REINHOLD ENVIRONMENTAL Ltd.

2011 NOx-Combustion Round Table & Expo Presentation

February 7-8, 2011, in Birmingham, AL / Hosted by Southern Company

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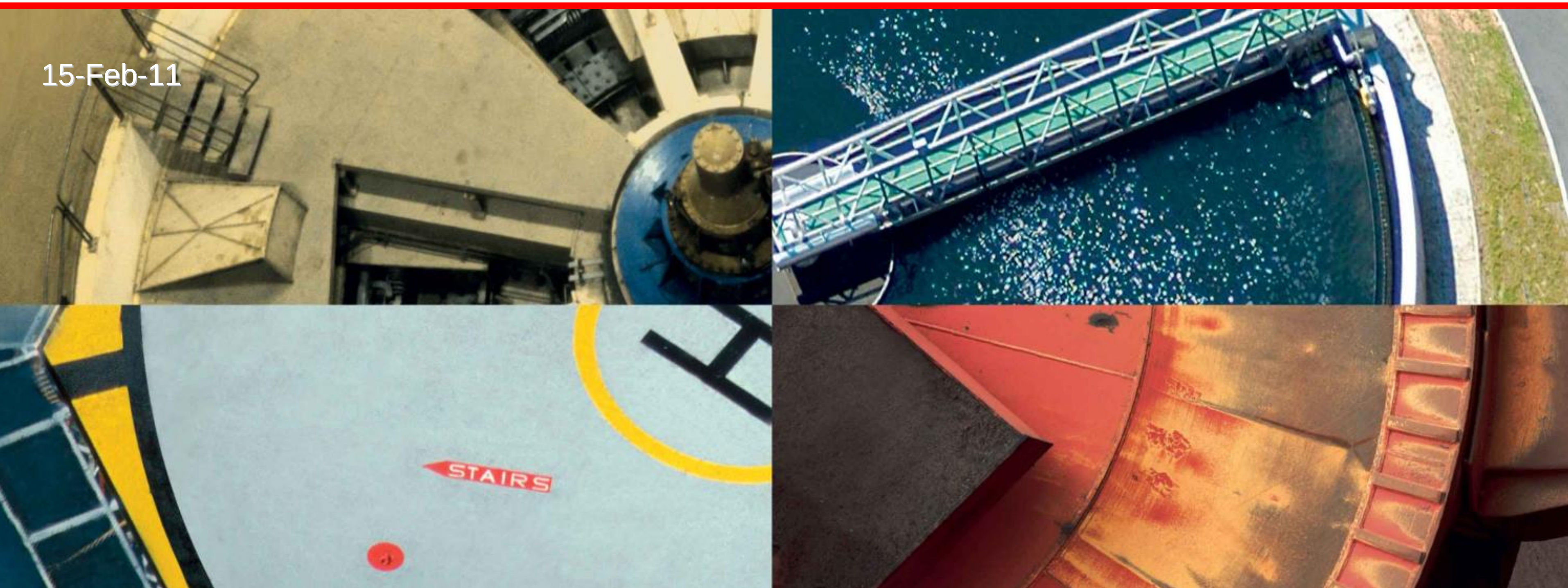
EcoNomics™

Low Cost Options for NO_X Reduction

February 7th, 2011

15-Feb-11



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Outline

- Introduction & Reason for NO_X Reduction Investigation
- Evolution of NO_X Reduction
- Current & Upcoming EPA Regulations
- In Furnace NO_X Reduction Technologies
  - Fuel Switching
  - Controls / Instrumentation Upgrades
  - Boiler Tuning
  - Burner Upgrades
  - Staged Combustion
  - SNCR
  - Gas Reburn
  - Flue Gas Recirculation
  - Layered Technology
- Performance Comparison
- Cost Comparison
- Additional Boiler Considerations

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Background

Intro

- Historically standards subject to continuous downward pressure
- More and more, burner auxiliary and support systems (e.g. mills and controls) need to be modified to address efficiency and performance factors degraded by direct NO_x control measures
- Competitive pressures have expanded spectrum of technologies available placing emphasis on cost/benefit analysis and application tailoring

Evolution of In-Furnace NO_X Control

- NO_X Reduction Techniques were initially slow to evolve and simplistic to keep costs low and maintain boiler efficiency
- Techniques included Trimming O_2 levels and operating Flue Gas Recirculation systems.
- In the late 1980's NO_X reduction techniques began to evolve into a scientific approach to major NO_X reducing technologies
- Low NO_X Burners and Staged Combustion offered reductions not previously achieved by boiler tuning
- Further NO_X Reduction technologies to remove NO_X instead of limit its formation developed for greater removal rates
- The latest generation of NO_X removal involves technologies outside the furnace (SCR, RSCR, ASCR, etc.) however are not the focus of this presentation but referenced as a layered technology approach

Current & Upcoming NO_X Regulations

- 40 CFR Parts 50 & 58 "Primary National Ambient Air Quality Standards for Nitrogen Dioxide; Final Rule"
- Final rule effective April 12, 2010 and establishes new 1-hour standard at a level of 100 ppb NO_2
- This limitation is based on the 3 year average of the 98^{th} percentile of the yearly distribution of 1 hour daily maximum concentrations
- EPA is also establishing NO_2 monitoring networks
- New monitoring network is to cover locations where maximum NO_2 concentrations are to occur
- This includes locations within 50 meters of major roadways as well as monitors sited to measure the area-wide NO_2 concentrations that occur more broadly across communities

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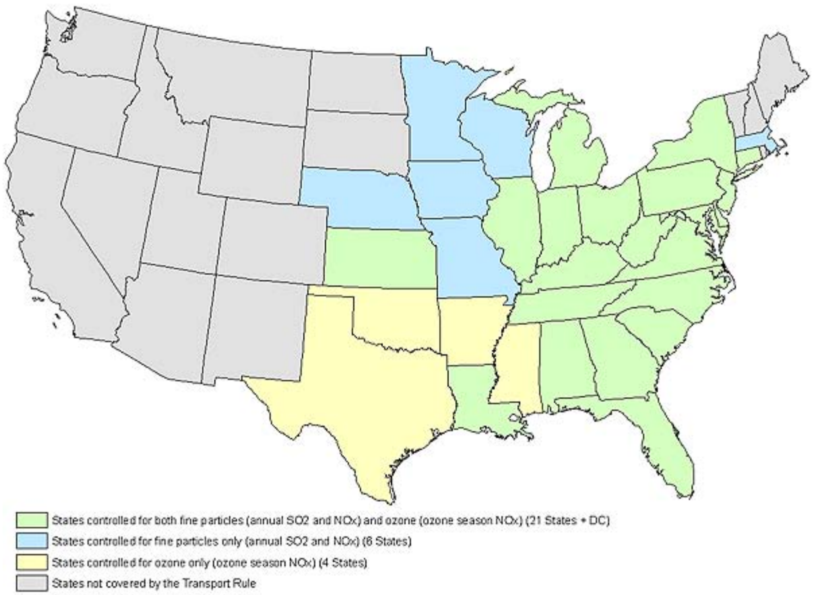
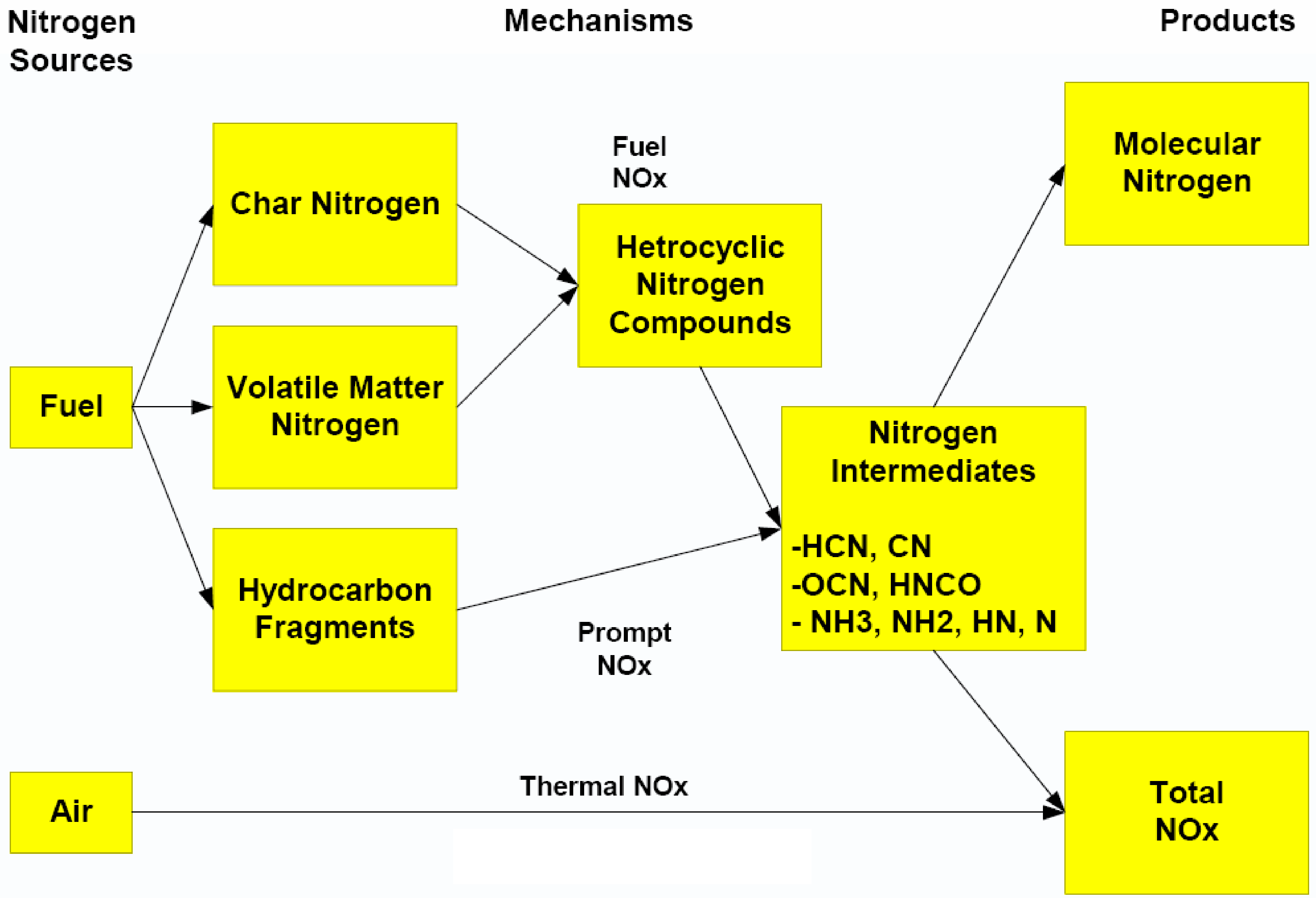
Current & Upcoming NO_X Regulations

- Clean Air Transport Rule (CATR)
- Proposed Rule to be place in effect in 2014 regulating NO_X & SO_2
- This Rule is expected to reduce power plant NO_X emissions by 52% and SO_2 emissions by 71%
- NO_X reduction regulations proposed by CATR apply to all states shown in Green, Blue, & Yellow



How NO_X Forms



NO_X Reduction Technologies

- Low Nitrogen Fuels
- Control / Instrumentation Upgrades
- Boiler Tuning
- Burner Upgrades
- Staged Combustion
  - Overfire Air (OFA)
  - Separated Overfire Air (SOFA)
  - Rotating Opposed Fire Air (ROFA)
- Selective Non-Catalytic Reduction (SNCR)
- Gas Reburn
- Flue Gas Recirculation
- Layered Technologies

Fuel Switching

Fuels with lower available Nitrogen content will produce less NO_X in combustion. In general, approximately 60% - 80% of the fuel nitrogen converts to NO_X (remainder 20% – 40% of NO_X is formed thermally)

Operational Benefits

- No additional capital equipment required
- No down time outage
- Immediate results

Potential Issues

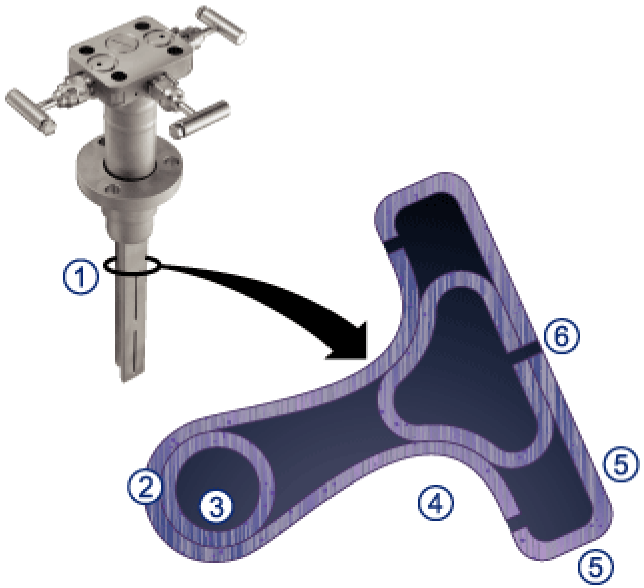
- Facility De-Rate Probable
- Additional Boiler Slagging
- Fuel Cost

Controls / Instrumentation Upgrades

Better measurement of fuel, primary & secondary air, ignitors, and flame will lead to better combustion control and lower NO_X generation

Operational Benefits

- Easy Installation & Commissioning
- Immediate results
- Real-Time measurement devices offer the ability to instantaneously adjust for changing conditions to reduce the potential of boiler slagging, high Furnace Exit Gas Temperature (FEGT), and balance proper temperature, O_2, and CO in furnace to optimize combustion



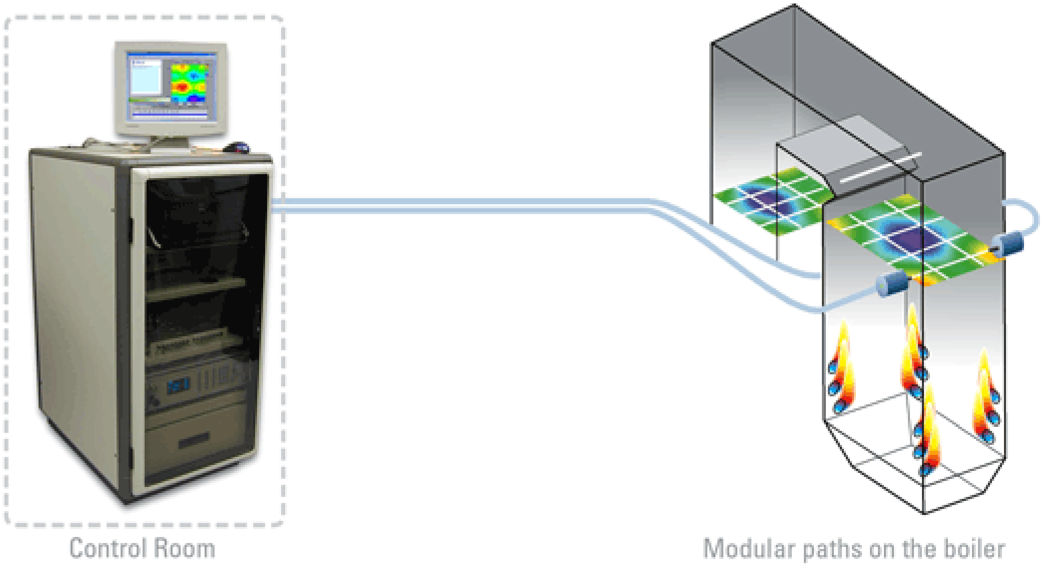
*Rosemount Annubar

Controls / Instrumentation Upgrades

Devices for real time coal flow measurement, airflow measurement, FEGT, O_2, CO are available for boiler installation and are compatible with almost all boiler control systems.

Potential Issues

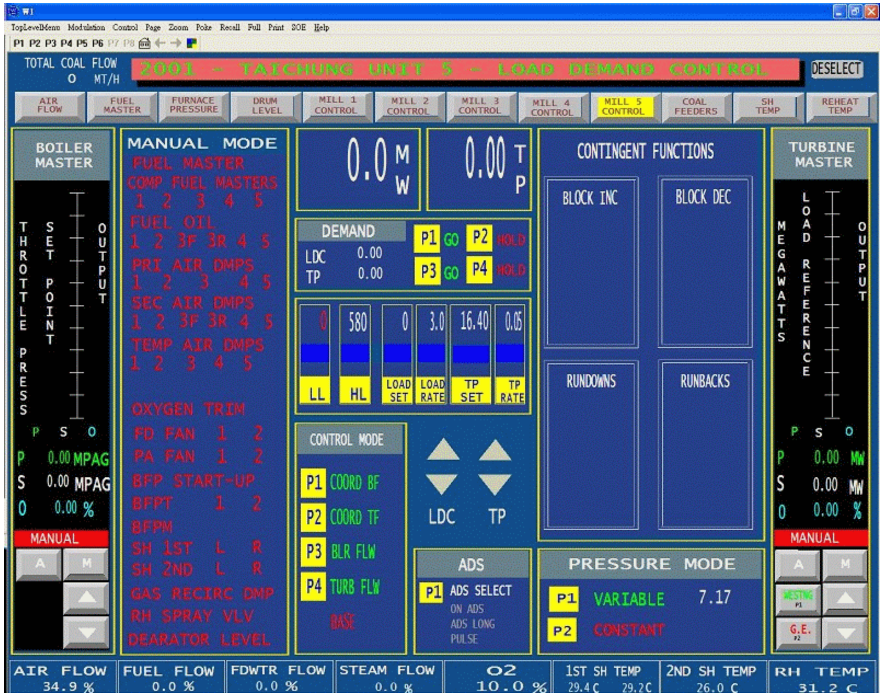
- Lack of regular maintenance / calibration will reduce effectiveness
- Potential to uncover additional capital expenses to be effective (replacing seals, dampers, etc.)



*Picture supplied from Zolo

Boiler Tuning

More precise O_2 control will produce lower NO_X



Operational Benefits

- Short Equipment Downtime if any
- Immediate results
- More precise O2 control
- Better Fuel & Air distribution in furnace

Potential Issues

- Potential to degrade over time requiring additional tuning
- Ineffective if operations staff does not follow revised procedures

Low NO_X Burners & Mill Performance

Controlling fuel and air mixing along with changing fuel distribution and heat release rate will result in lower flame temperature and less thermal NO_X generated

Operational Benefits

- Low Operating Costs
- Potential to reduce effects of coal "roping"
- Elimination of CO along sidewalls
- Potential Slagging Control
- Corrosion Control
- Very Effective NO_X Reduction Technique for Wall Fired Units (~50%)

*Siemens Opti-Flow Low NO_X Burner

Low NO_X Burners & Mill Performance

Potential Issues

- Extended Boiler Outage (~30 days) required for installation
- Less effective for T-Fired Units (~10% NO_X Reduction)
- Potential for additional boiler modification (burner tilts, windbox, pressure parts, etc.)
- Increase of LOI (Reduced Boiler Efficiency, Ash Composition Changed [sales, combustibility])
- Control Modifications / Upgrades
- Increased Furnace Exit Gas Temperature
- Higher Attemperation Rate
- Higher economizer outlet temperature
- Potential increase of flyash / bottom ash ratio
- Mill performance directly affects combustion performance (classification modification)
- Potential for additional slagging or "eyebrows" if not implemented and operated properly

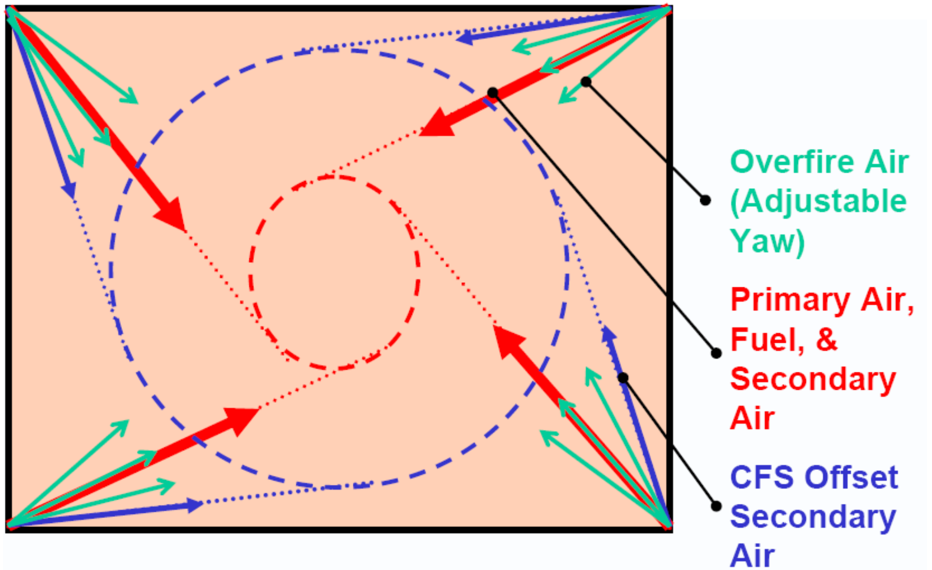
Concentric Firing System

Concentric Firing System is designed to created more in-furnace turbulence for better fuel & air mixing during combustion.

System will only work for a T-Fired Unit

Creates an Oxidizing Near-Wall Environment

Reduces CO & LOI

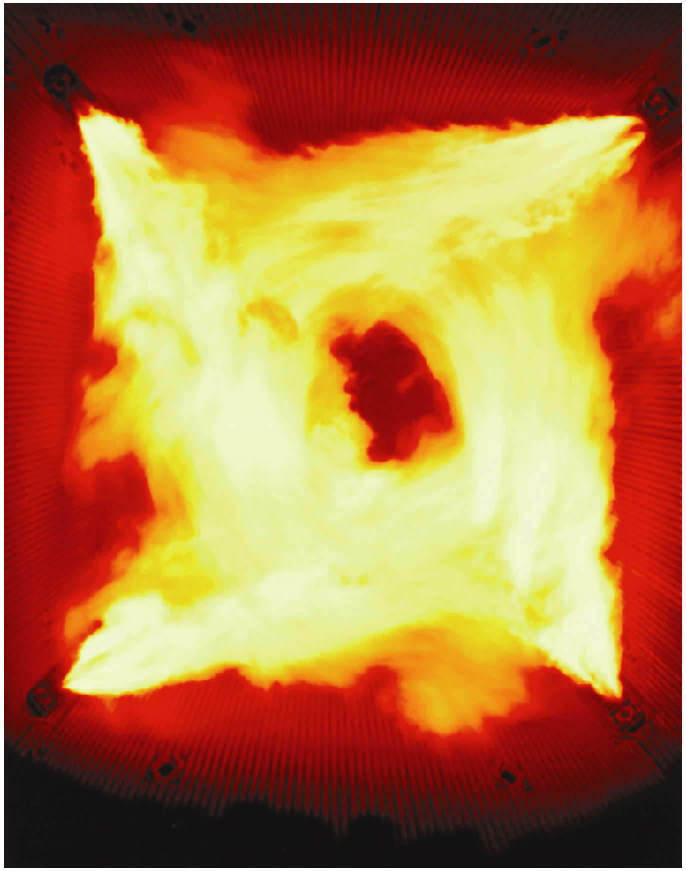


Plan View of Tangentially Fired Furnace

*Graphic Provided by Alstom

Overfire Air

Staged combustion results in lower peak flame temperature and less thermal NOx generation due to low combustion stoichiometry



Operational Benefits

- Low Operating Costs
- Very Effective NO_X Reduction Technique for T-Fired Units (~50%) due to high tolerance of low stoichiometry

Close-Coupled vs. Separated Over-Fire Air

- Close Coupled Over-Fire Air (CCOFA) generally used in T-Fired units only and located directly above the main burner zone.
- Separated Over-Fire Air System (SOFA) similar to CCOFA except placement is located higher in furnace above main burner zone.

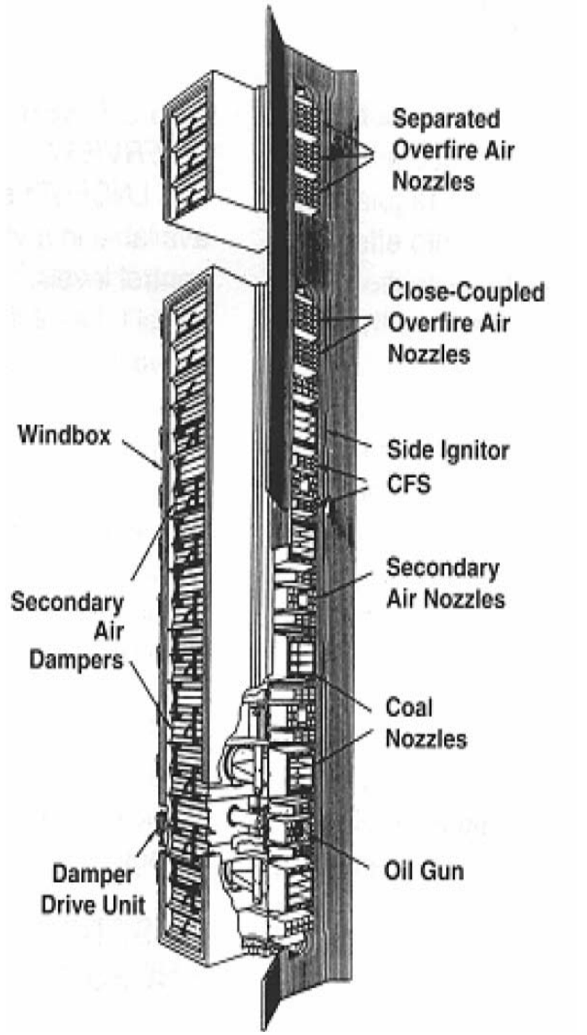
Overfire Air

Potential Issues

- Extended Boiler Outage (~30 days) required for installation
- Less effective for Wall Units (~10% NO_X Reduction)
- Additional Boiler Controls Required
- Water Wall Modifications
- Space and Support Considerations for Additional Duct Runs
- Potential Fan Limitations

Separated Overfire Air

Additional combustion staging results in lower peak flame temperature and less thermal NO_X generation. Additional staging reduces stoichiometry further in a controlled Manner.



Operational Benefits

- Low Operating Costs

Potential Issues

- Extended Boiler Outage (~30 days) required for installation
- Additional Boiler Controls Required
- Major Water Wall Modifications
- Space and Support Considerations for Additional Duct Runs
- Probable Fan Limitations
- Potential for Over-Staging reducing the effectiveness of NO_X Reduction

Rotating Opposed Fire Air

Staged combustion combined with high furnace turbulence will reduce Thermal NO_X generation, increase heat transfer efficiency, and increase combustion efficiency

Operational Benefits

- Flexibility for installation locations of Nozzles and Equipment (CFD Modeling)
- Potential to be coupled with additional NO_X Reduction Equipment

*Picture from Nalco-Mobotec

Potential Issues

- Extended Boiler Outage (~30 days) required for installation
- Additional Boiler Controls Required
- Large Fans Required (Additional Space, High Capital Cost, High Auxiliary Loads)
- Support Considerations for Additional Duct Runs
- Noise Considerations (Noise Abatement / OSHA Concerns)
- Large Dynamic Loads – Fans, if required (significant foundations required)

Selective Non-Catalytic Reduction (SNCR)

Ammonia and NO_X will react with the energy from combustion to break down to less harmful compounds (N_2 & H_2O)

NO_X Reduction with ammonia effective between 1,400 °F and 2,000 °F

Simplified, the reactions occur according to:

4 NO + 4 NH3 + O2 -> 4 N2 + 6 H2O

Below 1,400 °F there is not enough available energy for reaction to occur. Ammonia will pass through the system without reacting and exhaust into the atmosphere. Ammonia injected into the furnace at temperature greater than 2,000 °F will oxidize and increase the formation of NO_X by means of the following reaction:

4 NH3 + 5 O2 -> 4 NO + 6 H2O

Urea is also a preferred reagent for use in SNCR Systems. This is due to its easy handling and reduced toxicity. If urea is used for SNCR systems an additional reaction is required to convert urea to the ammonia needed in the NO_X reduction reaction:

NH2CONH2 + H2O -> 2NH3 + CO2

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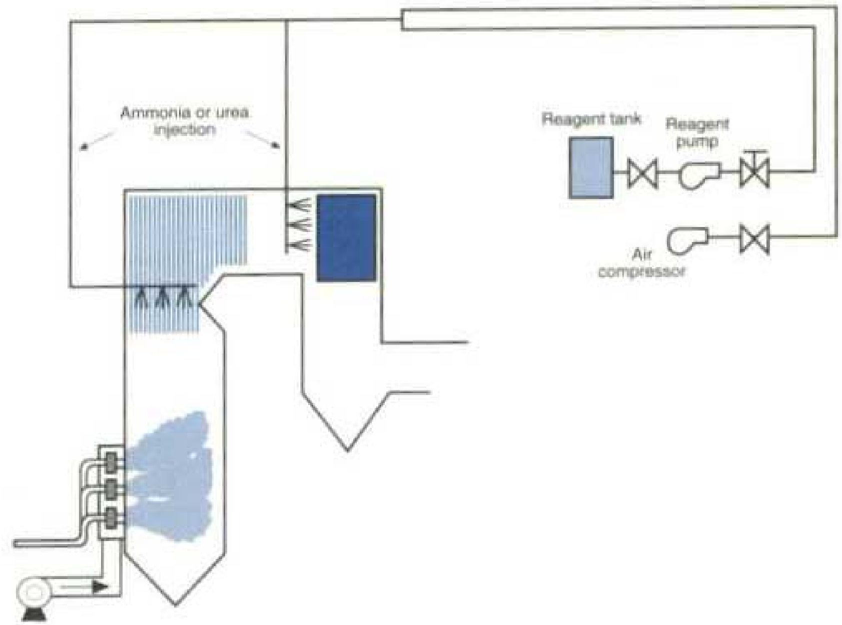
Selective Non-Catalytic Reduction (SNCR)



Operational Benefits

- Simple Boiler Installation
- Effective for all boilers and fuels

Potential Issues

- Additional Operating Costs
- Additional Controls Required
- Ammonia Slip (Ash Sales, Permitting, Ammonia Sulfate and Bisulfate formation)
- Urea vs. Aqueous Ammonia (reagent cost, shipping costs, handling requirements)
- Storage Requirements
- Ammonia Handling and Storage Safety

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Natural Gas Reburning

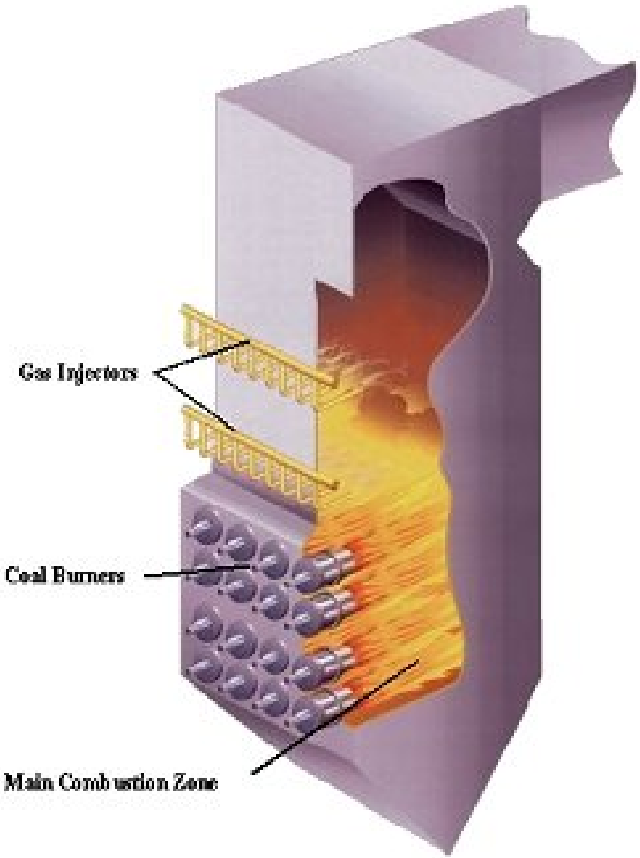
Natural Gas in supplied to a fuel-rich flue gas from the main combustion zone. Hydrocarbon fragments convert NO_X from main combustion to molecular nitrogen while over-fire air completes combustion

NO_X Reducing Equations:

CHi + NO -> HCN + O (1)
NO + NHi -> N_2 + H_2O (2)

Hydrogen Cyanide produced in reaction (1) is converted to N_2 by the following reactions:

O + HCN -> NCO + H (3)
NCO + H -> NH + CO (4)
NH + H -> N + H_2 (5)
N + NO -> N_2 + O (6)



Natural Gas Reburning

Operational Benefits

- Simple Boiler Installation
- Effective for all boilers and fuels

Potential Issues

- Potential for up to 25% of boiler heat input to be supplied by natural gas
- Furnace Exit Gas Temperature Increase (Tube Problems, Increased Economizer Exit Temp, ESP Performance)
- Additional Controls Required
- Potential metallurgical issues with superheaters & reheaters
- NFPA Requirements

Flue Gas Recirculation

Combustion neutral cooled flue gas is re-circulated into the furnace to generate higher air / fuel mixing and cooler flame temperature reducing thermal NO_X generation.

Operational Benefits

- Potentially already installed on most boilers, if oil or gas-fired (limited installations on coal-fired units)

Potential Issues

- Not Effective for PC Combustion
- Additional Controls Required
- Long Duct Runs
- Support issues to be addressed
- Aux Power
- Foundations
- Maintenance

Layered Technologies

Layered technologies considered jointly and integrated can achieve cumulative reductions when installed in sequence.

Operational Benefits

- Co-benefits of multiple technologies offering cumulative reductions and optimized removal

Potential Issues

- Interdependency of technologies operating jointly

Layered NOx Reduction

- Combustion NOx Control
  - Combustion Tuning
  - Low-NOx Burners
  - OFA
- Post-Combustion NOx Control
  - Rich Reagent Injection
  - Selective Non-Catalytic Reduction
  - Selective Catalytic Reduction

Advanced SCR Application

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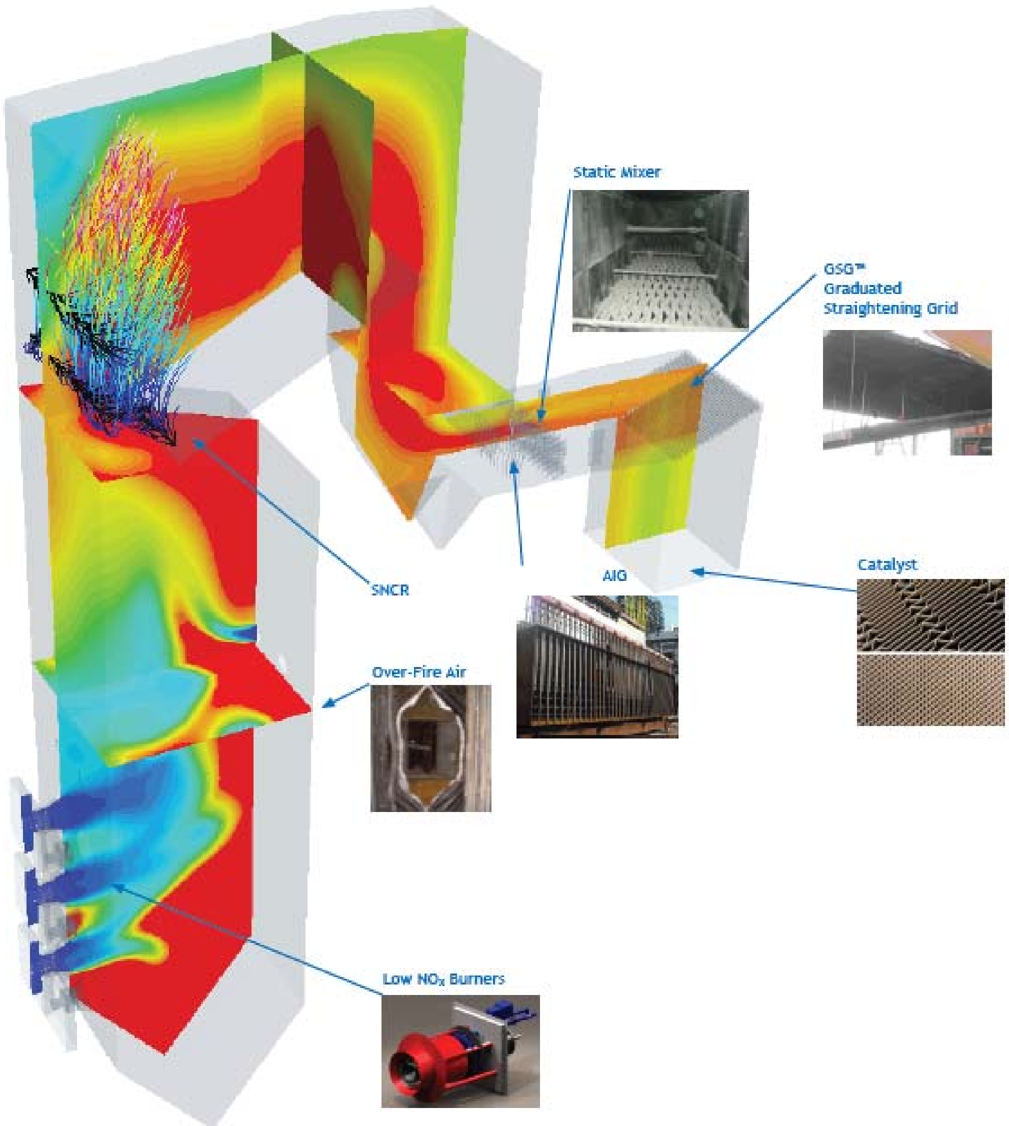
Technology	Reduction	Total %
Low-NOx Burners	30%	30%
Combustion Mods / OFA	30%	51%
SNCR	30%	66%
Single Layer SCR	45%	81%

Slide contents courtesy of FUEL TECH

ASCR™ Advanced SCR

- **80+% NO_x Reduction**
- **40-60% less than conventional SCR**



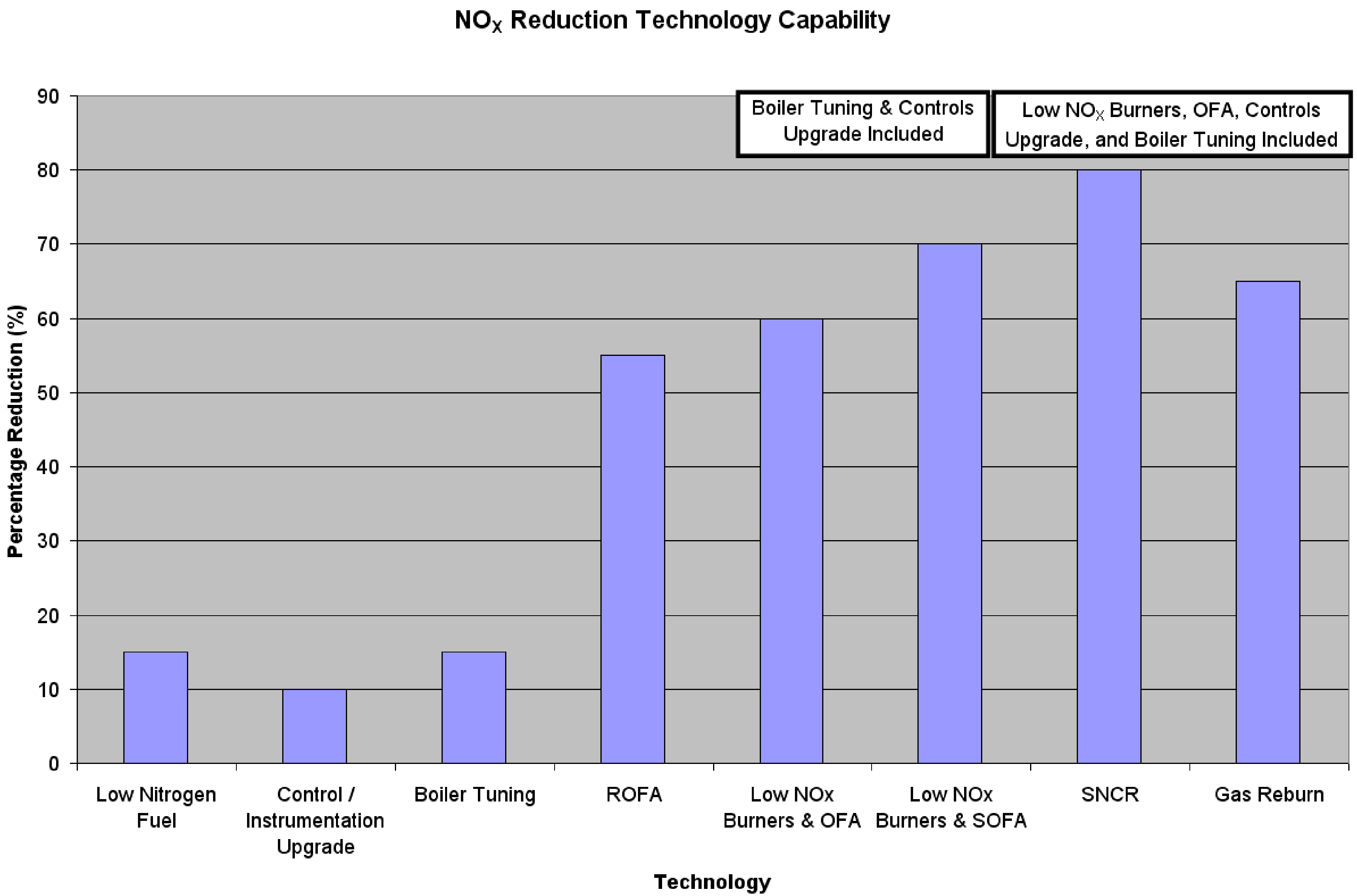
Slide contents courtesy of FUEL TECH

ASCR NOx Technologies

- ASCR Utilizes Integrated NOx Reduction Technologies
  - LNB/OFA, SNCR and RRI
  - High Performance SCR
- Optimized SNCR
  - Better Reagent Utilization
  - Higher Removal Efficiency
  - Higher NH_3 Slip
- Optimized SCR Utilizing Less Catalyst than Traditional SCR
  - Single Layer
  - Maintain the proper flue gas flow criteria
- Overall Reductions in Excess of 80%
- 60 – 85% NOx Reduction at 40 to 70% of Full Scale SCR Cost

Slide contents courtesy of FUEL TECH

NO_X Reduction Comparison



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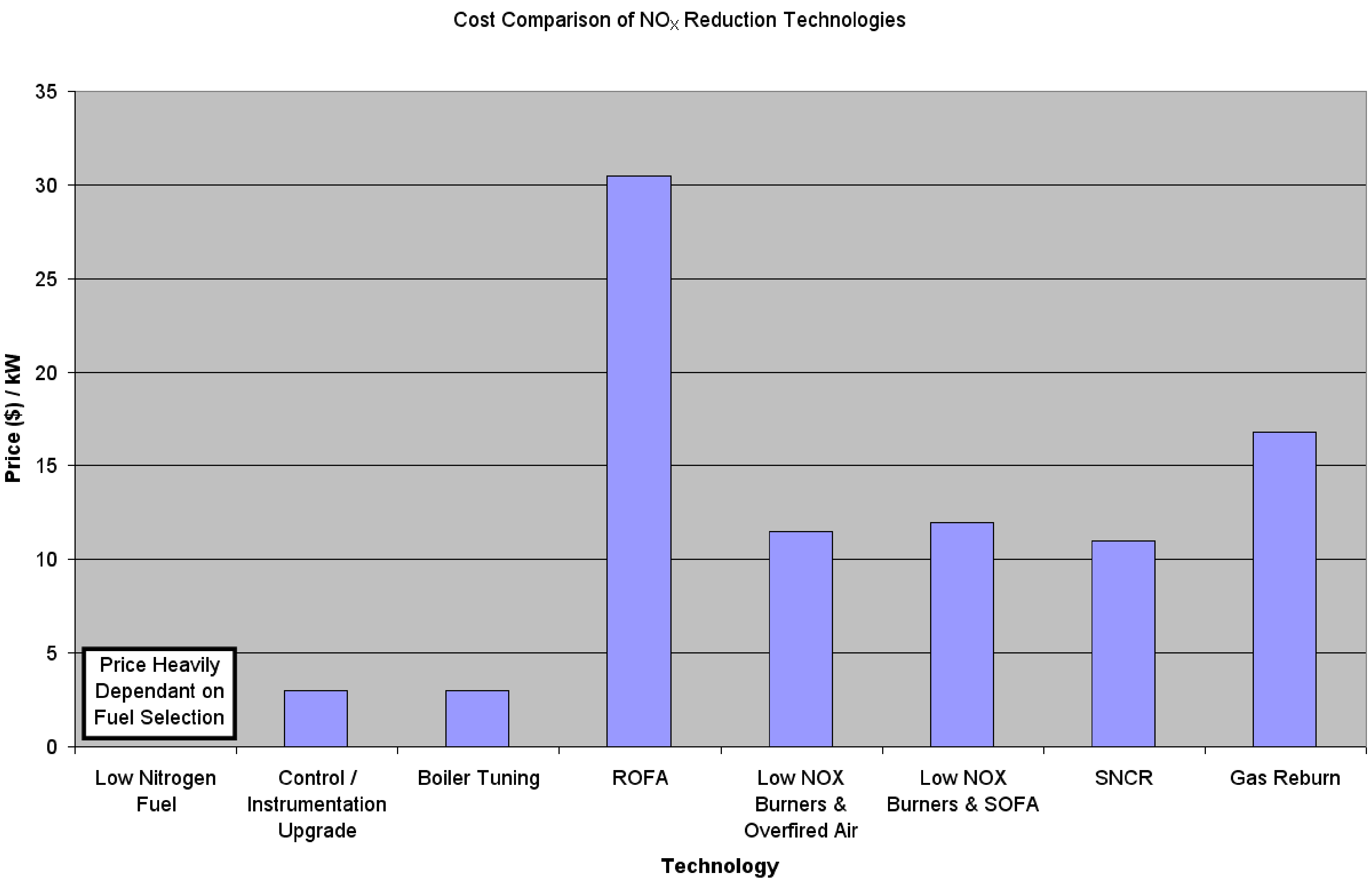
NO_X Reduction Cost Comparison



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Additional Considerations

- Pricing shown reflects material costs only (transportation, installation, commissioning, engineering, etc. extra)
- Additional Permitting may be required for boiler modifications
  - Air Permit
  - Water Permit
  - Ash Disposal
  - SWPPP
- Formation of substances harmful to other boiler equipment (e.g. ammonia sulfates corroding air heaters or clogging baghouses)
- Potential to generate additional CO
- NFPA Requirements need to be addressed

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