

Reinhold Environmental Ltd.



2007 NOx Round Table & Expo
Presentation

February 5-6, 2007 in Cincinnati, OH



An Integrated Approach to Boiler Optimization

Presented by:

Joe Naberhaus – Dynegy

Peter Spinney – NeuCo

Reinhold NOx Roundtable & Expo

February 6, 2007



DYNEGY





Agenda

- ◆ **Optimization Overview**
- ◆ Integrated Boiler Optimization
- ◆ Boiler Optimization Project at Baldwin

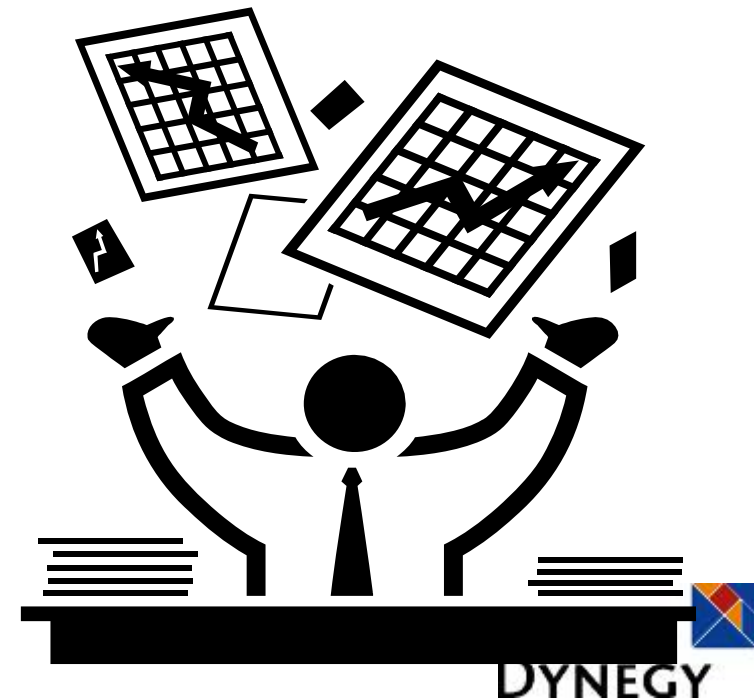


Role of Optimization

- ◆ The process of turning reams of complex data into **actionable** knowledge that delivers **bottom line** benefit
- ◆ An Optimizer Must:
 - **ACT:** continuously identify actions that can improve asset performance
 - **INFORM:** provide insight into what actions were taken or advice given and why
 - **QUANTIFY:** the benefits & missed opportunities

Data Sources:

ERPs (e.g. SAP)
CMMSs (e.g. Maximo)
Monitors (e.g. GeneralPhysics)
Analyzers (e.g. Zolo)
Detectors (e.g. SmartSignal)
Historians (e.g. OSI)
DCSs (e.g. ABB)





Types of Optimizers

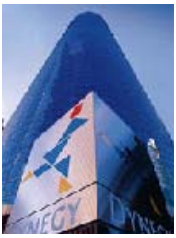
- ◆ **NeuCo currently has 4 commercially-available Optimizers:**
 - **CombustionOpt[®]:** Optimizes fuel & air mixing to lower emissions and improve heat rate
 - **SootOpt[®]:** Optimizes sootblowing activity to improve reliability, heat rate and emissions
 - **PerformanceOpt[®]:** Identifies efficiency and capacity bottlenecks and the actions required to control the corresponding losses
 - **MaintenanceOpt[™]:** A diagnostics center for the detection, diagnosis and prioritization of maintenance problems

- ◆ **And there are more on the way:**
 - DOE CCPI-2 NRG Texas Limestone
 - Customer Teaming



Importance of an Integration Platform

- ◆ Integrating disparate data and knowledge sources
- ◆ Standardizing metrics allowing performance comparisons and tradeoffs across equipment, units and plants
- ◆ Coordinating actions towards common business objectives, instead of competing
- ◆ Prioritizing the most important actions you can take to achieve your objectives
- ◆ Creating transparency and accountability by bridging islands of information and understanding



Agenda

- ◆ Optimization Overview
- ◆ **Integrated Boiler Optimization**
- ◆ Boiler Optimization Project at Baldwin



What does Integrated Boiler Optimization Mean?

- ◆ Integrated optimal operation of combustion, boiler cleanliness, steam temperatures, and total boiler performance
- ◆ Real-time management of multiple objectives, constraints, and tradeoffs:
 - Monetized objectives
 - Coordination of individual Optimizers toward global objectives
 - Sharing real-time knowledge between multiple solutions
 - CombustionOpt
 - SootOpt
 - PerformanceOpt
 - MaintenanceOpt
- ◆ Recognition that priorities and operating conditions change in dynamic and complex ways



Integrated Boiler Optimization Benefits

- ◆ Ensuring that total operating costs are minimized in face of changing conditions and cost factors
- ◆ Adhering to all applicable constraints
- ◆ Integration of real-time operations with maintenance needs
- ◆ Managing tradeoffs between instantaneous and longer-term costs and financial performance
- ◆ Making the whole more than the sum of the parts!



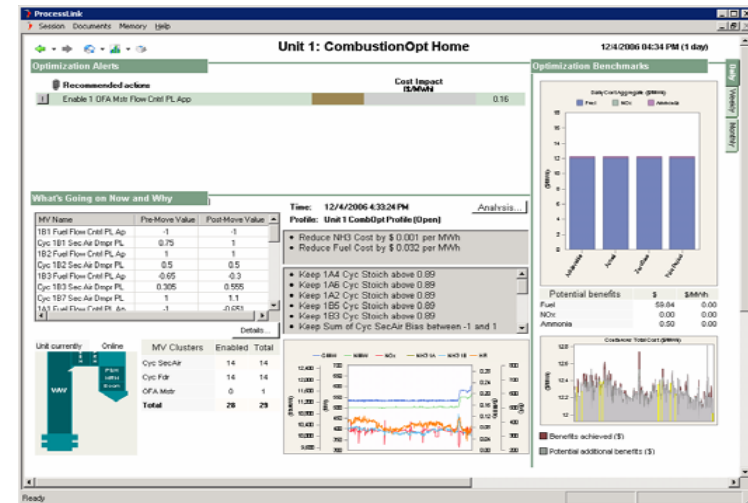
Boiler Optimization Components

- ◆ Optimizers
 - CombustionOpt
 - SootOpt
- ◆ Technologies
 - Neural Networks
 - Model Predictive Control
 - Expert Systems/Heuristics
 - Simulation Engine
 - Integrated Object Library
 - Analysis Tools



CombustionOpt Overview

- ◆ Context:
 - Combustion controls manipulate a few variables (such as O₂) as a function of load, leaving 35-100 fuel and air injection points that significantly impact combustion performance to infrequent offline tuning or operator tweaking
- ◆ What CombustionOpt Does:
 - Provides real-time closed-loop optimization of fuel and air mixing by manipulating all relevant fuel and air injection points
- ◆ Using:
 - Neural network and model predictive control technologies
- ◆ To Achieve:
 - NO_x, heat rate, steam temp, CO and opacity improvements





CombustionOpt Home

ProcessLink | Session Documents Memory Help

Unit 3: CombustionOpt Home 1/17/2007 06:10:00 AM (1 day)

Optimization Advice

Recommended actions

Action	Cost Impact (\$/MWh)
Enable WB FURN SEL BIAS	0.091
Enable G SOFA TILT SEL BIAS	0.072
Widen FUELAIR Limit	0.072
Enable O2 TRIM SEL BIAS	0.058
Enable H SOFA TILT SEL BIAS	0.048
Widen AUXDPR Limits	0.000

Optimization Benchmarks

Cost Aggregate (\$/MWh)

Scenario	Fuel (\$/MWh)	NOx (\$/MWh)
Aspirational	~13.9	~1.4
Actual	~13.9	~1.4
Baseline	~13.9	~1.4

Where are we Now and Why?

MV Name	Pre-Move Value	Pos
AUXDPR AA SEL BIAS	-2.649	
AUXDPR AB SEL BIAS	1.925	
AUXDPR BC SEL BIAS	2.459	
AUXDPR CD SEL BIAS	-2.621	
AUXDPR DE SEL BIAS	-0.12	
AUXDPR EF SEL BIAS	1.788	
AUXDPR FF SEL BIAS	-0.784	
FFFFR Δ SEL BIAS	-3.785	

Time: 1/17/2007 6:02:31 AM [Analysis...](#)

Profile: Unit 3 NN Supervisory Profile

- Reduce Fuel Cost by \$ 0.048 per MWh
- Reduce NOx Cost by \$ 0.003 per MWh
- Keep O2 Flue Gas Diff at 0 percent

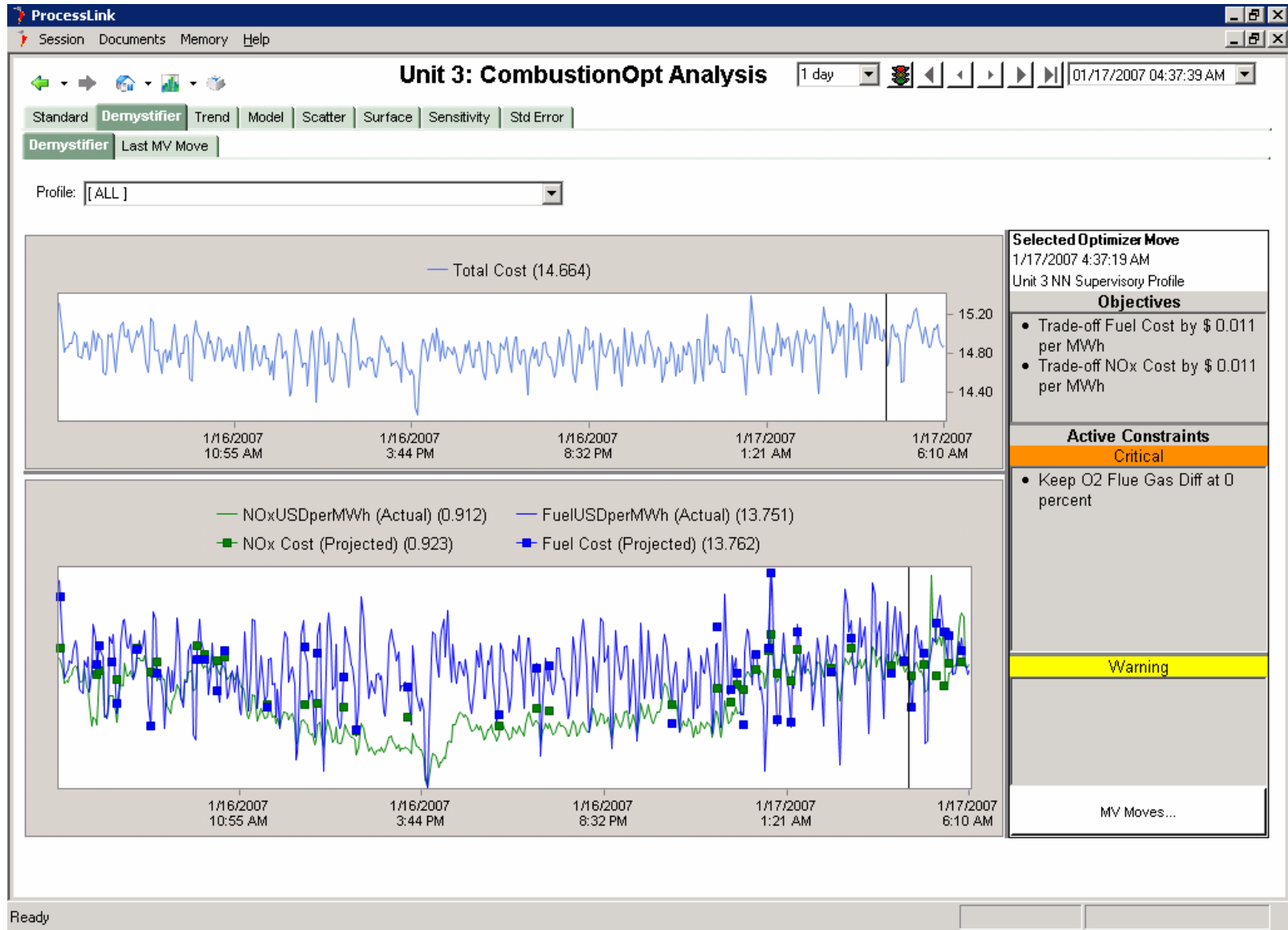
Unit currently	Online	MV Clusters	Enabled	Total
Aux Air	7	7	7	7
Fuel Air	6	6	6	6
Feeders	6	6	6	6
SOFA Tilts	0	2	0	2
SOFA Dmprs	4	4	4	4
O2, WB DP	0	2	0	2
Total	23	27		

Potential benefits	\$	\$/MWh
Fuel	429.62	0.03
NOx	-229.41	-0.02





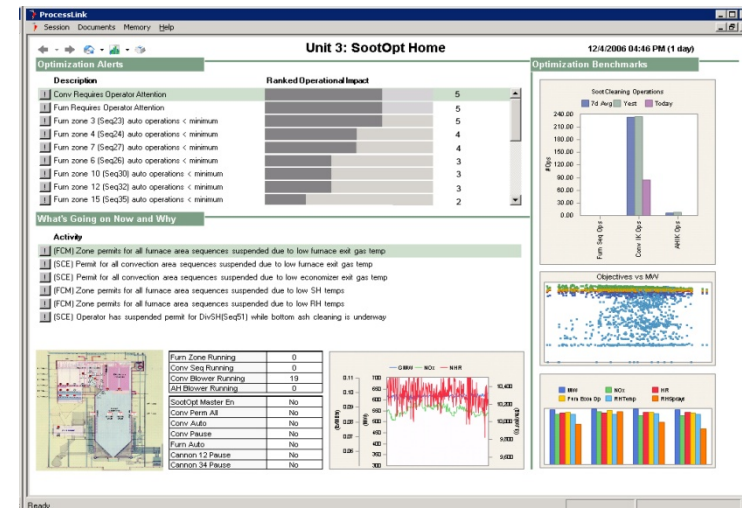
CombustionOpt Analysis





SootOpt Overview

- ◆ Context:
 - Sootblowing controls rely on interval-based or operator-initiated cleaning actions, or when using intelligent sootblowing systems, rely on zone cleanliness set points, ignoring the fact that optimal heat transfer requires varying cleanliness over time and across zones
- ◆ What SootOpt Does:
 - Provides real-time closed-loop optimization of unit performance by manipulating all relevant sootblowing controls
- ◆ Using:
 - Expert systems, neural networks and model predictive control
- ◆ To Achieve:
 - Reliability, heat rate, steam temp and emissions improvements



Unit 3: SootOpt Home

12/4/2006 04:46 PM (1 day)

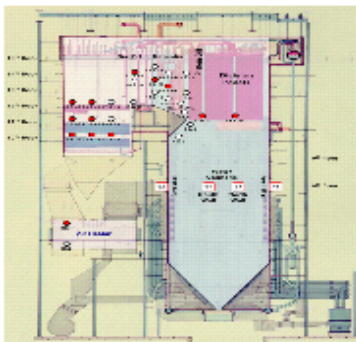
Optimization Alerts

Description	Ranked Operational Impact	
! Conv Requires Operator Attention		5
! Furn Requires Operator Attention		5
! Furn zone 3 (Seq23) auto operations < minimum		5
! Furn zone 4 (Seq24) auto operations < minimum		4
! Furn zone 7 (Seq27) auto operations < minimum		4
! Furn zone 6 (Seq26) auto operations < minimum		3
! Furn zone 10 (Seq30) auto operations < minimum		3
! Furn zone 12 (Seq32) auto operations < minimum		3
! Furn zone 15 (Seq35) auto operations < minimum		2

What's Going on Now and Why

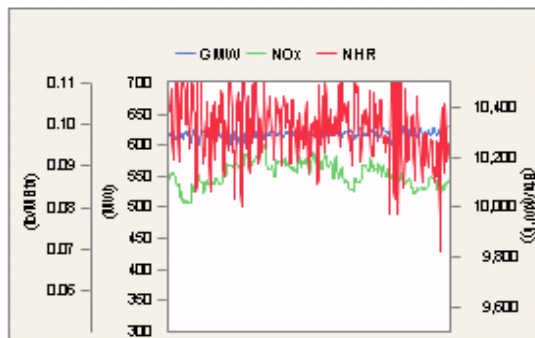
Activity

- ! (FCM) Zone permits for all furnace area sequences suspended due to low furnace exit gas temp
- ! (SCE) Permit for all convection area sequences suspended due to low furnace exit gas temp
- ! (SCE) Permit for all convection area sequences suspended due to low economizer exit gas temp
- ! (FCM) Zone permits for all furnace area sequences suspended due to low SH temps
- ! (FCM) Zone permits for all furnace area sequences suspended due to low RH temps
- ! (SCE) Operator has suspended permit for DivSH(Seq51) while bottom ash cleaning is underway

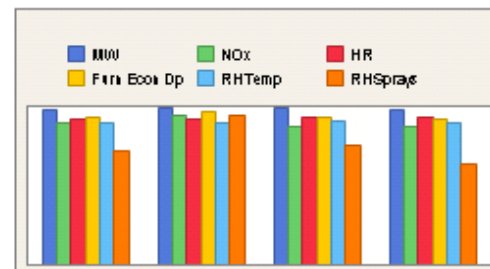
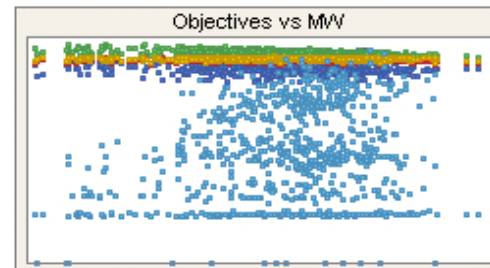
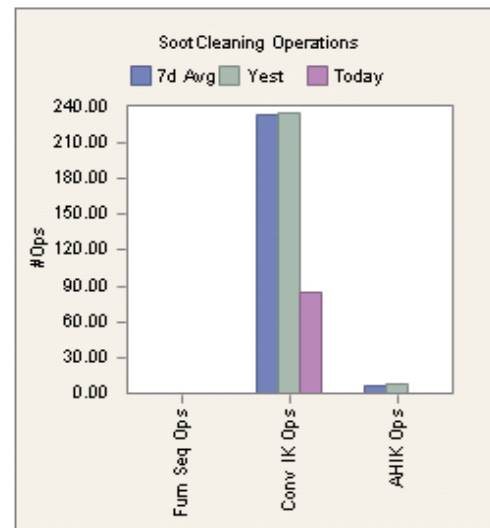


Furn Zone Running	0
Conv Seq Running	0
Conv Blower Running	19
AH Blower Running	0

SootOpt Master En	No
Conv Perm All	No
Conv Auto	No
Conv Pause	No
Furn Auto	No
Cannon 12 Pause	No
Cannon 34 Pause	No



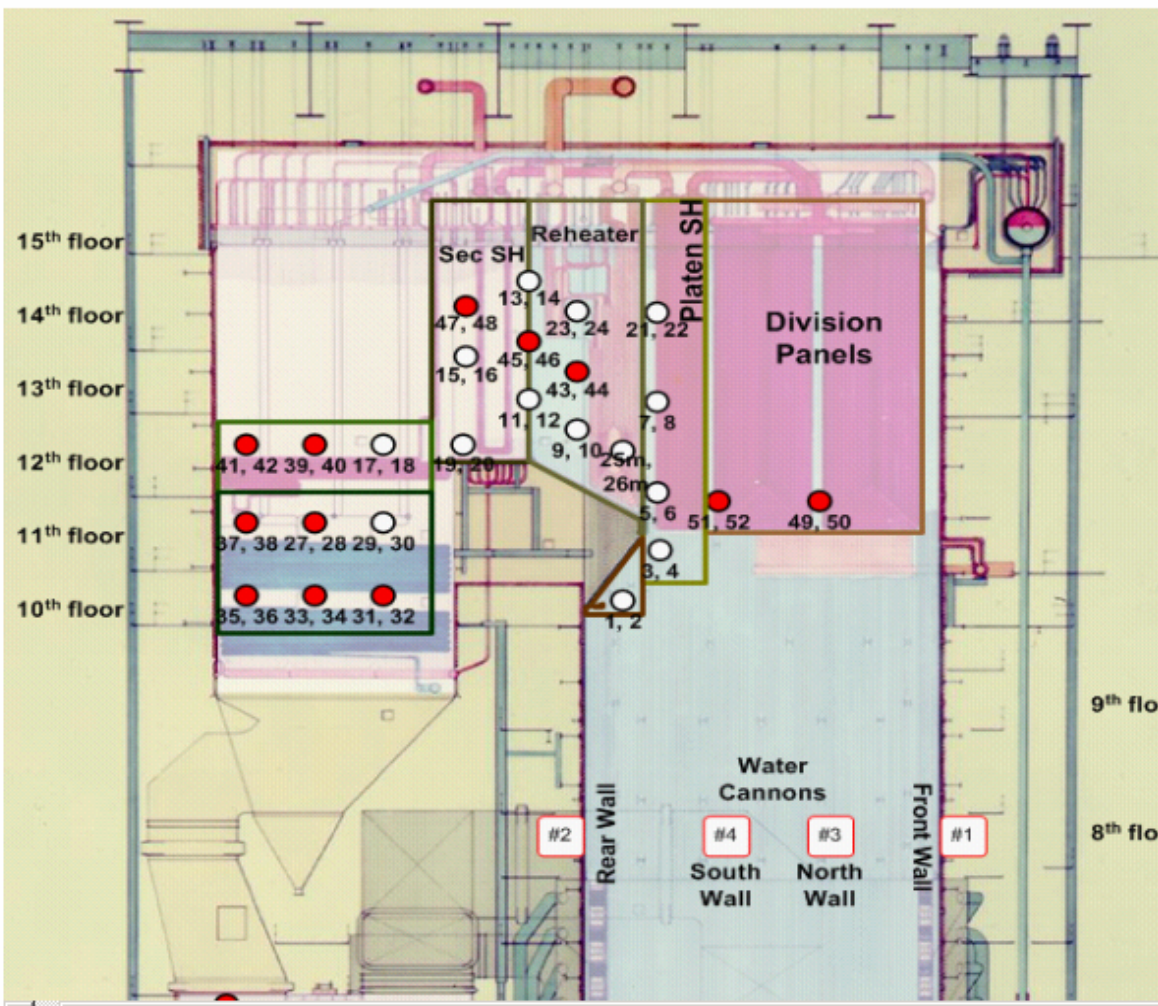
Optimization Benchmarks



Unit 3: SootOpt Analysis

- Standard
- Demystifier
- Trend
- Model
- Scatter
- Surface
- Sensitivity
- Std Error
- Custom

- Activity/Status
- Zone States
- Boiler Map**



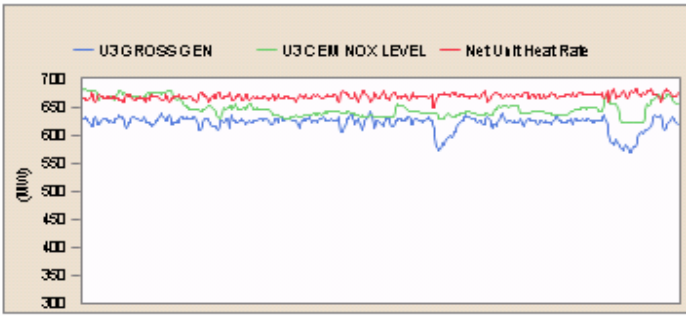
Zones	IKs
Nose Arch	1, 2
Division Panels	49, 50, 51, 52
Platen SH	3, 4, 5, 6, 7, 8, 21, 22
Reheater	9, 10, 11, 12, 13, 14, 23, 24, 43, 44, 45, 46
Secondary SH	15, 16, 19, 20, 47, 48
Primary SH	17, 18, 39, 40, 41, 42
Economizer	27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38

Unit 3: SootOpt Analysis

Standard Demystifier Trend Model Scatter Surface Sensitivity Std Error Custom

Activity/Status Zone States Boiler Map

Gross MW	620.12 MW
Net MW	592.35 MW
Opacity	16.46 %
Furnace to RH dP	0.41 inH2O
Furnace to Econ dP	6.2 inH2O
SH Temp	966.88 degF
RH Temp North	956.66 degF
RH Temp South	972.48 degF
SH Spray Flow	30 klb/h
RH Spray Flow	0 klb/h
Avg Furn Flux	40.65 f

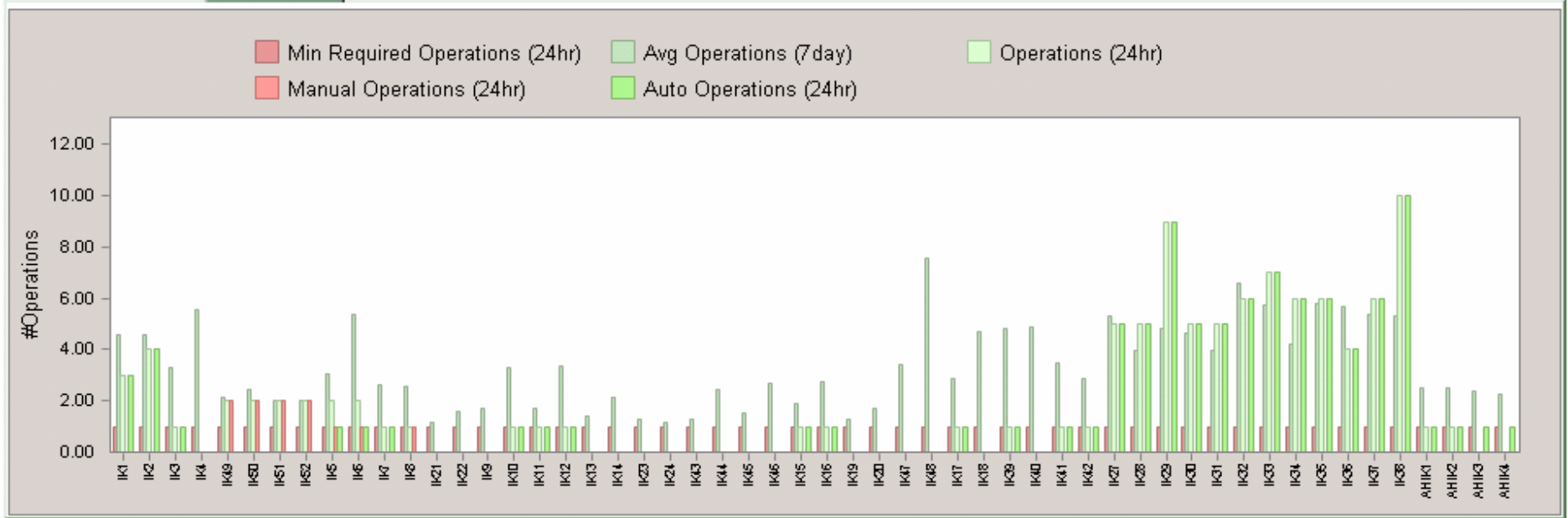


	7dAvg	Yest	Today
Seq Ops	93.96	56	43
Conv/AH Seq Ops	39.55	16	16
Furn Seq Ops	41.49	29	18
Conv IK Ops	170.54	131	83
AHIKOps	9.24	8	6

Furn Zone Running	5
Conv Seq Running	0
Conv Blower Running	0
AH Blower Running	0

SootOpt Master En	Yes
Conv Perm All	Yes
Conv Auto	Yes
Conv Pause	No
Furn Auto	Yes
Canon 12 Pause	No
Canon 34 Pause	No

Sequence Operations **IK Operations** Convection Details Furnace Details





Unit 3: SootOpt Analysis

1 day



Standard Demystifier Trend Model Scatter Surface Sensitivity Std Error

Visibility into Heuristics

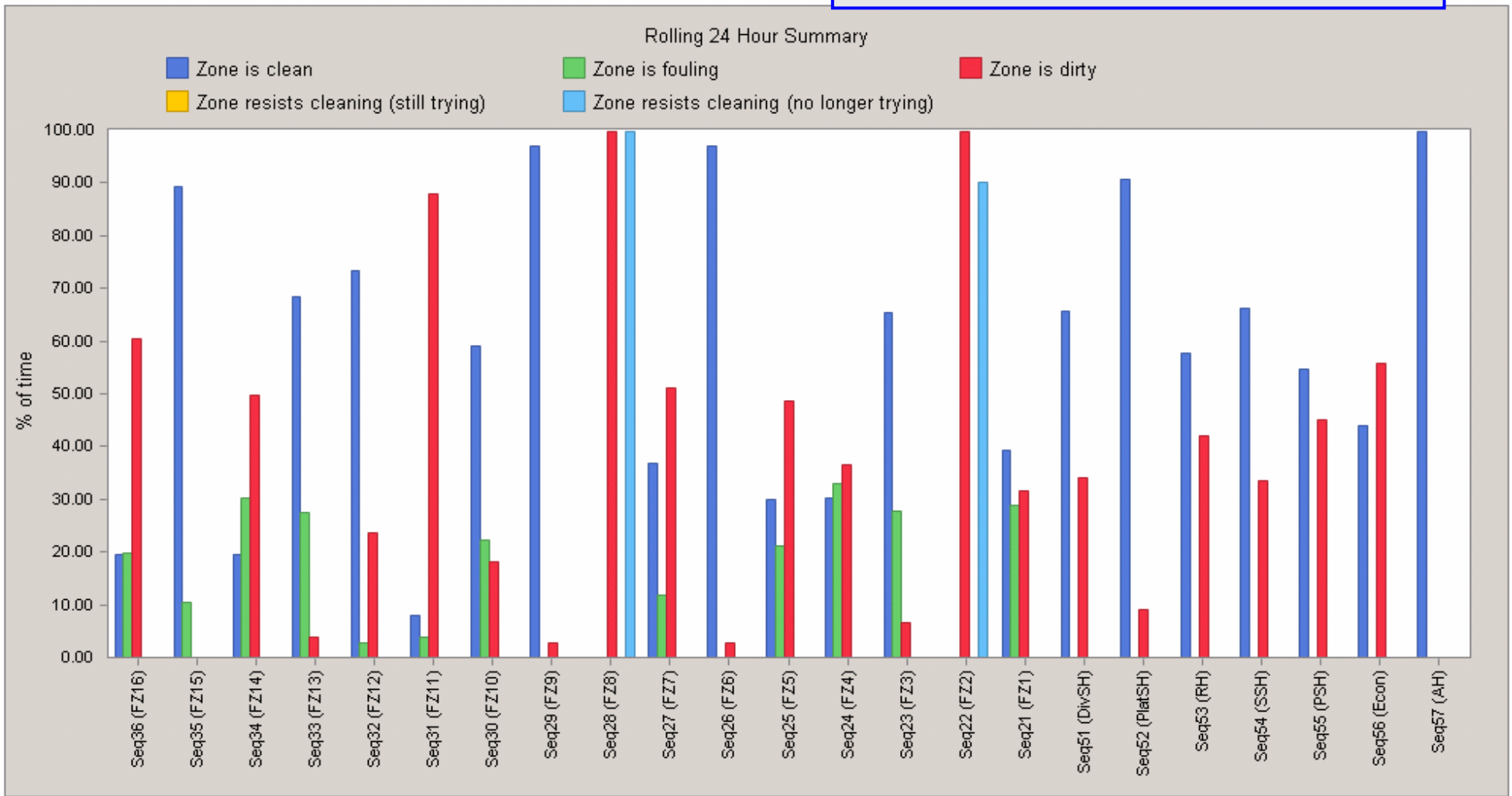
	Sys	Enabled	Active	Min	Actual	Max	Unit
Pause all convection sequences, FEGT violation	SCE	Yes	No	1,900	1,993.1		degF
Pause all convection sequences, load violation	SCE	Yes	No	400	633.8		MW
Pause all convection sequences, EEGT violation	SCE	Yes	No	600	693		degF
Pause all convection sequences, tilts violation	SCE	Yes	No		-0.3	5	%
Pause RH(53), RH spray violation	SCE	Yes	No		23.6	75	klb/h
Pause DivSH(51) and PlatSH(52), RH temp violation	SCE	Yes	No	975	995		degF
Pause Nose(58), RH(53) SH outlet temp violation	SCE	Yes	No	990	990.2		degF
Pause all convection sequences but DivSH(51), DivSH running	SCE	Yes	Yes				
Operator has inhibited DivSH(51)	SCE	Yes	No				
Pause all furnace sequences, tilts violation	FCM	Yes	No		-0.3	5	%
Pause all furnace sequences, FEGT violation	FCM	Yes	No	1,900	1,993.1		degF
Pause all furnace sequences, load range violation	FCM	Yes	No	400	633.8		MW
Pause all furnace sequences, SH outlet temp violation	FCM	Yes	Yes	995	990.2		degF
Pause all furnace sequences, RH spray violation	FCM	Yes	No	5	23.6		klb/h
Pause all furnace sequences, RH outlet temp violation	FCM	Yes	No	975	995		degF
Inhibit convect zones, high opacity	SCE	No	No		19	100	percent
Inhibit convection zones from cleaning while clean	FCM	No	No				
Allow convection to clean while clean, high Dp	FCM	No	No		5.9	6	inH2O
Adjust convection uRatio biases, high Dp	FCM	No	No		5.9	7	inH2O
Request convection clean on time, high Dp	SootOpt	No	No		6	8	inH2O
Inhibit furnace zones from cleaning while clean	SootOpt	No	No				
Allow furnace zones to clean while clean, high RH sprays	SootOpt	No	No		23.6	40 klb/h	klb/h
Adjust furnace flux biases, high RH sprays	SootOpt	No	No		23.6	100	klb/h
Request furnace clean on time, high RH sprays	SootOpt	No	No		23.6	100	klb/h

Unit 3: SootOpt Analysis

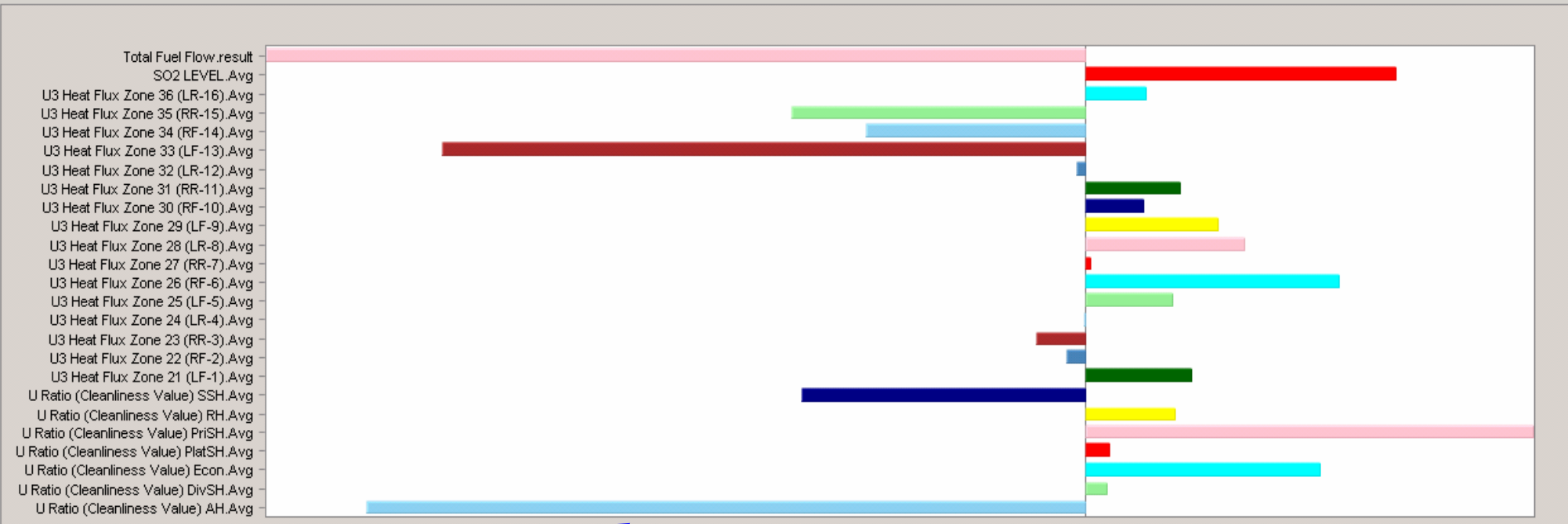
- Standard
- Demystifier
- Trend
- Model
- Scatter
- Surface
- Sensitivity
- Std Error
- Custom

SootOpt Analysis Tools

- Activity/Status
- Zone States
- Boiler Map

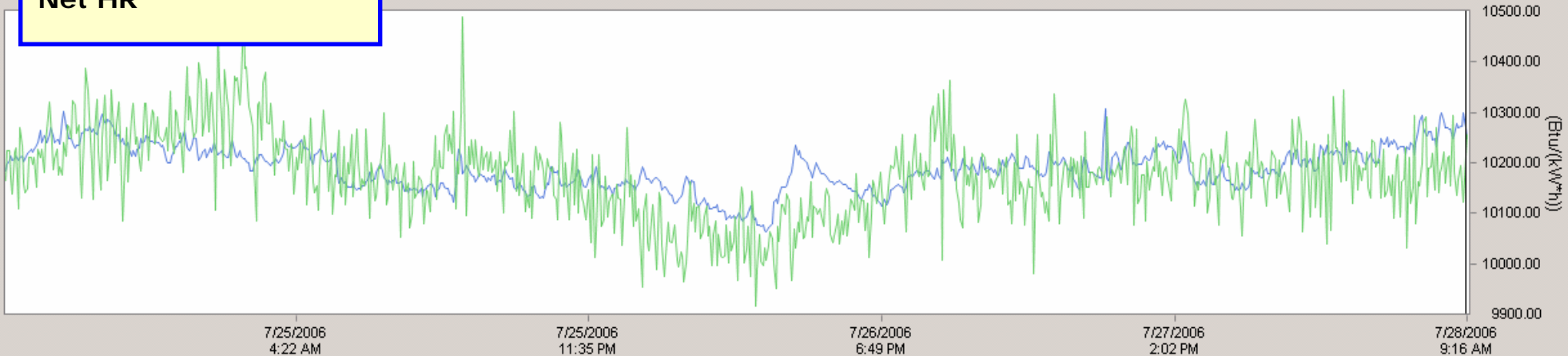


Modelled Function: Heat Rate All Inputs



**SootOpt Sensitivities:
Net HR**

— Heat Rate.OutputDef (10248.478) — Heat Rate.Corrected (10256.612)





Agenda

- ◆ Optimization Overview
- ◆ Components of Integrated Boiler Optimization
- ◆ **Boiler Optimization Project at Baldwin**

Dynegy's Baldwin Energy Complex



3 - 600 MW Units

1970-1975

Units 1 & 2 Cyclone Fired

14 Cyclones/Unit

Unit 3 Tangential-Fired

6 Mills

PRB Coal

Conversions

1999 & 2000





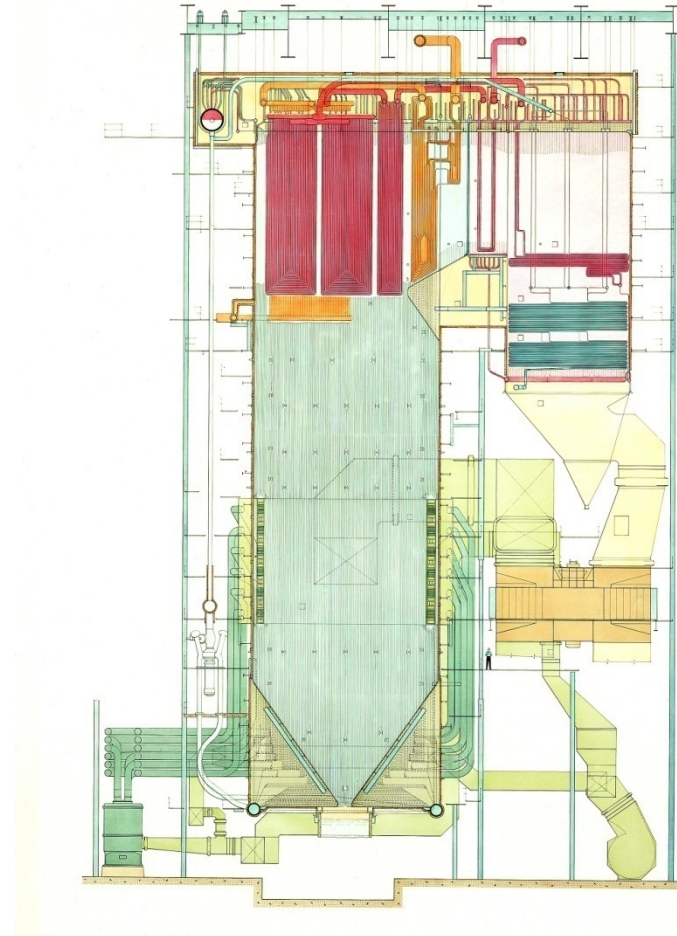
NeuCo's CCPI Project @ Baldwin

- ◆ About the Clean Coal Power Initiative (CCPI)
 - \$1.3 B initiative to demonstrate clean coal technologies in the field
 - Sponsored by DOE's National Energy Technology Laboratory
 - NeuCo's project at Baldwin selected as Round 1 winner in 2004
- ◆ Five integrated optimization modules, parallel development
 - SCR
 - **Combustion**
 - **Soot blowing**
 - Performance
 - Maintenance
- ◆ Products developed iteratively with multiple releases



Baldwin Unit 3

- ◆ CE Drum-type Boiler
- ◆ Pulverized T-Fired: Six Pulverizers
- ◆ Furnace Dimensions: 52' x 58', 180' tall
- ◆ SOFA, Low NO_x Burners
- ◆ Steam Conditions
 - Flow: 4.2 MLb/Hr
 - SH/ RH Temperature: 1005F/1005F
 - Throttle Pressure: 2425 Psig





Motivations for Optimization

- ◆ Full Load PRB operation requires tight control
 - Loss of spare mill at full capacity
 - Small process changes have significant effects
 - Seasonal impacts to heat rate

- ◆ Expectations
 - Ability to control key parameters on consistent basis
 - Ability to compensate for changes in coal quality
 - Improved understanding of available data and its use for improved operations
 - Ability to optimize controls to meet plant objectives



Initial CombustionOpt Benefits

- ◆ Reduction in NOx average and variability
 - BEC Unit 3 already one of the lowest NOx coal-fired units in North America
- ◆ Increased process knowledge
- ◆ Improved consistency across operators and shifts
- ◆ Empirical validation of boiler cleanliness interactions



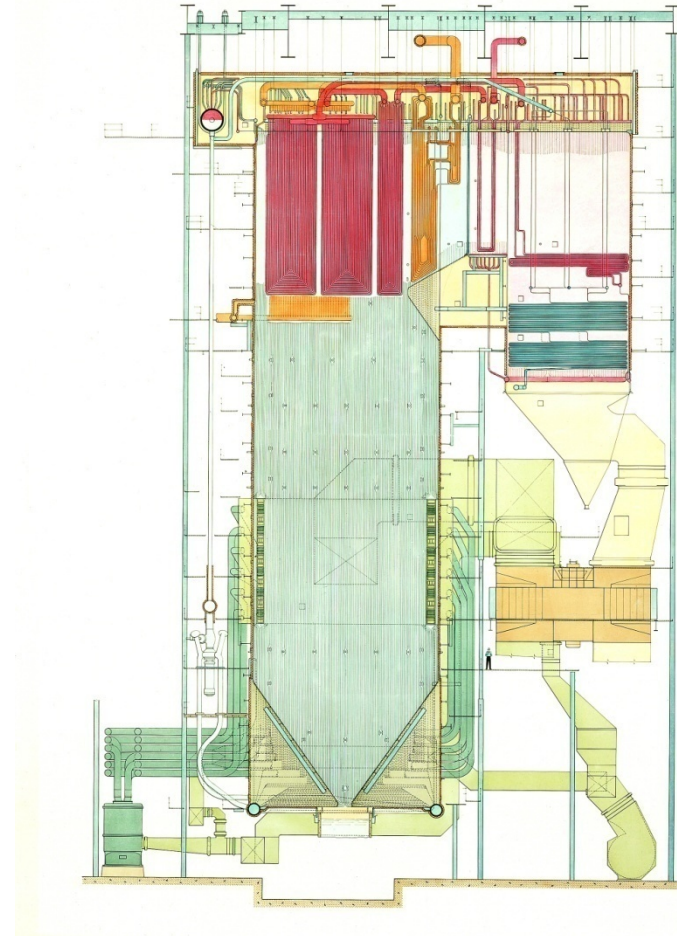
Unit 3 Sootblowing Operation prior to SootOpt

- ◆ High variability in PRB coal
- ◆ Water Cannons and Heat Flux Sensors in Furnace area
- ◆ PrecisionClean and standard IK's in convection pass
- ◆ Diamond (ASI) control system to operate water cannons & sootblowers
- ◆ Prevailing sootblowing guidelines:
 - Water cannons operator initiated when attemperation sprays high
 - Operator initiated sequences in the convection pass – normally a sequence of most IK's running continuously
 - Monitor furnace-to-economizer and furnace-to-reheater differential pressures; Increase sootblowing if differentials increase



Baldwin 3 – Ash Deposition

- ◆ PRB Coal
 - Intermittent Wall Deposition
 - Division Panels
 - SH Pendant
 - Horizontal SH



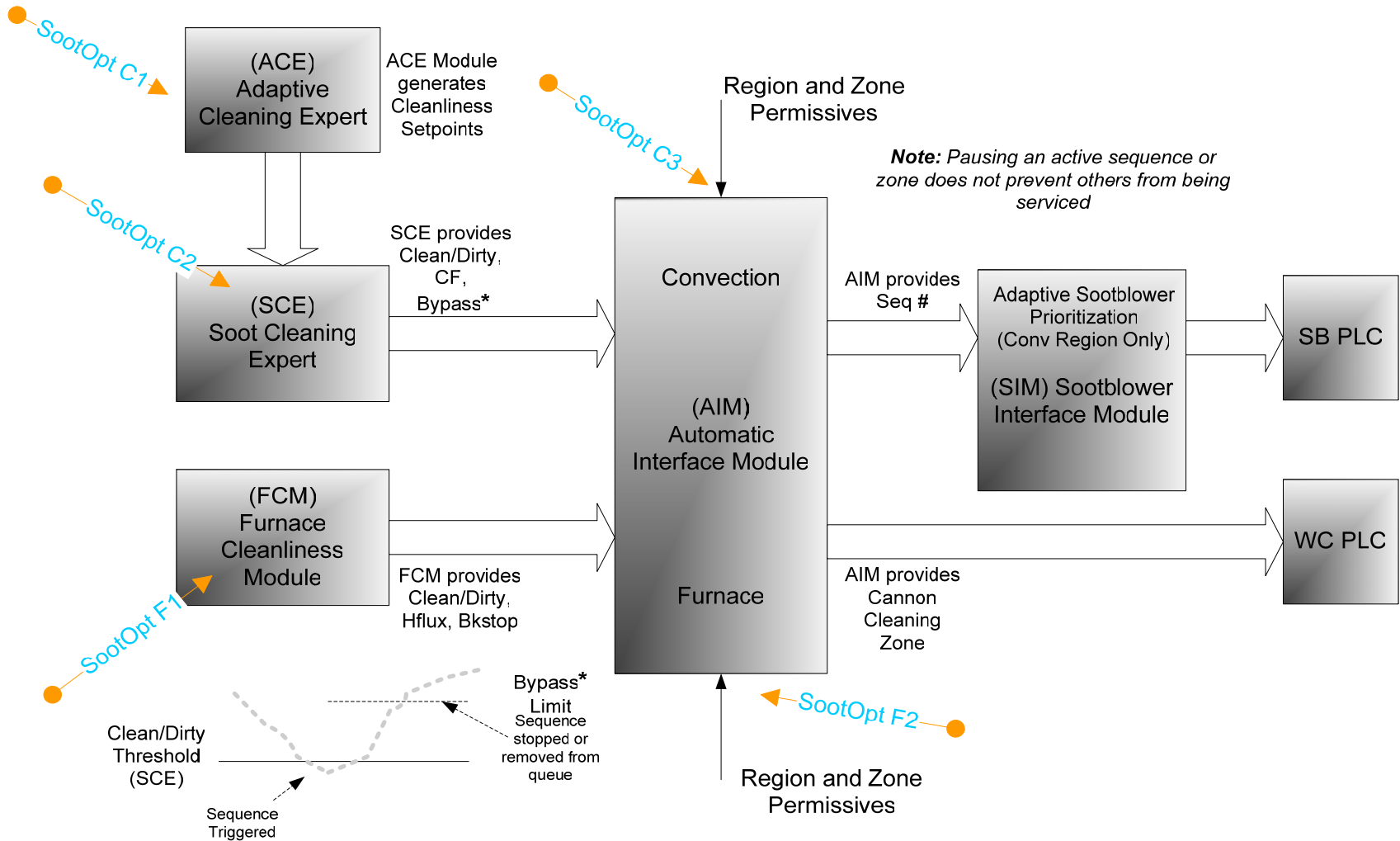


ISB & SootOpt installation @ Unit 3

- ◆ Upgraded sootblowing controls to Diamond SentrySeries 1500 Intelligent Sootblowing Control System (ISB)
- ◆ Added thermocouples and thermo-probe behind pendent reheater for heat transfer calculations
- ◆ Installed NeuCo's SootOpt for adaptive optimization of sootblowing operation
- ◆ Integrated SootOpt with Diamond furnace (FCM), backpass (SCE) and Automatic Interface module (AIM)

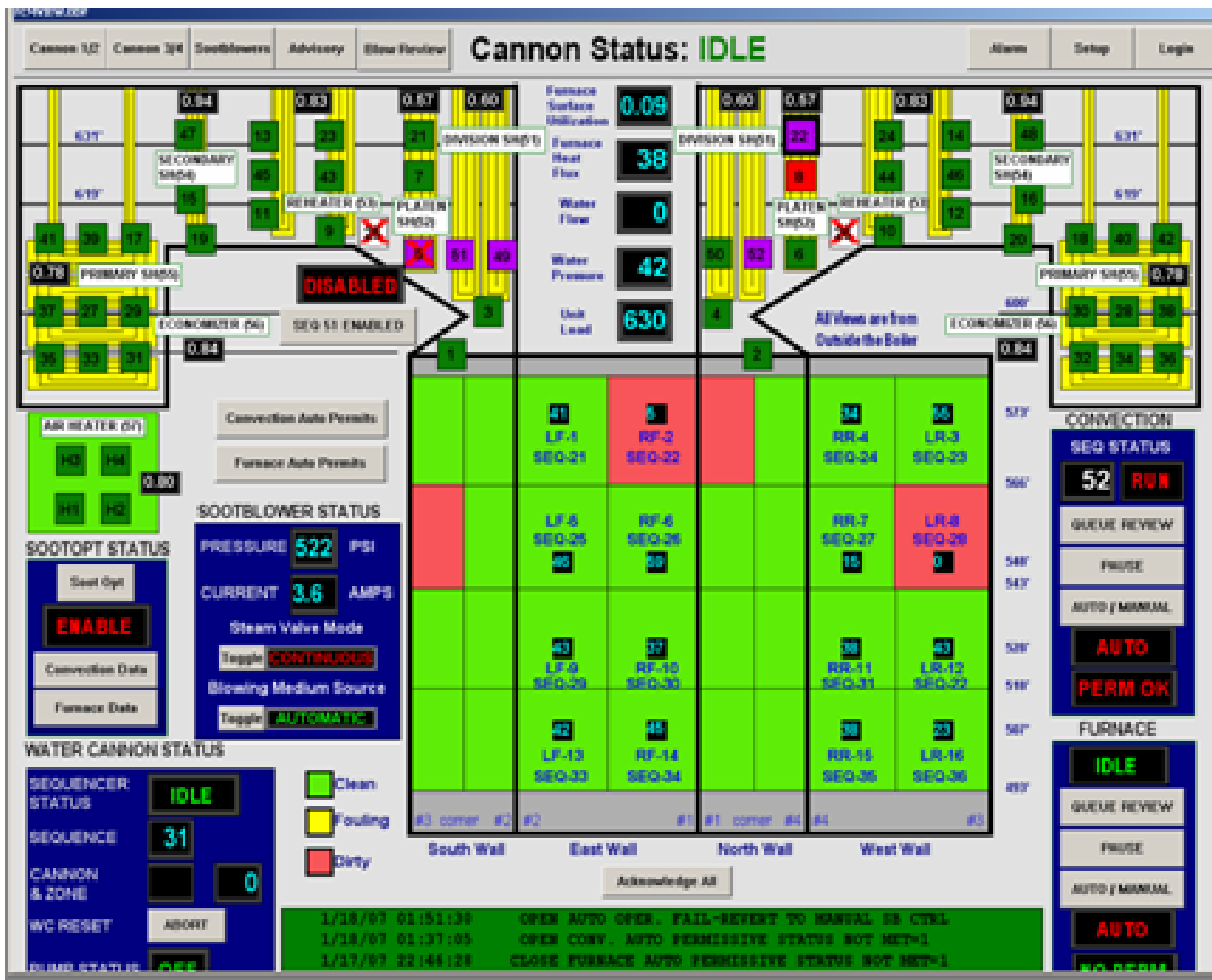


SootOpt - Diamond SentrySeries 1500 Interface



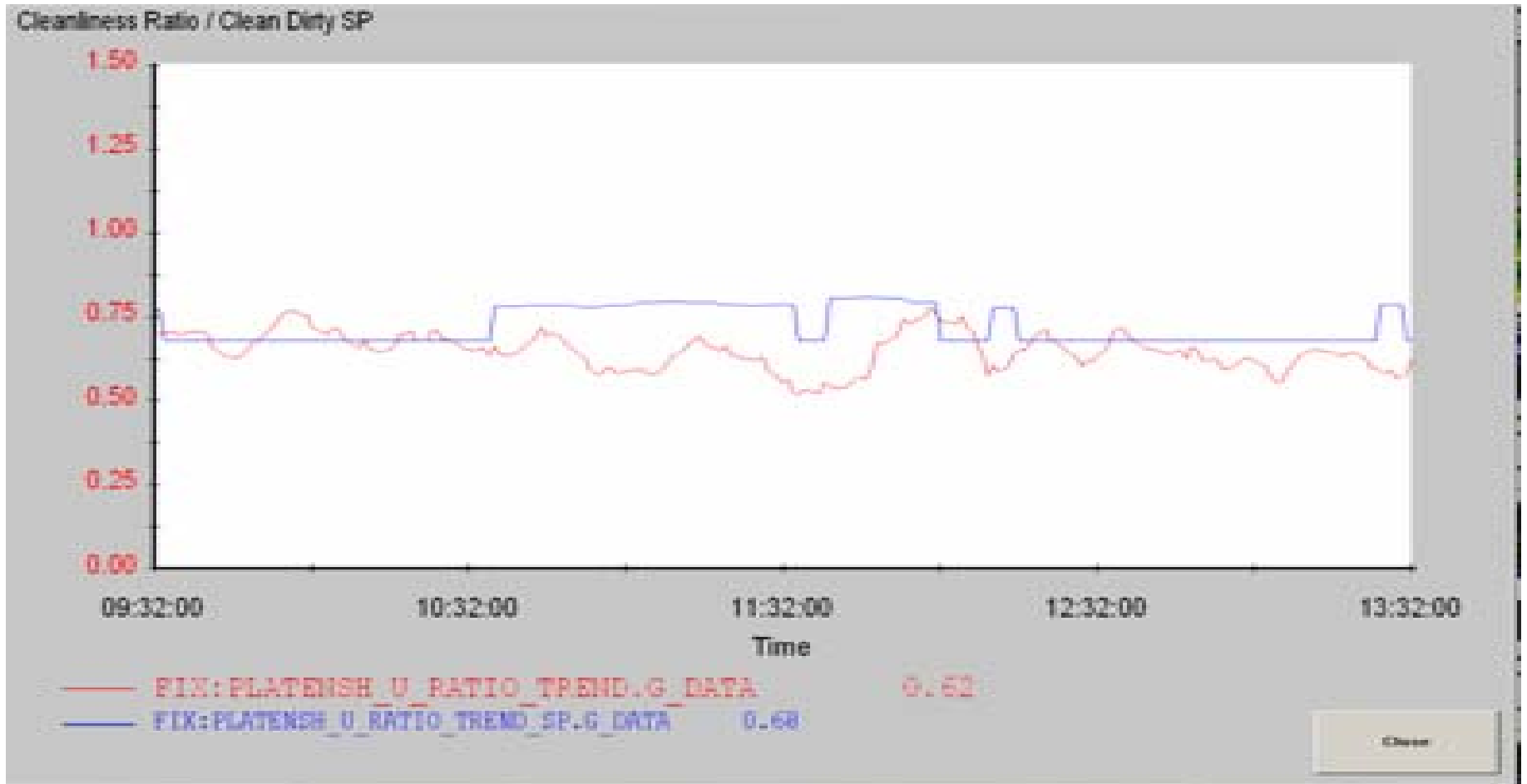


Diamond Intelligent Sootblowing System

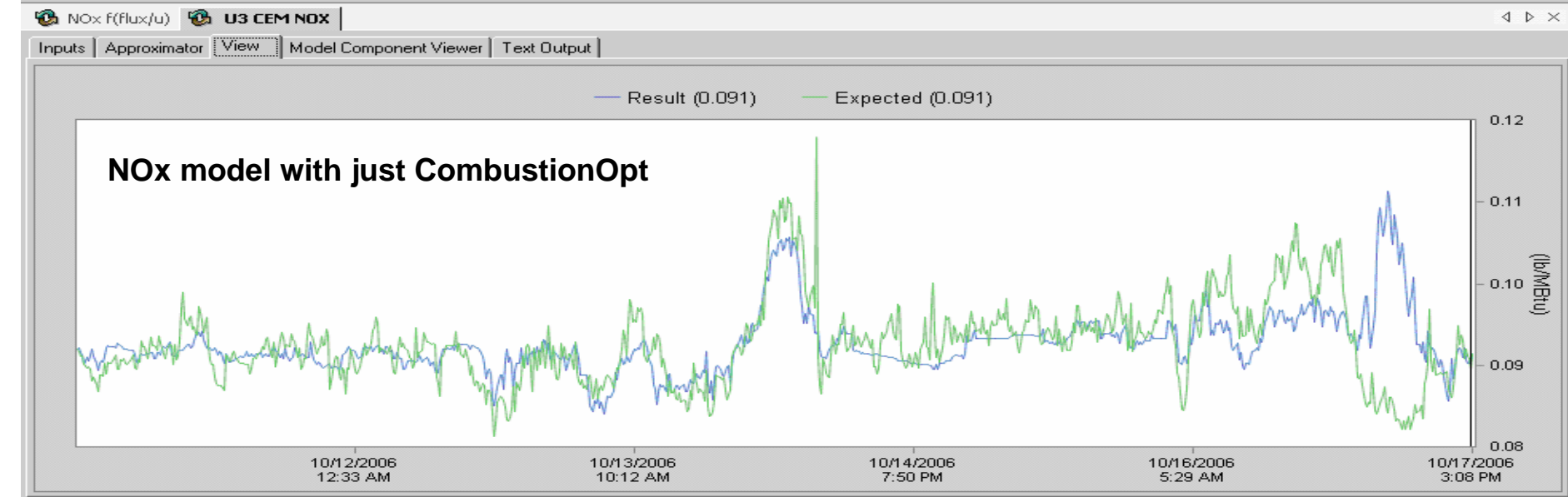
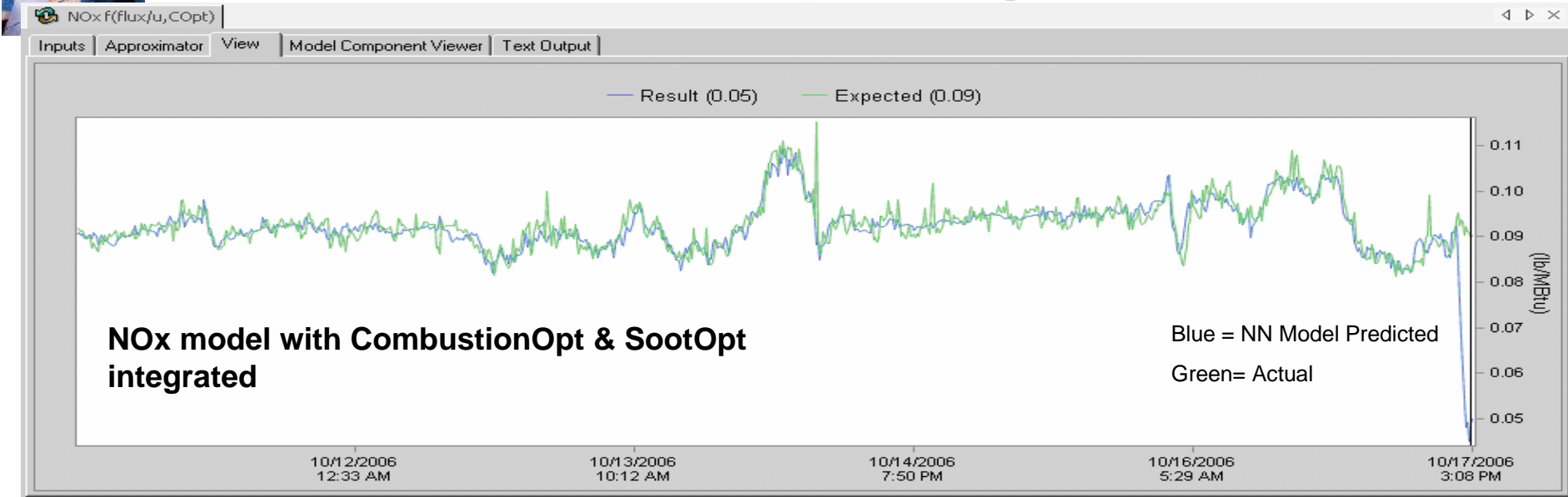




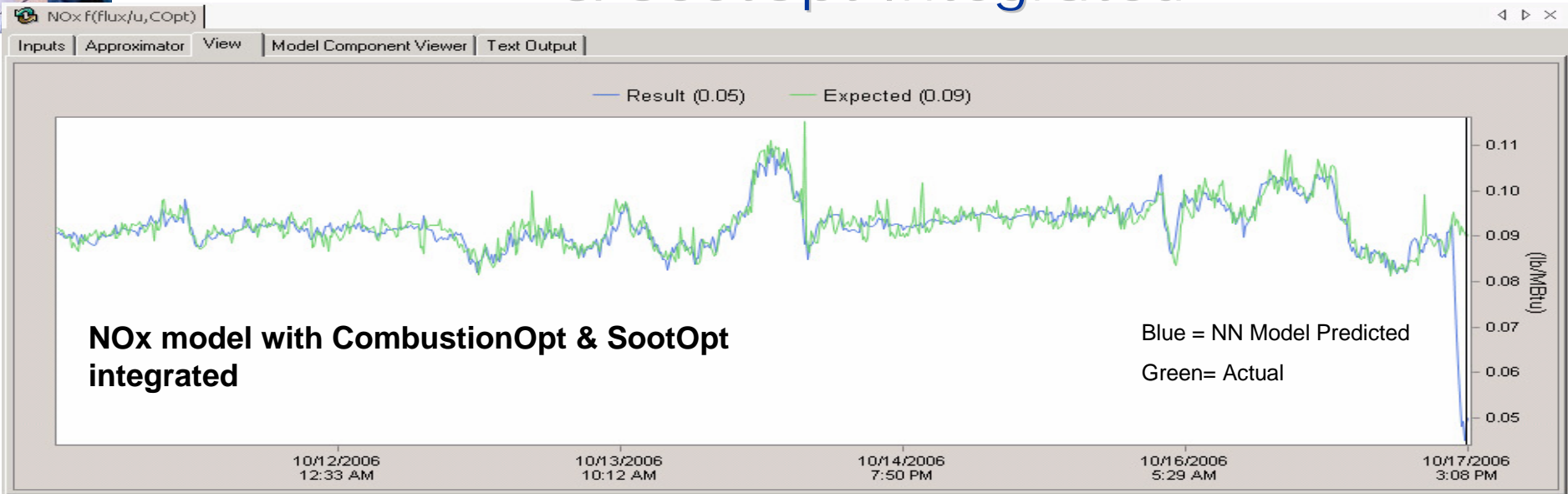
SootOpt/ISB Interaction



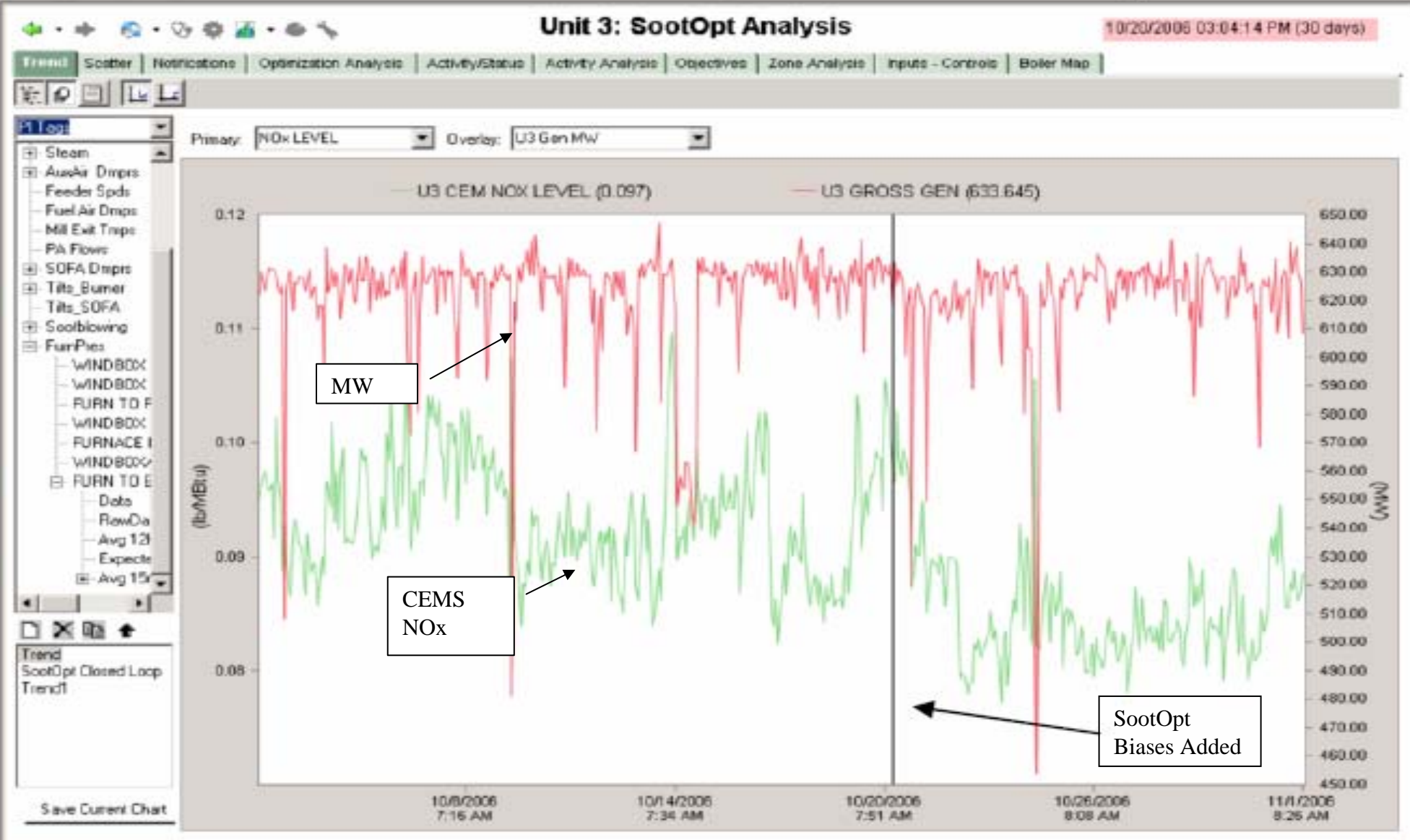
Improved Model Fidelity with CombustionOpt & SootOpt Integrated



Improved Model Fidelity with CombustionOpt & SootOpt Integrated



1 Year of Data (MW, NOx, SootOpt Biases)



CombustionOpt Impact on NOx

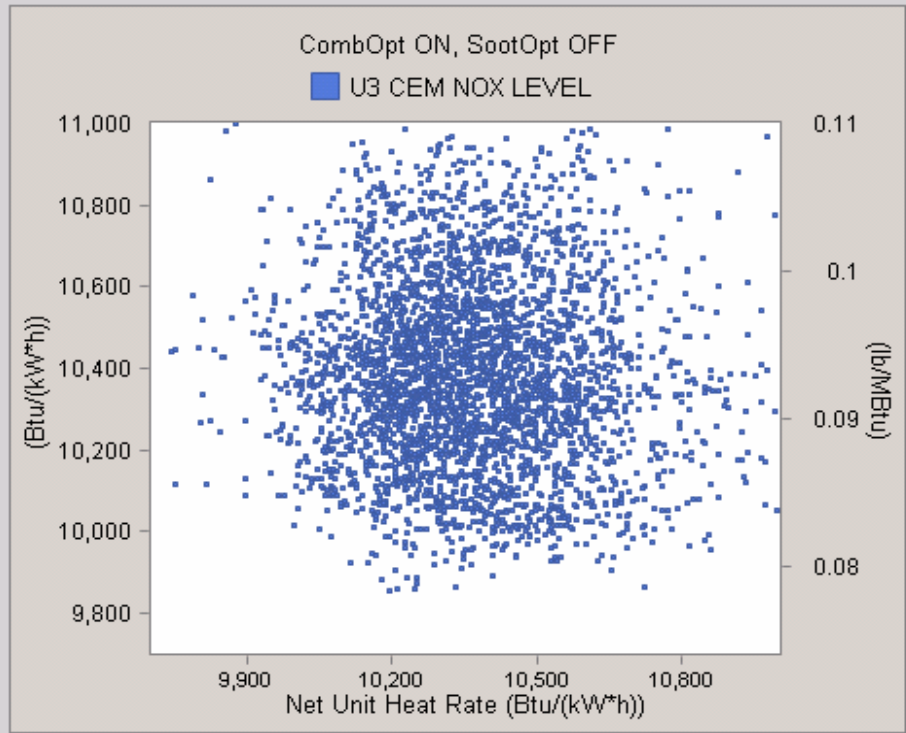
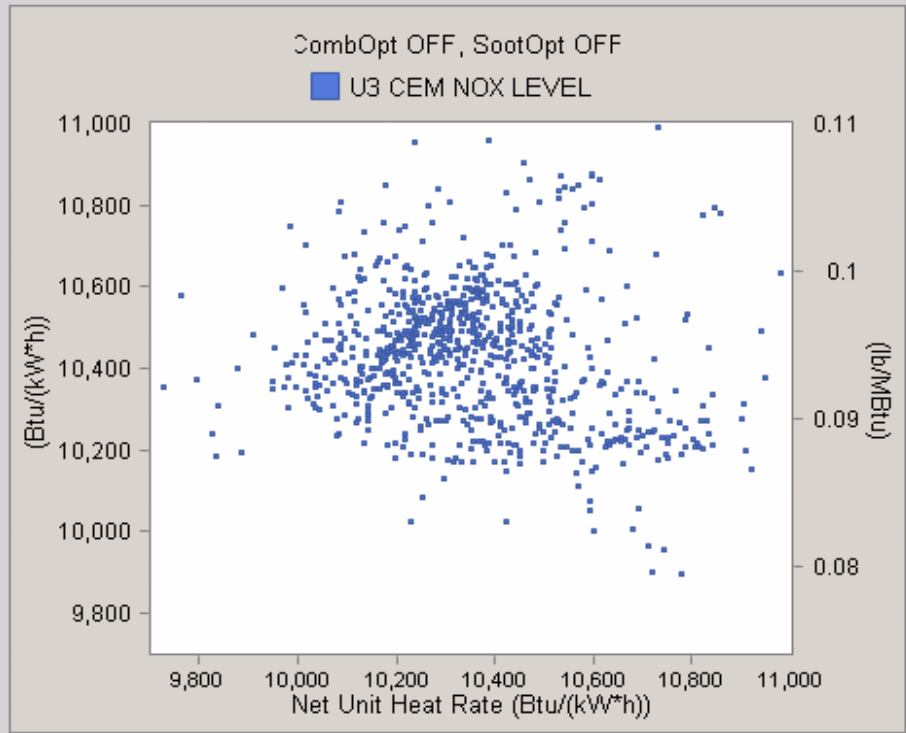
Standard ON/OFF Demystifier Trend Mo

Scatter Plots (30days)

Comb OFF, Soot OFF Comb ON, Soot ON Comb OFF, Soot ON **Comb ON, Soot OFF**

X-Axis: Net Unit Heat Rate

X-Axis: Net Unit Heat Rate



Reduced average NOx to ~ 0.09 & found lower NOx envelope

Unit 3

Combined Impact on NOx

Standard ON.OFF Denystifier Trend Model Scatter Surface Sensivity 3D Plot Custom

Scatter Plots (30days)

Comb OFF, Soot OFF

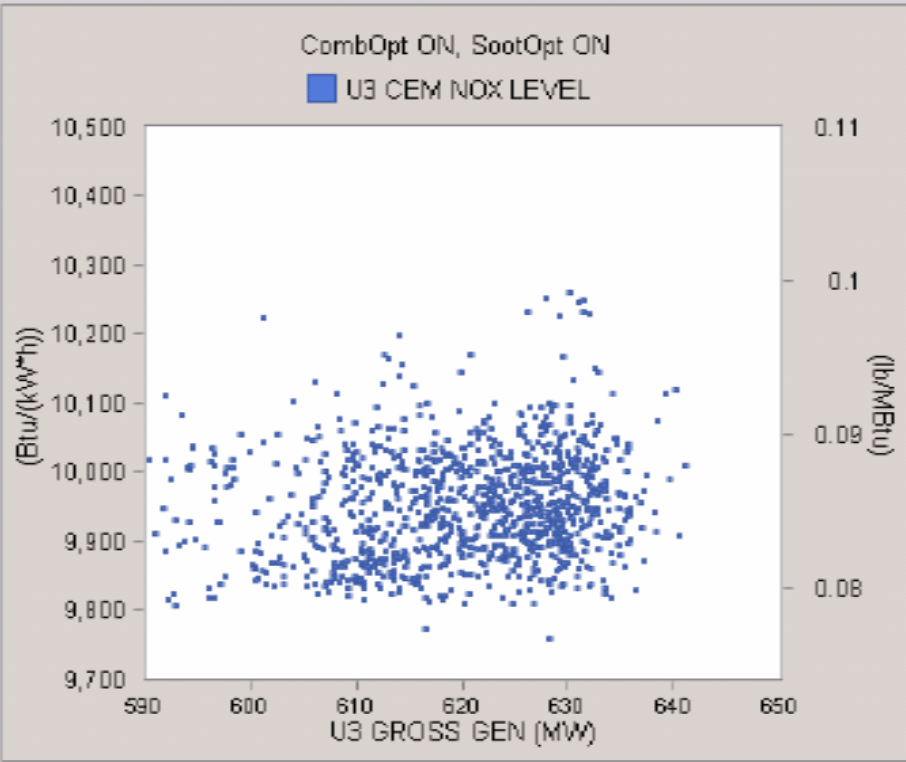
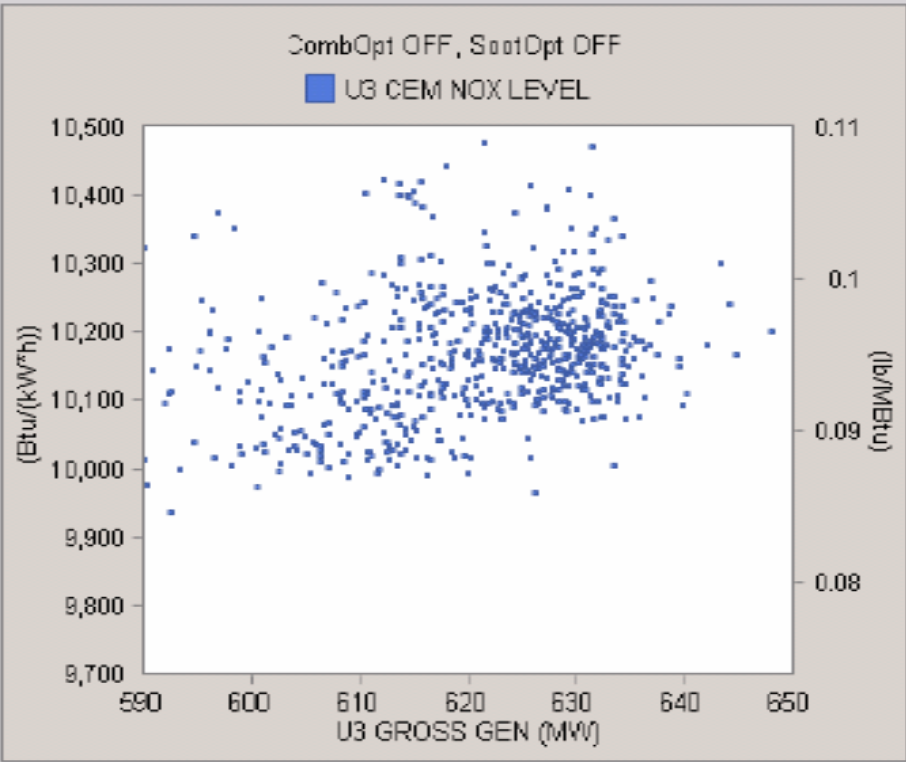
Comb ON, Soot ON

Comb OFF, Soot ON

Comb ON, Soot OFF

X-Axis: U3 GROSS GEN

X-Axis: U3 GROSS GEN



Significantly improved NOx reduction (0.085 range)

CombustionOpt Impact on Heat Rate

Standard

Scatter Plots (30days)

Comb OFF, Soot OFF

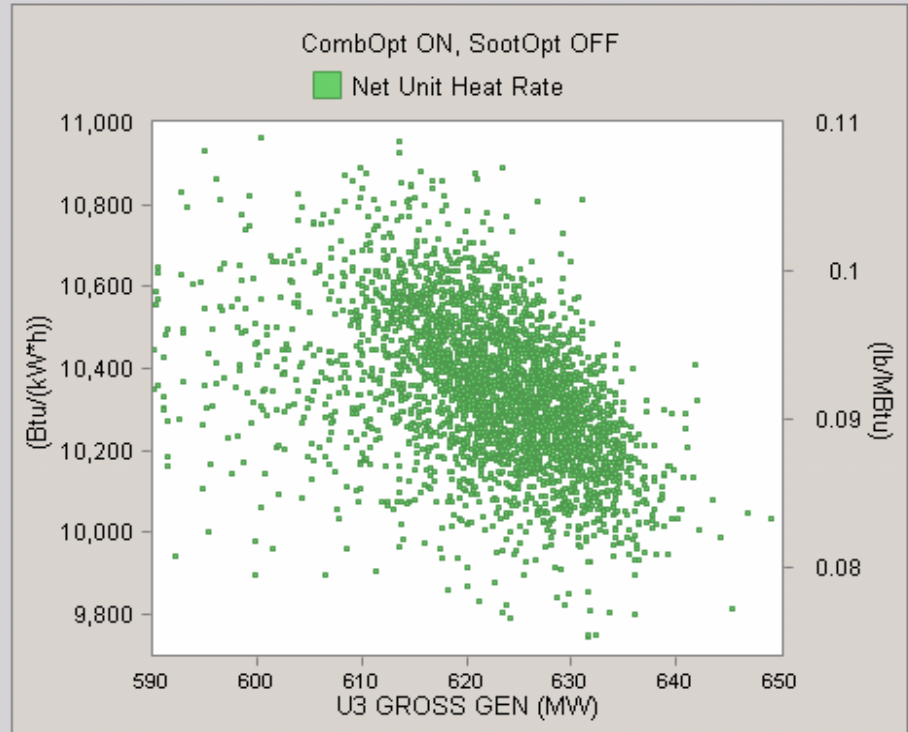
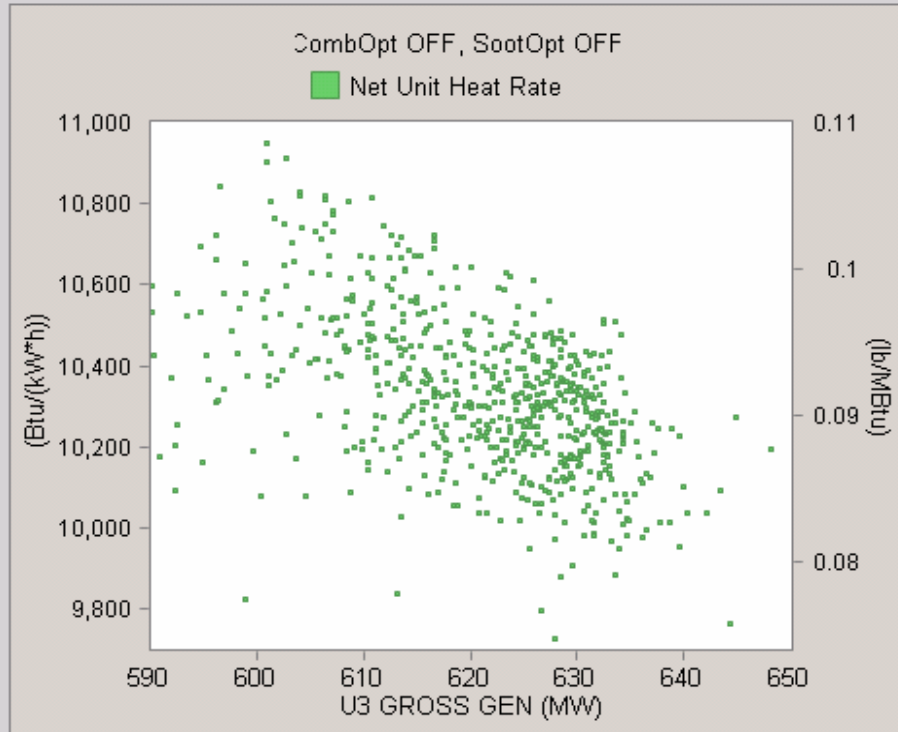
Comb ON, Soot ON

Comb OFF, Soot ON

Comb ON, Soot OFF

X-Axis: U3 GROSS GEN

X-Axis: U3 GROSS GEN



No significant impact on Heat Rate; trading off for NOx

Combined Impact on Unit Heat Rate

Standard ON/OFF Demys

Scatter Plots (30days)

Comb OFF, Soot OFF

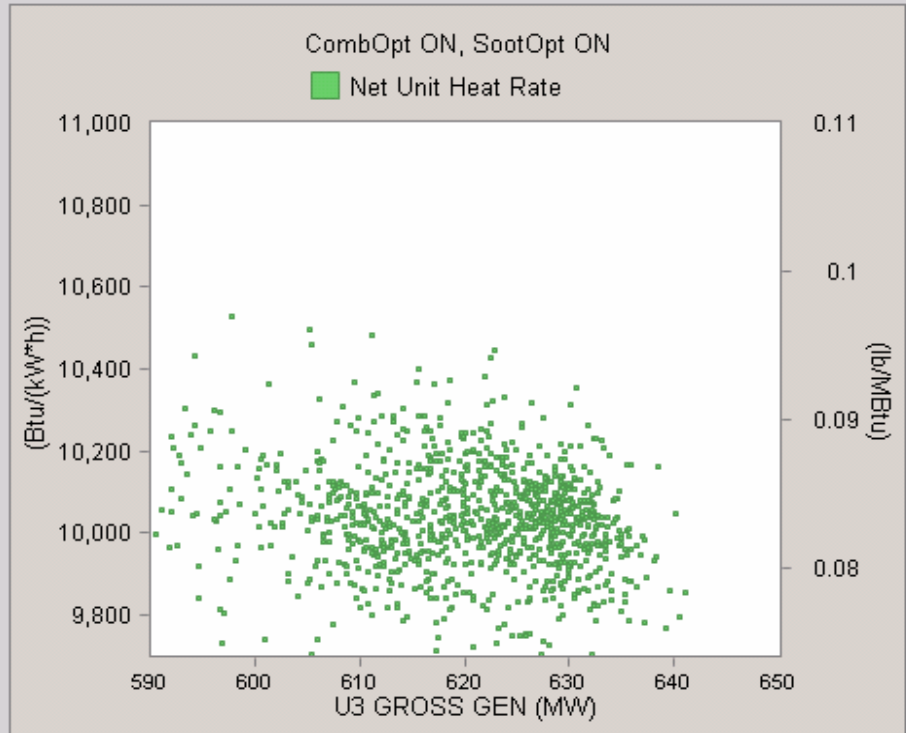
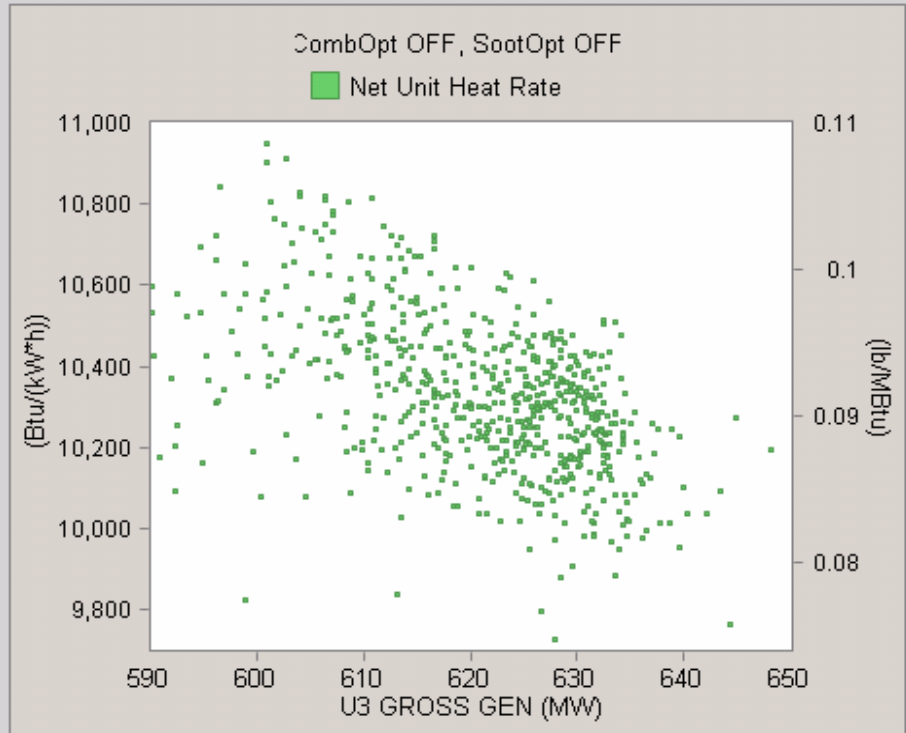
Comb ON, Soot ON

Comb OFF, Soot ON

Comb ON, Soot OFF

X-Axis: U3 GROSS GEN

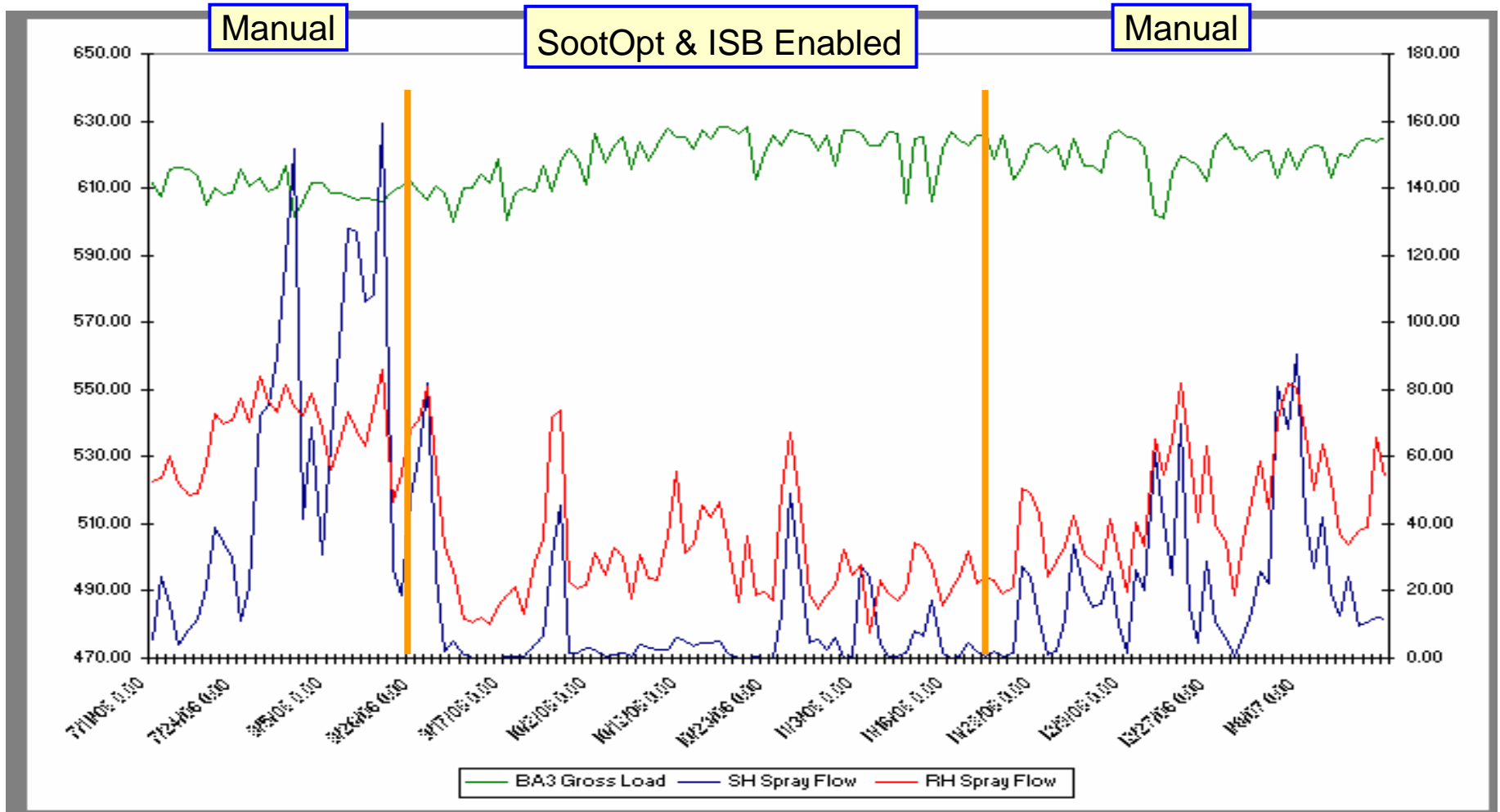
X-Axis: U3 GROSS GEN



Combined solution provided HR benefit while also lowering NOx



Average Daily Attenuation Spray Flows





IK Activity Manual vs ISB/SootOpt



SootOpt Helps Detect Underlying Problems:

Problems: Increased Pauses Due to FEGT < 1900 f.


Description	Ranked Operational Impact
Convection area no permit or not in auto	0.80
Some Econ IKs below min required ops	0.60
Some PlatSH IKs below min required ops	0.60
Some RH IKs below min required ops	0.60
Furn zone 2 (Seq22) auto operations < minimum	0.40
Furn zone 10 (Seq30) auto operations < minimum	0.40

Low freq of econ activity is a negative, result of heuristic in question.

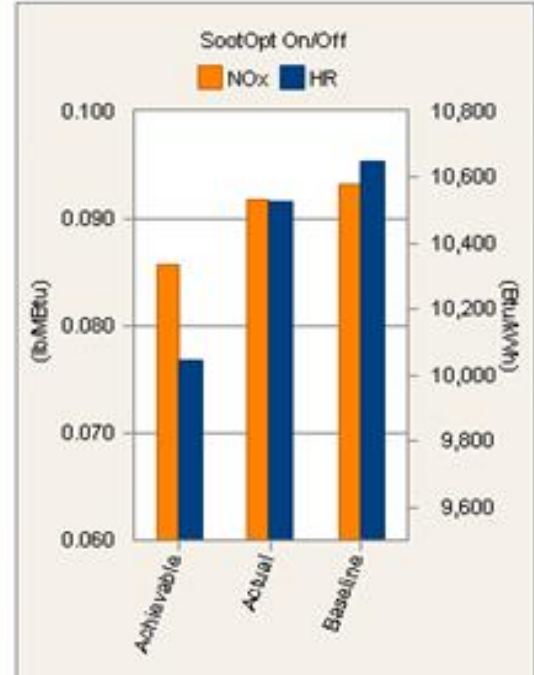
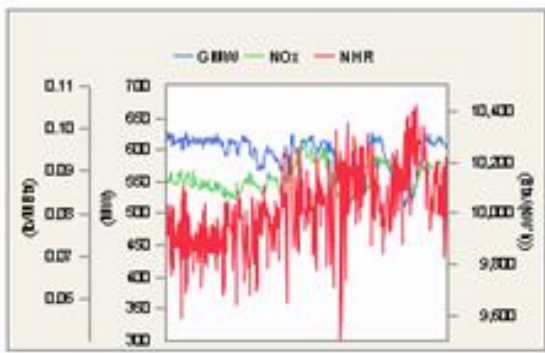
What's Going on Now and Why

Activity
(FCM) Zone permits for all furnace area sequences suspended due to low furnace exit gas temp
(SCE) Permit for all convection area sequences suspended due to low furnace exit gas temp
(SCE) Operator has suspended permit for DivSH(Seq51) while bottom ash cleaning is underway

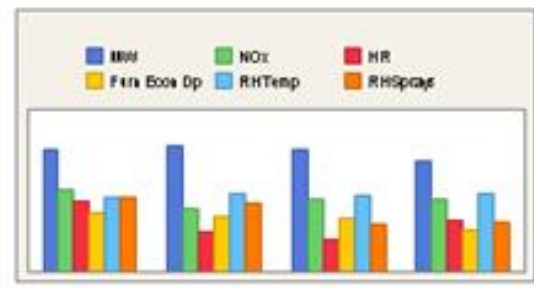
Heuristic is blocking convection area cleaning



Furn Zone Running	0
Conv Seq Running	56 (Econ)
Conv Blower Running	0
AH Blower Running	0
SootOpt Master En	Yes
Conv Perm All	No
Conv Auto	Yes
Conv Pause	No
Furn Auto	Yes
Cannon 12 Pause	No
Cannon 34 Pause	No



	Benefit	Missed
HR (Btu/MWh)	119	488
NOx (lb/Mbtu)	0.0015	0.0061





Boiler Optimization Results Thus Far

- Improved NOx and Heat Rate with decreased variability
- Decreased sootblower operation count
- Attemperation spray flows controlled to less than 50 klbhr with SootOpt/ISB whereas before spray flows would at times be above 100 klbhr
- Initially split in attemperation flow control caused steam temps drop to 950F which could effect MW output. Recent changes have reduced that drop to 980F
- Provided early detection into anomalies in ISB activity caused by instrumentation failure
- Improved transparency into complex behavior of ISB
- Real-time tradeoffs between objectives and performance benchmarking



Looking Ahead

- ◆ Complete Integration of CombustionOpt and SootOpt and at Unit 3
- ◆ Complete installation of SootOpt on Unit 2
- ◆ Integrate CombustionOpt, SCR-Opt, SootOpt, PerformanceOpt and MaintenanceOpt at Unit 2
- ◆ Further refine CombustionOpt, PerformanceOpt & MaintenanceOpt at Unit 1
- ◆ Further refine Unit and Plant Advisors
- ◆ Subsequent refinement and releases based on feedback from Baldwin and other NeuCo Showcase sites