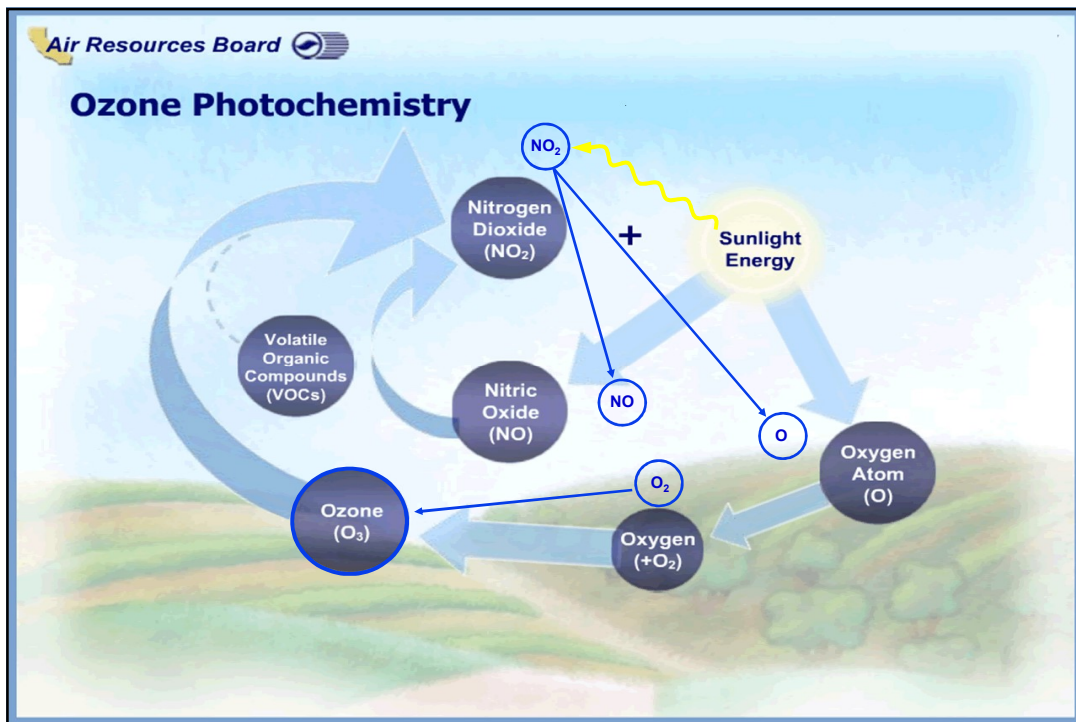




Course Overview

- ◆ Air Pollution *Why*
- ◆ Boiler Uses *What*
- ◆ Boiler Theory and Operation
- ◆ Air Pollution Formation
- ◆ Air Pollution Control Devices
- ◆ Boiler Regulations *How*
- ◆ Typical Permit Conditions
- ◆ Inspection Procedures



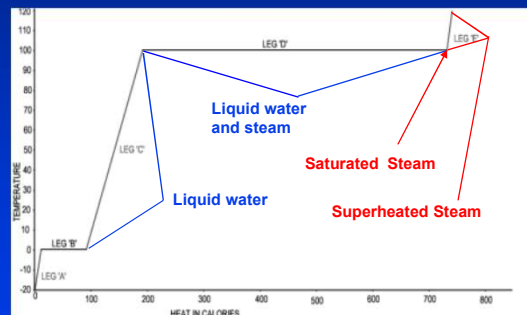


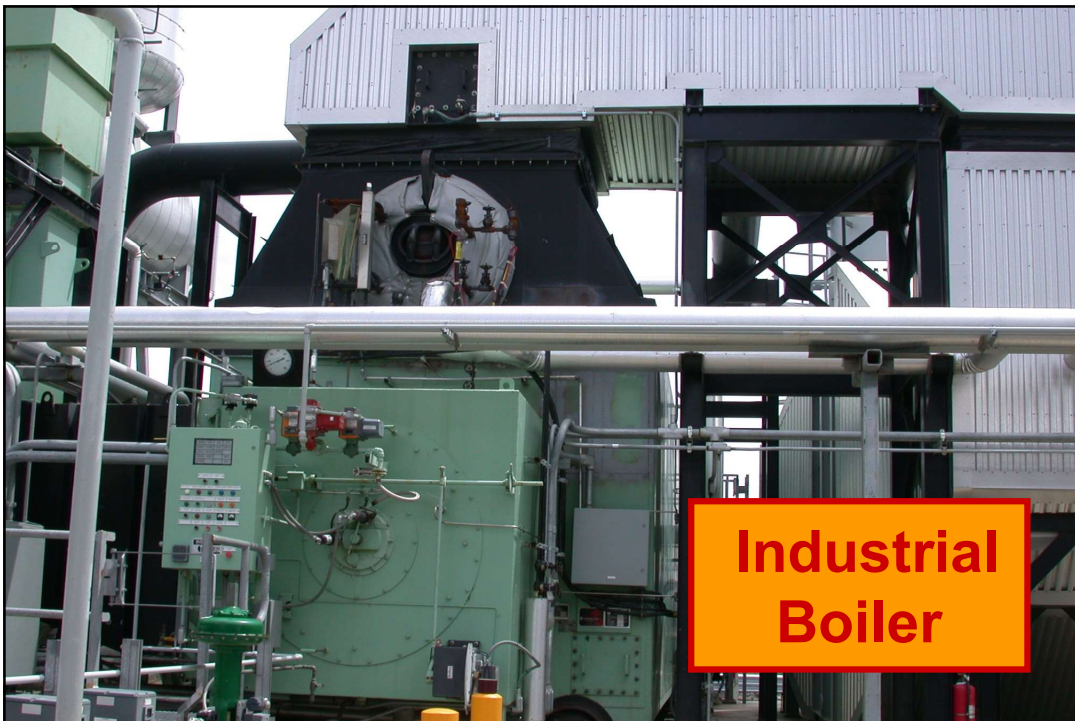
Uses of Boilers

- ◆ Electrical generation
- ◆ Space heating
- ◆ Food preparation
- ◆ Commercial laundries
- ◆ Pulp & paper industry
- ◆ Petroleum industry
- ◆ Chemical industry
- ◆ Municipalities : Water, Sewage & Garbage

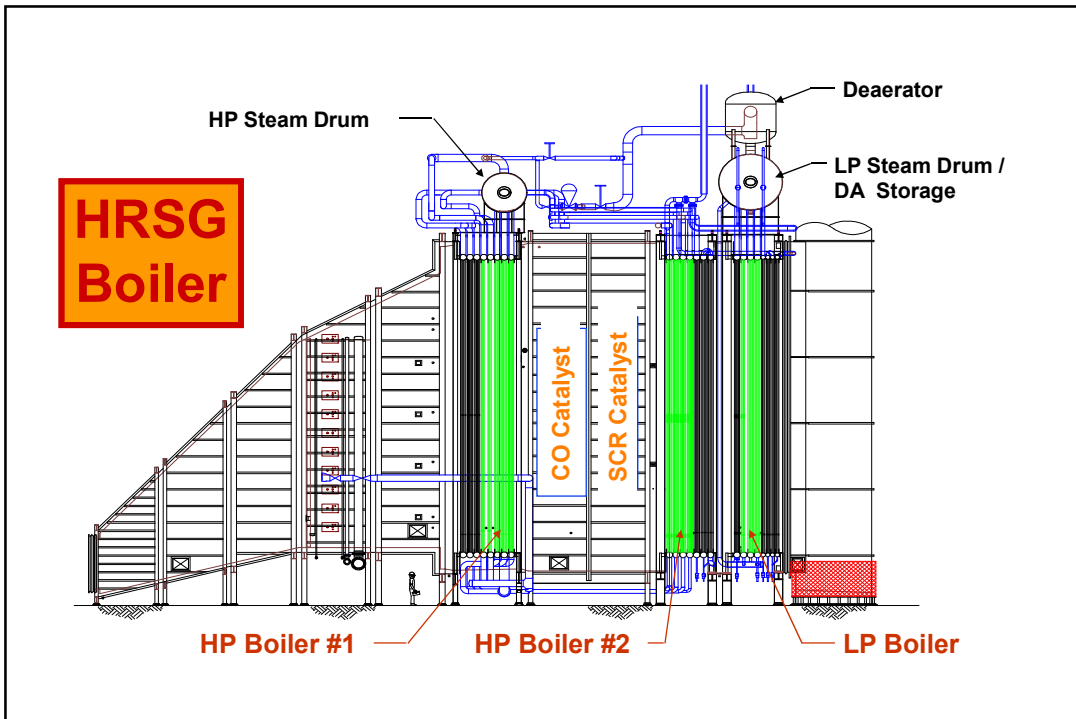
High Pressure (2,000 -3,800 psi)

Low Pressure (150 – 1,600 psi)





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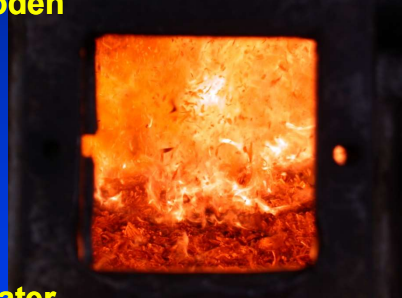


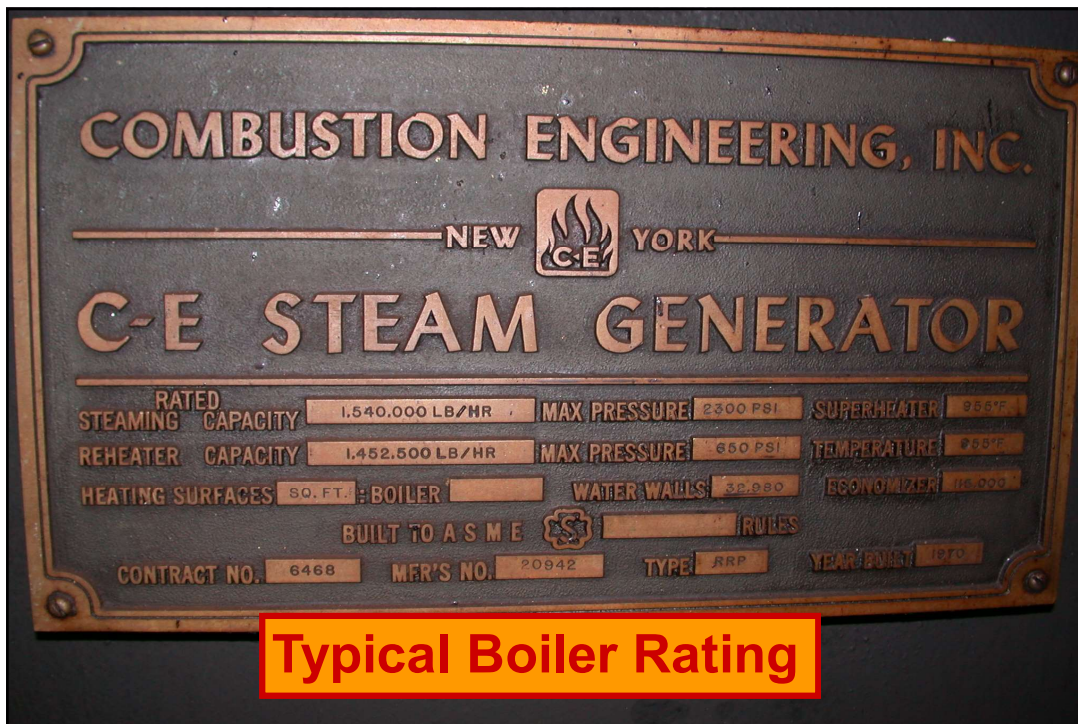
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Hot Numbers

- ◆ **British Thermal Unit (BTU)**
 - ◆ 1 BTU the amount of energy needed to heat one pound of water one degree Fahrenheit or \approx energy given off by burning one wooden match
- ◆ **Lower Heating Value (LHV)**
 - ◆ Heating value of a fuel not counting heat needed to vaporize water
- ◆ **Higher Heating Value (HHV)**
 - ◆ Heating value of a fuel including heat needed to vaporize water



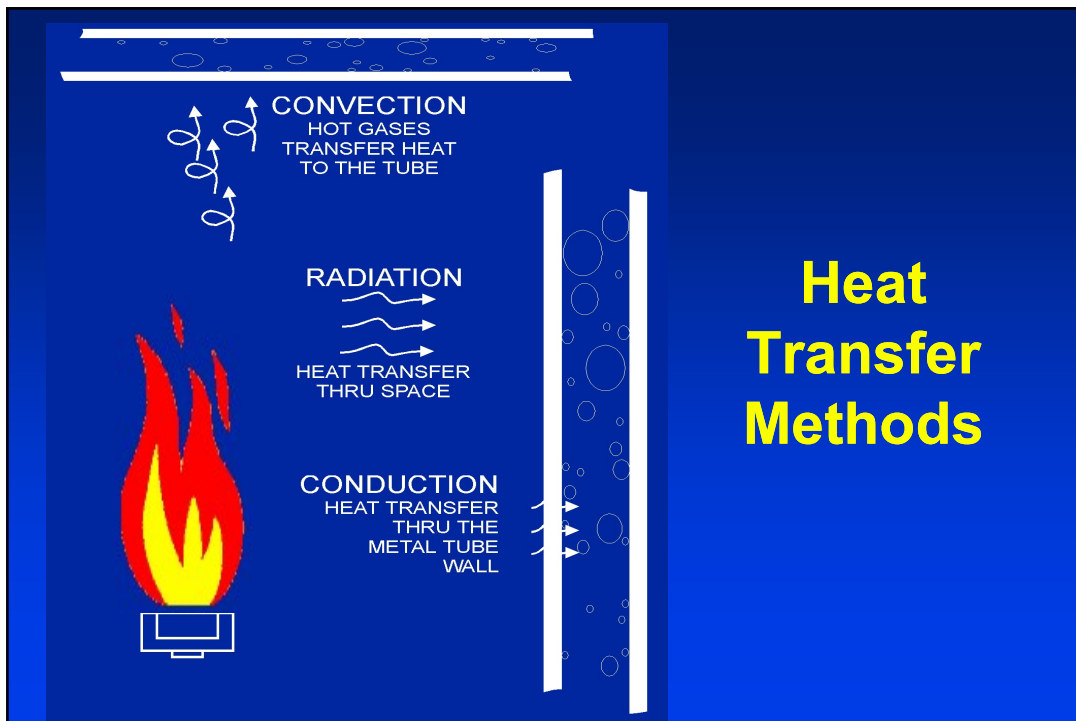
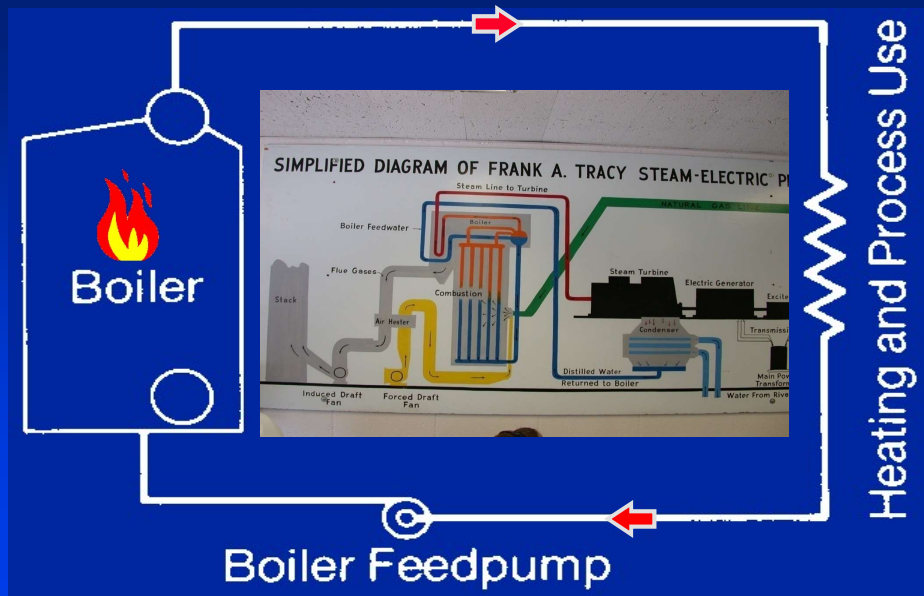


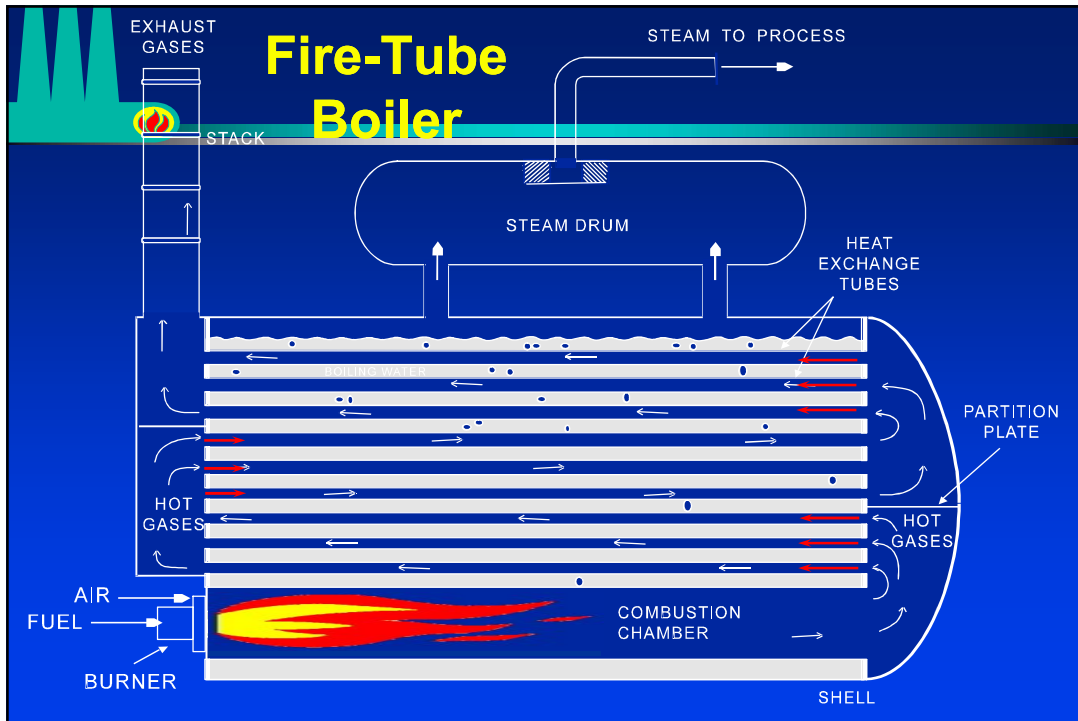
Boiler Fuels

- ◆ Natural gas
- ◆ Diesel fuel oils
- ◆ Tire Derived Fuel (TDF)
- ◆ Coal/Petroleum Coke
- ◆ Municipal waste
- ◆ Bio-Mass
- ◆ Waste gas
- ◆ Nuclear



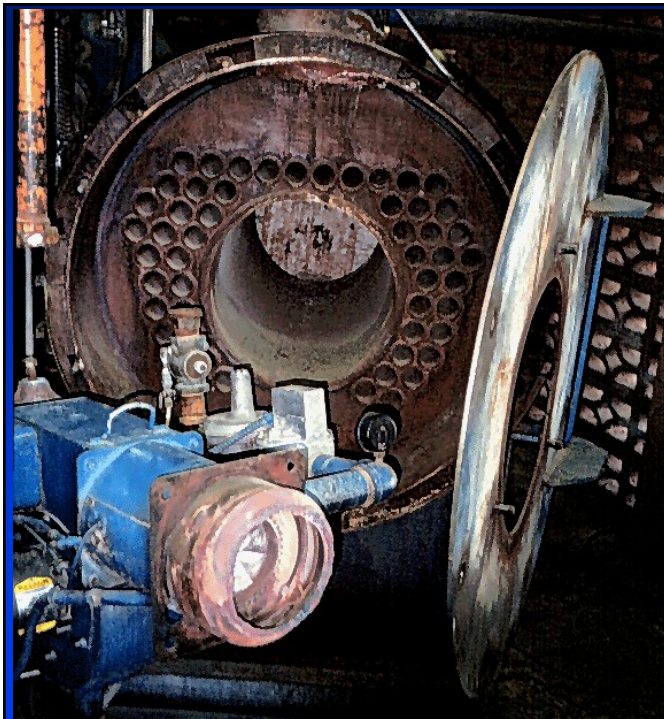
Steam Plant Basic Elements





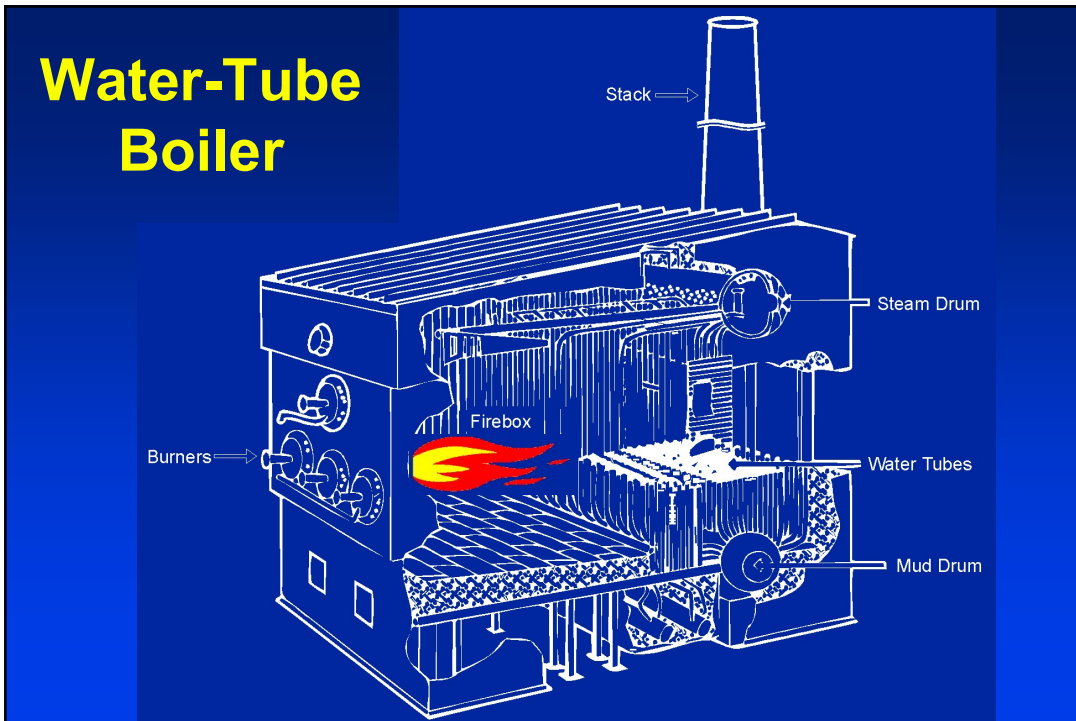


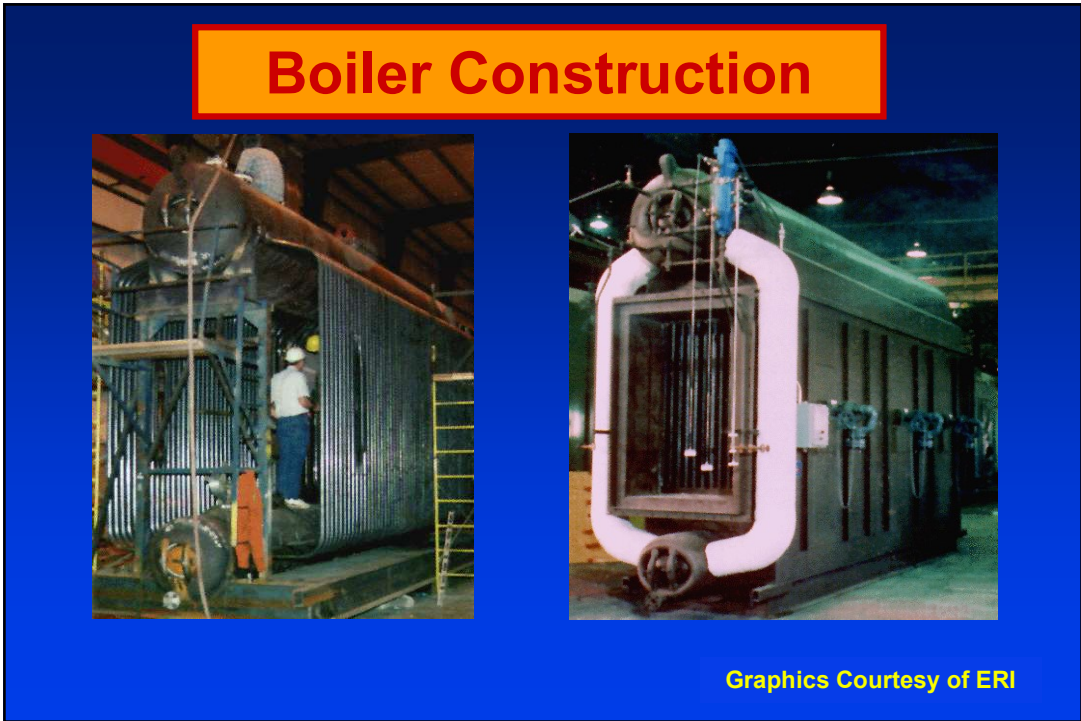
**Fire-Tube
Boiler**



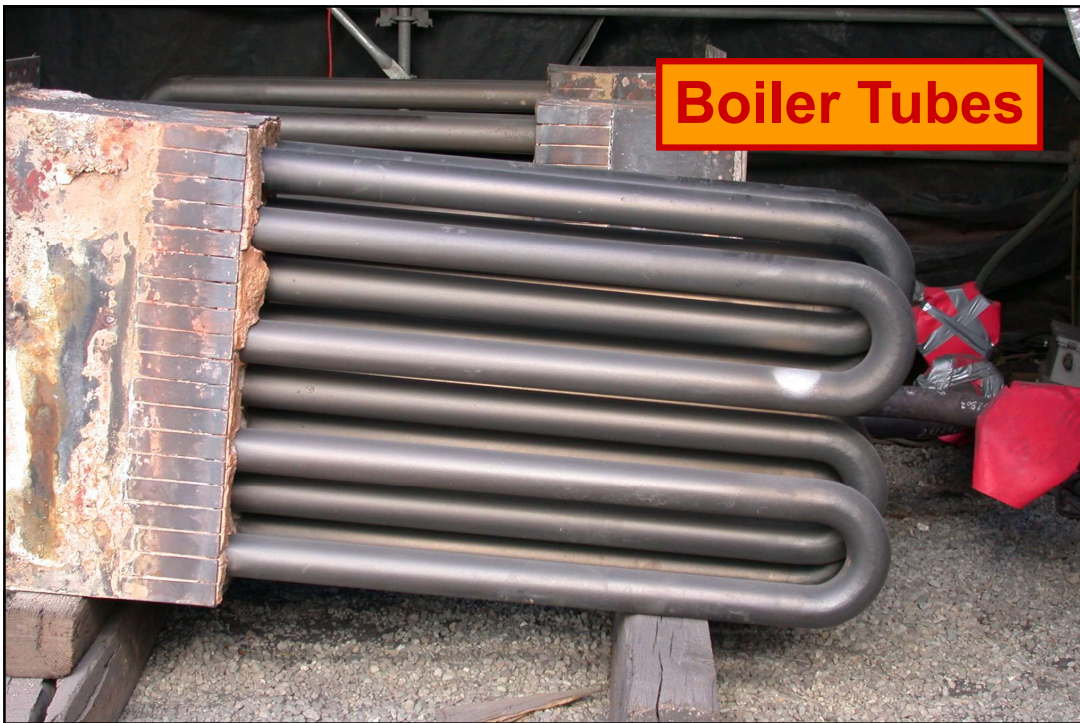
**Small
Fire-
Tube
Boiler**

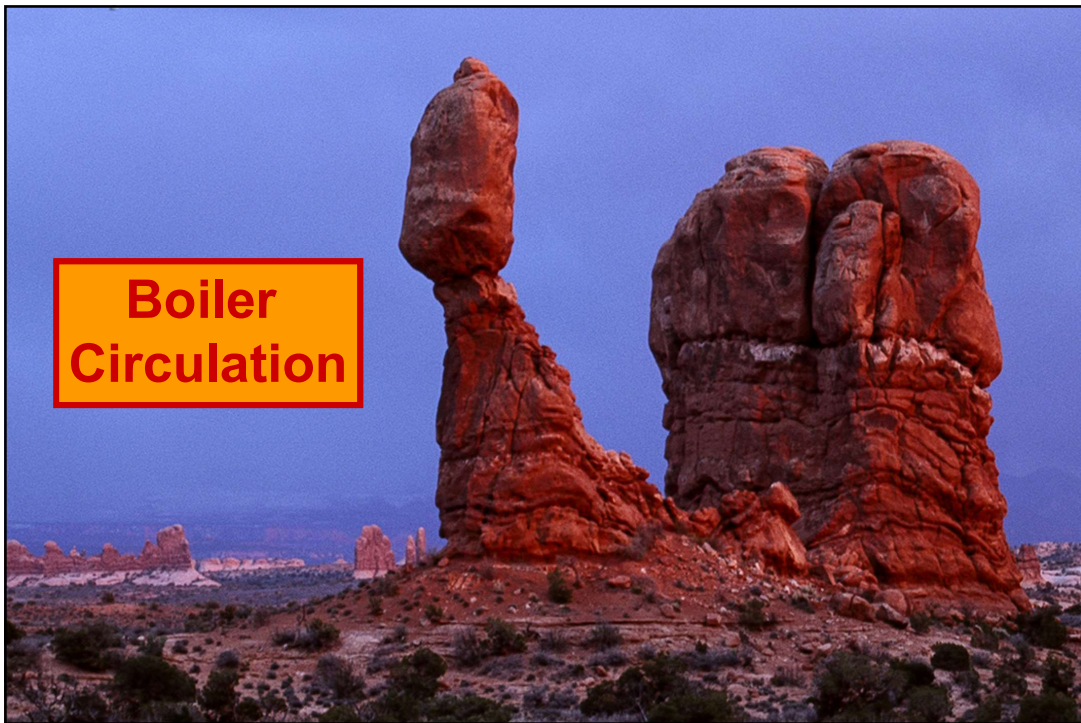
NACT Industrial Boilers #273



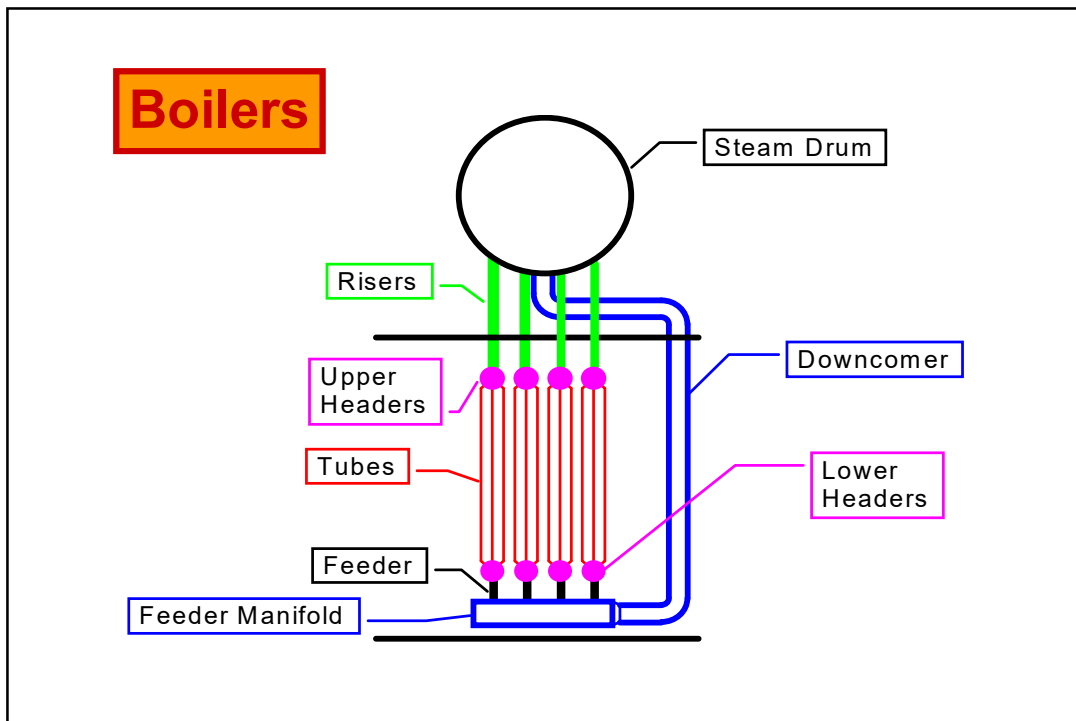
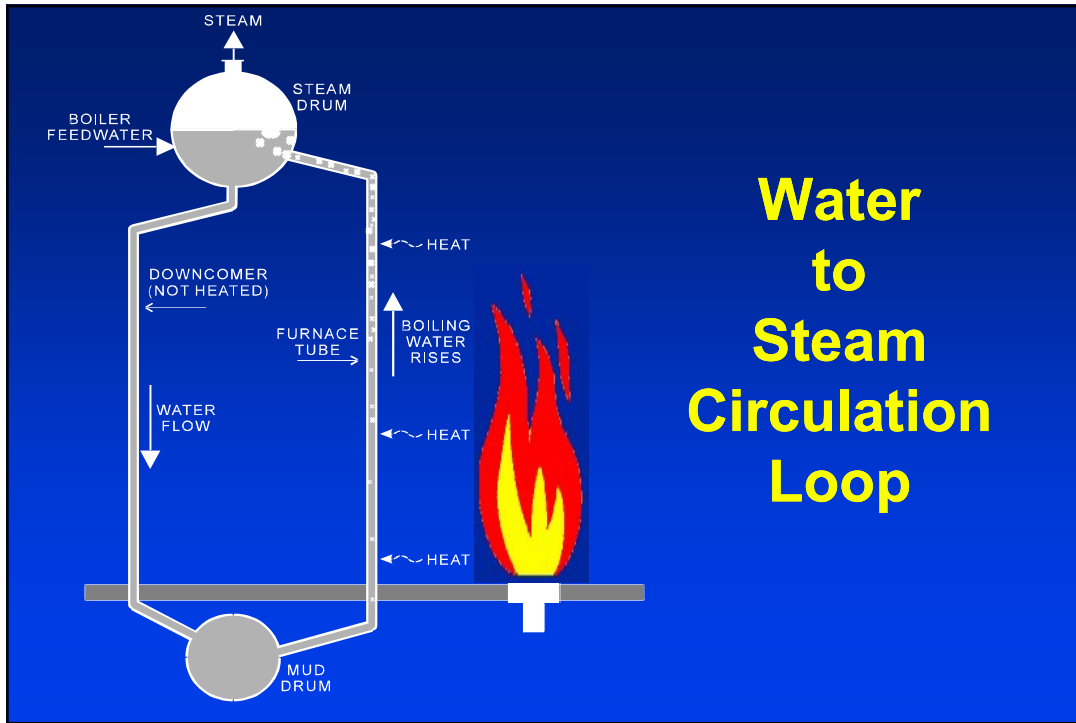


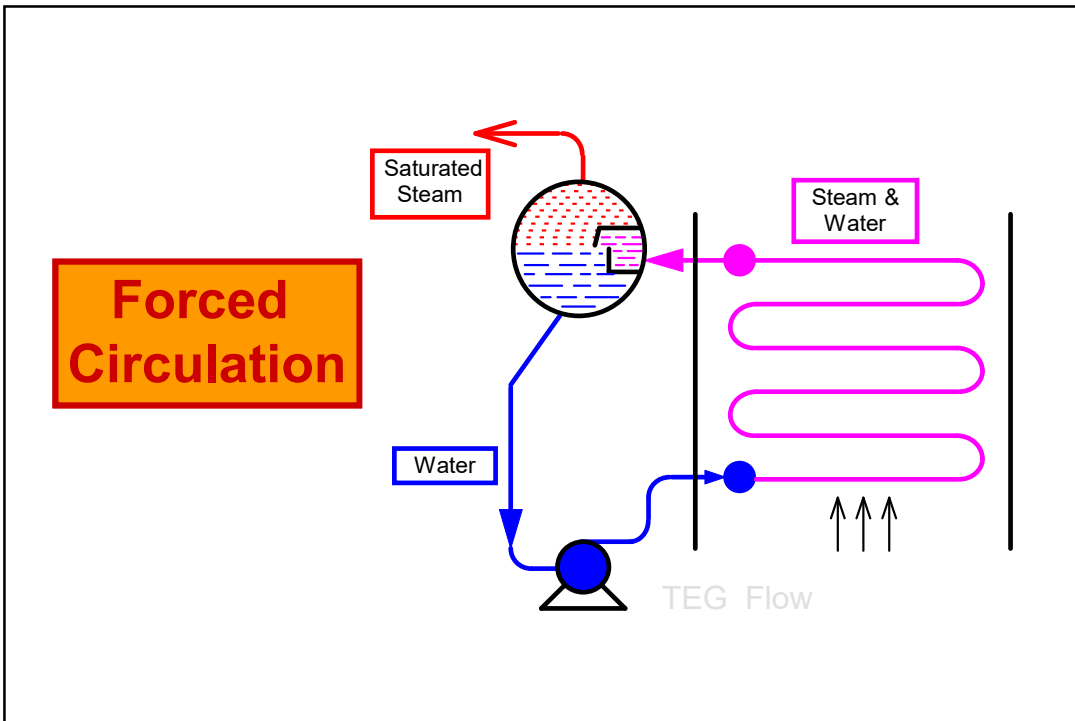
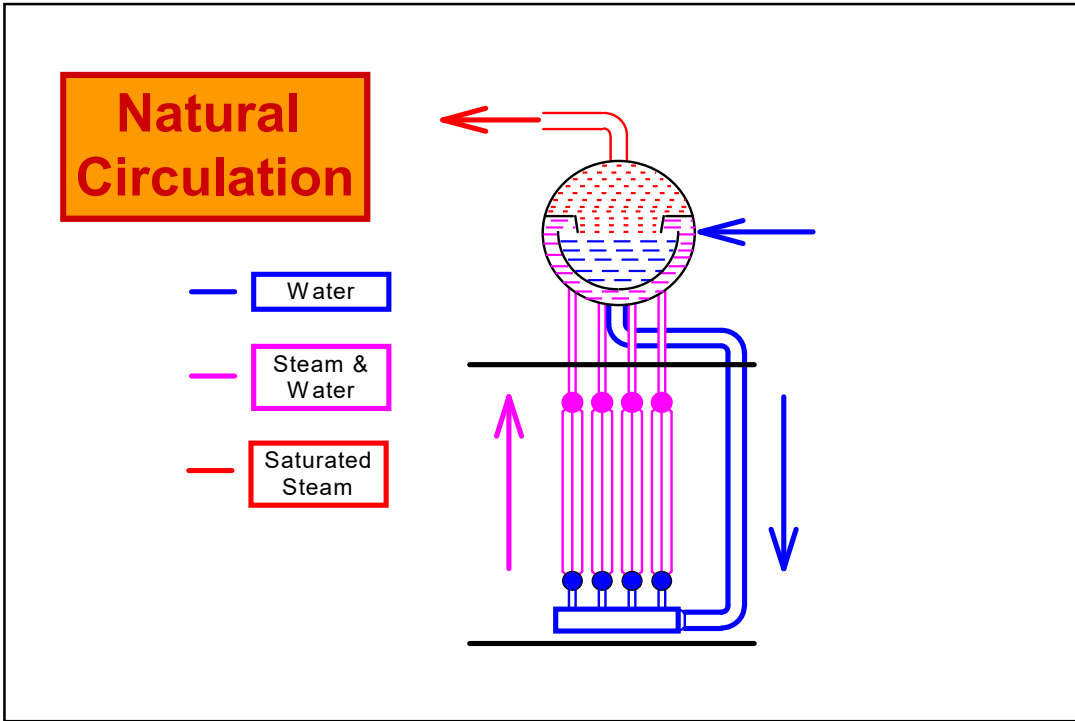
NACT Industrial Boilers #273





NACT Industrial Boilers #273

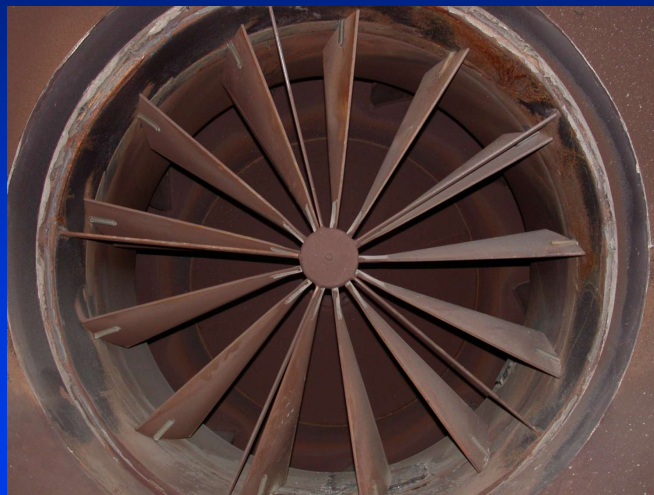




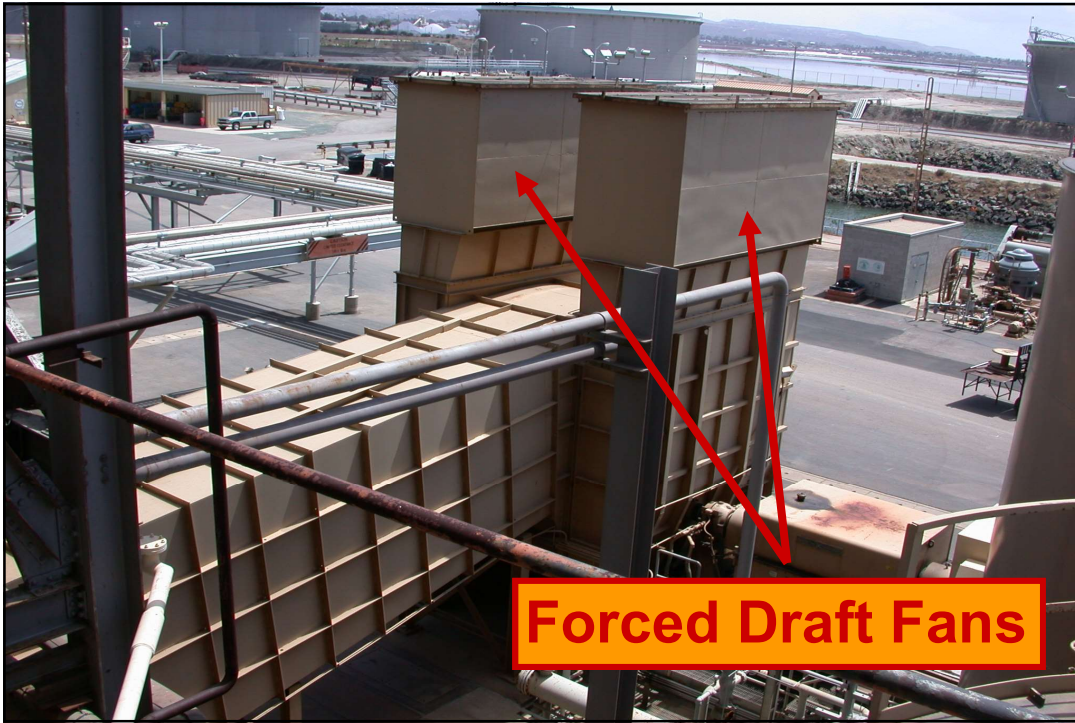


Boiler Air Requirements

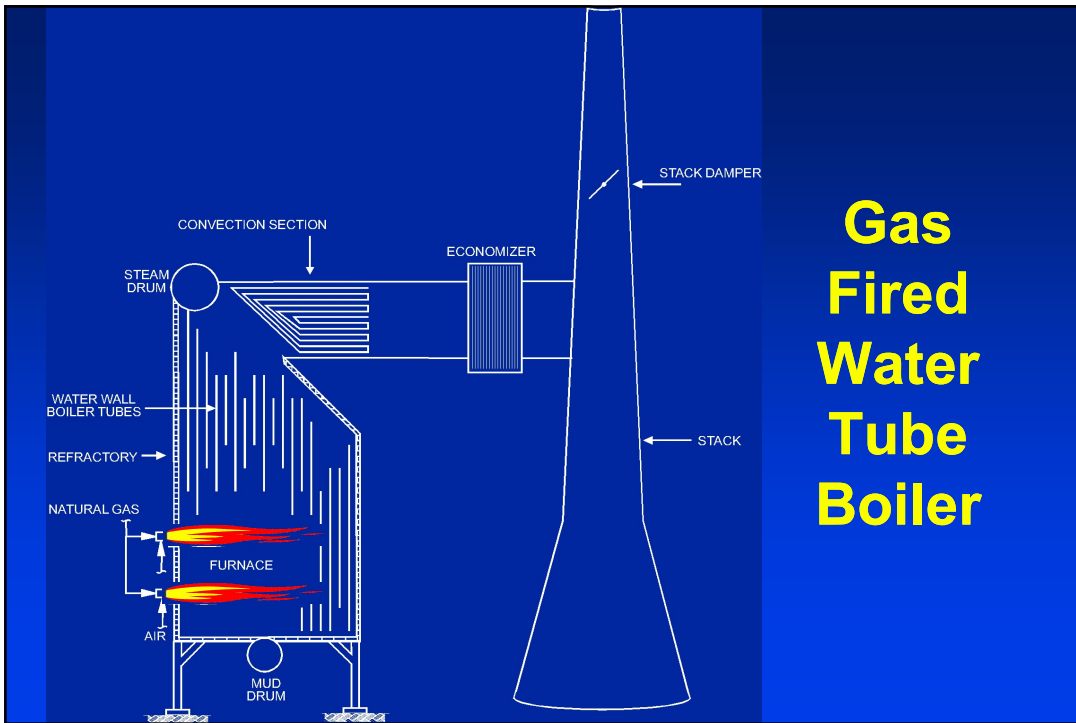
- ◆ **Draft**
 - ◆ **Natural**
 - ◆ **Forced**
 - ◆ **Induced**
- ◆ **Combustion air**
 - ◆ **Primary**
 - ◆ **Secondary**
 - ◆ **Excess**



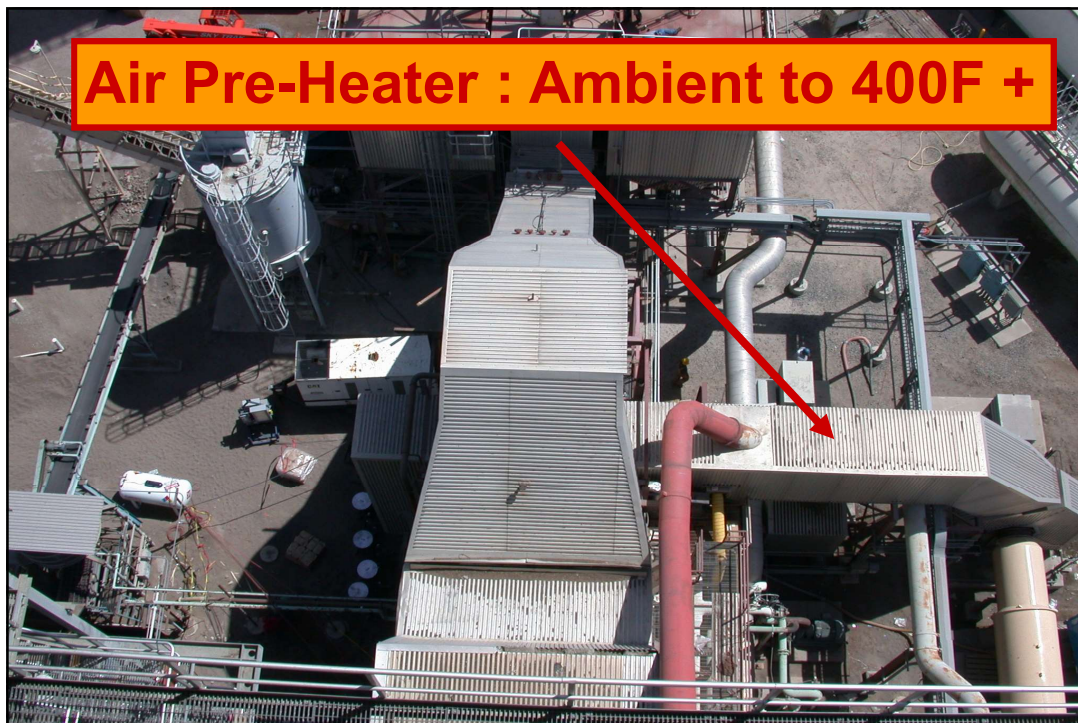
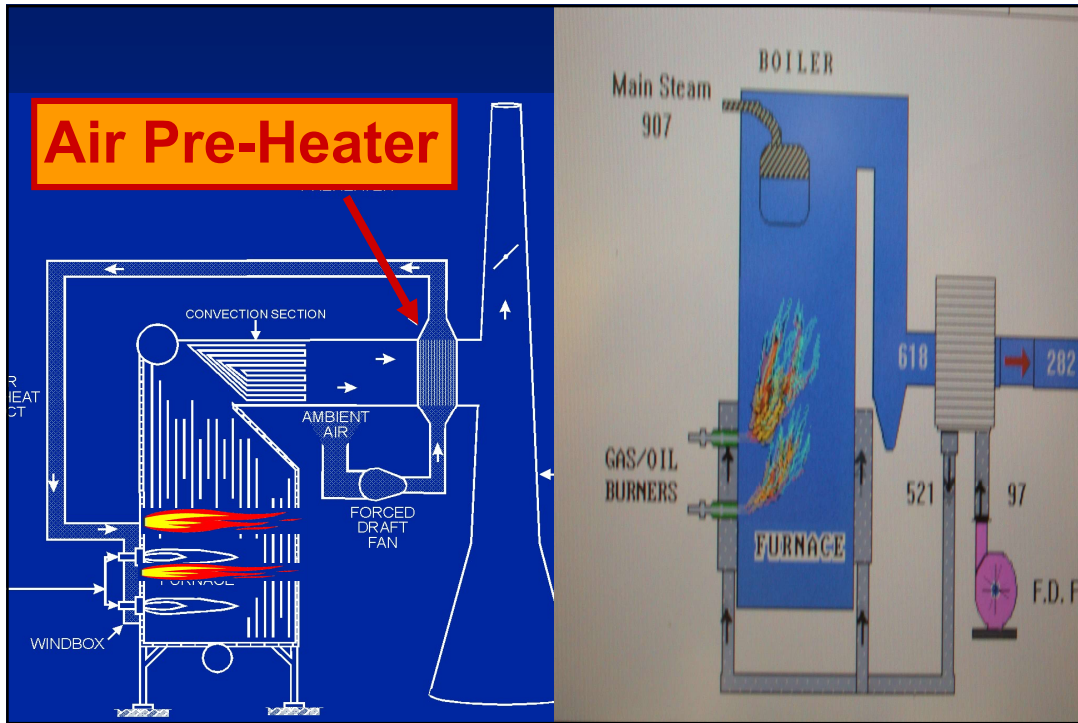
NACT Industrial Boilers #273



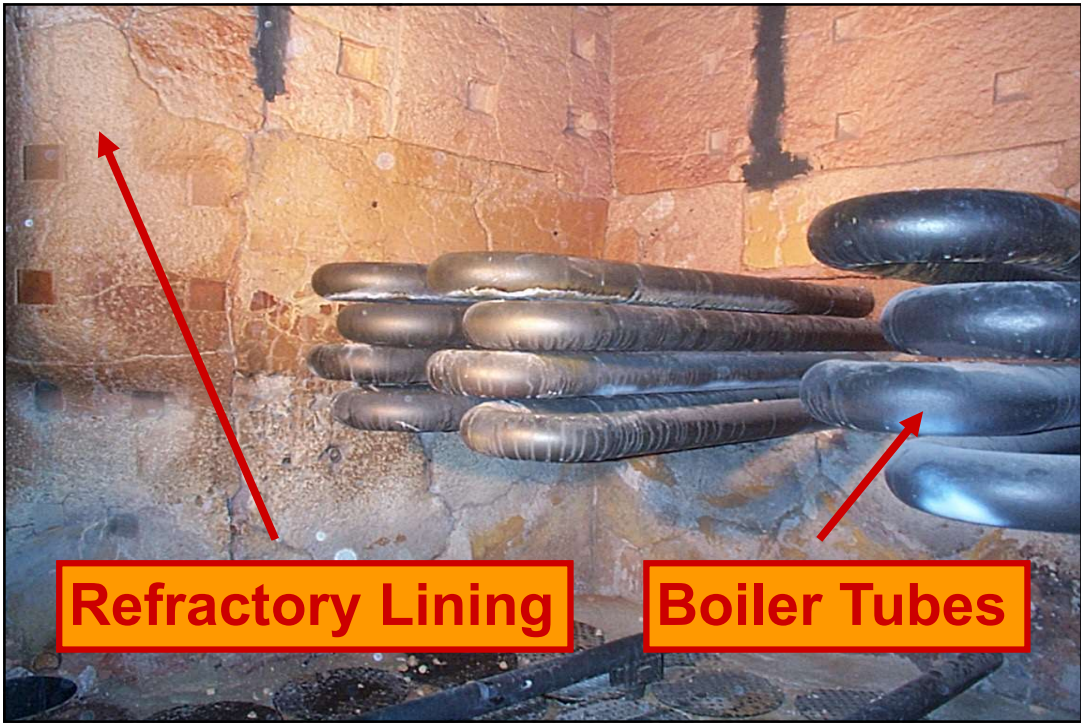
NACT Industrial Boilers #273





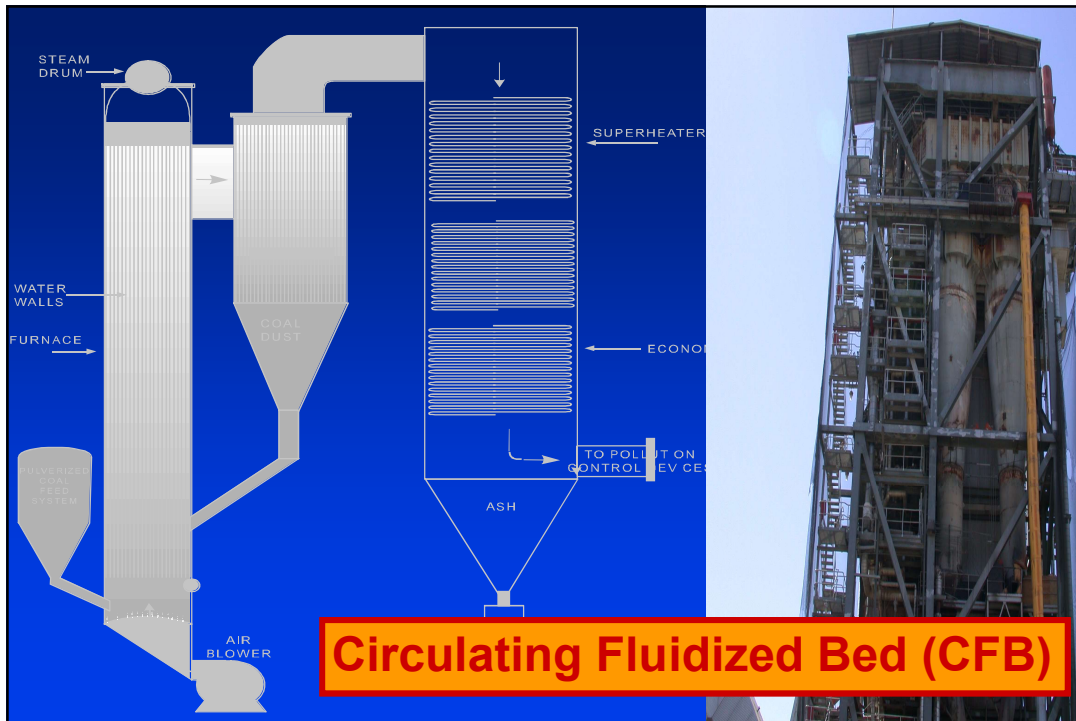
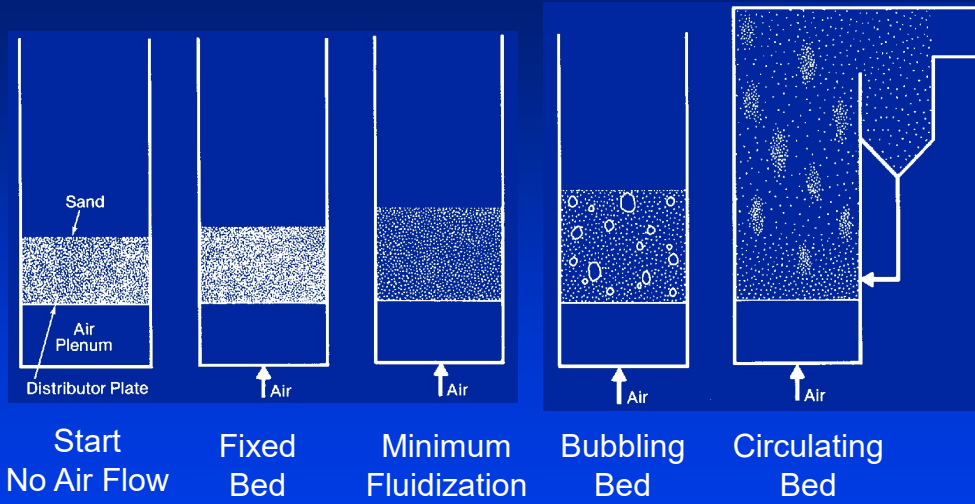


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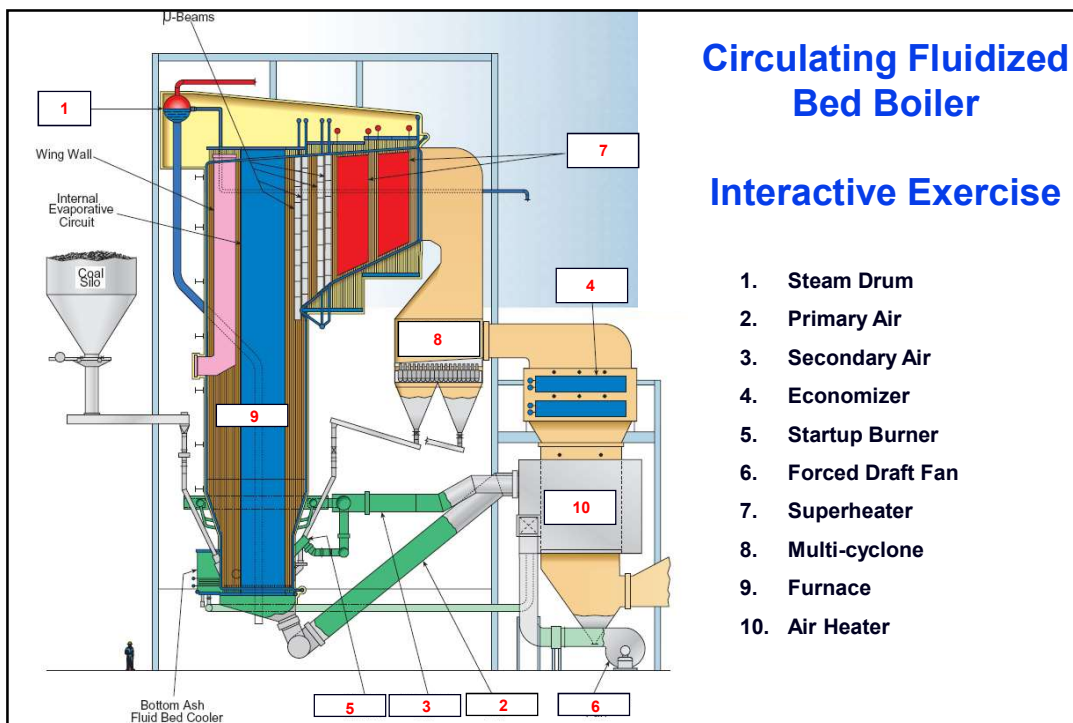
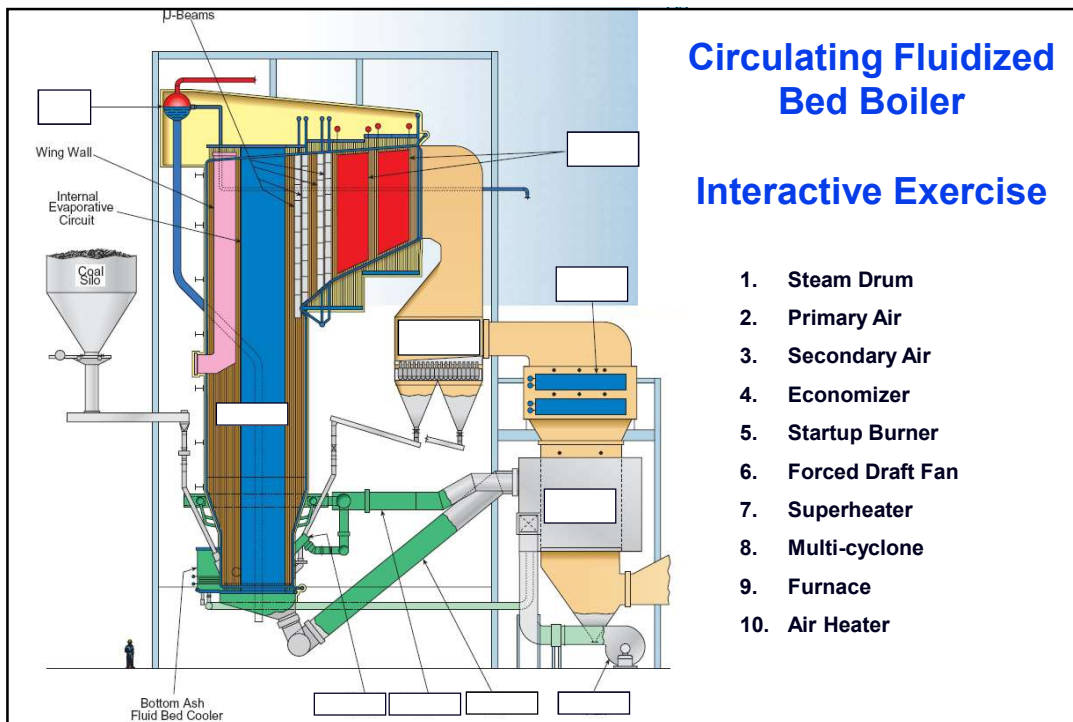


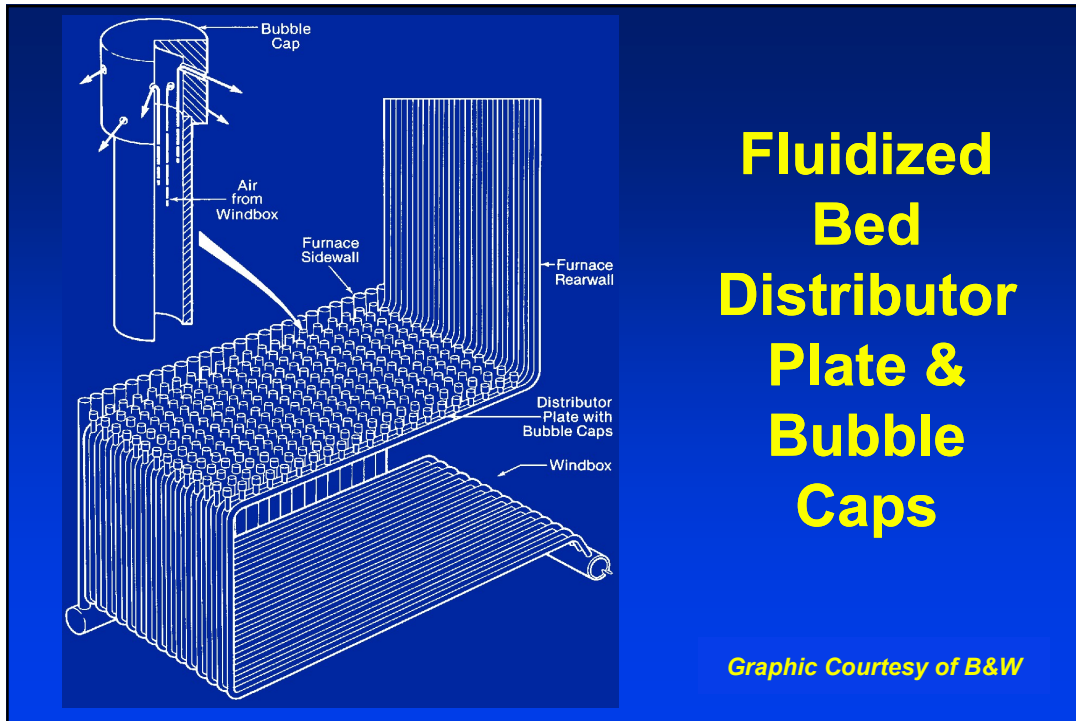


Fluidized Bed Modes

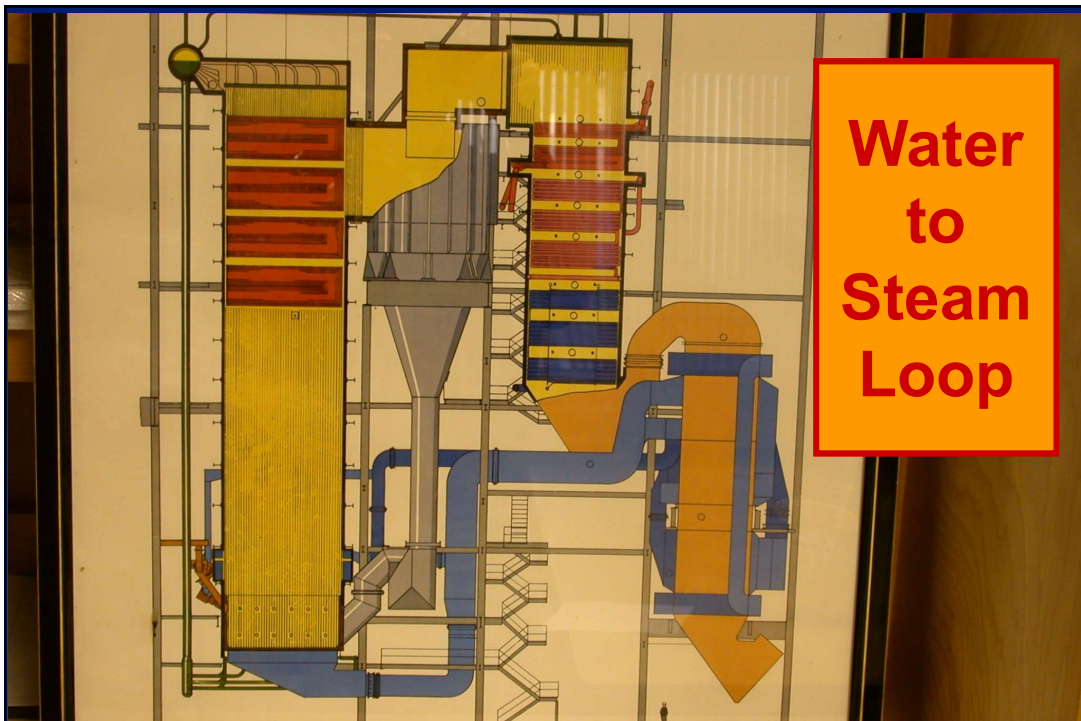
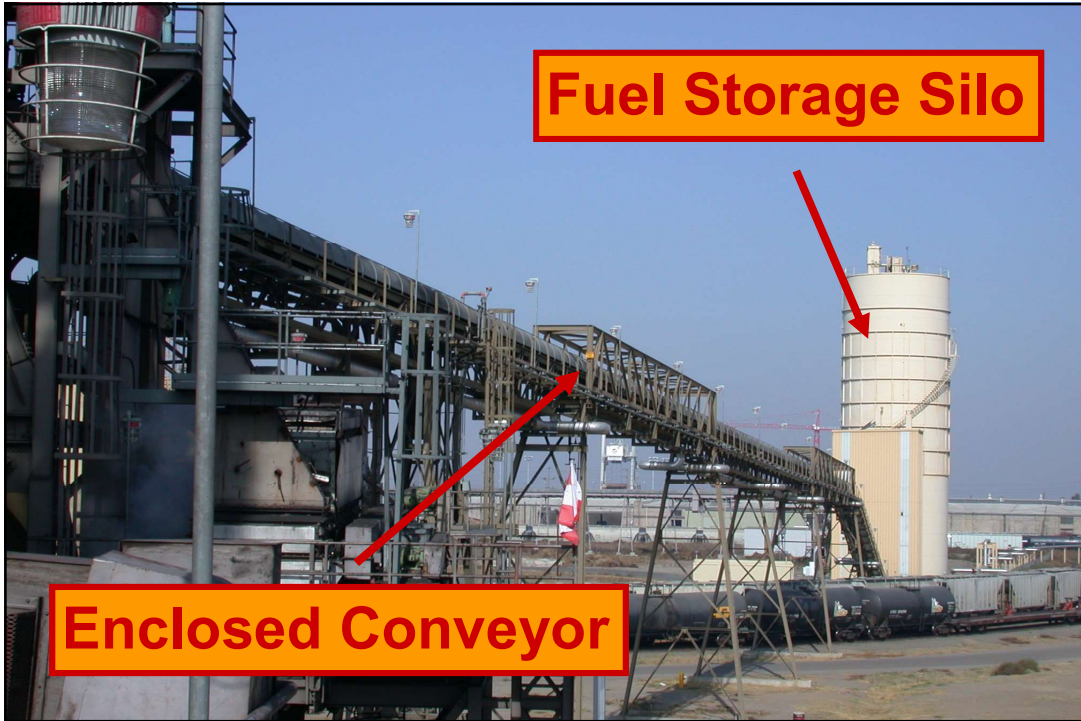


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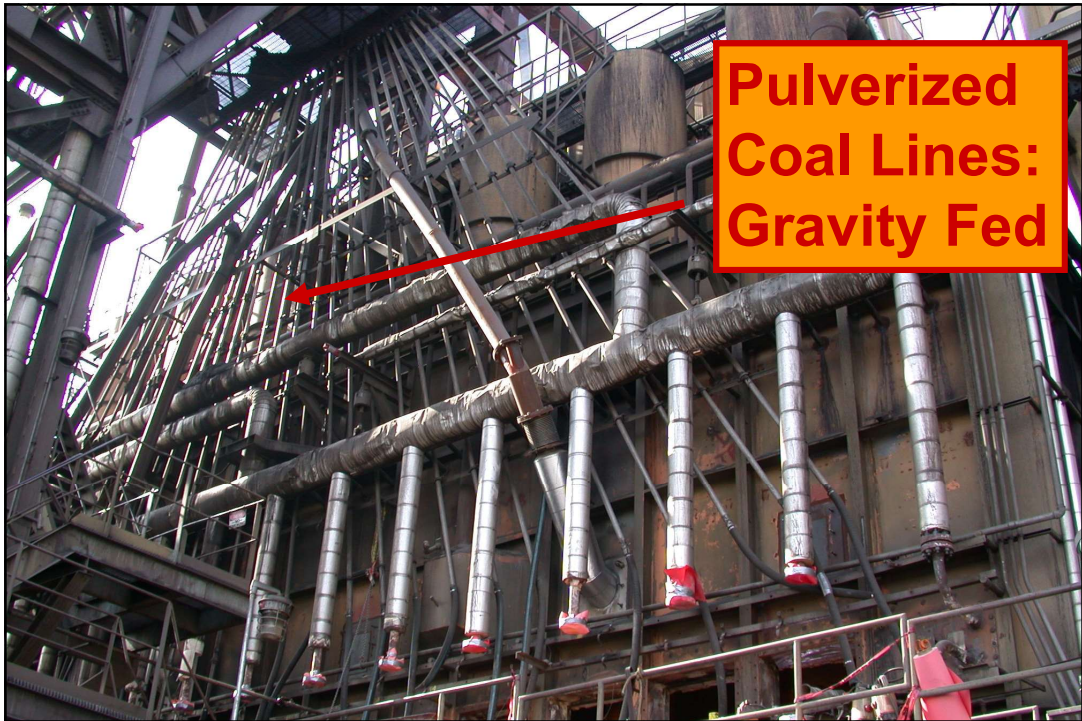
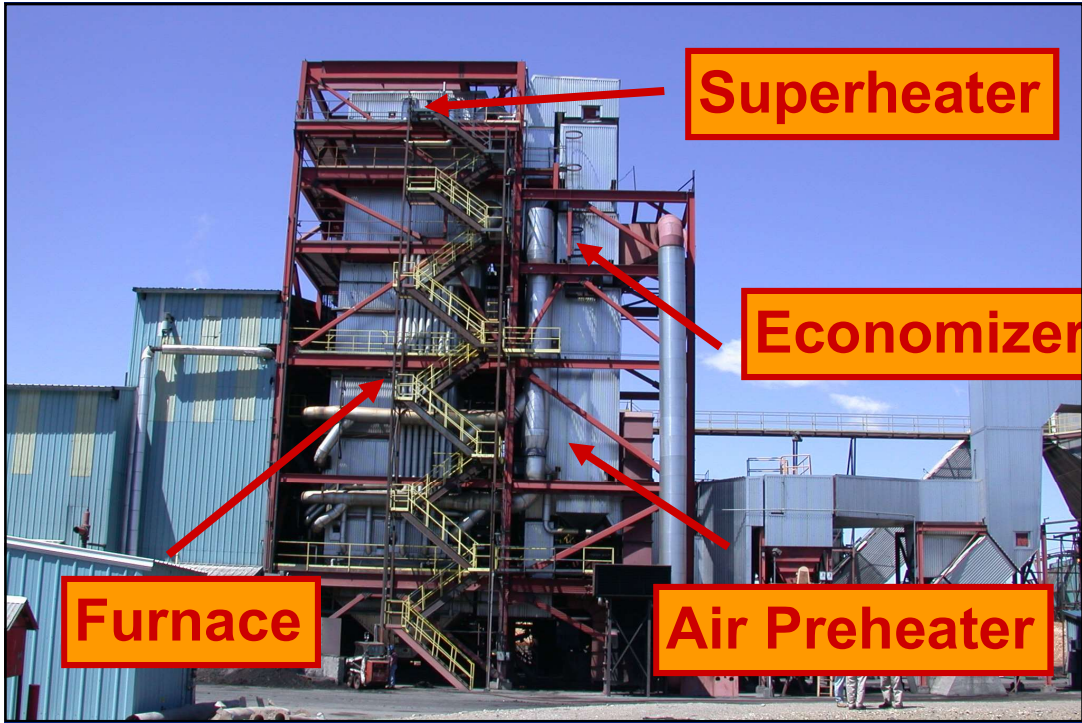




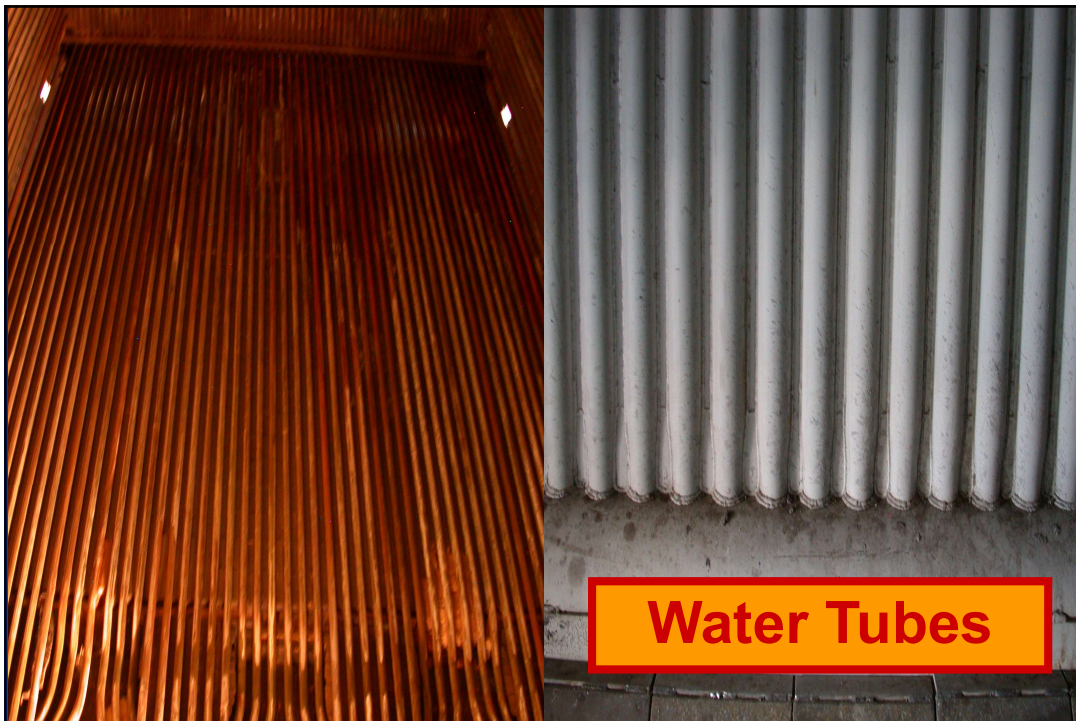
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NACT Industrial Boilers #273

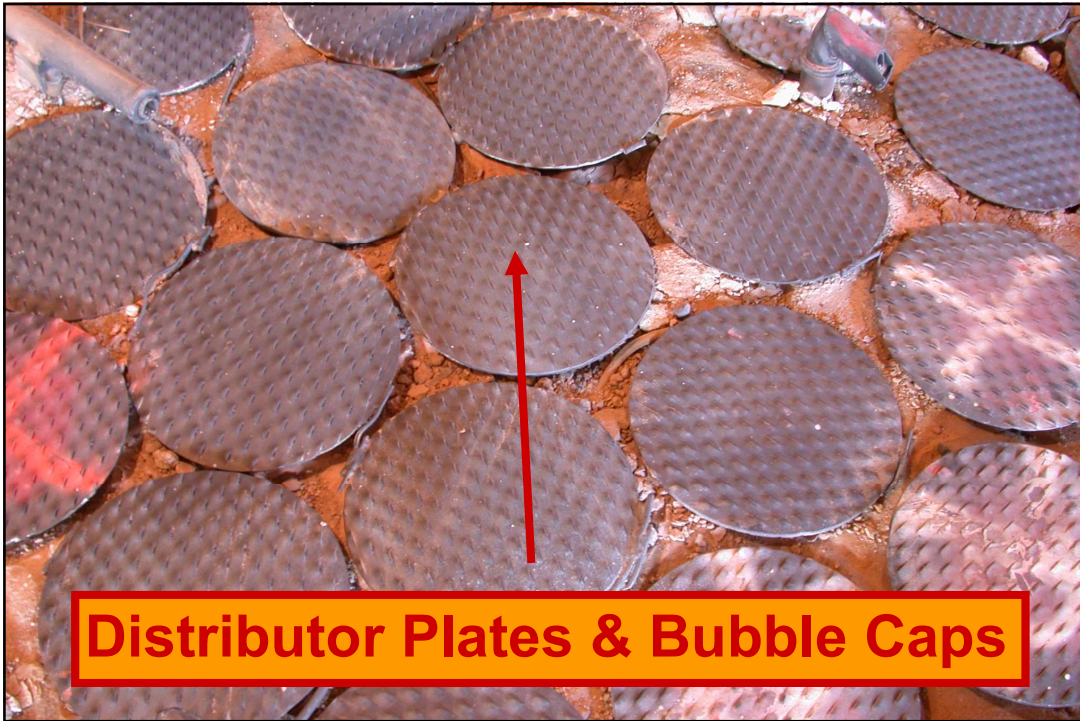


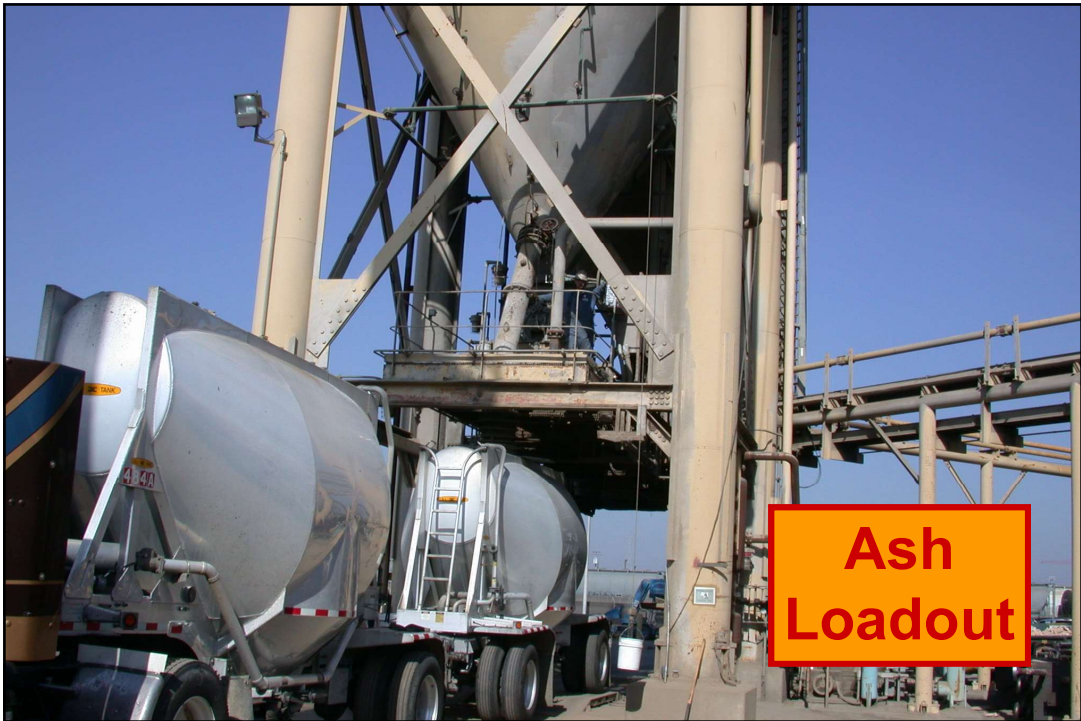
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NACT Industrial Boilers #273







NACT Industrial Boilers #273

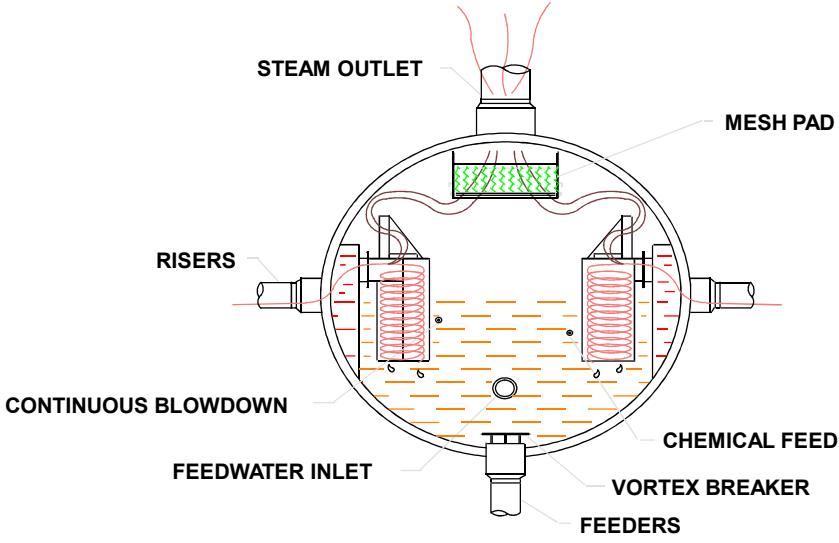


High Pressure Steam Drums

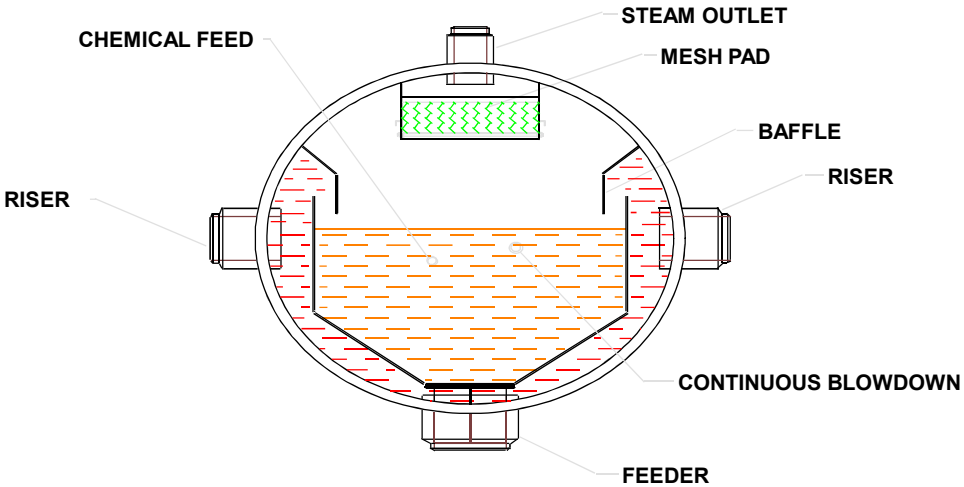


Steam Drum w/Cyclone & Chevron Separators

**STEAM DRUM INTERNALS
CYCLONES WITH MESH PAD**



**STEAM DRUM INTERNALS
BAFFLE PLATE WITH MESH PAD**



NACT Industrial Boilers #273

Circulating Fluidized Bed Boiler

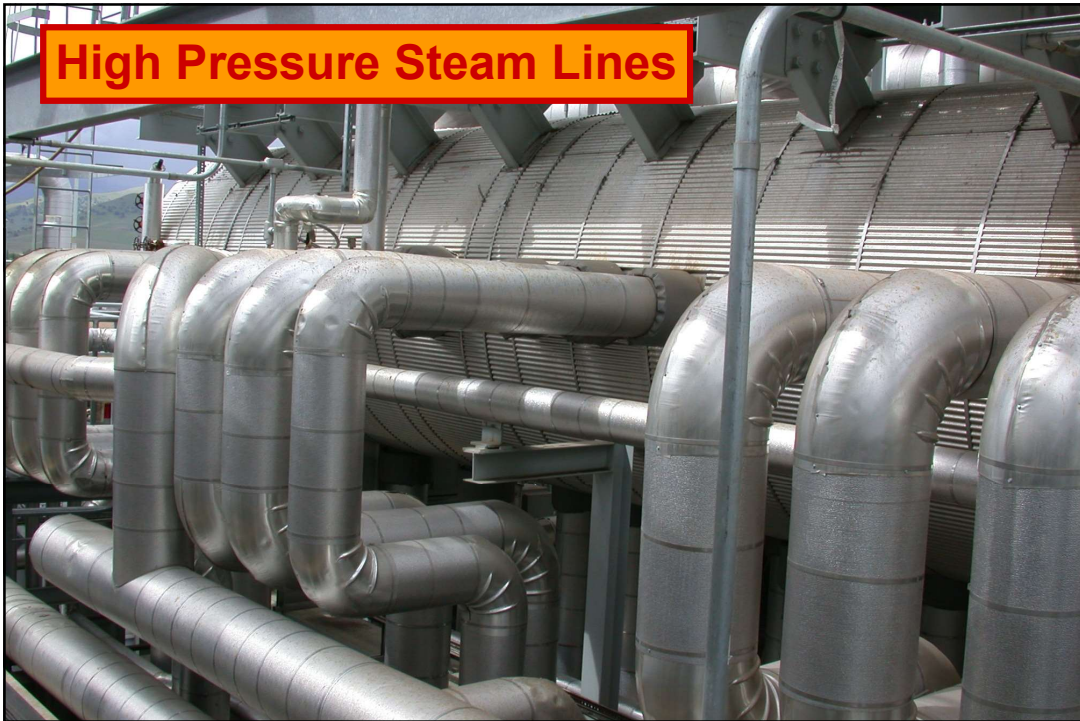
Interactive Exercise

1. Steam Drum
2. Primary Air
3. Secondary Air
4. Economizer
5. Startup Burner
6. Forced Draft Fan
7. Superheater
8. Multi-cyclone
9. Furnace
10. Air Heater

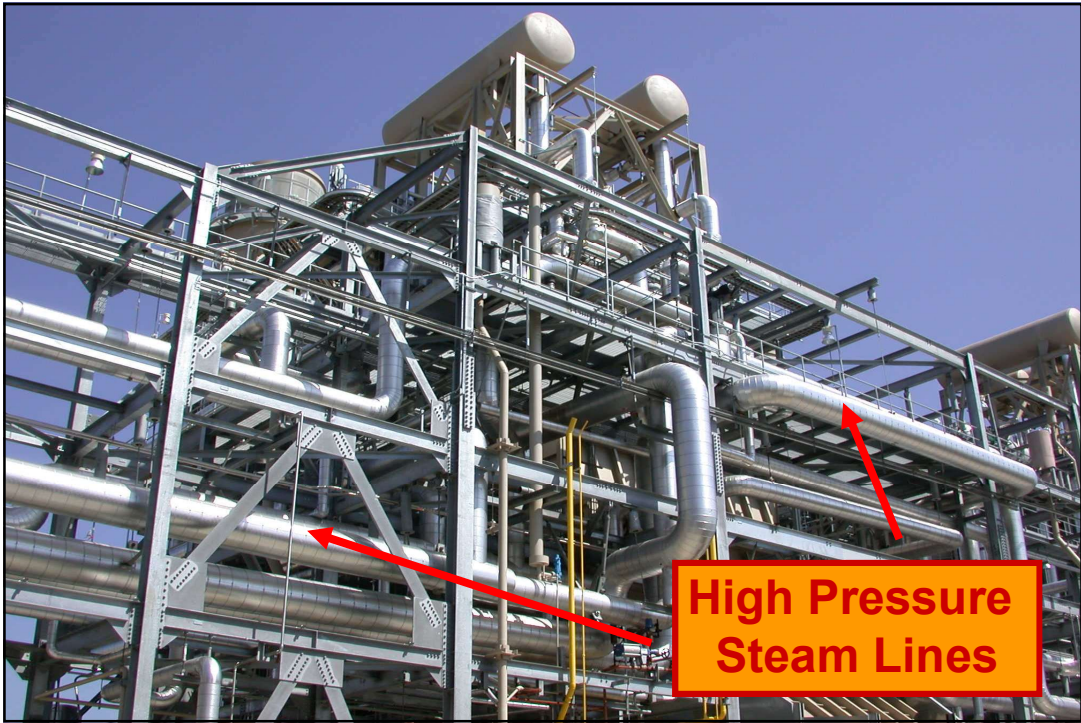
Circulating Fluidized Bed Boiler

Interactive Exercise

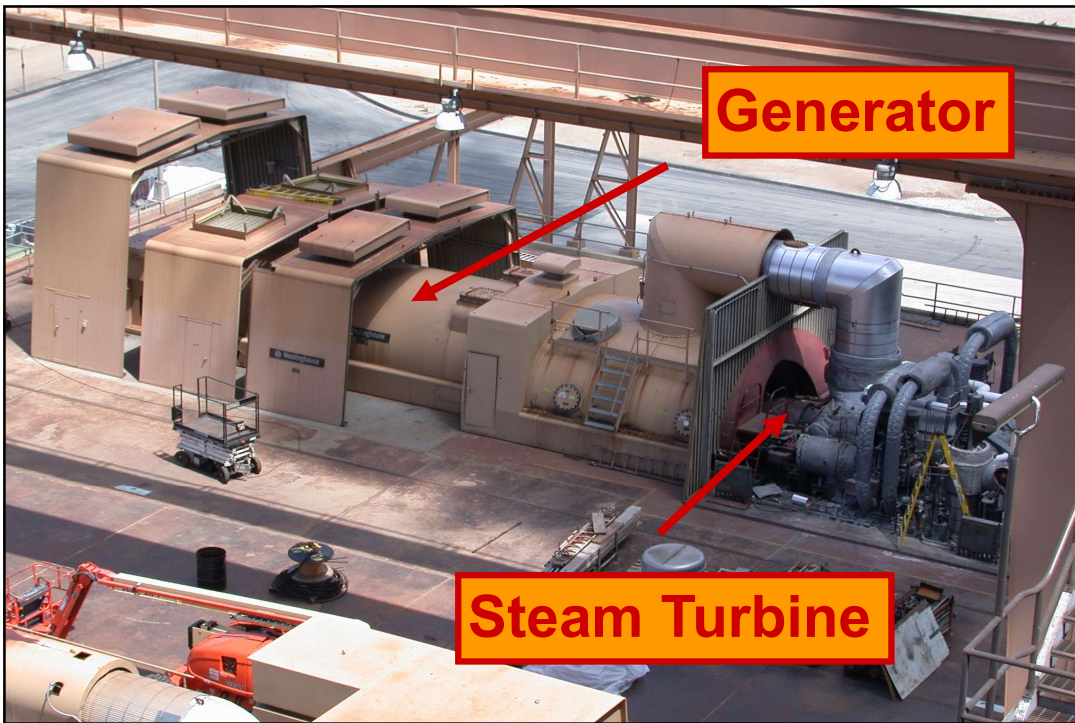
1. Steam Drum
2. Primary Air
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8. Multi-cyclone
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10. Air Heater



NACT Industrial Boilers #273



NACT Industrial Boilers #273



NACT Industrial Boilers #273



NACT Industrial Boilers #273



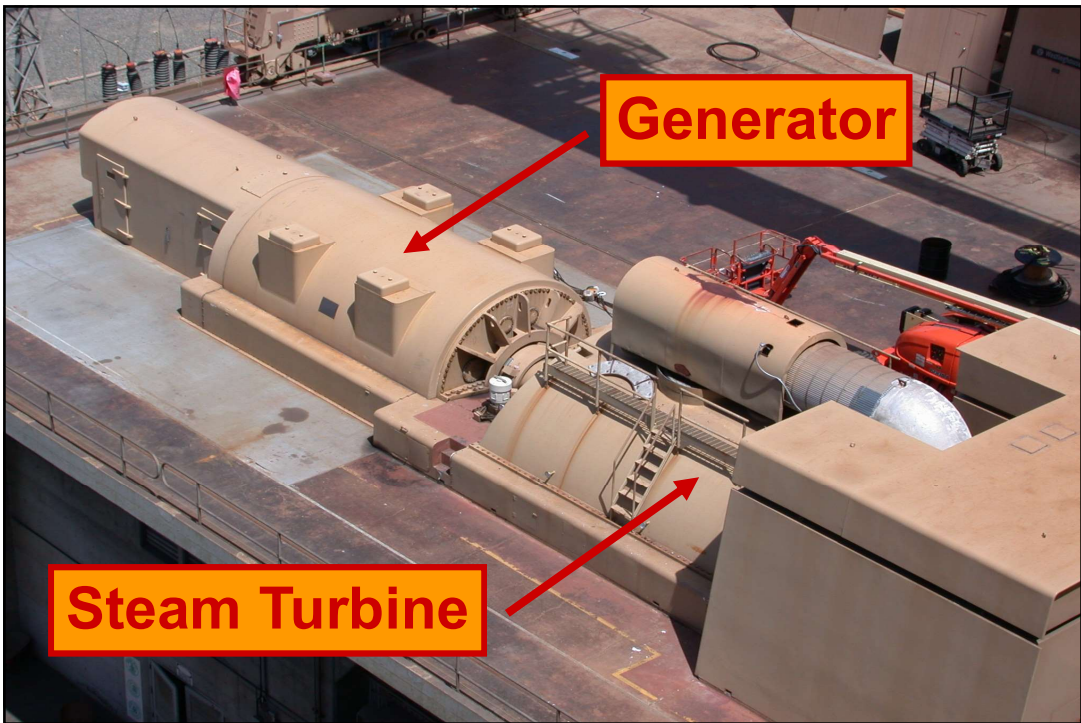


**Steam
Turbine
Blades**

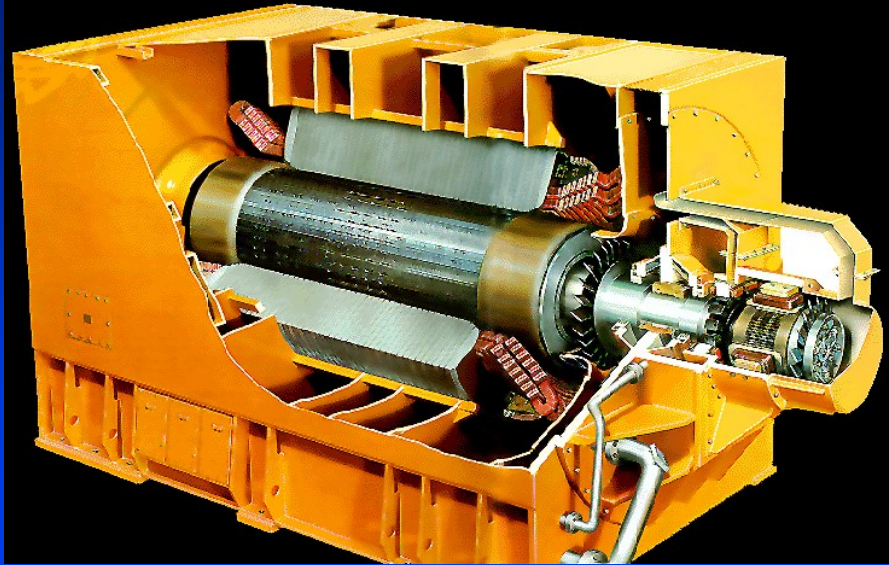


Steam Turbine

NACT Industrial Boilers #273

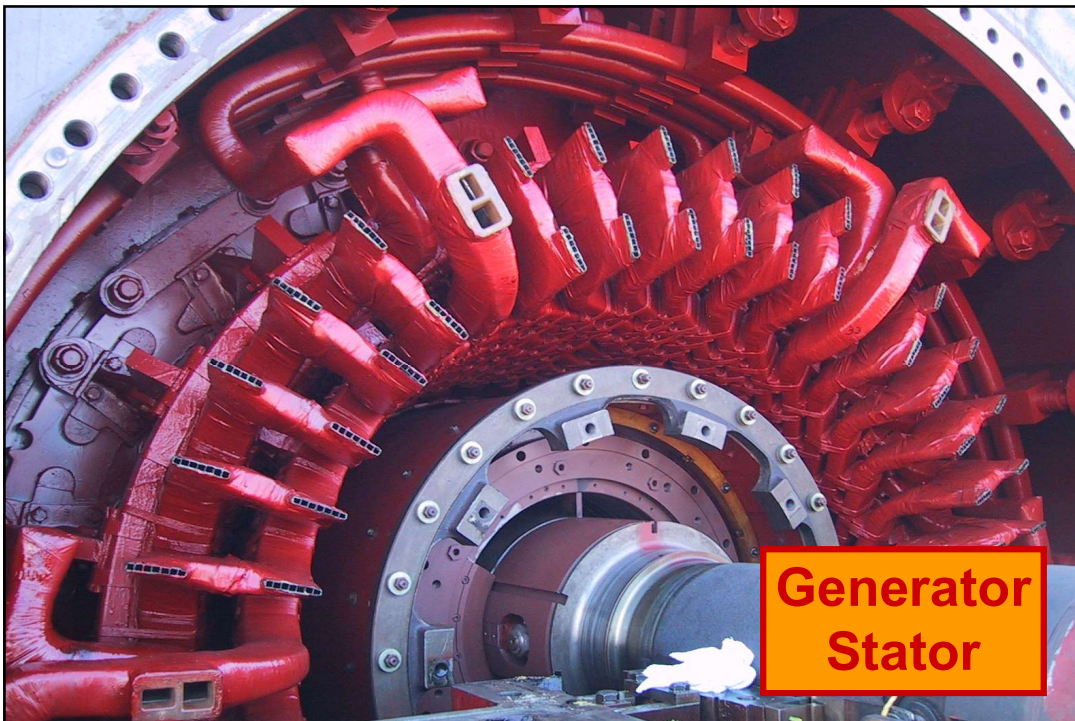


Brush DAX Turbogenerator



Generator Rotor

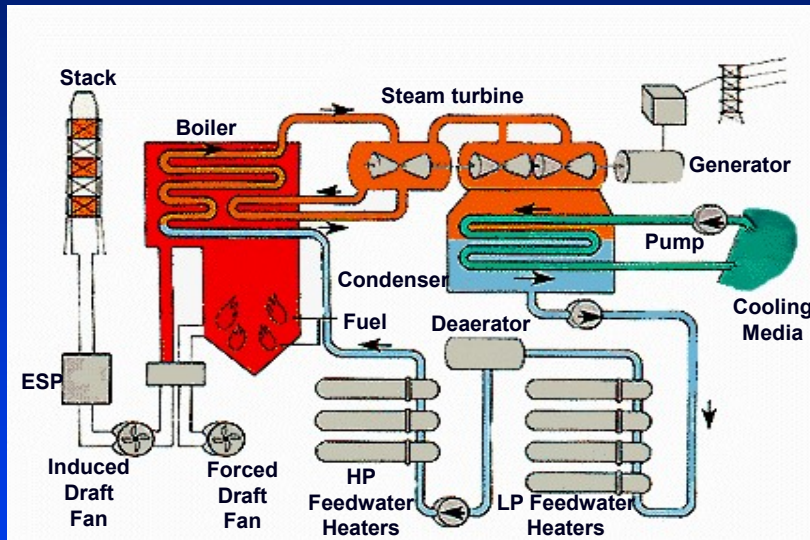
NACT Industrial Boilers #273

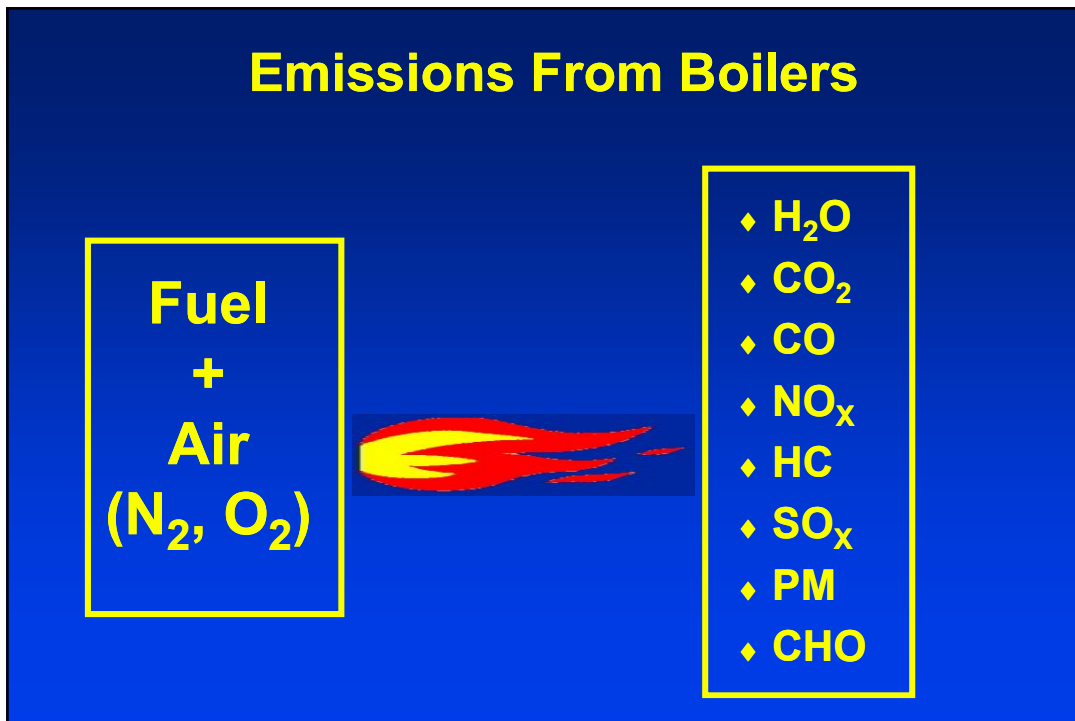
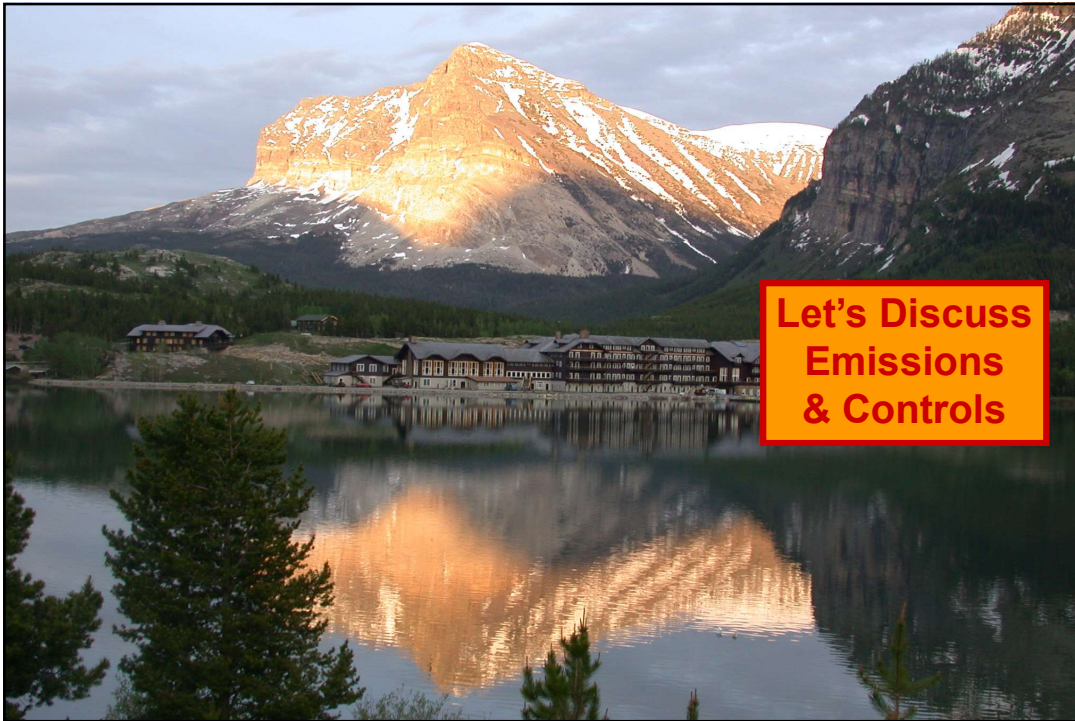


NACT Industrial Boilers #273



Typical Electric Utility Plant





Emissions Control Methods

- ◆ Boiler design
- ◆ Proper maintenance
- ◆ Operating conditions
- ◆ Fuel types
- ◆ Combustion modifications
- ◆ Exhaust treatment



Control of Gaseous Emissions

- ◆ Low-NOx burners
- ◆ OFA
- ◆ Ammonia injection (SNCR)
- ◆ Catalysts (SCR)
- ◆ FGR
- ◆ FGD



Combustion Considerations

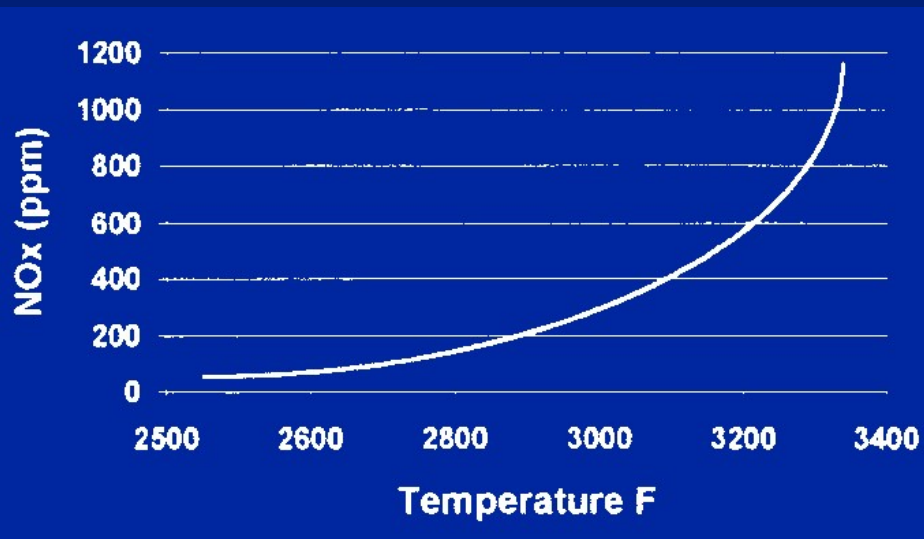
- ◆ Time
- ◆ Temperature
- ◆ Turbulence
- ◆ Oxygen
- ◆ Nitrogen



- ◆ Thermal NOx
- ◆ Fuel-bound NOx
- ◆ Prompt NOx

NOx Creation

Thermal NOx vs. Temperature



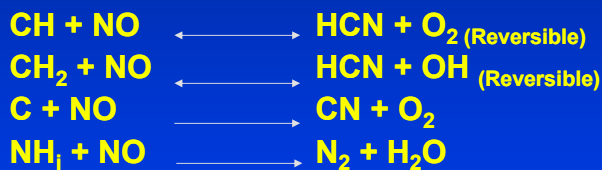
Graphic Courtesy of Coen

COMBUSTION MODIFICATION

◆ NOx FORMATION



◆ NOx REDUCTION



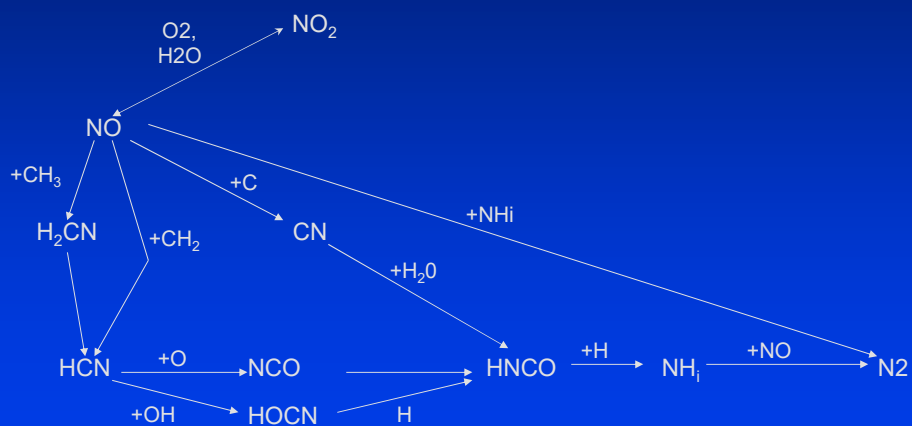
THESE NOx REDUCTANTS ARE FORMED BY PARTIAL COMBUSTION IN A REDUCING ATMOSPHERE

THE INTERMEDIATE SPECIES, HCN & CN, ARE CONVERTED TO N2, CO2 & H2O IN THE FINAL BURNOUT ZONE

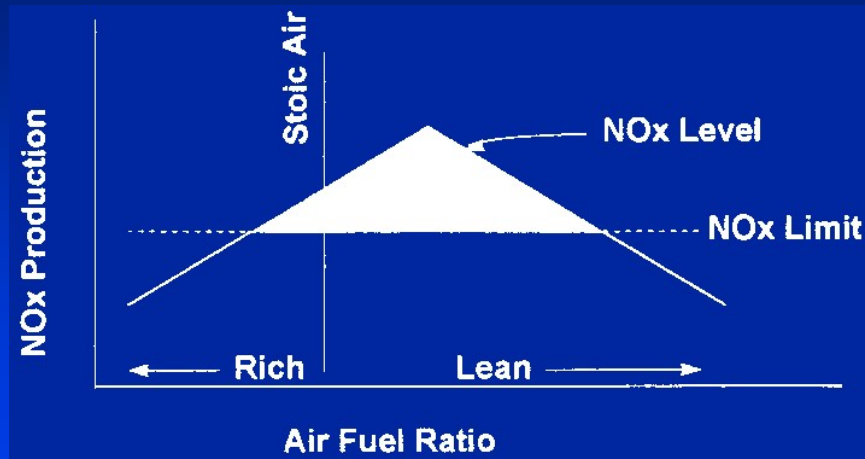
PROMPT NOx

- ◆ Rapid Formation <1ms.
- ◆ Little affect from temperature.
- ◆ Presence of CHi & HCN during initial combustion can contribute to prompt NOx formation in an oxidizing environment, but will inhibit NOx formation in a reducing environment.
- ◆ Presence of C & NHi in initial combustion process reduces the formation of prompt NOx.
- ◆ Reactor combustion is controlled to a stoichiometry <.6 and a temperature <2400F.

PROMPT NOx



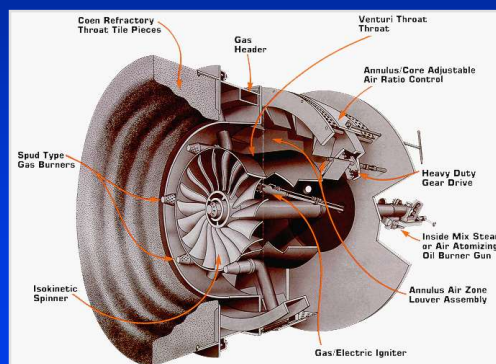
NOx Production vs. Air/Fuel Ratio

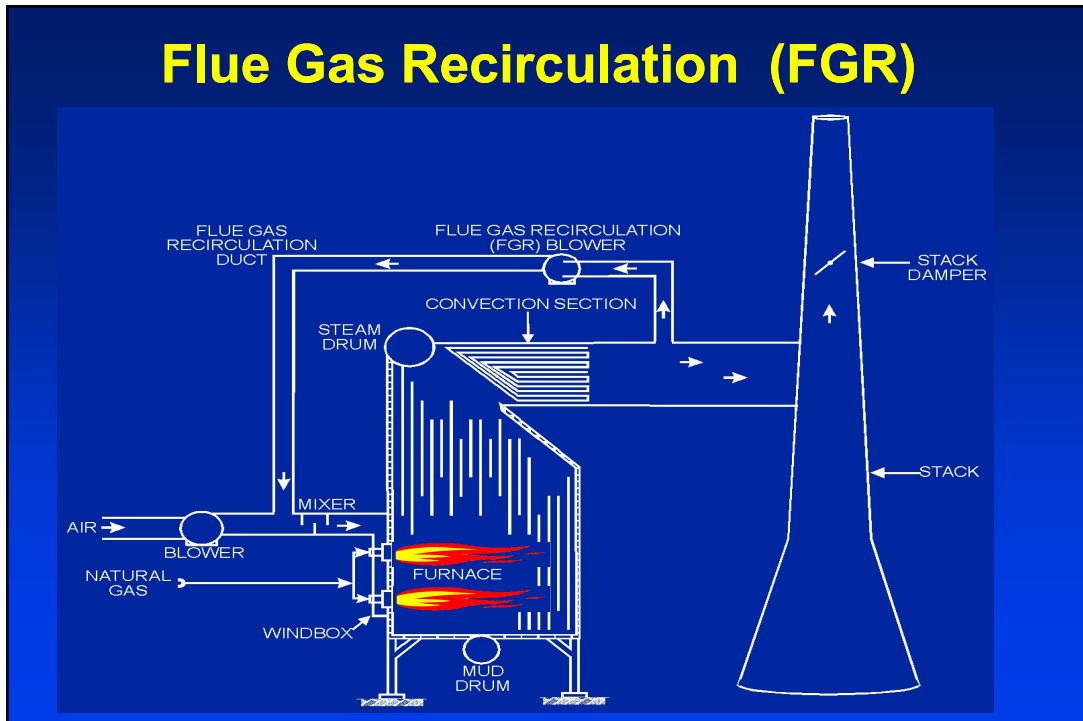


Graphic Courtesy of Coen

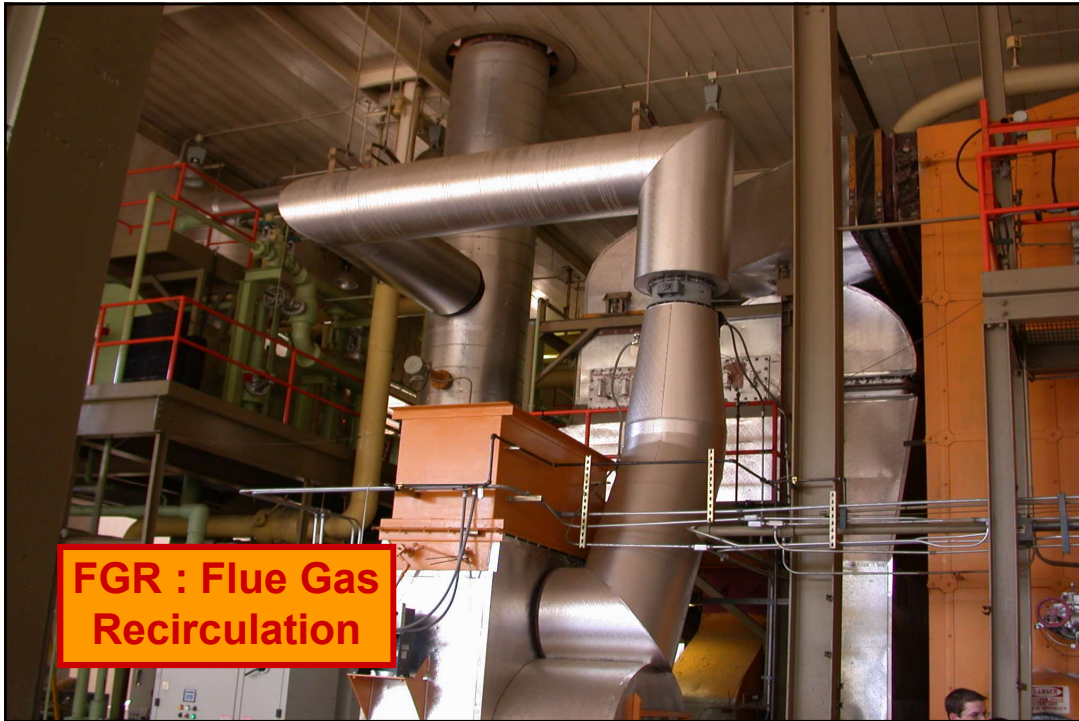
Industry Burner Definitions

- ◆ **Modern conventional burners**
 - ◆ NOx less than 80 ppm (<0.1 lb/MMBtu)
- ◆ **Low-NOx burners**
 - ◆ NOx less than 30 ppm (<0.04 lb/MMBtu)
- ◆ **Ultra Low-NOx burners**
 - ◆ 9 ppm NOx (<0.01 lb/MMBtu)









FGR BURNERS

FEATURES

- ◆ CAN USE FGR FLOWS AS HIGH AS 40% OF THE TOTAL STACK EFFLUENT
- ◆ SOME SYSTEMS OPERATE VERY CLOSE TO THE LIMITS OF FLAMABILITY
- ◆ SOME SYSTEMS OPERATE WITH VERY RAPID MIXING, VERY CLOSE TO STOICHIOMETRY.

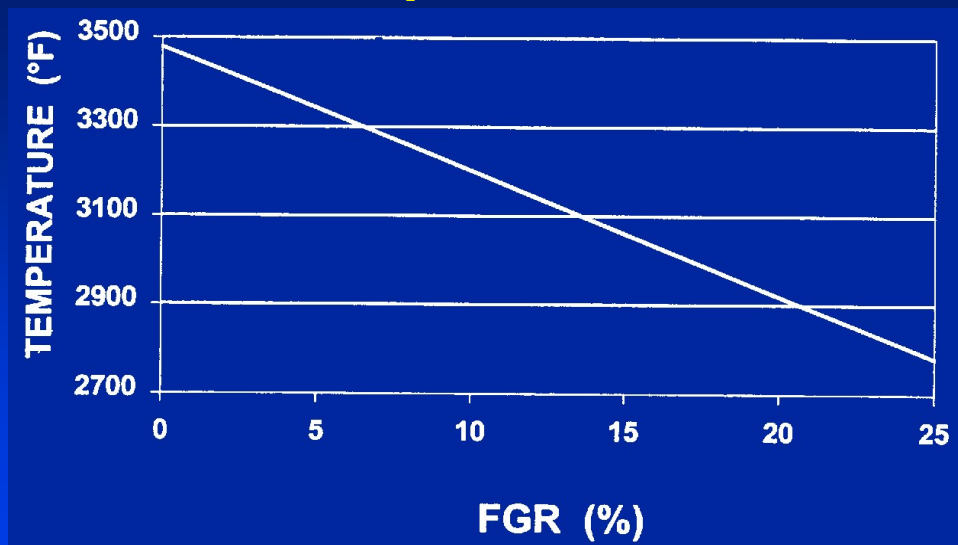
CON'S

- ◆ HIGH ELECTRICAL USAGE (*FGR fan HP doubled compared to RX system*)
- ◆ LOW TEMPERATURE, TRANSLUCENT, FLAME REDUCES HEAT TRANSFER & EFFICIENCY.
- ◆ COMBUSTION INSTABILITY
- ◆ CAN'T CHANGE FIRING RATE FAST ENOUGH TO FOLLOW CHANGING LOAD DEMANDS

Lower Cost to Industry

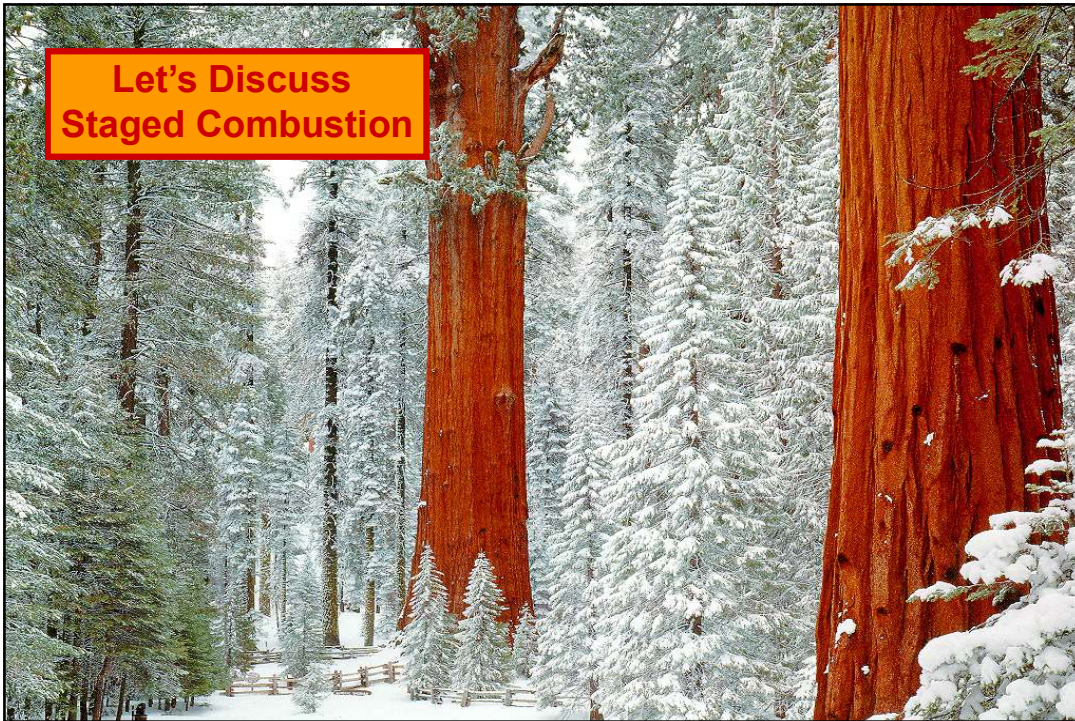
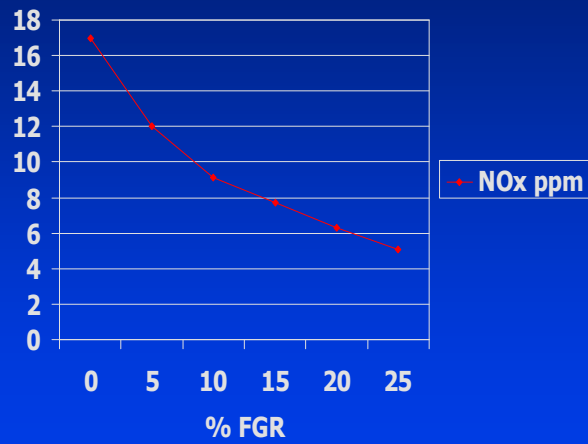
- ◆ **Simple durable refractory and steel construction results in:**
 - ◆ Lower initial cost
 - ◆ Lower maintenance costs
- ◆ **Lower operating cost**
 - ◆ Less stack losses due to low excess air and low FGR requirements
 - ◆ Lower fan costs
 - ◆ Eliminates the need for chemicals & catalysts

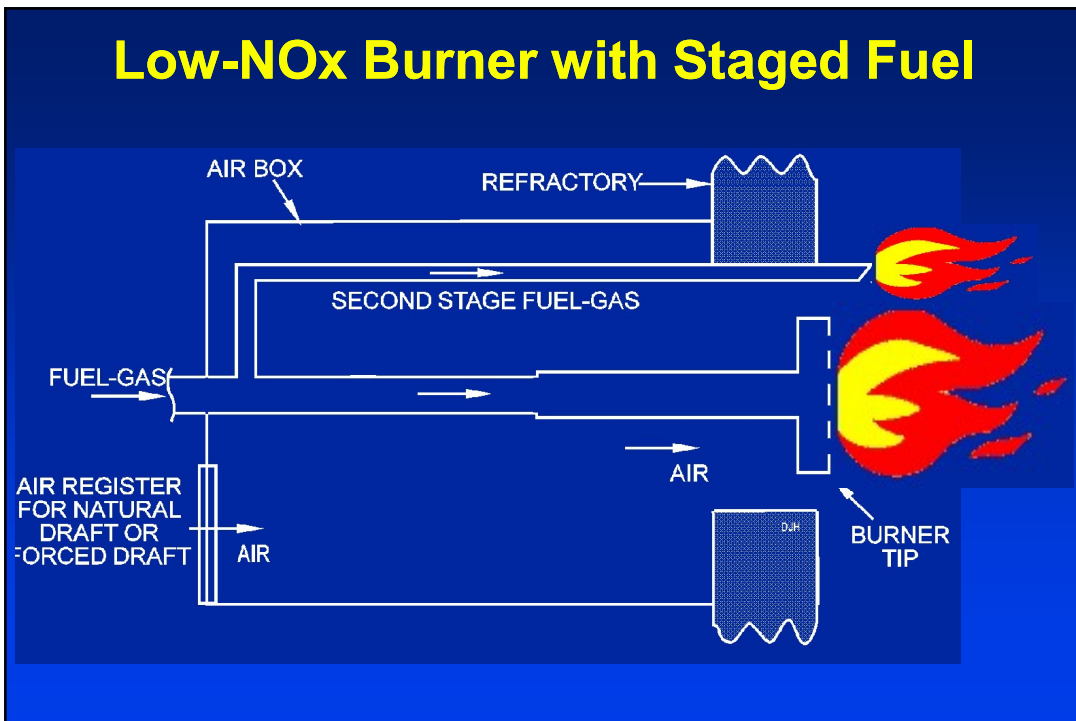
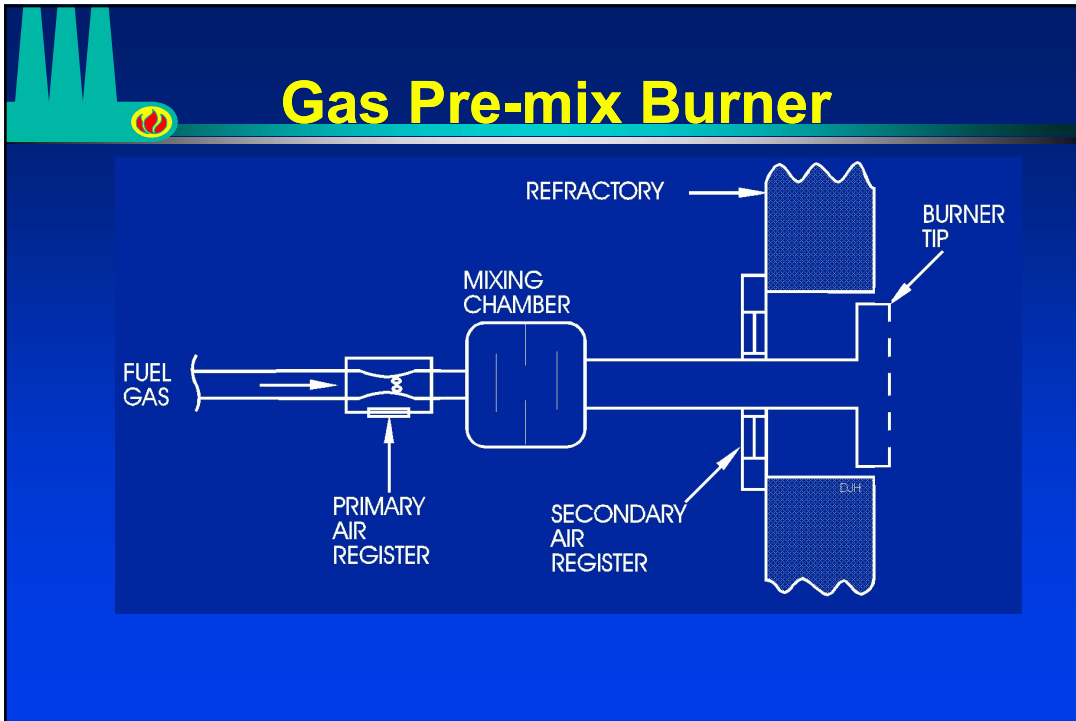
Flame Temperature vs. FGR



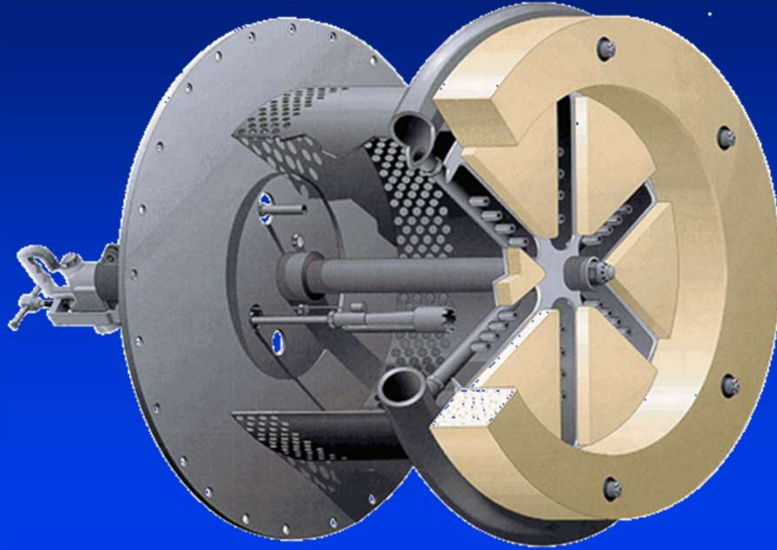
Graphic Courtesy of Coen

FGR Impact



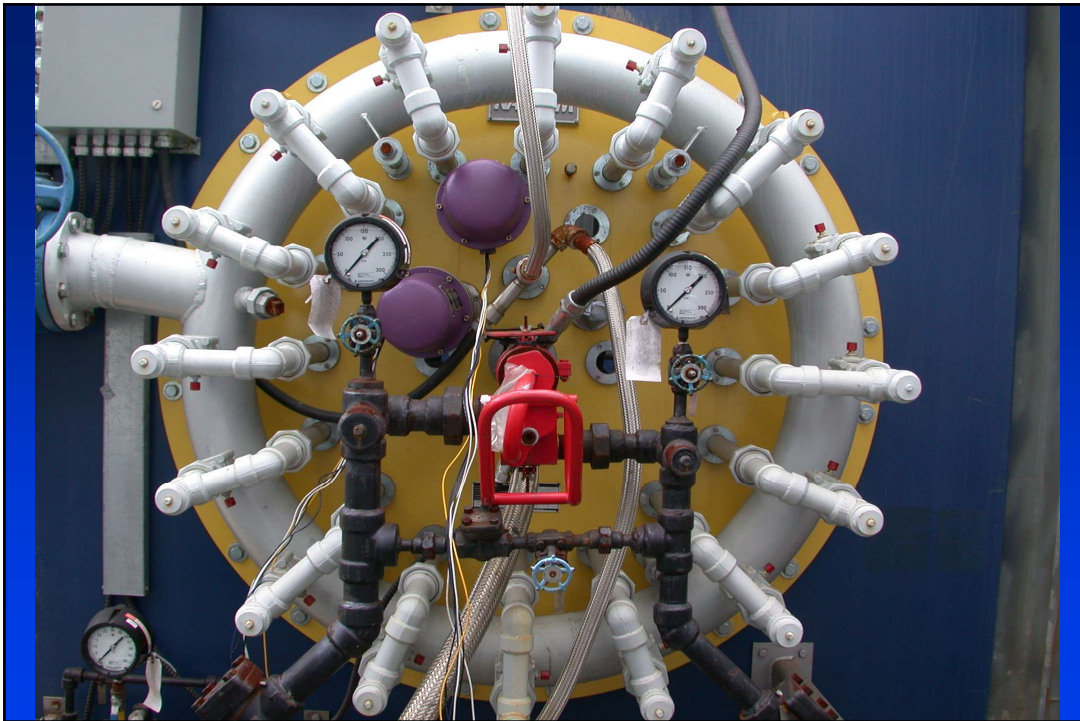
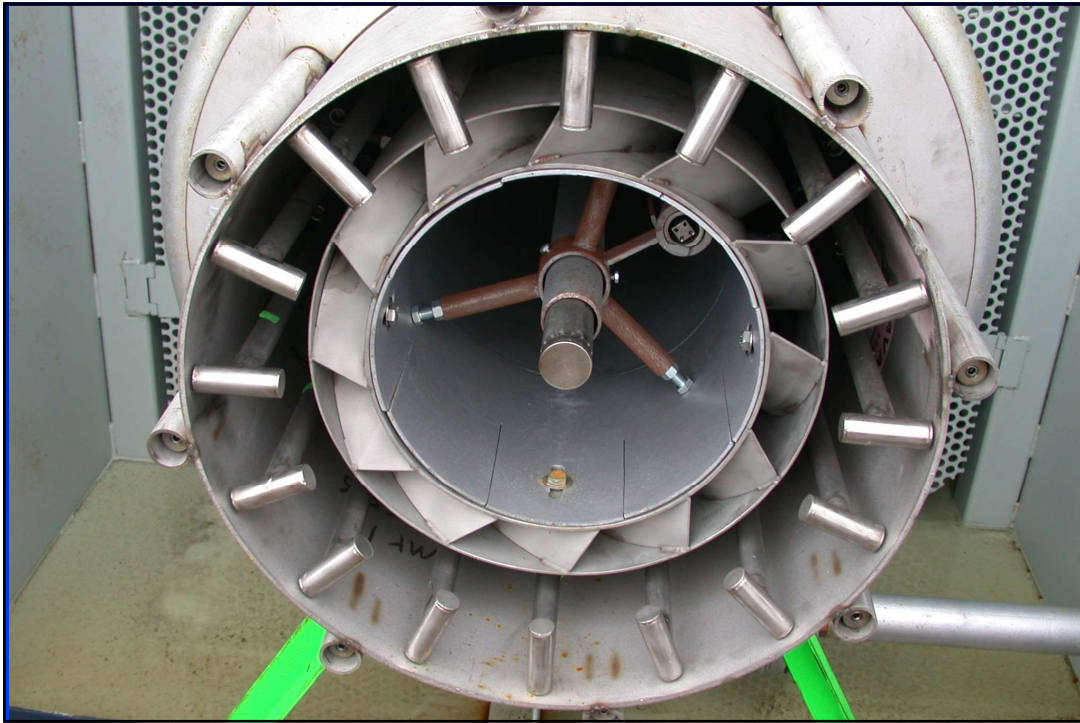


Low-NOx Burner with Staged Fuel

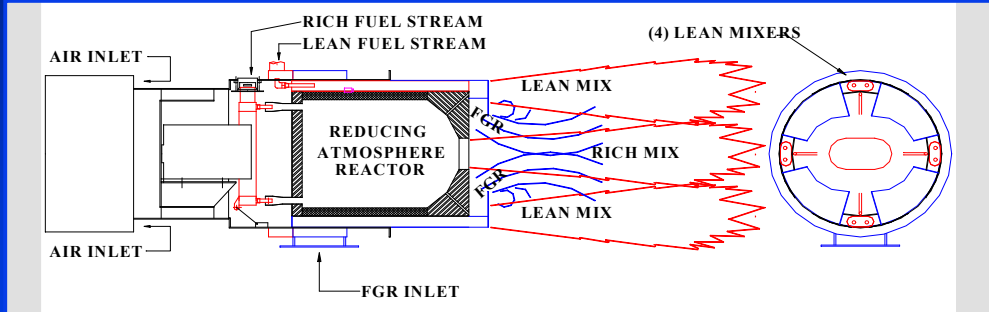


Ultra Low-NOx Burner (9 ppm)

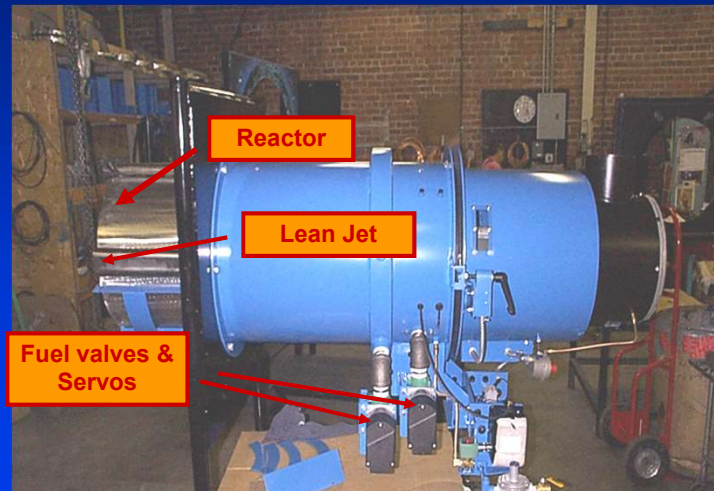
NACT Industrial Boilers #273



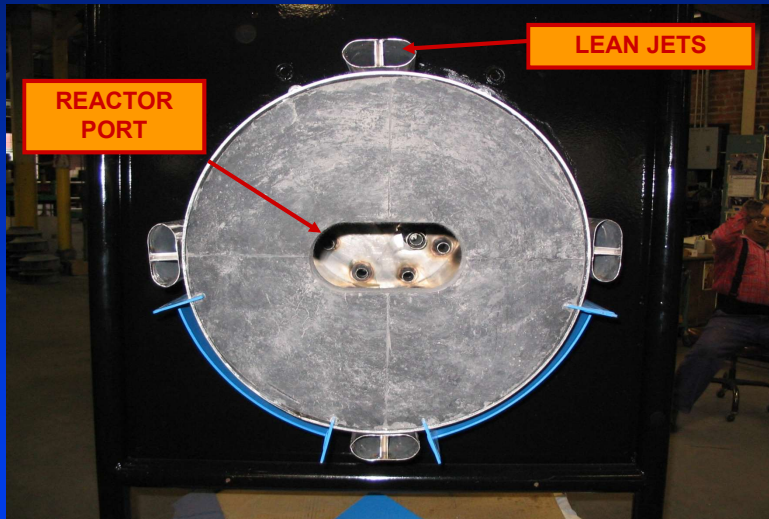
Burner Cross-sectional View



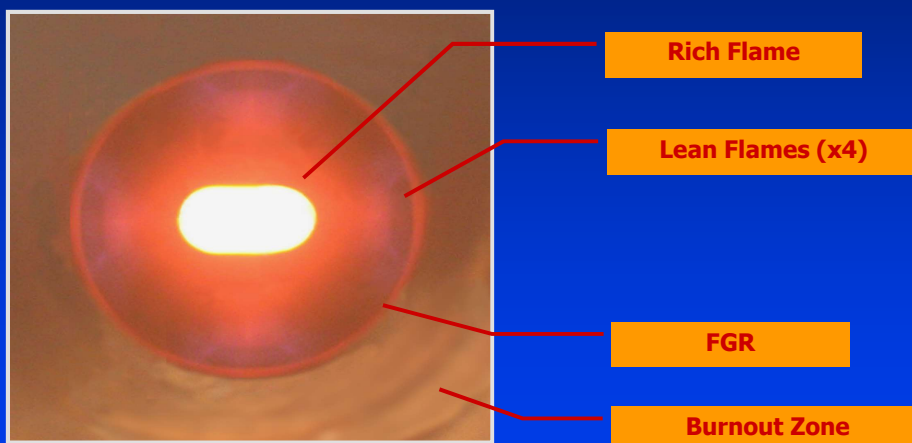
TYPICAL COMPONENTS



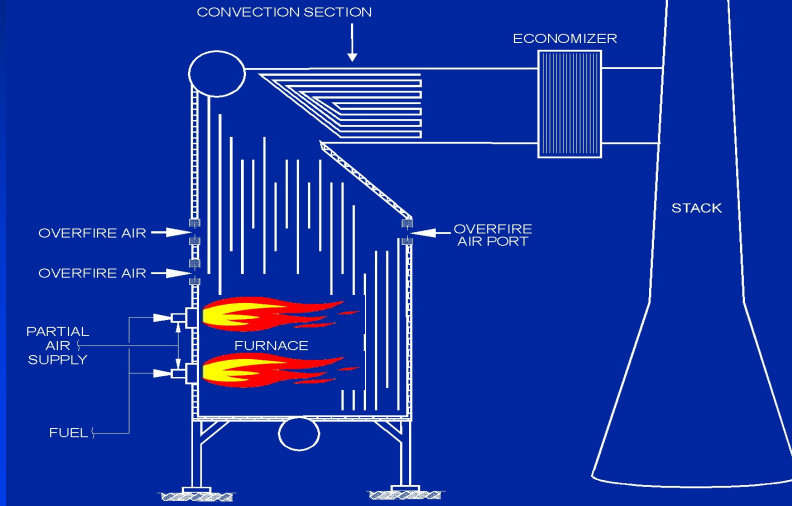
TYPICAL COMPONENTS



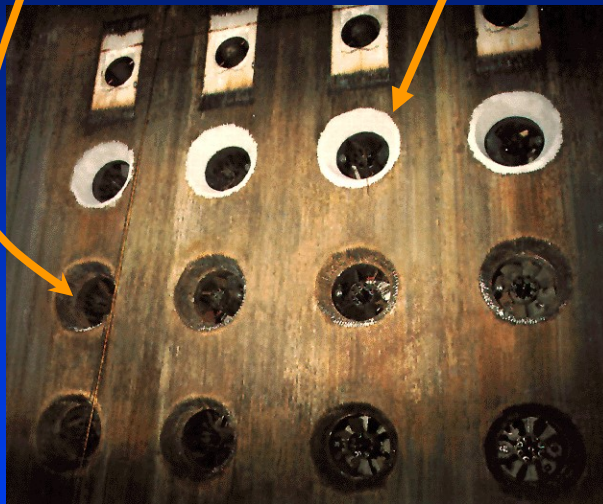
A Look Down the Furnace



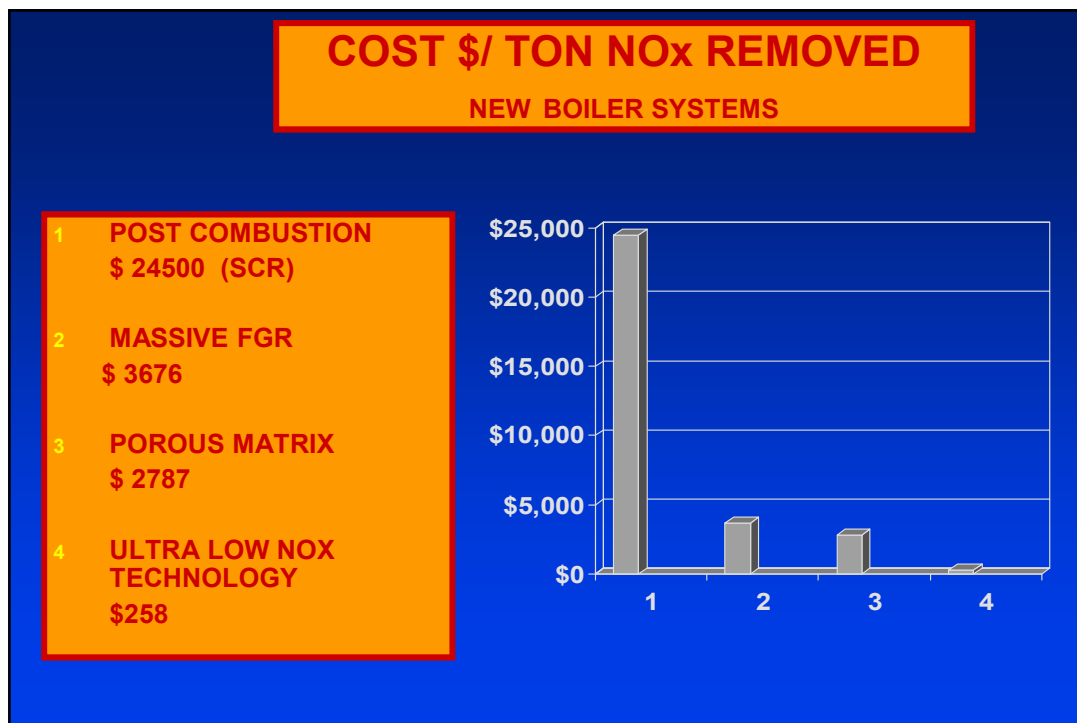
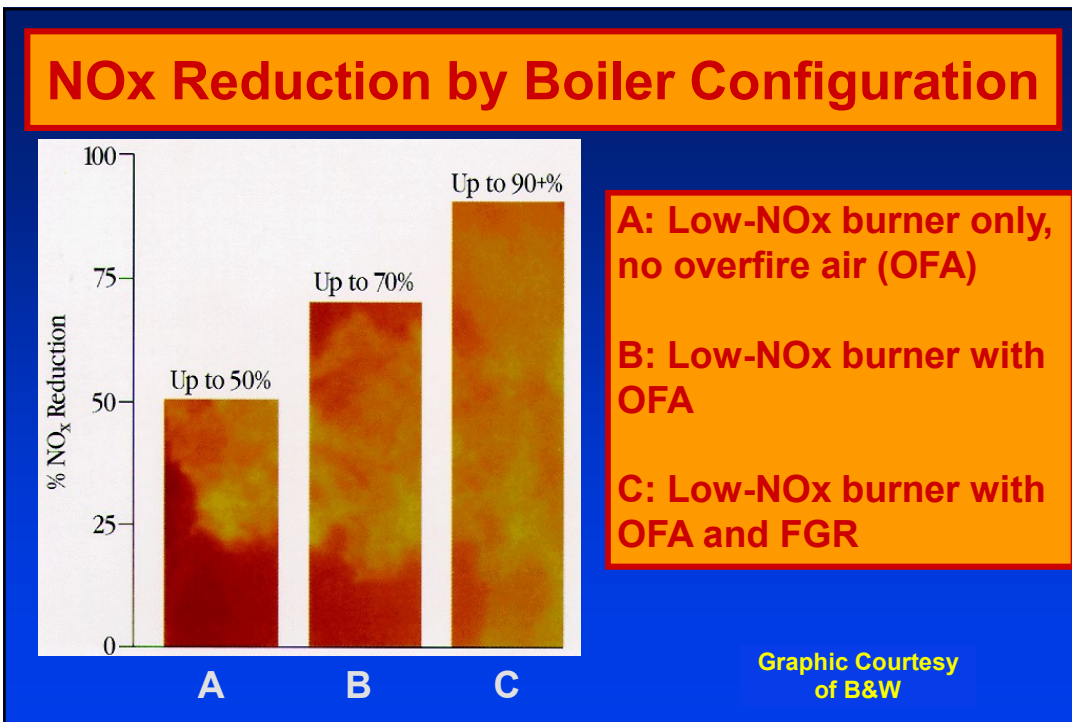
Staged Combustion with Overfire Air



Burners with Overfire Air



Graphic Courtesy of B&W



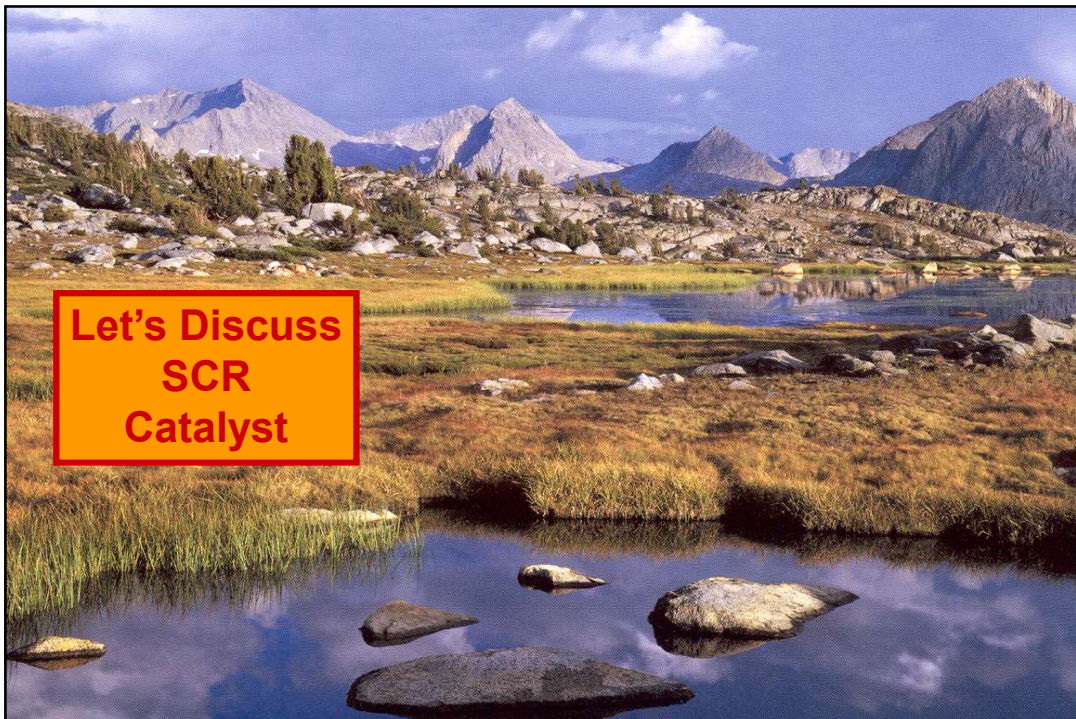
Existing Emissions & Goals

Emission	Existing	Proposed
NOx ppm@3% O2	25.3	5 - 6
CO ppm@ 3% O2	70.2	<50
Stack O2, %	6.2	2.5 – 3.2

Reduce NOx by 75%

Reduce O2 by 48 - 60%

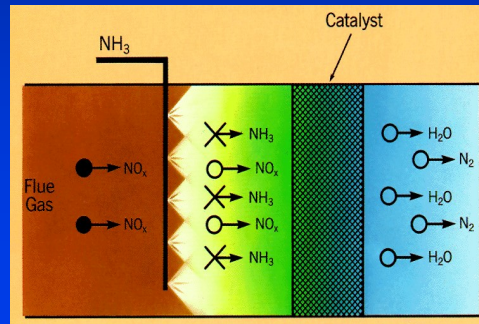
Reducing O2 from 6% to 3% saves this customer 273 CFH of nat gas

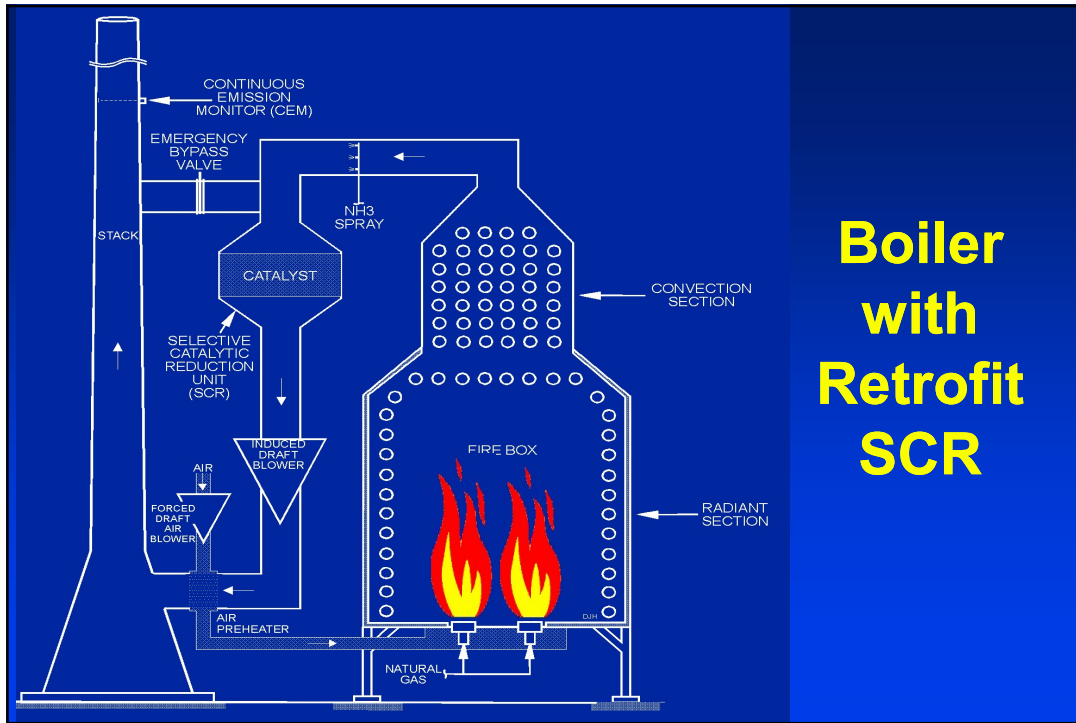


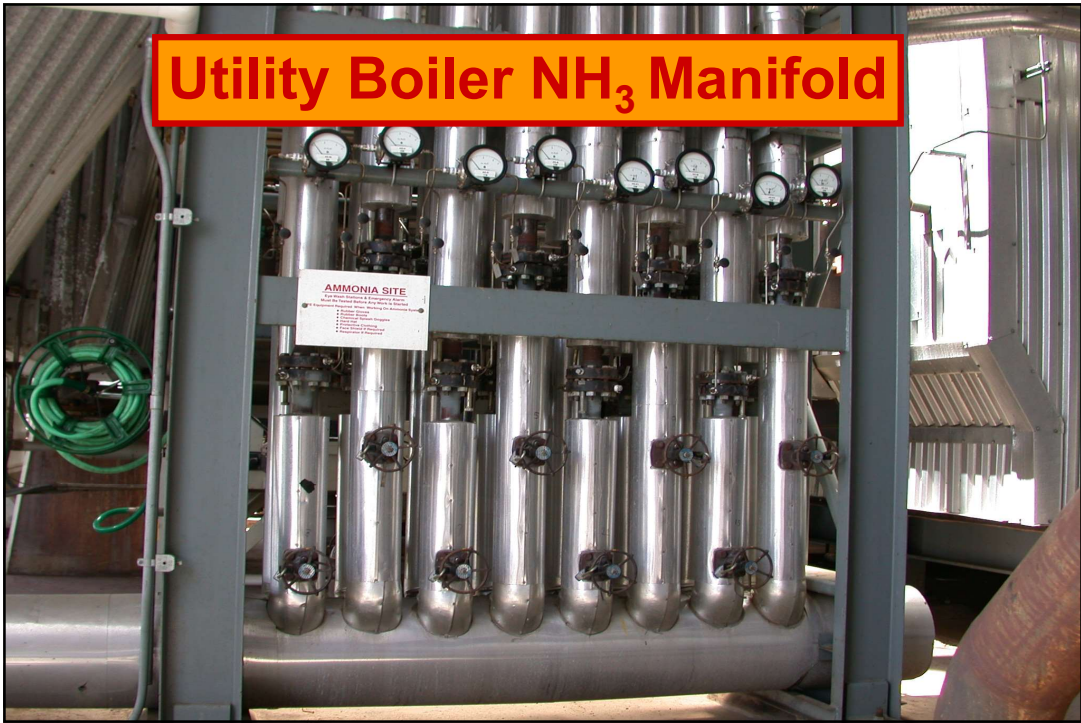
**Let's Discuss
SCR
Catalyst**

Selective Catalytic Reduction (SCR)

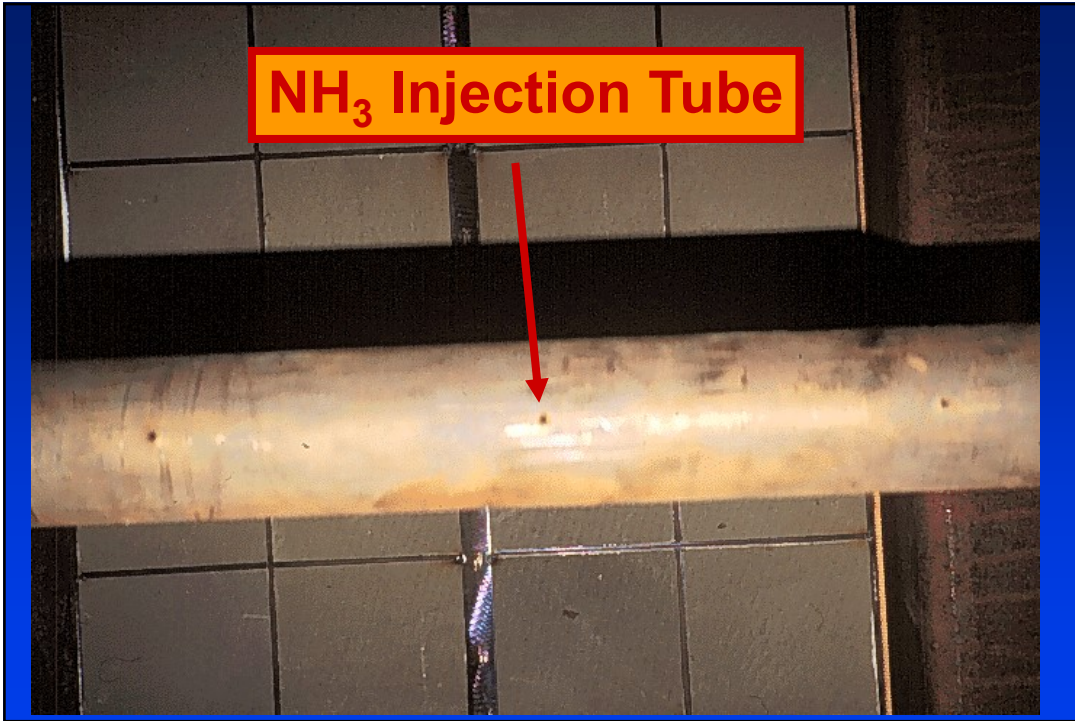
- ◆ NO_x control thru ammonia (NH₃) injection
- ◆ $4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O}$
- ◆ $2\text{NO}_2 + 4\text{NH}_3 + \text{O}_2 \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O}$
- ◆ 90-95% control
- ◆ Problems
 - ◆ Expensive
 - ◆ High maintenance
 - ◆ Ammonia “slip”
 - ◆ Catalyst replacement & disposal



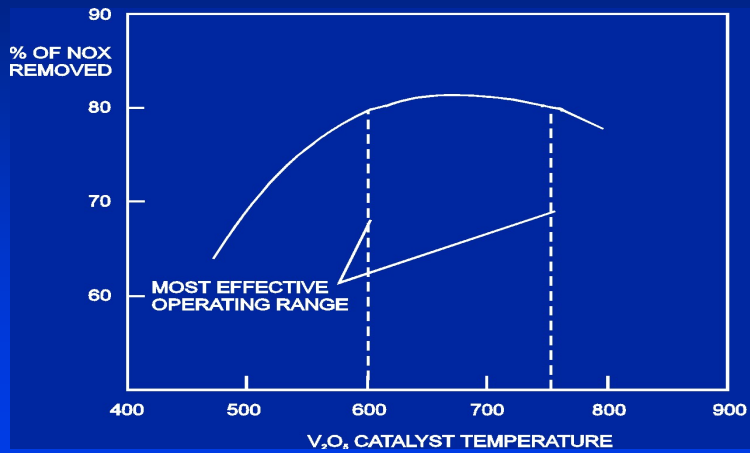


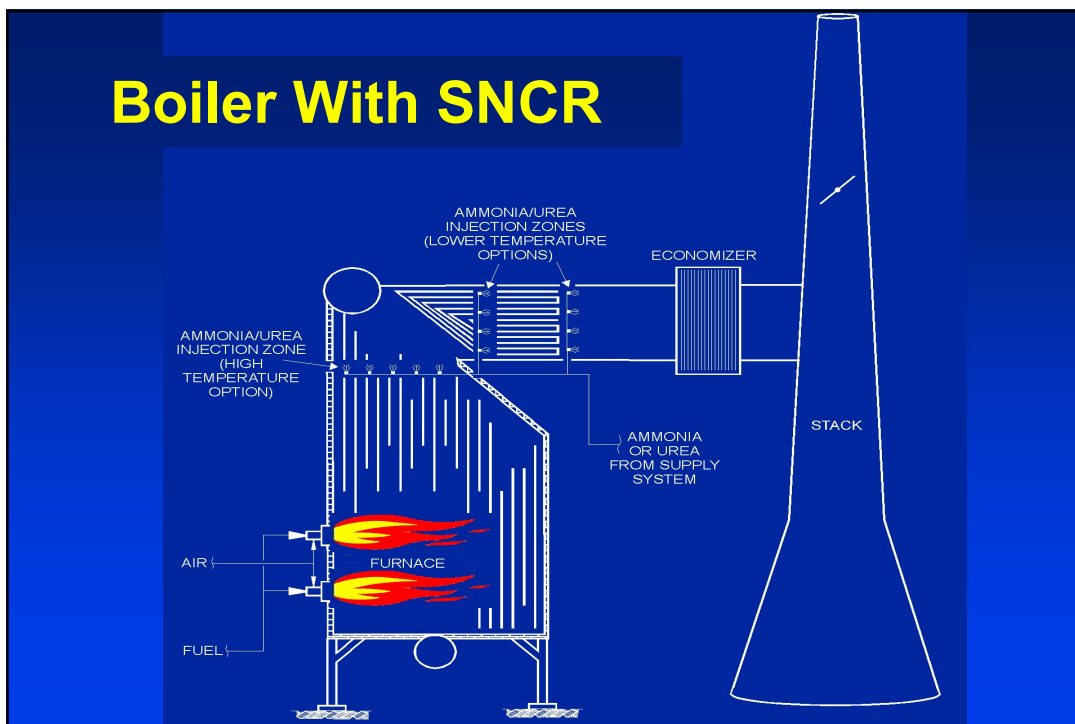


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% NOx Removed vs. Vanadium Pentoxide Catalyst Temperature





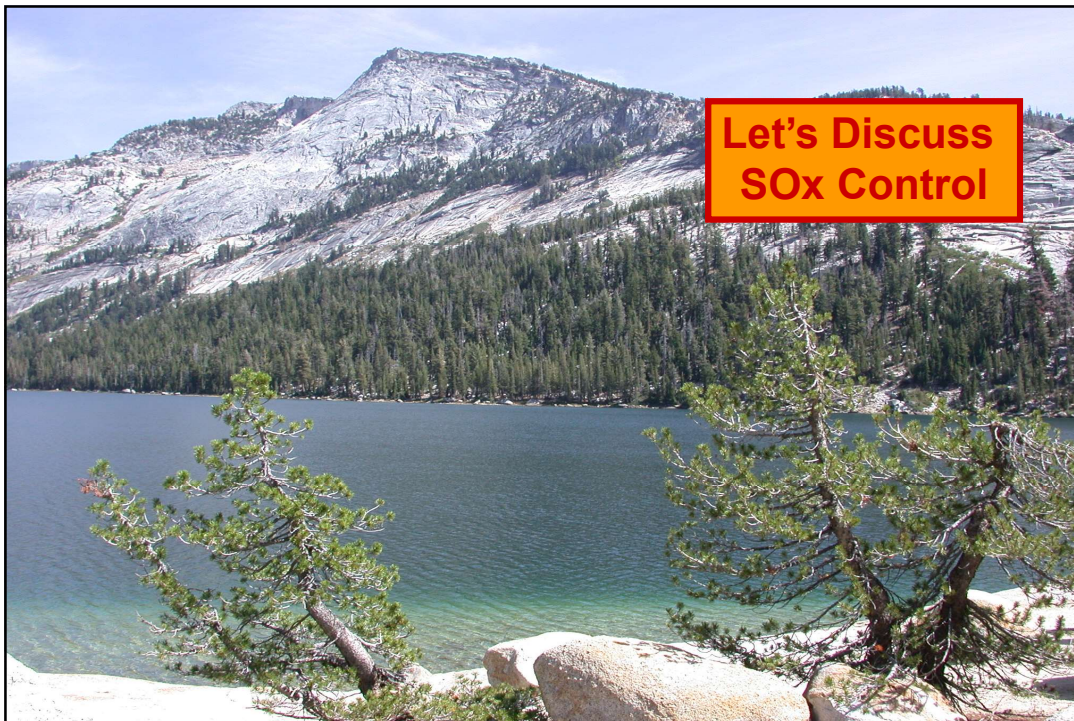
Selective Non-Catalytic Reduction

- ◆ NO_x control through ammonia or urea injection
- ◆ No catalyst necessary
- ◆ Temperature range 1400 °F – 1700 °F
- ◆ Injected upstream of convection section
- ◆ 80% control under normal conditions
- ◆ Problems:
 - ◆ Changing flue temperatures with changing load
 - ◆ Formation of ammonium salts
 - ◆ Ammonia slip



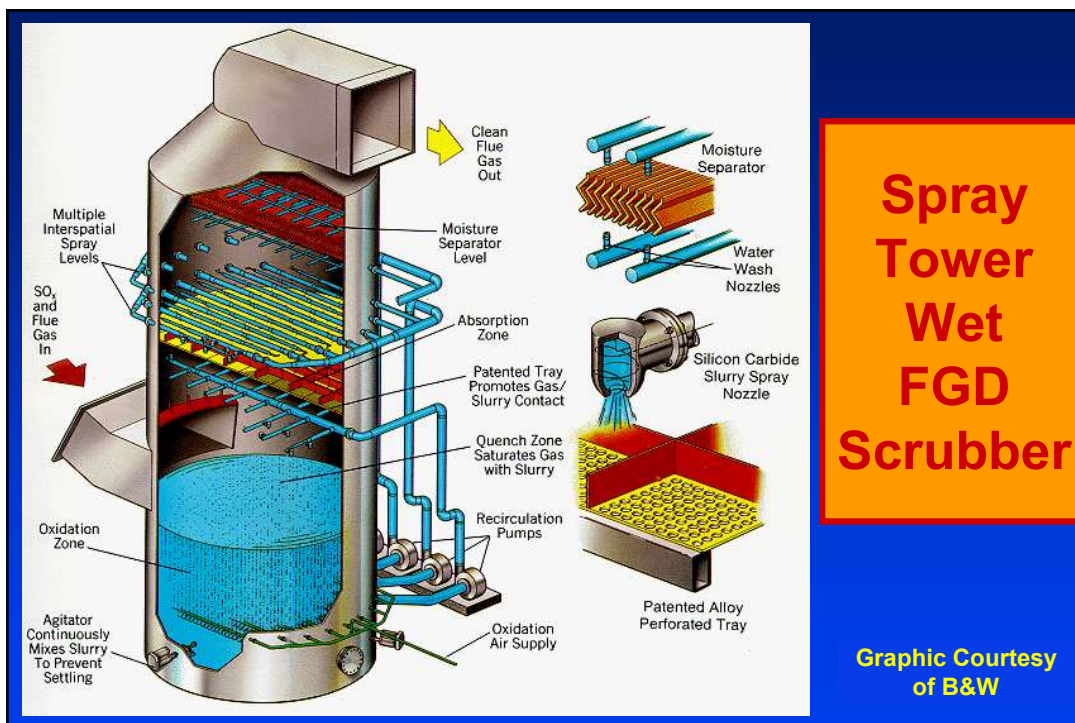
Comparison of NOx Reduction Technologies

Technology	Approx. Reduction	Approx. lbs/MMBTU	Approx. ppmv @ 3% O2
Standard burners	Base case	0.14	120
Low NOx burners	60%	0.06	45
Ultra Low NOx burners – 1 st gen.	80%	0.03	25 - 30
Ultra Low NOx burners – 2 nd gen.	95%	0.007	6 - 9
FGR	55%	0.025	20
Compu- NOx w/ FGR	90%	0.015	15 - 20
SNCR	80%	0.033 - 0.085	27 - 70
Catalytic Scrubbing	70%	0.017 - 0.044	14 - 36
SCR	90 – 95%	0.006 - 0.015	5 - 12



Sulfur Content of Various Fuels	
Fuel	Sulfur Percent by Weight
Natural gas	0.0005
LPG	0.001
Fuel Oil No. 1	0.01 to 0.3
Fuel Oil No. 2	0.05 to 0.5
Diesel Motor Fuel	0.0015
Fuel Oil No. 4	0.2 to 1.75
Fuel Oil No. 5	0.5 to 1.75
Fuel Oil No. 6	0.5 to 1.75
Low Sulfur Fuel Oil No. 6	0.5
Subbituminous coal from Rocky Mt. states	0.3 to 1
Petroleum coke	2 to 10

Fuel Sulfur Content



Spray Tower Wet FGD Scrubber

Graphic Courtesy of B&W

**Five FGD Scrubber Modules
on Utility Boiler**



Graphic Courtesy of B&W

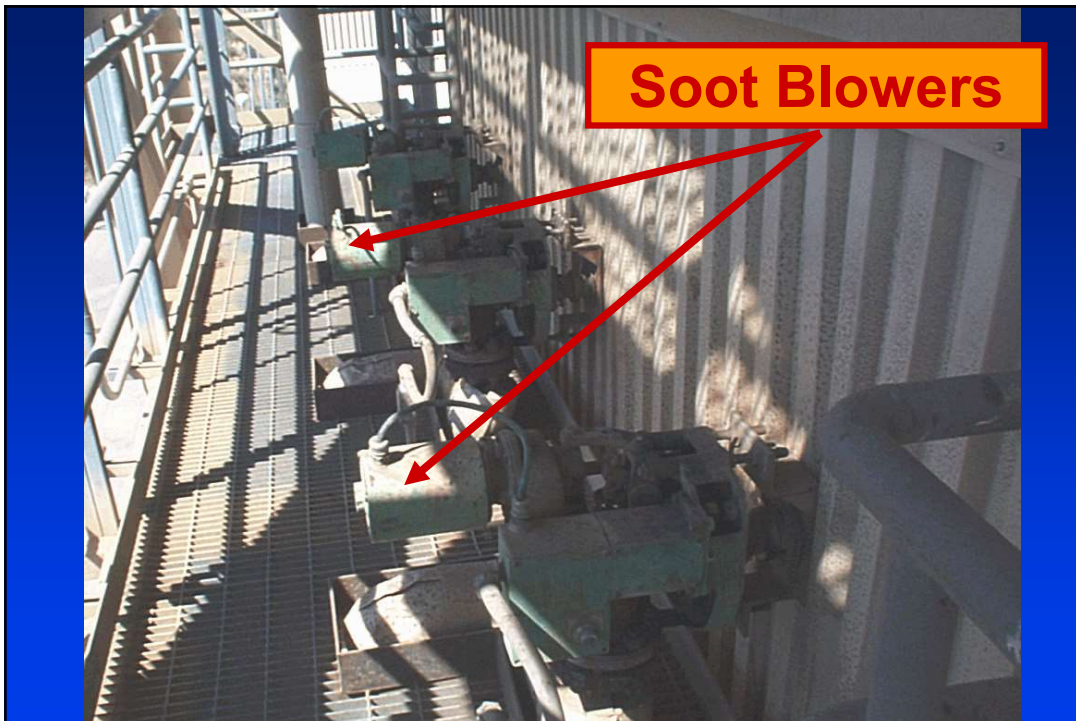
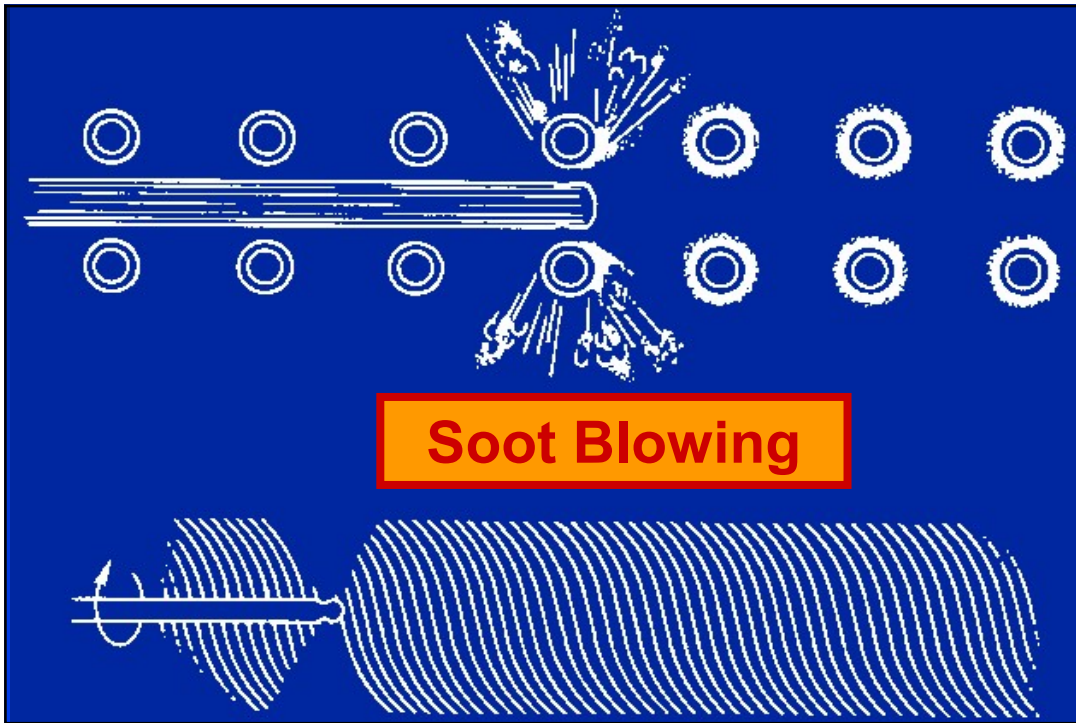
**Let's Discuss
PM Control**



Control of Particulate Emissions

- ◆ Settling chambers
- ◆ Cyclones
- ◆ Baghouses
- ◆ ESPs
- ◆ Scrubbers



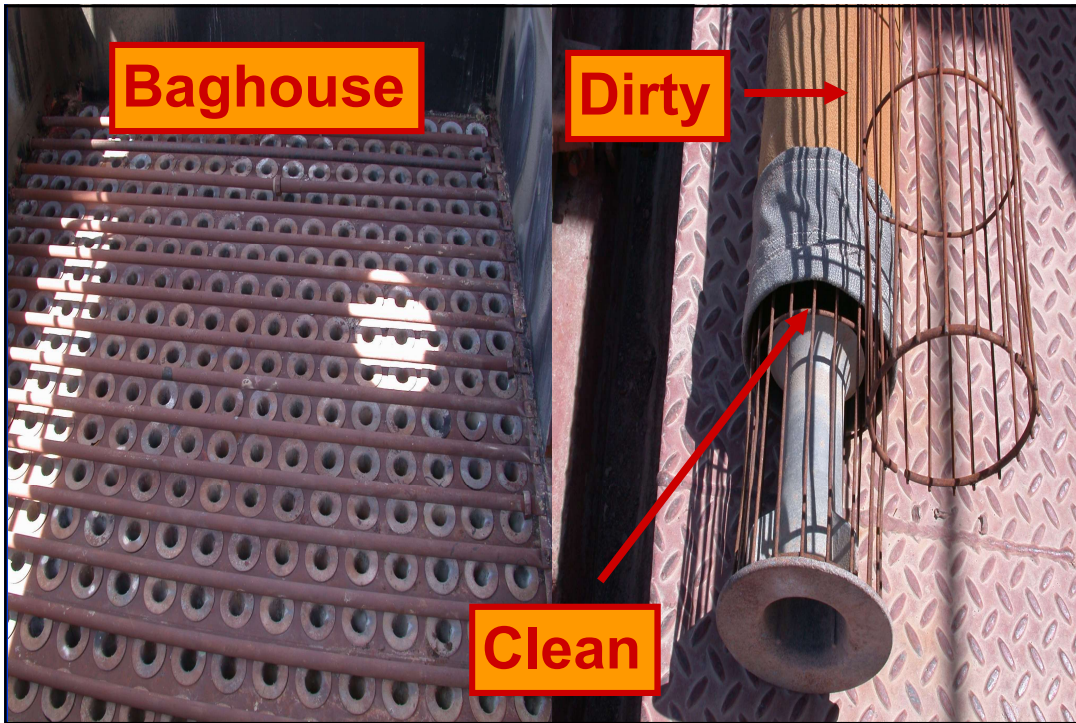


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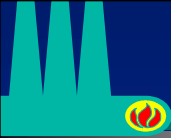




Regulatory Requirements


- ◆ Federal, state, and local requirements
- ◆ Boiler specific limits
- ◆ Permit requirements
- ◆ Monitoring requirements
- ◆ Visible emission limits
- ◆ Nuisance regulations
- ◆ Breakdowns & variances





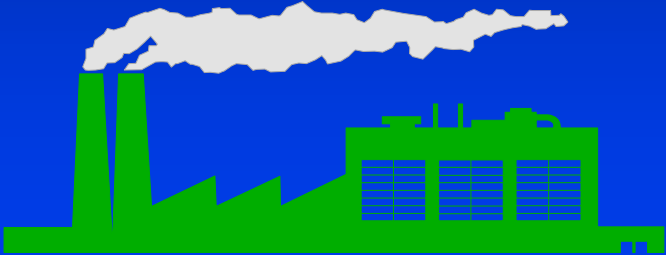
Boiler Regulations

- ◆ NSPS 40 CFR Part 60 Subpart D, Da, Db, Dc, Ea
- ◆ Acid Rain Provisions (Parts 72,73,74,75, 76, 77, 78)
- ◆ RCRA 40 CFR Parts 264 & 266
- ◆ State Regulations including VE
- ◆ SIP Requirements
- ◆ Local Regulations
- ◆ MACTs – JJJJJJ & DDDDD



Boiler Emission Limits

- ◆ NO_x, SO₂, particulate, and opacity values for boilers are based on applicable subpart, heat input, date built or modified, and fuel used
- ◆ States and districts may have more stringent limits



BACT in CA

Type of Control	NOx Limits
Natural Gas Fired with SCR or equal	6 - 9 ppmvd @3% O ₂ (0.011 lb/MMBTU)
Natural Gas Fired with Ultra Low NOx Burner	15 ppmvd @3% O ₂ (0.018 lb/MMBTU)
Natural Gas Fired with Low NOx Burner	20 ppmvd @3% O ₂ (0.024 lb/MMBTU)

BARCT & RACT

Type of Control	NOx Limits
Natural Gas Fired with Low NOx Burner	9 - 30 ppmvd @3% O ₂ 0.036 lb/MMBTU
Natural Gas Fired Units (< 40 MMBTU/hr)	74 ppmvd @3% O ₂ 0.085 lb/MMBTU
Solid Fuel Fired Boilers	0.20 lb/MMBTU
Municipal Solid Waste	200 ppmv @12% CO ₂ 0.24 lb/MMBTU

Permit Categories

1. Emissions Limitations
2. Equipment Requirements
3. Operating Conditions
4. Monitoring and Recording Requirements
5. Compliance Testing
6. General Requirements



Testing and Monitoring

- ◆ Continuous Monitoring System
- ◆ Stack Testing
- ◆ Process Monitors
- ◆ Recordkeeping

Continuous Monitoring Types

- ◆ Opacity Transmissometers
- ◆ NO_x
- ◆ SO₂
- ◆ CO
- ◆ O₂ and/or CO₂
- ◆ Ammonia
- ◆ Mercury Semi-Continuous

Source Testing

- ◆ Particulate Matter (PM, PM10, PM2.5)
- ◆ NO_x, SO₂, CO, Ammonia
- ◆ Mercury and Other Metals
- ◆ Hydrogen Chloride
- ◆ Formaldehyde
- ◆ Visible Emissions (Method 9)

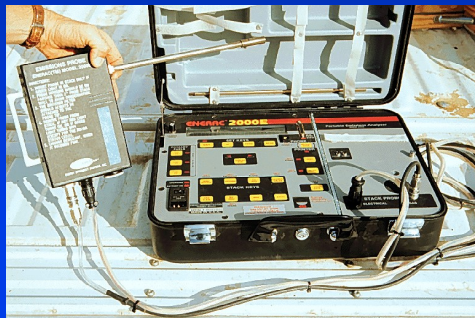
Control Device Parameters

- ◆ ESP Spark Rate and Fields in service
- ◆ Baghouse Pressure Drop
- ◆ Scrubber Pressure Drop and Liquor Flow Rate
- ◆ Fuel Usage

Alternative Monitoring

- ◆ Portable analyzer monitoring of NO_x, CO, O₂
- ◆ Determination of FGR rate
- ◆ Burner mechanical adjustments
- ◆ O₂ Trim concentration
- ◆ FGR valve(s) setting

Portable Combustion
Analyzer





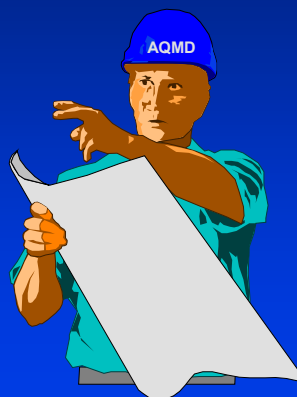
Pre-Inspection



- ◆ Prepare inspection form
- ◆ File review
- ◆ Regulation review
- ◆ Equipment check
- ◆ Pre-entry & entry
- ◆ Pre-inspection meeting
- ◆ Permit check

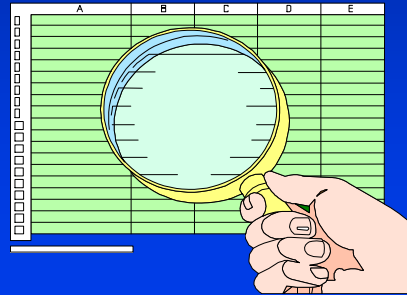
Reasons for Inspections

- ◆ Compliance determination
- ◆ Complaint investigation
- ◆ Source plan approval
- ◆ Review or renewal of permits
- ◆ Special studies



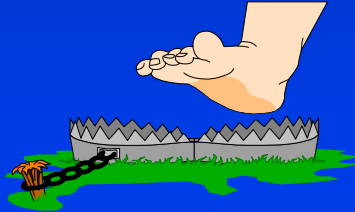
Inspection

- ◆ Visible emission evaluation
- ◆ General upkeep & maintenance
- ◆ Monitoring instruments & records
- ◆ Fuel type and quality
- ◆ Maintenance records
- ◆ Operational records
- ◆ Source tests



Inspector Safety

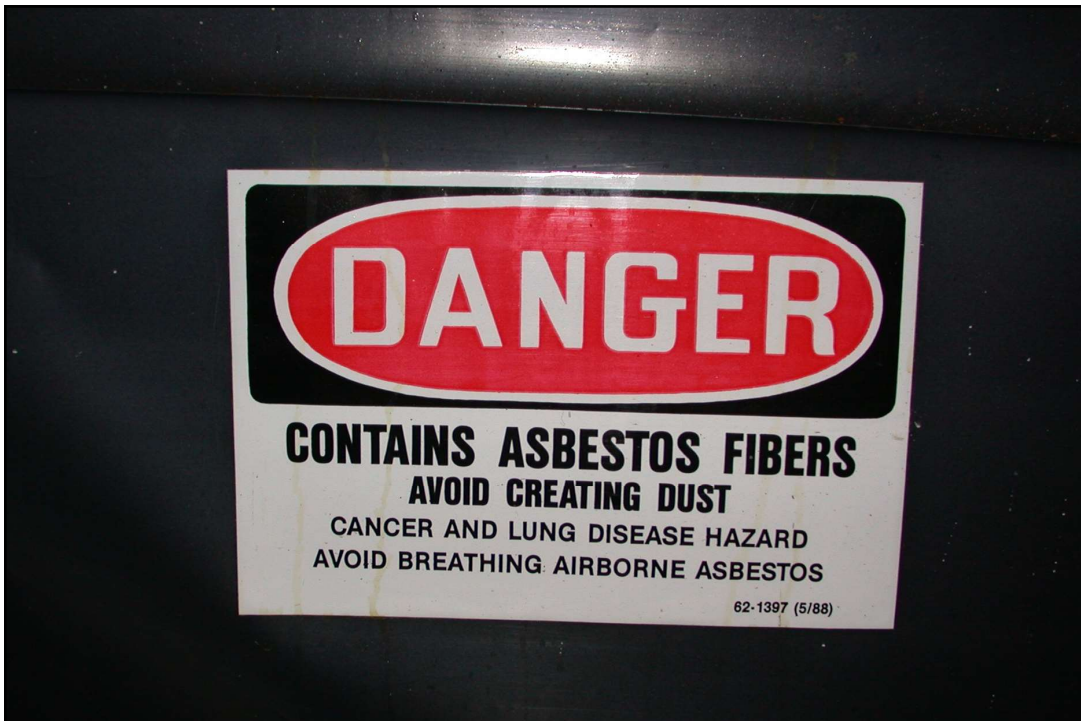
- ◆ Proper equipment
- ◆ Plant warnings
- ◆ Heat
- ◆ High pressure steam
- ◆ Electrical hazards
- ◆ Noise
- ◆ Moving parts
- ◆ Inhalation hazards
- ◆ Hazardous materials
- ◆ Machine disintegration
- ◆ Fires
- ◆ Other hazards & traps



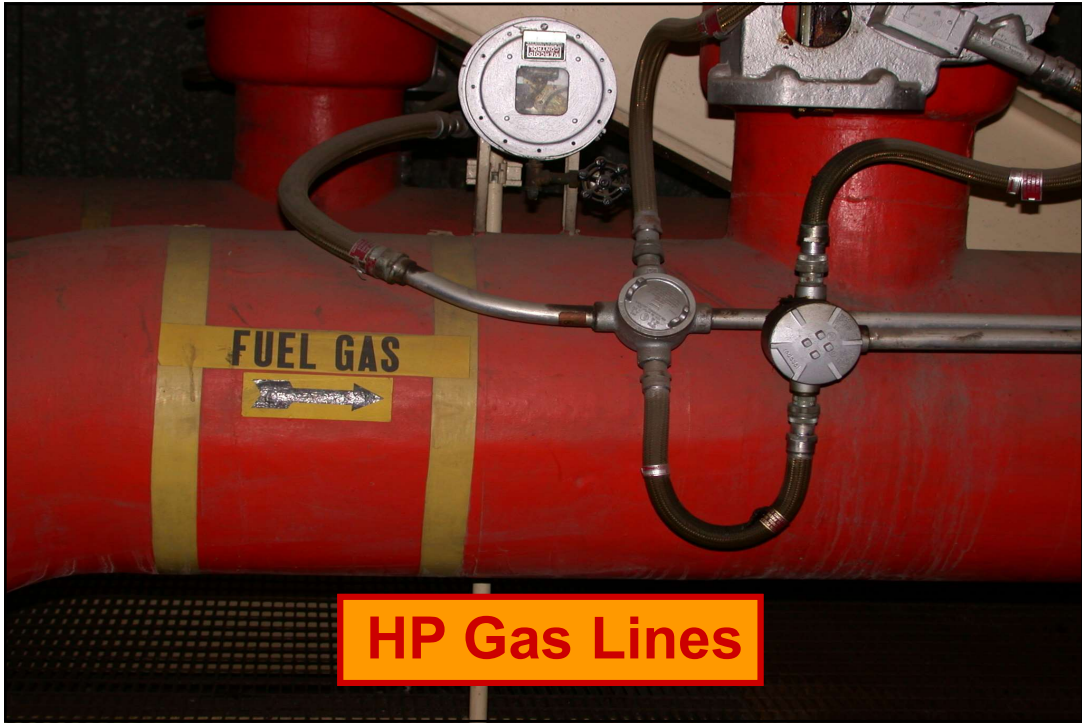
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