

REINHOLD ENVIRONMENTAL Ltd.



2016 NO_x-Combustion-CCR Round Table Presentation

February 1 & 2, 2016, in Orlando, FL / Hosted by OUC

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Low NO_x burner experience with multiple fuels



Keir McQuistan and Dan Rowley

2016 Reinhold NO_x-Combustion-CCR Round Table

Today's presentation

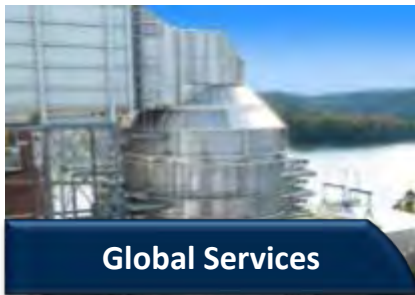
Two parts-

1) Low NOx pulverized coal experience

Focus on B&W advanced AireJet[®] ultra-low NOx burner

2) Low NOx natural gas conversions

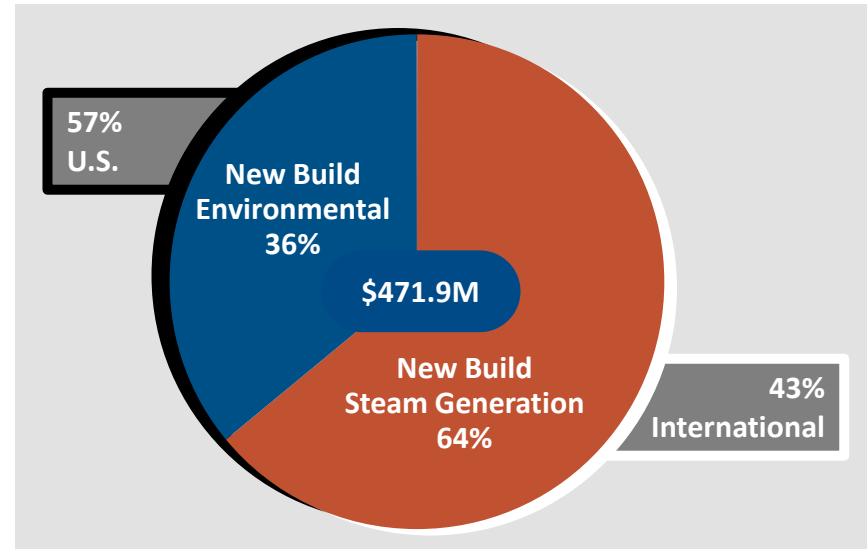
B&W Company Overview



Global Power Overview

- ▶ Steam generating systems for fossil fuels and renewable energy conversion for power generation and industrial uses
- ▶ Environmental solutions include emissions control products and related equipment
- ▶ Complex project execution from design through commissioning, offering predictable installation of reliable equipment

2014 Revenue by Segment



Utility Steam Generation



Renewable Power



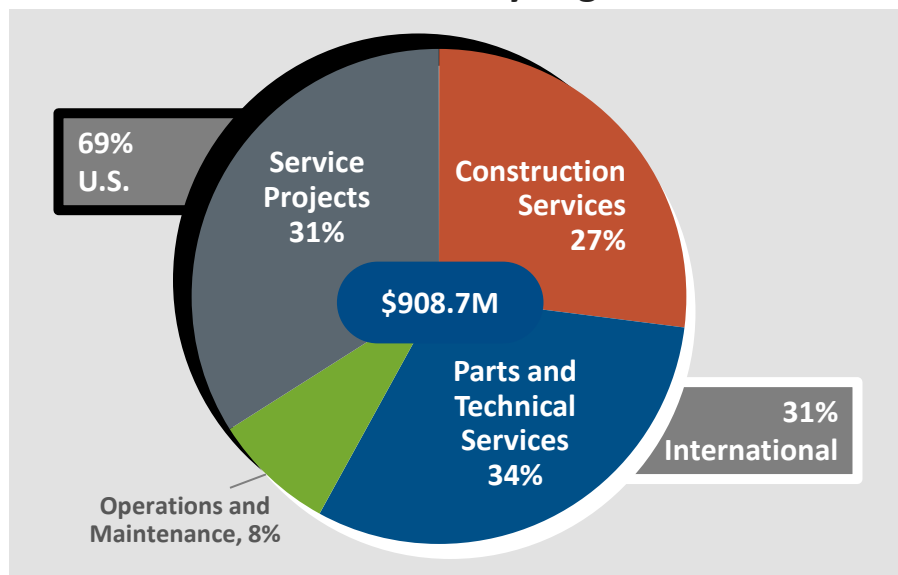
Industrial Power



Environmental Solutions

Global Services Overview

2014 Revenue by Segment



- ▶ Aftermarket products and services for steam generating equipment and associated environmental and auxiliary equipment
- ▶ Servicing B&W installed electricity generation capacity of approximately 300,000 MW in more than 90 countries plus competitor equipment
- ▶ Supports general industry and renewable boilers, including waste-to-energy and pulp & paper
- ▶ Extensive network of regionally located service centers, technical support personnel and global sourcing capabilities



Parts and Technical Services



Service Projects



Construction Services



Operations and Maintenance

Industrial Environmental Overview

- ▶ B&W acquired MEGTEC Systems, Inc. on June 20, 2014
 - 40+ year history with ~600 employees across 13 offices globally
 - Asset-light flexible manufacturing platform
 - Significantly expanded B&W's industrial environmental capabilities and provides additional channels to market
- ▶ Design, engineer, manufacture and service industrial equipment for process industries worldwide
 - Specific technologies for industrial air pollution abatement and recovery
 - Coating and drying equipment for various end markets (including energy storage)
 - Recurring aftermarket business



Air Pollution Control Systems



Coating and Drying Equipment

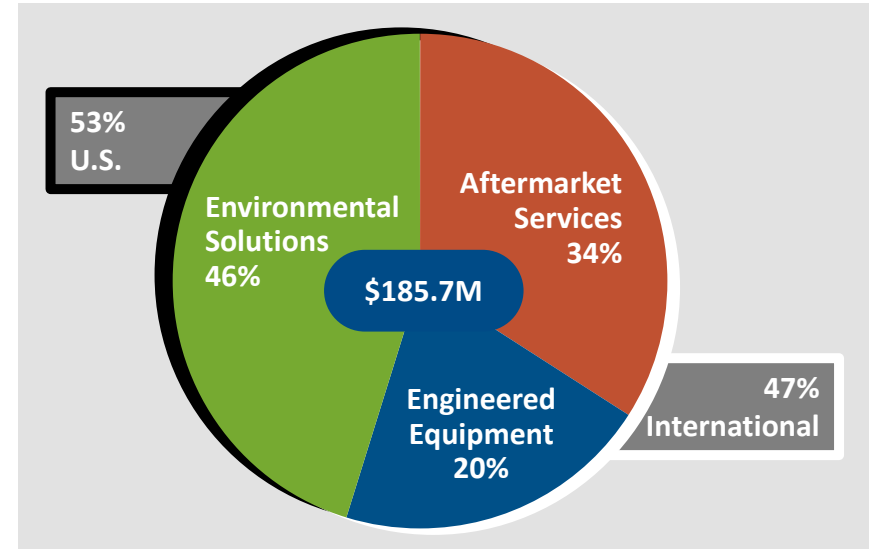


Replacement Parts



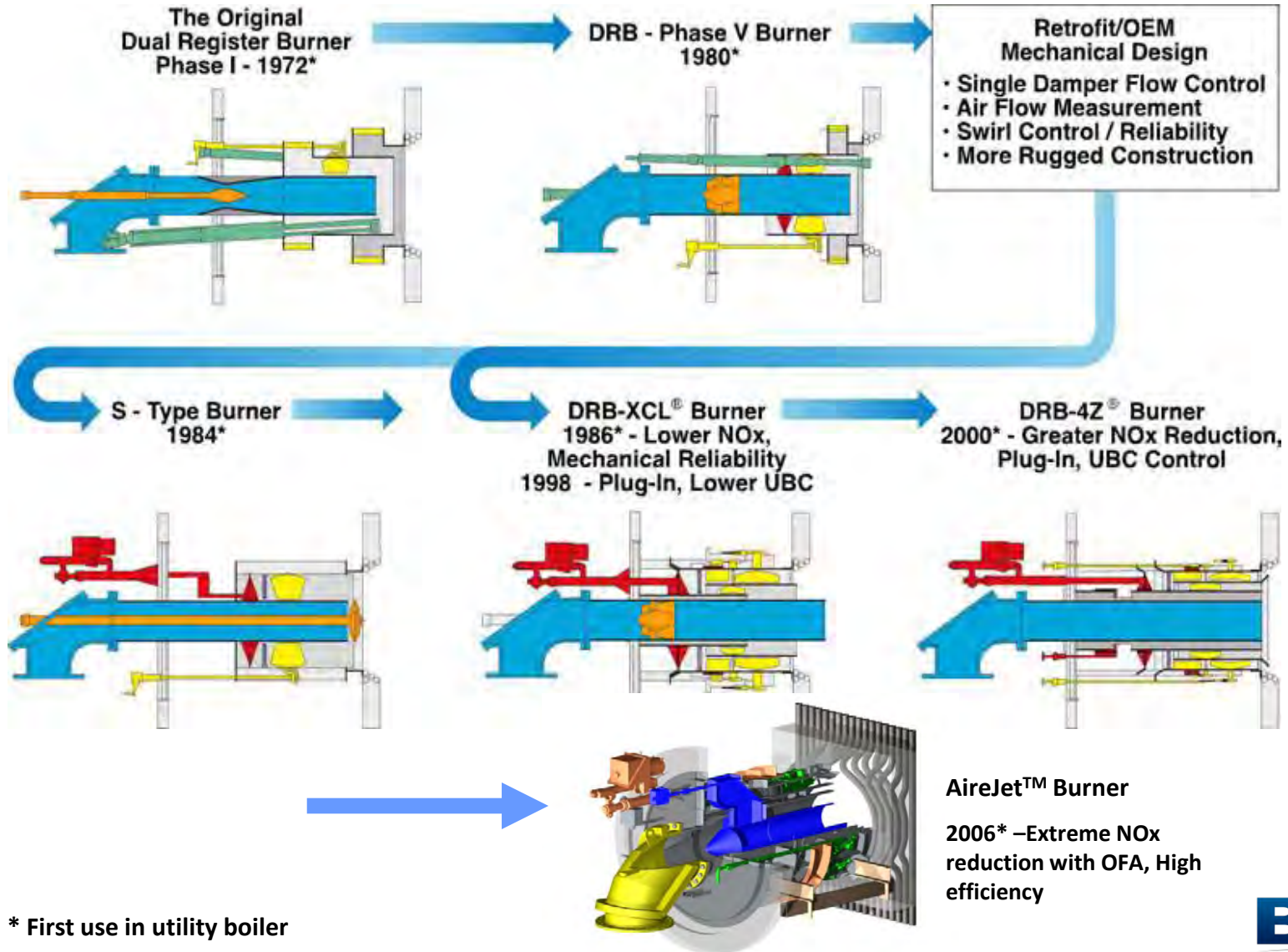
Preventive Maintenance

2014 Revenue by Segment⁽¹⁾



Footnote: (1) 2014 full-year segment revenue includes revenue attributable to previous owner and revenue attributable to B&W

40+ Years of NO_x Reduction Leadership with Coal-Fired Burners

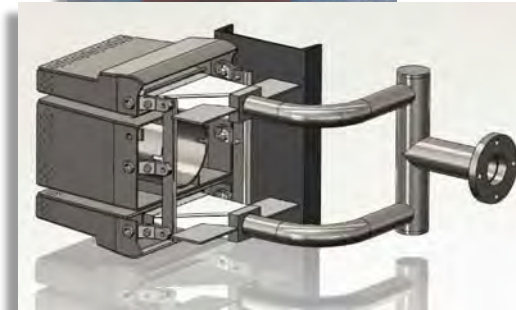


Tangentially-fired burner experience

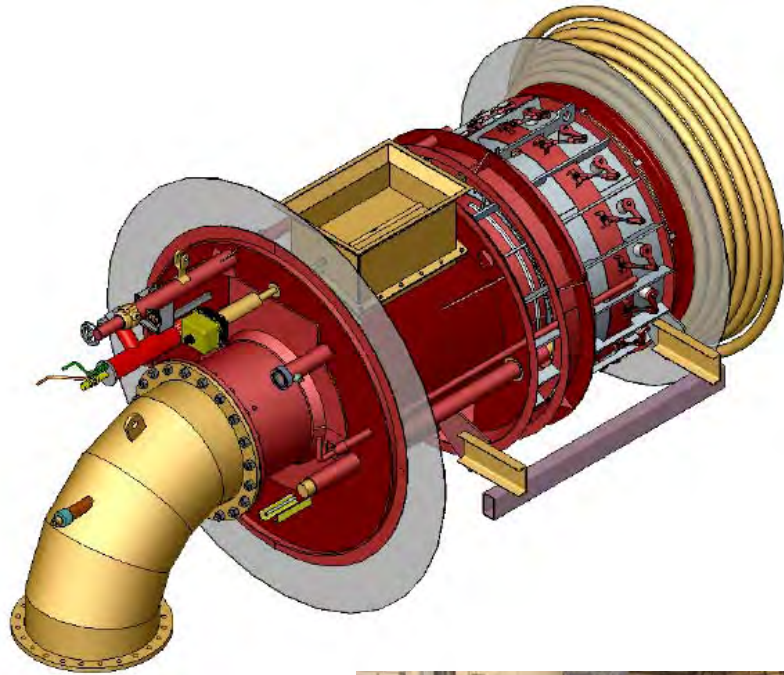
- **Converted 29 coal fired units to low NOx totaling 10,500 MWe**
- **Actively bidding natural gas conversions for 13 units totaling 2,500 MWe**
- **Recently received preliminary engineering release to add 8 gas burners to a coal fired power boiler**



Courtesy of RV Industries



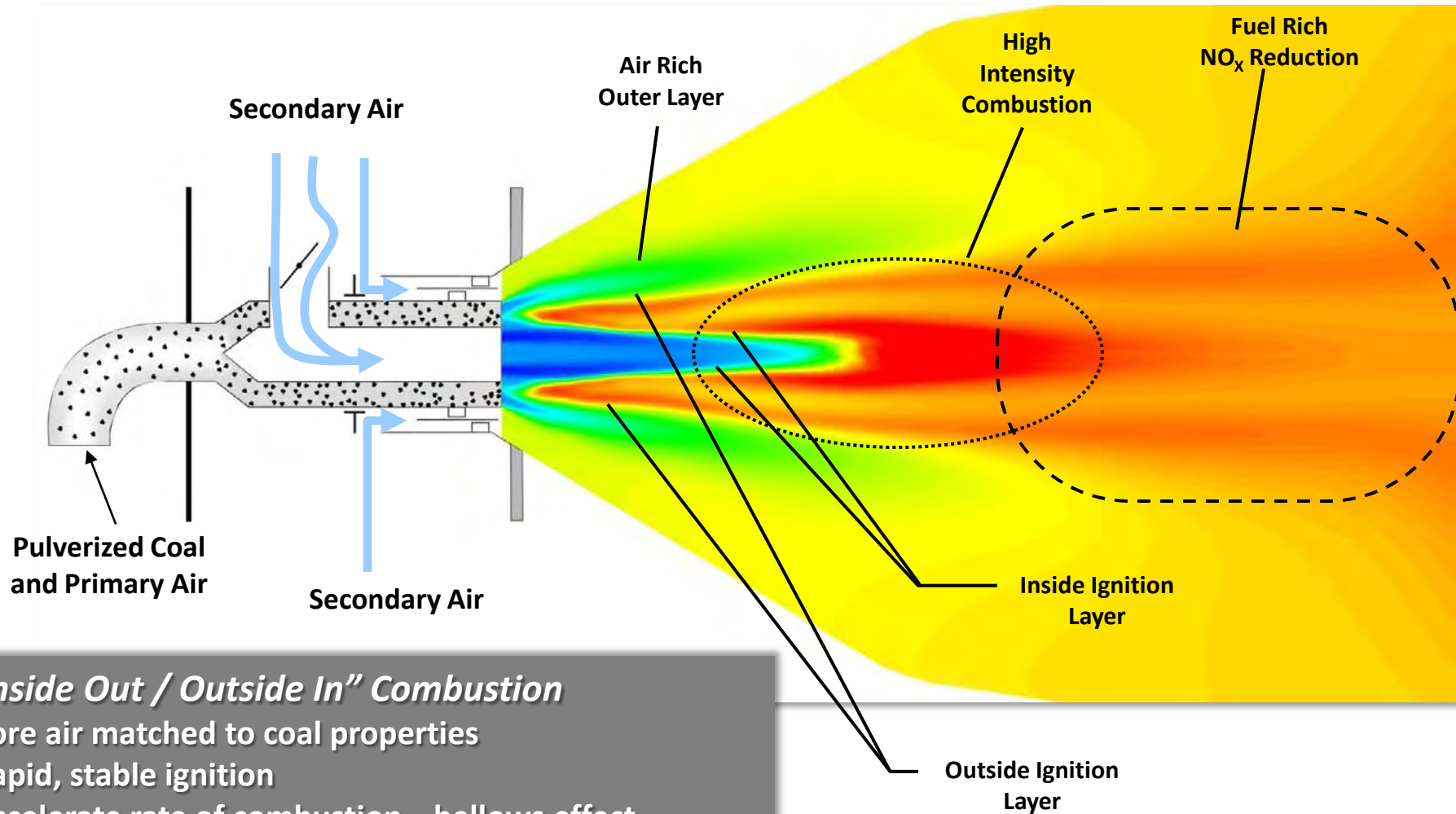
10 years of experience with B&W AireJet[®] burner



- **Developed 2004-2005**
 - **CFD analysis**
 - **Single burner testing at 10 MWe**
- **First commercial 2006**
 - **100 MWe PRB unit**
- **Over 11,000 MWe**
- **Nearly 700 burners on 29 units**
- **Bituminous and Sub-bituminous coal**
- **US and International**
- **New and Retrofit**
- **Opposed and Single-wall firing**



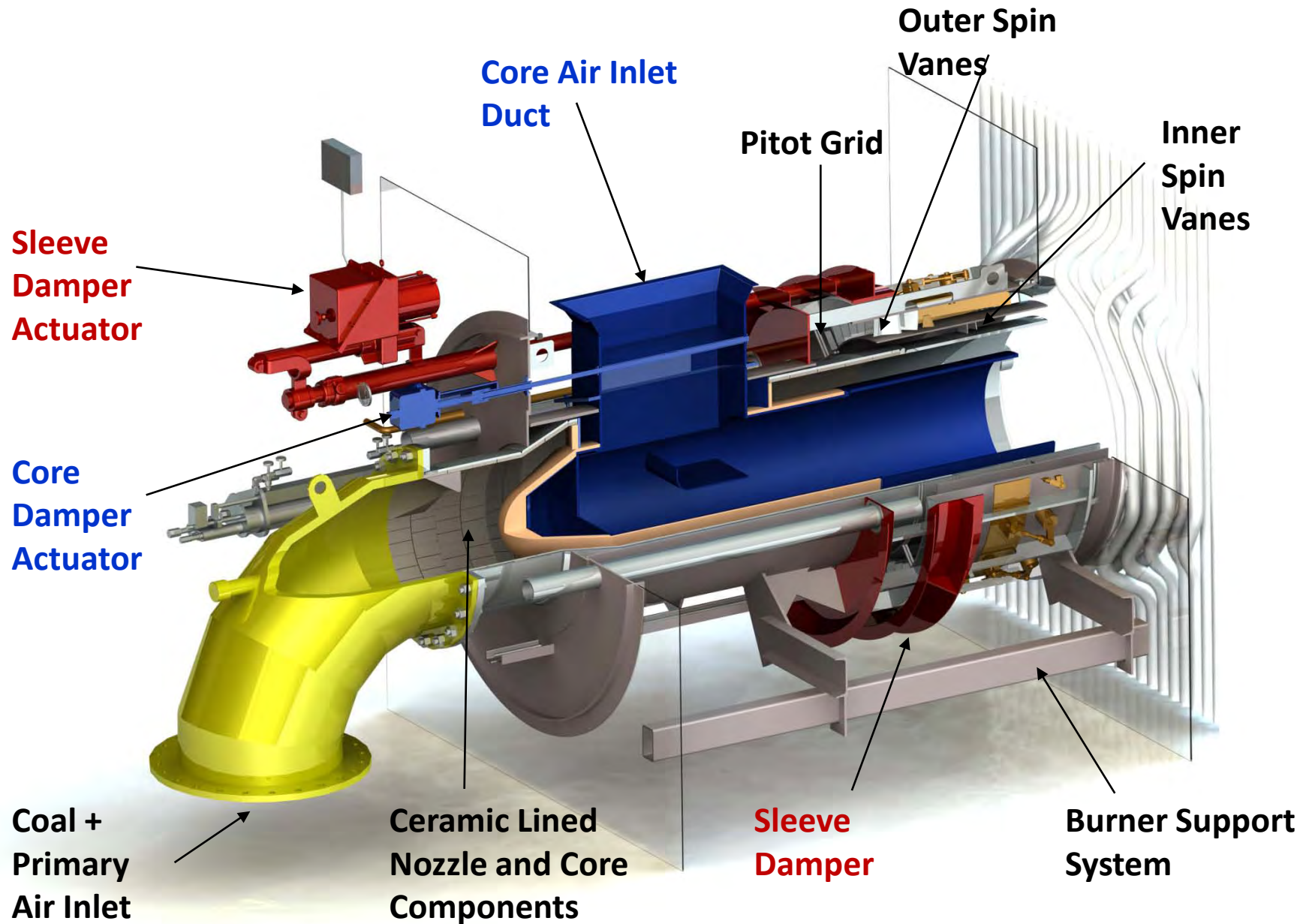
AireJet[®] Burner



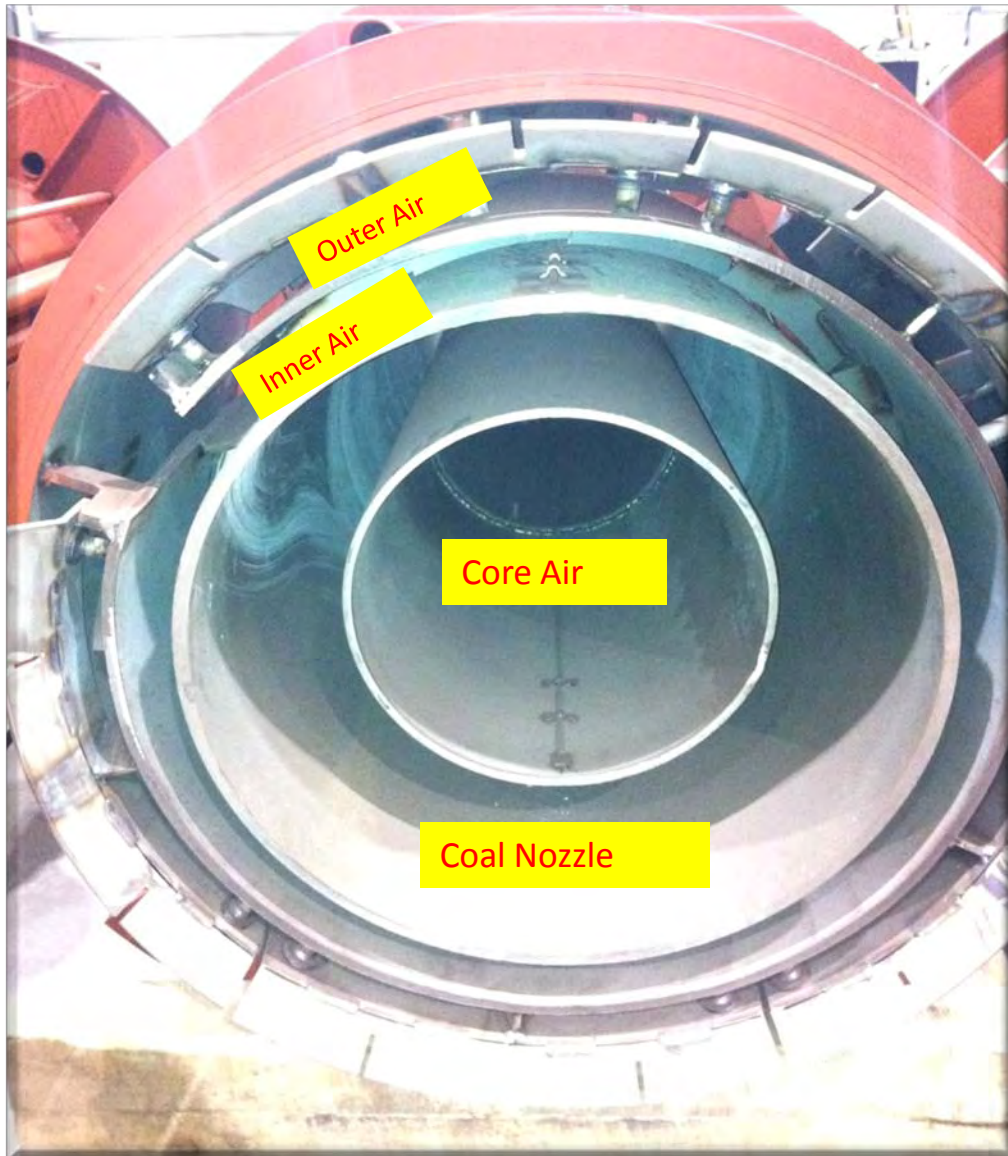
“Inside Out / Outside In” Combustion

- Core air matched to coal properties
- Rapid, stable ignition
- Accelerate rate of combustion—bellows effect
- Fuel rich longer = much lower NO_x
- Cleaner burning= lower XS air, higher efficiency

AireJet[®] Burner



AireJet[®] burner flame end



- Stainless construction for high temperature environment
- Temperature monitoring
- No additional hardware at burner tip for low maintenance

AireJet[®] diffuser cone

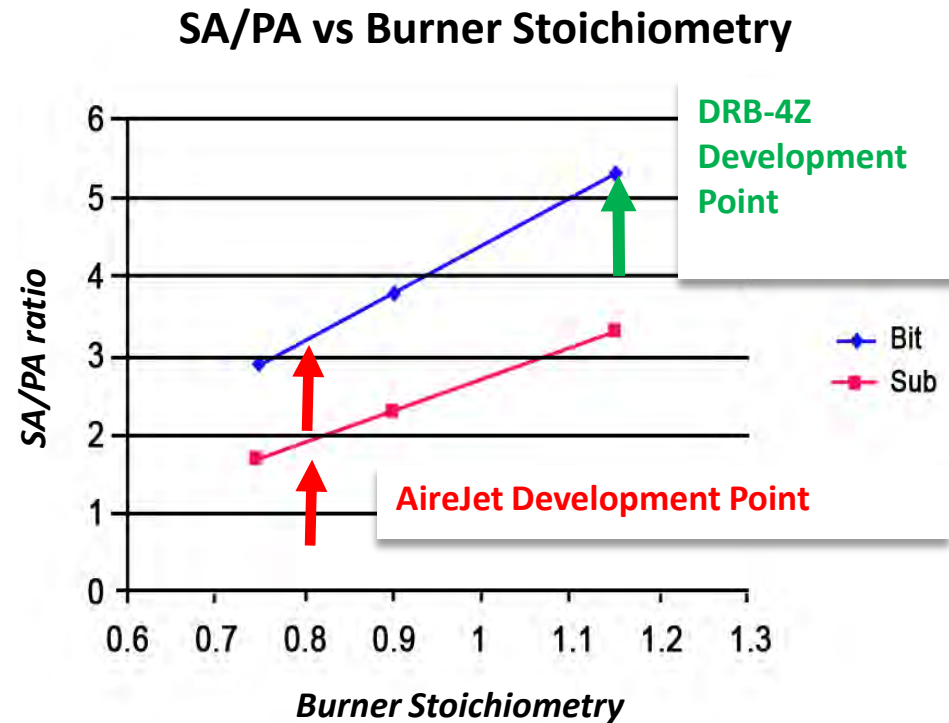
- Proven wear protection
- Multiple interlocking rings
- High alumina ceramic
- +1" solid as-fired rings
- Bolt-on design



AireJet[®] burner

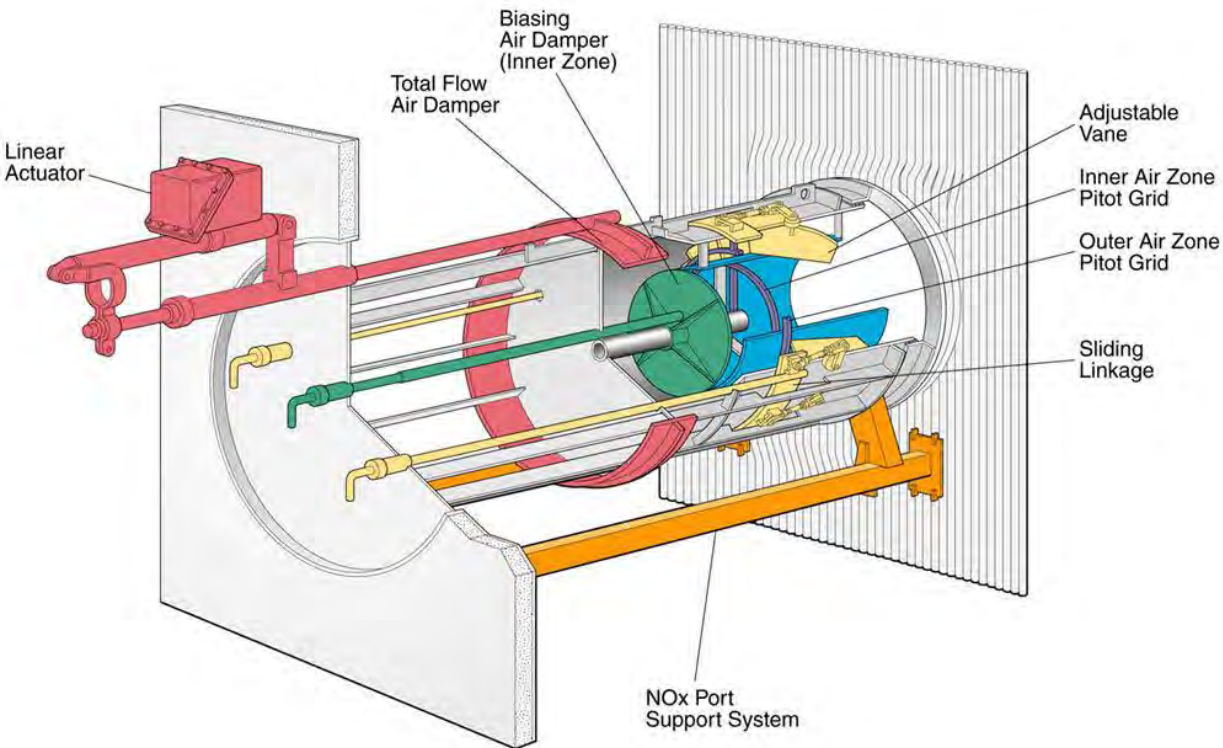
Designed for use with OFA systems

- Burner stoichiometry- 0.80-0.85
- SA/PA decreases with increased OFA (decreasing stoichiometry)
- Design SA/PA ratio
 - 3.5 for bituminous
 - 2.0 for sub-bituminous
- Flame characteristics fundamentally linked to SA/PA ratio
 - Stability
 - Intensity
 - Mixing rate
 - Shape
- AireJet[®] optimized for staging
 - Only used with OFA



Advanced OFA System Dual Zone NO_x Ports

Designed for flexibility to optimize OFA effectiveness



- Total air flow control damper with actuator
- Variable jet penetration with core zone
- Variable near field mixing with adjustable swirl vanes



Advanced OFA System

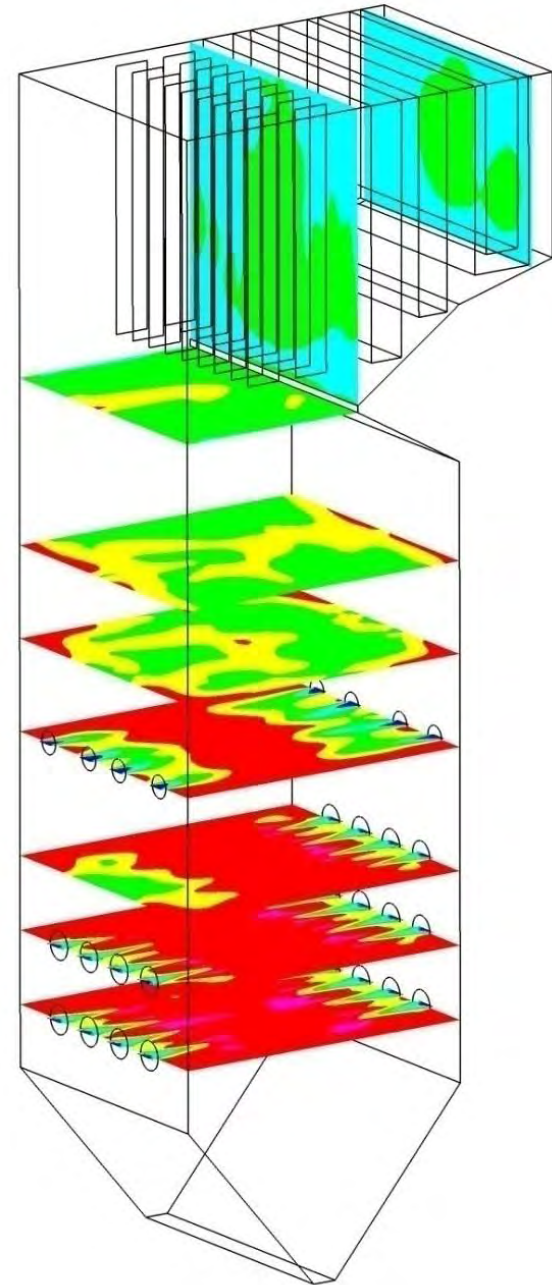
- Well - designed OFA system important to achieve low emissions

- Key design considerations

- Furnace design
- Burner arrangement
- NOx port location
- OFA flow rate
- Burner stoichiometry
- Furnace residence times
- Mixing – jet penetration in crossflow
- Pressure drop
- NOx port size and quantity
- Windbox design

- CFD analysis

- Optimize mixing
- Reduce CO



AireJet® Burner Contracts

Customer	Station	Capacity MWg	Coal Rank	SW/ OPP	Number of Burners ¹	Start-up Year	New or Retrofit	FC/VM
CSU Nixon	1	220	Sub-Bit	OPP	24	2016	Retrofit	1.10
AES Ventanas	2	218	Bituminous	SW	20	2015	Retrofit	1.38
AES Ventanas	1	120	Bituminous	SW	9	2015	Retrofit	1.38
Punta Catalina	1 & 2	2x360	Bituminous	OPP	24	2017-18	New	1.81
Mongolia	ZaoQuan	660	Bituminous	OPP	24+12	2016	New	1.73
Zhejiang	Wenzhou 1	660	Bituminous	OPP	24+12	2015	New	1.82
Xuanhua Thermal	Xuanhua 2	330	Bituminous	OPP	12+8	2015	Retrofit	1.72
Jiangsui	Yangzhou 1	630	Bituminous	OPP	25+5	2015	Retrofit	1.79
Zhejiang	Lanxi 1	660	Bituminous	OPP	30+6	2015	Retrofit	1.83
Pingwei	Pingwei 1 & 2	2x1000	Bituminous	OPP	50 + 10	2015-16	New	1.50
Mongolia	Zhunger 1,2,3 &4	4x330	Bituminous	OPP	12 + 8	2013-14	Retrofit	1.45
Zhejiang	Changxing 1,2,3 &4	4x330	Bituminous	OPP	12 + 8	2012-13	Retrofit	1.49
City of Sikeston	Sikeston 1	260	Sub-Bit	OPP	24	2013	Retrofit	1.08
Nebraska Public Power Dis	G. Gentleman 2	700	Sub-Bit	OPP	48	2012	Retrofit	1.09
Basin Elec. Power Coop	Laramie River1,2 &3	3x615	Sub-Bit	OPP	49	2012-14	Retrofit	1.09
PacifiCorp	Wyodak	380	Sub-Bit	OPP	30	2011	Retrofit	1.07
Basin Elec. Power Coop	Dry Fork 1	450	Sub-Bit	OPP	20	2011	New	1.10
Pub. Power Gen. Agency	Whelan 2	245	Sub-Bit	OPP	18	2011	New	1.08
Black Hills Generation	WYGEN 3	110	Sub-Bit	OPP	12	2010	New	1.06
Black Hills Generation	WYGEN 2	96	Sub-Bit	OPP	12	2008	New	1.06
Black Hills Generation	Neil Simpson 2	92	Sub-Bit	OPP	12	2007	Retrofit	1.06
Black Hills Generation	WYGEN 1	96	Sub-Bit	OPP	12	2006	Retrofit	1.06

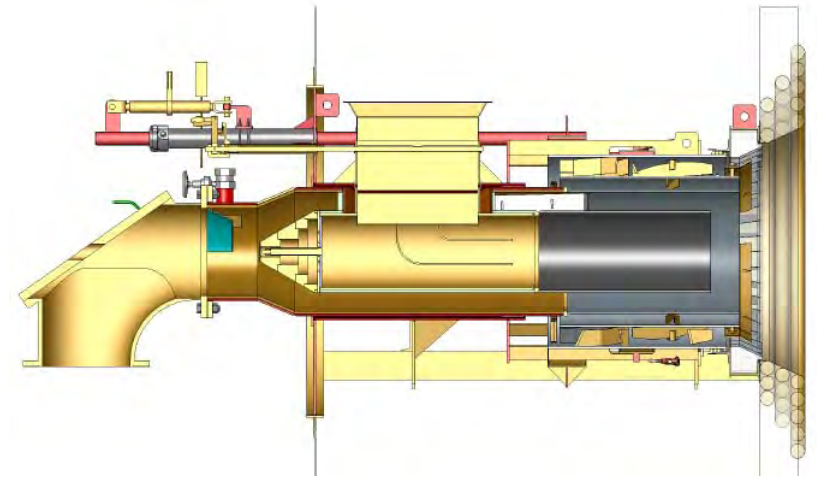
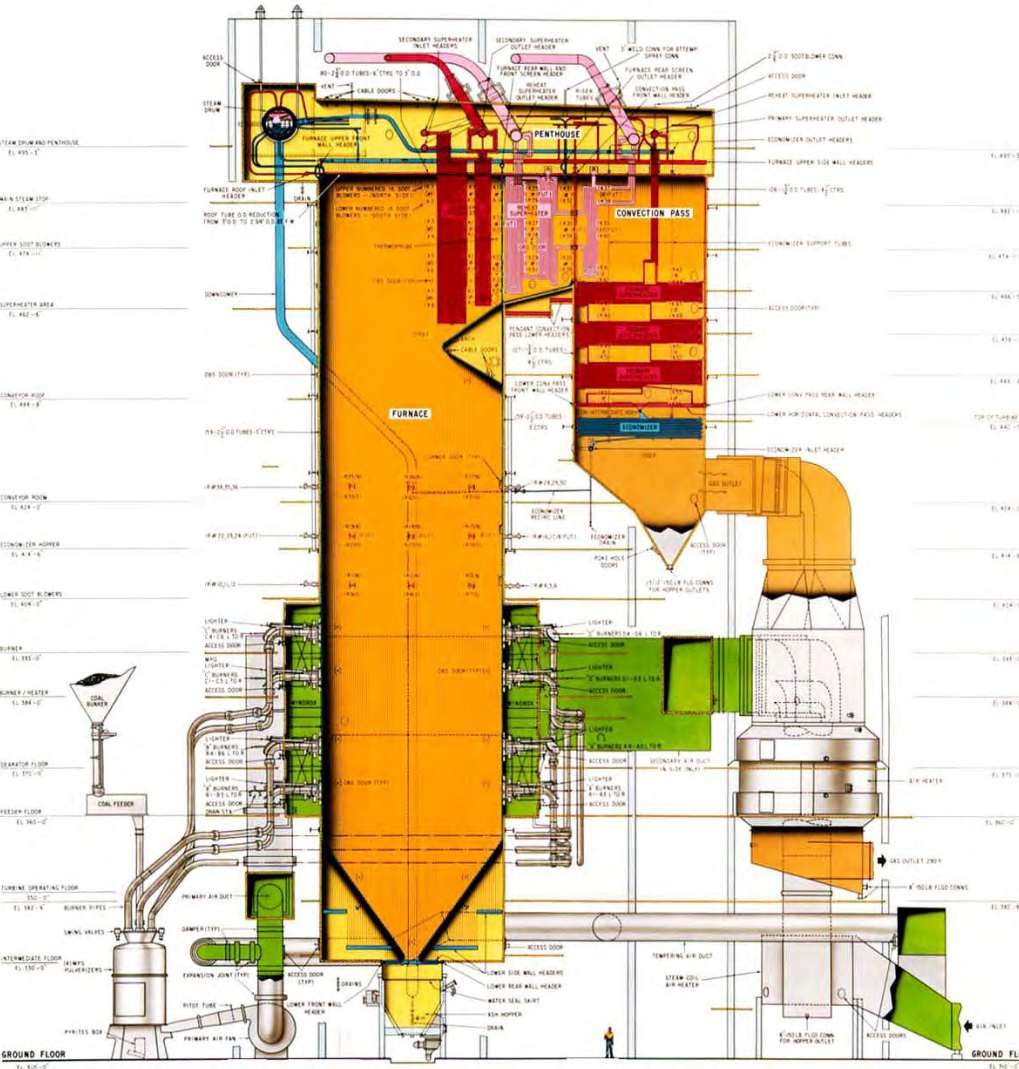
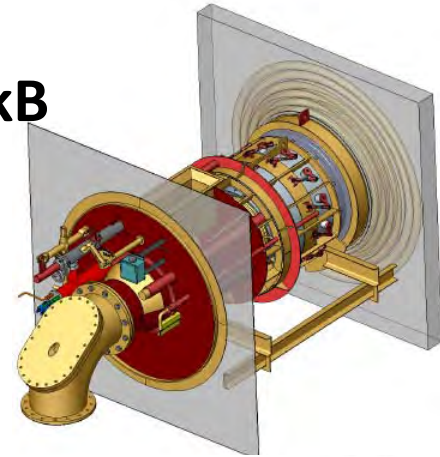


Opposed wall-fired retrofit (Western US)

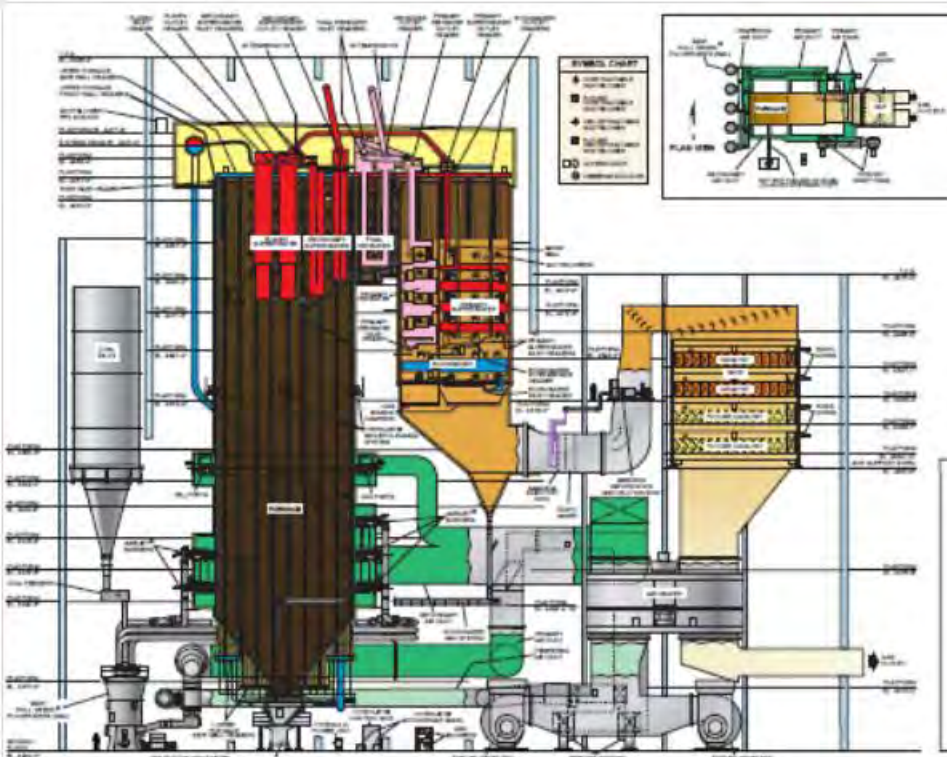
260 MWe
 24 AireJet® burners
 4 high, 3 wide
 6 dual zone OFA ports

Sub-bituminous

NO_x 0.10 lb/MkB
 CO_x <50 ppm
 econ at 2% O₂



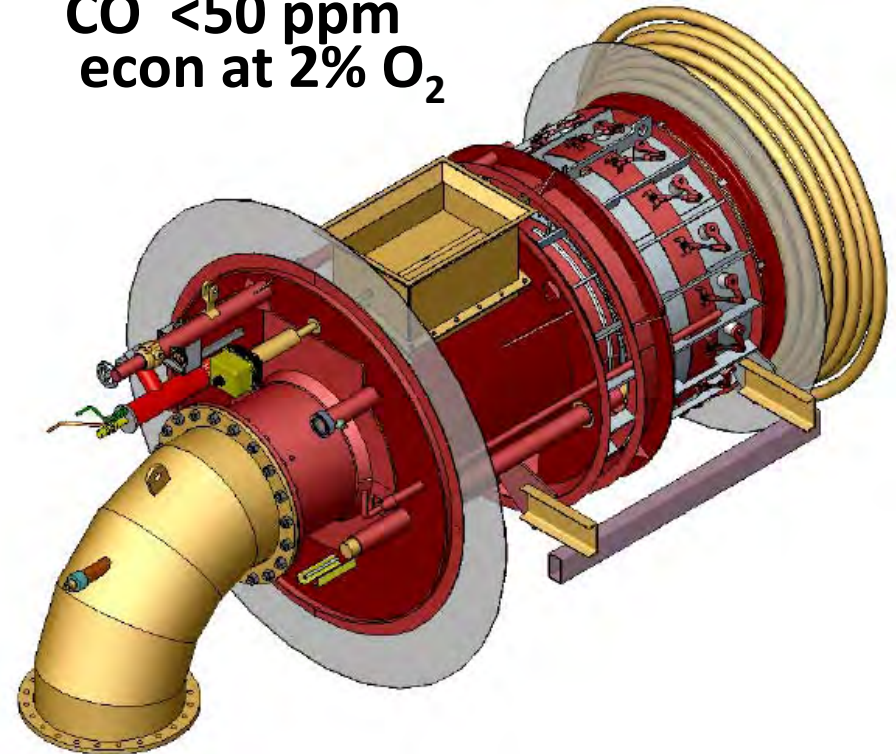
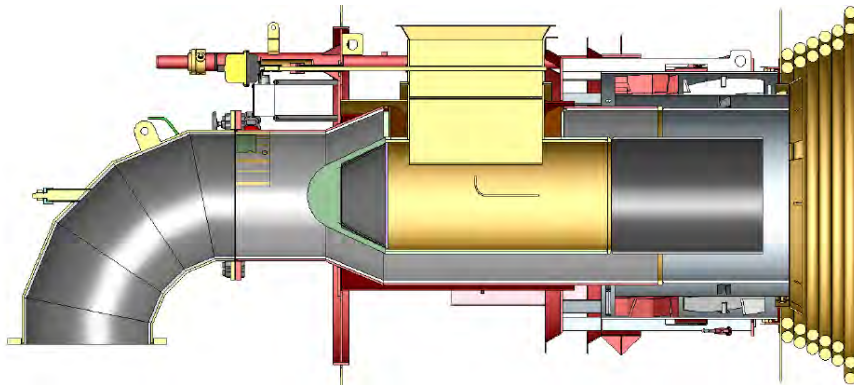
New opposed wall-fired unit (Western US)



410 MWe
20 AireJet® burners
3/2 high, 4 wide
8 dual zone OFA ports

Sub-bituminous

NO_x 0.13 lb/MkB
CO_x <50 ppm
econ at 2% O₂



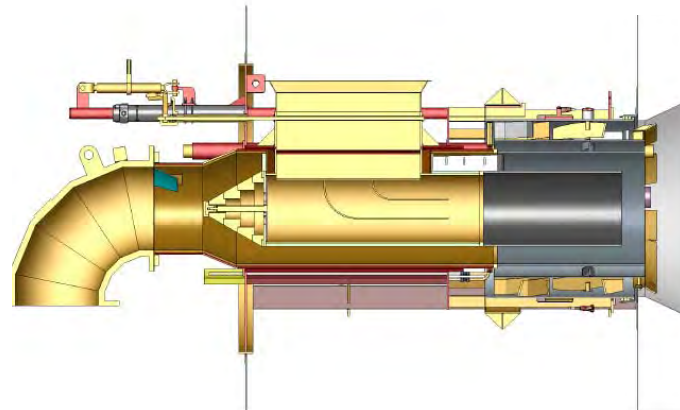
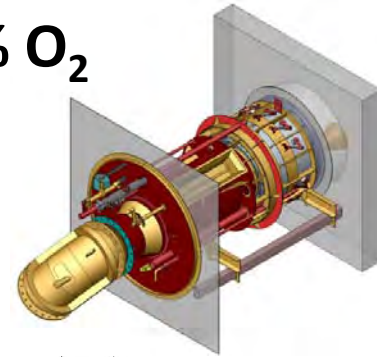
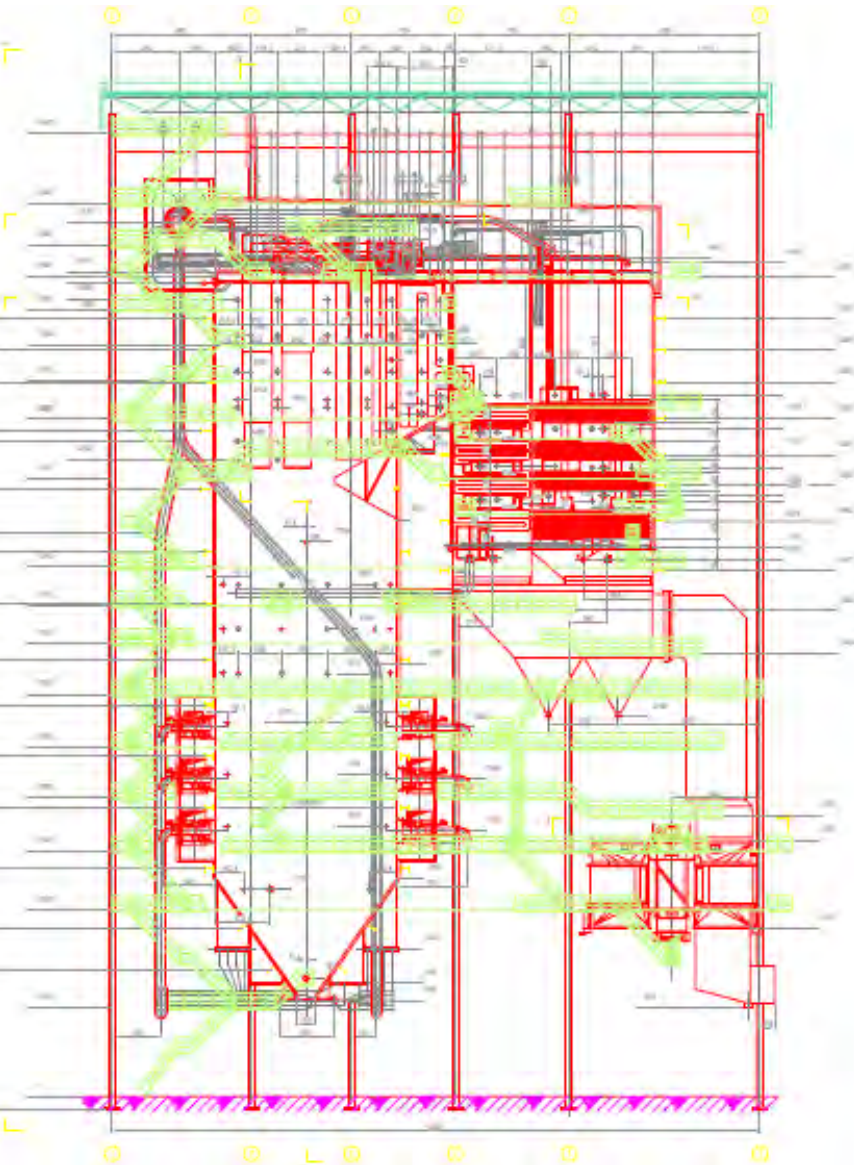
Opposed-fired bituminous retrofit (China)

300 MWe
20 AireJet® burners,
5 pulverizers
45'X40' unit cross-section

High volatile bituminous

NO_x 0.18 lb/MkB
CO <150 ppm at 3% O₂

4Z burners with
plasma ignitors
in bottom row



Single wall-fired bituminous retrofit (Chile)

218 MWe, original FuelTech
burners

20 AireJet® burners

5 high, 4 wide

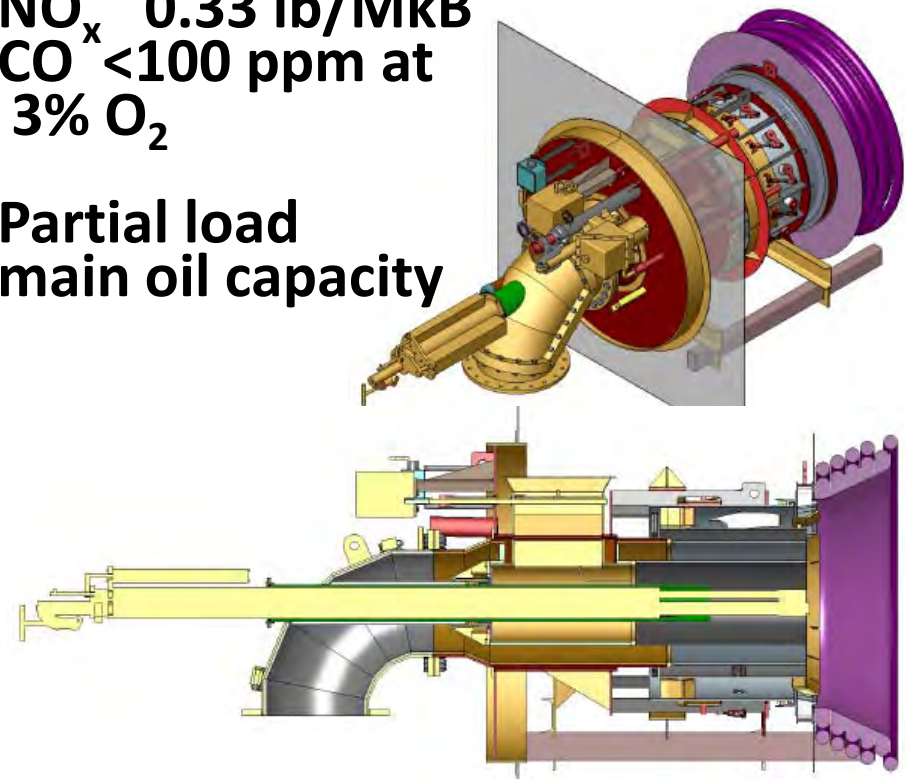
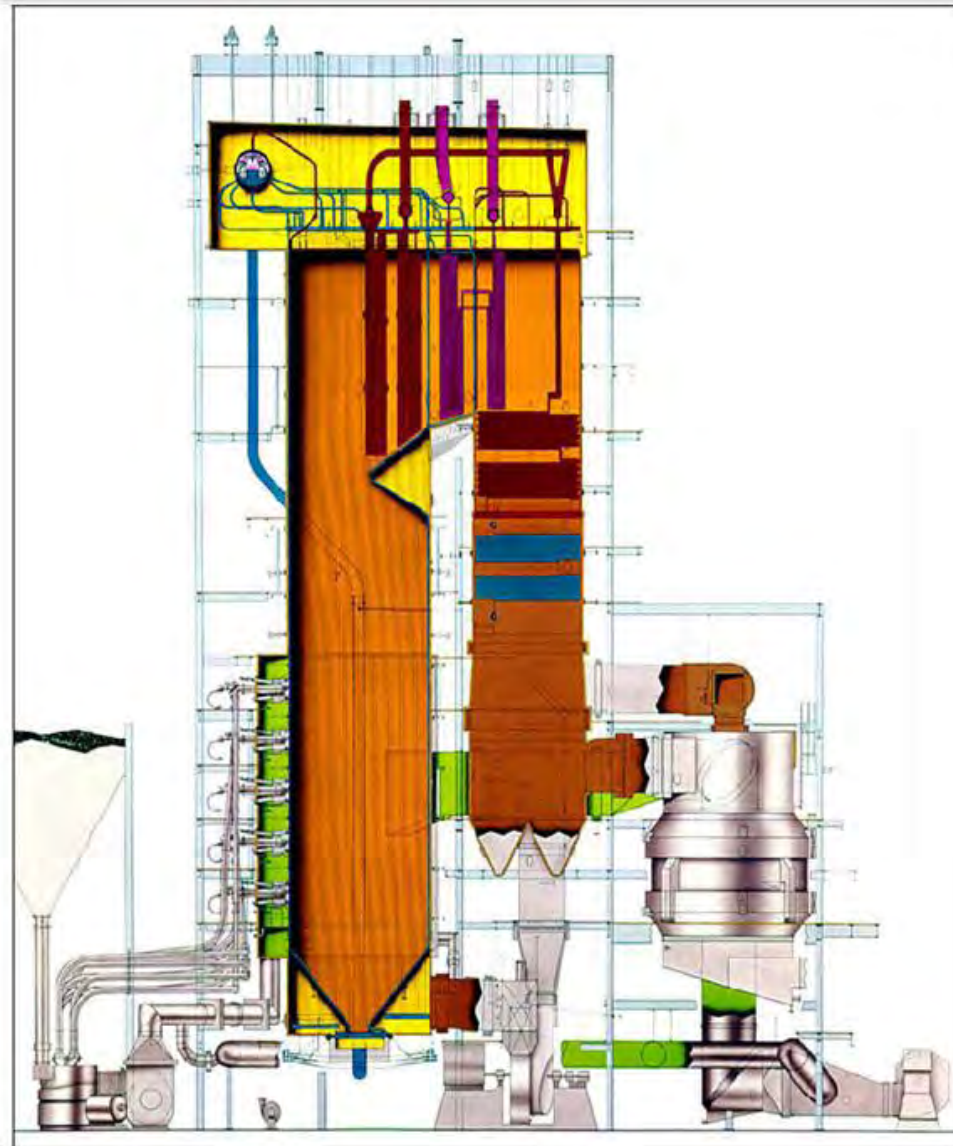
5 upgraded EL pulverizers

High volatile bituminous

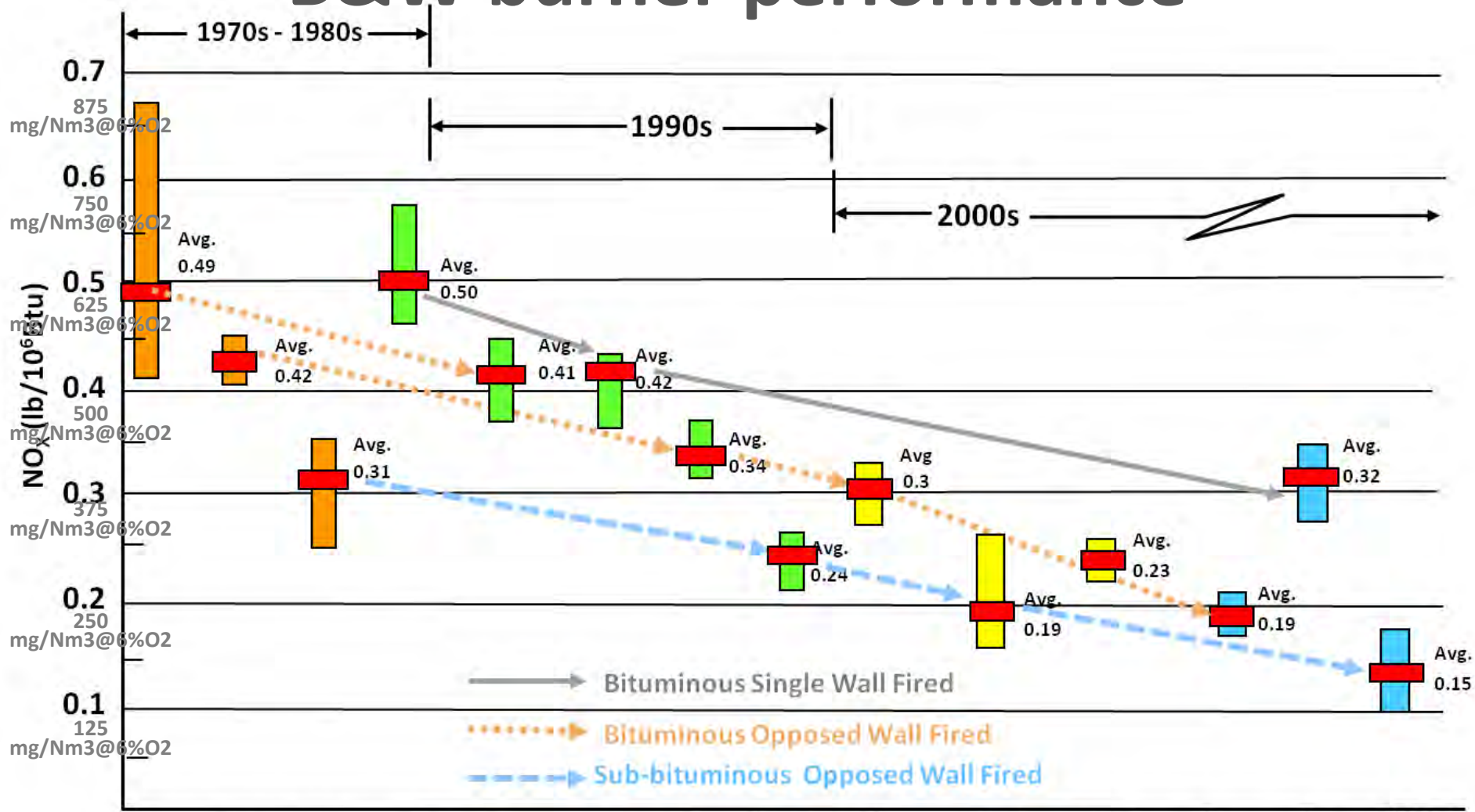
NO_x 0.33 lb/MkB

CO_x <100 ppm at
3% O₂

Partial load
main oil capacity



B&W burner performance



Bit	Bit	Sub-Bit	Bit	Bit	Bit	Bit	Sub-Bit	Bit	Sub-Bit	Sub-Bit	Bit	Bit	Sub-Bit
DRB	DRB + OFA	DRB	DRB-XCL	DRB-XCL	DRB-XCL	DRB-XCL	DRB-XCL	DRB-4Z	DRB-4Z	DRB-4Z	Airejet	Airejet	Airejet
(opp)	(opp)	(opp)	(Single)	(Opp)	+ OFA	+ OFA	+ OFA	+ OFA	+ OFA	+ OFA	+ OFA	+ OFA	+ OFA
(opp)	(opp)	(opp)	(Single)	(Opp)	(Single)	(Opp)	(Opp)	(opp)	(opp)	(Single)	(opp)	(Single)	(opp)

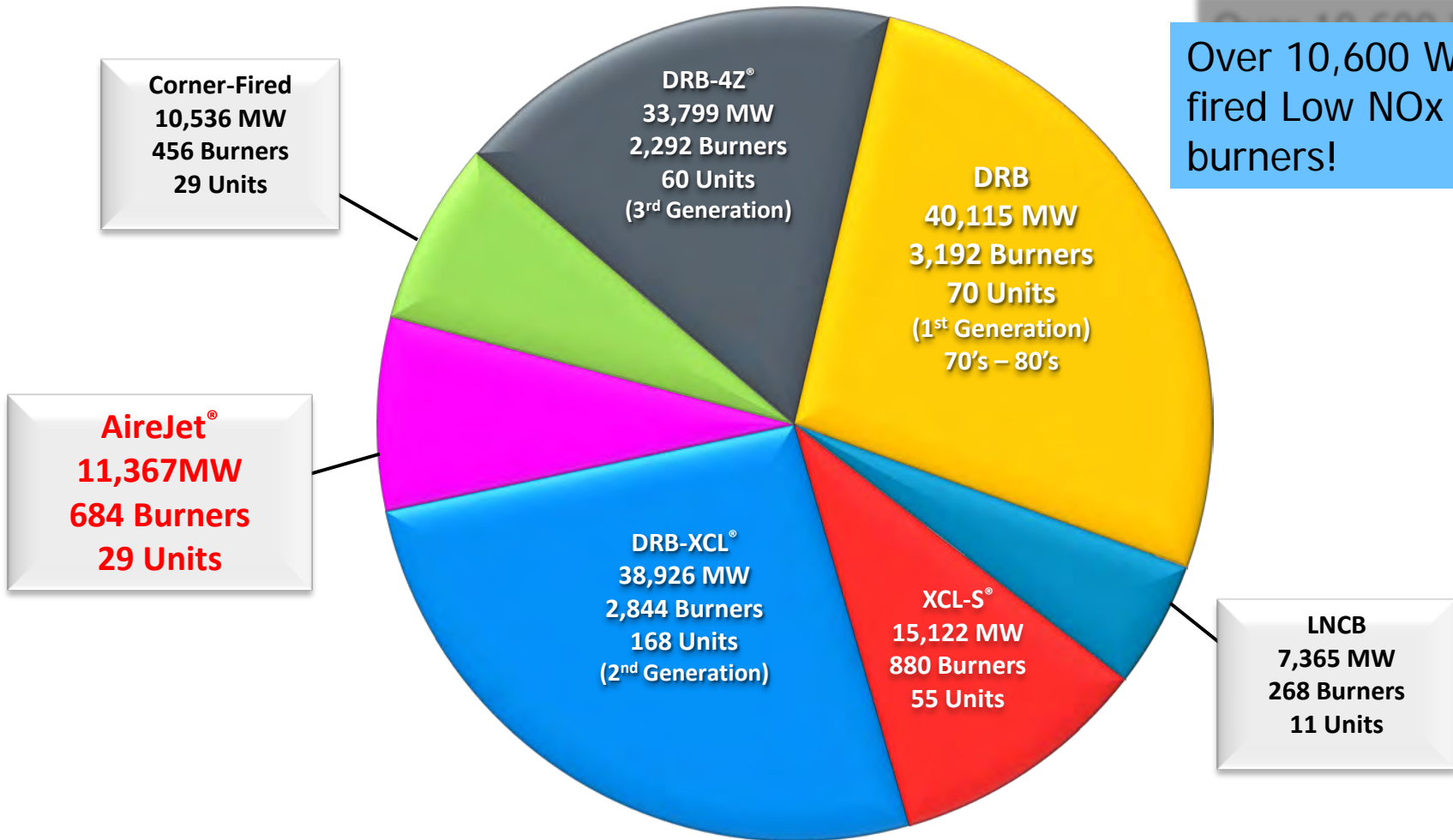
Avg. MW 713 480 564 155 335 169 556 550 480 564 150

•Lowest AireJet NOx shown with all burners in service (125 mg/Nm³@6%O₂ = 0.100 lb/MkB)



B&W Low NOx Burner Experience

Over 10,600 Wall-fired Low NOx burners!



Over 157,000 MW of Installed Experience



Low NOx gas conversions

Converting a Furnace From PC to Nat. Gas

Pros:

- **MATS Compliance: Reduce or eliminate the need for back end environmental technologies: SO_x (scrubbers), PM (baghouse/ESP), Hg (Act. Carbon)**
- **Possibly to comply with NO_x limits or reductions without SCR**
- **Reduced CO₂ emissions**
- **Increased availability of inexpensive Natural Gas via fracking technologies**
- **Fluid – fuel can be piped and distributed**
- **Extend functional life of existing generating assets and transmission infrastructure**
- **Eliminate wear parts and associated maintenance**
- **Eliminate Coal & Ash handling systems**
- **Aesthetics of coal/ash storage/transport and particulate transport around residential, industrial developments (NIMBY)**



Converting from PC to Natural Gas

Cons:

- **On demand system, limited/no stockpile of fuel which replaces the coal yard**
- **Increased operating risk & price volatility**
- **Green House Gas emissions/CO₂ credits not acknowledging field emissions of CH₄ at wellheads**
- **Leaking of fracking fluids into potable water aquifers**
- **Limited gas pipelines and access (\$3M+ per mile of pipe)**

Furnace Operation:

- **Less radiant heat transfer from flames**
- **All combustion air must enter burner as Secondary Air**
- **No primary combustion air supplied through PA fan/mill/coal nozzles**
 - Not as much of an issue with hot PA fan
 - Big issue with cold PA fans – potential load limitations
- **Potential for pulsations - strict flame design / burner sizing standards**
- **Potential for fuel leaks to be explosive (less so with solid fuel) – observe startup permissives and leak checks**

Engineering, Design, and Validation



Comparison of Gas to PC Firing

Fuel	Natural Gas	Subbituminous (PRB)	
Conversion Strategy	preserve PC firing capability	Lowest NO _x emissions using combustion staging	
Burner Design	Airejet + Superspud & OFA	Airejet & OFA	
MS Flow	2,622	2,622	kpph
Fuel heat input	4,000	3,950	MkB/h
XS Air at econ	12	16	%TA
fuel flow	3,872	x	1000 ft ³ /h
fuel flow	175	500	kpph
HHV	1,033	x	BTU/ft ³
HHV	22,872	7,900	BTU/lb
Theor. Air	7.23	7.59	lb/10kBtu
Flue gas flow at econ exit	3454.17	4024.58	kpph
coal contract cost (PRB)		11.00	\$/short ton
Nat gas contract cost	2.85		\$/mmBtu
fuel operating cost	11,400	2,513	\$/h
fuel operating cost		~11,800 \$/h for eastern Bituminous	



Products of Combustion

Reduction of CO2 emissions:

CO2 emissions	269	171	lb/100 lb fuel
CO2	469,846	854,250	CO2 lb/h
% of PC CO2	55%	100%	
CO2 reduction	45%		

Increase in H2O emissions

fuel H2O	0	31.4	wt%
H2O emissions	237	68	lb/100 lb fuel
H2O emissions	414,462	342,044	lb/h
% of PC H2O	121%	100%	
H2O increase	21%		

NOx emissions

Ha/Sc-bruner zone	461	461	kBtu/h-ft ²
NOx emissions	0.175	0.178	lb/MkB
NOx emissions	700	703	lb/h
NOx reduction	0%		

Sulfur emissions

SO2 emissions	0	0.84	lb/100 lb fuel
SO2 emissions	0.00	4,200	lb/h
SO2 emissions	0.00	1.06	lb/MkB
SO2 reduction	100%		

Mercury emissions:

Hg reduction	100%		
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Multiple Fuel Design Approach

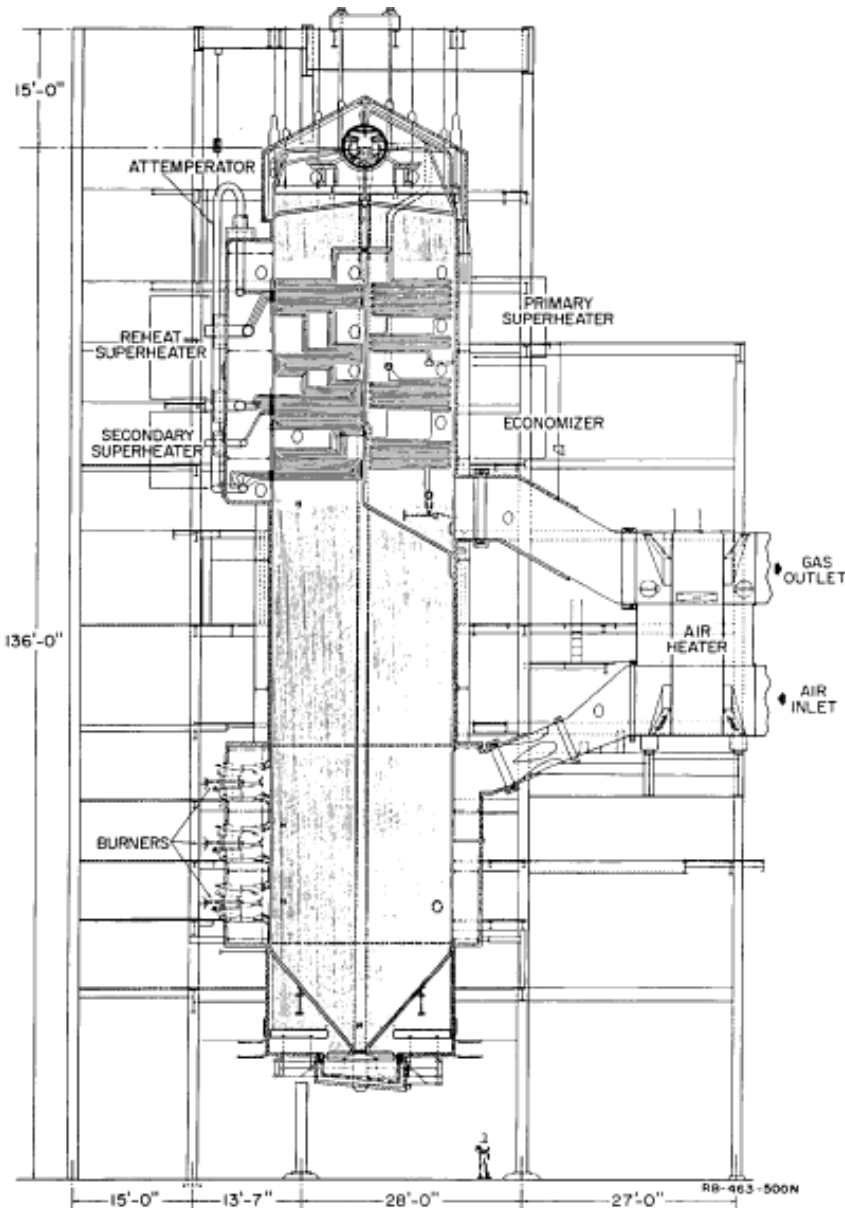
- **Combustion systems are dissimilar, non-commodity, engineered products**
- **Many different manufacturers, design standards, and requirements for steam generation throughout history**
- **Design engineering evaluates the existing system and selects the technology that will provide the best combination of components and will achieve the required performance (heat input, steam flow, stability, safety, emissions, guarantees, flexibility, cost)**
- **B&W has multiple burner technologies that are provided as engineered products & designs new product features as necessary to meet new and demanding applications and tighter emissions requirements**

Gas Firing Design & Retrofit Experience

3 Example Projects

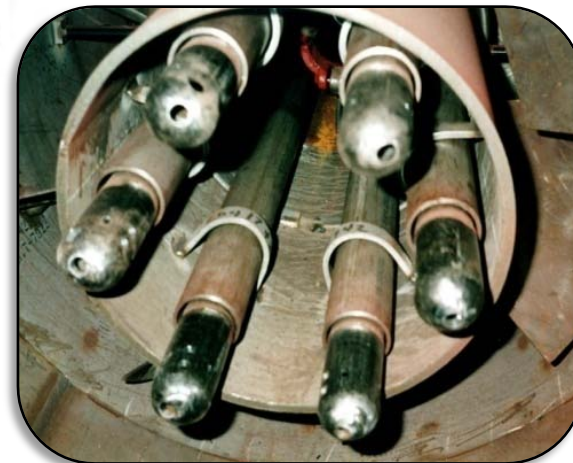
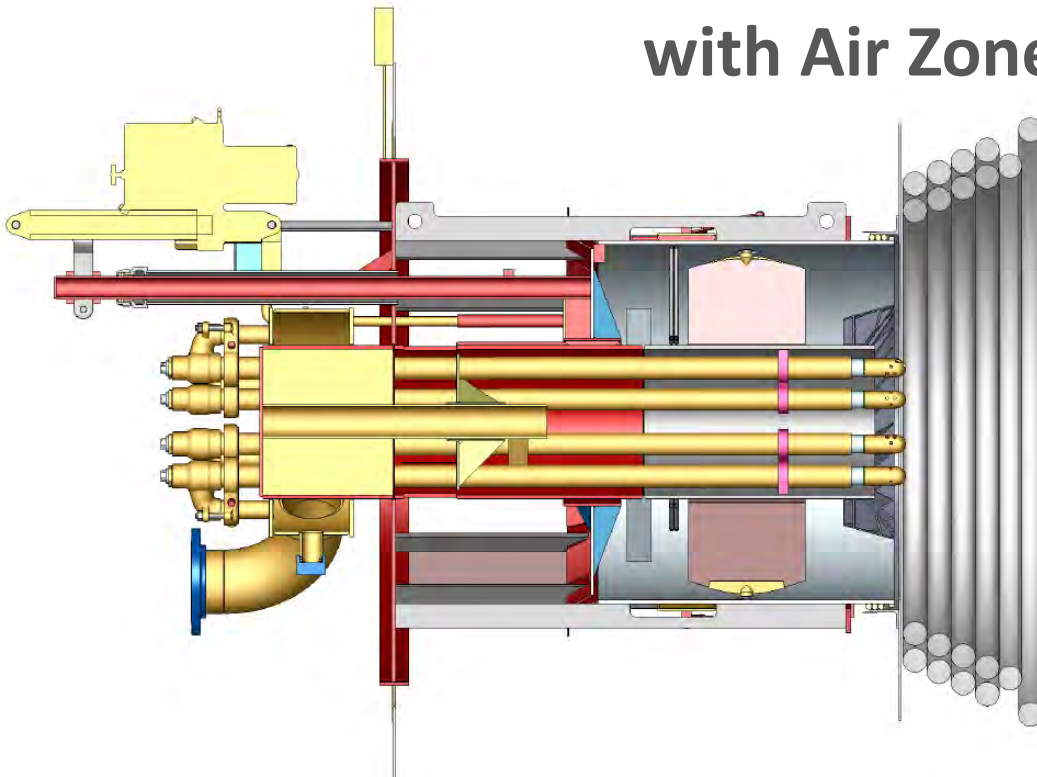
- 1. Replacement of high NOx gas burners with new technology to meet lower emissions standards**
- 2. Conversion from pulverized coal to natural gas**
- 3. Addition of natural gas firing to a pulverized coal burner**

Gas upgrade to Low NOx gas burners



- B&W RB-439, 463, 474 were originally designed to provide 770,000 lb/h of main steam at 1960 psig and 1005°F to produce 110MWe. Each unit was equipped with 8 gas equipped circular burners.
- The 3 units were retrofit to decrease NOx emissions. The existing circular burners were replaced with XCL-S gas burners and used Hemispuds and Air Zone Swirlers.
- The 3 units achieved a NOx emissions rate below 0.15 lb-NOx/MkB across the load range with CO emissions less than 75ppm.

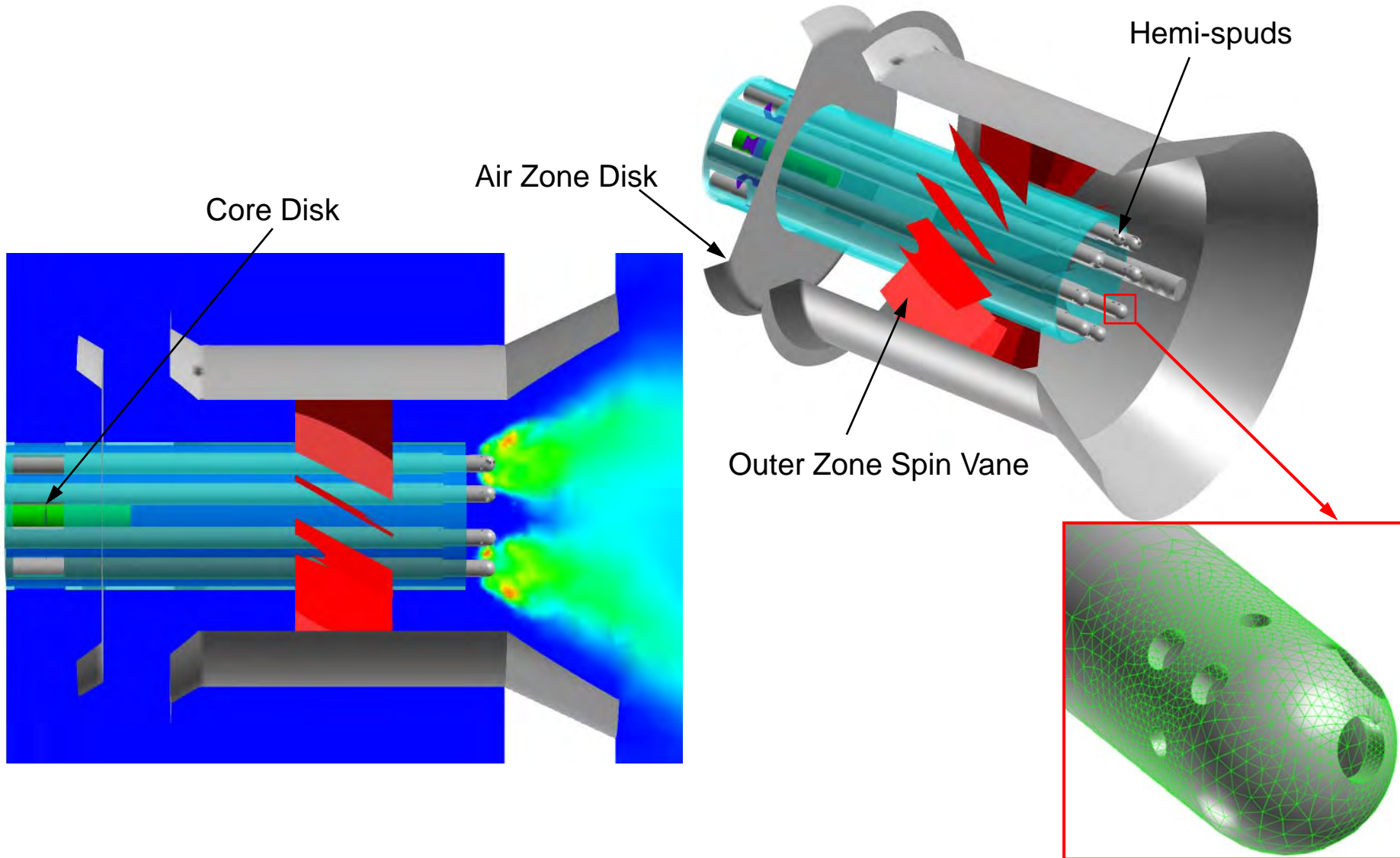
B&W XCL-S Gas Burner with Radial Array of Hemispud Gas Lances with Air Zone Swirler



Hemispherical gas spud design with asymmetric drilling allows for rotational tuning adjustments

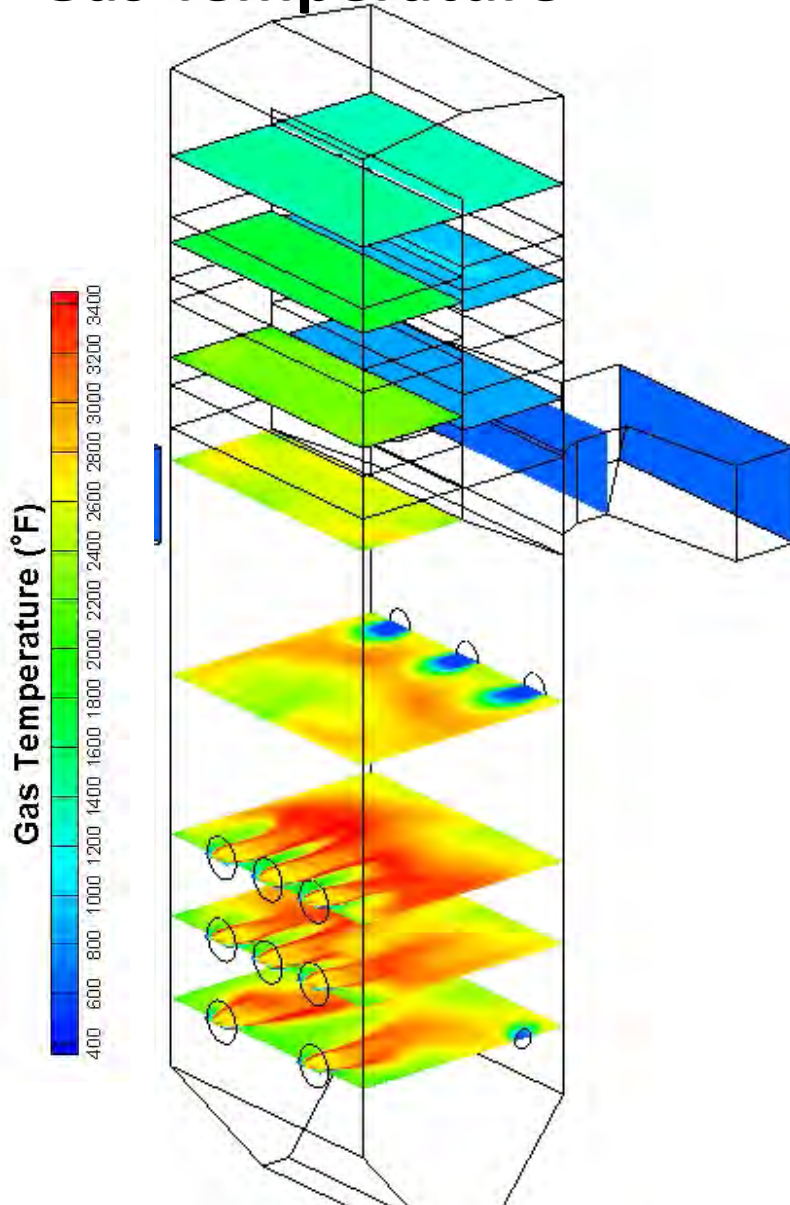
Single Burner Model

Gas, Liquid, or Solid Fuels

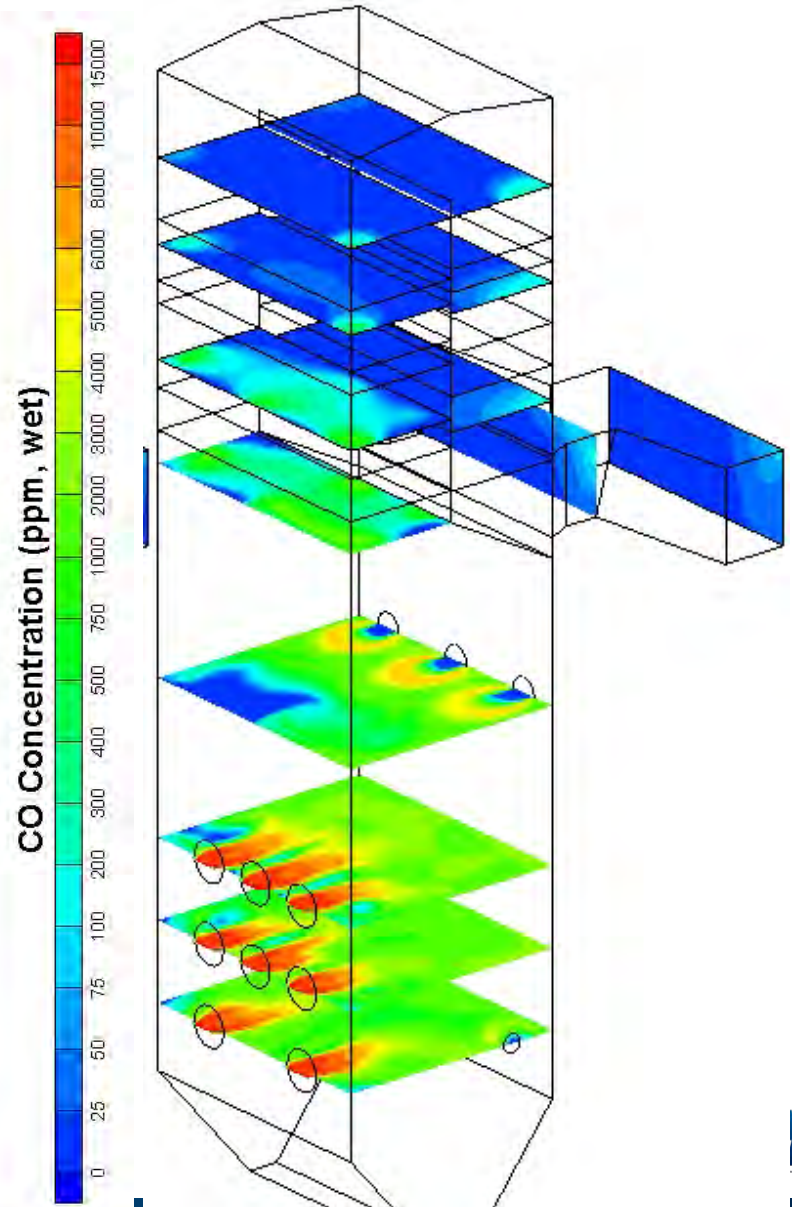


CFD Modeling of Burner, OFA, Furnace

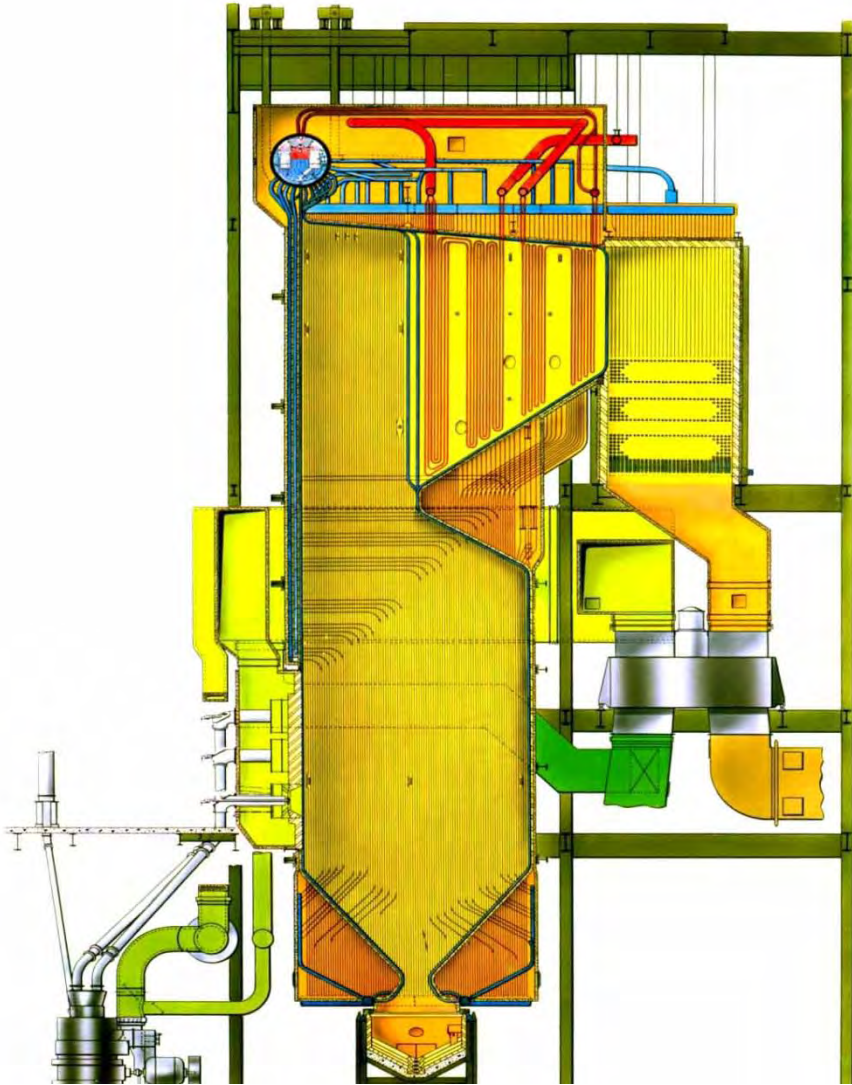
Gas Temperature



CO Distribution

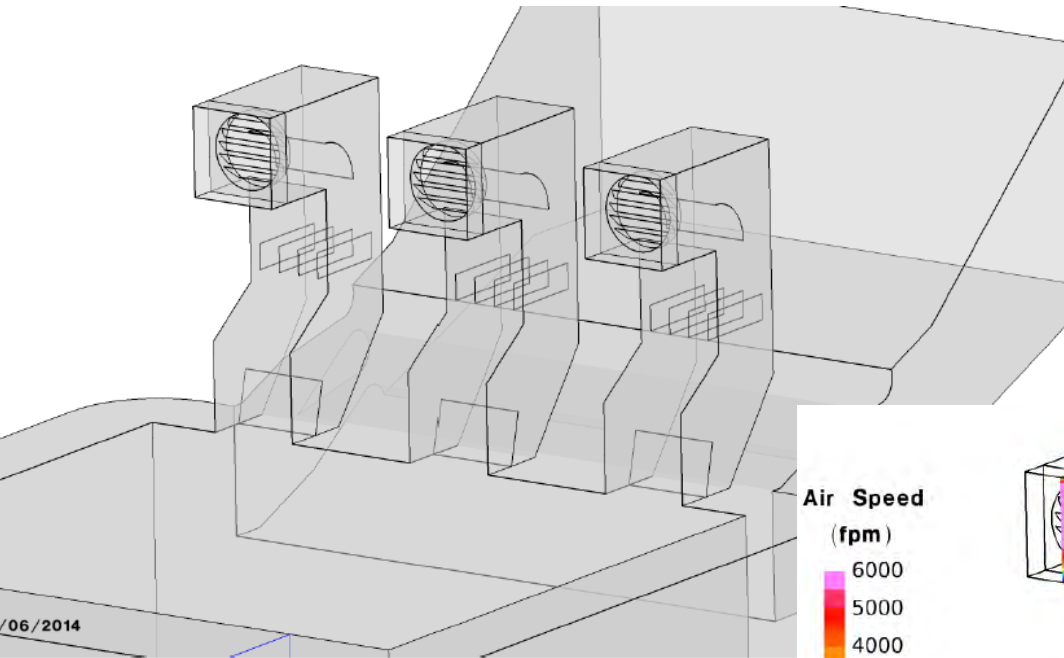


PC to 100% Gas Conversion



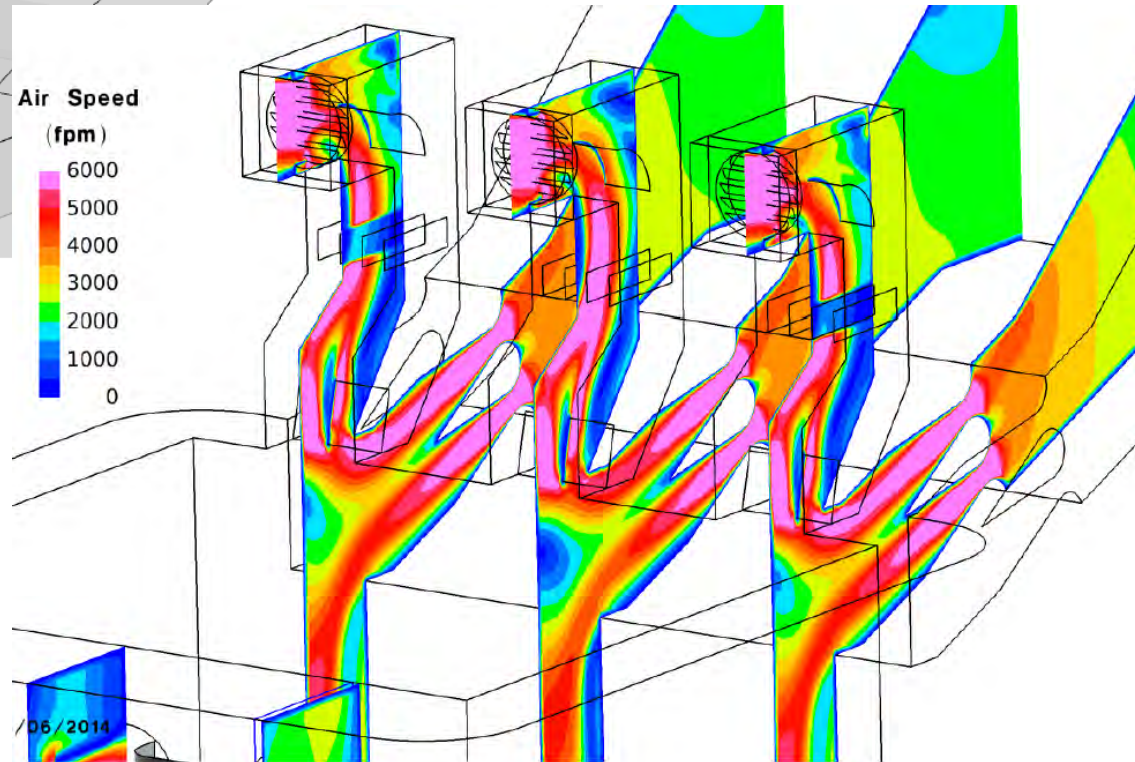
- B&W RB-93 was originally designed to produce 625,000 lb/hr of main steam at 1300 psig and 950 °F to produce 80MWe. The unit is front wall fired and was equipped with 4x EL-56 pulverizers and 12 circular burners.
- This single wall fired unit was retrofitted with 12x B&W XCL-S burners and used an over fire air system designed for optimum combustion staging for minimizing NO_x and CO emissions to achieve BMCR firing 100% natural gas.
- The unit achieves a NO_x emissions rate below 0.15 lb-NO_x/MkB across the load range with CO emissions less than 100ppm.

CFD Windbox / OFA Model



Air Speed
(fpm)

6000
5000
4000
3000
2000
1000
0

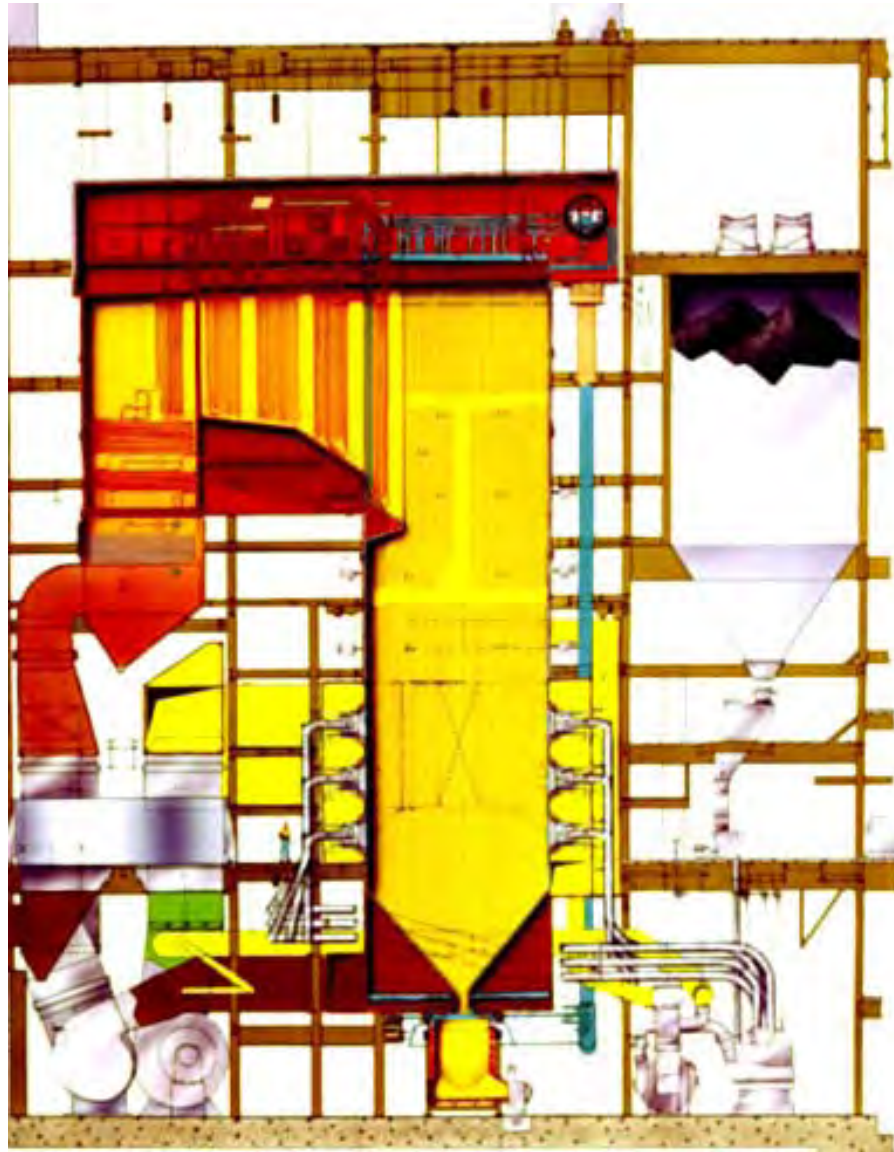


XCL-S Gas Burner

with center fired igniter & secondary air actuator

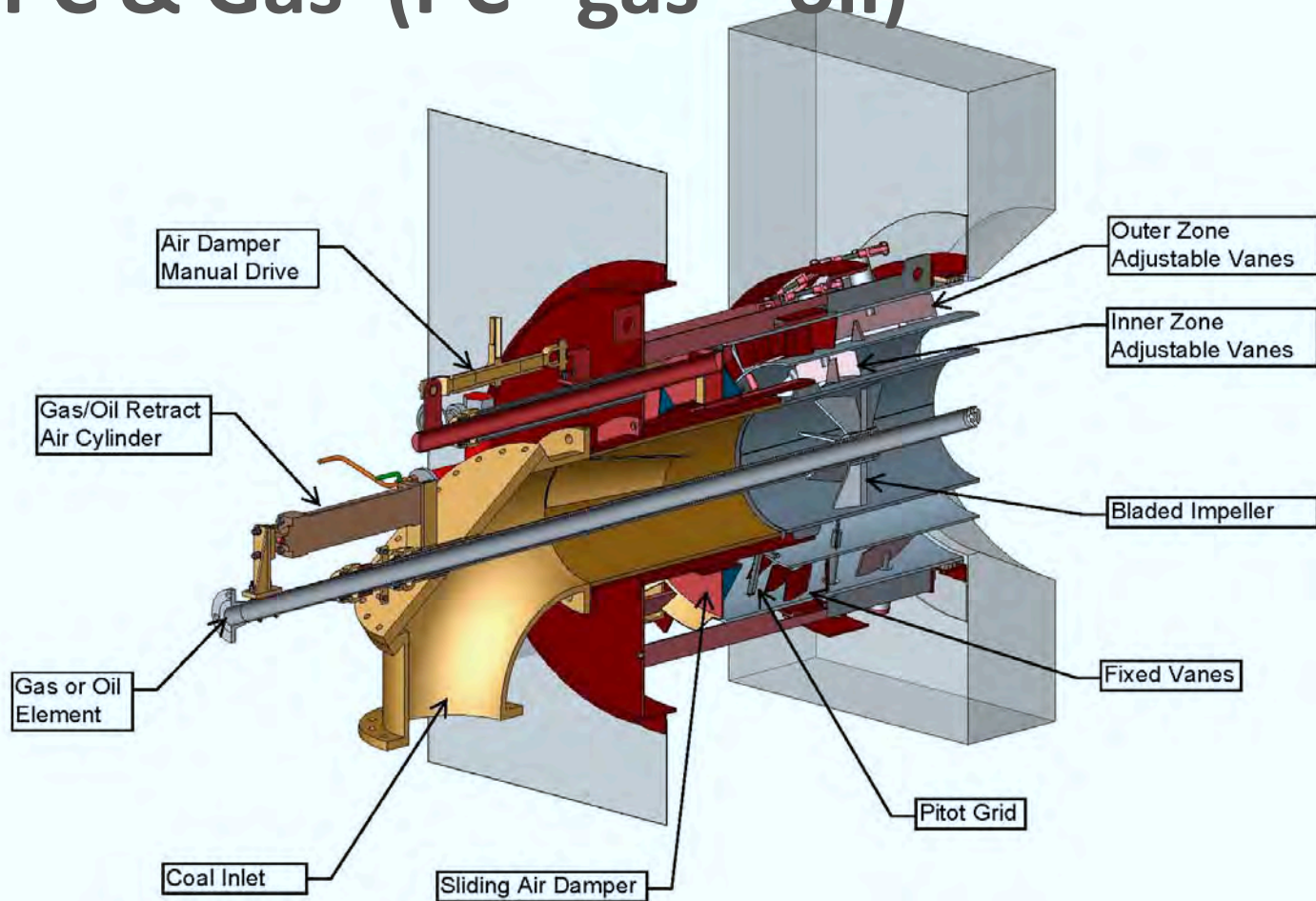


100% Gas Addition to PC Burners without OFA



- B&W RB-329.1, 329.2, 352, 362 were originally designed to provide 1,892,700 lb/h main steam flow at 1000°F to produce 248MWe. Each unit is equipped with (indirectly opposed) 18x XCL burners which replaced the originally equipped circular-cell burner arrangement.
- The 4 units were retrofit to add 100% gas firing capacity to the PC fired burners while retaining the PC firing capacity. The existing B&W XCL burners were fitted with gas Superspuds to achieve BMCR firing 100% natural gas.
- The 4 units achieved NOx emissions rate below 0.17 lb-NOx/MkB across the load range with CO emissions less than 100ppm.

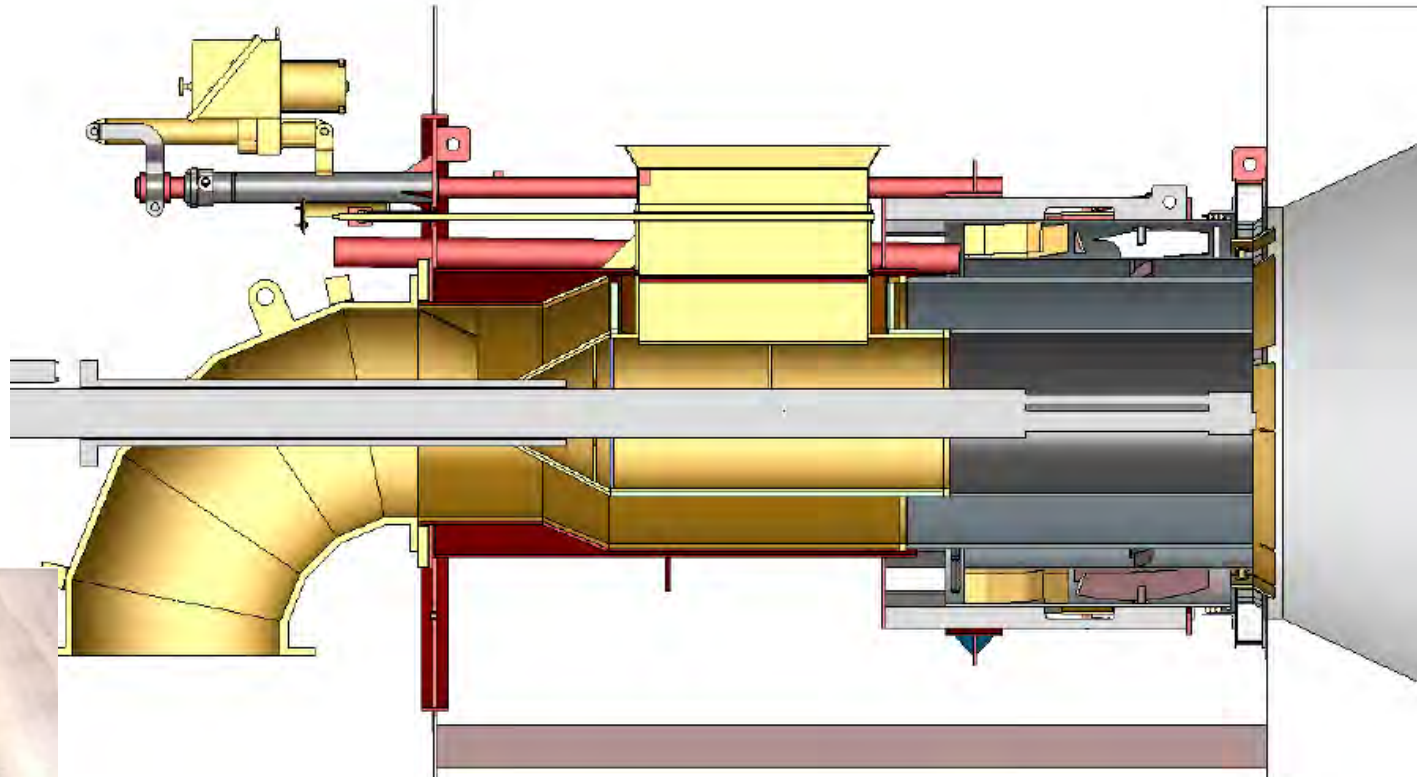
PC or Gas Firing DRB-XCL Multi fuel burner PC & Gas (PC –gas – oil)



Super Spuds

PC or Gas firing with OFA Airejet[®] Burner with center fired Gas (or Oil) lance

Gas or Oil Lance
located at
centerline of
burner

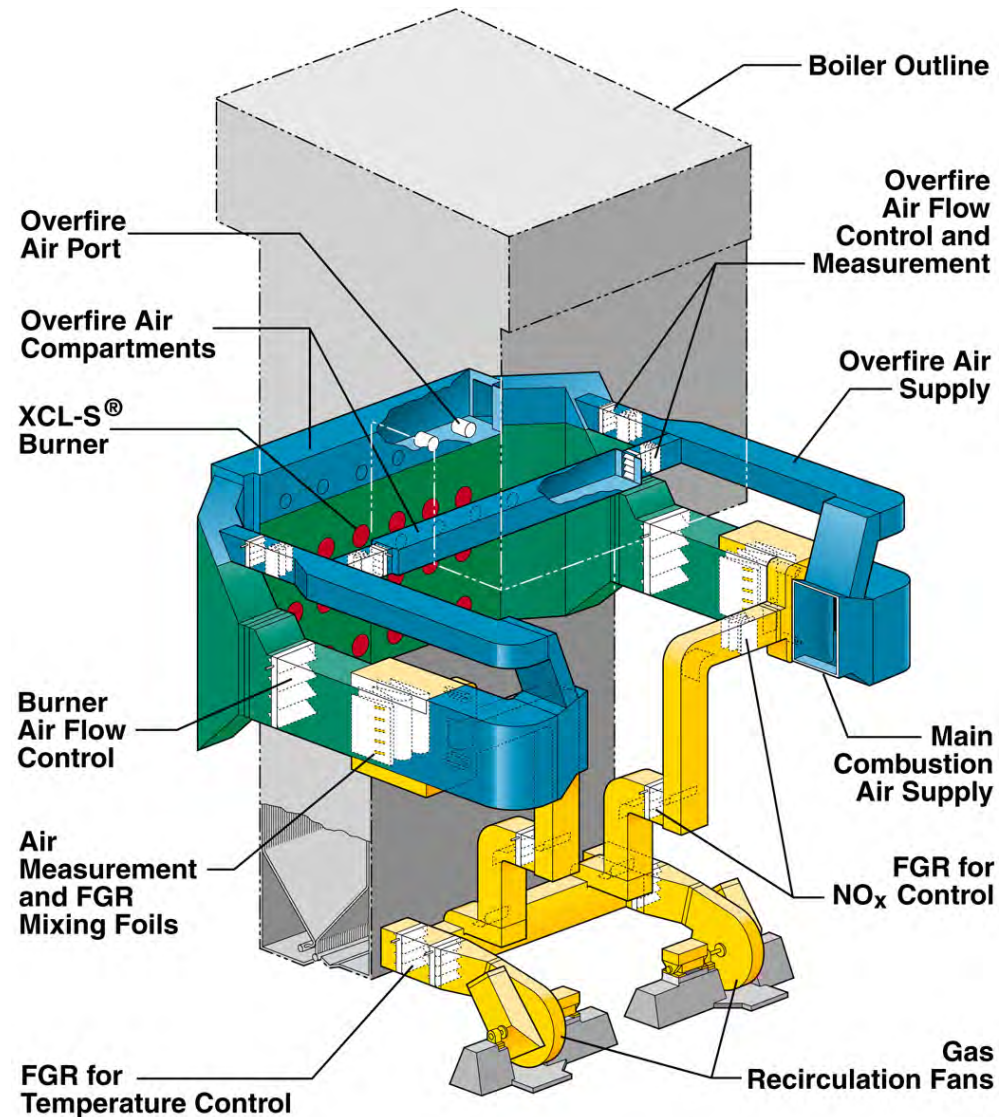


Single Superspud injection with symmetric
injection pattern provides limited adjustability



Flue Gas Recirculation for NO_x Reduction

- Significant reduction in thermal NO_x (70% max)
- Flame stability limited by low Oxygen to the burner
- Increases flue gas weight which will increase thermal stresses
- Not for PC firing
- FGR for RH temp control at low load is not the same.



Thanks for your attention!

