

REINHOLD ENVIRONMENTAL Ltd.



**2015 NO<sub>x</sub>-Combustion Round Table  
& Expo Presentations**

February 23 & 24, 2015, in Richmond, VA / Hosted by Dominion

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# Using ROFA<sup>®</sup> and LoTOx<sup>™</sup> in Combination for Cost-effective NO<sub>x</sub> Control

Blake Stapper, AECOM  
Mike Klump, Mobotec

February 24, 2015



# Background

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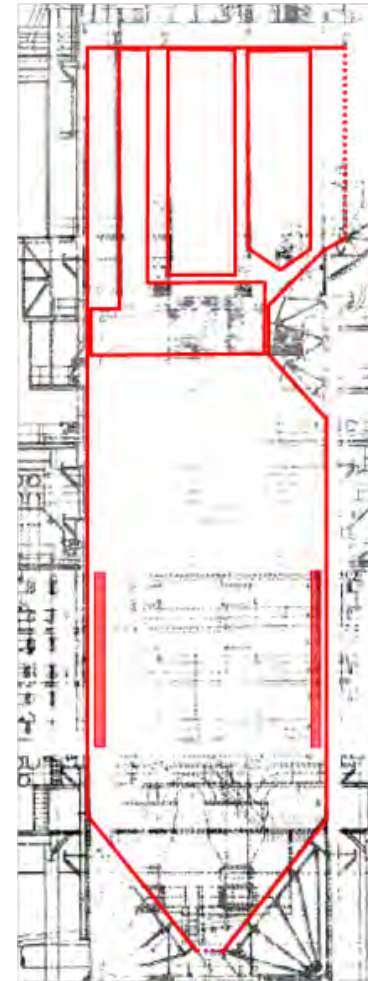
- Historically, NO<sub>x</sub> control strategy was to install SCR on large units with high baseline emissions
  - Provided most cost-effective solution since costs were offset by large number of TPY NO<sub>x</sub> removed
  - Greater certainty of long-term operation of coal-fired assets
  - Capital investment could be passed along to ratepayers
- Currently, regulatory pressure increasing for non-SCR units to achieve significant reductions

# ROFA<sup>®</sup> / Rotamix<sup>®</sup> Installation at SSE Fiddler's Ferry

# Unit Description

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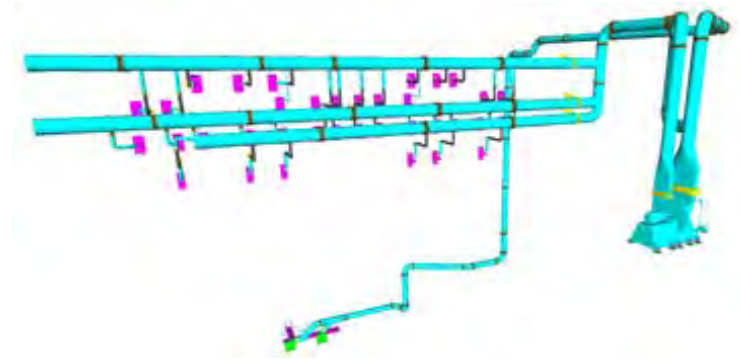
- SSE's Fiddlers Ferry Unit 2 in UK
- 500 MWe supercritical unit
- Twin tangential furnace
- Equipped with CCOFA and SOFA
- Burning Columbian and Russian coals
- Baseline Avg. NOx: 0.44 lb/mmBtu



# Integrated NOx Reduction System

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- Rotating Opposed Fire Air (ROFA)
  - Two ROFA fans
  - 12 ROFA boxes
  - Modulated dampers
  - Ductwork
- Rotamix SNCR
  - Rotamix fan
  - Rotamix boxes
  - Urea solution handling and dilution
  - Injection lances and devices
- Burner modifications
- **Keep existing SOFA/CCOFA**



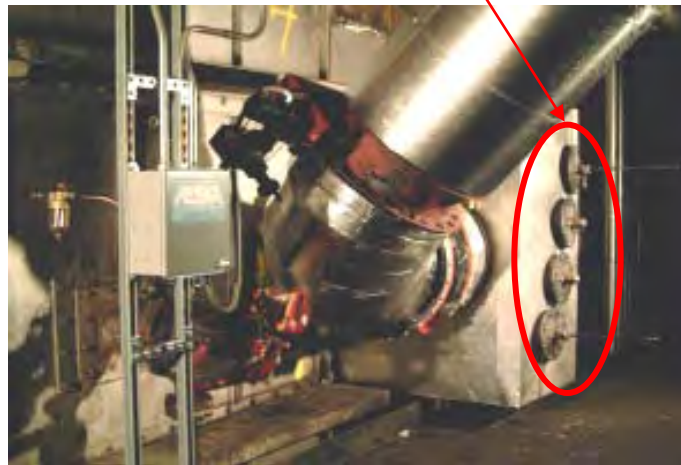
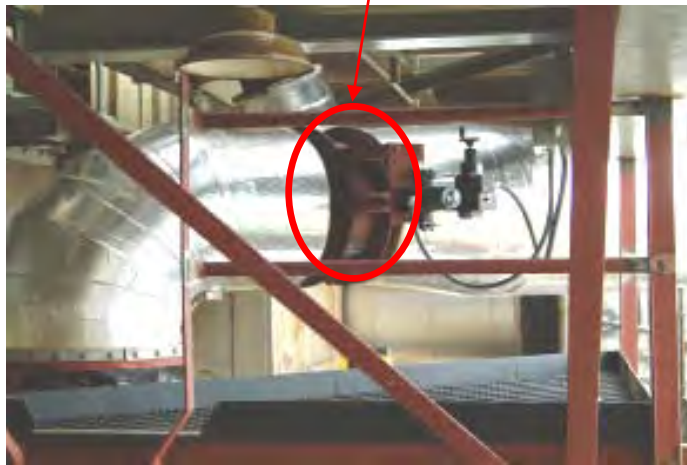
# ROFA Box Design

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Modulated damper  
for flow control

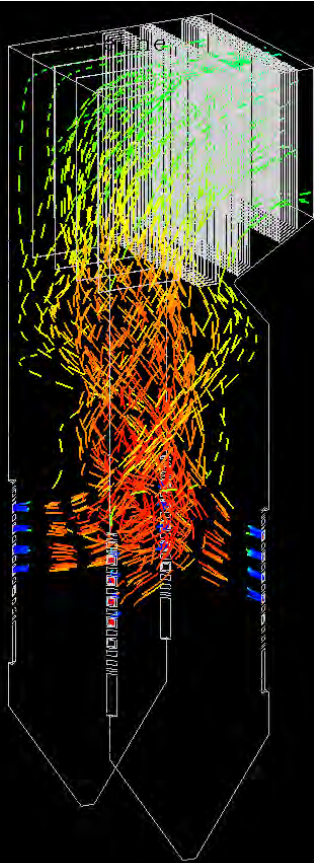
Multiple nozzle  
ROFA box

Specially designed  
ROFA nozzles

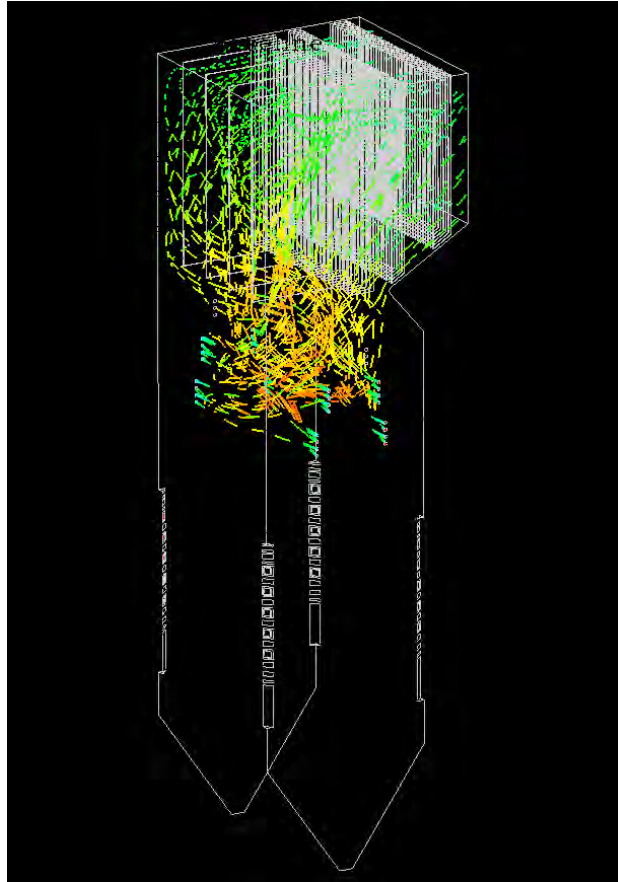


# ROFA® - Enhanced Mixing

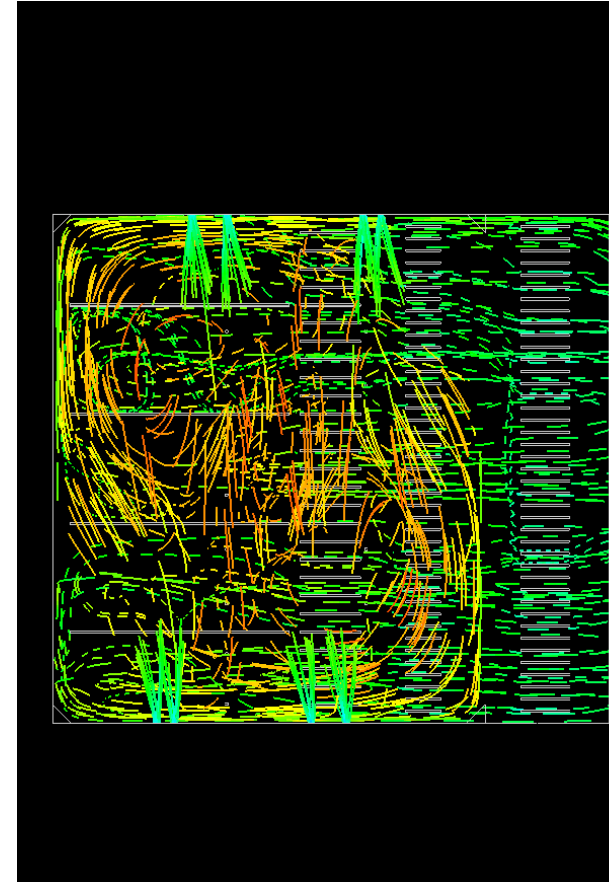
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Baseline

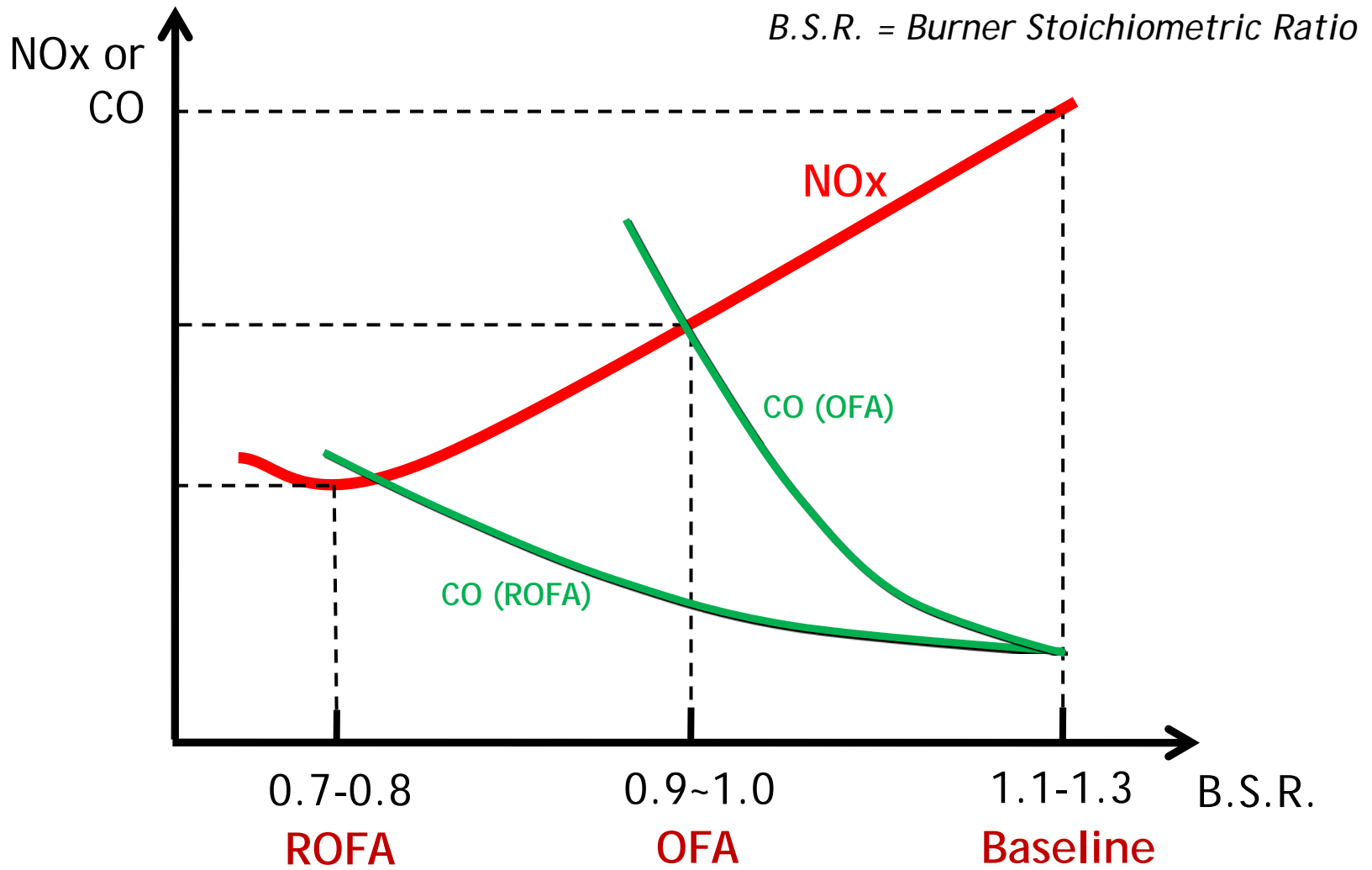


ROFA



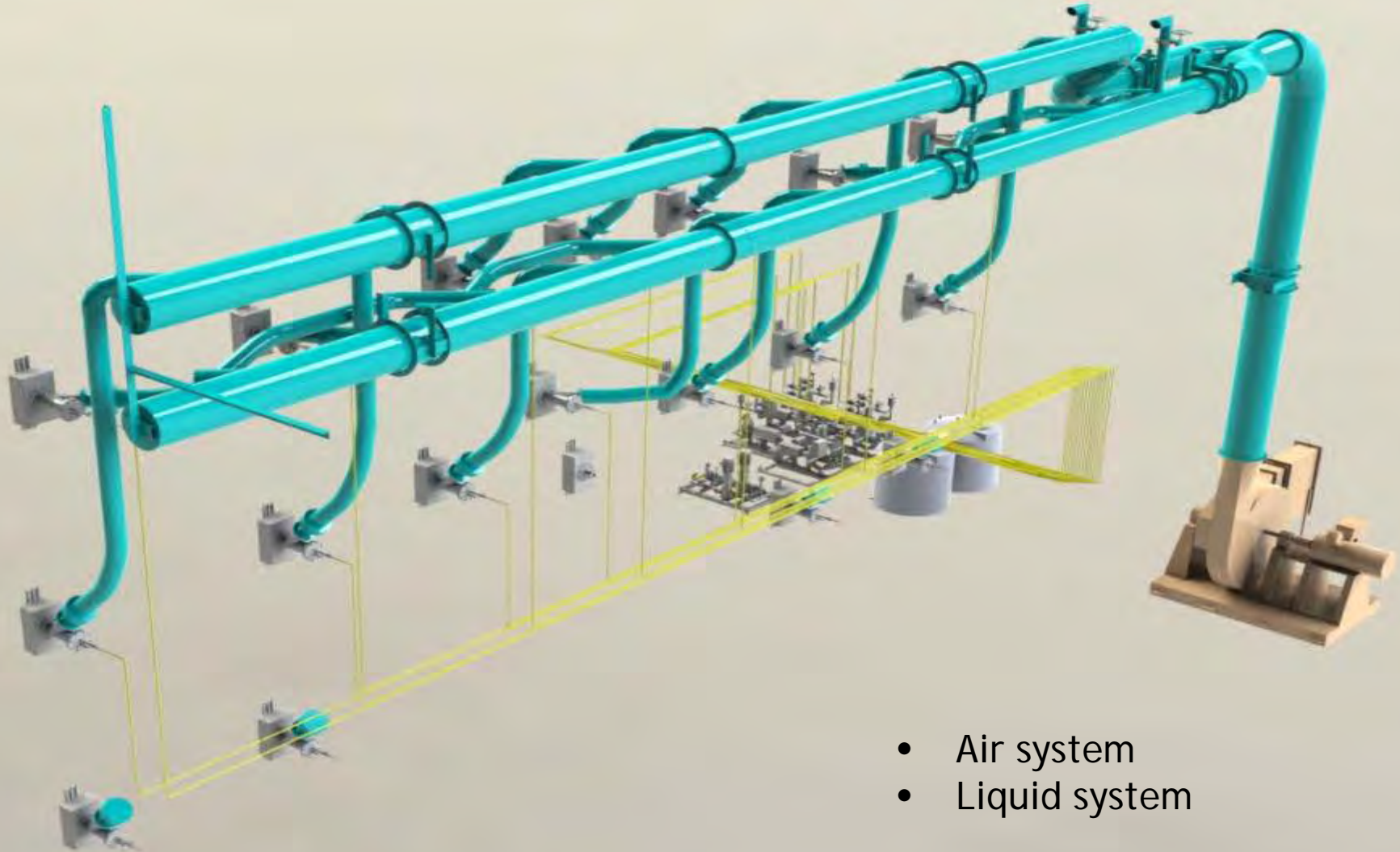
ROFA

# ROFA vs. OFA



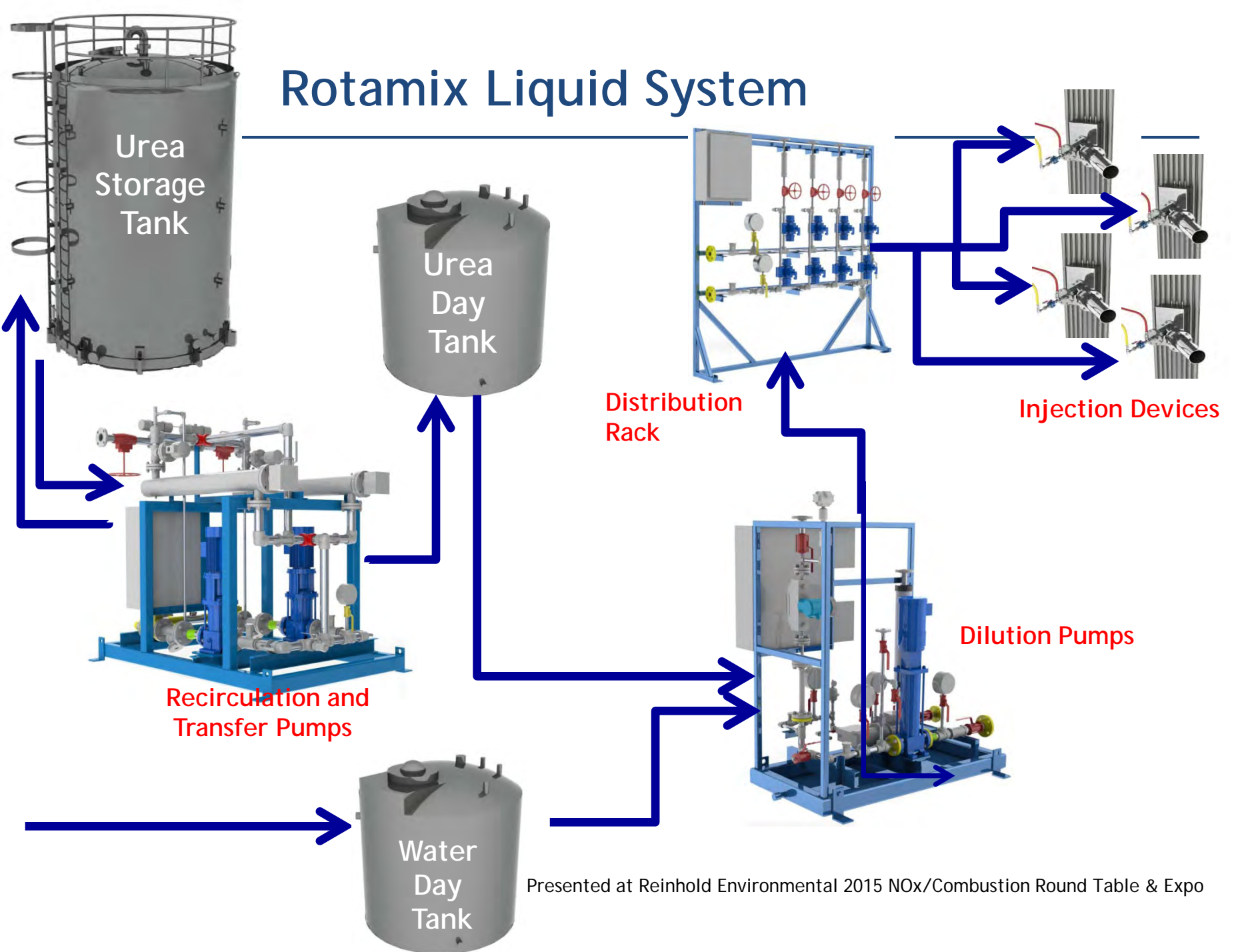
# Rotamix - Advanced SNCR

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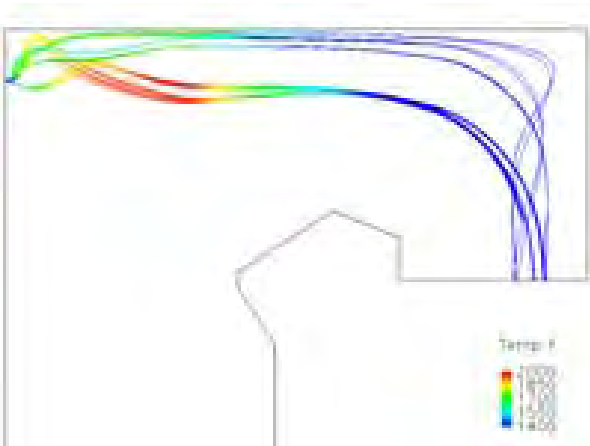
- Air system
- Liquid system

# Rotamix Liquid System

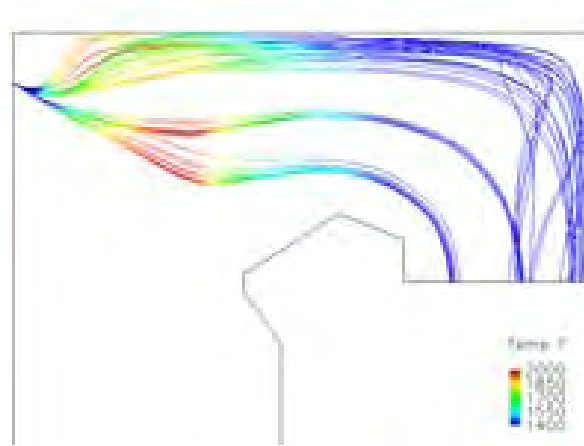


# Impact of Rotamix Air Velocity

1 inwg ~ 20 m/s  
(Traditional SNCR)



20 inwg ~ 70 m/s



30 inwg ~ 110 m/s

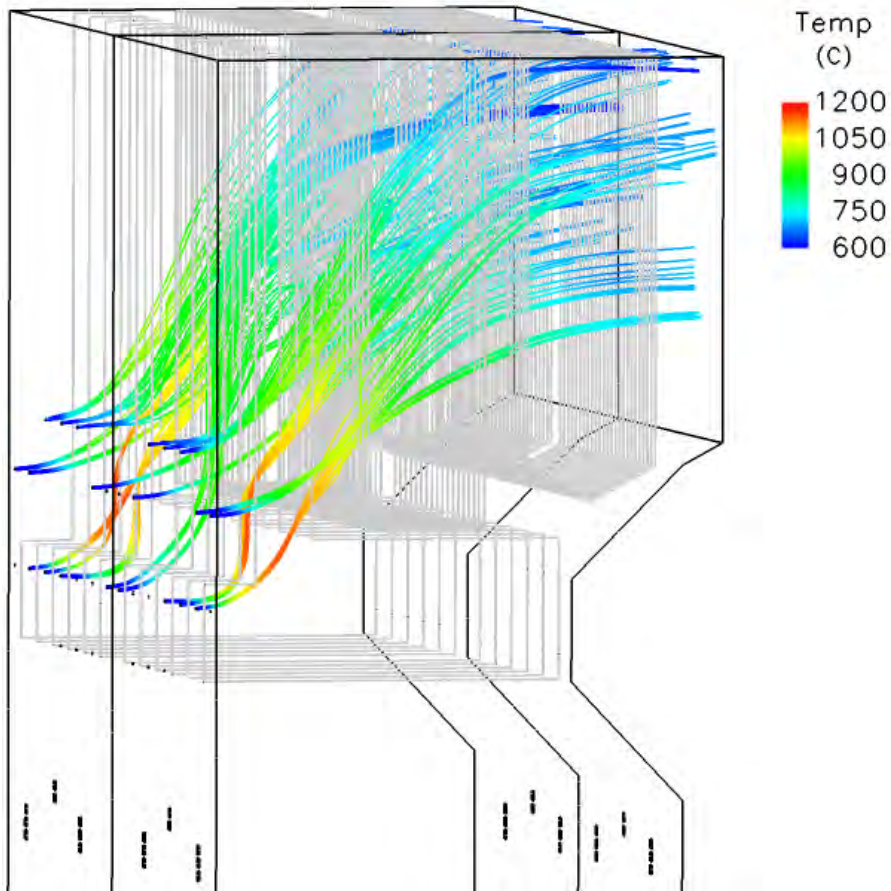


| Rotamix Air Pressure | SNCR NOx Reduction |
|----------------------|--------------------|
| [inwg]               | [%]                |
| 30                   | 25                 |
| 20                   | 24                 |
| 1                    | 16                 |

High Rotamix pressure improves penetration and coverage, hence enhances NOx reduction.

# Urea Injection Locations

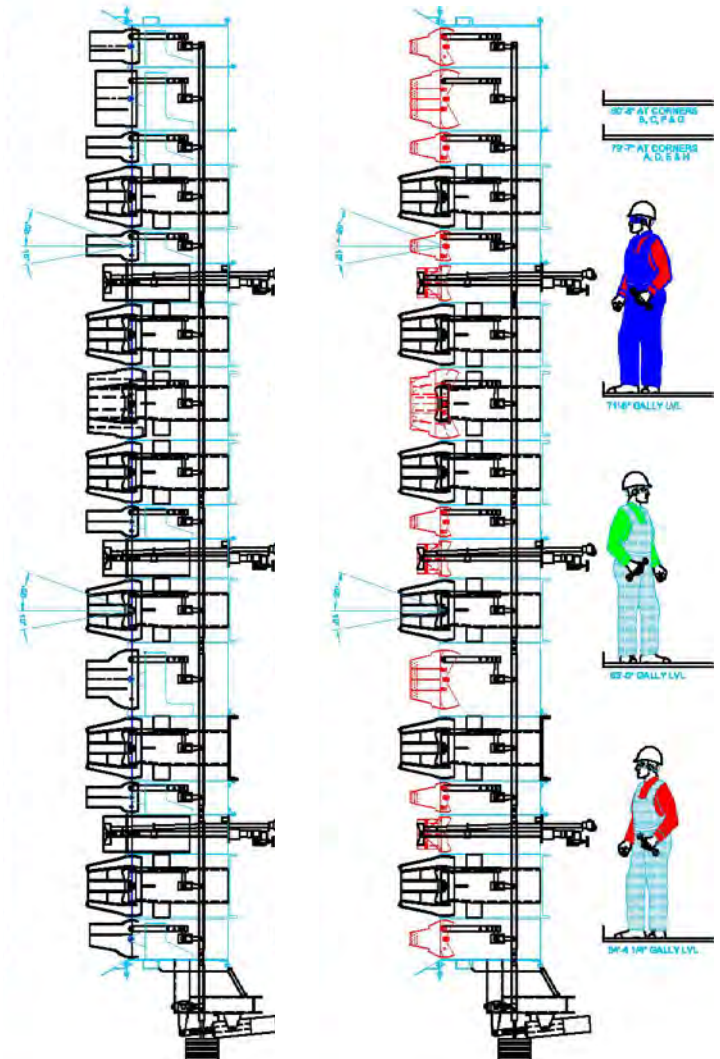
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- Three levels to cover load variation
- Sufficient chemical coverage in the upper furnace
- 34 ports in total

# Burner Modifications

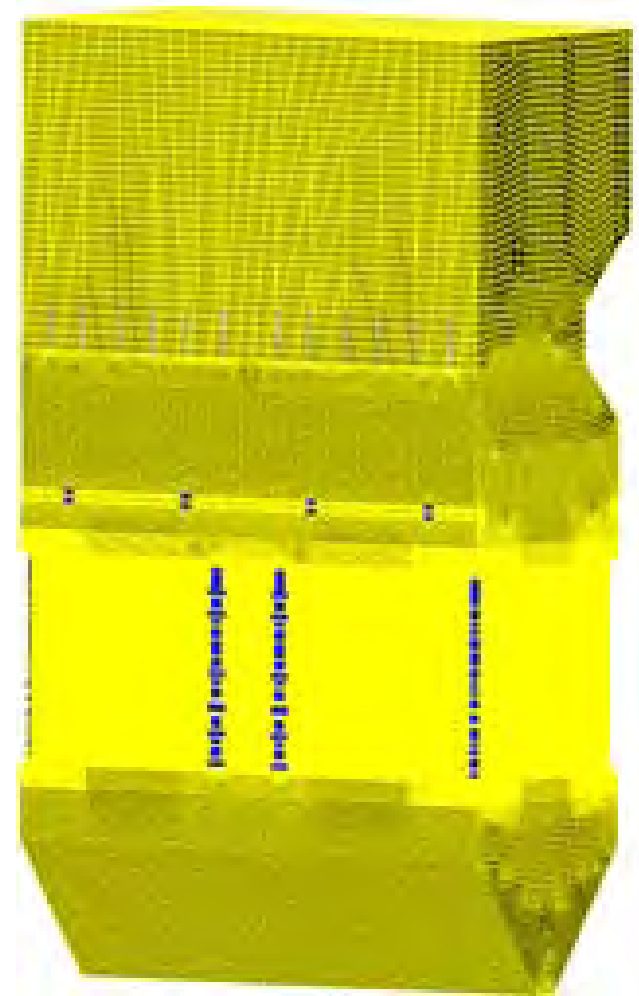
- Objective: to make sure ROFA system integrated with burner system for optimized combustion performance
- Reduced SA nozzle area to maintain windbox pressure when ROFA in service
- Using special designed air nozzle with better cooling
- Increased burner tilt range to  $\pm 27^\circ$



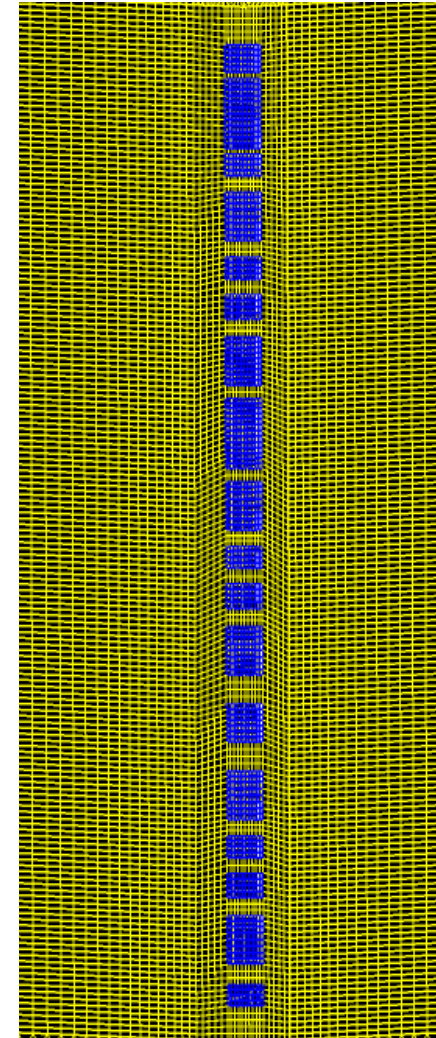
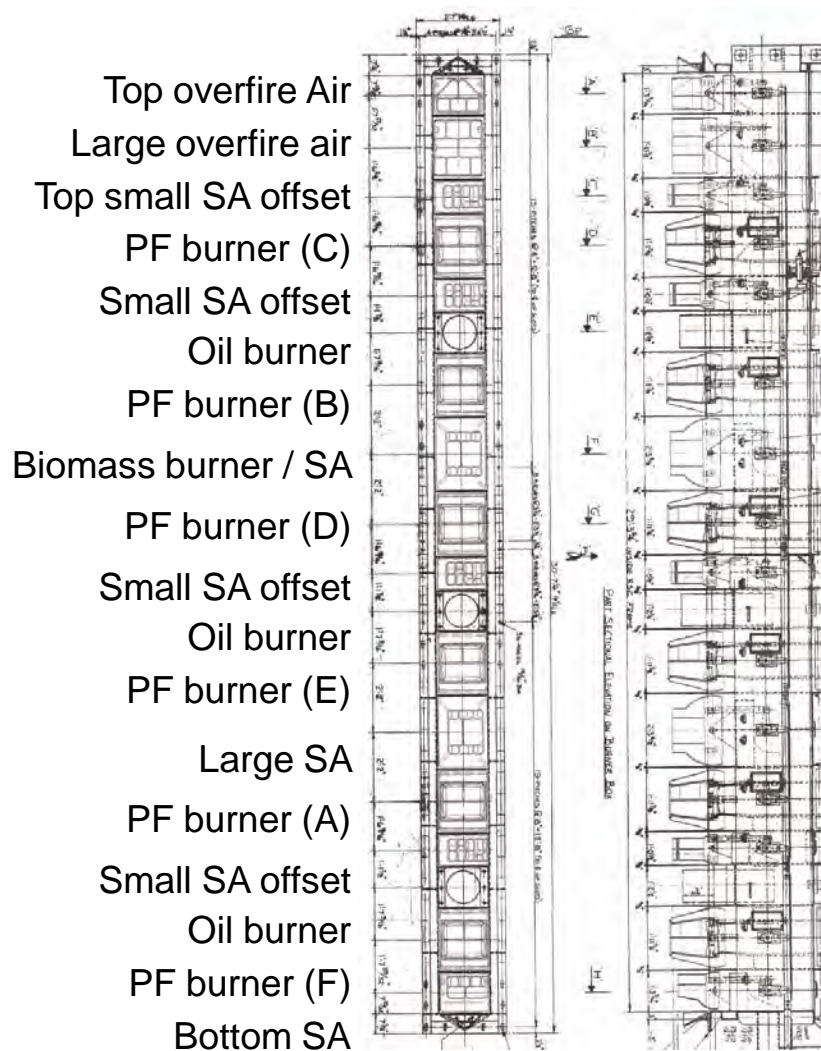
# CFD Modeling

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- ANSYS Fluent
- Coal combustion modeling
- NOx chemistry modeling
- Use modeling for in-furnace combustion understanding, and optimize system design
- Over 80 modeling experience



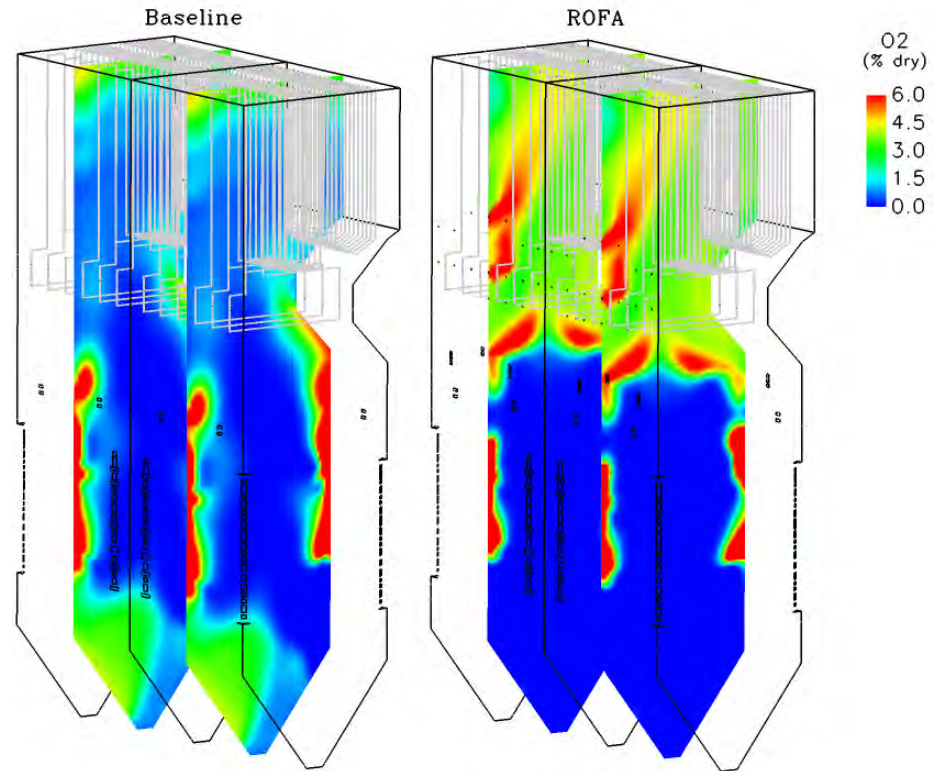
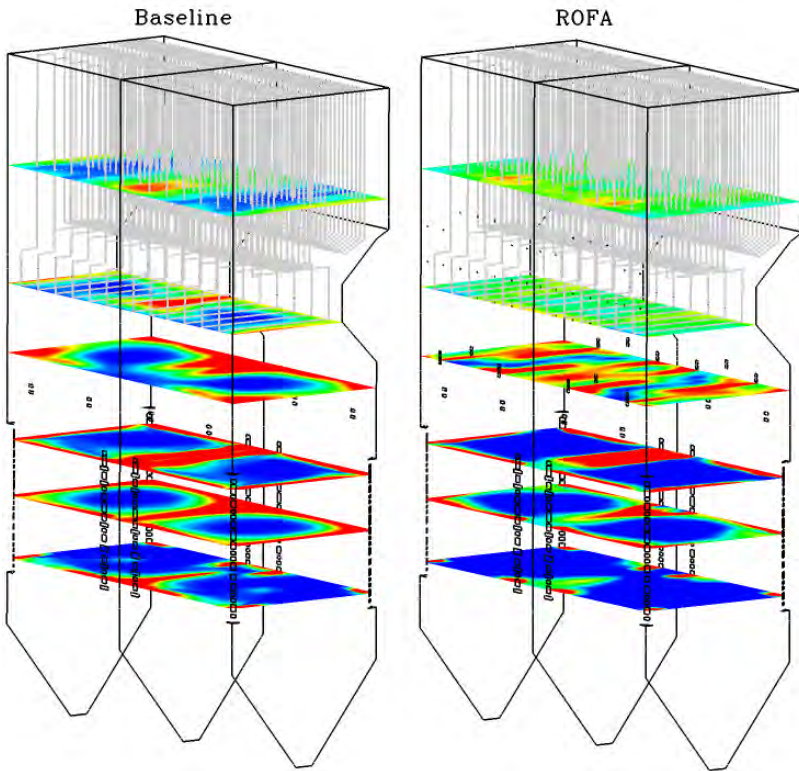
# Burner Group and Its Representation in Model



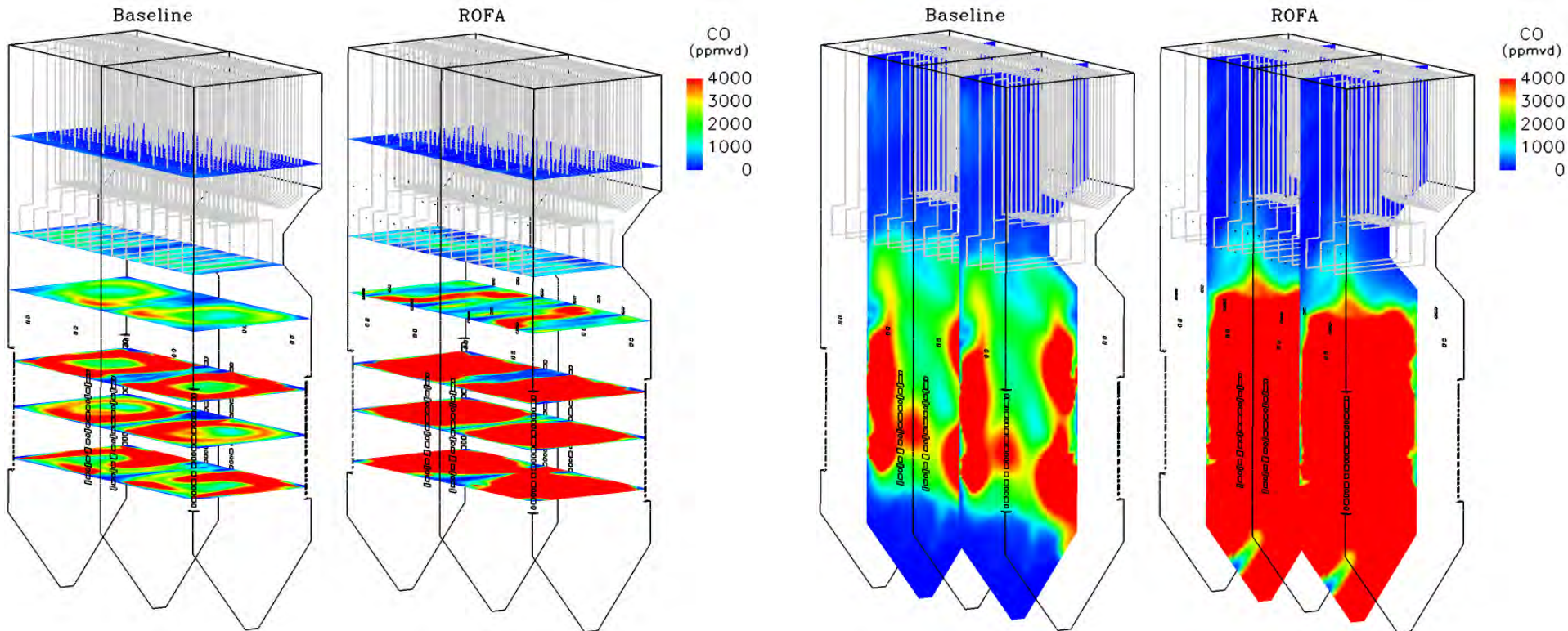
# Operating Conditions and Fuel Analysis

|                                   | Unit                     | Value |
|-----------------------------------|--------------------------|-------|
| System Firing Rate (based on NCV) | [MW <sub>th</sub> ]      | 1245  |
| System Load                       | [MW <sub>e gross</sub> ] | 511   |
| System Excess Air                 | [%]                      | 14.4  |
| System Excess O <sub>2</sub>      | [% dry]                  | 2.70  |
| System Excess O <sub>2</sub>      | [% wet]                  | 2.45  |
| System Fuel Flow                  | [kg/s]                   | 50.0  |
| System Air Flow                   | [kg/s]                   | 497.8 |
|                                   | Unit                     | Value |
| Moisture                          | [%wt]                    | 12.30 |
| Ash                               | [%wt]                    | 9.05  |
| Volatile Matter                   | [%wt]                    | 31.05 |
| Fixed Carbon                      | [%wt]                    | 47.60 |
| Carbon                            | [%wt]                    | 66.25 |
| Hydrogen                          | [%wt]                    | 4.07  |
| Oxygen                            | [%wt]                    | 5.95  |
| Nitrogen                          | [%wt]                    | 1.43  |
| Sulphur                           | [%wt]                    | 0.95  |
| Chlorine                          | [%wt]                    | 0.02  |
| GCV                               | [kJ/kg]                  | 26068 |
| NCV                               | [kJ/kg]                  | 24898 |

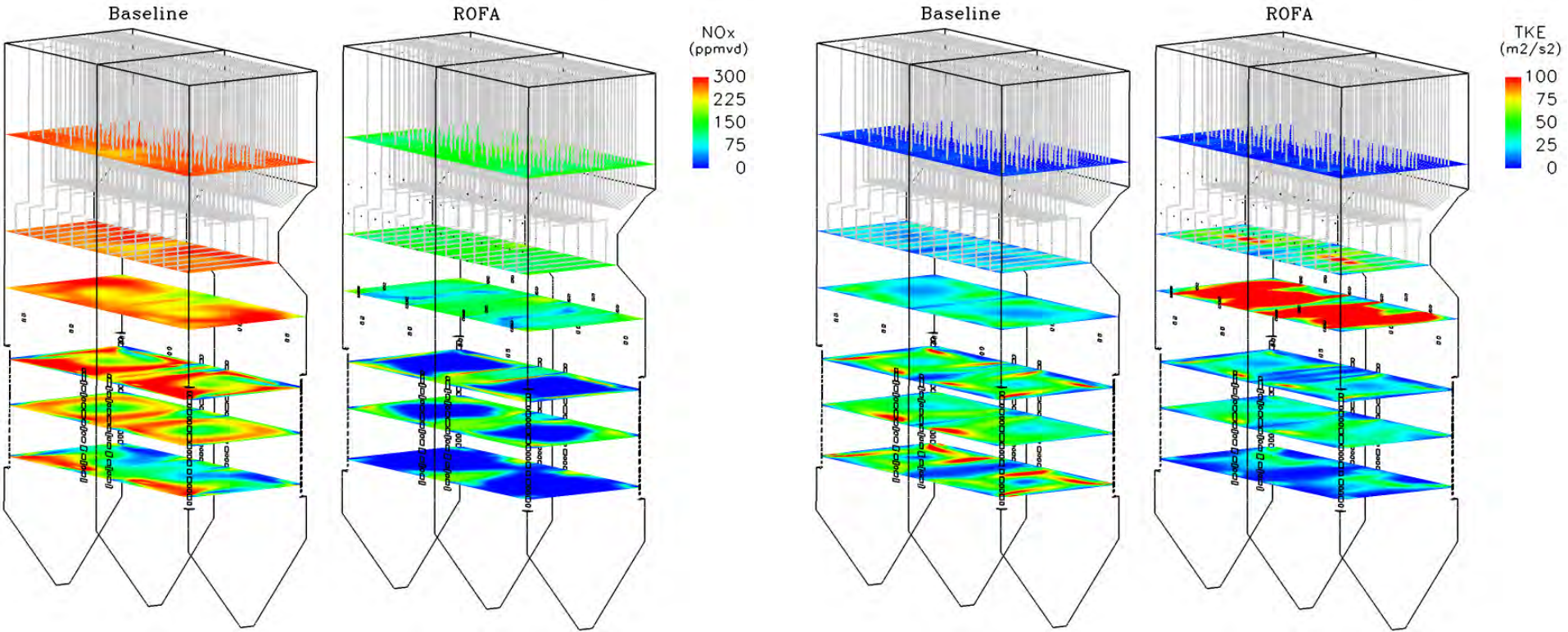
# O<sub>2</sub>



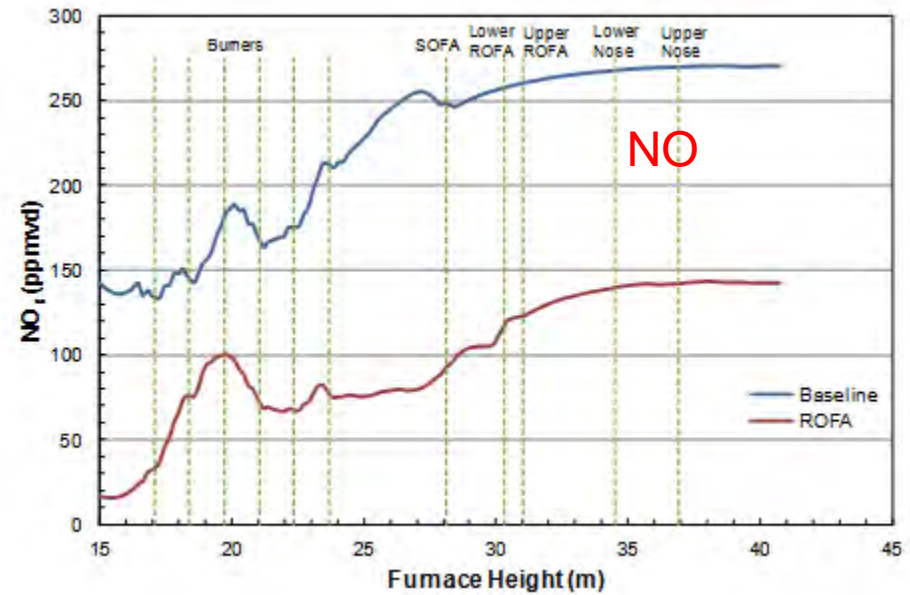
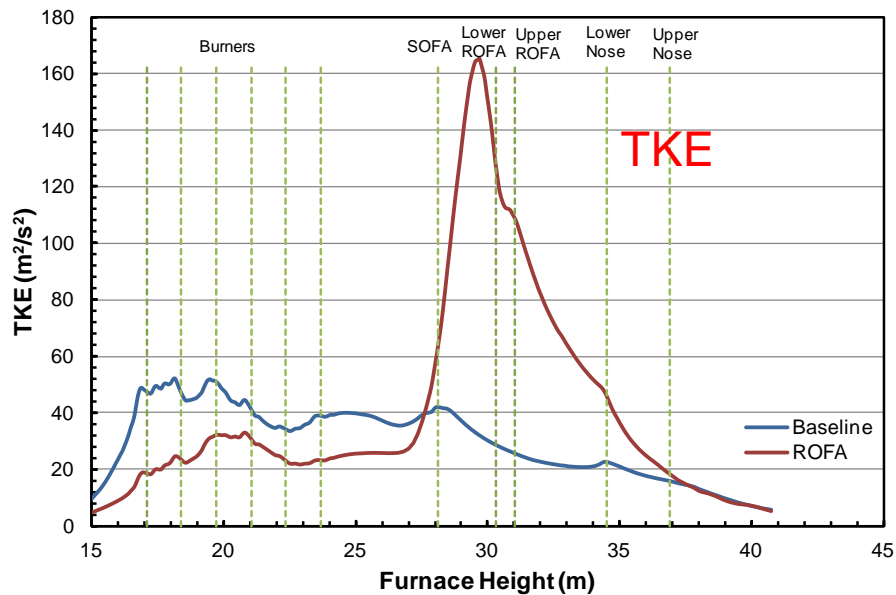
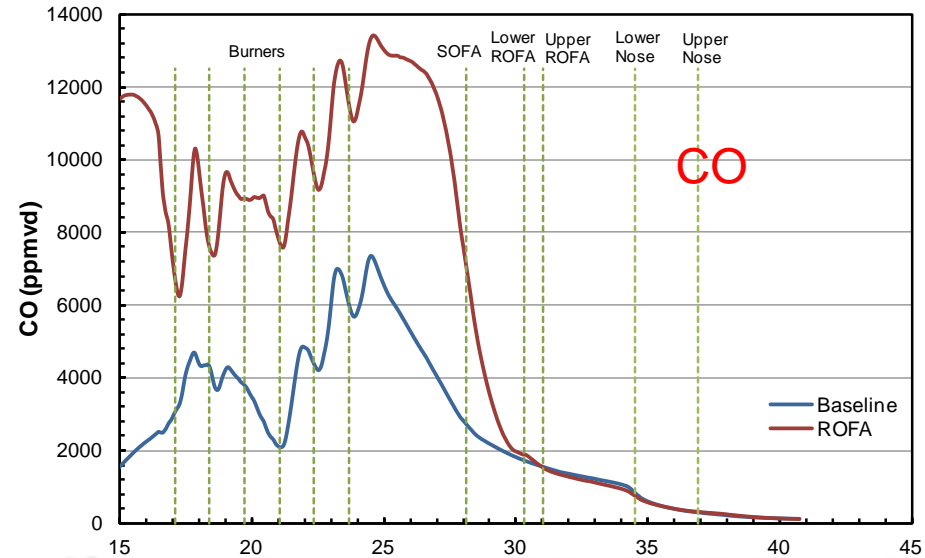
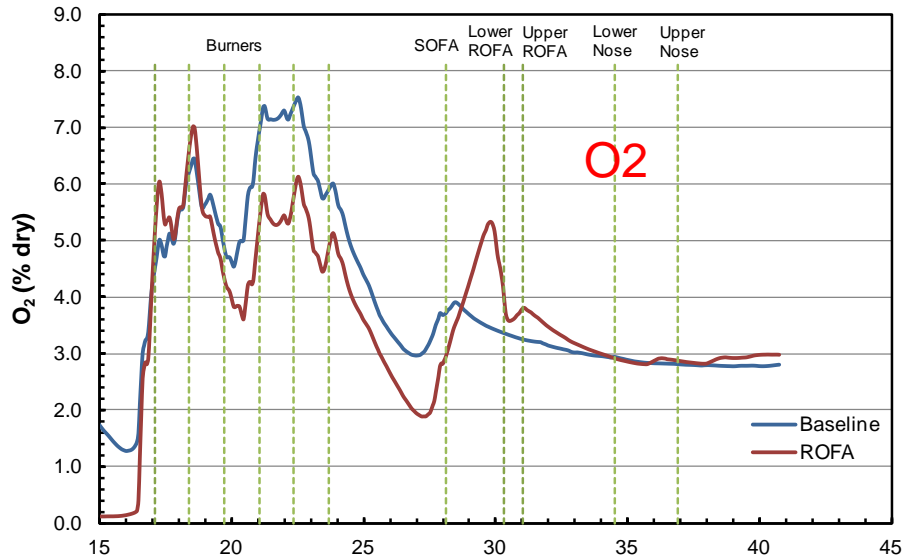
# CO



# NOx



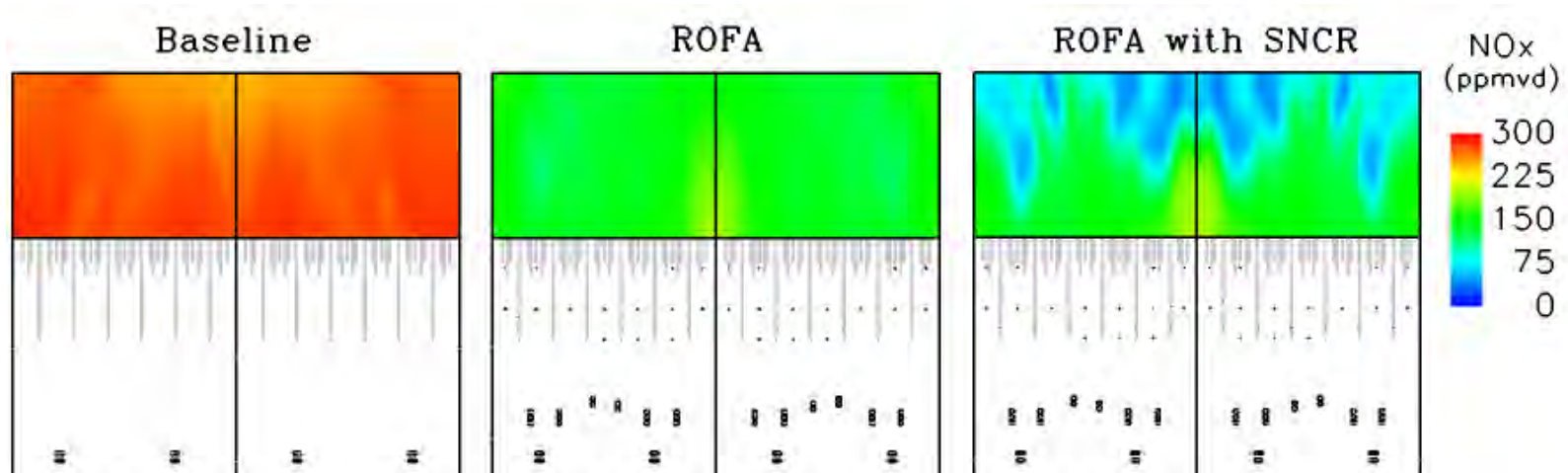
# Mass-Weighted Averaged Variables



# Predicted Baseline vs. ROFA

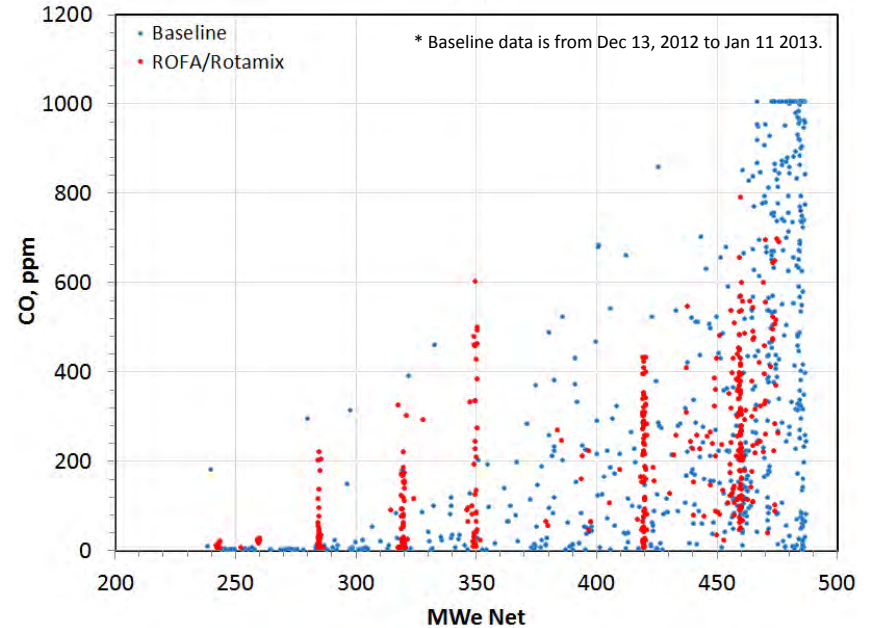
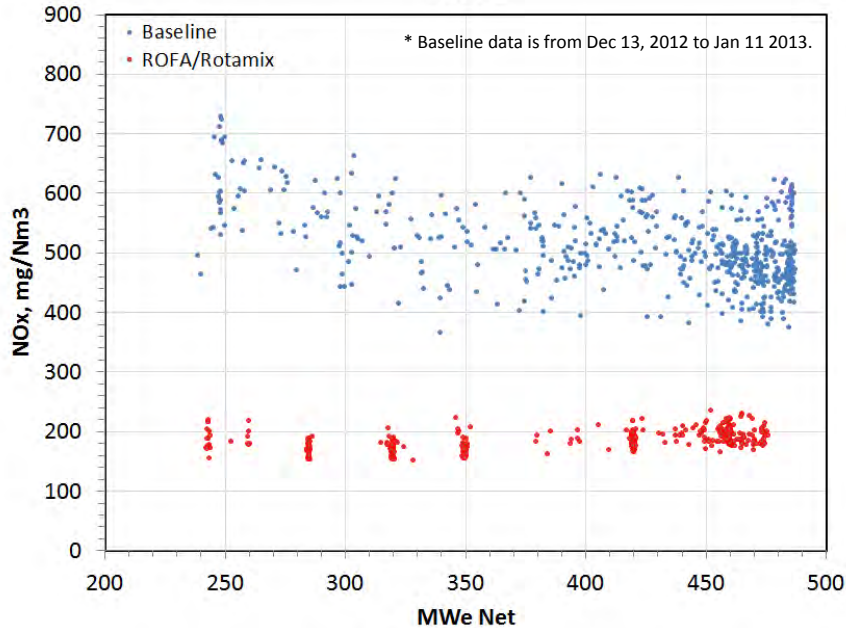
|                            |            | Baseline | ROFA |
|----------------------------|------------|----------|------|
| <b>Below Nose @31.06 m</b> |            |          |      |
| Temperature                | [°F]       | 2482     | 2482 |
| O <sub>2</sub>             | [% ,dry]   | 3.3      | 3.7  |
| CO                         | [ppm ,dry] | 1484     | 1483 |
| NO <sub>x</sub>            | [ppm ,dry] | 260      | 124  |
| <b>Modeled Outlet</b>      |            |          |      |
| Temperature                | [°F]       | 1380     | 1395 |
| O <sub>2</sub>             | [% ,dry]   | 2.6      | 2.6  |
| CO                         | [ppm ,dry] | 27       | 39   |
| NO <sub>x</sub>            | [ppm ,dry] | 274      | 146  |
| NO <sub>x</sub>            | [lb/mmBtu] | 0.44     | 0.23 |
| NO <sub>x</sub> Reduction  | [%]        | -        | 47%  |
| LOI                        | [%]        | 12.3     | 12.6 |

# Predicted Baseline v.s. ROFA/Rotamix



|                        | Unit       | Predicted Value |
|------------------------|------------|-----------------|
| NSR                    | [-]        | 1.3             |
| 40% urea solution flow | [gal/min]  | 3.80            |
| NOx before urea        | [lb/mmBtu] | 0.201           |
| NOx after urea         | [lb/mmBtu] | 0.149           |
| Rotamix NOx reduction  | [%]        | 25%             |
| Ammonia slip           | [ppm]      | ~ 5             |

# 17-Days Trial Test Results



- NOx reduced from around 0.44 lb/mmBtu to below 0.16 lb/mmBtu. Averaged NOx after modifications is 0.153 lb/mmBtu.
- CO reduced from up to 1000 ppm to below 400 ppm.

# 24-hr Performance Test Results

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|                           |          | Baseline | ROFA/Rotamix |           |
|---------------------------|----------|----------|--------------|-----------|
|                           |          | Actual   | Actual       | Predicted |
| Load                      | MWe      | 510      | 500          | 511       |
| NOx                       | lb/mmBtu | 0.441    | 0.153        | 0.149     |
| CO                        | ppm      | 184      | 157          | 39        |
| LOI                       | %        | 8.4      | 8.9          | 12.6      |
| Boiler Efficiency         | %        | 92.4     | 92.1         | -         |
| 40% urea flow             | gal/min  | -        | 3.49         | 3.80      |
| NH <sub>3</sub> Slip      | ppm      | -        | 1.2          | 1.3       |
| NH <sub>3</sub> in flyash | mg/kg    | -        | 39           | -         |
| NH <sub>3</sub> in gypsum | mg/kg    | -        | < 8          | -         |

# Summary

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- ROFA and Rotamix have been applied to a 500 MWe unit, and have achieved the following results:
  - NO<sub>x</sub> emissions reduced over 60% from baseline with SOFA in service to about 0.15 lb/MMBtu
  - Efficient combustion (via LOI, CO and boiler efficiency)
  - Average ammonia slip - 1.2 ppm
  - CFD predictions are in good agreement with actual performance results.
- The technologies have proven to meet the IED compliance limit, and are a cost-effective strategy for lowering baseline NO<sub>x</sub> emissions

# LoTOx Implementation as an Alternative to SCR

# Changing NO<sub>x</sub> Control Market

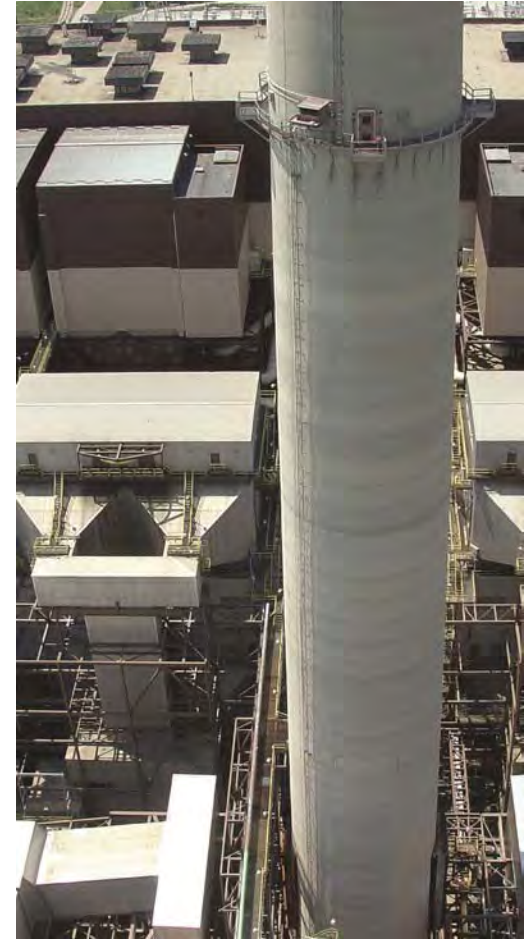
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- New limits may involve installation of advanced combustion controls and/or SNCR, *but*
- Some units being forced as low as 0.06 lb/MMBtu NO<sub>x</sub>, often leaving choice between SCR and retirement
- SCR is less desirable because marketplace has changed
  - Lower baseline NO<sub>x</sub> and lower capacity factors make SCR less cost-effective
  - Large capital investments are no longer desirable due to market uncertainties
- Life extension need of existing fleet requires cost-effective alternatives to SCR

# Non-SCR NO<sub>x</sub> Reduction Strategy

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- Minimize baseline emissions by applying advanced combustion controls, as at Fiddler's Ferry
- Implement LoTOx™ (low-temperature ozone injection) to achieve cost-effective SCR-like NO<sub>x</sub> emissions



# LoTOx<sup>®</sup> NO<sub>x</sub> Control Technology

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- Low-temperature oxidation
- Offered by Linde Group
- NO<sub>x</sub> scrubbing
- Widely used in refining industry with ~30 FCCU installations
- 25 MW coal-fired institutional boiler installation
- EPRI pilot demonstration at Coal Creek
- 90% NO<sub>x</sub> removal



# Reaction Kinetics

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- $\text{NO}_x$  scrubbing
  - Inject ozone downstream of air heater
  - Convert insoluble  $\text{NO}_x$  to highly-soluble  $\text{N}_2\text{O}_5$
  - Requires  $\frac{1}{2}$  second residence time at  $300^\circ\text{F}$
  - Capture in scrubber
- No  $\text{SO}_2$  oxidation to  $\text{SO}_3$

| Reaction   | Rate constants @ $25^\circ\text{C}$ |
|--|-------------------------------------|
| $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$              | 62,500                              |
| $2 \text{NO}_2 + \text{O}_3 \rightarrow \text{N}_2\text{O}_5 + \text{O}_2$ | 125                                 |
| $\text{CO} + \text{O}_3 \rightarrow \text{CO}_2 + \text{O}_2$              | 1                                   |
| $\text{SO}_2 + \text{O}_3 \rightarrow \text{SO}_3 + \text{O}_2$            | 5                                   |

# Performance and Operational Advantages

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- NO<sub>x</sub> Performance
  - Capable of 90% removal
  - Select % removal by treating fraction of gas flow
- Multi-pollutant control
  - 50-70% Hg oxidation
  - Offset CaBr<sub>2</sub> addition rate
- Ozone supply flexibility
- Advantage over SCR
  - No MOT constraints
  - No AH fouling
  - No catalyst deactivation



# Utility Boiler Applications - What's Changed?

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- Lower NO<sub>x</sub> baselines
- Smaller units
- Reduced capacity factors
- Improved utilization of oxygen in ozone production
- More flexible ozone delivery options
- Effluent regulations driving more plants to ZLD
- FCCU long-term operation

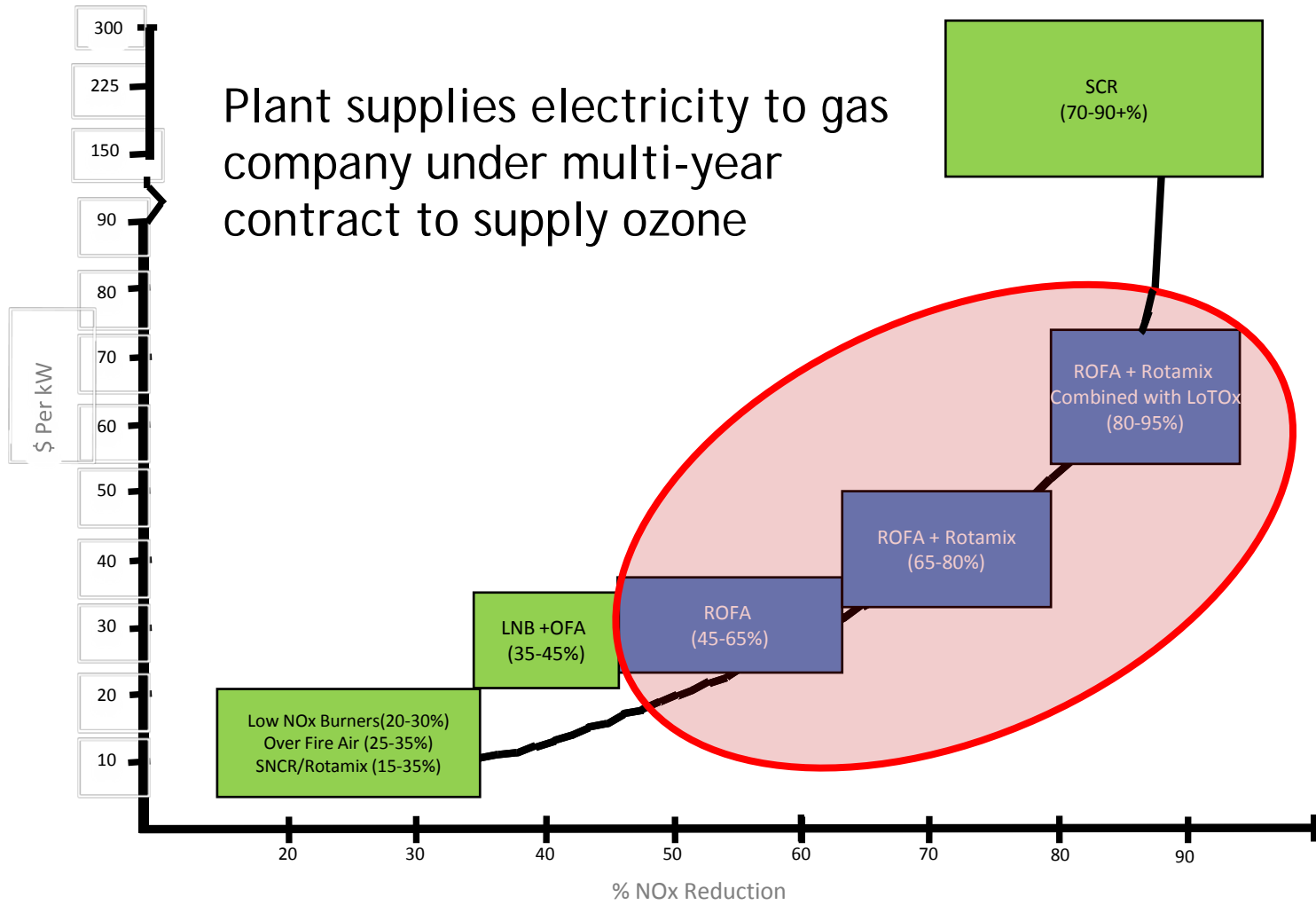


# On-site Oxygen/Ozone Generation Cost Model

- Case Study - 400 MW unit
  - 0.32 lb/MMBtu baseline
  - Apply ROFA to reduce NO<sub>x</sub> to 0.16 lb/MMBtu
  - Control to 0.06 lb/MMBtu
  - Air separation unit for oxygen supply
  - Ozone generator
- Capital cost ~ 2/3 of SCR
- O&M costs are comparable



# 'Over the Fence' Ozone Supply Cost Model



# Summary and Conclusions

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- Non-SCR boilers are being pushed to further reduce NO<sub>x</sub> emissions
- ROFA and Rotamix are cost-effective, but cannot achieve SCR-like emissions reductions
- LoTOx is best-suited to applications with low baseline NO<sub>x</sub> emissions
- The combination of ROFA and LoTOx provides a cost-effective alternative to SCR, with fewer operational constraints

Questions?