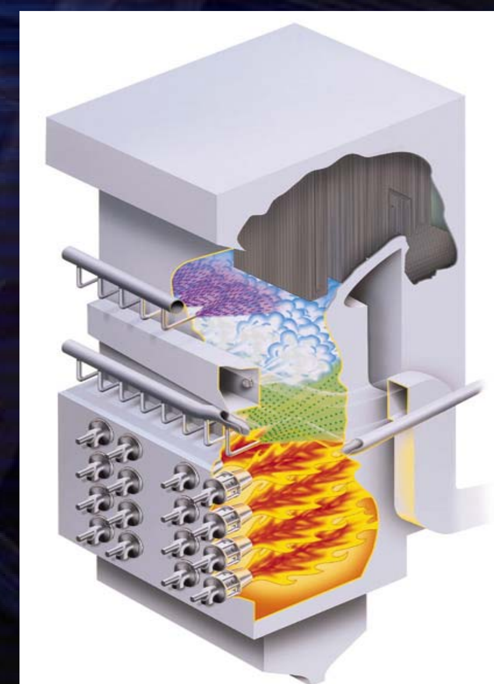
imagination at work

Reburn & Advanced NOx Control Technologies

U.S.-China NOx and SO2 Control Workshops

Shenyang, Liaoning Province, P.R. China

3-7 November 2003



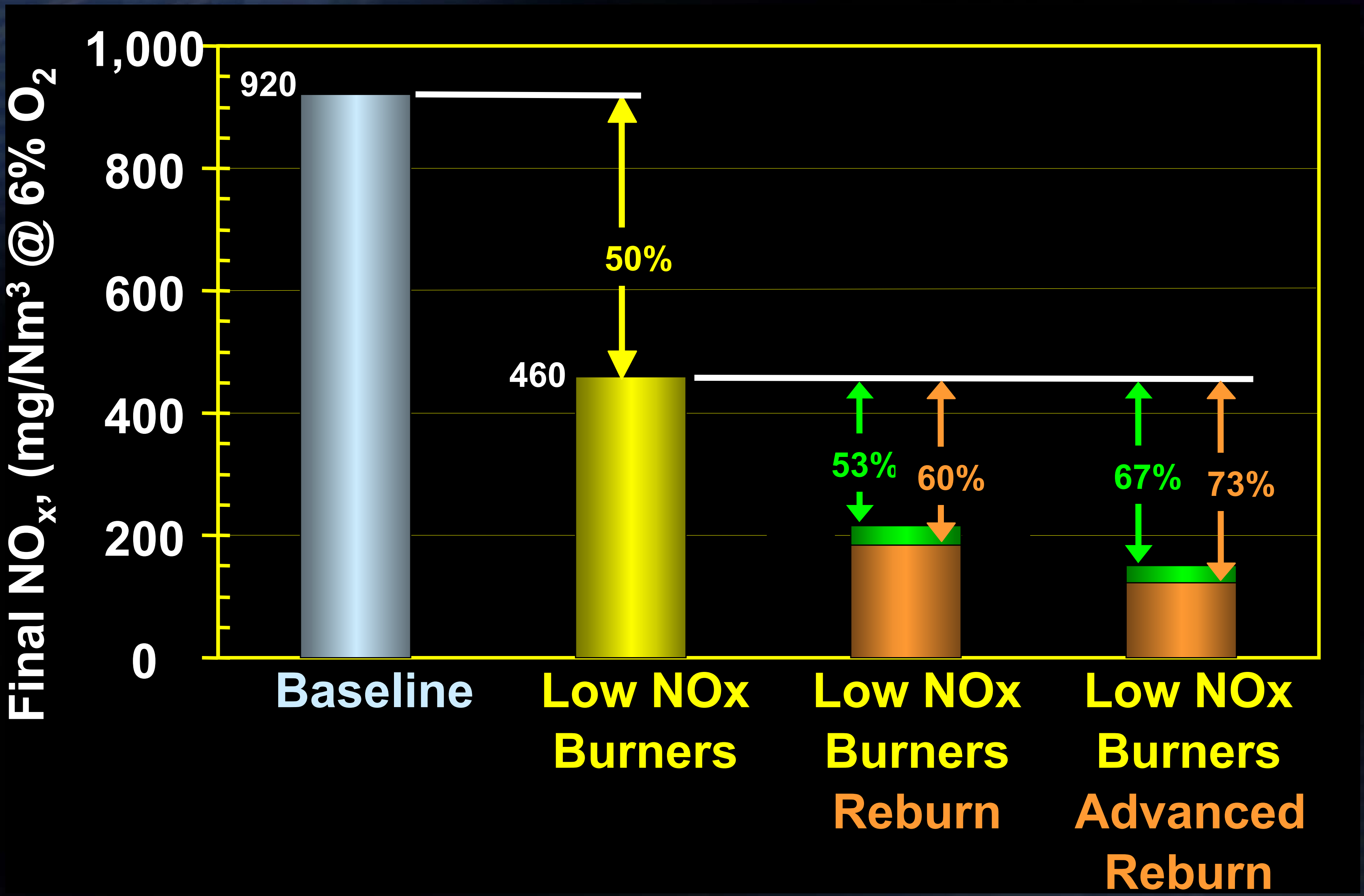
GE Environmental Energy

GE NOx Control Offering Summary

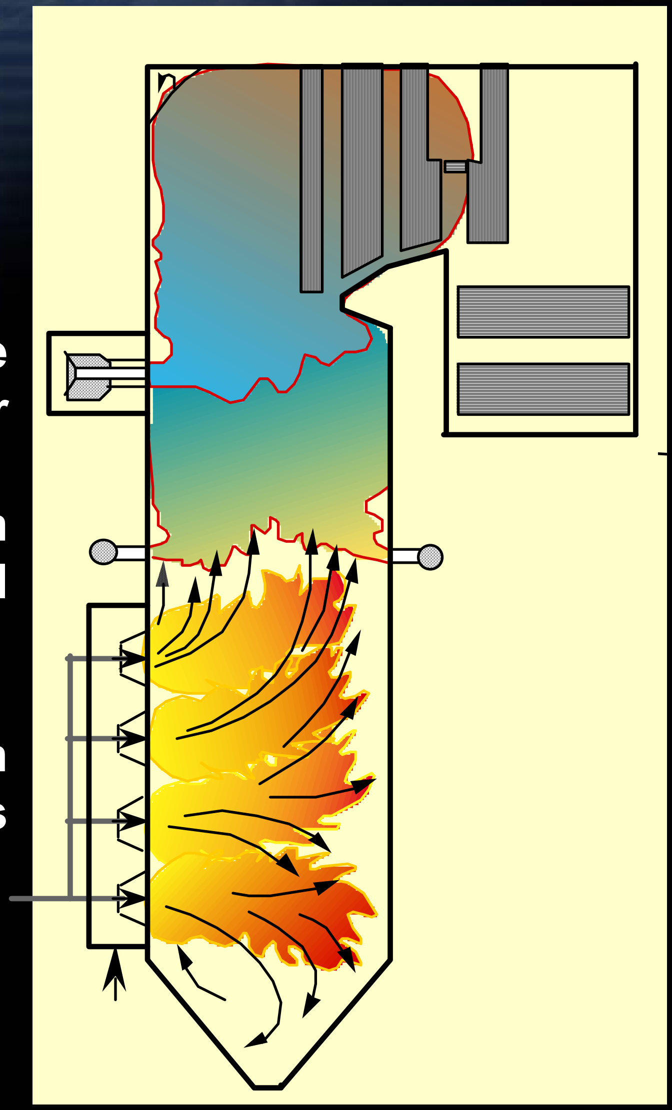
- Low-NOx Burners & Existing Burner Modifications
  - Coal burners for wall-fired applications
  - 30 to 150 MMBtu/hr
- Overfire Air (OFA) & Underfire Air
  - For wall-fired and tangentially-fired systems
  - Close coupled and separated OFA installations
- Reburn System
  - Applicable all boiler types
  - Gas, coal, fuel oil applicable as main fuel and reburn fuel
- Hybrid Systems (Reburn / SNCR / Additives)
- Integrated Sensors for Combustion Optimization Systems

Engineered Combustion Modification Solutions

Typical Combustion NOx Control Solutions



The Reburn Process



Reburn NOx Control

3-Stage Combustion

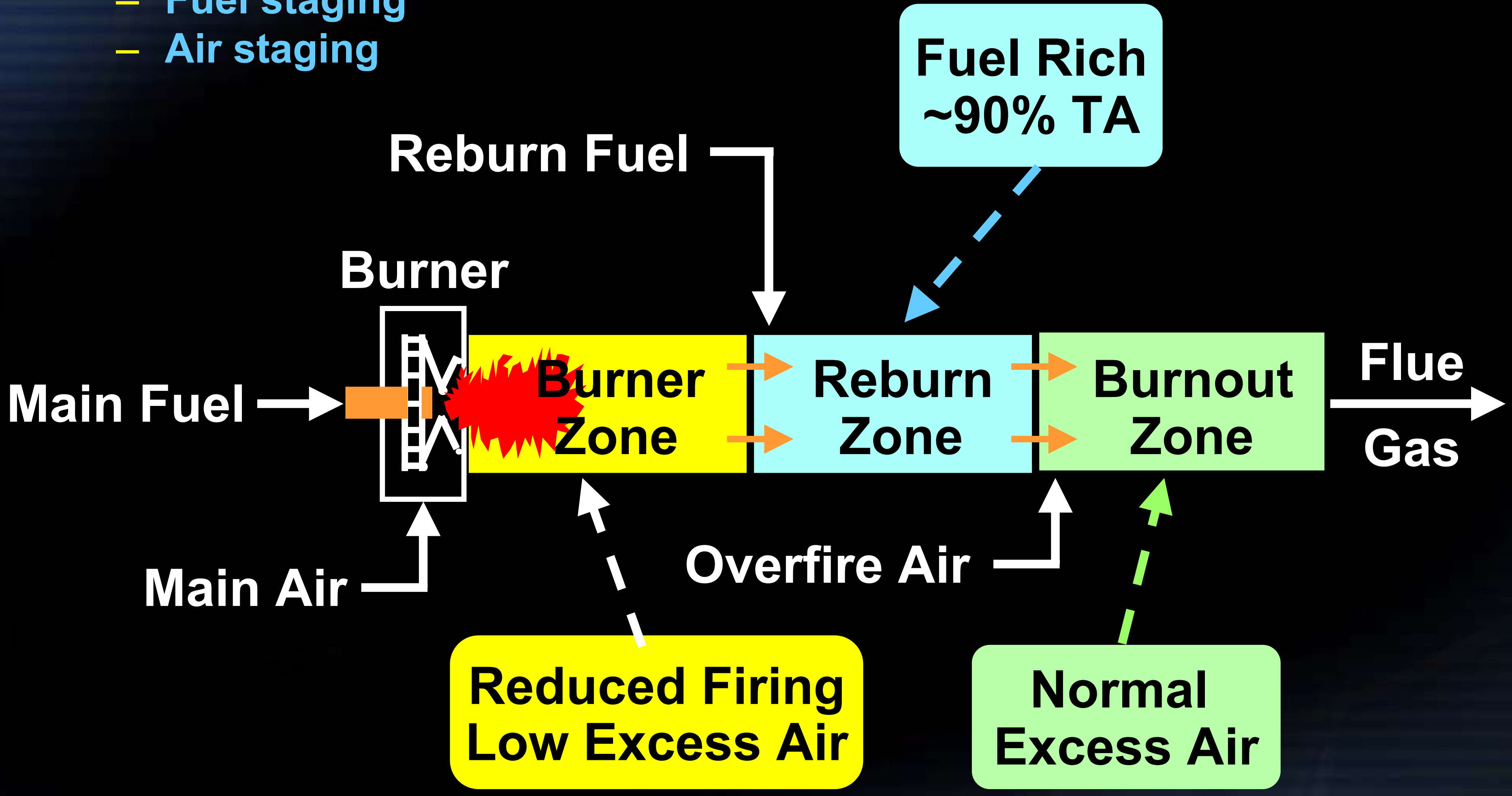
i) Main combustion zone

ii) NOx generated in the main burner zone reacts with fuel fragments injected into the reburn zone, reducing it to molecular nitrogen

iii) The overfire air addition completes combustion in the burn-out zone

Reburning Process Diagram

- Three stage combustion process
  - Burner staging
  - Fuel staging
  - Air staging



Reburn and Advanced Reburn

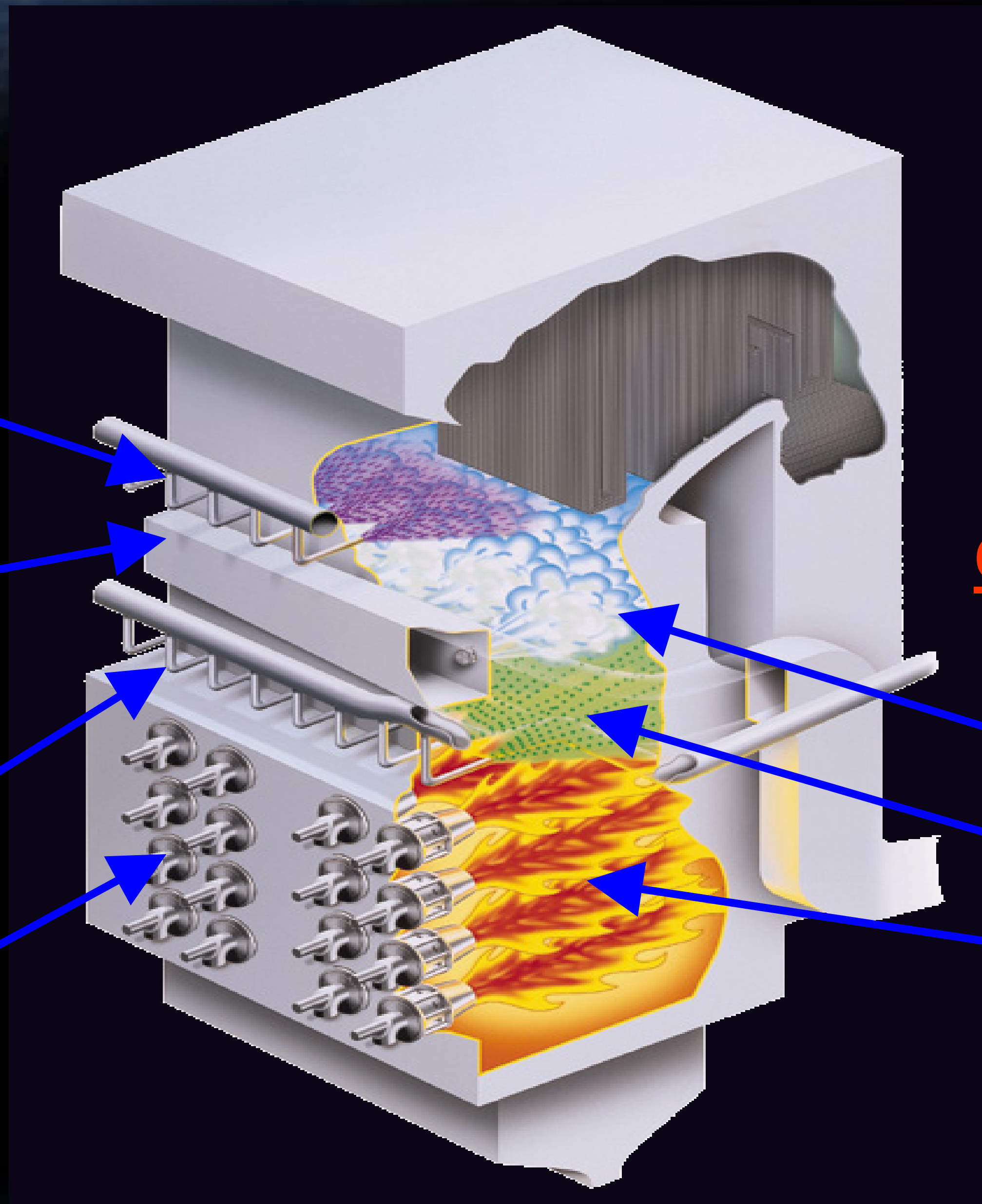
<u>Components</u>

Nitrogen Agent Injectors

Overfire Air Ports

Reburn Fuel Injectors

Main Burners



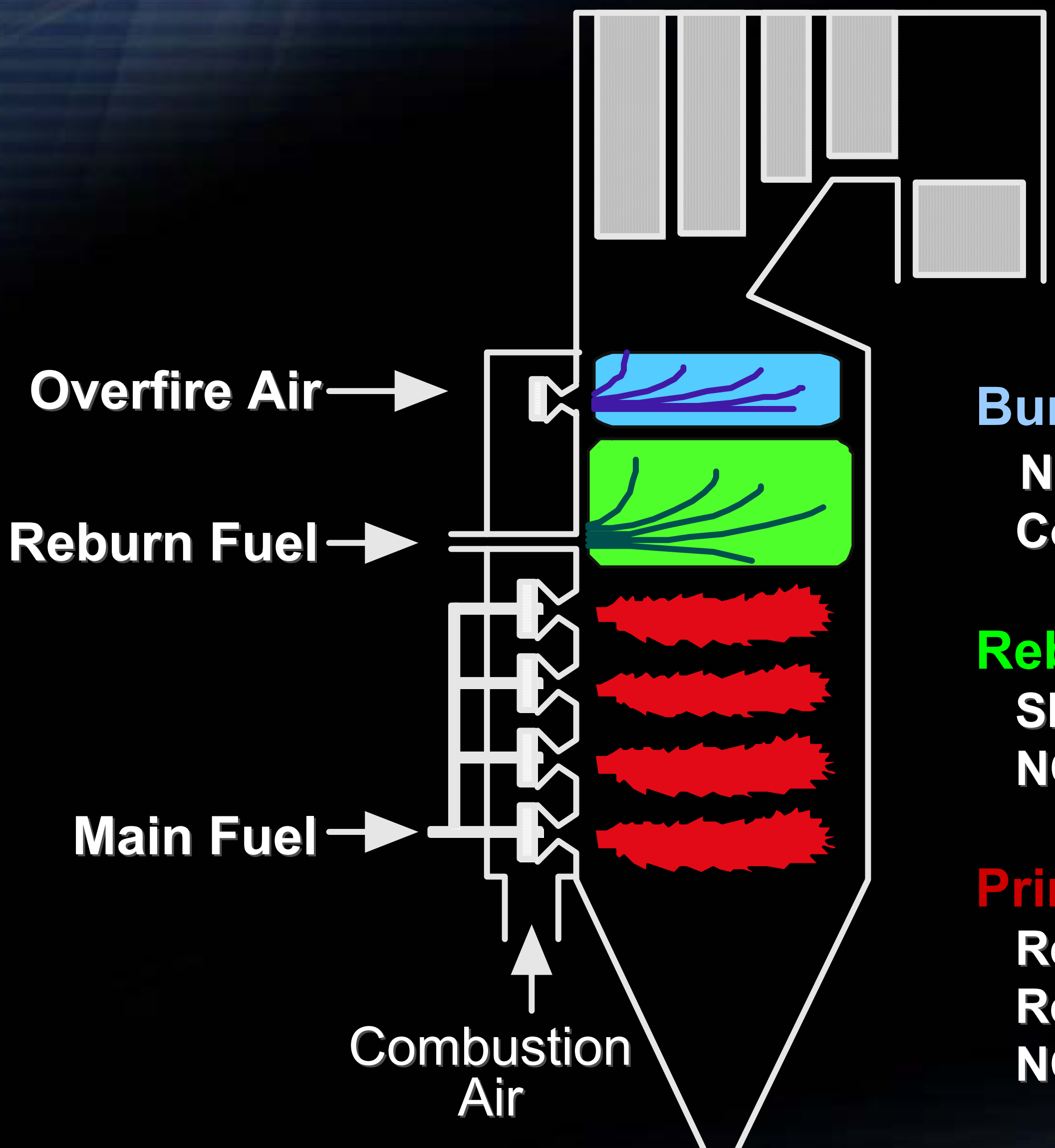
<u>Combustion Zones</u>

Burnout

Reburn

Main

Reburn Application



Burn Out Zone
- Normal Excess Air
- Complete Combustion

Reburning Zone
- Slightly Fuel Rich
- NO_X Reduction Reactions

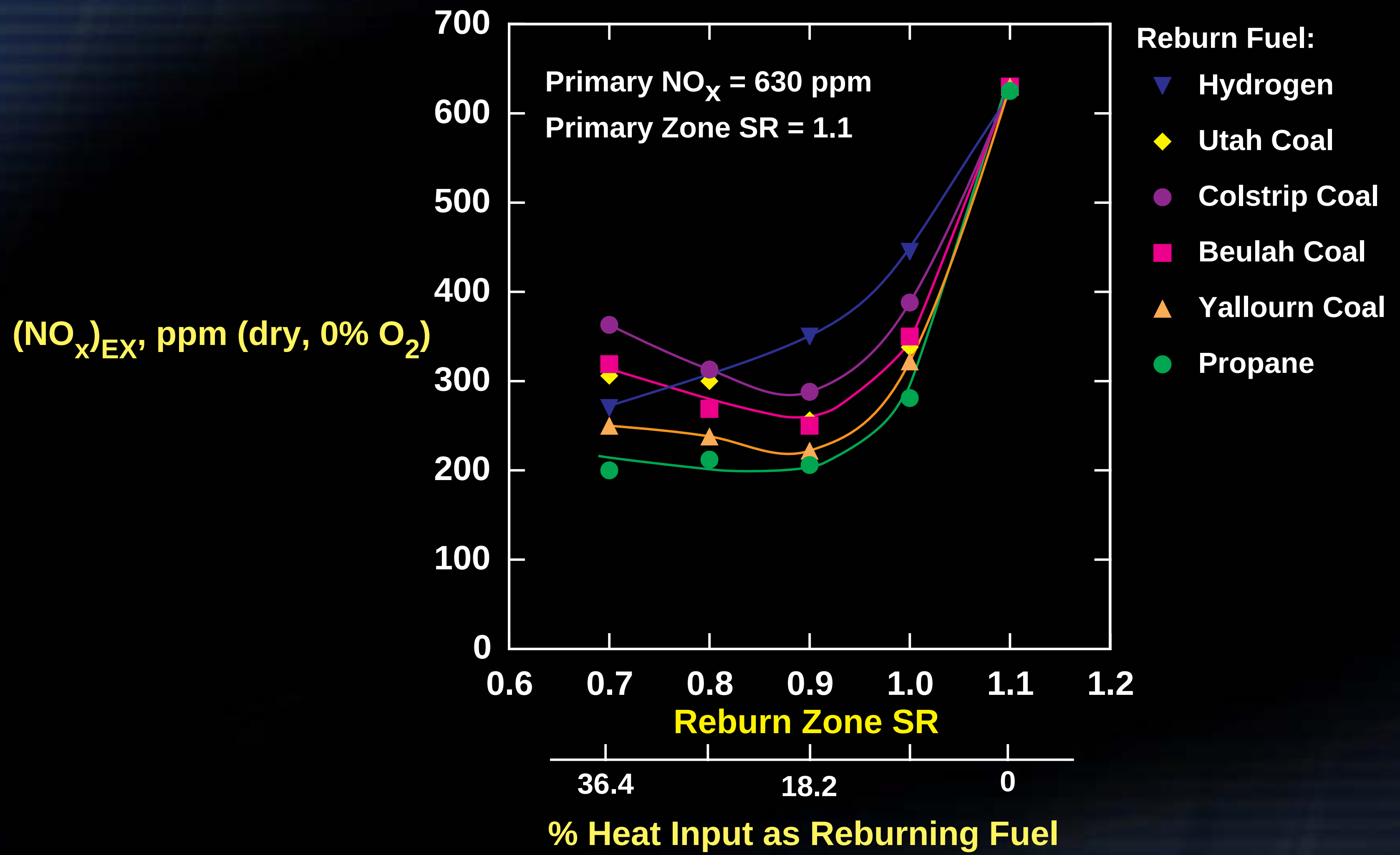
Primary Zone
- Reduced Excess Air
- Reduced Fuel Firing
- NO_X Slightly Lower

Reburn and Advanced Reburn

- Reburn:
  - An advanced NO_x control technology using fuel and air staging to achieve high levels of NO_x reduction (50–70%)
  - Can be applied to all boiler firing configurations & types (tangential, wall, cyclone, arch)
  - Can be applied to boilers firing coal, fuel oil, natural gas, process gases, or waste streams
  - Can use the primary boiler fuel <u>or</u> an alternate fuel depending upon availability, operator preferences, and emissions control requirements
  - Provides flexibility for optimizing emissions reductions throughout the year
- Advanced Reburn:
  - Couples reagent injection (SNCR) with reburning to achieve deep levels of NOx control

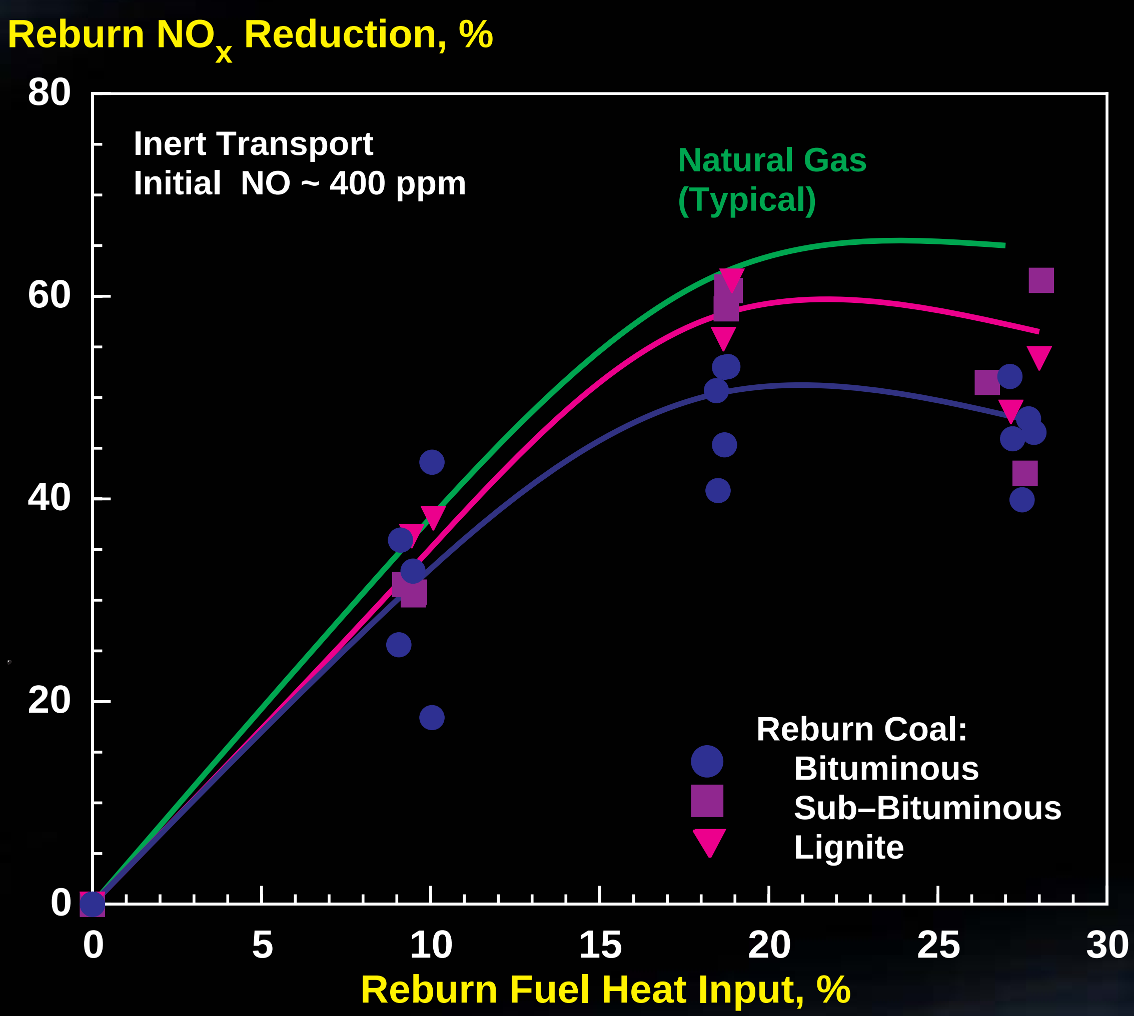
Reburn Performance

Impact of Reburn Zone Stoichiometry



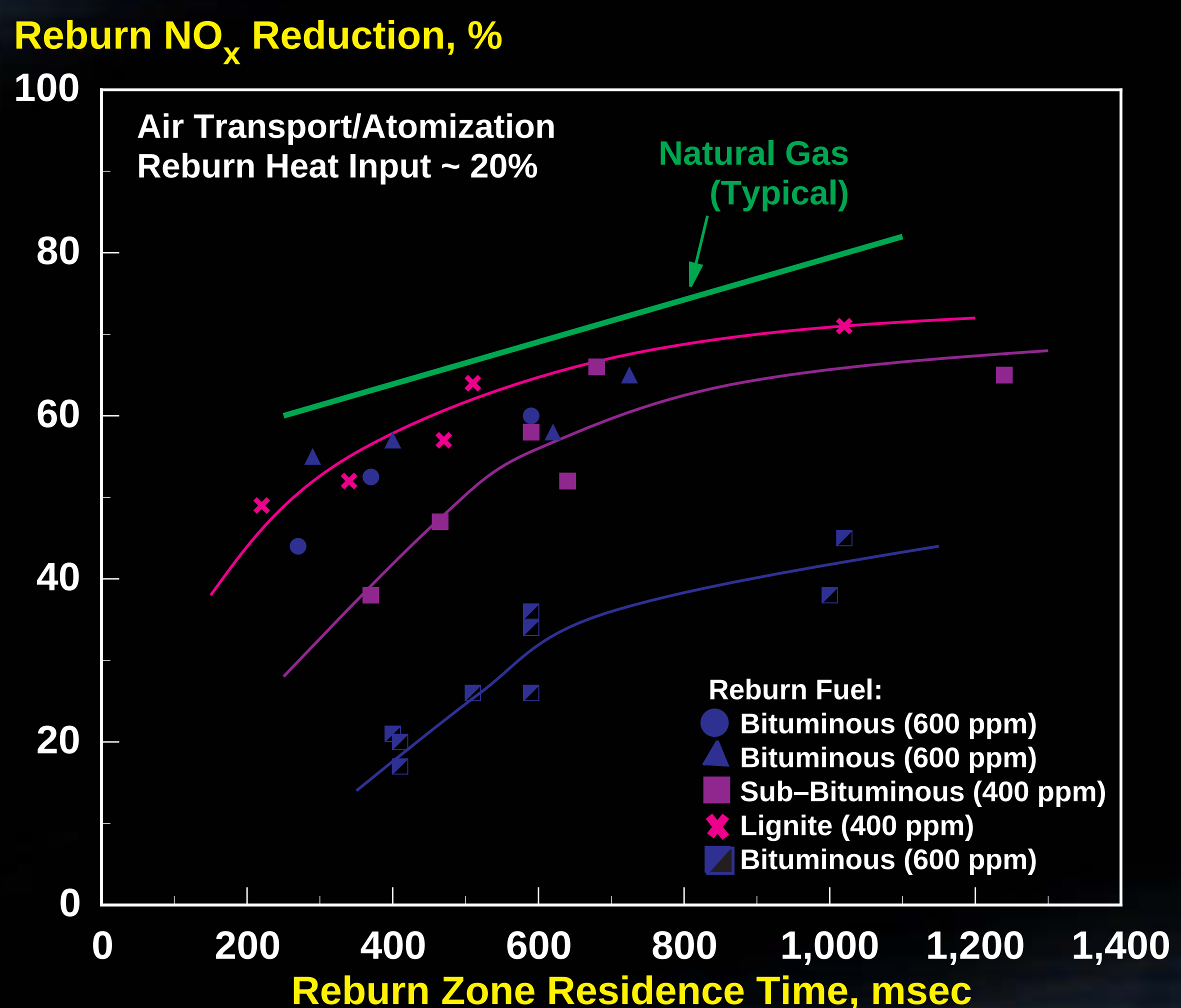
Reburn Performance

Impact of Reburn Fuels



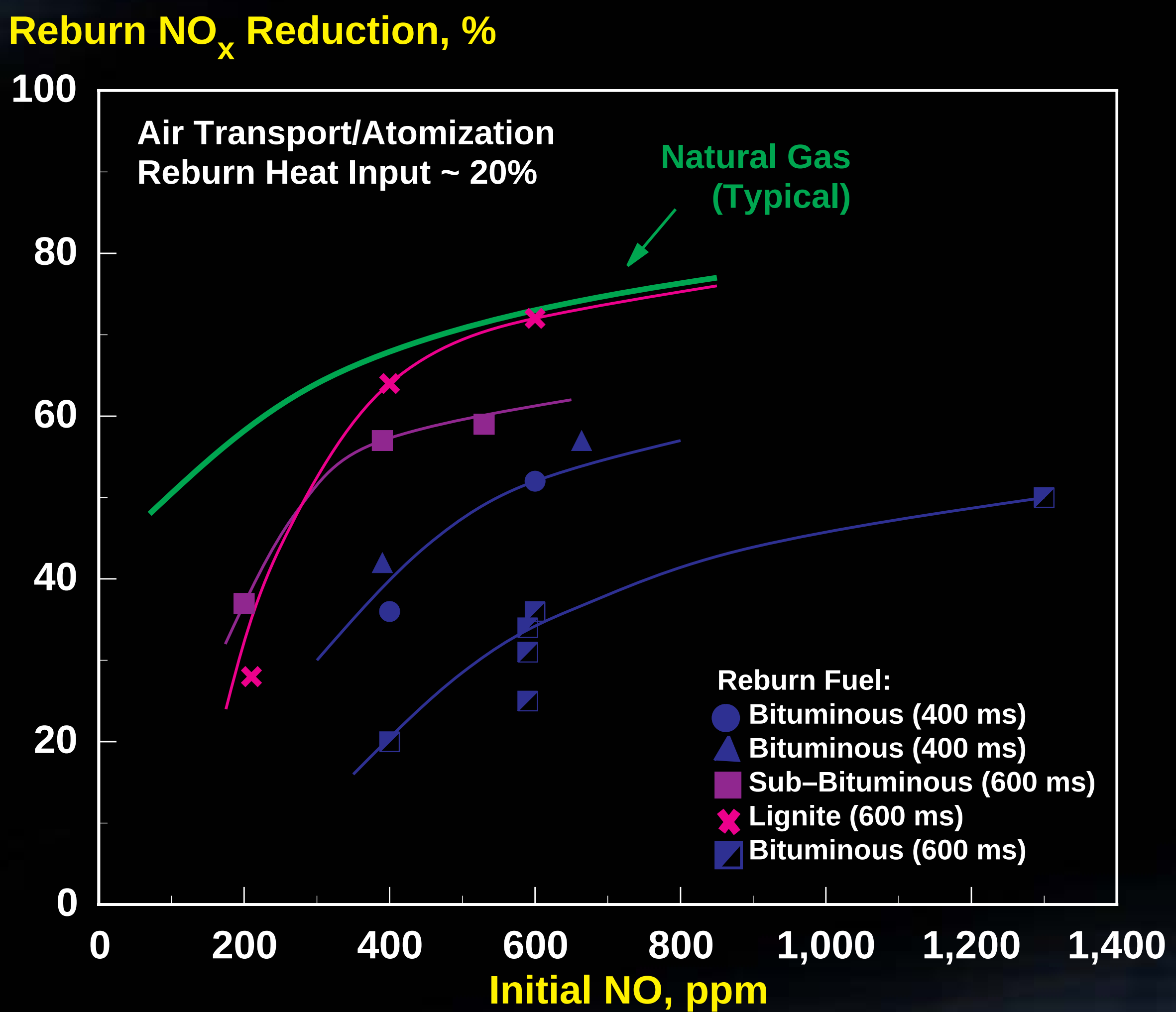
Reburn Performance

Reburn Zone Residence Time



Reburn Performance

Primary NO Level



Reburn Process

Application Considerations

- Boiler specific factors can influence reburn performance:
  - Boiler design generally sets reburning zone residence time and temperature, and initial NO_x
  - Firing configuration and fuel have a minor impact, except where they influence first order parameters
  - Primary excess air does not influence reburn effectiveness, but does set amount of reburn fuel needed for optimum boiler emissions control
- Reburn system design parameters that dictate level of control which can be achieved for a particular boiler:
  - Reburning zone stoichiometry
  - Reburning fuel type
  - Reburning fuel mixing

Reburning

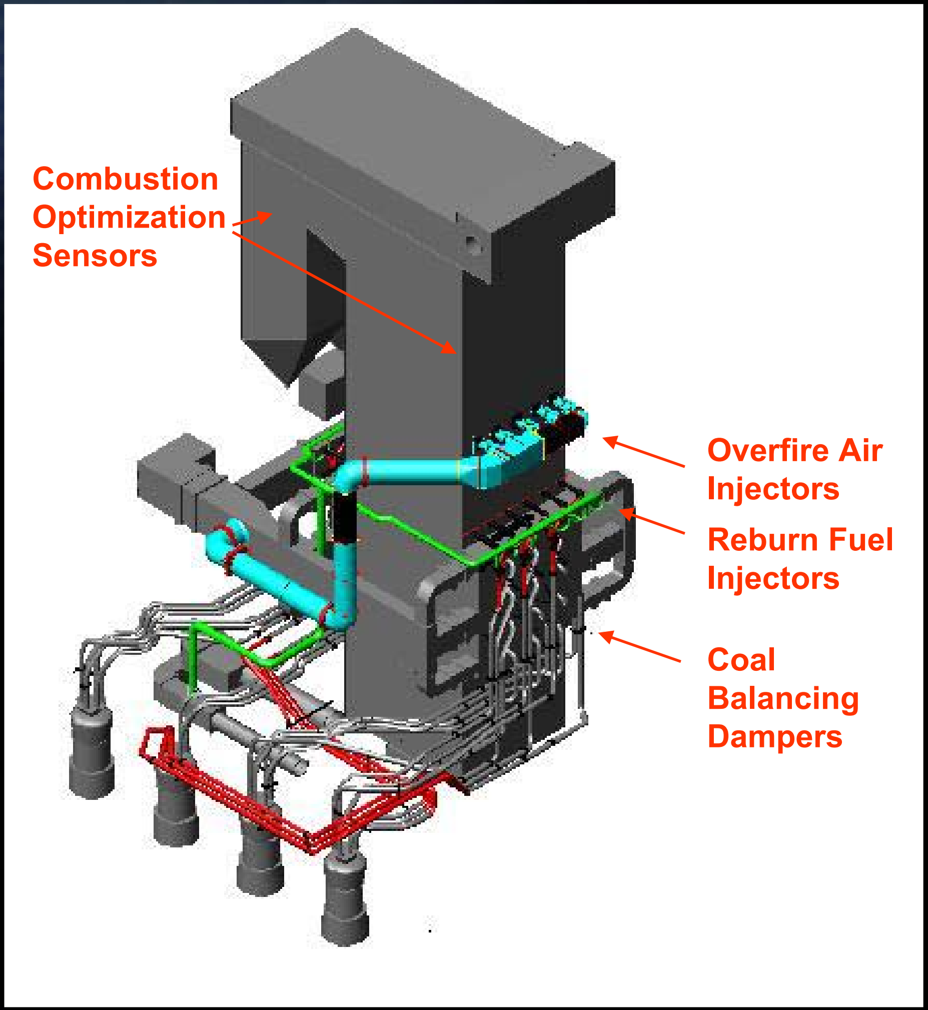
GE EER Experience

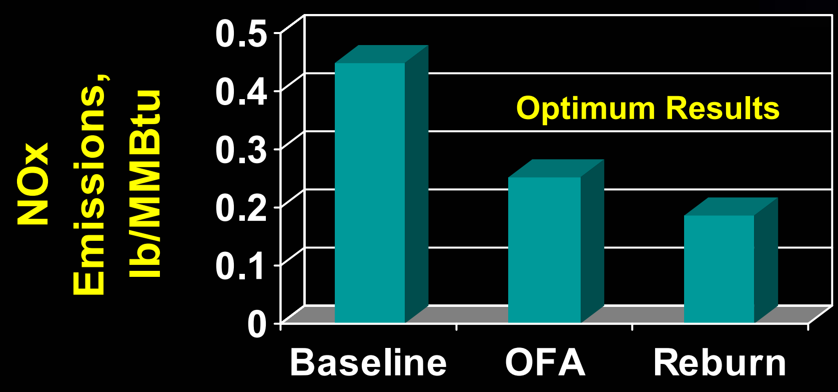
- Firing Configuration
  - Cyclone
  - Cell
  - Wall
  - Tangential
  - Stoker
- Capacity
  - Min. = Package boiler (2MW)
  - Max. = 800 MW

- Main Fuels
  - Coal
  - Oil
  - Gas
- Reburn Fuels
  - Gas
  - Fuel Oil
  - Orimulsion
  - Pulverized Coal / CWS

GE Environmental Energy is the World Leader in Reburning Technology, > 4,800 MW Operating

Opposed Wall Fired Boiler - Coal Reburn

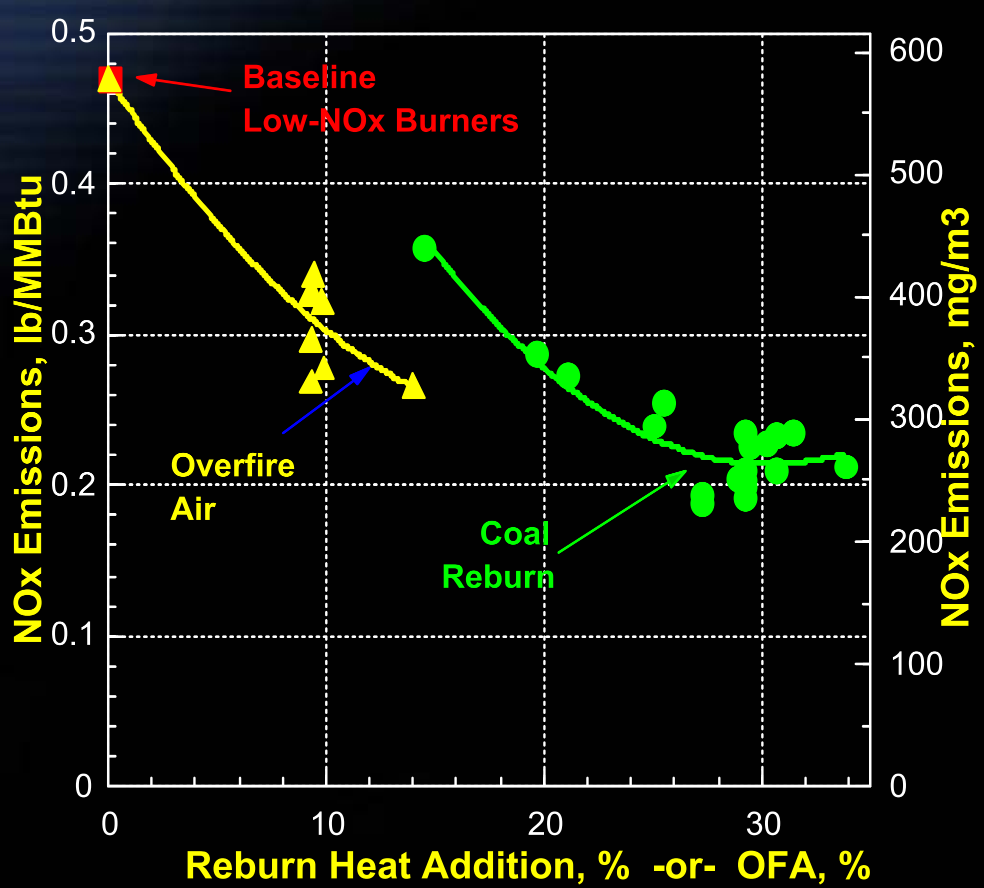




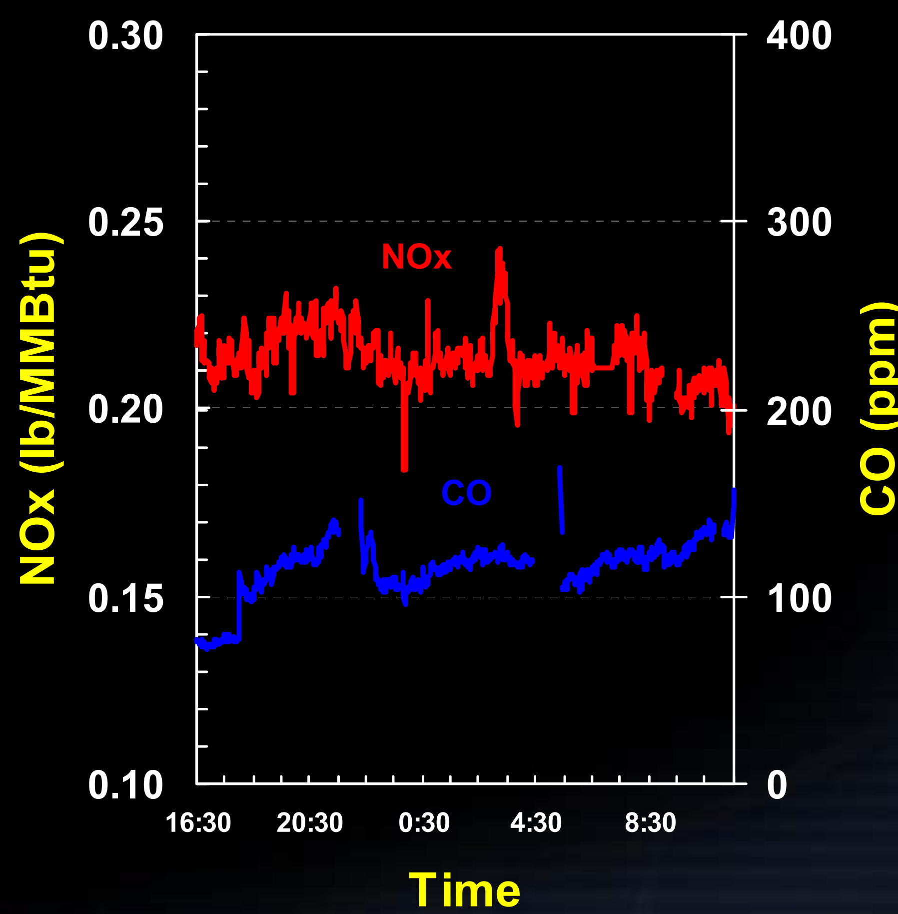
- Capacity: 250 MW
- Fuel: Bituminous Coal / Pet coke
- Optimization Solution:
  Coal Reburn, Advanced Combustion Sensors, Coal Balancing Dampers
- Coal Reburn Performance Test Results (Nov. ´02):
  - NOx Emissions = 0.21 lb/MMBtu
  - CO Emissions = 120 ppm
  - LOI (Unburned Carbon) = No impact

Opposed Wall Fired Boiler – Coal Reburn

Impact of Reburn Fuel



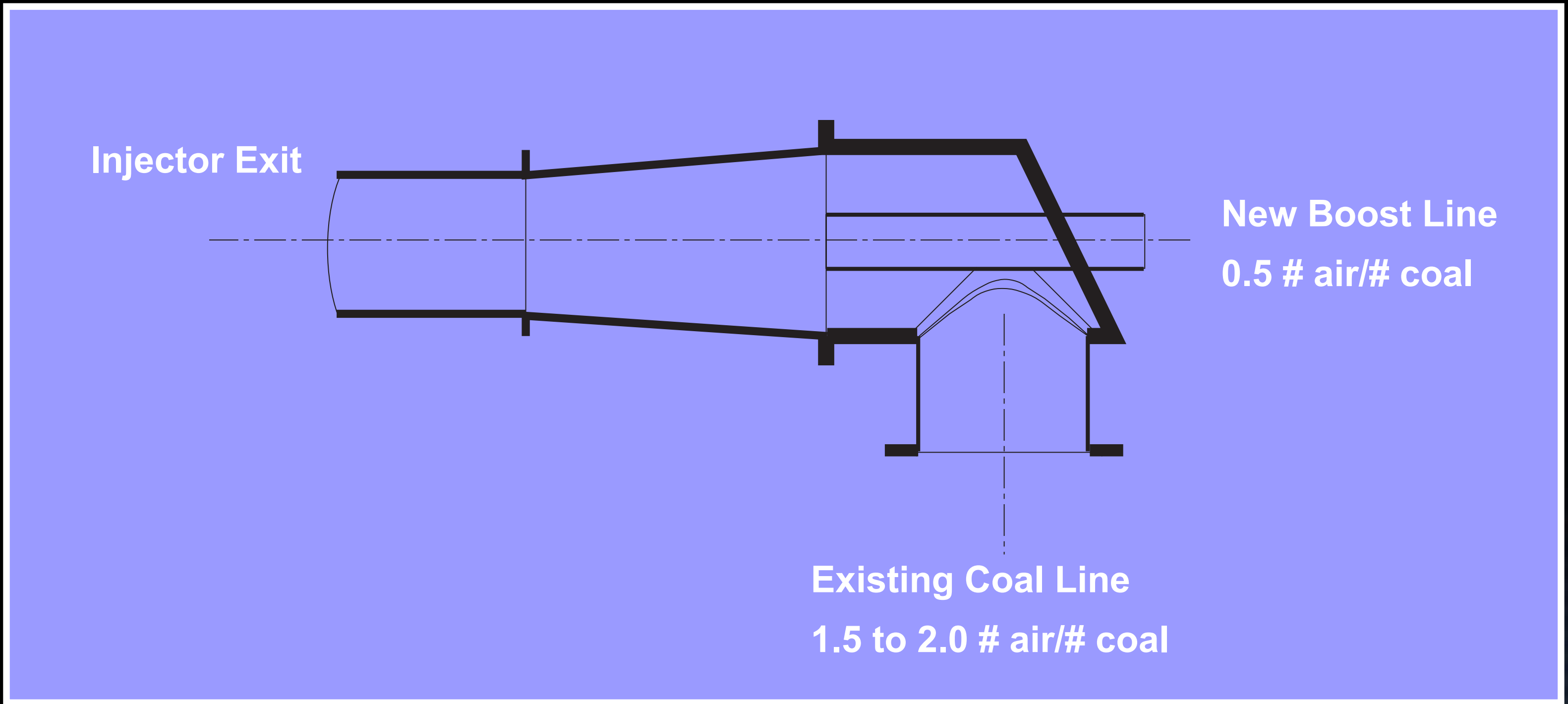
Emissions vs. Time



Coal Reburn Application

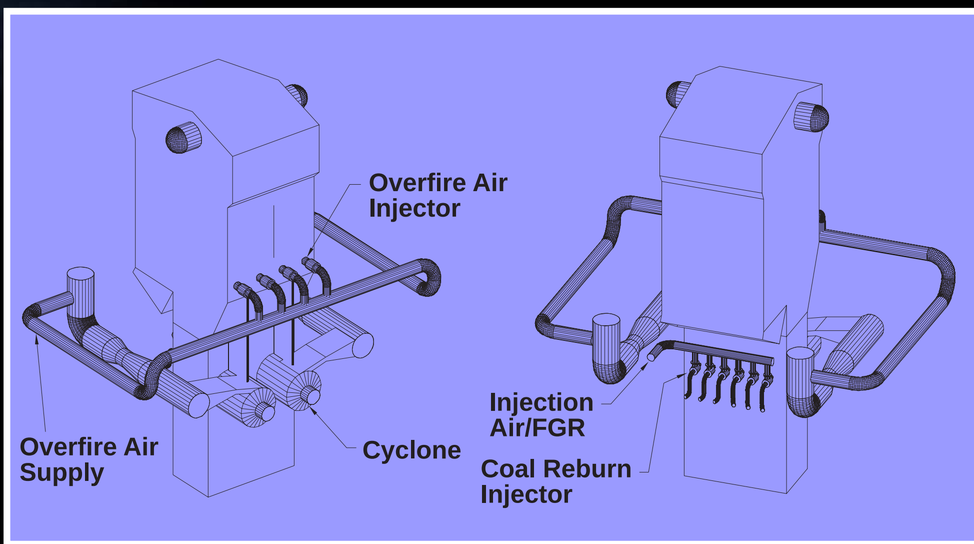
EER Reburning Coal Injector, Wall Fired Boilers

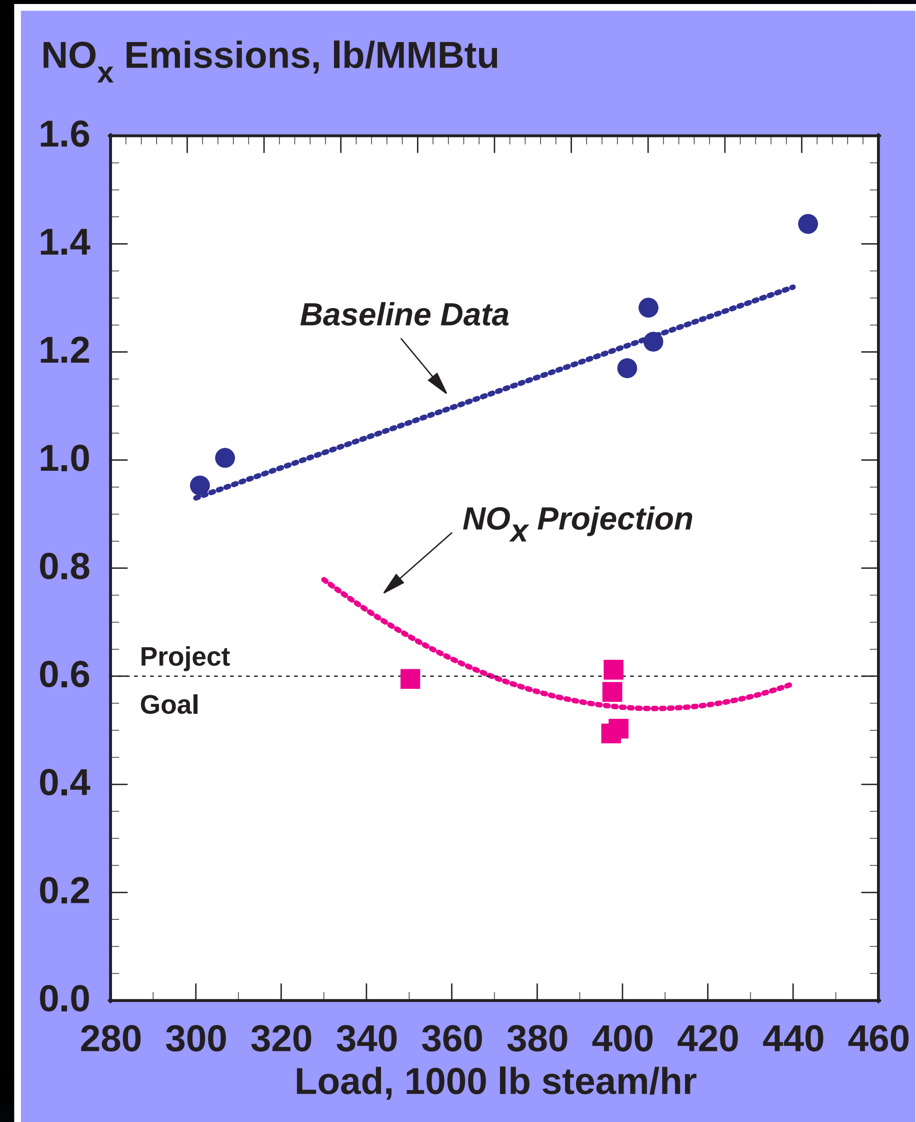
- Boosted Injector Design
  - Boost flow (air/FGR) improves jet penetration
  - Flow from new booster fan discharge



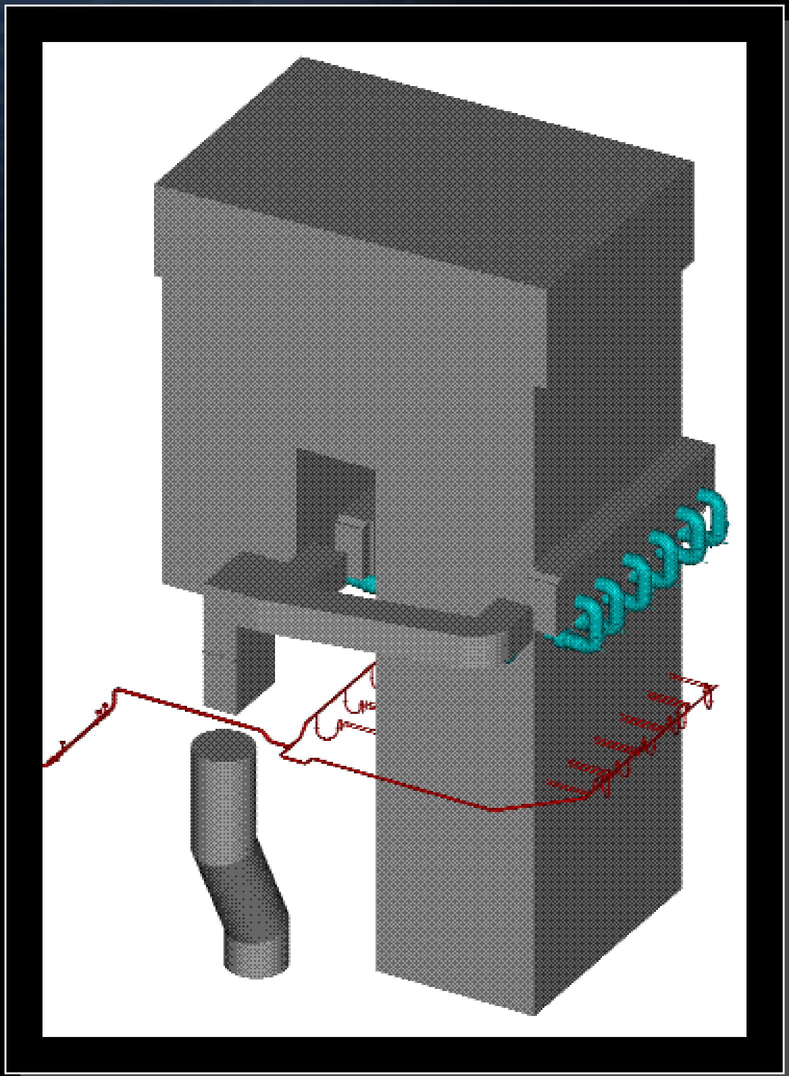
Coal Reburning

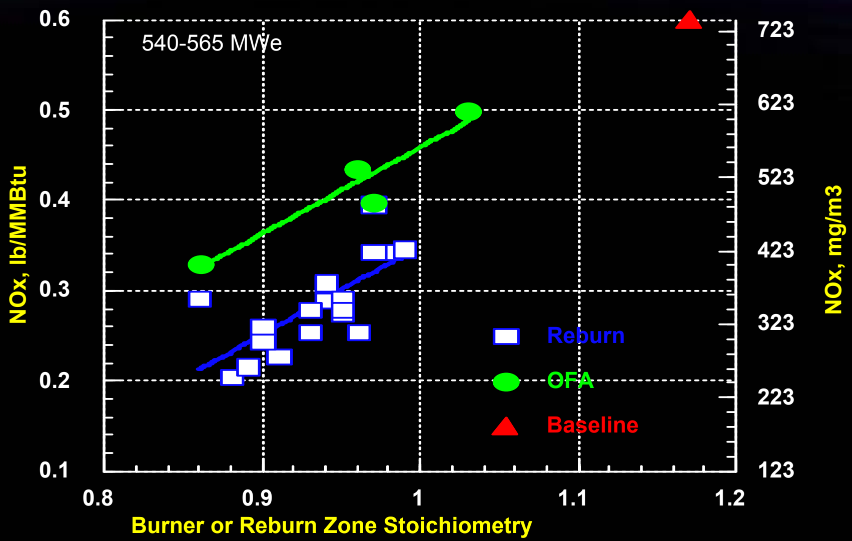
- Coal-Fired Boiler (~30 MW)
- Cyclone Fired





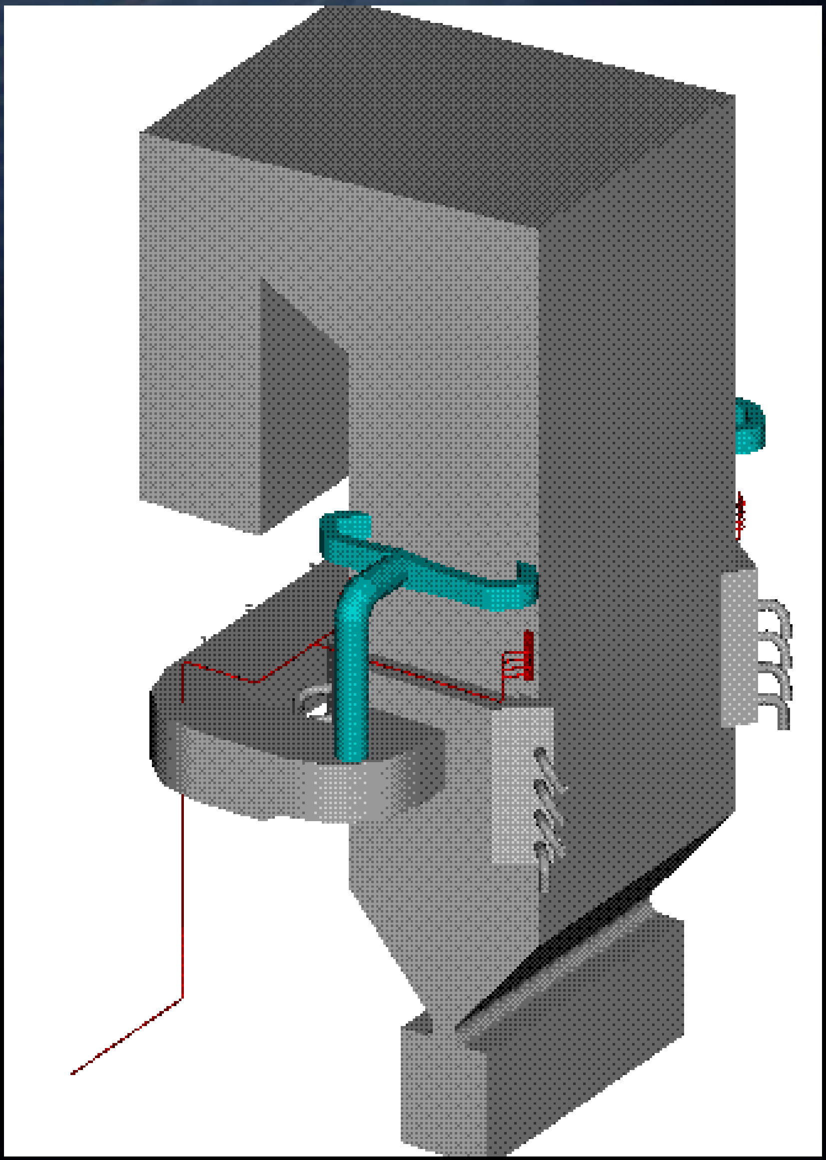
Opposed Wall Fired Boiler - Gas Reburn

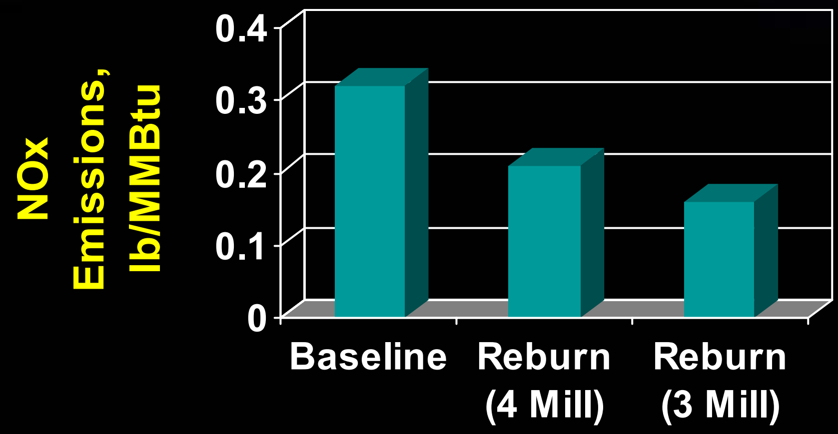




- Capacity: 560 MW
- Fuel: Bituminous Coal
- Baseline NOx: 0.62 lb/MMBtu (760 mg/m3) with Low-NOx Cell-Burner Arrangement
- Coal Reburn Performance:
  - NOx Emissions = 0.20 lb/MMBtu (~250 mg/m3)
  - CO Emissions = 10 ppm
  - LOI (Unburned Carbon) = < 4%

Tangentially Fired Boiler – Gas Reburn

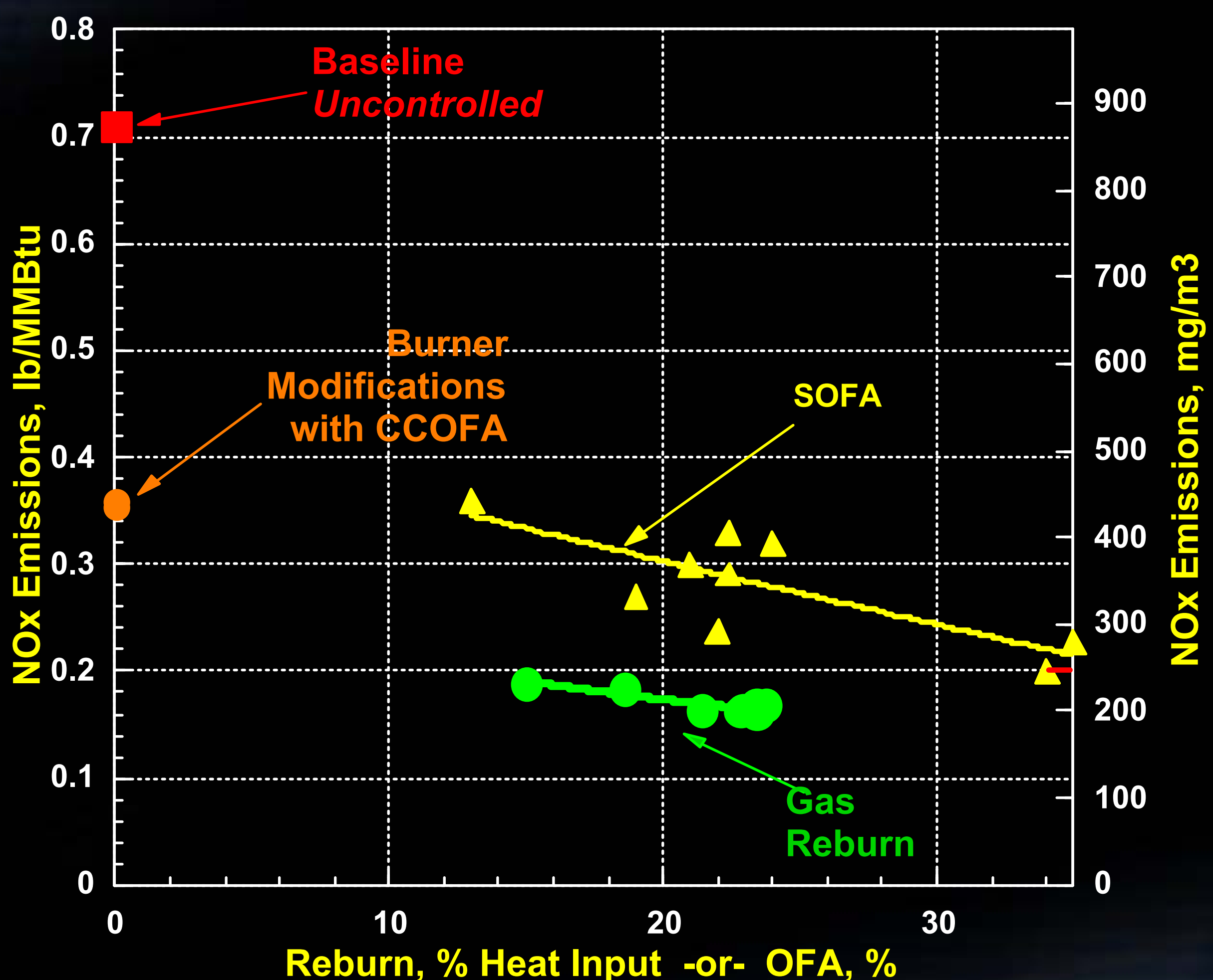




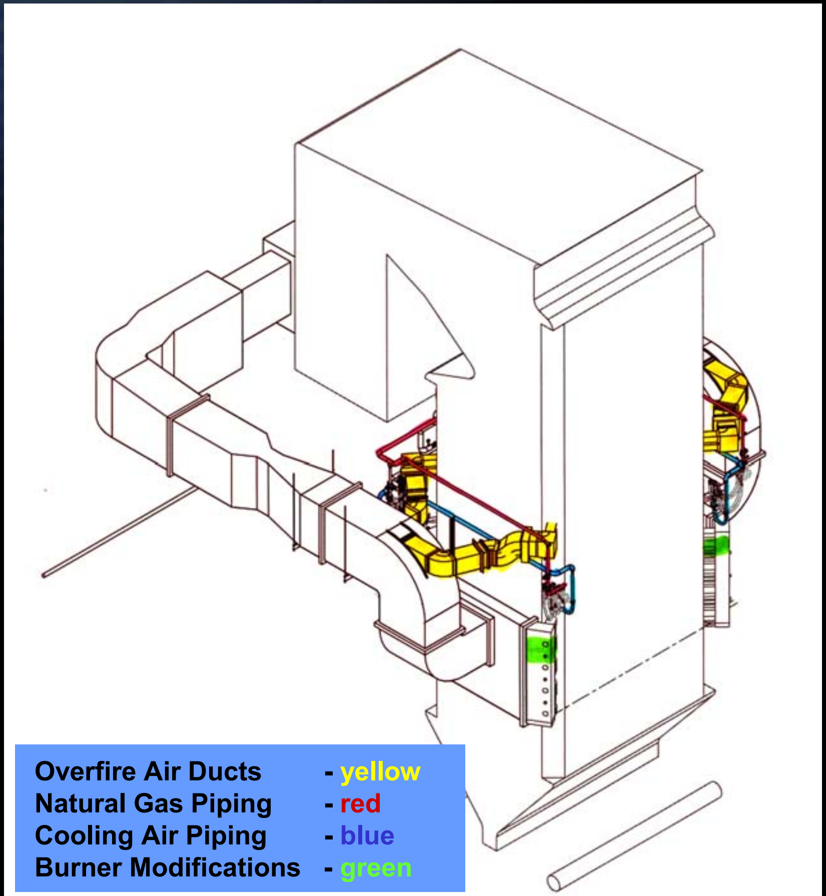
- Capacity: 160 MW
- Fuel: Bituminous Coal
- NOx Control System: LNCFS II, Gas Reburn.
- 4 Multi-Nozzle Gas Injectors
- 4 Dual-Compartment Overfire Air Injectors

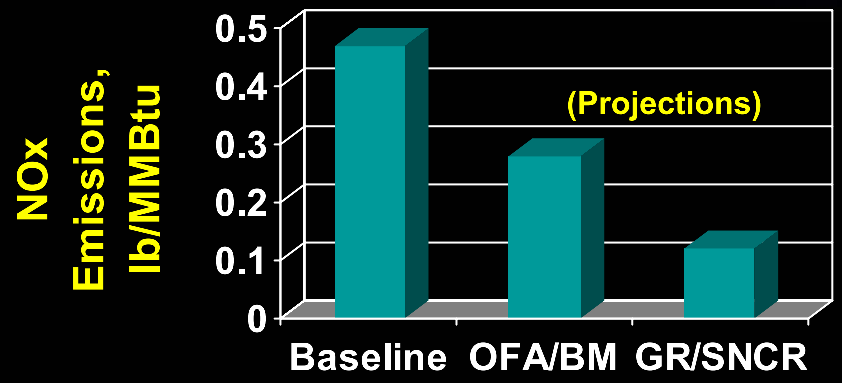
Tangentially Fired Boiler – Gas Reburn

Impact of Reburn Fuel — 160 MWe — Impact of CCOFA



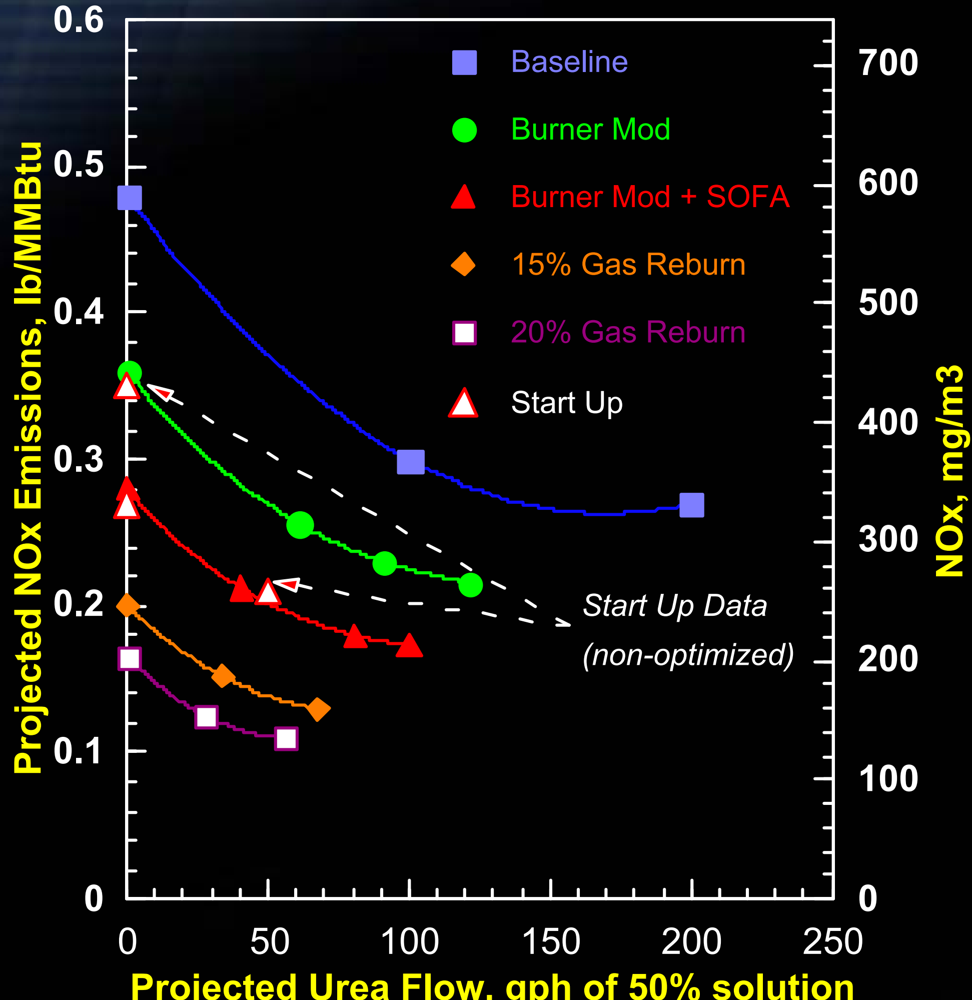
Tangentially Fired Boiler – Gas Reburn/SNCR





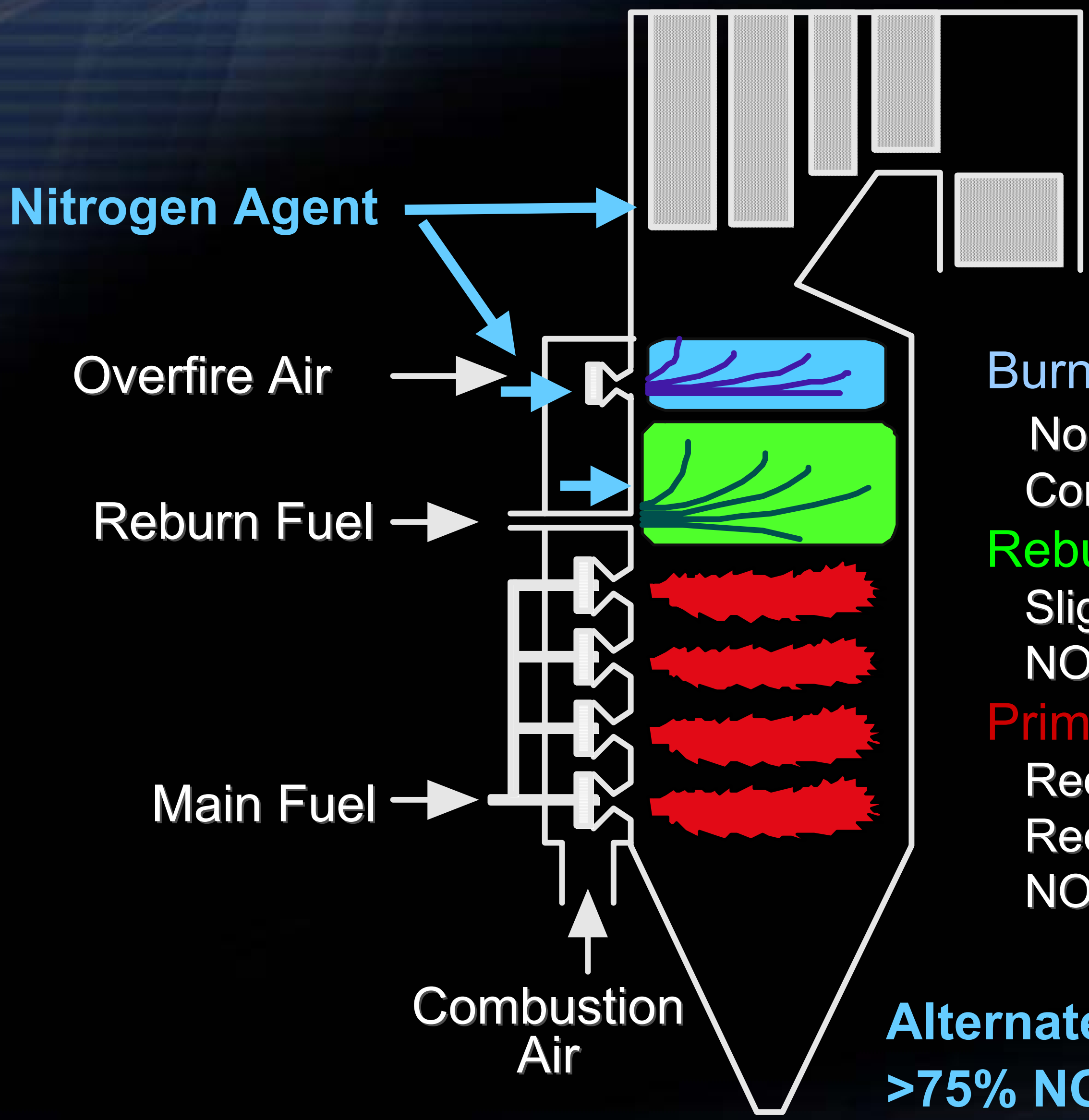
- Capacity: 120 MW
- Fuel: Bituminous Coal
- NOx Control System: Burner Modifications & SOFA, Gas Reburn, SNCR.
- 4 Multi-Nozzle Gas Injectors
- 4 Dual-Compartment Overfire Air Injectors

Tangentially Fired – Gas Reburn/SNCR



- Baseline NOx
  - 0.48 lb/MMBtu (590 mg/m3) uncontrolled
  - 0.28 lb/MMBtu (345 mg/m3) with SNCR
- Start-Up Sept. '03
  - 0.25 lb/MMBtu (307 mg/m3) with Burner Mods. and SOFA
  - < 0.20 lb/MMBtu (250 mg/m3) with SNCR
- Gas Reburn Oct. '03
  - < 0.16 lb/MMBtu (200 mg/m3) with Gas Reburn
  - < 0.12 lb/MMBtu (150 mg/m3) with Reburn and SNCR

Advanced Reburn Application



Burn Out Zone
- Normal Excess Air
- Complete Combustion

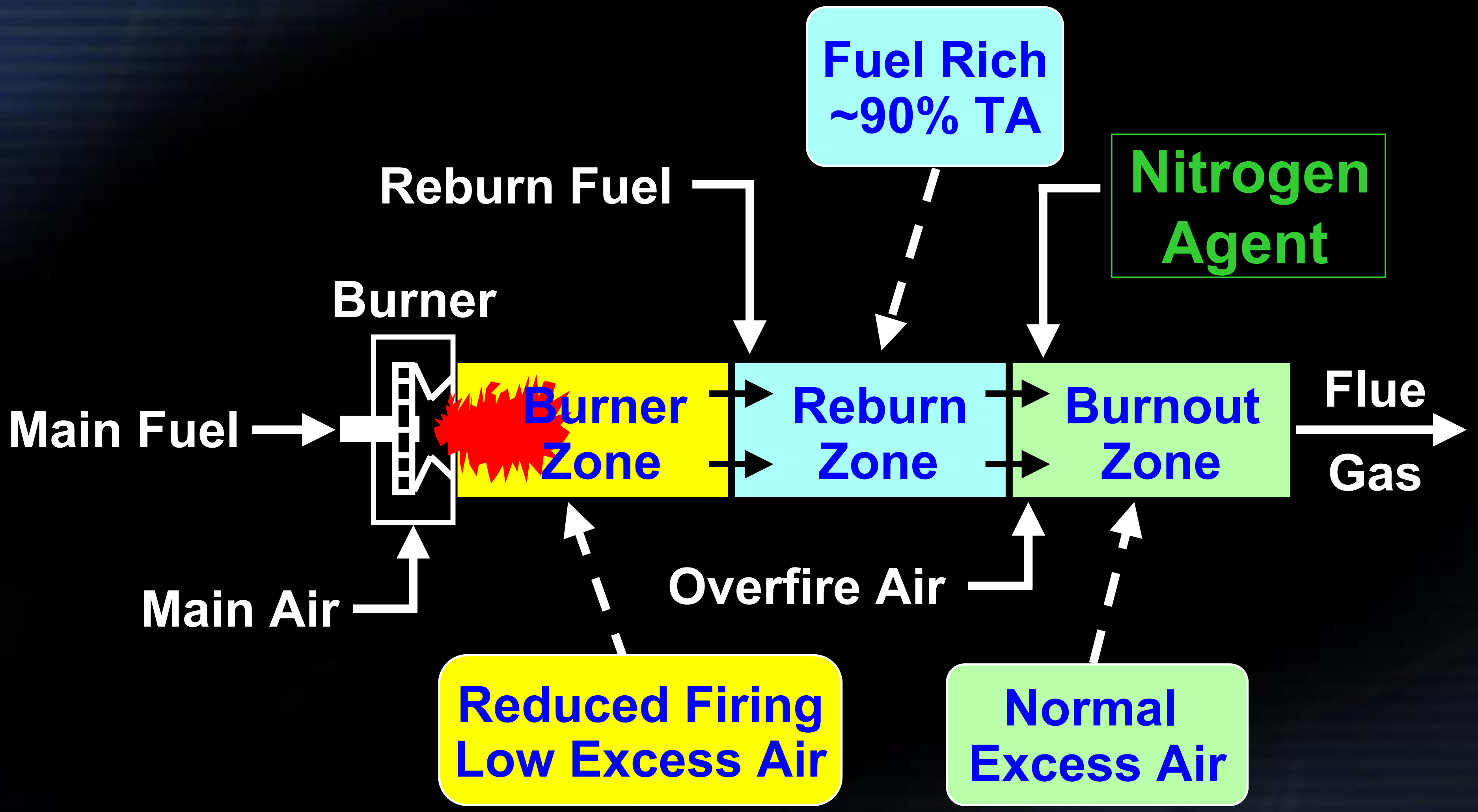
Reburning Zone
- Slightly Fuel Rich
- NO_X Reduction Reactions

Primary Zone
- Reduced Excess Air
- Reduced Fuel Firing
- NO_X Slightly Lower

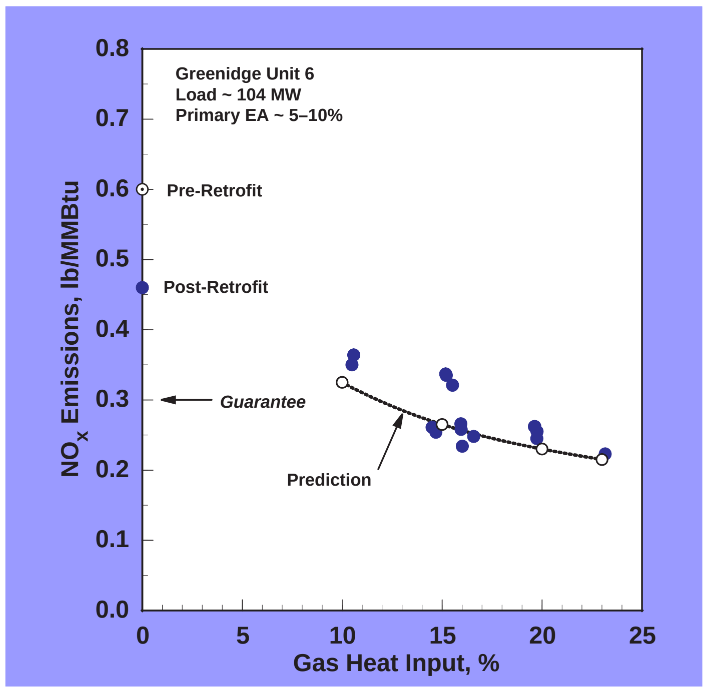
Alternate Injection Options

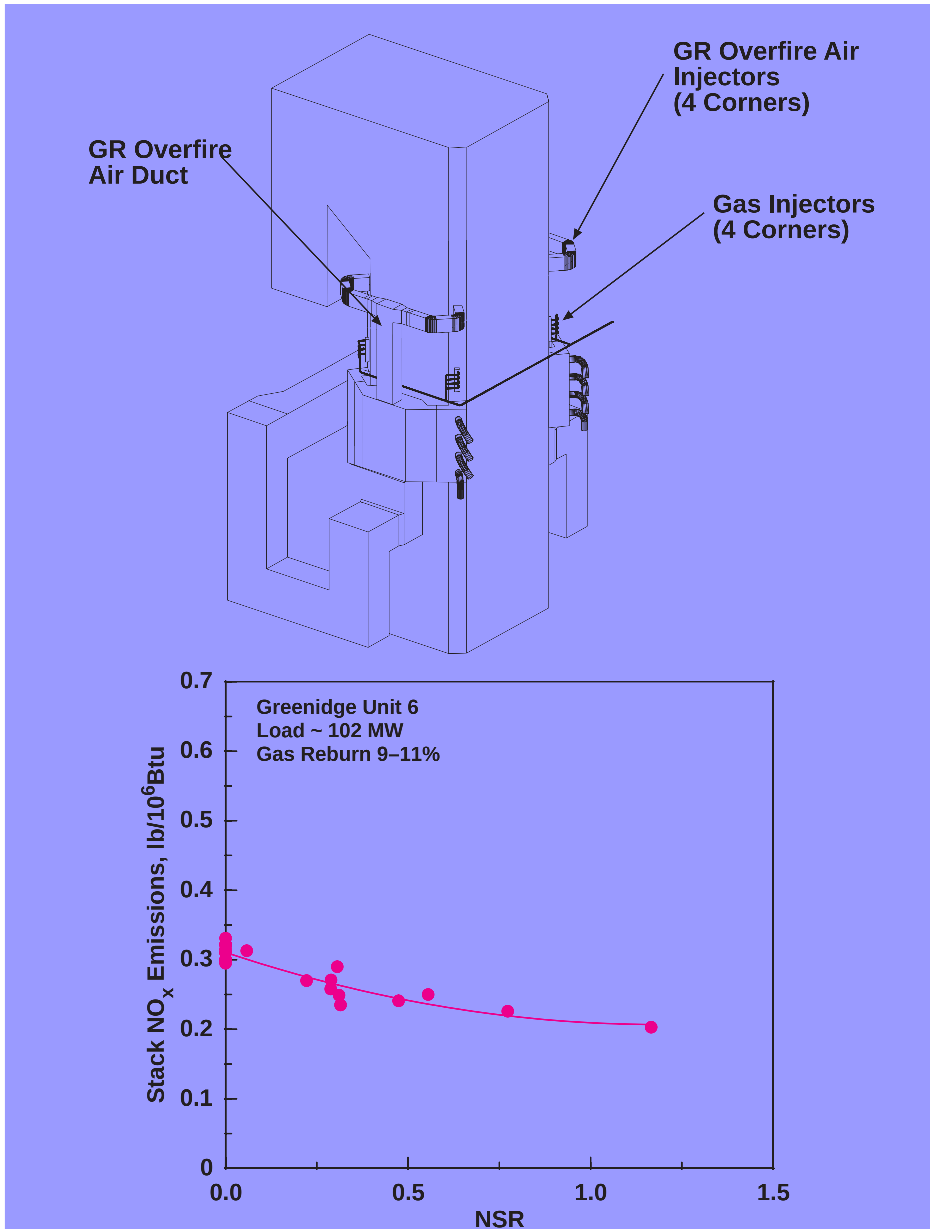
>75% NO_X Reduction

Advanced Gas Reburn Process



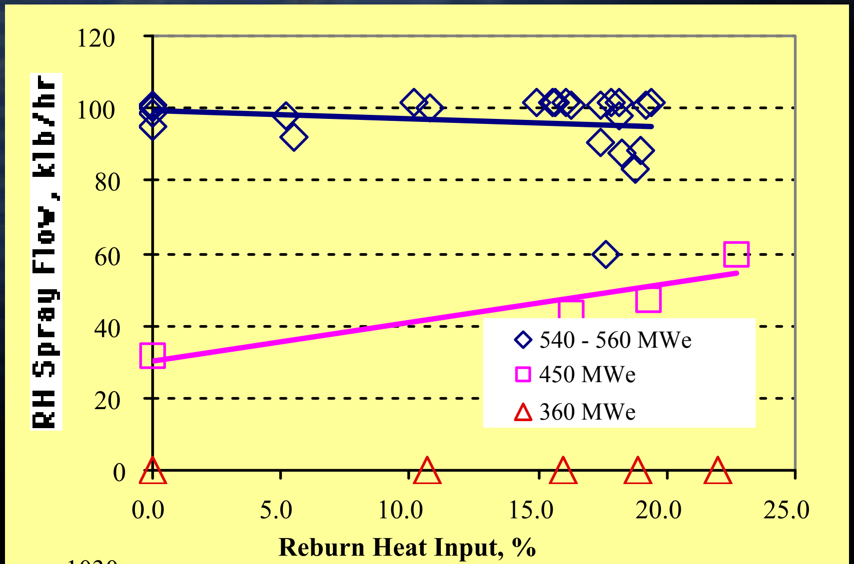
AGR (Advanced Gas Reburn) Application





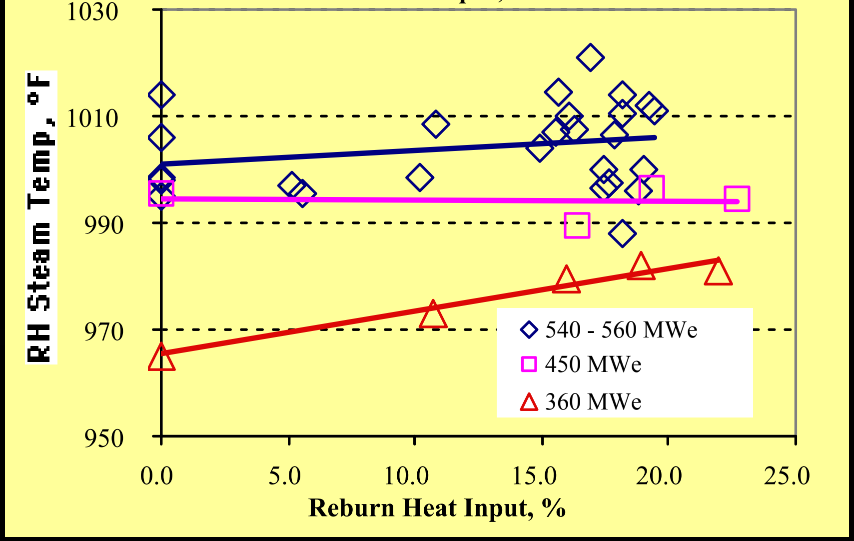
Gas Reburning and Advanced Gas Reburning Performance

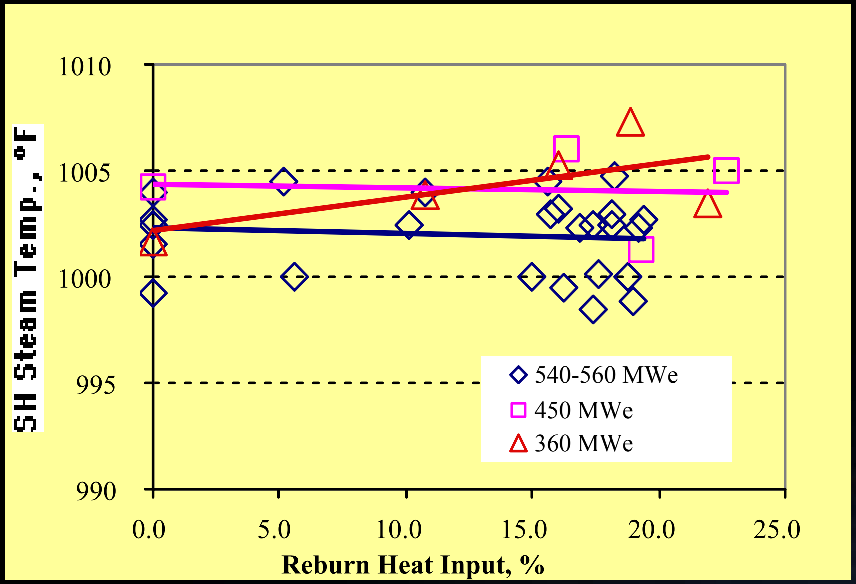
Steam Temperature Control



Impact of Reburn on Steam Temperature Control

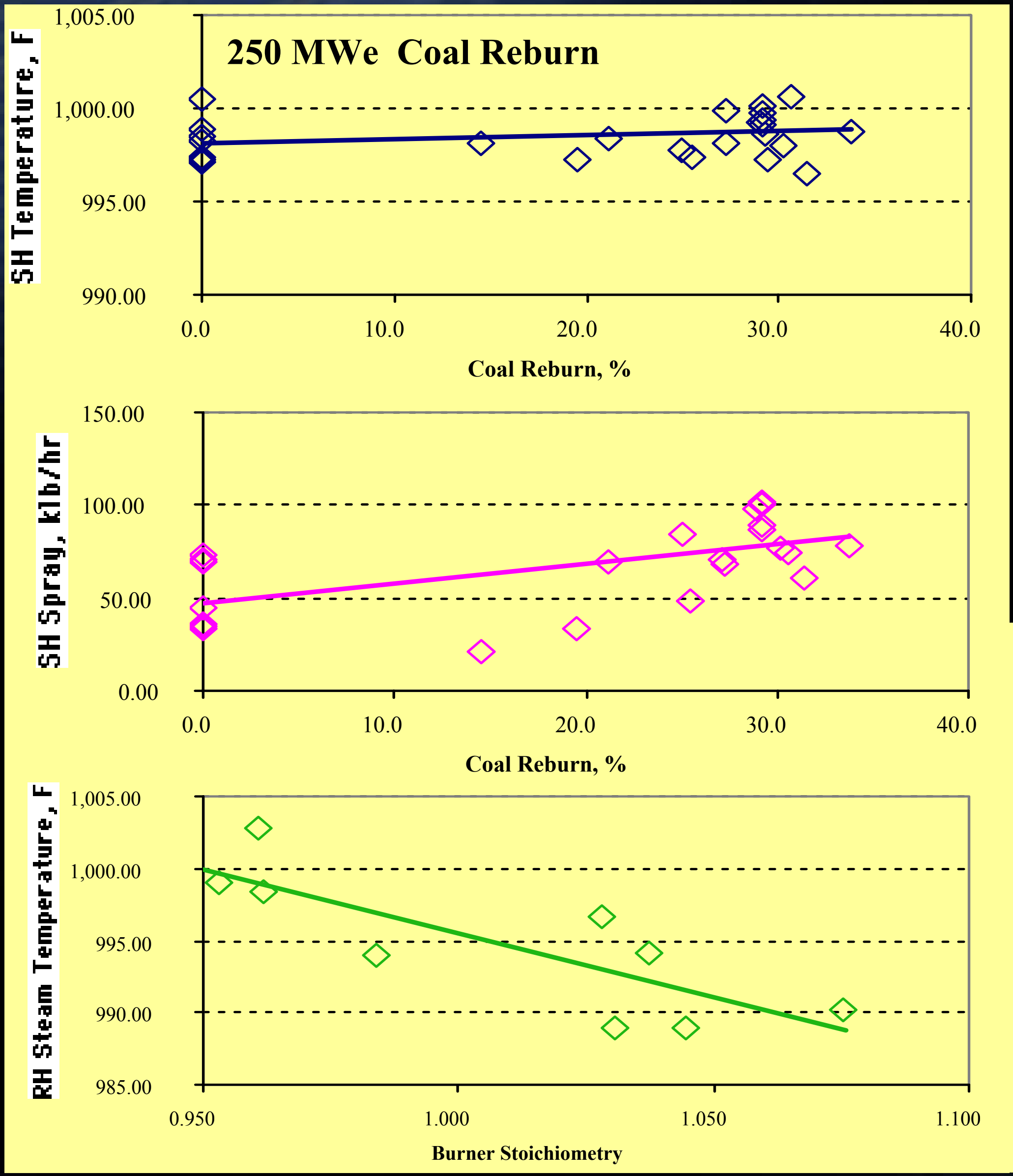
Gas Reburn - 560 MWe
2.5% Sulfur Coal





Steam Conditions Maintained Within Normal Control Range

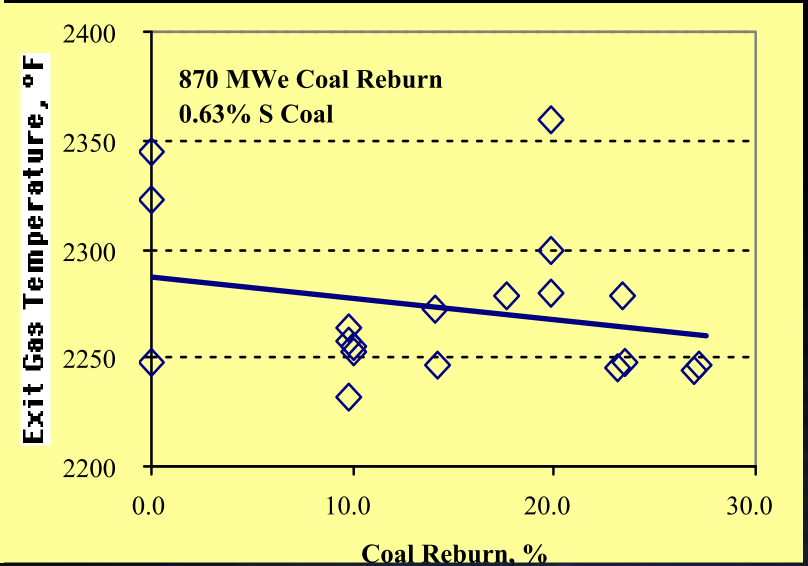
Thermal Performance



Coal Reburning 250 MWe and 850 MWe

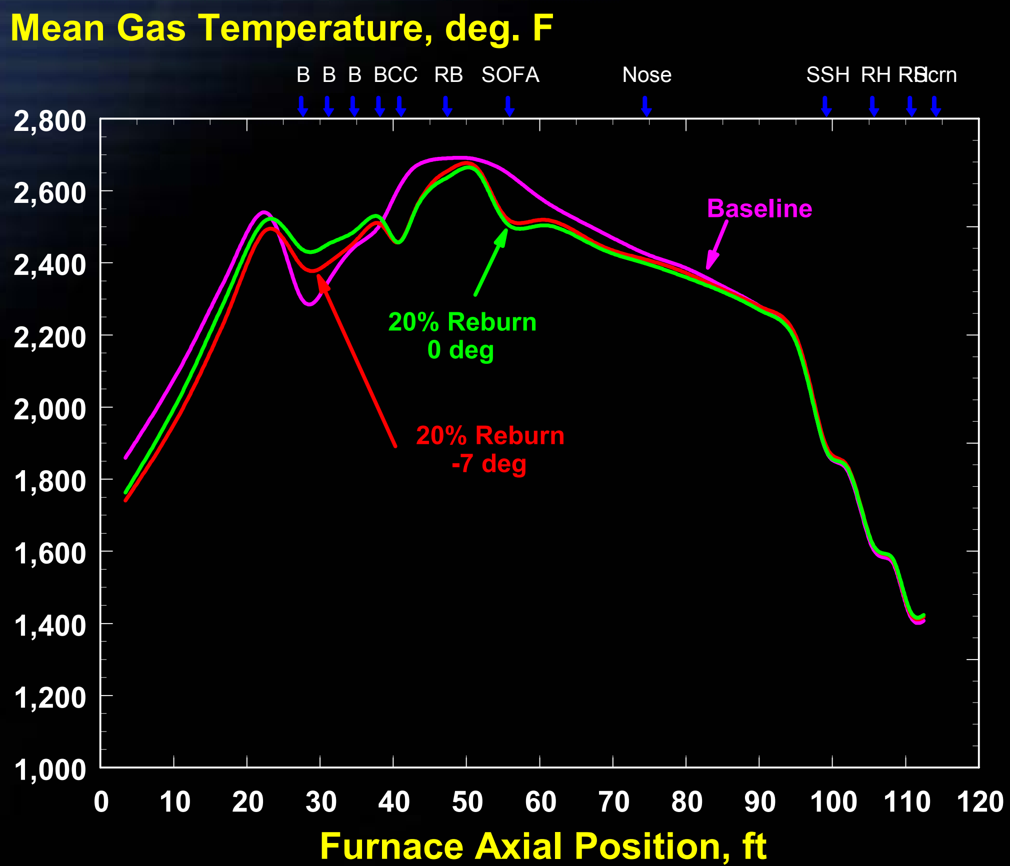
FEGT (Exit Gas Temp), SH (Superheater) & RH (Reheater) Temperatures

FEGT

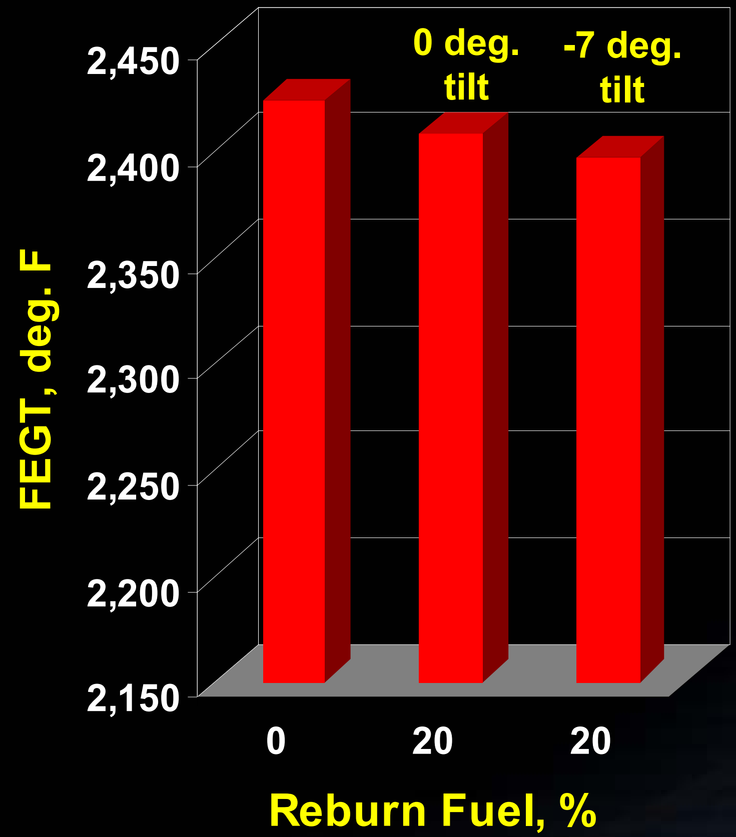


Reburn Evaluation

Thermal Performance Analysis



Flue Gas Temperature

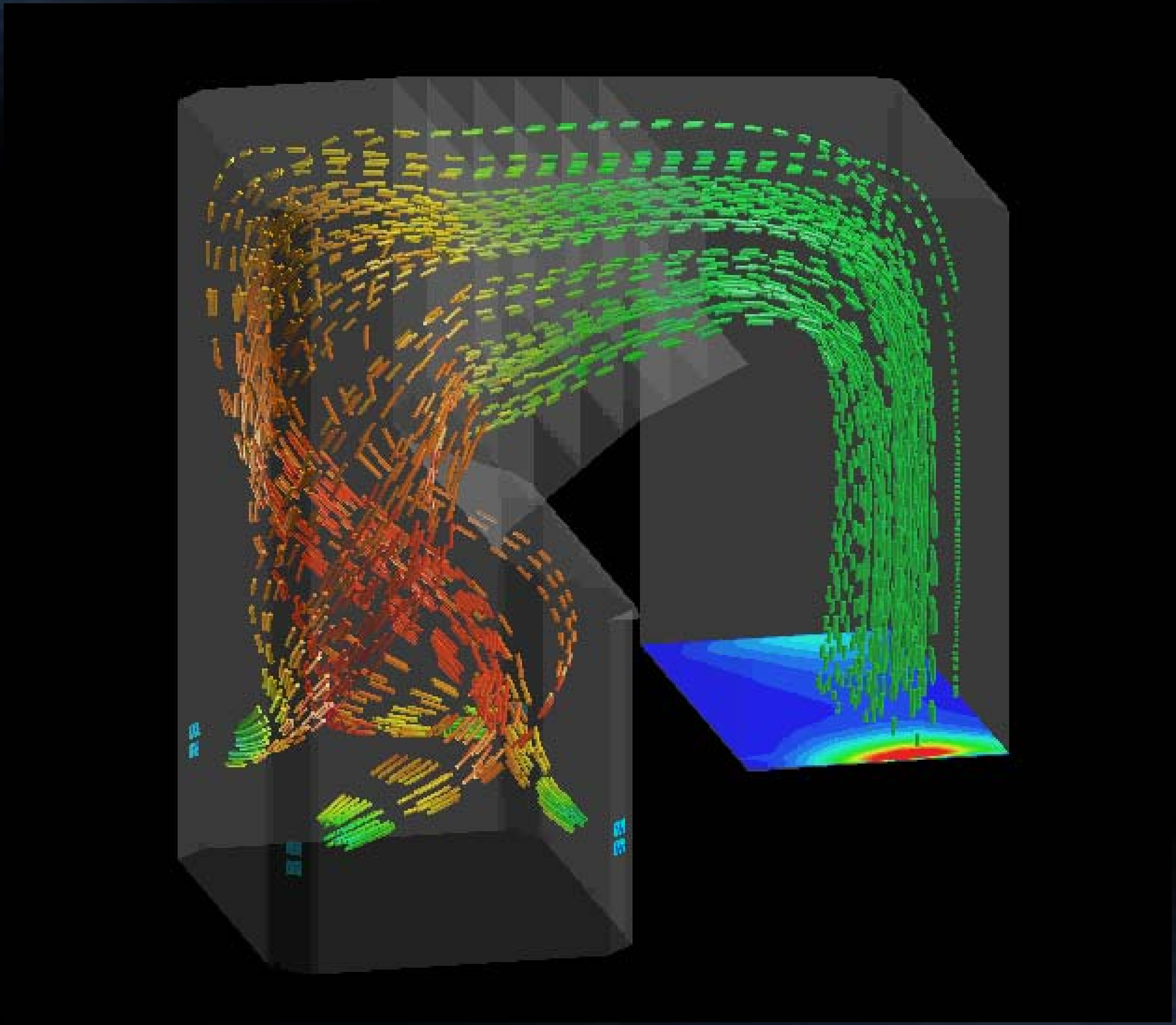


FEGT

OFA Evaluation

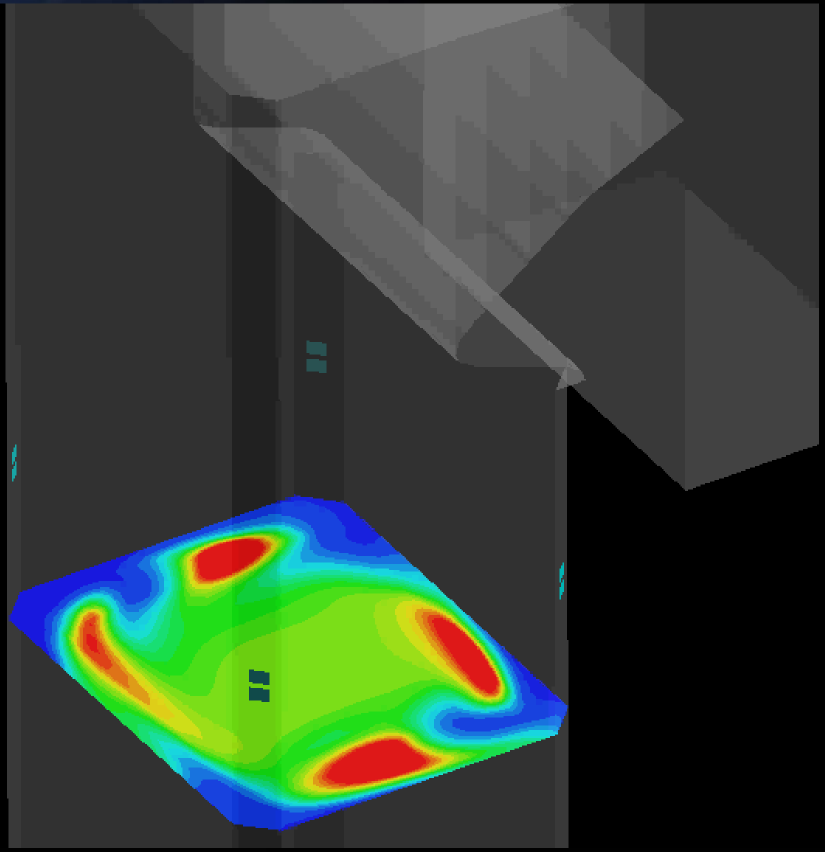
Overfire Air Operation

OFA Pathlines

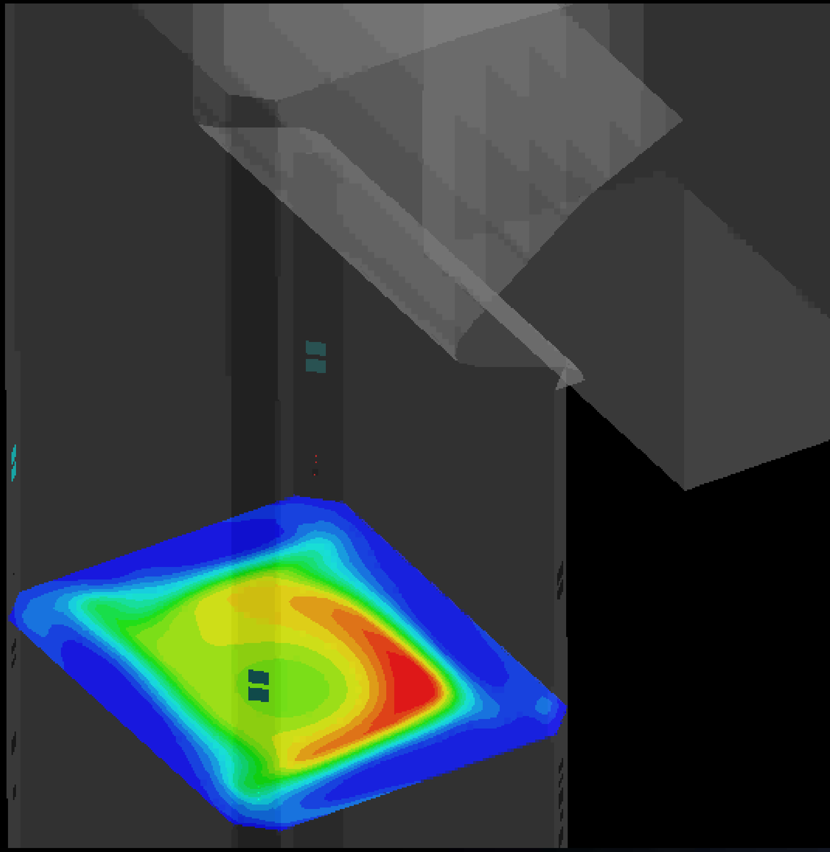


OFA/Reburn Evaluation

CO Concentration



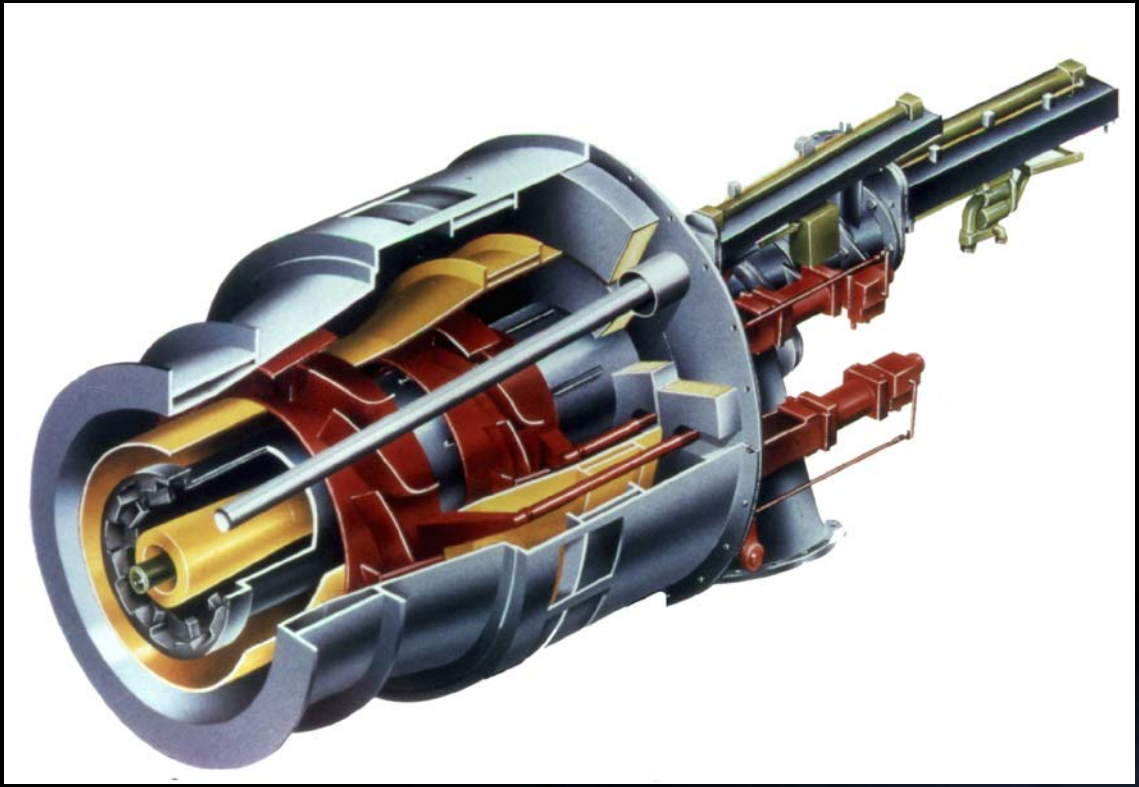
OFA



Reburn

FlamemastEERTM Low NOx Burners

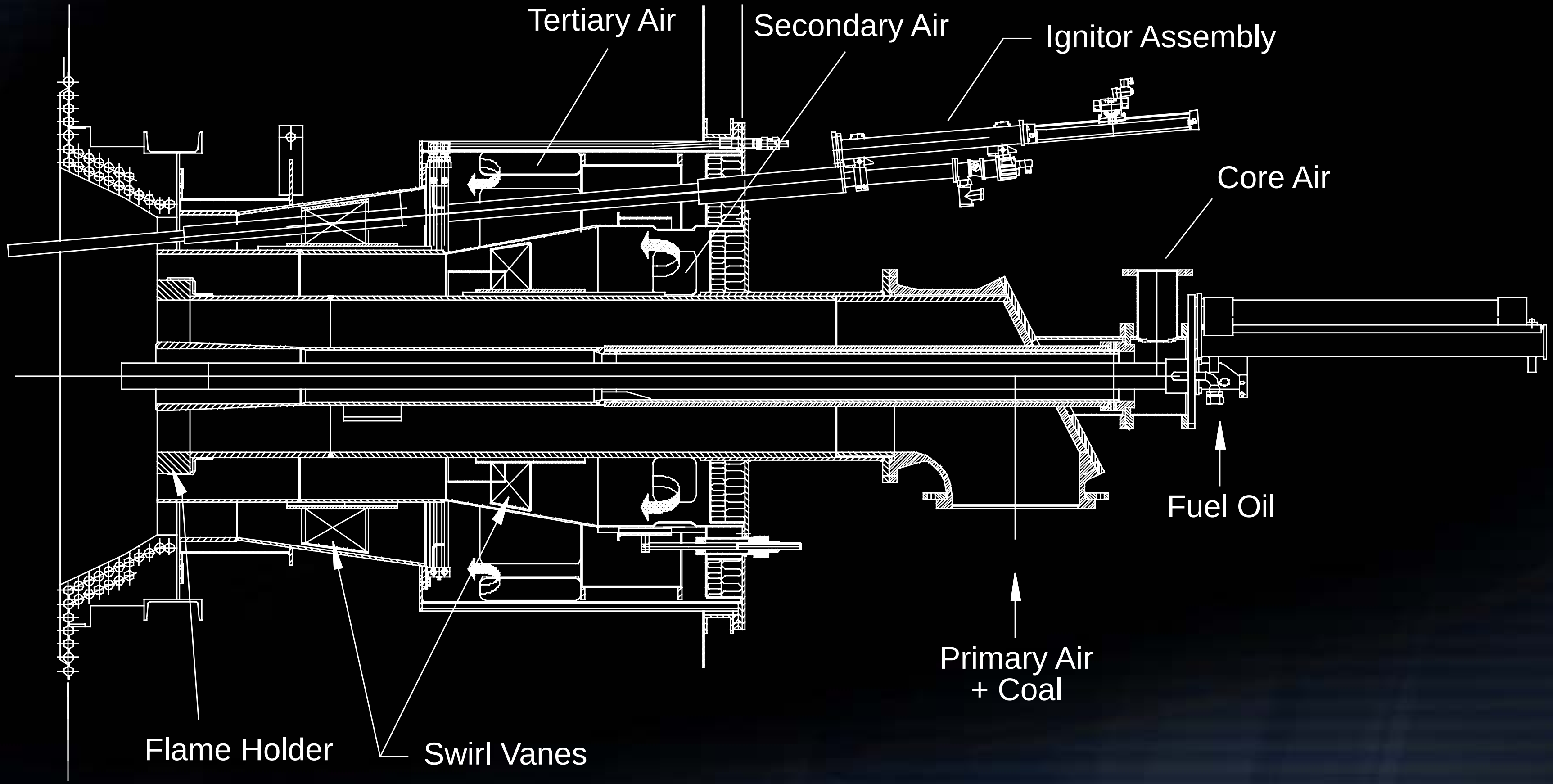
- 30-50% NOx Reduction
- Independent Air Flow and Air SwirlKillen BurnerStuart #2 Burners
- Low Cost Option: Burner Modifications



Low-NOx Coal Burners

Key Design Features

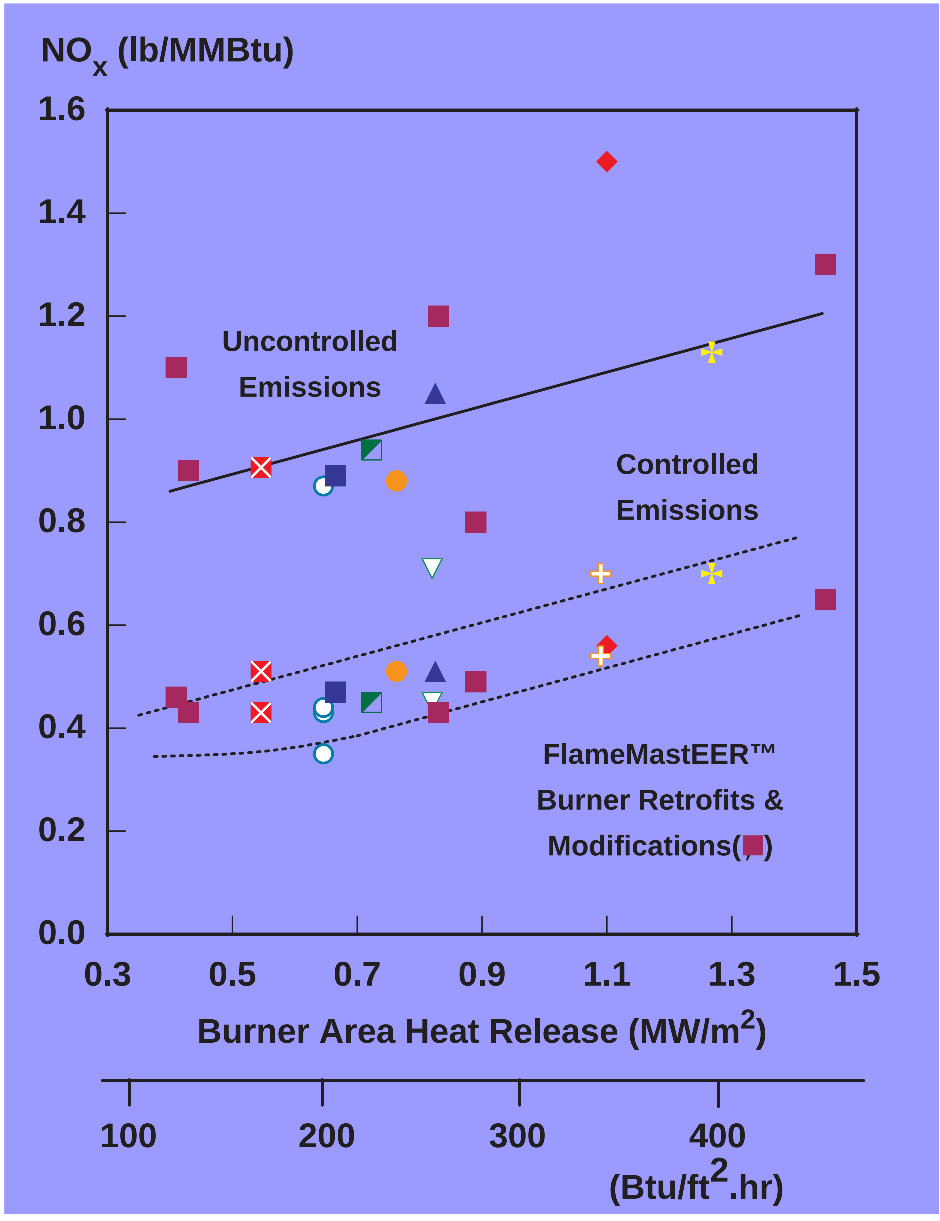
- Flame Stabilizer anchors flame to coal pipe
- Divided Air Register provides air staging, oxidizing envelope
- Variable Air & Swirl Distribution control NOx and flame shape



Low-NOx Coal Burner

Performance

- Comparison of uncontrolled and retrofit low-NOx burner performance
- Typically 30-50% NOx reduction can be achieved for most applications
- Performance depends on boiler design and retrofit flexibility, coal type, available firing depth, etc.
- Burner Modifications comparable to new burner performance.
- Unit size from 50 to 868 MWe.



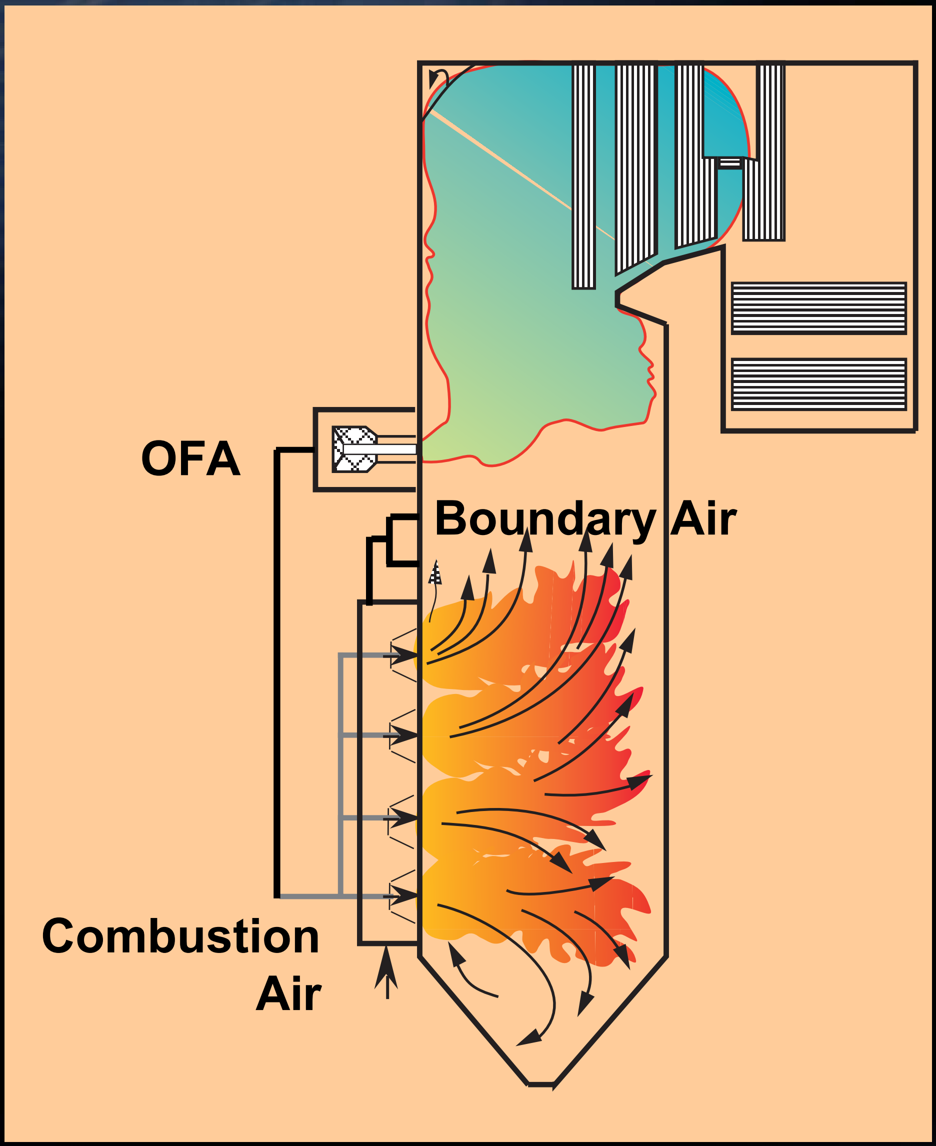
GE Low NOx Burner Modification Experience

(Wall-Fired)

3,426 Total MWe

Company	Application	Unit Size (MW)	Fuel	Base NOx lb/MMBtu	NOx Reduction	Year
Louisville Gas & Electric/ Cane Run #4	Low NOx Burner Modifications Gas Ignitors	170	Bituminous	1.2	64%	1996
Louisville Gas & Electric/ Cane Run #5	Low NOx Burner Modifications Gas Ignitors	180	Bituminous	0.8	40%	1996
Jamestown Board of Public Utilities/Boiler #9	Low NOx Burner Modifications	17	Bituminous	0.6	20%	1996
Jamestown Board of Public Utilities/Boiler #10	Low NOx Burner Modifications	17	Bituminous	0.6	20%	1996
Jamestown Board of Public Utilities/Boiler #12	Low NOx Burner Modifications	25	Bituminous	0.9	52%	1996
Jamestown Board of Public Utilities/Boiler #11	Low NOx Burner Modifications	17	Bituminous	1.1 1	58%	1997
Dayton Power & Light/ J.M. Sturat #3	Low NOx Burner Modifications	605	Bituminous	1.15	41-52%	1997
Conectiv/ Indian River #1	Low NOx Burner Modifications and Overfire Air	89	Bituminous	0.67	43%	1998
Conectiv/ Indian River #2	Low NOx Burner Modifications and Overfire Air	89	Bituminous	0.81	53%	1998
Dayton Power & Light/ J.M. Stuart #1	Low NOx Burner Modifications	605	Bituminous	1.15	41-52%	1998
Dayton Power & Light/ J.M. Stuart #2	Low NOx Burner Modifications	605	Bituminous	1.15	41-52%	1999
Wisconsin Public Service/Weston #2	Low NOx Burner Modifications	91	PRB	0.89	55%	1999
Mid-American Power LLC/Stoneman #1	Low NOx Burner Modifications	24	Bituminous	1	55%	1999
Mid-American Power LLC/Stoneman #2	Low NOx Burner Modifications	24	Bituminous	1	55%	1999
Dynegy Havana #6	Low NOx Burner Modifications and Overfire Air	460	Bituminous	0.4	33%	2001
TVA Widows Creek #4	Low NOx Burner Modifications	125	Bituminous	0.9	40%	2001

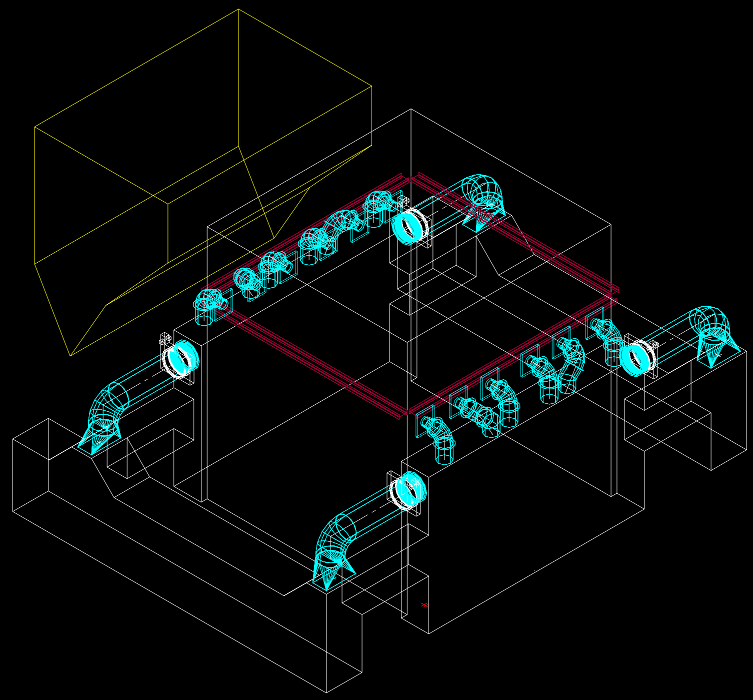
Overfire Air (OFA)



- 20-30% of combustion air diverted to an elevation above the main burners
- 20 - 50% NOx control with standard and low-NOx burners
- Applicable to wall- and tangentially-fired systems
- Reduced excess air levels in burner zone may require boundary air to control corrosion
- Design tools:
  - Empirical databases
  - Physical and computational fluid dynamic modeling

Burner Modifications with Overfire Air

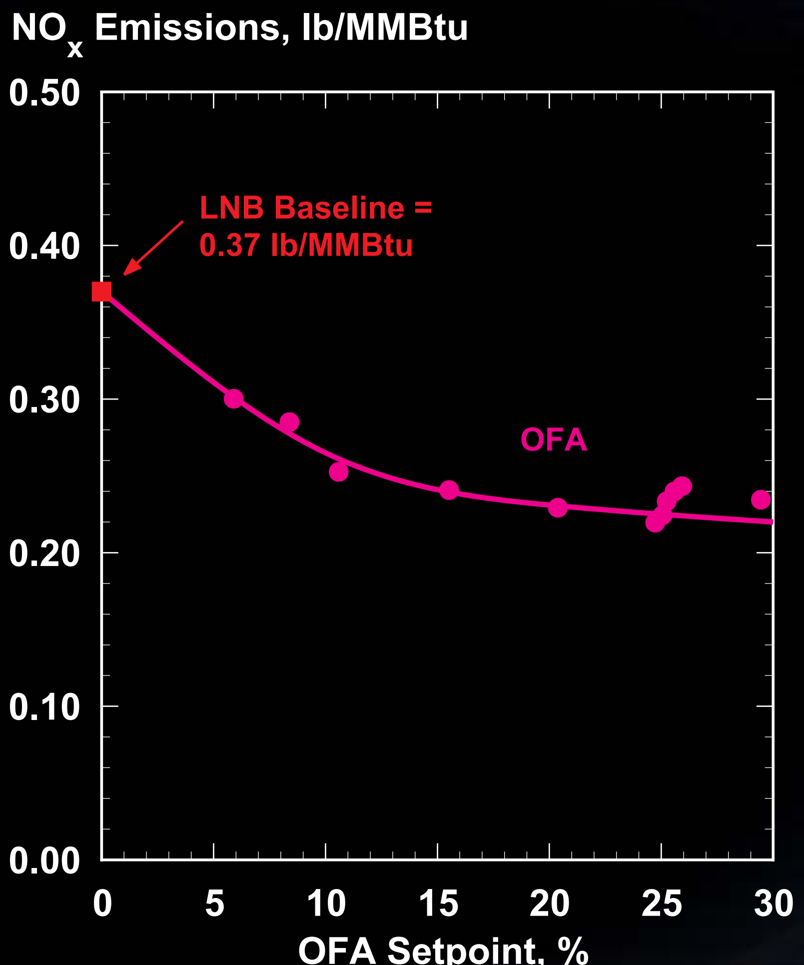
- **Furnace**
  - Unit Capacity: 490 MW
  - Opposed wall
  - Divided furnace
  - Depth = 51′, width = 52‘
- **OFA Injectors**
  - Design capacity = 30% Total Air
  - Opposed wall (6 x 2 = 12 injectors)
  - Duel concentric design
  - Adjustable swirl
- **Burner Modifications**
  - Flame stabilizers
  - Divided air register with flow control damper



GE OFA Experience

LNB and OFA Performance

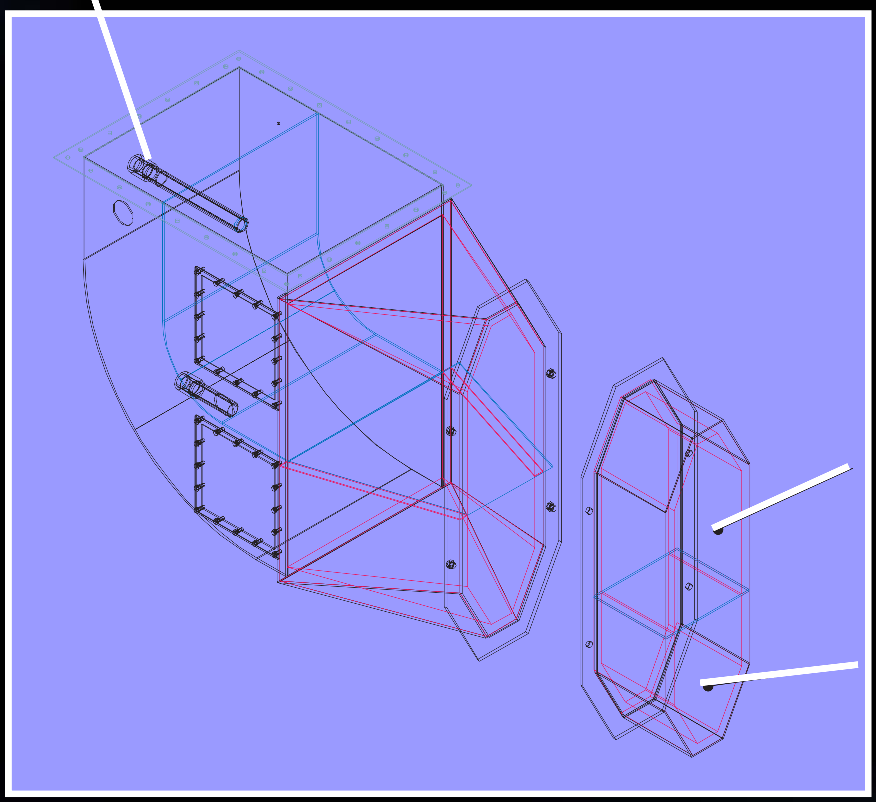
- Unit Capacity: 490 MW
- Firing Design: Opposed Wall
- Fuel: Bituminous Coal
- NO_X Control System:
  - Low-NO_X Burners
  - Overfire Air
- System Performance:
  - $NO_X < 0.22$ lb/MMBtu
  - CO < 100 ppm
  - LOI < 5%



OFA can provide significant emissions reduction

OFA Injector Design

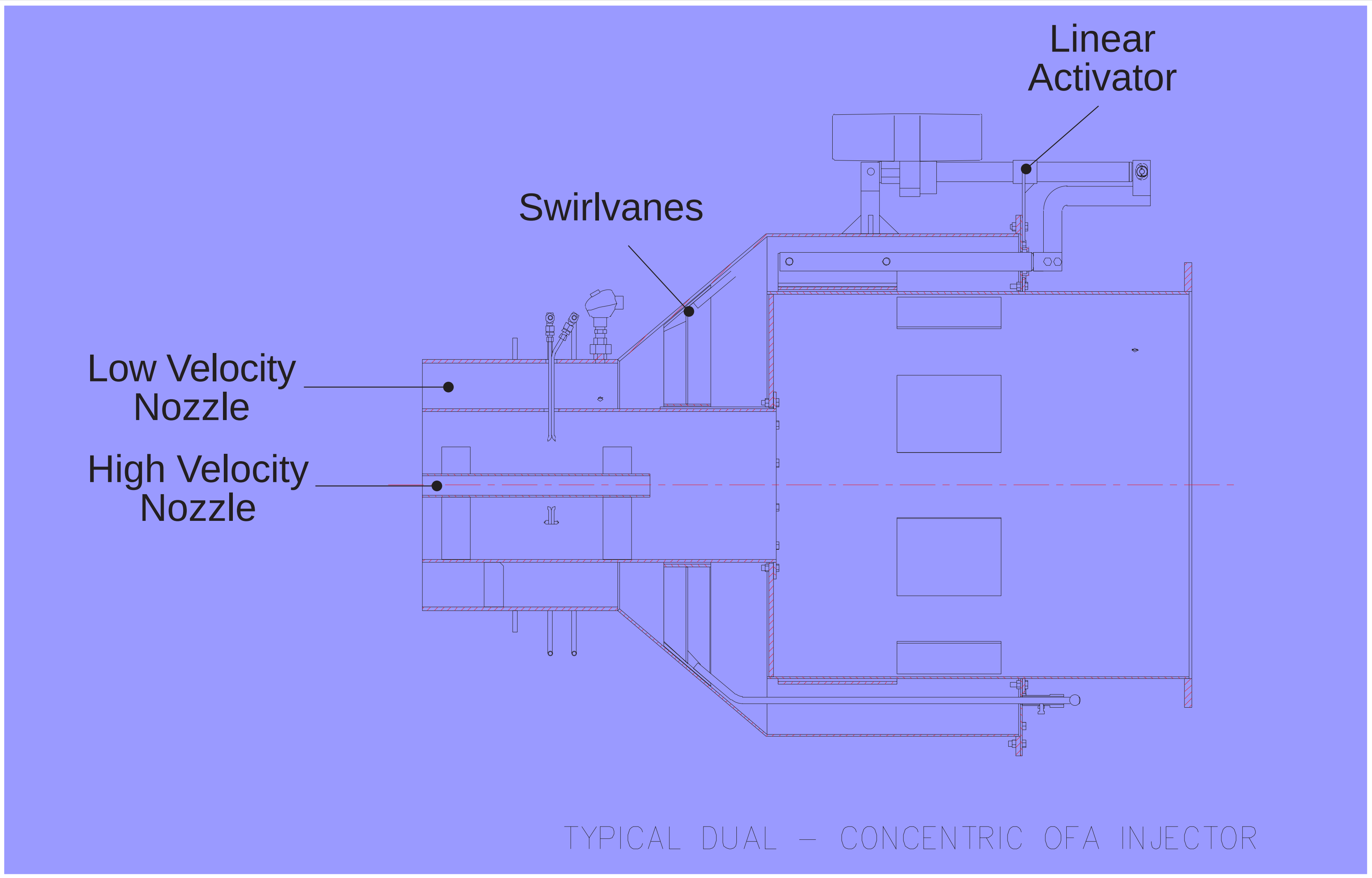
Tangentially Fired Boilers



- Placement
  - One per corner
  - 350 ms from top burner elevation for overfire air
  - Under nose for reburn
- Control
  - Flow monitoring (8)
  - High velocity dampers (4)

OFA Injector Design

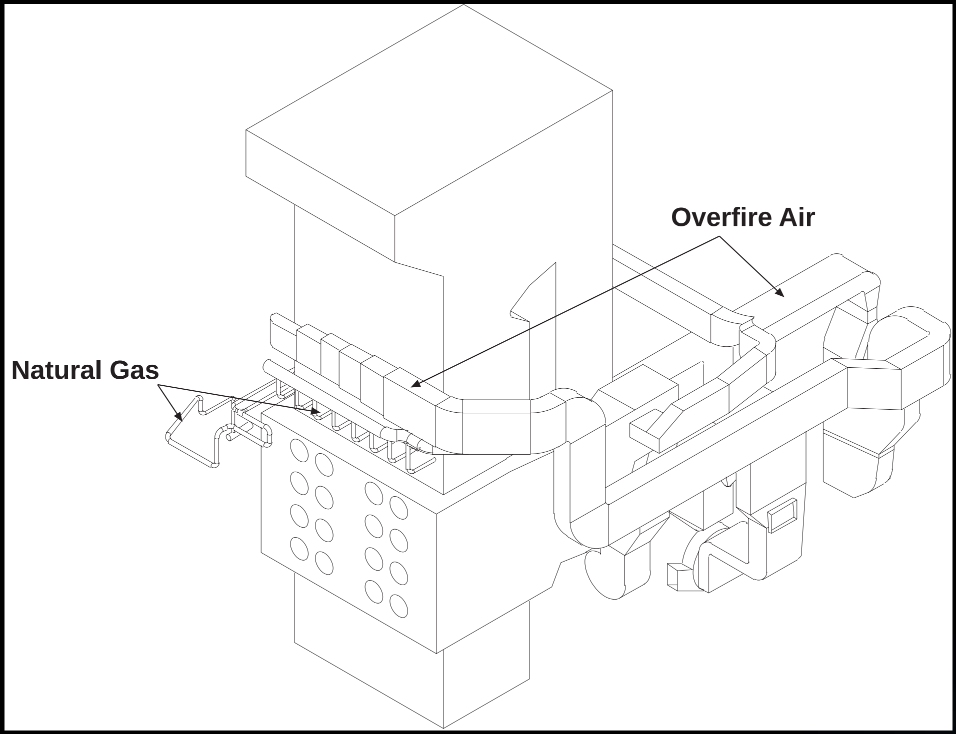
Wall-Fired Boilers



GE OFA Experience

OFA System Design

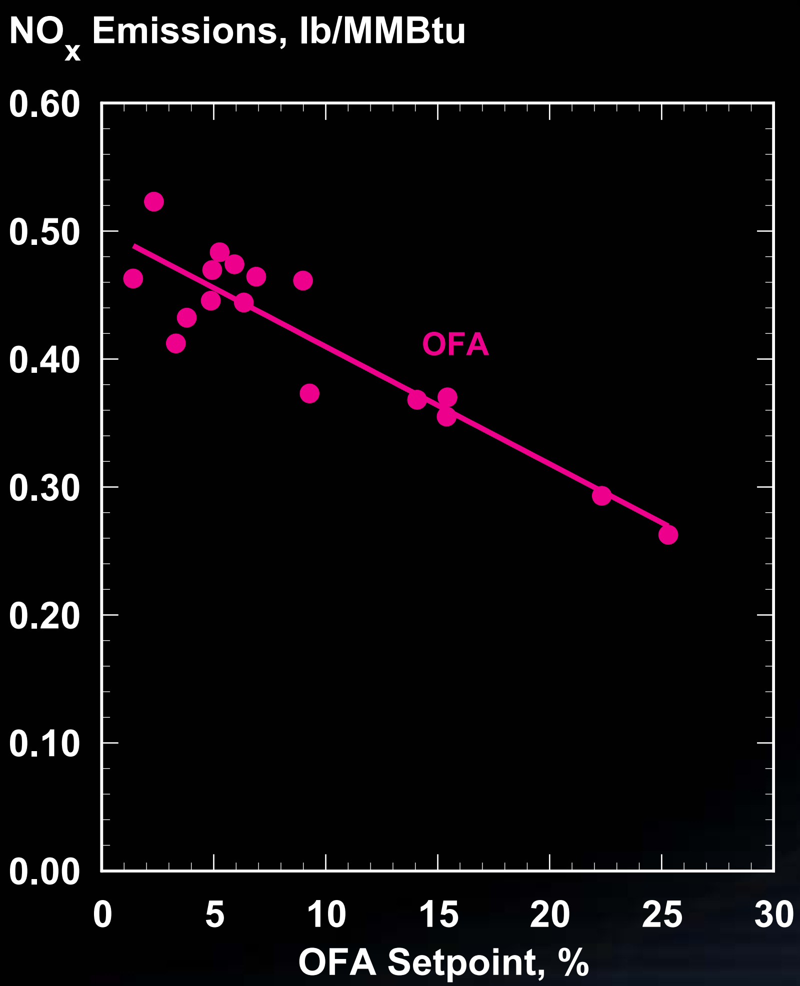
- Furnace
  - Unit Capacity: 150 MW
  - Single wall
  - Partial division wall
- OFA Injectors
  - Design capacity = 25% OFA
  - Front wall (6 injectors)
  - Duel concentric design
  - Adjustable swirl



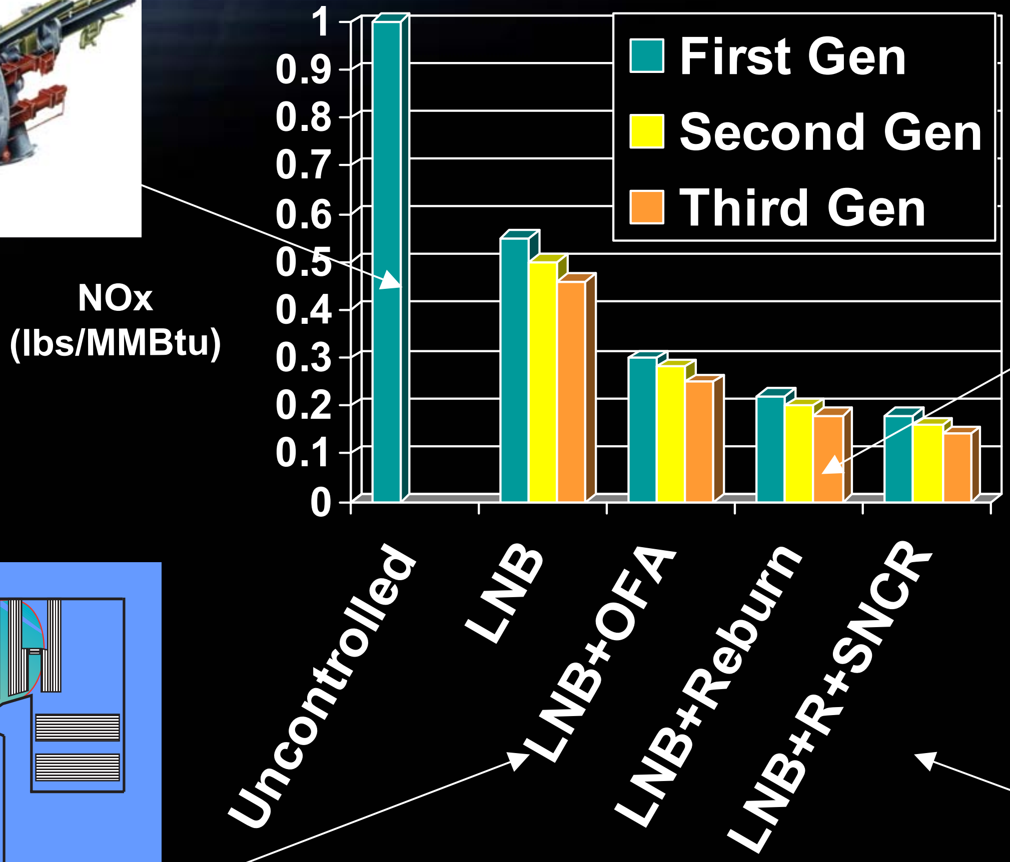
GE 'OFA + LNB' Experience

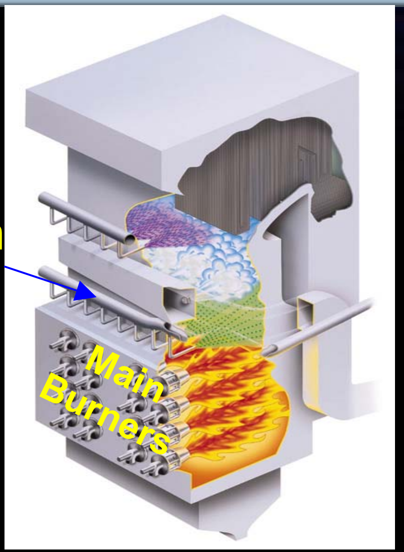
LNB and OFA Performance

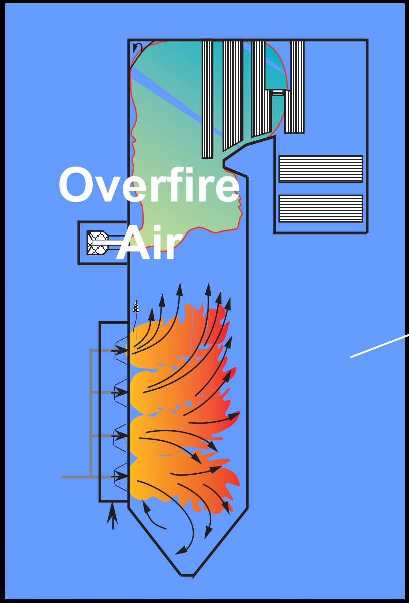
- Unit Capacity: 150 MW
- Firing Design: Single Wall
- Fuel: Bituminous Coal
- NO_X Control System:
  - Low-NO_X Burners
  - Overfire Air
- System Performance:
  - NO_X < 0.26 lb/MMBtu
  - CO < 100 ppm
  - LOI < 12%

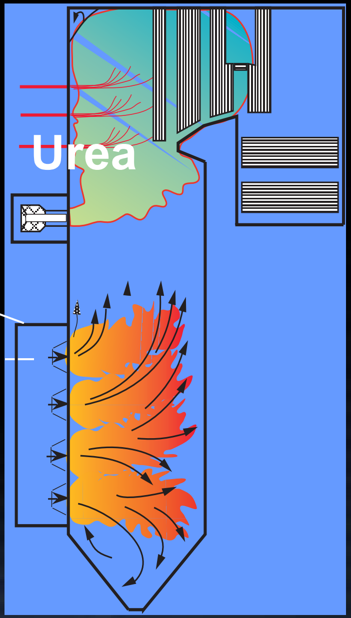


Multi-Generational NOx Performance









Recent Reburn Construction Retrofits

5,443 Total MWe

Company	Unit	Application	Unit Size (MW)	Fuel	Base NOx lb/MMBtu	NOx Reduction	Year Comm
City Water, Light & Power	Lakeside #7	Gas Reburning system w/OFA Incl. Cyclone Fired	33	Eastern Bituminous	0.95	74%	1992
New York State Electric and Gas	Greenidge #6	Gas Reburning Tangential (LNCFS)	100	Eastern Bituminous	0.53	47%	1996
Gas Research Institute / New York State Electric and Gas	Greenidge #6	Advanced Gas Reburning Tangential w/ Gas Reburning	100	Eastern Bituminous	0.53	72%	1996
Eastman Kodak	Kodak Park #16	Micronized Coal Reburning Cyclone	50	Bituminous	1.21	63%	1996
Illinois Power	Hennepin #1	Orimulsion Reburning w/OFA, T-Fired	71	Eastern Bituminous	0.75	65%	1997
Tennessee Valley Authority	Allen #1	Gas Reburning Cyclone	300	Western Bituminous & PRB	1.29	67%	1998
Tennessee Valley Authority	Allen #2	Overfire Air	300	Western Bituminous & PRB	1.29	53%	1999
Tennessee Valley Authority	Allen #3	Overfire Air	300	Western Bituminous & PRB	1.29	45%	1999
Baltimore Gas and Electric	CP Crane #1	Gas Reburning Cyclone	200	Bituminous	1.84	65%	1999
Baltimore Gas and Electric	CP Crane #2	Gas Reburning Cyclone	200	Bituminous	1.8	68%	1999
Conectiv	Edge Moor #4	Gas Reburning Tangential	160	Bituminous	0.31	48%	1999
Allegheny	Hatfield #2	Gas Reburning Wall-Fired	600	Bituminous	0.62	68%	1999
PEPCO	Chalk Point #1	Gas Reburning Wall-Fired	350	Eastern Bituminous	0.6	43%	2000
PEPCO	Chalk Point #2	Gas Reburning Wall-Fired	350	Eastern Bituminous	0.6	45%	2000
Cheng Loong	Cheng Loong #1	Coal Reburning Wall-Fired	N/A	Bituminous	410 ppm @ 6% O2		2000
Georgia Power	Scherer #1	Coal Reburning Tangential	887	Eastern Bituminous	0.36		2000
Allegheny	Hatfield #1	Gas Reburning Wall-Fired	600	Bituminous	0.62		2002
Allegheny	Hatfield #3	Gas Reburning Wall-Fired	600	Bituminous	0.62		2003

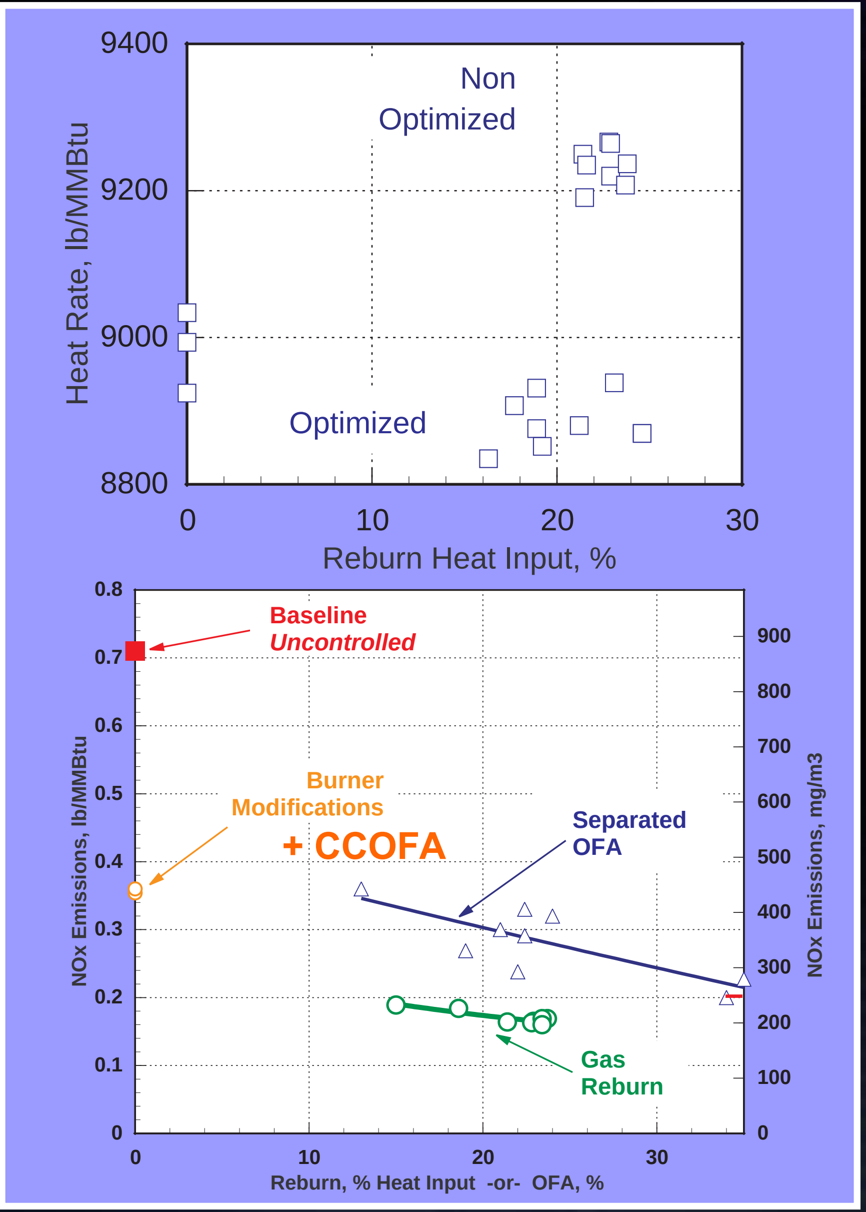
Reburn Combustion NOx Control

Gas Reburn & SOFA

(Separated Overfire Air)

- 165 Mwe
- Tangentially-fired
- 4 burner elevations
- Bituminous coal
- Technology
  - Gas reburn
  - SOFA

40% Reduction with OFA
52% Reduction with Reburn
1% Heat Rate Improvement



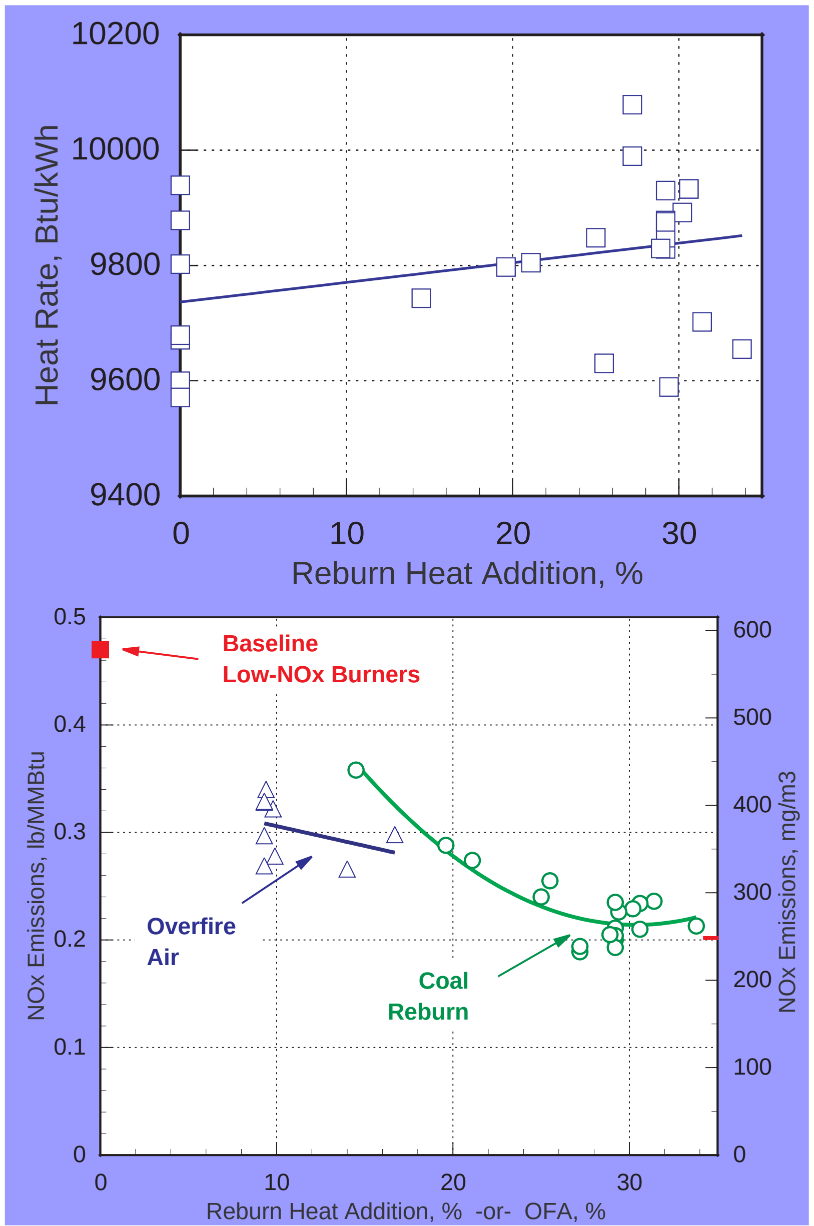
Reburn Combustion NOx Control

Gas Reburn & SOFA

(Separated Overfire Air)

- 240 Mwe
- Wall fired
- Opposed
- 24 Burners
- Fuels
  - Bituminous coal
  - Coal + Pet Coke Blend
- Technology
  - Coal Reburn
  - SOFA

36% Reduction with OFA
52% Reduction with Reburn
1% Heat Rate Degradation



Typical Project: Scope of Material Supply

Combustion Modifications

- Reburn Fuel Injectors
- OFA Injectors
- Tubewall Penetrations
- OFA Instrumentation and Control Devices
- OFA Ductwork
- Cooling Air Piping/Ductwork/Dampers
- Reburn Fuel I&C Devices
- CCOFA Ports
- OFA Ductwork
- Piping/Ductwork Hangars & Supports

Selective Non-Catalytic Reduction (SNCR)

- Agent Injection Lances or Grid
- Agent Unloading, Storage, and Transfer System
- Transport and Injection Air Skid
- Tubewall Penetrations
- Agent Distribution Skid

GE Reburning & Advanced NOx Technologies

Summary

- Significant operational experience with Reburning using natural gas, fuel oil, coal, and other fuels
- Reburning has been applied to all major classes of boiler designs (i.e., tangential, wall, and cyclone)
- Reburning has been applied to coal, natural gas, and fuel oil fired units, with minimal impacts on unit performance or operability
- Reburning may be combined with other NOx control technologies (e.g. low-NOx burners) and with post combustion NOx control (i.e. SNCR)
- NO_x reductions of between 50–70%, relative to uncontrolled baseline, can be achieved depending upon the reburning fuel used and site-specific factors (e.g., unit design, retrofit difficulty, etc.)
- Success is based upon application of a validated design methodology. This methodology is used to design systems that optimize NO_x reduction and minimize impacts on boiler performance
- GE continually develops advancements in reburning technology that reduce costs, extend fuel and operating flexibility, and improve performance (e.g., Advanced Reburning).

imagination at work

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