8th International Conference on Clean Coal Technologies, Cagliari, Italy

8-12th May 2017

EXPERIENCE WITH LARGE SNCR SYSTEMS

FUEL TECH
Technologies to enable clean efficient energy

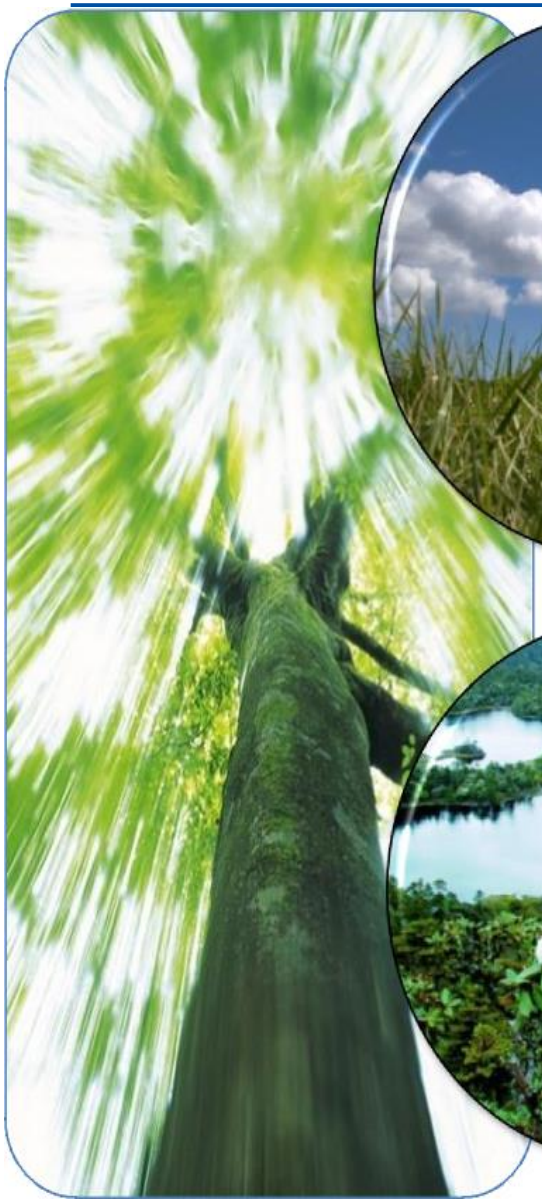
Prepared by: Dr John Boyle

Presented by: Piers de Havilland

CCT 2017 AGENDA

- Fuel Tech background
- Selective Non-Catalytic Reduction (SNCR) of NOx
  - SNCR Fundamentals
  - CFD Modelling and the effective of CO
  - The MNL
- Case Study
  - CLECO
- Questions

VISION AND MISSION



Vision

A cleaner, more energy-efficient, sustainable environment to benefit the world's present and future generations.

Mission

We provide our customers innovative solutions to produce clean, efficient energy by applying advanced technologies through engineering excellence and our knowledge of complex combustion processes.

We create long-term value for our employees and our stockholders, and for the communities in which we do business, through our continued pursuit of innovation and growth.

FUEL TECH INC.

FTI is an industry leading producer of state-of-the-art air pollution control and combustion process optimization technology for power generation boilers

- **A pioneer** in the development of Nitrogen Oxide (NOx) emissions reduction using SNCR technology
- **Over 30 years** experience serving as a trusted partner helping international governments and power producers achieve their emission reduction objectives
- Solutions used in **over 900** utility and industrial boilers in **26 countries**
- In-house laboratories and a focus on research & development ensure access to **leading edge technologies and solutions**

FUEL TECH
Technologies to enable clean efficient energy

- **Founded in 1981**
- **Listed on NASDAQ since 1993 ("FTEK")**

★**OFFICE LOCATIONS:**

Warrenville, IL | Cleveland, OH | Stamford, CT | Durham, NC | Milan, Italy | Beijing, China | Santiago, Chile

FTI has a clear corporate vision to create "a cleaner, more energy-efficient, sustainable environment to benefit the world's present and future generations"

FUEL TECH INC.

For 30+ years, Fuel Tech has offered an evolving suite of custom solutions that reduce NO_X $PM_{2.5}$ SO_x CO_2 and other hazardous emissions

Air Pollution Control (APC)

- Robust and comprehensive suite of low capital, high efficiency NO_x reduction solutions that meet global regulatory mandates
- Applicable to all project sizes and geographies
- Capital project sale, typically fixed-price, with turn-key capabilities
- Primary customers are utilities and industrial companies that own coal-fired power generation facilities

Chemical Technologies

- Reduces slag and corrosion in the boiler
- Utilizes proprietary technology combined with boiler modeling expertise to improve unit efficiency, reliability and environmental status
- Annuity-type model producing stable margins and cash flow
- Allows fuel flexibility as customers can burn cheaper, lower quality coal without sacrificing performance
- Decreases maintenance requirements, lowering labor costs and extending the useful life of the equipment

Performance Modeling and R&D Labs

- Unique and highly sophisticated combination of Computational Fluid Dynamics (CFD) modeling, physical flow modeling, custom Chemical Kinetics Modeling (CKM) and proprietary virtual reality-based visualization
- Modeling allows FTI's engineers to design, recommend and showcase technology solutions and establish accurate performance
- Enables fully optimized system performance and guarantee positions
- Three R&D labs dedicated to product development and enhancement

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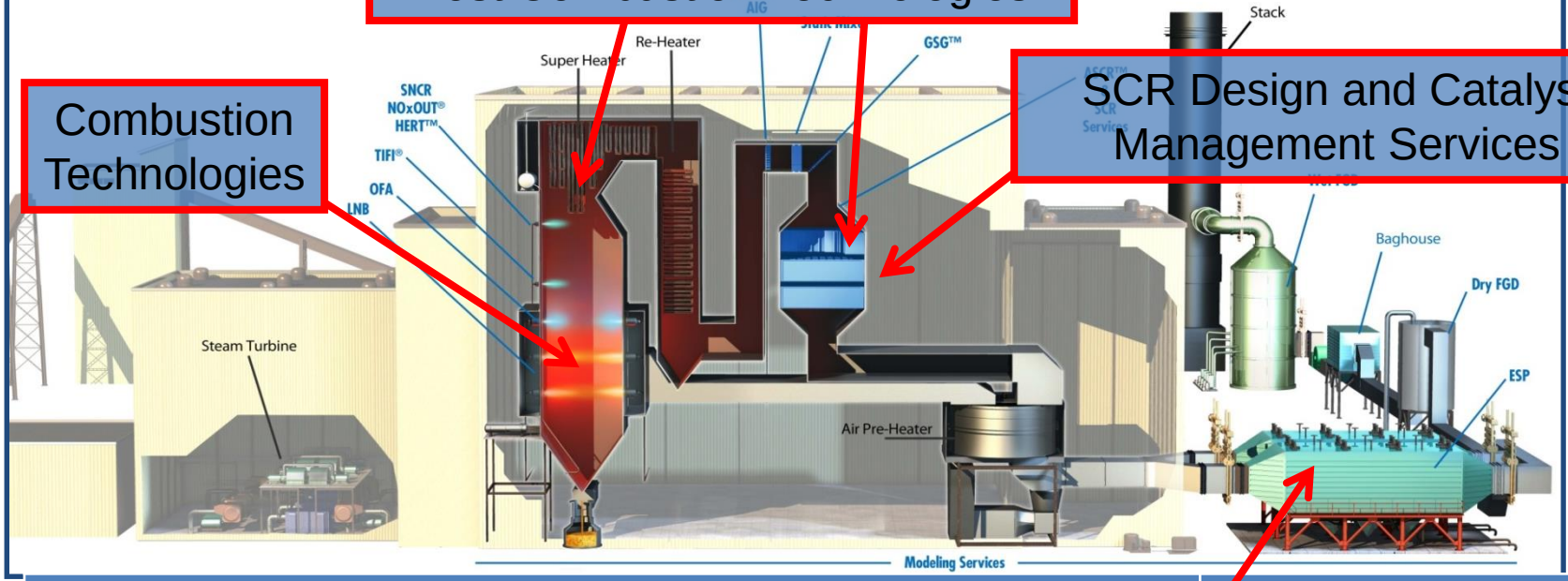
TYPICAL POWER PLANT

Advanced Modeling Services – All Technologies

Post Combustion Technologies

Combustion Technologies

SCR Design and Catalyst Management Services



FGC and ESP Retrofits

Fuel Tech Technologies		Non-Fuel Tech Supplied
• **ASCR™ Advanced SCR:** System which combines LNB + OFA + SNCR + AIG + GSG™ + Catalyst • **AIG:** Ammonia Injection Grid • **GSG™:** Graduated Straightening Grid • **HERT™:** SNCR system using high energy injectors • **LNB:** Low NOx Burners • **NOxOUT®:** SNCR system using high momentum injectors • **ULTRA™:** Urea-based ammonia generation system for SCR • **SCR:** Selective Catalytic Reduction • **SNCR:** Selective Non-Catalytic Reduction	• **SCR Services:** Selective Catalytic Reduction Services which include: optimizing process design, catalyst selection, and improving the overall performance of SCR • **Static Mixer:** Equipment used to mix temperature, velocity, and NOx to optimize SCR performance ahead of the AIG • **TIFI® Targeted In-Furnace Injection™:** Chemical Injection Programs used to target slag control SO_3 mitigation, and fuel flexibility	• **Baghouse:** Controls Particulate Matter (PM) from flue gas • **Dry FGD:** Scrubber to maximize SO_2 removal using Flue Gas De-Sulfurization (FGD) • **Wet FGD:** Scrubber to maximize SO_2 removal using Flue Gas De-Sulfurization (FGD) • **Dry FGD:** Scrubber to remove SO_2 with less water than Wet FGD

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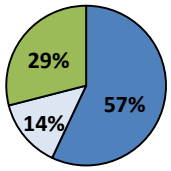
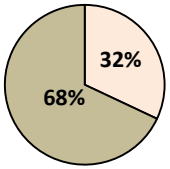
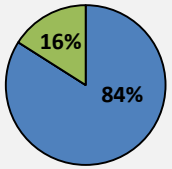
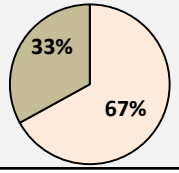
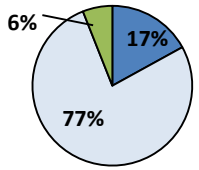
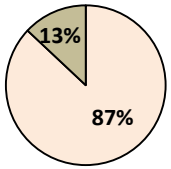
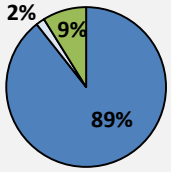
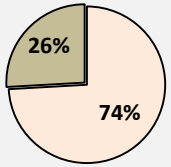
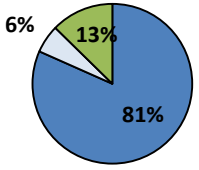
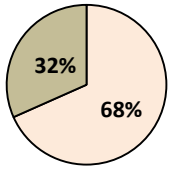
SELECT FTEK EXPERIENCE

Technology	Total Deployments / MW	Deployments by Geography	Deployments by End Market	FTI Advantage
SNCR	**570+ / 51,300**			• Sophisticated modular and unique process design • Unparalleled system installation experience and know-how • Proprietary modeling enables industry leading system efficiency and design
TIFI®	**110+ / 21,900**			• Unique construction and modeling, injection system design, equipment and chemical solutions • Skilled system design experience across all operating conditions • Ability to lower operating costs without sacrificing performance
ULTRA®	**110+ / 27,700**			• FTI invented the technology and therefore has the most scientific basis, design expertise and experience • Recently began deploying the fifth generation of the technology • Enhanced safety
Combustion Modifications	**110+ / 16,400**			• Unique Insight – The combination of unparalleled experience (>110 system installations) and unique in-house modeling systems create highly differentiated capabilities • Balanced Combustion Performance – Focus on complete system optimization, not just NO_x reduction
SCR, ASCR and Catalyst Management Services	**150+ / 63,200**			• Over 20 years of SCR design experience • Extensive modeling experience to design and or fix underperforming systems • Unique ability to layer smaller SCR systems with other NO_x control technologies to achieve similar results to full size SCRs

U.S. China Rest of World

Utility Industrial

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Selective Non-Catalytic Reduction (SNCR) of Nitrogen Oxides

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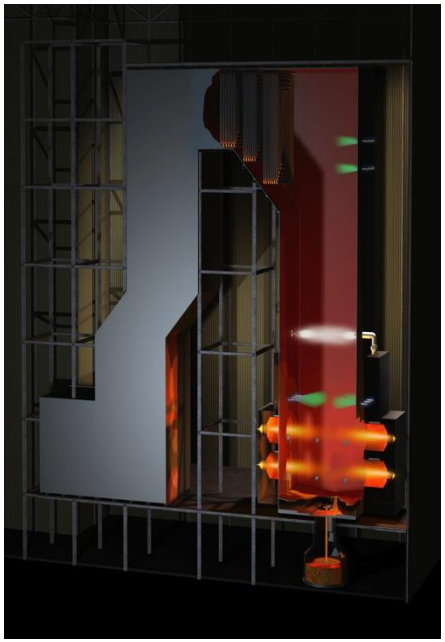
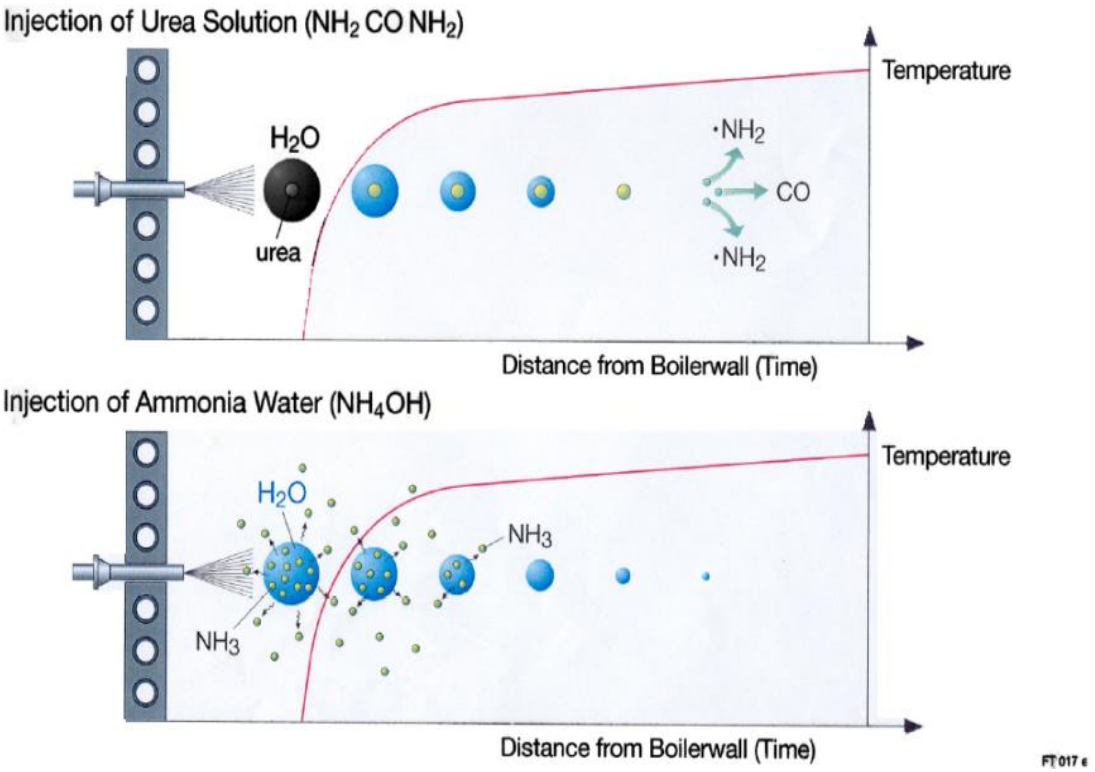
FUEL TECH SNCR FEATURES

In-furnace, Post-combustion NO_x Control



- Reagent choice is dependent upon application
  - Urea Solution or Aqueous Ammonia.
- Multiple Technologies
  - NO_xOUT® Technologies and ASNCR with ATM
  - High Energy Reagent Technology (HERT)
- **Multiple Nozzle Lances (MNLs) for precise droplet control in large boilers.**
- Multiple injection zones and SCR combination for high NO_x Reduction with NH_3 Low Slip Control

SNCR FUNDAMENTALS



Urea droplets formed by FTI injectors are characterized in test facilities using Laser Doppler techniques.

SCALE-UP TO LARGE FURNACES

- Extensive Modelling predicts effective zone
  - Dependent on Temperature, NOx, CO
  - Validated with field measurements
- Chemical distribution in effective zone
  - Requires a suite of injector options
- Large furnaces offer unique challenges
  - Low NOx baseline
  - High gas temperatures (and often high CO)
  - Large sectional area makes reagent distribution difficult

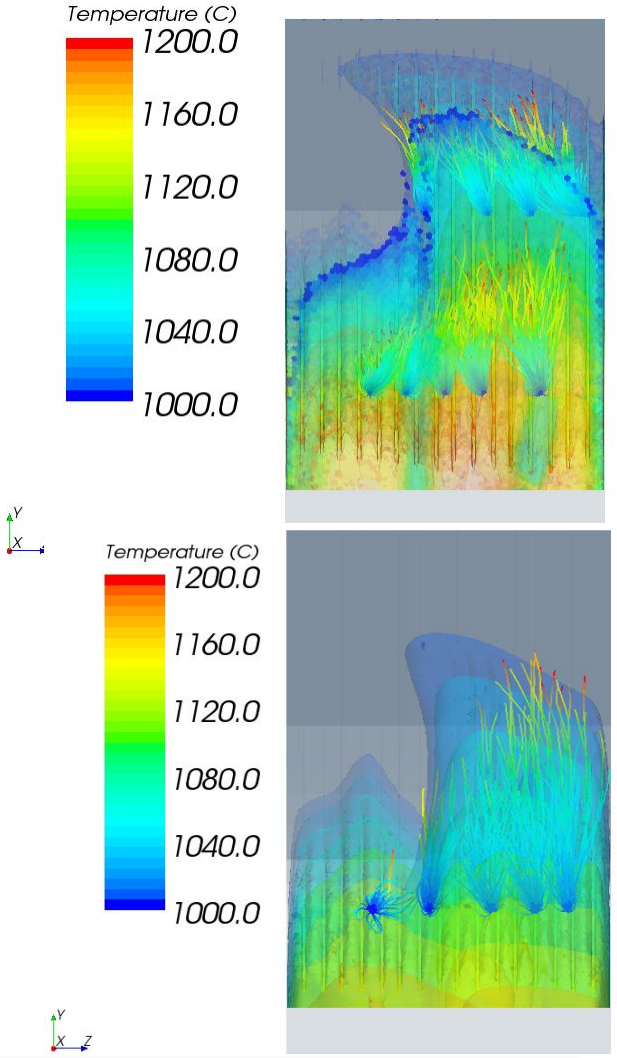
FUEL TECH SNCR ON UNITS > 400MW

- Continuously improving applications on large utility furnaces since 1989
- NOx baselines have decreased
- LNBs have generally caused higher CO
  - High CO at high temperature can inhibit SNCR NOx reduction
- NOx emissions limits have decreased
- NOx reductions still average 30%
- Wide variation in required reduction
  - Client needs determine system design

Fuel Tech is unique with 32 GWe of experience on units > 400 MWe

MODELLING AND 3-D VISUALIZATION KEY FOR SNCR DESIGN

- Proprietary Software with Strong IP Protection; Patented Technology
- 29 years of Computational Fluid Dynamics (CFD) Modelling Experience for NOx control
- Understanding NOx propagation allows better NOx mitigation
- Technology advance in online temperature measurement allowing higher NOx reduction with the control of individual injectors



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SNCR BASICS

Selective Non Catalytic Reduction of NOx is a temperature dependent reaction typically using urea or ammonia as the reagent.

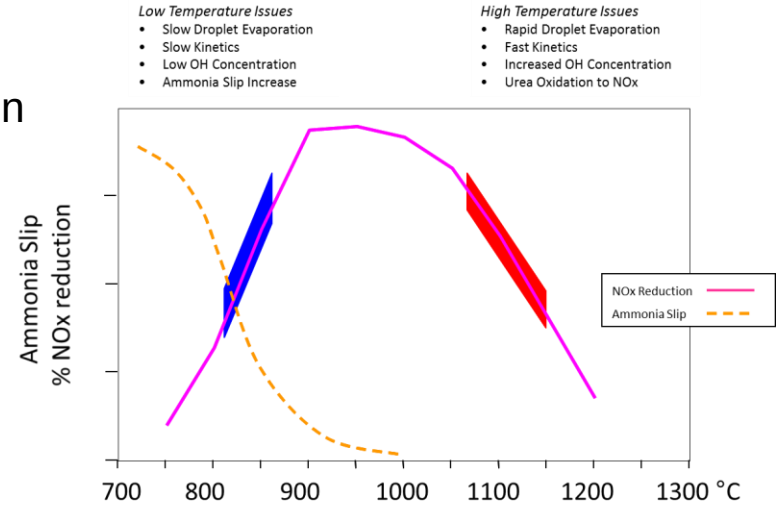
Urea based SNCR eliminates the safety aspects of handling ammonia and is also better suited to high temperature applications and the chemistry can be summarised as:

$$4NO \quad + 2CO(NH_2)_2 + O_2 = 4N_2 + 2CO_2 + 4H_2O$$

(Nitrogen Oxides + Urea + Oxygen = Nitrogen + Carbon Dioxide + Water)

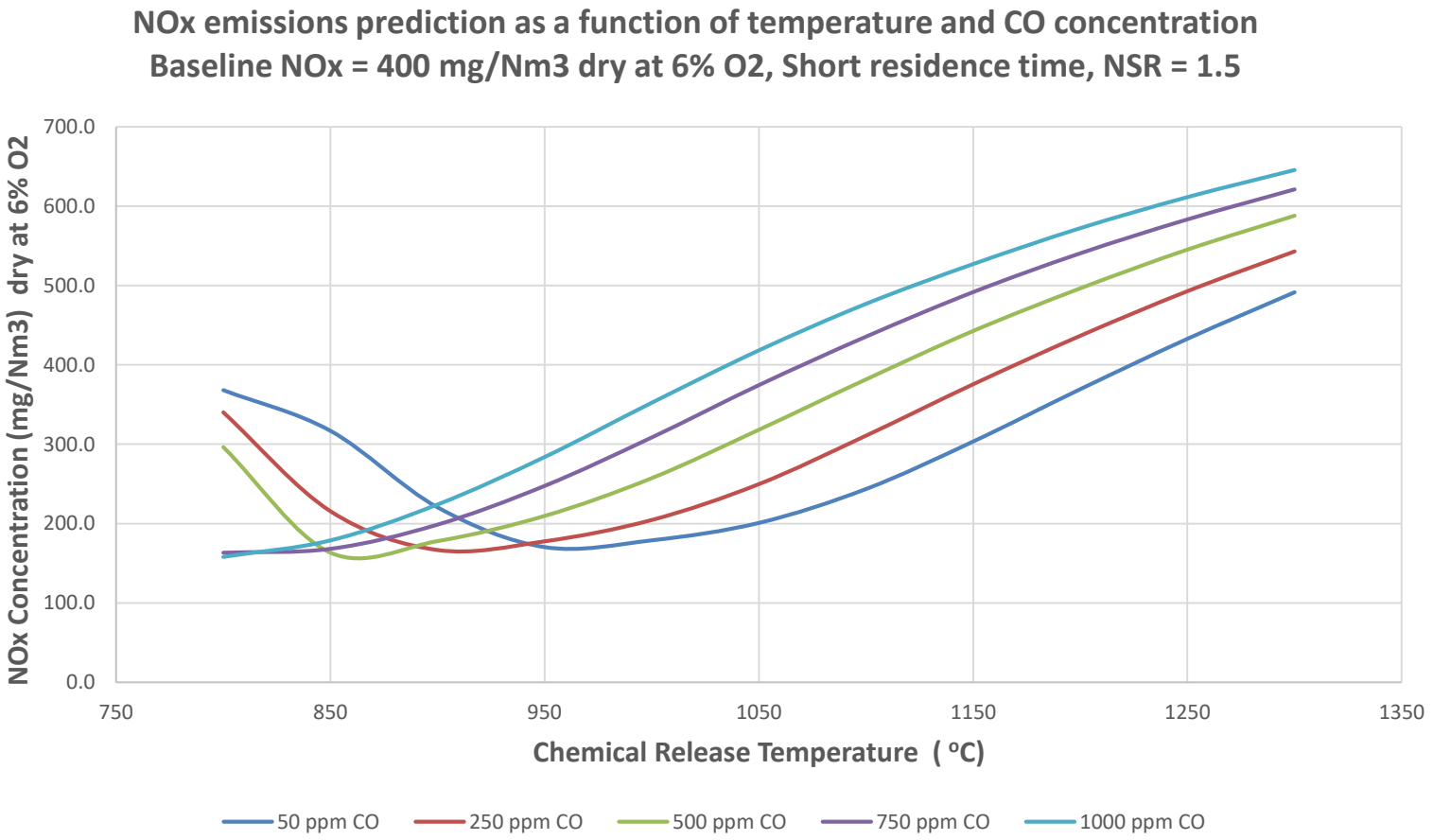
$$2NO_2 + 2CO(NH_2)_2 + O_2 = 3N_2 + 2CO_2 + 4H_2O$$

The overall efficiency of the reaction depends upon the release of the reagent within the temperature window, if the temperature is too high, NOx can form thereby counteracting NOx reduction, if the temperature is too low, ammonia slip can be formed.



IMPORTANCE OF CO

This example shows the relationship between temperature and CO for a particular boiler :



As CO levels at the point of chemical release increase, the ideal temperature changes from 960°C to 860°C.

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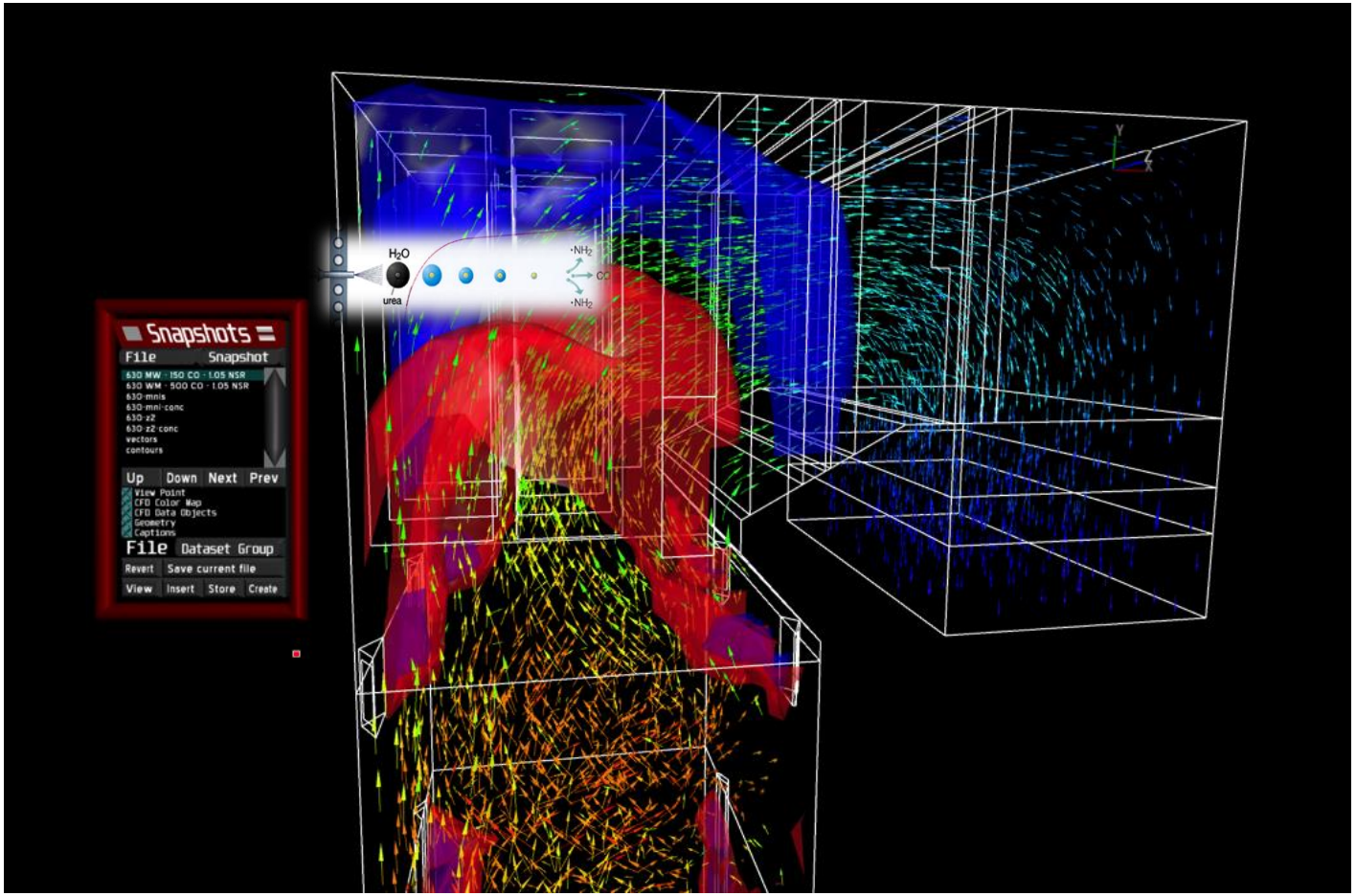
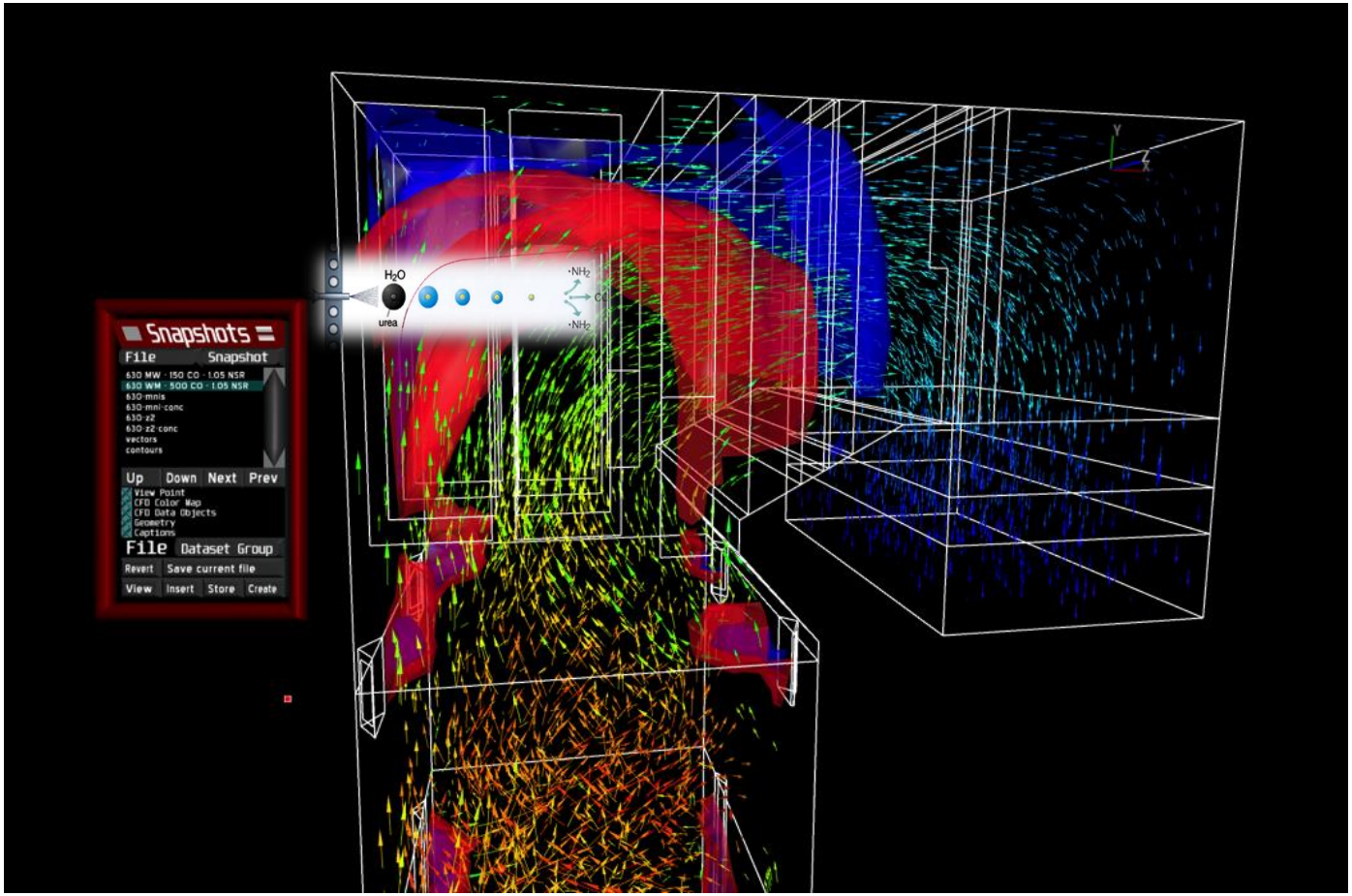
TEMPERATURE WINDOW 150 ppm CO



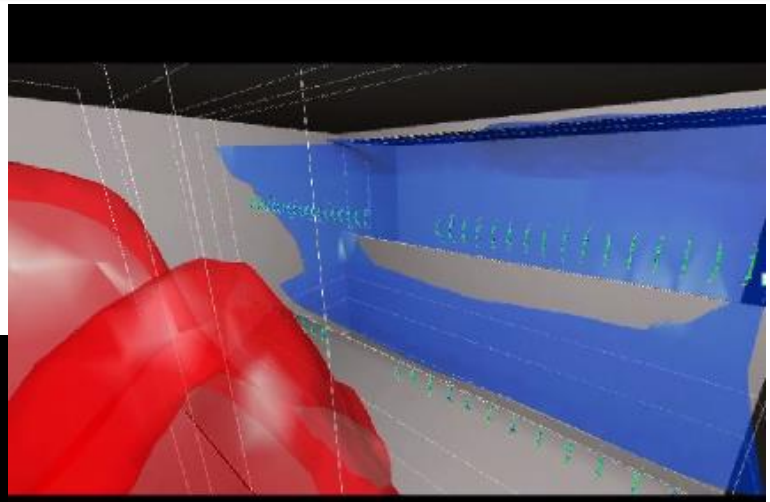
TEMPERATURE WINDOW 500 ppm CO

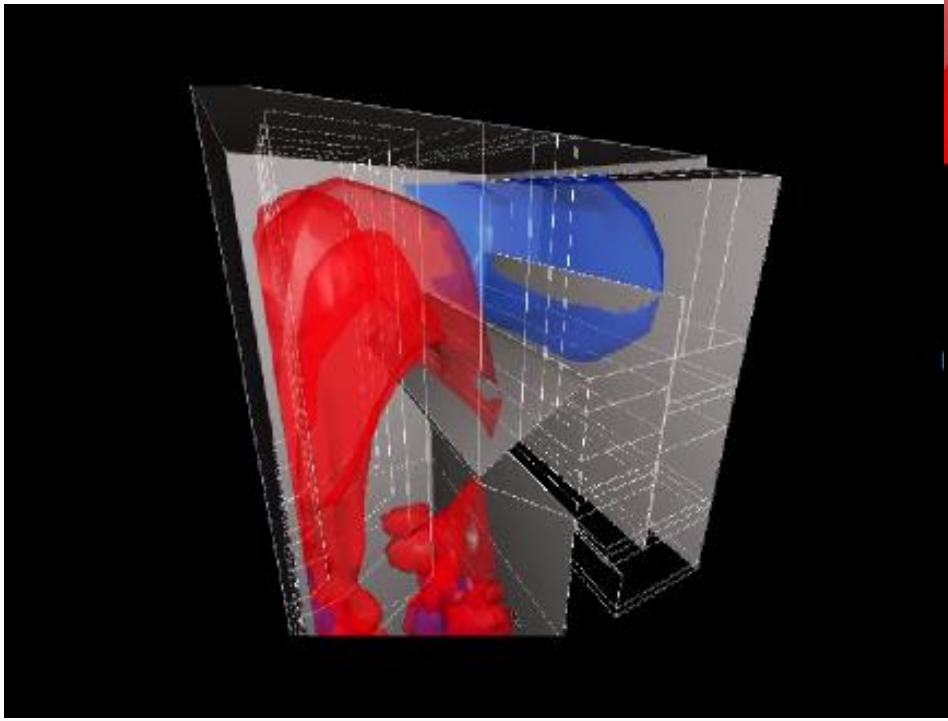


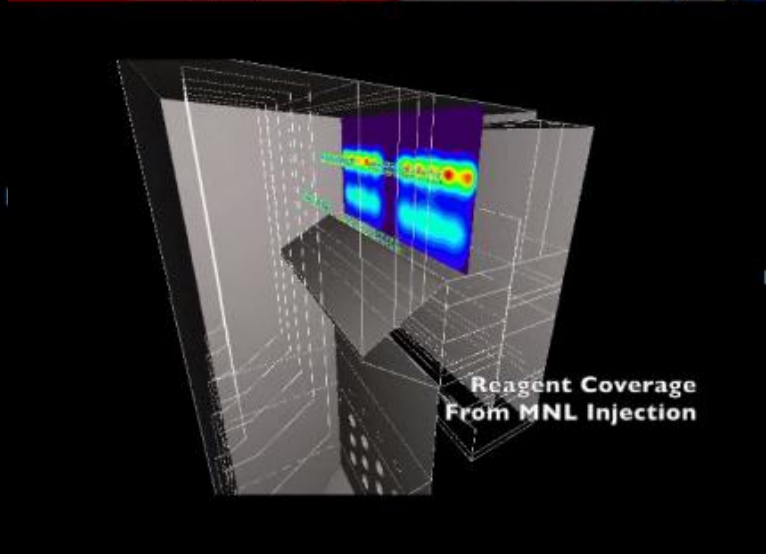
CFD RESULTS FOR MULTI-NOZZLE LANCE

In order to reach the temperature window, a special injector is required which will release the reagent within the temperature window without risking tube damage.

Fuel Tech invented the multi-nozzle lance (MNL) for this purpose







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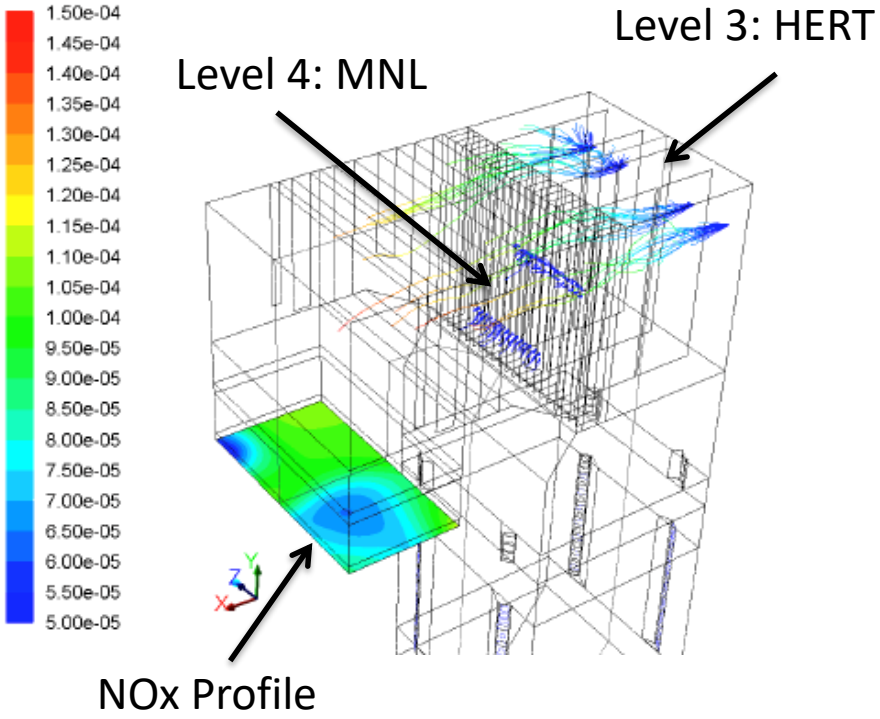
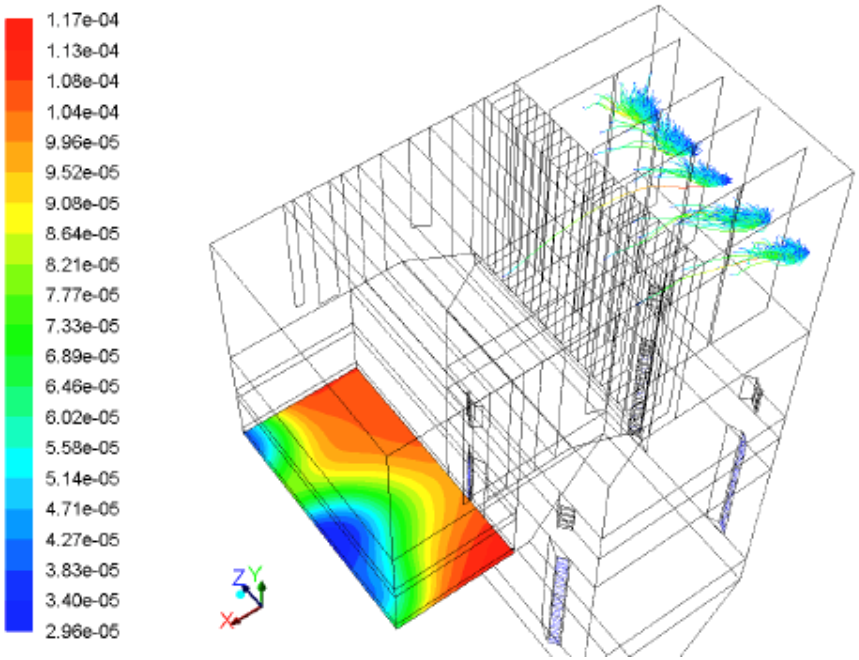
CFD RESULTS FOR MULTI-NOZZLE LANCE



Full Load:
Wall Injectors and Multiple Nozzle Lances (MNLs)



65% Load: Wall Injectors Only

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WATER-COOLED MULTI-NOZZLE LANCE

MULTIPLE NOZZLE LANCE
NOZZLE DETAIL

FUEL TECH MNL HISTORY

- Original In-Furnace Injector tested at BEWAG Lichterfelde – 1989
- First water cooled injectors tested in Linz 1990
- Further developments in Enel Piombino 1991/1992
    - LILCO Port Jefferson 1993
- Present family commercialized in 1995
- Diamond Power sootblower mechanism for movement into the boiler
- Triple Zone MNL developed for Concetiv Indian River Station in 1998
- 2000 design improvements and operating length increased to 25’ (7.6 m)

- More than 40 plants in operation with MNLs

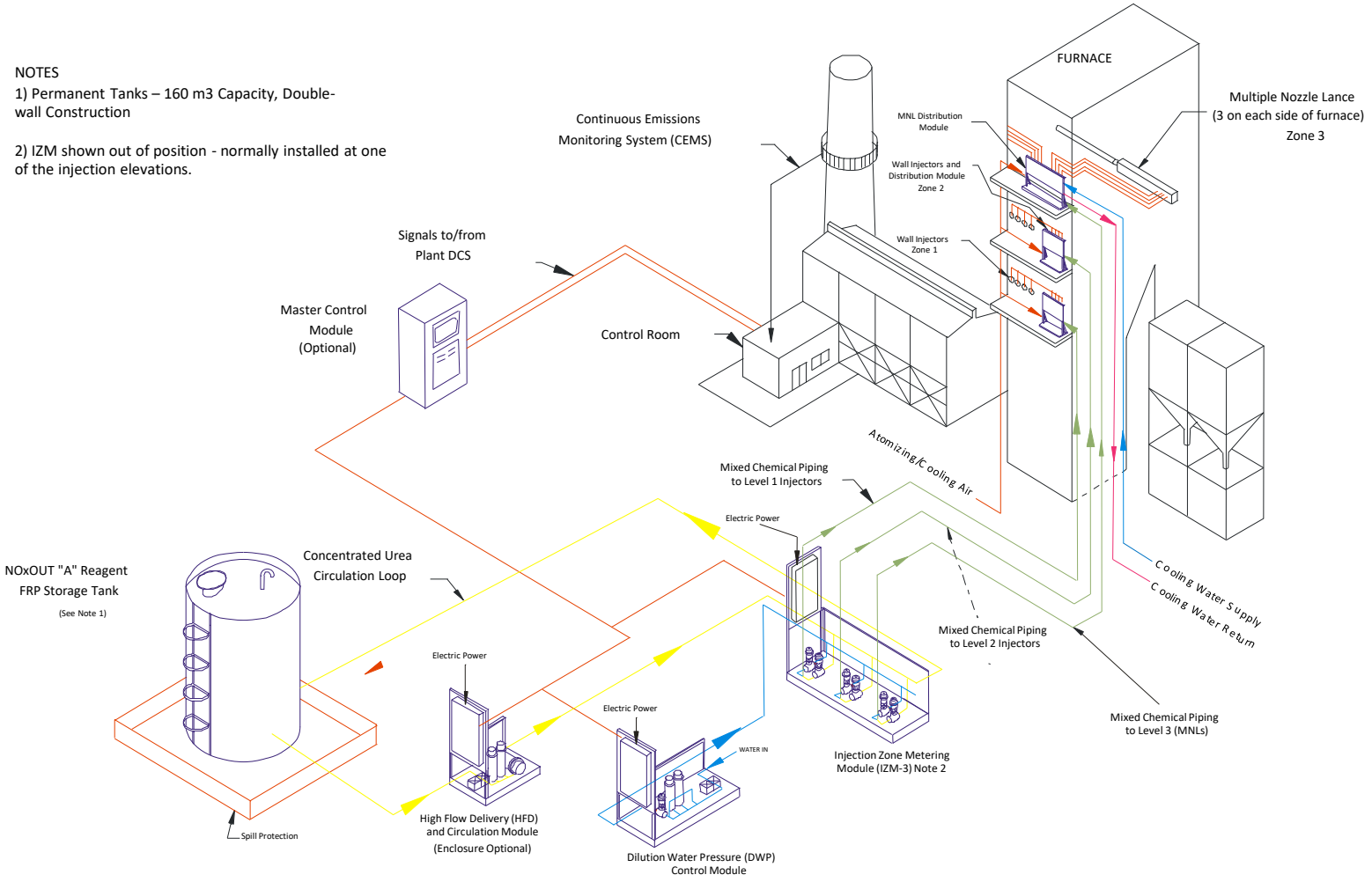
MULTI-NOZZLE LANCE

- Water-cooled retractable lance for Urea injection
- Provides excellent chemical coverage
  - Improves Chemical utilization
  - Decreases water consumption compared to wall injection
- Use of the water cooled MNL began in 1990
- Can provide more than 8 meters of insertion depth
- Fine spray pattern appropriate for super-heat section
- Large spray pattern can be used in upper furnace
- Numerous applications in use for more than 10 years
  - Robust design and safety considerations
  - Coal ash levels as high as 27.5%
  - On-line cleaning through periodic retraction

SNCR SYSTEM LAYOUT

NOTES
1) Permanent Tanks – 160 m3 Capacity, Double-wall Construction

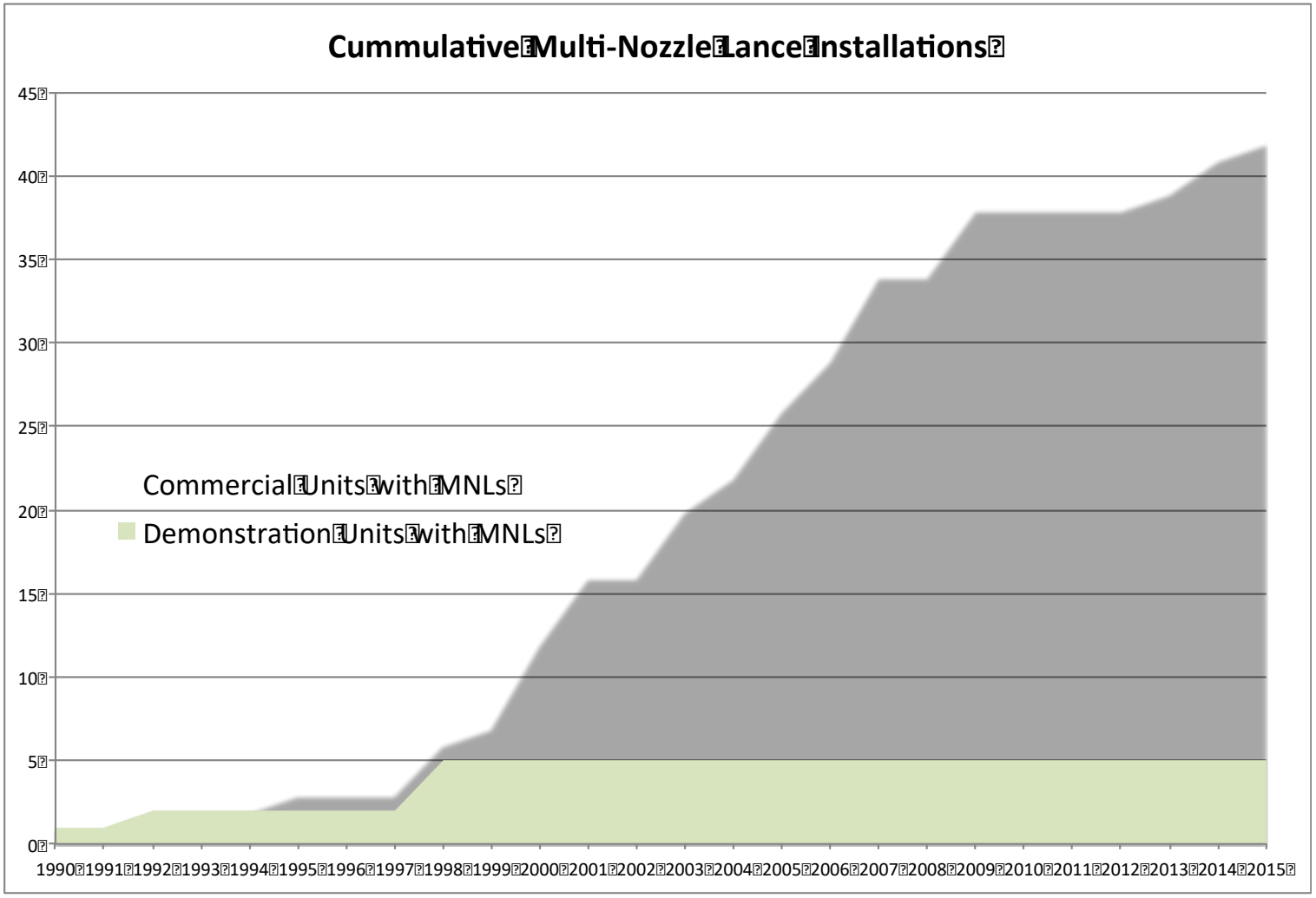
2) IZM shown out of position - normally installed at one of the injection elevations.



MNL EXPERIENCE

- Most installations use between 2 and 6 lances
- Advanced SNCR installations utilize best injection
- Wall-injection zones where appropriate
  - Low and mid-load operation
  - Low-temperature injection zones
  - First stage of injection at full load
- MNLs provide safe injection in the superheat section
- Especially useful on large furnaces (>400MW)
- Also effective on deeply staged, high CO furnaces

MNL EXPERIENCE OVER TIME



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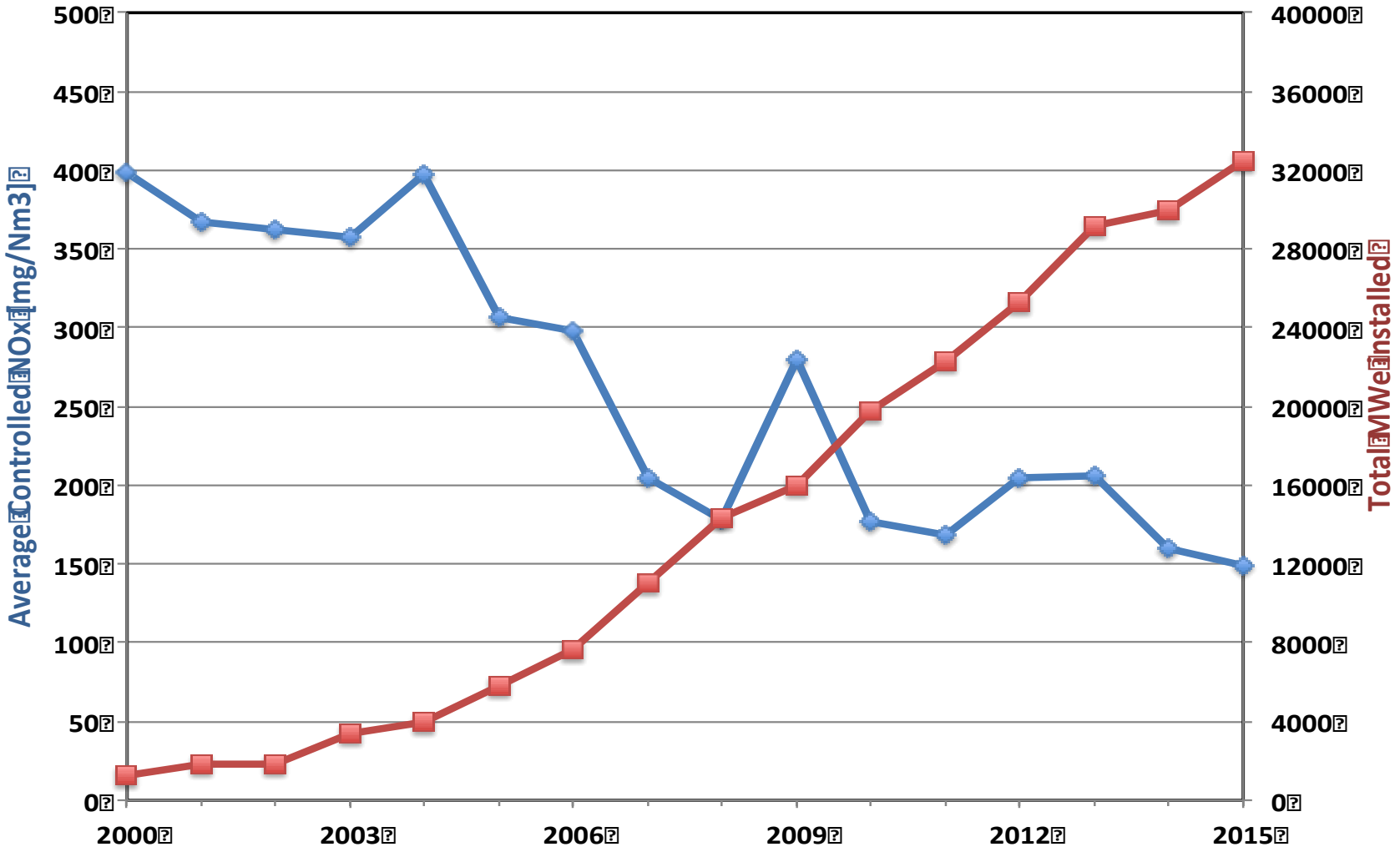
FUEL TECH SNCR ON UNITS > 400MW



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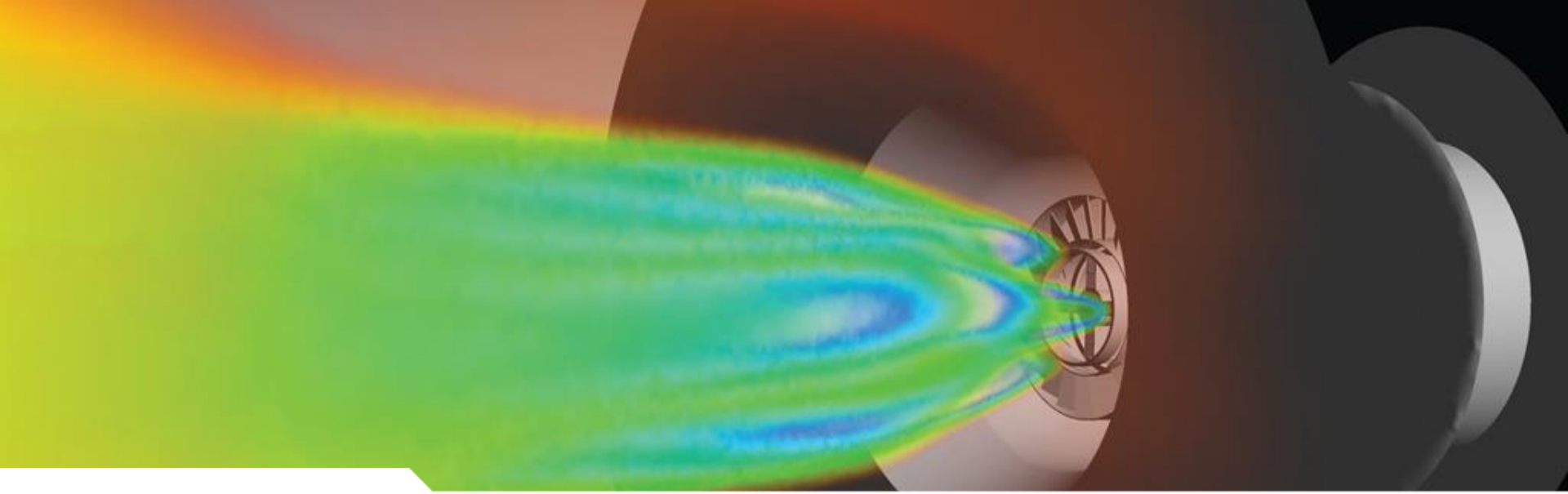

FTEK REFERENCE SYSTEM

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CLECO POWER LLC – RODEMACHER 2

- 1982 Vintage Foster Wheeler
- 523 MWn, PRB-fired
- Balanced Draft, Subcritical Boiler
- ABT Burners
- ESP with Wet FGD
- 2012 SNCR Retrofit Driven by CSAPR
- BOP Engineer – S&L
- Installation Contractor – PMSI
- System Installed and Currently Idle Pending Regulatory Driver

CLECO POWER LLC – DOLET HILLS 1

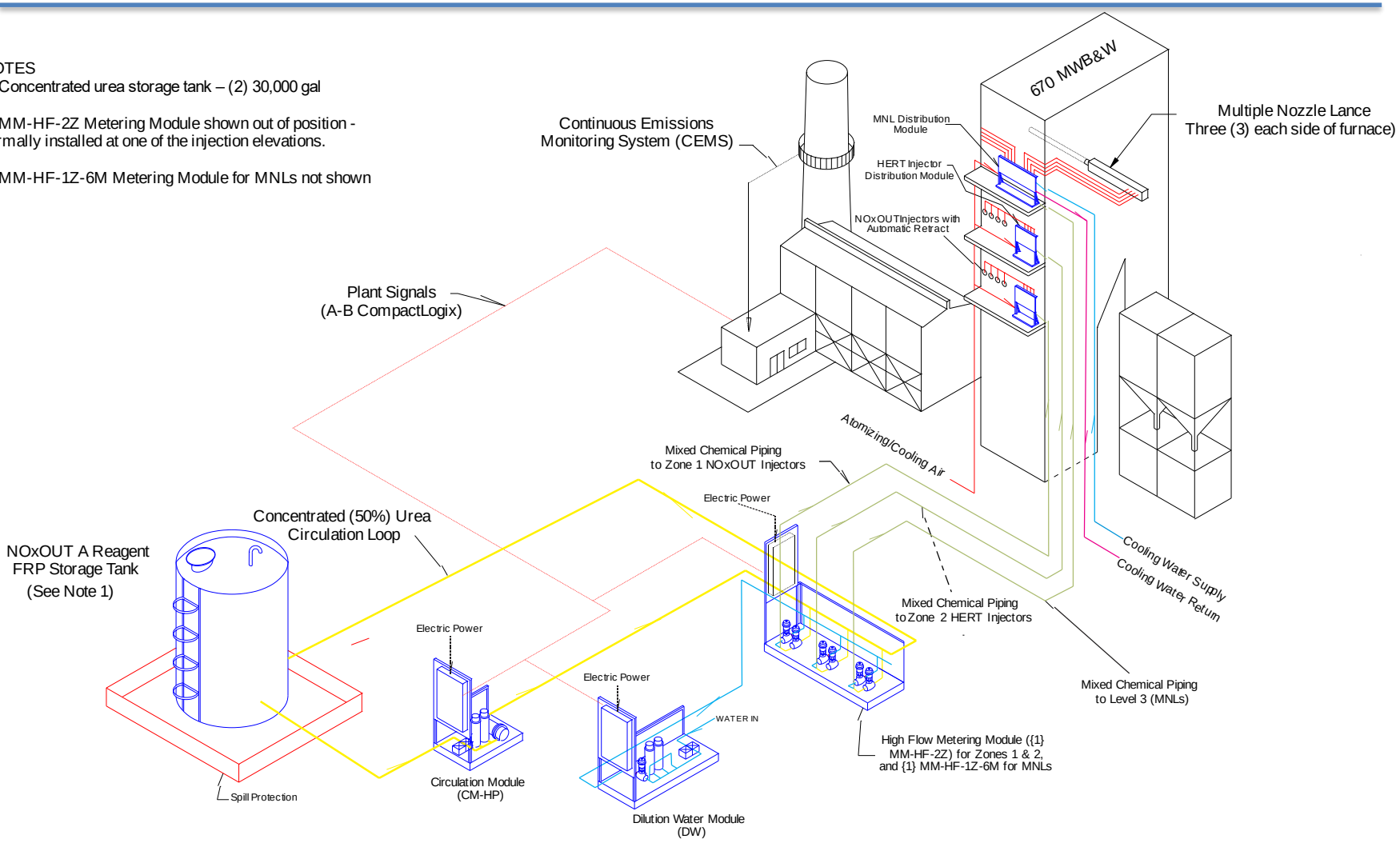
- 1986 Vintage B&W
- 650 MWn B&W, Lignite-fired
- Balanced Draft, Subcritical Boiler
- B&W Burners
- ESP with Wet FGD
- 2012 SNCR Retrofit Driven by CSAPR
- BOP Engineer – S&L
- Installation Contractor - PMSI
- System Installed and Currently Idle Pending Regulatory Driver

DOLET HILLS 1 SNCR SYSTEM SCHEMATIC

NOTES
1) Concentrated urea storage tank – (2) 30,000 gal

2) MM-HF-2Z Metering Module shown out of position - normally installed at one of the injection elevations.

3) MM-HF-1Z-6M Metering Module for MNLs not shown



CLECO SNCR EQUIPMENT DETAILS

Scope Details	Dolet Hills 1	Rodemacher 2
FRP Storage Tank	2 × 30,000 gallons	2 × 30,000 gallons
Circulation Module	1 × CM-HP	1 × CM-HP
Dilution Water Module	1 × DW	1 × DW
Metering Module, Zones 1 & 2	1 × MM-HF-2Z	1 × MM-HF-2Z
Metering Module, Zone 3	1 × MM-HF-1Z-6M	1 × MM-HF-1Z-4M
Distribution Module	2 × DM-NX-6 (Zone 1) 2 × DM-HT-4 (Zone 2)	2 × DM-NX-4 (Zone 1) 1 × DM-HT-6 (Zone 2)
NOxOUT Injectors	12 × INJ-NX	8 × INJ-NX
HERT Injectors	8 × INJ-HT	6 × INJ-HT
Blower Skid	1 × BM-HT	1 × BM-HT
Multiple Nozzle Lances	6 × 5”OD × 26’ IL	4 × 5”OD × 26’ IL
SNCR Injector Tube Panels	LOT	LOT

CLECO SNCR PERFORMANCE

Design Parameter	Dolet Hills 1		Rodemacher 2	
Boiler OEM	B&W		Foster Wheeler	
Coal Fired	Lignite		PEB	
Gross Load (MW)	700	495	530	250
Gross Heat Input (GJ/hr)	7180	5384	5665–5772	2854
Baseline NOx Emissions (mg/Nm3)	302	226	308	220
NOx Reduction (%)	27.5	15	20–25	10
Controlled NOx Emissions (mg/Nm3)	220	193	228 – 247	197
CO Baseline Concentration (ppm, avg)	995	50	400	100
Flue Gas O2 at Boiler Exit (%)	2.3	4.6	3.1-3.3	3.4
Furnace Exit Gas Temperature (°c)	1054	910	1157	926

FUEL TECH EXPERIENCE AND BENEFITS

- Extensive Commercial Experience
  - Over 100 LNB/OFA Systems from 20 MW to 1200 MW
  - Over 700 NOxOUT and HERT Systems Worldwide, More Than 100 Utility Applications
  - Over 55,000 MW of SCR Design, 20,000 MW AIG Tuning Experience Worldwide
  - NOxOUT ULTRA® Systems, Over 80 Units to Date, 2.5 to 550 kg/h of SCR Reagent Feed Systems
- Fuels and Boiler Types
  - Coal, Biomass (Wood, MSW, Bagasse, Etc.), Gas, Oil, Tires, Etc.
  - T-Fired, Stoker, Wall Fired, Down Fired, Incinerators, Etc.
- Quality Equipment with Low Maintenance Cost
  - Stainless Steel Design for Long Life and Durability
- Guaranteed Performance
  - NOx Reduction, NH3 Slip, Reagent Consumption, CO, LOI

Questions

FUEL TECH
Technologies to enable clean efficient energy