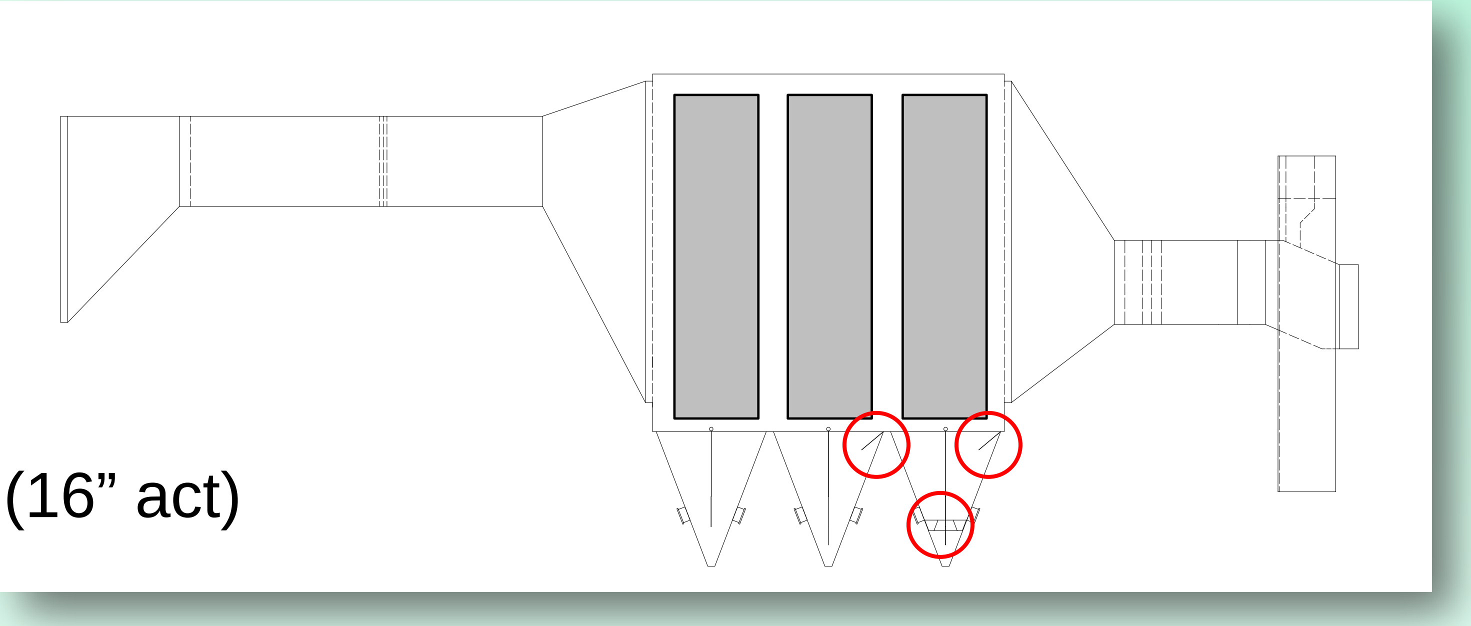
CONFIGURATION

- 100 MW
- Single casings
- 363/299 SCA @ 9”



MATS Program

- Hammond 4
  - SMPS in inlet fields
  - CFD & Physical Model
  - Normal flow correction
  - Carbon PM capture devices



CONFIGURATION

- 500 MW
- Single casing
- 379 SCA @ 9” (16” act)

MATS Program

- Other projects pending
  - Miller 1&2 (Rebuild, conversion to 16” & 83Kv)
  - Green County (Hot to cold conversion)
  - Barry 4 (ESP mods)

Overall Conclusions

- Special attention is necessary to hopper flows when an ESP faces high LOI or PAC
- Custom design hopper grating, baffling, and flow control devices showed very positive results on Crist Unit 6
- Same CFD & physical modeling approach is being applied system-wide for SoCo MATS compliance with PAC on ESPs