REINHOLD ENVIRONMENTAL Ltd.

2016 NOx-Combustion-CCR Round Table Presentation

February 1 & 2, 2016, in Orlando, FL / Hosted by OUC

Enhanced Gas Cofiring
Update on Stanton 1 Installations

Presented by: Cal Lockert/Breen Energy

February 1, 2016

Now plants must also consider this:

Technical Support Document (TSD) for
Carbon Pollution Guidelines for Existing Power Plants:
Emission Guidelines for Greenhouse Gas Emissions from Existing Stationary Sources:
Electric Utility Generating Units

Docket ID No. EPA-HQ-OAR-2013-0602

GHG Abatement Measures

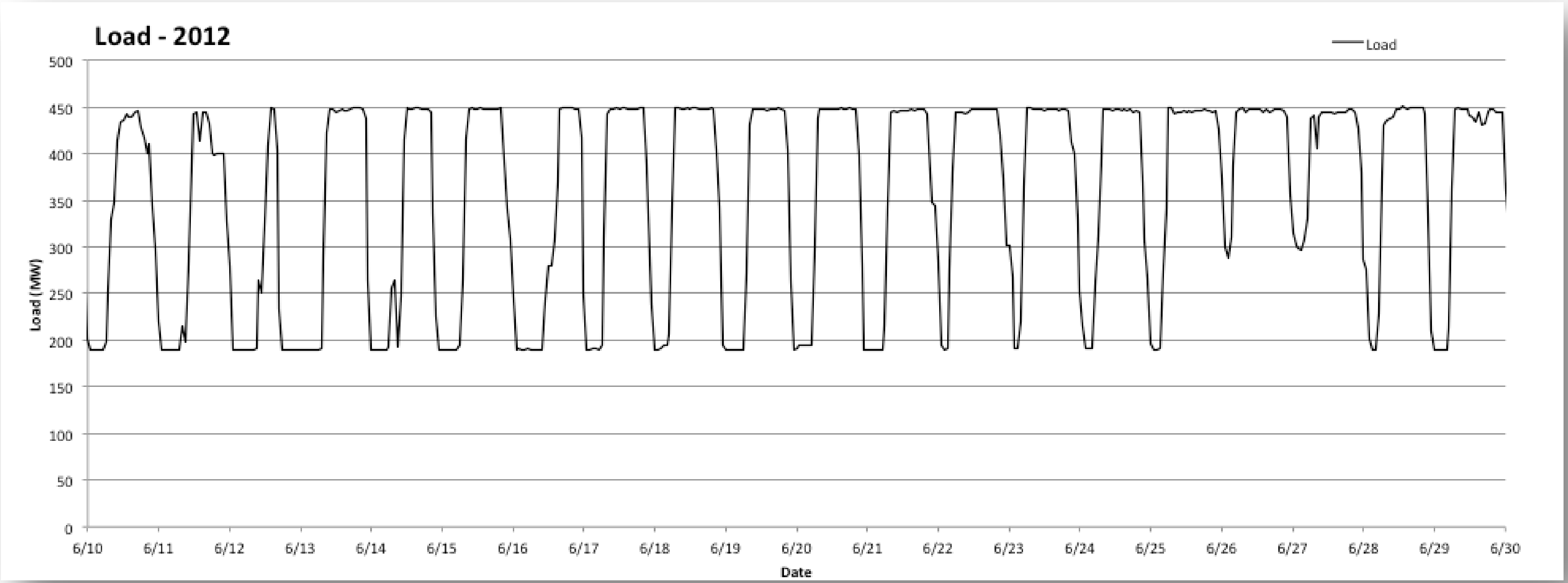
U.S. Environmental Protection Agency
Office of Air and Radiation

June 10, 2014

Economy Considerations

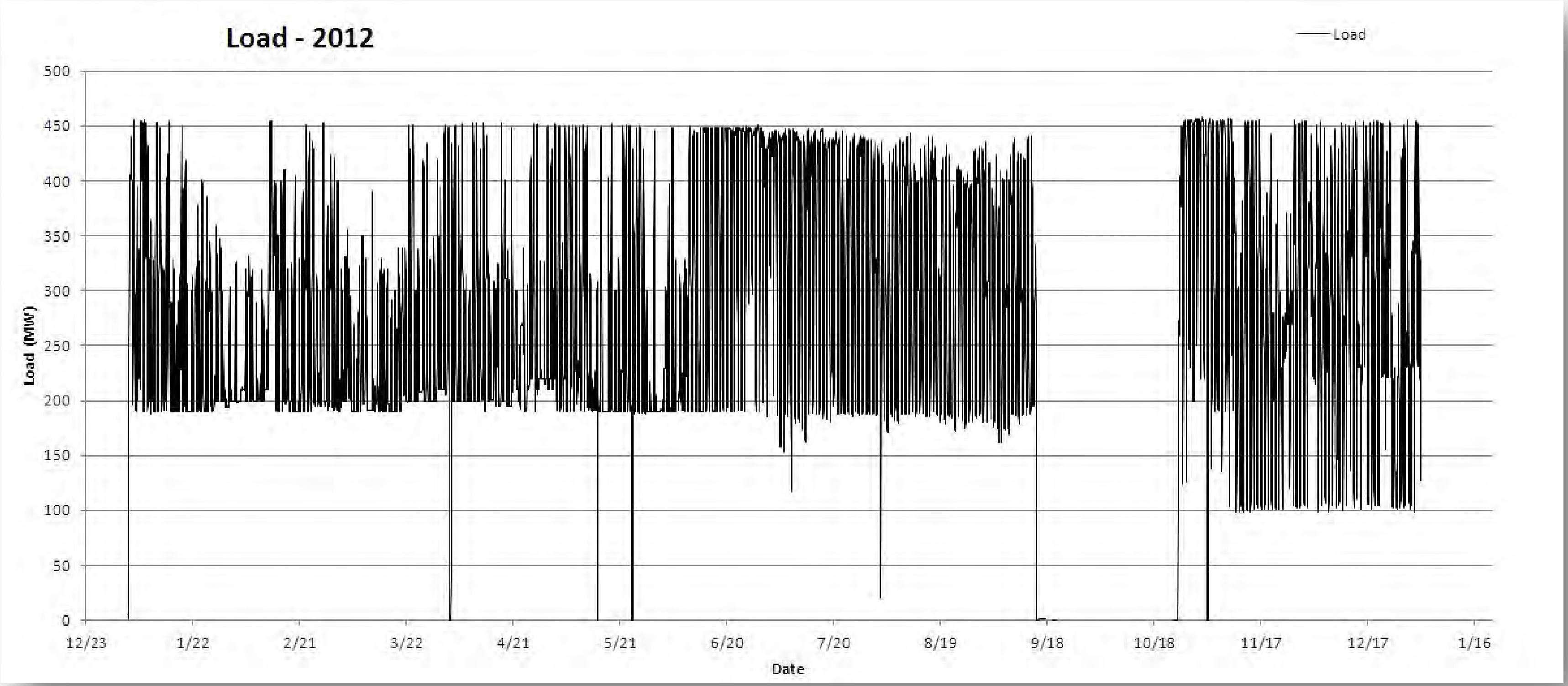
LOAD CYCLING

Typical Load Cycling Curve



In the presence of solar and wind supply, coal plants are being forced to cycle more dramatically than in the past. All emissions are affected by load transition and unstable firing conditions.

Minimum Load Considerations



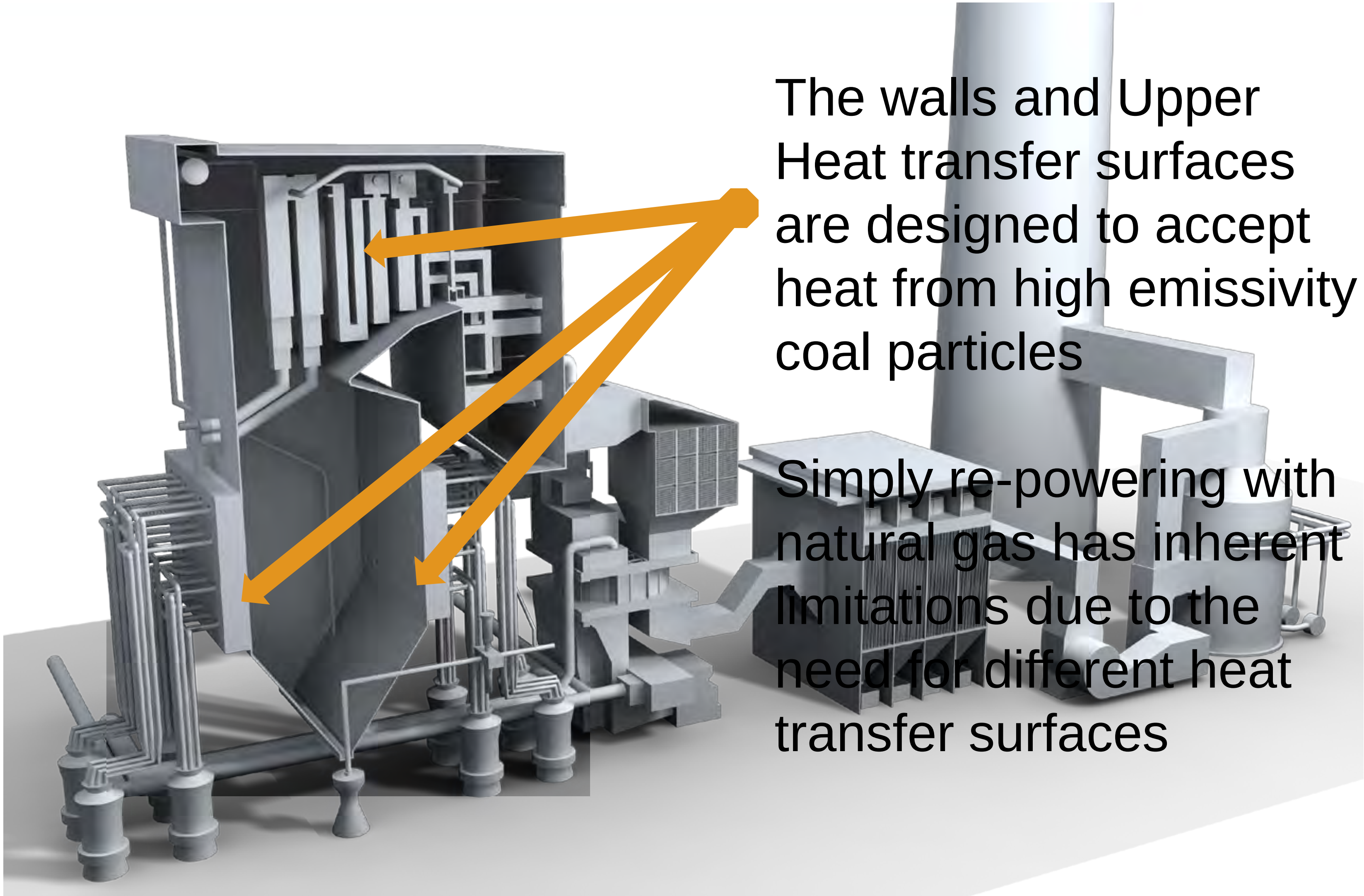
Source: EPA Acid Rain Database

Cycling has a major effect on total system dispatch effectiveness. Allowing the coal plant to achieve a much lower minimum load can have dramatic system wide cost and emissions implications.

Enhanced Gas CoFiring

THE BEST OF BOTH WORLDS

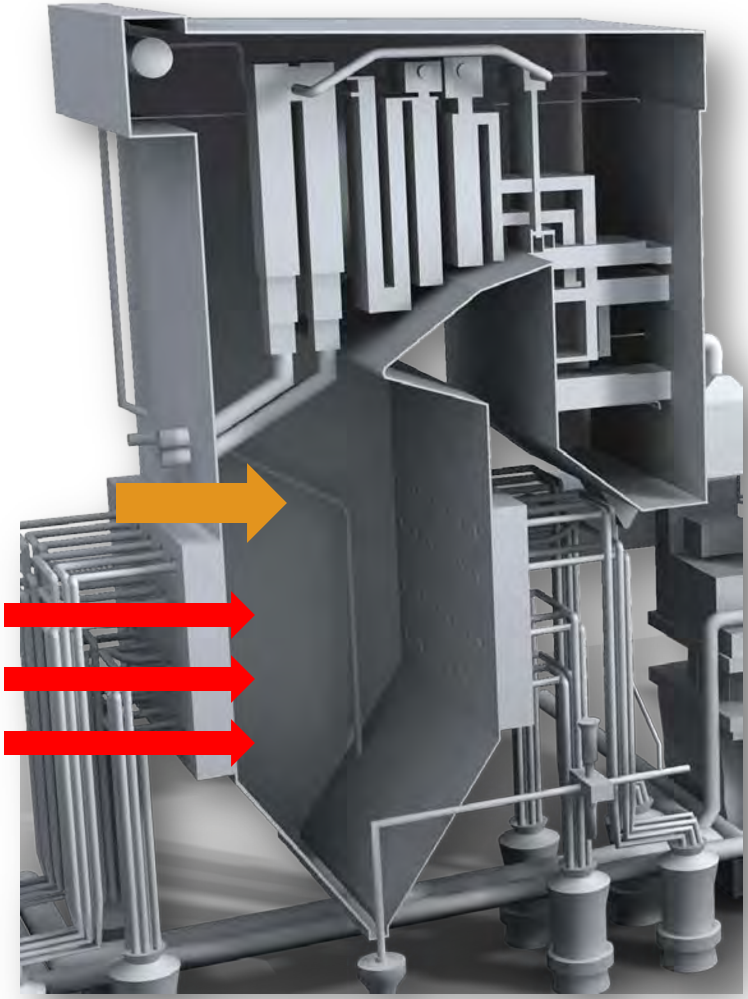
CoFiring Coal and Gas



The walls and Upper Heat transfer surfaces are designed to accept heat from high emissivity coal particles

Simply re-powering with natural gas has inherent limitations due to the need for different heat transfer surfaces

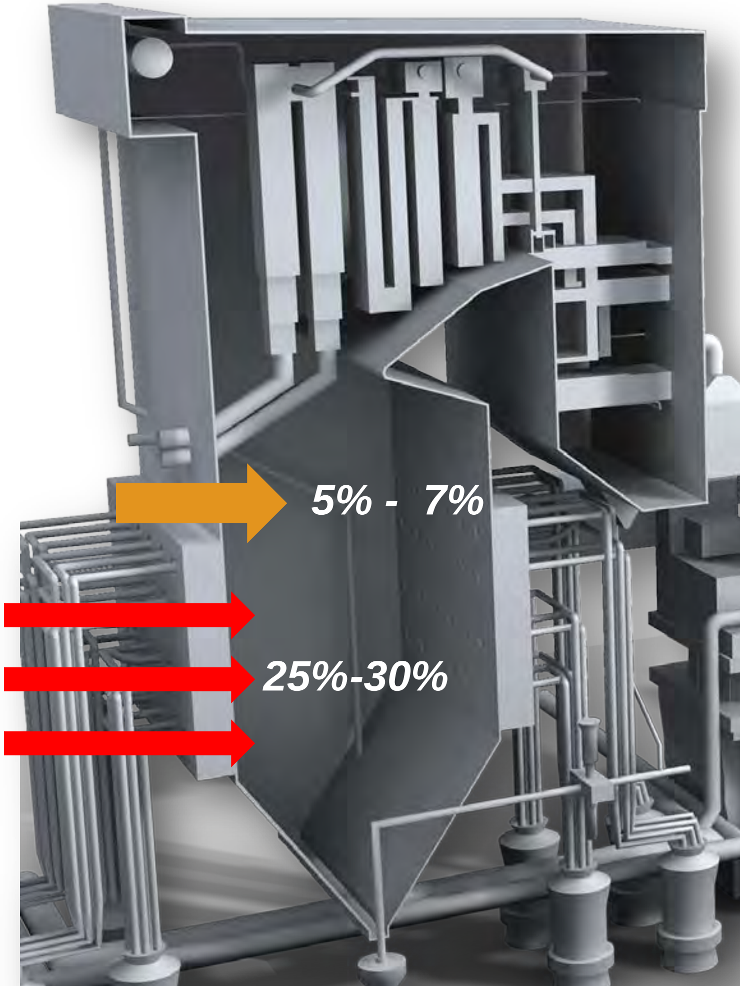
Boiler Focus



Gas CoFiring marries natural gas and coal at each burner, injected through a modified igniter.

It also adds a portion of the total heat input as gas in the upper furnace. This is known as Fuel Lean Gas Reburn.

Boiler Focus



The Goal is to get up to 35% of the total heat input converted from coal to gas.

With 25% - 30% of that coming at the igniter location and 5% - 10% coming at the FLGR location.

Dual Orifice CoFire Igniter

NFPA Class 1 Igniter

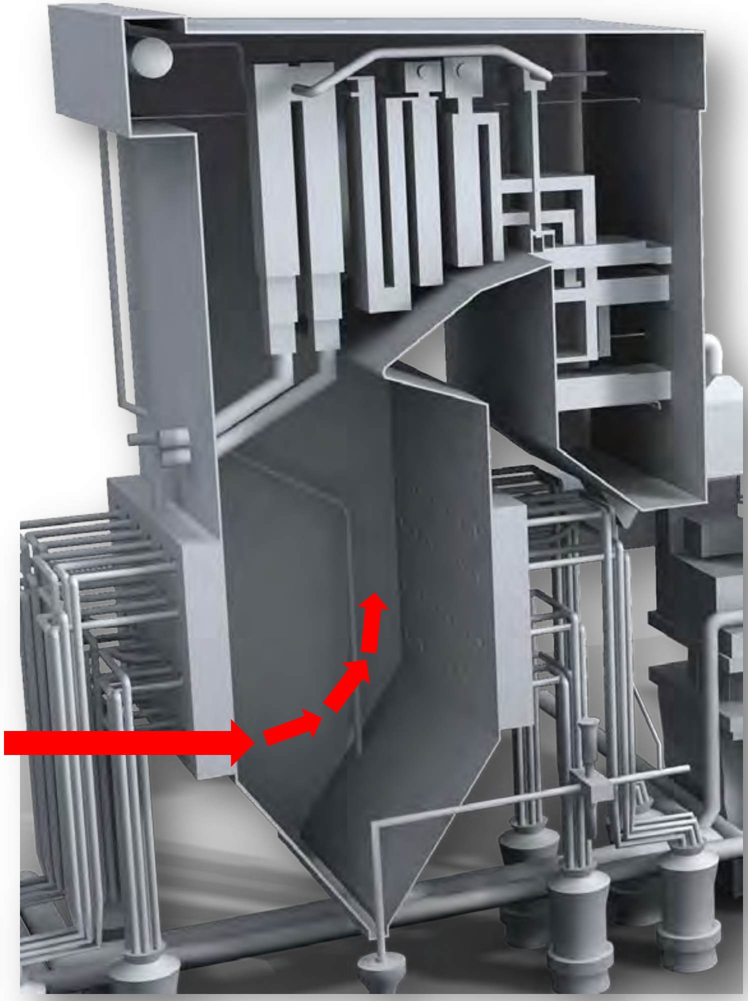
A typical NFPA Class 1 Igniter:

- **10% of the Heat Input of the associated burner,**
- **Single, fixed size fuel spud,**
- **Single, fixed flow air supply**

Providing Higher Gas Volume:

- **Requires higher gas inlet pressure,**
- **Increases gas igniter flame velocity and penetration**

25% Heat Input Igniter



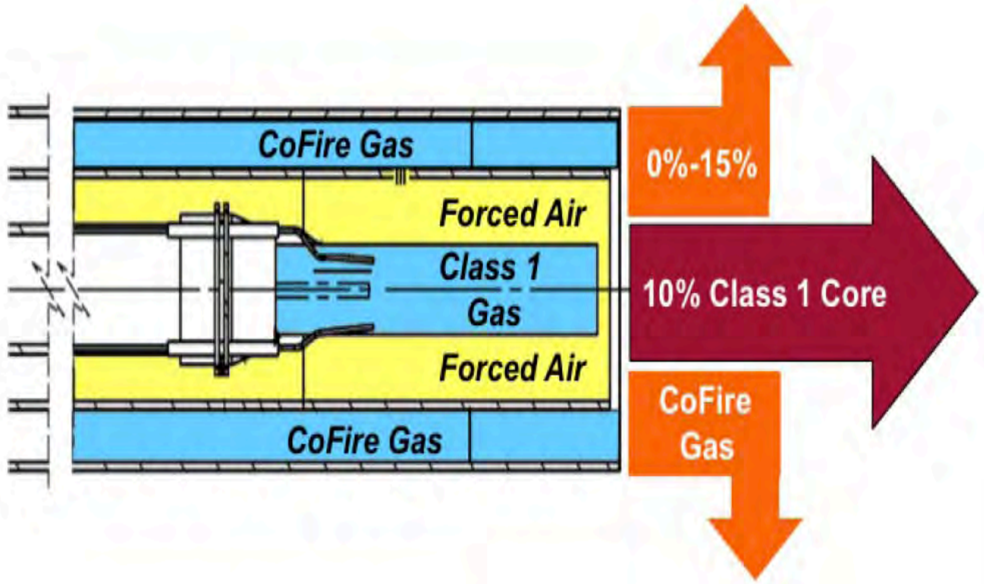
Providing 25% of the Heat to the boiler through a Class 1 igniter will extend the ignition flame into the center of the furnace.

This will have the effect of driving Furnace Exit temperatures UP, but keeping wall steam generation LOW.

Resizing the igniter for 25% standard throughput will make it unstable at low throughputs

Dual Orifice Design

Maximizes Gas flow while maintaining heat proximity to the furnace walls



Cofire gas comes from a higher area secondary annulus

Site Installation

System Requires:

- 80 CFM Forced Combustion Air/Igniter
- Isolation Valve between Core and CoFire sides
- Pressure Control on the Core side

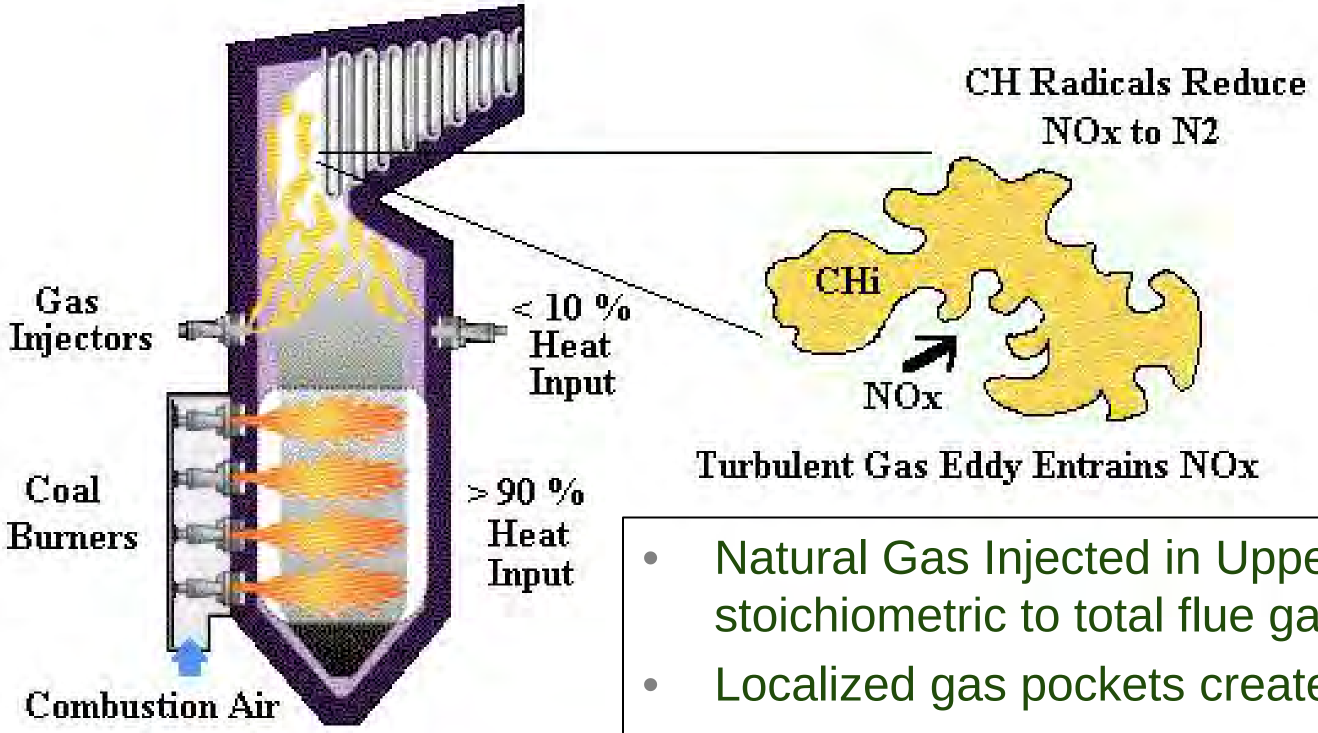
- Additionally we remotely monitored:

- Gas Pressure
- Air Pressure
- Core Flame Stability

Fuel Lean Gas Reburn

COAL DISPLACEMENT WITH NO_X REDUCTION

FLGR - Reactions



- Natural Gas Injected in Upper Furnace in amount sub stoichiometric to total flue gas oxygen,
- Localized gas pockets create fuel RICH zones:
  - CHx + NOx -> .CN + .NH2 + H2O
  - NOx + .NH2 -> N2 + H2O
  - NOx + .CN -> N2 + CO
  - NOx + CO -> N2 + CO2
- Upon re-entrance into O_2 rich zones, CO completes to CO_2
- When passing the 1750 F temperature zone, NHi radicals provide a secondary SNCR action

Historical Data On NOx Removal

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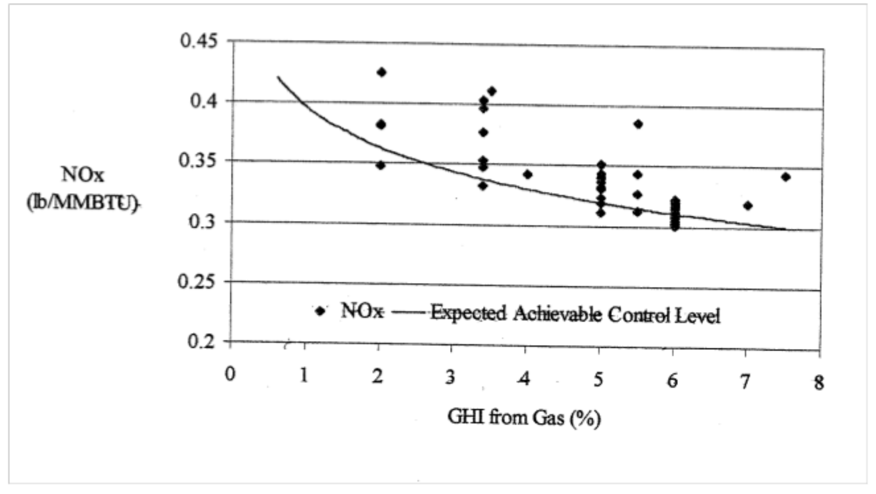
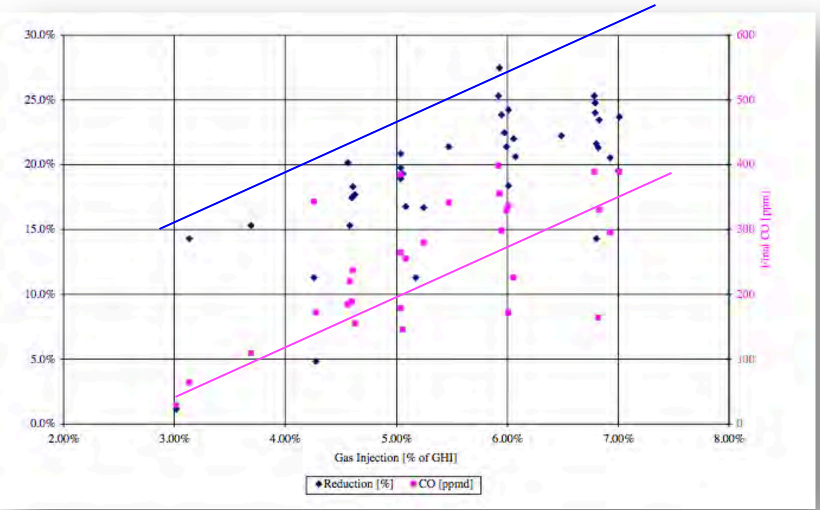




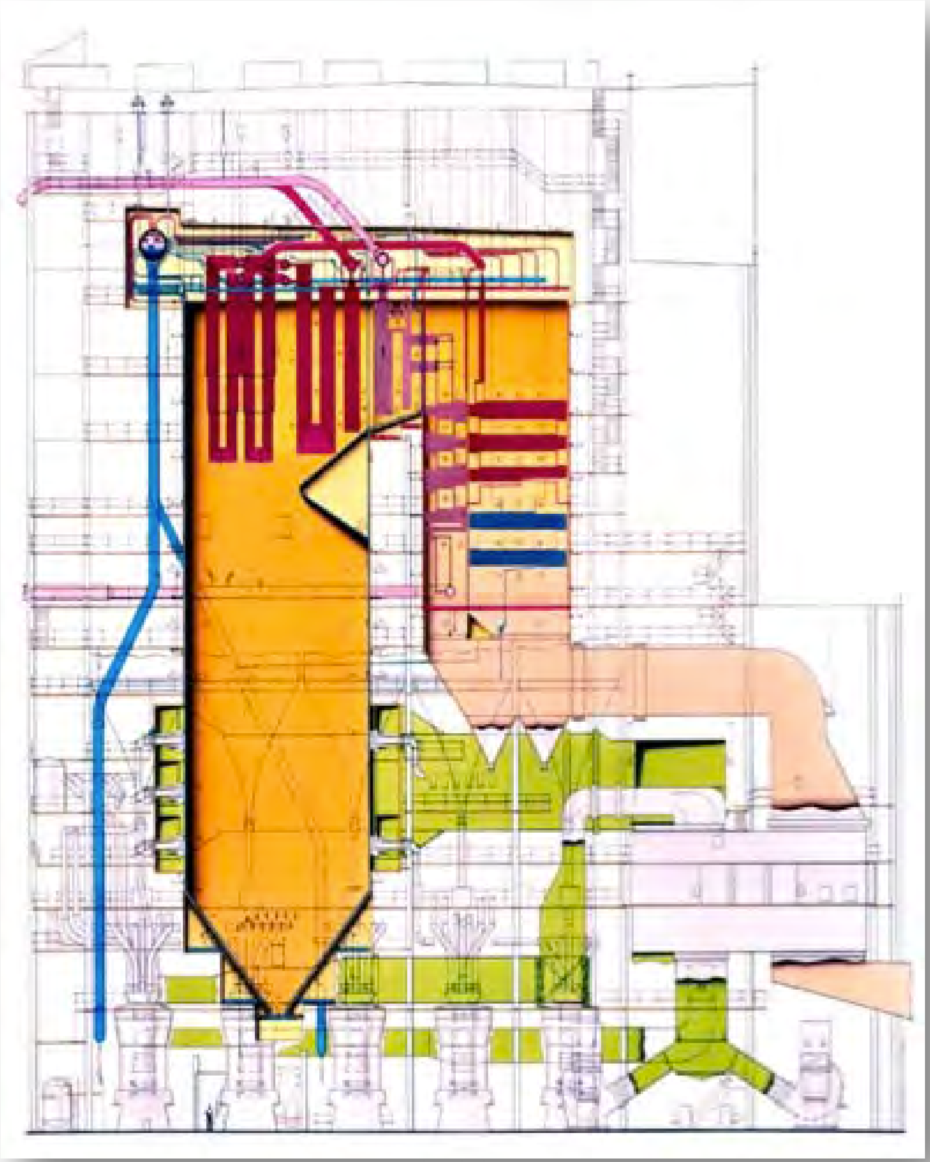
13 System were deployed between 1998 – 2001.

On average a 5% - 7% Gas Heat Input realized a 25% - 30% reduction in NOx prior to the current SCR location

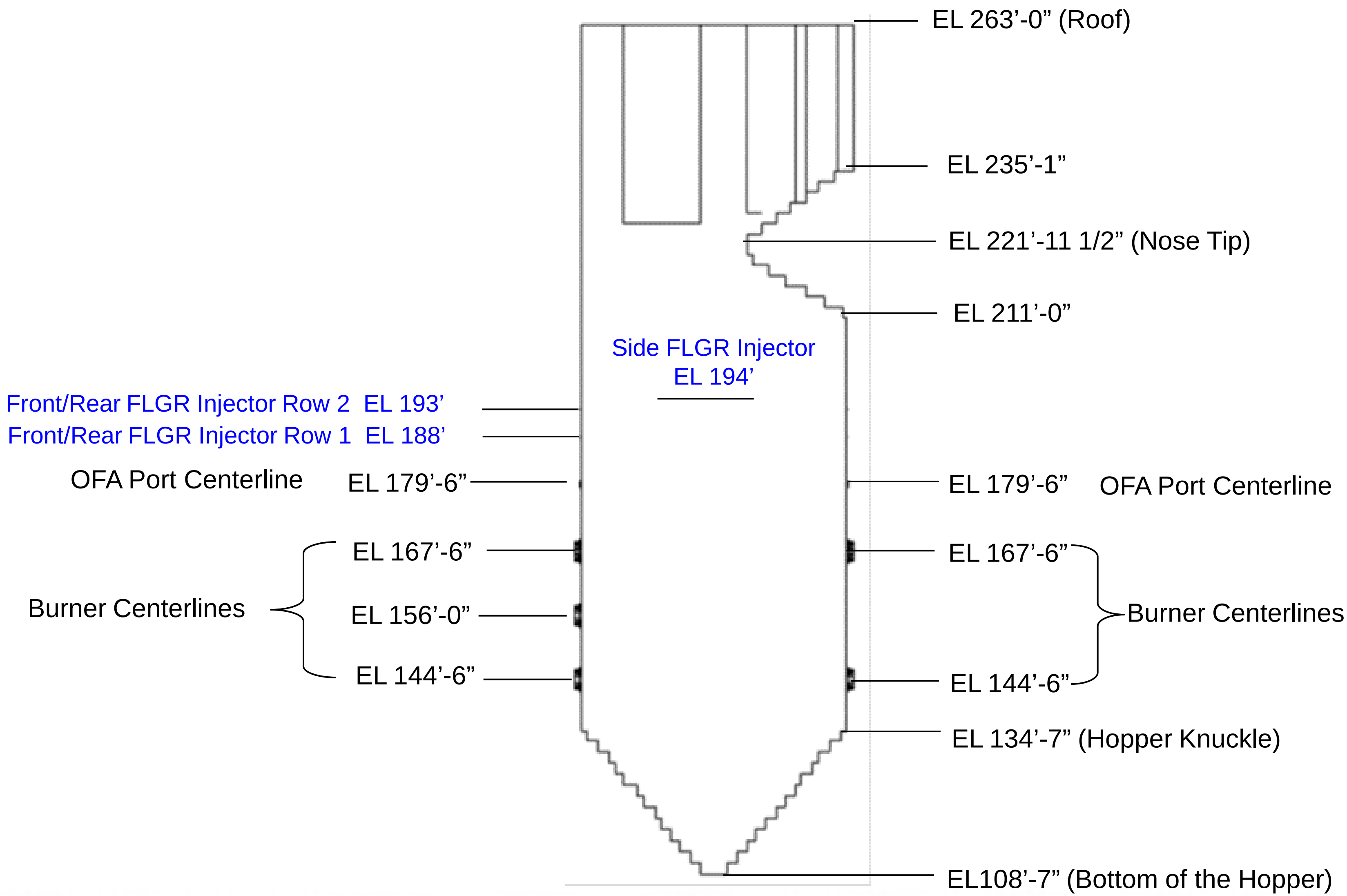
Experience & Lessons Learned

FLGR/COFIRE - STANTON

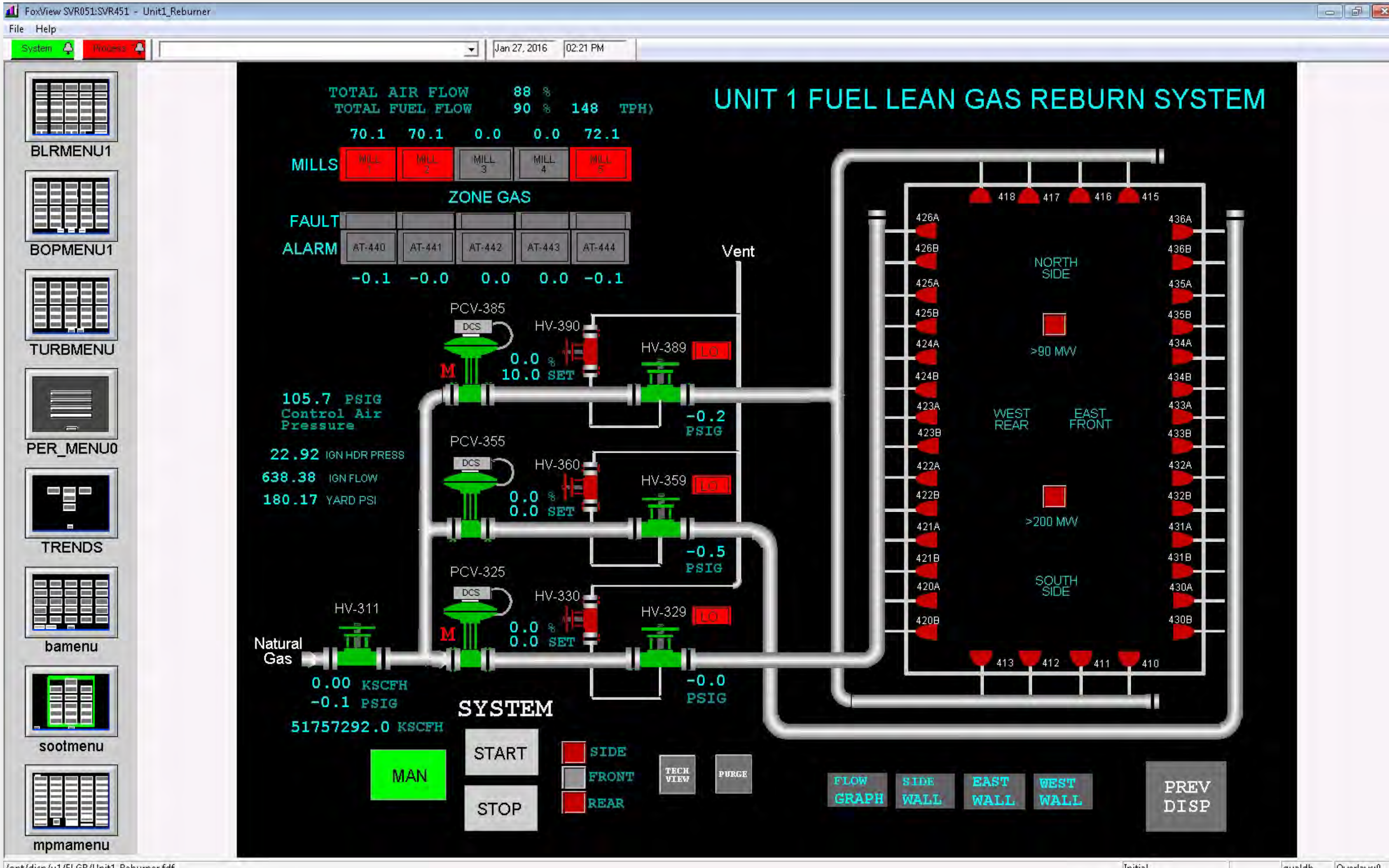
Stanton 1



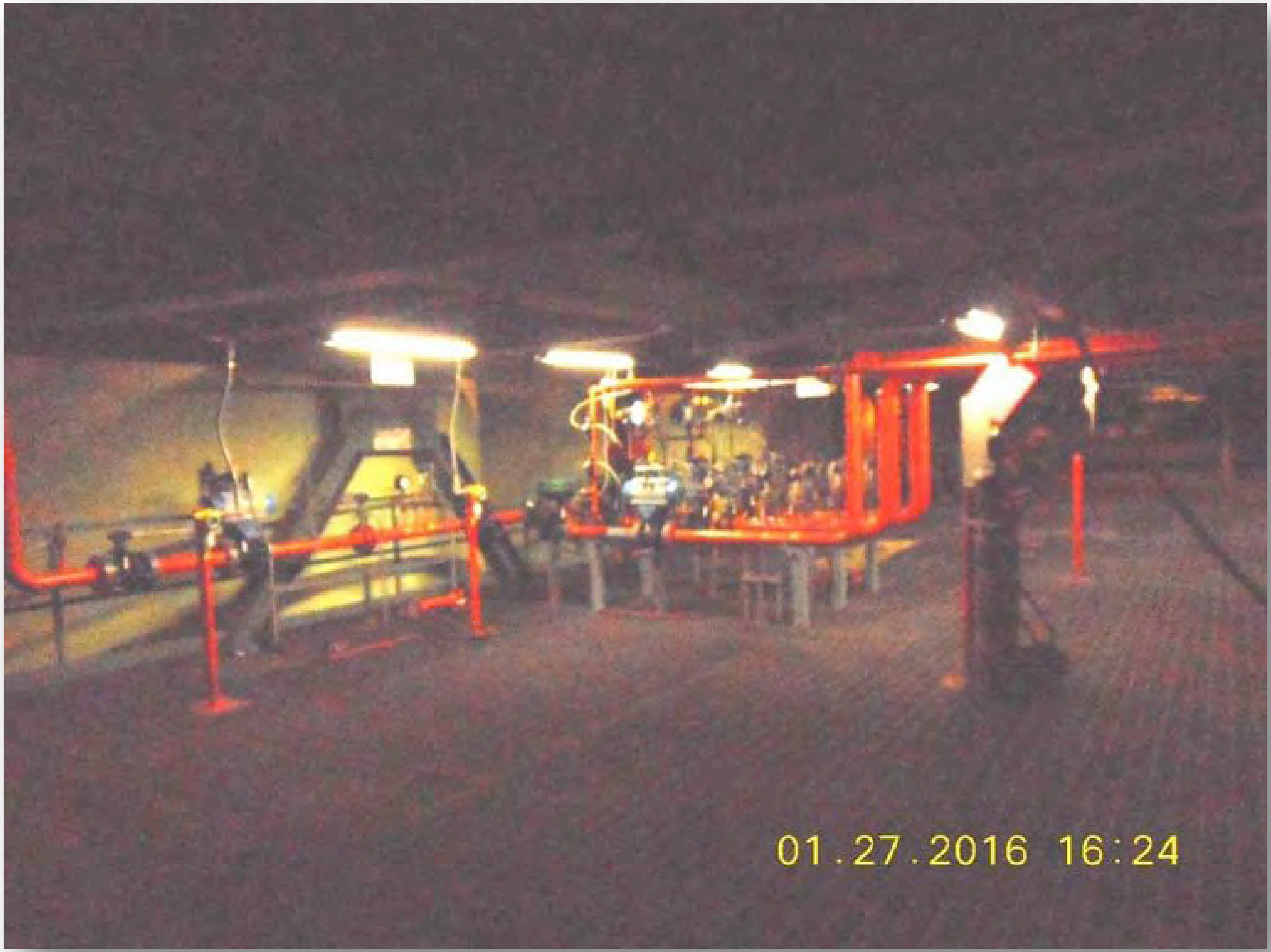
Boiler Elevations



FLGR Control Screen

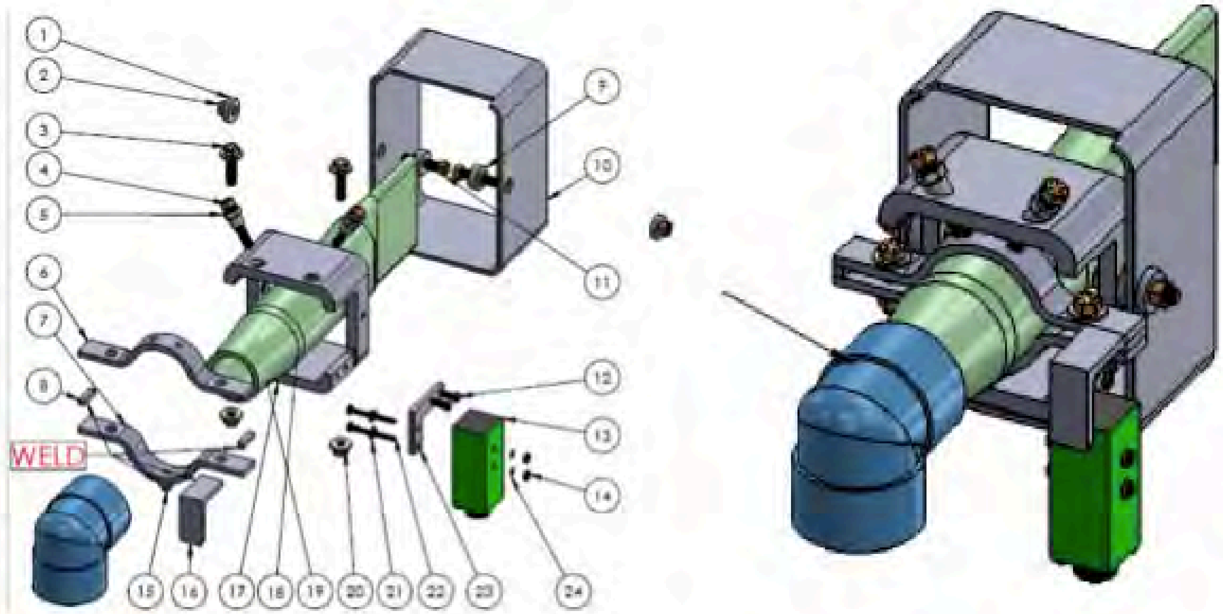


Gas Control Skid

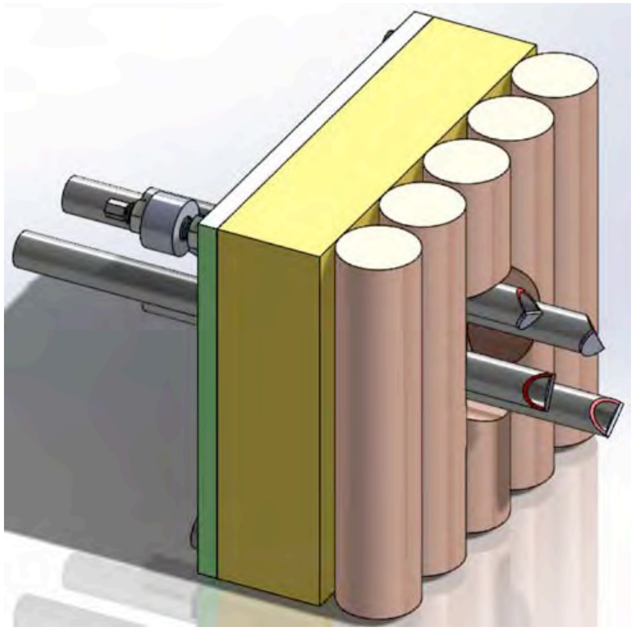


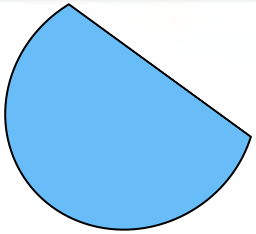
Rear Wall Piping

Original Injectors – 8th Floor



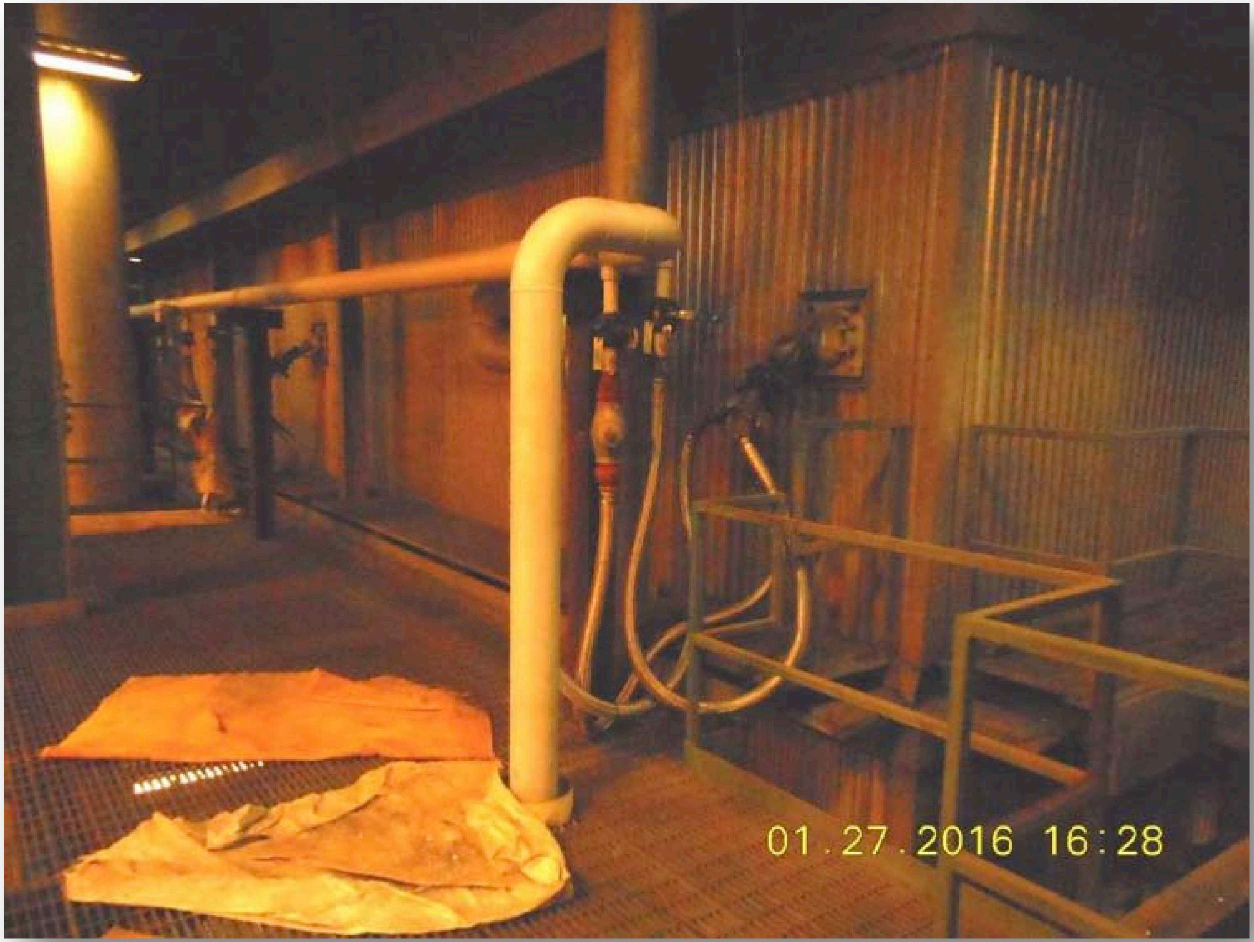
New injector profile





- **Better aspect ratio**
- **Lower heat xfer**
- **Less surface area for oxidation**
- **Better for producing fuel-rich eddies**
- **Directional control**

10th Floor Injectors



OUC Perspective:

Actual execution of the implementation OUC's perspective:

- **Engineering of Hardware and functionality worked as planned**
  - **DBB valves lead times longer than quoted**
- **Software Implementation took a little longer than planned, but minimal operator interaction was needed when completed**
- **Basically a Turn-on <-> Turn-off system**

OUC Perspective

What did you have to do to support installation?

- Provide a part-time Facilitator/Coordinator for overseeing safety, equipment/hardware deliveries, in-house support and quality control.
- Instrument & Electrical Technicians to pull wire, terminate, and perform the software addition/modification to the DCS, also start-up support.

OUC Perspective

What did you have to do to help train the operators?

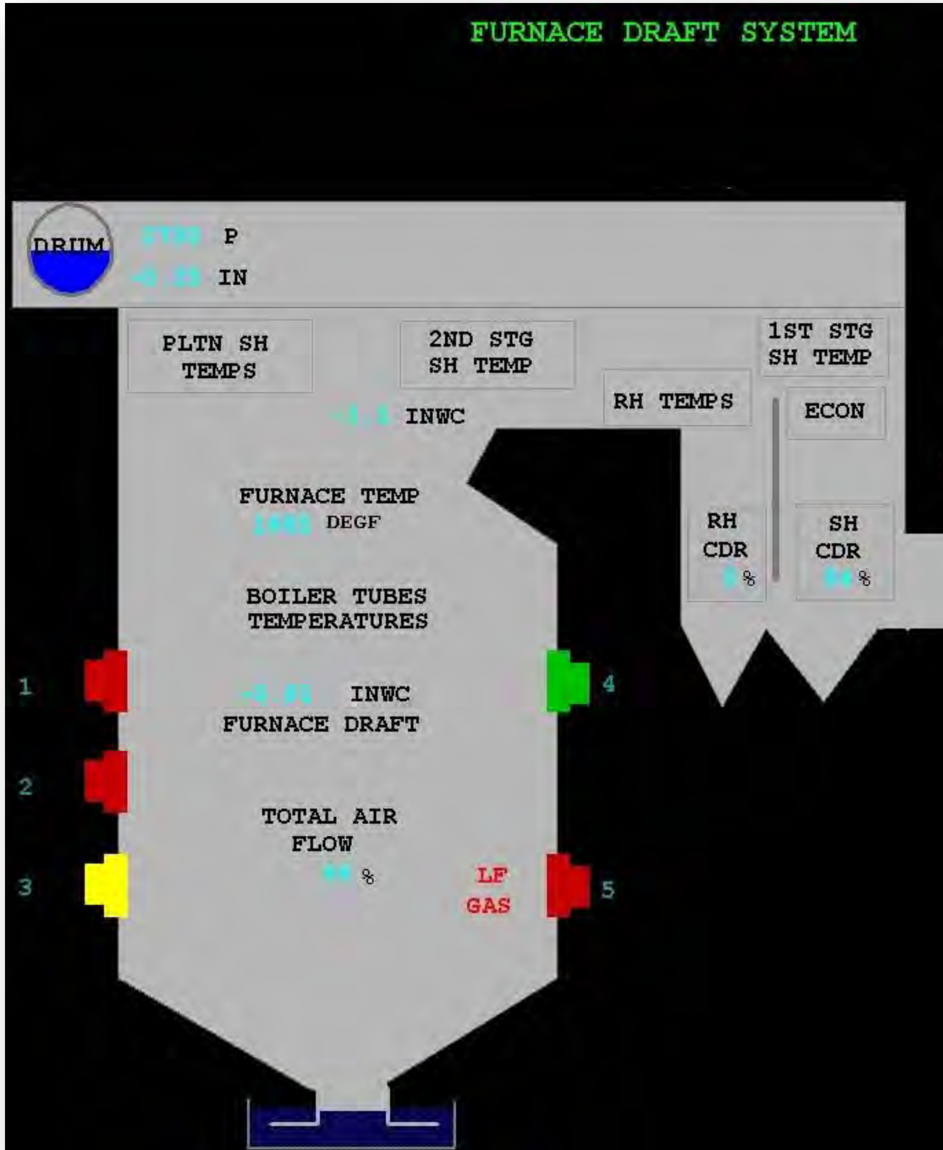
- BREEN Provided training to all operational shifts before commissioning and during start-up/testing ph
- BREEN provided "User's Manual"
- Did preliminary HVT probing to assure we meet Code for FLGR (concerns with adding natural gas downstream of igniters).

OUC Perspective

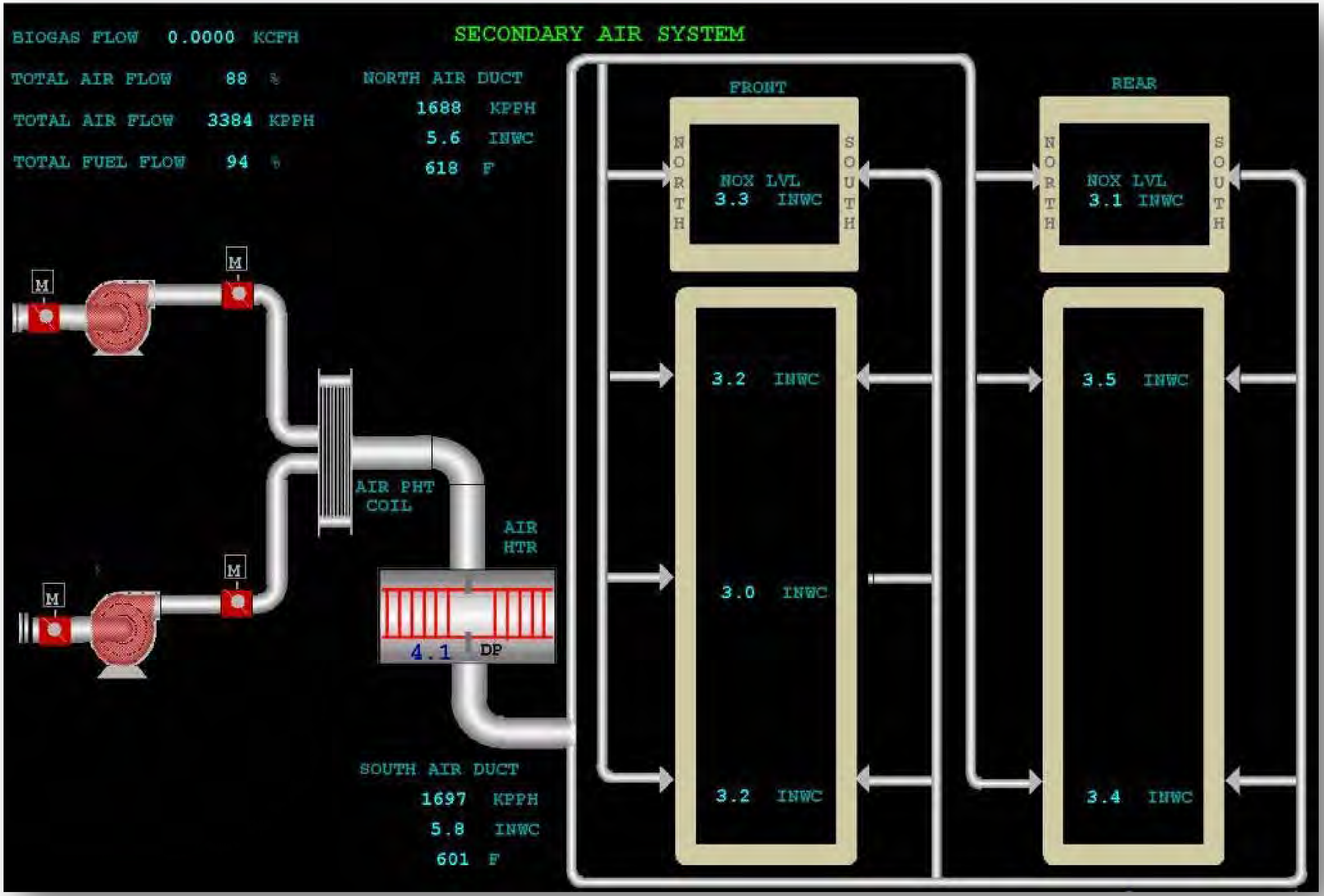
What did you have to do to re-tune the boiler in response to the reallocated fuel makeup and location?

- **With 10% of total fuel was coming from FLGR, three mill operation was only needed to make full load on steam unit.**
  - OFA settings had to change to different mill configurations to maintain sub-stoichiometric conditions
  - Boiler Master was adding more air to coal burners when FLGR was in service, had to reduce O2 trim

Control Screen

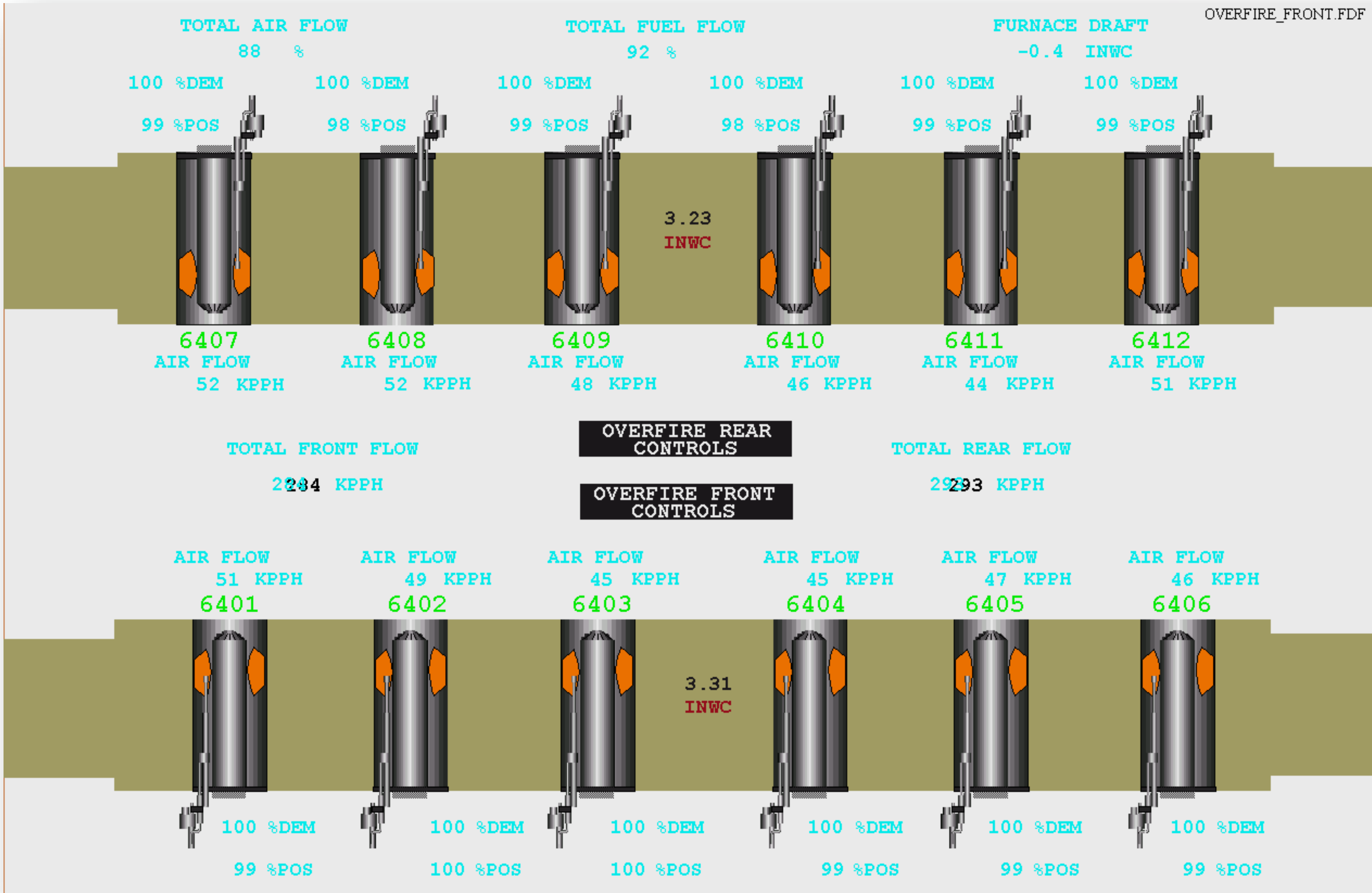


Main Air



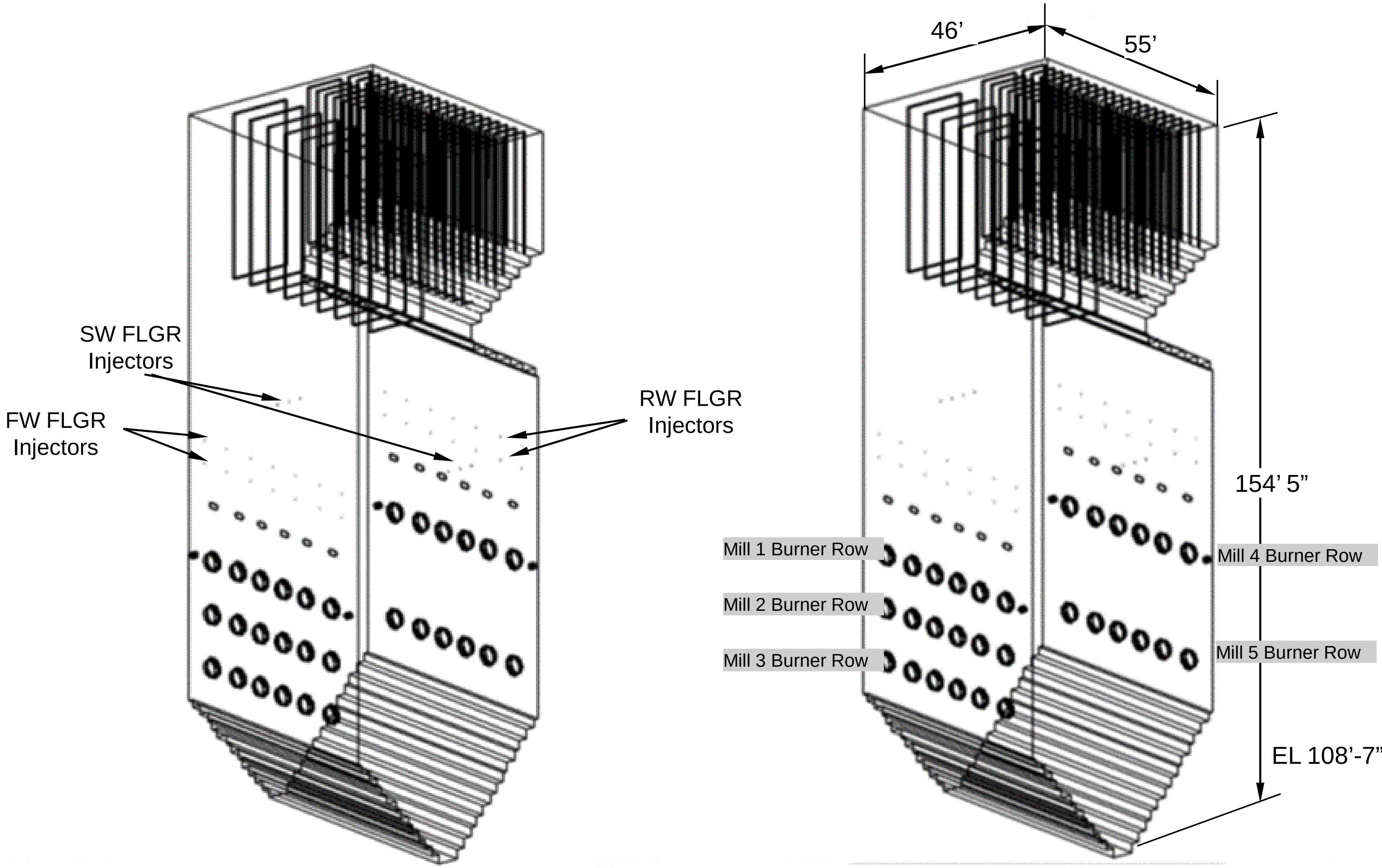
BIOGAS FLOW 0.0000 KCFH
TOTAL AIR FLOW 88 %
TOTAL AIR FLOW 3384 KPPH
TOTAL FUEL FLOW 94 %
SECONDARY AIR SYSTEM
NORTH AIR DUCT
1688 KPPH
5.6 INWC
618 F
FRONT
REAR
NORTH
SOUTH
NOX LVL
3.3 INWC
3.1 INWC
3.2 INWC
3.5 INWC
3.0 INWC
3.2 INWC
3.4 INWC
AIR PHT
COIL
AIR
HTR
4.1 DP
M
SOUTH AIR DUCT
1697 KPPH
5.8 INWC
601 F

OFA Control Screen



Modeling vs. Actual

Overall FLGR Geometry



Comparison between Baseline and Corresponding FLGR Case

- Same Firing Rate
- Same excess O_2 level (wet) in the Flue gas
- Same Lower Furnace (excluding OFA) and Burner in-service Stoichiometric Ratio
- Maintain same gas co-firing heat input through the burner igniters at low load

Overall Model Inputs
(Full Load)

	Baseline Full Load	FLGR Full Load
Furnace Gross Load (MW)	460	460
Gross Heat Rate (Btu/hr/KW)	9262.9	9262.9
Total Firing Rate (MMBtu/hr)	4260.9	4260.9
Total Natural Gas Firing Rate (MMBtu/hr)	0.0	319.6
Low Furnace Natural Gas Firing Rate (MMBtu/hr)	N/A	0.0
FLGR Natural Gas Firing Rate (MMBtu/hr)	N/A	319.6
FLGR in the Total Firing Rate (%)		7.5%
Front wall FLGR Natural Gas Firing Rate (MMBtu/hr)		159.8
Rear wall FLGR Natural Gas Firing Rate (MMBtu/hr)		159.8
Side wall FLGR Natural Gas Firing Rate (MMBtu/hr)		0.0
Natural Gas HHV (Btu/lb)	N/A	22823.6
Total Natural Flow Rate (Klb/hr)		14.002
Coal Firing Rate (MMBtu/hr)	4,260.9	3,941.4
Coal Type	IB-Sugar	IB-Sugar
Coal HHV (Btu/lb) as received	11,731	11,731
Coal Flow Rate (klb/hr)	363.220	335.979
Excess O_2 in Flue Gas (%, wet)	3.56	3.56
Excess O_2 in Flue Gas (%, dry)	3.91	3.93
Total Combustion Air (TCA) Flow (klb/hr)	3,935.14	3,925.96
Furnace Stoichiometric Ratio	1.223	1.224

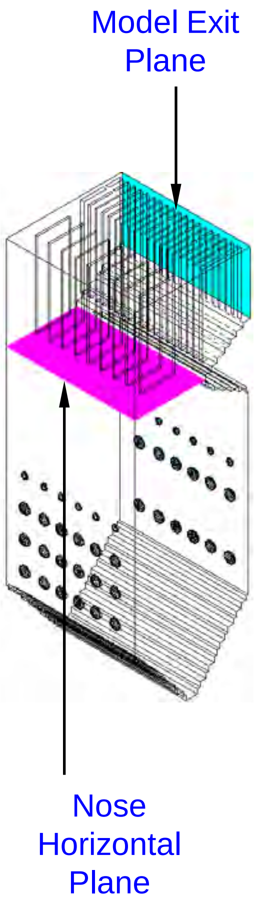
	Baseline Full Load	FLGR Full Load
Mill in Service (Burner row in service)	1, 2, 3, 5	1, 2, 3, 5
Natural Gas Ignitor in Mill row	N/A	N/A
Number of Burners in Services	24	24
Mill Out of Service (Burner row out of service)	4	4
Number of Burners Out of Services	6	6
Total Natural Gas Igintor in Service	N/A	N/A
In Service Burners		
In service Burner Stoichiometric Ratio	0.96	0.96
In service Burner Primary Air/Coal Ratio	1.87	1.87
Total In Service Burner Primary Air Flow (klb/hr)	680.00	629.00
Total In Service Burner Secondary Air Flow (klb/hr)	2400.00	2220.00
Out of Service Burners		
Total out of Service Burner Primary Air Flow (klb/hr)	0.0	0.0
Total out of Service Burner Secondary Air Flow (klb/hr)	90.00	83.25
Secondary Air Flow (klb/hr) per Out of Service Burner	15.00	13.88
Upper Wing Ports Air Flow (klb/hr)	165.14	152.76
Lower Furnace Stoichiometric Ratio	1.037	1.037
OFA Flow (klb/hr)	600.00	840.95
OFA Flow (klb/hr) per port	50.00	70.08
Primary Air Temperature (°F)	180	180
Secondary Air/OFA Temperature (°F)	584	584

Notes:

For High Load , when coal firing rate is reduced, air to the service burner, out of service burner and wing port is reduced proportionally to keep burner in service and low furnace SR same as Baseline

Overall Baseline Results

	High Load Baseline	Mid Load Baseline	Low Load Baseline
Nose Horizontal Plane			
Gas Temperature (° F)	2336	2234	1630
CO Concentration (ppmvw)	8905	7868	< 1
O_2 Concentration (wet%)	4.52	4.78	7.50
NO_x Concentration (ppmvw)	151	147	166
Model Exit Plane			
Gas Temperature (° F)	1943	1834	1329
CO Concentration (ppmvw)	792	24	< 1
O_2 Concentration (wet%)	3.65	4.01	7.50
NO_x Concentration (ppmvw)	153	153	172
NO_x Emission (lb/MMBtu)	0.244	0.249	0.351
Unburned Carbon in Fly Ash	5.7%	1.6%	< 0.1%



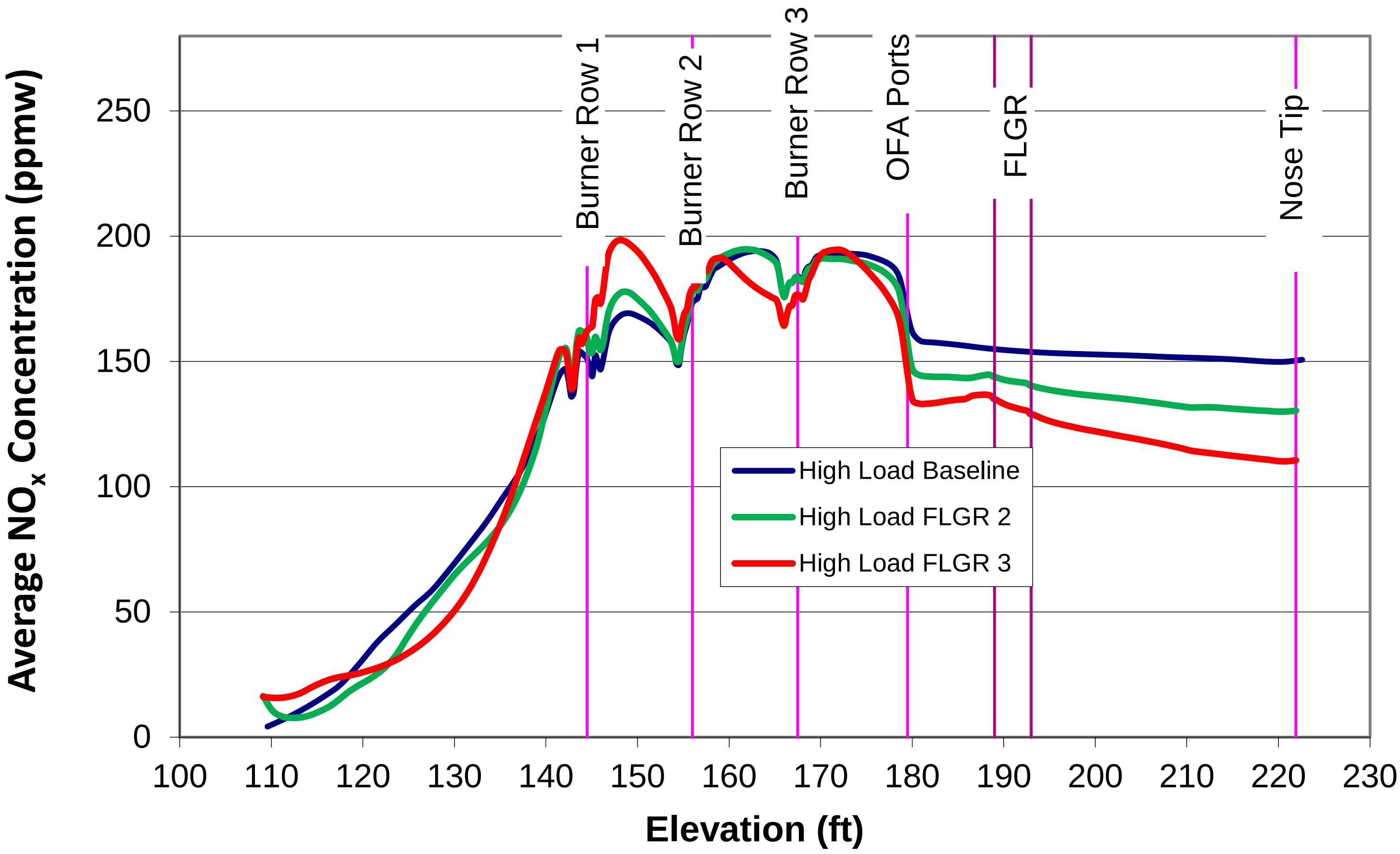
Key variables to manipulate

- **Injection Velocity**
- **# of Injectors in service**
- **Gas distribution between Front Wall / Rear Wall / Side Walls**

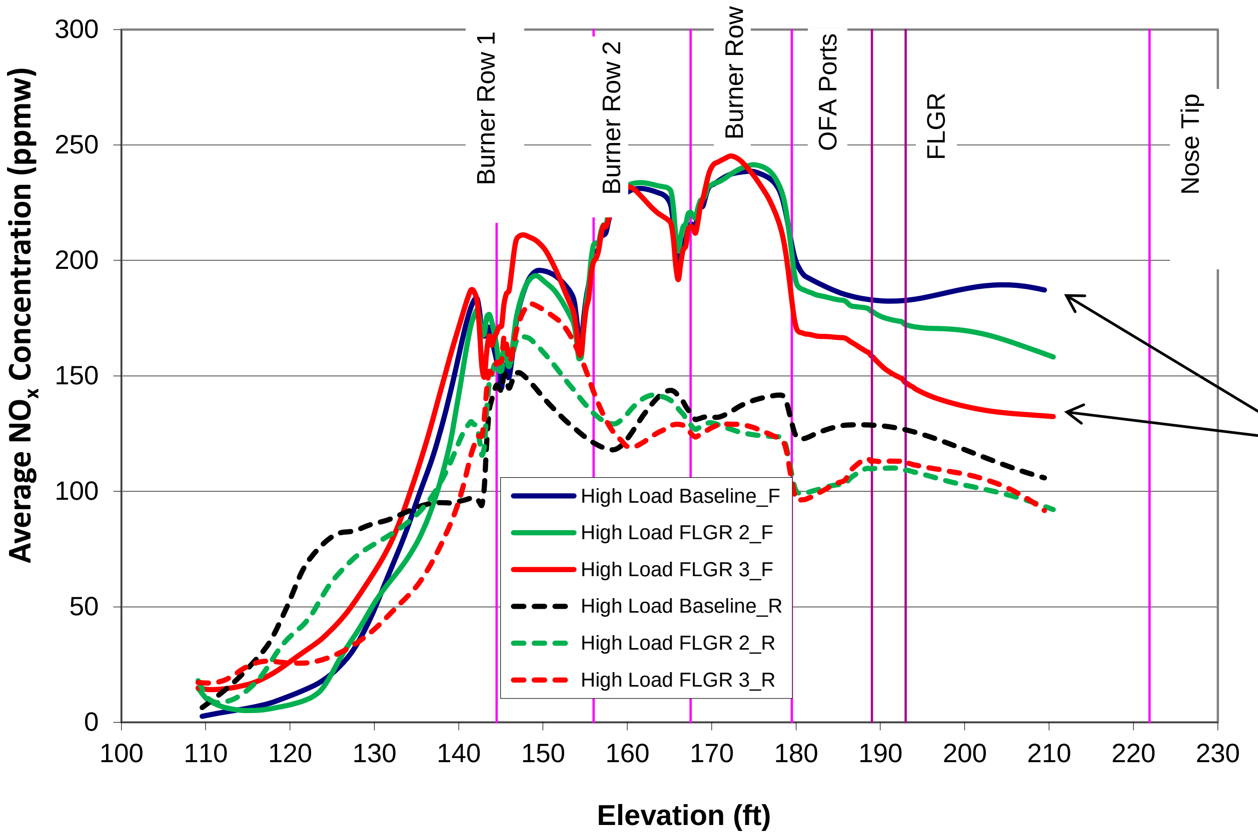
Overview of FLGR Results

Case	# FW/RW/RSW/LSW Injectors	Size FW/RW Inj. (H x W)	Size SW Inj. (HxW)	FLGR Vel (fps)	Gas Heat Input (%)	NOx Reduction (%)	Comments
FLGR1	14 / 14 / 0 / 0	4.06 x 0.25	NA	460	7.5	12.4	Relatively poor gas penetration
FLGR2	14 / 14/ 0 / 0	4.06 x 0.25	NA	460	7.5	12.9	Relatively poor gas penetration. Slightly better Nox reduction with 20^{o} down tilt on injectors in this case compared with no tilt in FLGR1.
FLGR3	14 / 14 / 0 / 0	3.06 x 0.25	NA	814	10	27.8	Improved NOx reduction due to increased gas heat input combined with increased penetration.
FLGR4a	7 / 7 / 0 / 0	4.06 x 0.25	NA	920	7.5	21.2	Improved NOx reduction compared to FLGR2 due to improved gas penetration and increased NOx reduction in burner zone due to indirect influence of high FLGR momentum on burner zone fluid mechanics.
FLGR4b	7 / 7 / 4 / 4	2.97 x 0.25	1.89 x 0.25	920	7.5	22.1	Slight improvement over FLGR4a

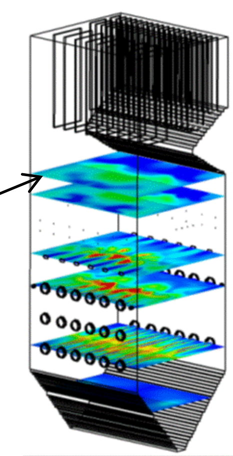
Average NOx Concentration Versus Elevation



Average NOx Concentration Versus Elevation



Impact of increased FLGR velocity and increased FLGR mass flow in FLGR 3 vs. FLGR 2 is seen more clearly near the front wall than near the rear wall.



Bottom of nose arch

Elevation 209 (Bottom of nose arch)

NOx (ppmvw)	Baseline	FLGR2	FLGR3
Average	152	132	115
Front	187	160	133
Rear	106	94	92

Comparison of Tests with Predictions

1 Mill Out of Service

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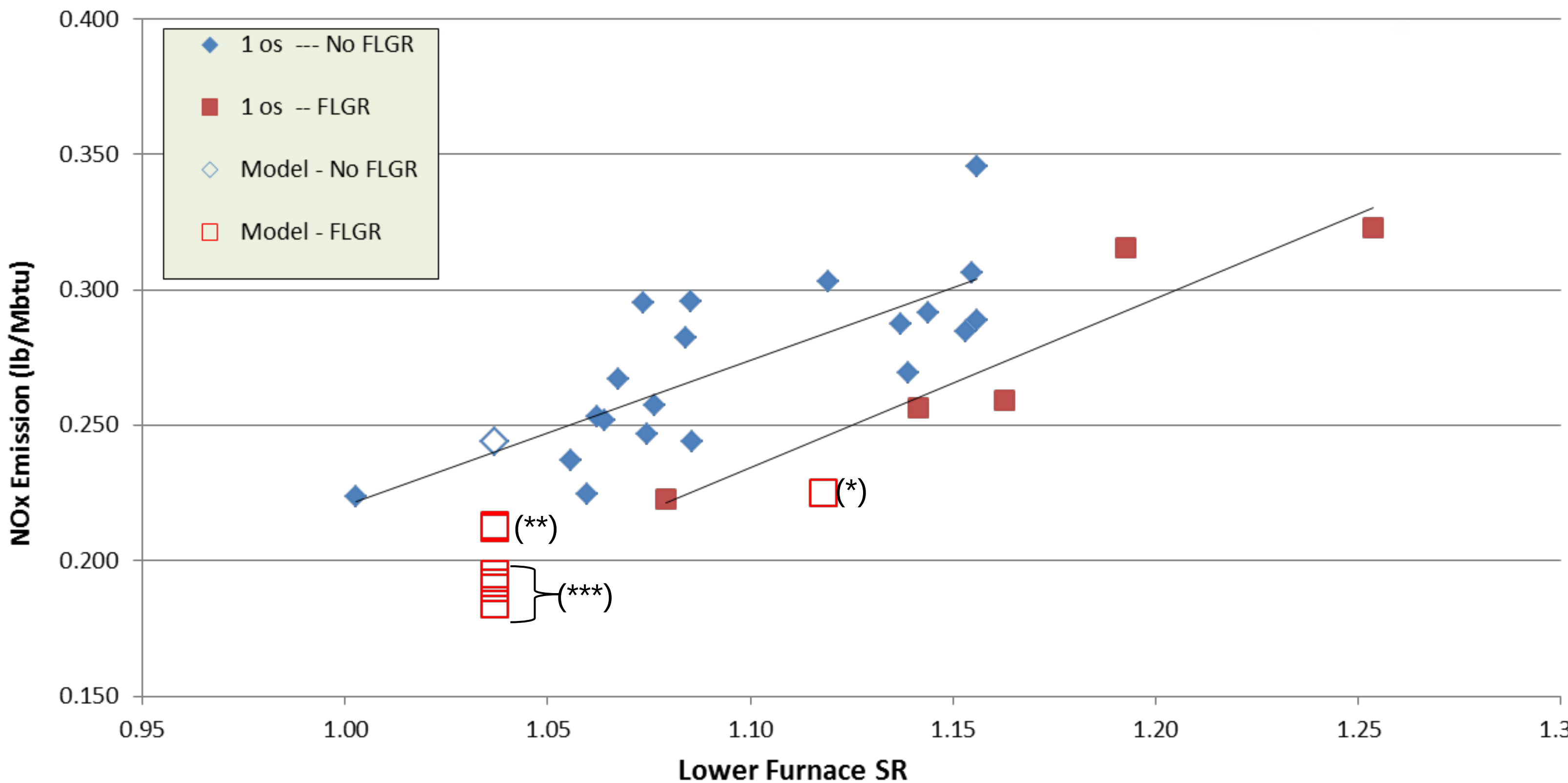

* REI CFD predictions showed very limited NOx reduction would be achieved (up to 7.6%), if the burner zone SR is not maintained when FLGR is put into service

Test results showed no NOx reduction is achieved when burner SR is not maintained when FLGR is put into service

** FLGR test results are consistent with REI predictions based on BES originally specified inlet velocity of 460 fps

*** CFD results showed improved FLGR performance with increasing injector velocity, which was not observed in the tests

OUC Stanton – ZGR Plan

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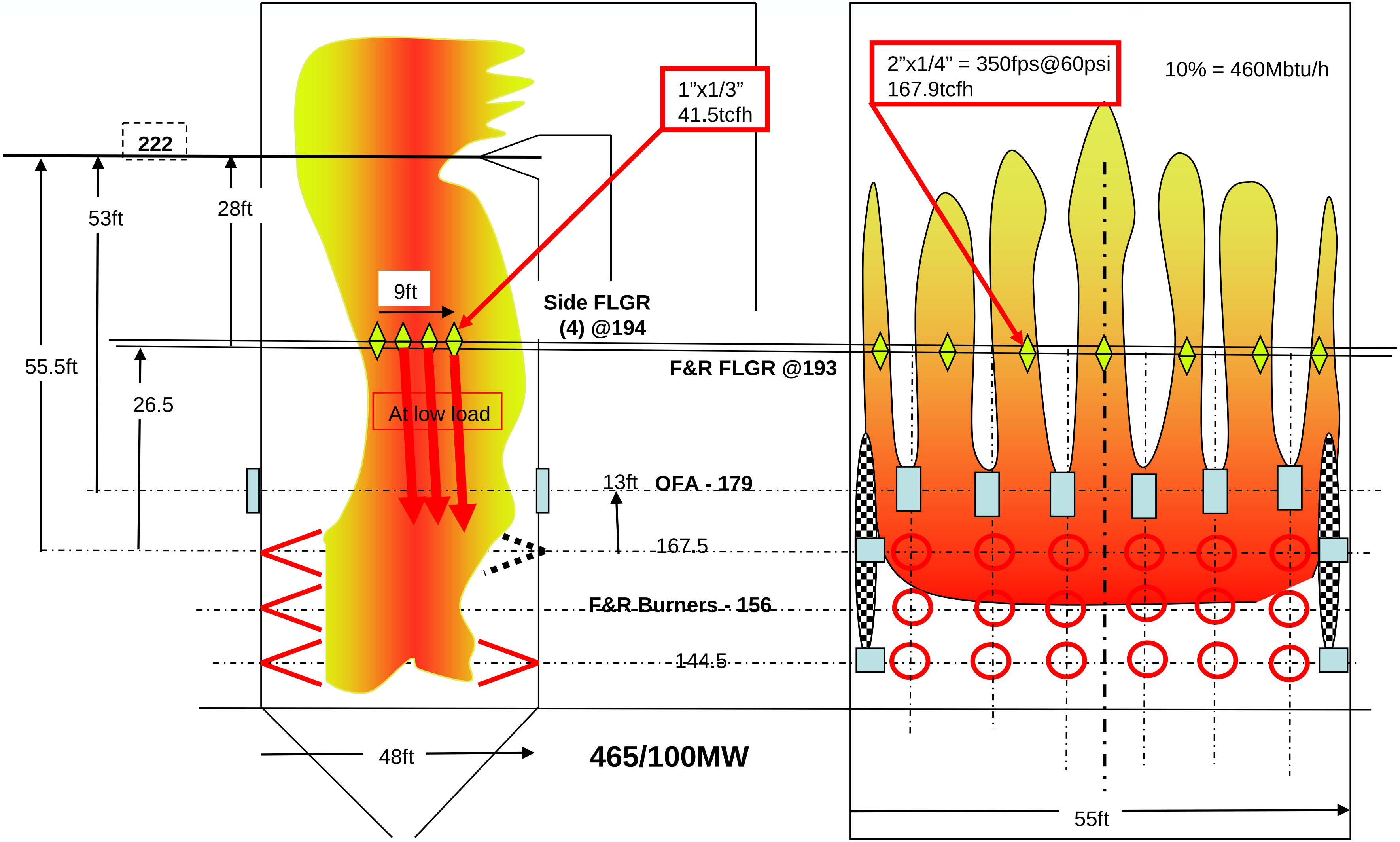
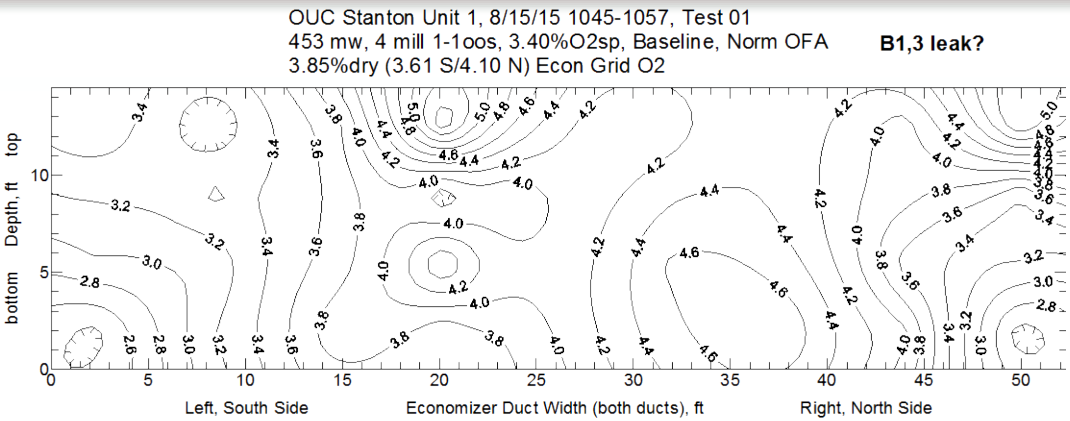
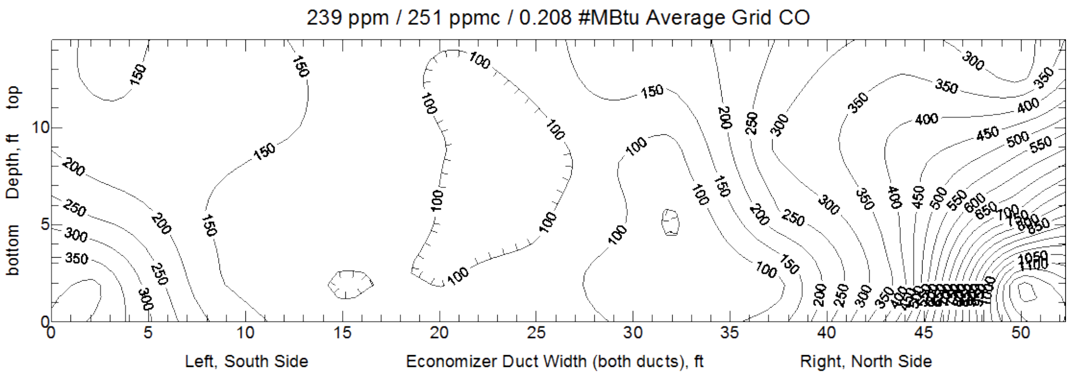
Placement of FLGR Injectors to Penetrate into Regions Expected to be High NOx

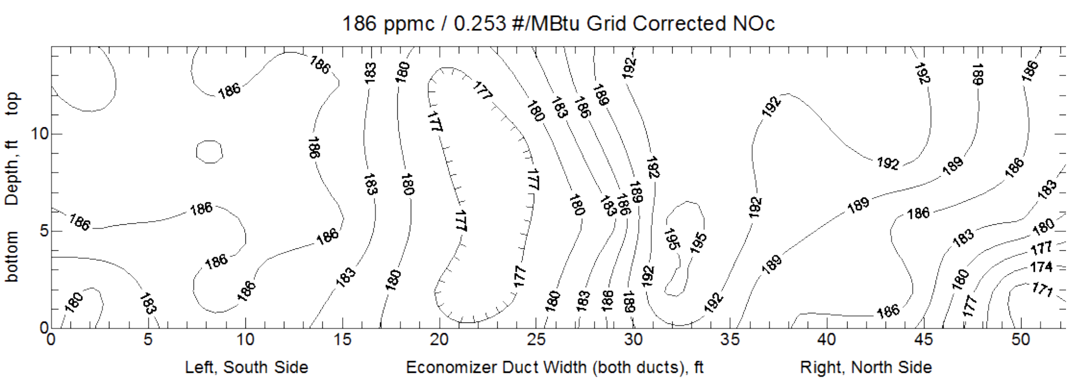


Gas in the OFA air columns is wasted as far as NOx reduction, and may even form NOX

Boiler Baseline testing

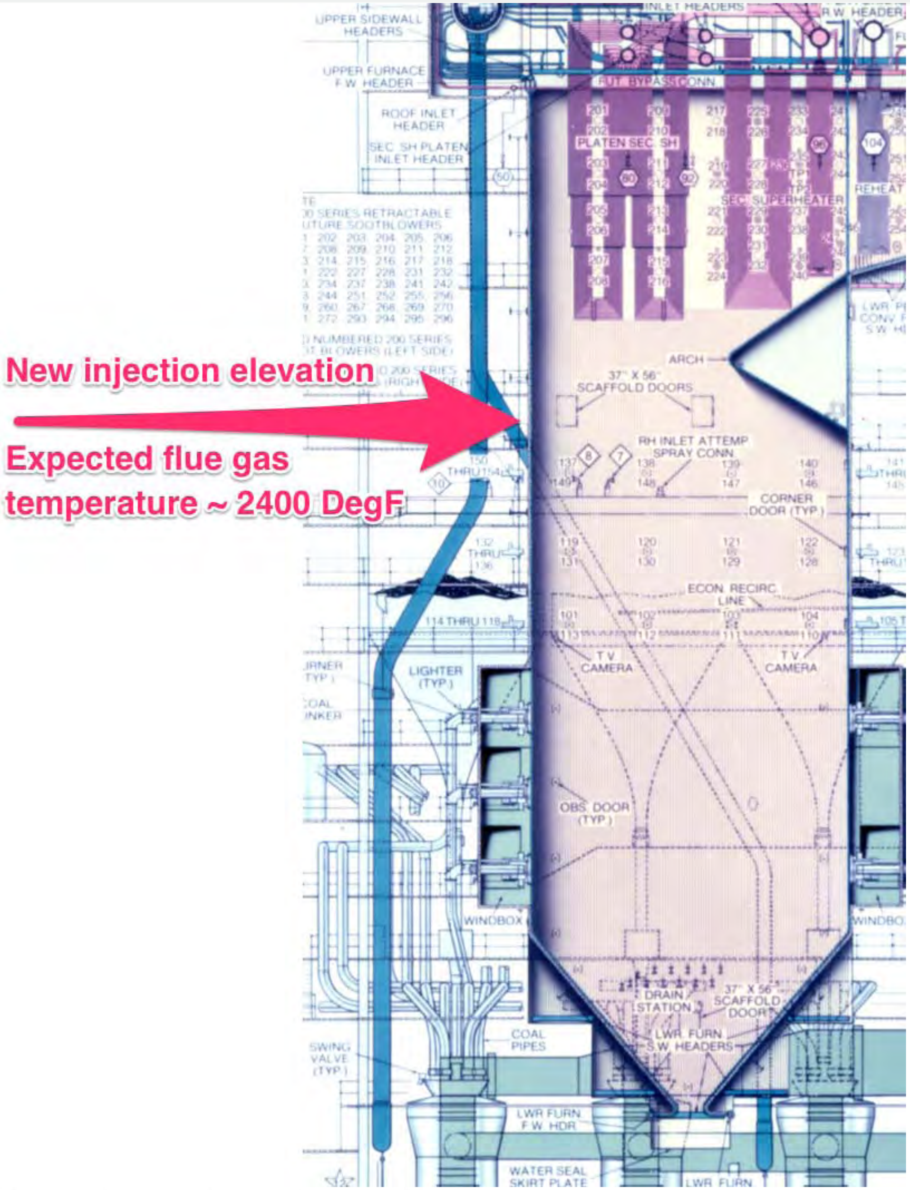






- Uniform NO_x observed across the boiler
- No pockets of High CO/O_2 or NO_x
- Initial gas injection testing revealed gas burnout with no Reburn effect
- Conditions look conducive for a traditional FLGR

New injection elevation



Front/Rear FLGR Injectors

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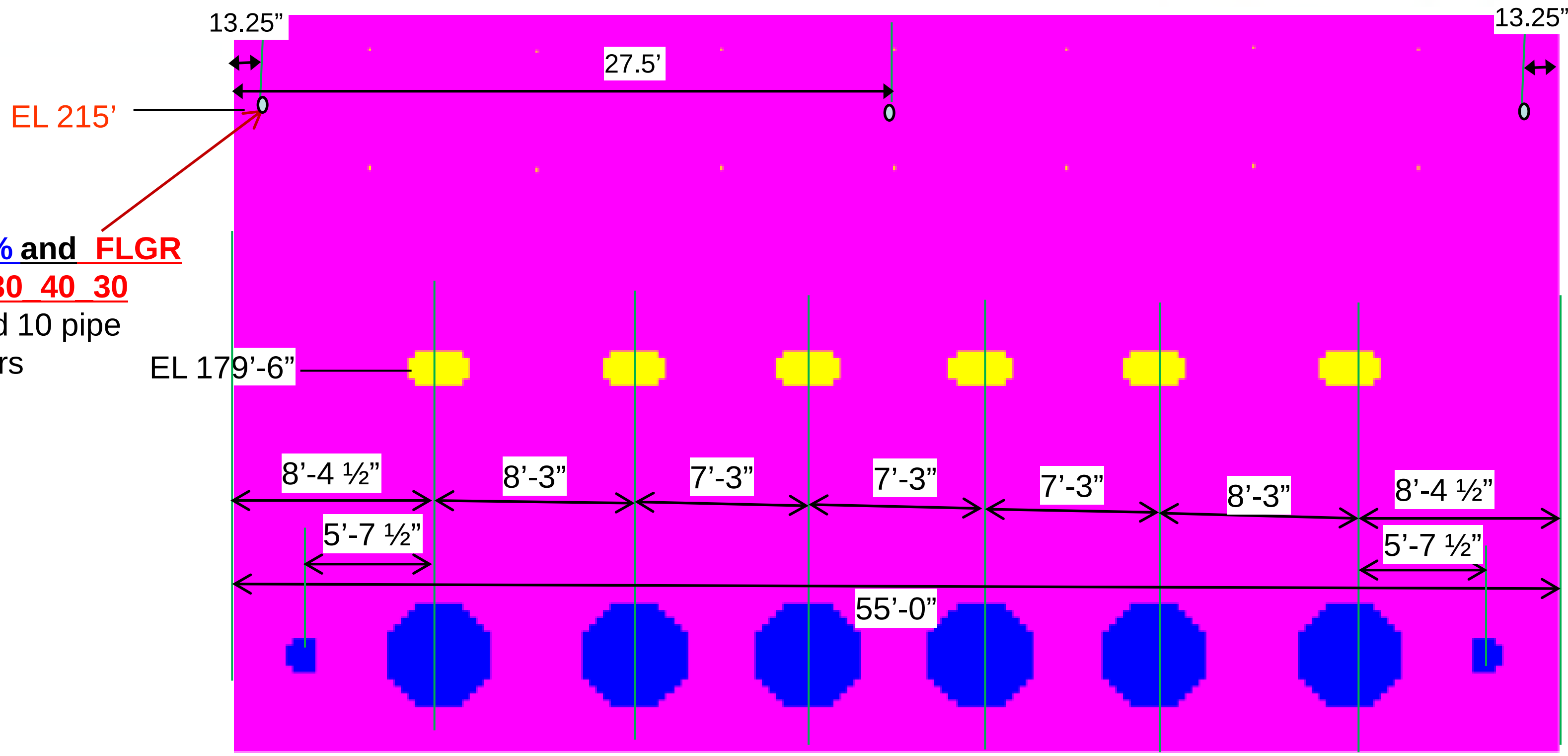


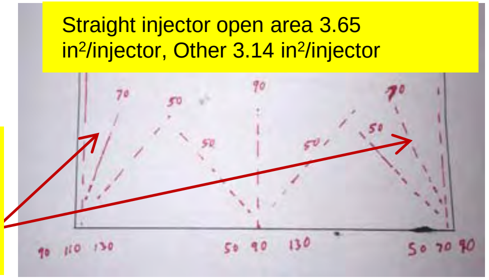
FLGR 3_3_3_10% and **FLGR 3_3_3_10%_30_40_30**

Nine 2” Sched 10 pipe injectors

FLGR Fuel Velocity 585 ft/sec

Straight injector open area 3.65 in²/injector, Other 3.14 in²/injector

This two injectors have vertical velocity component to achieve 70⁰ lateral

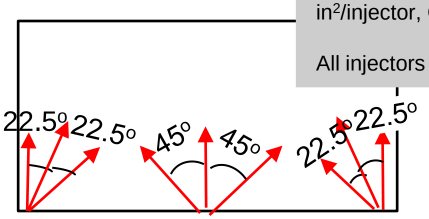


FLGR 3_3_3_10%

FLGR Fuel Velocity 708 ft/sec

Side injector: Open area 2.46 in²/injector
Middle injectors: Straight injector open area 3.65 in²/injector, Other 3.14 in²/injector

All injectors have no vertical velocity component



FLGR 3_3_3_10%_30_40_30

Overall Model Inputs
Full Load

	Baseline Full Load	FLGR3_3_3_10% and FLGR3_3_3_10%_30_40_30
Furnace Gross Load (MW)	460	460
Gross Heat Rate (Btu/hr/KW)	9262.9	9262.9
Total Firing Rate (MMBtu/hr)	4260.9	4260.9
Total Natural Gas Firing Rate (MMBtu/hr)	0.0	426.1
Low Furnace Natural Gas Firing Rate (MMBtu/hr)	N/A	0.0
FLGR Natural Gas Firing Rate (MMBtu/hr)	N/A	426.1
FLGR in the Total Firing Rate (%)		10.0%
Front wall FLGR Natural Gas Firing Rate (MMBtu/hr)		426.1
Rear wall FLGR Natural Gas Firing Rate (MMBtu/hr)		N/A
Side wall FLGR Natural Gas Firing Rate (MMBtu/hr)		N/A
Natural Gas HHV (Btu/lb)	N/A	22823.6
Total Natural Flow Rate (Klb/hr)		18.669
Coal Firing Rate (MMBtu/hr)	4,260.9	3,834.8
Coal Type	IB-Sugar	IB-Sugar
Coal HHV (Btu/lb) as received	11,731	11,731
Coal Flow Rate (klb/hr)	363.220	326.898
Excess O_2 in Flue Gas (%, wet)	3.56	3.56
Excess O_2 in Flue Gas (%, dry)	3.91	3.94
Total Combustion Air (TCA) Flow (klb/hr)	3,935.14	3,923.16
Furnace Stoichiometric Ratio	1.223	1.224

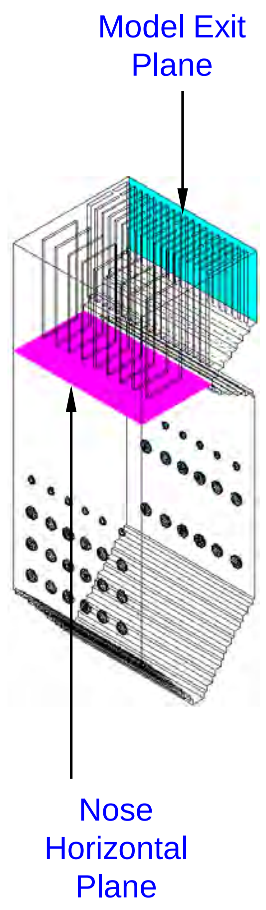
	Baseline Full Load	FLGR3_3_3_10% and FLGR3_3_3_10%_30_40_30
Mill in Service (Burner row in service)	1, 2, 3, 5	1, 2, 3, 5
Natural Gas Ignitor in Mill row	N/A	N/A
Number of Burners in Services	24	24
Mill Out of Service (Burner row out of service)	4	4
Number of Burners Out of Services	6	6
Total Natural Gas Igintor in Service	N/A	N/A
In Service Burners		
In service Burner Stoichiometric Ratio	0.96	0.96
In service Burner Primary Air/Coal Ratio	1.87	1.87
Total In Service Burner Primary Air Flow (klb/hr)	680.00	612.00
Total In Service Burner Secondary Air Flow (klb/hr)	2400.00	2160.00
Out of Service Burners		
Total out of Service Burner Primary Air Flow (klb/hr)	0.0	0.0
Total out of Service Burner Secondary Air Flow (klb/hr)	90.00	81.00
Secondary Air Flow (klb/hr) per Out of Service Burner	15.00	13.50
Upper Wing Ports Air Flow (klb/hr)	165.14	148.63
Lower Furnace Stoichiometric Ratio	1.037	1.037
OFA Flow (klb/hr)	600.00	921.53
OFA Flow (klb/hr) per port	50.00	76.79
Primary Air Temperature (˚F)	180	180
Secondary Air/OFA Temperature (˚F)	584	584

Notes:
For High Load , when coal firing rate is reduced, air to the in-service burners, out of service burners, and wing ports is reduced proportionally to keep lower furnace SR same as Baseline

Notes:
FLGR 3_4_3, FLGR 3_3_3_10%_30_40_30 and FLGR 3_3_3_10%; FLGR Natural gas injector direction and gas velocity magnitude see slide 8

Overall Results

	High Load Baseline	High Load FLGR 3_3_3_10%	High Load FLGR 3_3_3_10%_30_40_30
Nose Horizontal Plane			
Gas Temperature (° F)	2336	2281	2287
CO Concentration (ppmvw)	8905	8110	8209
O_2 Concentration (wet%)	4.52	5.05	4.94
NO_x Concentration (ppmvw)	151	133	131
Model Exit Plane			
Gas Temperature (° F)	1943	1913	1912
CO Concentration (ppmvw)	792	2668	1734
O_2 Concentration (wet%)	3.65	3.94	3.78
NO_x Concentration (ppmvw)	153	120	119
NO_x Emission (lb/MMBtu)	0.244	0.189	0.188
Total NO_x Reduction	N/A	22.3%	22.9%
NO_x Reduction due to Coal Replacement with Natural gas	N/A	6.9%	8.5%
NO_x Reduction due to FLGR Chemistry	N/A	15.4%	14.4%
Unburned Carbon in Fly Ash	5.7%	2.6%	2.4%



Lower Furnace SR – O2 Probes

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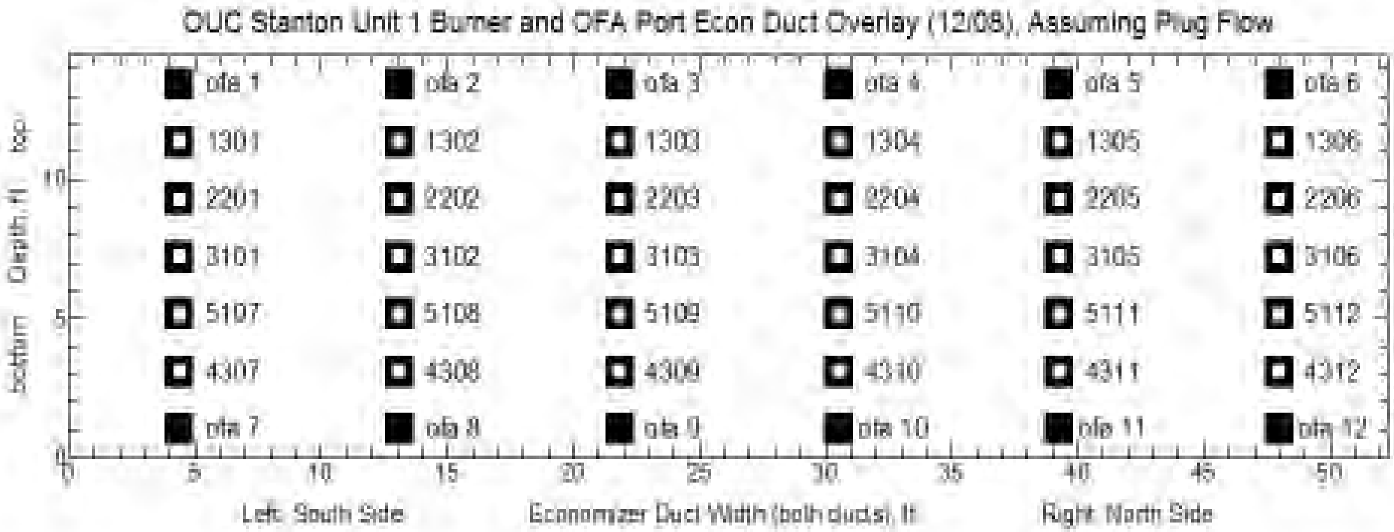
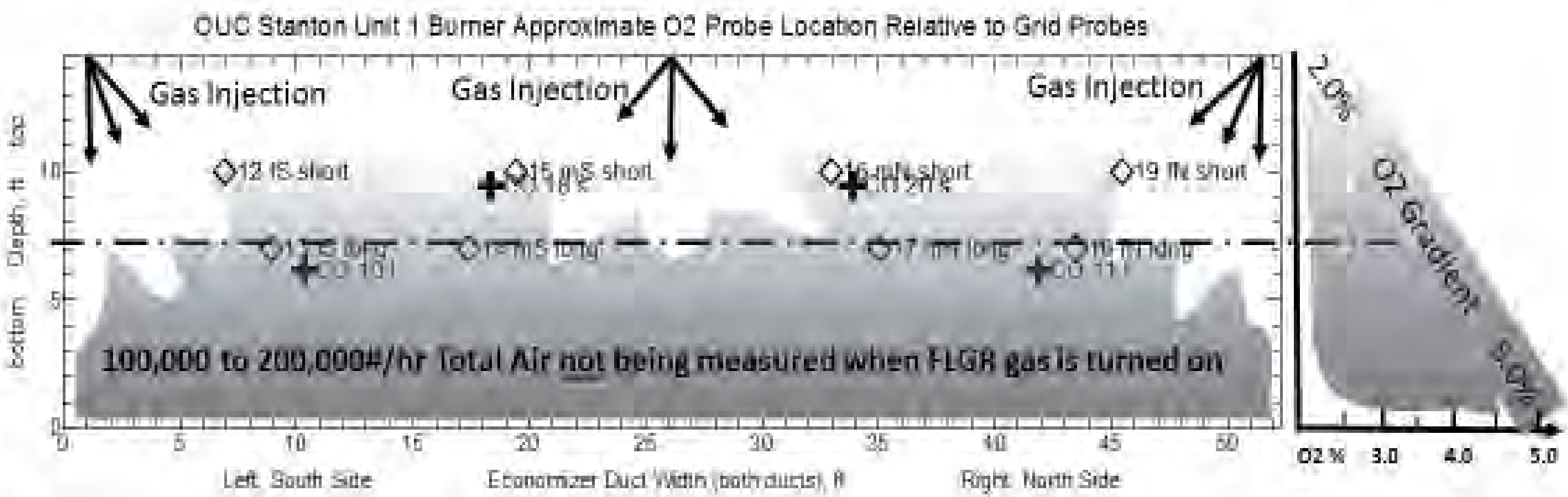
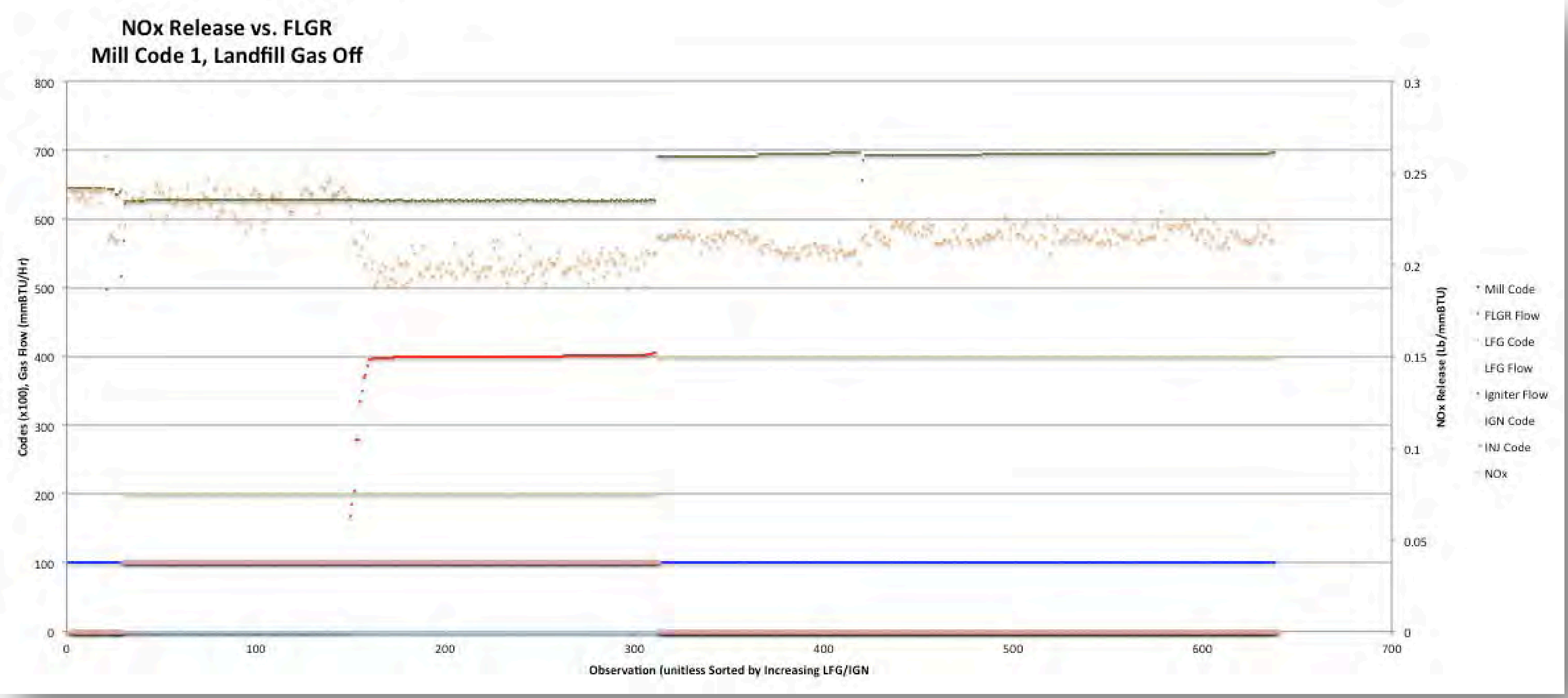


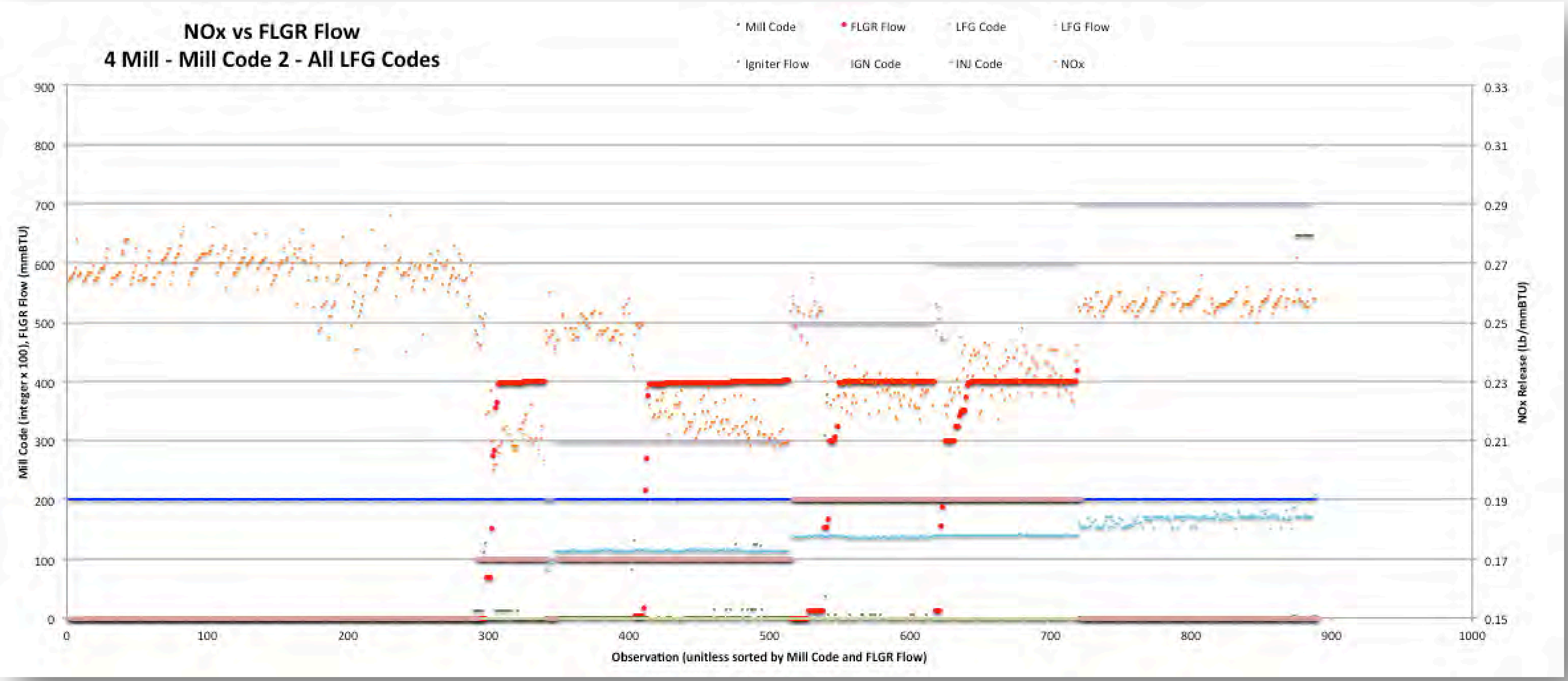


10^{th} Floor Result Analysis

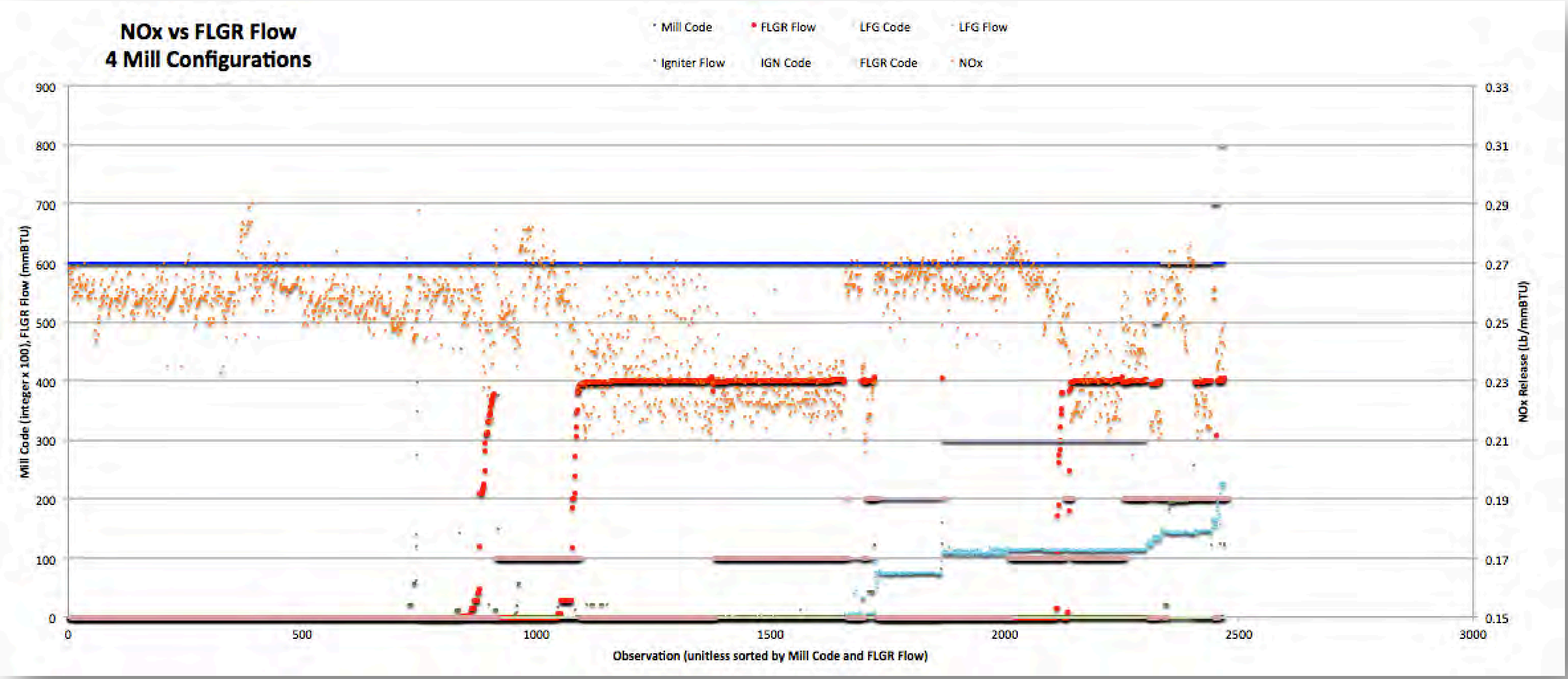
3 Mill/Landfill Gas Off/HV Inj.



4 Mill – MC2 – All LFG Codes/Mxd Inj.



4 Mill MC6 All LFG Codes/Mxd. Inj.



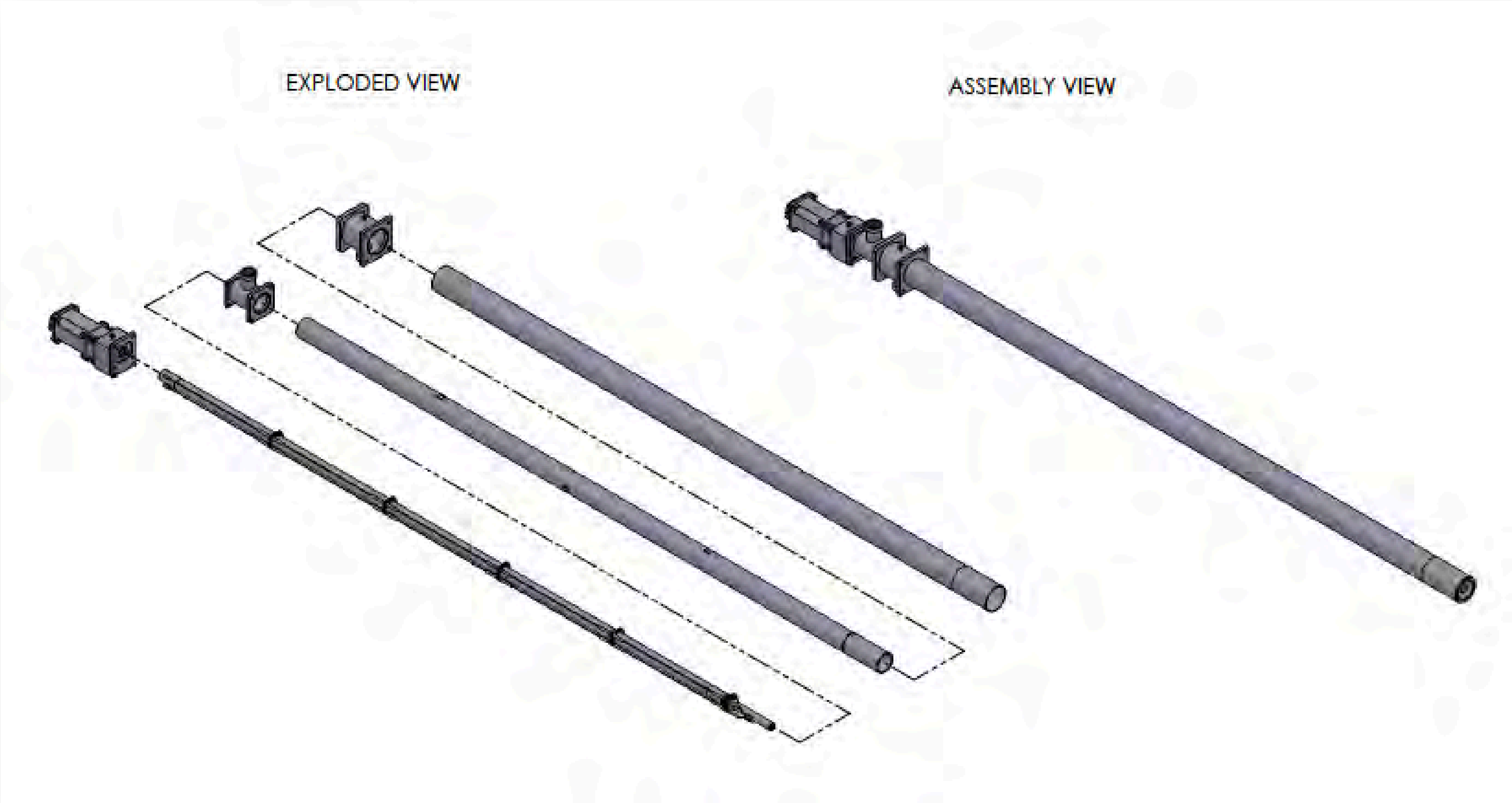
Data Summary – High Load

	AVG NO FLGR	AVG Full FLGR Orig Inj	AVG Full FLGR HV Inj	AVG Full FLGR SHV Inj	FLGR Impact Orig Inj	FLGR Impact HV Inj	FLGR Impact SHV Inj
2B-SD-HL-3M-MC1-IC2-LC0	0.235		0.199			15.2%	
2B-SD-HL-3M-MC1-IC2-LC3	0.248			0.216			12.8%
2B-SD-HL-3M-MC1-IC2-LC4	0.240			0.220			8.4%
2B-SD-HL-3M-MC1-IC2-LC5	0.232			0.196			15.8%
2B-SD-HL-3M-MC1-IC2-LC6	0.234			0.190			18.9%
3A-SD-HL-4M-MC2-IC0-LC0	0.267		0.211			21.1%	
3A-SD-HL-4M-MC2-IC0-LC3	0.250		0.217			13.2%	
3A-SD-HL-4M-MC2-IC0-LC5	0.250			0.226			9.3%
3A-SD-HL-4M-MC6-IC0-LC0	0.259	0.237	0.227		8.5%	12.4%	
3A-SD-HL-4M-MC6-IC0-LC3	0.263		0.227	0.242		13.9%	7.9%

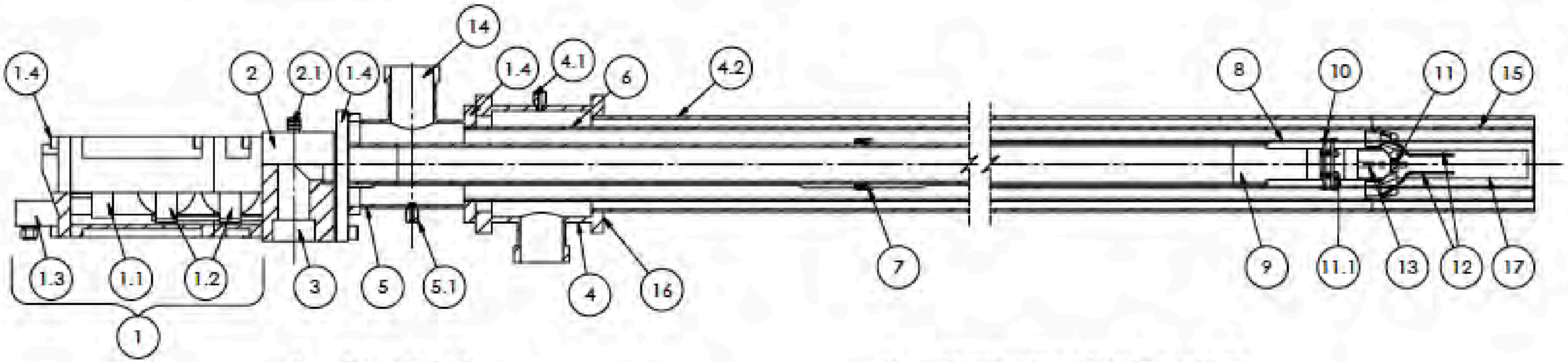
CoFire Igniter Update

The Device

Exploded Internals



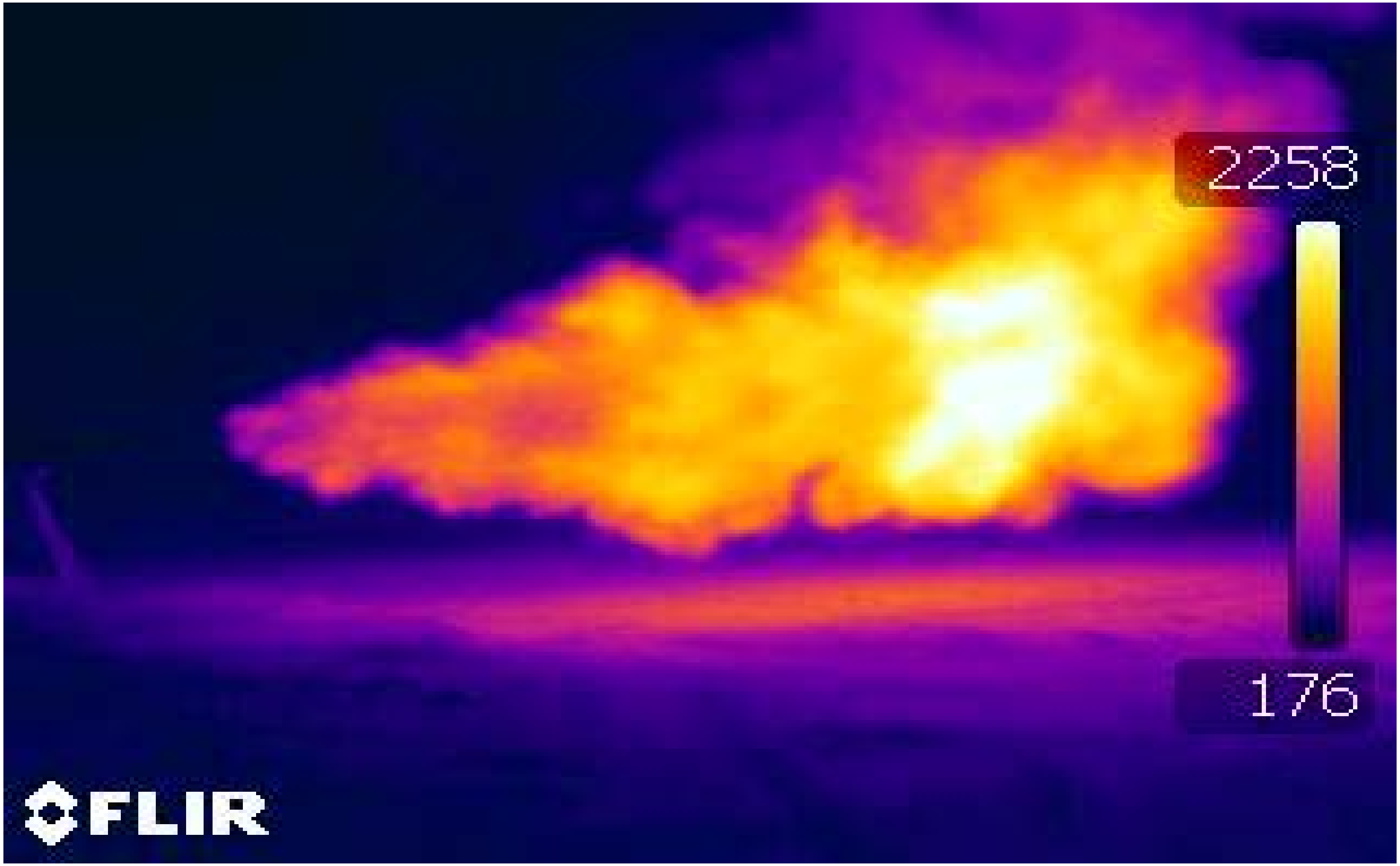
Side View



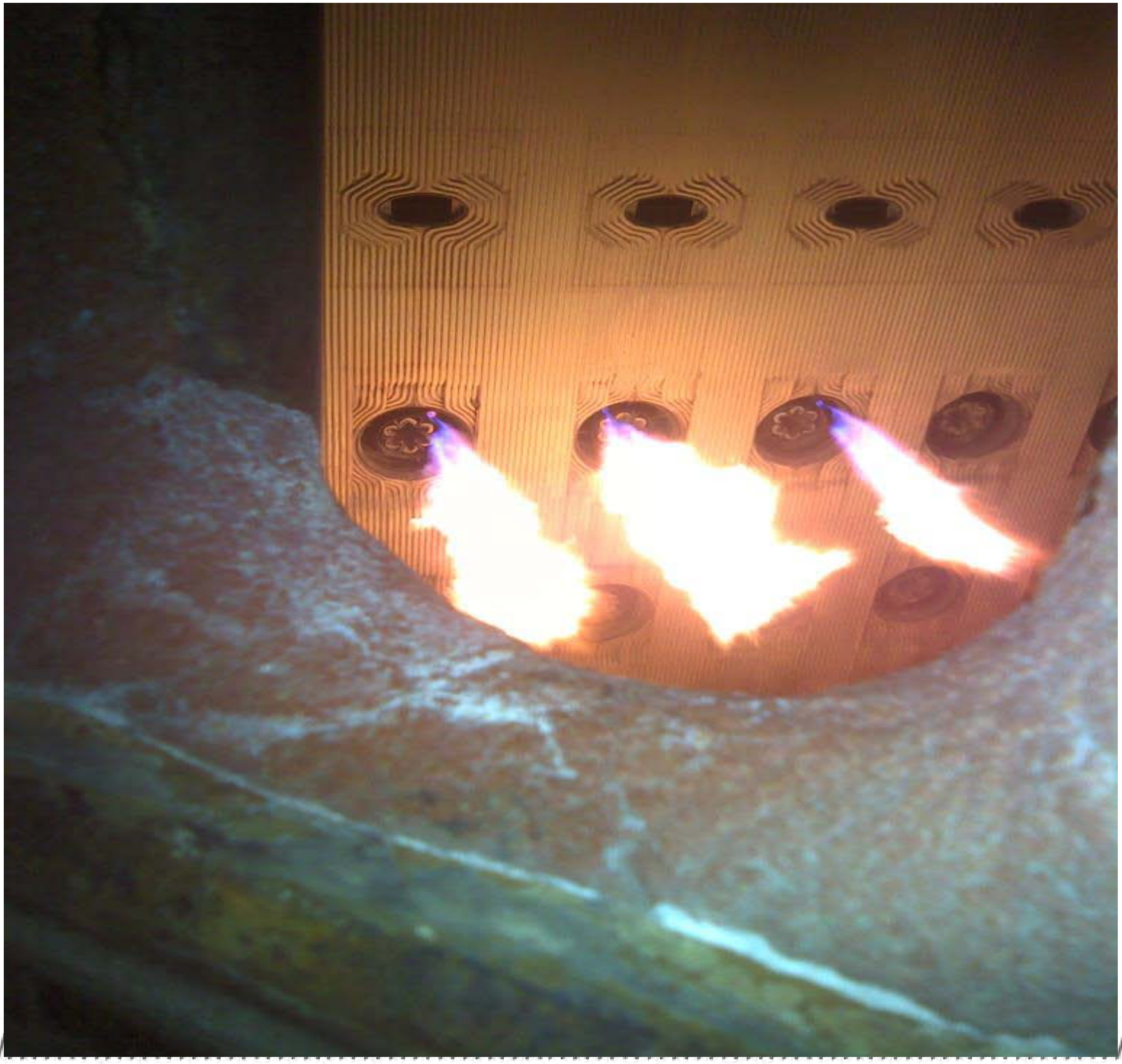
1. Power head
1.1 Ionization flame monitor with flame signal converter
1.2 Spark transformers
1.3 Electrical plug
1.4 Allen screw
2. Igniter gas manifold
2.1 Igniter gas pressure test nipple
3. Igniter gas inlet port
4. Gas co-fire manifold
4.1 Gas pressure test nipple
4.2 Gas co-fire tube
5. Combustion / Cooling air manifold
5.1 Combustion / Cooling air pressure test nipple
6. Combustion / Cooling air tube
7. Intermediate electrode support rings
8. Electrical connecting rods
9. Igniter gas tube
10. Final electrode support ring with three ceramic insulators
11. Pilot gas connector
11.1 Gas pilot ports (6)
12. Ignition electrodes
13. Flame rod (reverse side)
14. Combustion / Cooling air inlet port
15. Mixing chamber
16. Mounting flange
17. Main gas outlet port

BREEN Outside Demonstration

IR of outside demonstration



BREEN Co-fire guns in-service



BREEN @ Burner Front

Existing Forney Gas Igniter

Landfill Gas Injectors

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Overheated Tip of BREEN Igniter

New Inconel Tip

After 1 year in-service approximately 75% of the time

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Close up after 1 year

Igniter without outer tip

Summary & Conclusions

Summary

- **FLGR is a Work-In-Progress but encouraging**
- **Gas Cofire Igniter is proving to be a reliable and inexpensive method for bringing increased, and variable, levels of natural gas to Coal Fired Combustion**
- **Thanks to OUC Staff:**
  - Jim Czarniecki
  - Tony Engelmeyer
  - Matt Blankner
  - Wade Gillingham
  - Rob McCarty

Questions?