Boiler NOx Emissions and Energy Efficiency

Prepared For:

Boiler Operators and Facility Managers

Prepared By:

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AGENDA

Introduction

Boiler NOx Formation

- Types of NOx
- How NOx is Formed

NOx Reduction and Compliance Strategies

- Control Combustion
- Treat Exhaust After Combustion

Combining Energy Efficiency with NOx Reduction

- Benefits
- Example Energy Efficiency Upgrades

Summary

ABOUT ENOVITY

Enovity:

- Is an energy engineering and sustainability consulting firm
- Offers an array of services:
  - *Utility Programs*
  - *Energy Services*
  - *Building Commissioning*
  - *Building Automation*
  - *Advanced Operations and Maintenance*
  - *Sustainability Services*
- Has a team of 75+ mechanical and controls engineers, project managers, O&M, and admin staff
- Operates offices in San Francisco, Sacramento, Irvine, and Phoenix

BOILER NOx FORMATION

BOILER NOx FORMATION OVERVIEW

Key points:

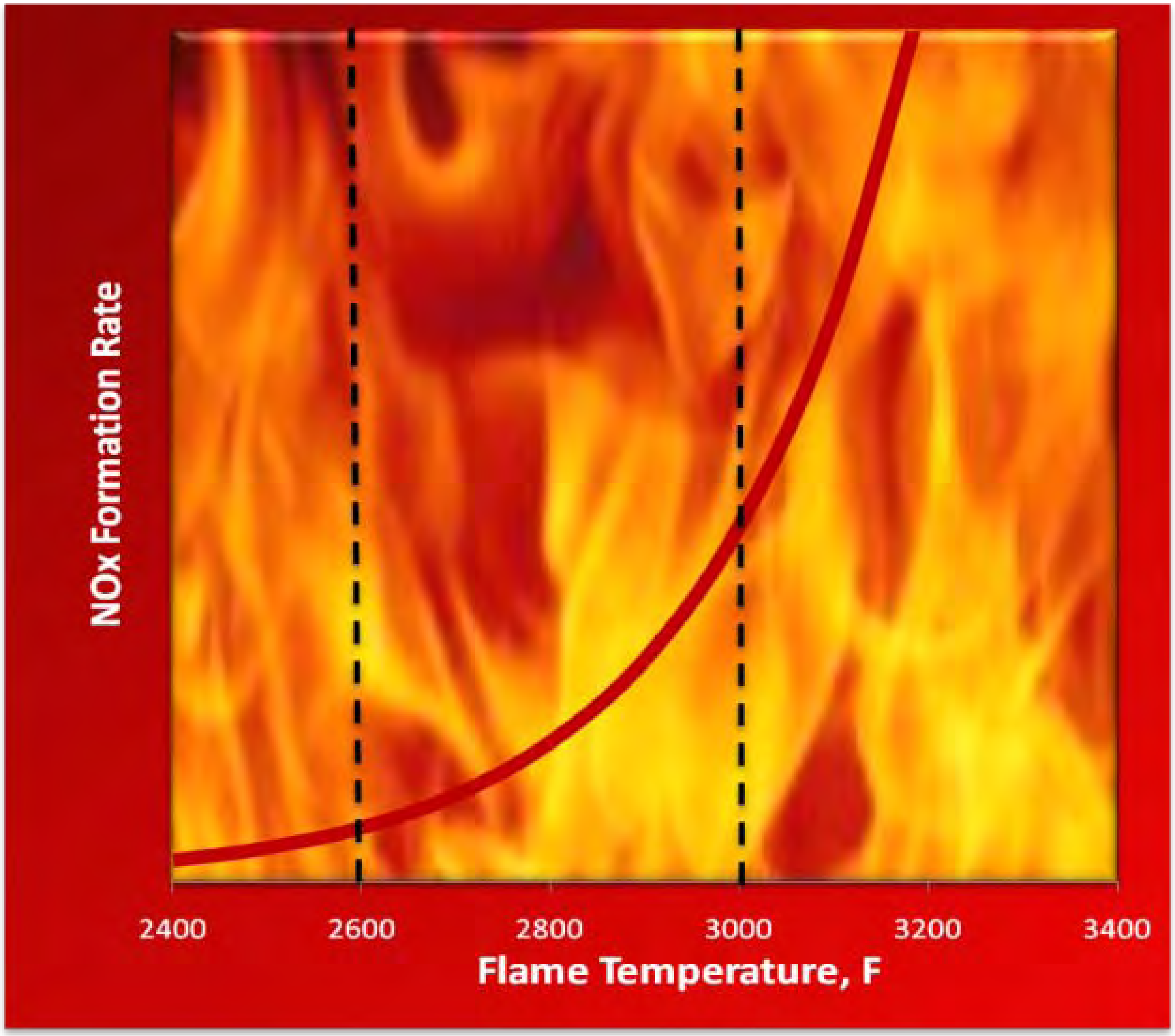
- Boiler burners use combustion to produce heat to make steam or hot water
- NOx is:
  - *A by-product of combustion*
  - *A pollutant that contributes to*
    - Ozone
    - Particulate matter
    - Acid rain
- NOx has three sources:
  - *Thermal NOx*
  - *Prompt NOx*
  - *Fuel-bound NOx (not typically a concern with natural gas)*

THERMAL NOx

Thermal NOx formation:

- Is the largest contributor to overall NOx emissions
- Occurs under high temperatures of combustion
  - *Combustion: Fuel + Air (O_2 + N_2) + Ignition*
  - *Ideal Natural Gas Combustion: CH_4 + O_2 + N_2 => CO_2 + H_20 + N_2 + O_2 + Heat*
  - *Above 2600 F: N_2 + O_2 + Heat => NOx*
- Is an exponential function of flame temperature

THERMAL NOx


NOx Formation Rate
2400
2600
2800
3000
3200
3400
Flame Temperature, F

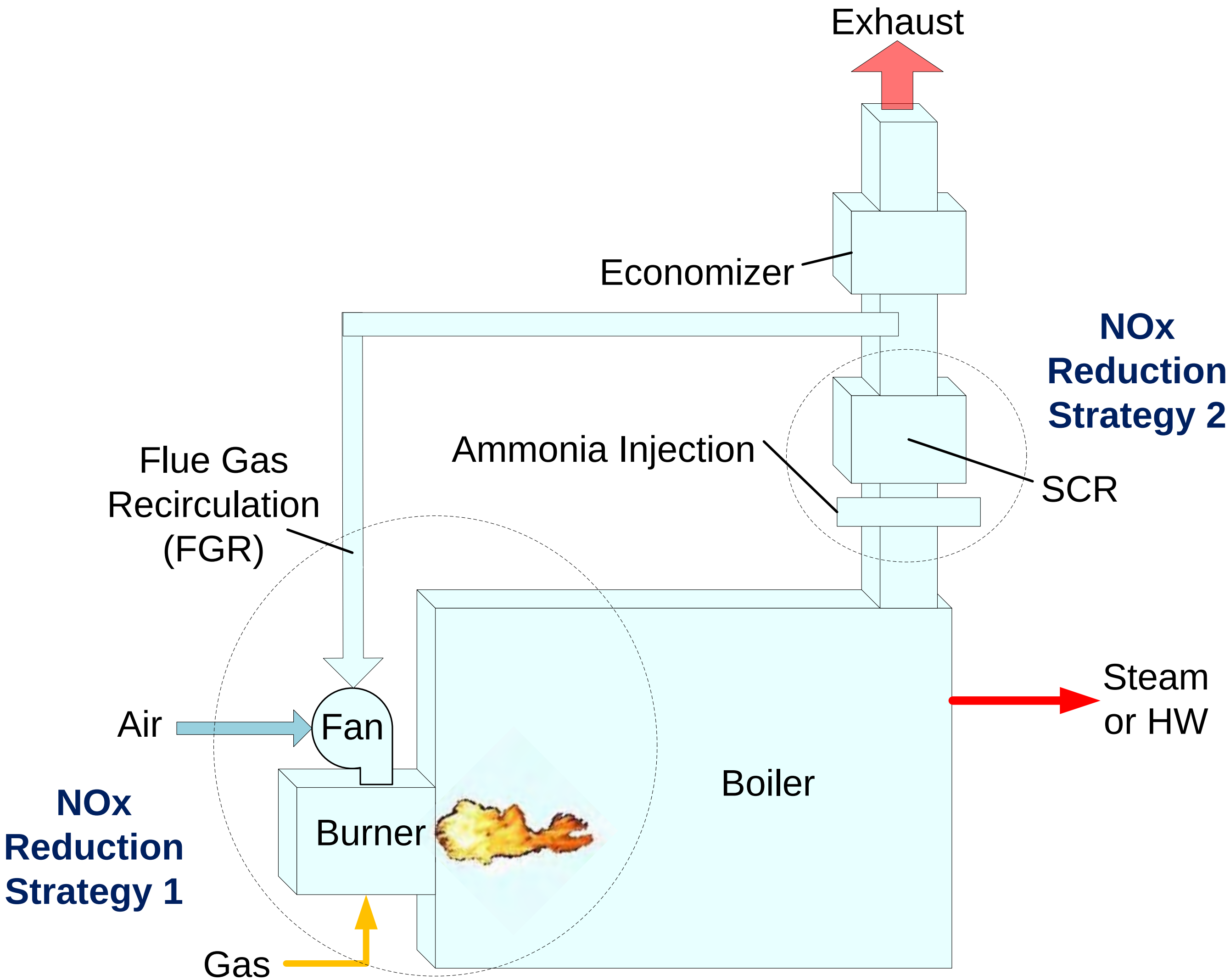
BOILER NOx REDUCTION STRATEGIES

OVERVIEW OF STRATEGIES

There are two basic strategies to reduce NOx emissions:

1. Reduce thermal NOx formation
   - *Requires modifying or replacing the boiler burner*
   - *Can achieve emissions of 7 ppm or lower*
   - *Is typically less expensive than exhaust treatment*
   - *May decrease efficiency(depending on the burner type)*
2. Treat the boiler exhaust to remove NOx after it is formed
   - *Requires installing a Selective Catalytic Reduction (SCR) system*
   - *Uses ammonia and a catalyst to remove NOx from the exhaust*
   - *Can achieve emissions of 5 ppm or lower*
   - *Has less impact on efficiency*
   - *Is typically more expensive than burner retrofit/replacement*
   - *May not be applicable to boilers smaller than 30 MMBtu/hr*

OVERVIEW OF STRATEGIES



REDUCING NOx FORMATION

Techniques to reduce NOx formation :

- Include:
  - *Adding flue gas recirculation (FGR)*
  - *Altering the fuel/air ratio and excess O_2*
  - *Using staged fuel or air*
  - *Improving fuel/air distribution and mixing*
  - *Improving flame distribution to reduce hot spots*
  - *Using staged combustion (both fuel and air)*
- Are typically focused on lowering the flame temperature
  - *The challenge: how to lower flame temperature without reducing efficiency and/or flame stability?*
    - Increasing excess O_2 will decrease efficiency
    - Using FGR has less impact on efficiency, but requires additional fan energy

COMBUSTION EFFICIENCY

Excess (%)		Combustion Efficiency				
		Exhaust Stack Temperature minus Combustion Air Temperature (F)				
Air	Oxygen	200	300	400	500	600
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

LOW- AND ULTRA-LOW-NOx BURNERS

Low-NOx Burners (30 ppm):

- Use FGR
- Can maintain 3 to 5% excess O_2 with good controls
- Offer good turndown (> 8:1) and flame stability

Ultra-Low-NOx Burners (7 to 15 ppm):

- Use FGR, adjusted fuel/air ratios, and staging
- May have (in some designs):
  - *Higher excess O_2 (anywhere from 5 to 9%)*
  - *Larger combustion air fans (15% to 50% increase in required HP)*
  - *Reduced turndown (3:1 or 4:1) and flame stability*
- Are improving
  - *Many now in the 5% to 7% O_2 range*

ULTRA-LOW-NOx BURNERS

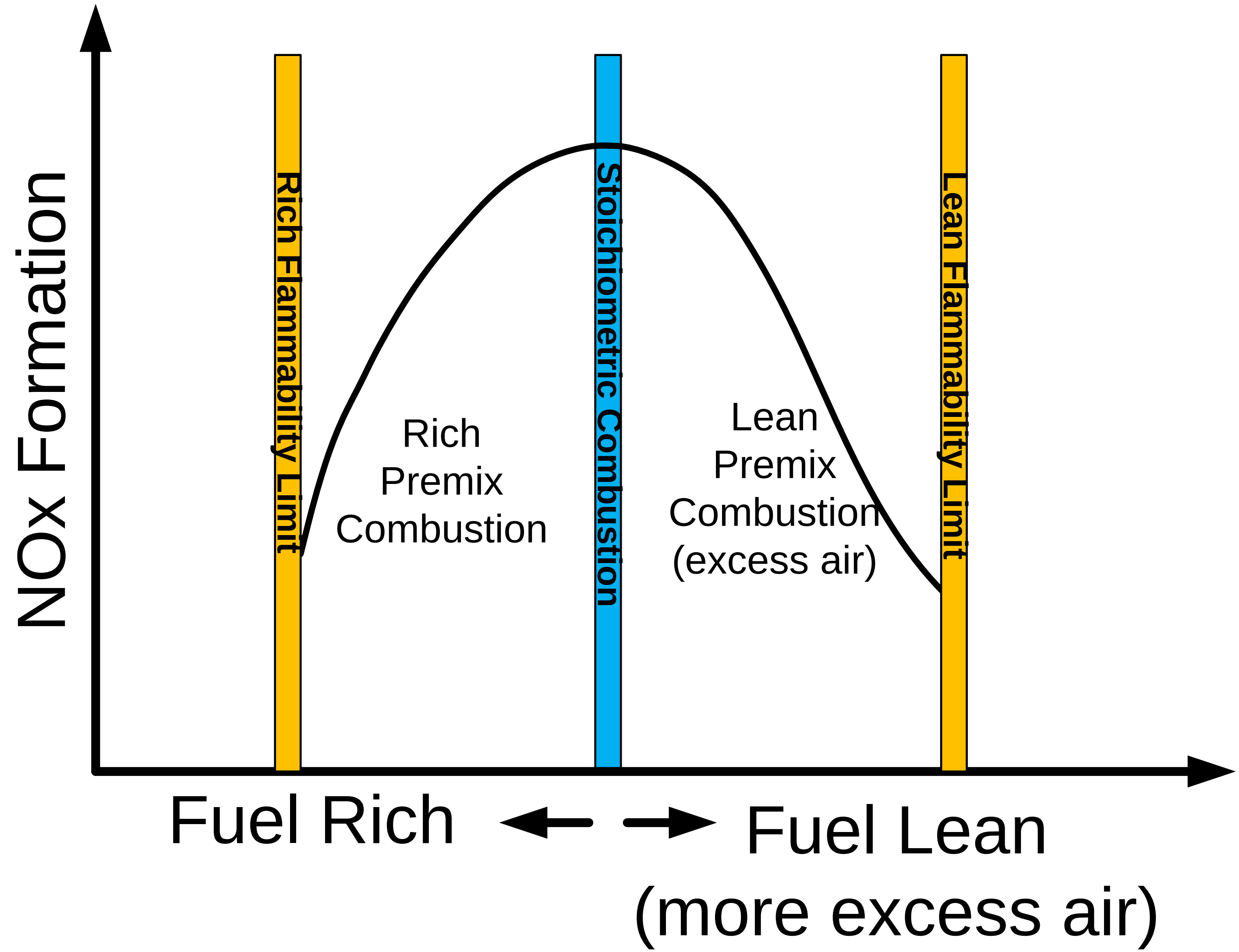
Conventional designs:

- Utilize higher FGR and lean mixture designs
  - *Lean premix: Gas nozzles and metal fiber*
  - *Lean rapid mix: Gas nozzles*
  - *With or without secondary fuel staging*

Newer Designs:

- Are aimed at improving efficiency
- Use less excess air (3% to 5%), less FGR and therefore less fan energy
- May use staged combustion
  - *Fuel and air are combusted in multiple stages (rich and lean)*
  - *Low NOx in each stage of combustion*
- Remain unknown in terms of availability and performance

NOX FORMATION AND FUEL/AIR RATIO



TREATING BOILER EXHAUST

Selective Catalytic Reduction (SCR) systems:

- Use ammonia injection and a catalyst to remove NOx from exhaust
- Are engineered solutions
- Require sufficient space and proper design, installation, and control
- Need fairly high exhaust temperatures (350 F or higher)
- Have some potential issues
  - *Excessive boiler cycling*
  - *Ammonia slip and/or leakage*
- Are recommended (instead of burner upgrade) for large water-tube boilers
- May soon be available for fire-tube boilers
  - *Stack temperature and cost are issues*

SUMMARY OF COMPLIANCE OPTIONS

Options for reducing NOx emissions include:

1. Retrofit or modify the existing burner
   - *From 15 ppm to 9 ppm*
   - *From 9 ppm to 7 ppm (only available for some burners)*
2. Replace the burner
   - *To meet 30 ppm, 15 ppm, or 9 ppm limits*
   - *Perhaps to meet 7 ppm (availability?)*
3. Replace the boiler
   - *Cost vs. efficiency improvement*
4. Install SCR system
   - *Good option for water-tubes, but for fire-tubes?*
5. De-rate boiler below threshold of regulation
6. Pay an annual emission fee (only in San Joaquin Valley APCD)

RECOMMENDATIONS

When deciding on a compliance strategy:

- Evaluate site-specific options and proposals
  - *Address design or installation issues*
  - *Evaluate experience and expertise of contractors and suppliers*
  - *Look at condition of existing equipment (retrofit vs. replace)*
  - *Obtain actual (as opposed to design) performance data for a site-specific installation*
  - *Ask for a performance guarantee!*
  - *Consider that regulations may change again in the future*
  - *Assess impact on energy efficiency and other spending activities*
- Evaluate total operating cost
  - *Energy*
  - *Operations*
  - *Compliance*

COMBINING ENERGY EFFICIENCY WITH BOILER NOx UPGRADES

WHY INCLUDE ENERGY EFFICIENCY?

Reasons to include energy efficiency with NOx upgrades include:

- Mitigating efficiency decrease and/or operating cost increase from NOx reduction
- Energy and utility cost savings
- Some advantages of implementing as a single project:
  - *Downtime is limited*
  - *Upgrades may be more cost-effective*
  - *Project will generate a return*
- Greenhouse gas emission reductions
- Taking advantage of rebates available for energy efficiency upgrades
- Increasing boiler capacity
- Improving operations and maintenance
- Replacing aged equipment

BURNER-RELATED UPGRADES

Combine energy efficiency with burner upgrades by:

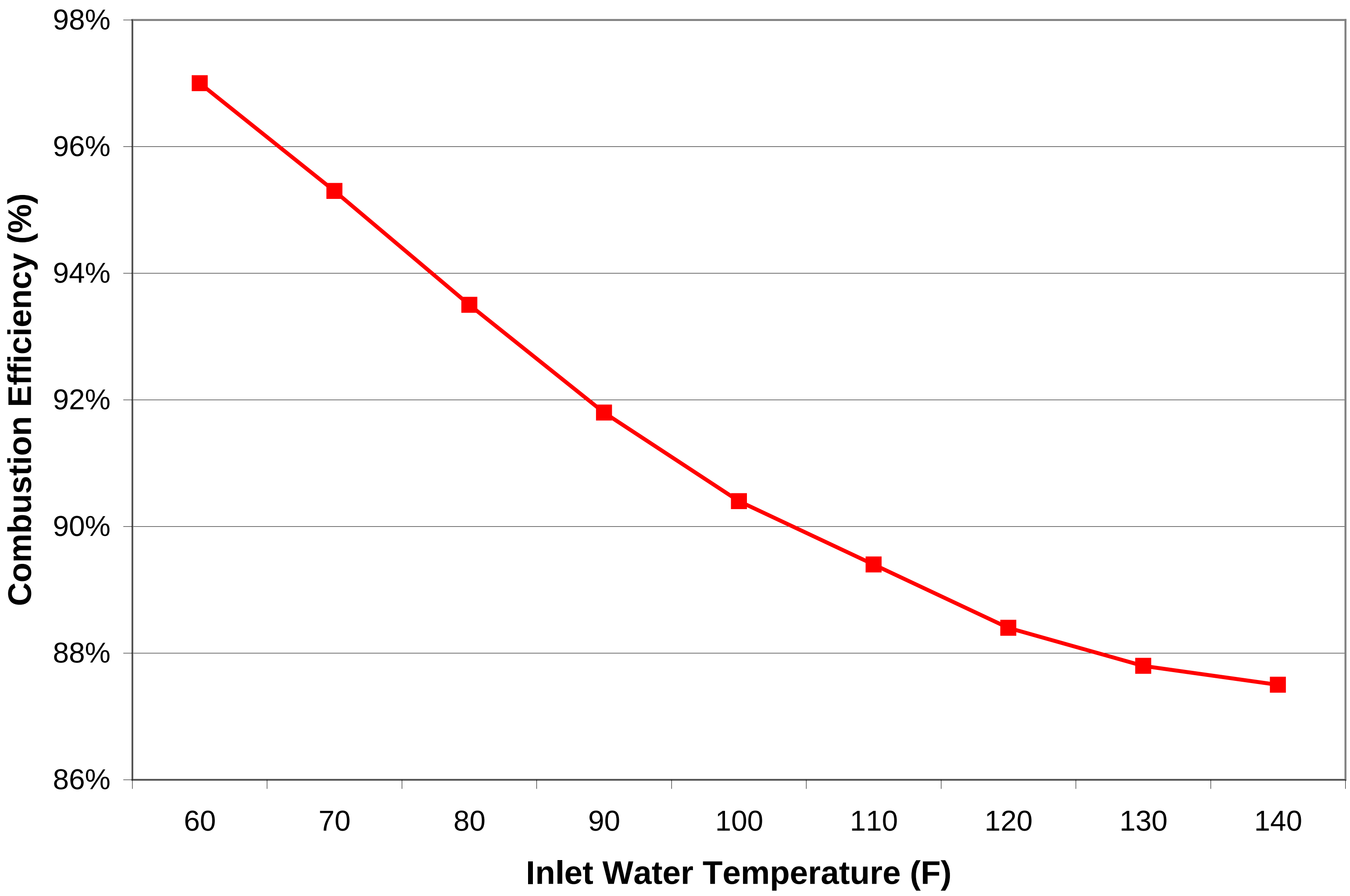
- Installing a variable frequency drive (VFD) on the burner fan
  - *Cost-effective for larger fans and longer operating hours*
- Installing a SCR system and replacing an existing ultra-low-NOx burner
  - *If using an older, high-excess air ULN burner, replace with a high-efficiency 30 ppm burner*
  - *Applicable for boilers larger than 30 MMBtu/hr*
  - *Can save both natural gas and electricity*

NEW BOILERS

When replacing a boiler, consider:

- High-efficiency boilers
- Condensing boilers
- Direct-contact water heaters
- Steam generators
- Switching from steam to hot water

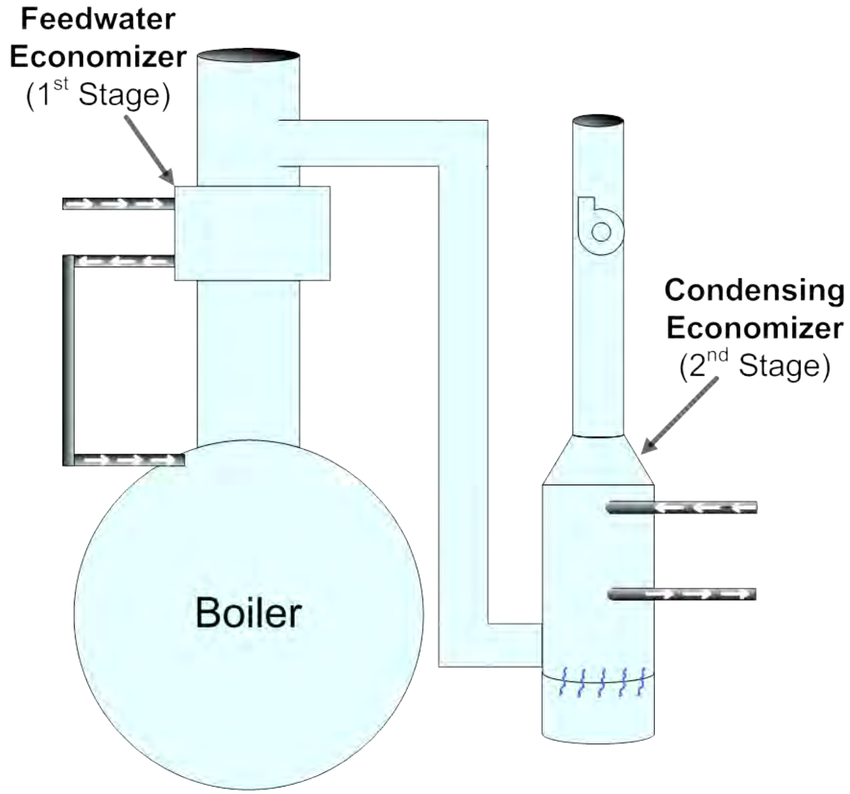
HIGHLIGHT: CONDENSING BOILERS



HEAT RECOVERY OPPORTUNITIES

- Pipe, tank, and other heated surface insulation
- Exhaust stack economizers (feedwater or condensing)
- Blowdown heat recovery
- Condensate recovery
- Mechanical vapor recompression or other custom efficiency upgrades for evaporators
- Flash steam recovery
- Thermosorber heat pump
- Process heat recovery

HIGHLIGHT: CONDENSING ECONOMIZERS

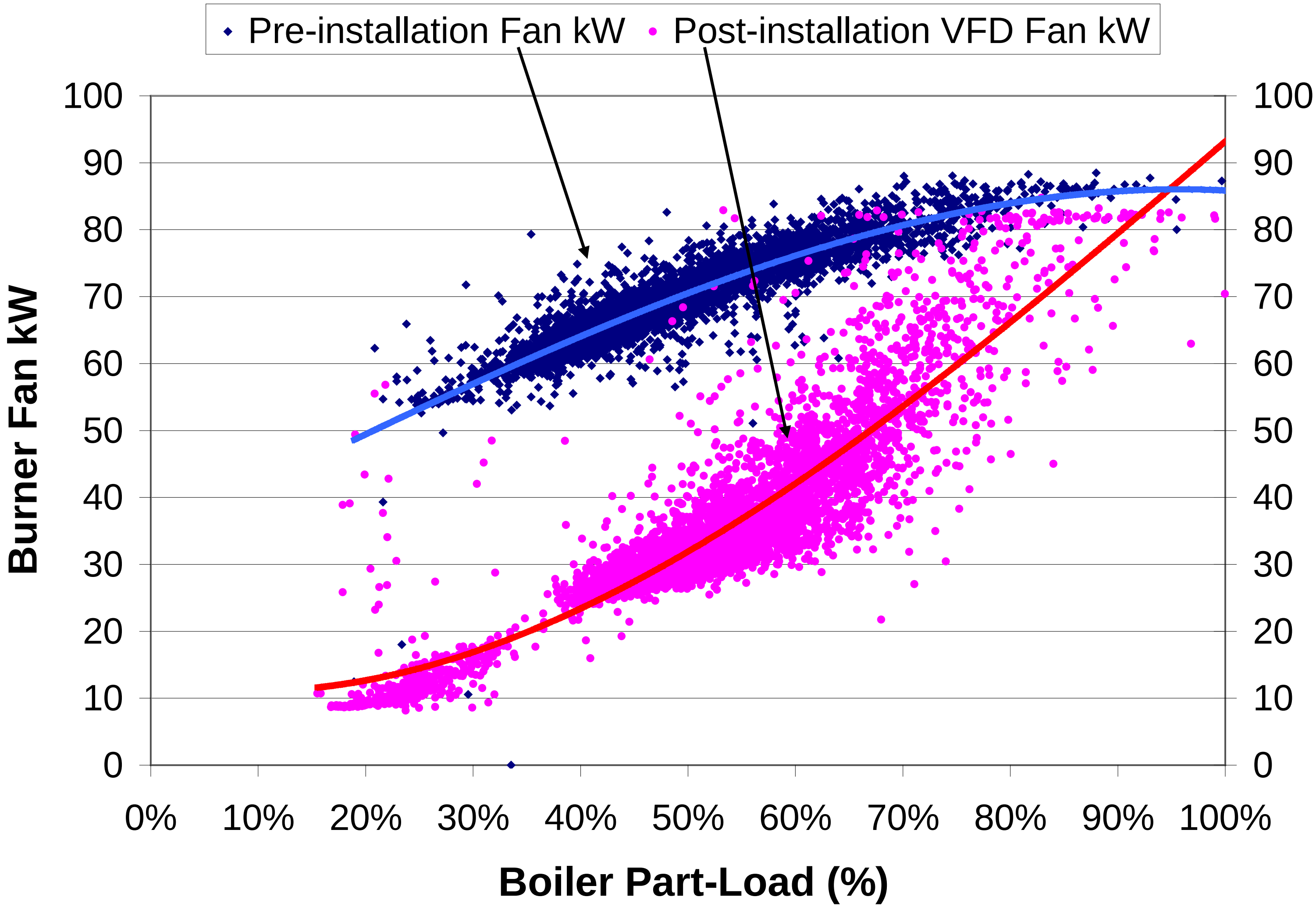


- Applicable to larger boilers with nearby low-temperature water demand (domestic hot water, process water, clean-in-place)
- Preheats water up to 140°F to reduce steam consumption
- Most efficient when combined with a first-stage feedwater economizer

VARIABLE FREQUENCY DRIVES

- Boiler burner combustion air fan
- Feedwater pumps
- Condensate return pumps
- Process water pumps

EXAMPLE BURNER FAN VFD RESULTS



REPAIRS AND SETTING CHANGES

- Replace old or failed steam traps
- Repair/replace control linkage
- Repair/replace failed blowdown controls or reduce excessive blowdown
- Reduce or eliminate boiler cycling
- Repair/replace dirty heat exchanger or boiler economizer
- Replace boiler refractory
- Reduce boiler steam pressure or hot water supply temperature set points
- Repair/replace failed VFD

OTHERS

- Reverse osmosis water treatment systems (for reduced boiler blowdown)
- High-efficiency boiler burners
- Electronic parallel positioning fuel-air controls (with or without oxygen trim)
  - *Only for burners ≥ 30 ppm NOx*

SUMMARY

Key points to review:

- New regulations may require boiler upgrades
- Evaluate your options for compliance
- Combine energy efficiency with NOx-related upgrades
  - *Save energy, reduce operating cost and greenhouse gas emissions*
  - *Create a payback*
  - *Make the most of down time*
- Take advantage of utility energy efficiency rebates and no-cost technical services

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