

Worldwide Pollution Control Association

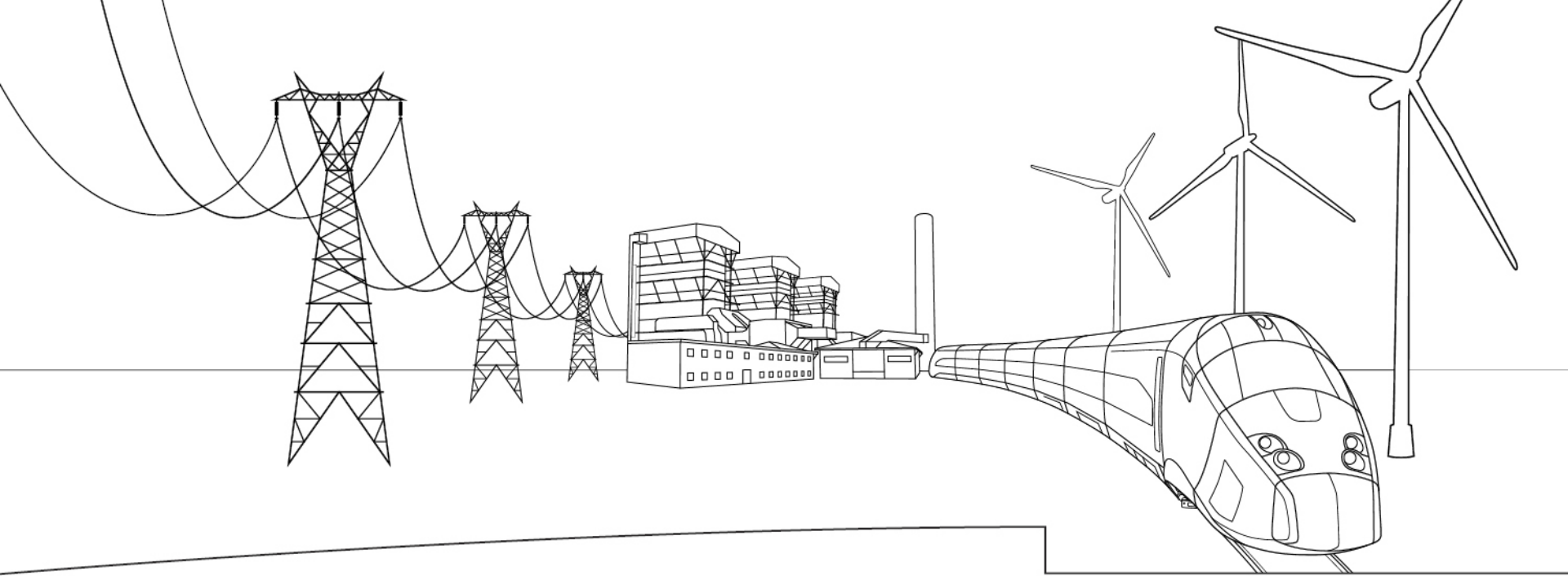
WPCA-Entergy
“Increasing Energy Efficiency of Existing Units” Seminar
January 22, 2014

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Plant Optimization for Increased Efficiency

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Alstom Power

22 Jan 2014

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



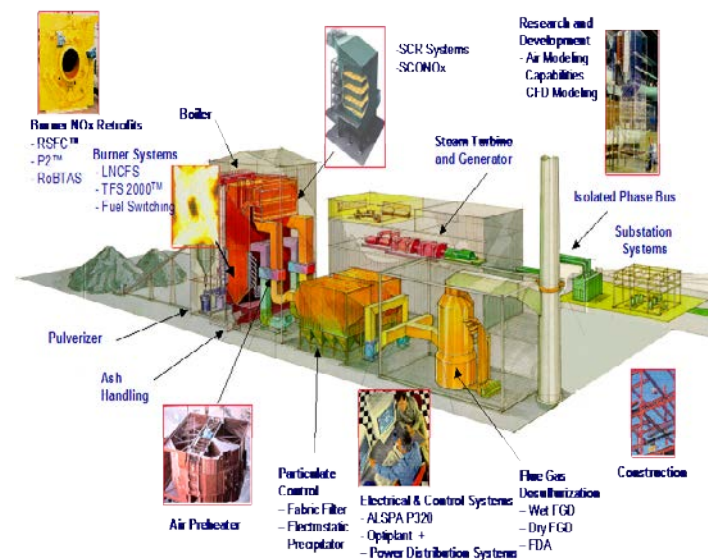
Objective

- 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.

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



Integration of Key Capabilities



O&M Experience

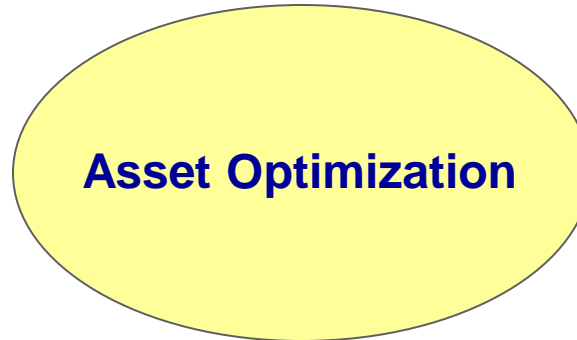
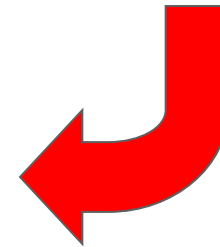
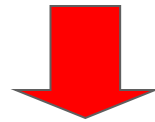
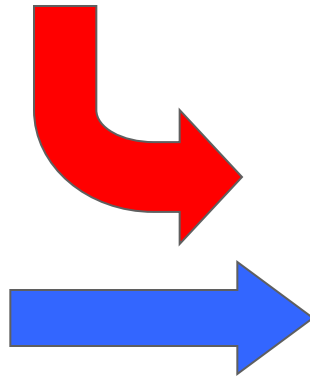


Plant Design



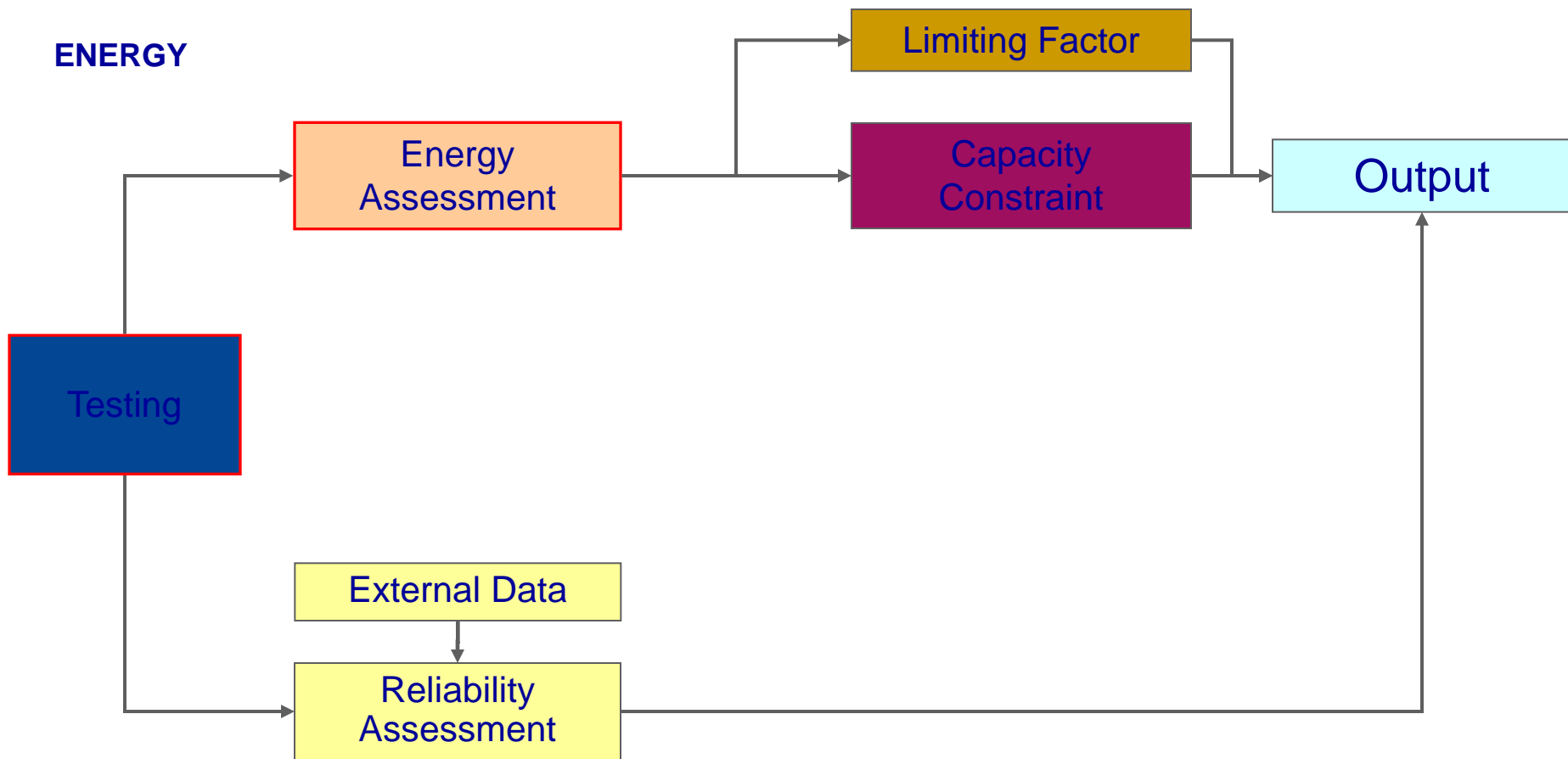
Product Knowledge

Customer



Process Overview

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



RELIABILITY

WPCA 22Jan 2014 Slide 6

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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



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

Asset Optimization

Energy Efficiency and Thermal Performance

iLifeCycle™ 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.

Energy Assessment

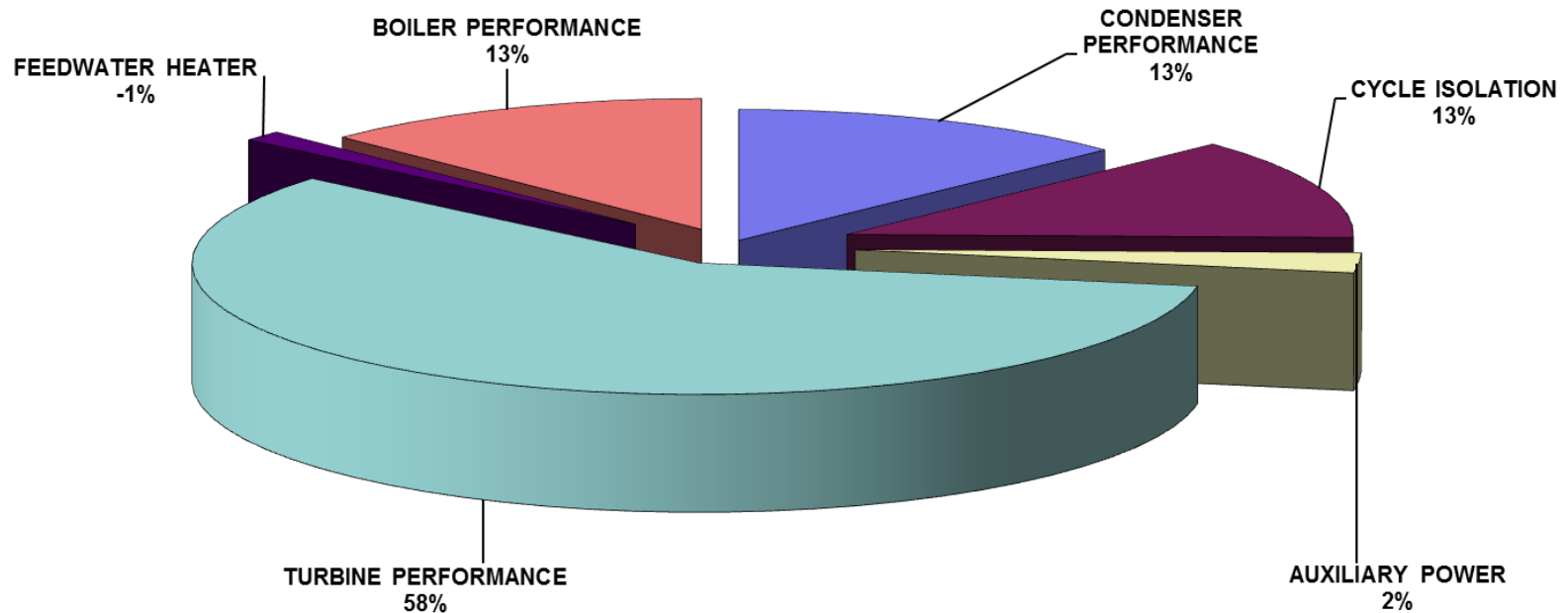
- Energy Assessment/Thermal Cycle Analysis
 - Engineering & Economic Evaluation
 - Design basis review and benchmarking
 - Plant staff interviews
 - Use of Plant Instrumentation
 - VWO Test/Prior test results review
 - As-Found vs. Design Heat Balance comparison
 - Operational Adjustments to deliver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

Energy Assessment

Unit #1 Energy Losses

Design Heat Rate 9192 BTU/kWhr
Design Heat Rate 2316 kcal/kWhr
Design Heat Rate 9692 kJ/kWhr

As Found Heat Rate 9488 BTU/kWhr
As Found Heat Rate 2396 kcal/kWhr
As Found Heat Rate 10004 kJ/kWhr



Energy Assessment - Savings

Unit 1 Net Heat Rate		DESIGN		CURRENT		
		9,192		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				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)		

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

		N2 Fixed and No CRH to			
		RH Fixed	no CRH	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

Background – Why is Energy Efficiency Important

- Increasing Global Concern for Greenhouse Gas Emissions
- US Congress will eventually pass CO₂ 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 CO₂ limits implementation of UN Clean Development Mechanism (CDM) under the Kyoto Protocol

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 CO₂ \$10/Ton
- Cost of Coal \$25.10/Ton delivered
- Cost of NO_x Credits \$1000/Ton
- Cost of SO₂ Credits \$250/Ton
- Cost of Ash Disposal \$50/Ton

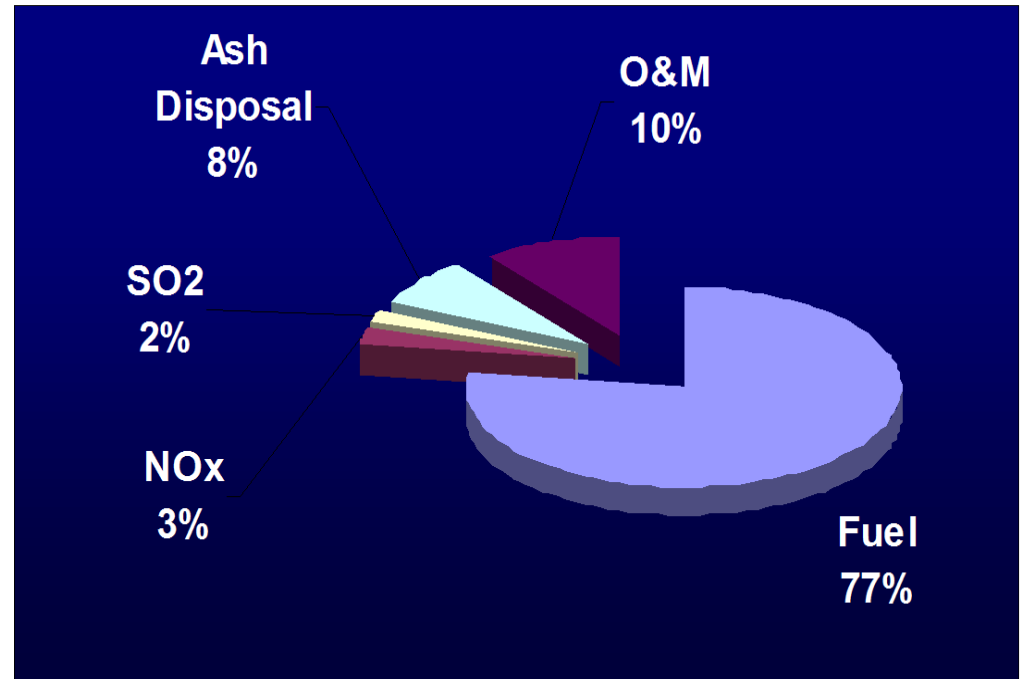
Existing Economics

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



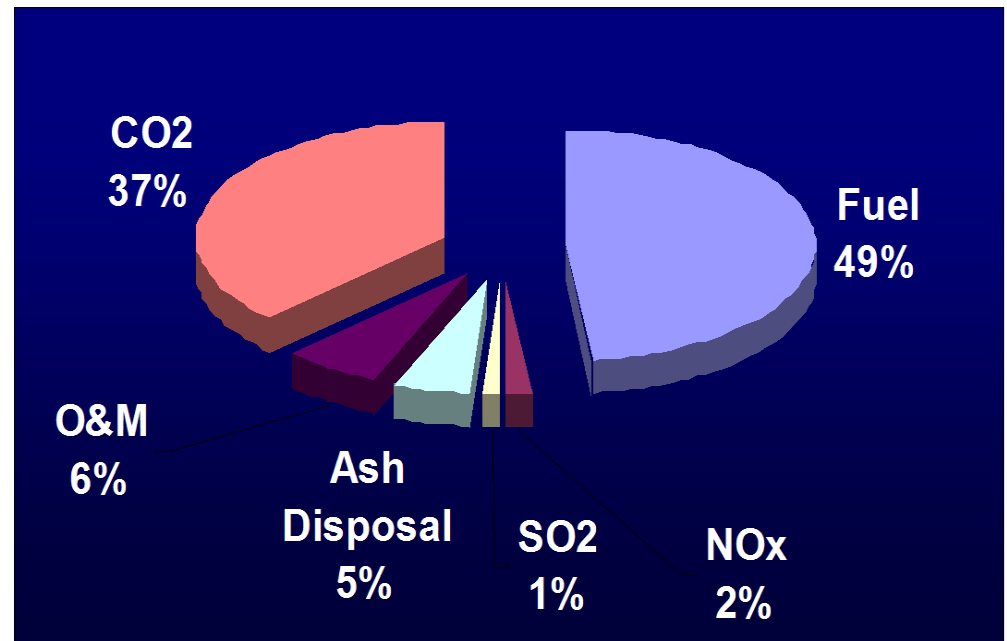
Carbon Economics

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

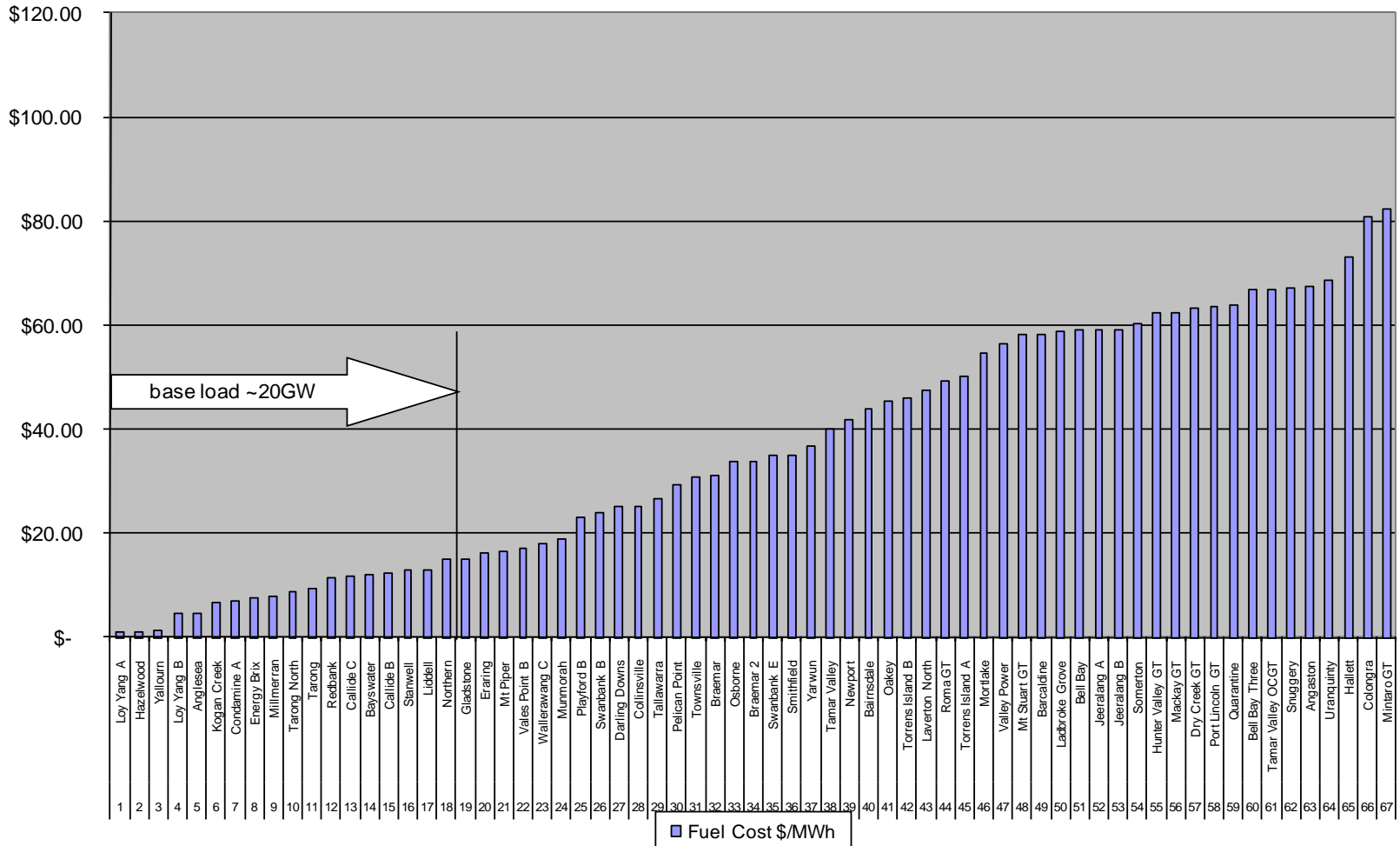
Cost per MWhr \$ 29.12



Market Drivers – Fuel

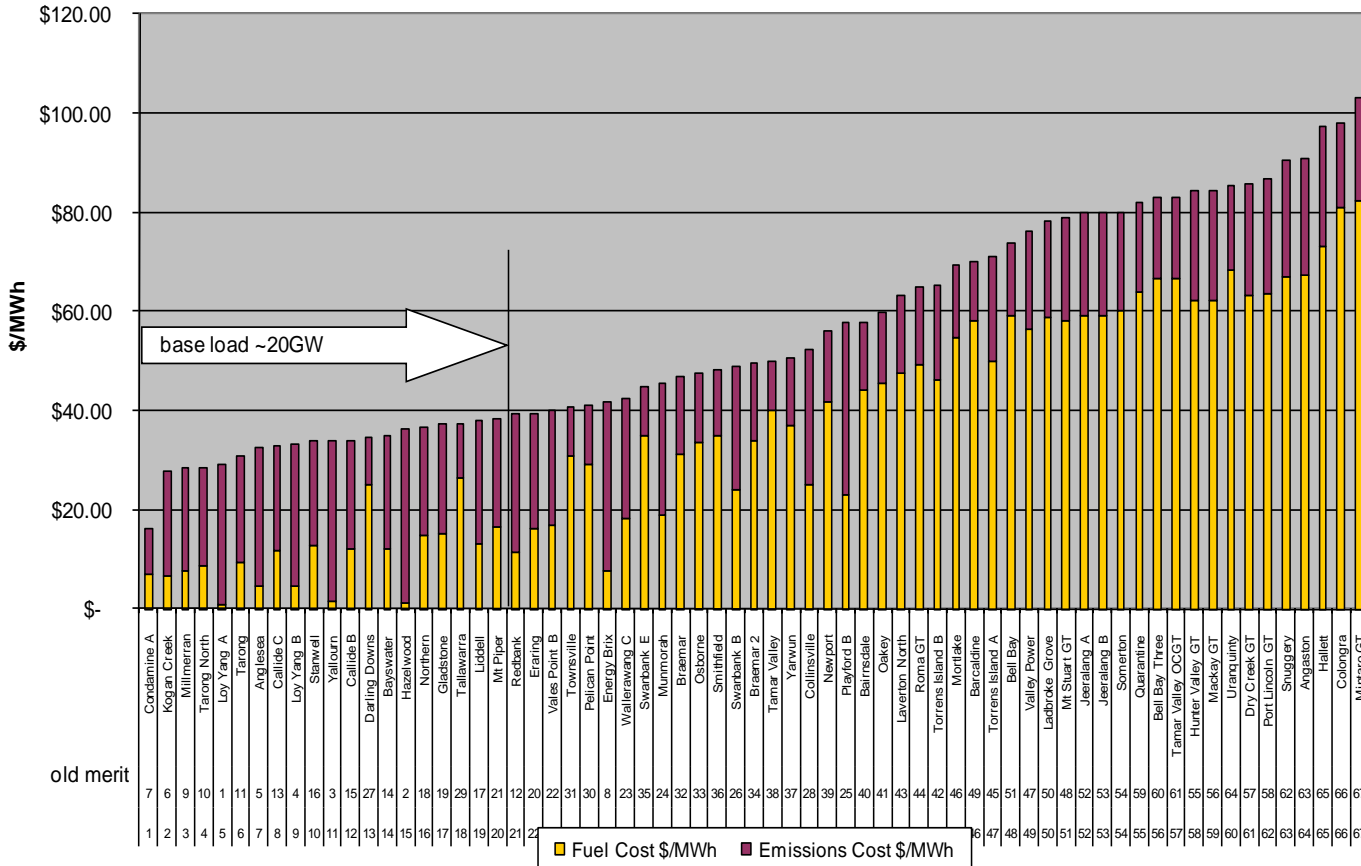
Fuel Cost – Merit Order

Fuel Cost \$/MWh

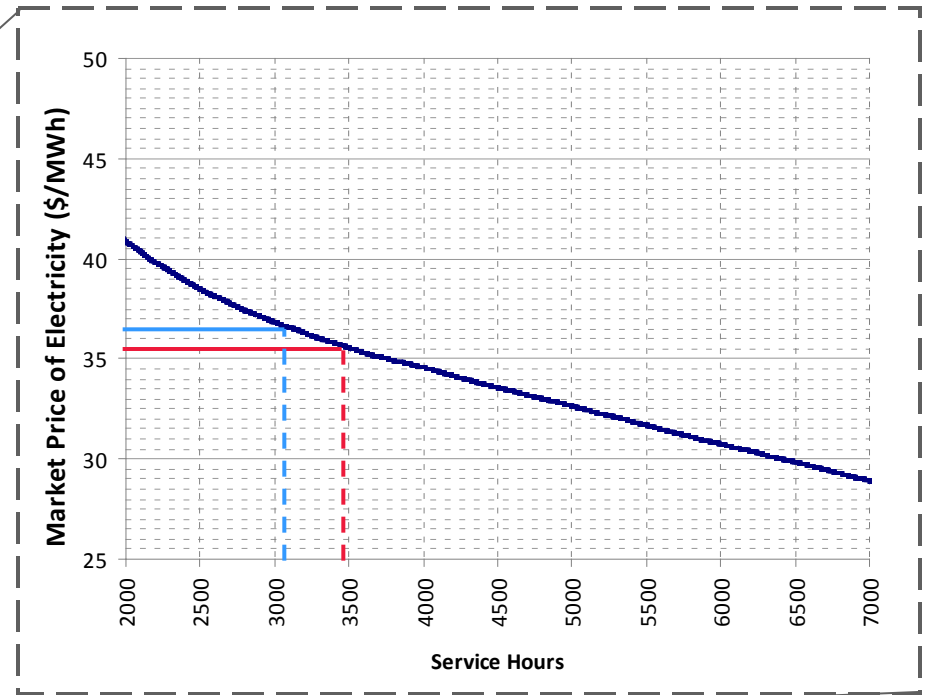
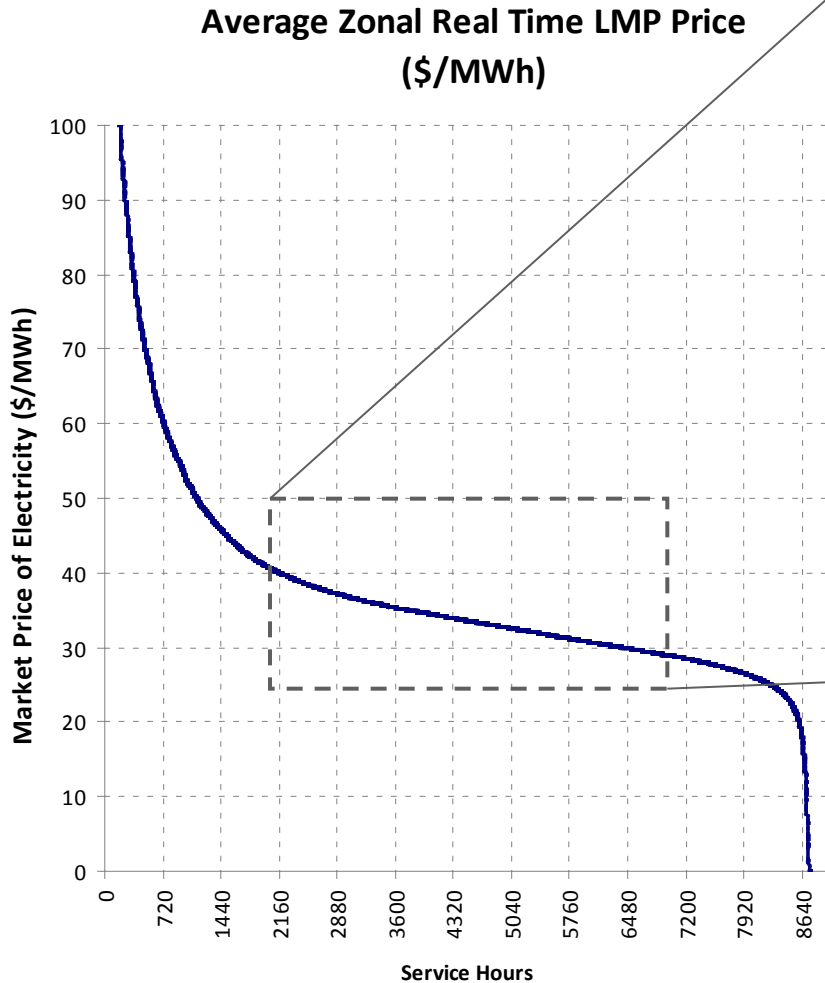


Market Drivers – Merit Order - Fuel + CO2 cost (CO2 @ \$23/t converted to \$/MWh by station emission intensity)

Fuel Cost + CO2 cost @ \$23/t
\$/MWh



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%

US Coal Plants 2008 CO₂ Data

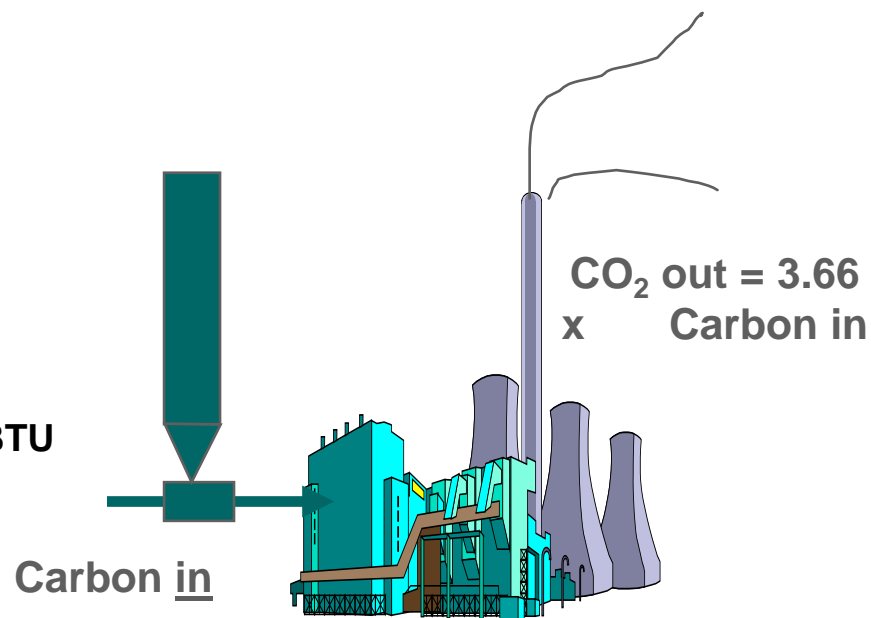
Weighting typical ultimate values

Coal Source	Fixed Carbon (%)	Higher Heating Value (Btu/lb)	Coal Fired in Utility Boilers (Million Tons)	Carbon Fired (Million Tons)	CO ₂ 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

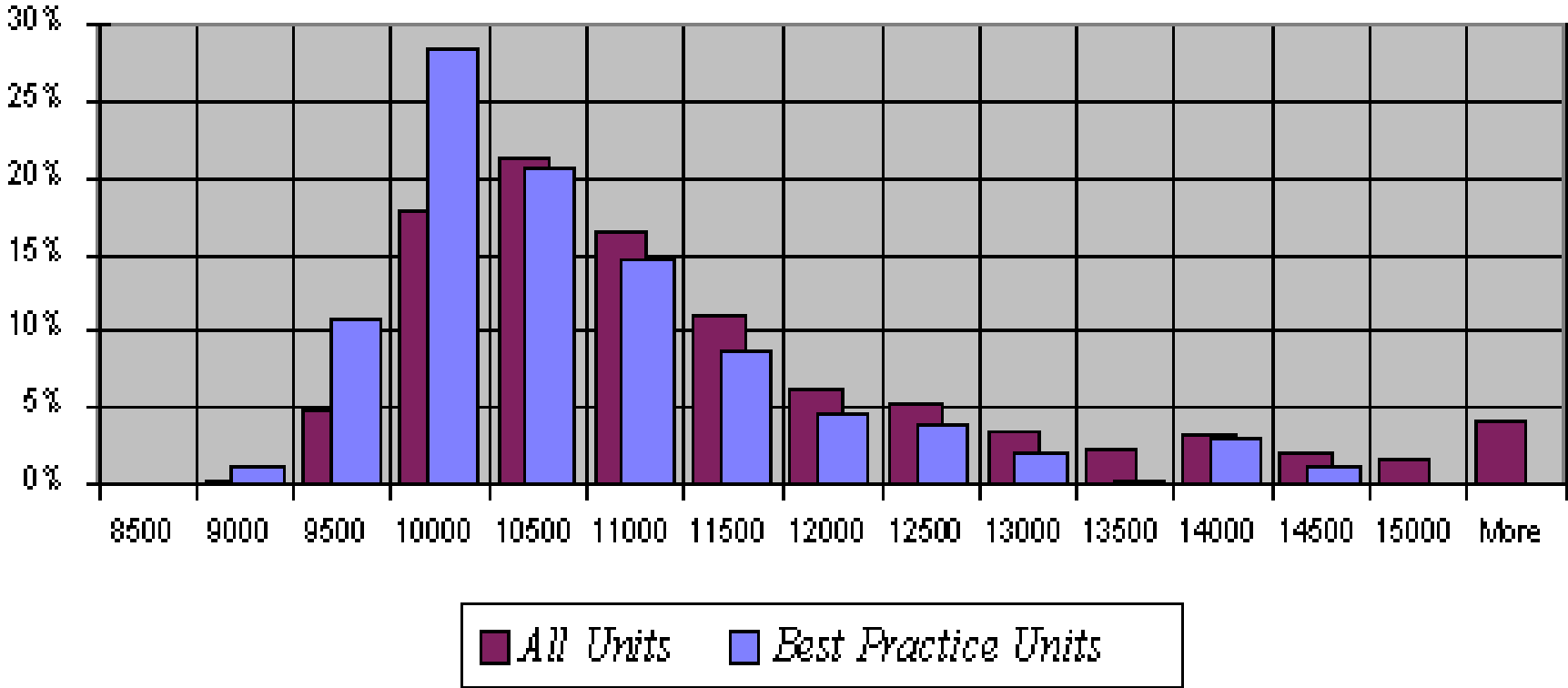


Source: US EIA and Alstom Fuel databases.

CO₂ in top table from fuel analysis CO₂ in lower table from EIA

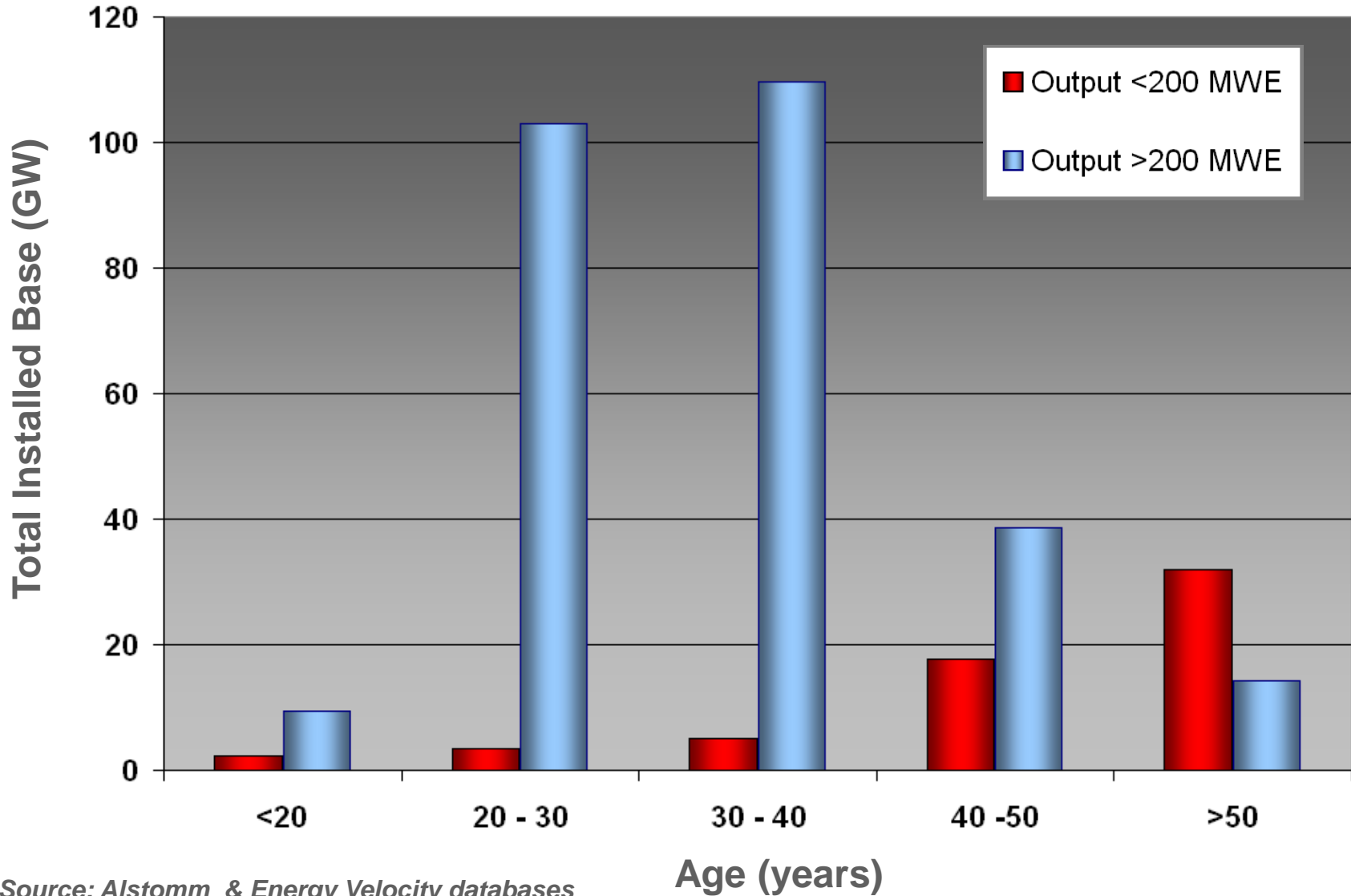
Range of Heat Rates - 1,098 US Boilers

Distribution of Heat Rates for Coal-fired Generating Units



US Coal Power Plants

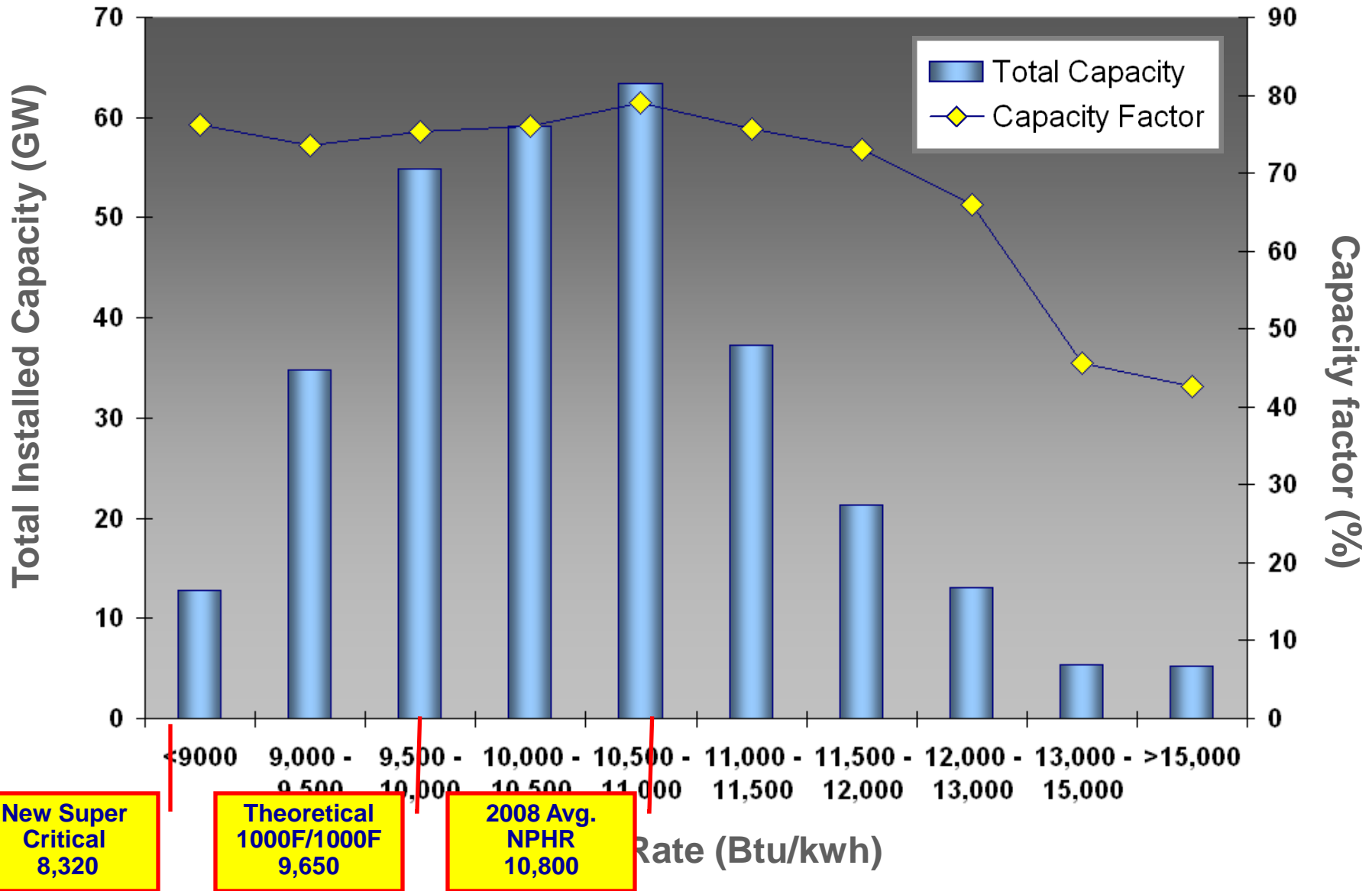
Installed Base (GW) vs. Age (years)



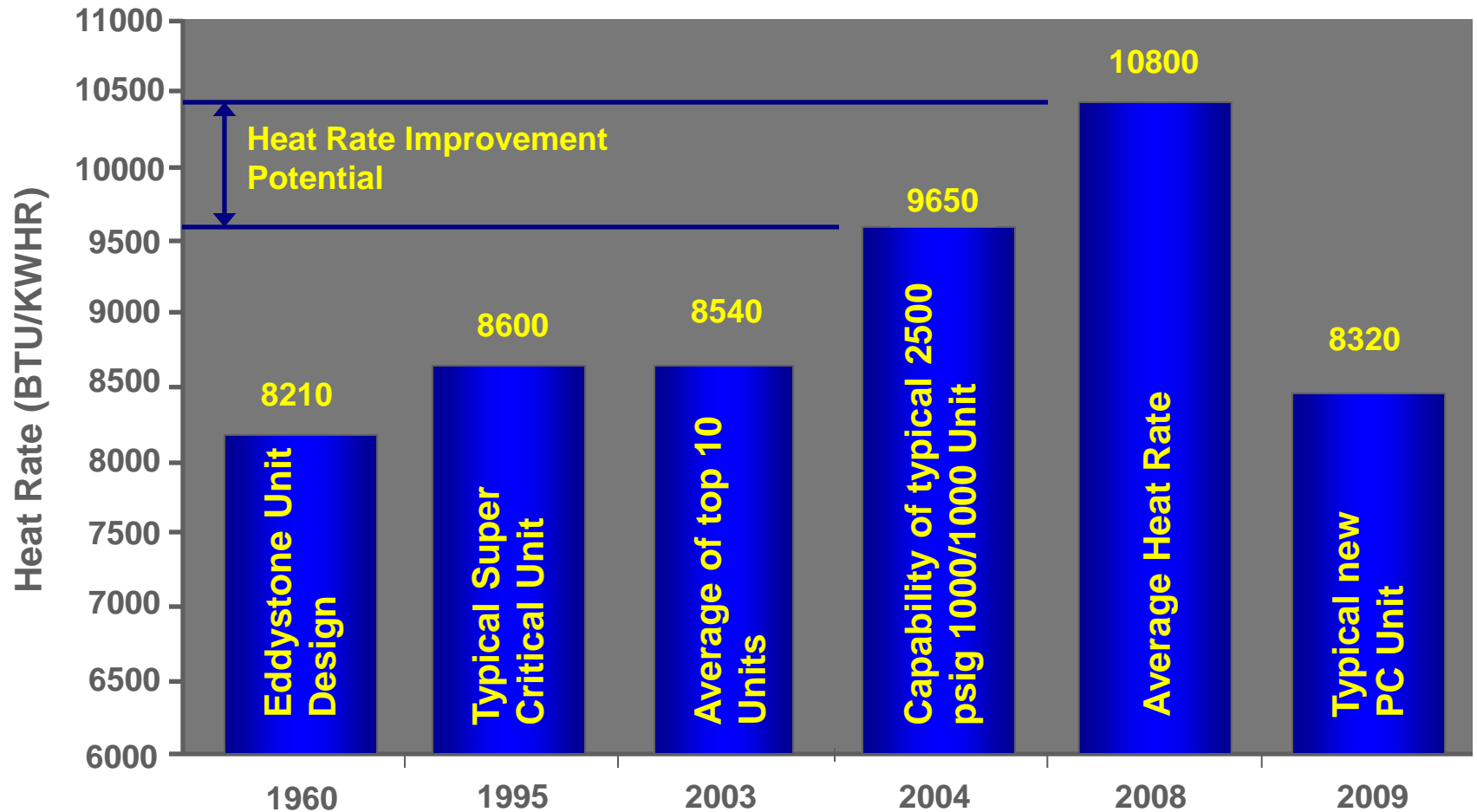
Source: Alstom & Energy Velocity databases

Coal Power Plant

Installed GW and Capacity Factor vs. Heat Rate



Heat Rate Capability



CO₂ 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 CO₂ !
- Even greater reductions would be achieved with new Super Critical Boilers

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.

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.”

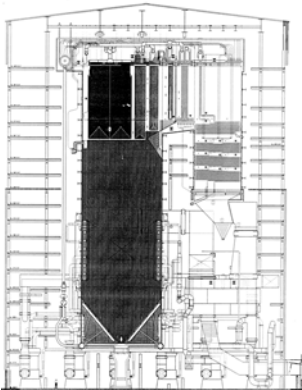
Source: EPA - New Source Review: Report to the President June 2002

Improving Existing Plant Performance

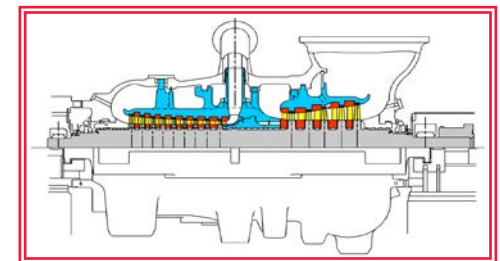
- Establish Target Performance
- Test Existing Unit
 - Using ASME PTC 46 Methodology
- Analyze Differences
- Identify Root cause of performance Issues
- Plan and Implement repairs

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			



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

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 Classifiers etc, to reduce Carbon Loss
- AH – Leakage control, high efficiency baskets
- Variable speed drives for Fans, CW pumps for part load operation

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 CO₂

Base

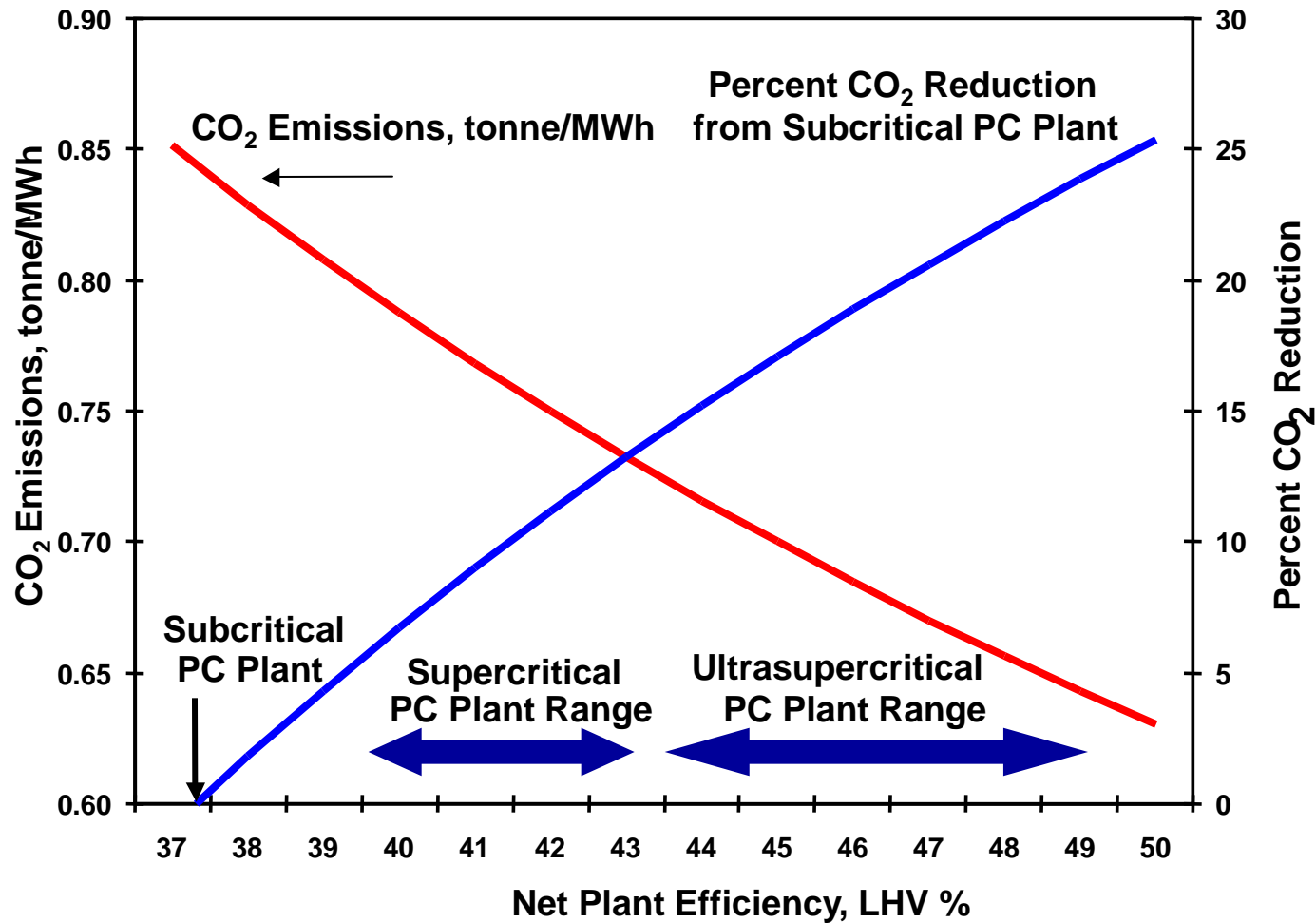
Base-8%

Base-17%



*** HHV Basis**

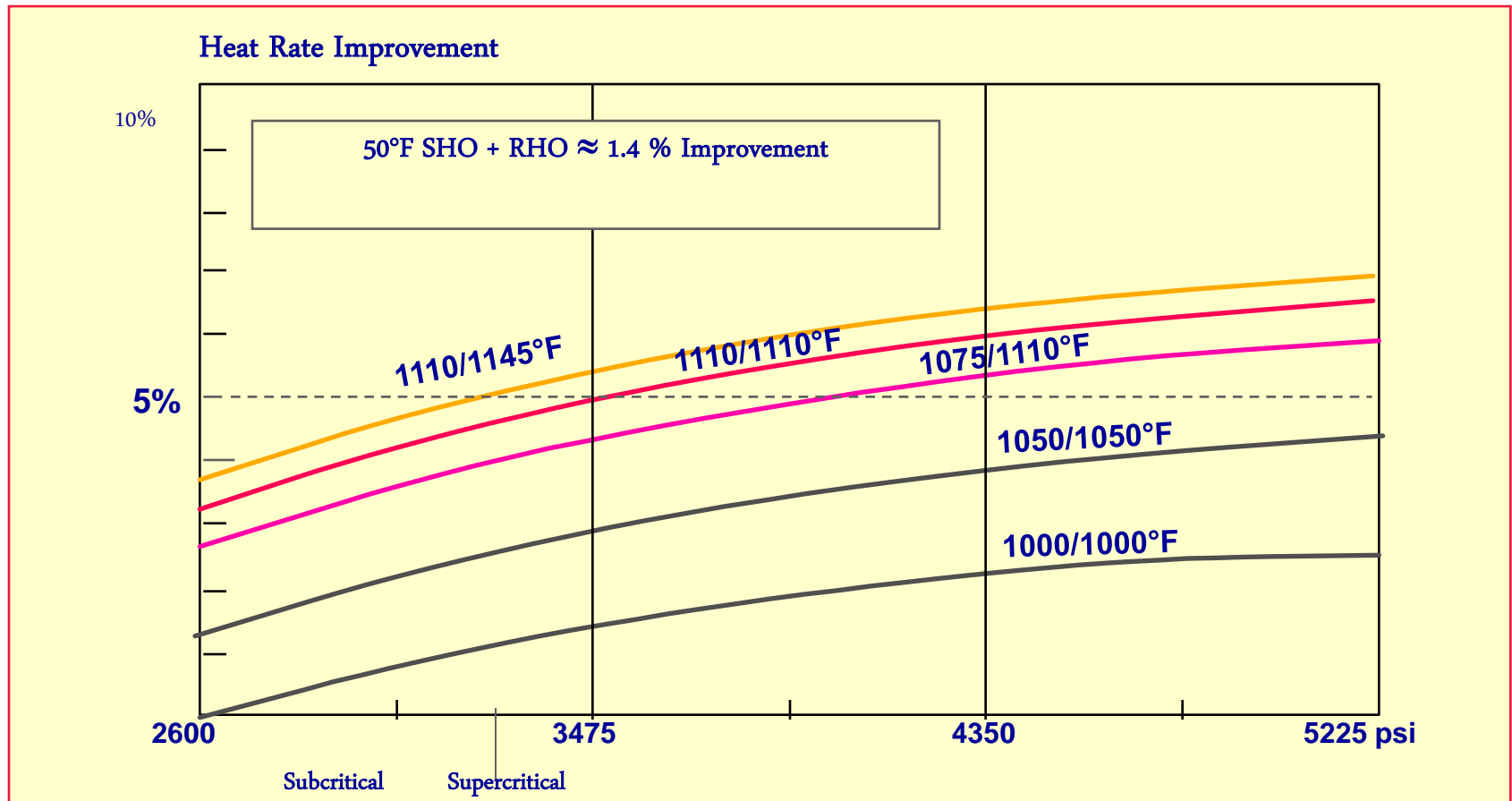
CO₂ Emissions vs Net Plant Efficiency



Subcritical to USC yields up to 25% CO₂ reduction

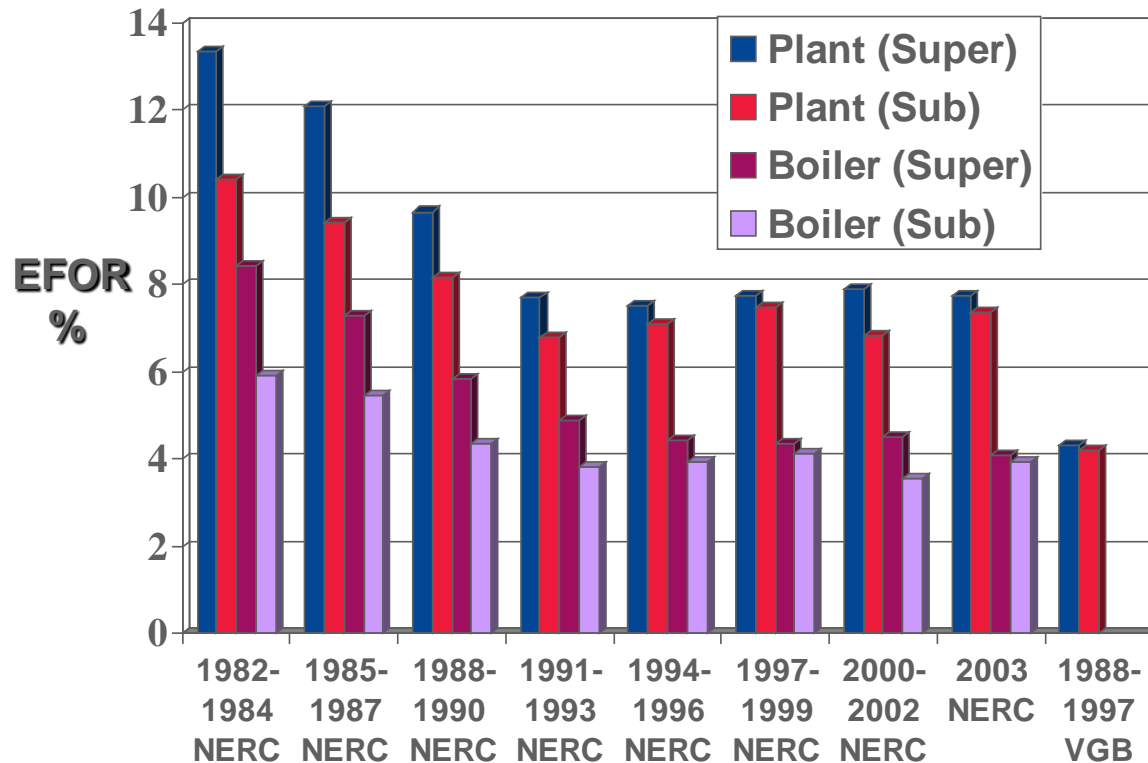
Sub vs. Supercritical / Ultra-Supercritical Cycles

Heat rate improvement vs. steam conditions (single reheat)



Lower Fuel Consumption and Lower Emissions/ kWh

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”

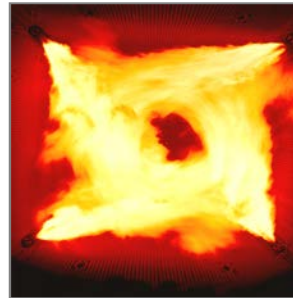
Optimized Plant Retrofit

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

+



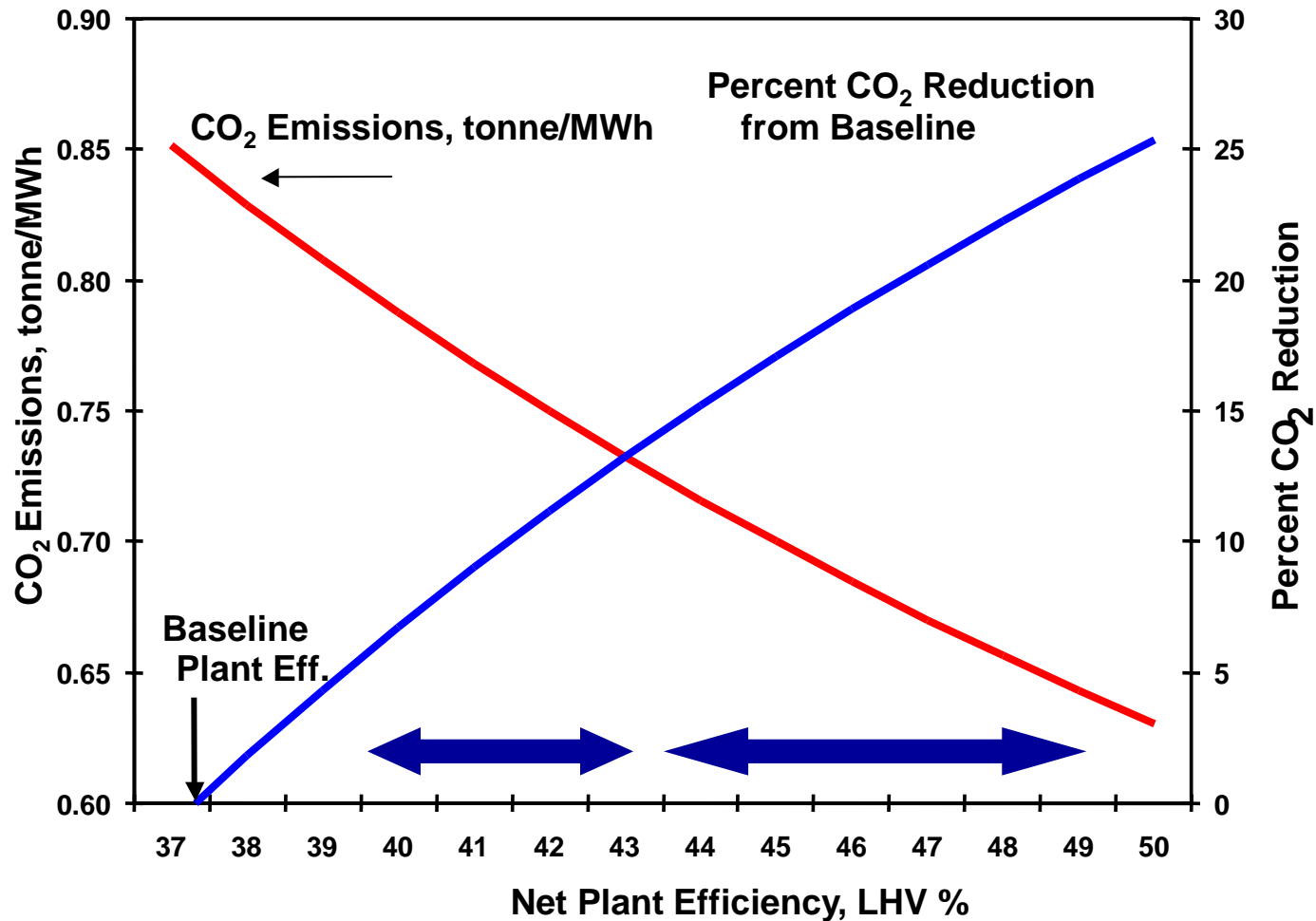
Environmental
Retrofit

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

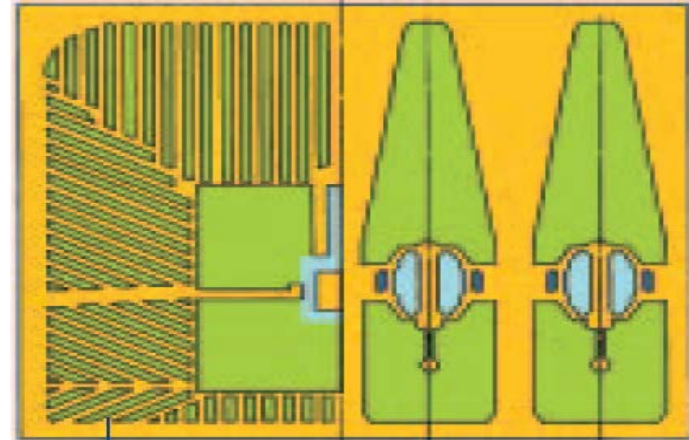


CO₂ Emissions vs Net Plant Efficiency



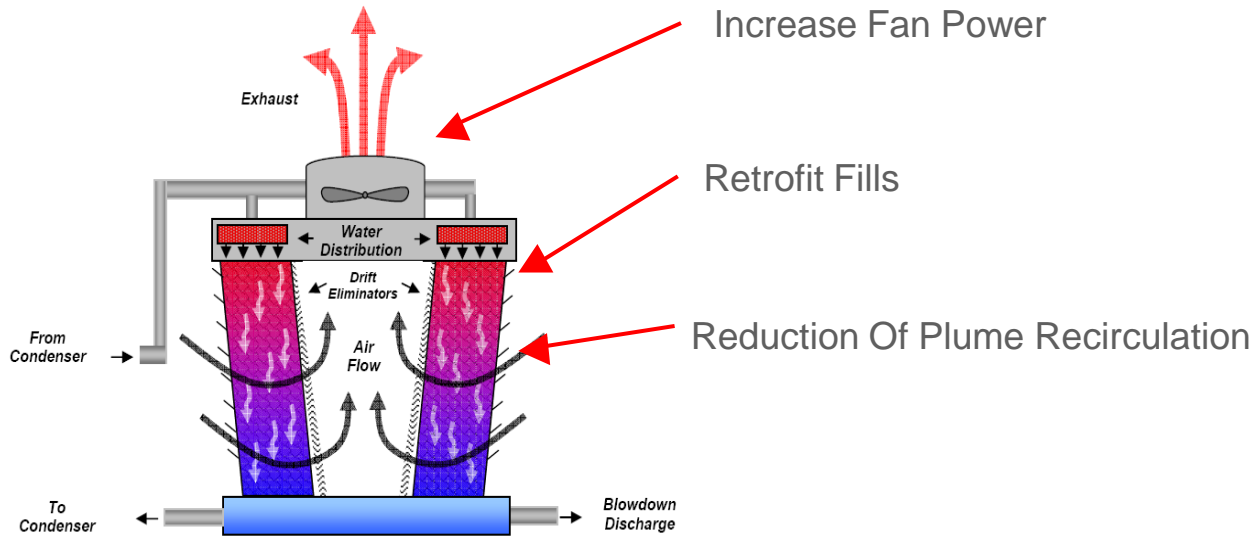
New Condenser Design

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



Cooling Tower Improvements

Improvement Cell Cooling Towers



Presentation title - 01/01/2007 - P 15

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Controls Modification

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



Before and After Controls Upgrade



The Performance & Environmental Monitor

This system has two objectives;

- To be a state of the art measurement system for CO₂ 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.

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



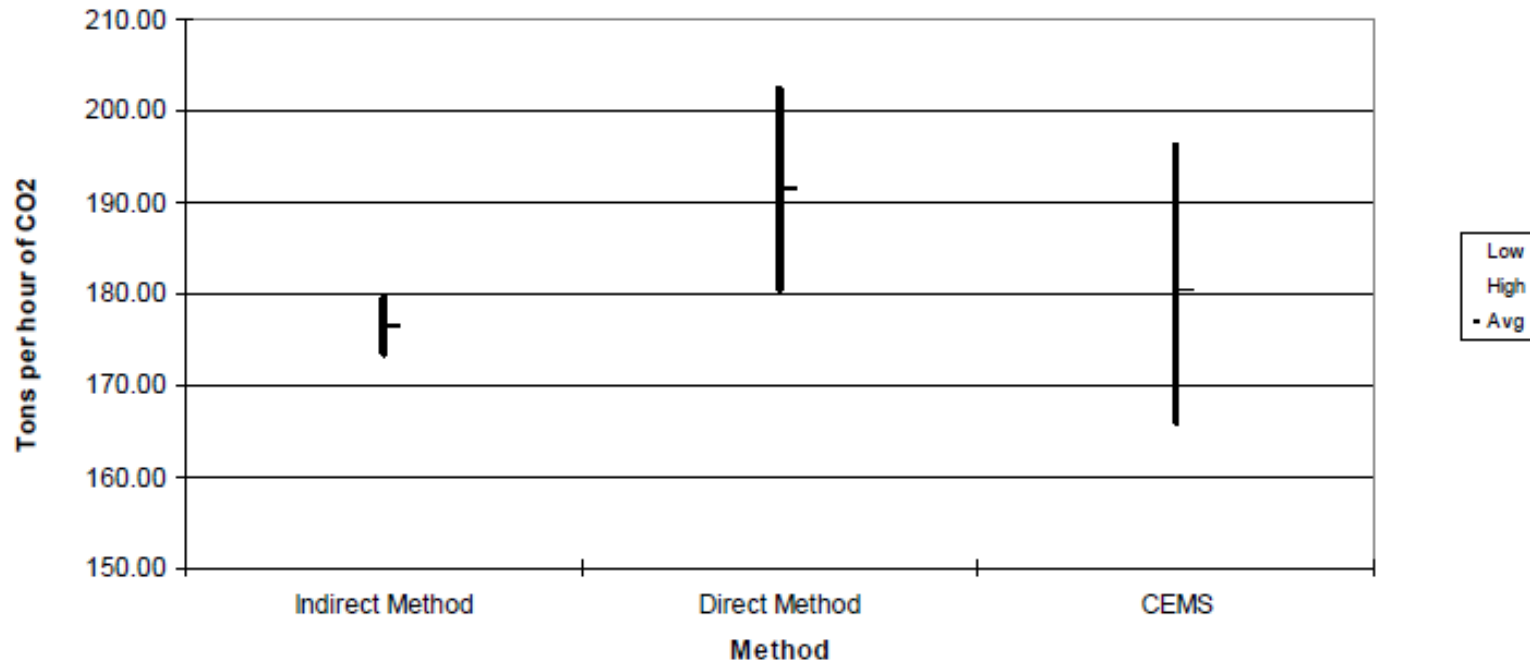
*US Patent 8626450

Methodology

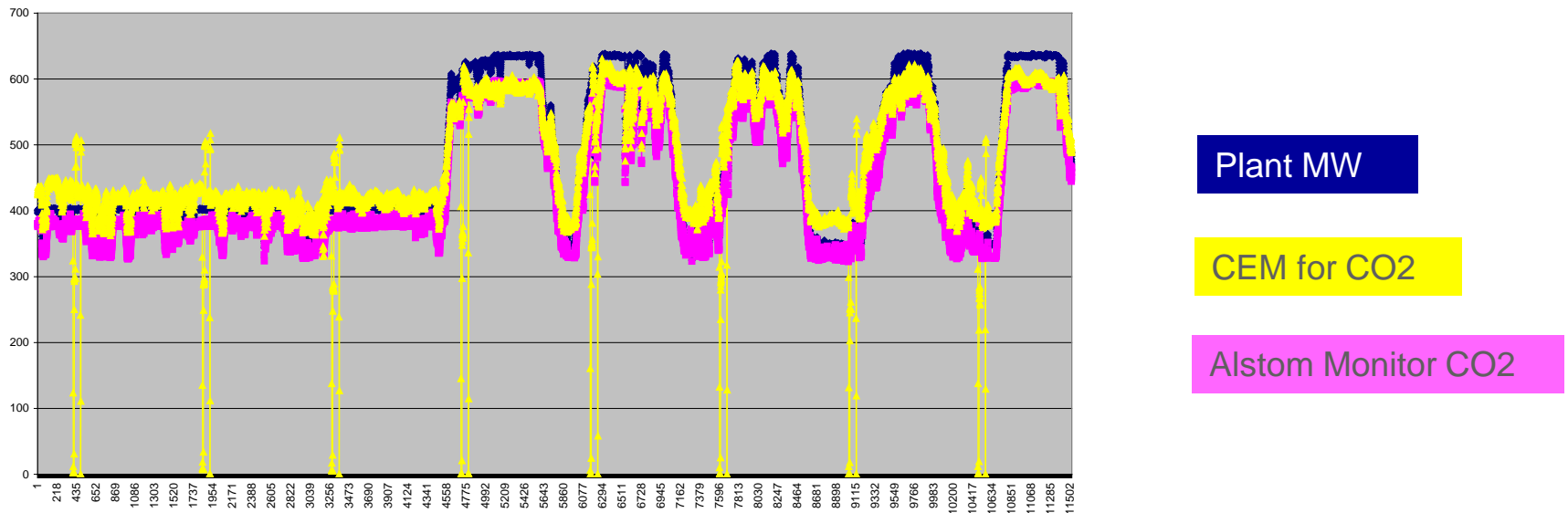
- Boiler Efficiency by Heat Loss Method
- Heat absorbed by steam divided by Boiler Efficiency to determine heat input per hr
- Pounds of CO₂ per million BTU determined from fuel analysis
- Product of Lb CO₂ per MMBTU x Heat Fired = lbs of CO₂ per hr

Uncertainty Analysis Result

- CEMS are +/- 7.5%
- Direct Coal Flow Method +/- 5.7% (Estimate is probably low)
- Alstom Energy Balance CO₂ monitor +/- 1.6%



Comparison of a 600 MW Unit Emissions using Alstom Energy Balance CO₂ Monitor vs. Conventional Techniques



Eight Day Period - 11,520 Scans

Alstom Monitor tons of CO₂ reported was 5,603 tons less than the CEMS CO₂ reported, or about 700 tons per day

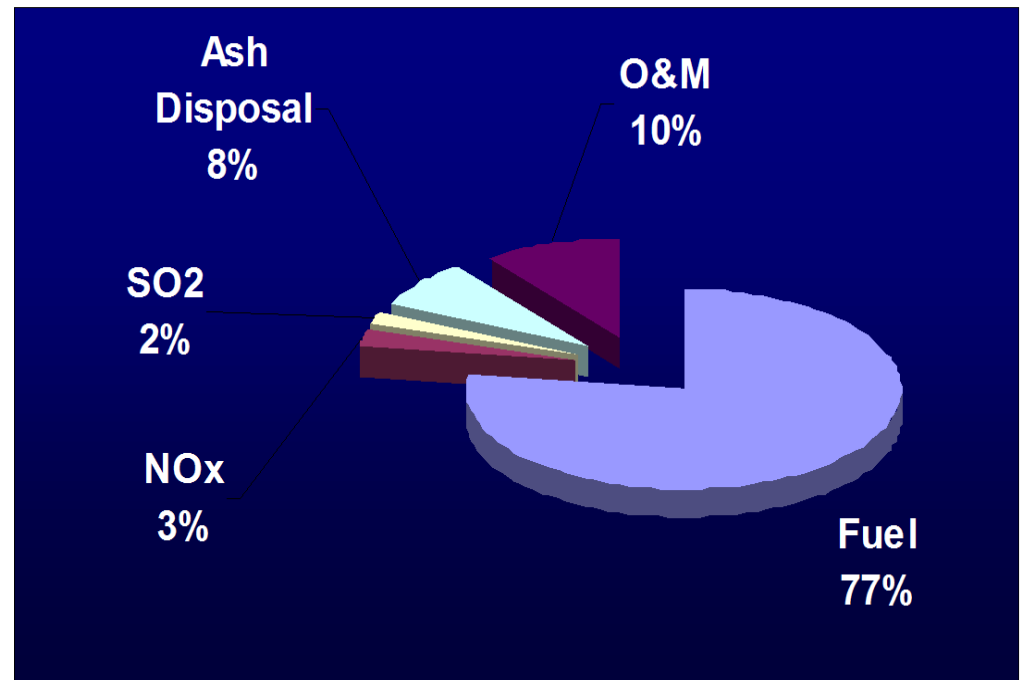
Existing Economics

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



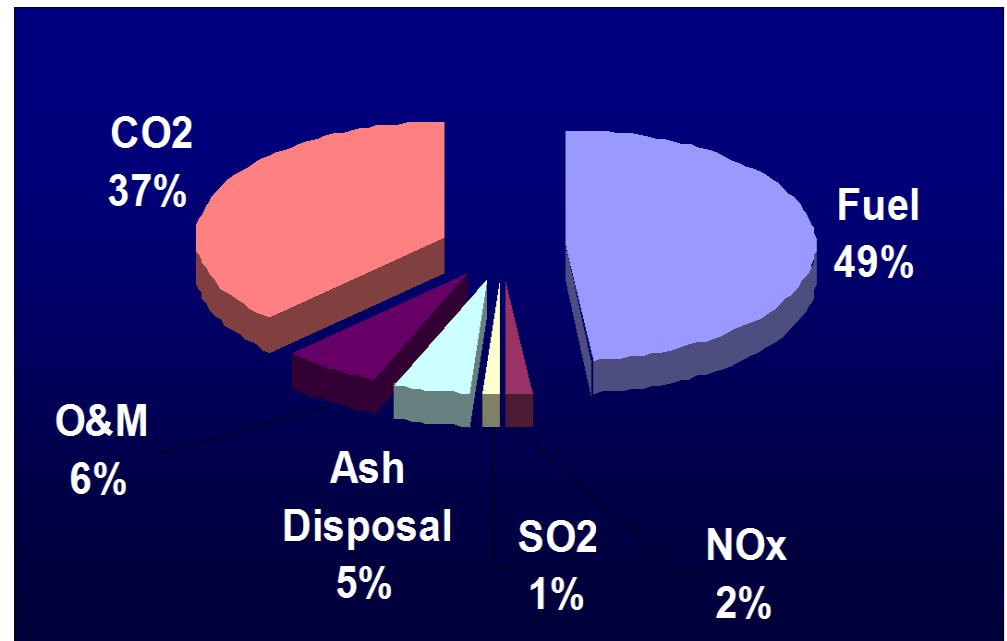
Carbon Economics

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



Carbon Economics

(with more accurate CO2 Measurement)

Cost of Generation

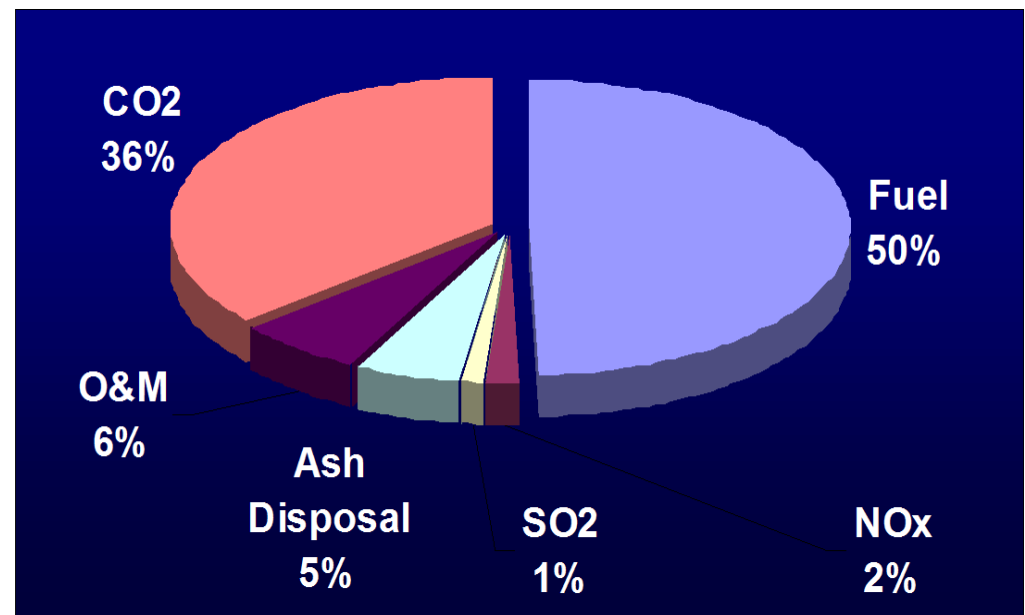
Annual Costs Million \$

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



Q&A

