REINHOLD ENVIRONMENTAL Ltd.

2015 NOx-Combustion Round Table & Expo Presentations

February 23 & 24, 2015, in Richmond, VA / Hosted by Dominion

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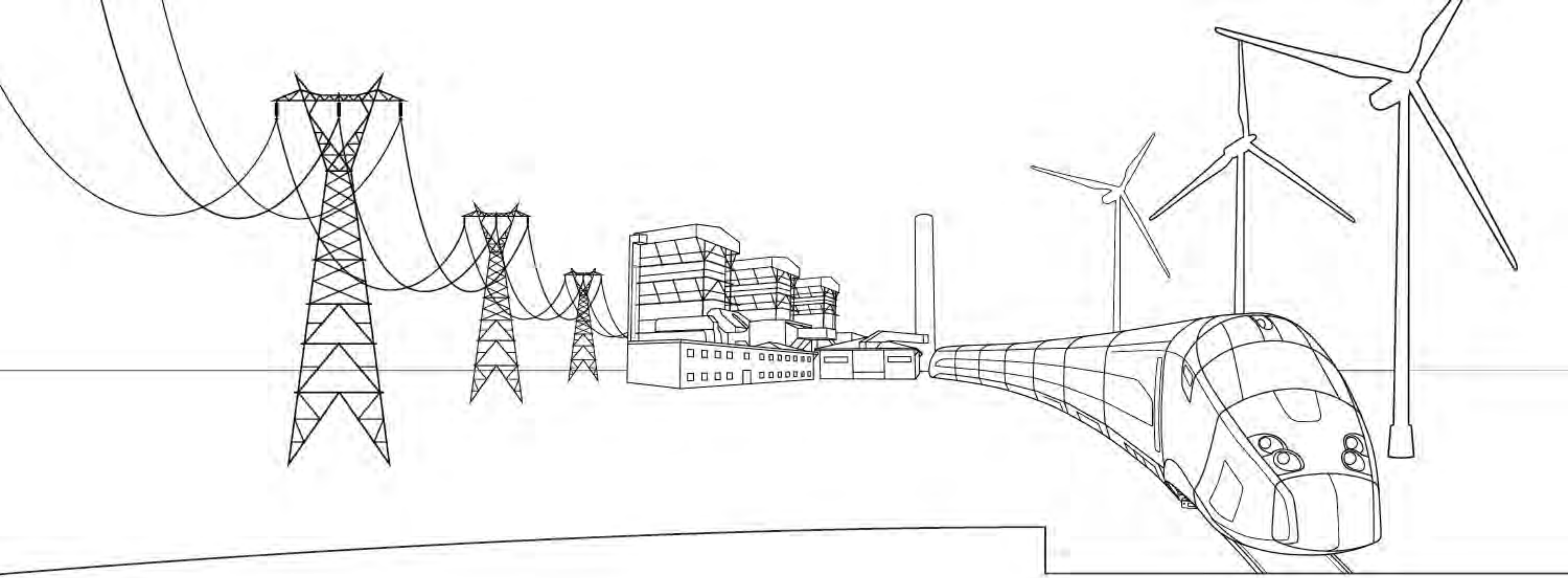

Plant Optimization for Increased Efficiency

Matt Dooley

Alstom Power

23 Feb 2015

ALSTOM
Shaping the future

Agenda

- Objective
- Brief Introduction to ALSTOM Asset Optimization Group
  - –Reliability
  - –Energy Efficiency Thermal Performance
- Background on CO2 Emissions
- Impact of Carbon Regulation on Plant Profitability
- Energy Efficiency Improvement Process
- New Technologies for Energy Efficiency
- Improving the Measurement of CO2 Emissions

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Objective

- It should be obvious that improved energy efficiency will result in less fuel being burned to produce power at a lower cost, but also produce less emissions of all types. Energy efficiency is a win-win for everybody.
- The objective of this presentation is to explain Alstom’s approach to improving the profitability of a power generation facility through improved reliability and increased energy efficiency.

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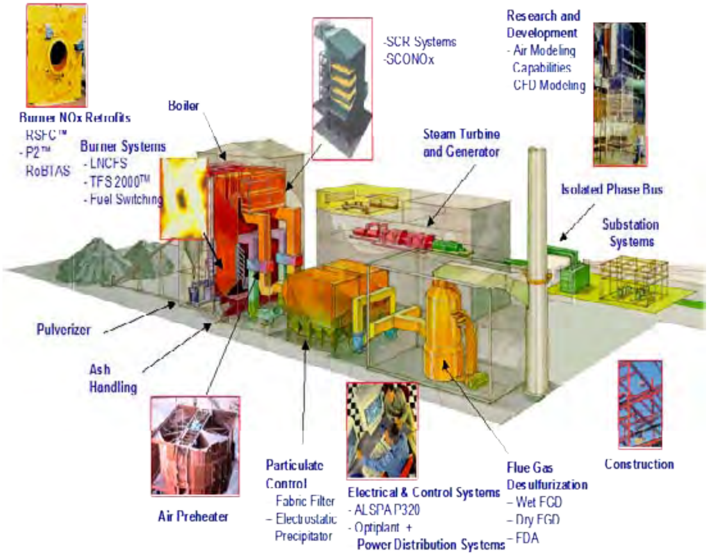
ALSTOM Power Plant Optimization

Fleet → Plant → System → Component

- Performance Improvement
  - Efficiency
    - Heat Rate/Retrofits
  - Capacity/Parasitic Load
    - OPR Power Block/Cold End/Plant Systems
  - Flexibility
    - Fuel/Cycling
  - Regulatory
    - Emissions/Closed Cooling/Water Usage
- **Reliability/Availability**
  - Revenue Maximization
  - Maintenance/Outage Spend Optimization



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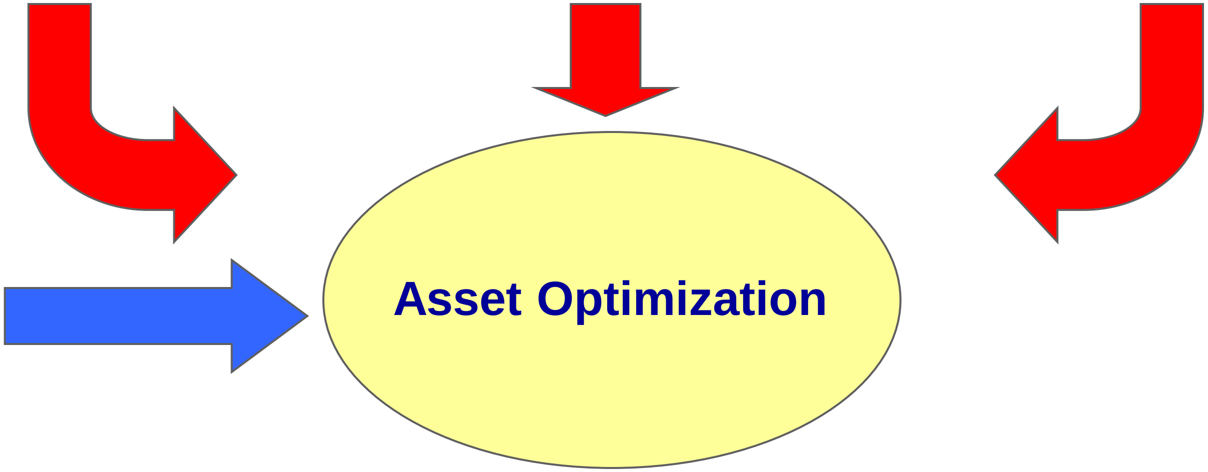
Integration of Key Capabilities

O&M Experience

Plant Design

Product Knowledge



Customer

Asset Optimization

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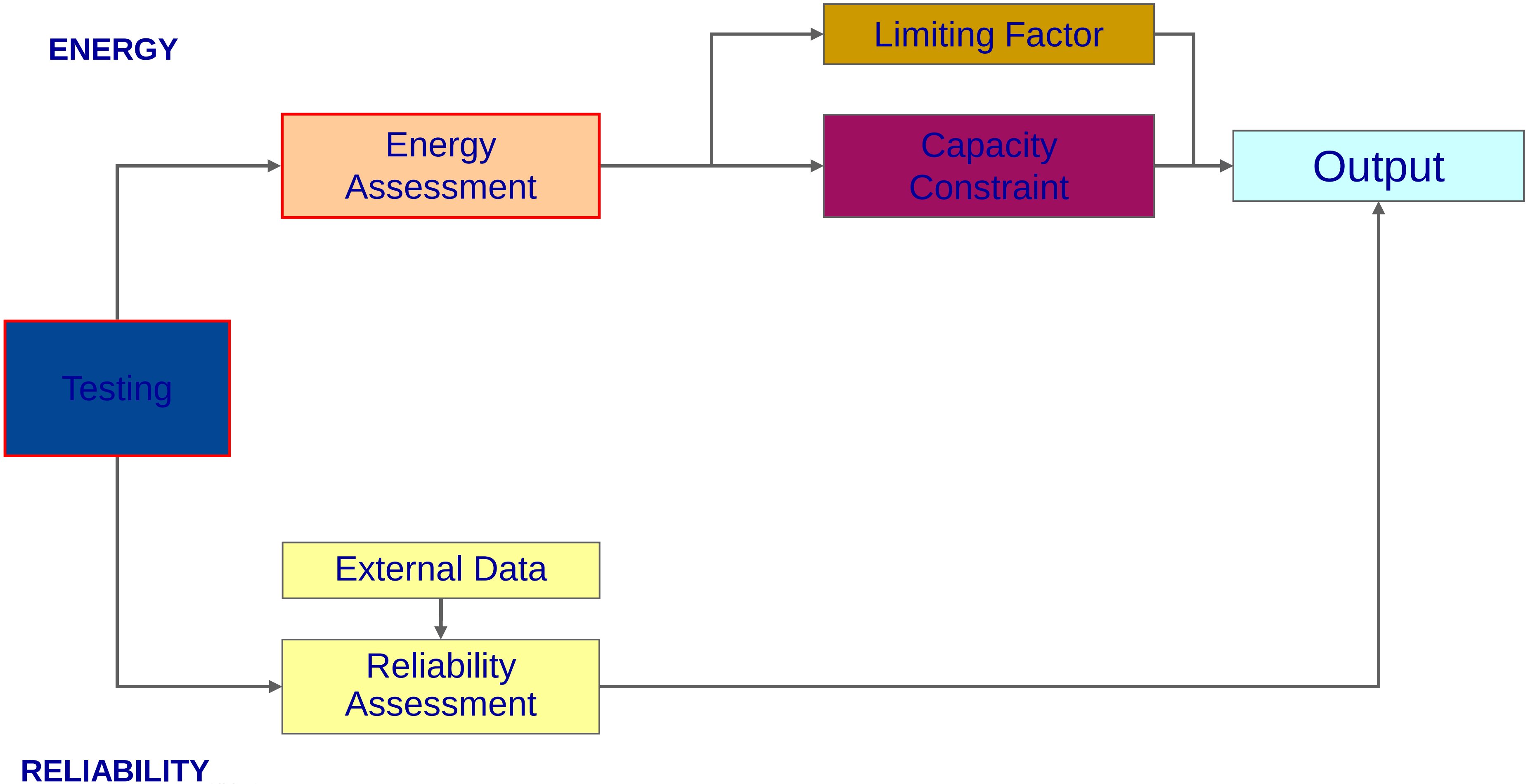
Process Overview

The processes are integrated, and they share and exchange the same data for accuracy and standardization



ENERGY

Energy Assessment

Limiting Factor

Capacity Constraint

Output

Testing

External Data

Reliability Assessment

RELIABILITY

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PRA Based Reliability Assessment Program

OBJECTIVE: Create a dynamic decision model that…

- Integrates the data from the existing Customers databases
- Predicts where and when failures may occur - Fleet/Plant/Unit
- Quantifies the impact on Operations, Maintenance and O&M budgets
- Provides “real time” input for integrated plans and actions at: all levels (plant/planning/upper management)

Example of Application

- Mid-West Utility 4 x 600 MW Coal-Fired Plant
  - Modeling and Data Statistics:

Number of Systems Modeled	12
Total Number of Components	65
CMMS Events Analyzed	53,744
NERC Events Analyzed	2,789

- Results of Reliability Program
  - Simulation closely correlated with Plant KPIs & NERC Analyses
  - Simulation results used to justify and reprioritize major capital replacements driving EFOR

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Reliability Assessment

Results - System Analysis

Analyzed GADS data from 2004-2008, ran a discrete event simulation, projected the results for 2009 and compared them to the actual values.

Furnace Walls	Predicted 2009	Actual 2009
Mean Availability (All Events)	94.1%	95.3%
Expected Number of Failures	8.2	8
Mean Time To First Failure (MTTF)	40	34
System Up Time (Days)	343	349
System Down Time (Days)	21.6	15.9
Total Throughput (MW Days)	211,865	215,414

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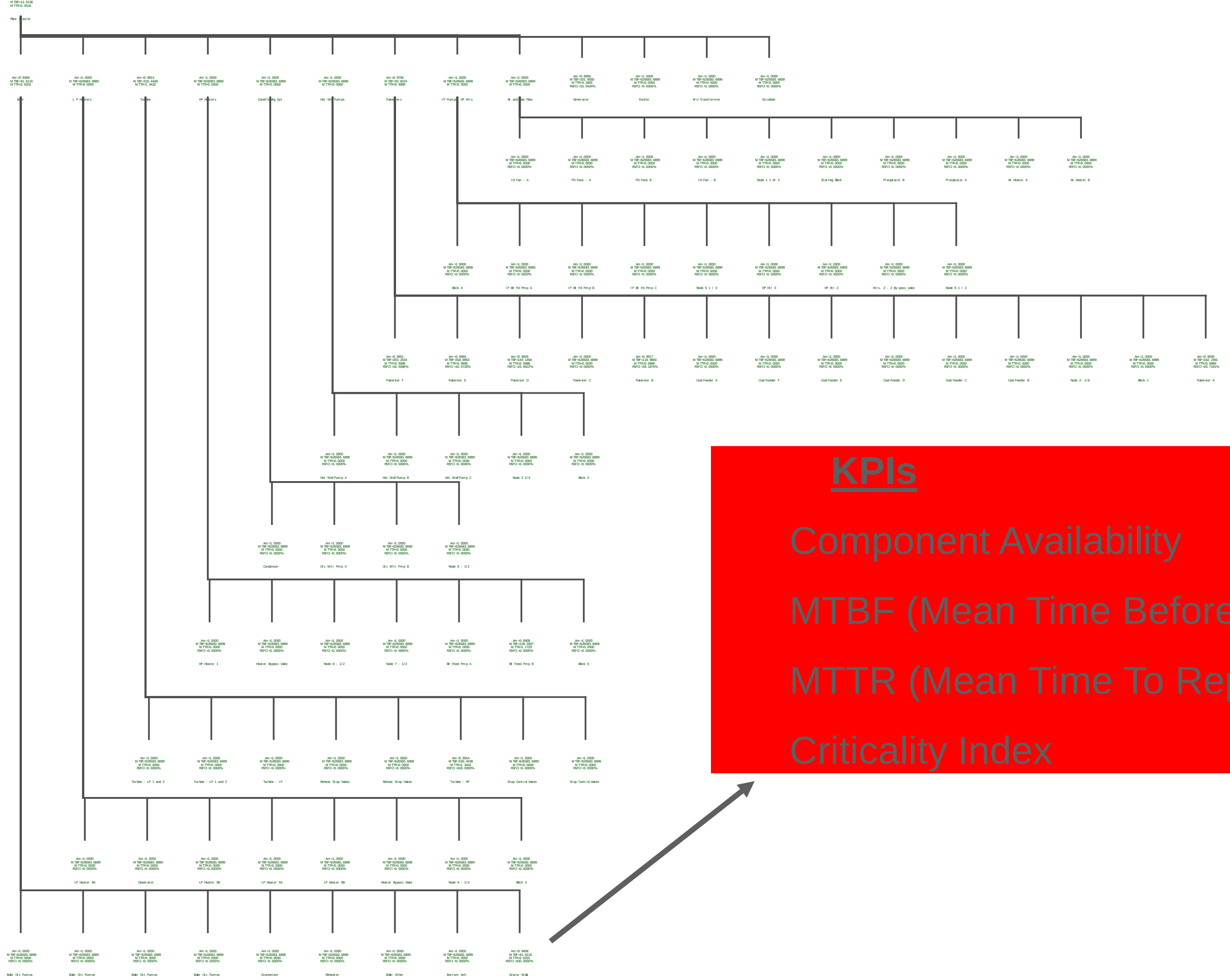
Plant/System/Component KPI Dashboard



KPIs

Component Availability

MTBF (Mean Time Before Failure)

MTTR (Mean Time To Repair)

Criticality Index

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Asset Optimization
Energy Efficiency and Thermal Performance

*i*LifeCycle^{TM} Energy Assessment Process

The Energy Efficiency and Thermal Performance area looks at the operating plant as a complete system. Consideration is given on how changes in performance in one area impact other equipment in the cycle.

The Energy Assessment identifies areas where the current plant can improve efficiency by making repairs or operational changes. It also considers possibilities for cycle design changes which could further improve efficiency.

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Energy Assessment

- Energy Assessment/Thermal Cycle Analysis
  - Engineering & Economic Evaluation
    - Design basis review and benchmarking
    - Plant staff interviews
    - Use of Plant Instrumentation
    - VWO Test/Prior test results review
    - As-Found vs. Design Heat Balance comparison
  - Operational Adjustments to deliver short term results
  - Point solutions on a $/BTU/kWh pick-up
  - Programmatic and ‘Best in Class’ recommendations

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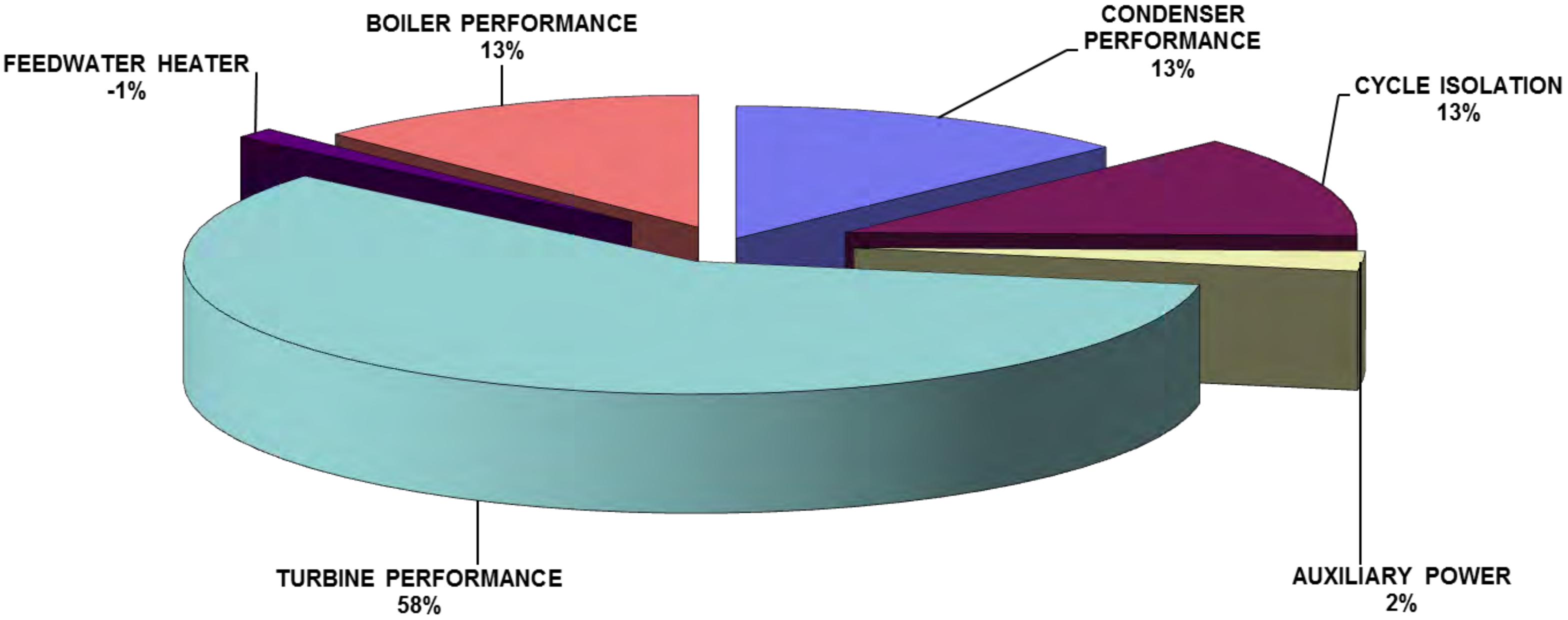
Energy Assessment

Unit #1 Energy Losses

Design Heat Rate	9192 BTU/kWhr	As Found Heat Rate	9488 BTU/kWhr
Design Heat Rate	2316 kcal/kWhr	As Found Heat Rate	2396 kcal/kWhr
Design Heat Rate	9692 kJ/kWhr	As Found Heat Rate	10004 kJ/kWhr



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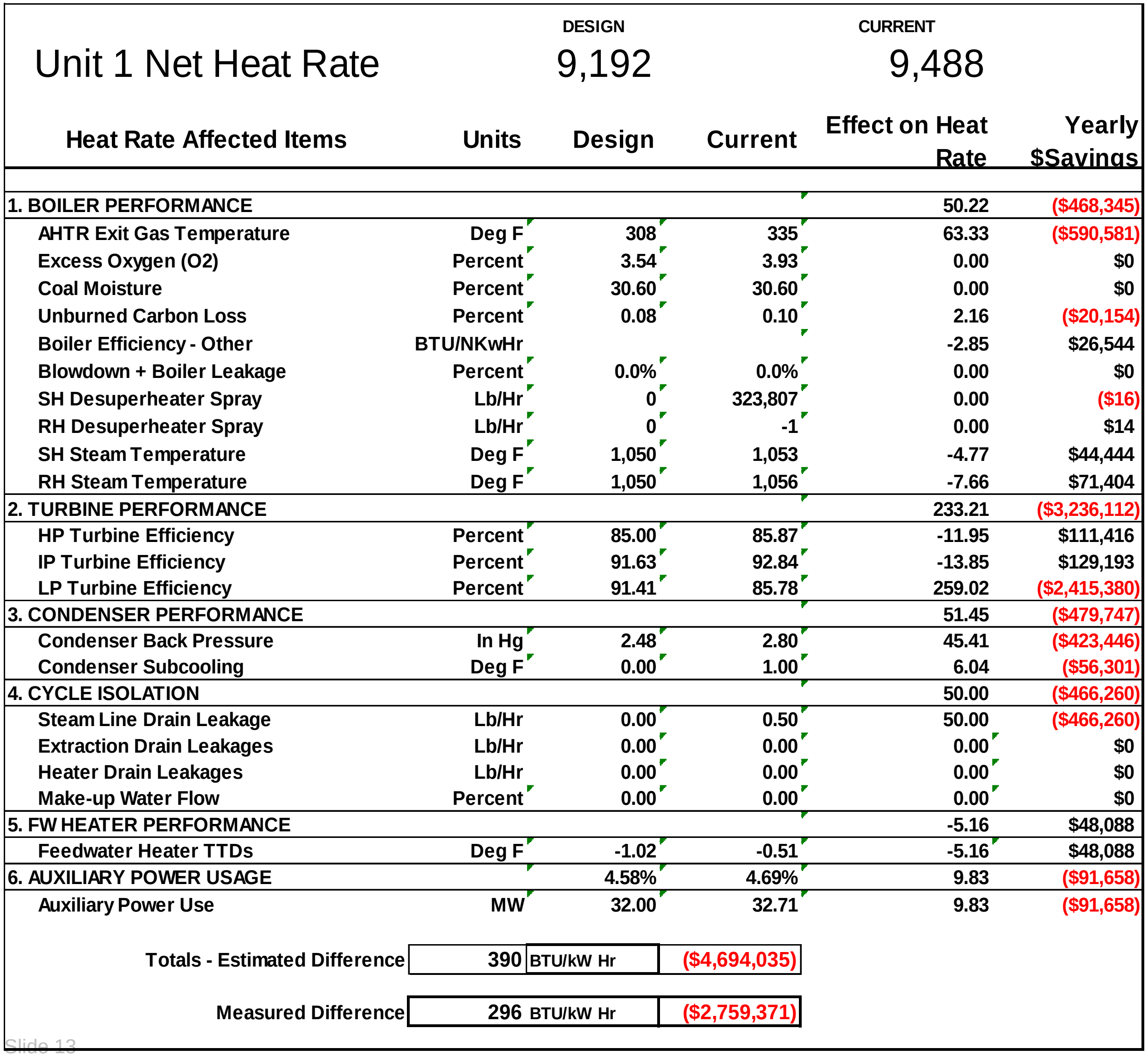
Energy Assessment - Savings



Unit 1 Net Heat Rate — DESIGN 9,192 — CURRENT 9,488

Heat Rate Affected Items	Units	Design	Current	Effect on Heat Rate	Yearly $Savings
1. BOILER PERFORMANCE				50.22	($468,345)
AHTR Exit Gas Temperature	Deg F	308	335	63.33	($590,581)
Excess Oxygen (O2)	Percent	3.54	3.93	0.00	$0
Coal Moisture	Percent	30.60	30.60	0.00	$0
Unburned Carbon Loss	Percent	0.08	0.10	2.16	($20,154)
Boiler Efficiency - Other	BTU/NKwHr			-2.85	$26,544
Blowdown + Boiler Leakage	Percent	0.0%	0.0%	0.00	$0
SH Desuperheater Spray	Lb/Hr	0	323,807	0.00	($16)
RH Desuperheater Spray	Lb/Hr	0	-1	0.00	$14
SH Steam Temperature	Deg F	1,050	1,053	-4.77	$44,444
RH Steam Temperature	Deg F	1,050	1,056	-7.66	$71,404
2. TURBINE PERFORMANCE				233.21	($3,236,112)
HP Turbine Efficiency	Percent	85.00	85.87	-11.95	$111,416
IP Turbine Efficiency	Percent	91.63	92.84	-13.85	$129,193
LP Turbine Efficiency	Percent	91.41	85.78	259.02	($2,415,380)
3. CONDENSER PERFORMANCE				51.45	($479,747)
Condenser Back Pressure	In Hg	2.48	2.80	45.41	($423,446)
Condenser Subcooling	Deg F	0.00	1.00	6.04	($56,301)
4. CYCLE ISOLATION				50.00	($466,260)
Steam Line Drain Leakage	Lb/Hr	0.00	0.50	50.00	($466,260)
Extraction Drain Leakages	Lb/Hr	0.00	0.00	0.00	$0
Heater Drain Leakages	Lb/Hr	0.00	0.00	0.00	$0
Make-up Water Flow	Percent	0.00	0.00	0.00	$0
5. FW HEATER PERFORMANCE				-5.16	$48,088
Feedwater Heater TTDs	Deg F	-1.02	-0.51	-5.16	$48,088
6. AUXILIARY POWER USAGE		4.58%	4.69%	9.83	($91,658)
Auxiliary Power Use	MW	32.00	32.71	9.83	($91,658)

Totals - Estimated Difference	390	BTU/kW Hr	($4,694,035)
Measured Difference	296	BTU/kW Hr	($2,759,371)

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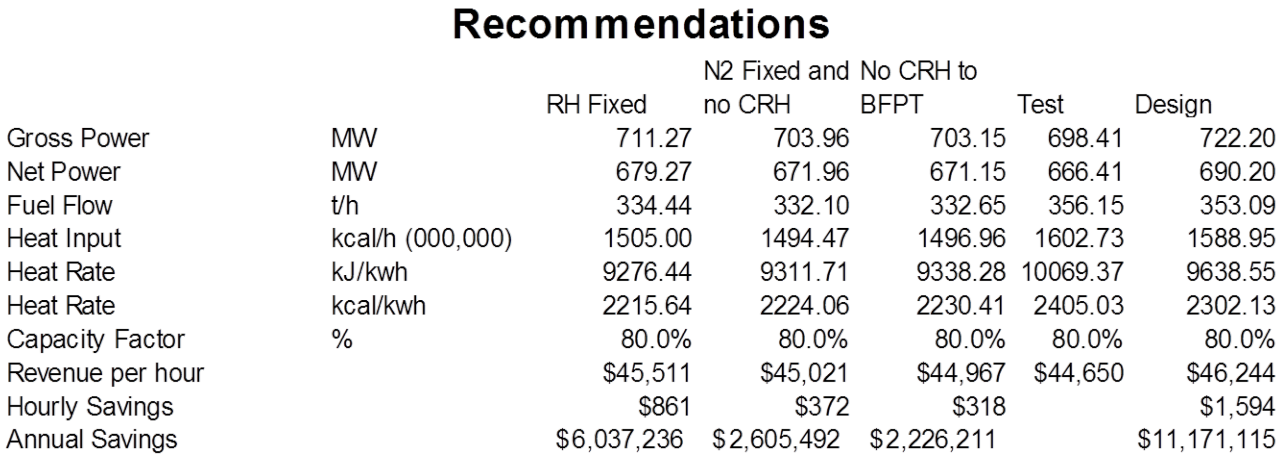
Energy Assessment – Prioritized Recommendations

Recommendations for Improving Net Heat Rate

	Cost	Heat Rate Impact	Annual Savings	IRR	NPV
1 Gland Steam + Leaking MS Stop Valve Repair	$ 400,000	196.6	$ 4,054,785	1013.7%	$16,985,912
2 Clean Condenser	$ 100,000	52.5	$ 1,082,789	1082.8%	$4,542,223
3 Repair Air Heater	$ 400,000	53.9	$ 1,112,075	277.9%	$4,389,806
4 Reduce Aux Power	$ 1,000,000	53.1	$ 1,095,163	108.2%	$3,761,859
5 Increase RH temperature	$ 100,000	21.8	$ 448,996	449.0%	$1,829,311
6 Improve FW Heater Performance	$ 200,000	22.8	$ 470,446	235.1%	$1,828,532
7 Repair LP Section of Turbine	$ 9,000,000	100.8	$ 2,078,542	10.2%	$563,748



Recommendations

		RH Fixed	N2 Fixed and no CRH	No CRH to BFPT	Test	Design
Gross Power	MW	711.27	703.96	703.15	698.41	722.20
Net Power	MW	679.27	671.96	671.15	666.41	690.20
Fuel Flow	t/h	334.44	332.10	332.65	356.15	353.09
Heat Input	kcal/h (000,000)	1505.00	1494.47	1496.96	1602.73	1588.95
Heat Rate	kJ/kwh	9276.44	9311.71	9338.28	10069.37	9638.55
Heat Rate	kcal/kwh	2215.64	2224.06	2230.41	2405.03	2302.13
Capacity Factor	%	80.0%	80.0%	80.0%	80.0%	80.0%
Revenue per hour		$45,511	$45,021	$44,967	$44,650	$46,244
Hourly Savings		$861	$372	$318		$1,594
Annual Savings		$6,037,236	$2,605,492	$2,226,211		$11,171,115

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Background – Why is Energy Efficiency Important

- Increasing Global Concern for Greenhouse Gas Emissions
- US Congress will eventually pass CO_2 Legislation or EPA will regulate
- Some Form of Cost for emitting Carbon likely
- Increasing recognition of the role of Energy Efficiency in reducing GHG as well as other emissions
- Lack of accurate methodology to measure CO_2 limits implementation of UN Clean Development Mechanism (CDM) under the Kyoto Protocol

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Example of Carbon Economics

- 610 MWE Net Coal plant burning Coal
  - 8368 Btu/lb coal with 5.21 % ash
  - Current heat rate 9395 Btu / Net Kwh
  - 85% capacity factor
  - Burns 2551 kTons of coal annually
  - Produces 4.61 million tons of CO2 annually
- Cost of CO_2 $10/Ton
- Cost of Coal $25.10/Ton delivered
- Cost of NOx Credits $1000/Ton
- Cost of SO_2 Credits $250/Ton
- Cost of Ash Disposal $50/Ton

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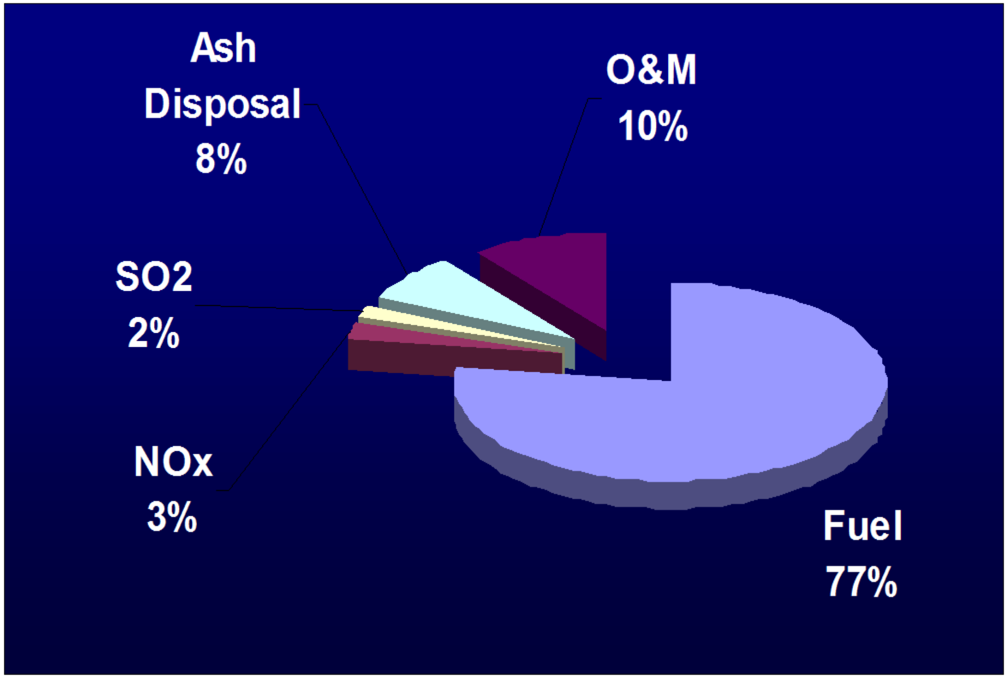
Existing Economics

Cost of Generation

Annual Costs Million $	
Cost of Fuel	64.0
Cost of NOx Credits	2.1
Cost of SO2 Credits	1.6
Cost of Ash Disposal	6.6
O&M Costs	8.3
Total Cost	82.7
Cost per MWhr	$ 18.21



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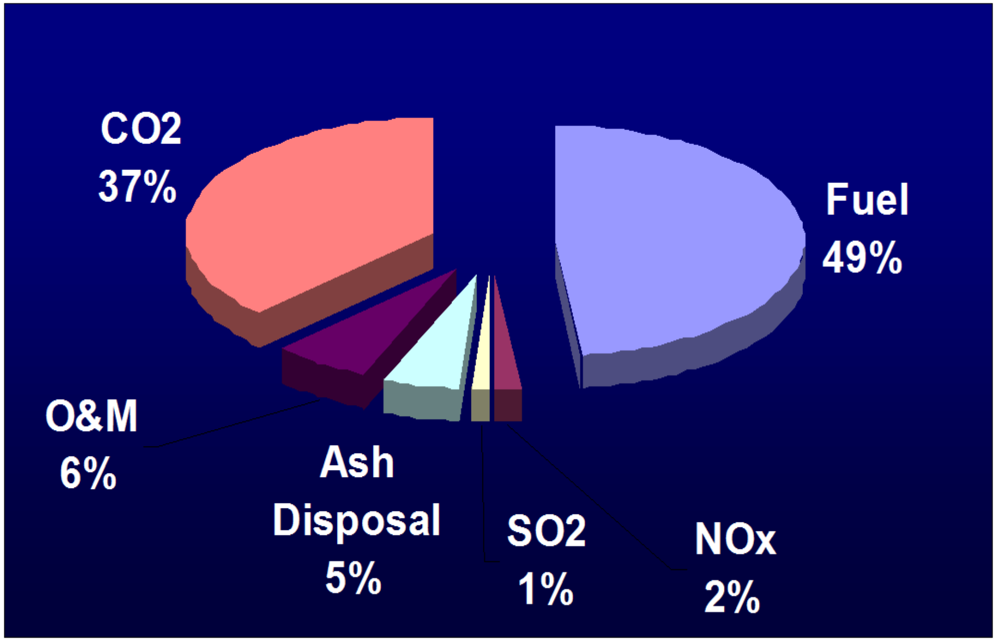
Carbon Economics

Cost of Generation

Annual Costs Million $	
Cost of Fuel	64.0
Cost of NOx Credits	2.1
Cost of SO2 Credits	1.6
Cost of Ash Disposal	6.6
O&M Costs	8.3
Cost of CO2 Credits	49.6
Total Cost	132.3
Cost per MWhr	$ 29.12



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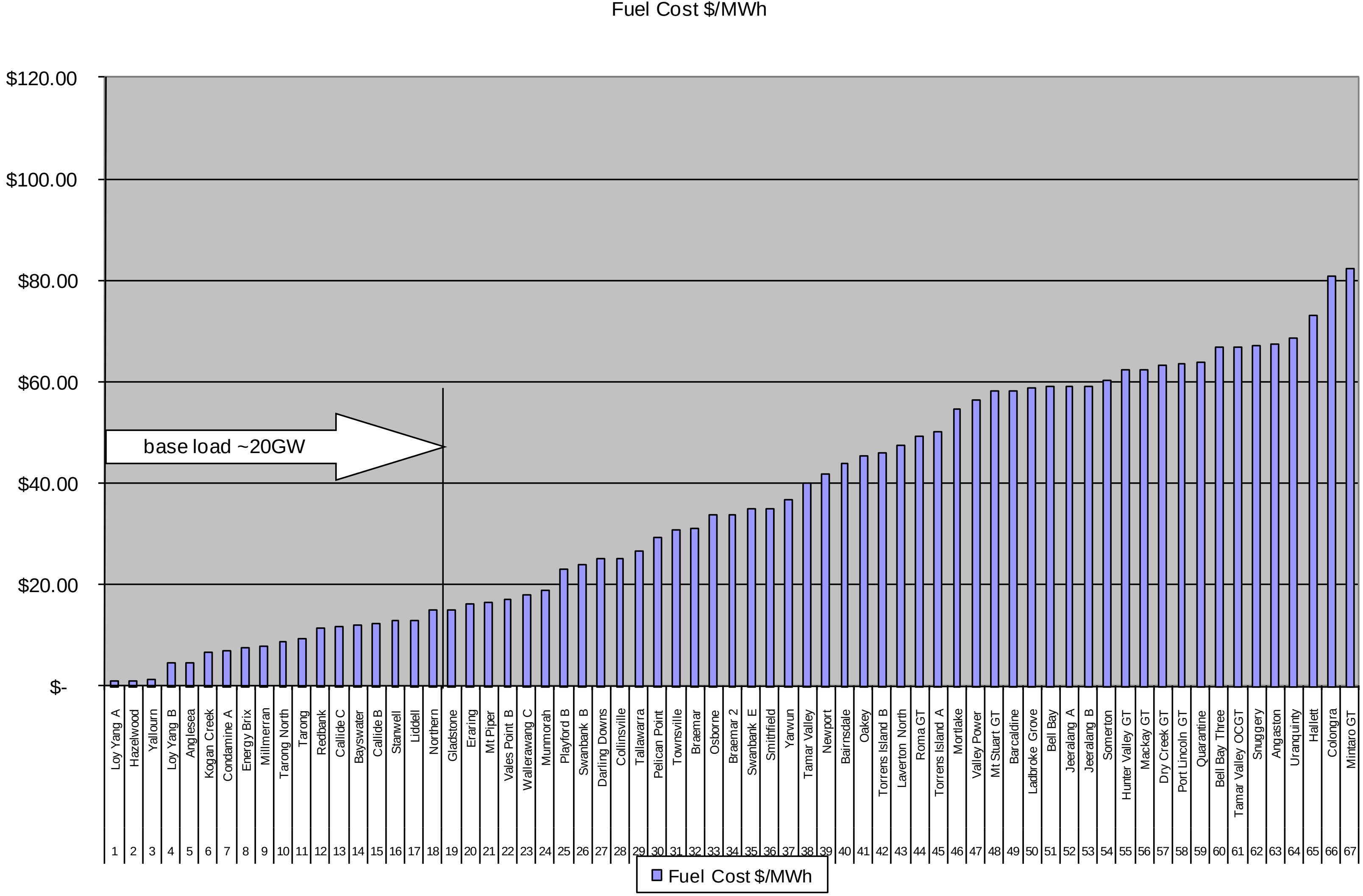
Market Drivers – Fuel

Fuel Cost – Merit Order



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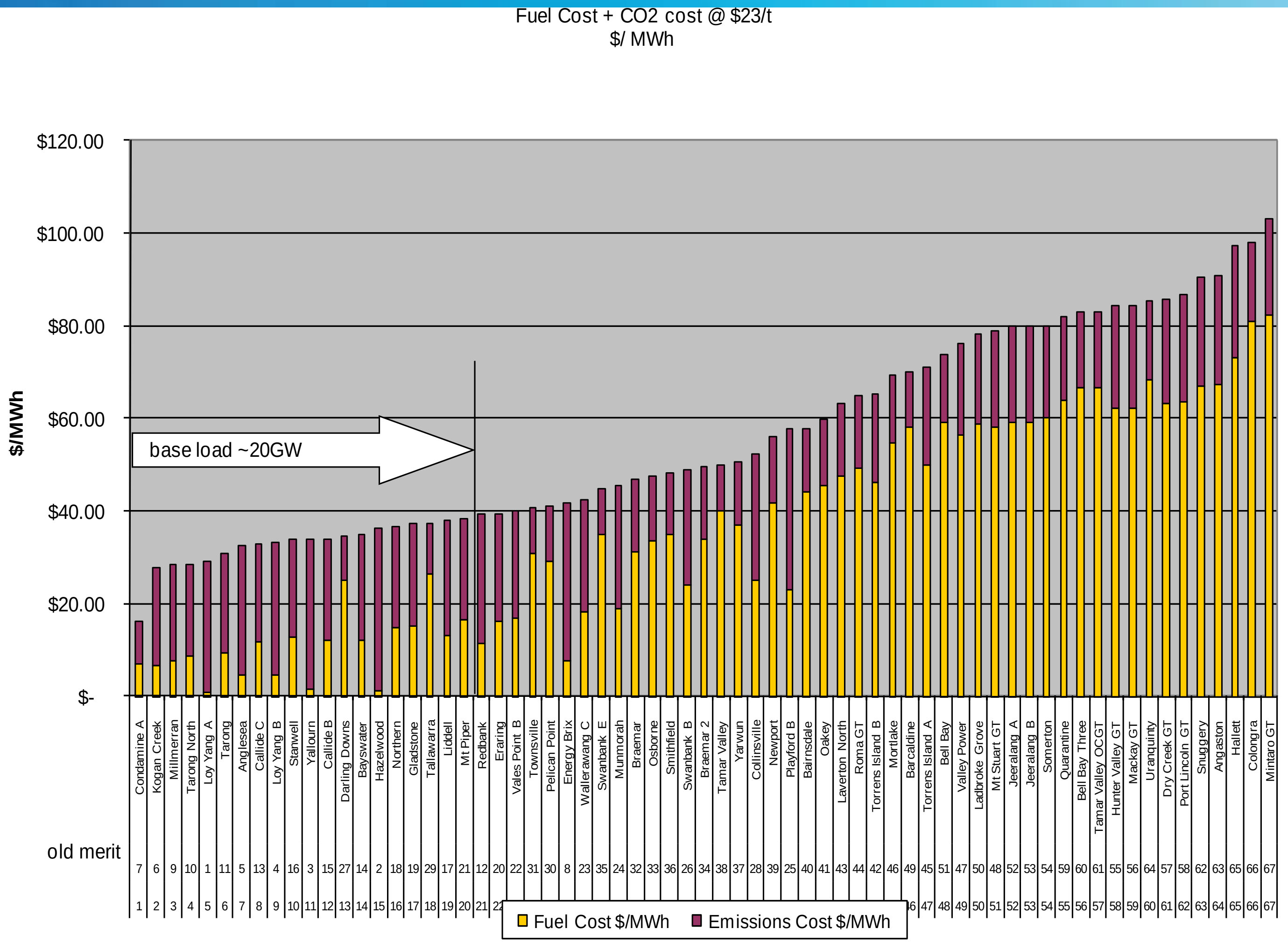
Market Drivers – Merit Order - Fuel + CO2 cost

(CO2 @ $23/t converted to $/MWh by station emission intensity)



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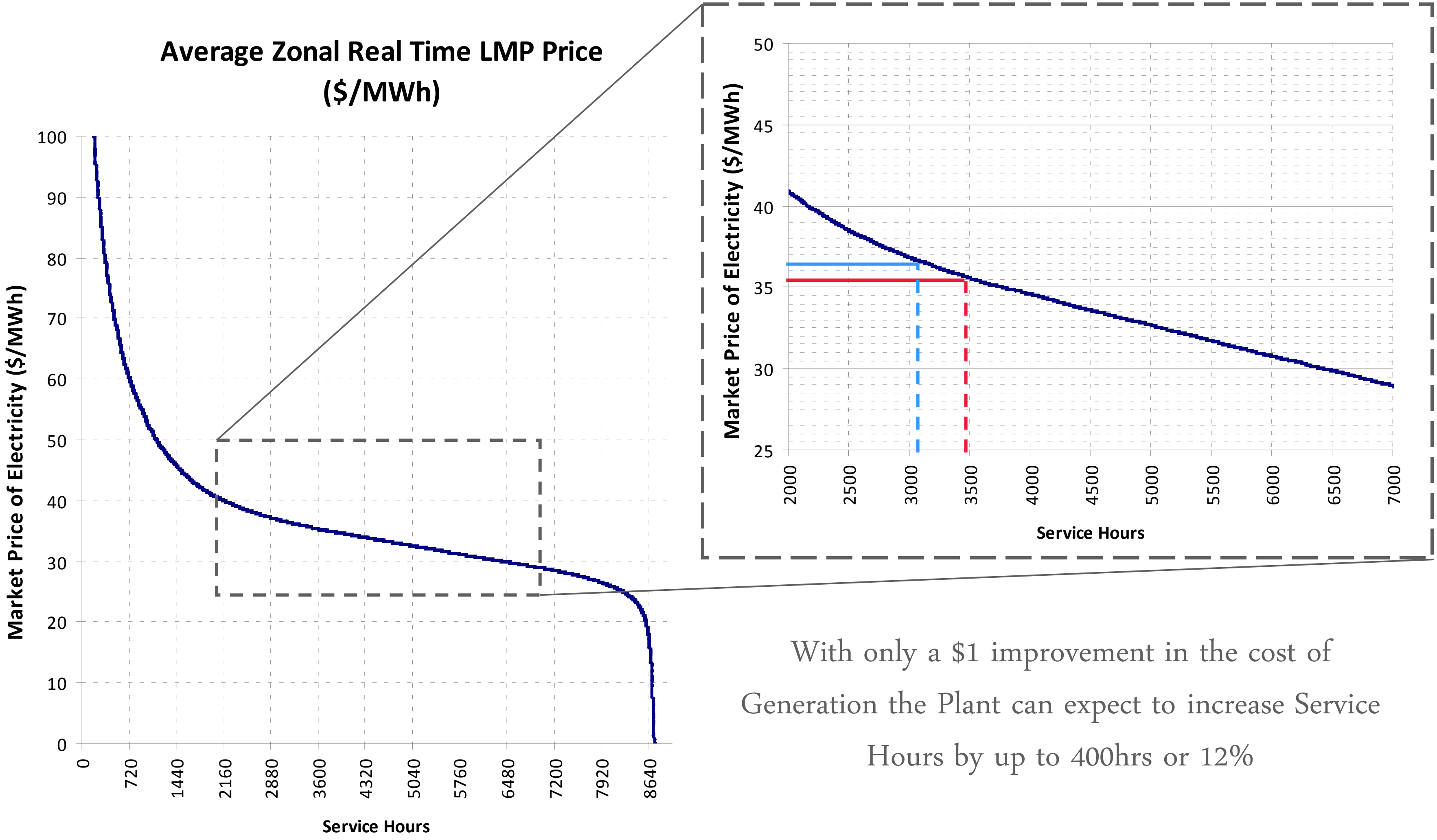
Effect of Cost Reduction on Service Factor



With only a $1 improvement in the cost of Generation the Plant can expect to increase Service Hours by up to 400hrs or 12%

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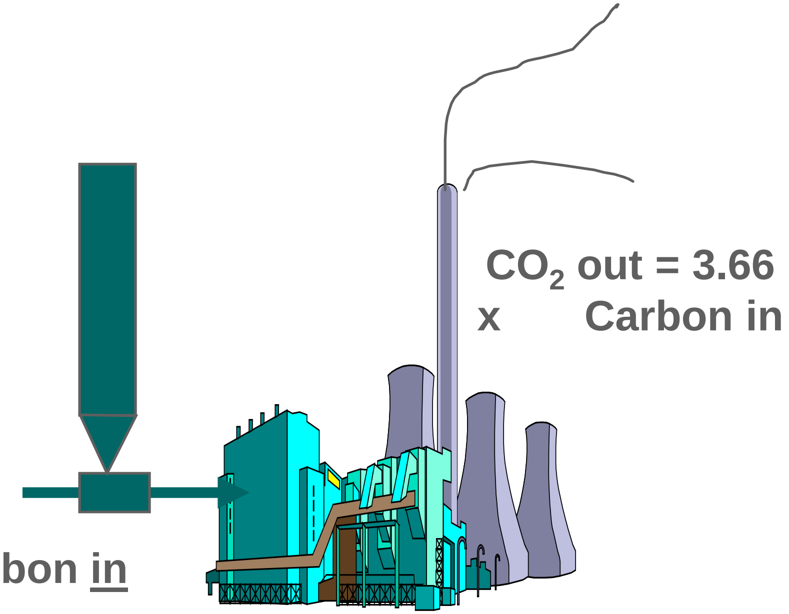
US Coal Plants 2008 CO_2 Data

Weighting typical ultimate values

Coal Source	Fixed Carbon (%)	Higher Heating Value (Btu/lb)	Coal Fired in Utility Boilers (Million Tons)	Carbon Fired (Million Tons)	CO2 produced (Million Tons)	Heat Produced (Million Btu's)
Western	47%	8000	565.5	263.0	964.2	9.0E+09
Appalachian	77%	13650	347.9	266.5	977.0	9.5E+09
Interior	62%	11200	130.2	80.2	294.1	2.9E+09
Total			1043.6	609.6	2235.3	2.1E+10

US Electricity Production	2.0E+12	KW-hr
US CO2 Production	2.1E+09	Tons
US Coal Thermal Energy	2.1E+16	BTU
Net Plant Heat Rate	10,761	BTU/kw-hr
Overall Efficiency	31.71	%
CO2 Conversion Rate	0.10	Ton CO2/MMBTU
CO2 Efficiency	2.15	lbs/kwhr

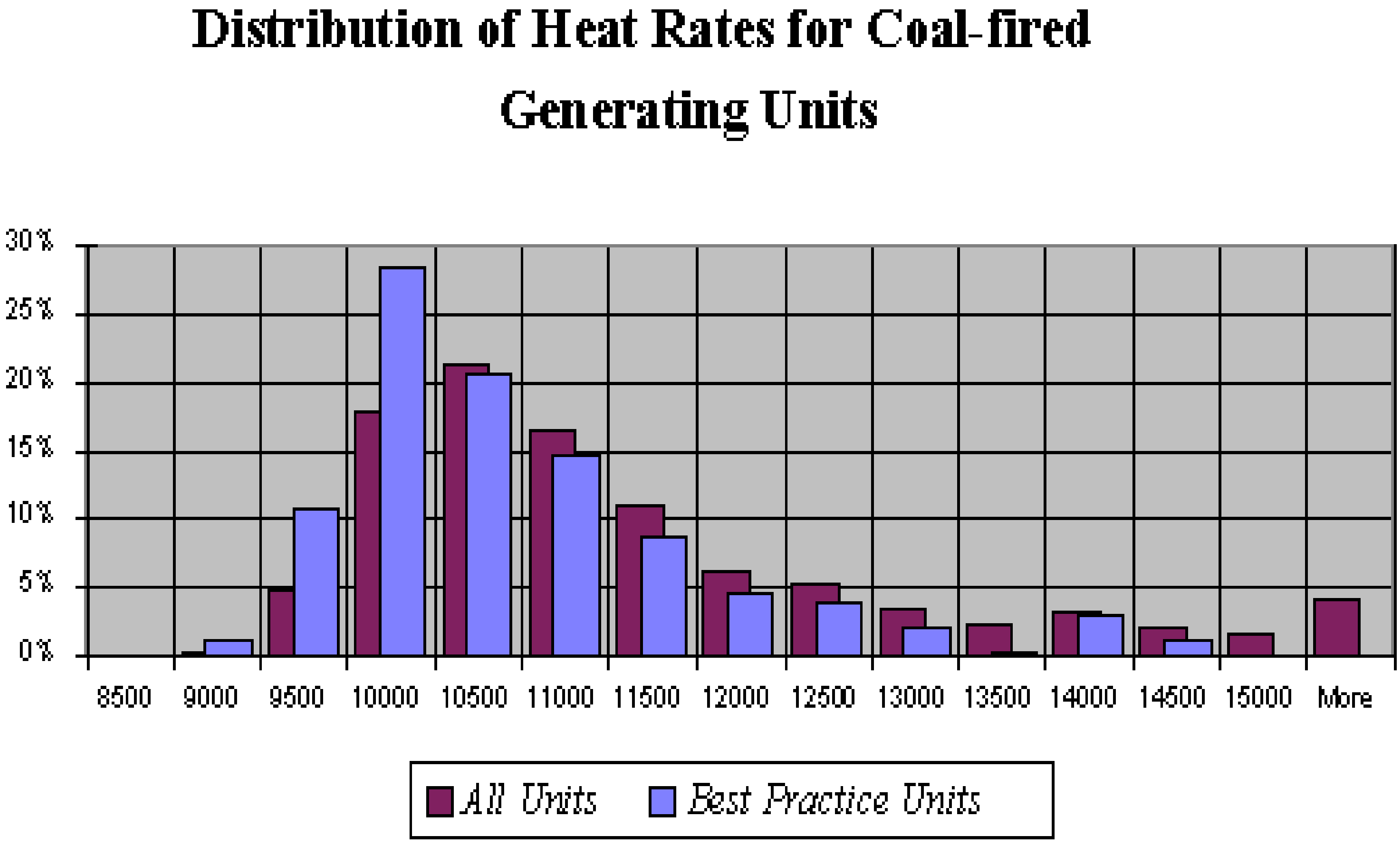


CO_2 out = 3.66 x Carbon in

Carbon in

Source: US EIA and Alstom Fuel databases.
CO2 in top table from fuel analysis CO2 in lower table from EIA

Range of Heat Rates - 1,098 US Boilers



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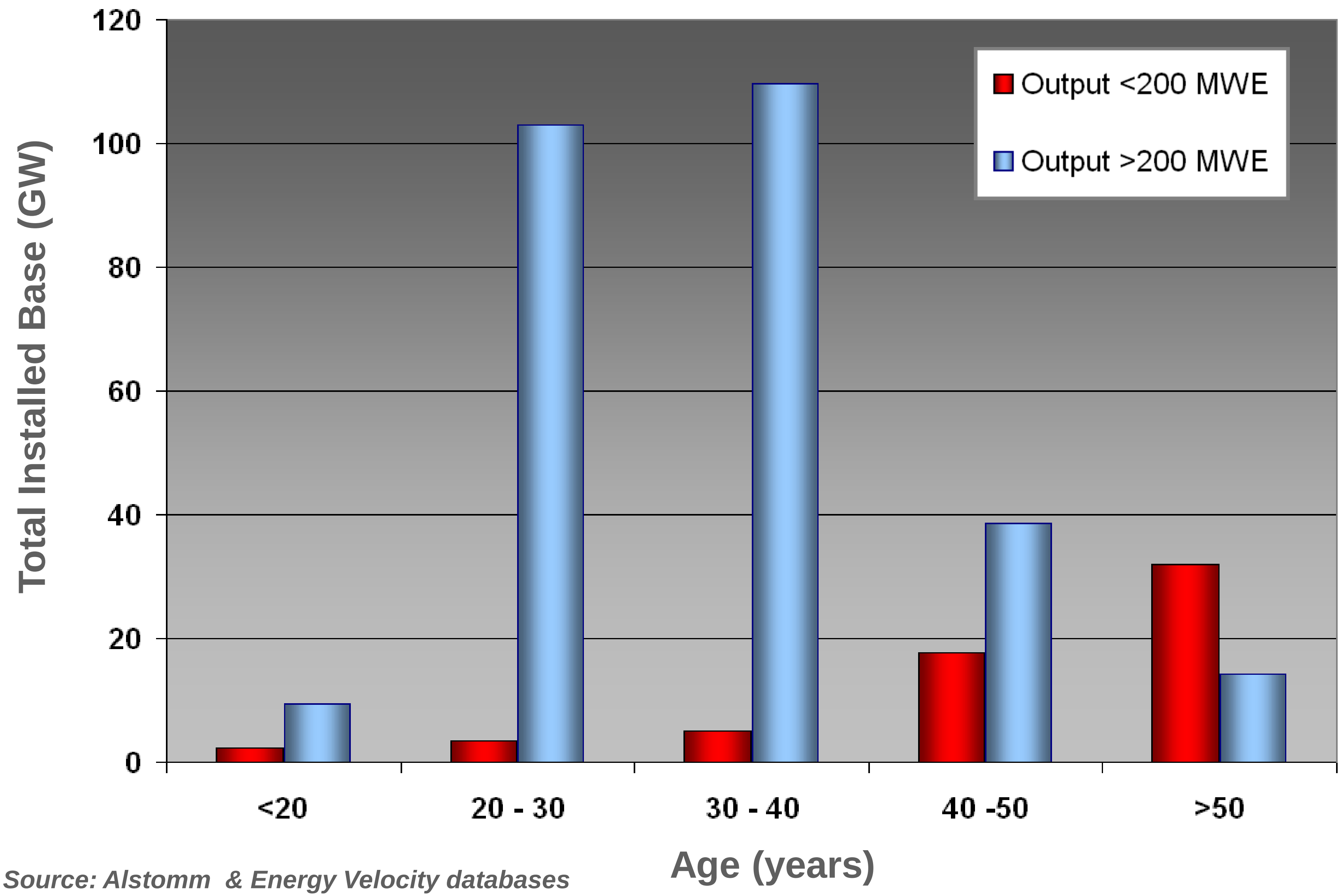
US Coal Power Plants

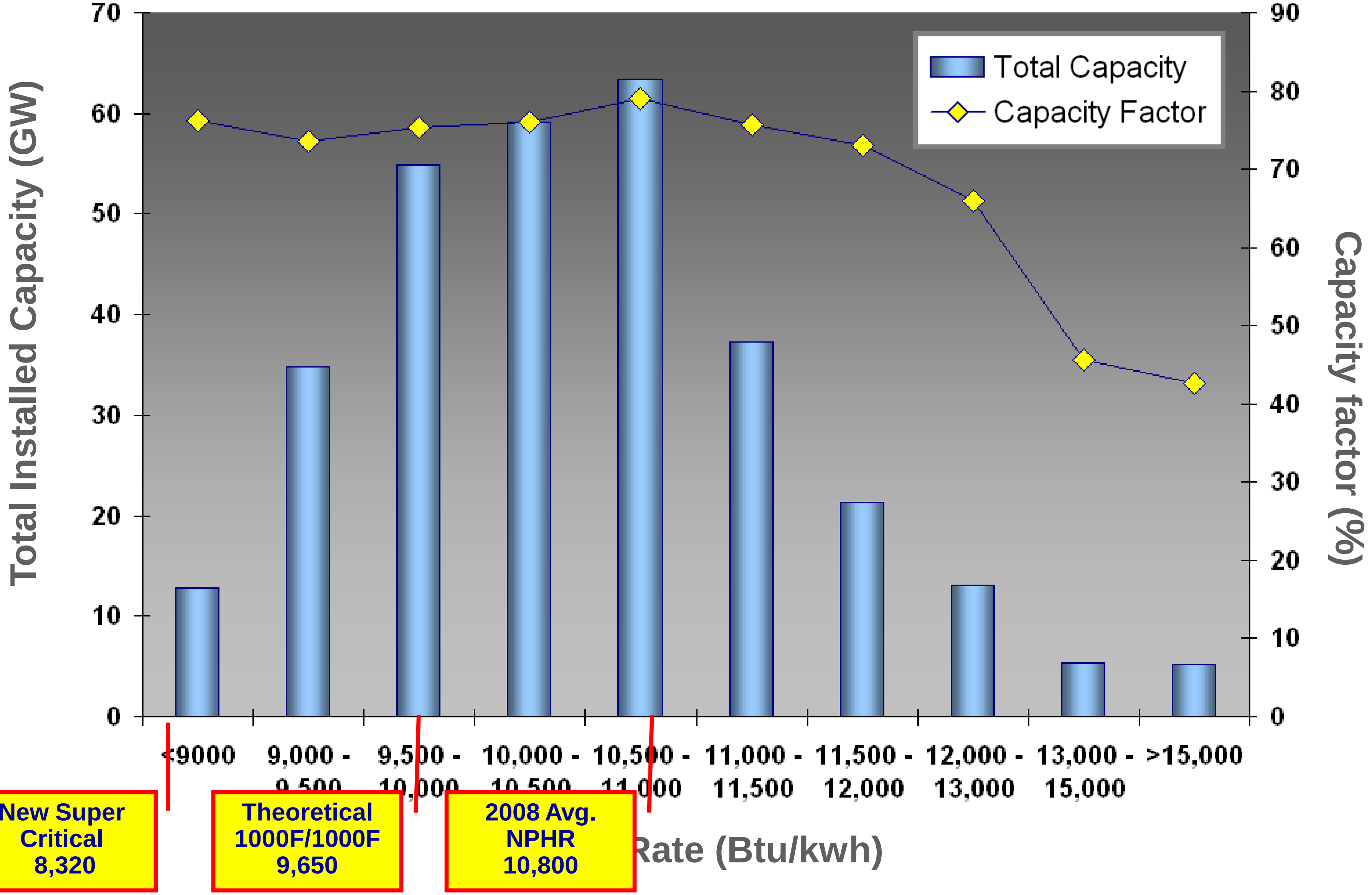
Installed Base (GW) vs. Age (years)



Source: Alstomm & Energy Velocity databases

Coal Power Plant

Installed GW and Capacity Factor vs. Heat Rate

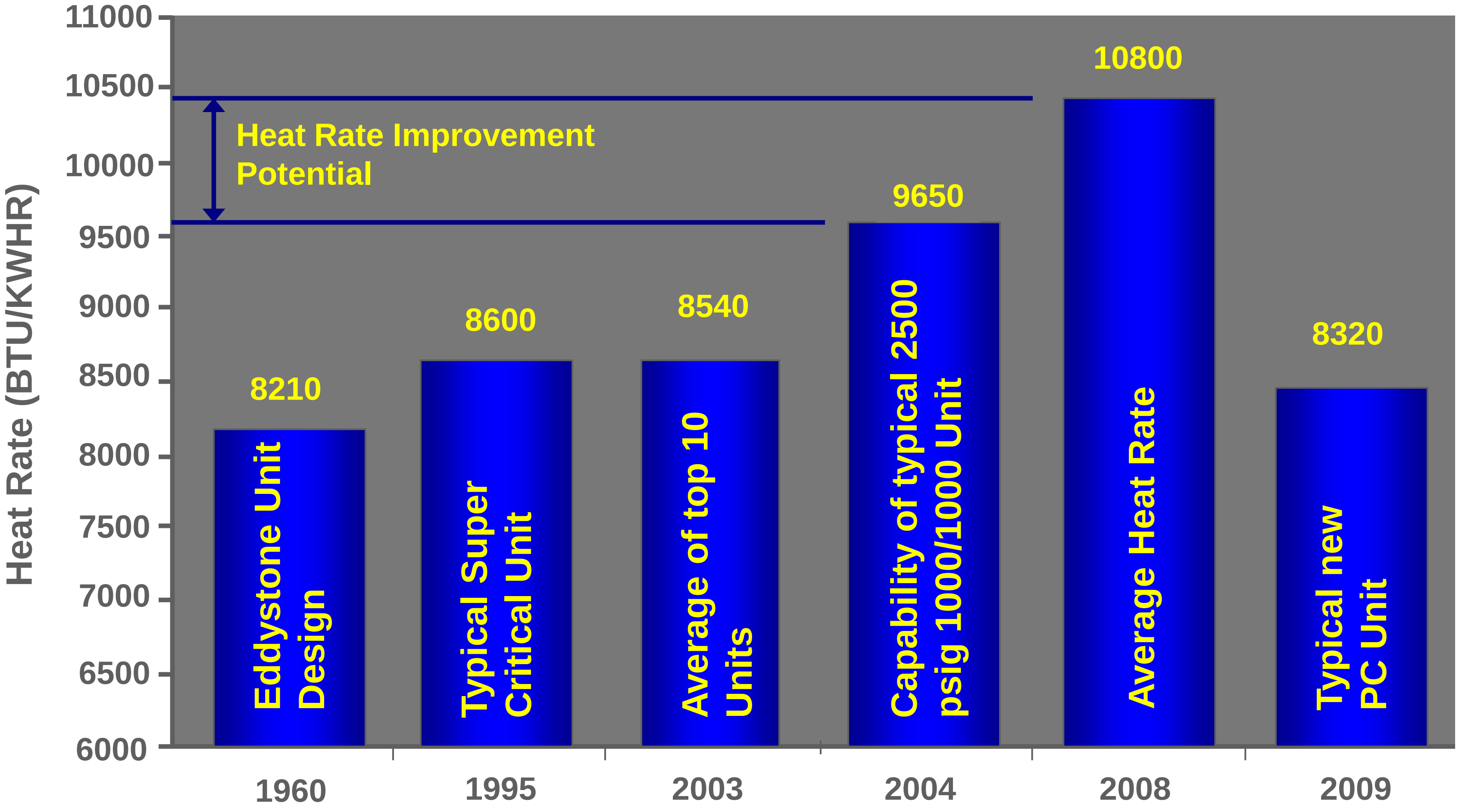


New Super Critical 8,320

Theoretical 1000F/1000F 9,650

2008 Avg. NPHR 10,800

Heat Rate Capability



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CO_2 Reduction Potential

- Given our current annual electric production from coal (1.99×10^{12} kWhr),
- If we reduce losses by 500 BTU/kW per plant (~5%),
- We would achieve an annual reduction of 100 million tons of CO_2 **!**
- Even greater reductions would be achieved with new Super Critical Boilers

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Lower Cost of Energy Leads to Long Term Jobs for Industry

- Increasing the energy efficiency reduces the cost of generation and thus the cost to the Consumer
  - Lower fuel costs
  - Lower maintenance costs
  - Lower operating costs
  - Less emissions
- In the Industrial market reducing energy costs allows industry to be more competitive globally.
  - Lower electric rates by the utility

    And or
  - Lower internally produced energy costs
- More competitive Industry keeps and increases jobs in the USA for the long term.

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So what is stopping us?
New Source Review - NSR

Even the EPA admits that NSR has unintended consequences:

“As applied to existing power plants and refineries, EPA concludes that the NSR program has impeded or resulted in the cancellation of projects which would maintain and improve reliability, efficiency and safety of existing energy capacity. Such discouragement results in lost capacity, as well as lost opportunities to improve energy efficiency and reduce air pollution.”

Source: EPA - New Source Review: Report to the President June 2002

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EPA Math (Abbott & Costello video)

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Improving Existing Plant Performance

- Establish Target Performance
- Test Existing Unit
  - Using ASME PTC 46 Methodology
- Analyze Differences
- Identify Root cause of performance Issues
- Plan and Implement repairs

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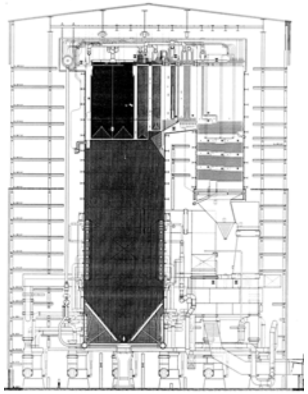
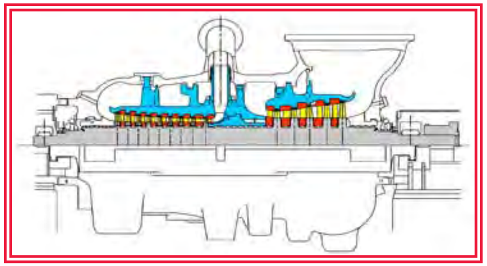
EPRI Heat Rate Approximate Impacts for Various Deviations on Plant Performance

HP Turbine Efficiency	18.8	BTU/kWh/%	19.8	kJ/kWh/%
IP Turbine Efficiency	14.5	BTU/kWh/%	15.3	kJ/kWh/%
Throttle Temperature	1.4	BTU/kWh/°F	2.7	kJ/kWh/°C
Throttle Pressure	0.35	BTU/kWh/Psi	5.36	kJ/kWh/bar
RH Temperature	1.3	BTU/kWh/°F	2.5	kJ/kWh/°C
SH Spray Flow	0.246	BTU/kWh/kLb/Hr Flow	0.03	kJ/kWh/kg/s
RH Spray Flow	2.15	BTU/kWh/kLb/Hr Flow	0.29	kJ/kWh/kg/s
Excess O2	29.4	BTU/kWh/%	31.0	kJ/kWh/%
AH Outlet Temp	2.7	BTU/kWh/°F	5.1	kJ/kWh/°C
Condenser Backpressure	204	BTU/kWh/In. Hg	6.36	kJ/kWh/mbar
Make Up	24	BTU/kWh/%	25.3	kJ/kWh/%
Top FW Htr	2.1	BTU/kWh/Deg F(TTD)	4.0	kJ/kWh/°C(TTD)
Next to Top FW Htr	0.54	BTU/kWh/Deg F(TTD)	1.03	kJ/kWh/°C(TTD)
Top FW Htr out of Service	94	BTU/kWh	99	kJ/kWh



14.504	PSI	=	1	bar	=	100	kPa
7.937	klb/h	=	1	kg/s			
0.948	BTU	=	1	kJ			



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Efficiency Improvement Options (Steam Power Plants)

Steam Plant Efficiency = (Boiler Efficiency) x (Steam Cycle Efficiency) x (1- Auxiliary power fraction)

Boiler Efficiency Improvements

- Reduce Stack Loss
  - Reduce Stack Temperature
    - Air Heater Upgrade
    - Inc Air Flow Through AH
      - Minimize Tempering air flow
      - Minimize air leakage
    - Condensing Heat Exchanger
    - Sootblowing Optimization
      - Timing
      - Sequence
      - Locations
      - Nozzles
      - Pressure
      - Medium
  - Reduce Stack Flow
    - Low Excess Air
      - Reduced Air Infiltration
  - Reduce Stack Moisture
    - Fuel Change
- Reduce Other Losses
  - Less Unburned Carbon / CO etc.
    - Flyash carbon separation/combustion
    - OFA / Burner / Mill optimization
  - Better Insulated Unit
  - Heat Recovery from Ash
  - Pulverizer Rejects

Steam Cycle Efficiency Improvements

- Higher Steam Conditions
  - Pressure, Temperature
  - Additional Reheat Stages
- Additional Regeneration
  - More FWH's
  - Topping De-superheaters
- Lower Condenser Pressure
  - Cooling Tower Improvements
- Better Steam Expansion
  - Blade Profile Improvements
  - Minimize leaks
  - Reduce Exhaust Loss
    - Larger LP Turbines
- Lower Pressure Drops
  - Steam and Water
- Better Pump Efficiency
  - Boiler Feed Pump
  - Condensate Pump
  - Cooling System Pumps
- Smaller Leakage Quantities
- Minimize De-superheater Spray Quantities
  - Reheater(s)
  - Superheater

Auxiliary Power Reductions

- Lower Excess Air
- Lower Pressure Drops
  - Air and Gas Side
    - CFB combustor, FBHE
    - Less combustor inventory
  - Water Steam Side
- Better Component Efficiencies
  - Fans
    - Pressurized unit (no ID fan)
  - Pulverizers
  - Pumps
  - Generator
  - Transformer
  - Drive Motors
- Air Pollution Control System
  - Adipic acid addition
  - Coarser limestone
  - Reduce flue gas bypass
  - ESP instead of Fabric Filter
- Miscellaneous
  - Sootblowing Optimization
  - Reduce Air Heater Leakage

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ALSTOM

Proven New Technologies to help improve Efficiency

- New Unit Technologies – Supercritical and Ultra Supercritical
- Turbine upgrades with new higher efficiency blading
- New Condenser Designs
- New Cooling Tower designs
- New Controls
- Boiler design changes to reflect current operation
- Pulverizers – Dynamic Classiffiers etc, to reduce Carbon Loss
- AH – Leakage control, high efficiency baskets
- Variable speed drives for Fans, CW pumps for part load operation

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Supercritical versus Subcritical Cycle - Impact on Emissions

	Subcritical	Supercritical
Plant Efficiency, %*	34 - 37	37 - 41
Plant Heat Rate, Btu / kW-hr	10,000 - 9,200	9,200 - 8,300

Plant Efficiency, %	34%	37%	41%
Fuel Consumption and Total Emissions including CO_2	Base	Base-8%	Base-17%

*** HHV Basis**

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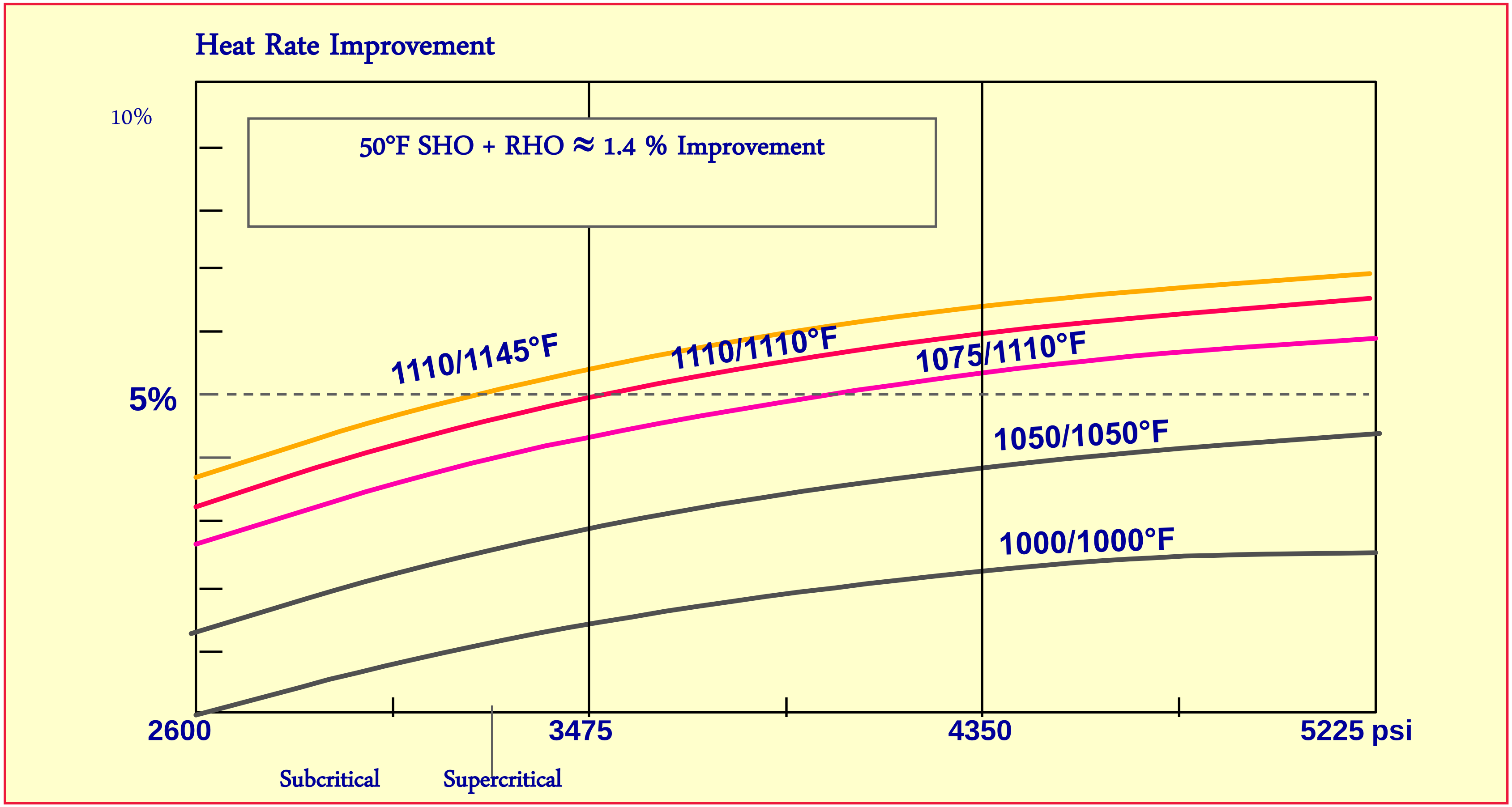
Sub vs. Supercritical / Ultra-Supercritical Cycles

Heat rate improvement vs. steam conditions (single reheat)



Lower Fuel Consumption and Lower Emissions/ kWh

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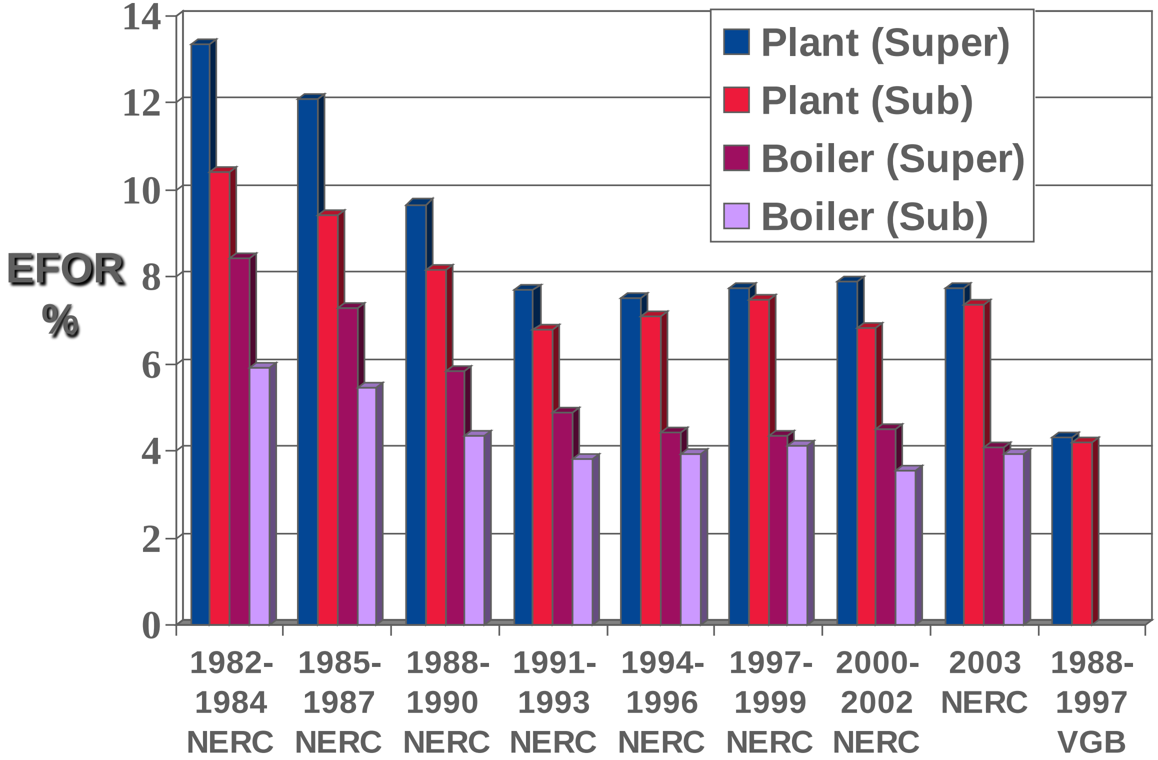
Comparable Availability of Supercritical and Subcritical Units



Studies to investigate differences in availability due to subcritical / supercritical steam parameters:

- **NERC-US (1989): "Boiler tube failure trends"**
- **VGB-D (1988-97): "Availability of thermal power plants"**

All studies came to the conclusion:
"There is no significant difference in availability due to subcritical/supercritical steam parameters for today's plant designs"

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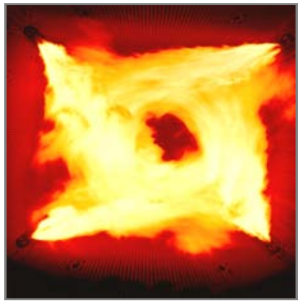
Optimized Plant Retrofit

Essentially a Steam Turbine ***and*** Boiler Retrofit ***and*** Emissions Control System Evaluation and Upgrade conforming to a thermal specification which is established by a team of plant specialists (Alstom & Customer) to optimize the plant as a whole.

Turbine Retrofit

+



Boiler Retrofit

+

Environmental Retrofit

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Optimized Plant Retrofit Objectives & Scope

- Maximize potential of existing power plant assets
  - Identify latent steam generating capability of boiler
  - Determine requirements for turbine to accept full boiler output

- Optimize increase in Heat Rate, Efficiency, & Power Output

- Assess Balance of Plant capabilities/limitations
    - Assess BOP systems and components (fans, pumps, ash handling, water handling, etc.) to support boiler turbine island

- Reduce Relative Emissions with Efficiency and/ or Equipment Improvements

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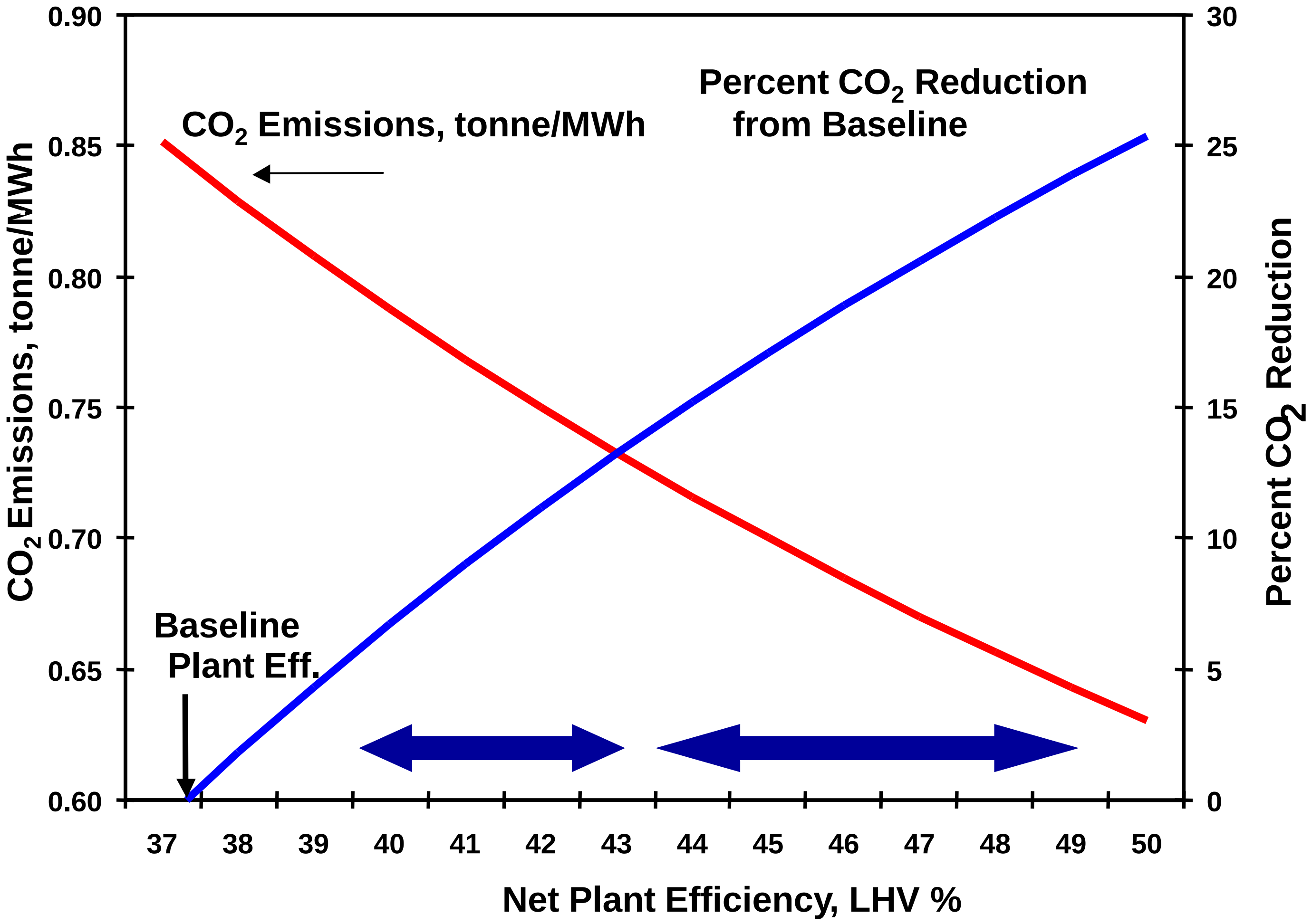
CO_2 Emissions vs Net Plant Efficiency



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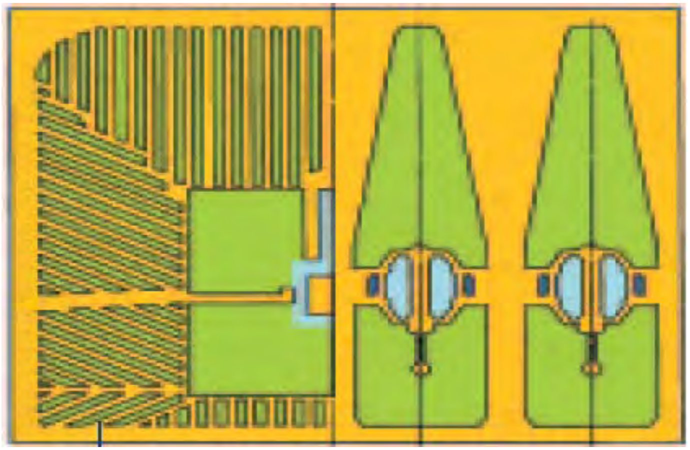
New Condenser Design

- Optimizes Thermal Performance
  - Minimizes air binding
  - Less Condensate sub cooling



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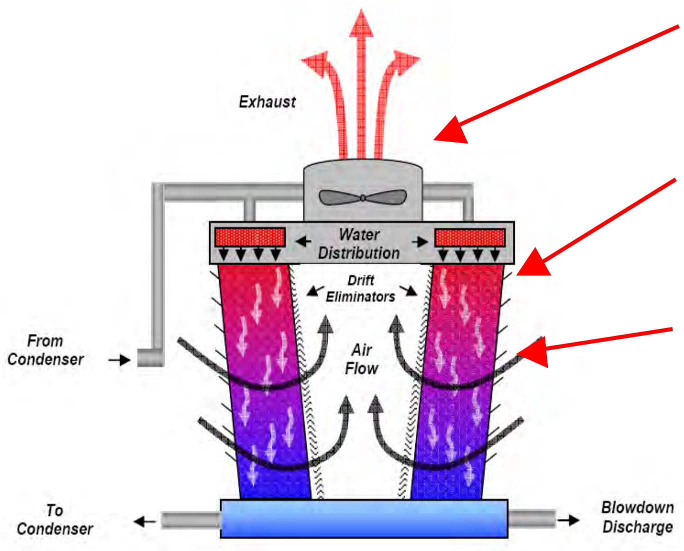
Cooling Tower Improvements

Improvement Cell Cooling Towers



Increase Fan Power

Retrofit Fills

Reduction Of Plume Recirculation

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Controls Modification

- Modern DCS Controls
- Neural Net Controls
- Intelligent Sootblowing
- Advanced Steam Temperature Control

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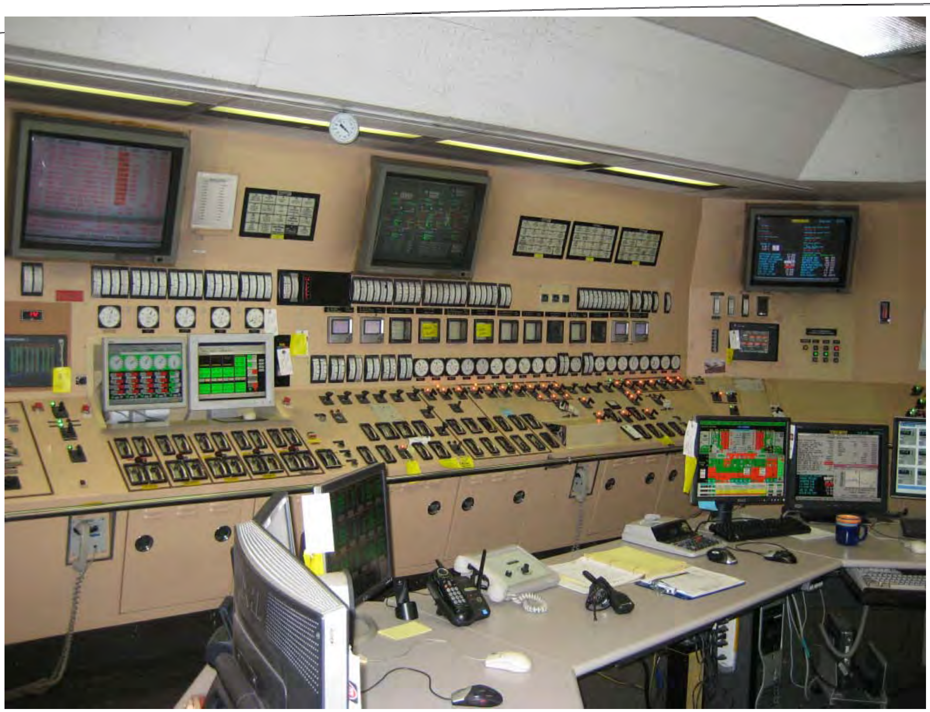
Before and After Controls Upgrade



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Boiler Modifications to Improve Efficiency

- Optimizing Boiler Pressure Parts Surfaces
  - Attaining Full Steam Temperatures
  - Optimizing Sprays
  - Controlling Exit Gas Temperature
  - Optimizing Excess Air Levels

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Air Heater Heat Transfer Surface Development

Cold End - DNF® Surface

Old NF profile

Upgrade

Latest DNF® profile

Upgrading the cold end layer to the latest design of DNF® heat transfer surface profiles can enhance thermal recovery while maintaining closed channel cold end cleanability of the surfaces.

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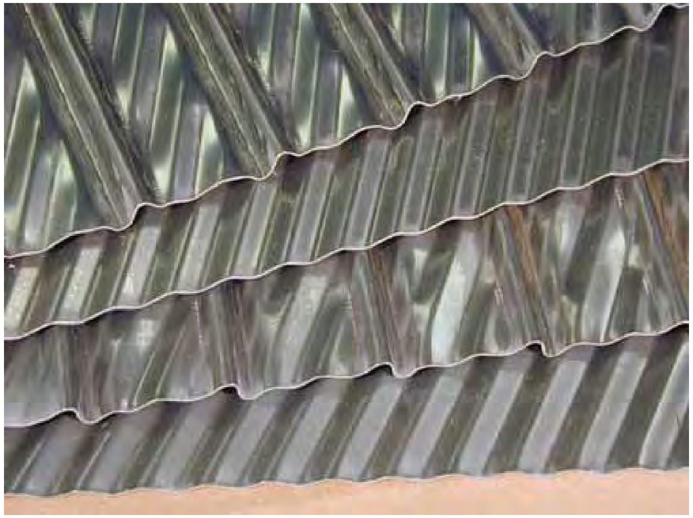
Heat Transfer Surface Development

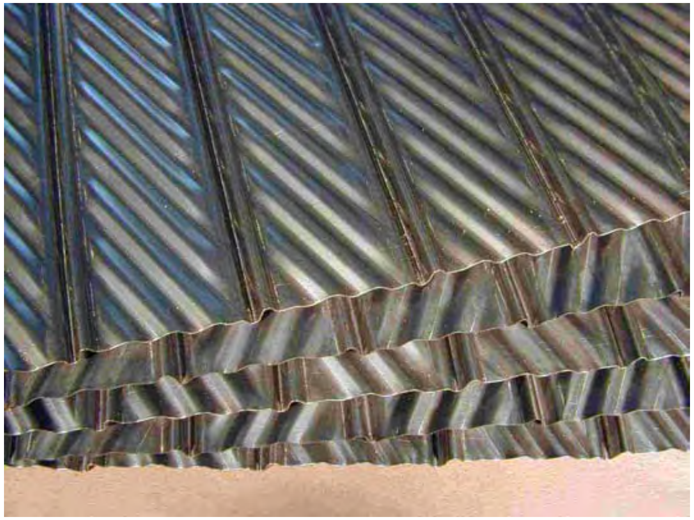
Hot End - DN7™ Surface

Old DU profile



Upgrade

Latest DN7™ profile



Upgrading the hot end layers to the latest design of DN7™ heat transfer surface profiles can enhance thermal recovery, and improve flow distribution through the layers.

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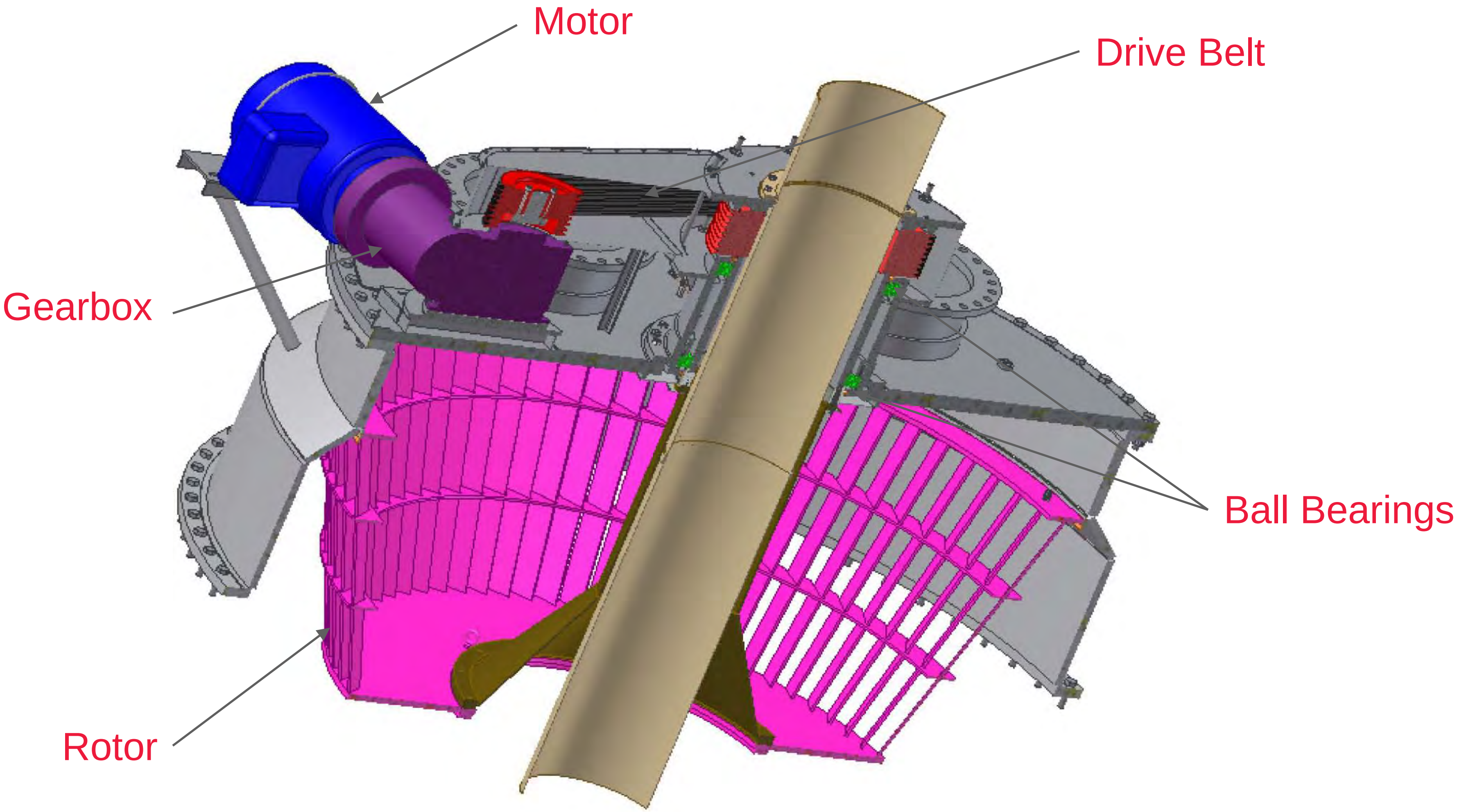
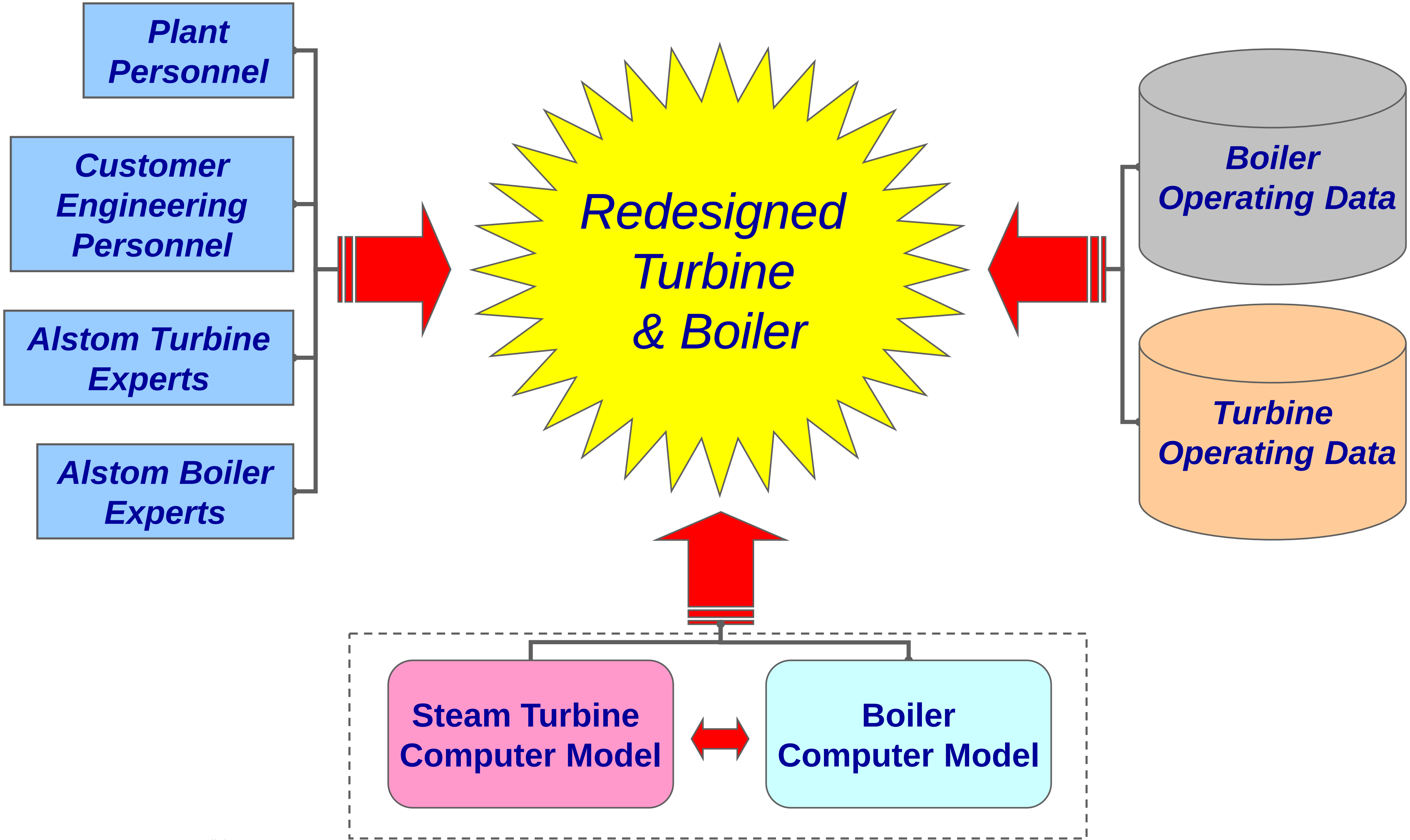
Pulverizer DYNAMIC™ Classifier Applications



DYNAMIC™ Classifier Applications – Case Study

	Unit # 2	
Test	Base Line Test	Guarantee
% UBC	6.24%	2.85%
% UBC Reduction		54%
% Thru 200 Mesh	58.5% to 68.4%	81.1% to 88.1%
% Thru 50 Mesh	97.9% to 99.1%	99.9% to 99.97%

Joint Project Team Design (JPTD) Process



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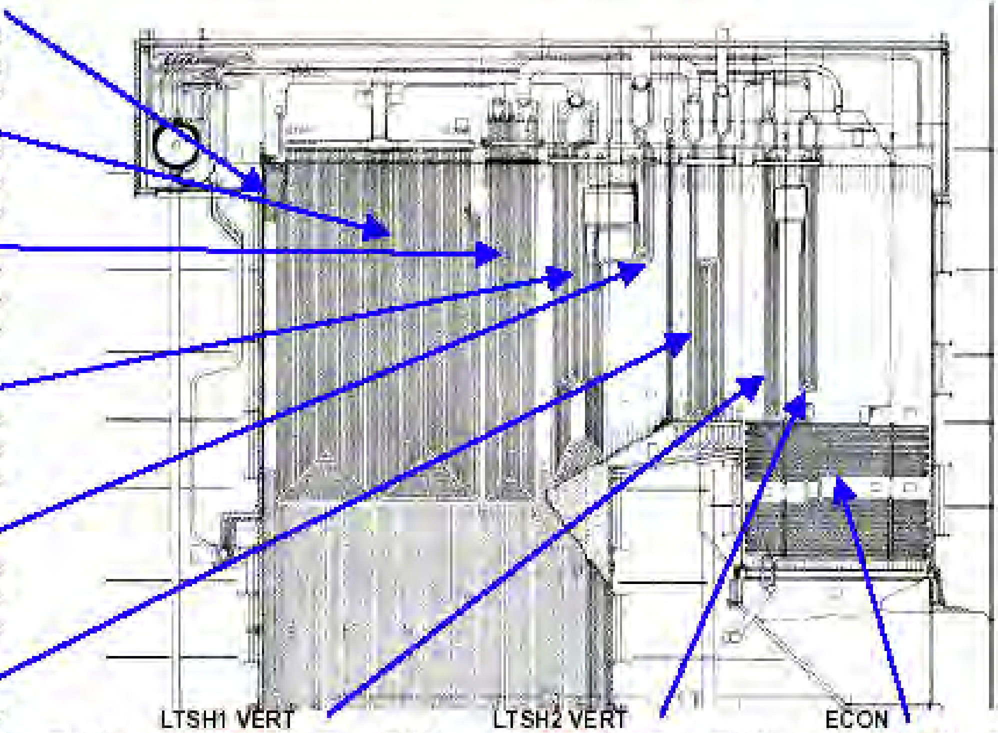
JPTD Boiler & Turbine Modeling Results Example

Run No. 21 Run Type Same as Run 20 (with new Steam Turbine Condition with RH Finishing on 9.5" centers - platenized & New In-Line SFS Econ) but running Steam Turbine a
2470psig Throttle pressure and increase main steam flow and 6 mill in Service



RH RADWALL		
Fluid In	609.9	deg. F
Fluid Out	649.3	deg. F
Gas In	2711	deg. F

SH PANELS		
Fluid In	714.5	deg. F
Fluid Out	788.7	deg. F
Gas In	2711	deg. F

SH PLATEN		
Fluid In	786.2	deg. F
Fluid Out	876.0	deg. F
Gas In	2338	deg. F
SEF	0.87	

RHI FINISH		
Fluid In	649.3	deg. F
Fluid Out	909.5	deg. F
Gas In	2179	deg. F
SEF	1.01	

RHO FINISH		
Fluid In	909.5	deg. F
Fluid Out	1003.9	deg. F
Gas In	1871	deg. F
SEF	1	

SH FINISH		
Fluid In	876.0	deg. F
Fluid Out	1000.6	deg. F
Gas In	1709	deg. F
SEF	1.16	

LTSH1 VERT		
Fluid In	697.7	deg. F
Fluid Out	714.5	deg. F
Gas In	1479	deg. F
SEF	0.88	

LTSH2 VERT		
Fluid In	689.8	deg. F
Fluid Out	697.7	deg. F
Gas In	1379	deg. F
SEF	0.85	

ECON		
Fluid In	491.4	deg. F
Fluid Out	654.3	deg. F
Gas In	1284	deg. F
Gas Out	769	deg. F
SEF	0.69	
Subcooling	30.6	deg. F

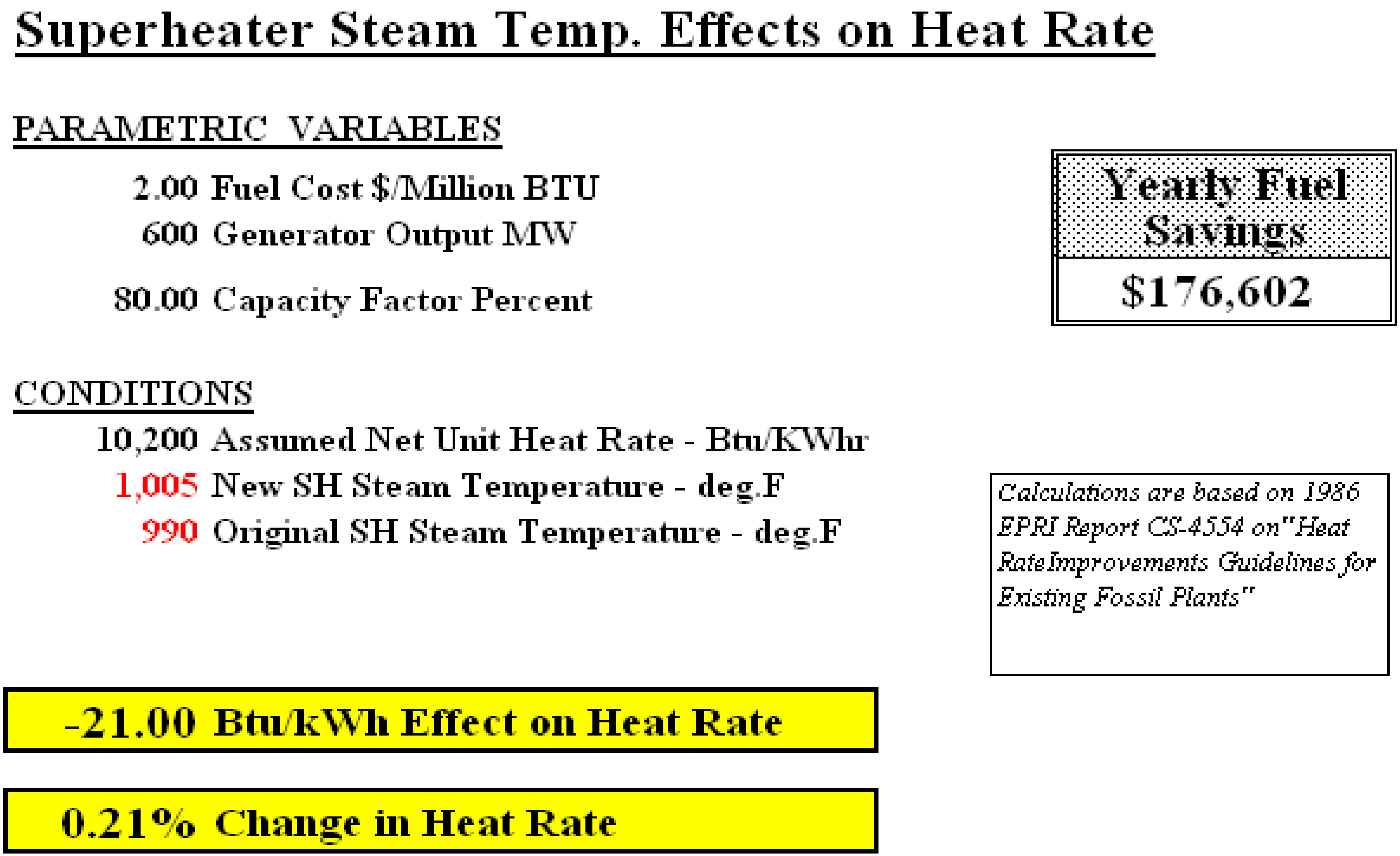
General Performance Information		
SH Steam Flow	3,935,613	lbs/hr
RH Steam Flow	3,535,221	lbs/hr
SHO Temp	1001.0	°F
SH Desup Spray	0.30	%
RH Desup Spray	1.10	%
SHDesuperheater Spray	11263	lbs/hr
RHDesuperheater Spray	39359	lbs/hr
RHO Temp	1004.0	°F
RHDESUP OUT TMP	610.0	°F
Feedwater Temp	491.0	°F
Econ Exit Gas Temp	769.0	°F
AH TGO Uncorr	320.0	°F
AH TGO Corr	306.0	°F
Tilt	-11	degree
Excess Air	26	%
Fuel Fired	618,334	lbs/hr
Boiler Efficiency	85.45	%
NHI/PA	2.08	Mbtu/h

Steam Turbine Performance		
Output	571,060	KWs
Turbine Heat Rate	8,128	BTU/K
Superheater Outlet Flow	3,935,613	lbs/hr
Main Steam Temp.	1,000	°F
Throttle Pressure	2,470	psia
Cold RH Flow	3,495,862	lbs/hr
Cold RH Pressure	638	psia
Cold RH Temp.	633	°F
Hot RH Flow	3,531,173	lbs/hr
Hot RH Pressure	569	psia
Hot RH Temp.	1,000	°F
Reheater Spray Flow	35,312	lbs/hr
Main Condenser Pressure	1.8	psia

Mill Performance

Air In Per Mill		197,938	lbs/hr	Outlet Moisture	15.66	%
COAL FLOW PER MILL		103,056	lbs/hr	Hot Air Temperature Required	569.6	°F
NO. MILLS IN SERVICE		6 OF 6		TEMPERING AIR TEMP.	82	°F
Grinding Capacity		79.1	%	AVAILABLE HOT AIR TEMP.	691	°F
MIXTURE TEMPERATURE		146	°F			

Boiler Parameters Impact on Heat Rate



Superheater Steam Temp. Effects on Heat Rate

PARAMETRIC VARIABLES

2.00 Fuel Cost $/Million BTU
600 Generator Output MW
80.00 Capacity Factor Percent

Yearly Fuel Savings
$176,602

CONDITIONS

10,200 Assumed Net Unit Heat Rate - Btu/KWhr
1,005 New SH Steam Temperature - deg.F
990 Original SH Steam Temperature - deg.F

Calculations are based on 1986 EPRI Report CS-4554 on"Heat RateImprovements Guidelines for Existing Fossil Plants"

-21.00 Btu/kWh Effect on Heat Rate

0.21% Change in Heat Rate

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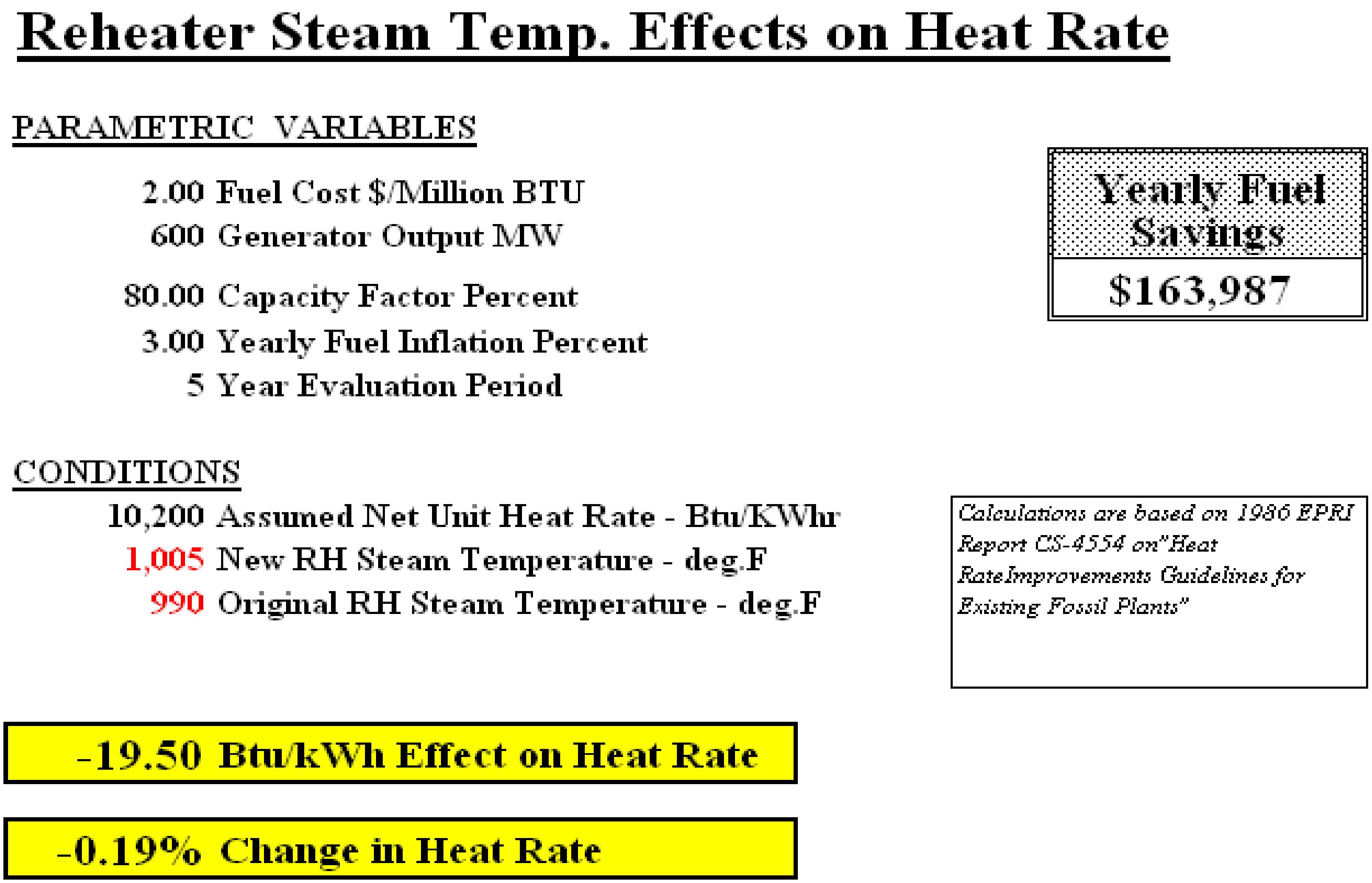
Boiler Parameters Impact on Heat Rate



Reheater Steam Temp. Effects on Heat Rate

PARAMETRIC VARIABLES

2.00	Fuel Cost $/Million BTU
600	Generator Output MW
80.00	Capacity Factor Percent
3.00	Yearly Fuel Inflation Percent
5	Year Evaluation Period

Yearly Fuel Savings

$163,987

CONDITIONS

10,200	Assumed Net Unit Heat Rate - Btu/KWhr
1,005	New RH Steam Temperature - deg.F
990	Original RH Steam Temperature - deg.F

Calculations are based on 1986 EPRI Report CS-4554 on"Heat RateImprovements Guidelines for Existing Fossil Plants"

-19.50 Btu/kWh Effect on Heat Rate

-0.19% Change in Heat Rate

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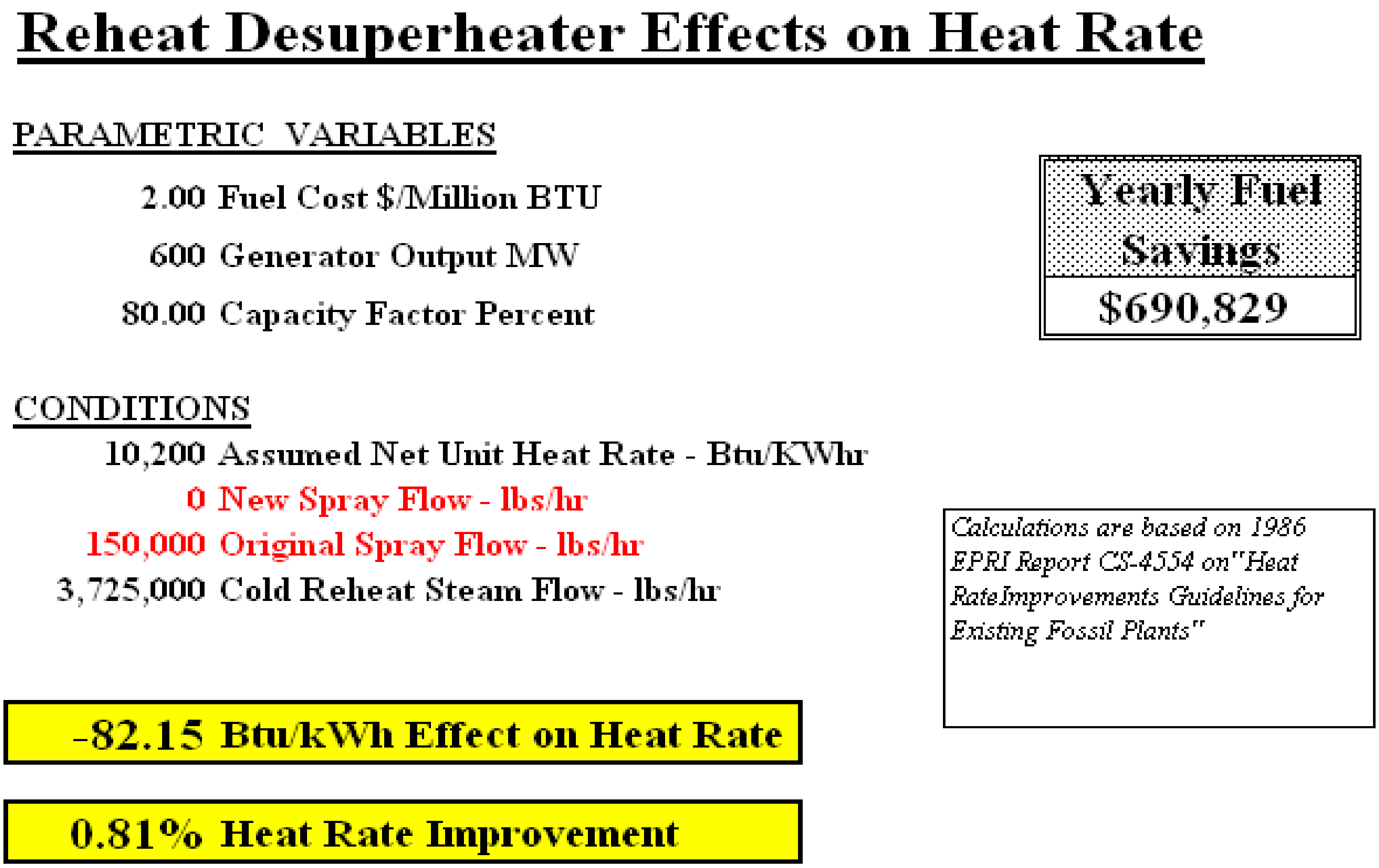
Boiler Parameters Impact on Heat Rate



Reheat Desuperheater Effects on Heat Rate

PARAMETRIC VARIABLES

2.00	Fuel Cost $/Million BTU
600	Generator Output MW
80.00	Capacity Factor Percent

Yearly Fuel Savings
$690,829

CONDITIONS

10,200	Assumed Net Unit Heat Rate - Btu/KWhr
0	New Spray Flow - lbs/hr
150,000	Original Spray Flow - lbs/hr
3,725,000	Cold Reheat Steam Flow - lbs/hr

Calculations are based on 1986 EPRI Report CS-4554 on "Heat RateImprovements Guidelines for Existing Fossil Plants"

-82.15 Btu/kWh Effect on Heat Rate

0.81% Heat Rate Improvement

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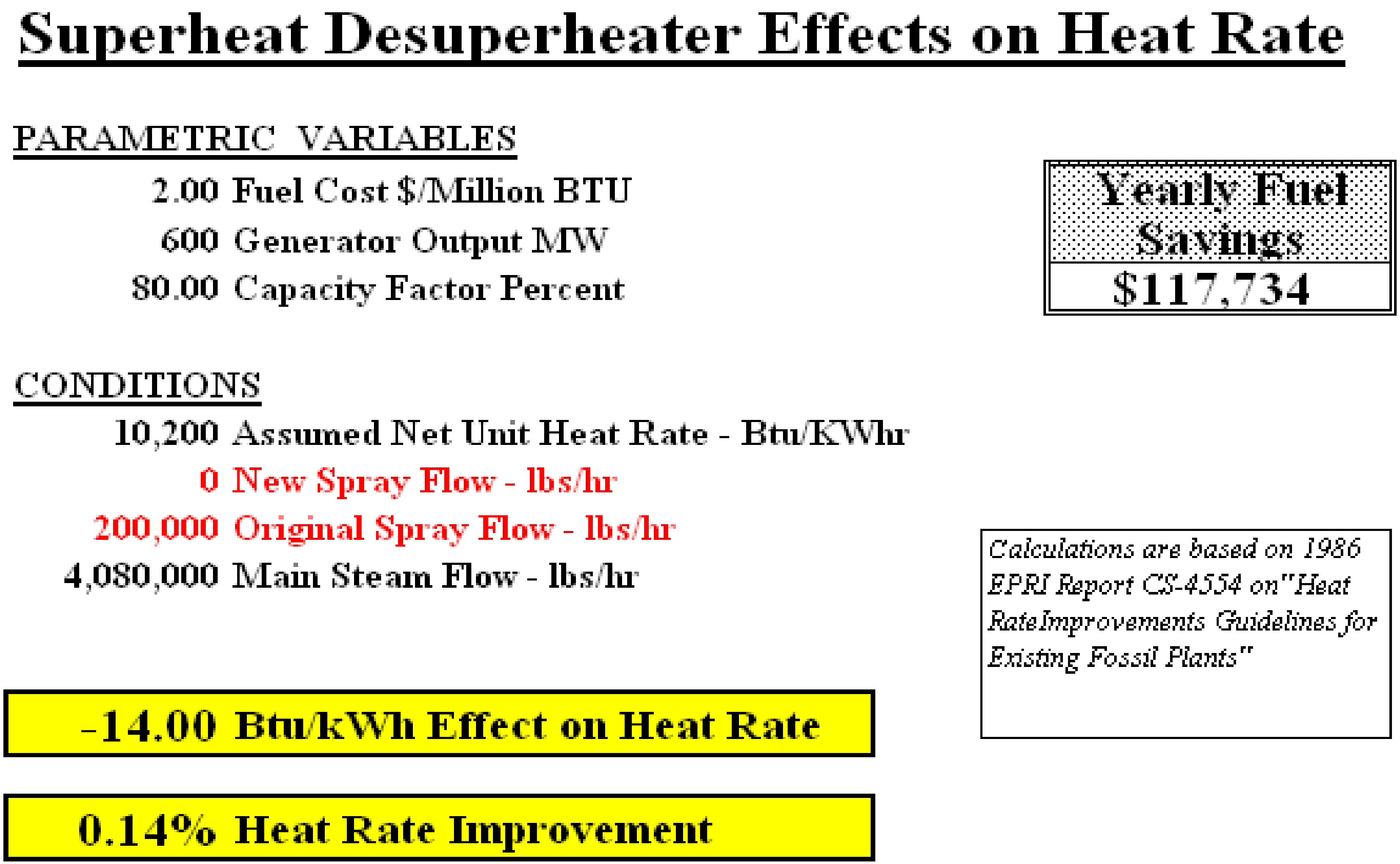
Boiler Parameters Impact on Heat Rate



Superheat Desuperheater Effects on Heat Rate

PARAMETRIC VARIABLES

2.00	Fuel Cost $/Million BTU
600	Generator Output MW
80.00	Capacity Factor Percent

Yearly Fuel Savings
$117,734

CONDITIONS

10,200	Assumed Net Unit Heat Rate - Btu/KWhr
0	New Spray Flow - lbs/hr
200,000	Original Spray Flow - lbs/hr
4,080,000	Main Steam Flow - lbs/hr

Calculations are based on 1986 EPRI Report CS-4554 on "Heat RateImprovements Guidelines for Existing Fossil Plants"

-14.00 Btu/kWh Effect on Heat Rate

0.14% Heat Rate Improvement

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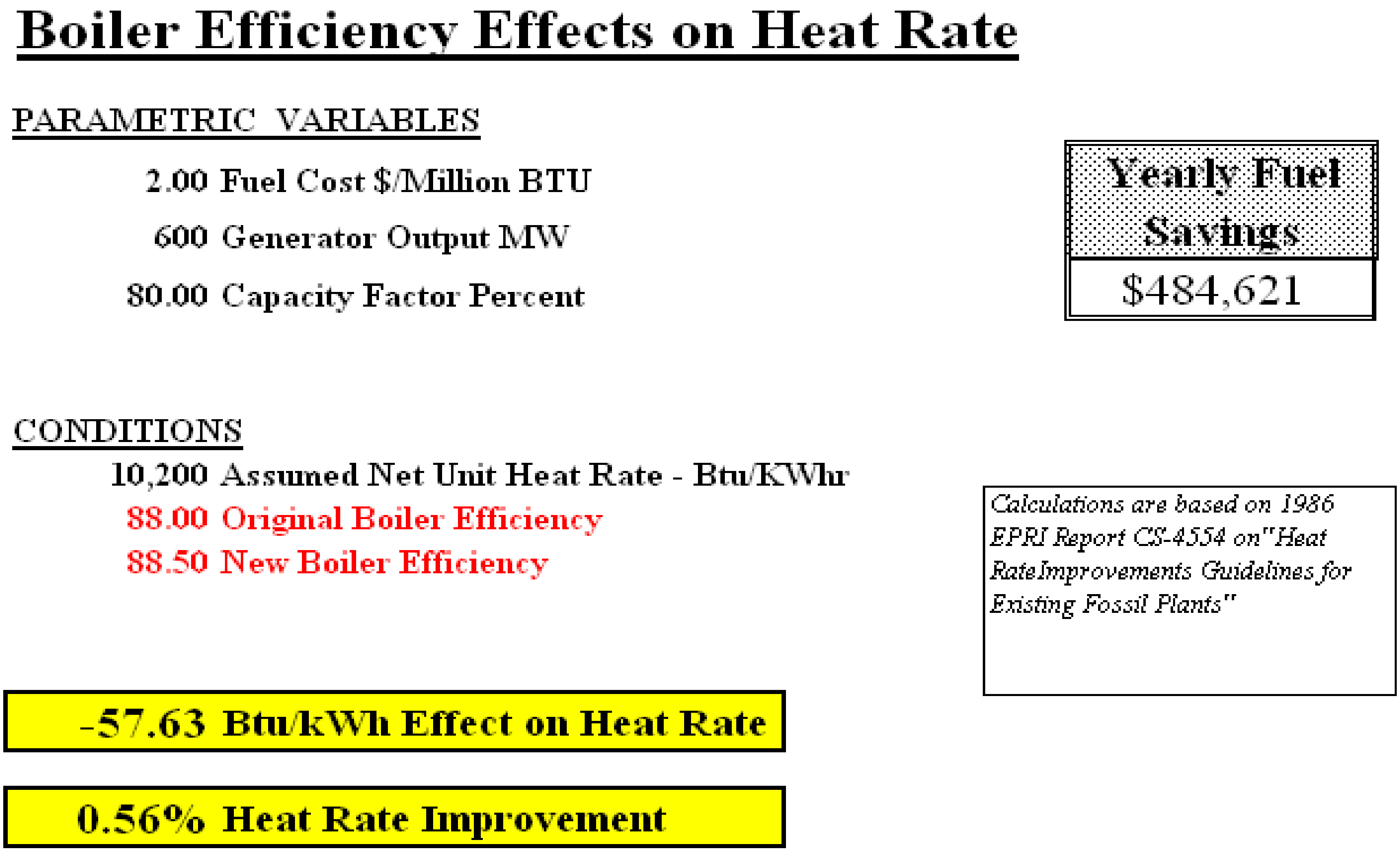
Boiler Parameters Impact on Heat Rate



Boiler Efficiency Effects on Heat Rate

PARAMETRIC VARIABLES

2.00 Fuel Cost $/Million BTU
600 Generator Output MW
80.00 Capacity Factor Percent

Yearly Fuel Savings
$484,621

CONDITIONS

10,200 Assumed Net Unit Heat Rate - Btu/KWhr
88.00 Original Boiler Efficiency
88.50 New Boiler Efficiency

Calculations are based on 1986 EPRI Report CS-4554 on "Heat Rate Improvements Guidelines for Existing Fossil Plants"

-57.63 Btu/kWh Effect on Heat Rate

0.56% Heat Rate Improvement

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The Performance & Environmental Monitor

This system has two objectives;

- To be a state of the art measurement system for CO_2 emissions exceeding by far the accuracy of anything available today
- A performance enhancement service where experts from Alstom work with plant personnel to improve energy efficiency (heat rate) and thus reduce the carbon footprint of the facility.

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The Performance and Environmental Monitor*

- CO2 Monitor
  - More accurate than conventional CEMS (CEMS are potentially +/- (more likely +) 7.5% Alstom CO2 monitor +/- 1.6%)
  - CEMS tend to overestimate stack flow & Factors are biased high
  - The 5.9% difference is worth $2.7 Million additional per year for a typical 600 MW Coal-Fired Unit (CO2 @ 10$/T)
- Heat Rate Deviation reporting
  - Identifies areas where efficiency is being lost

- Remote Expert Support
  - Helps customer sort through data and identify causes of heat rate deviations
  - Recommends solutions to identified problems

*US Patent 8626450

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Methodology

- Boiler Efficiency by Heat Loss Method
- Heat absorbed by steam divided by Boiler Efficiency to determine heat input per hr
- Pounds of CO_2 per million BTU determined from fuel analysis
- Product of Lb CO_2 per MMBTU x Heat Fired = lbs of CO_2 per hr

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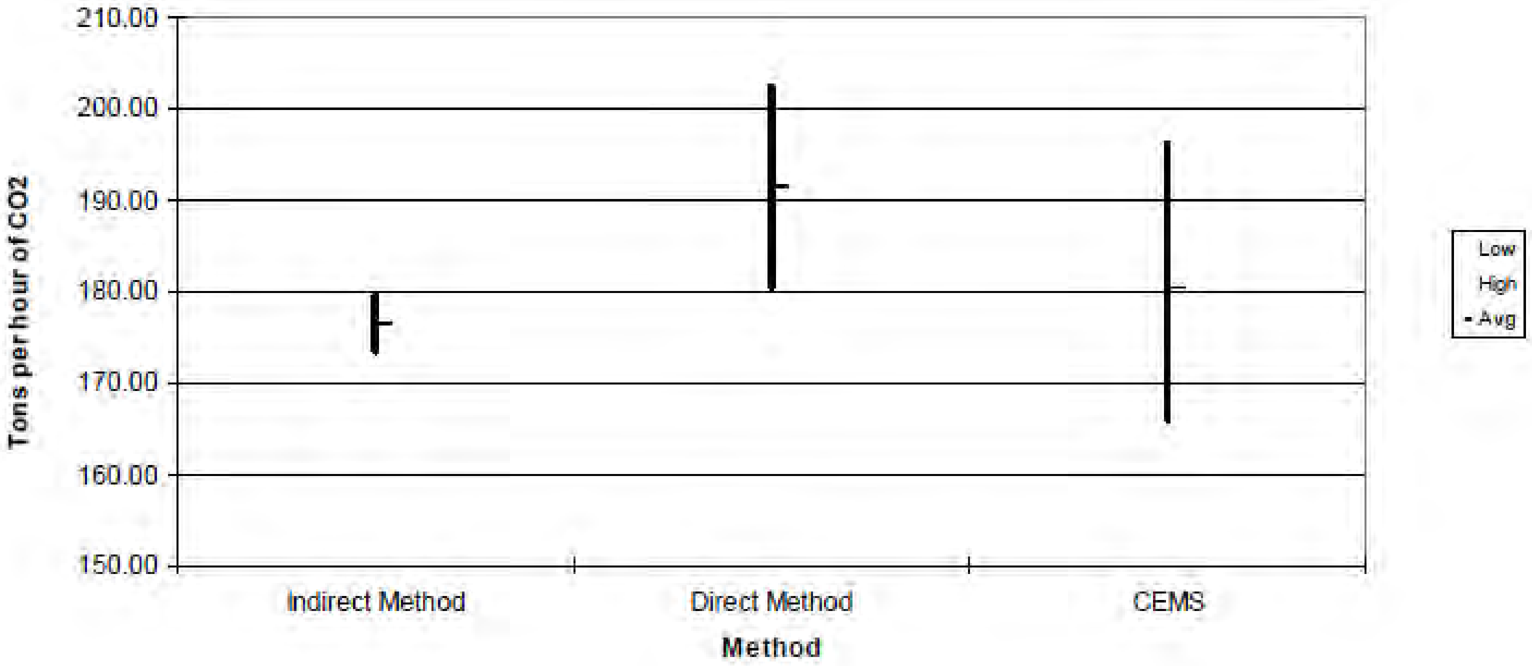
Uncertainty Analysis Result

- CEMS are +/- 7.5%
- Direct Coal Flow Method +/- 5.7% (Estimate is probably low)
- Alstom Energy Balance CO_2 monitor +/- 1.6%



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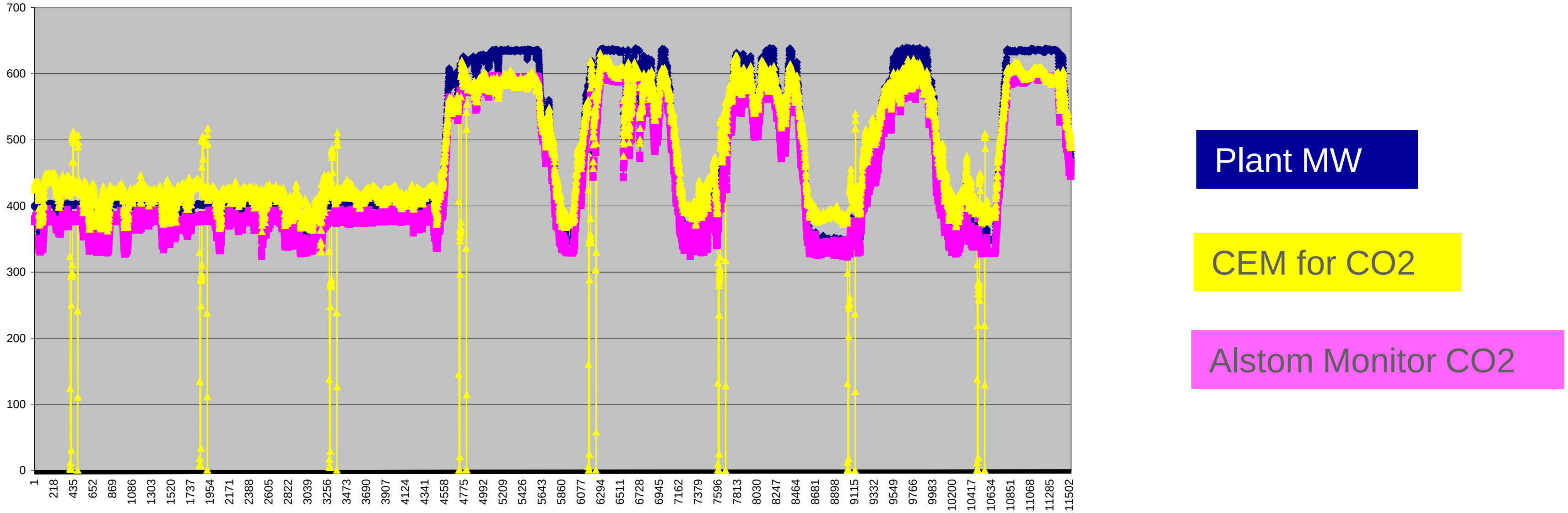
Comparison of a 600 MW Unit Emissions using Alstom Energy Balance CO$_2$ Monitor vs. Conventional Techniques



Eight Day Period - 11,520 Scans

Alstom Monitor tons of CO$_2$ reported was 5,603 tons less than the CEMS CO$_2$ reported, or about 700 tons per day

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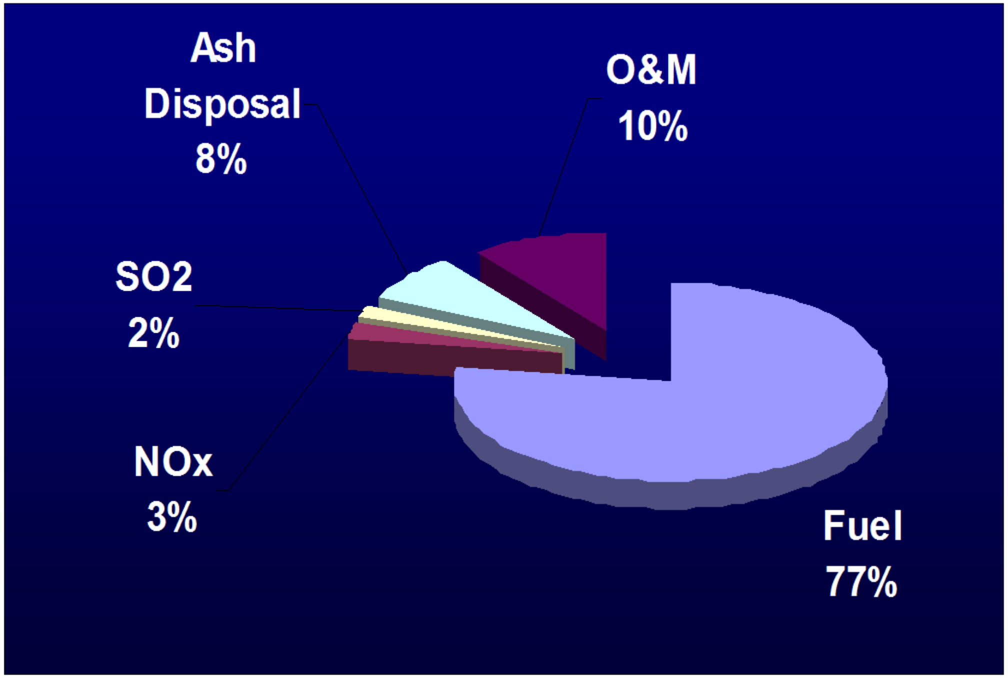
Existing Economics

Cost of Generation

Annual Costs Million $	
Cost of Fuel	64.0
Cost of NOx Credits	2.1
Cost of SO2 Credits	1.6
Cost of Ash Disposal	6.6
O&M Costs	8.3
Total Cost	82.7
Cost per MWhr	$ 18.21



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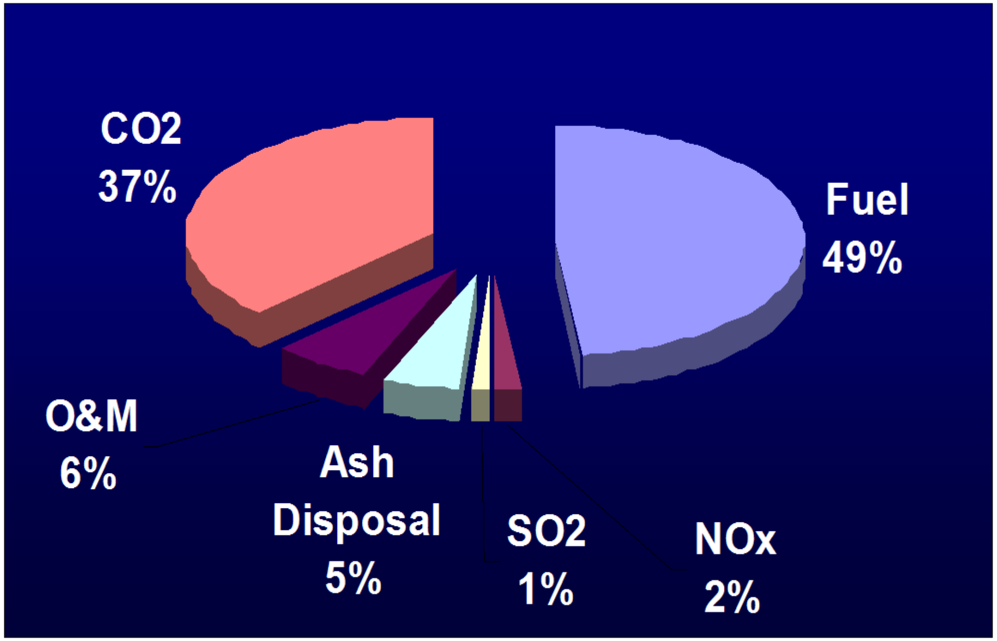
Carbon Economics

Cost of Generation

Annual Costs Million $	
Cost of Fuel	64.0
Cost of NOx Credits	2.1
Cost of SO2 Credits	1.6
Cost of Ash Disposal	6.6
O&M Costs	8.3
Cost of CO2 Credits	49.6
Total Cost	132.3
Cost per MWhr	$ 29.12



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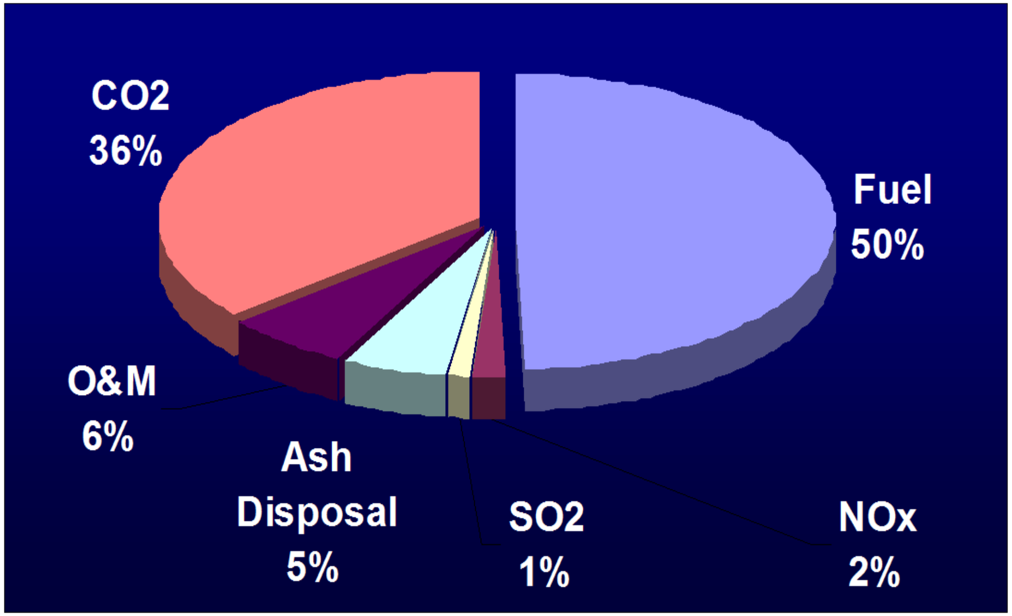
Carbon Economics
(with more accurate CO2 Measurement)

Cost of Generation

Annual Costs Million $	
Cost of Fuel	64.0
Cost of NOx Credits	2.1
Cost of SO2 Credits	1.6
Cost of Ash Disposal	6.6
O&M Costs	8.3
Cost of CO2 Credits	46.8
Total Cost	129.6
Cost per MWhr	$ 28.52

5.9% reduction



Total Savings = $2.7 Million annually

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Q&A

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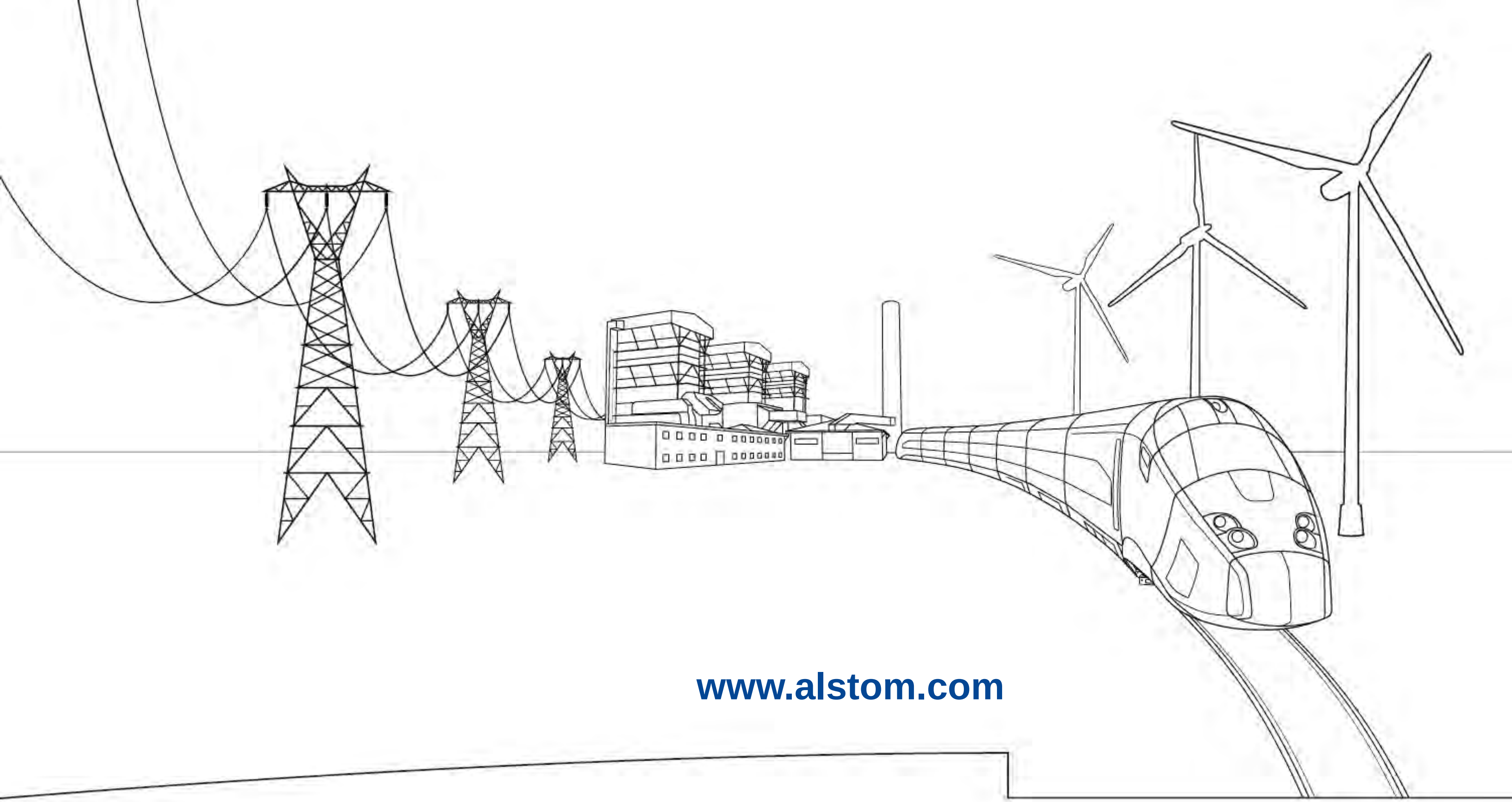

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Shaping the future

Methodology

INPUT = OUTPUT + LOSSES

Input-Output or Direct Method

$$\eta_{blr} = \frac{Output}{Input}$$

$$\eta_{blr} = \frac{Input - Losses}{Input}$$

Energy Balance or Heat Loss Efficiency

Indirect Method

$$\eta_{blr} = 1 - \frac{Losses}{Input}$$

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Calculate Boiler efficiency η_{BLR} in accordance with ASME PTC 4

1) Calculate the heat supplied to the boiler using the relationship

$$HeatInput = \frac{EnergyAbsorbed}{BoilerEfficiency}$$

$$Q_{FIRED} = \frac{Q_{BLR}}{\eta_{BLR}}$$

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Uncertainty Comparison

	Average Value	**Total Positive**		**Total Negative**		**Student t**	**Random Component**	**Positive Systematic**	**Negative Systematic**
Customer 1		%	Tons	%	Tons		Tons	Tons	Tons
Indirect Method	628.84	2.6%	16.06	2.4%	14.88	2	0.26	16.05	14.87
Direct Method	735.26	5.7%	41.68	5.7%	41.68	2	0.56	41.67	41.67
CEMS	609.14	8.3%	50.36	7.5%	45.65	2	0.36	50.35	45.64
Customer 2									
Indirect Method	176.54	2.9%	5.17	2.3%	4.10	2	0.11	5.16	4.09
Direct Method	191.54	5.7%	10.86	5.7%	10.86	2	0.11	10.85	10.85
CEMS	180.47	8.8%	15.82	8.0%	14.51	2	0.35	15.81	14.50

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Uncertainty Analysis

Random Component

Standard Deviation of the Sample

$$S_x = \sqrt{\sum_{i=1}^{N} \frac{(X_i - \bar{X})^2}{(N-1)}}$$

Standard Deviation of the Mean

$$\bar{S}_x = \frac{S_x}{\sqrt{N}}$$

$$S_R = \sqrt{\sum_{i=1}^{N} (\theta_i' \bar{S}_x)^2}$$

Sensitivity Coefficient

$$\theta = \frac{(\Delta R)}{(\Delta X)}$$

Systematic Component

$$\bar{b}_x = \sqrt{b_{\%}^2 + b_{UOM}^2}$$

$$b_R = \sqrt{\sum_{i=1}^{N} (\theta_i' \bar{b}_x)^2}$$

$$U = \sqrt{tS_r^2 + b_r^2}$$

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$$M_{qCO_2} = \frac{\%C}{HHV} \times \frac{MW_{CO_2}}{MW_C} \times 10^6 = \frac{\%C}{HHV} \times \frac{44}{12} \times 10^6$$

Lb CO2/ Million BTU

$$M_{eCO_2} = \frac{M_{qCO_2} \times Q_{Fired}}{kW}$$

Lb CO2 / kW

$$M_{TCO_2} = \frac{M_{qCO_2} \times Q_{Fired}}{2000}$$

Tons CO2 / hr

Note: Q_{Fired} is in Million BTU/hr

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Calculate Boiler efficiency η_{BLR} in accordance with ASME PTC 4

1) Calculate the heat supplied to the boiler using the relationship

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$$Q_{FIRED} = \frac{Q_{BLR}}{\eta_{BLR}}$$

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