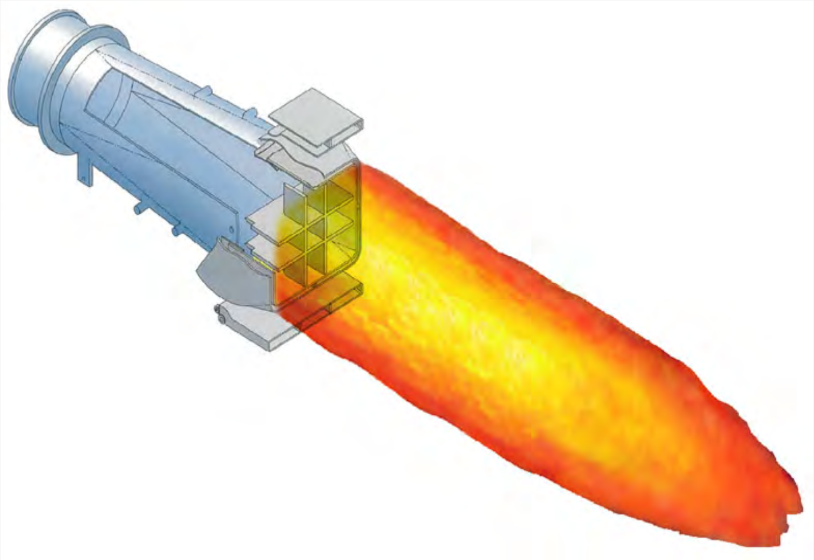
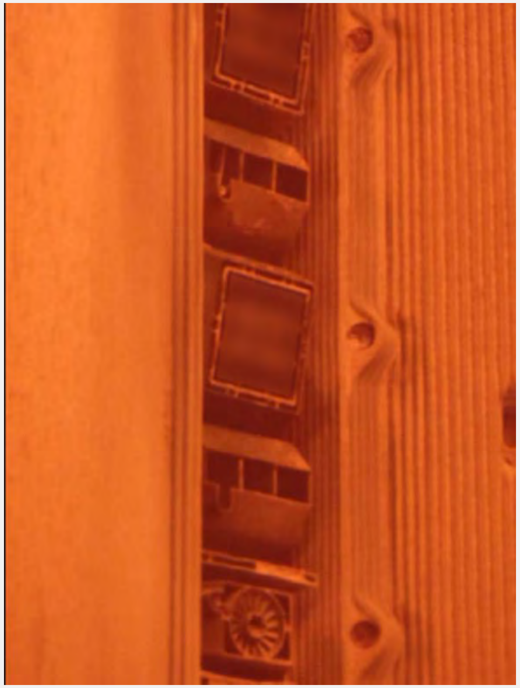
REINHOLD ENVIRONMENTAL Ltd.

2017 NOx-Combustion-CCR Round Table Presentation

February 27 & 28, 2017, in Cleveland, OH / Hosted by FirstEnergy

2017 NOx-Combustion-CCR Round Table





How to reduce SCR O&M costs and increase operational flexibility utilizing combustion advancements

Nate Hart

Synergies of MHI/Hitachi Merger for Solid Fuel Applications

MITSUBISHI HEAVY INDUSTRIES, LTD.

Technologies:

- T-fired Boilers
- Boiler Performance Model
- T-fired Coal Burners
- Hot Gas SCRs
- Honeycomb Catalyst
- Pulverizers
- Mercury Controls (ORP)
- Wastewater Treatment

HITACHI Inspire the Next

Technologies:

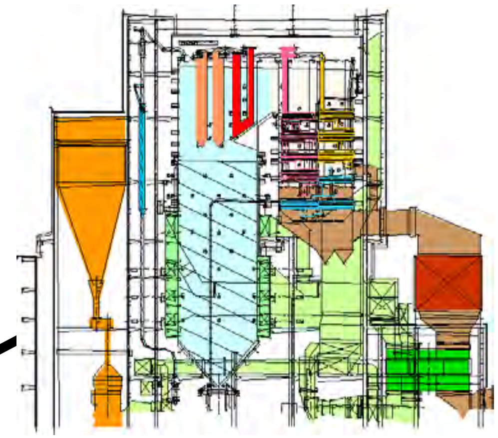
- Wall-fired Boilers
- Boiler Performance Model
- Wall-fired Coal Burners
- Coal SCRs
- Plate Catalyst
- Pulverizers (MPS)
- Mercury Oxidation
- Pulse Jet Fabric Filter

Integrated solutions and services for any operating unit across an entire Utility's fleet

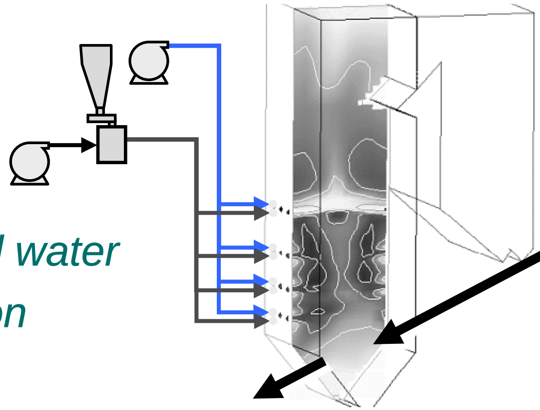
Unique CFD Model - CRAFT Simulation

Original Simulation Models

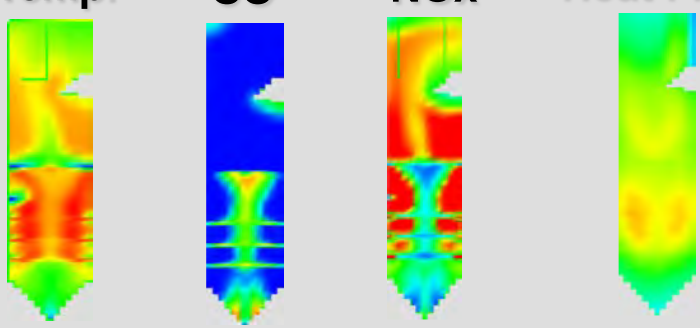
1. Char gasification model
2. Hydrocarbon NOx reduction model
3. Multi-grid discrete transfer radiation model



Combustion,
***RA**diation and water*
***F**low simulation*
***T**ool*



Predicted Performance Lead to Technical Solutions



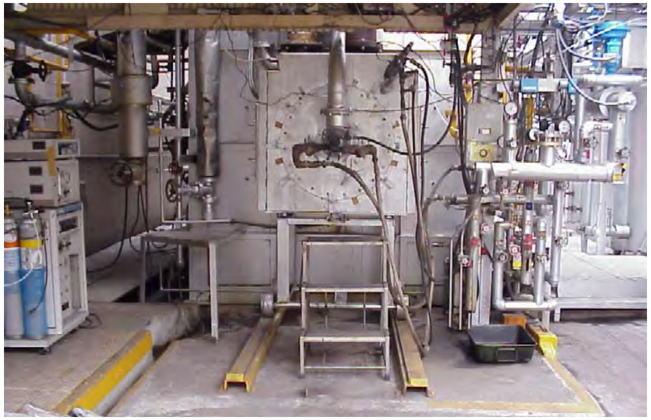
- **Furnace Exit Gas Temperature**
- **VOC Emission**
- **Unburned Carbon**
- **Slagging**
- **H_2S and SO_2 Corrosion**

Proprietary, in-house, modeling software validated with global operating experience

Burner Combustion R&D Facilities

Small scale, low NOx burner combustion test facility

- 100kg/h(220lb/h) firing rate (3MMBtu/h)
- Coal, oil, and gas capable



Medium-pilot scale, low NOx burner design combustion test facility

- 500kg/h(1100lb/h) firing rate (15MMBtu/h)
- Coal, oil, and gas capable

Burner Combustion R&D Facilities – Nagasaki, Japan (40MW)

Large-pilot scale (40 MW)

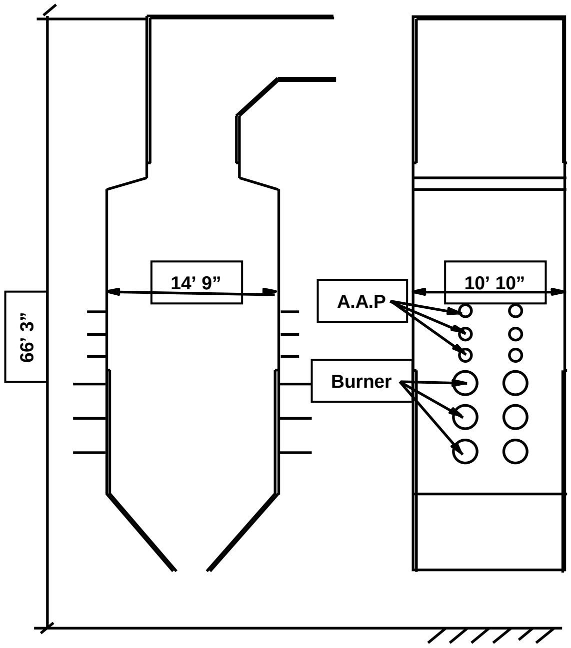
Low NOx burner design combustion test facility

- 4t/h(8800lb/h) firing rate (100MMBtu/h)
- Coal, oil capable
- Developed burner in test facility using actual size for optimal performance testing

Burner Combustion R&D Facilities – Kure, Japan (30 MW)

Purpose

Evaluation of multiple burner arrangements
Over Fire Air configurations
Simulation of load change etc.



Specification

Furnace : Water Jacket, Vertical
Heat Input : 30MW Units
Dimensions : Wide 15 feet
Depth 11 feet
Height 66 feet

Burner Combustion R&D Facilities – Italy (35MW)

R&D – New Burner Development Process

Process from development to actual boiler application

100kg/h single burner test furnace
- Concept verification

500kg/h single burner test furnace
- Burner shape design

4t/h single burner test furnace
- Burner performance confirmation

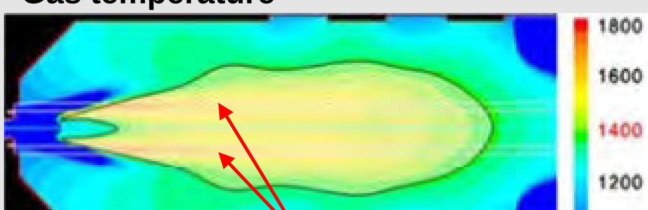
Concept

Verification and Feedback

Install to Actual boiler

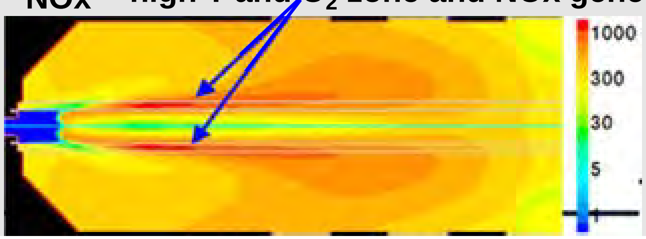
Large scale Combustion simulation

Gas temperature



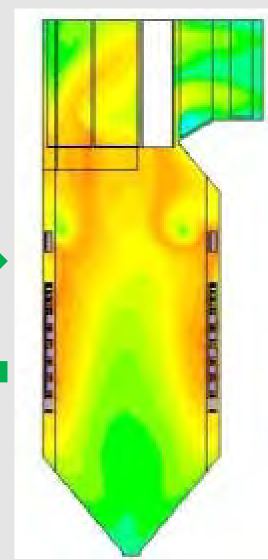
Good correspondence between high T and O_2 zone and NOx generation zone

NOx



Actual boiler performance evaluation

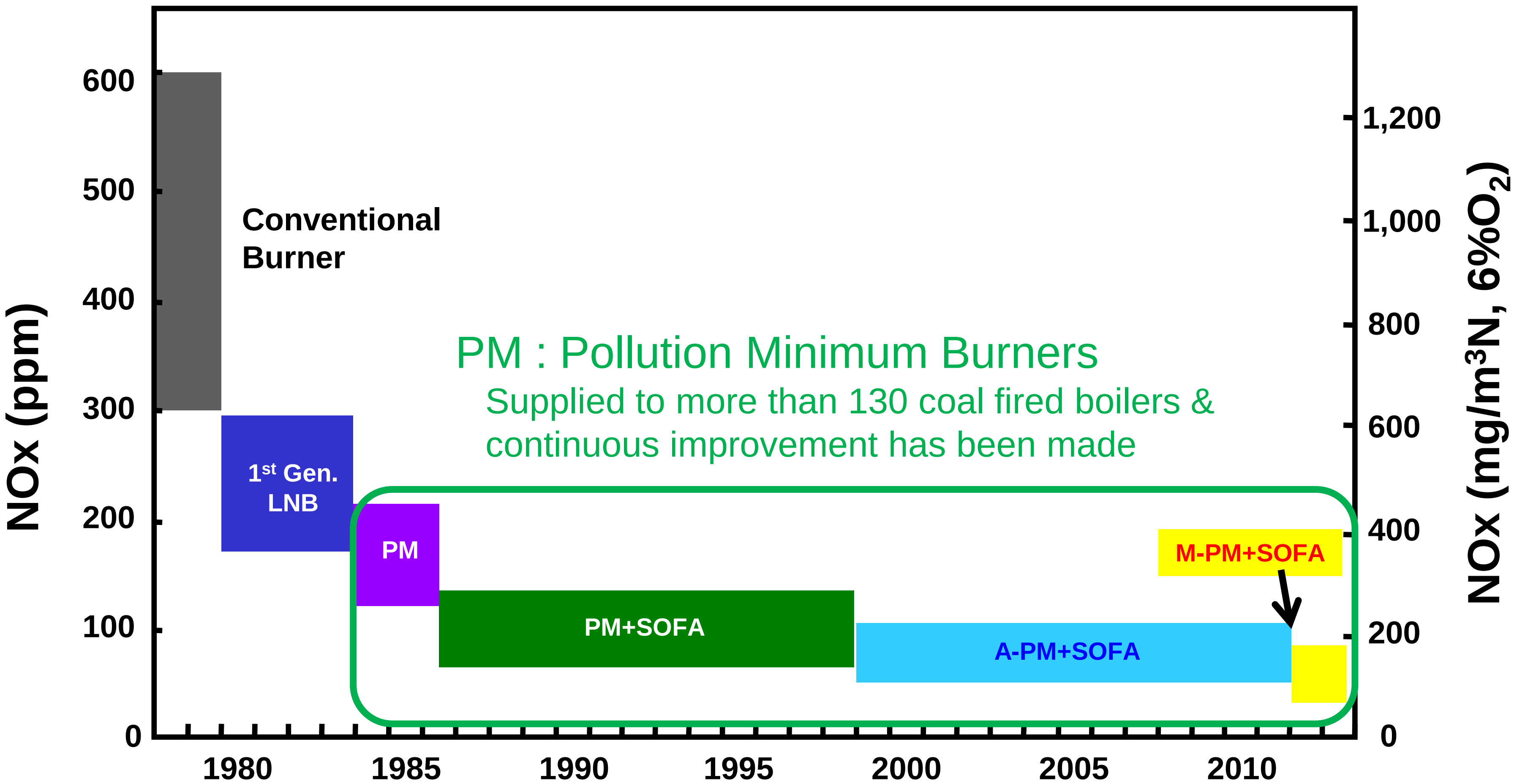
Feedback of actual boiler operation result



Advanced flame measurement

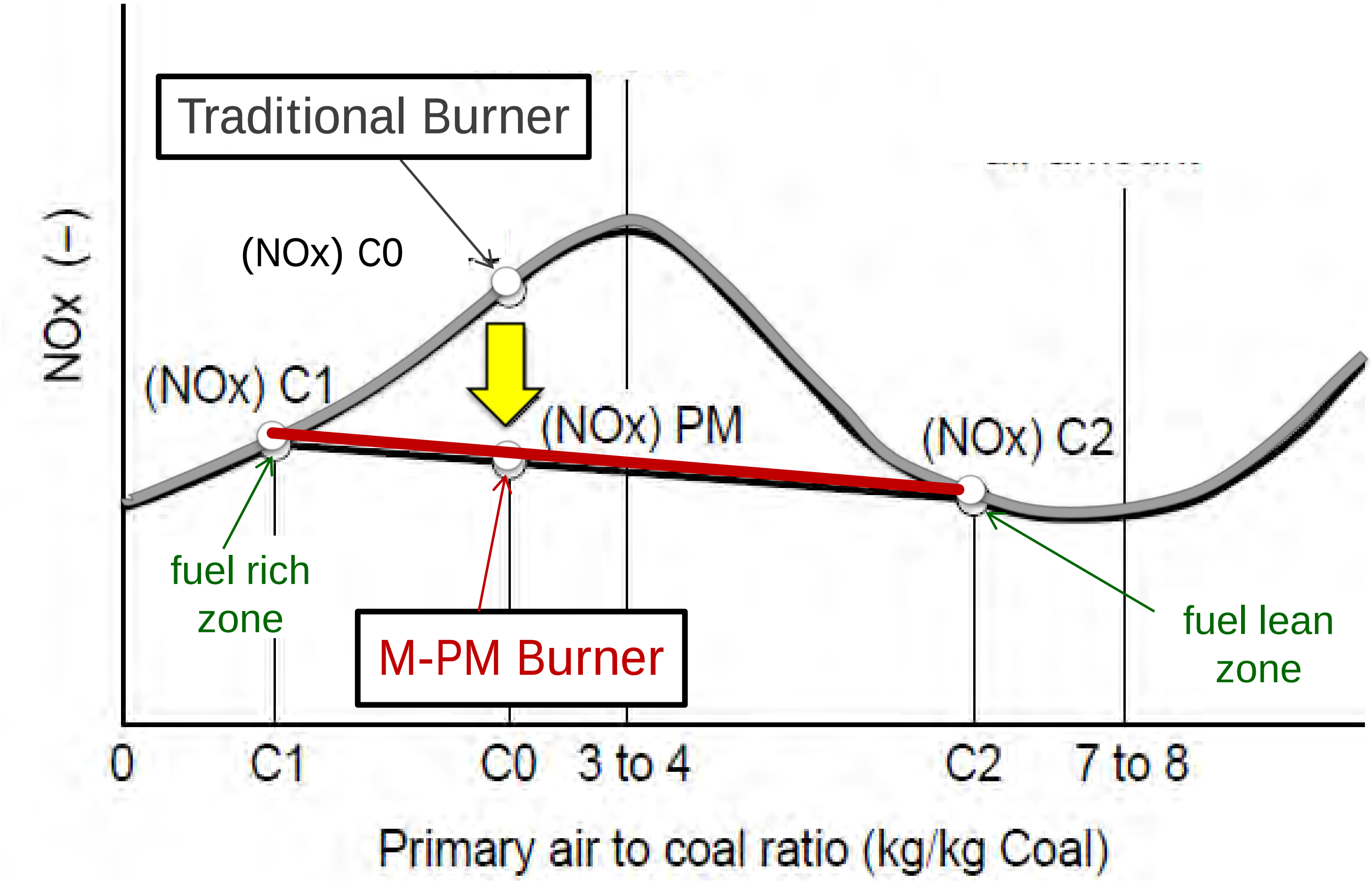
- Matrix measurement of inside of flame
- Optical temperature measurement
- Infrared camera
- Flame measurement
- Particle measurement
- Unburned carbon measurement
- Heat flux measurement
- Online monitoring system
- Laser Doppler velocimeter (LDV: in future)
- Laser Induced Fluorescence (LIF: in future)

MHPSA's NOx Reduction History for T-Fired Boilers



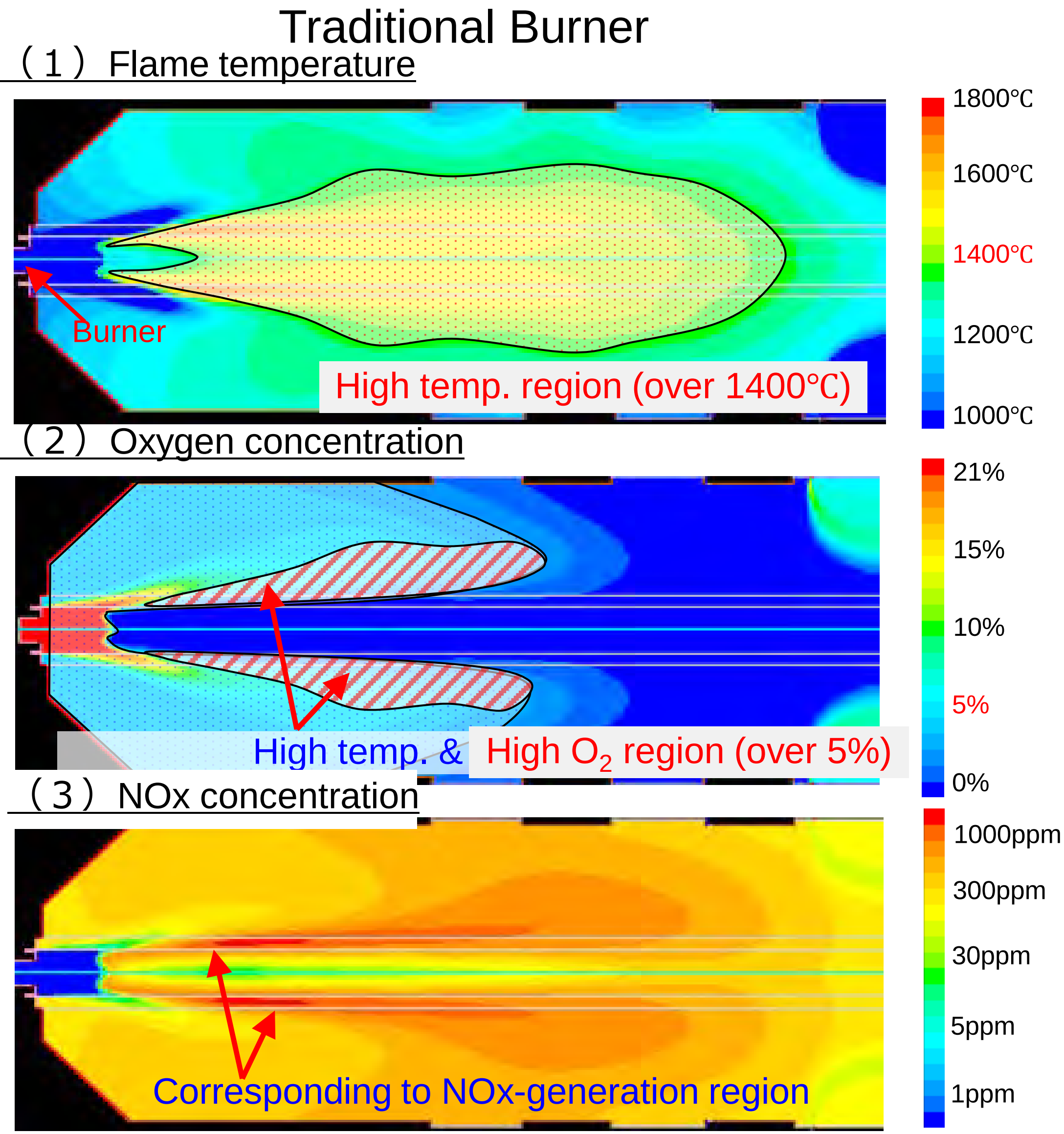
PM : Pollution Minimum
A-PM : Advanced PM
M-PM : Latest version of A-PM
SOFA : Separated Over Fired Air

M-PM Burner: How Does it Work



Patented technology drastically reduces NOx by splitting the flame into two zones

CFD of Traditional Burner



High Temperature & O2 region corresponds to High NOx region

This region must be minimized to reduce NOx

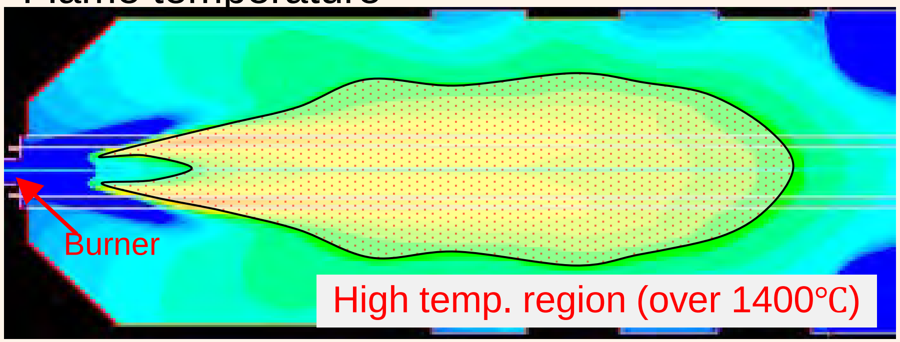
Burner Ignition Characteristics must be optimized

Comparison of Traditional and M-PM Burners (CFD)

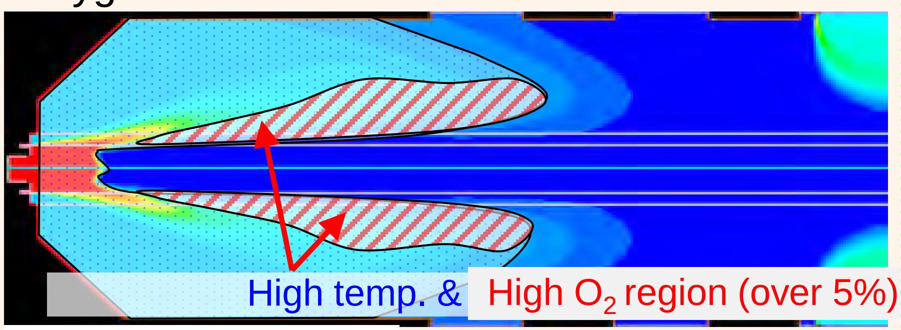
＜Traditional burner＞

NOx generated at the high temp.& high O_2 region

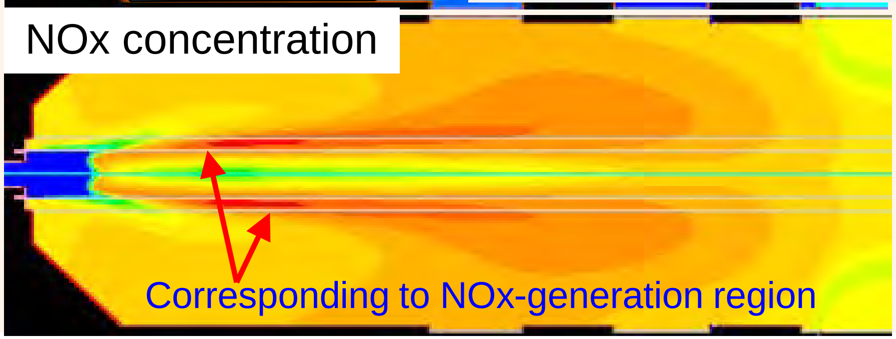
Flame temperature



Oxygen concentration



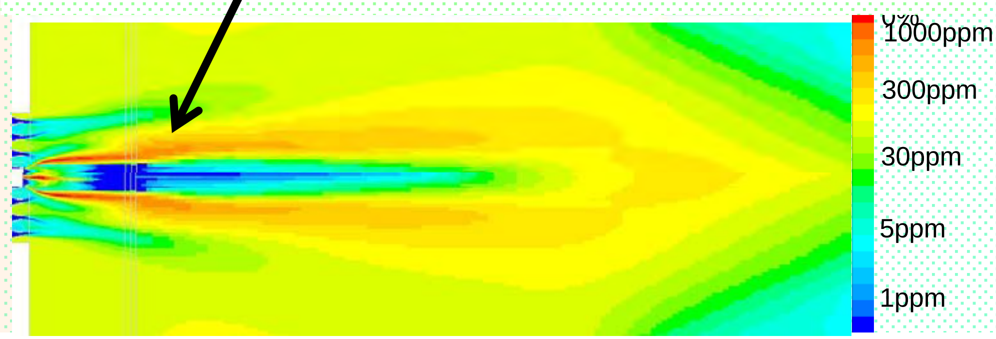
NOx concentration



＜M-PM burner＞

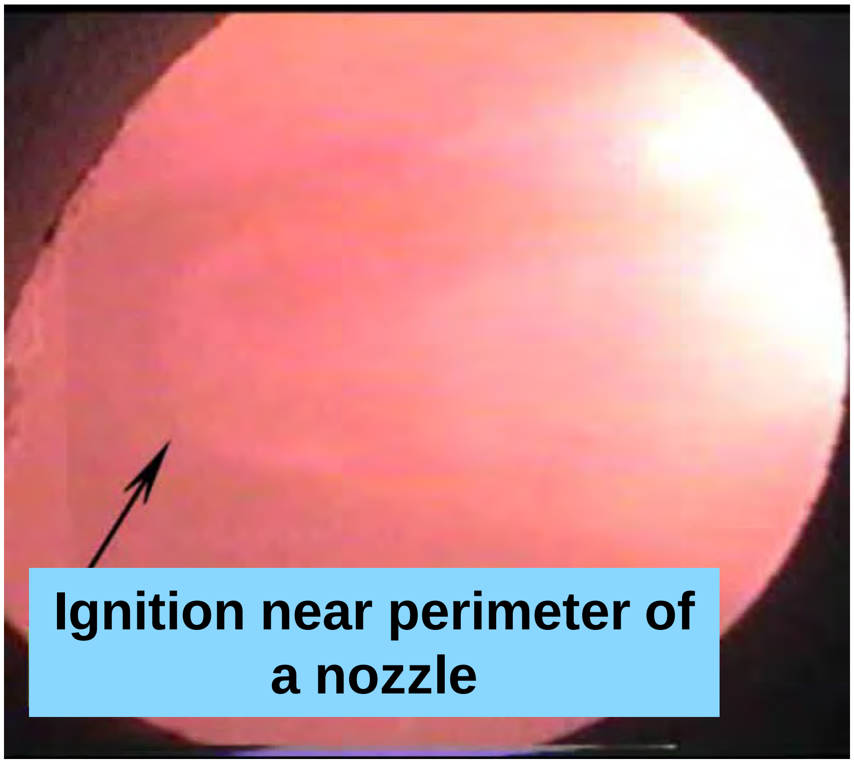
NOx reduced by the temperature control of outer flame

High NOx generation area at the outer flame is reduced



Comparison of A-PM and M-PM Burners (Combustion Test)

A-PM burner



M-PM burner

Combustion test (4 t/h)

Retrofit Operating Experience

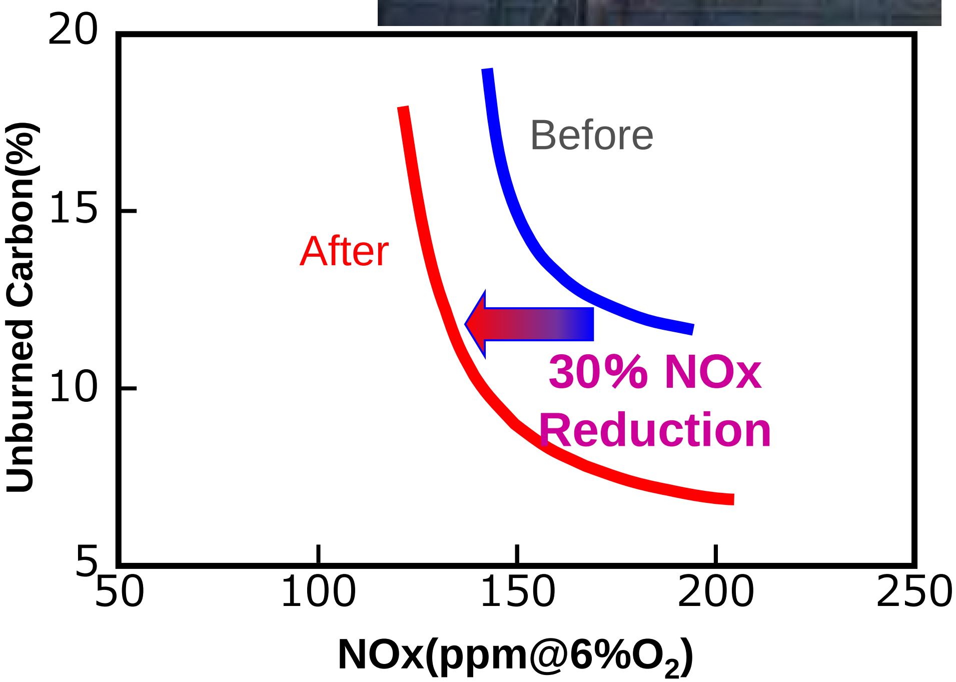
Plant	Houfu Unit 5 (Japan)	Carbon2 Unit 2 (Mexico)	Zhuhai Unit 1 (China)	Zhuhai Unit 2 (China)	Baoshan Unit 3 (China)	Hirono Unit 5 (Japan)	Norgener Unit 1 (Chile)	Norgener Unit 2 (Chile)
Output	25 MW	350 MW	700 MW	700 MW	350 MW	600MWe	132 MW	132 MW
Burner Elevations	2	5	6	6	5	6	4	4
SOFA added	No	No	Yes	Yes	Yes	No	No	No
Existing NOx	178 ppm	275 ppm	175 ppm	175 ppm	158 ppm	150 ppm	197 ppm	199 ppm
Retrofit NOx	125 ppm	220 ppm	68 ppm	65 ppm	65 ppm	108 ppm	143 ppm*	111 ppm
NOx Reduction	30%	20%	62%	64%	59%	30%	27%	44%
Fuel-Bound Nitrogen	1.7% (Indonesia)	1% (Mexico)	0.8% (China)	0.8% (China)	0.9% (China)	1.53% (Australia)	1.34% (USA)	1.3% (USA)
Fuel Ratio	1.5	1.46	1.73	1.73	1.65	1.55	1.28	1.34

M-PM Burner has provided significant NOx reduction on multiple Units

Houfu - Unit 5 (Japan) Effect of Modification

NOx was decreased by 30% from the existing PM burner with the same Unburned Carbon

Item	Specifications
Boiler Output	25MWe
No. of Burner Elevation	2 Elevation
Steam Temp.	543℃
Modification Contents	PM ⇒ M-PM （All Nozzles Replacement） SOFA was originally installed and no change was made
Process	Burner Retrofit：Sept. 2012 Combustion Test：Nov. 2012



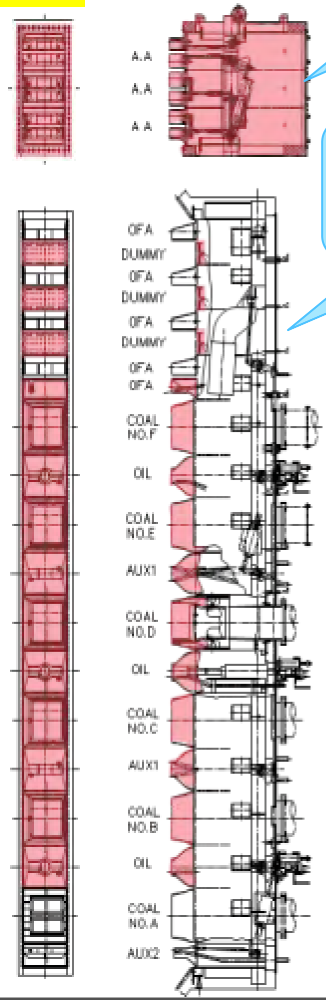
Zhuhai - Unit 2 (China) Effect of Modification

All burner nozzles replaced and SOFA installed

64% reduction in NOx emission

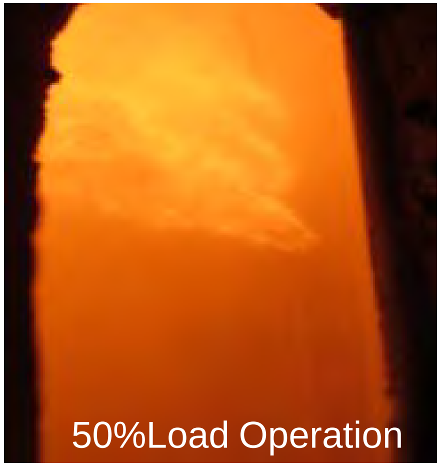
Items	Specification
Unit output	700MW
Number of burner level	6 levels
Boiler type	Forced circulation boiler
Combustion type	4 corners
Modicationi	(1) Change of burner nozzles (to M-PM) (2) Addition of SOFA

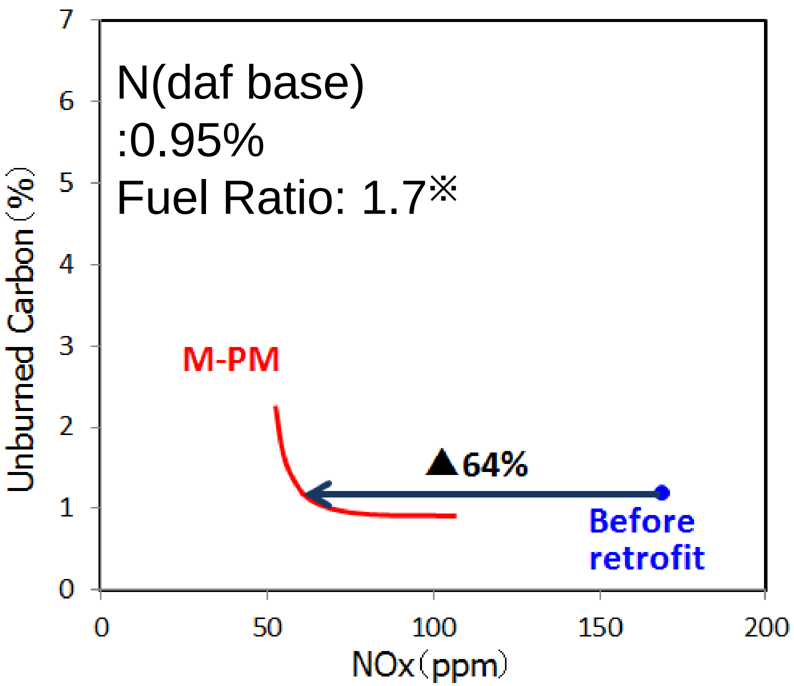
※Fuel Ratio: Fixed carbon／Volatile matter
（Index of combustibility）



Added SOFA

Coal, Oil, Aux Nozzle Replacement



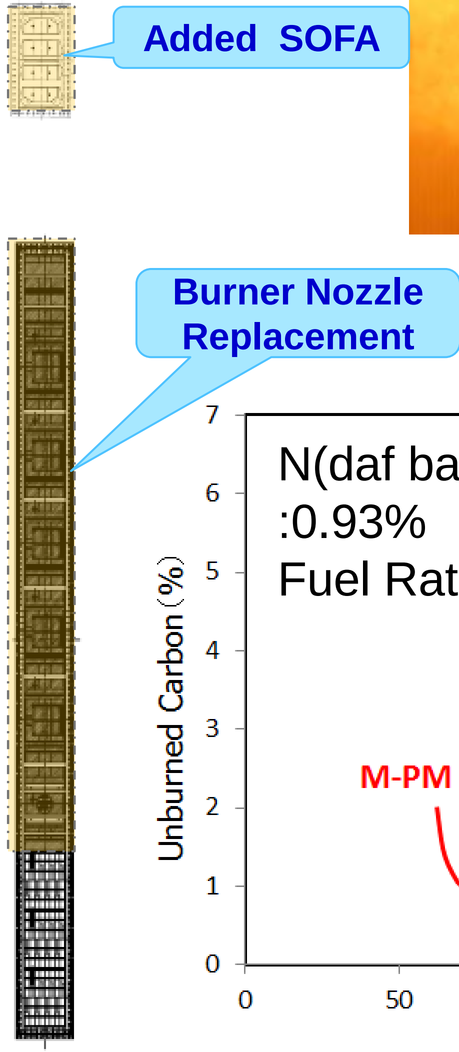


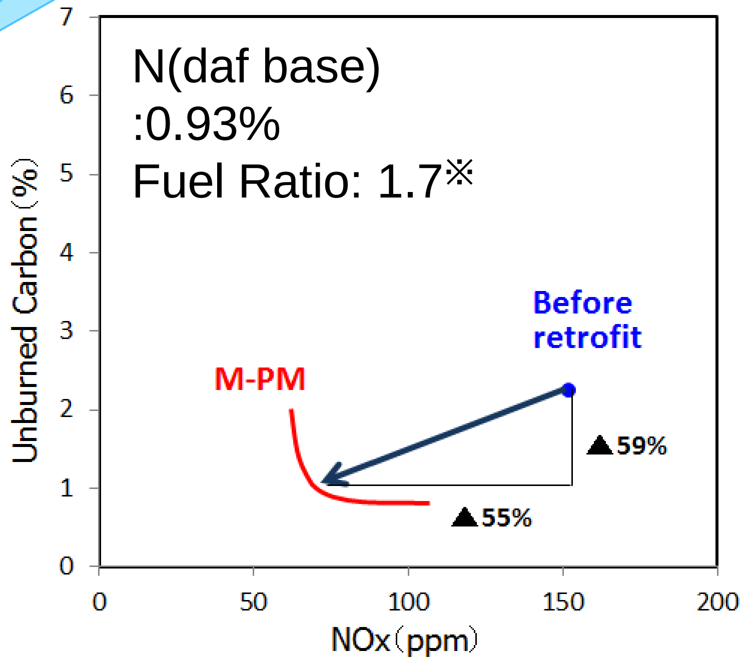
Baoshan - Unit 3 (China) Effect of Modification

All burner nozzles replaced and SOFA installed

- 55% reduction in NOx emission
- 59% reduction in unburned carbon

Items	Specification
Unit Output	300MW
Number of Burner Elevations	5 elevations
Boiler type	Forced Circulation Boiler
Combustion type	4 Corners, Corner firing
Modification parts	(1) Changing of burner nozzles to M-PM (2) Addition of AA (Aditional Air)





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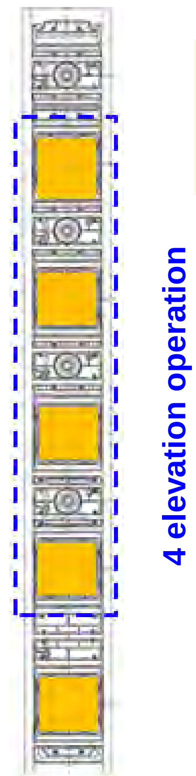
Carbon - Unit 2 (Mexico) Effect of Modification

NOx was decreased by 20% compared with the existing burner (without SOFA)

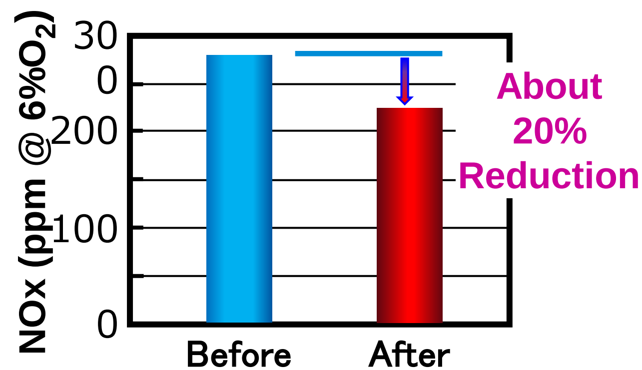
Item	Specification
Boiler Output	350MWe
No. of Burner Stages	5 elevation
Steam Temp.	541℃ / 541℃
Modification Contents	Only coal nozzles replacement SOFA has not been installed
Schedule	Burner Retrofit：Dec. 2012 Combustion Test：Feb-Mar 2013

Normal Operation （100%Load）



Only coal nozzles were replaced
2ry air nozzles were not replaced
NOx reduction effect was rather small

NOx Before/After Modification (100%Load)



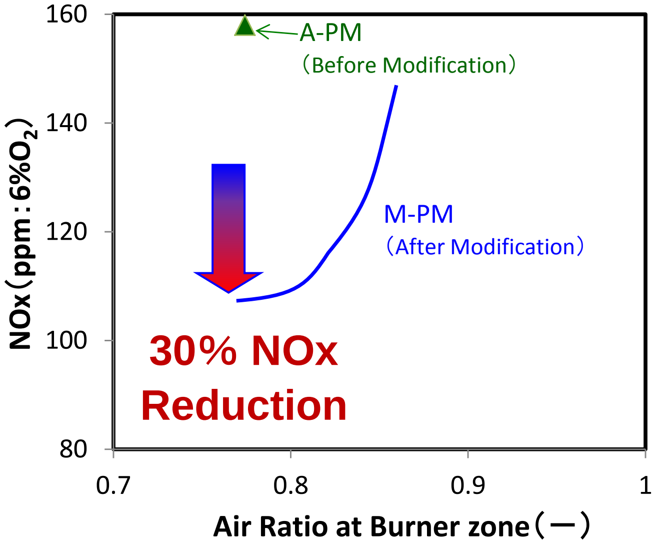
Hirono - Unit 5 (Japan) Effect of Modification

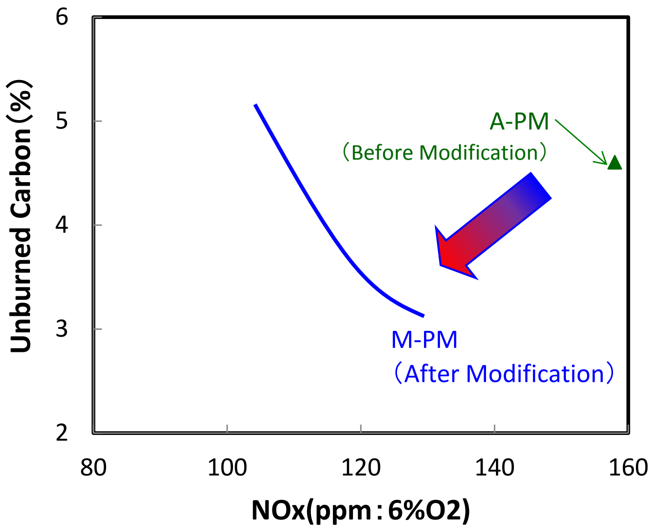
A-PM burner was replaced to M-PM burner

30% reduction in NOx emission
at same air ratio at burner zone

Improvement of NOx-UBC characteristic

Item	Specification
Boiler Output	600MWe
No. of Burner Stages	6 elevation
Steam Temp.	600℃ / 600℃
Modification Contents	A-PM ⇒ M-PM （All Nozzles Replacement） SOFA was originally installed and no change was made
Schedule	Burner Retrofit：Mar.~Jun. 2014 Combustion Test：Jul. & Oct. 2014



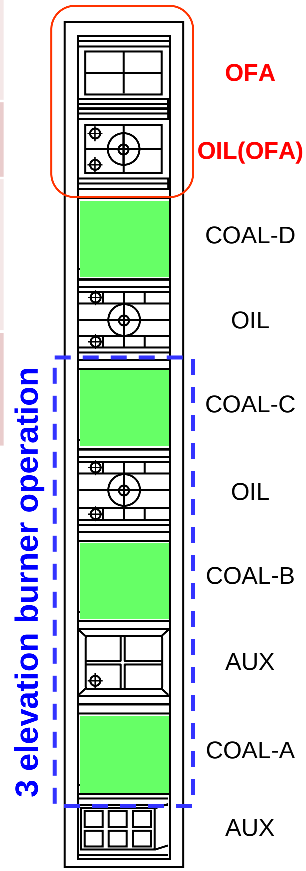


Norgener - Unit 2 (Chile) Effect of Modification

NOx was decreased by 44% compared with the existing burner (without SOFA)

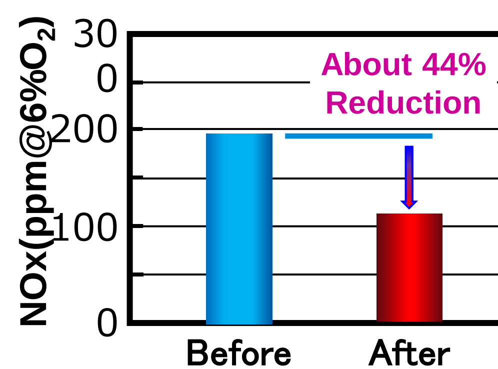
Item	Specification
Boiler Output	132.4MWe
No. of Burner Stages	4 elevation (3 elevation burner operation)
Steam Temp.	SH:540℃ / RH:540℃
Modification Contents	All nozzles replacement Modification to OFA AA has not been installed
Schedule	Burner Retrofit：Mar.-Apr. 2015 Combustion Test：Jun. 2015

Guaranty Operation (100%Load)



- Upper oil burner: Modification to double as OIL and OFA (Over Fire Air)
- Upper Compartments: Modification to OFA
- Tilt mechanisms of OFA nozzles: Modification to separate from other nozzles
- Replace to M-PM, all burners able to adjust tilt
- USA Coal

NOx Before/After Modification (100%Load)



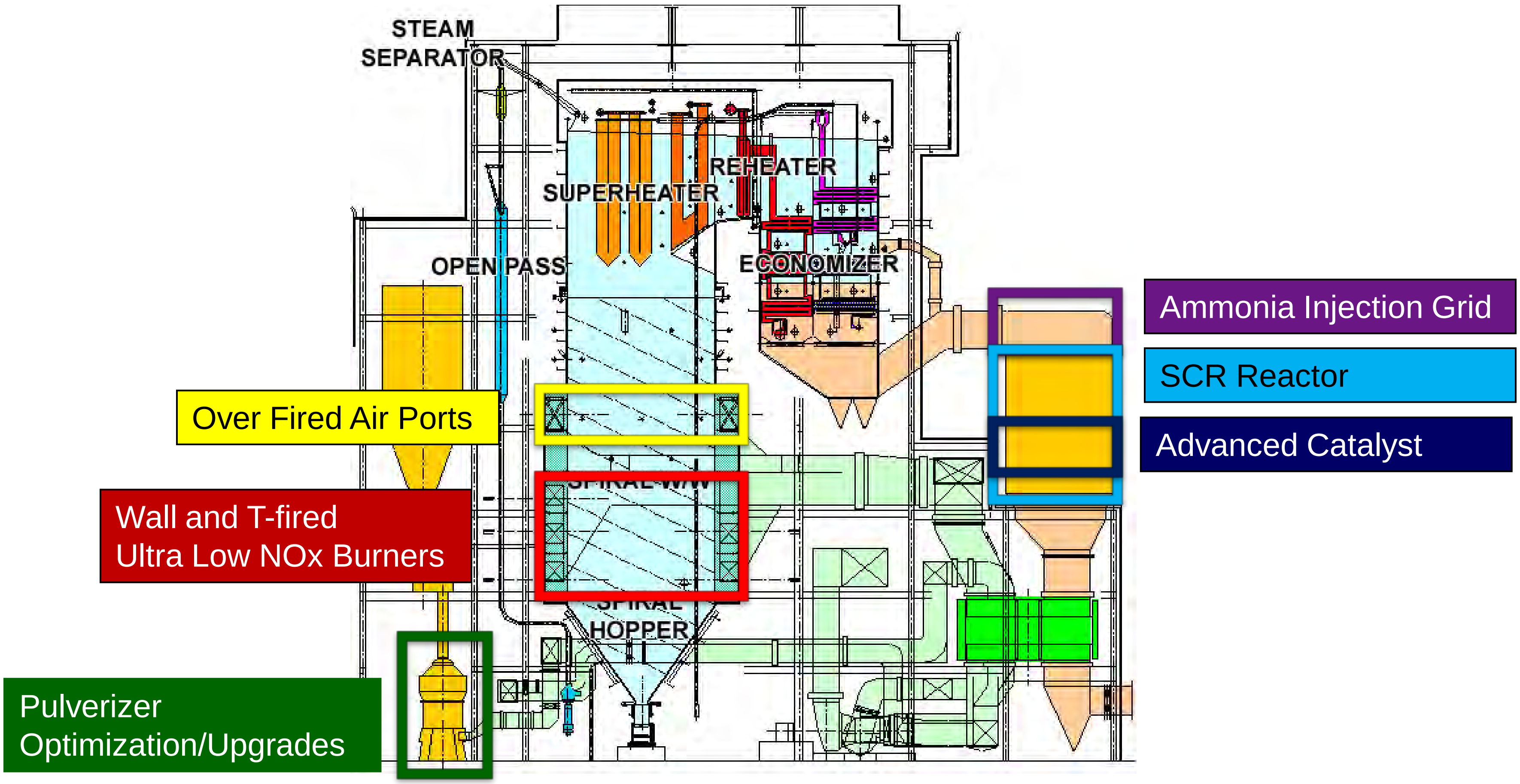
Recent US Utility Evaluation for M-PM Burner Applications

Plant	Unit(s)	Total MW	Existing NOx	Predicted M-PM NOx	NOx Reduction	Coal
Maryland Plant	1-3	588	0.26	**0.18**	**31%**	Eastern Bit
Kentucky Plant	2	282	0.30	**0.17***	**43%**	Illinois Basin
New York Plant	2	167	0.33	**0.20**	**39%**	Bituminous
Texas Plant	1	917	0.25	**0.14**	**44%**	Lignite
Virginia Plant	1-2	848	0.29	**0.21***	**28%**	Eastern Bit
Illinois Plant	1	726	0.18	**0.12**	**33%**	PRB
Iowa Plant	4	591	0.22	**0.12**	**45%**	Lignite
Illinois Plant	1	186	0.11	**0.08**	**31%**	PRB

* - Separated Over Fire Air was added

Supported multiple Utilities burning various fuels: Predicted an average NOx Reduction of 37%

MHPSA DeNOx Technologies

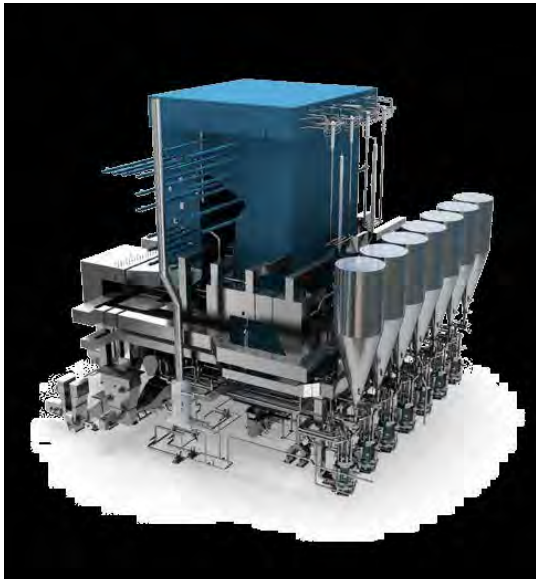


MHPSA has extensive experience in all aspects of DeNOx Systems

Ultra-LNB Benefits for SCR Operation

<u>Example Case – 500 MW T-Fired Boiler</u>

- O&M costs for SCR systems are greatly impacted by inlet (furnace) NOx levels
- DeNOx System Approach:
  - Replace existing burners with Ultra-LNB
  - Optimize SCR ammonia consumption
  - Reduced catalyst replacement cycles
  - Lower mercury emissions
  - Reduced SCR minimum operating temp

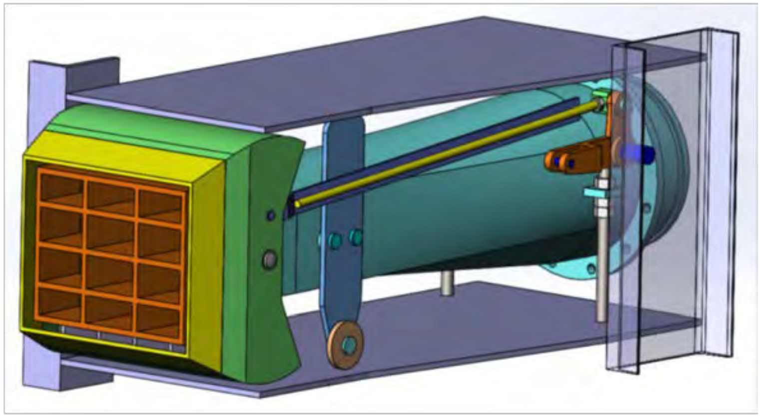


- 500 MW T-fired boiler
- Bituminous Coal
- 3 Layer SCR

M-PM burner performance reduces O&M costs

Step 1: Burner Improvement

<u>Existing Burner Conditions</u>:
- NOx emissions - 0.28 lb/MMBtu with Separated OFA
- Unburned Carbon - 3%



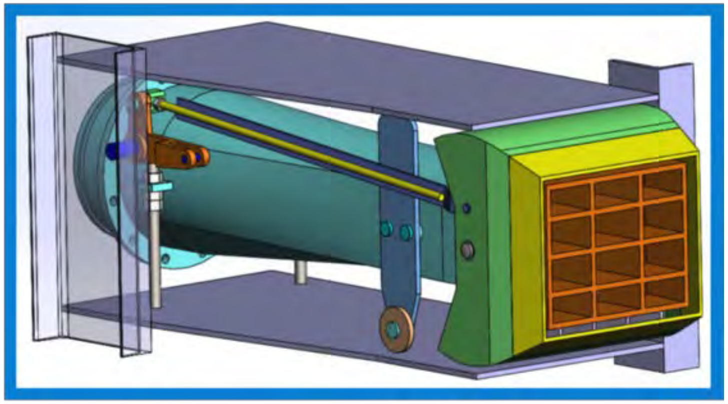
<u>Utilizing MHPSA Ultra-LNB</u>
- NOx emissions - 0.17 lb/MMBtu ⬇
- Unburned Carbon - <3%
- No changes to the Separated OFA
- Installed cost of LNB - $3.5M

Burner replacement results in NOx emission reductions of 39%

Step 2: Ammonia Consumption Reduction

Existing Ammonia Injection Conditions:

- Ammonia Injection - 450 lb/hr at full load
- SCR NOx reduction - 0.23 lb/MMBtu (82%)
- Annual Ammonia cost - $1.85M



Ammonia Consumption improvement by Utilizing Advanced LNB

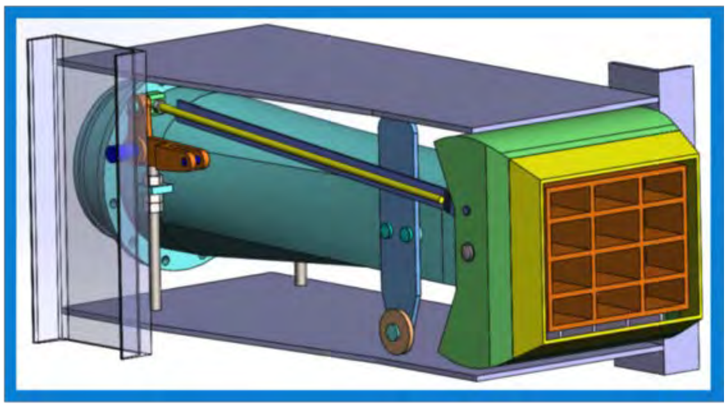
- Ammonia Injection - 234 lb/hr (48% less) at full load ⬇
- SCR NOx reduction - 0.12 lb/MMBtu (70%) ⬇
- Annual Ammonia cost - $0.95M ⬇

Annual Ammonia savings is $0.9M

Step 3: Catalyst Life Extension

Existing Catalyst Conditions:

- Catalyst activity potential required – 3.2
- Catalyst Life - 24k hrs
- Annual Catalyst cost - $0.4M + installation - $0.17M

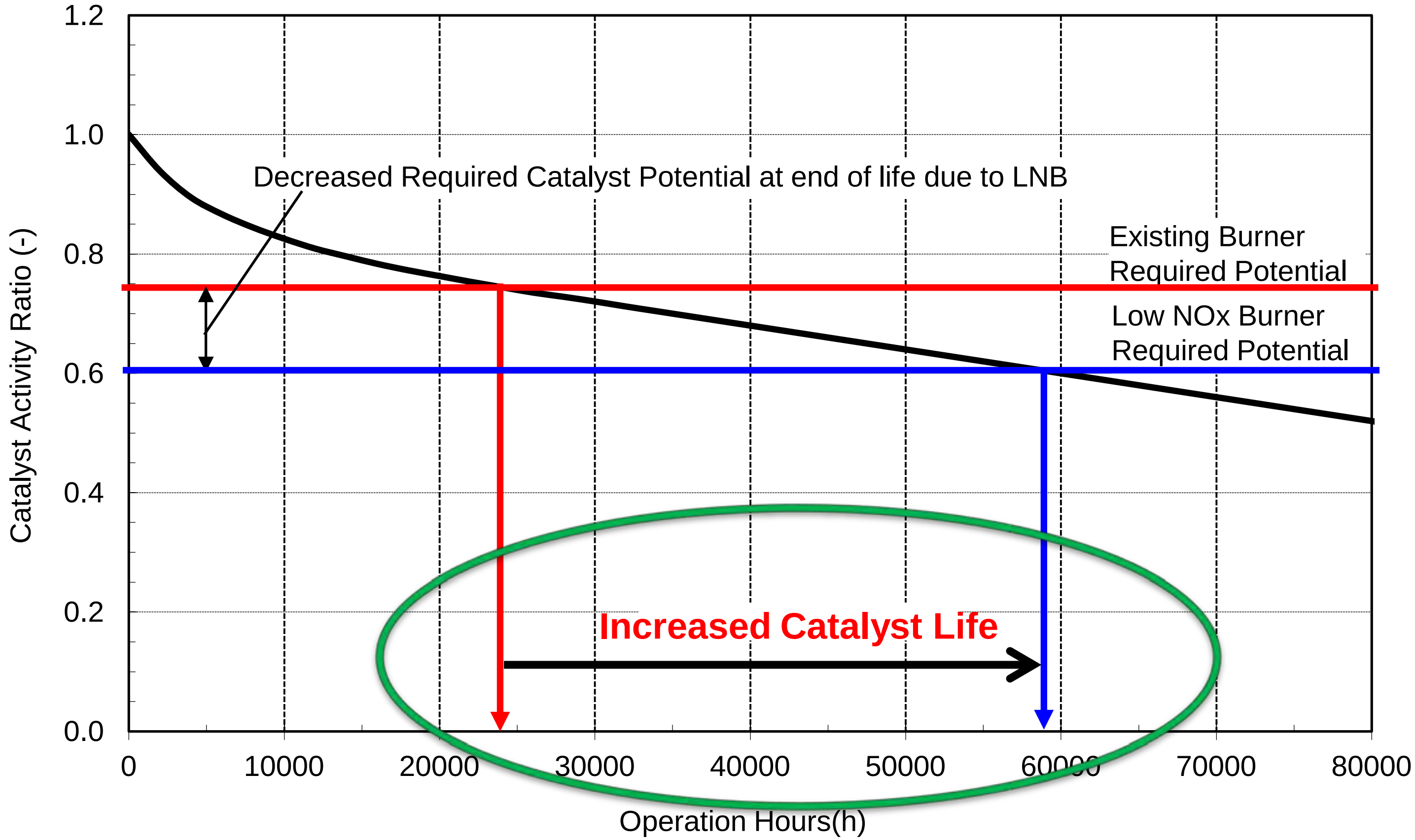


Catalyst Effect of Utilizing Advanced LNB

- Catalyst activity potential required – 2.6 ↓
- Catalyst Life - 58k hrs ↑
- Annual Catalyst cost - $0.166M + installation - $0.06M ↓

Annual Catalyst/Installation savings is $0.35M

Advanced LNB Impact to Catalyst Life



Small Changes in Catalyst Potential provides 2+ year catalyst life extension

Summary: SCR Benefit Analysis

	Existing Burners	Existing Annual Cost	MHPSA Burners	Retrofit Annual Cost
NOx Rate (lb/mmbtu)	0.28		0.17	
SCR NOx Workload to 0.05lb/mmBtu	0.23		0.12	
Ammonia Usage	100%	$1,850,000	52%	$950,000
Catalyst Life	24k hrs	$570,000	58k hrs	$225,000

Capital Cost Investment:

- $3.5M – Design, Supply and Installation of Ultra LNB

Annual O&M Savings:

- $0.9M – Ammonia Consumption
- $0.35M – Catalyst Life Extension

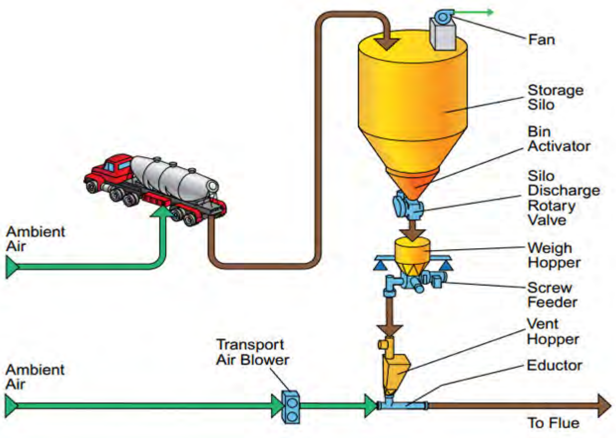
NPV = $2.0M with 30% ROI

Payback Period of <3 Years

MHPSA can Contract a Long Term NOx Agreement for O&M Savings with Guarantees

Guarantee O&M savings of $12.4M over an 10 year period

Additional Benefits



Mercury Oxidation ⬆

- Ammonia acts as an inhibitor to Mercury Oxidation
- Reducing Ammonia increases Mercury Oxidation
- Minimize Activated Carbon, Calcium bromide, etc.

Minimum Operating Temperature (MOT): ⬇

- MOT is defined Ammonia concentration
- Reducing Ammonia allows for a lower MOT
- Lower MOT gives boiler more operating load flexibility

New Burners and Air Nozzles ⬆

- Performance, Reliability, Longer life

Additional improvements in Mercury oxidation and reduction in operating temperature are further co-benefits to Utility operating costs

Power for a Brighter Future

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