Reinhold Environmental Ltd.

2010 NOx-Combustion Round Table & Expo Presentation

February 8 & 9, 2010   Chattanooga, TN

Boiler, Economizer Cleaning 101

2010 NOx – Combustion Round Table
Chattanooga

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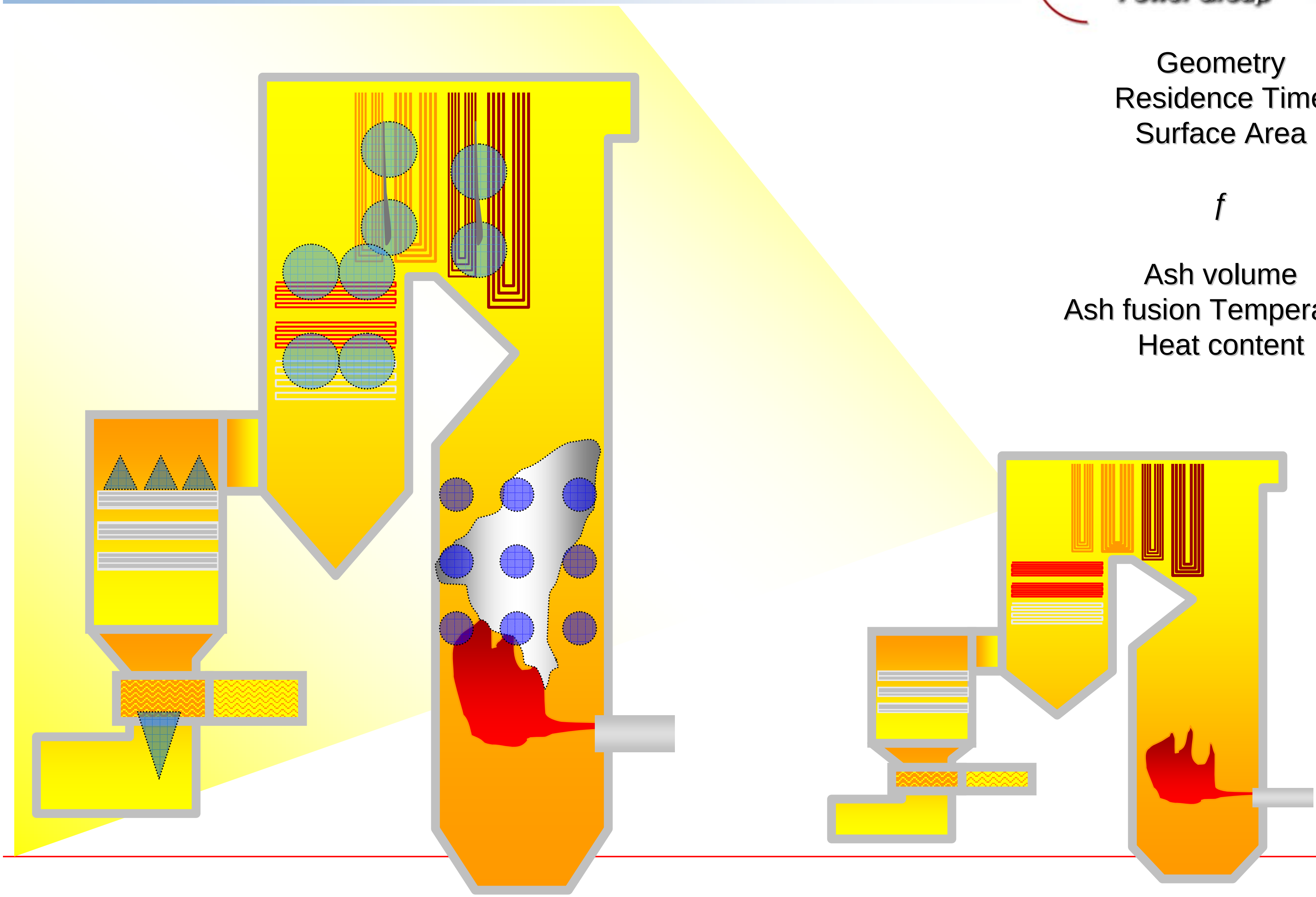
Today .... Focus on Boiler Cleaning

- After 90 years of dormancy we have rapidly advanced boiler cleaning technology in the past 10 years
- Culminating with the current state-of-the-art of Intelligent Sootblowing (ISB)
- Today we would like to present overviews of:
  - Impact of Cleanliness on Process
    - Fuel changes
    - Fuel quality
    - Efficiency
    - Process interruption
    - Air quality
  - Ash Removal Mechanisms
  - Ash Removal Technology
  - Controlling Cleanliness

Boiler Cleaning and Boiler Design

- The published boiler design handbooks tell us that the ash (*incombustible mineral matter*) composition in the fuel is the principal consideration in designing a boiler
  - 1/8" coating of ash restricts thermal transfer by ~ 20%
- Making boiler cleaning one the most important consideration in designing and operating our power plants
- We are introducing 76 of the 92 known elements into a myriad of conditions
  - Temperature
  - Stoichiometry
- "Boiler Cleaning" is the science of locating and removing these deposits safely and efficiently commensurate with plant process objectives

How the Ash Impacts the Boiler Design



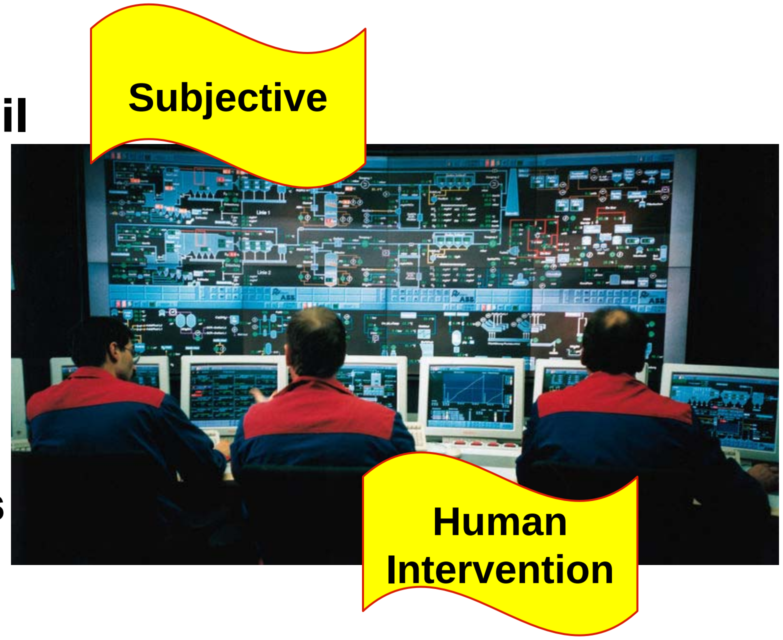
Geometry
Residence Time
Surface Area

f

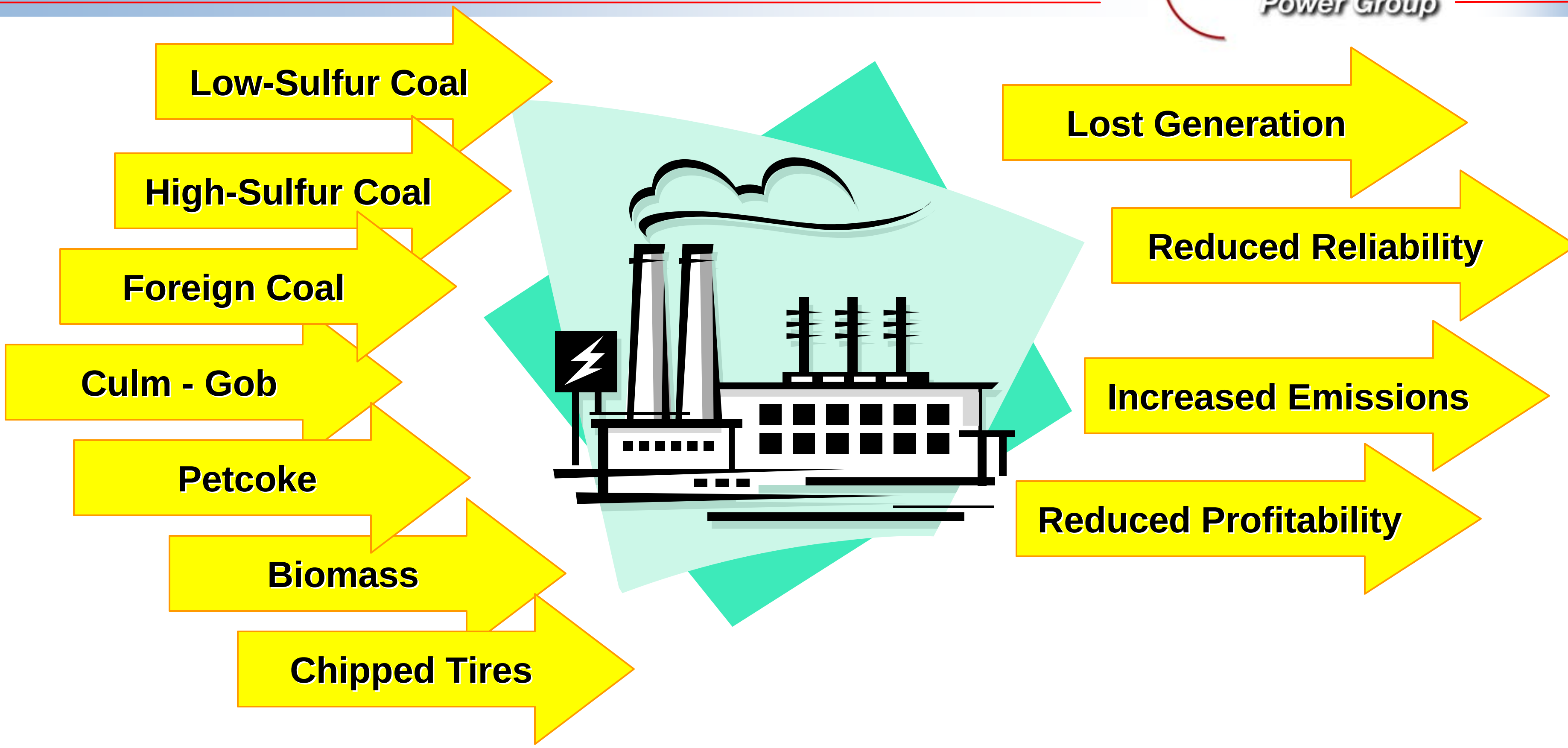
Ash volume
Ash fusion Temperature
Heat content

Boiler Cleaning from Operator's View

- **Operators used global measurements to determine states of cleanliness in the various heat exchange sections**
  - **Operated various cleaning devices until such time as global measurements responded**
    - ➲ **Temperatures ?**
    - ➲ **Δ P**
  - **As the process was relatively stable operators developed fixed frequencies for individual and group sootblowing**
  - **These preprogrammed frequencies were programmed based on operator experience and judgment**
    - ➲ **Timing**



Our Current Challenge - Fuel



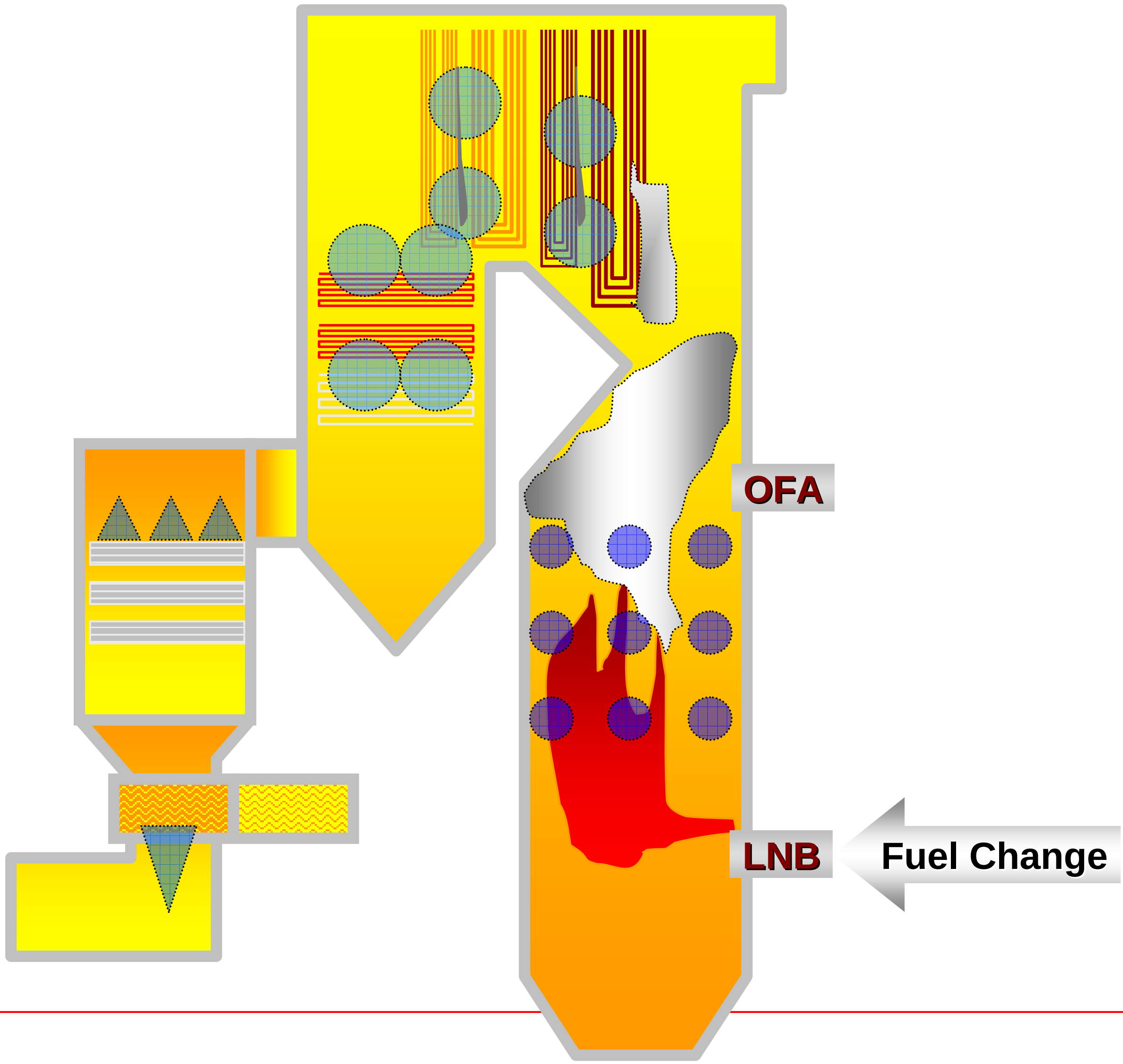
Current business conditions require a wide variety of compliance fuels to be burned

In a static boiler designed for a single fuel …

With no detrimental impact on operations …

And … most also modified their combustion systems which exacerbates the problem…

We Have Changed the Operating Variables



If we change:
Ash volume
Ash fusion Temperature
Heat content

Via:
Fuel Changes
LNB / OFA

Without changing:
Geometry
Residence Time
Surface Area

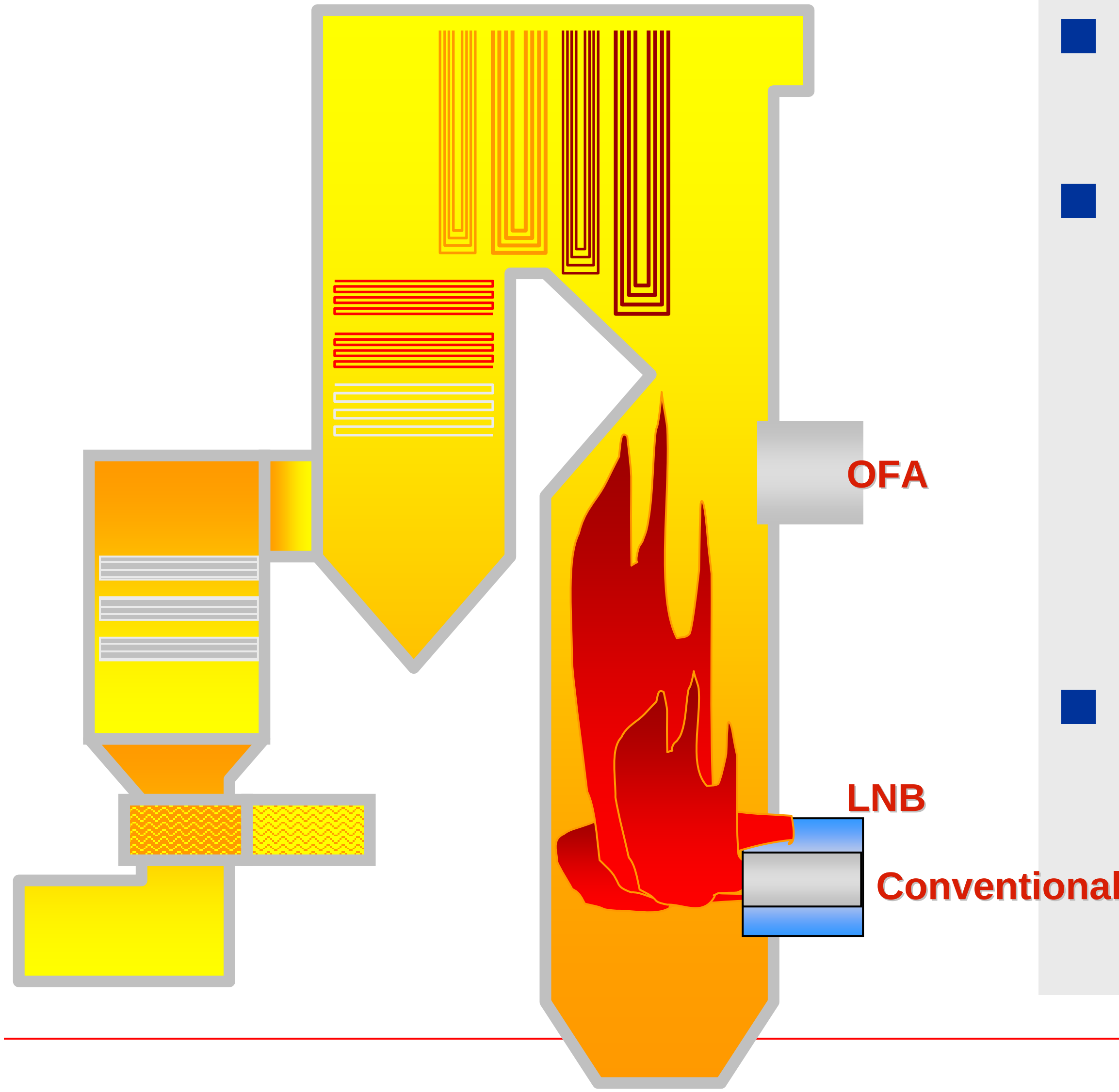
- Ash deposition rates increase
- Location of deposits changes
- Ash tenacity increases

Sootblower System becomes ineffectual

CHANGE - Combustion Modifications

- Combustion modifications seek to reduce the amount of thermally created nitrous oxides by reducing combustion temperatures through staged combustion
- Low NOx Burners – LNB
  - Stabilizes flame and increases mixing
  - Initiates partial combustion by creating a fuel-rich reducing atmosphere
  - Provides only 70% to 90% of required oxygen
  - Reduces NOx production by 30% to 55%
- Over-Fire Air Ports – OFA
  - Provides balance (10% to 30%) of required combustion air downstream of primary combustion
  - Combined with LNB may reduce total NOx production 40% to 60% even higher (70%) when gas re-burn technology is added

Impact of Combustion Modifications



- **Effect on Cleanliness:**
- **LNB**
  - **Creates reducing atmosphere**
  - **Reduces residence time**
  - **Altered flame characteristics**
- **OFA**
  - **Moves transition zone close to convection surfaces**

CHANGE - Varying Fuel Types

- Economic and Legislative pressures are currently forcing the use of a wide variety of fuels that deviate from that which the boiler was designed to burn – Compliance Fuels
- Lo-Sulfur
  - Typically sub-bituminous fuels burned in boilers designed for bituminous
  - Typically a loss in radiant heat transfer is experienced due to lower ash fusion temperatures
- Hi-Sulfur
  - Typically found in scrubbed units where economics dictate lower cost, higher sulfur fuels
  - Typically in conjunction with LNB/OFA, these fuels have a higher range of plasticity in a reducing atmosphere
  - With sulfur comes iron
  - Typically a loss in furnace heat transfer is experienced
- Alternates
  - Waste coal
  - Petcoke
  - Biomass, Tires, etc..

CHANGE - Varying Fuel Quality

Varying Fuel Quality

CLYDE BERGEMANN Power Group

- Variations / Degradation in several coal quality metrics will have a substantial impact on slagging and fouling tendencies
- Mineral Composition
  - Quartz
  - Pyrites
- Chemical Composition
  - Iron
  - Alkalis
    - Calcium
    - Potassium
    - Sodium
    - Magnesium
  - Silicates

+ or -

If you tune for + quality and get – quality = UNDERCLEAN

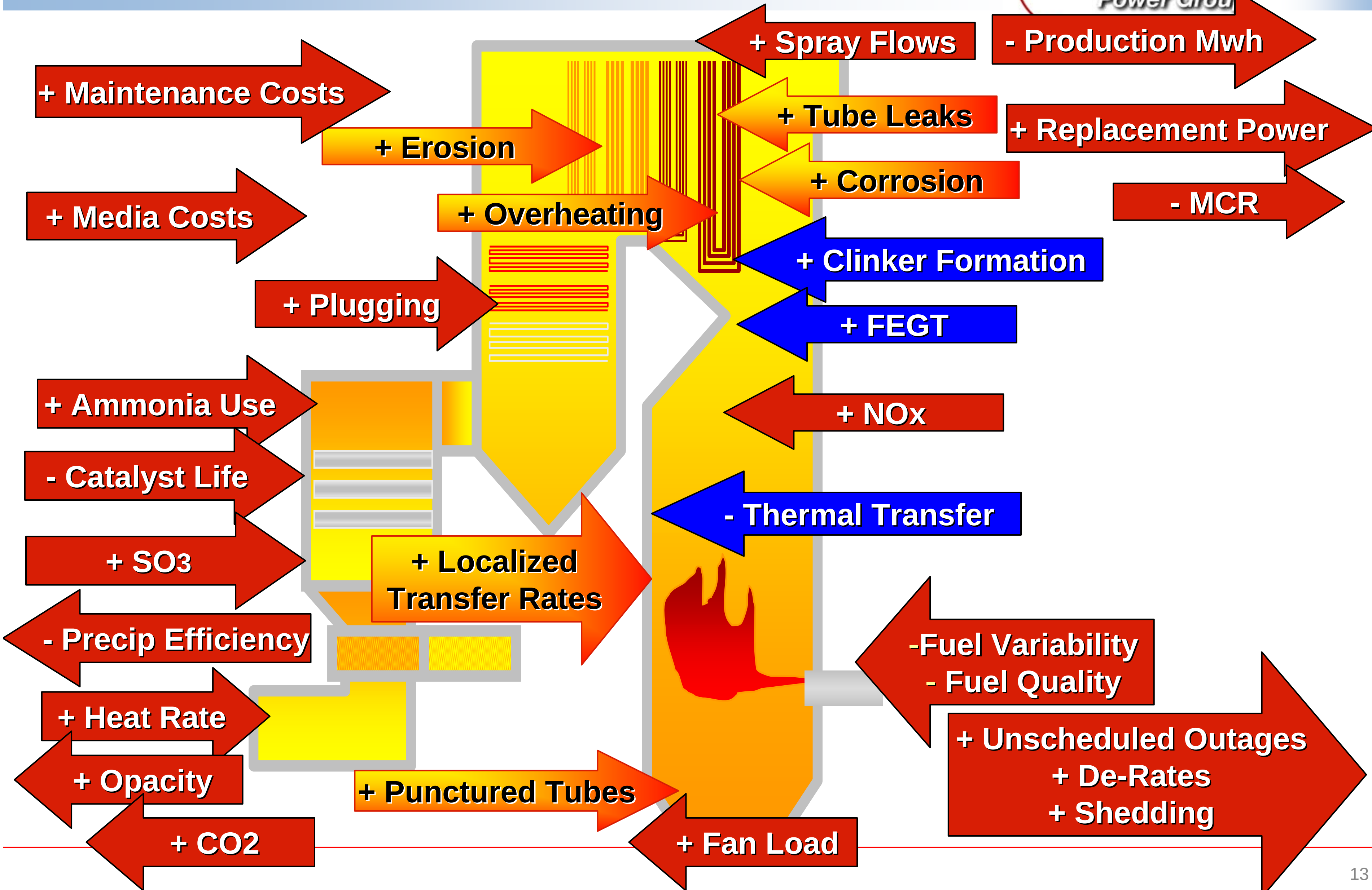
If you tune for - quality and get + quality = OVERCLEAN

Driving need for DYNAMIC, Intelligent Cleaning System

Resulting in ...

- **The operator's subjective cleaning cycles no longer working**
  - **Over-Cleaning**
  - **Under-Cleaning**
- **Culminating in lost generation**

Measurable Impact on the Process



Dealing with the new slagging & fouling problems…

- **Reactive:**
  - Aggressive Over-Cleaning, increase frequency and intensity using only cleaning tools available
    - Tube leaks
    - Increased maintenance costs
    - Increased media consumption
  - Load Shed & De-rate
  - Off-Load blasting
- **Proactive**
  - Mill performance
  - Combustion optimization
  - Coatings
  - Overlay
  - MagOx
  - SST Pendants

ISB ⟷ Strategic

Effective Cleaning System

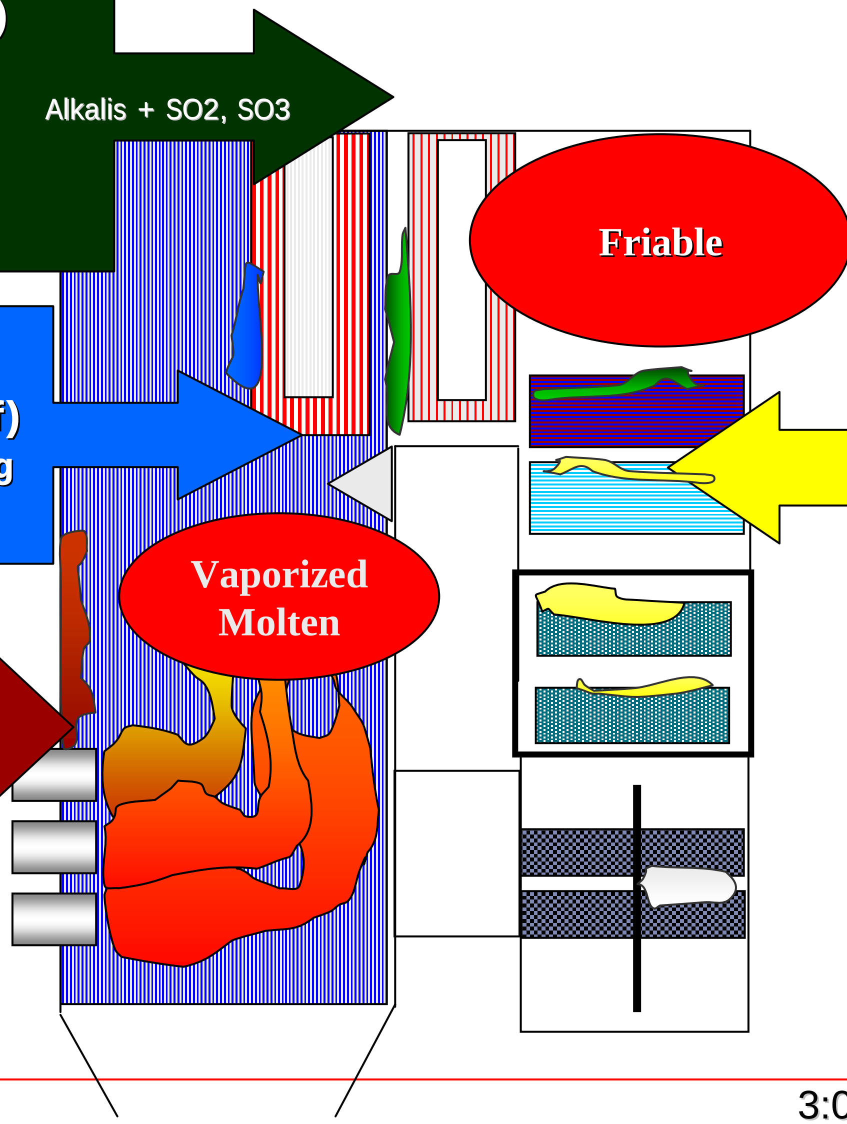
- **EFFECTIVE SYSTEM DESIGN:**
  - Matches the proper removal mechanism to the appropriate deposit type
- **CONVENTIONAL SYSTEM:**
  - Initiates sequences
    - Manually
    - Preprogrammed frequencies
- **INTELLIGENT SYSTEM:**
  - Dynamically Initiates Cleaning Events:
    - Only **WHEN** needed
    - Only **WHERE** needed
    - Using the proper medium **INTENSITY**

Classifying the Deposits

Intermediate-Temp Fouling(1000f-1750f)
- Sulfates present
  - Sodium
  - Potassium
  - Calcium
  - Magnesium

High-Temp Fouling (1600f-2400f)
- Silicates act as bonding agents

Radiant-Temp Slagging
- Temperature
- Chemistry
- Particle Size
- Stoichiometry

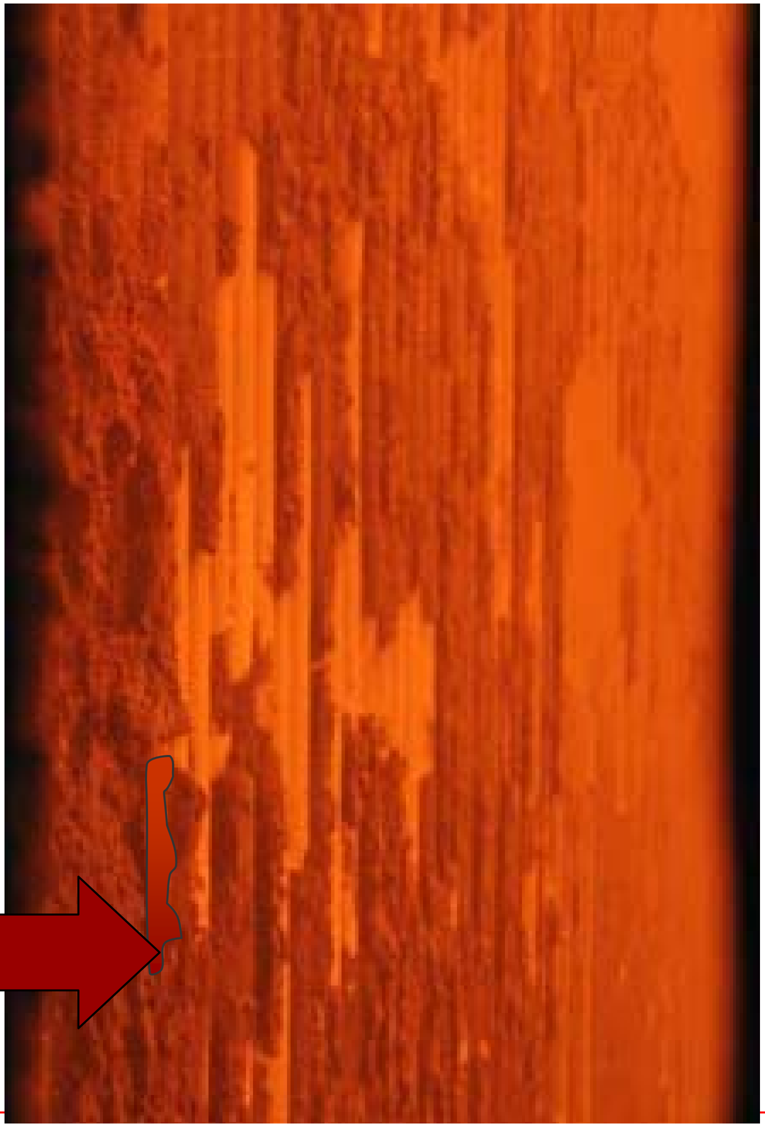


Lo-Temp Sintering (650f-1000f)
- Temperature
- Stoichiometry

3:0 – 4:0

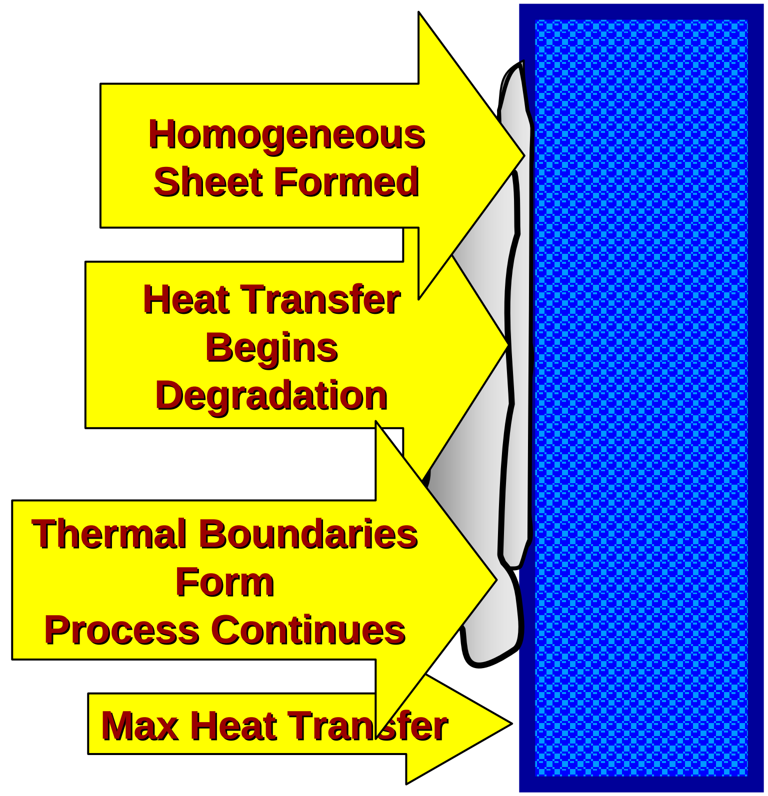
Furnace First !!!!!!!!!!

- Furnace cleanliness sets the stage for cleanliness in the rest of the process
- Majority of heat release
- Be aware of the:
  - Deposit mechanisms
  - Principal heat transfer mechanisms



A Closer Look at the Deposits

- **With both mechanisms we see deposits form similarly:**
  - **Flight deposition causes small deposits to adhere to heat transfer surfaces**
  - **Deposits conjoin**
  - **Surfaces break down and begin to flow together**
  - **Groups of smaller deposits now form a homogeneous sheet**
  - **Subsequent flight deposits cause rapid increase in mass**
  - **Thermal boundaries form**
  - **Process continues**



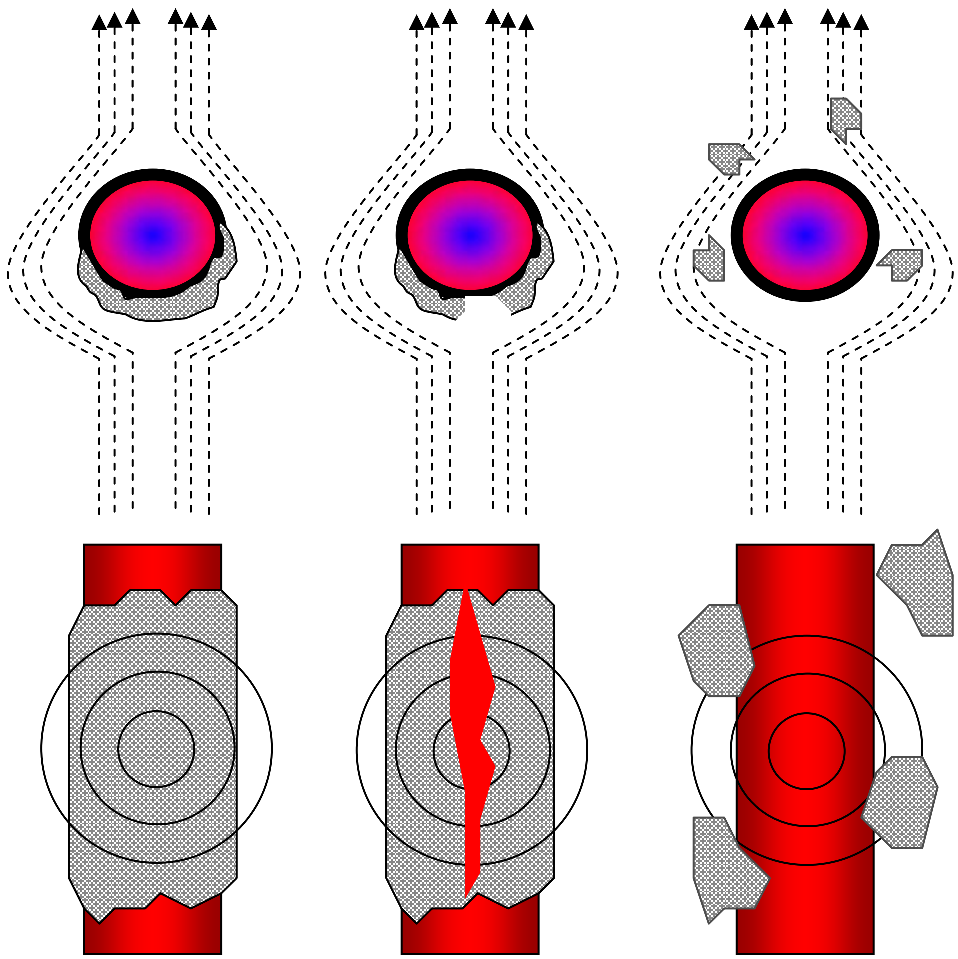
Now the Removal Mechanisms

- Now that we know a bit about the cause of the problem and the types of ash deposits that we are faced with we will review the methods of on-load removal.
- **Ten Basic On-Load Ash Removal Mechanisms are currently available**
  - Hi-Impact – Impingement
  - Lo-Impact Impingement
    - Variable Dwell
    - Variable Helix
  - Lo-Impact Lateral
  - Hi-Impact Thermal
  - Lo-Impact Draft
  - Lo-Impact Acoustic
  - Lo-Impact Shockwave
  - Mechanical Vibration

Cleaning Medium Selection

- **Steam**
  - **Most common due to availability of volume & pressure**
- **Air**
  - **Typically as effective as steam but supply volume & pressure typically not adequate or stable**
- **Water**
  - **Where deposits are expected to be in a plastic state**
- **Sound**
  - **Friable ash**
- **Detonation**

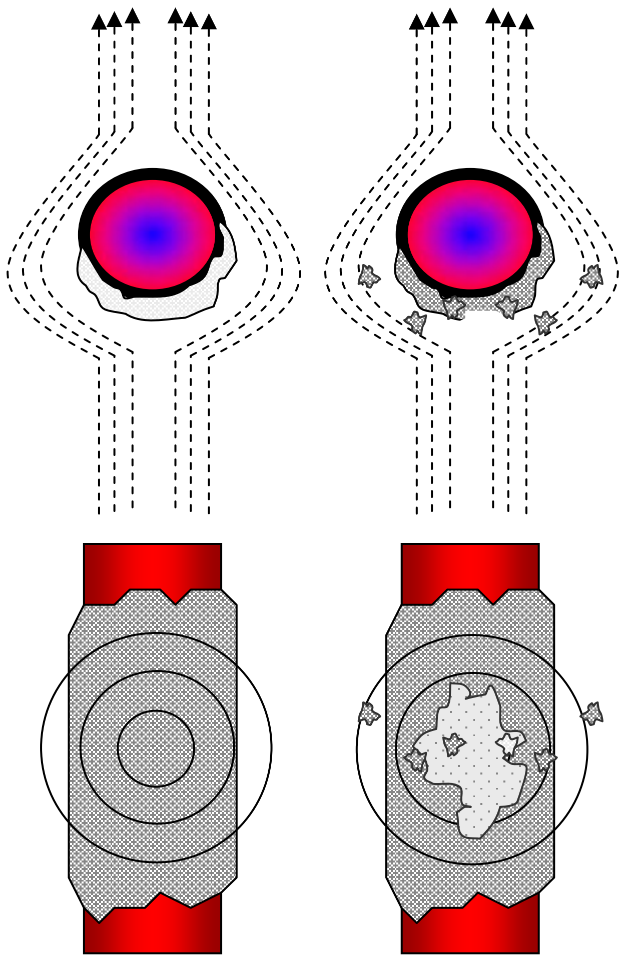
Hi-Impact - Impingement



Plasticity increases deposit strength

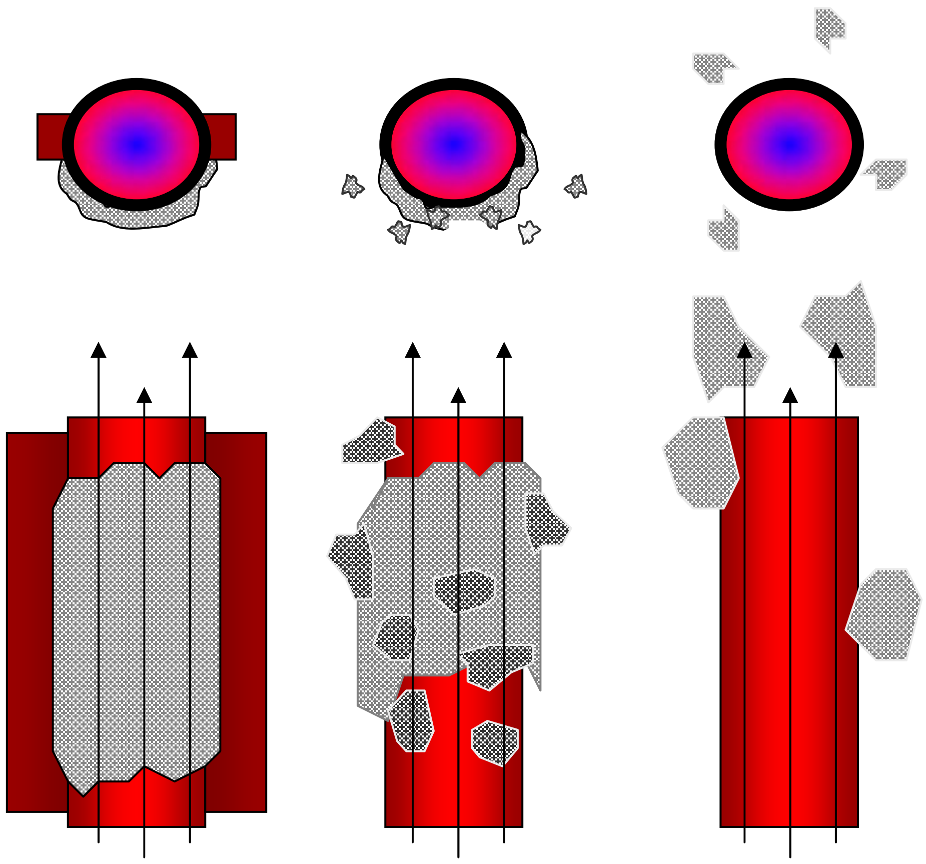
- **Characteristic:**
  - **Direct Impingement**
  - **Impact pressure exceeds deposit strength**
- **Media impacts with high force**
- **Sets up laminar flow boundary – surface drag**
- **Circumferential shear forces create axial fissure**
- **Deposit instantaneously yields to:**
  - **High impact**
  - **Drag**
- **Single strike typically sufficient for removal**

Lo-Impact - Impingement



Plasticity increases deposit strength

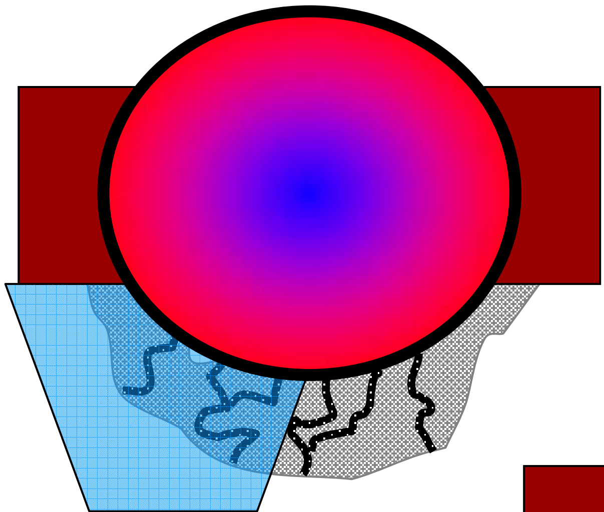
- Characteristic:
  - Direct Impingement
  - Impact pressure less than deposit strength
- Media impacts with low force
- Laminar flow & surface drag is insufficient to fracture deposit
- Surface of deposit begins to pit and erode
- Normal sootblower dwell times are insufficient to remove deposit
- Deposit requires:
  - Longer dwell times
  - Multiple strikes

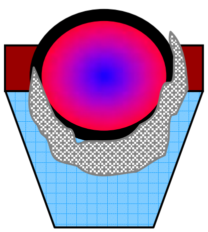


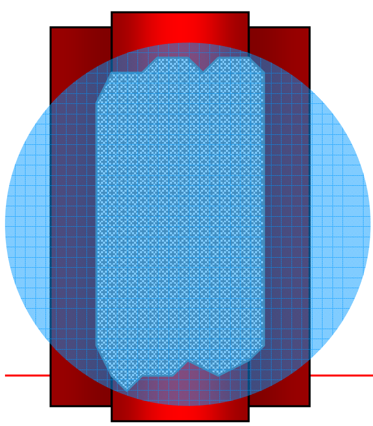
- Characteristic:
  - Parallel flow
- Media drags deposit with low force
- Impact pressure : deposit strength determines effective cleaning radius

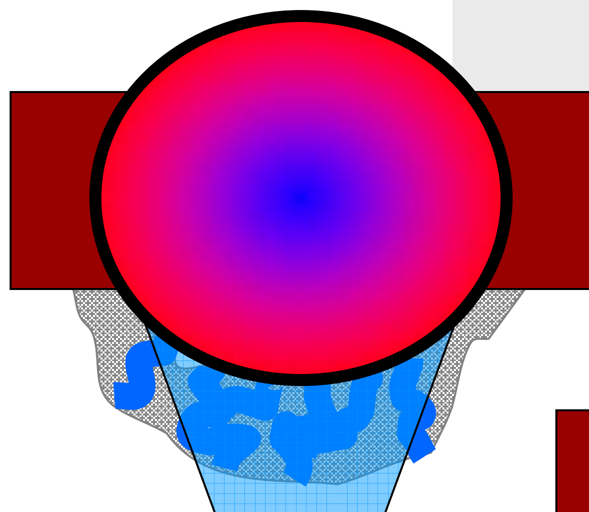
Plasticity increases deposit strength and reduces cleaning radius sometimes to "0"

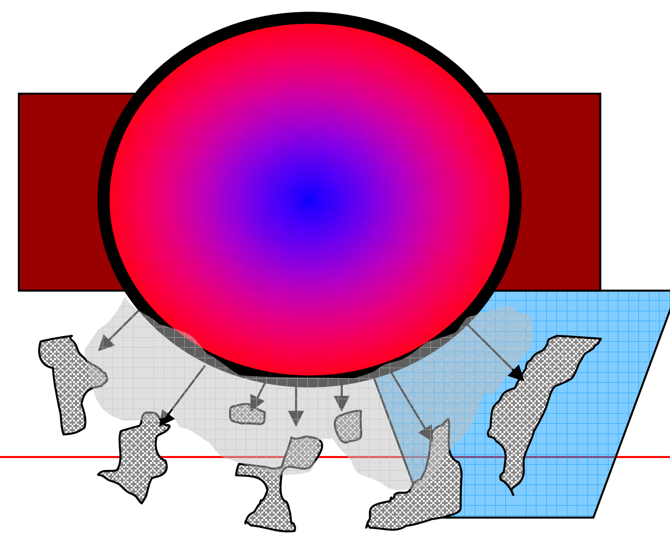
Hi-Impact - Thermal





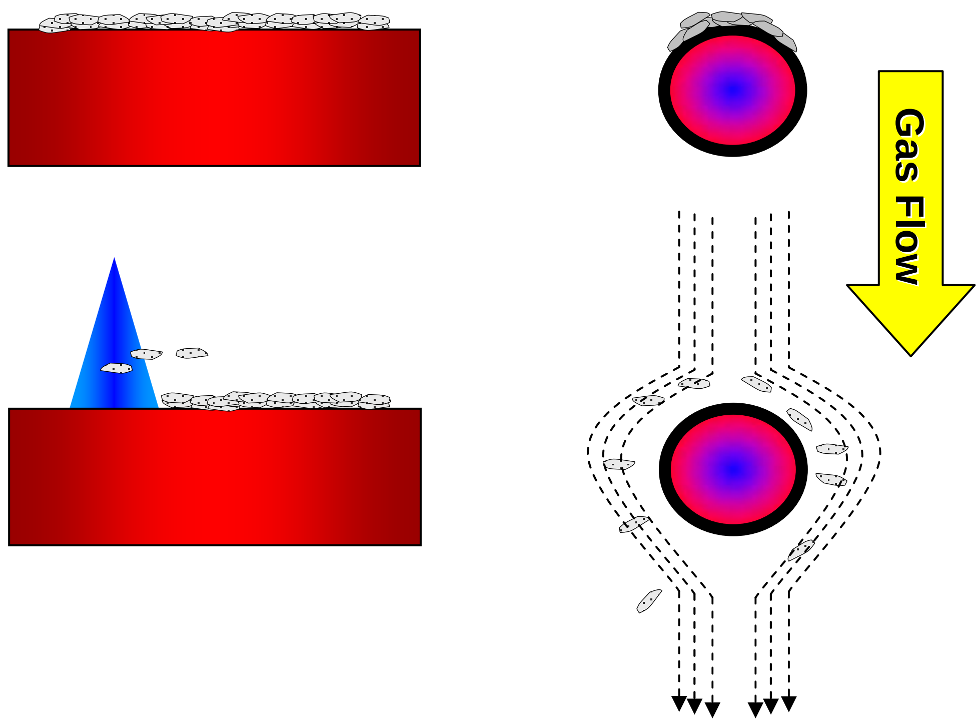






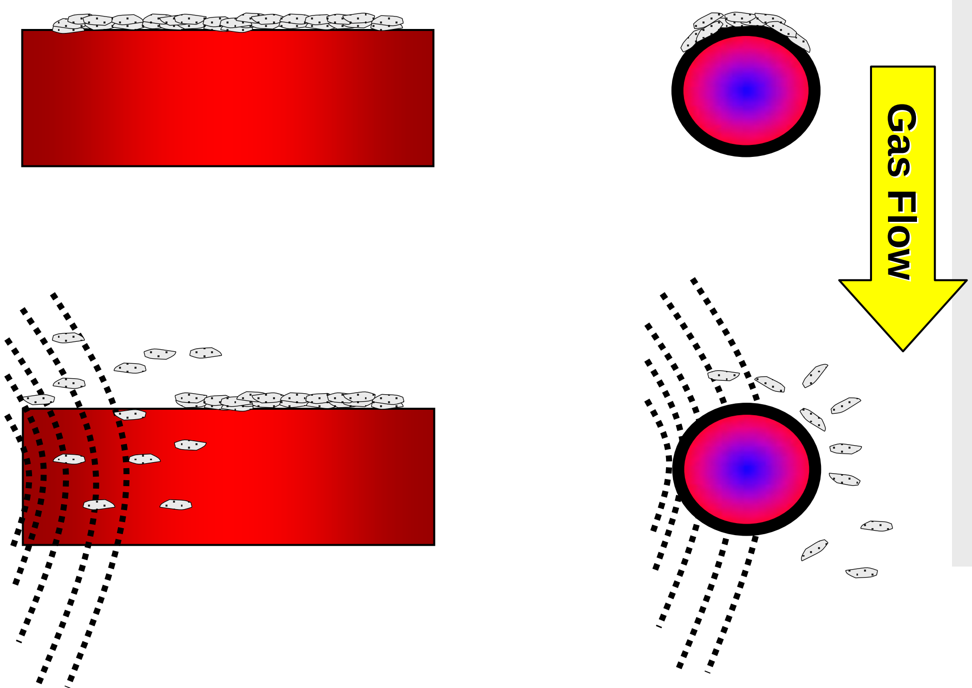
- **Characteristic:**
  - **Direct Impingement**
  - **Surface is “wetted”**
  - **ΔT shrinks deposits mass**
  - **Fissures form**
  - **Water flashes to steam**
  - **Volumetric expansion lifts deposit**

Lo-Impact - Draft



- **Characteristic:**
  - **Ash not sintered into a cohesive deposit**
  - **Adhesion and tensile strength low**
  - **Drag of boundary layer sufficient to dislodge deposit**
  - **Low impact pressure "dusting" with steam or air maintains surface cleanliness**
  - **Relies principally on flow through open annulus area as opposed to direct impingement**

Lo-Impact - Acoustic



- **Characteristic:**
  - Ash not sintered into a cohesive deposit
  - Adhesion and tensile strength low
  - Frequent low impact acoustic "dusting" maintains surface cleanliness if:
    - Moisture not present
    - Sufficient air pressure available to sonic cleaners
    - Maldistribution not an issue

Lo-Impact - Shockwave

- **Characteristic:**
  - **Rapid expansion of detonated gases creates shockwave**
  - **Wave propagates throughout cavity to dislodge ash particles from surface**
- **Form**
  - **Off-load explosives**
  - **Propane driven detonation device**

Mechanical Vibration - Rapping

- As opposed to sonic & pulse which vibrate the atmosphere rapping vibrates the heat exchange surface through direct & intermittent mechanical force
- Two basic technologies:
  - Tumbling hammers
  - Piston

Evolution of Cleaning Tools

RETRACTABLE

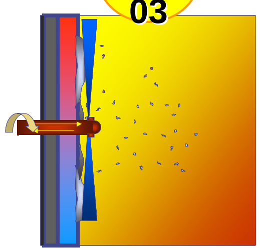
- Fixed Helix
- Fixed Media
- Subjective Actuation

2005

SMART Retractable

- Variable Helix
- Open-Loop Control or Full Closed-Loop Control

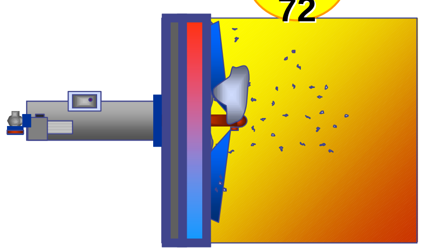
1903



WALLBLOWER

- Parallel Cleaning Jet
- Subjective Actuation

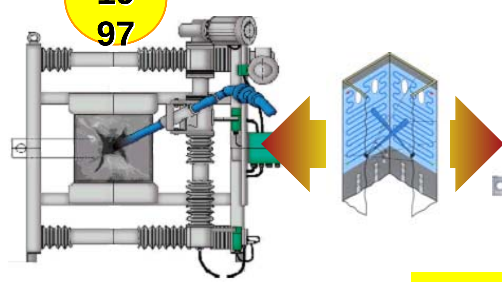
1972



WATER LANCE

- Back-raked Cleaning Jet
- Subjective Actuation

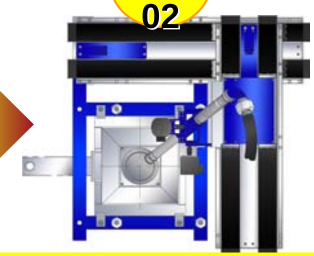
1997



WATER CANNON

- Opposed Wall Cleaning Jet
- Intelligent Actuated

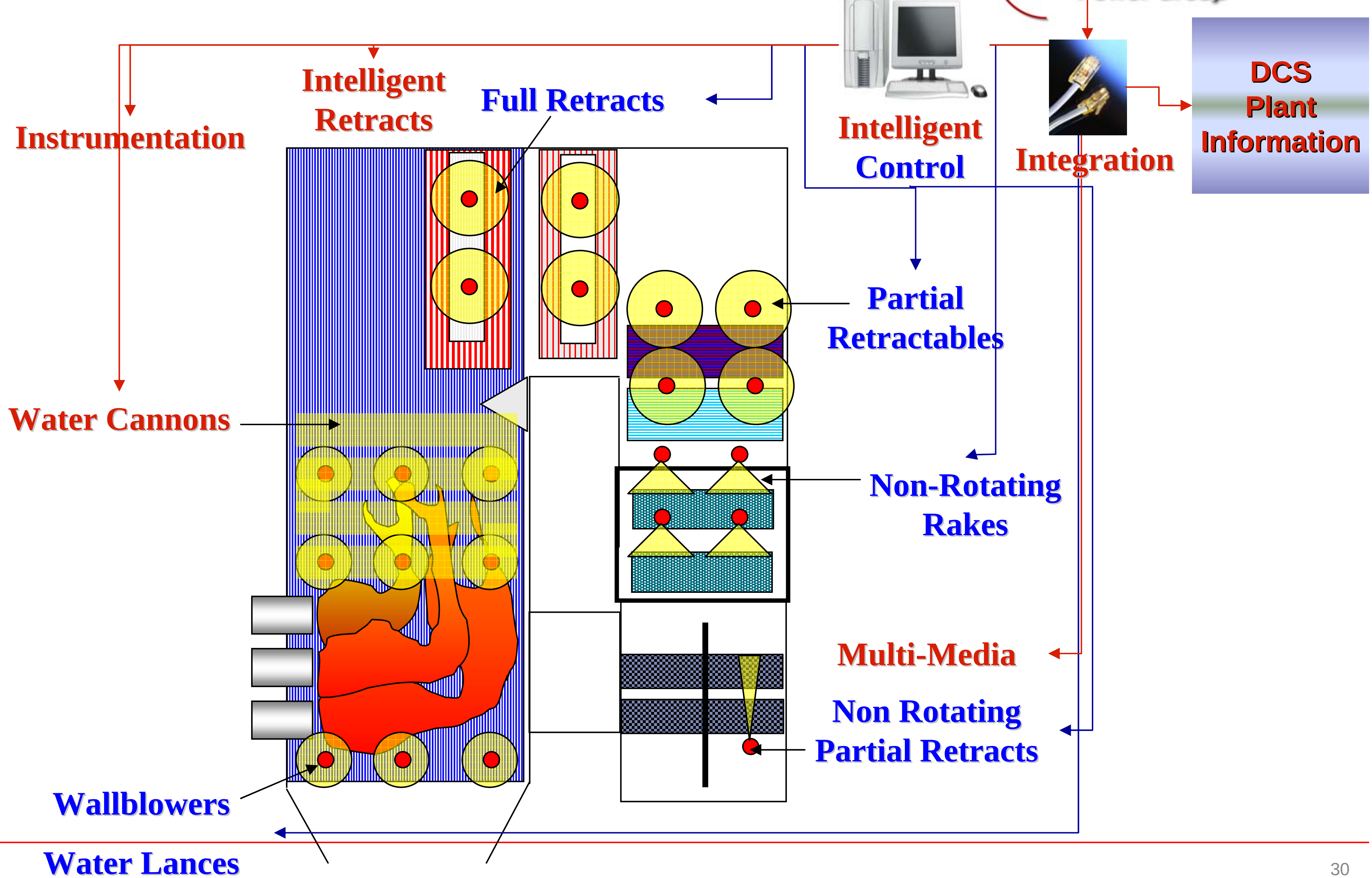
2002



SMART CANNON

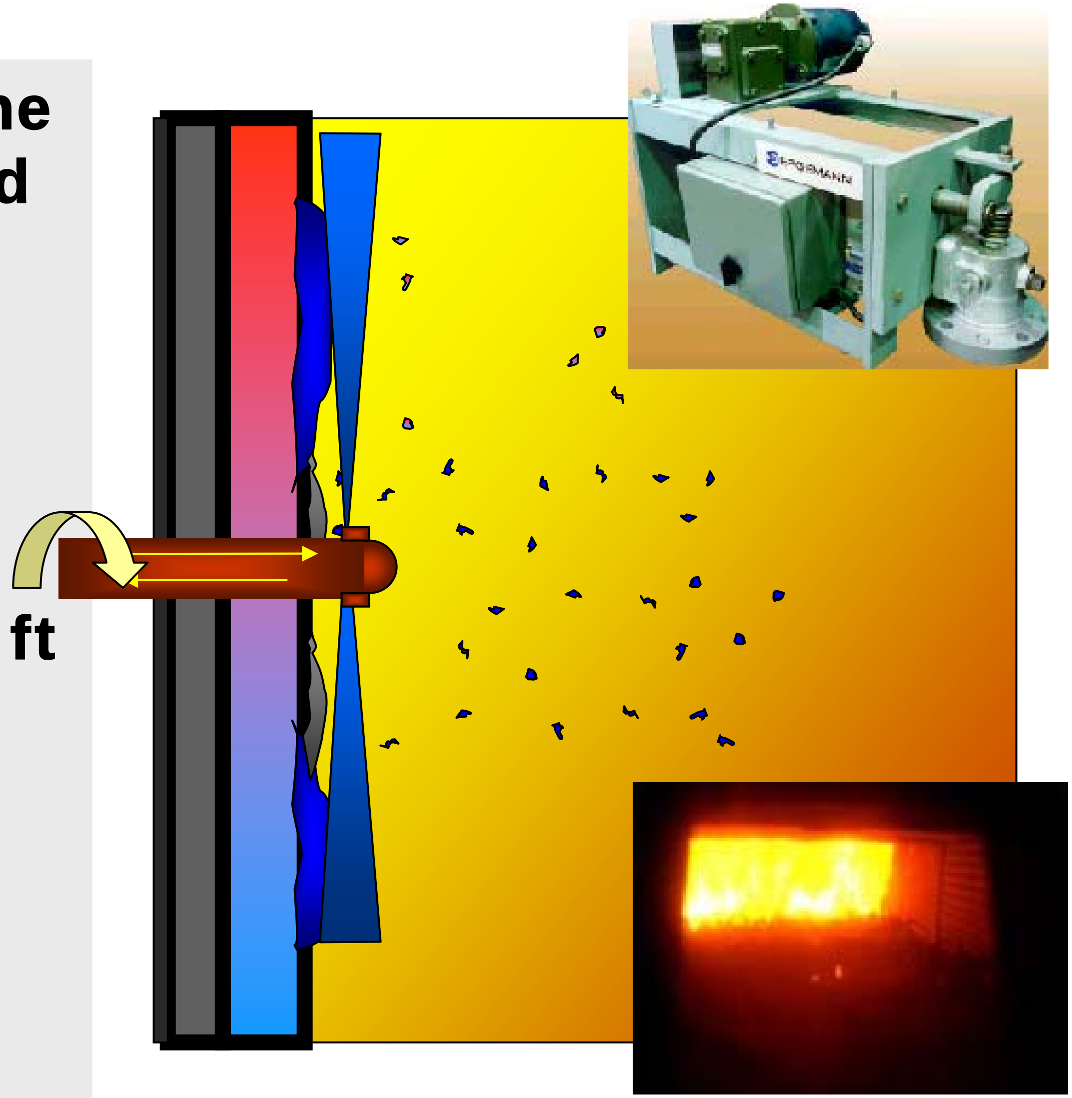
- Opposed Wall Cleaning Jet
- Full Closed-Loop Actuation

Sootblower System Overview

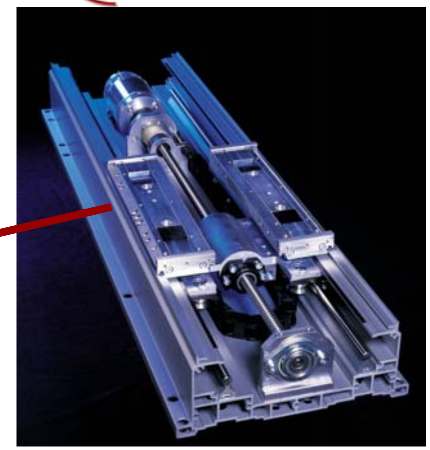


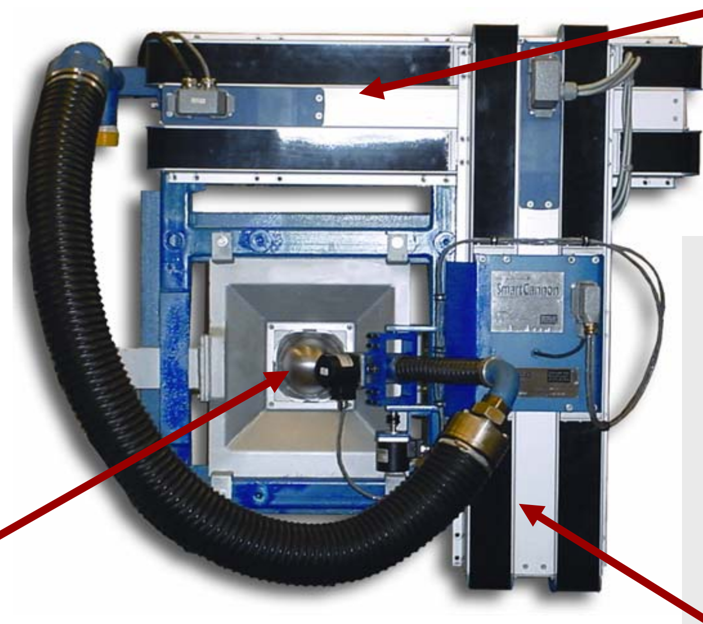
Traditional Furnace Cleaning

- **Traditional Radiant Zone Cleaning utilized a fixed cleaning device which positions a steam / air cleaning jet parallel to the water wall tube**
- **Affected areas range from 28 sq ft to 115 sq ft depending on deposit strength**
- **Limited treatment of < 20% of critical surface area**

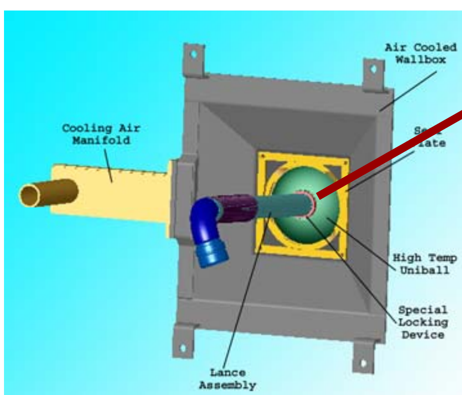


SmartCannon® Reliable - Accurate

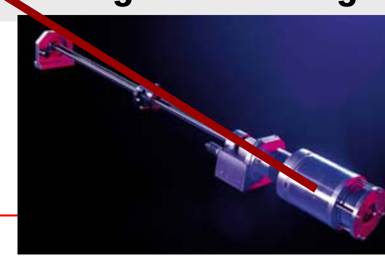




- Sealed Linear Screw Drives
    - 24V Brushless DC Servo Motors
    - Gear Reducer
    - Linear Drives
    - Ball Caster Spindle
    - Magnetic Sealing

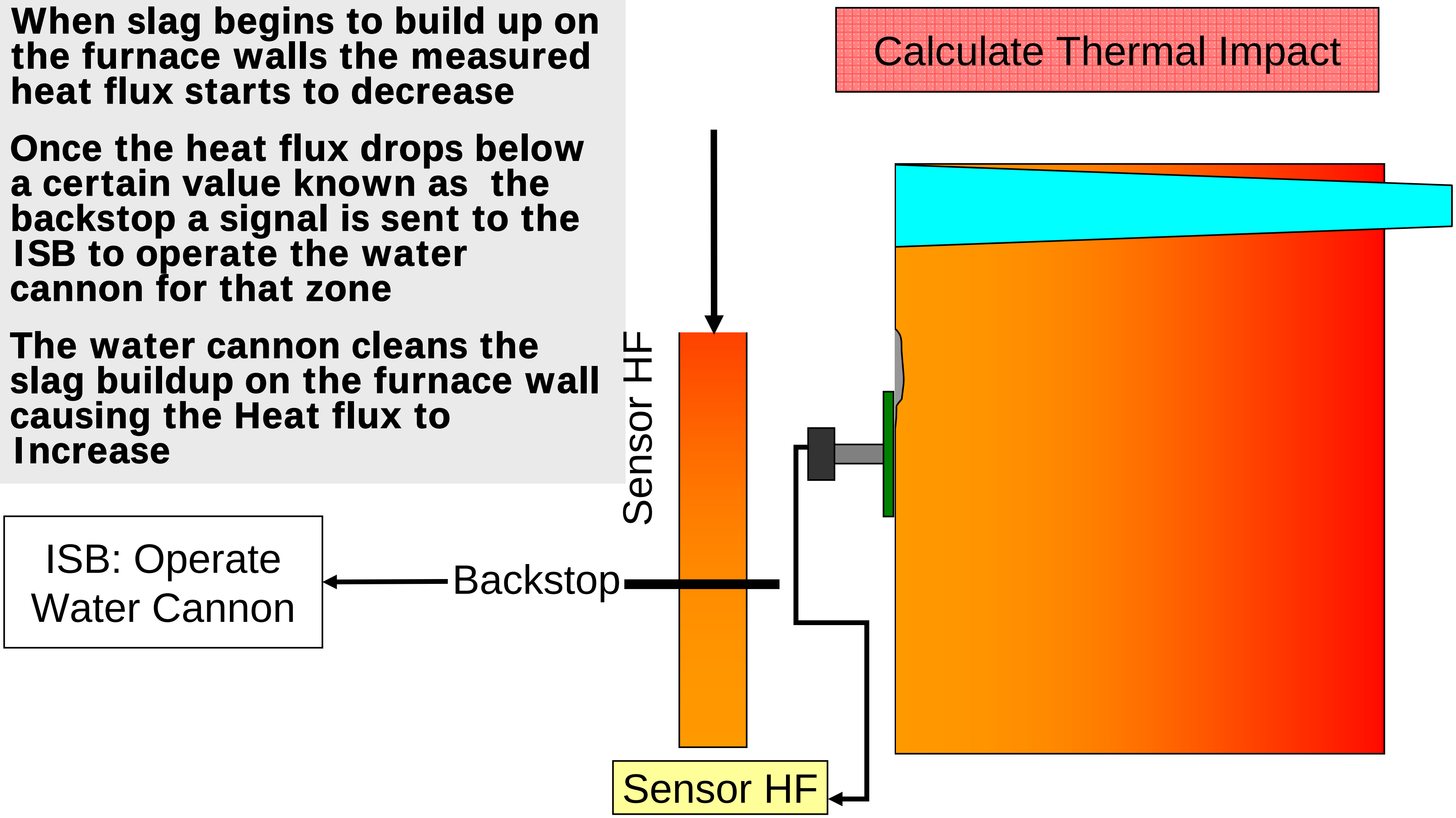


- Positive Seal Wallbox
    - Uni-Ball Construction



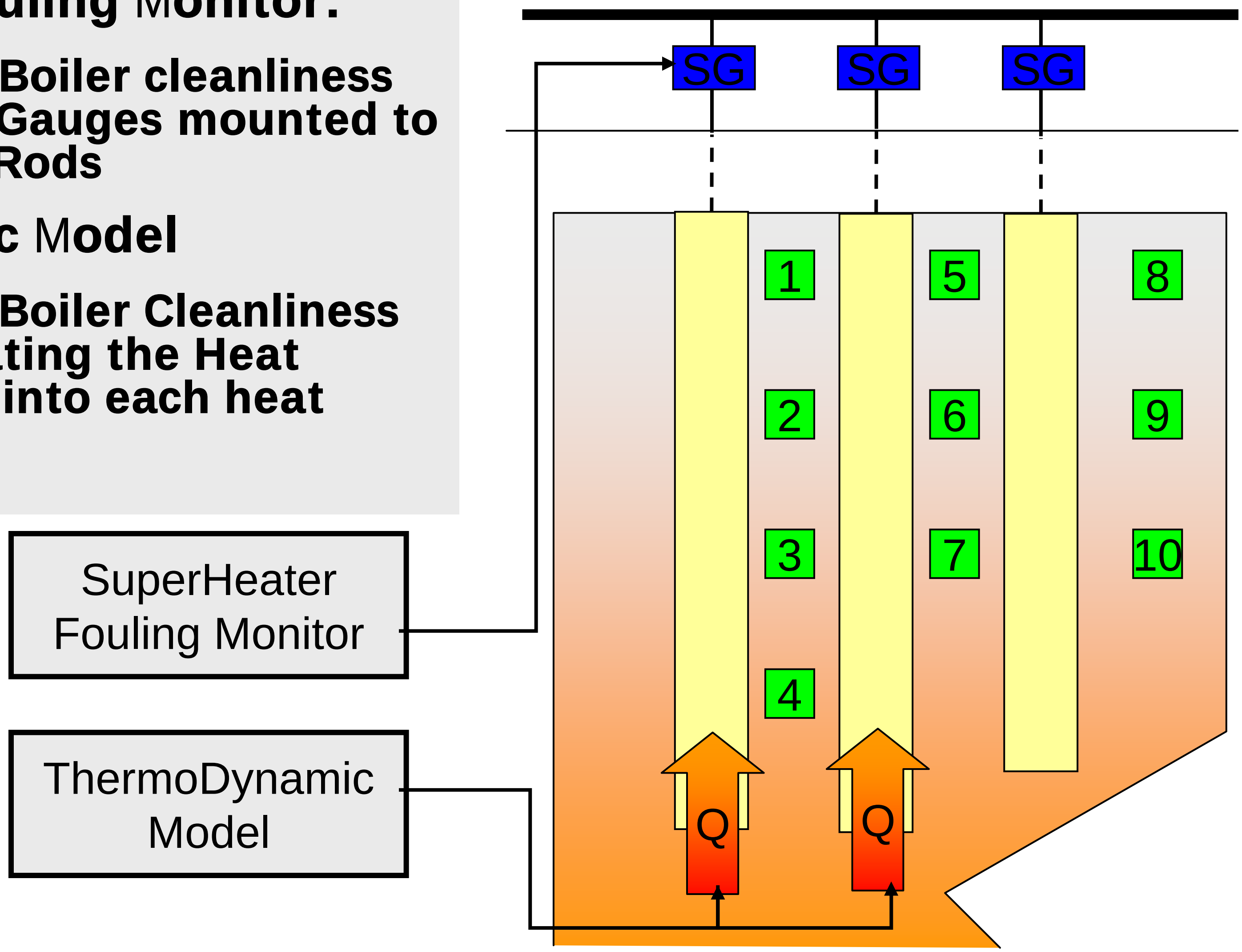
Smart Furnace: Heat Flux Sensors

- When slag begins to build up on the furnace walls the measured heat flux starts to decrease
- Once the heat flux drops below a certain value known as the backstop a signal is sent to the ISB to operate the water cannon for that zone
- The water cannon cleans the slag buildup on the furnace wall causing the Heat flux to Increase



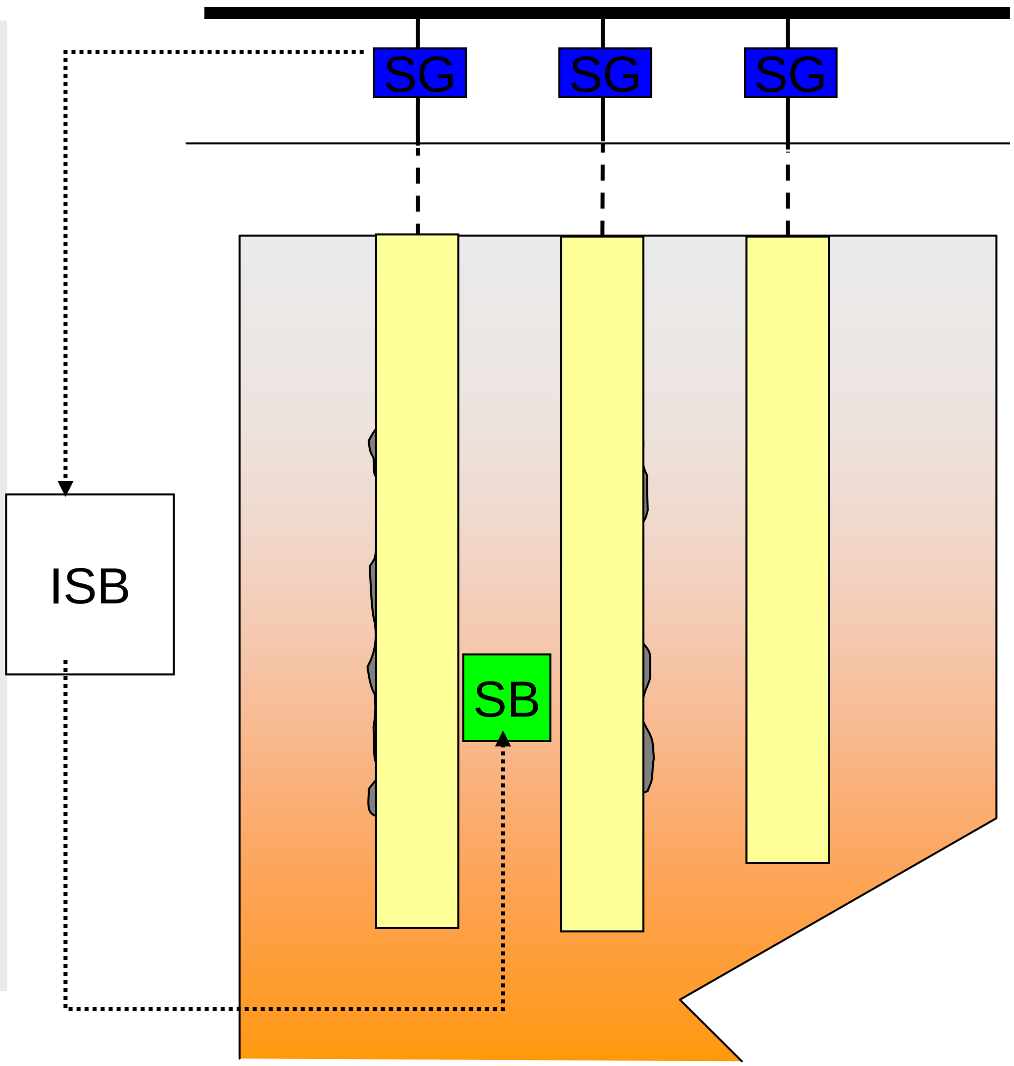
Smart Convection

- SuperHeater Fouling Monitor:
  - **Determines Boiler cleanliness from Strain Gauges mounted to the Hanger Rods**
- ThermoDynamic Model
  - **Determines Boiler Cleanliness from calculating the Heat Transferred into each heat exchanger**



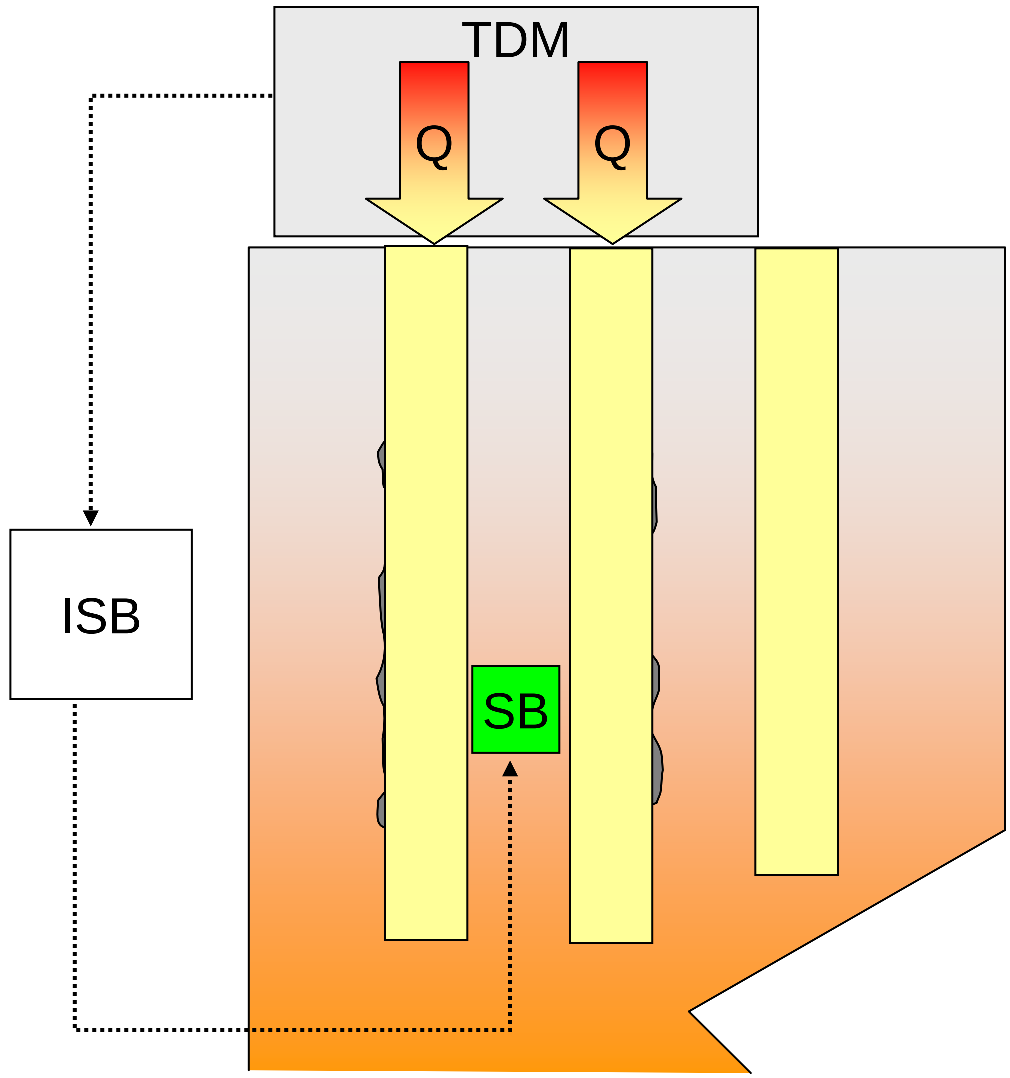
SuperHeater Fouling Monitor

- Monitors Weight Accumulation on pendants
- As deposits stick to the tube banks the overall weight of the tube bank increases
- This increase in weight is detected by the Smart Gauges located on the hanger rods
- The strain gauges relay the increase in weight to the ISB system
- The ISB system then operates the correct sootblower to remove the deposit



ThermoDynamic Model

- Monitors Inlet and Exit Temperatures and Flows for each heat exchanger
- As deposits stick to the tube banks the overall heat transferred (Q) to the tube banks decreases
- This decrease in heat transfer is detected by the Thermodynamic model
- The TDM relays the decrease in heat transfer to the ISB system
- The ISB system then operates the correct sootblower to remove the deposit



Relationship Direct:Global Measurement

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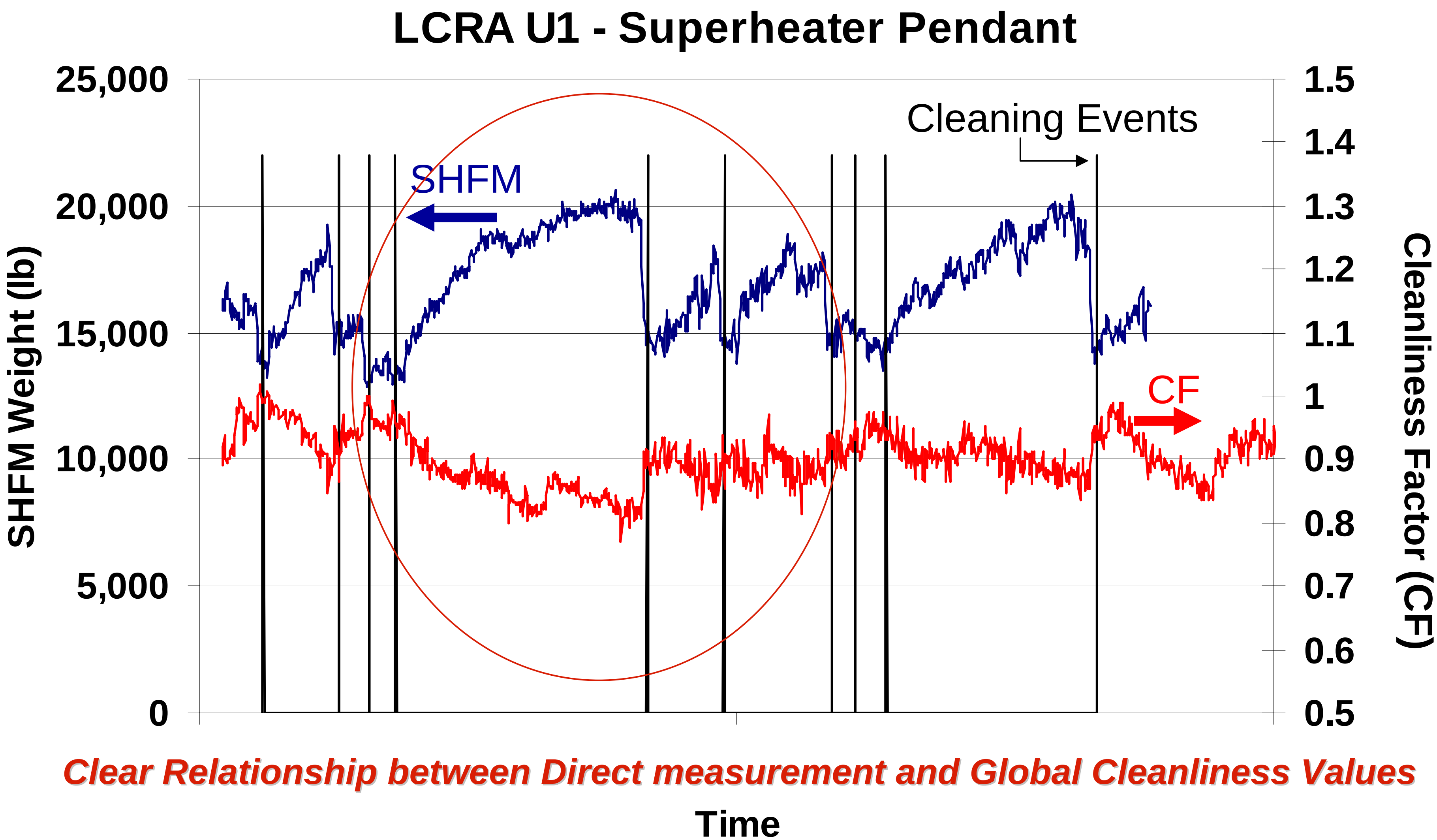
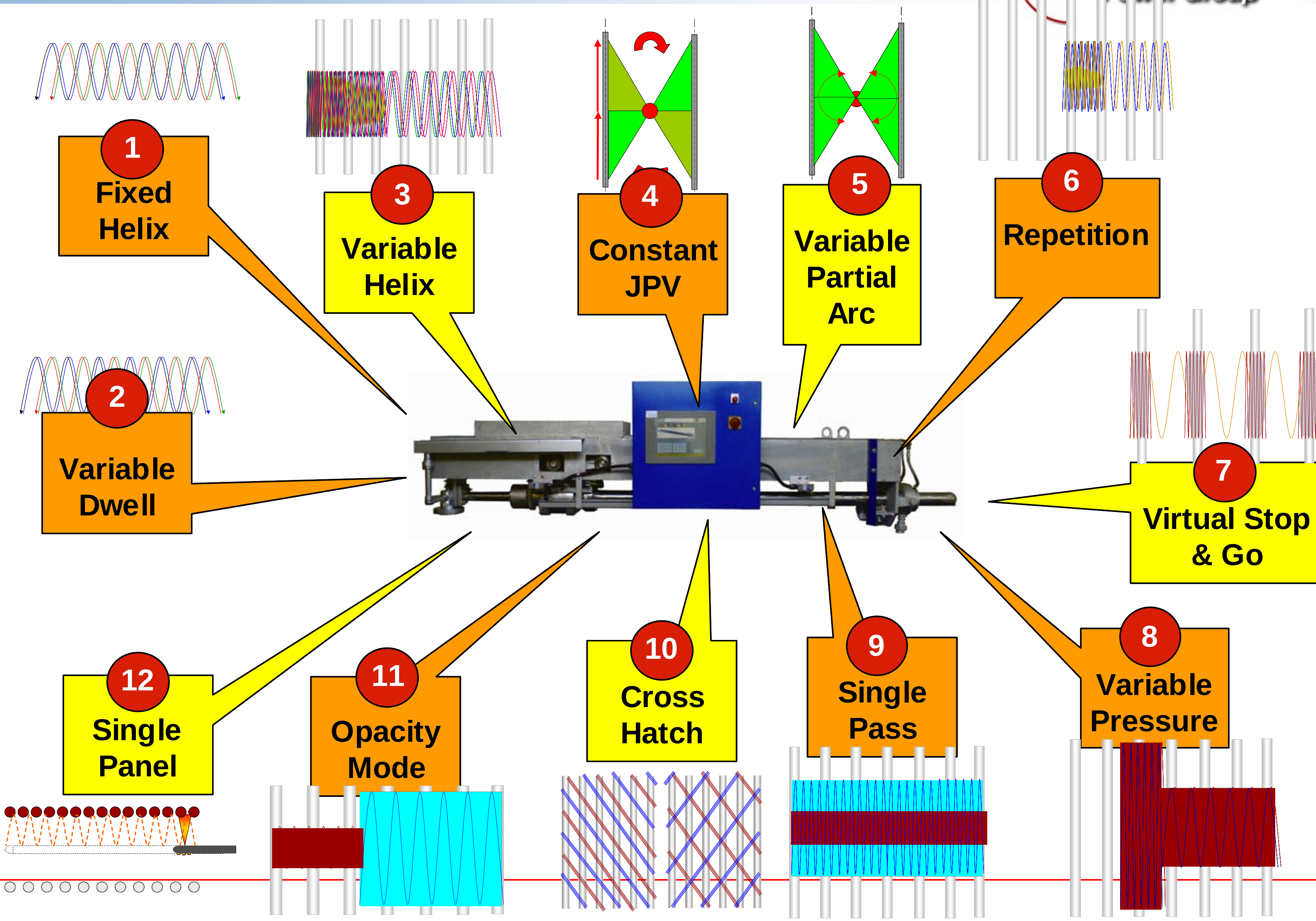
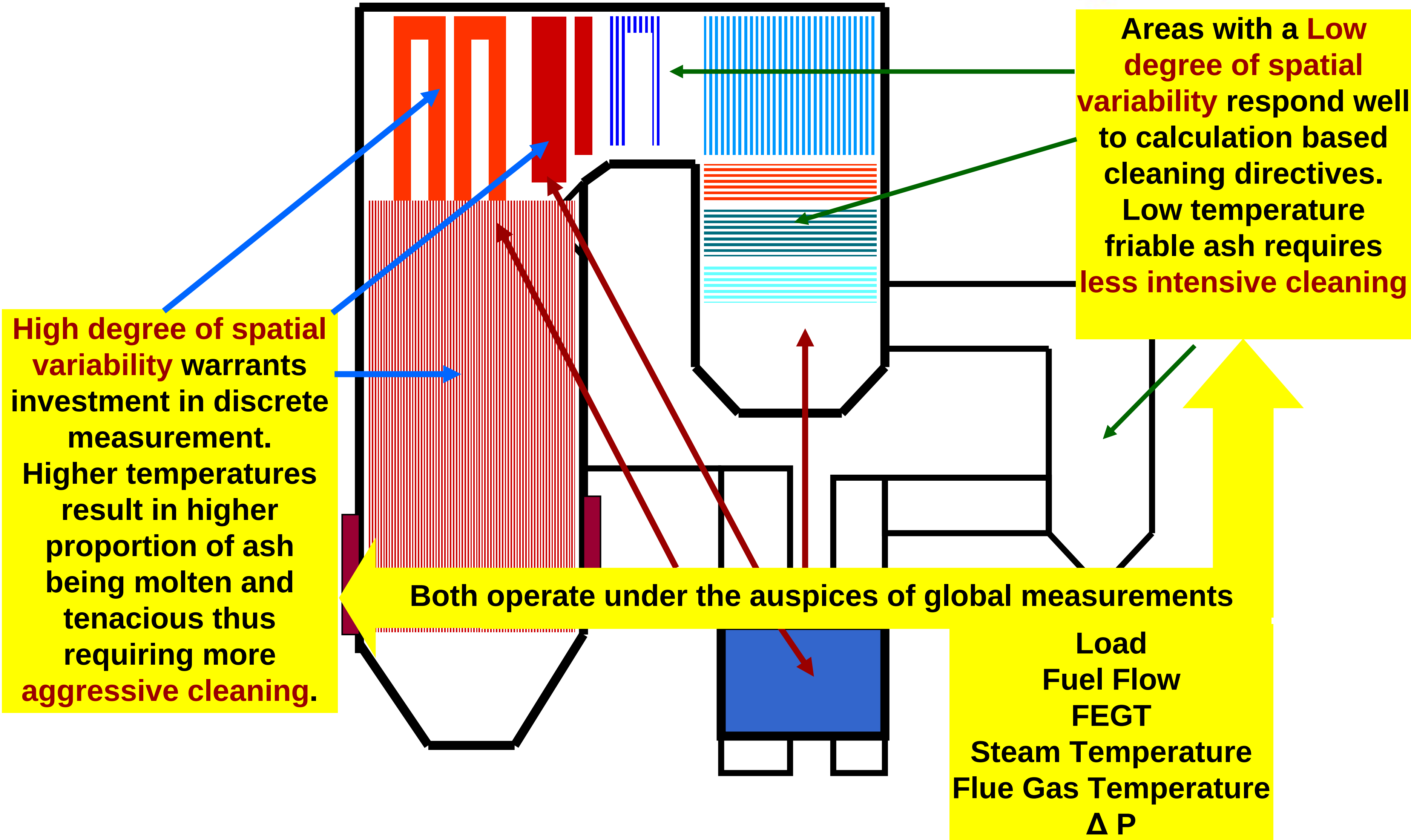


Clear Relationship between Direct measurement and Global Cleanliness Values

Tools – Smart Retractable Cleaners



When to Instrument - Global:Discrete



Instruments

SmartGauge

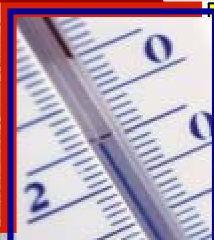
Monitors pendant ash accumulations to intelligently guide sootblower operation

SmartVision

Developmental system providing analog and digital mapping of hidden ash deposits

Infrared Imaging

Provides operators with visual confirmation of instrument output relative to current slagging and fouling conditions



Pyrometer

Pyrometry provides accurate FEGT to serve as a background permissive

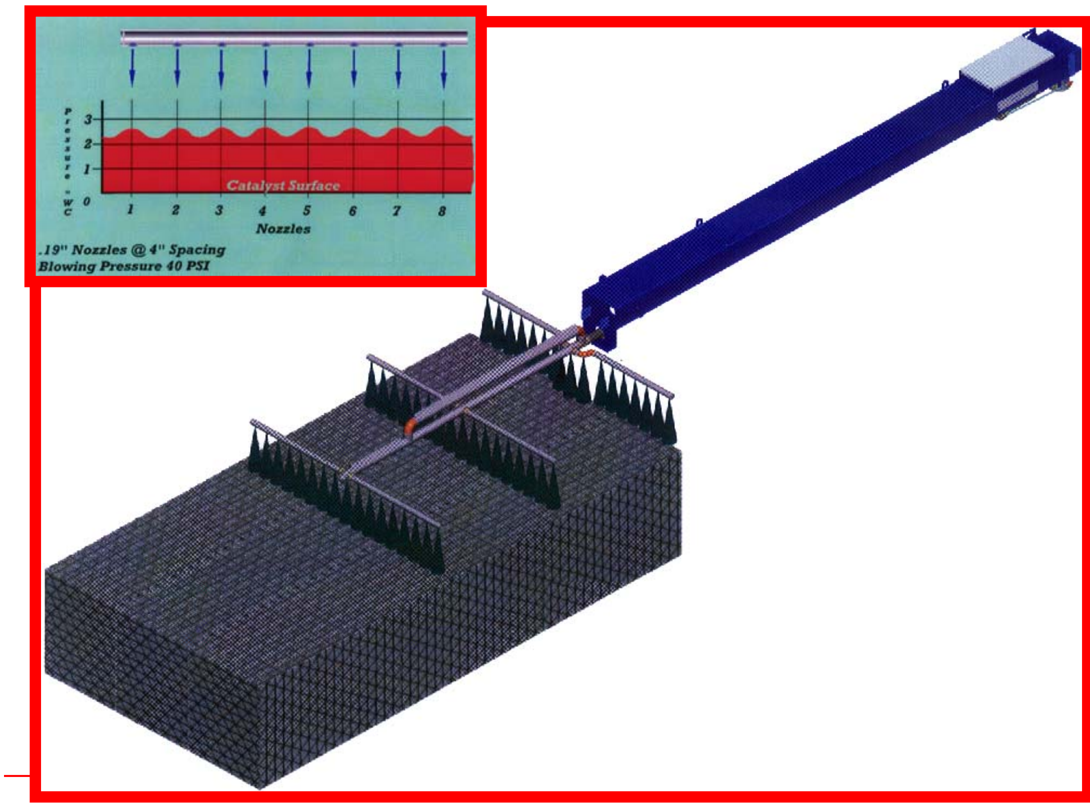
SmartSensor

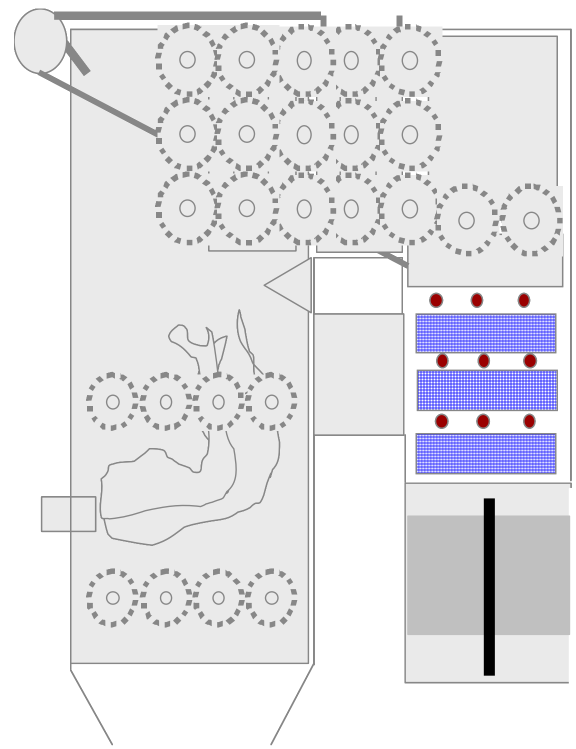
Monitoring heat flux and thermal impact simultaneously to guide cannon operation

Membrane Sensor

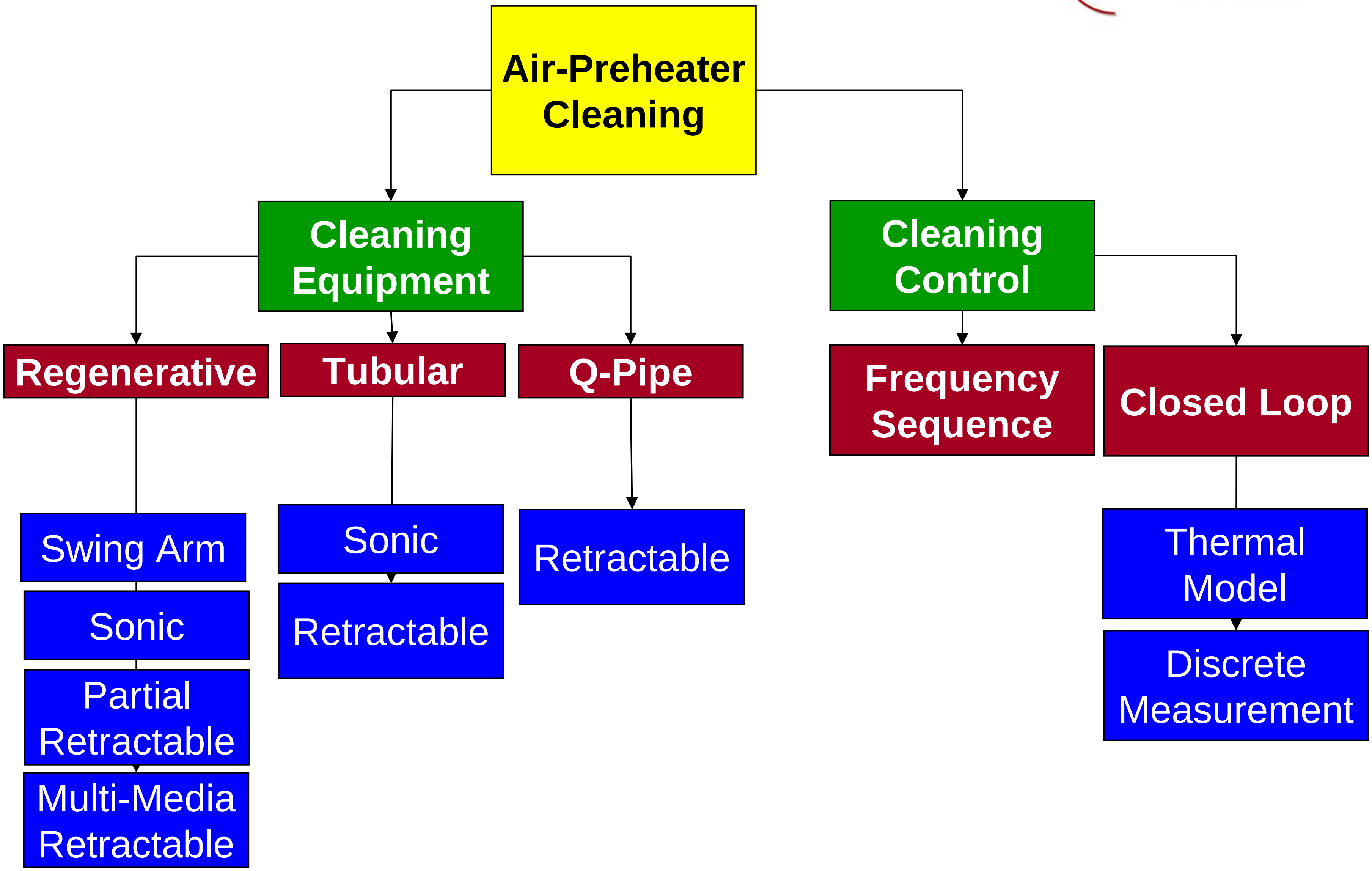
Provides positive feedback on Cannon impact accuracy

- Non-rotating variant of the US Retractable
  - Appendages with nozzles on 4” centers clean entire surface



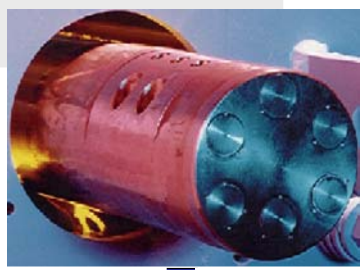


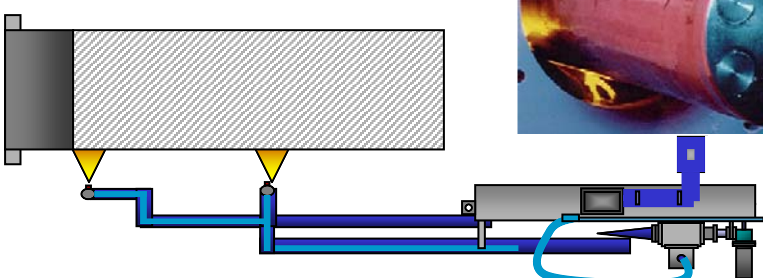
Air-Preheater Cleaning

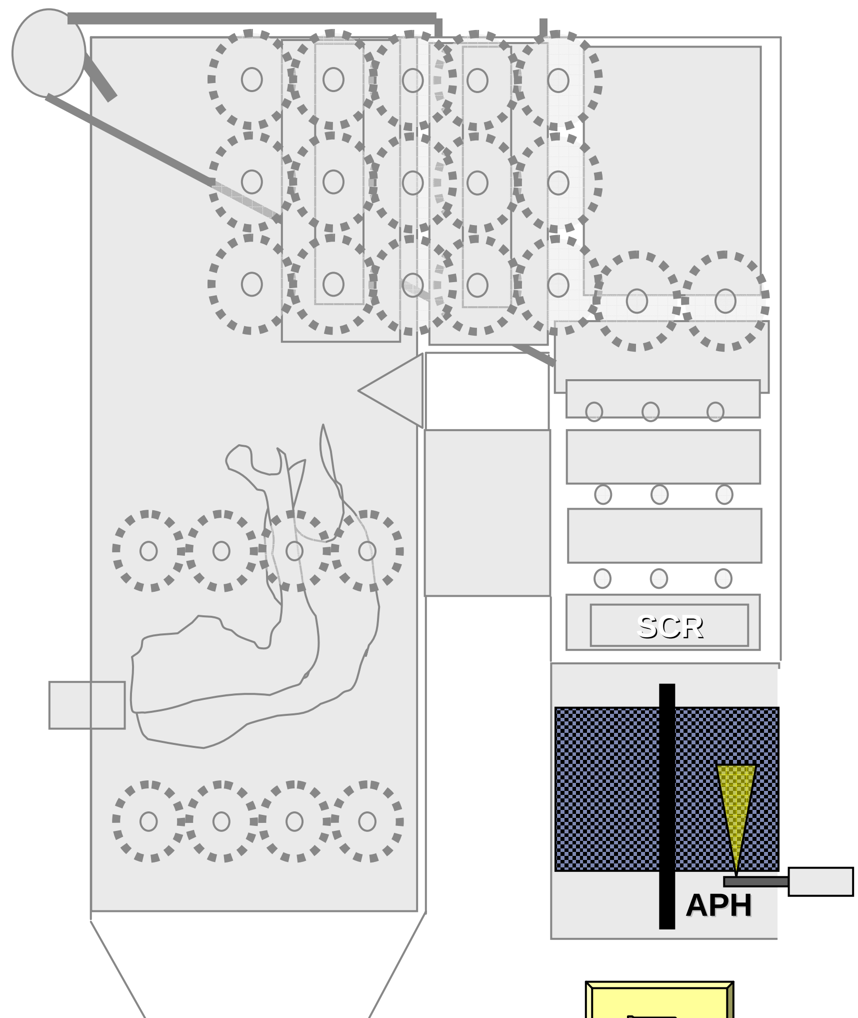


APH Cleaning

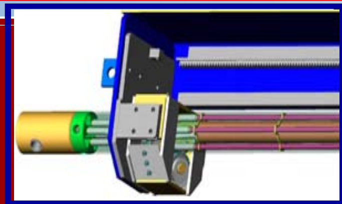
- **With the advent of the SCR and potential ammonia bisulphate deposits integral water wash capabilities have become increasingly important**
- **Multi-Media APH cleaners are fully programmable to vary dwell time and step size for both steam and water cleaning**







Cleaning Tools

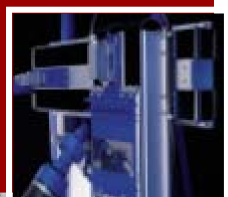


SmartLance
The ultimate in retractable cleaner technology offering both Multi-Mode and Multi-Media flexibility

SmartUS
Eliminates the constraints of traditional retractables by providing the world's only full-feature retractable

Rake Cleaners
Proven effective safe SCR Catalyst Cleaning

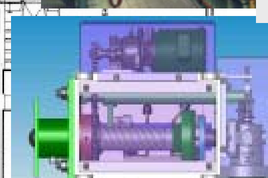
US / USX
Severe-Duty single motor drive retractable sootblower platform



SmartCannon
Safe, precise cleaning of furnace walls from hoppers to nose arch

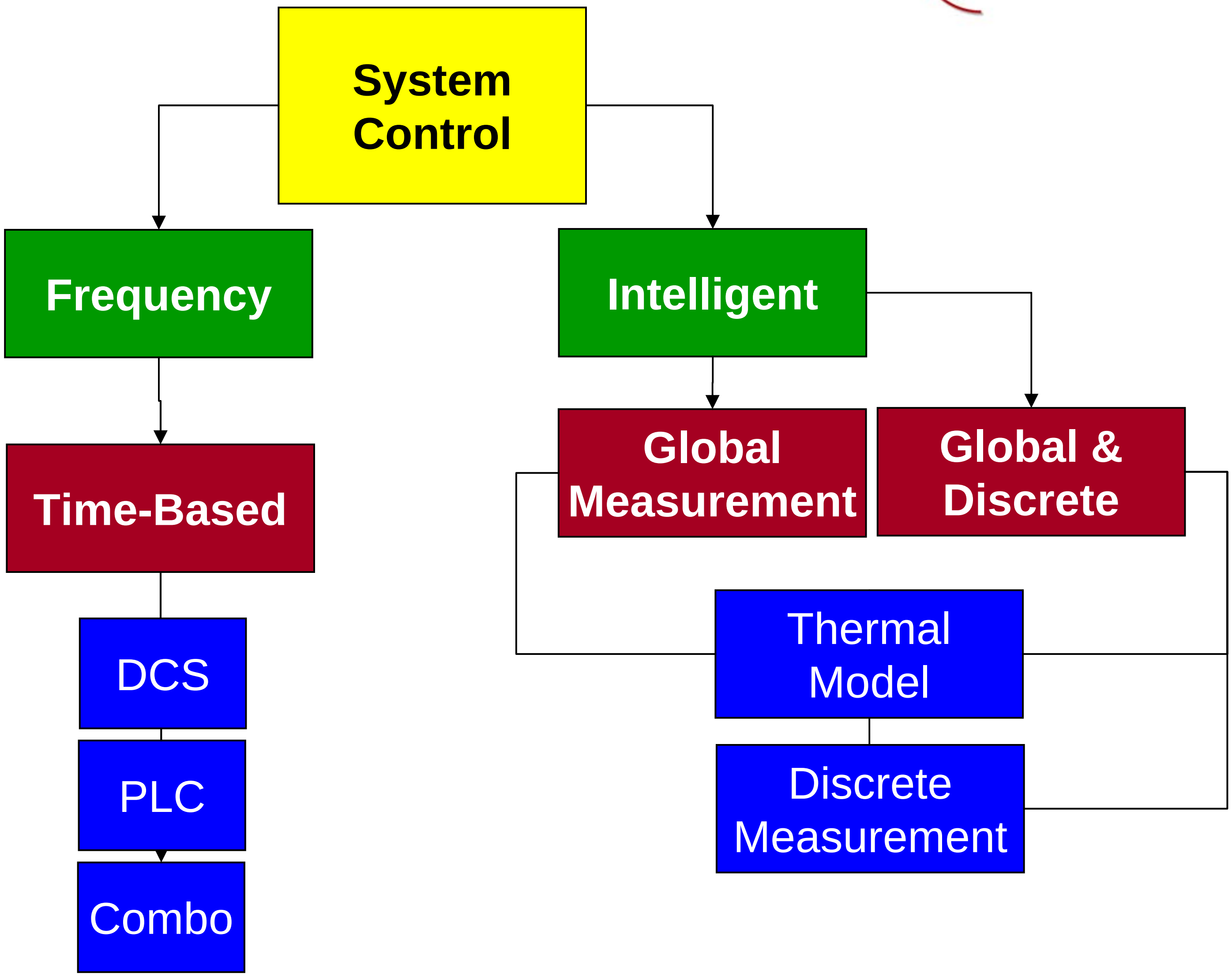
APH Cleaner
Multi-Media Air Preheater cleaner alternates between normal steam cleaner and high-pressure washing

WS
Precision Water Lance

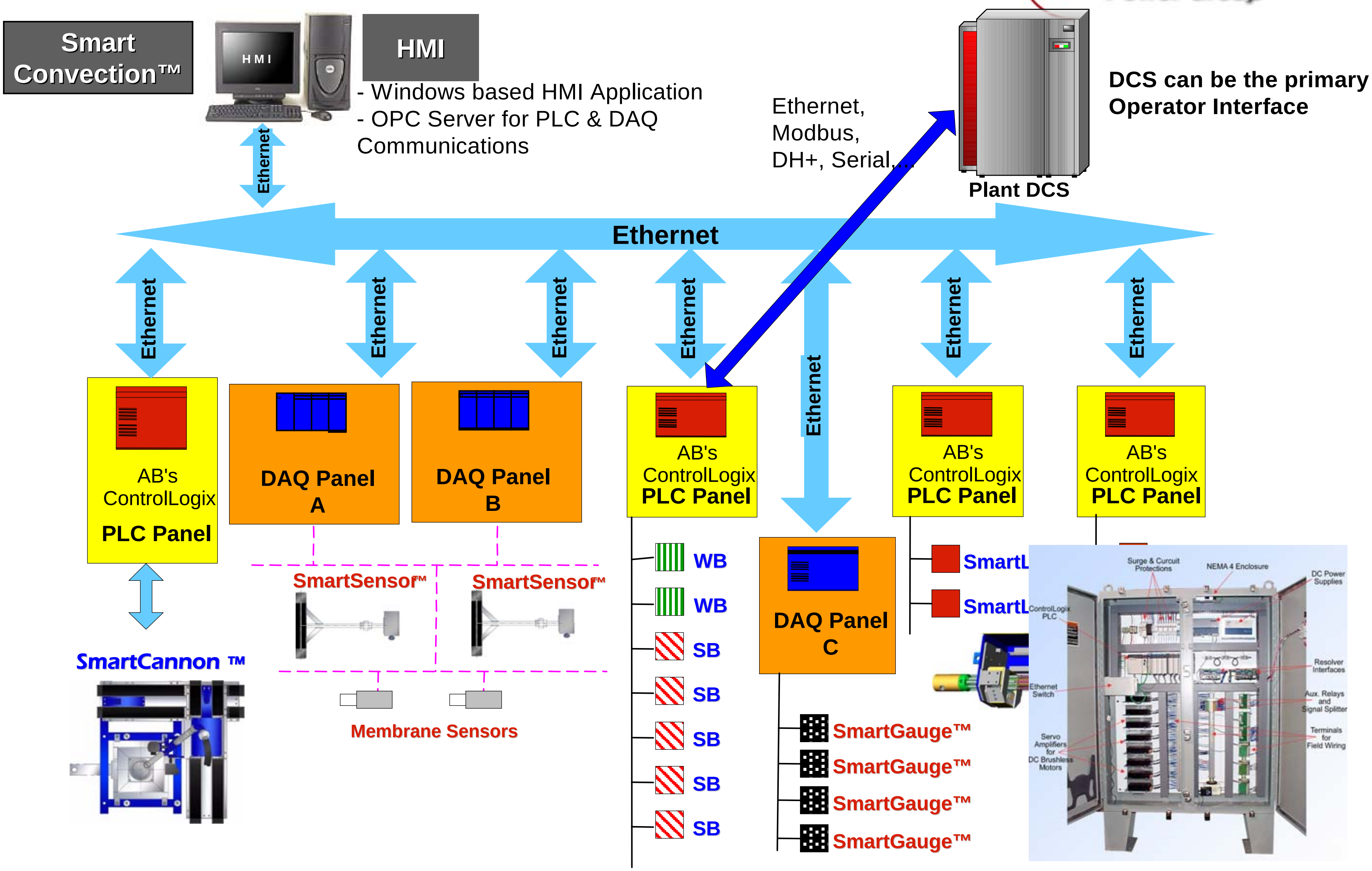


VS
Severe-Duty furnace wallblower

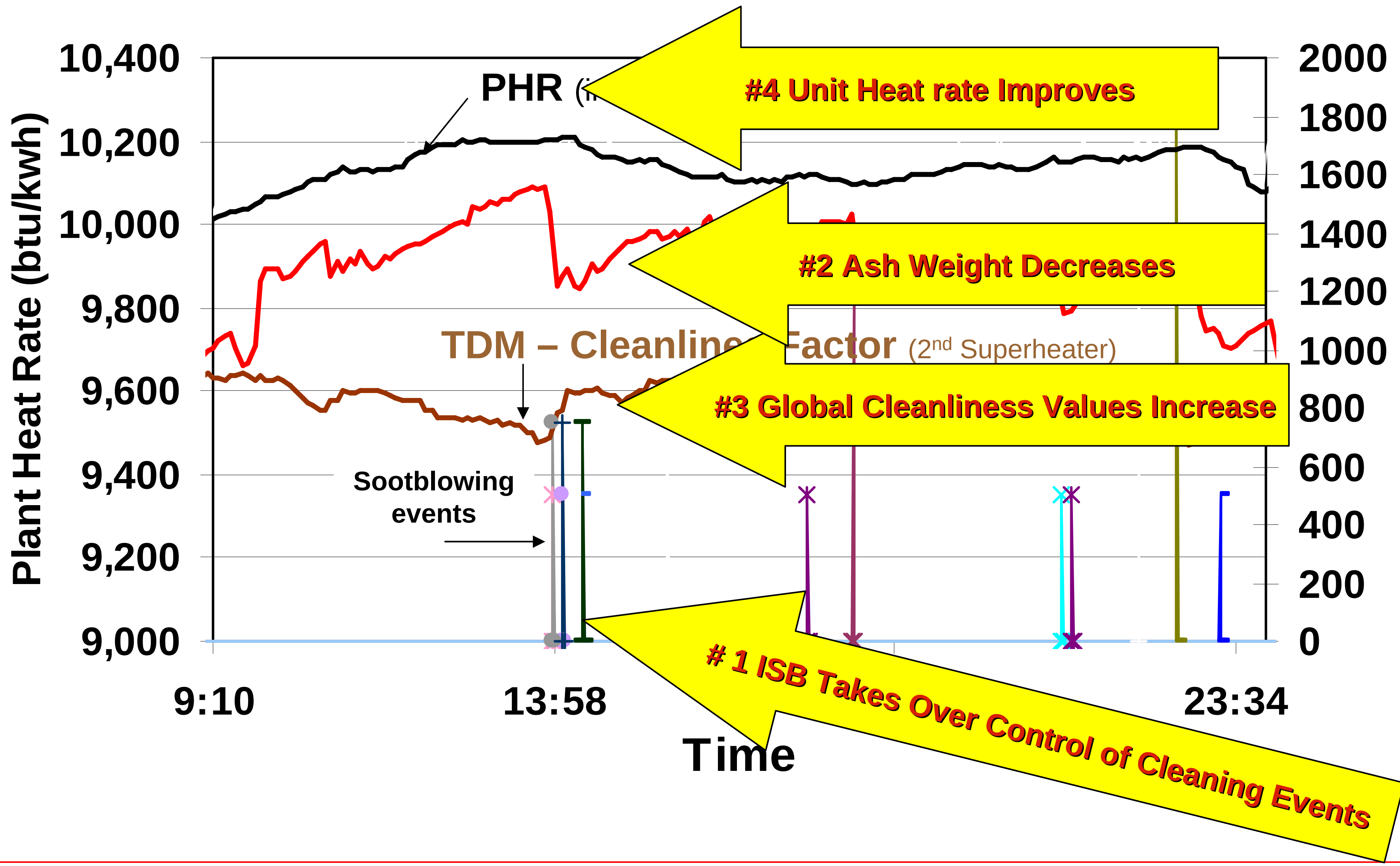
System Control



Control - Intelligent



Relationship Cleanliness:Heat Rate



In Practice – Actual ISB Results

Post – LNB, OFA and Fuel Switch

INDIVIDUAL GENERATING BANK CLEANLINESS VALUES						
Cleanliness Coefficient	Platen SH	SSH	RH OUT	Pri SH	RH IN	ECO
24 hours after stop ISB	91	91	85	95	90	97
24 Hours after resume ISB	93	93	87	97	93	99
Net Change	**2%**	**2%**	**2%**	**2%**	**3%**	**2%**

Cleanliness Factors Improved For ALL Zones

AVERAGE HEAT FLUX (2 HRS)		
24 Hours after stop ISB	50	k/Btu/sqft/hr
24 hours after resume ISB	54	k/Btu/sqft/hr
Net Change	**8%**	

Furnace Heat Flux Improved

AVERAGE FEGT (2 HRS)		
24 Hours after stop ISB	2545	F
24 hours after resume ISB	2505	F
Net Change	**-2%**	

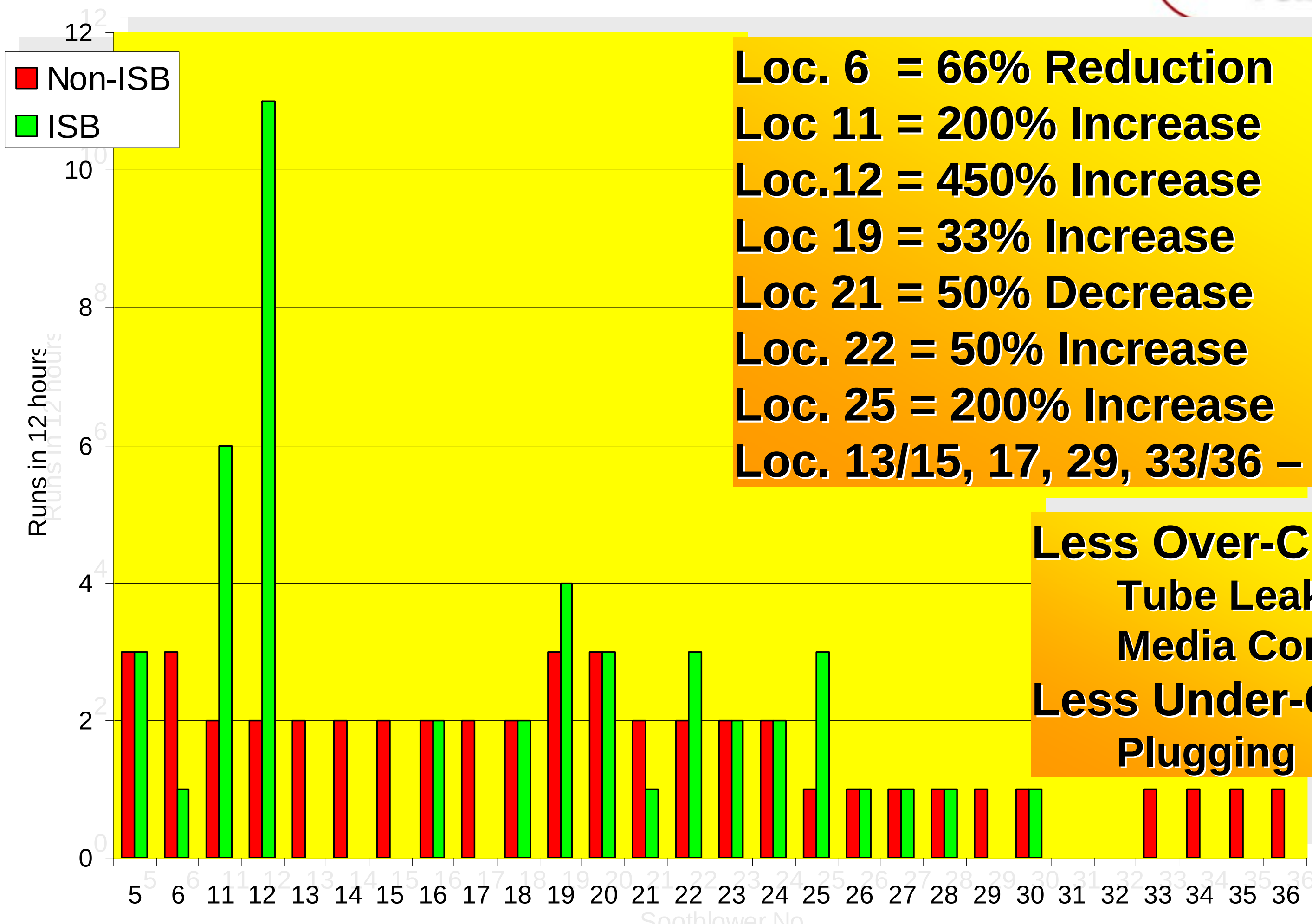
40º F Reduction In FEGT

AVERAGE RH SPRAY FLOW (12 hours)		
ISB not in service	27	k/pph
ISB in service	21	k/pph
Net Change	**-23%**	

Substantial Spray Flow Reduction

24 HOUR BASELINE TEST
NORMAL SEQUENTIAL OPERATION VS. ISB OPERATION

In Practice – Actual ISB Results



Loc. 6 = 66% Reduction
Loc 11 = 200% Increase
Loc.12 = 450% Increase
Loc 19 = 33% Increase
Loc 21 = 50% Decrease
Loc. 22 = 50% Increase
Loc. 25 = 200% Increase
Loc. 13/15, 17, 29, 33/36 – Eliminated

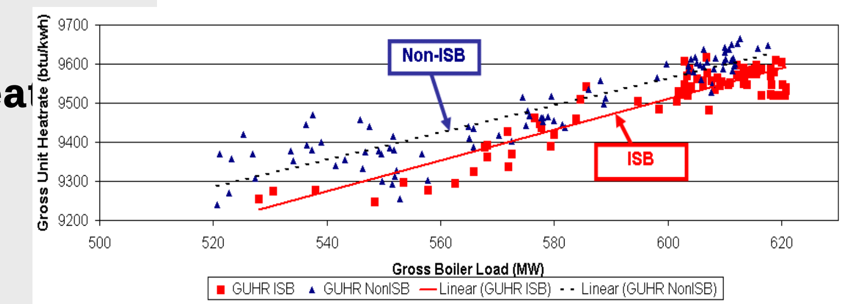
Less Over-Cleaning
- **Tube Leaks**
- **Media Consumption**

Less Under-Cleaning
- **Plugging**

To Achieve These Results the ISB System Dramatically Altered Individual Sootblower Frequencies Based on Real-Time Conditions

Case Study: Heat Rate Improvement

- NRG Big Cajun Unit 3
- 630 MW B&W Boiler
- Fuel: PRB Coal
- Challenges: Severe slagging causing unplanned outages
- Solution: SmartClean System installed
  - Automated Cleaning
  - Fouling Sensors in Furnace and Super heat
  - SmartCannon for furnace cleaning
- Annual Benefits:
  - 1% Heat rate improvement $1M
  - Eliminate outage $3M
  - Total $4M
- Payback: Less Than 1 year



PHR Improvement = 9590 – 9500 = 90 Btu/KWh

Power saved = 90 Btu/KWh * 1000 KWh/MWh * 600 MW = 57.10^6

Cost reduction = 57.10^6 Btu/hr * 1KWh/9500Btu * 1000Kwh/MWh * $20/MWh

= $968,589 per year (355 days)

Justification Tools Available

- Quantify individual plant situation
- Establish discounted cash flow analysis

Net Present Value (NPV) Calculator for Boiler Cleaning Projects

Project: John Doe Power Station - Water Cannons

Cost of Capital 10%

Year:	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
Capital Equipment	$ (650,000)	$ -	$ -	$ -	$ -	$ -	$ (650,000)
Labor	$ (350,000)						$ (350,000)
Other Capital Costs							
Incremental Operating Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Outflows	**$ (1,000,000)**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ (1,000,000)**
Operating Profit from Incremental Generation	$ 875,000	$ 875,000	$ 875,000	$ 875,000	$ 875,000	$ 875,000	$ 5,250,000
Avoided Outage Costs	$ 220,000	$ 220,000	$ 220,000	$ 220,000	$ 220,000	$ 220,000	$ 1,320,000
Fuel Savings From Improved Heat Rate	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 3,000,000
Fuel Savings From Lower Fuel Price	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 2,500,000	$ 15,000,000
Avoided Ammonia Cost	$ 65,000	$ 65,000	$ 65,000	$ 65,000	$ 65,000	$ 65,000	$ 390,000
Avoided Catalyst Replacement	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 140,000	$ 840,000
Avoided NOx Credit Cost	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Avoided Media Costs	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 35,000	$ 210,000
Other	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Depreciation Rate	40%	30%	20%	5%	3%	3%	
Depreciation	$ 400,000	$ 300,000	$ 200,000	$ 50,000	$ 25,000	$ 25,000	$ 1,000,000
Corporate Tax Rate	30%	30%	30%	30%	30%	30%	
Corporate Tax	$ (1,180,500)	$ (1,210,500)	$ (1,240,500)	$ (1,285,500)	$ (1,293,000)	$ (1,293,000)	$ (7,503,000)
Total Inflows	**$ 3,154,500**	**$ 3,124,500**	**$ 3,094,500**	**$ 3,049,500**	**$ 3,042,000**	**$ 3,042,000**	**$ 18,507,000**
Cash Flow	**$ 2,154,500**	**$ 3,124,500**	**$ 3,094,500**	**$ 3,049,500**	**$ 3,042,000**	**$ 3,042,000**	**$ 17,507,000**
6-yr Discounted Cash Flow - NPV/IRR	**$ 1,958,636**	**$ 2,582,231**	**$ 2,324,944**	**$ 2,082,850**	**$ 1,888,843**	**$ 1,717,130**	**$ 12,554,633**

6-yr Return on Investment - ROI 1255%

Payback Period 0.48 Years

	Boiler Cleanliness Configurator	CLYDE BERGEMANN Power Group				**Commercial Release Revision 1.3**
1.0	**Plant:**	Mirant Chalk Point			**Unit #:**	1 and 2
2.0	**Driver**	**Value**	**U/M**	**Day**	**Month**	**Year**
3.0	**Plant Data**					
4.0	**Production Data**					
5.0	**Capacity:**	355	Mw	**Boiler Mfg:**	BW	
6.0	**Demand Factor:**	85%		**Boiler Type:**	Supercritical	
7.0	**Average Demand:**	302	Mwh	7,242	220,273	2,643,272
8.0	**Steam Production:**	2,196,740	PPH	52,721,760	1,603,585,052	19,243,020,626
9.0	**Feedwater Flow:**	3,207,240	PPH	**Type of Air Preheater:**		Dual Regenerative
10.0	**Wheeled Revenue Potential:**	$ 70.00	Mwh	$ 506,940	$ 15,419,087	$ 185,029,044
10.1	**Avg Replacement Power Cost:**	$ 40.00	Mwh			
11.0	**Sootblower Compliment**					
12.0	**Cleaning Media:**	Steam	360	PSIG	575	F
13.0		**Qty**	**Travel(')**	**Model**	**Cycles per Day**	**Media Consumption per Day**
14.0	**Wallblower:**	42	1.0	IR	3	10,710
15.0	***Average Availability:***	95%				
16.0	**Water Lance:**	0				na
17.0	***Average Availability:***					
18.0	**Water Cannon:**	0				na
19.0	***Average Availability:***					
20.0	**Full Retract:**	20	25.0	IK525	2	64,615
21.0	***Average Availability:***	90%				
22.0	**1/2 Retract:**				1	-
23.0	***Average Availability:***	90%				
24.0	**APH:**	2	10.0	Retractable	6	25,200
25.0	**Sonic:**	0				
26.0	**Daily Cleaning Media Consumption (lbs for steam blowing and scf for air blowing)**					100,525

Thank You

Clean Energy Solutions
CLYDE BERGEMANN Power Group
Serving the Power Industry Worldwide
Air Pollution Control Systems
Advanced On Load Boiler Cleaning
Intelligent Control Systems
High Performance Ash Handling
Efficient Injection Systems