REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy

Boiler Load Cycling and NOx

Issues and Strategies

Charlotte, NC

February 10, 2013

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The Problem

Regulatory Pressures Combined With Current Economic Conditions Are Forcing Coal Fired Units Out Of Their Traditional Base Load Role And Into A Load Following Mode Of Operation.

A New Paradigm

Increased Turndown = Increased Profits

Say What?

A New Paradigm

Increased Turndown = Increased Profits

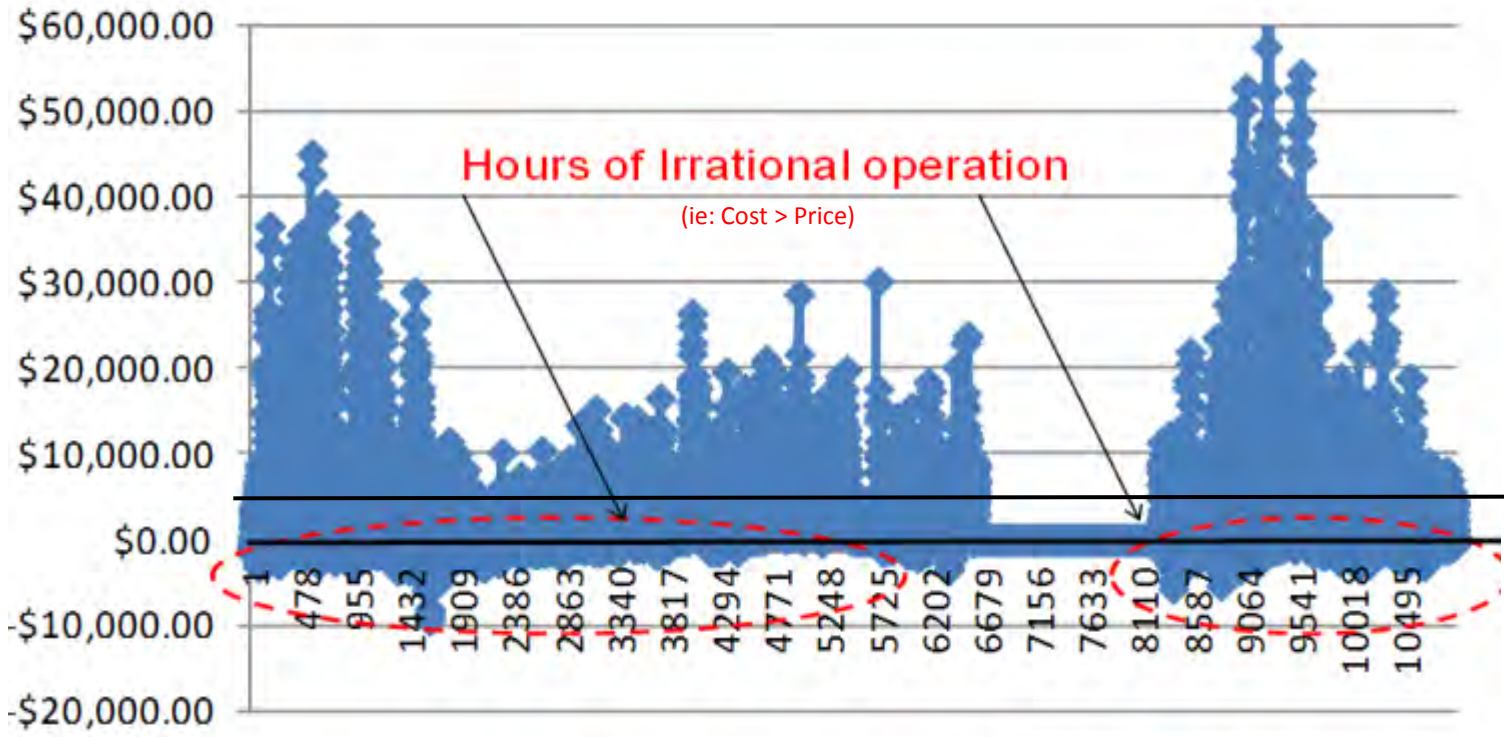
Why?

"Must Run" plants must accept the price of the lowest bid that can carry the load

This can result in plants "selling" power at prices below their cost to generate

A New Paradigm
A Look at Marginal Revenue (7/1/10 to 10/1/11)

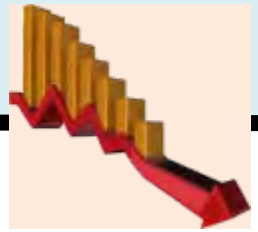
600MWg Midwestern Super-critical Unit



What Has Caused This?

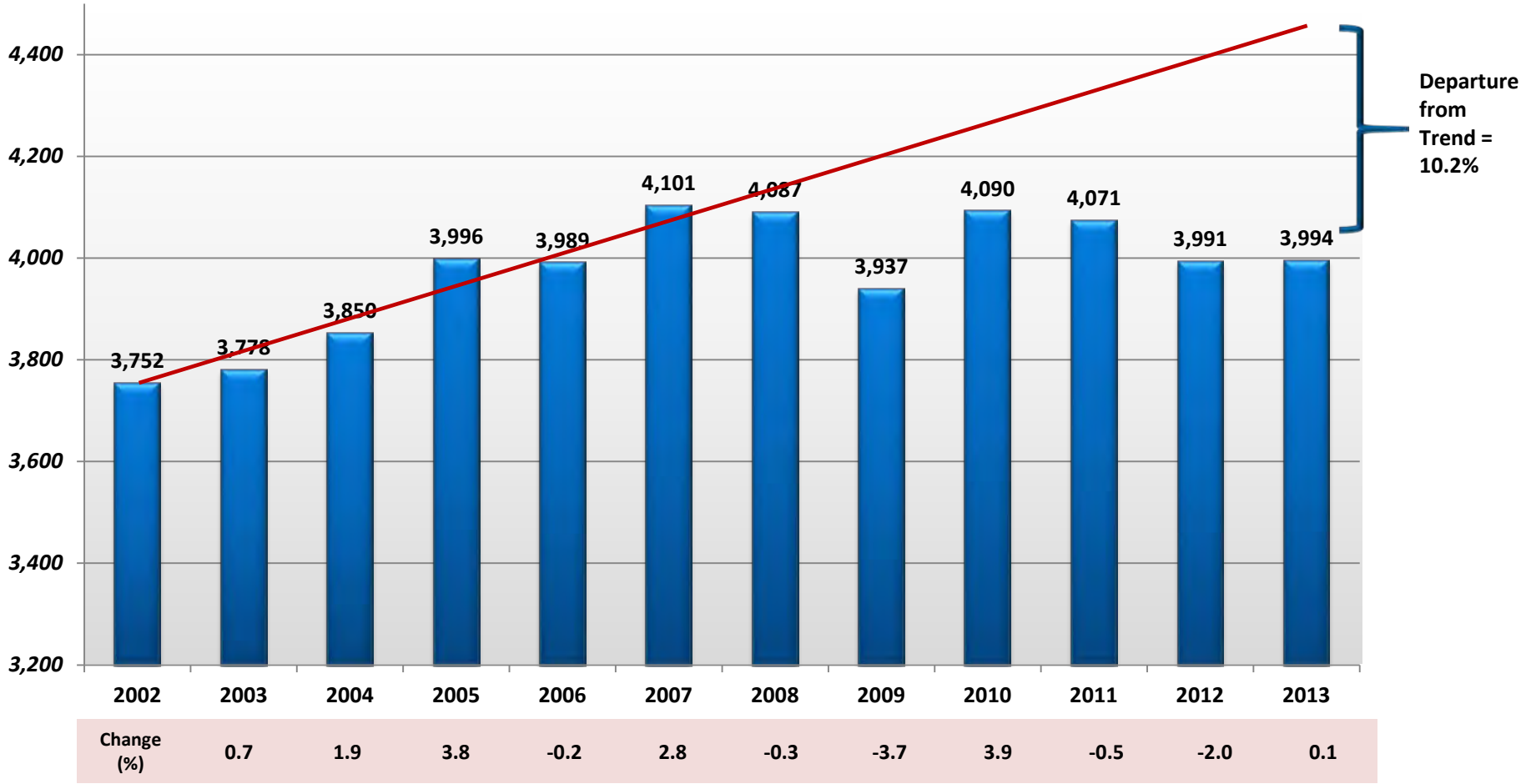
- **Lower Demand Growth**






U.S. Electric Output, Trailing 52 Weeks – Ending in Week 52

If the 2002-2008 trend had continued, the most recent 52 week U.S. Electric Output would have been 4,448 TWh



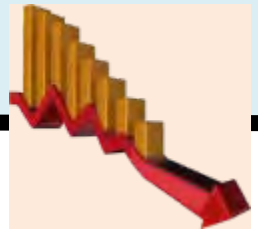
Source: Edison Electric Institute, Weekly Electric Output

EEI Edison Electric Institute

What Has Caused This?

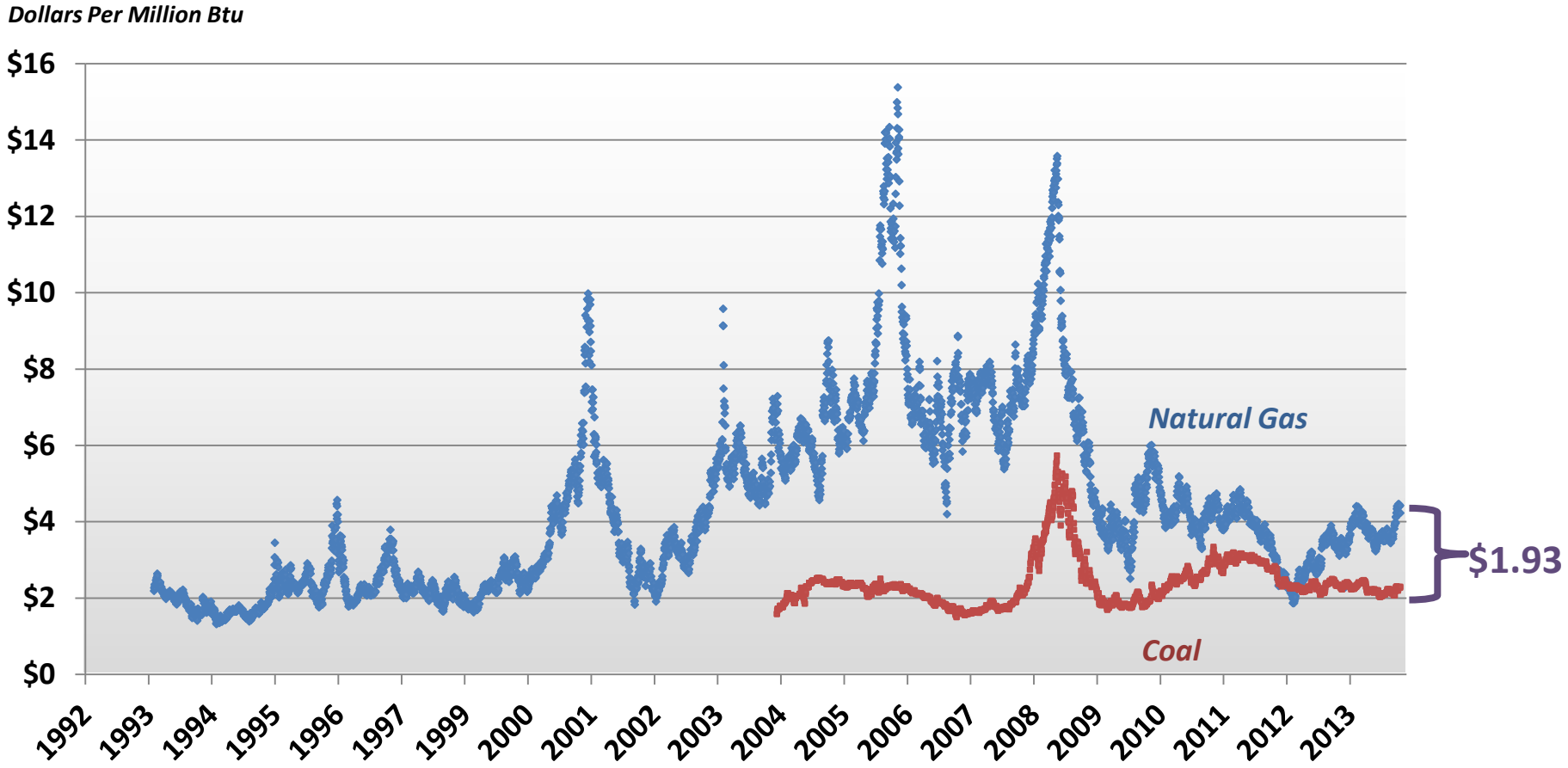
- Lower Average Demand
- Lower Natural Gas Prices






Natural Gas and Coal Prices in $ per Million Btu
On the Futures Exchange, for the coming month

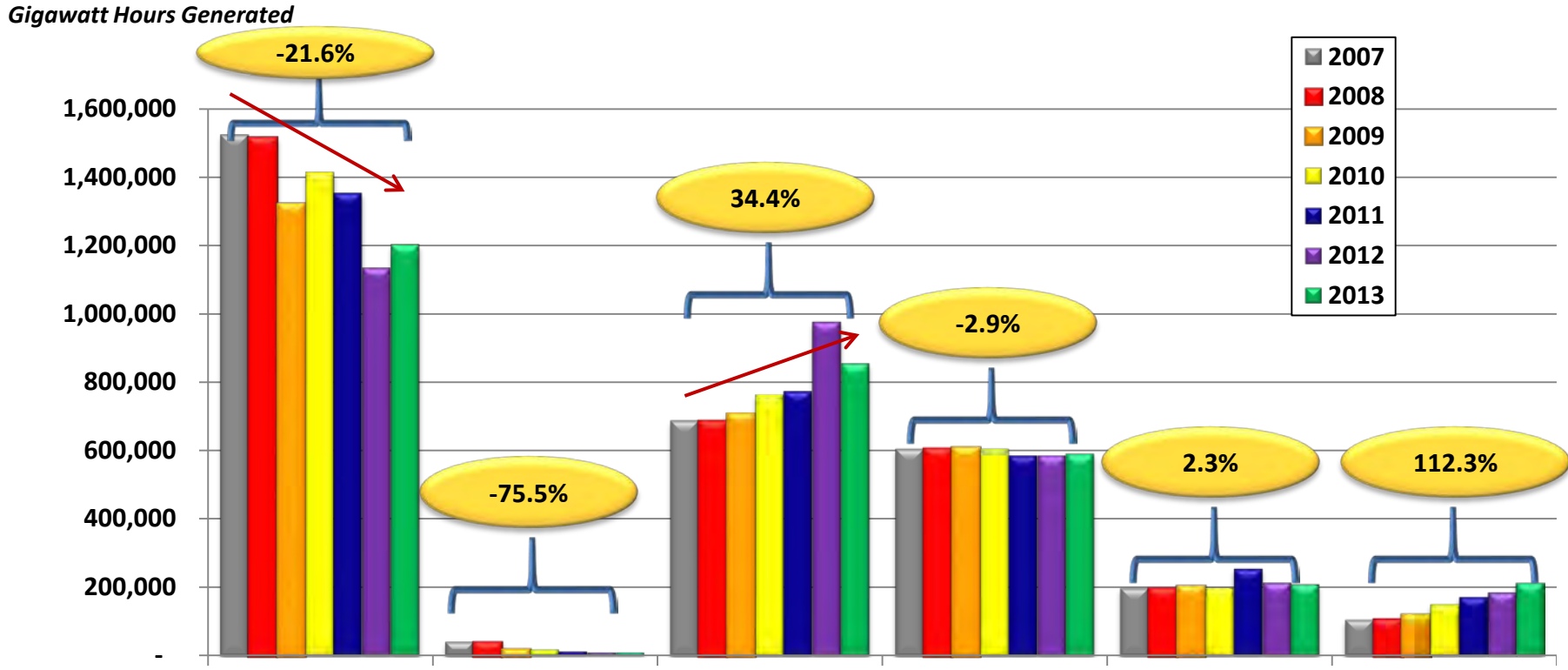
Key Point: in recent months, the spread between the price of Natural Gas and the price of Coal, when measured on the basis of equivalent heat content, has been growing, but is still smaller than it has traditionally been.



U.S. Electric Generation by Fuel,

Change from First Three Quarters 2007 to First Three Quarters 2013

Key Point: since 2007, power companies have reduced the quantity of electricity generated from coal and oil while dramatically increasing generation from natural gas and renewables.

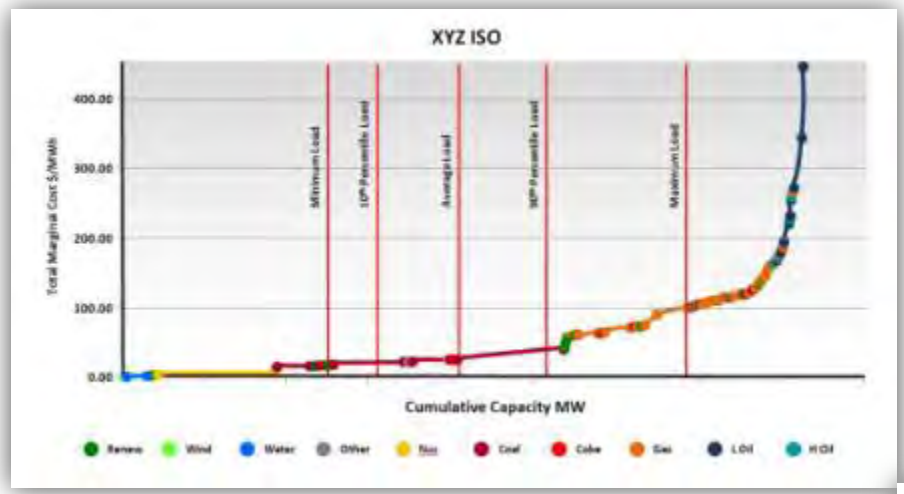


% of Total Generation Mix	Coal	Petroleum	Natural Gas	Nuclear	Hydroelectric	All Other
2007	48.2%	1.3%	21.7%	19.1%	6.3%	3.4%
2013	39.0%	0.3%	27.7%	19.2%	6.8%	6.9%

Source: *Electricity Monthly Update*, Energy Information Administration, U.S. Department of Energy November 20, 2013

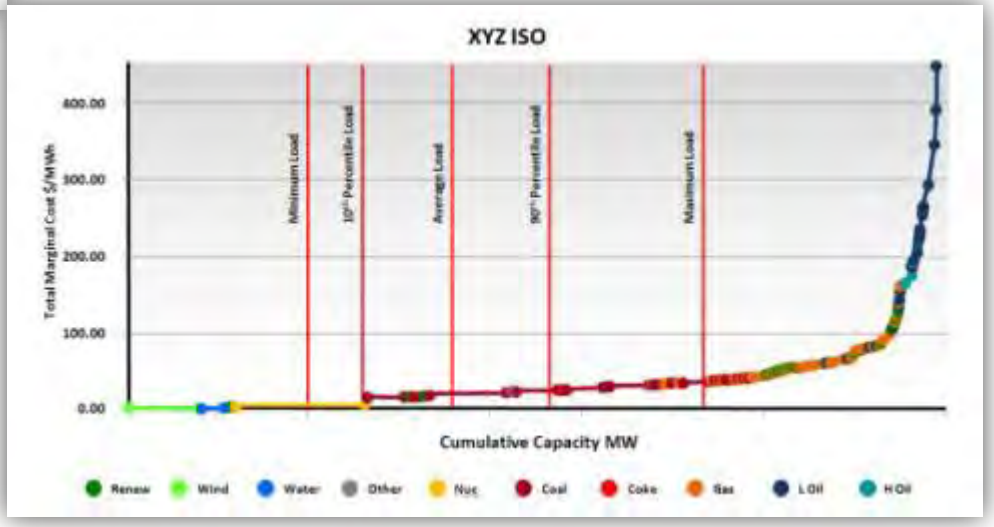
The Dispatch Stack…

Yesterday



VS.

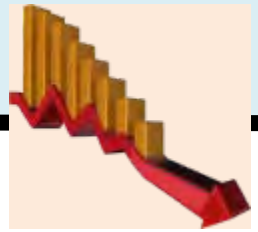
Today



What Has Caused This?

- Lower Average Demand
- Lower Natural Gas Prices
- Retirements






Retirements

- **Older smaller units were often used for swings**
- **These units may be retired to comply with environmental regulations**

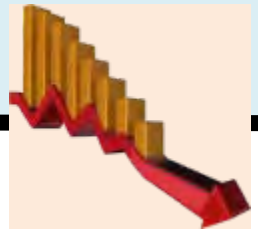
Result:

Larger units will now be subjected to more frequent and deeper cycles

What Has Caused This?

- Lower Average Demand
- Lower Natural Gas Prices
- Retirements
- Increased Penetration of Intermittent Renewables

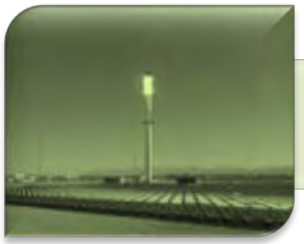





Increased Penetration of Intermittent Renewables

Wind

Photovoltaics (PV)



Concentrated Solar Power (CSP)

Photos Courtesy of : Conserve-energy-future.com, Bioclimaticdsng.blogspot.com

Summary

- **Existing Fleet Was Designed for "Base Load" Service**
- **Current Economics are Encouraging:**
  - **Load Cycling**
  - **Prolonged Low Load Operation**
  - **On-Off Cycling**
- **To Stay Profitable We Need to Adapt to This New Reality**

Have We Been Here Before?

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Yes

"Conventional fossil fuel fired boilers can meet the demands of utility systems for rapid and wide variations in load, including complete shutdown and restart, without sacrificing either heat rate or cycle life. But to do the best job, some new strategies, equipment, controls and operating methods are recommended."

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AH Rudd - OW Durrant
"Designs and Systems for Large Fossil Fuel Units Intended for Cycling Service"
April 29 – May 1, 1974

What Did We Do Then?

We Developed Boiler Component Designs That Could Handle Cycling

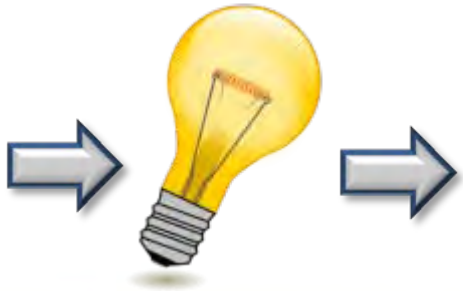
Issues

- Low Load Burner Stability
- Turbine Temperature Matching
- Cyclic Thermal Stresses
- Low Load Steam Temperatures
- Low load fan stability
- Start-Up air temperatures
- Low load feed pump performance
- Water Quality

&

Tools

- Part Mill Firing
- Auto Spring Loading System
- RB or UP Bypass Systems with Steam Attemperation
- Variable Speed Fan Drives
- Steam or Water Coils
- Start-Up Feedwater Pump
- Condensate Polishing Upgrades



What's Different Now?

Environmental Regulations Have Become More Stringent

CalSO View of Needs

"..resources required for integration of renewables .. :
- generation, storage, demand response ...

Generation portfolio characteristics –

quick-start units,
fast-ramp capability,
wide operating range (back way down in load & not exceed emissions limits),
regulation capability.

Storage to balance energy –

off-peak to on-peak,
mitigate over-generation,
provide voltage support and regulation.

Demand response –

frequency correction,
rapid response to gaps in wind energy production,
respond quickly to ISO dispatches,
distinguish between loads that are price sensitive and those that are not. …"

Low Load NOx Considerations

- **NOx vs. Load Characteristic**
- **SCR Gas Inlet Temperature (EEGT)**
- **SNCR Temperature Window**
- **Low Load Instrument Accuracy**
- **Air In-Leakage**

Low Load NOx Considerations

- **NOx vs. Load Characteristic**
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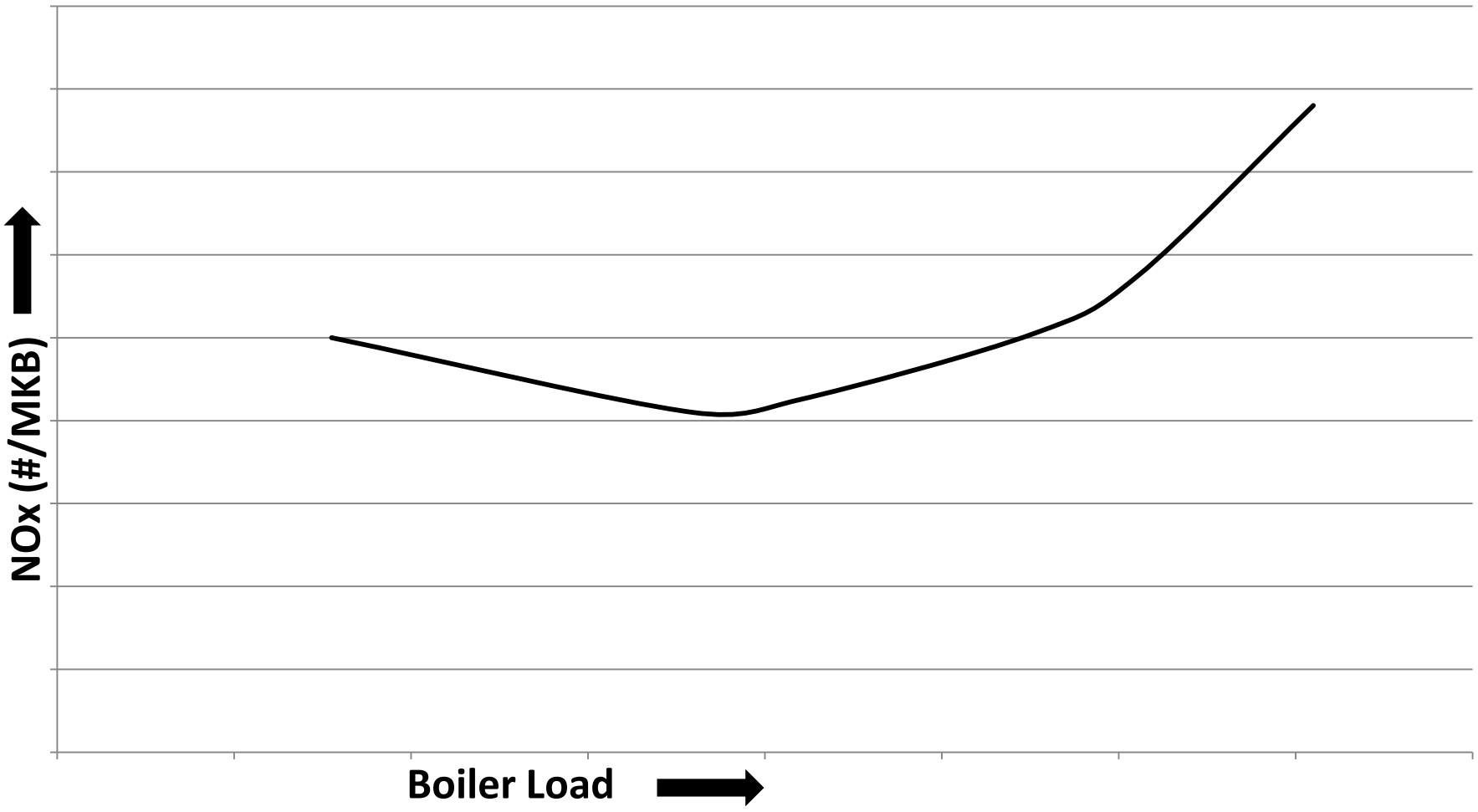
Coal Combustion NOx Control

- **Low Burner Zone Release Rate – Thermal NOx**
- **Aerodynamic Control Of Mixing Rates – Fuel NOx**
- **Staging – Fuel NOx**

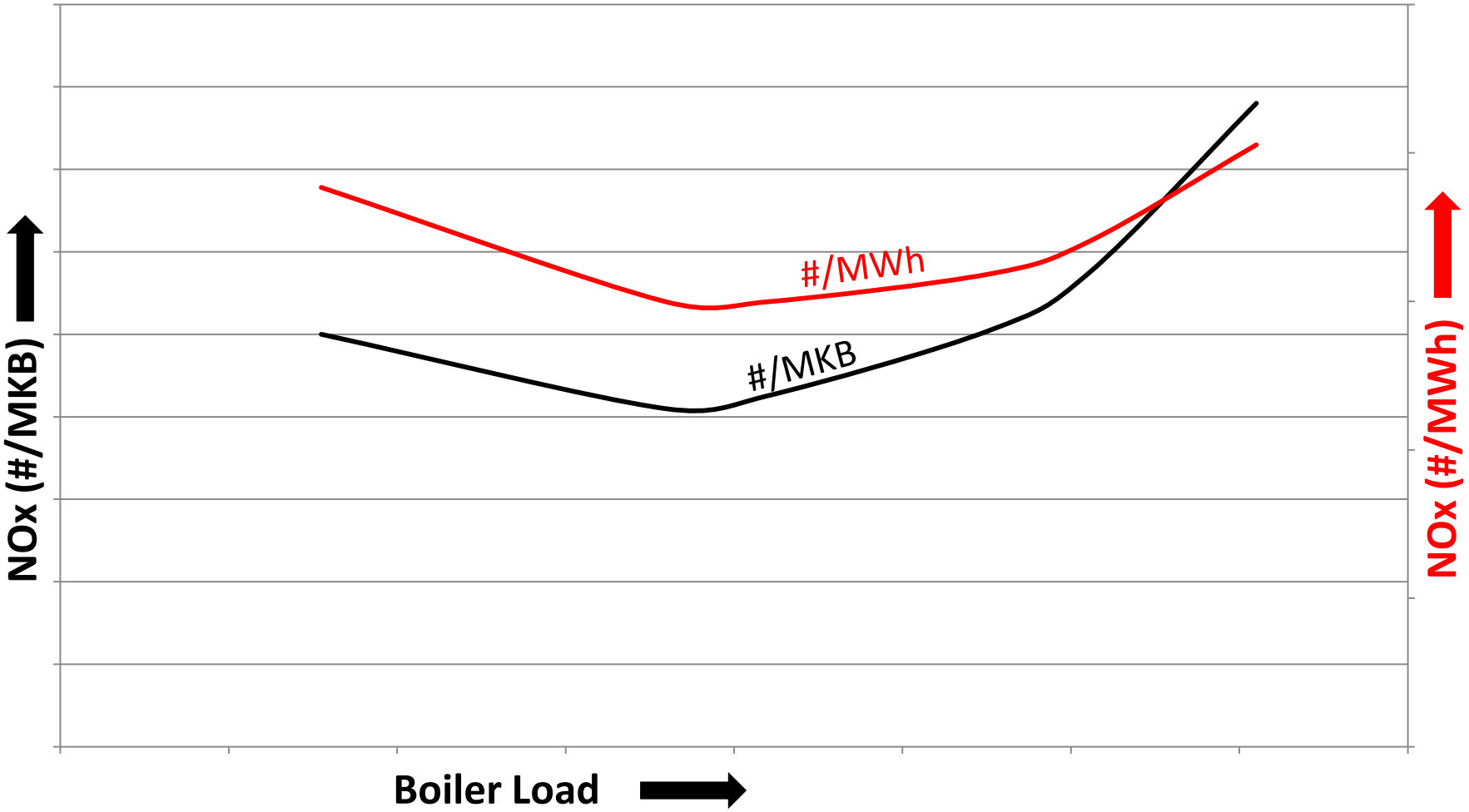
"Typical" Combustion NOx vs. Load

#/MKB



"Typical" Combustion NOx vs. Load

#/MKB & #/MWh



Possible Strategies

- **Minimize Air to Idle Burners/Compartments**
- **Tighten Up**

Low Load NOx Considerations

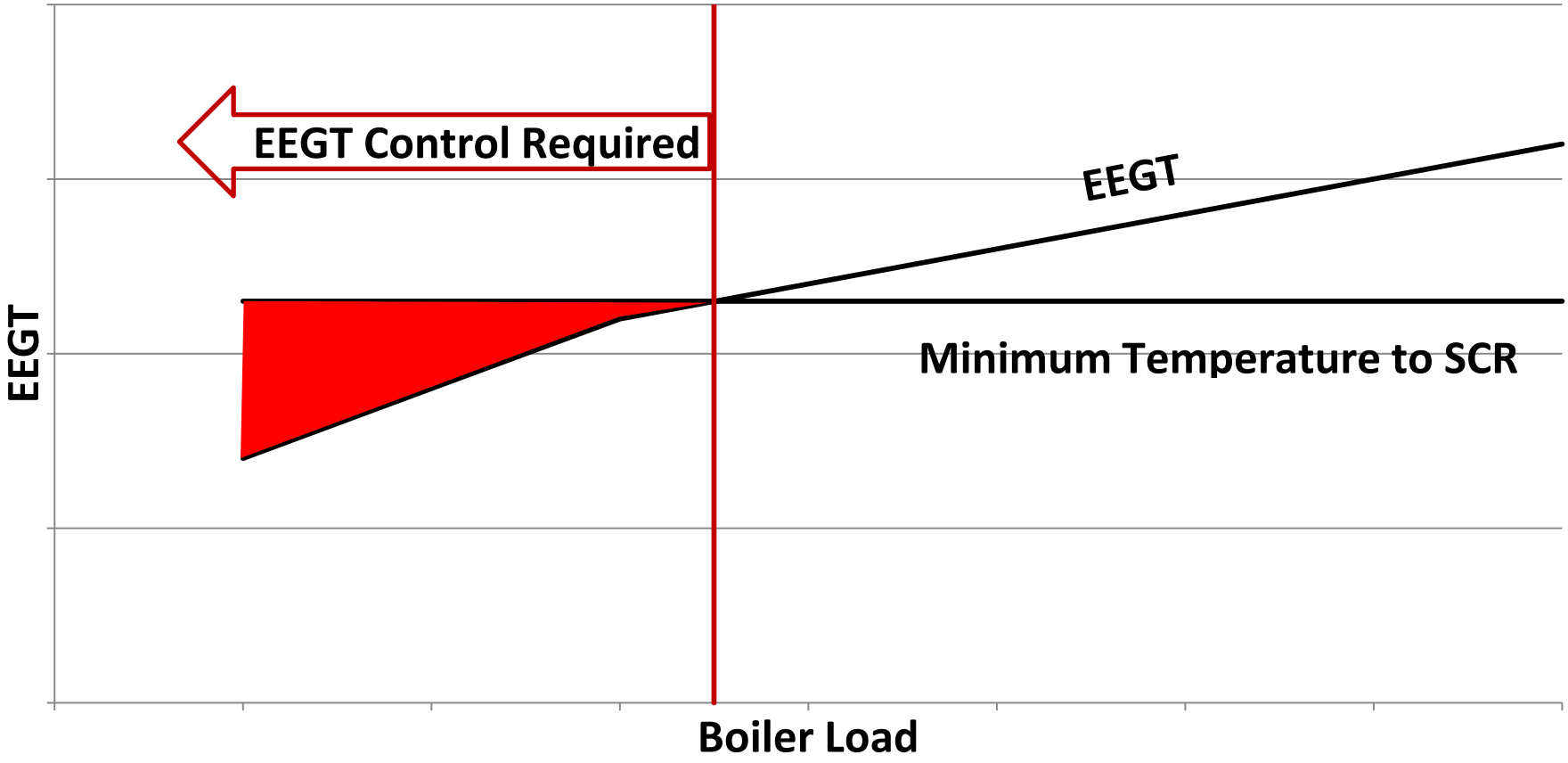
- NOx vs. Load Characteristic
- **SCR Gas Inlet Temperature (EEGT)**
- SNCR Temperature Window
- Low Load Instrument Accuracy
- Air In-Leakage

SCR

The Basics:

- NOx + NH_3
- In The Presence Of A Catalyst
- In The Right Temperature Regime
- Becomes N_2 + H_2O
- SO_3 + NH_3 Can Become NH_4HSO_4 (ABS)

Economizer Exit Gas Temperature



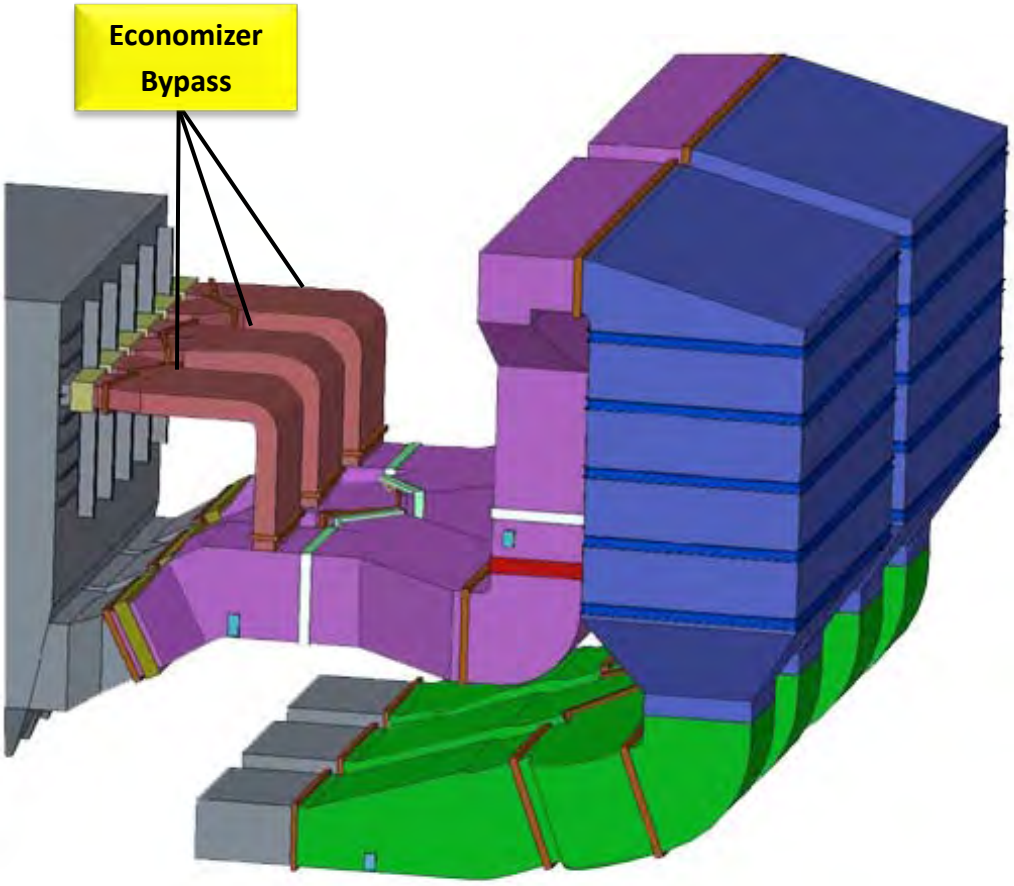
Possible Strategies

Options to Raise EEGT

Wide Load Operating Temperature Achieved by:

- **Economizer flue gas bypass**
- **Economizer heating surface removal**
- **Split economizer**
- **Feed water/boiler water mix system**
- **Economizer water bypass**
- **V-Temp™ Economizer**

Economizer Flue Gas Bypass



Advantages

- Quick gas temperature change
- Damper control
- Minimal η penalty at MCR
- Wide load range, with economizer outlet damper
- No steaming economizer issues

Disadvantages

- Expensive
- Convection Pass tie-in (wall openings, buckstays, etc.)
- Limited load range w/o economizer outlet damper
- Ash accumulation
- Gas mixing (Δ P)

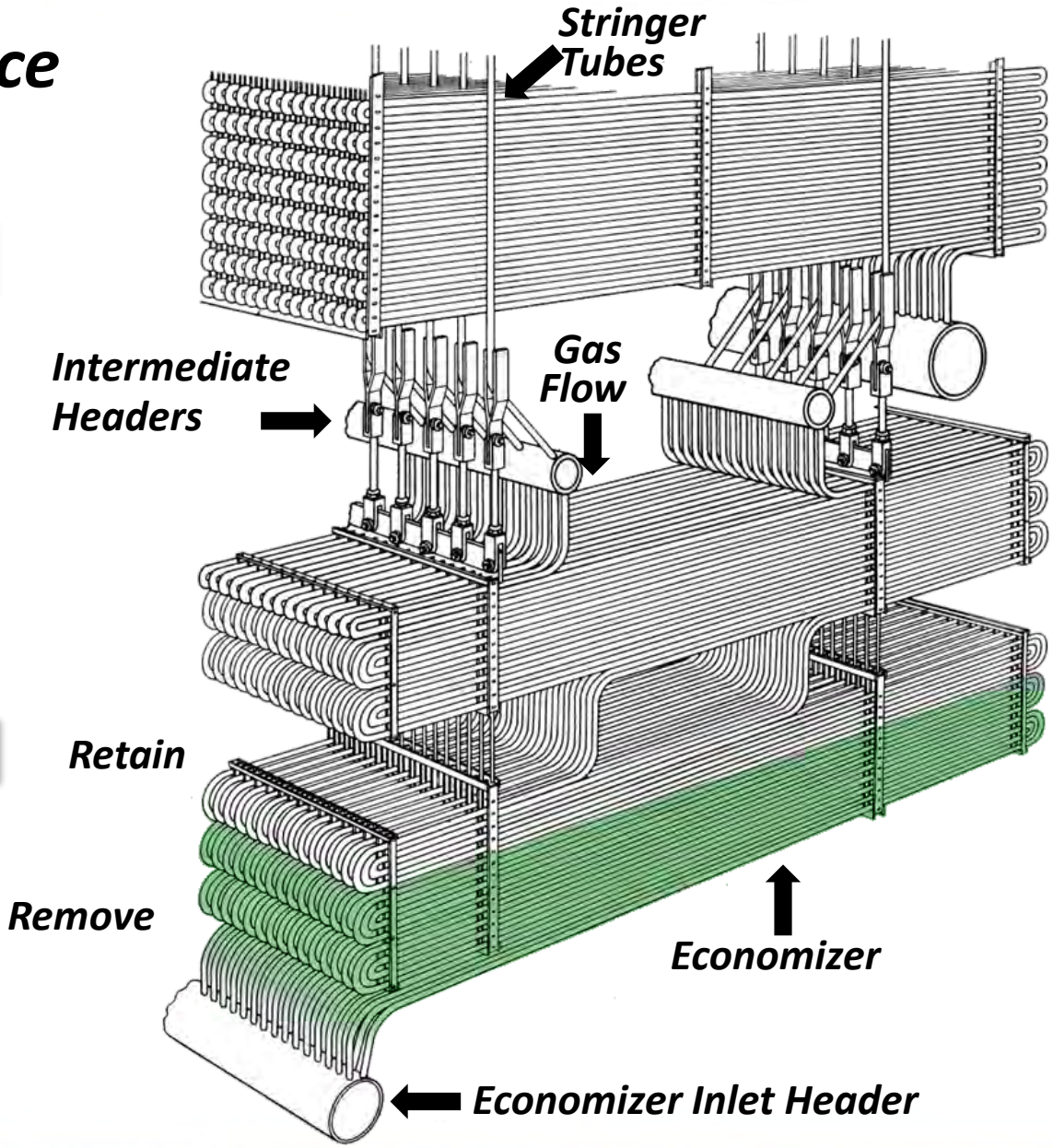
Economizer Surface Removal

Advantages

- Least expensive
- Predictable load range
- No control loop
- No dampers & exp. Joints
- No CP breach
- No gas mixing
- No ash accumulation

Disadvantages

- Increased EEGT design
- Limited load range
- No adjustment
- Loss of η across load range



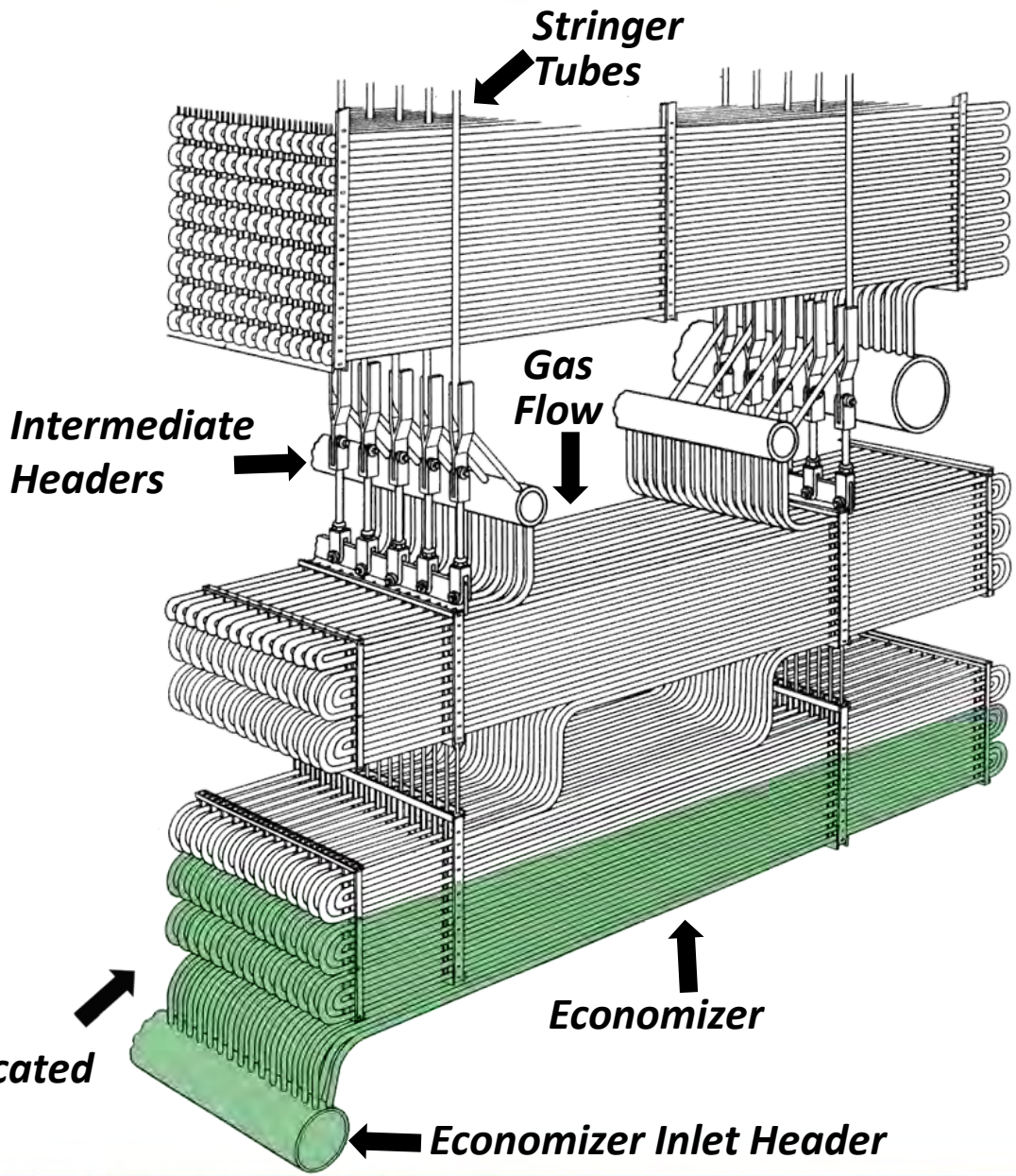
Split Economizer

Advantages

- No control loop
- Predictable load range
- No loss of η across load range
- No dampers & exp. joints
- No CP breach
- No gas mixing
- No ash accumulation

Disadvantages

- No adjustment
- Limited load range
- Limited EEGT design
- Increased draft loss



Economizer Tubes to be relocated between SCR and Air Heater

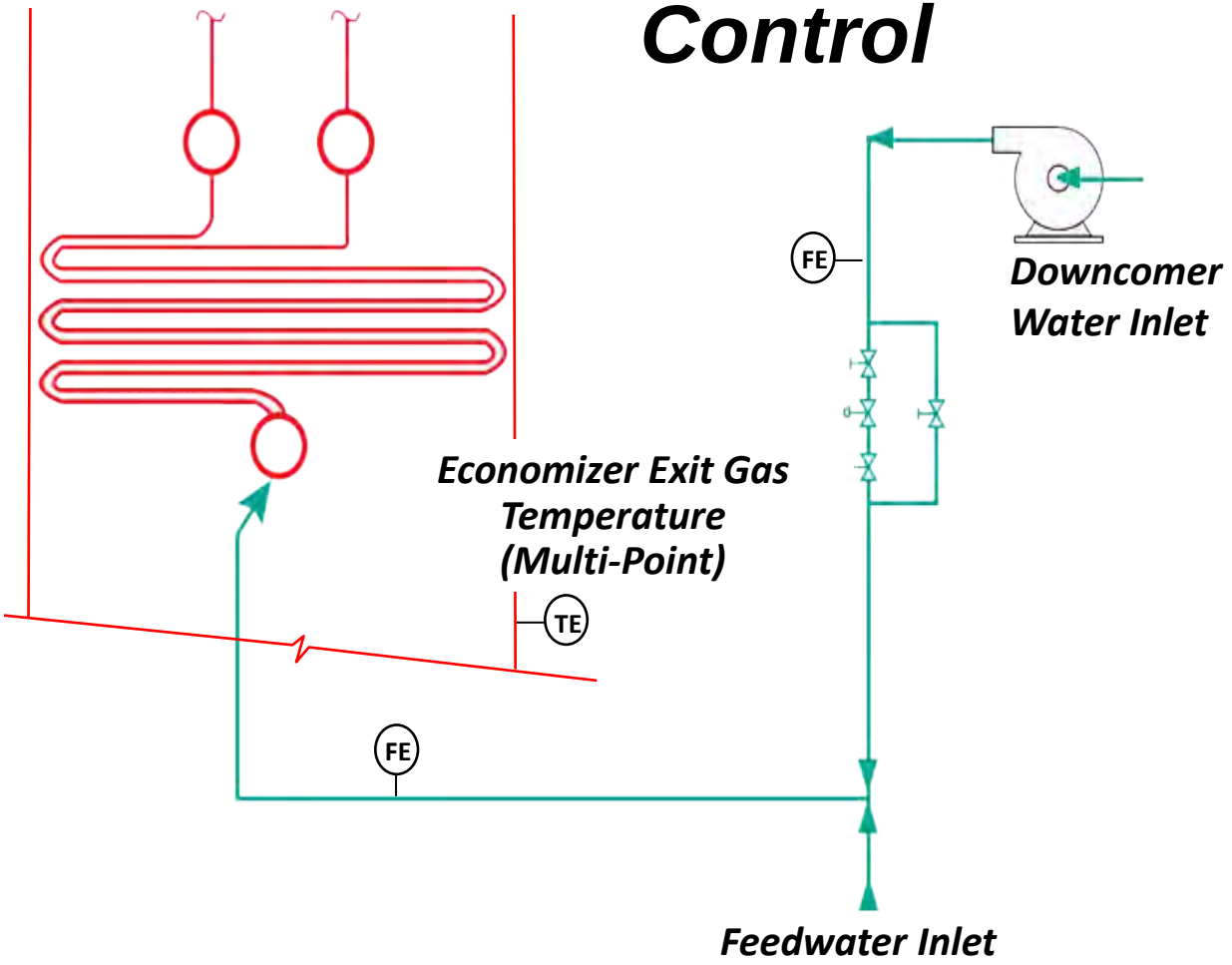
Feedwater Temperature Control

Advantages

- Extended control range
- Predictable load range
- No loss of η at MCR
- No dampers & exp. joints
- No CP breach
- No gas mixing
- No ash accumulation

Disadvantages

- Controls
- Limited load range
- Circulation analysis
- Additional pumps, piping & valves
- Steaming economizer



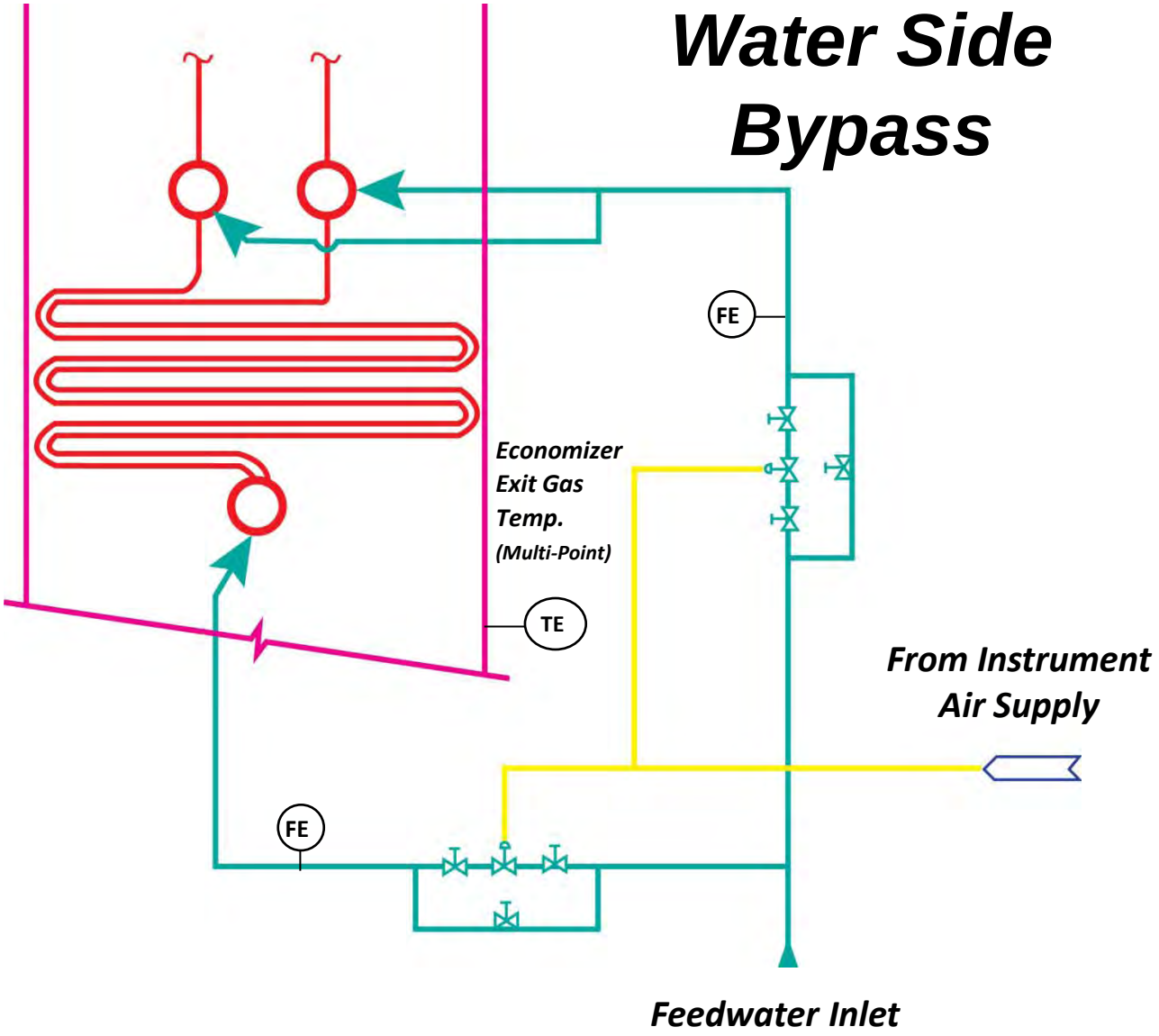
Water Side Bypass

Advantages

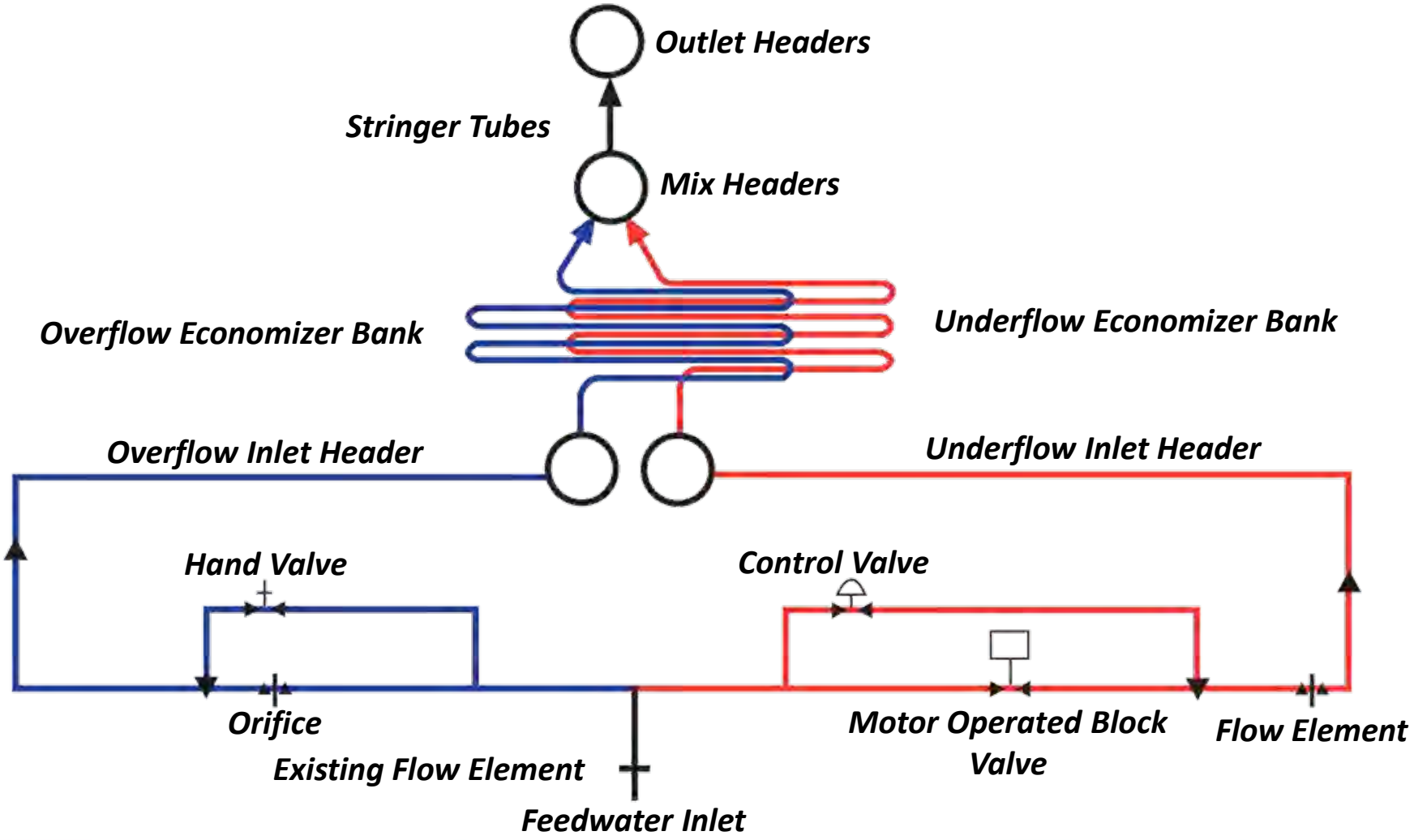
- Extended control range
- Predictable load range
- No loss of η at MCR
- No dampers & exp. joints
- No CP breach
- No gas mixing
- No ash accumulation

Disadvantages

- Controls
- Limited load range
- Circulation analysis
- Additional piping & valves
- Steaming economizer
- Stringer mix headers



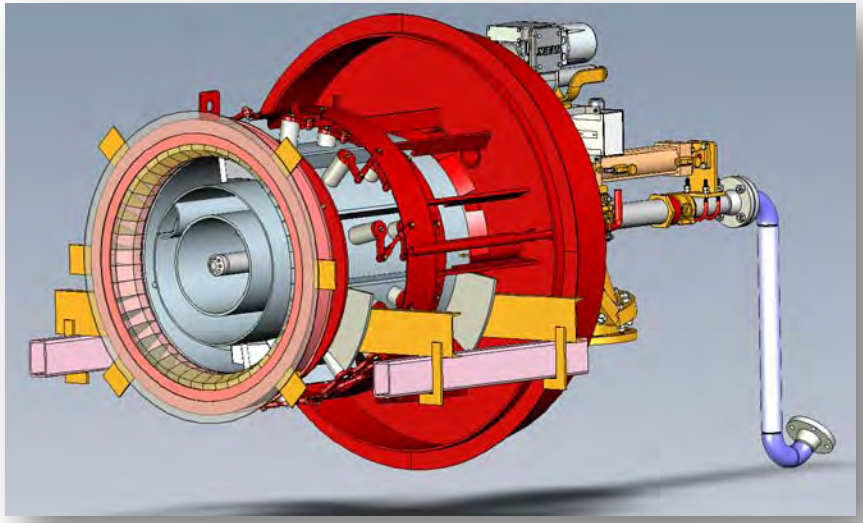
V-Temp™ Economizer



Another Approach

Replace existing coal nozzles with new ones that incorporate gas elements on selected burner elevations.

- Relatively low cost & short outage times
- Minimizes low load catalyst issues
- Eases issues surrounding taking mills in and out of service at low loads
- Combustion NOx typically lower than PC.



Low Load NOx Considerations

- NOx vs. Load Characteristic
- SCR Gas Inlet Temperature (EEGT)
- **SNCR Temperature Window**
- Low Load Instrument Accuracy
- Air In-Leakage

SNCR

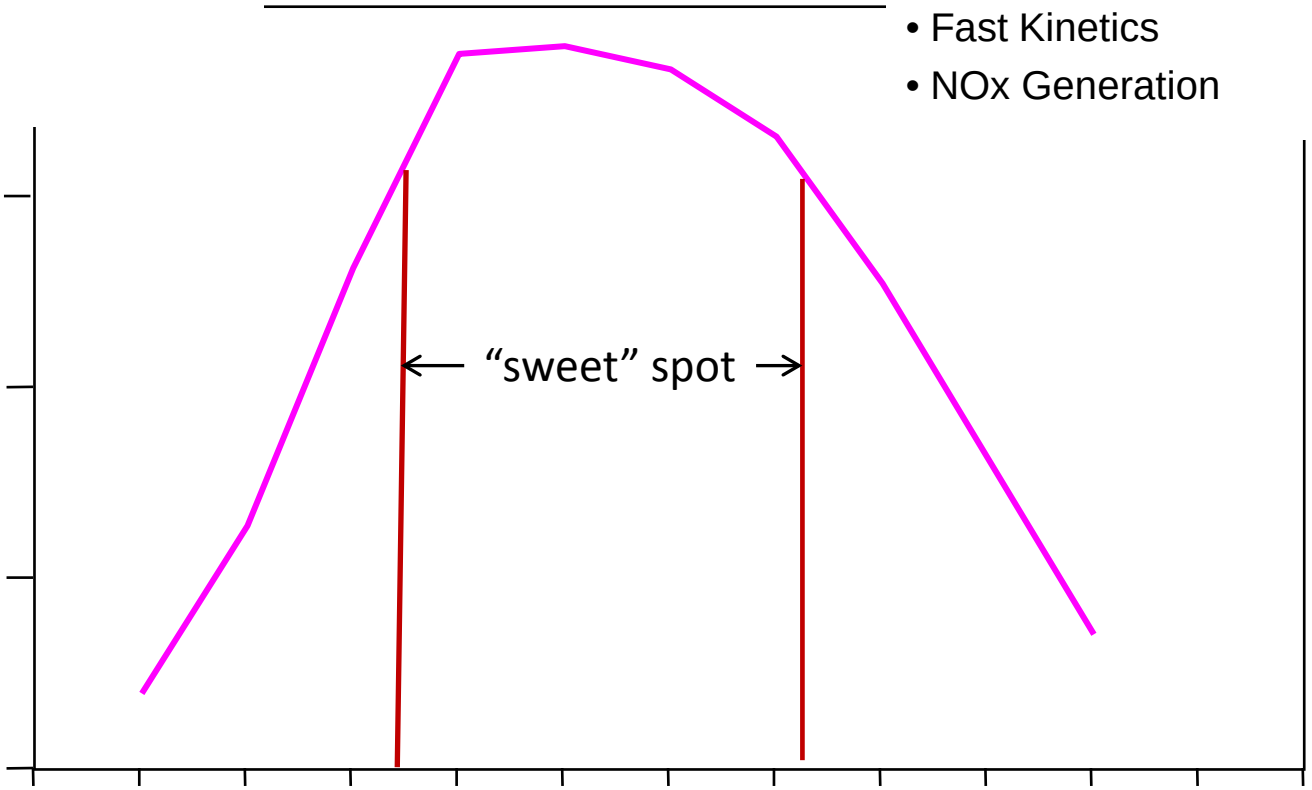
The Basics:

- NO_x + NH_3
- In The Right Temperature Regime
- Becomes N_2 + H_2O

SNCR Temperature Regime

Low Temperatures
- Slow Droplet Evaporation
- Slow Kinetics
- Ammonia Slip

High Temperatures
- Rapid Droplet Evaporation
- Fast Kinetics
- NOx Generation



Possible Strategy

- **Additional SNCR Injection Points Lower in the Furnace**

Low Load NOx Considerations

- NOx vs. Load Characteristic
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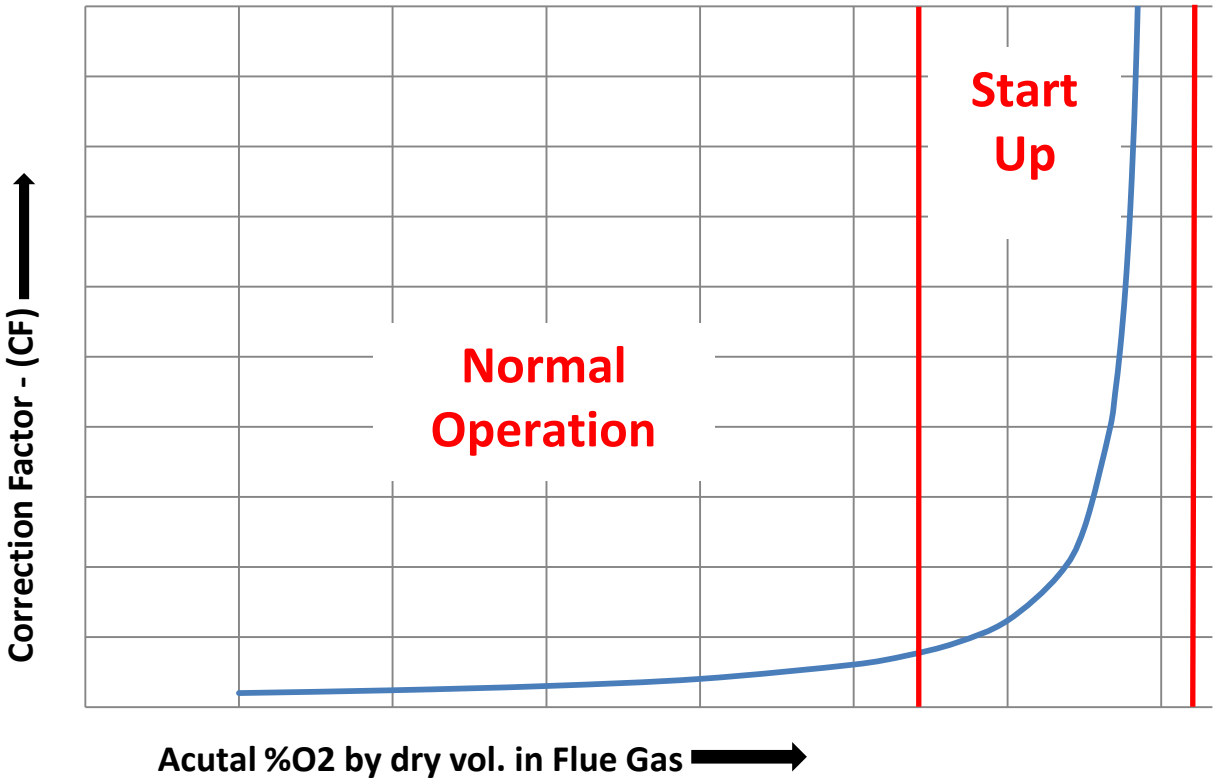
- **Low Load Instrument Accuracy**
- Air In-Leakage

Inaccuracies During Start-Up



PPM @ 3% O2 = PPM @ act %O2 * (CF)

Possible Strategies

- **Instrument Tuning/Calibration**
- **Separate Low Load/Start-Up Instrumentation**

Low Load NOx Considerations

- NOx vs. Load Characteristic
- SCR Gas Inlet Temperature (EEGT)
- SNCR Temperature Window
- Low Load Instrument Accuracy
- **Air In-Leakage**

Possible Strategies

- **Minimize Air to Idle Burners/Compartments**
- **Tighten Up**

Summary

- **Current Economics Are Driving Coal Fired Units Towards Prolonged Operation At Reduced Loads And/Or Cycling Service**
- **There Are A Number Of Hurdles To Doing This With Our Existing Fleet – Compliance With NOx Regulations Is One Of These**
- **There Are Changes In Maintenance Practices, Operational Practices and Hardware That Can Overcome These Hurdles**

Questions?

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