GAS-SIDE OPTIMIZATION OF FOSSIL-FIRED POWER GENERATION

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MCILVAINE HOT TOPICS

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THE POWER INDUSTRY IS CHANGING

Generational Turnover in Equipment and Staff

30% of the electric utility workforce is projected to retire within the next 5 years

But large uncertainties in emissions regulation

Impact of Renewables & Changing Costs, Demand & Regulations

Renewable energy predicted to become the world's largest source of electricity within 15 years

Coal based power expected to contribute over 30% of the world's electricity through 2025 [1]

Variable fuel prices & quality affect operating margins

Units designed for baseload now cycling continuously

Growing pressure to reduce emissions affect operations

[1] U.S. Energy Information Association (EIA), 2016

[redacted]

MAJOR FOSSIL-STEAM-FIRED BOILER DESIGNS

- Pulverized Coal
  - Wall-fired
  - Tangentially Fired
  - Turbo
- Circulating Fluidized Bed (CFB)
  - Pressurized
  - Atmospheric
  - Bubbling
- Stoker
- Integrated Gasified Coal Combined Cycle

OPPORTUNITIES FOR EFFICIENCY & EMISSIONS PERFORMANCE

- Boiler
  - Thermal performance monitoring
  - Boiler tuning
  - Combustion optimization
  - Boiler cleanliness optimization
- Air Quality Control Systems (AQCS)
  - SCR tuning
  - SCR/SNCR optimization
  - FGD optimization
  - Hg optimization
- Turbine
  - Thermal performance monitoring
  - Sliding pressure throttle control
- Balance of Plant
  - Cooling tower, condenser, outlet water temperature, etc.

COAL QUALITY IS IMPORTANT

- Heat content, sulfur, hardness, grind-ability and other chemical constituents have big implication .

- Major classifications based on heat content: in descending order:
  - Anthracite
  - Bituminous
  - Subbituminous
  - Lignite
  - Peat
- Powder River Basin (PRB) coal in US a major emissions compliance strategy
- Boilers burning off-design fuels have challenges and opportunities
- Large wave of conversions from coal to natural gas in early phase
- Outcome will be affected by both regulation and natural gas proces

BOILER OPTIMIZATION

- Applies AI optimization in a real-time closed-loop application
  - ✓Integrates fuel / air and sootblowing management
  - ✓The same brain operates 24 X 7 X 365
  - ✓Integrates directly into plant control
  - ✓Provides analytics on premise and to remote users
  - ✓Deploys integrated optimization – MPC, neural networks, heuristics, first principals – to best address complex, real world problems in closed loop

TYPICAL BOILER OPTIMIZATION BENEFITS

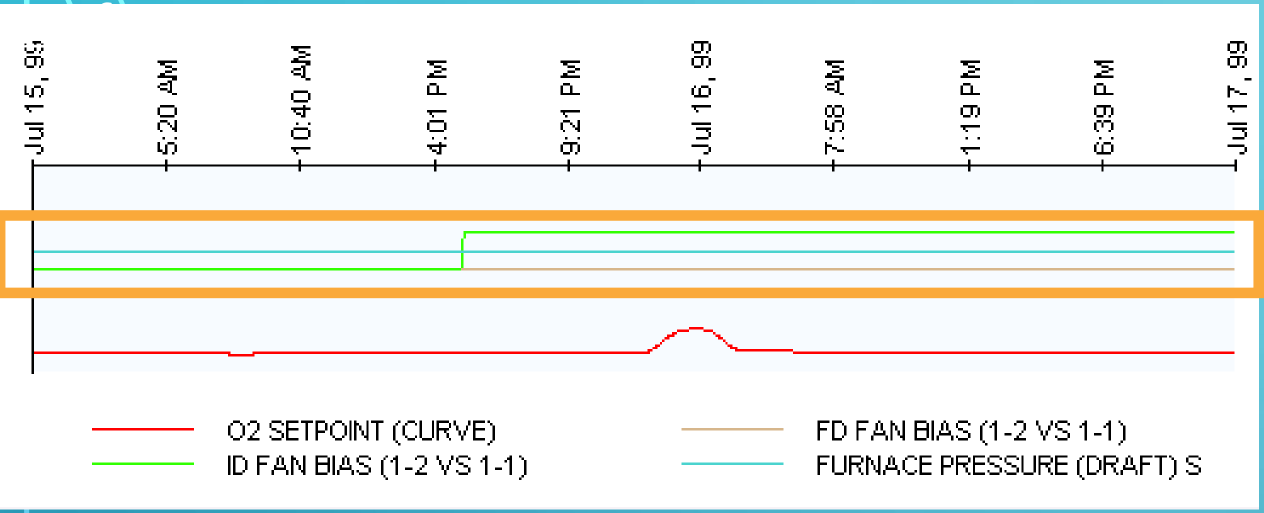
400 MW UNIT FIRING PRB W/80% CAPACITY FACTOR

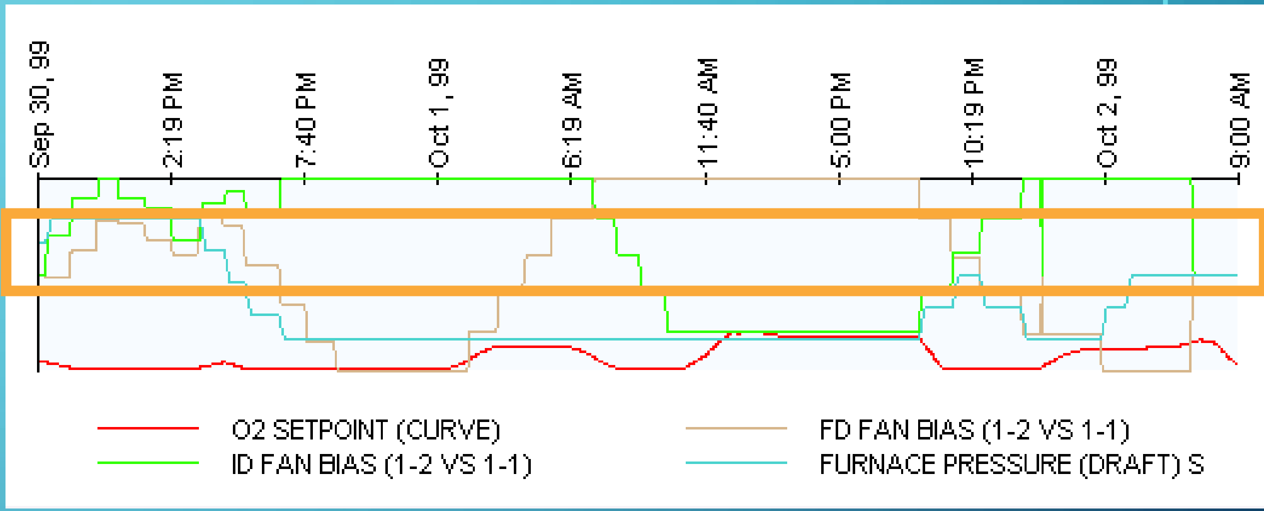
Benefit Type	**Plant Y Unit 1**
Availability (W/Avoided MATS Lost Revenue)	$811,286
Fuel Savings	$567,148
NOx Reduction Value	$26,254
Avoided MATS Inspection/Tuning/Testing Costs	$86,667
Total Availability, Fuel, Nox & MATS Benefits	***$1,491,355***
Potential CO2 Benefits	$357,500
Total Potential Benefits	***$1,848,855***

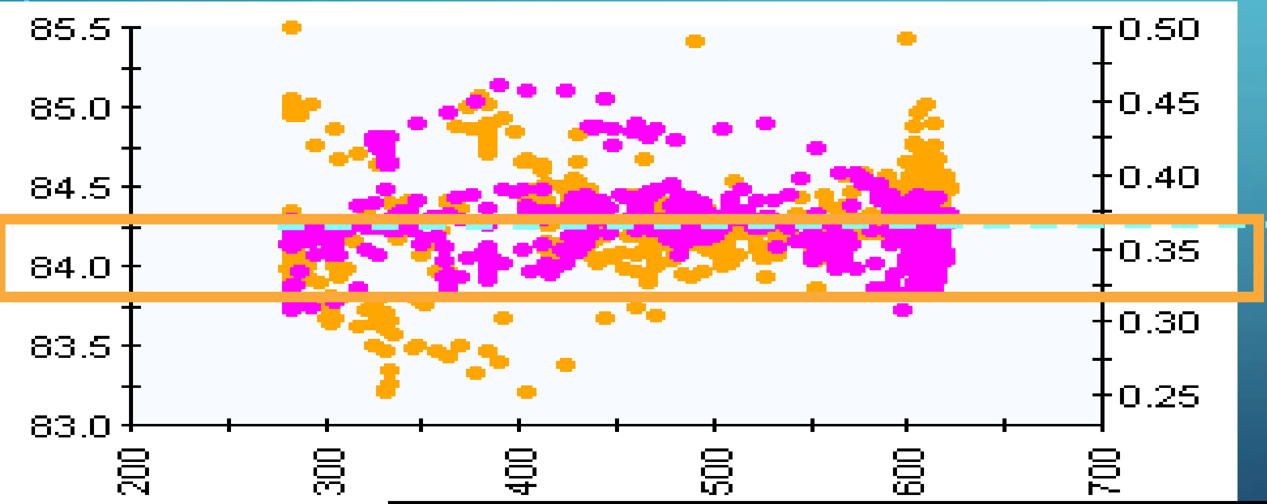
TYPICAL COMBUSTIONOPT BENEFITS

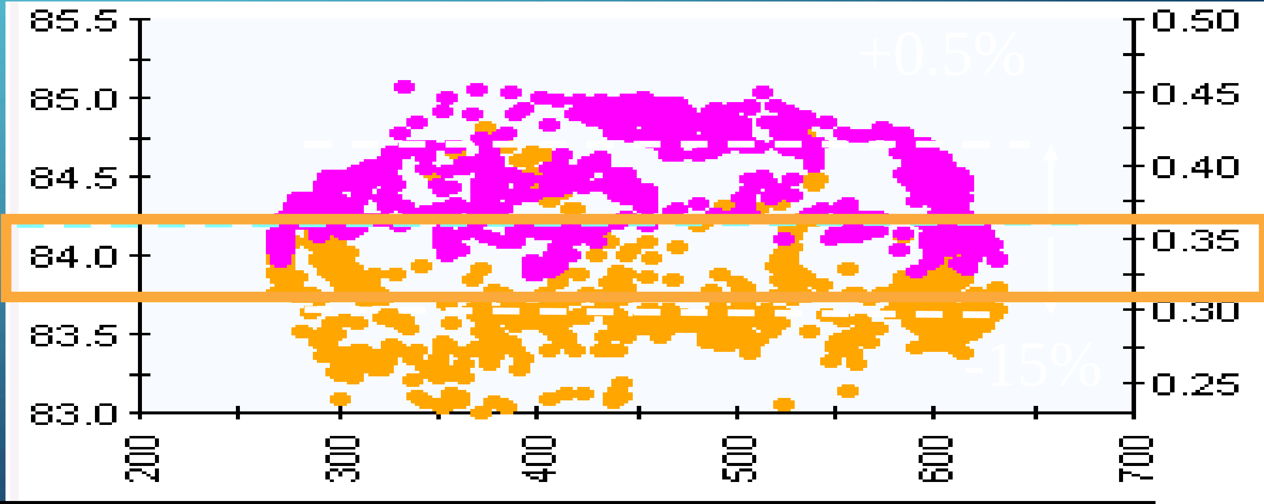
- NOx reductions of 10-15%
- Boiler efficiency increase of 0.5-0.75%
- CO controlled to desired limit
- Better ramping and load-following performance
- Reduced opacity excursions
- Avoided tail-chasing behavior
- Better adherence to fan and mill amp limits
- Improved situational awareness and process insight

IMPACT ON OPERATIONS & PERFORMANCE





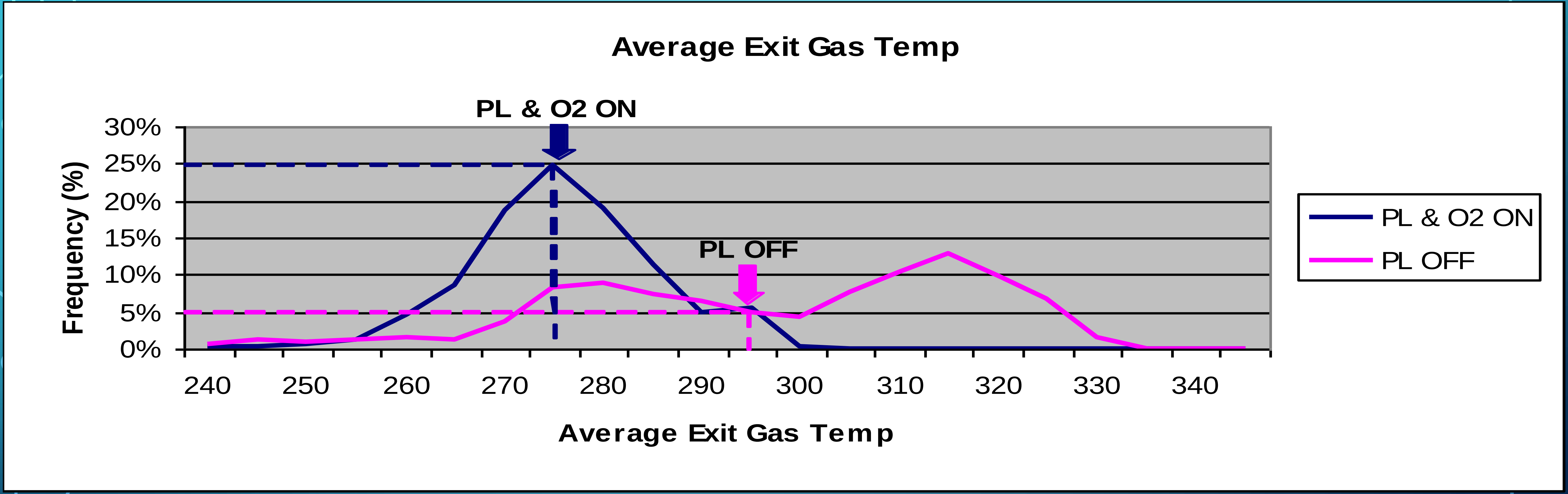




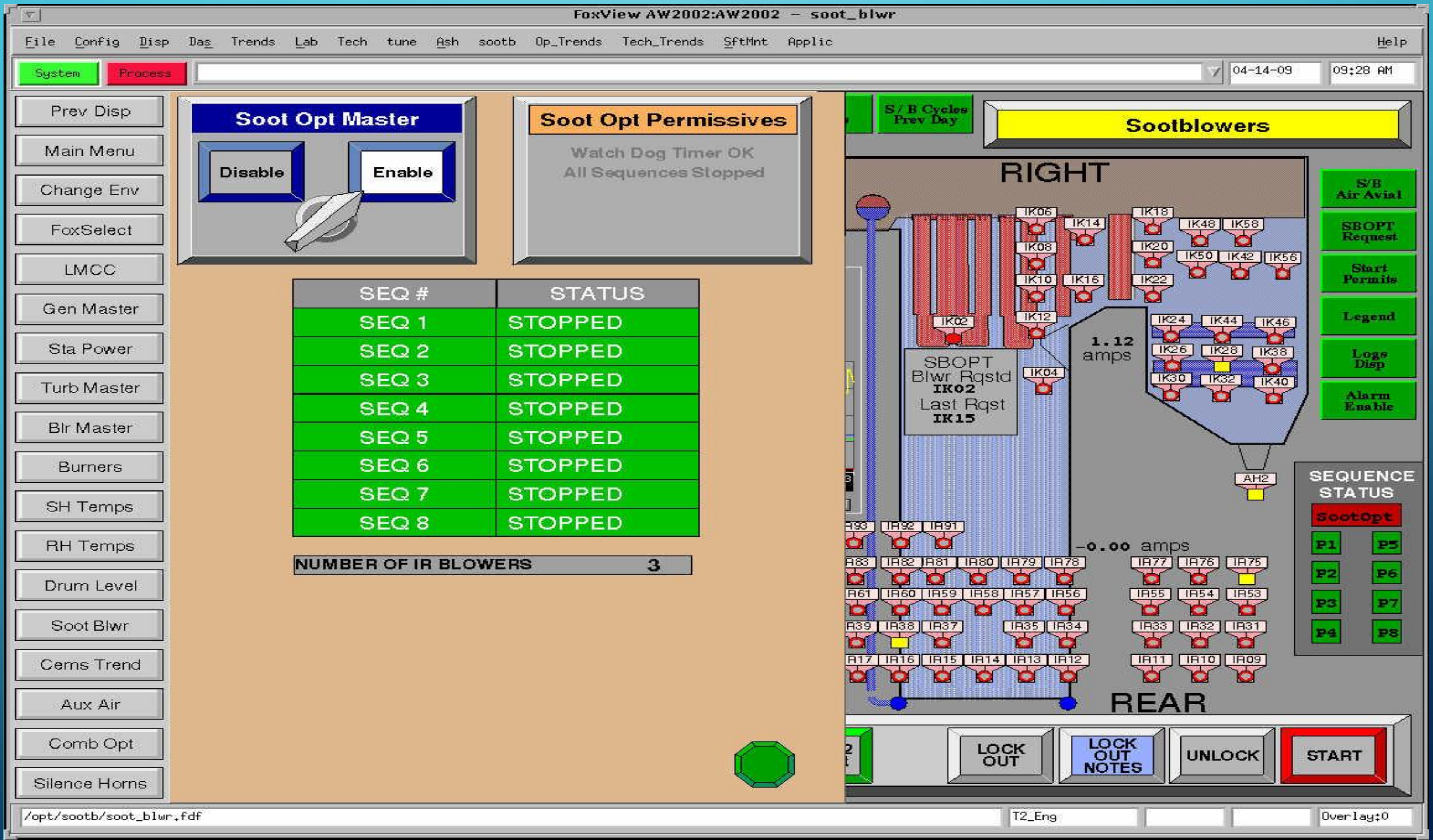
Boiler Efficiency NOx

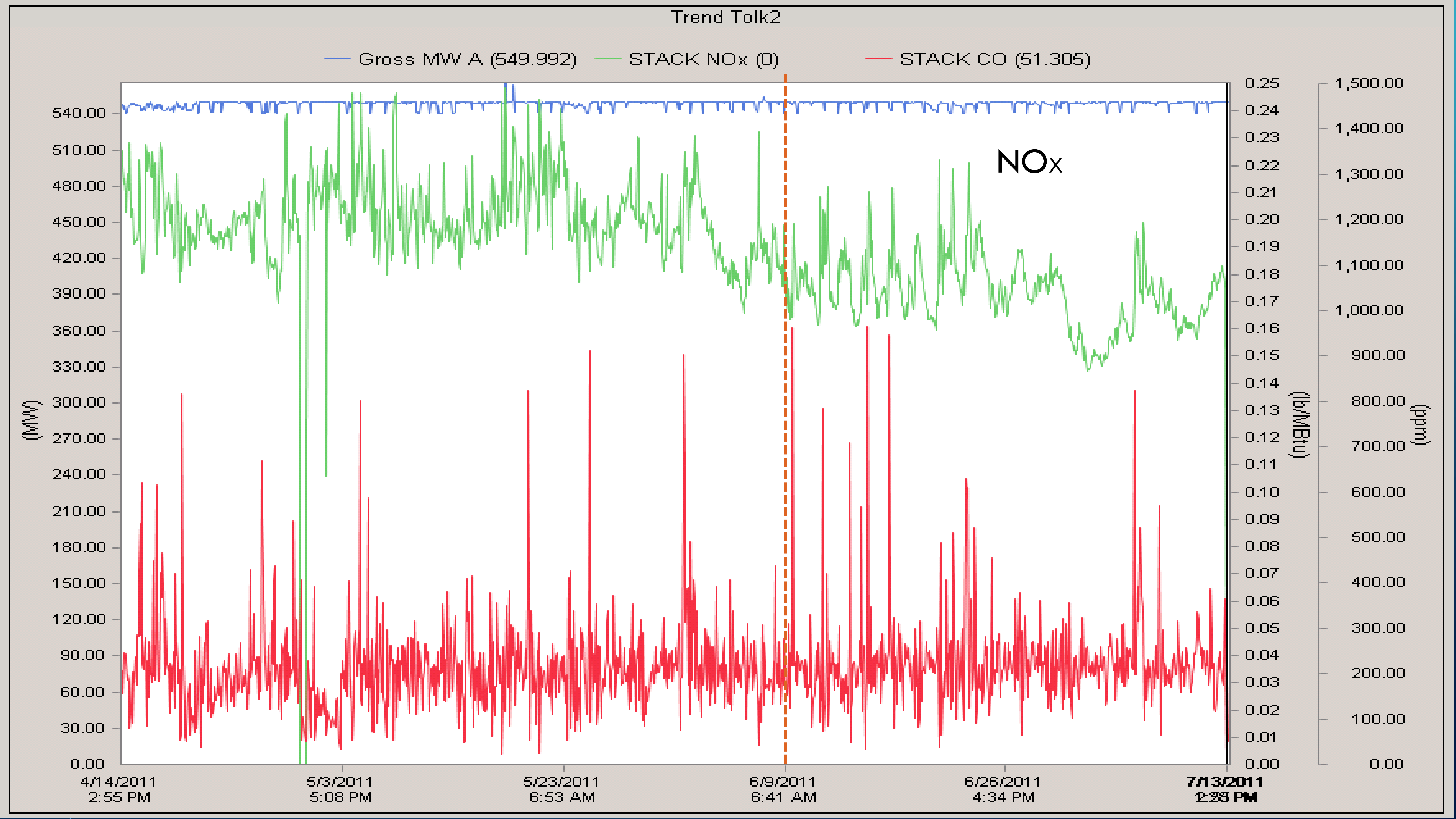
SAME UNIT 1 FIVE YEARS LATER (1/1/05)

EXIT GAS TEMPERATURE IMPACT

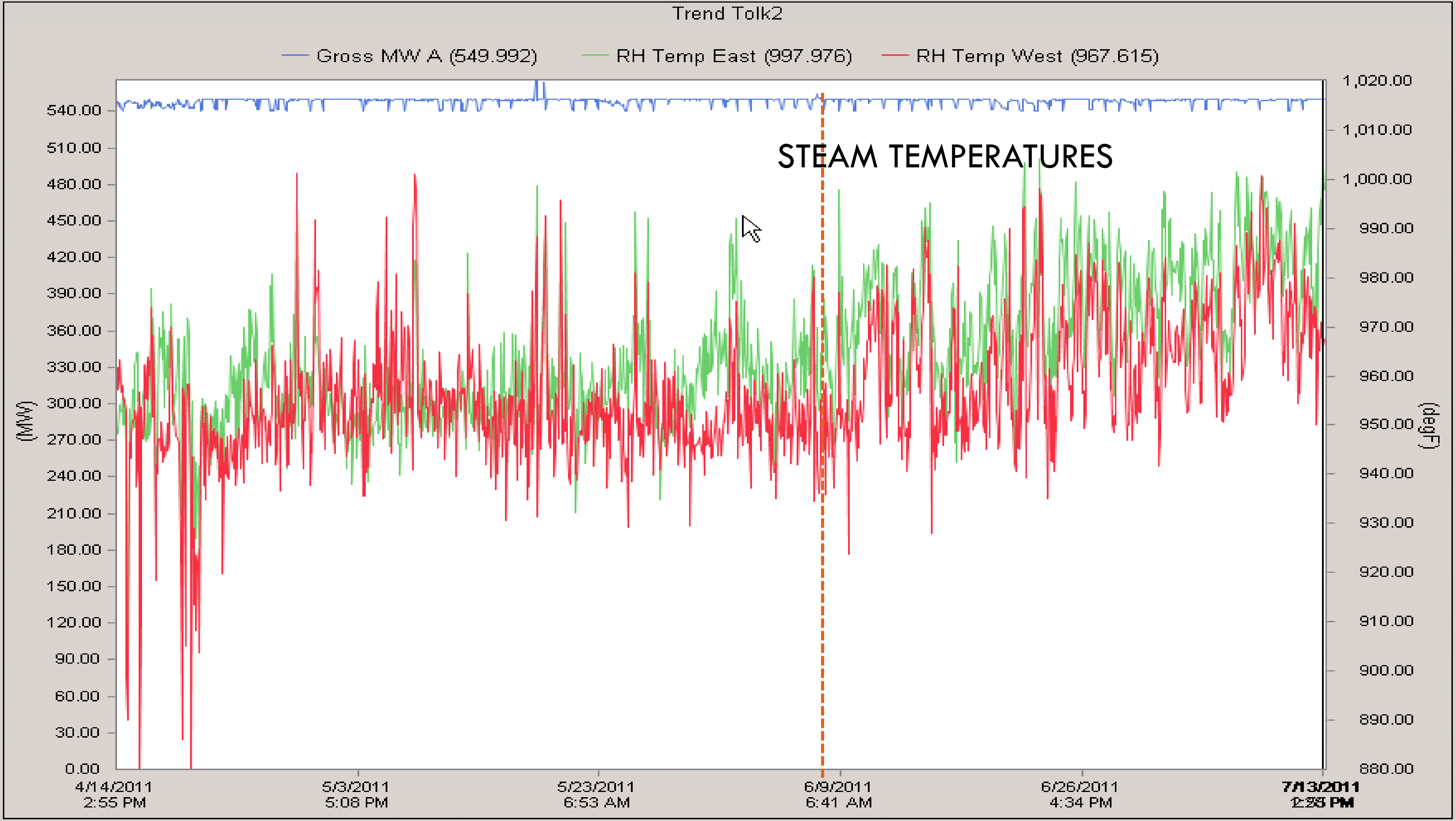


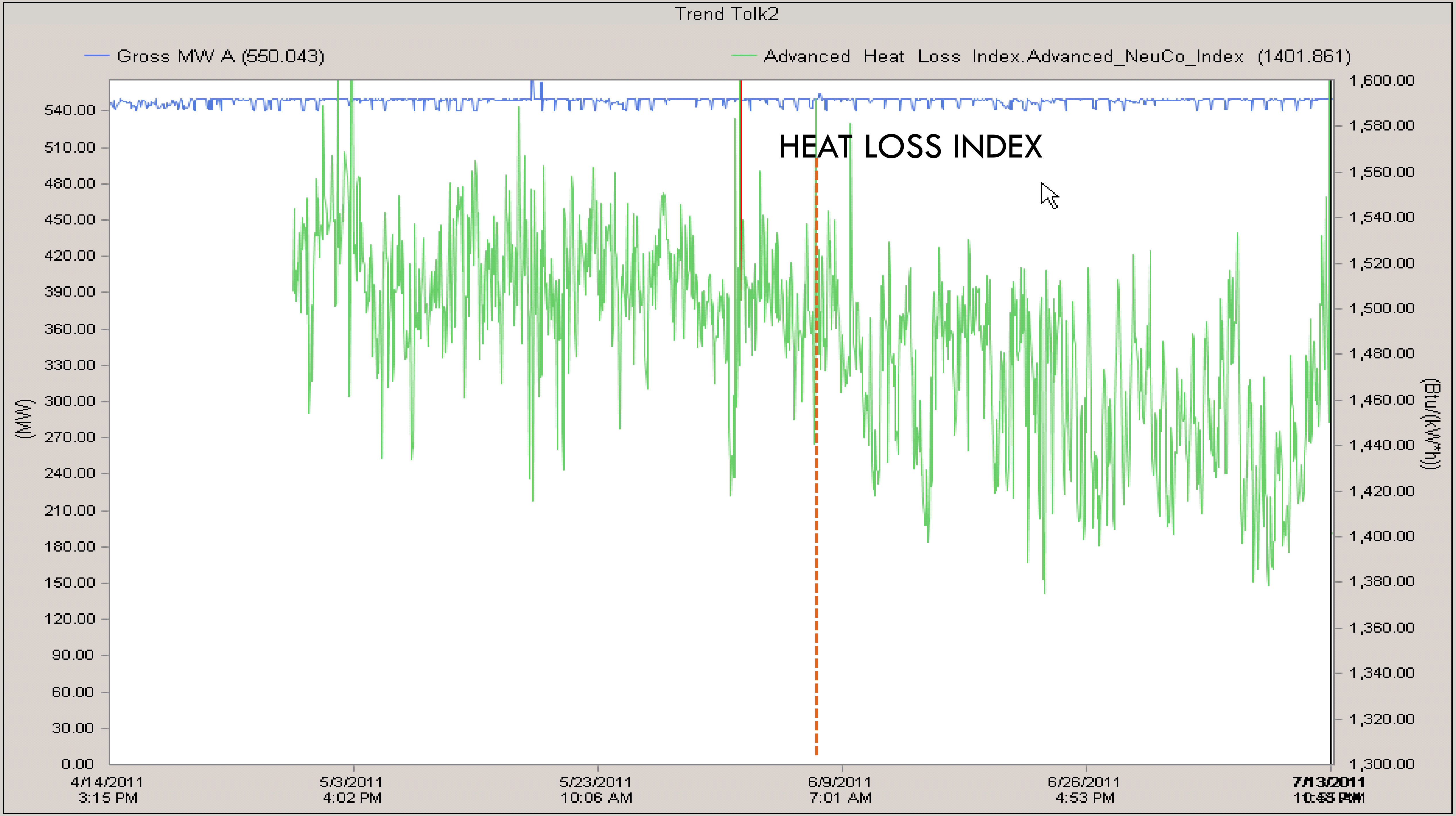
Soot Blower Control System HMI





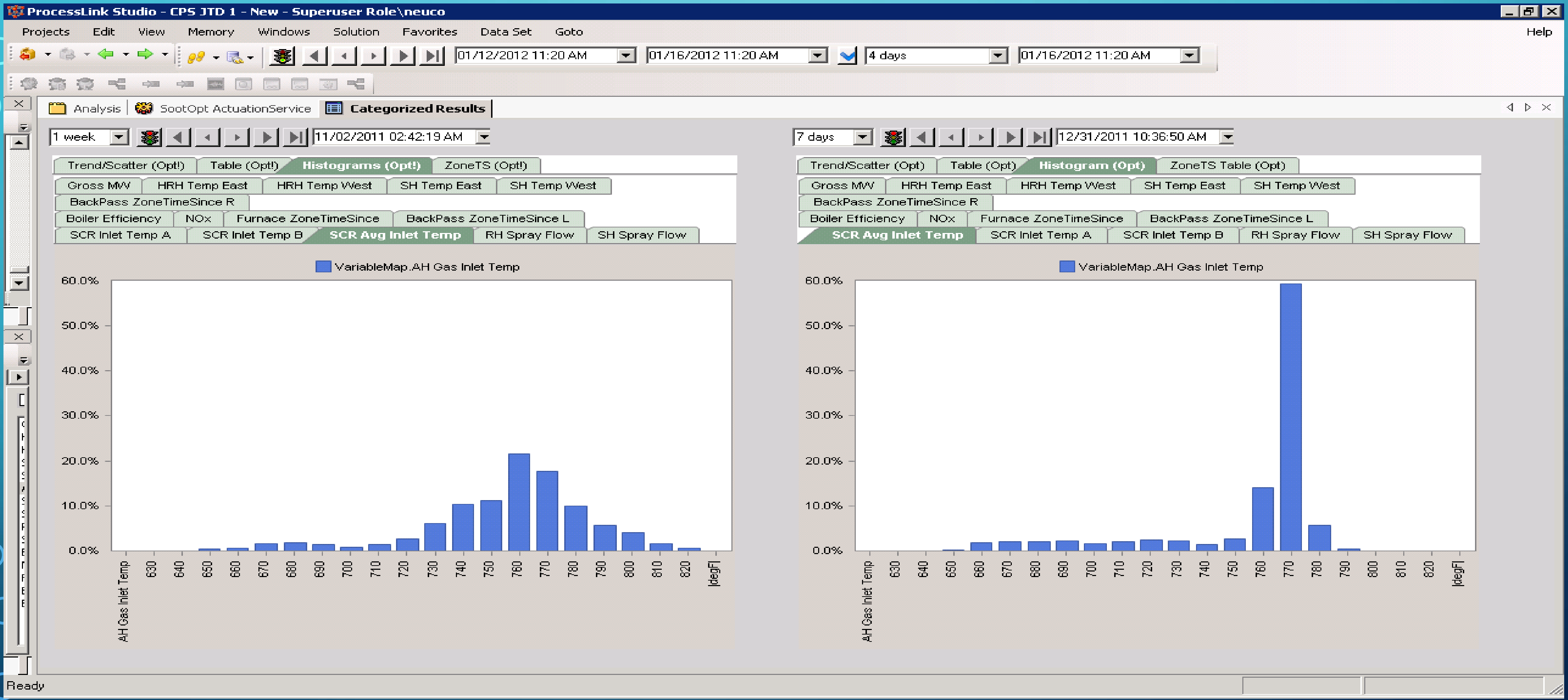
Trend Tolk2
Gross MW A (549.992)
STACK NOx (0)
STACK CO (51.305)
NOx
(MW)
(lb/MBtu)
(ppm)
540.00
510.00
480.00
450.00
420.00
390.00
360.00
330.00
300.00
270.00
240.00
210.00
180.00
150.00
120.00
90.00
60.00
30.00
0.00
0.25
0.24
0.23
0.22
0.21
0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1,500.00
1,400.00
1,300.00
1,200.00
1,100.00
1,000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
4/14/2011 2:55 PM
5/3/2011 5:08 PM
5/23/2011 6:53 AM
6/9/2011 6:41 AM
6/26/2011 4:34 PM
7/13/2011


Trend Tolk2
Gross MW A (549.992)
RH Temp East (997.976)
RH Temp West (967.615)
STEAM TEMPERATURES
(MW)
(degF)
540.00
510.00
480.00
450.00
420.00
390.00
360.00
330.00
300.00
270.00
240.00
210.00
180.00
150.00
120.00
90.00
60.00
30.00
0.00
1,020.00
1,010.00
1,000.00
990.00
980.00
970.00
960.00
950.00
940.00
930.00
920.00
910.00
900.00
890.00
880.00
4/14/2011 2:55 PM
5/3/2011 5:08 PM
5/23/2011 6:53 AM
6/9/2011 6:41 AM
6/26/2011 4:34 PM
7/13/2011



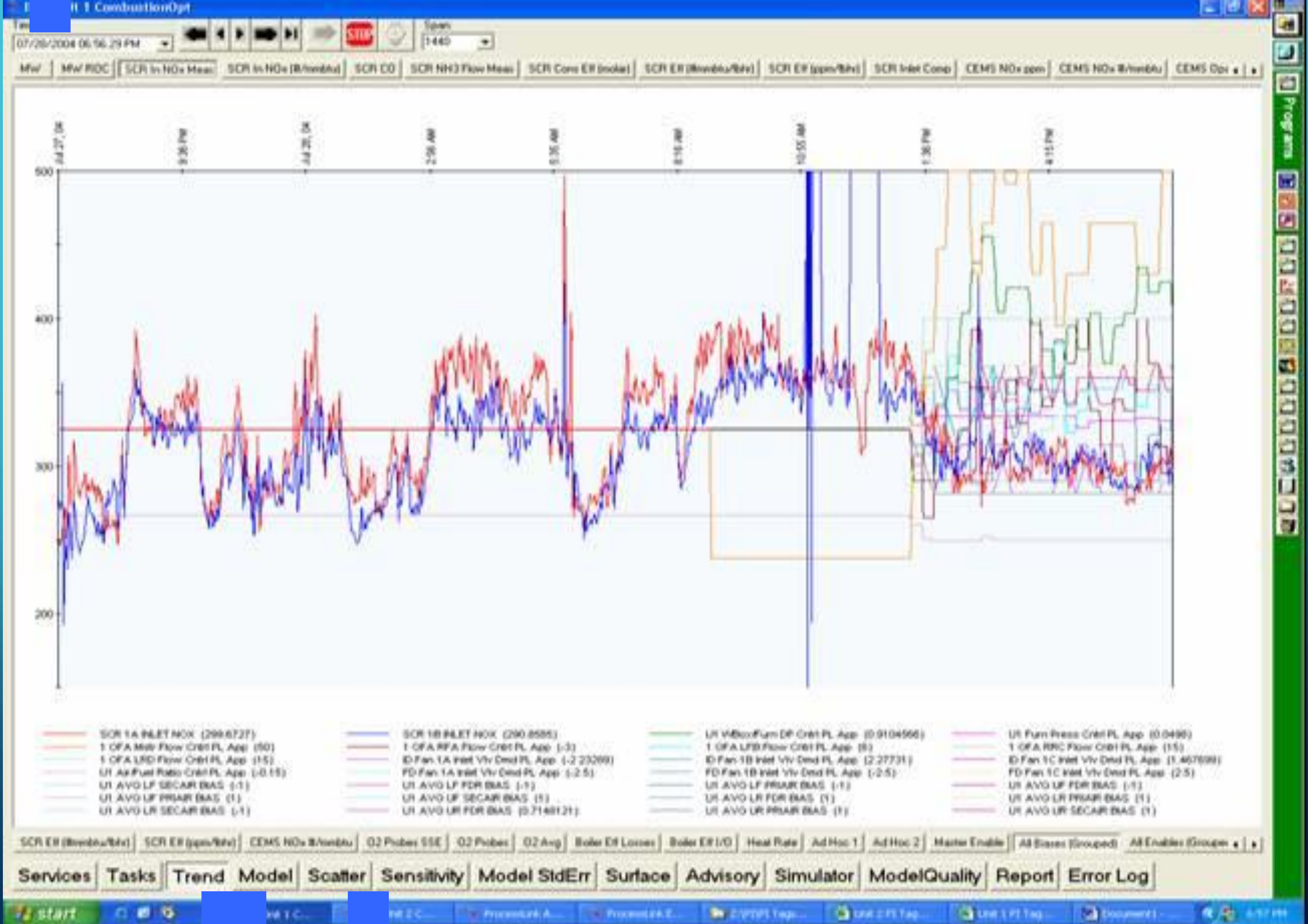
Trend Tolk2
Gross MW A (550.043)
Advanced Heat Loss Index.Advanced_NeuCo_Index (1401.861)
HEAT LOSS INDEX
(MW)
(Btu/(kW*h))
540.00
510.00
480.00
450.00
420.00
390.00
360.00
330.00
300.00
270.00
240.00
210.00
180.00
150.00
120.00
90.00
60.00
30.00
0.00
1,600.00
1,580.00
1,560.00
1,540.00
1,520.00
1,500.00
1,480.00
1,460.00
1,440.00
1,420.00
1,400.00
1,380.00
1,360.00
1,340.00
1,320.00
1,300.00
4/14/2011 3:15 PM
5/3/2011 4:02 PM
5/23/2011 10:06 AM
6/9/2011 7:01 AM
6/26/2011 4:53 PM
7/13/2011

TYPICAL GAS INLET TEMPS SOOTOPT OFF VS. ON



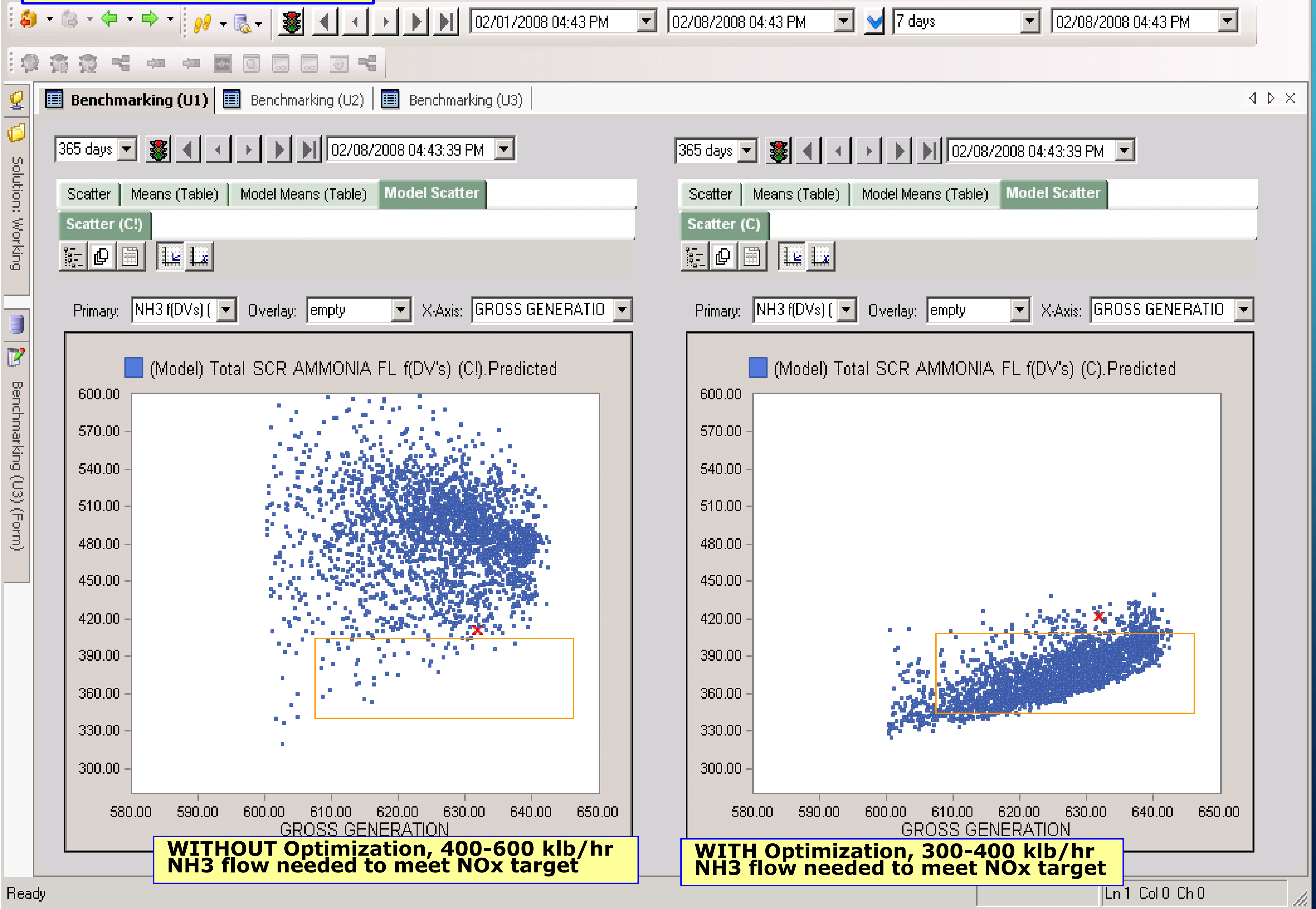
SCR/SNCR SYSTEMS & OPTIMIZATION

- Reduce Reagent Usage
- Lengthen Maintenance Intervals
- Avoid Ammonia Slip
- Reduce risk of Ammonium Bisulfate & Sulfur Trioxide deposits
- Control “Blue-Plume” Opacity Excursions
- Tighter, condition-based gas temperature control
- Better Manage System Interactions



500
400
300
200
Services
Tasks
Trend
Model
Scatter
Sensitivity
Model StdErr
Surface
Advisory
Simulator
ModelQuality
Report
Error Log

Impact on NH_3 Usage



WITHOUT Optimization, 400-600 klb/hr NH_3 flow needed to meet NO_x target

WITH Optimization, 300-400 klb/hr NH_3 flow needed to meet NO_x target

DCS SCREEN EXAMPLE

Boiler and Back-end Process Causality Chain