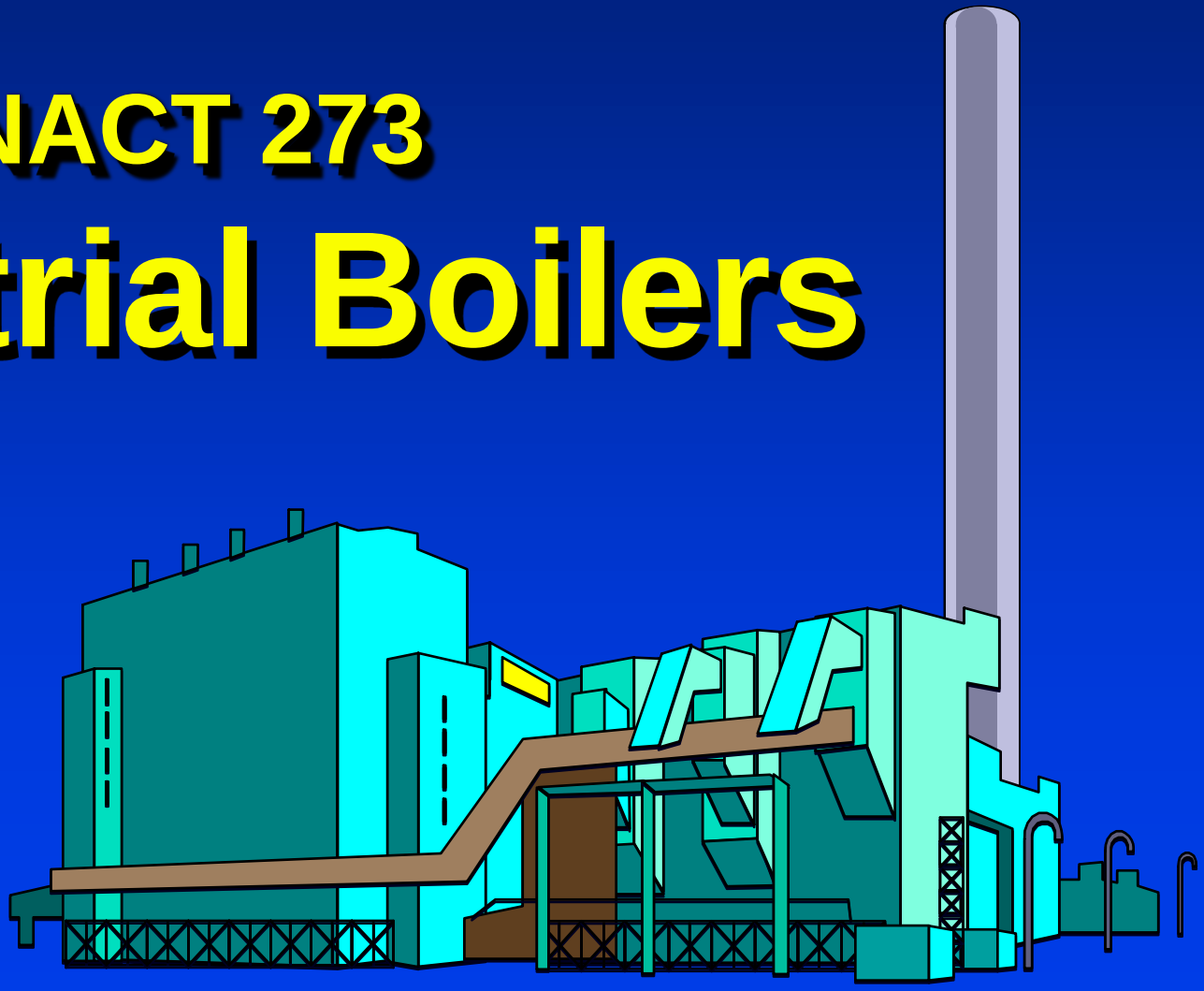
NACT 273

Industrial Boilers

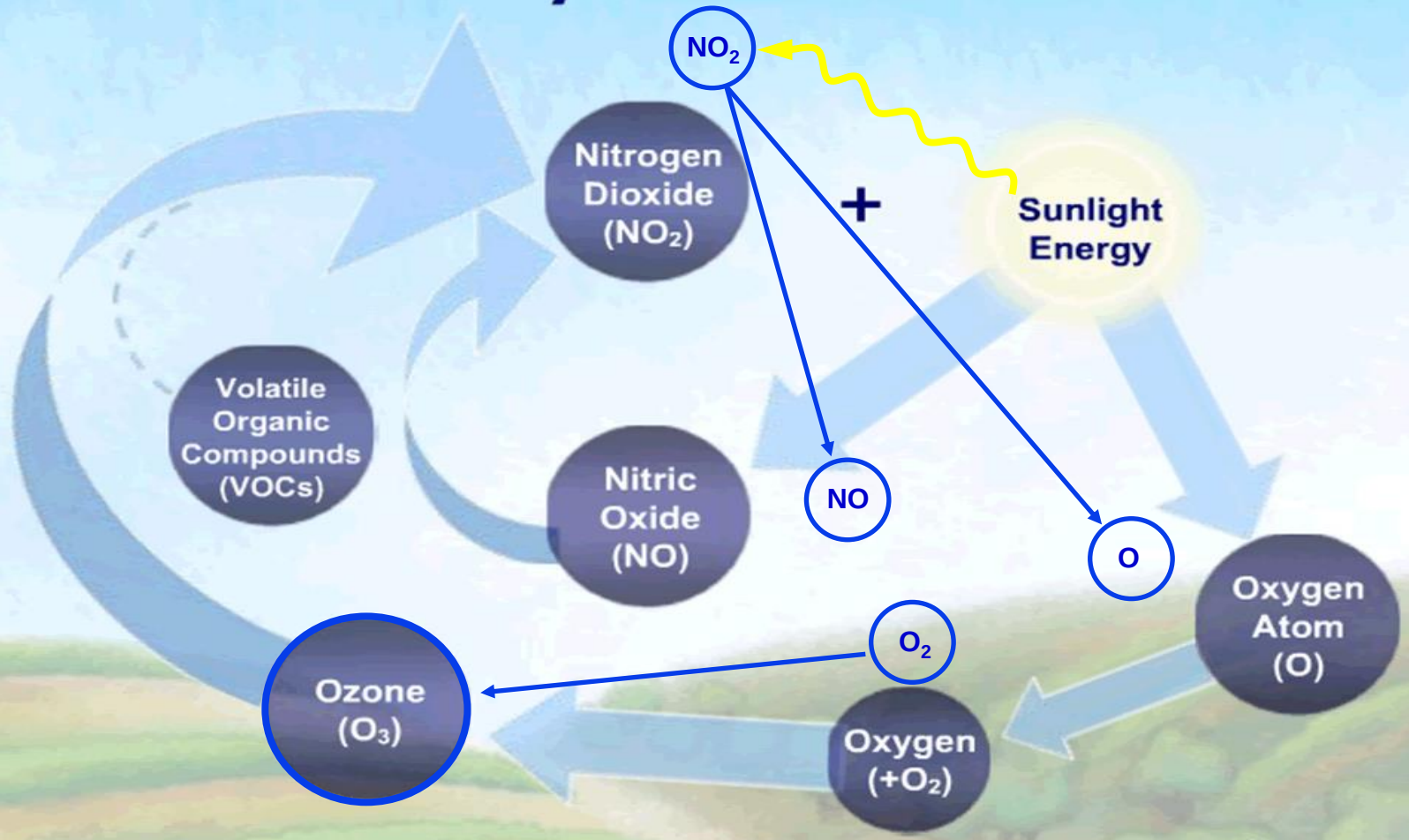


Course Overview

- 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

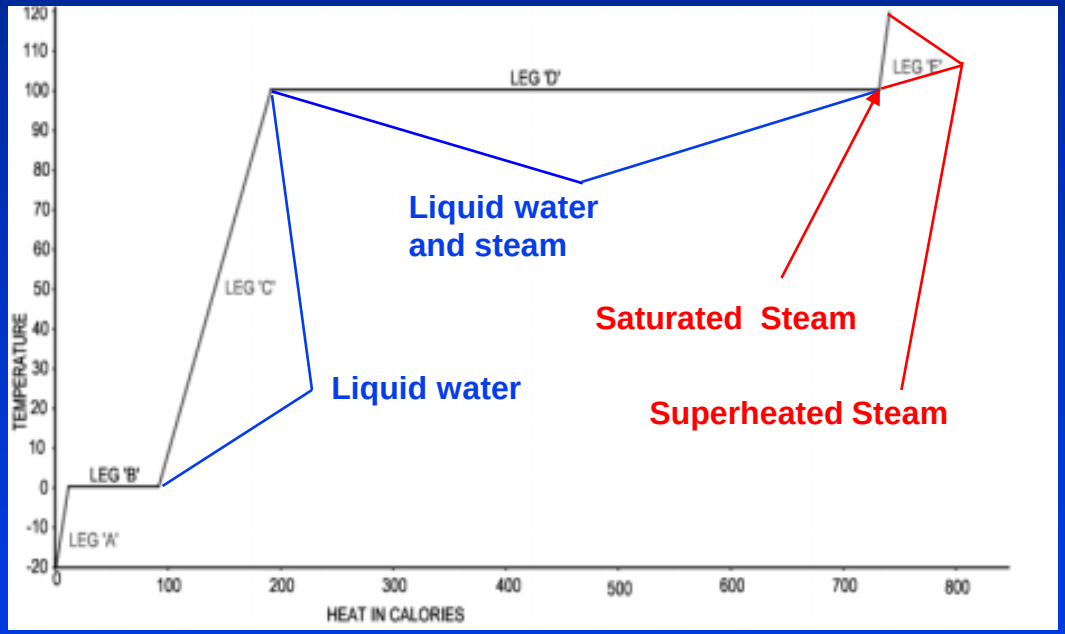
Air Resources Board

Ozone Photochemistry



Uses of Boilers

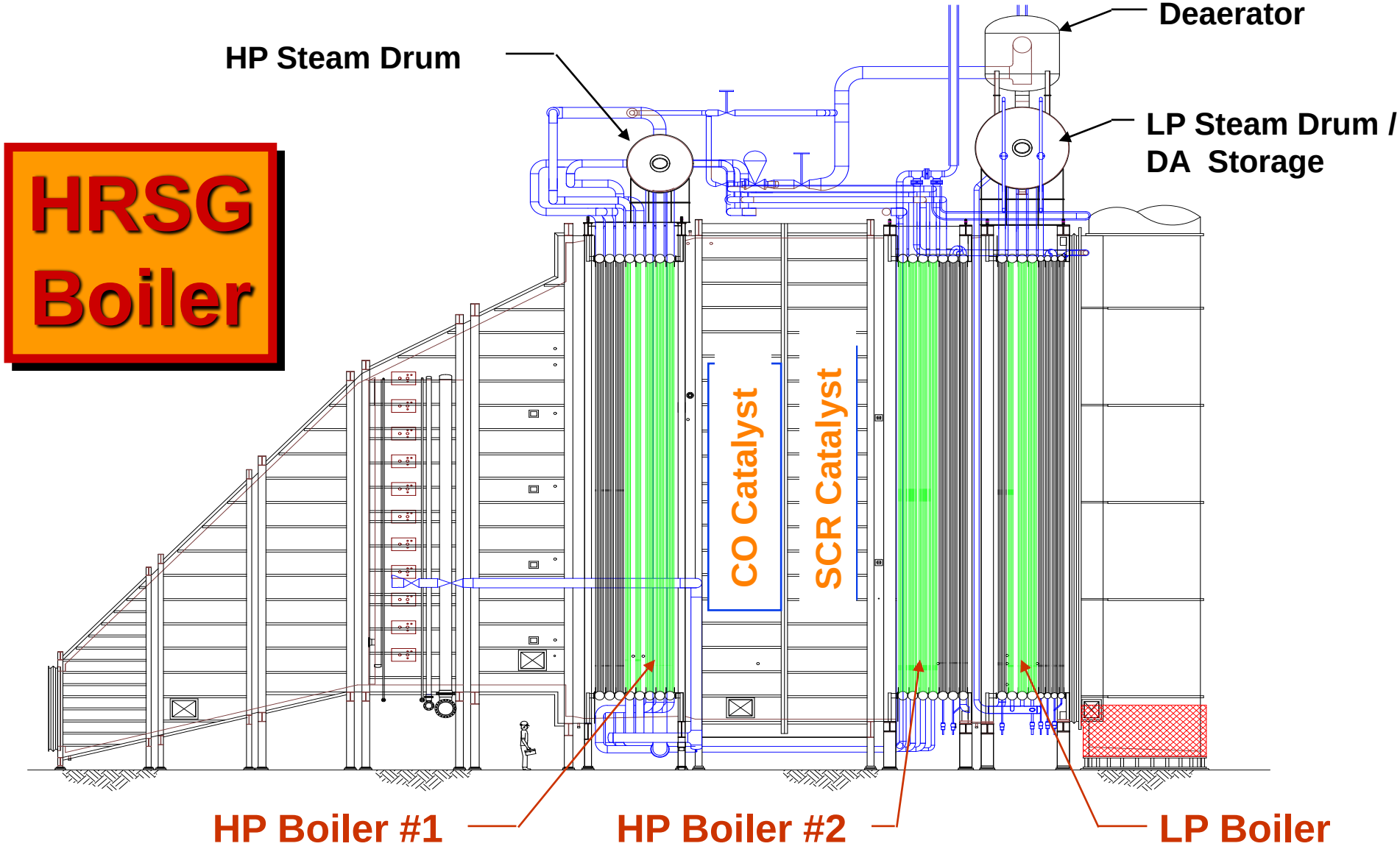
- Electrical generation — High Pressure (2,000 -3,800 psi)
- Space heating — Low Pressure (150 – 1,600 psi)
- Food preparation
- Commercial laundries
- Pulp & paper industry
- Petroleum industry
- Chemical industry
- Municipalities : Water, Sewage & Garbage



Small Firetube Boiler


Industrial
Boiler

Babcock & Wilcox Utility Boiler


HRSG Boiler
HP Steam Drum
Deaerator
LP Steam Drum / DA Storage
CO Catalyst
SCR Catalyst
HP Boiler #1
HP Boiler #2
LP Boiler

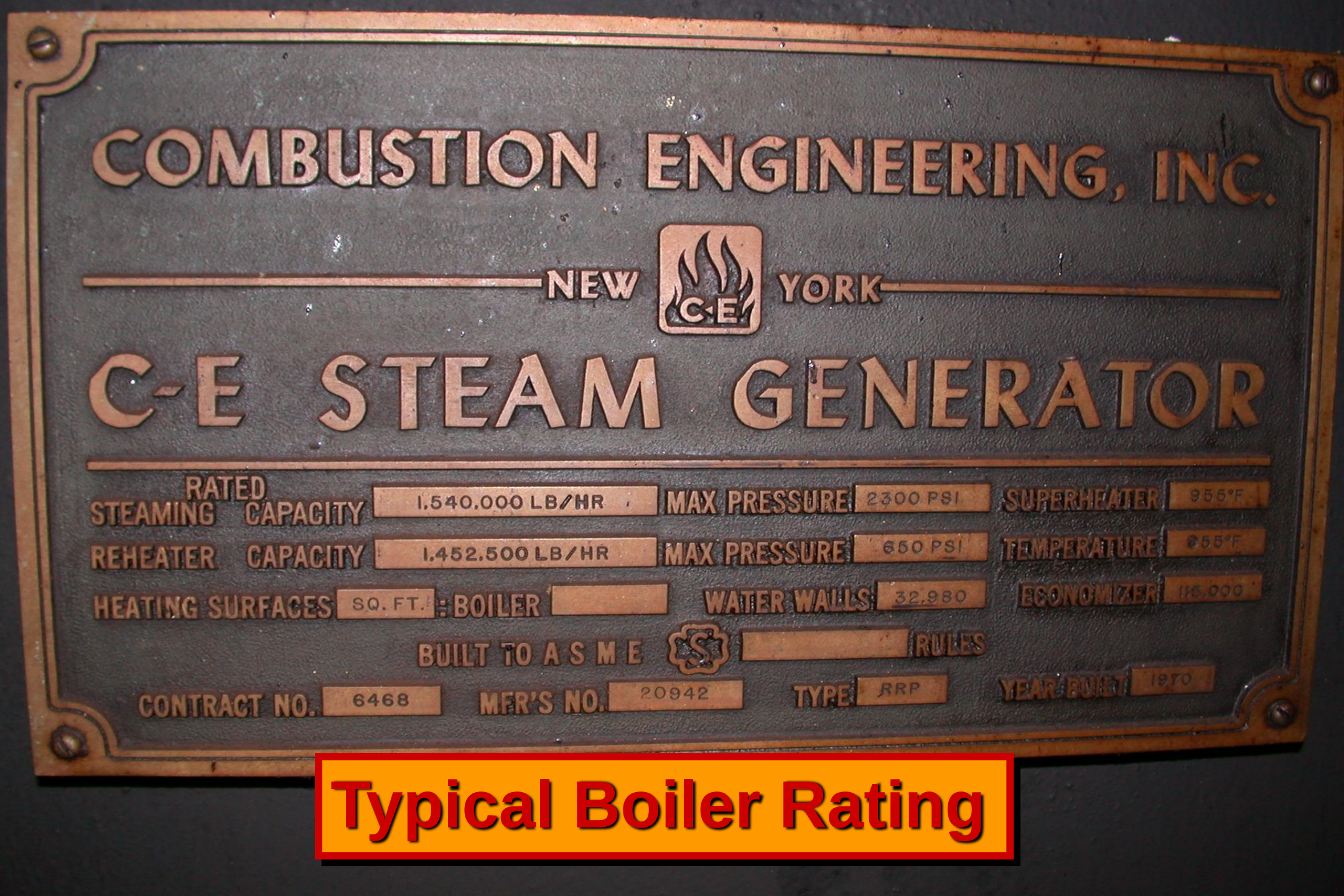

Boilers &
Opacity

History of Boilers : Ringelmann Chart

Hot Numbers

- British Thermal Unit (BTU)
  - 1 BTU the amount of energy needed to heat one pound of water one degree Fahrenheit or ≈ 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 Ratings
Millions of BTU/hr
Boiler HP
Pounds of Steam/hr
Megawatts
Tons per day

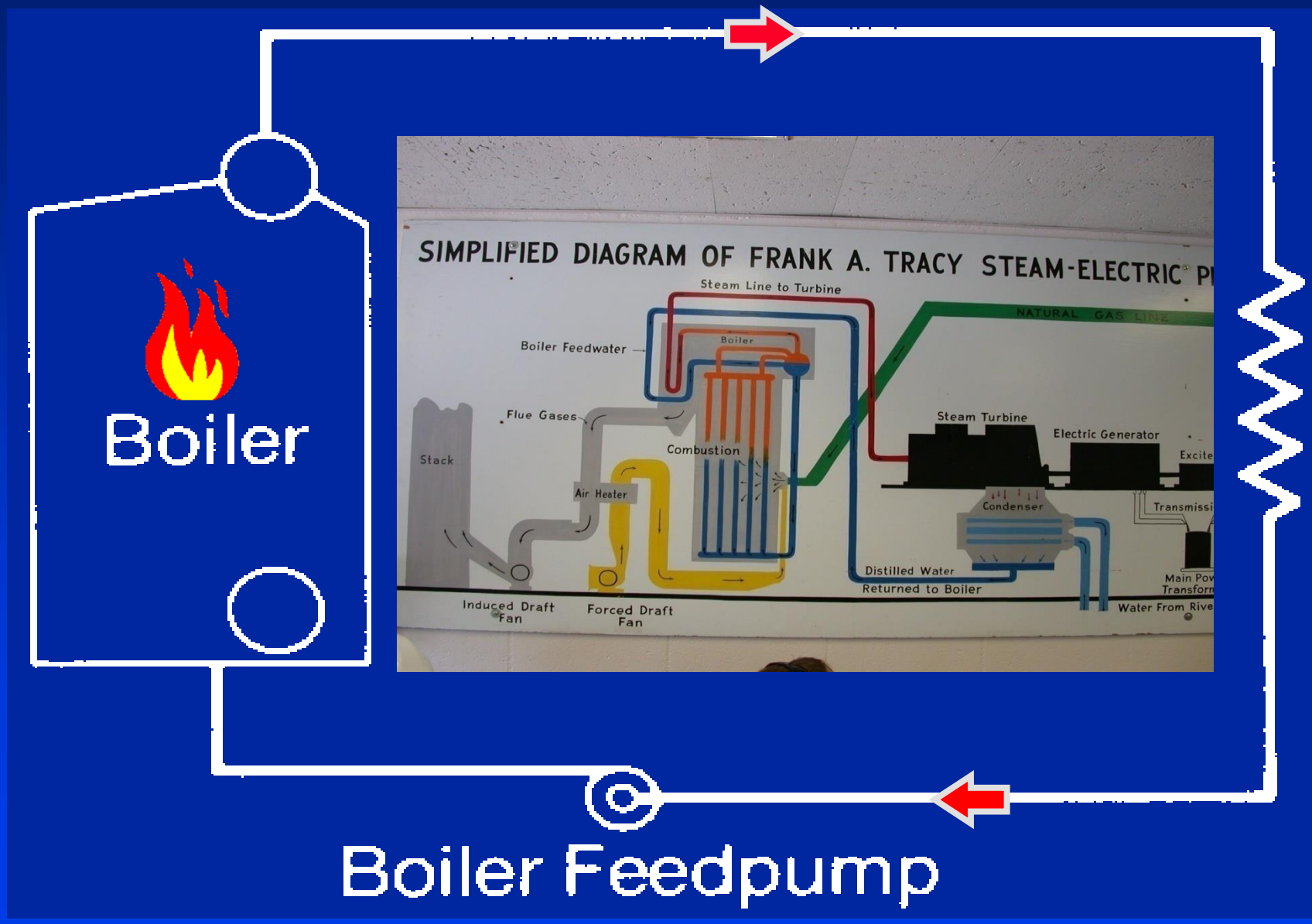


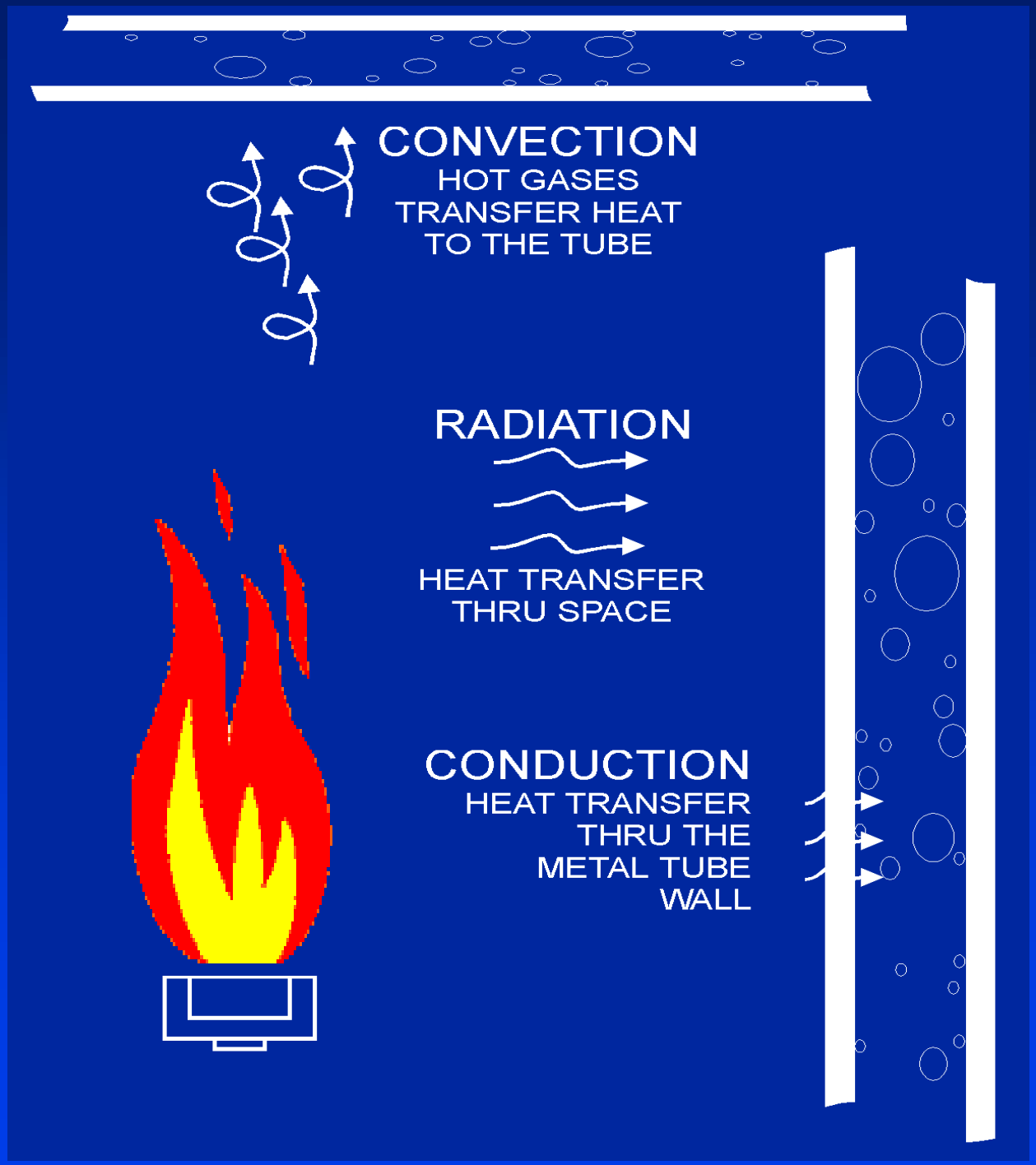
Typical Boiler Rating

Boiler Fuels

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

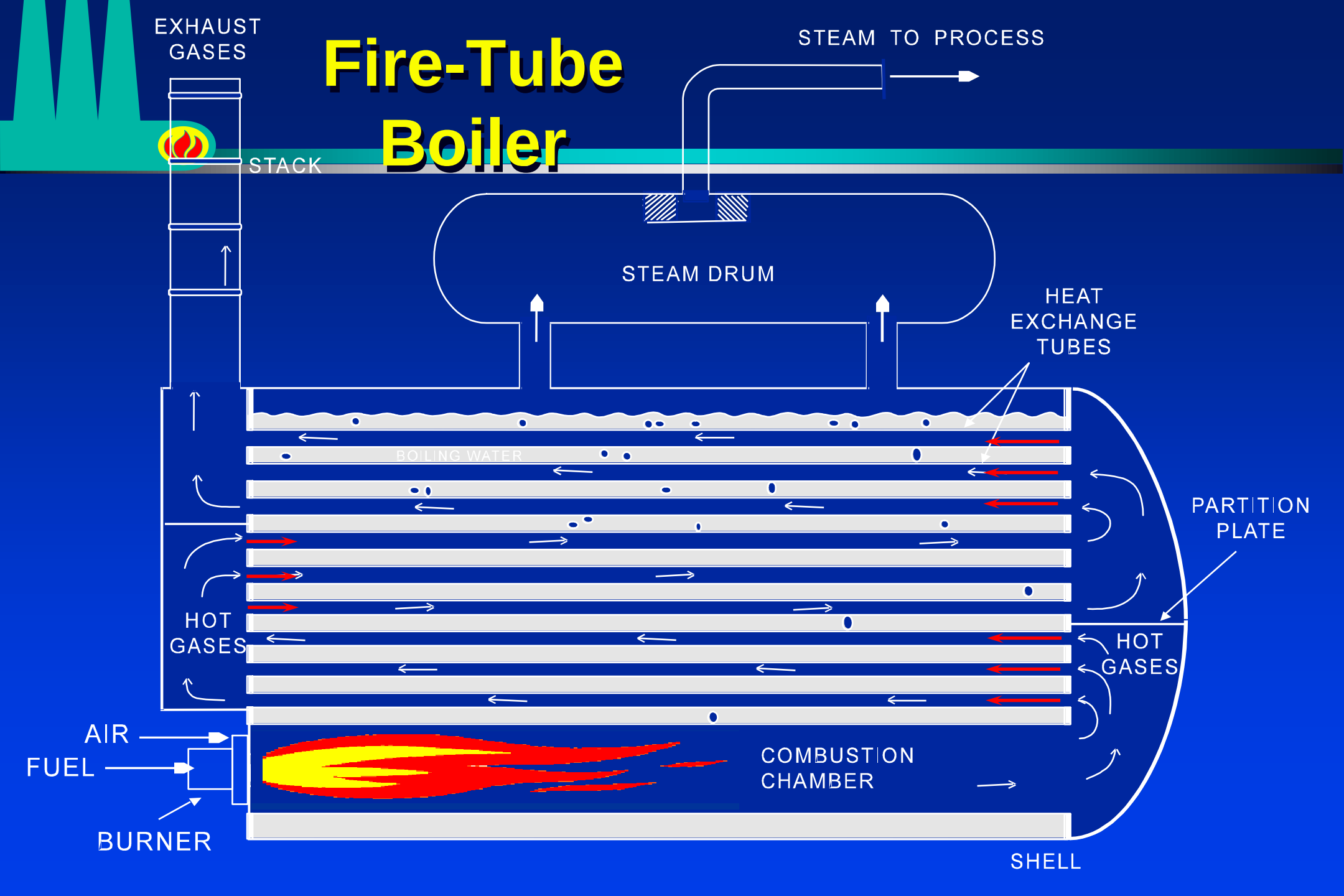
Steam Plant Basic Elements



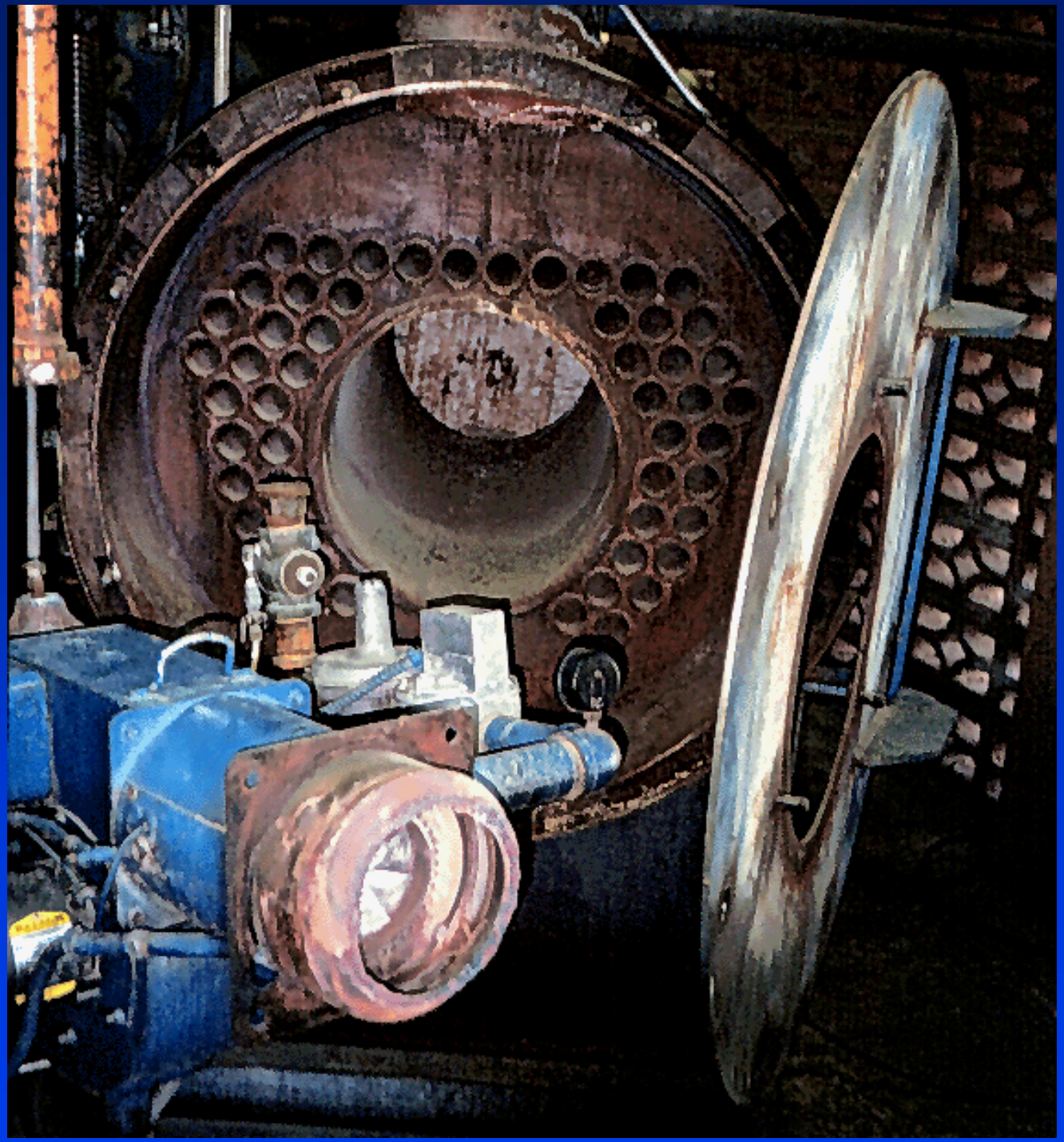


Heat Transfer Methods


Let’s Discuss Firetube &
Watertube Boilers


Fire-Tube Boiler
EXHAUST GASES
STACK
STEAM TO PROCESS
STEAM DRUM
HEAT EXCHANGE TUBES
BOILING WATER
PARTITION PLATE
HOT GASES
HOT GASES
AIR
FUEL
BURNER
COMBUSTION CHAMBER
SHELL

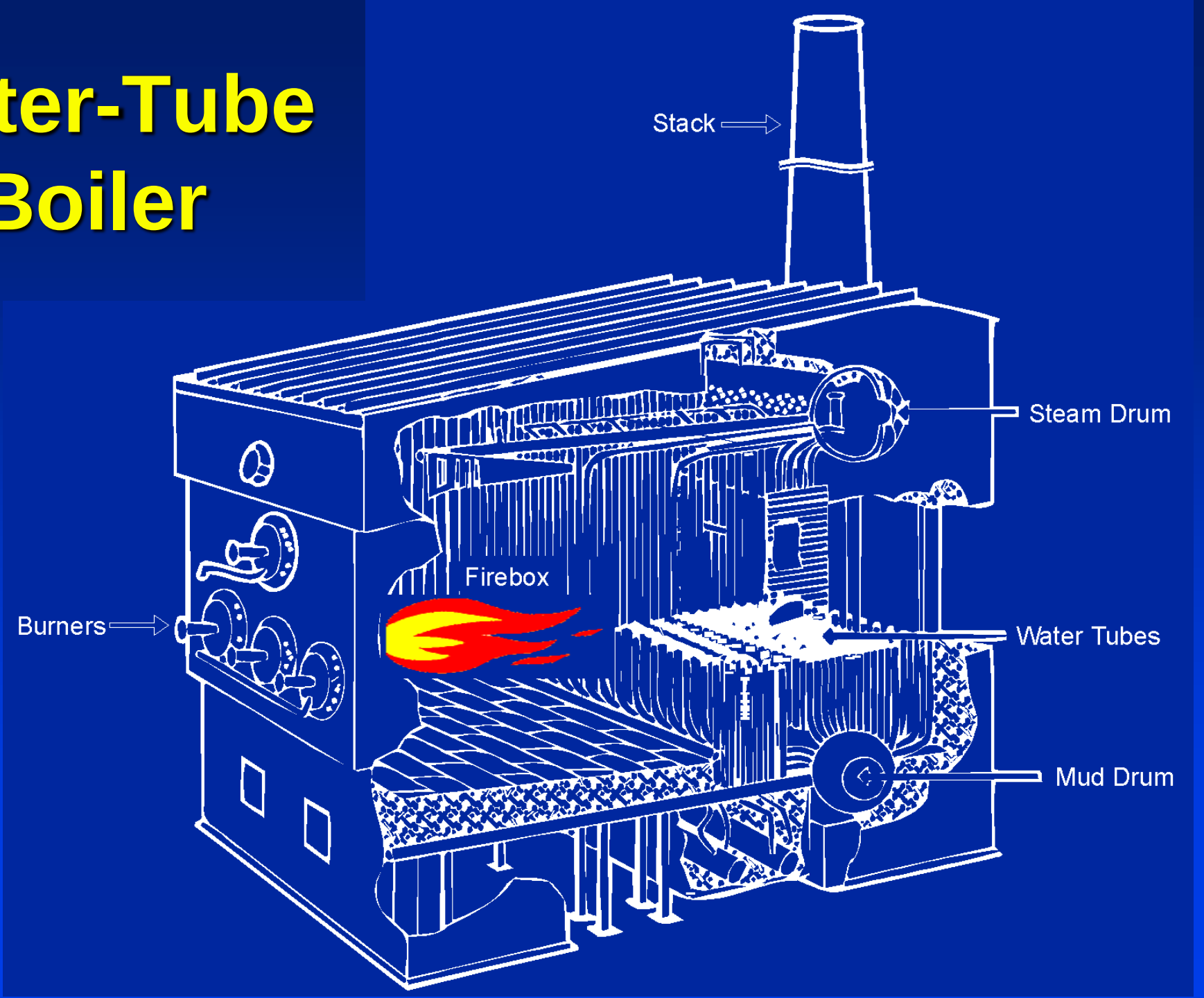
Fire-Tube Boiler



Small Fire-Tube Boiler

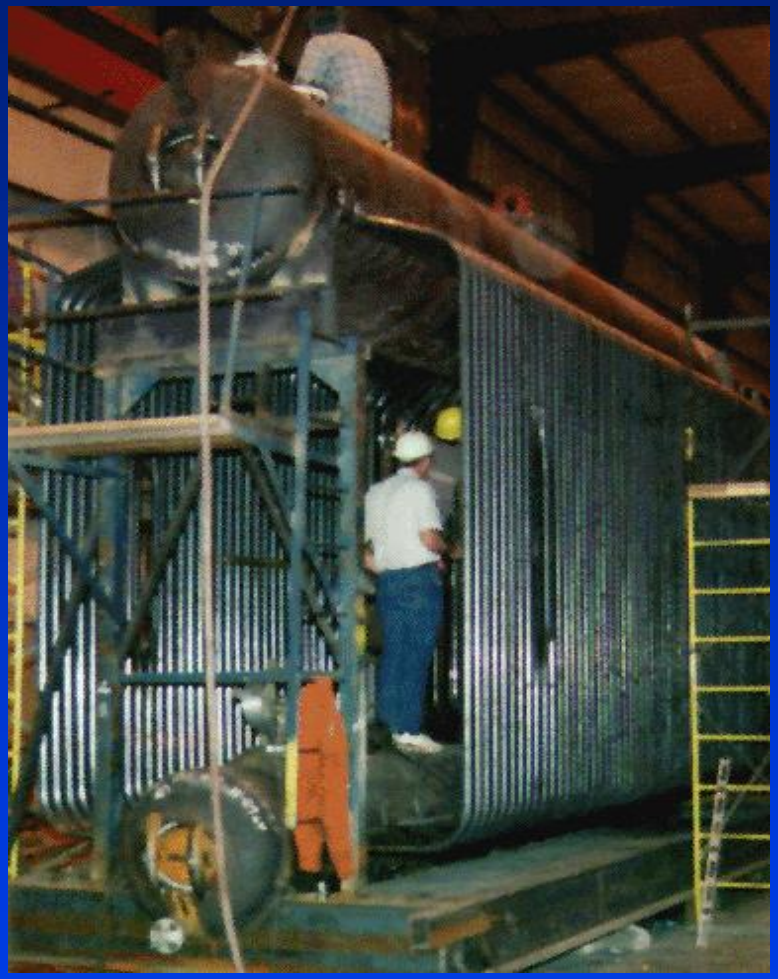

Fire-Tube Boiler

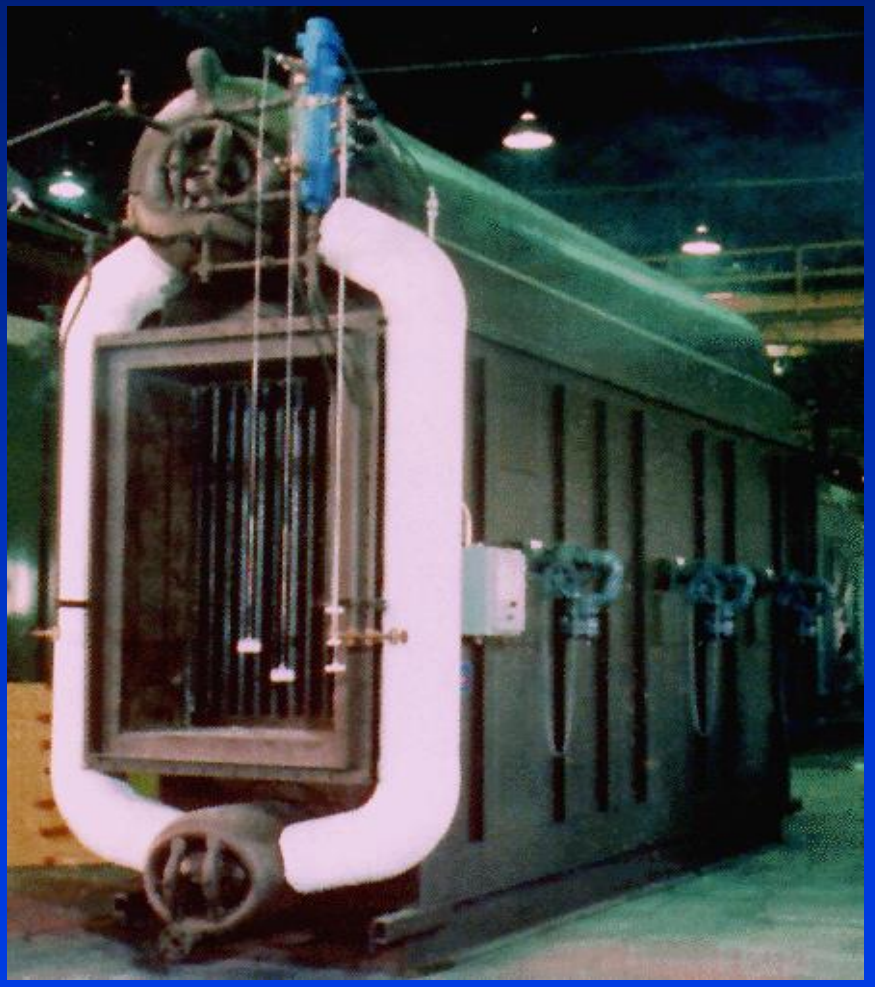
Water-Tube Boiler



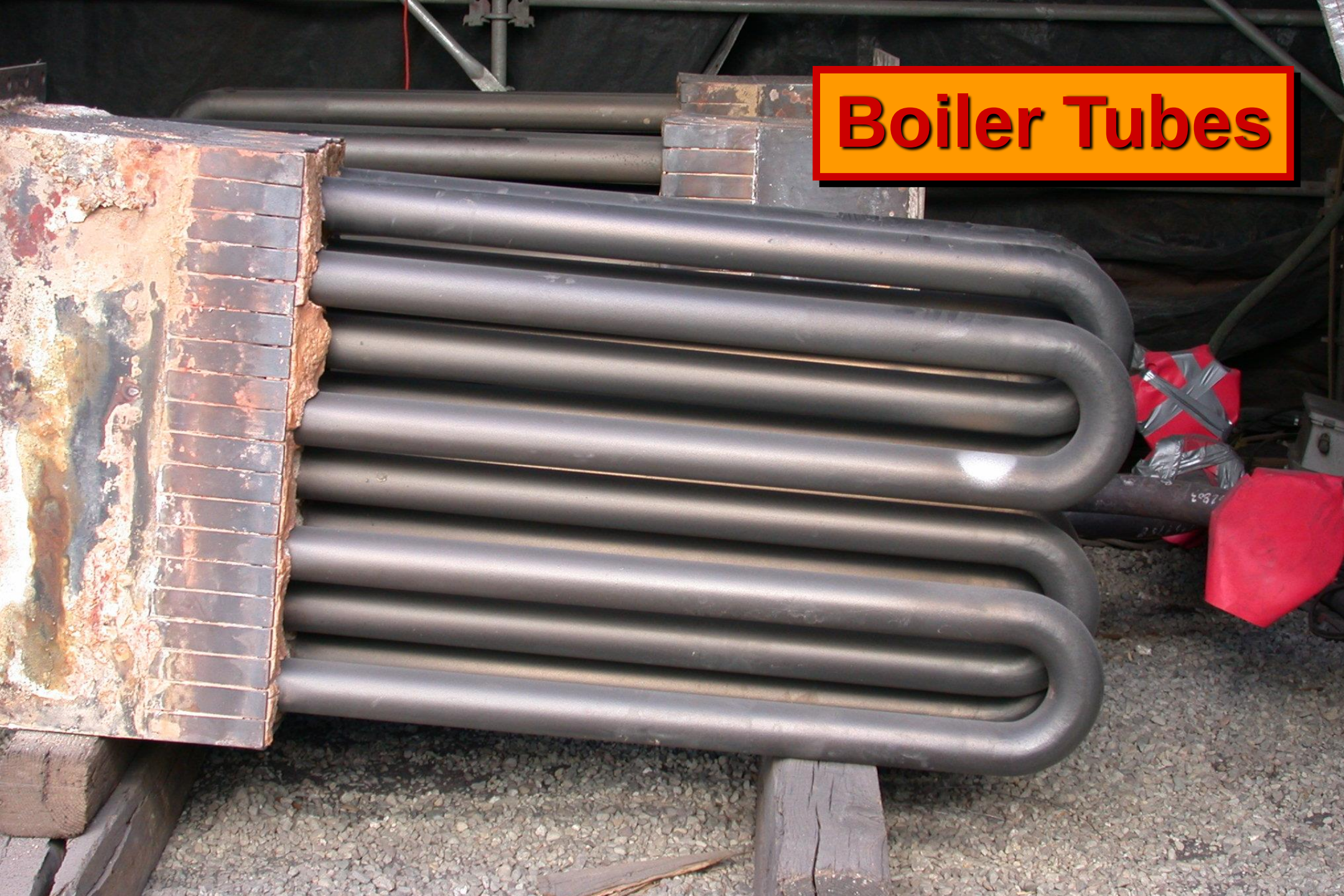

Water-Tube Boiler

Boiler Construction



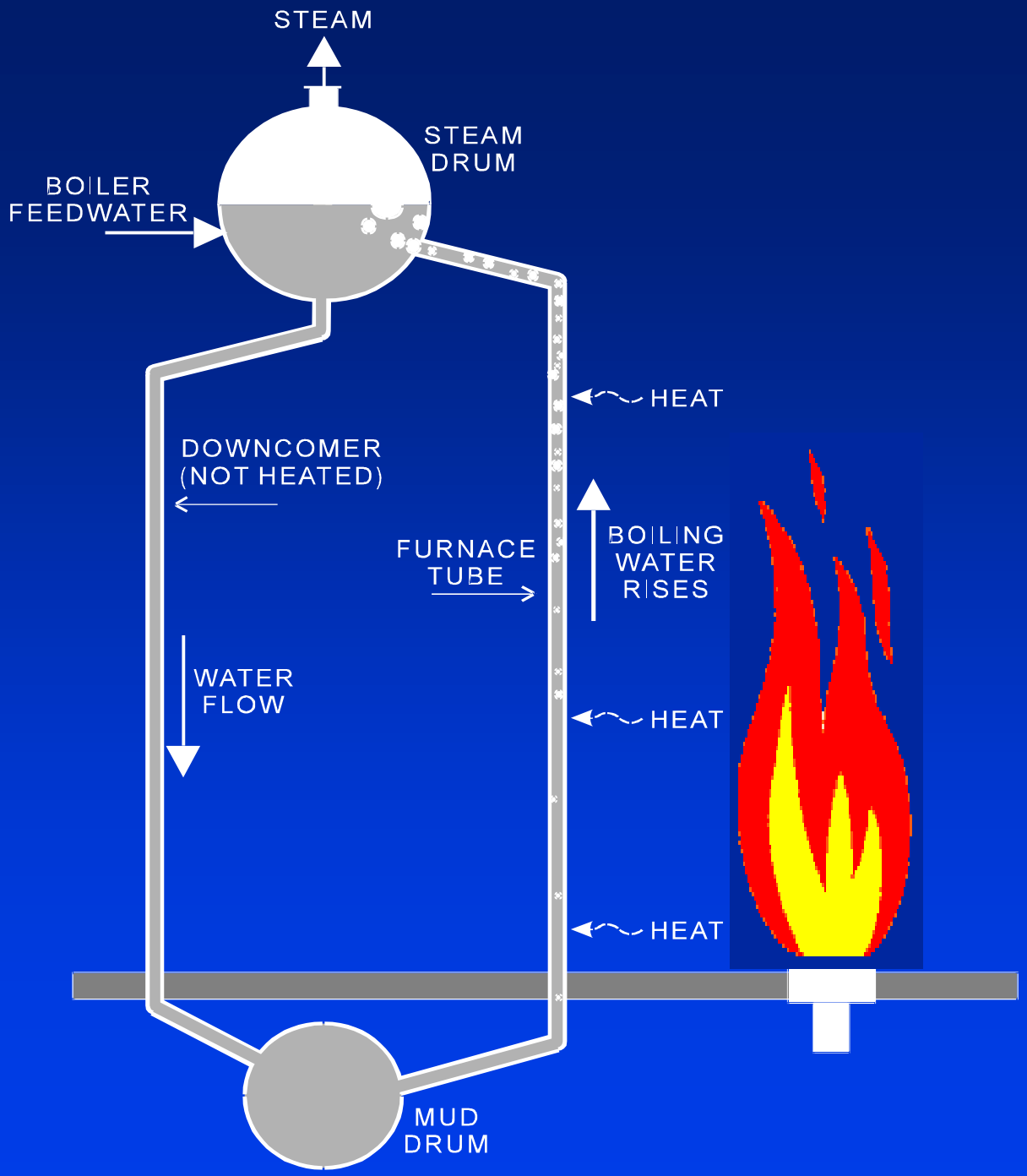


Graphics Courtesy of ERI


Boiler Tubes

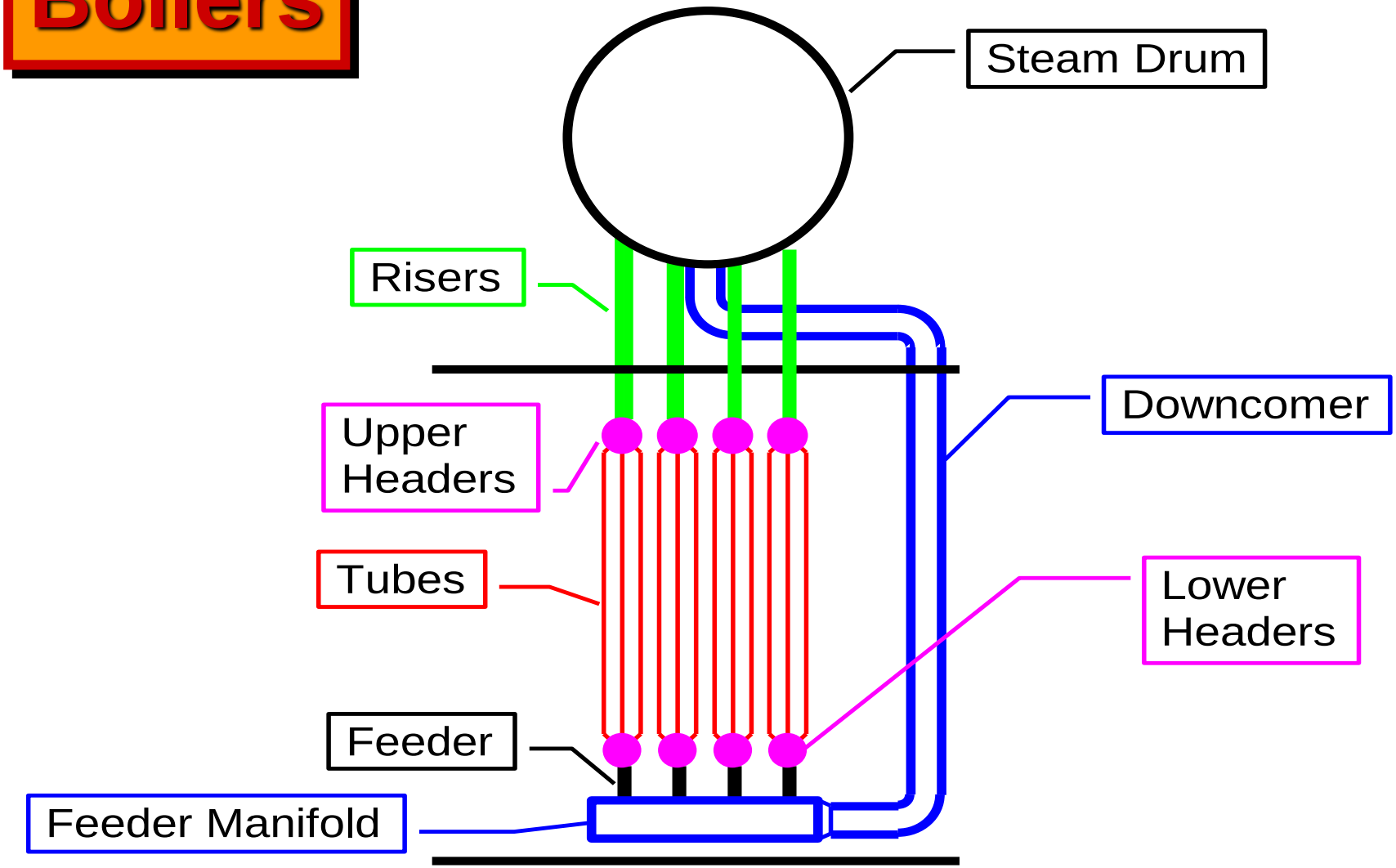

Boiler Tubes with Fins


Boiler
Circulation



Water to Steam Circulation Loop

Boilers

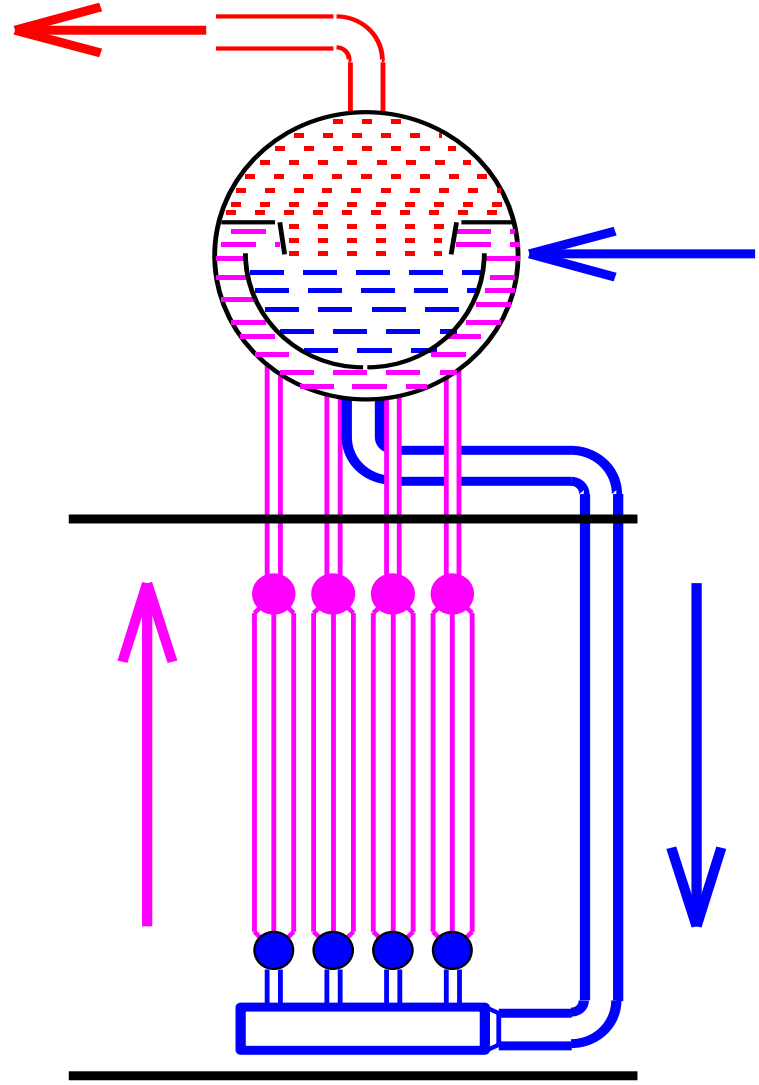

Steam Drum
Risers
Downcomer
Upper Headers
Tubes
Lower Headers
Feeder
Feeder Manifold

Natural Circulation

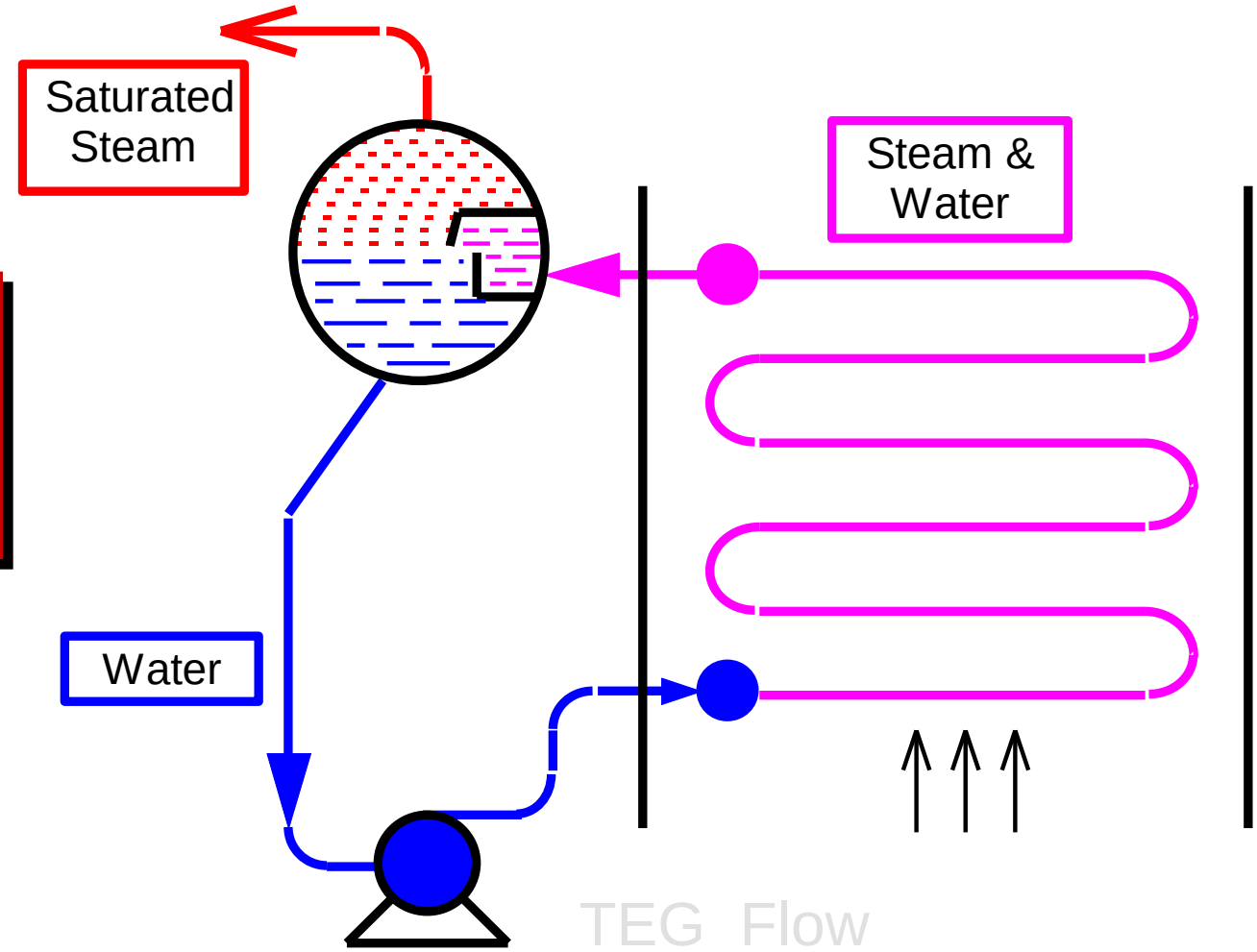
Water

Steam & Water

Saturated Steam



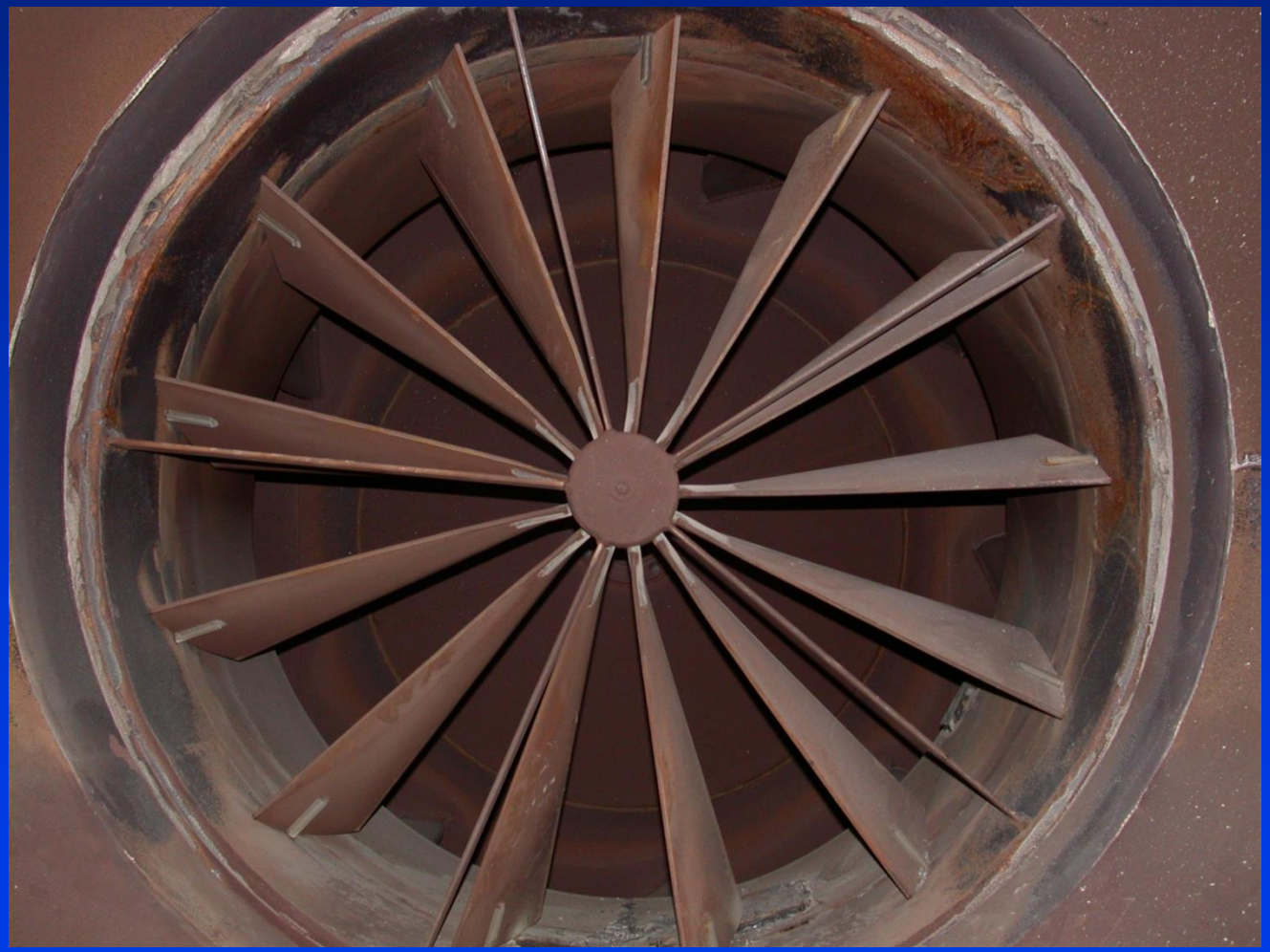
Forced Circulation

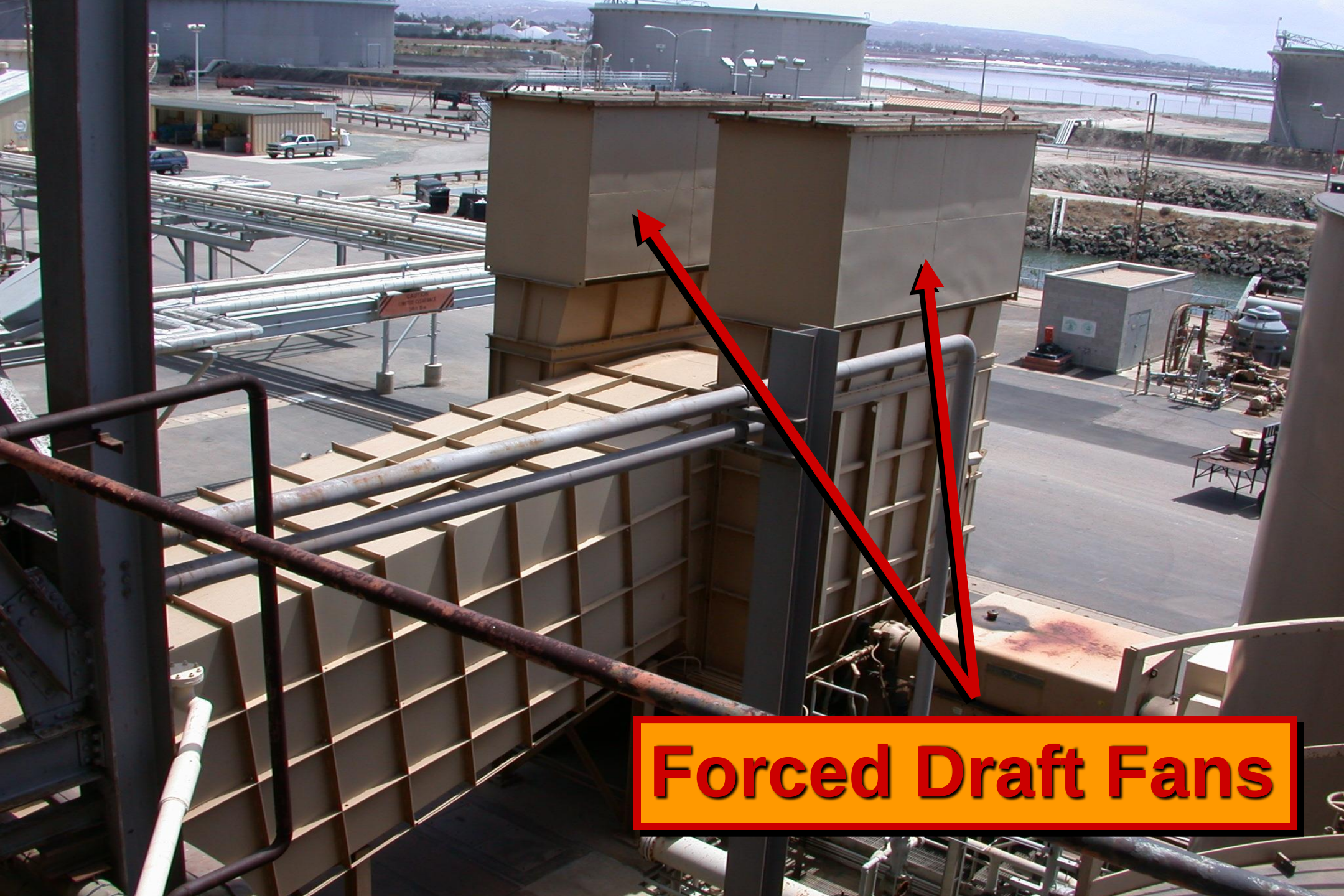



Let’s Discuss Boiler
Air Requirements

Boiler Air Requirements

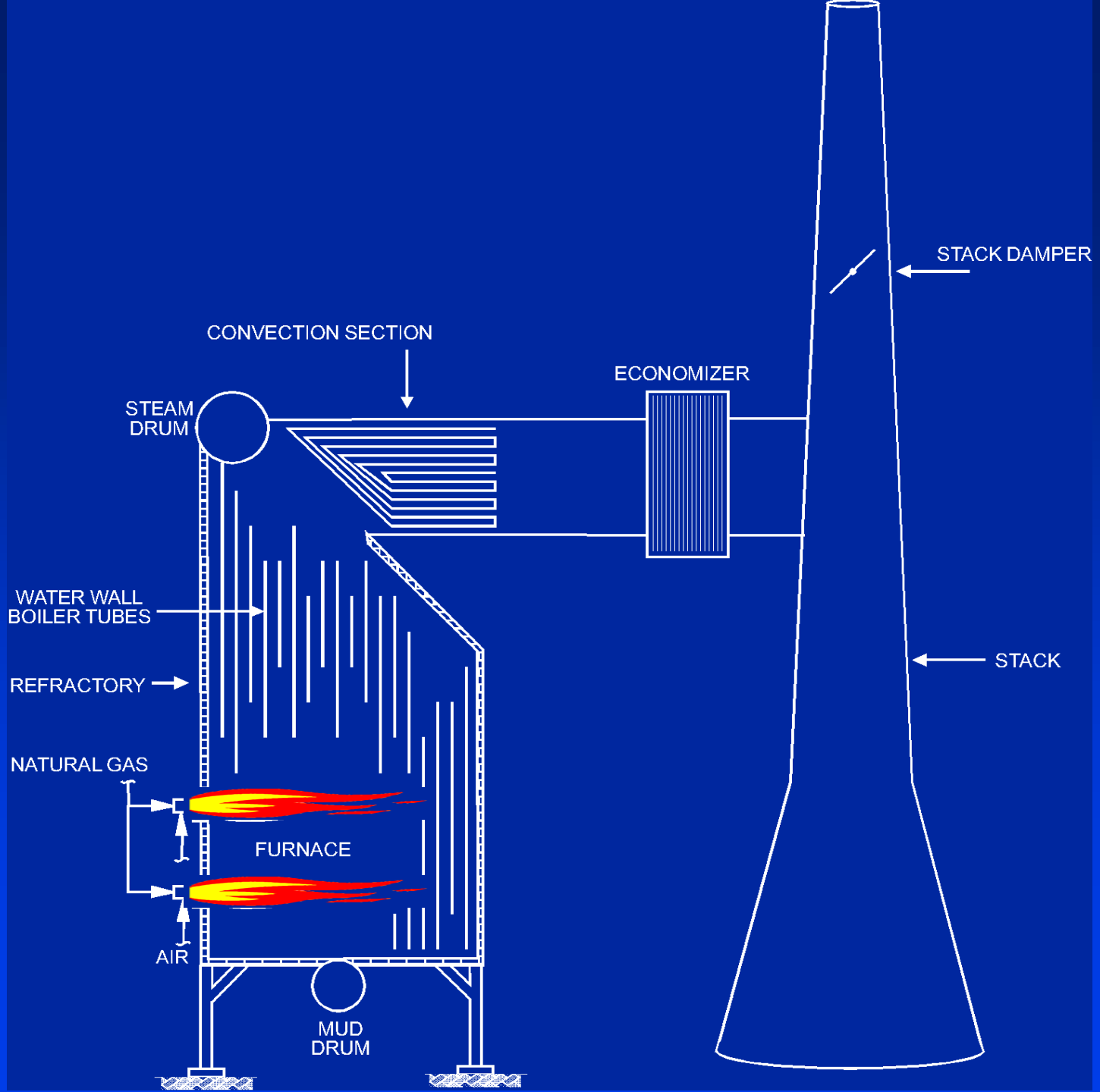
- Draft
  - Natural
  - Forced
  - Induced
- Combustion air
  - Primary
  - Secondary
  - Excess




Forced Draft Fans


Induced Draft Fan


Induced Draft Fans

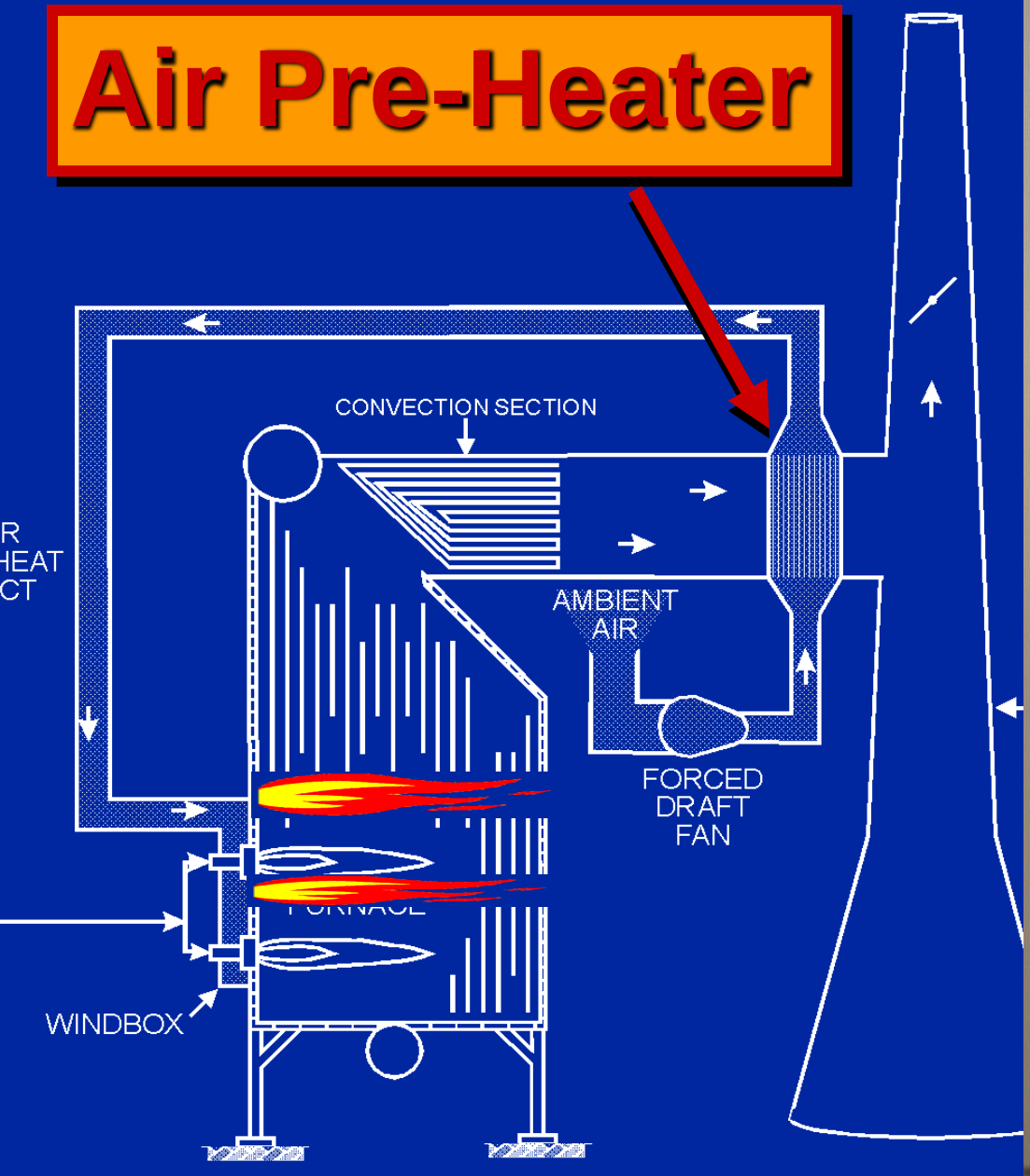


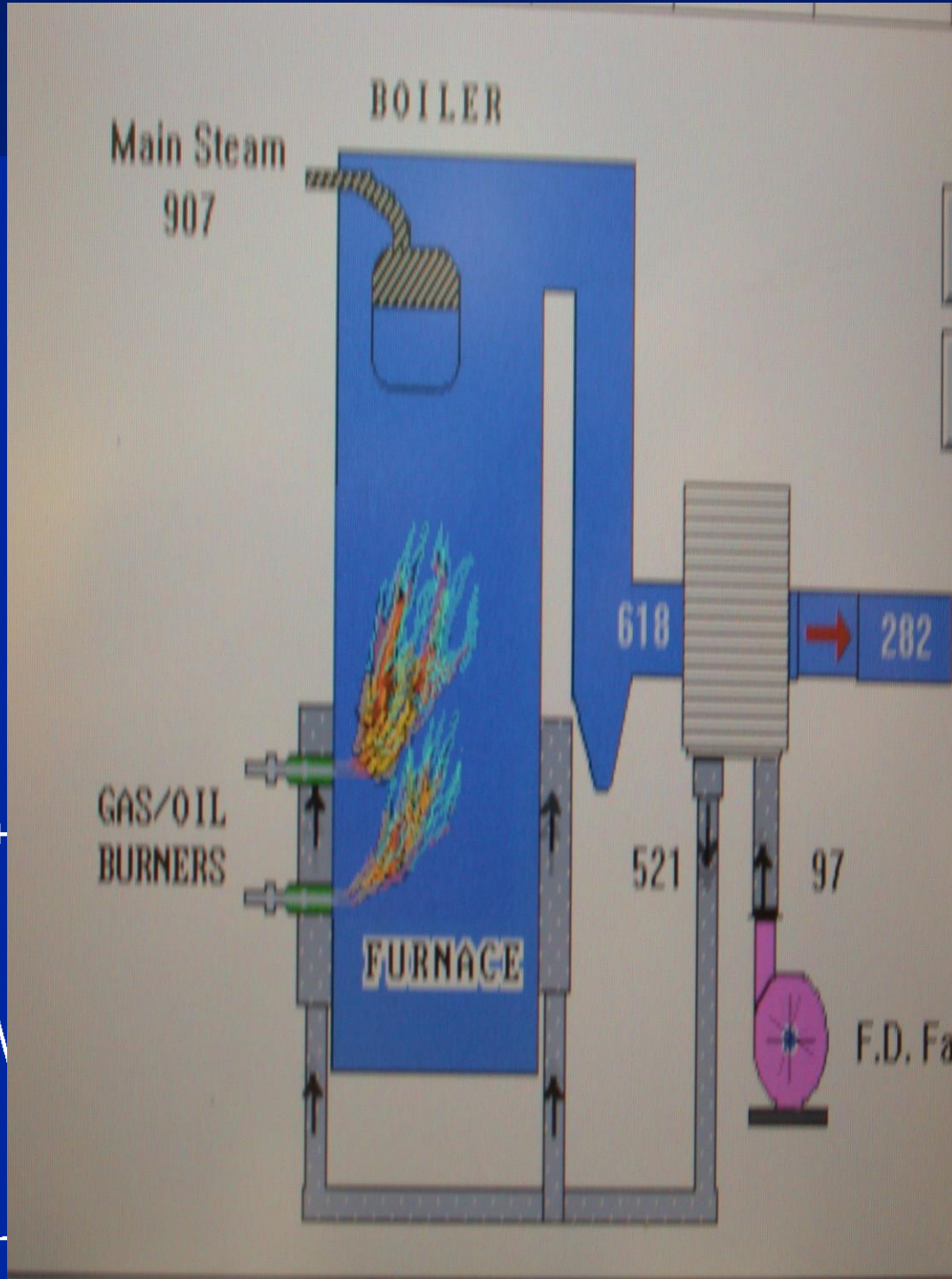
Gas Fired Water Tube Boiler

Let's Discuss Economizers & Air-Preheaters

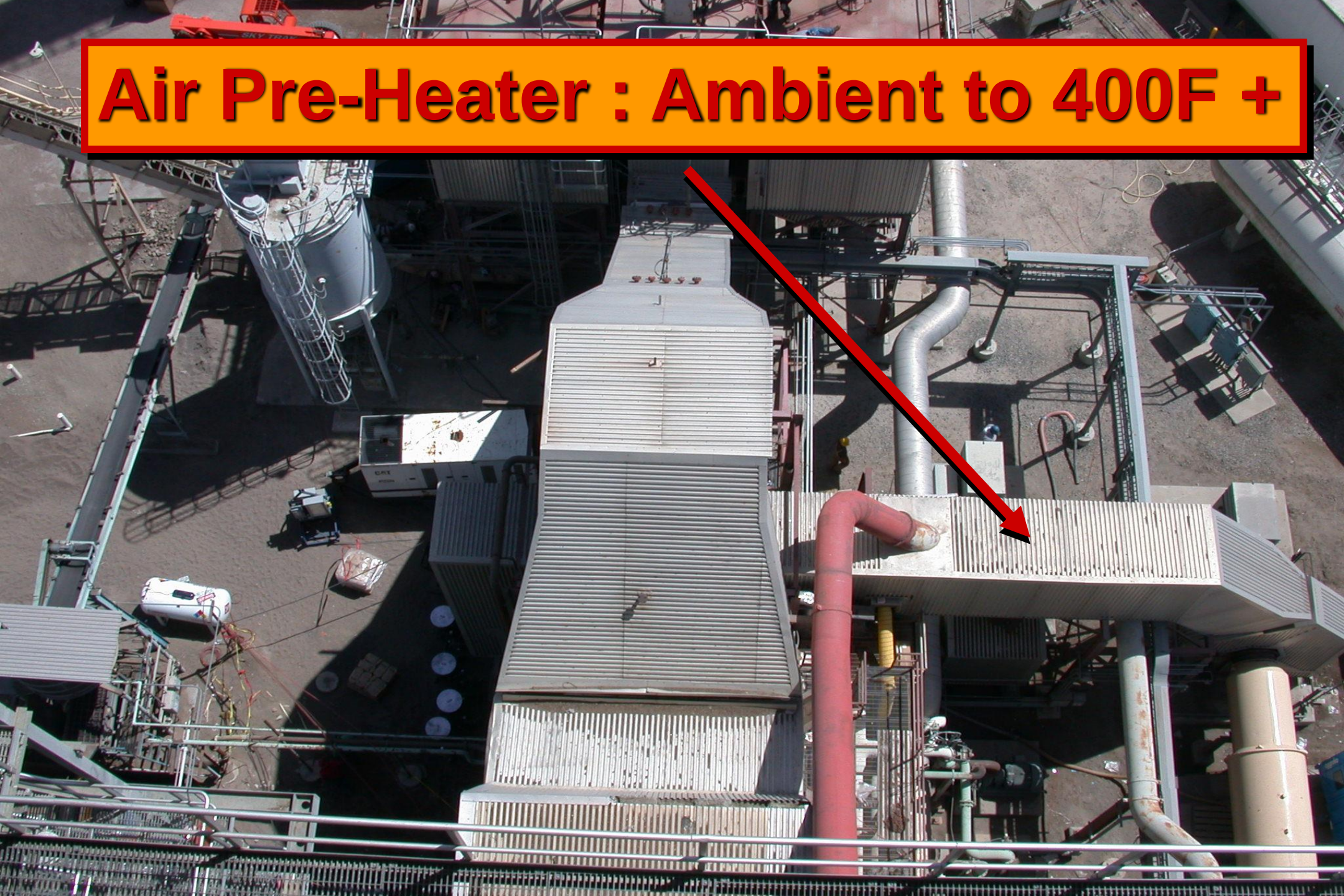
Economizer – H_2O Inside Tubes

Air Pre-Heater

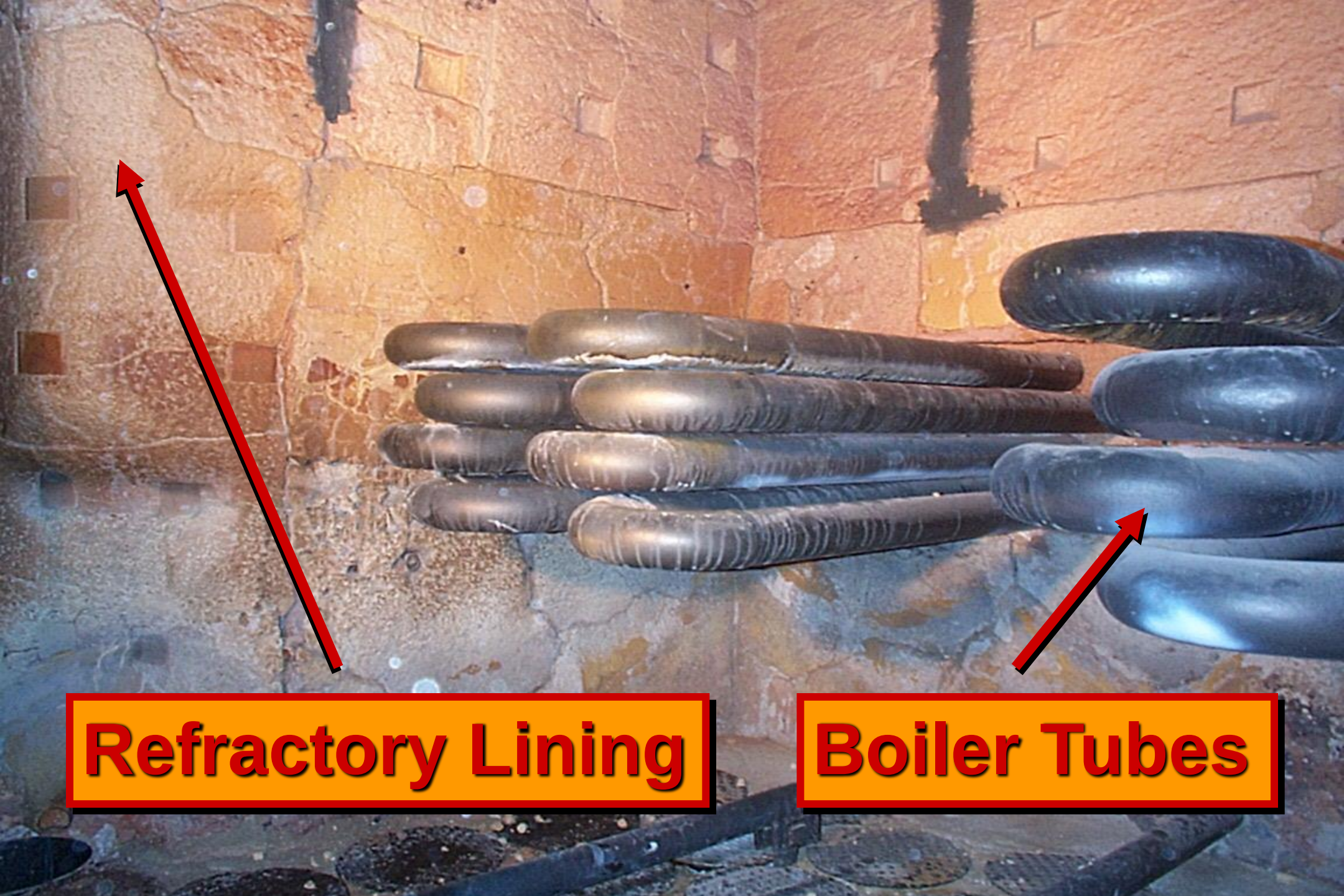




Air Pre-Heater : Ambient to 400F +



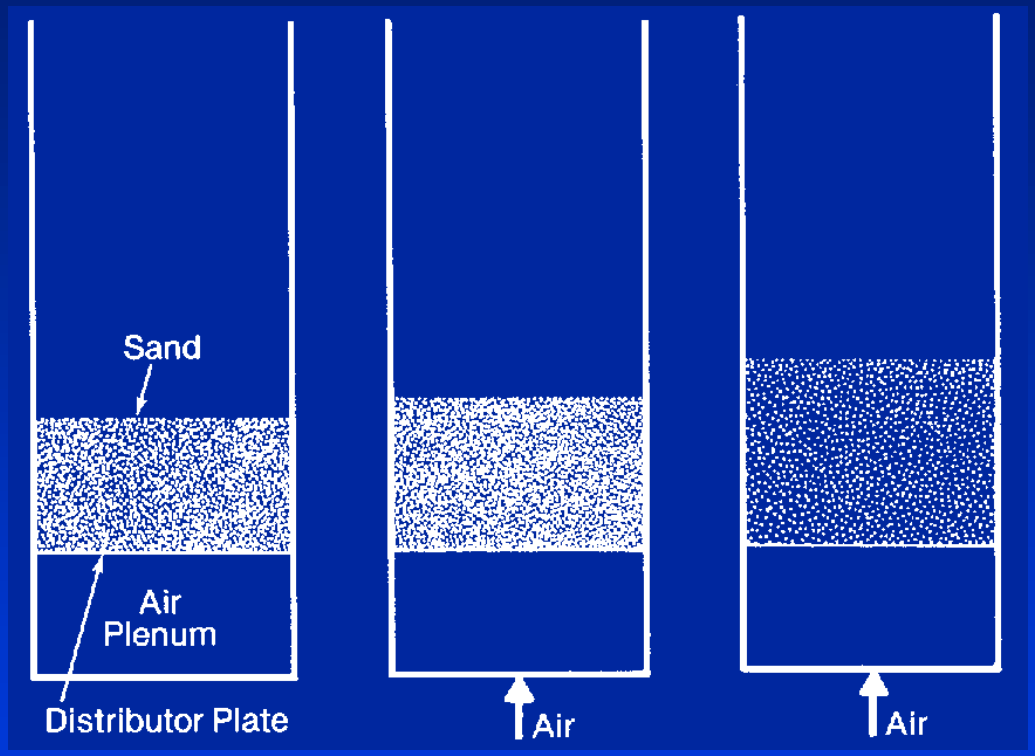

Fire Wall

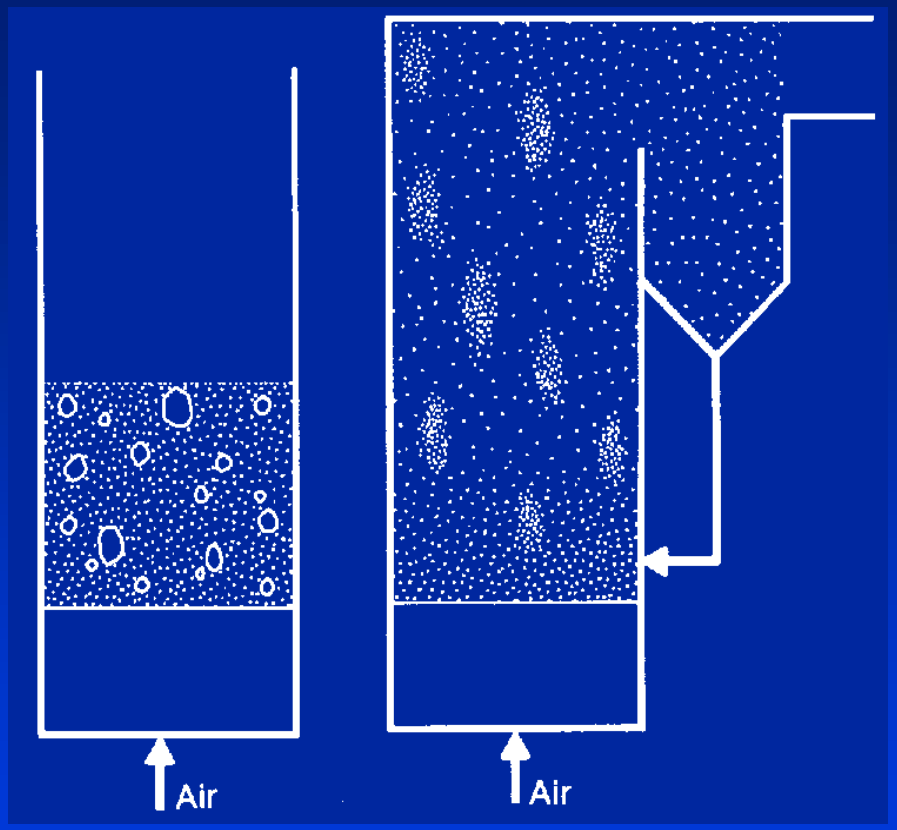

Refractory Lining
Boiler Tubes


Boiler Tubes


Let's Discuss Fluidized
Bed Boilers

Fluidized Bed Modes





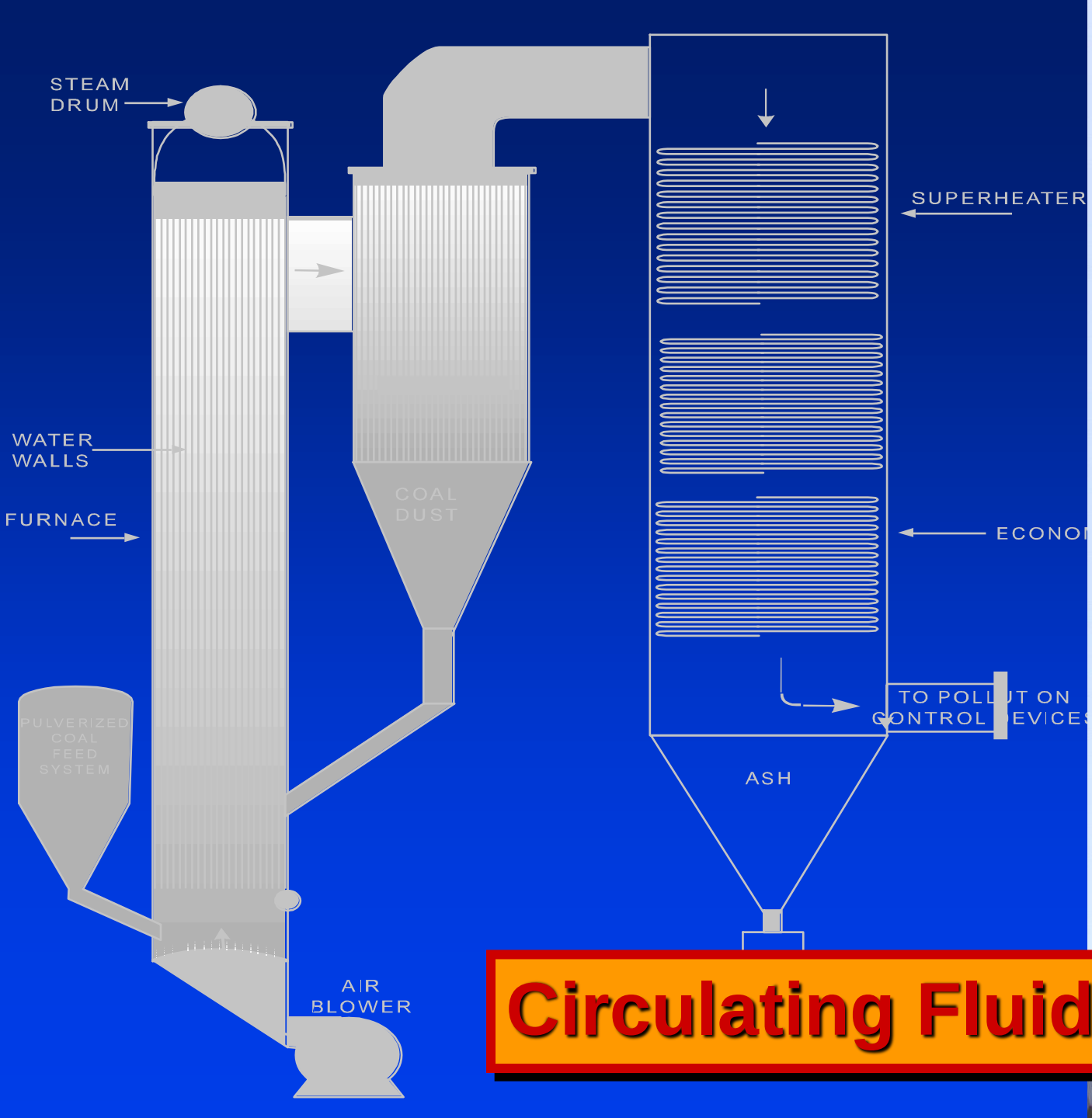
Start
No Air Flow

Fixed
Bed

Minimum
Fluidization

Bubbling
Bed

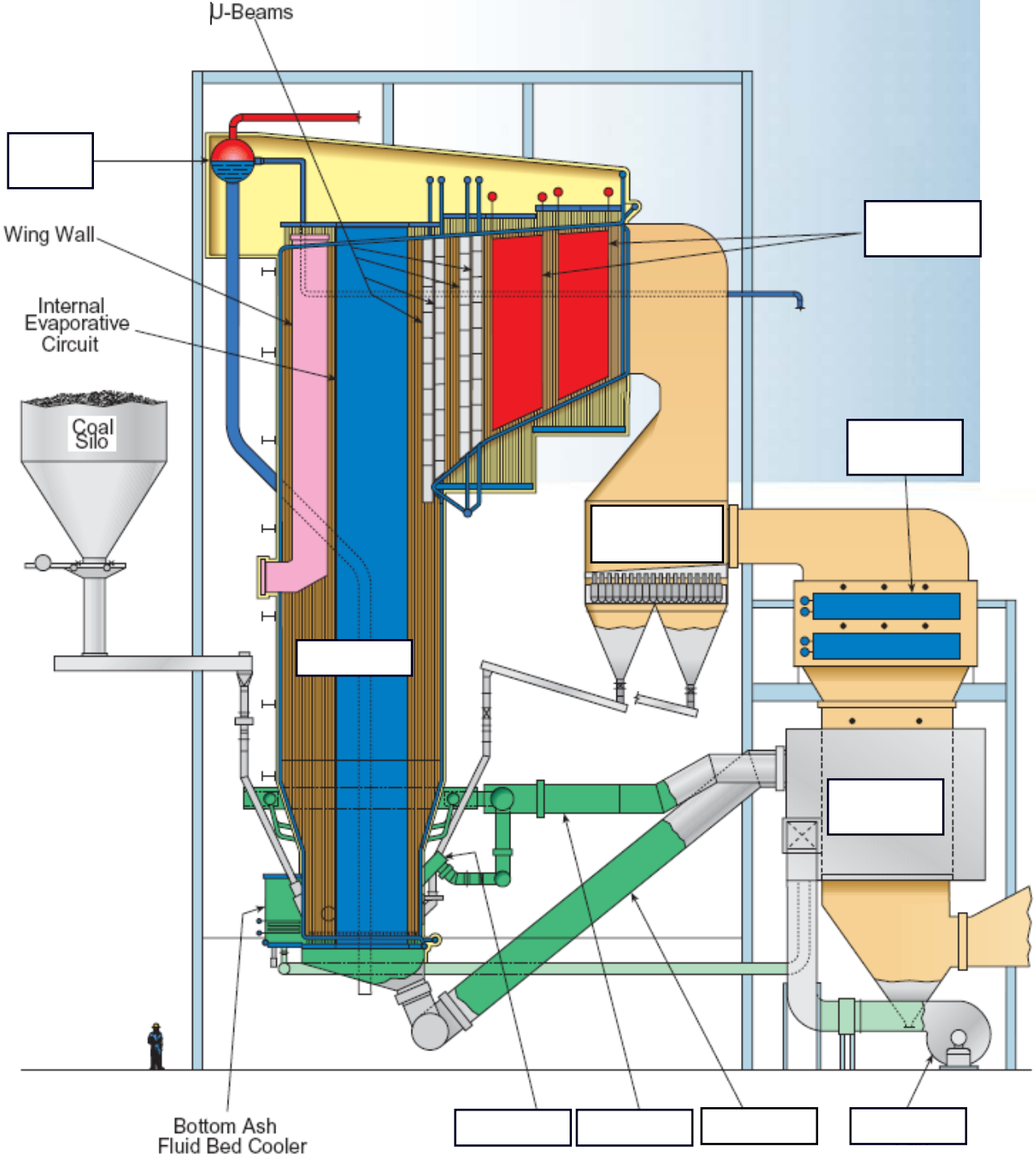
Circulating
Bed



Circulating Fluidized Bed (CFB)

Circulating Fluidized Bed Boiler

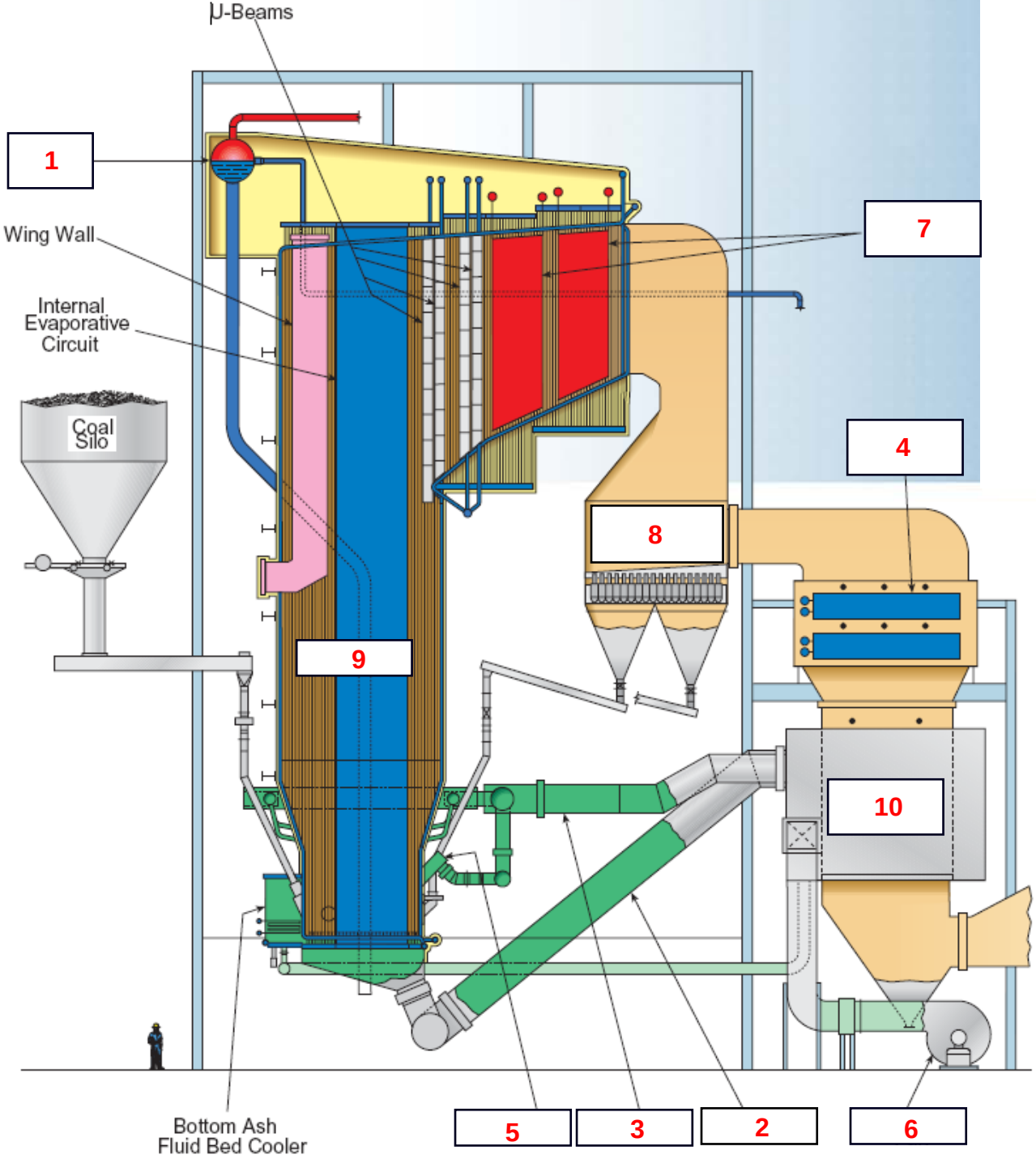
Interactive Exercise



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



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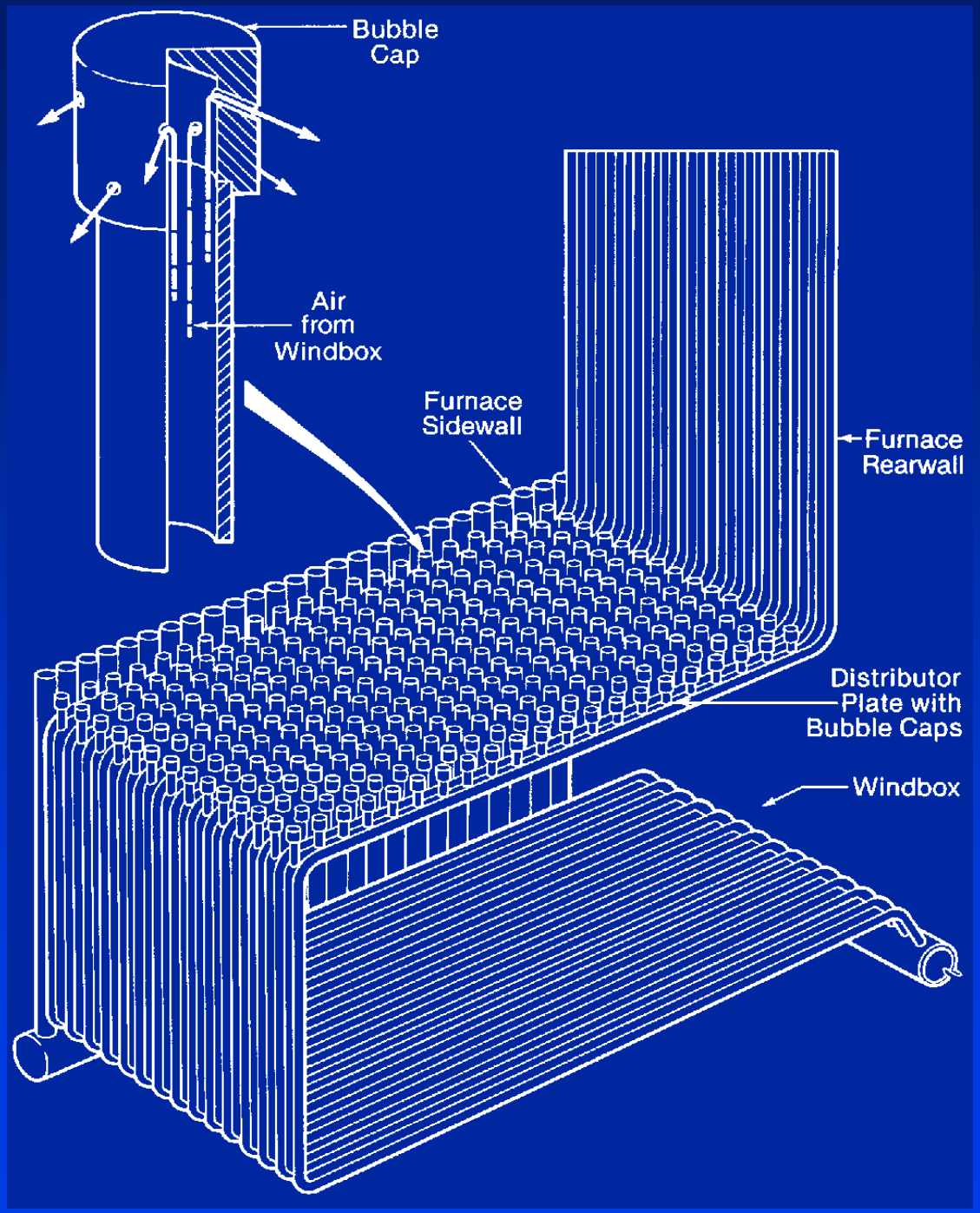
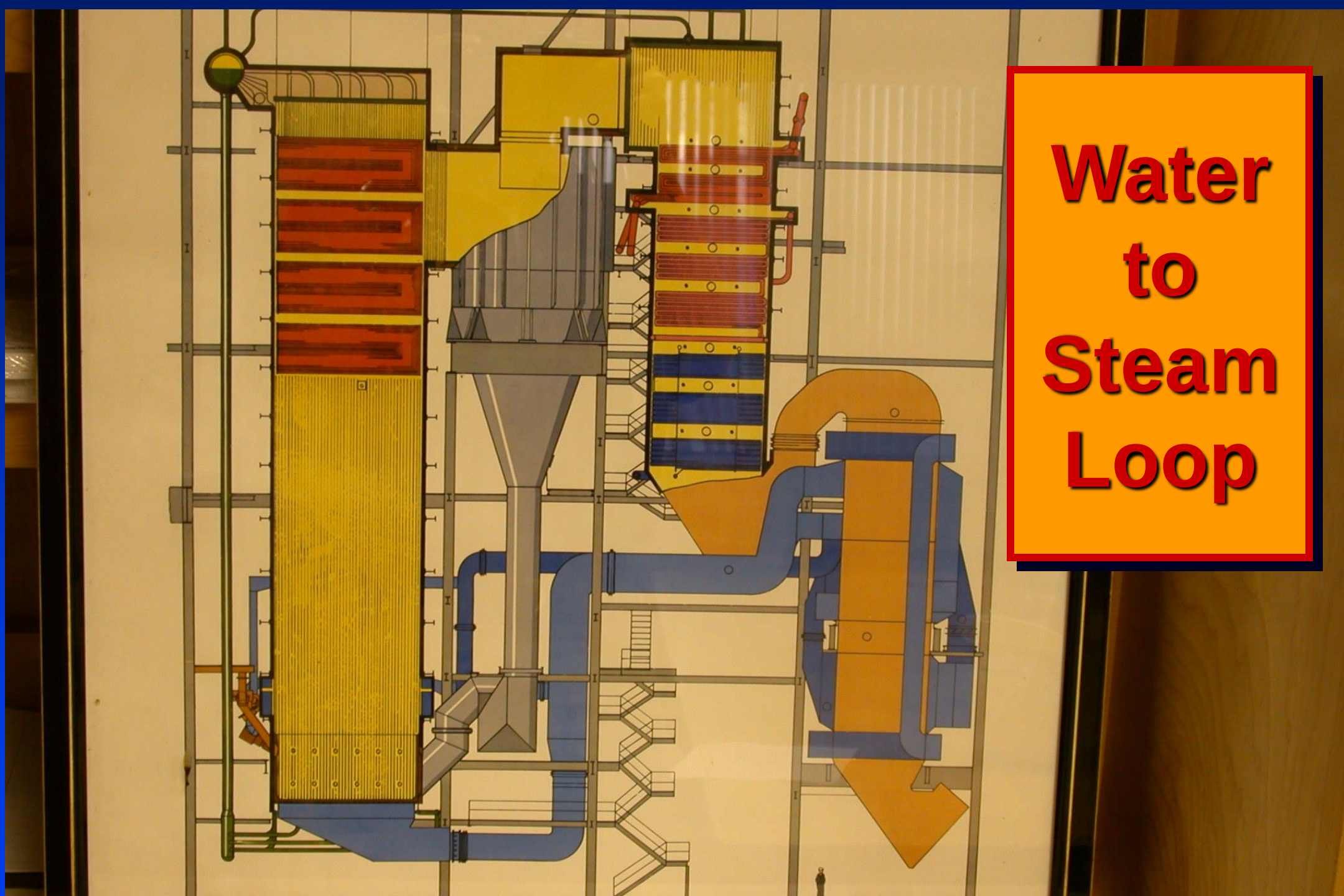


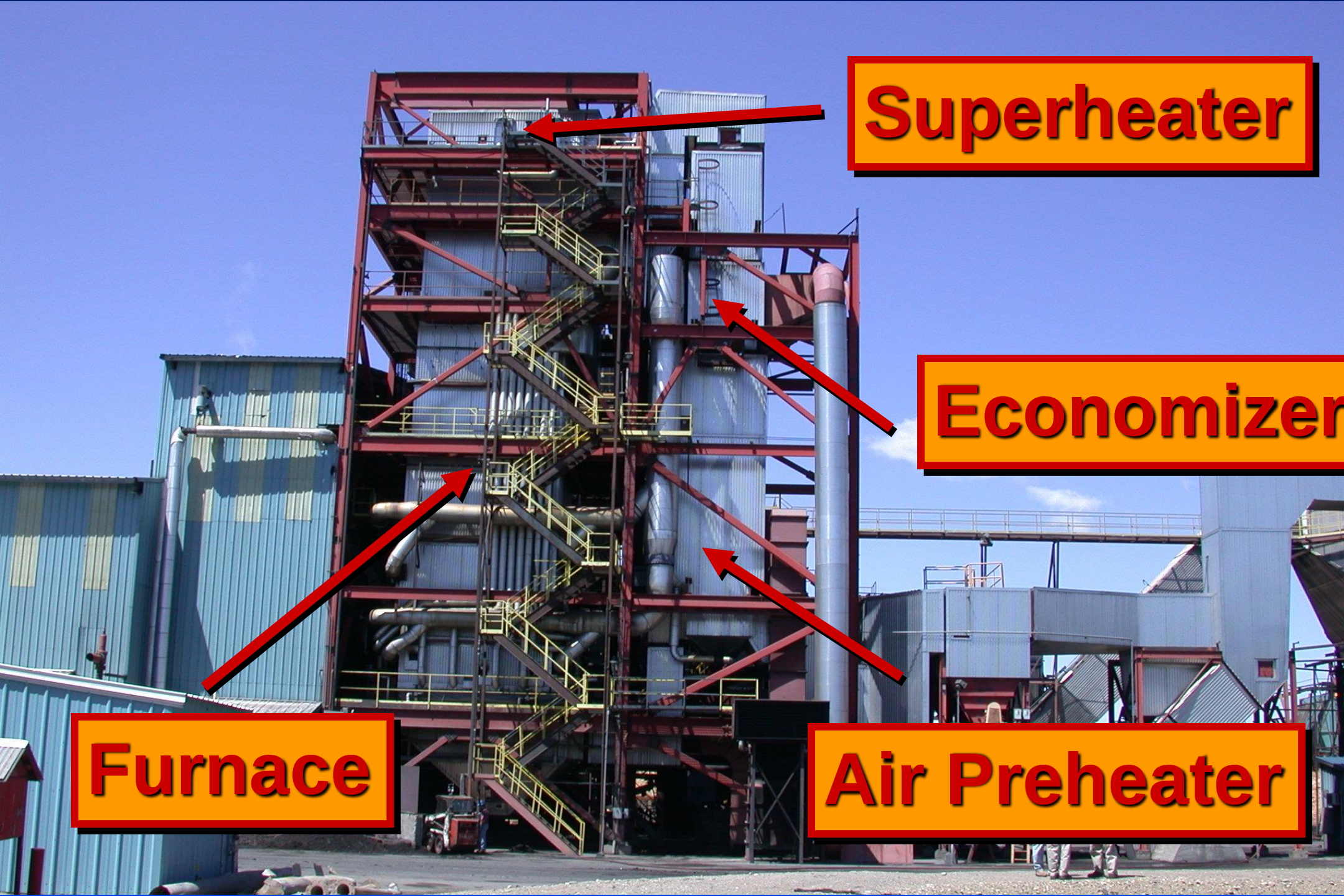
Fluidized Bed Distributor Plate & Bubble Caps

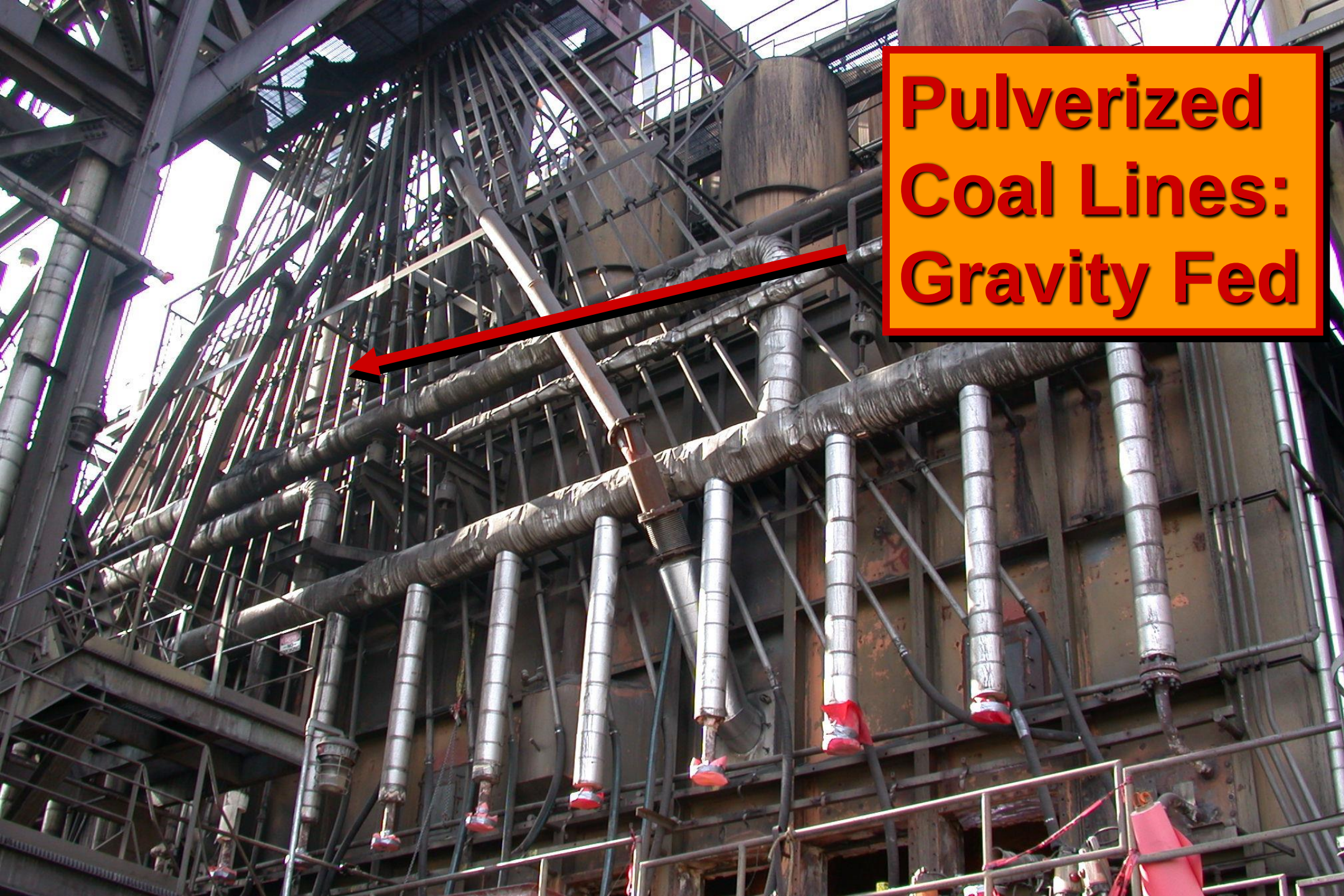
Graphic Courtesy of B&W


Feed Lot
Enclosed Conveyors

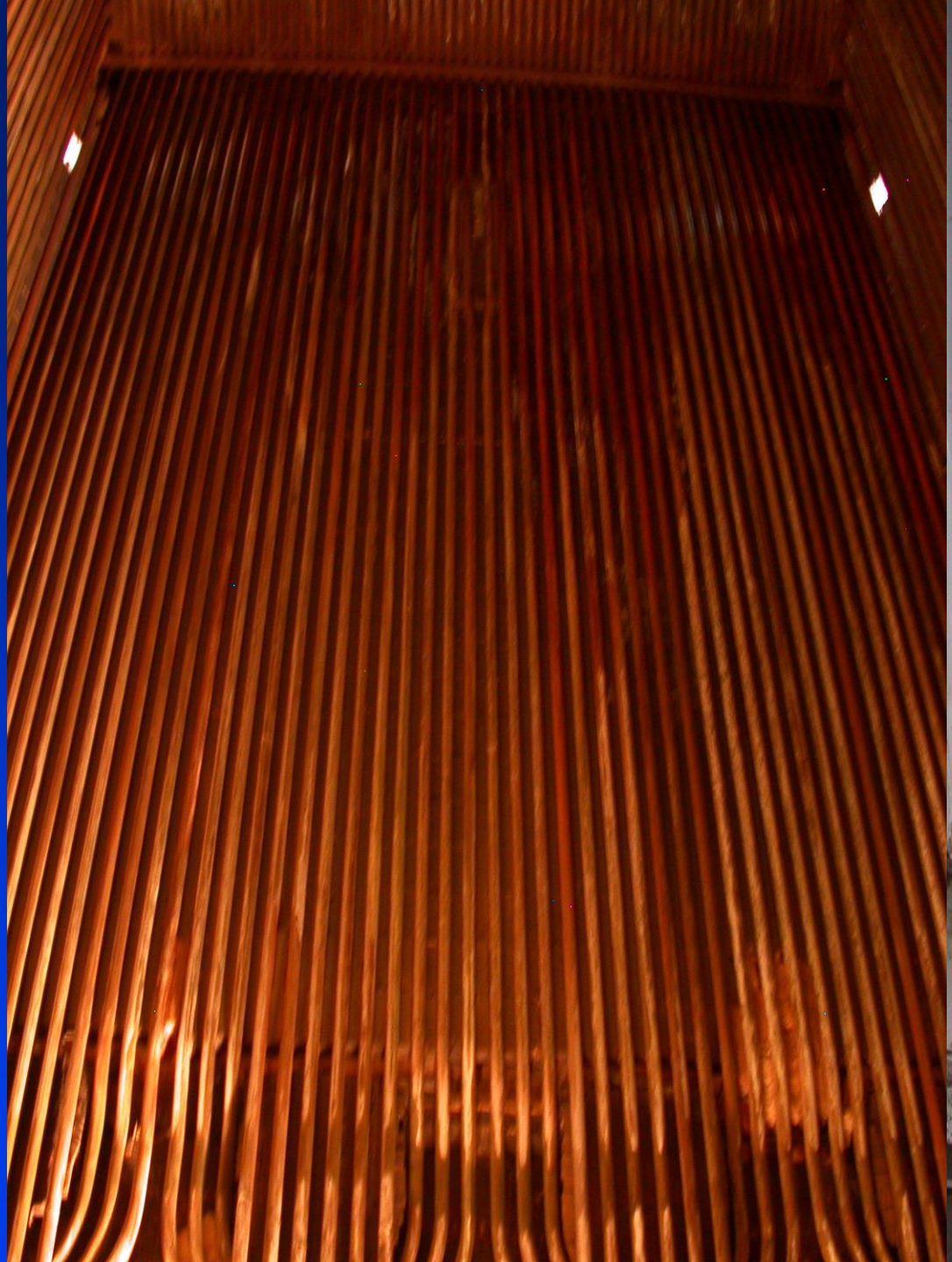

Fuel Storage Silo
Enclosed Conveyor

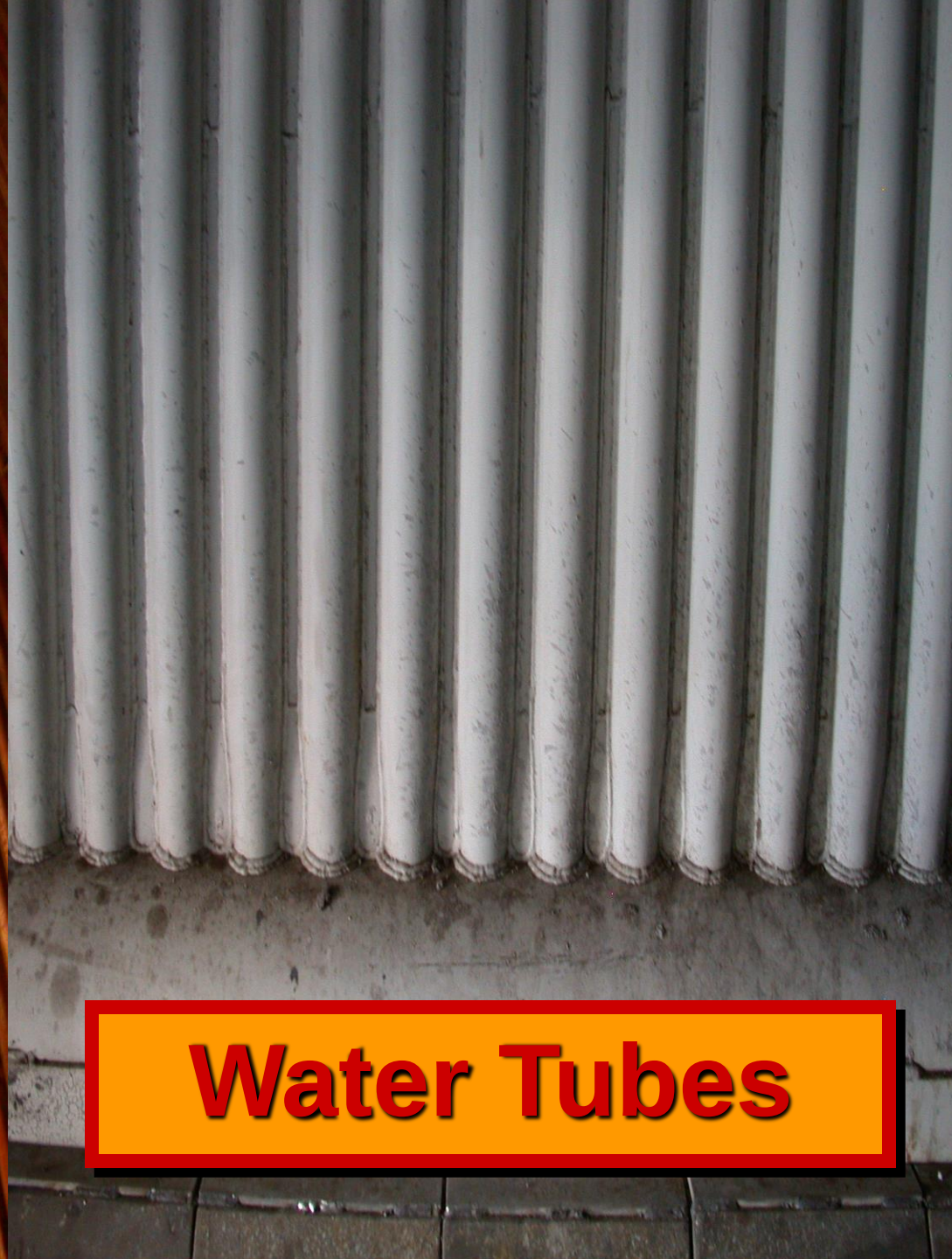

Water
to
Steam
Loop


Superheater
Economizer
Furnace
Air Preheater


Pulverized
Coal Lines:
Gravity Fed

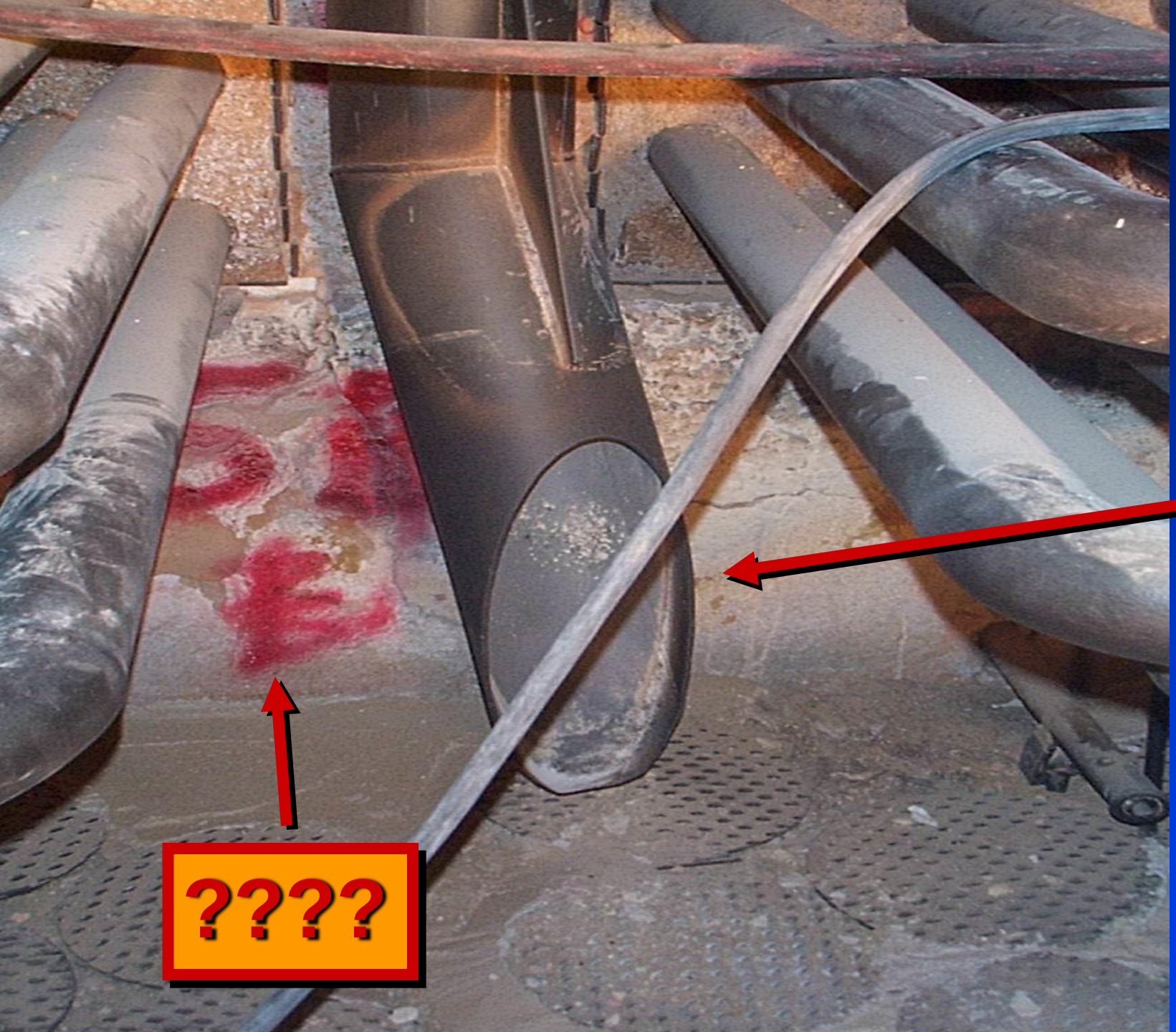

Inside
the
Boiler

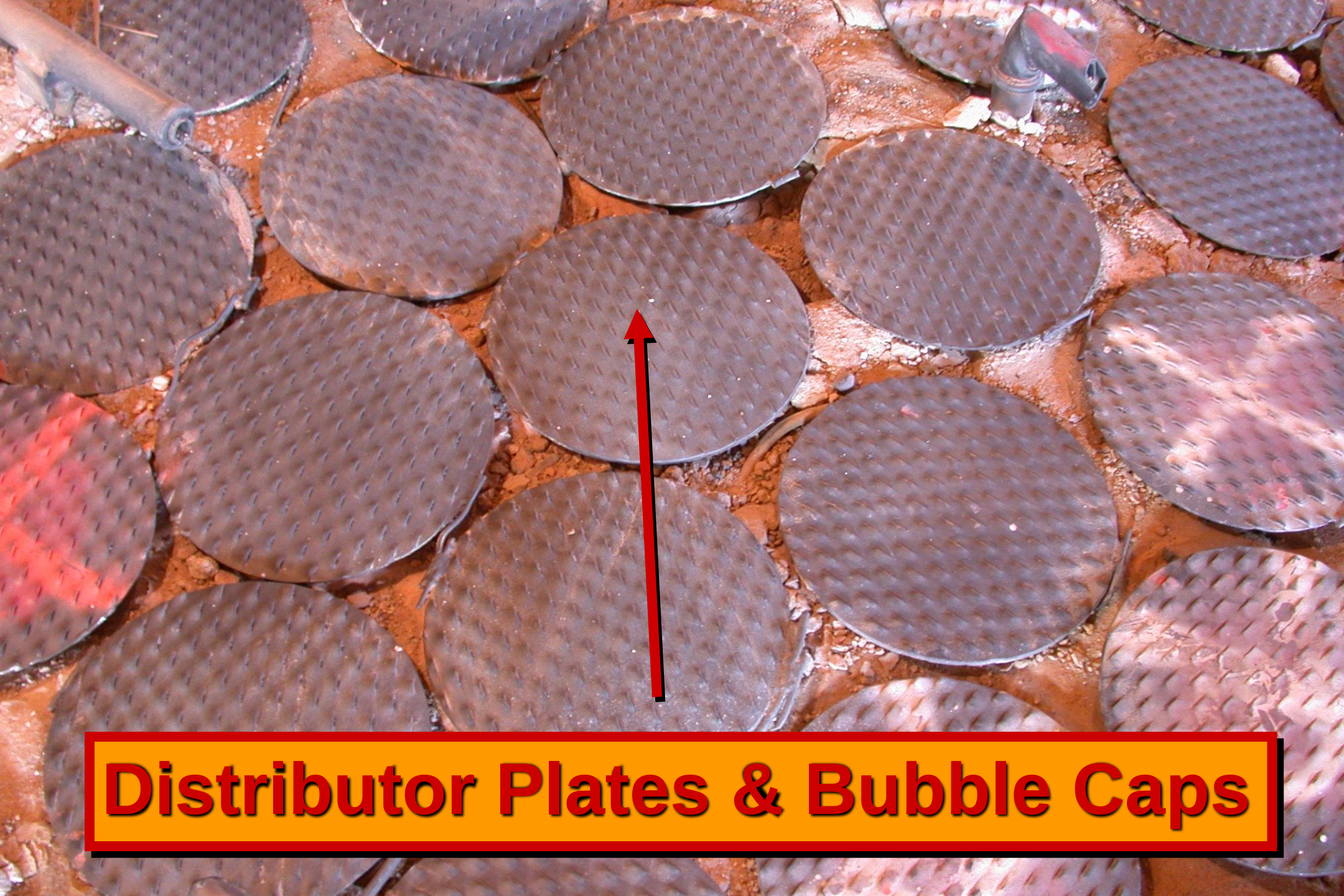




Water Tubes


55
Water
Tubes


Re-cir.
Fines
Nozzle
????


Distributor Plates & Bubble Caps


Bubble
Caps

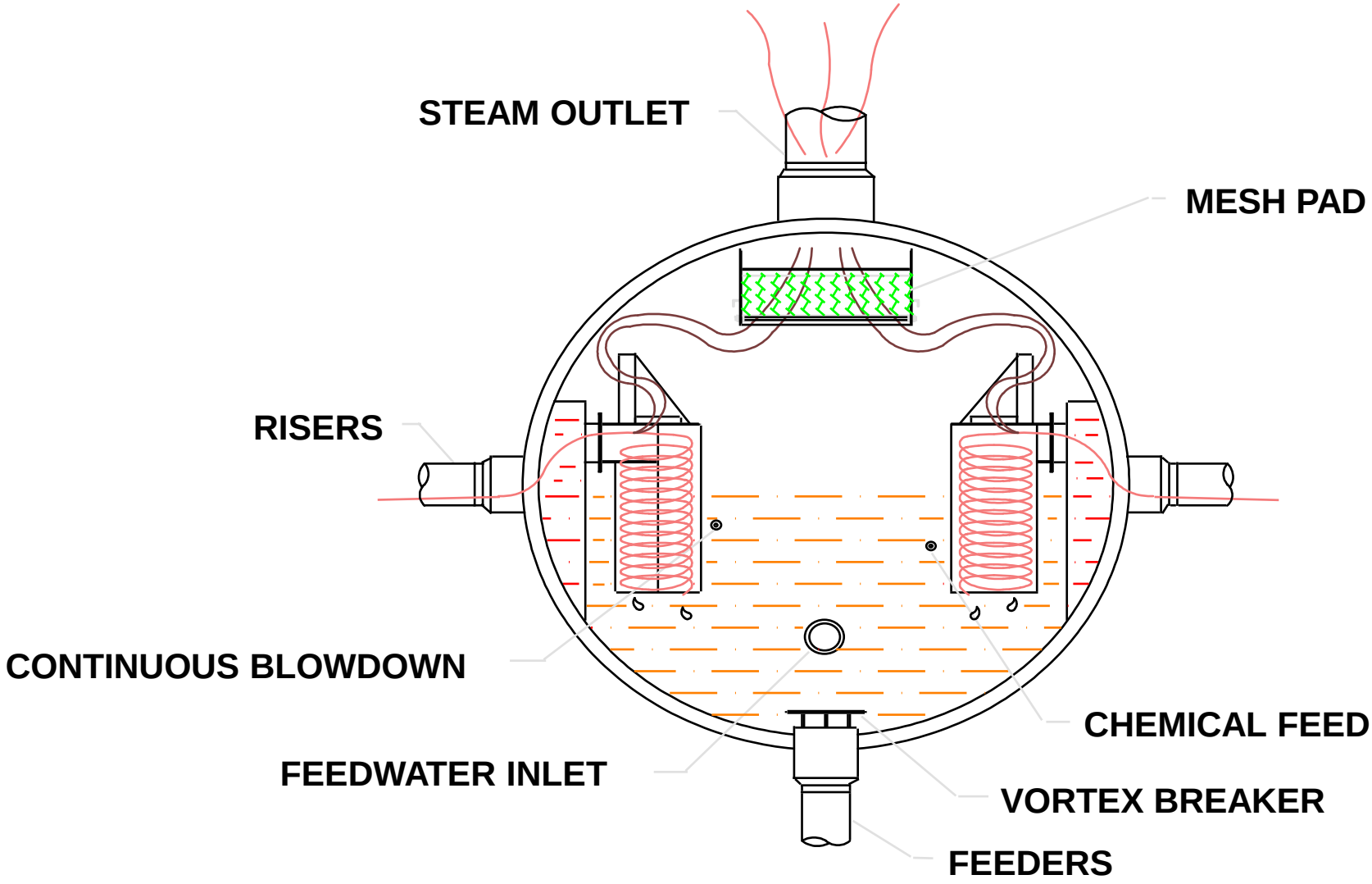
Bed Nozzles & Underfire Air


Ash
Loadout

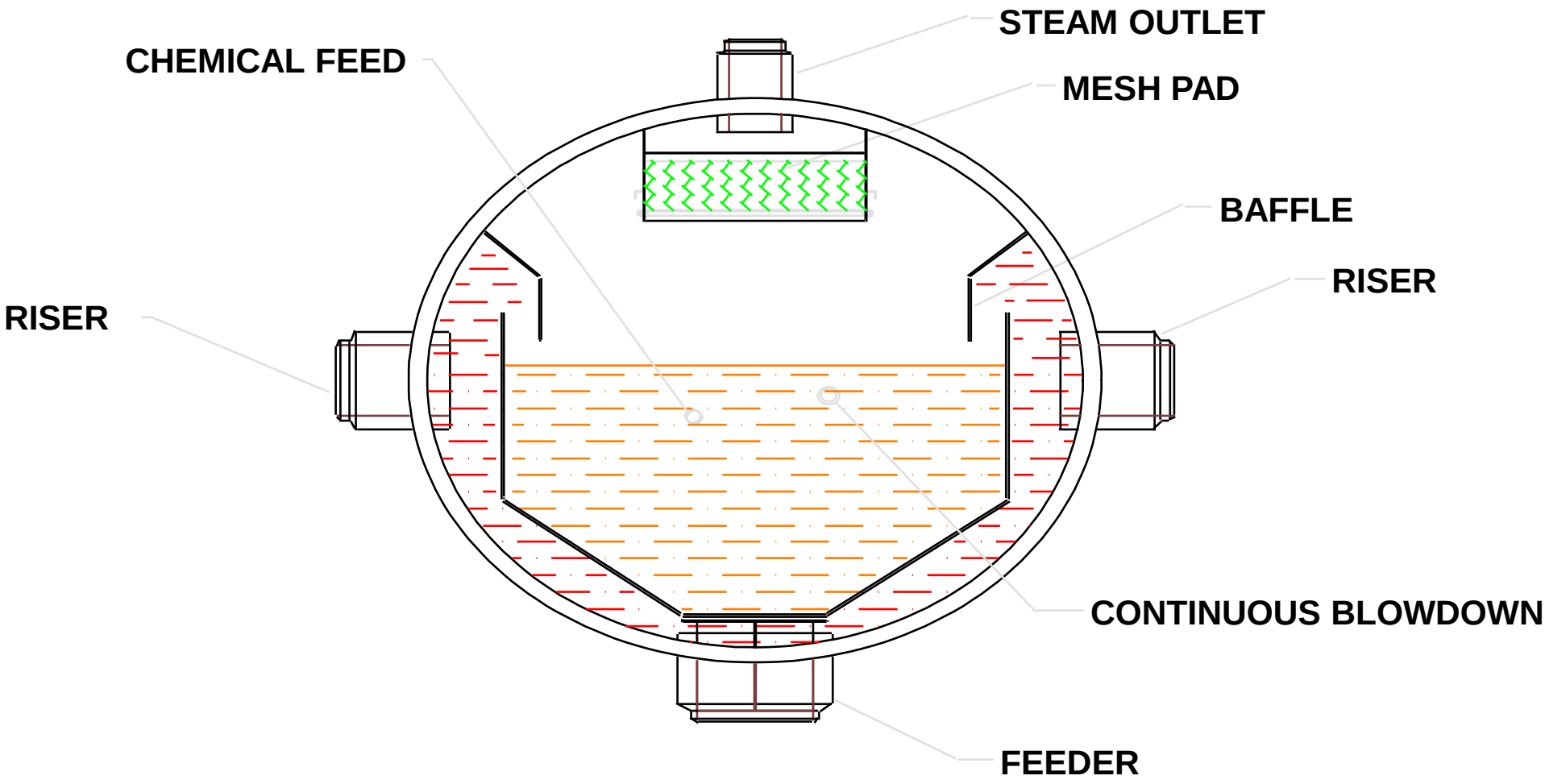

High Pressure Steam Drums


Steam Drum w/Cyclone &
Chevron Separators

STEAM DRUM INTERNALS
CYCLONES WITH MESH PAD

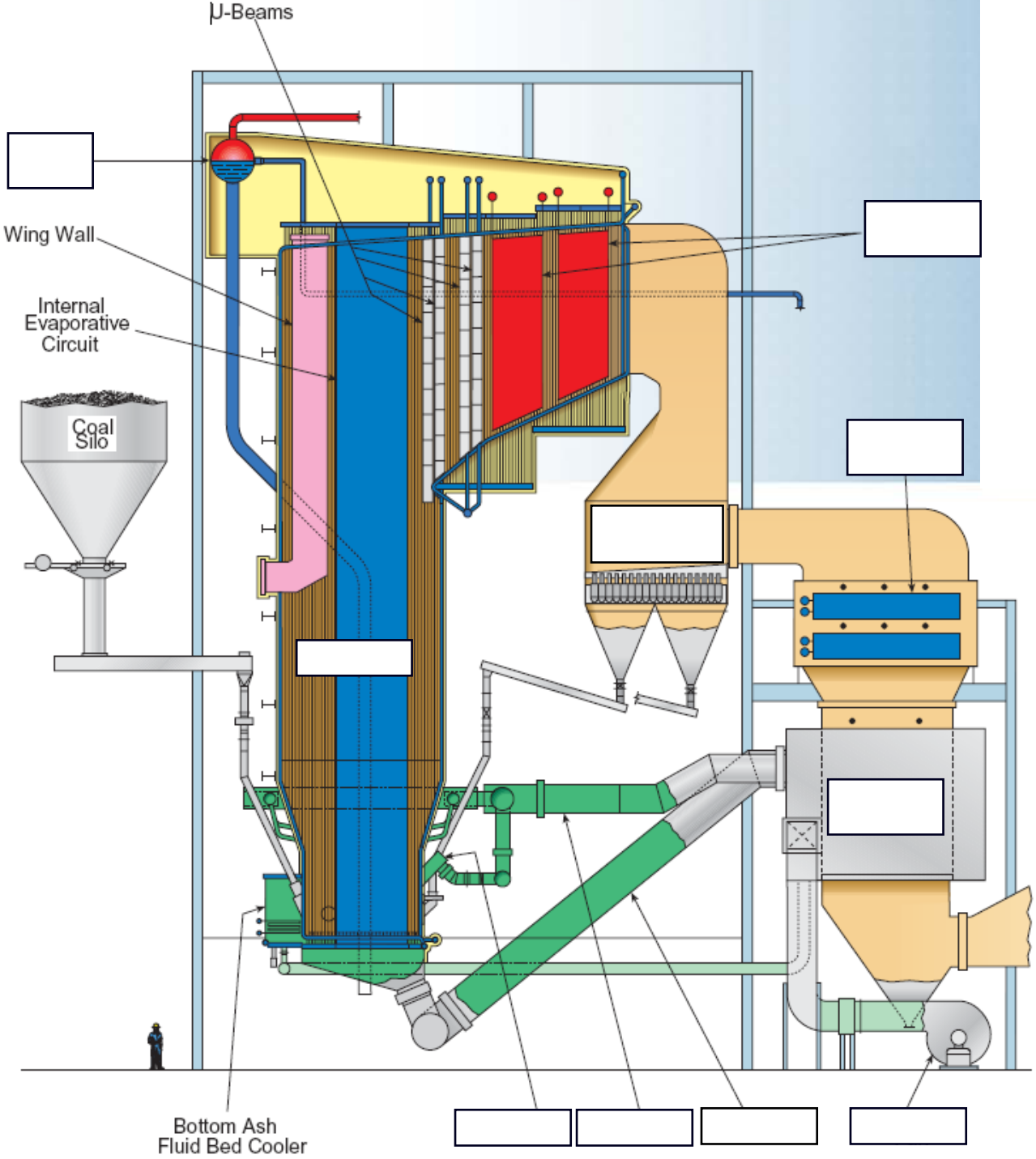


STEAM DRUM INTERNALS
BAFFLE PLATE WITH MESH PAD



Circulating Fluidized Bed Boiler

Interactive Exercise



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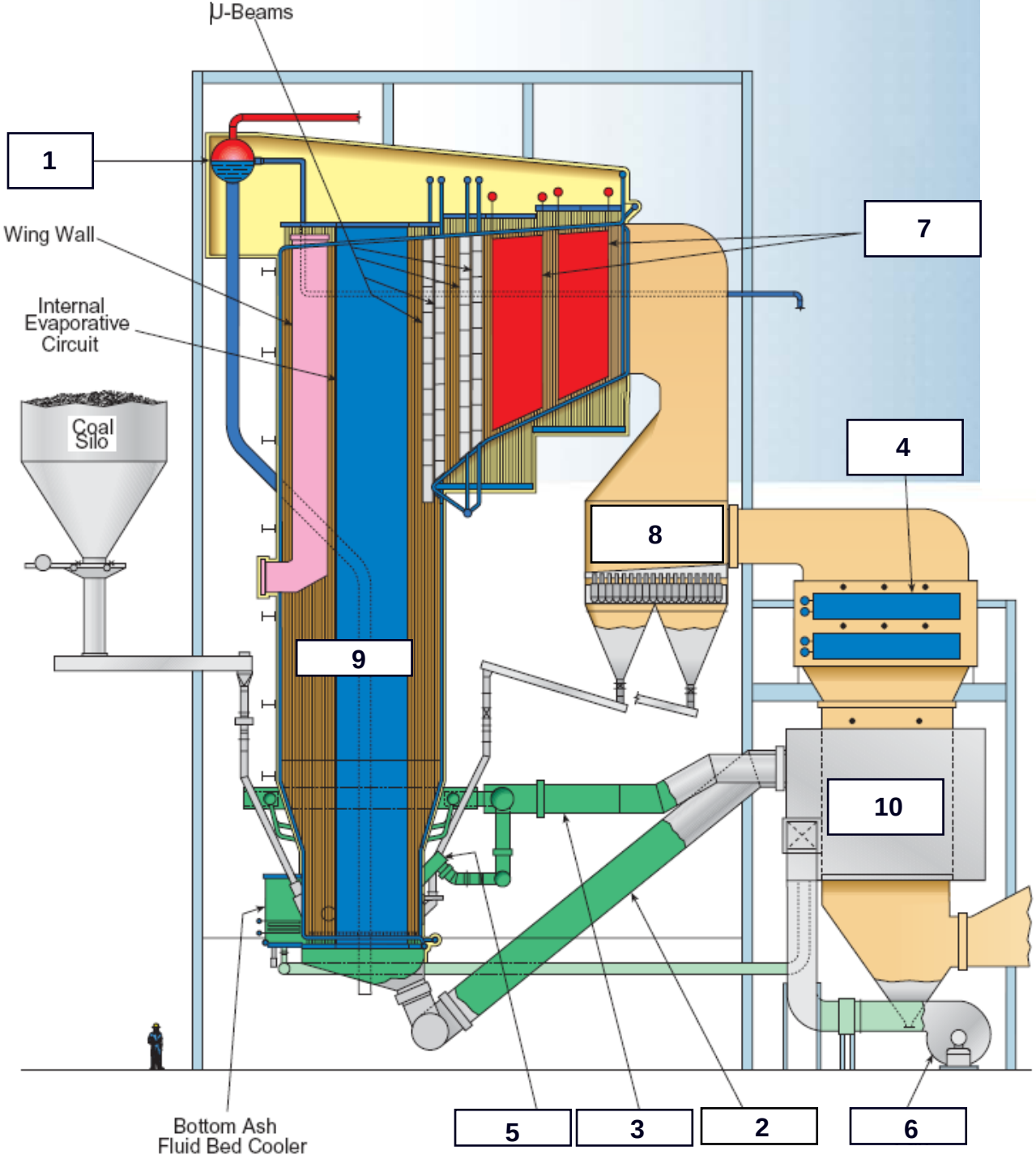
Circulating Fluidized Bed Boiler

Interactive Exercise



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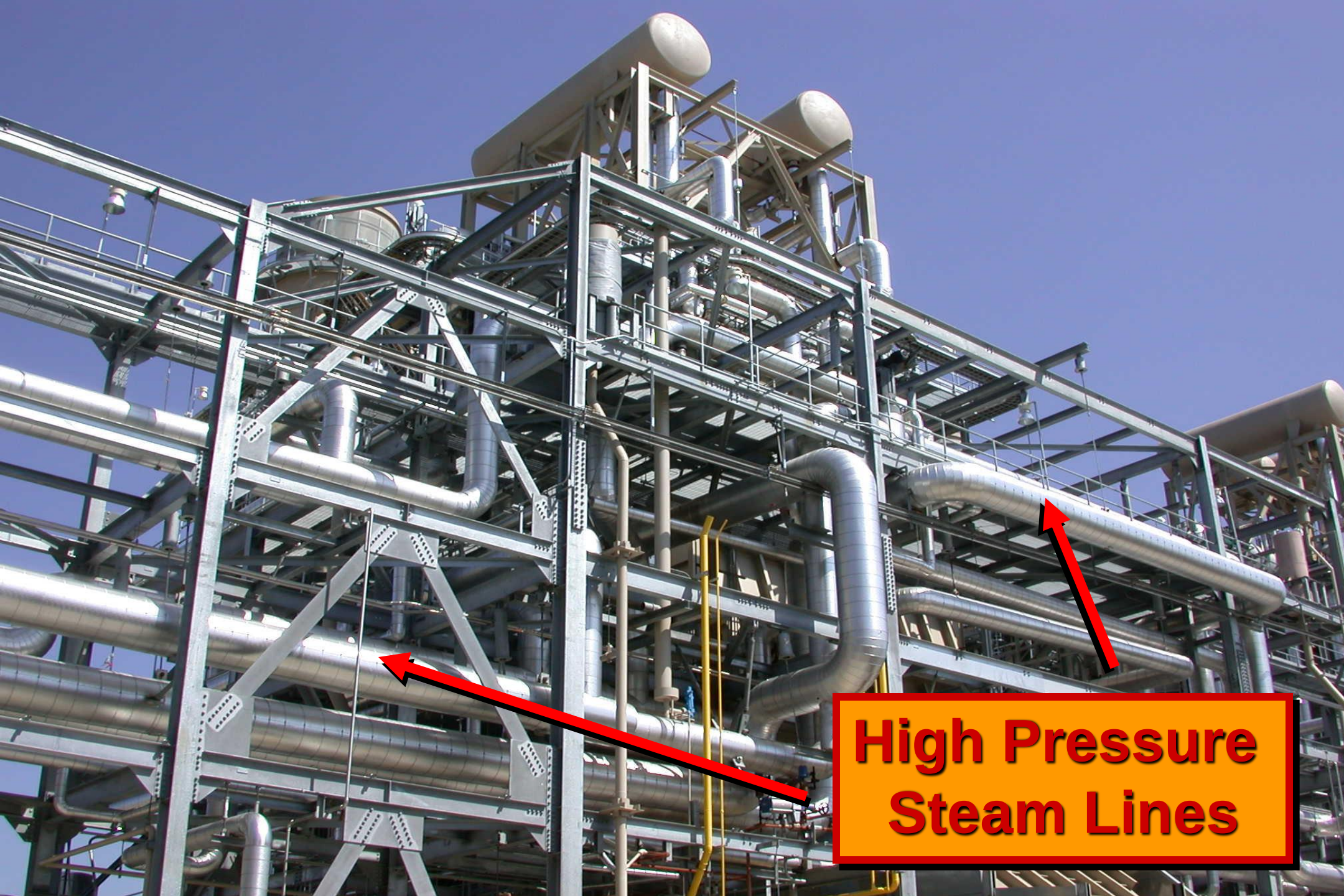
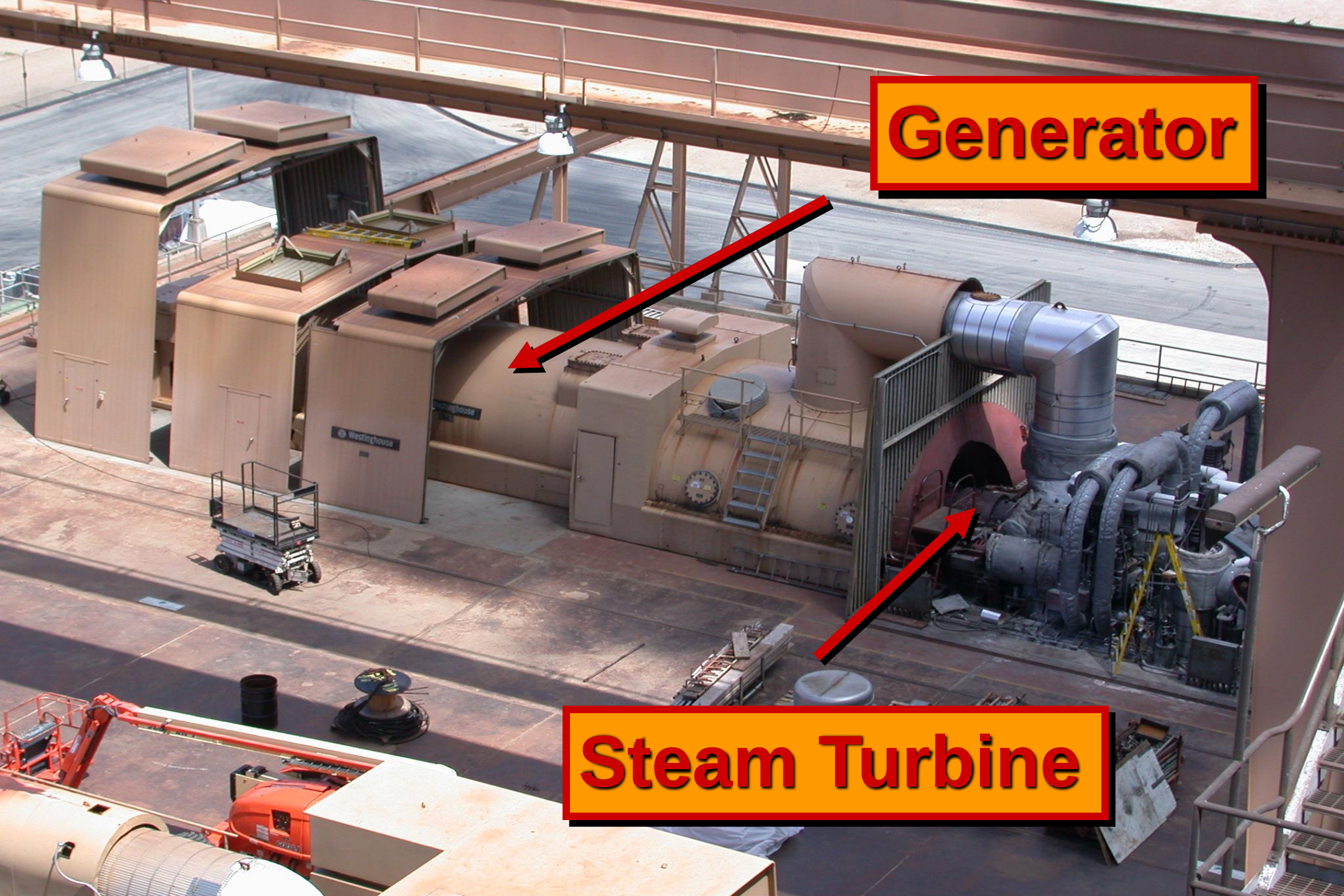
Let’s Discuss
Power
Generation

High Pressure Steam Lines


High Pressure
Steam Lines


Steam
Turbine

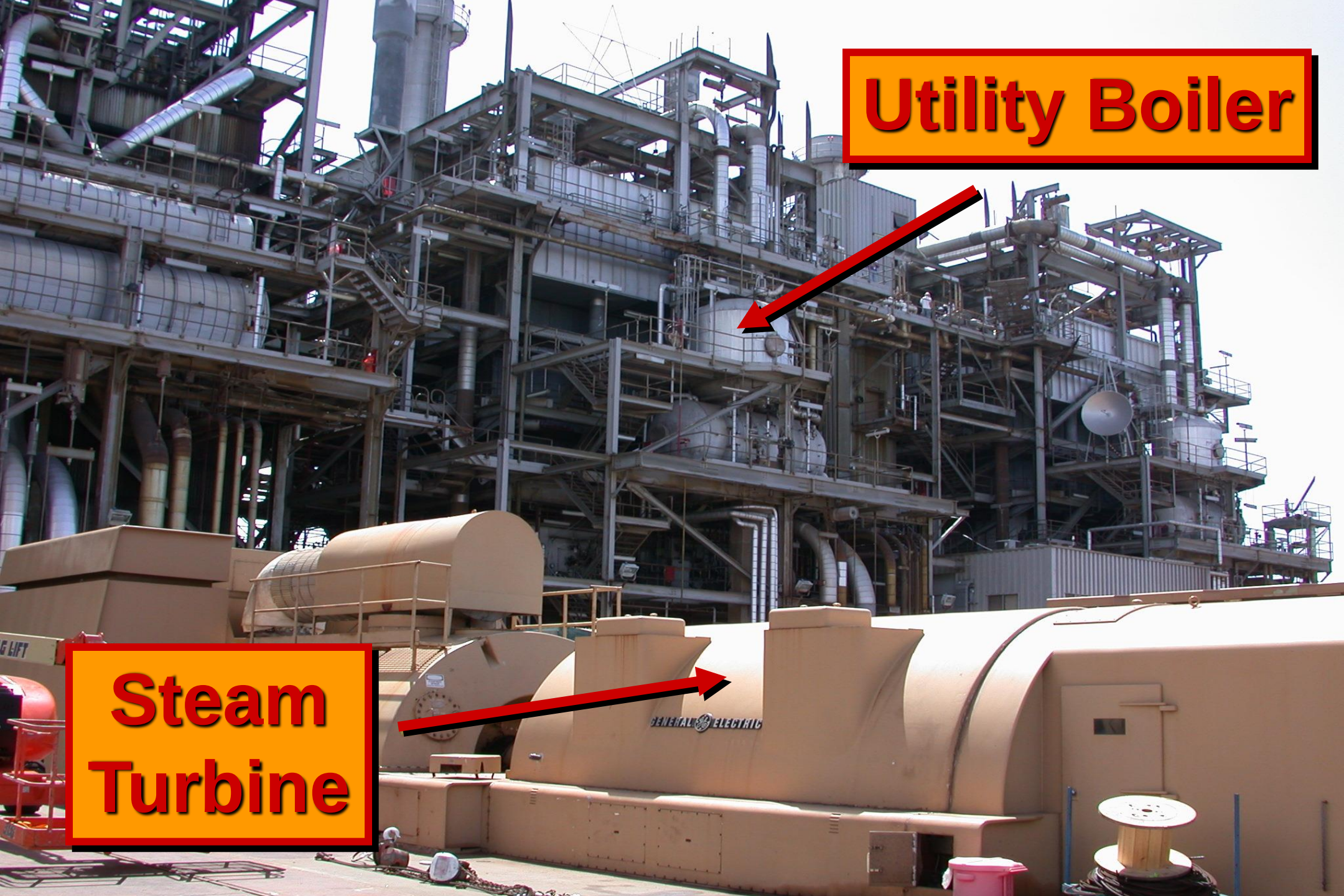

Steam
Turbine


Generator
Steam Turbine


Cooling Towers


Cooling Tower Shell

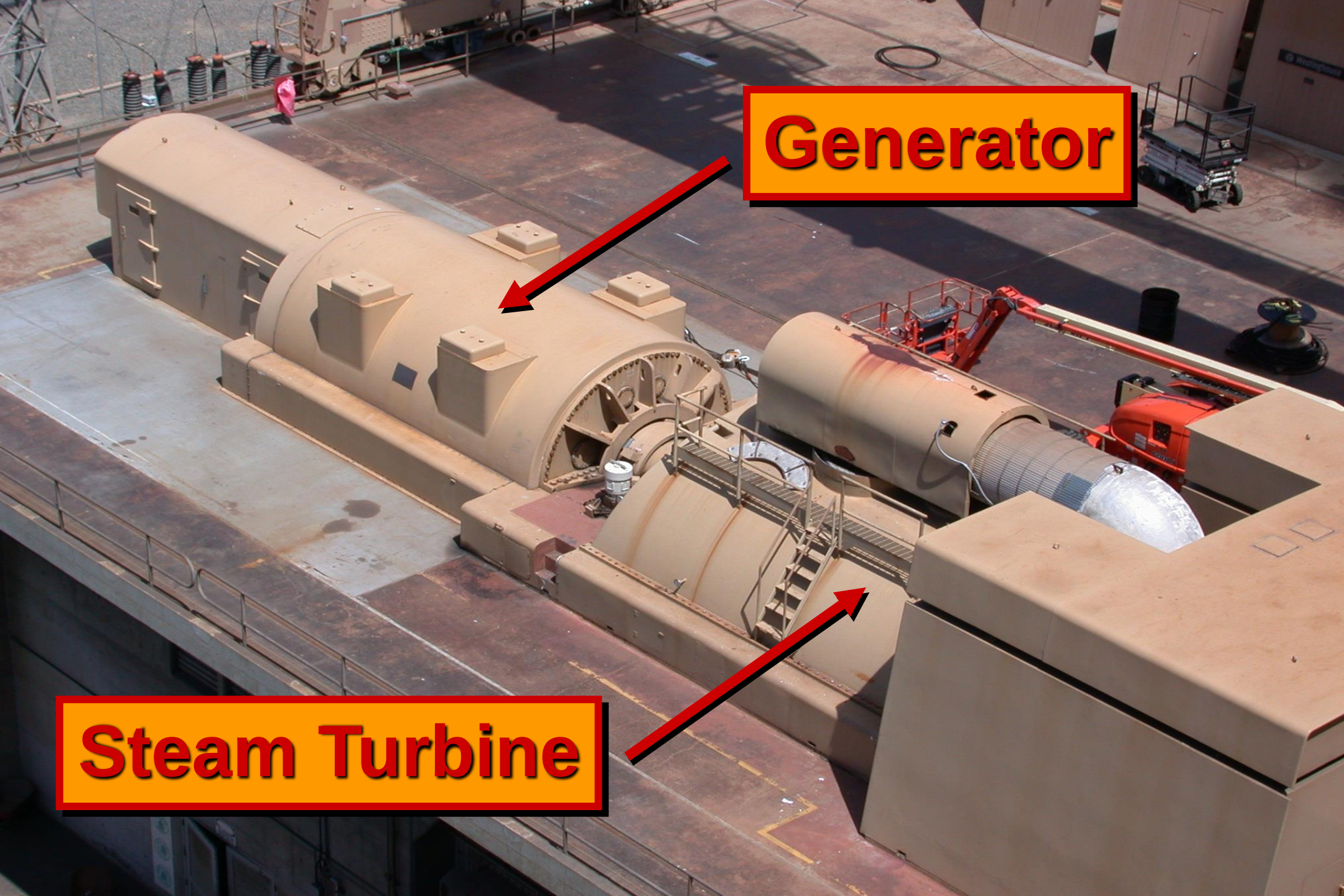
Typical Control Room


Utility Boiler
Steam Turbine
GENERAL ELECTRIC

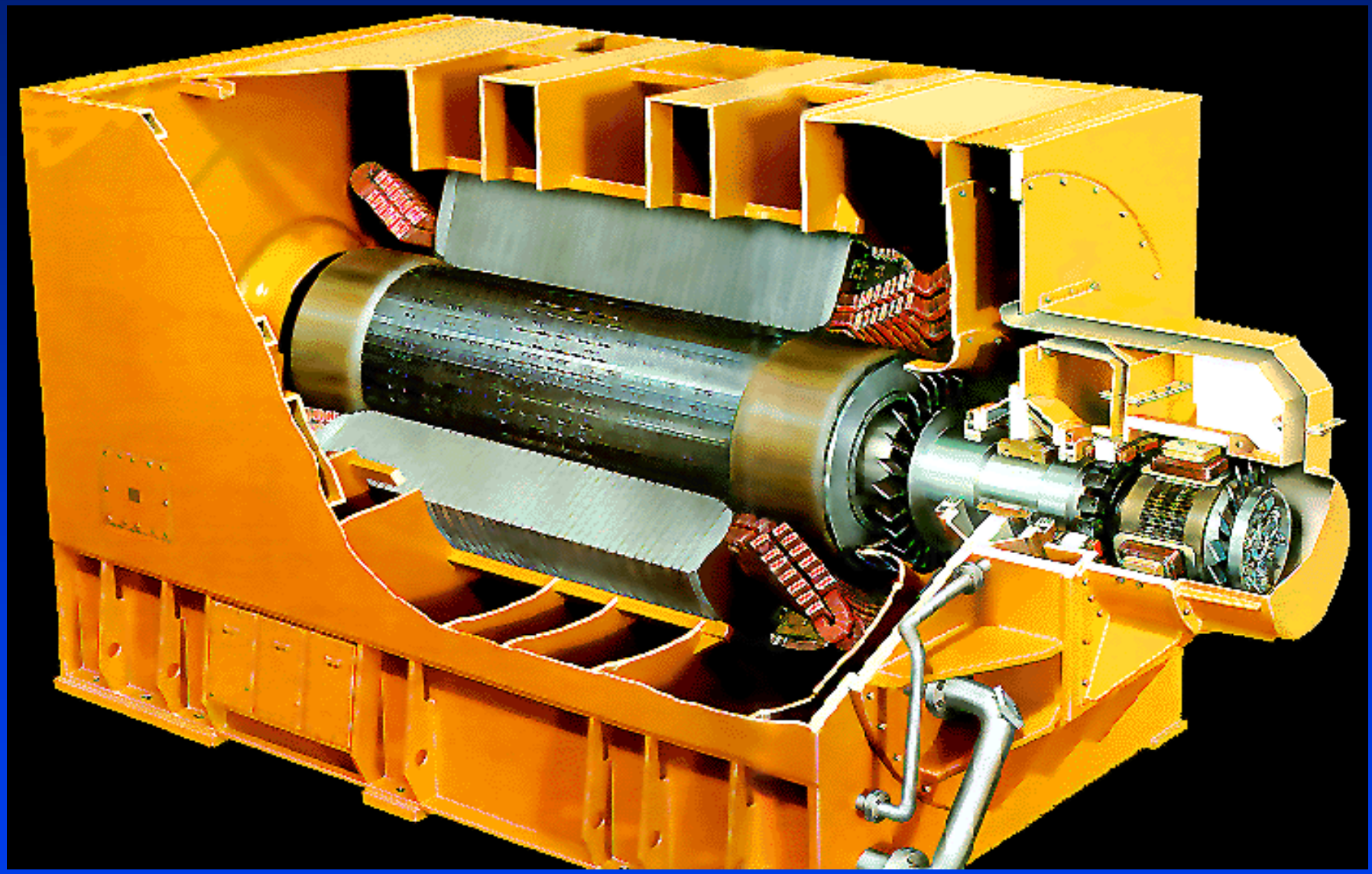
Steam Turbine Blades

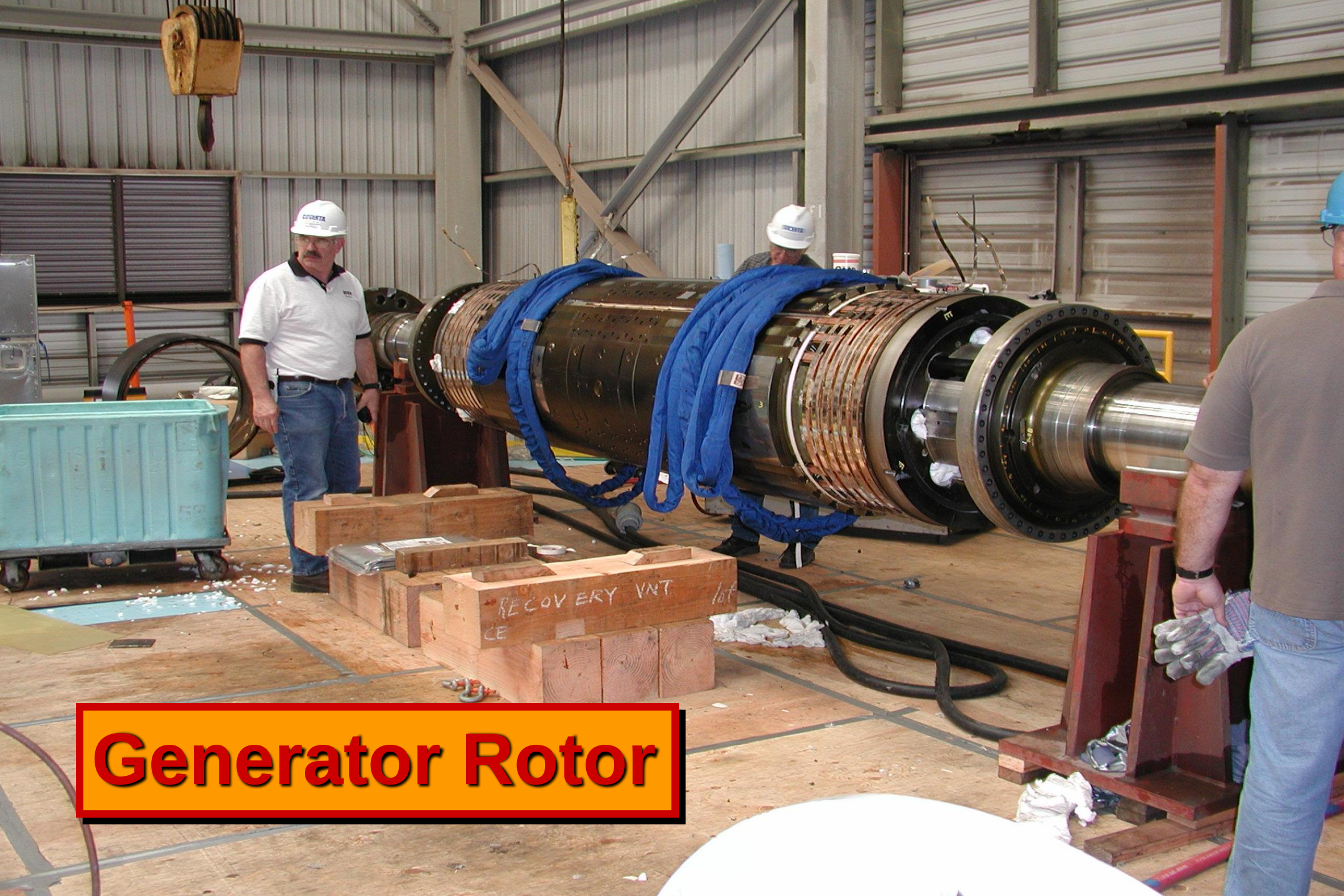

Steam Turbine


HP Steam
Turbine


Generator
Steam Turbine

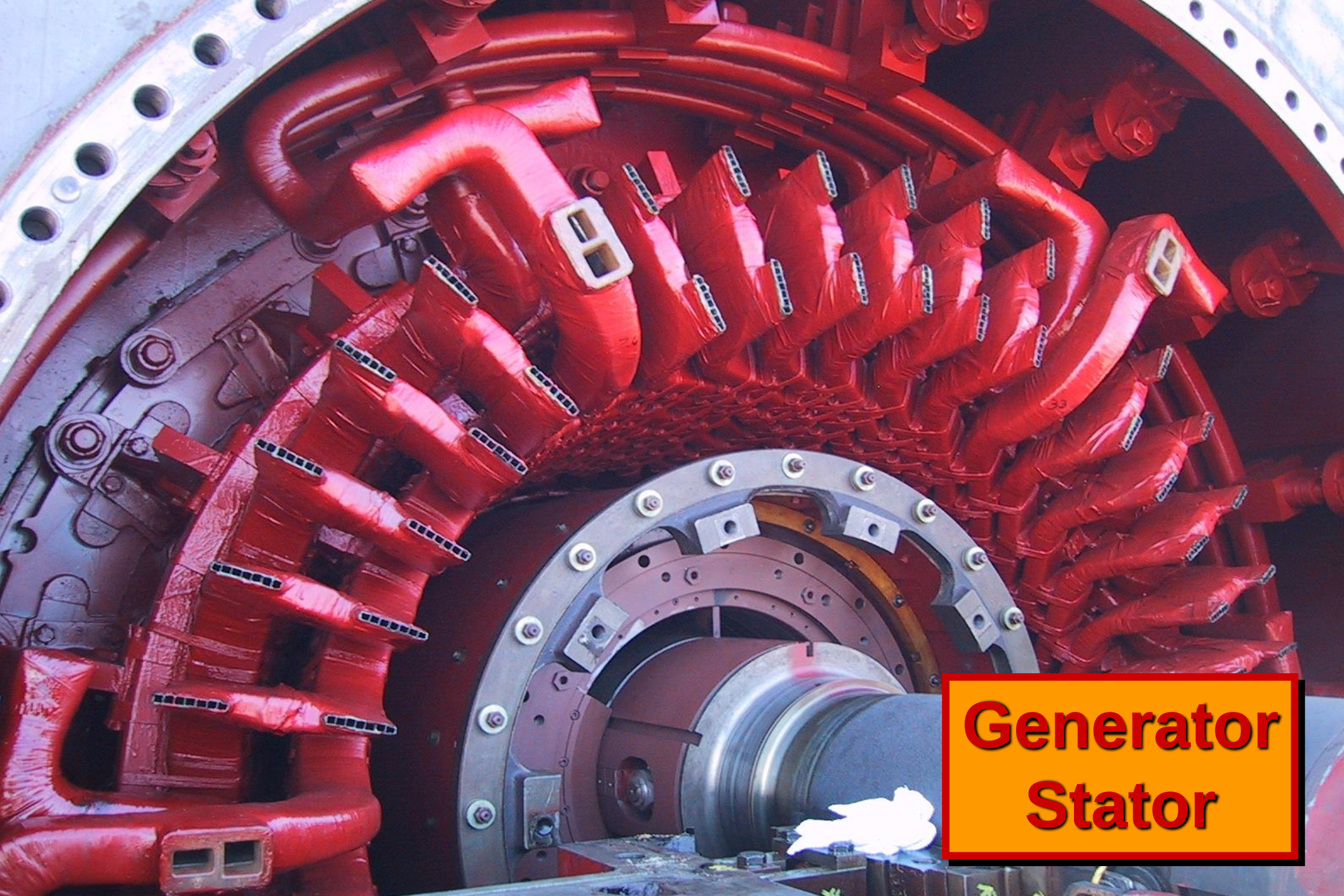
Brush DAX Turbogenerator





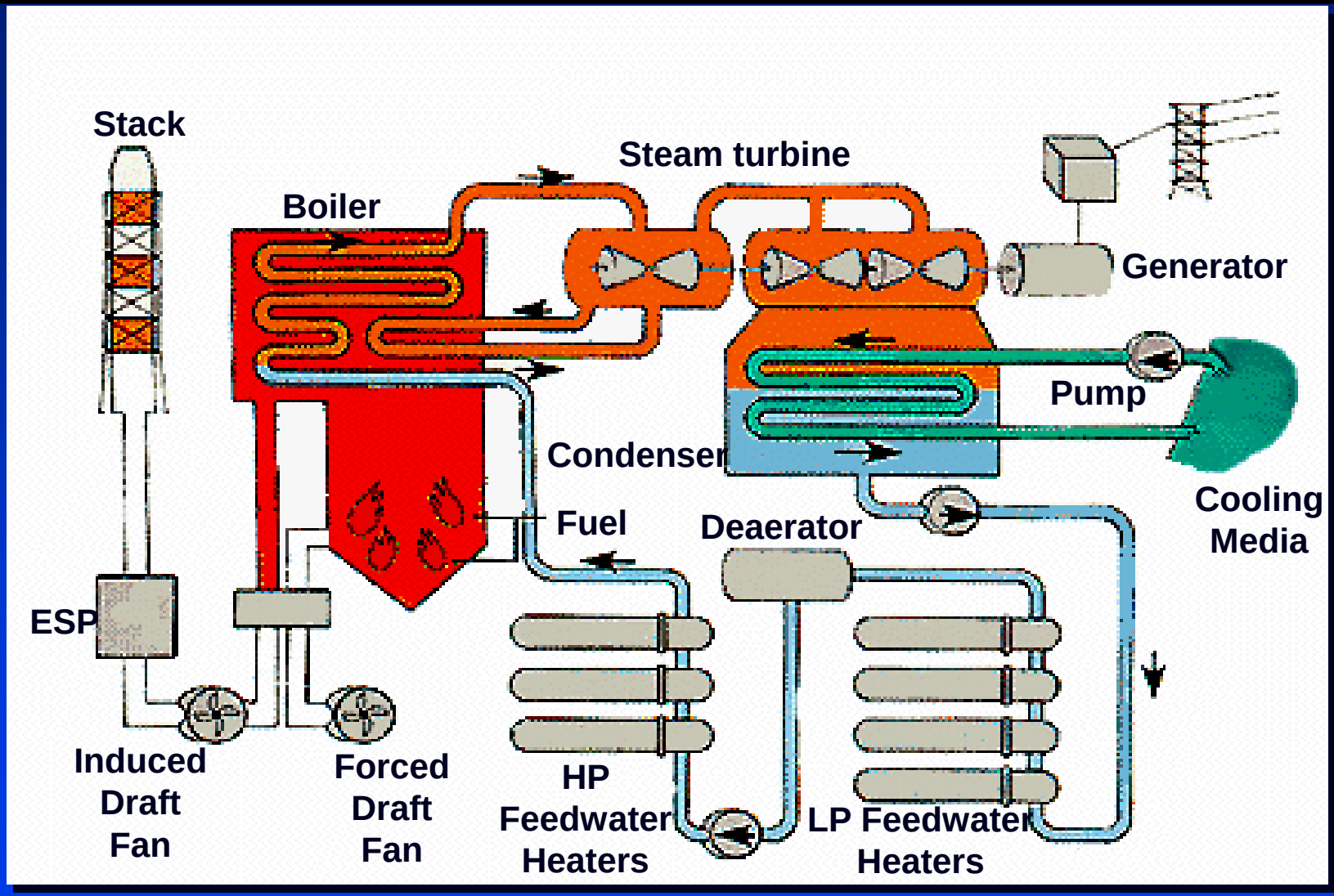
Generator Rotor


Generator Rotor


Generator
Stator

Step-Up Transformers

Typical Electric Utility Plant




Let's Discuss
Emissions
& Controls

Emissions From Boilers

Fuel
+
Air
(N_2, O_2)

- H_2O
- CO_2
- CO
- NO_X
- HC
- SO_X
- PM
- CHO

Emissions Control Methods

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

Control of Gaseous Emissions

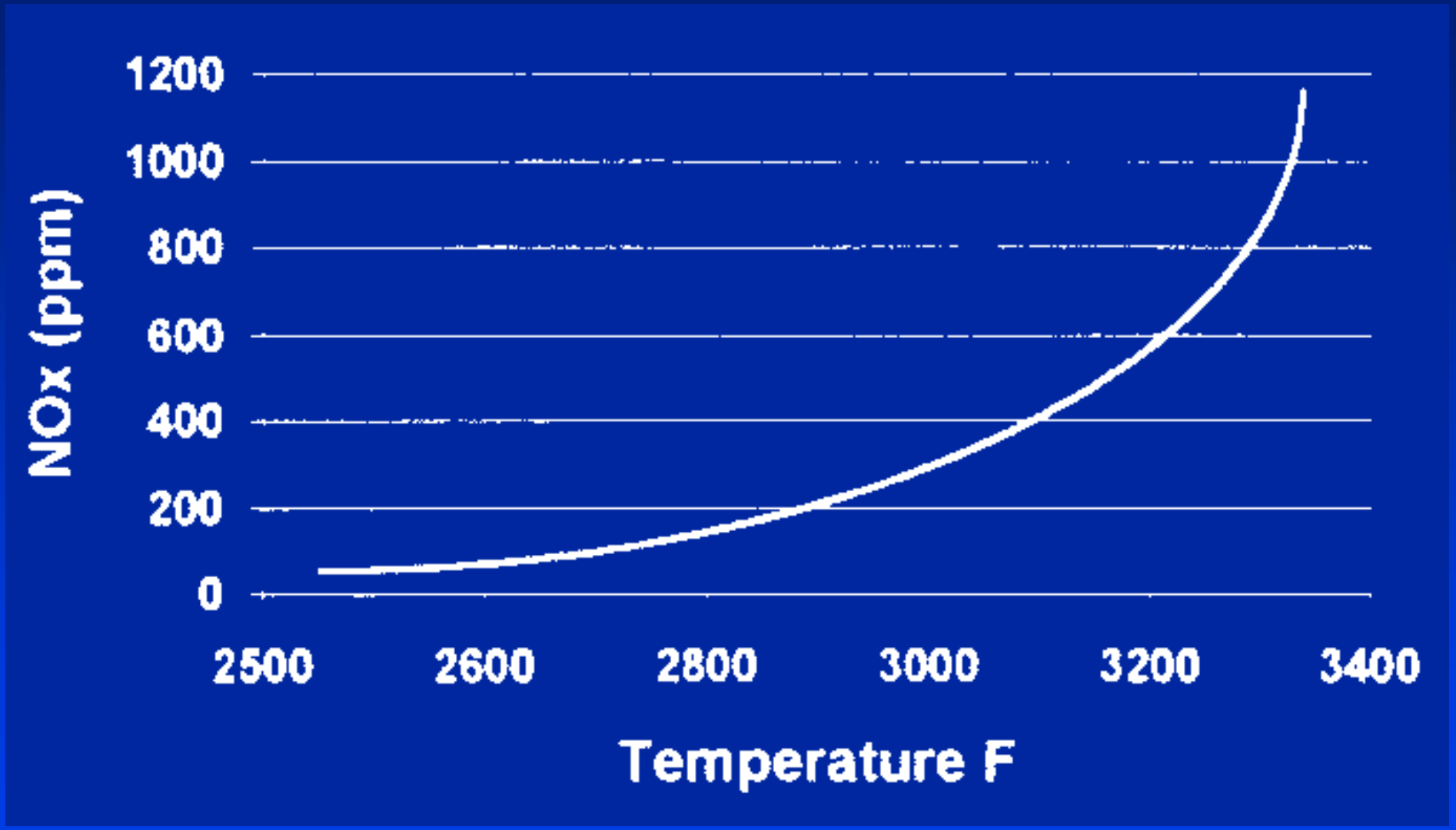
- Low-NOx burners
- OFA
- Ammonia injection (SNCR)
- Catalysts (SCR)
- FGR
- FGD

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

$$N + O \longrightarrow NO$$

$$N + OH \longrightarrow NO + H$$

- NOx REDUCTION

$$CH + NO \longleftrightarrow HCN + O_2 \text{ (Reversible)}$$

$$CH_2 + NO \longleftrightarrow HCN + OH \text{ (Reversible)}$$

$$C + NO \longrightarrow CN + O_2$$

$$NH_i + NO \longrightarrow N_2 + H_2O$$

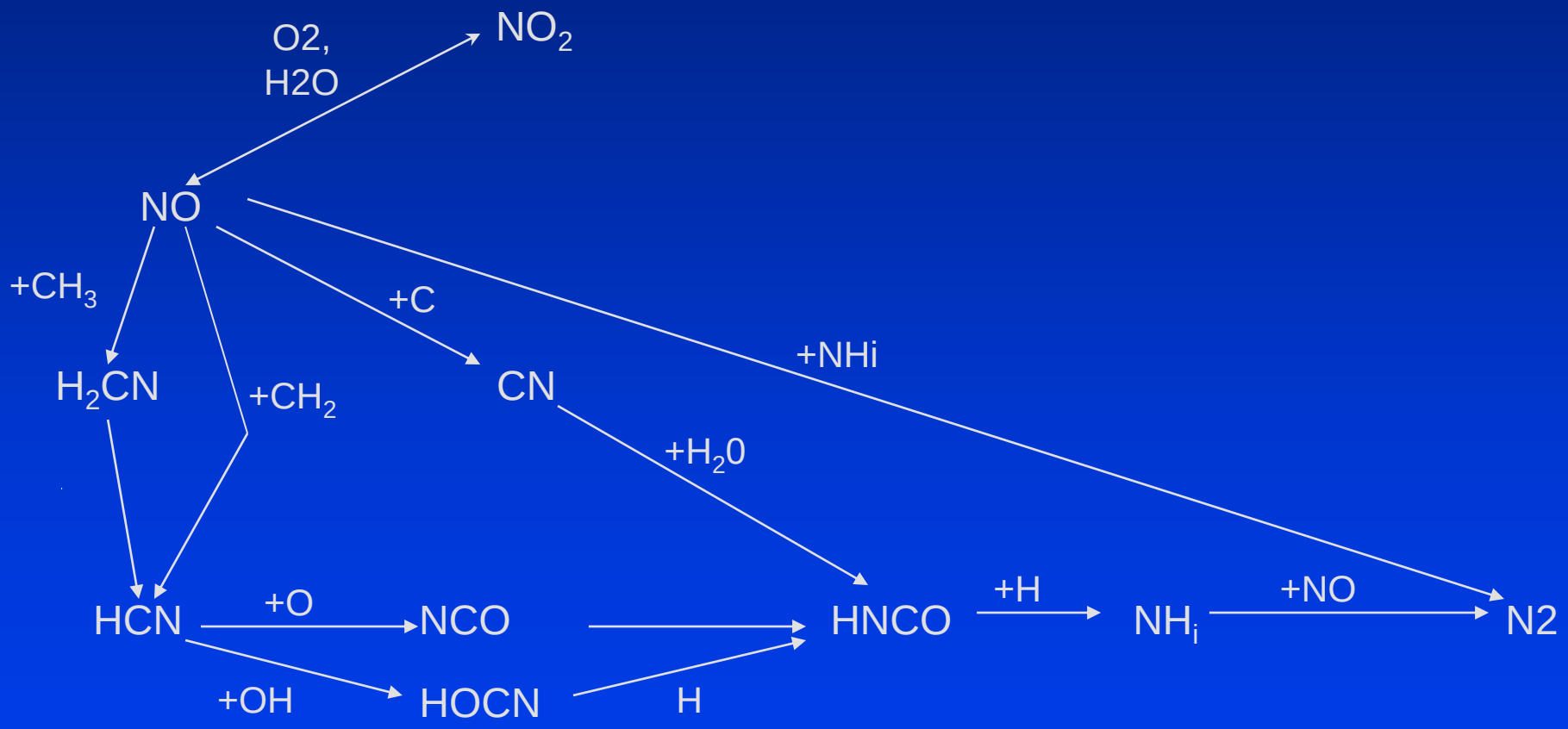
THESE NOx REDUCTANTS ARE FORMED BY PARTIAL COMBUSTION IN A REDUCING ATMOSPHERE

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

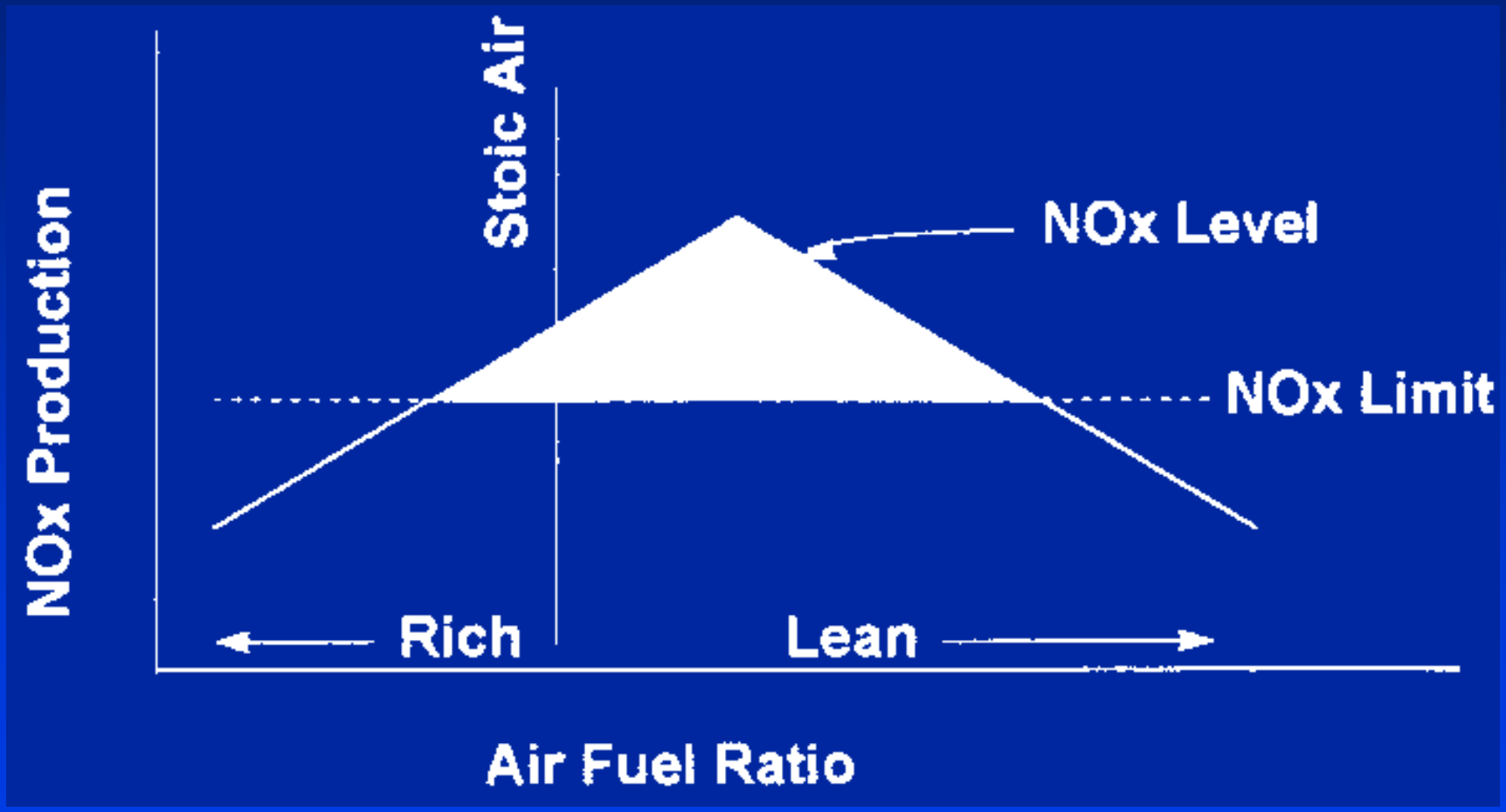
PROMPT NOx

- 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


O2,
H2O
NO_2
NO
$+CH_3$
$+CH_2$
+C
+NHi
H_2CN
CN
$+H_20$
HCN
+O
NCO
HNCO
+H
NH_i
+NO
N2
+OH
HOCN
H

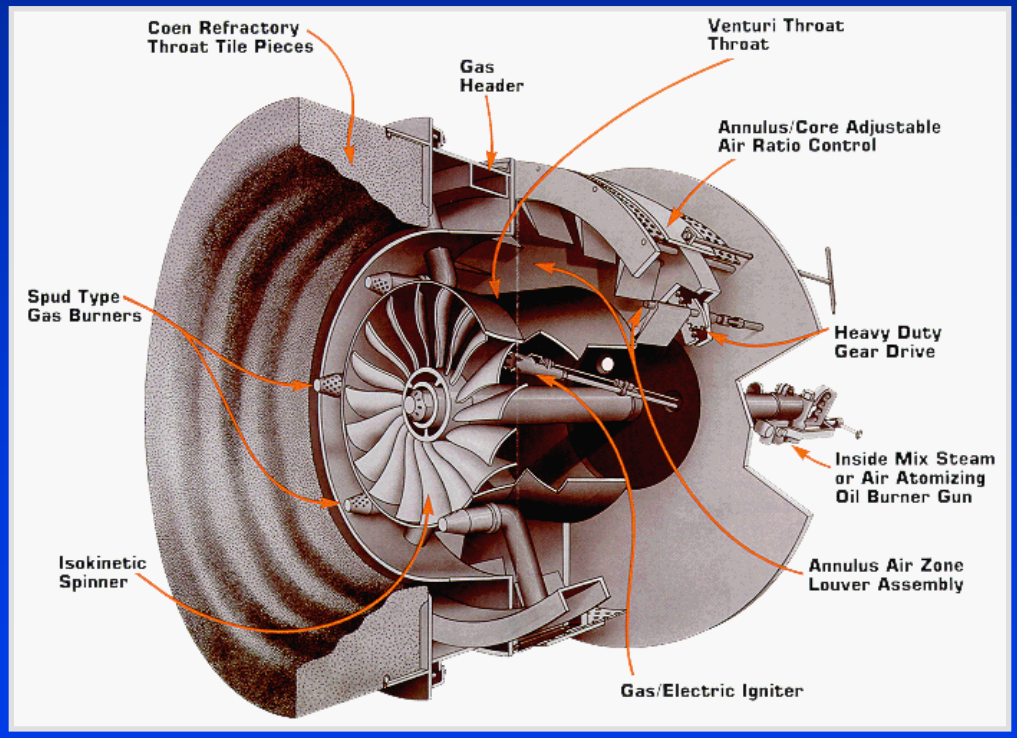
NOx Production vs. Air/Fuel Ratio



Graphic Courtesy of Coen

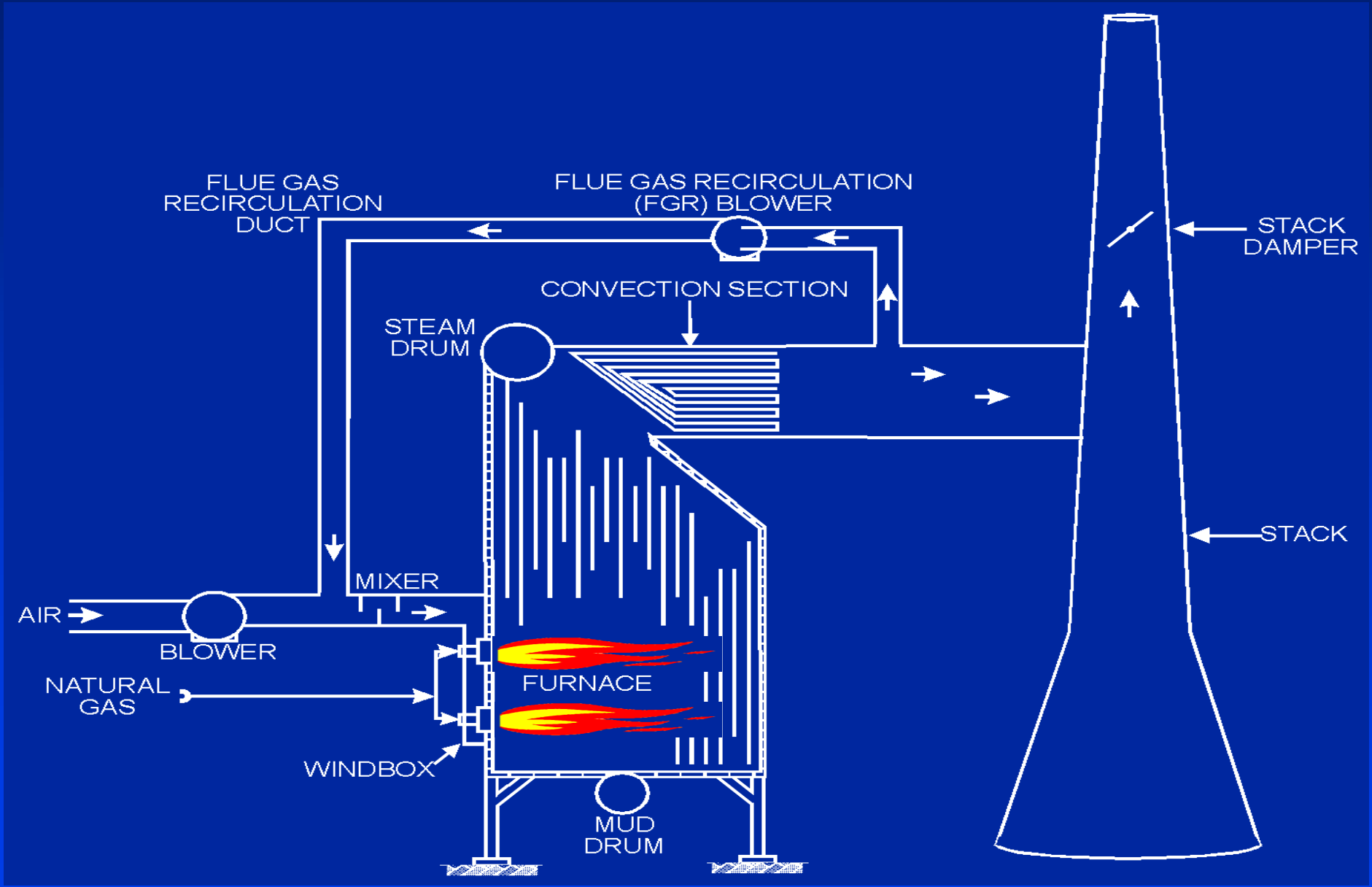
Industry Burner Definitions

- 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)



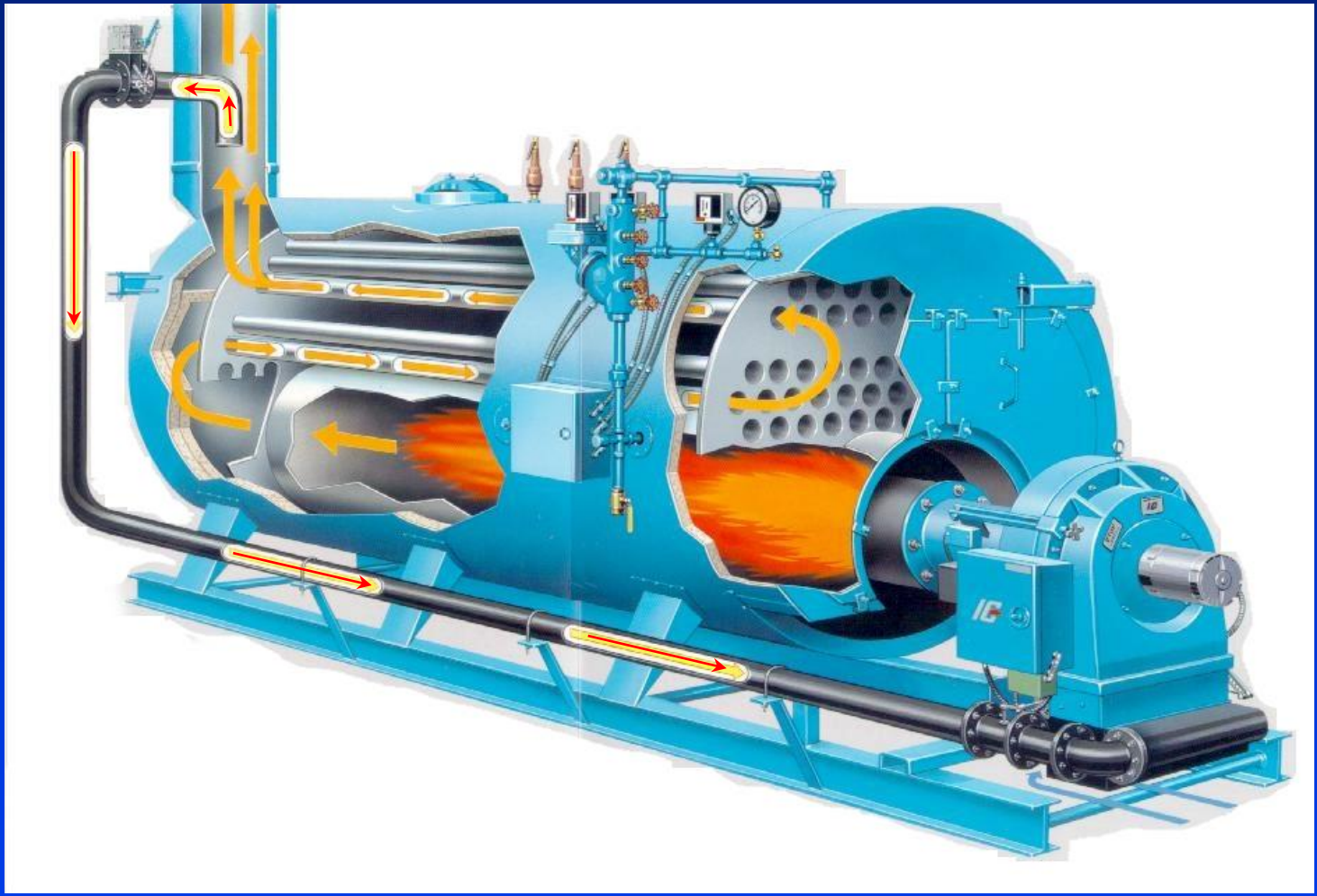

Let’s Discuss FGR

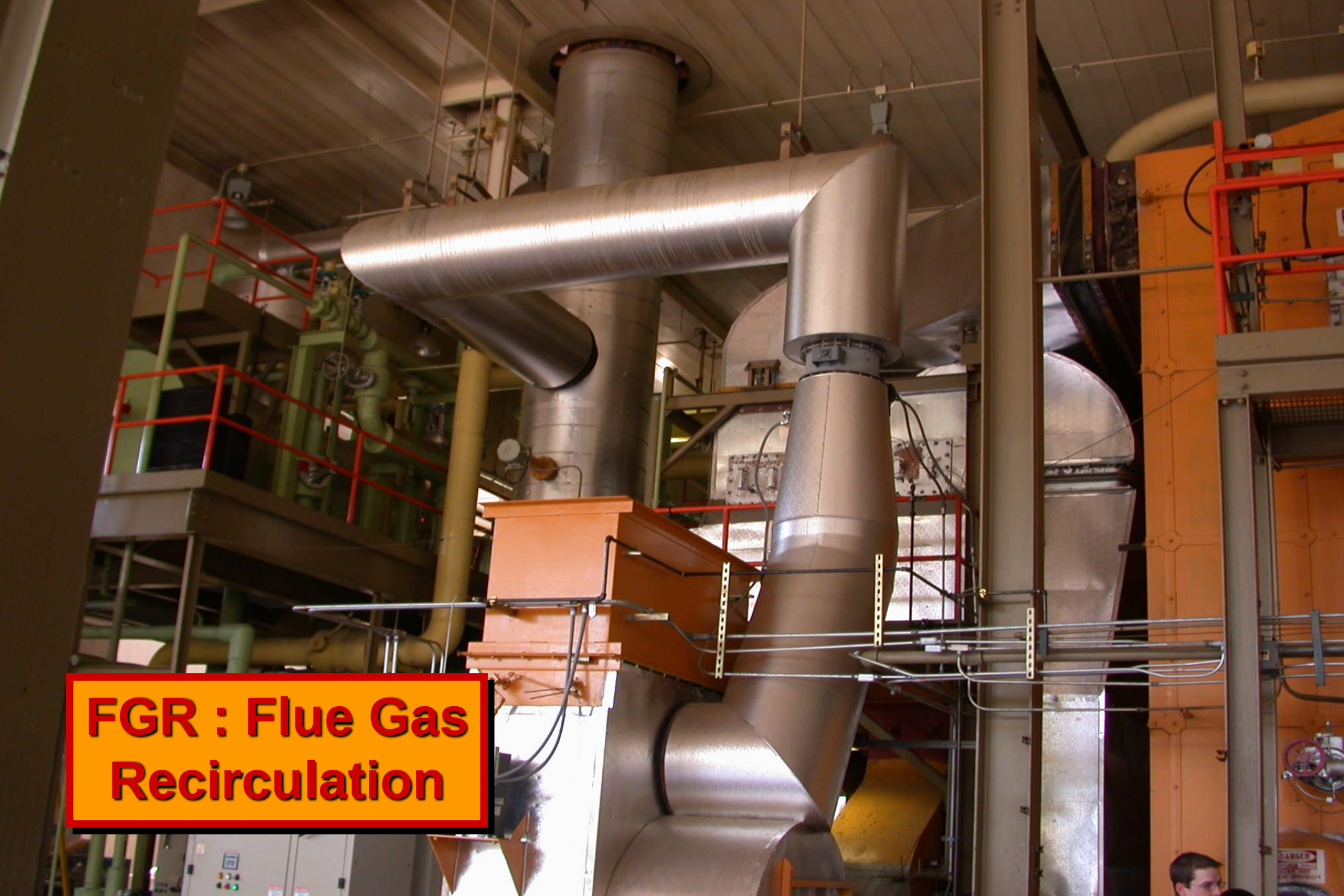
Flue Gas Recirculation (FGR)



Flue Gas Recirculation (FGR)

Flue Gas Recirculation (FGR)




FGR : Flue Gas
Recirculation

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 STOICHIOMETERY.

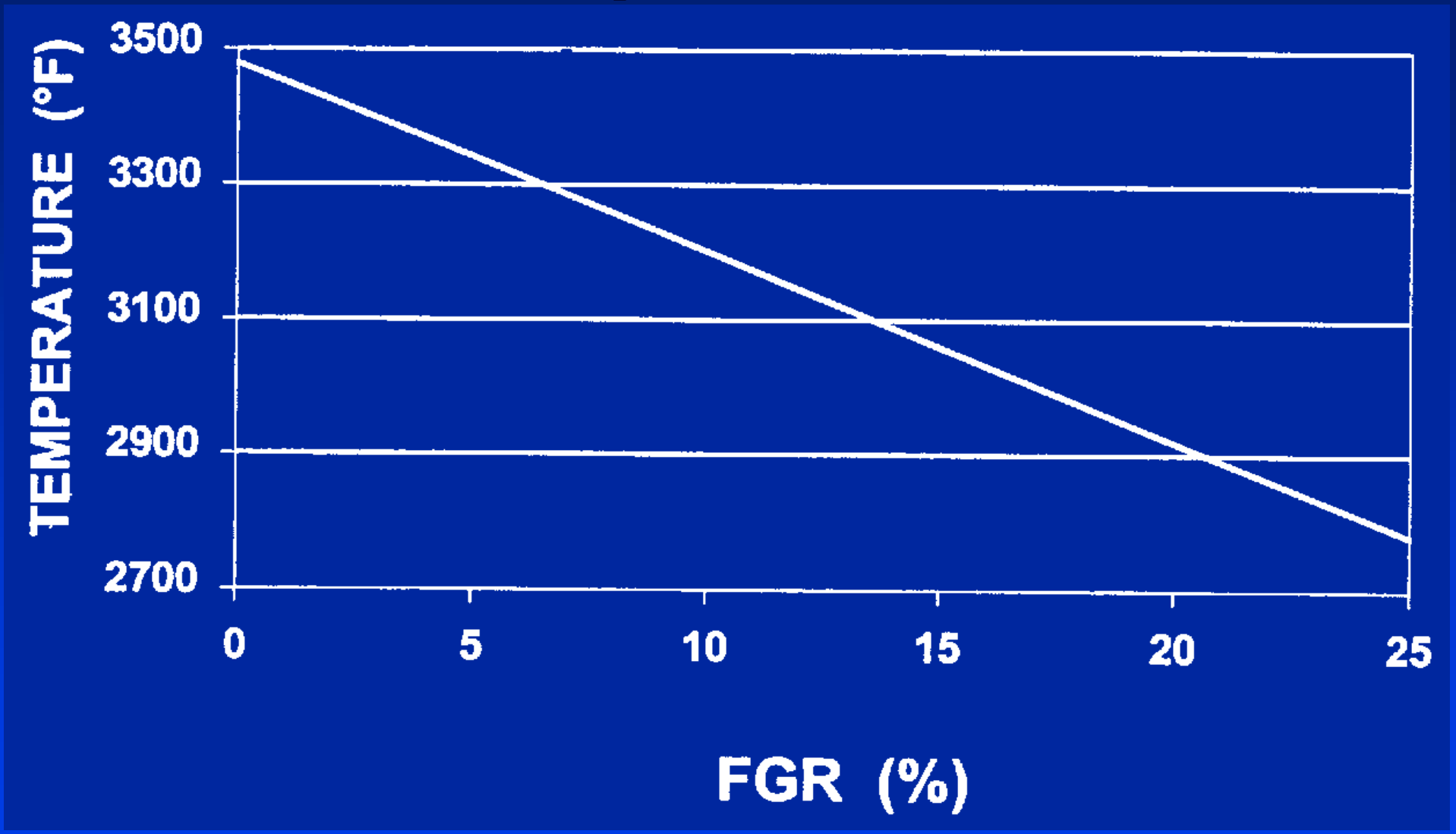
CON'S

- 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

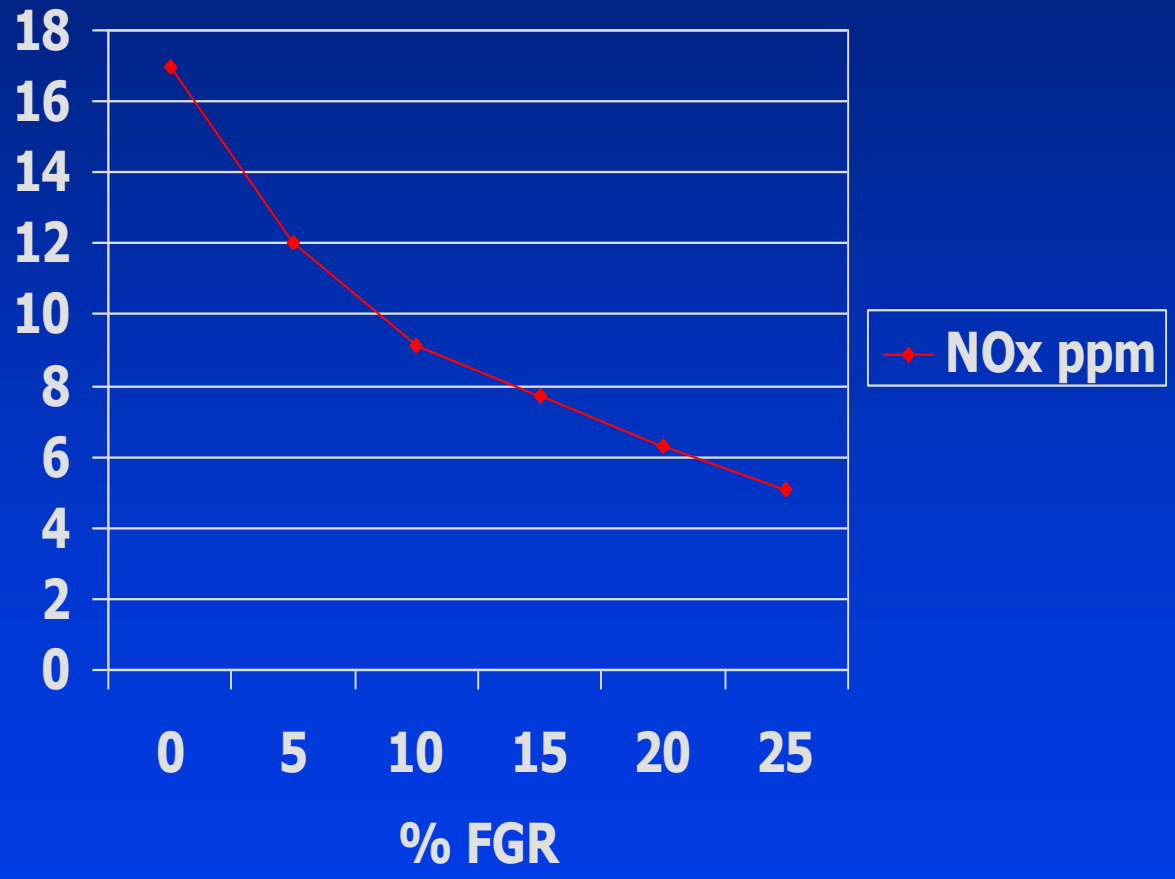
- Simple durable refractory and steel construction results in:
  - Lower initial cost
  - Lower maintenance costs
- Lower operating cost
  - Less stack losses due to low excess air and low FGR requirements
  - Lower fan costs
  - Eliminates the need for chemicals & catalysts

Flame Temperature vs. FGR



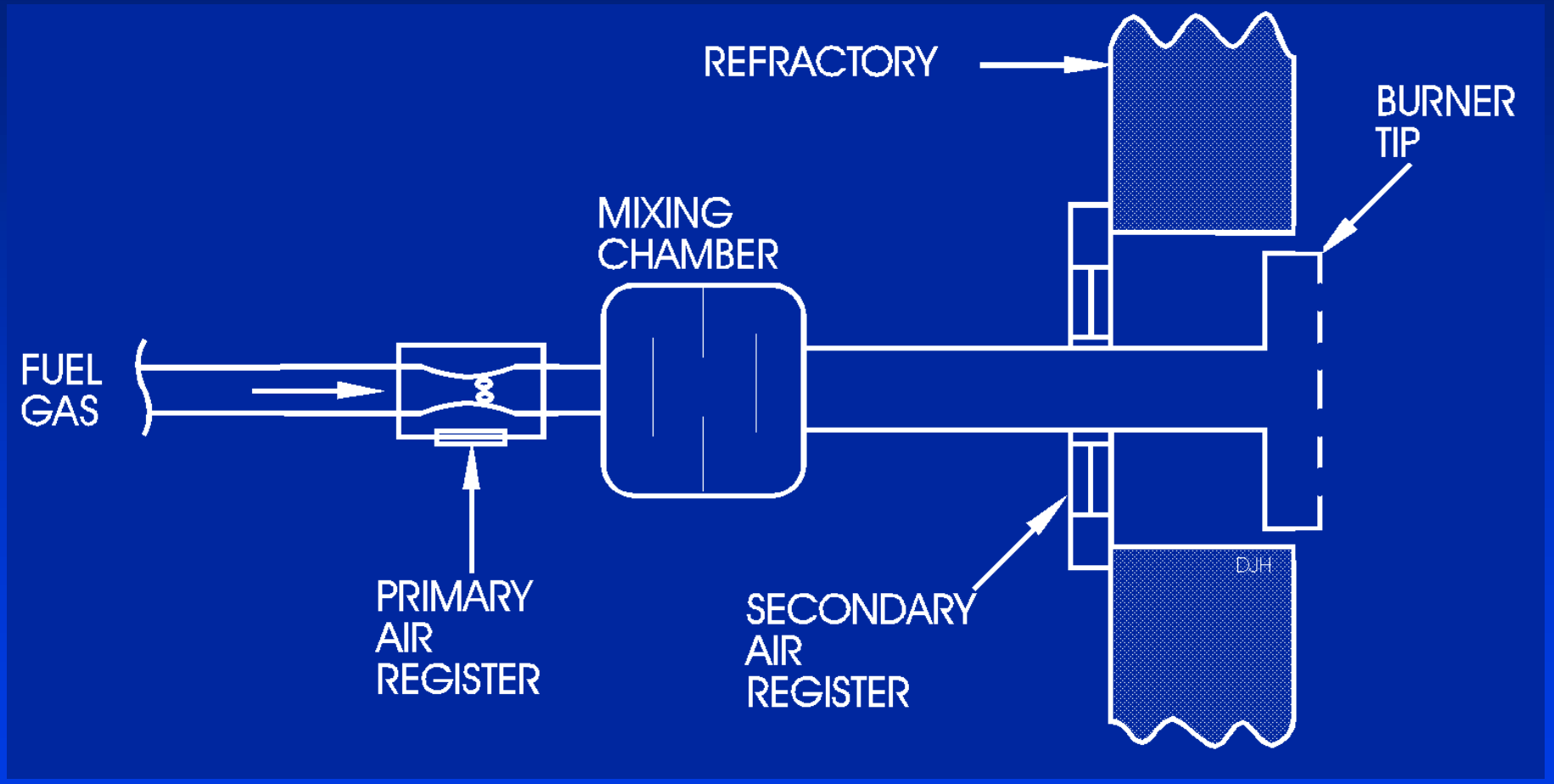
Graphic Courtesy of Coen

FGR Impact

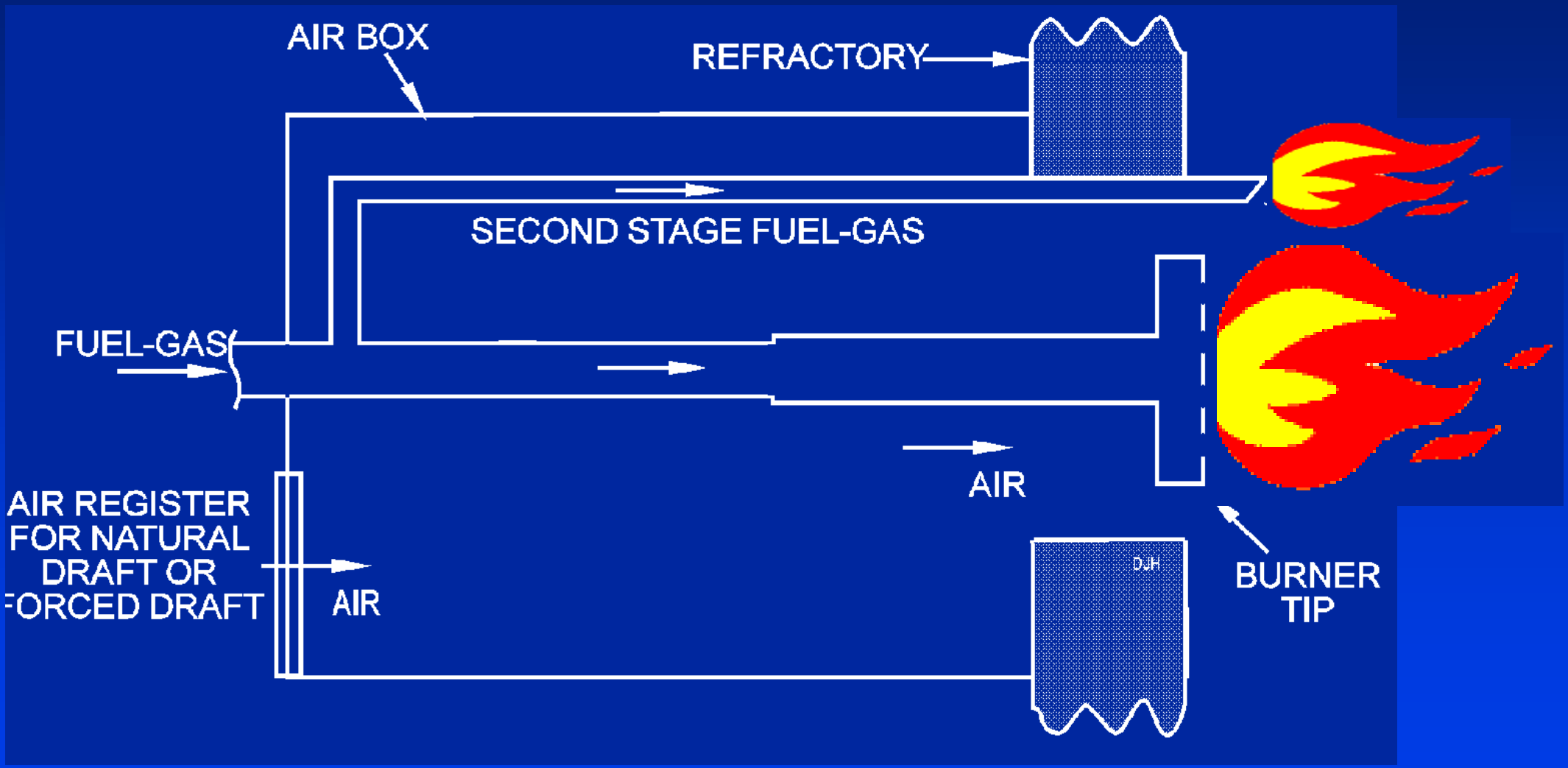



Let's Discuss
Staged Combustion

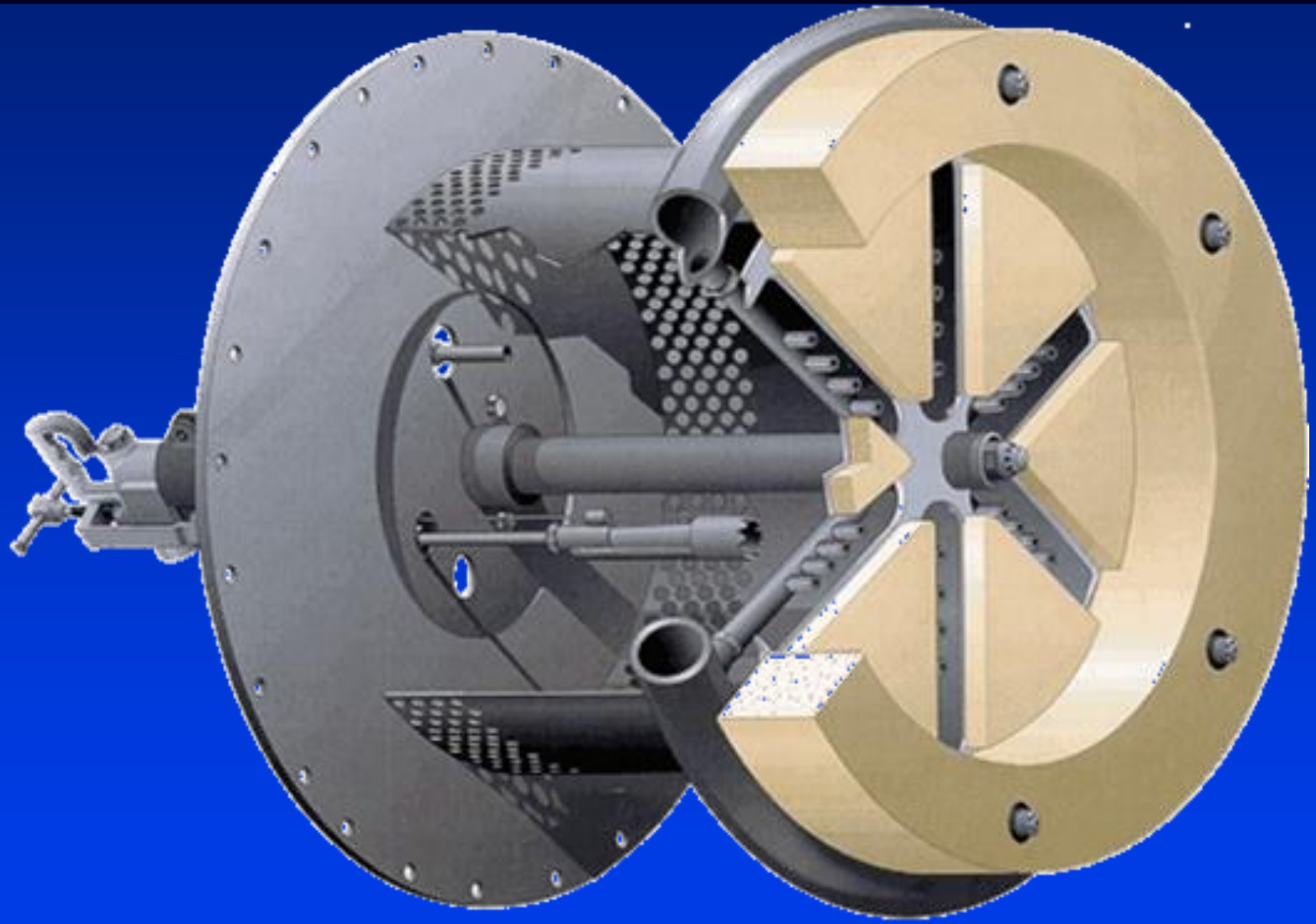
Gas Pre-mix Burner



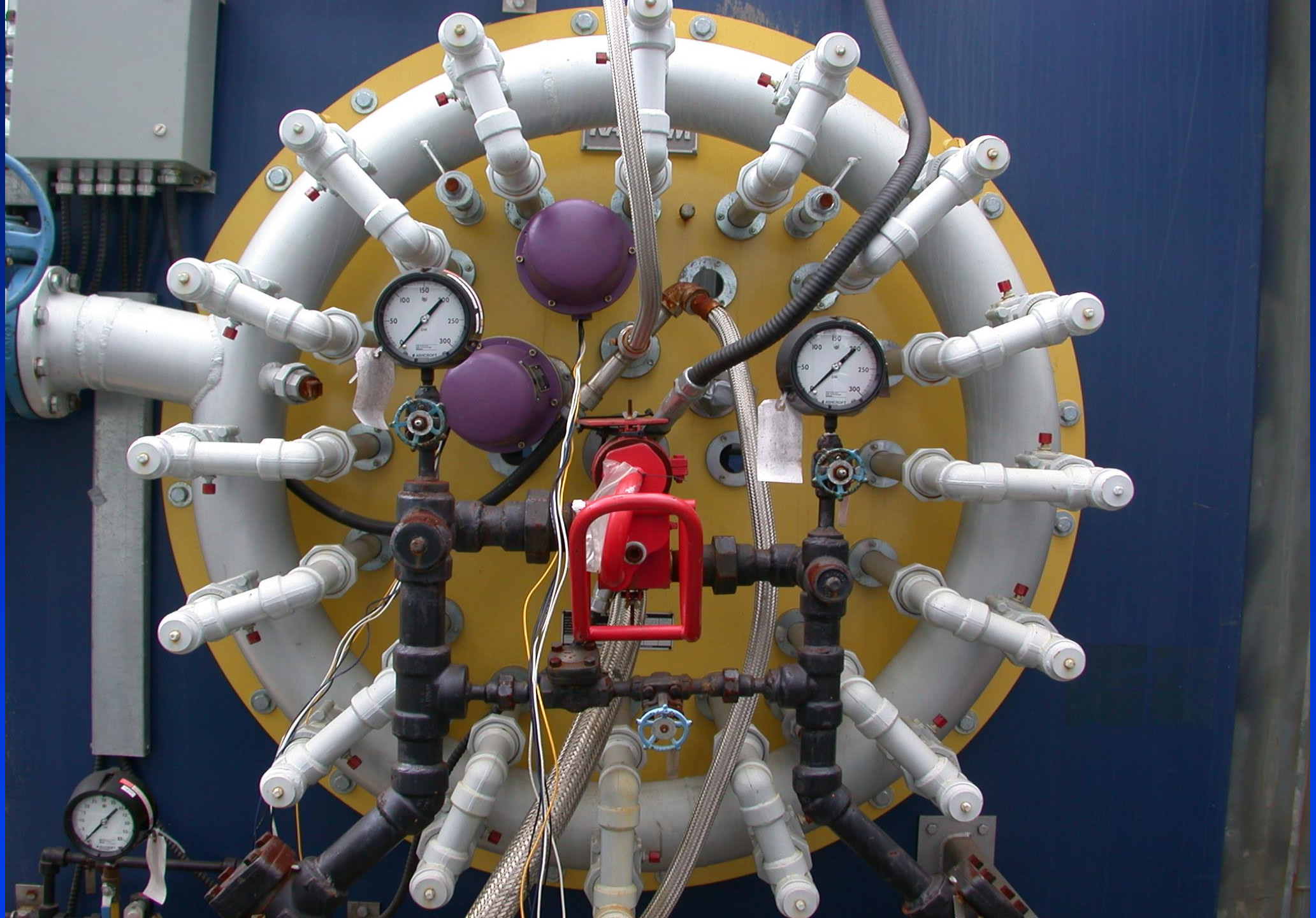
Low-NOx Burner with Staged Fuel



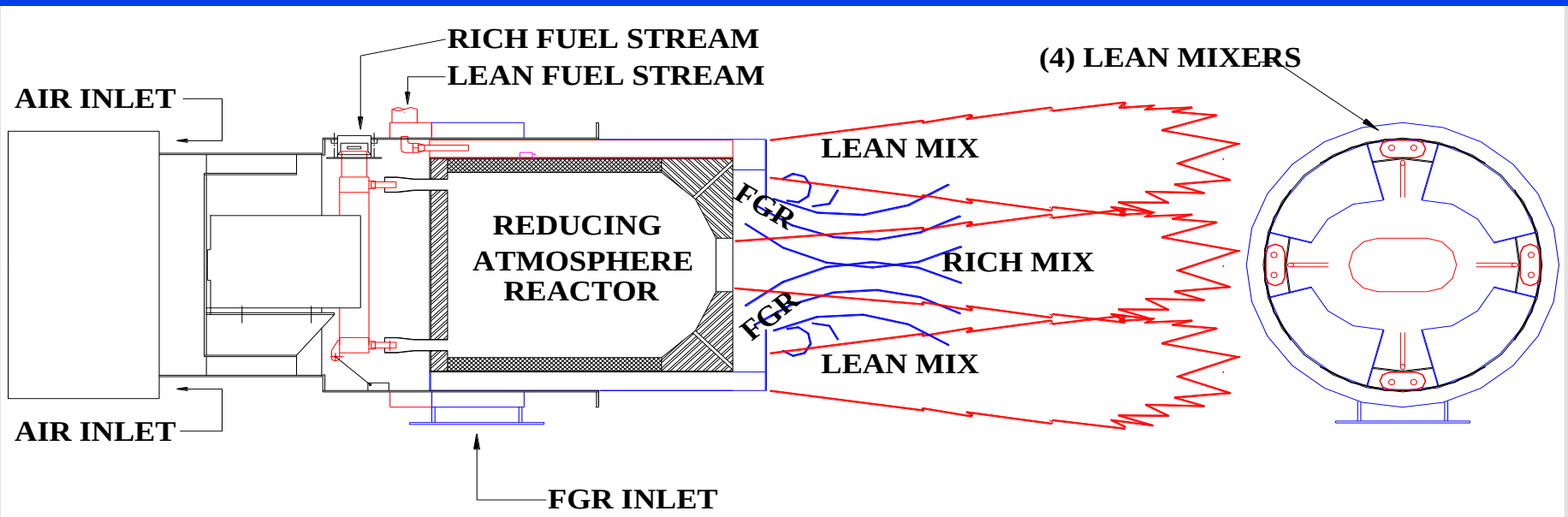
Low-NOx Burner with Staged Fuel



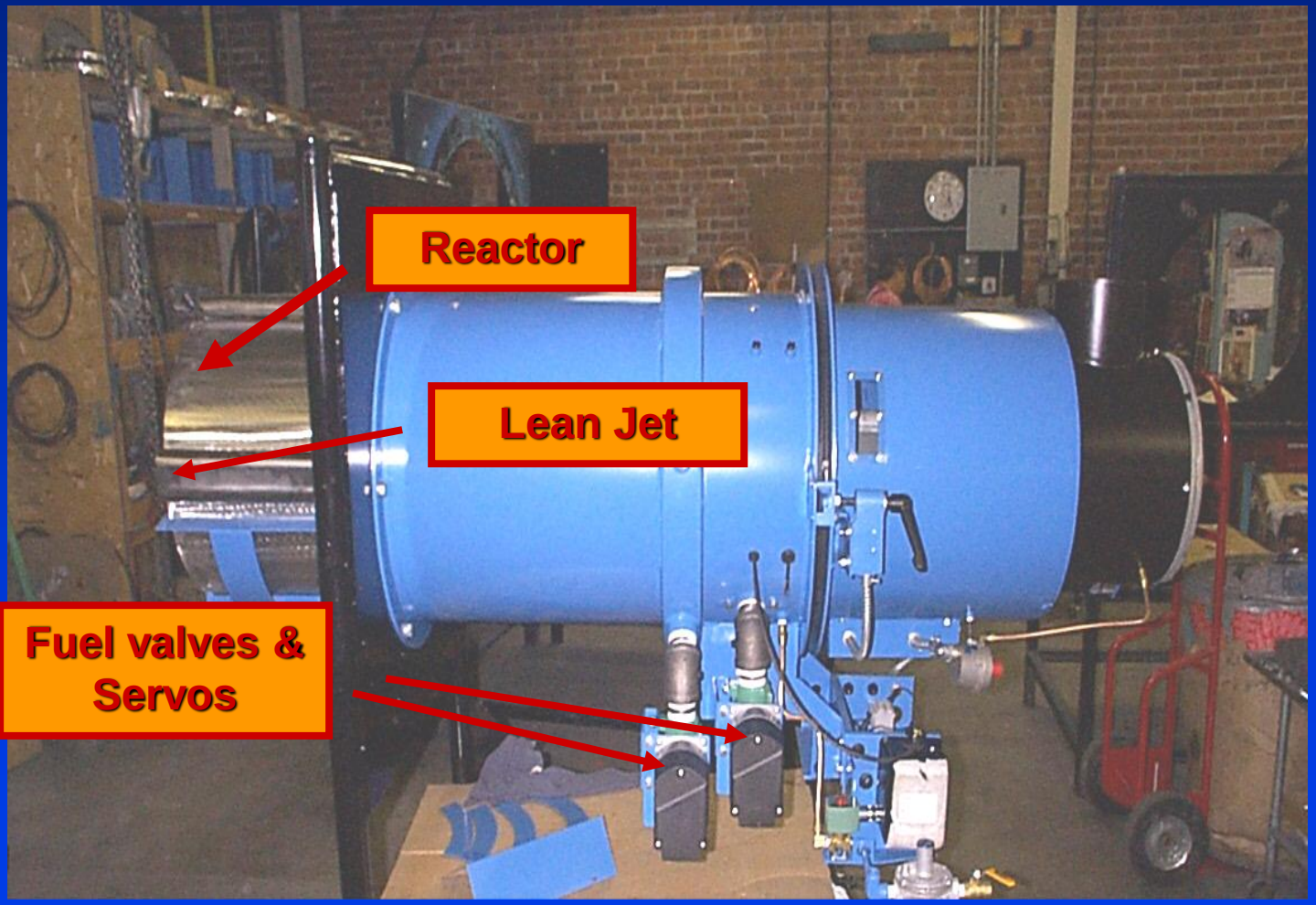
Ultra Low-NOx Burner (9 ppm)



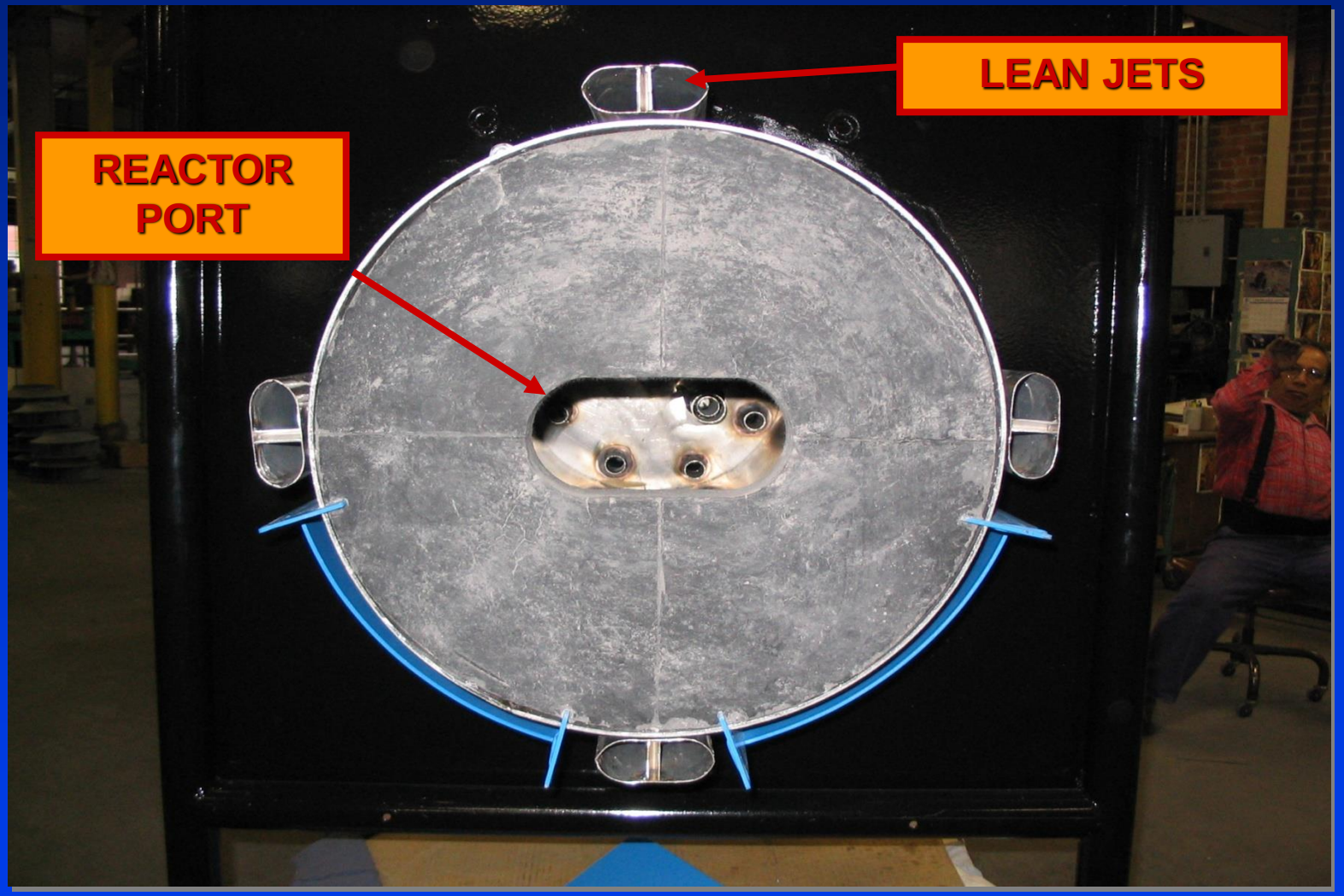
Burner Cross-sectional View



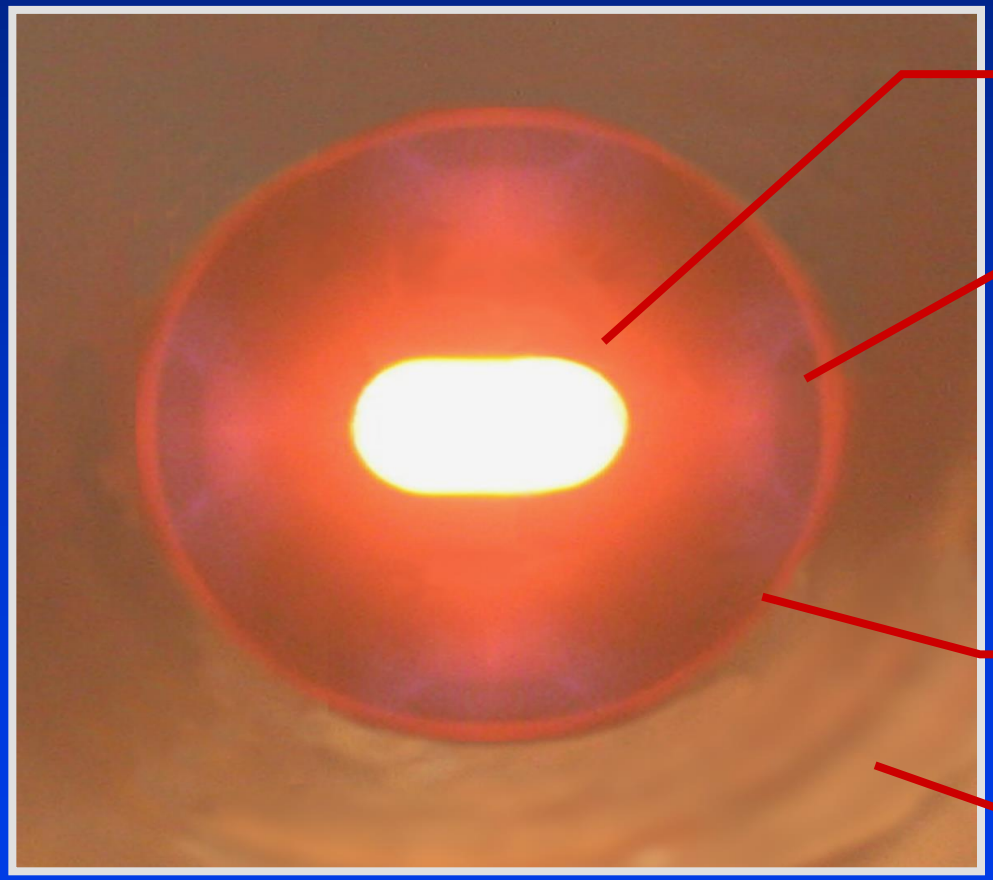
TYPICAL COMPONENTS



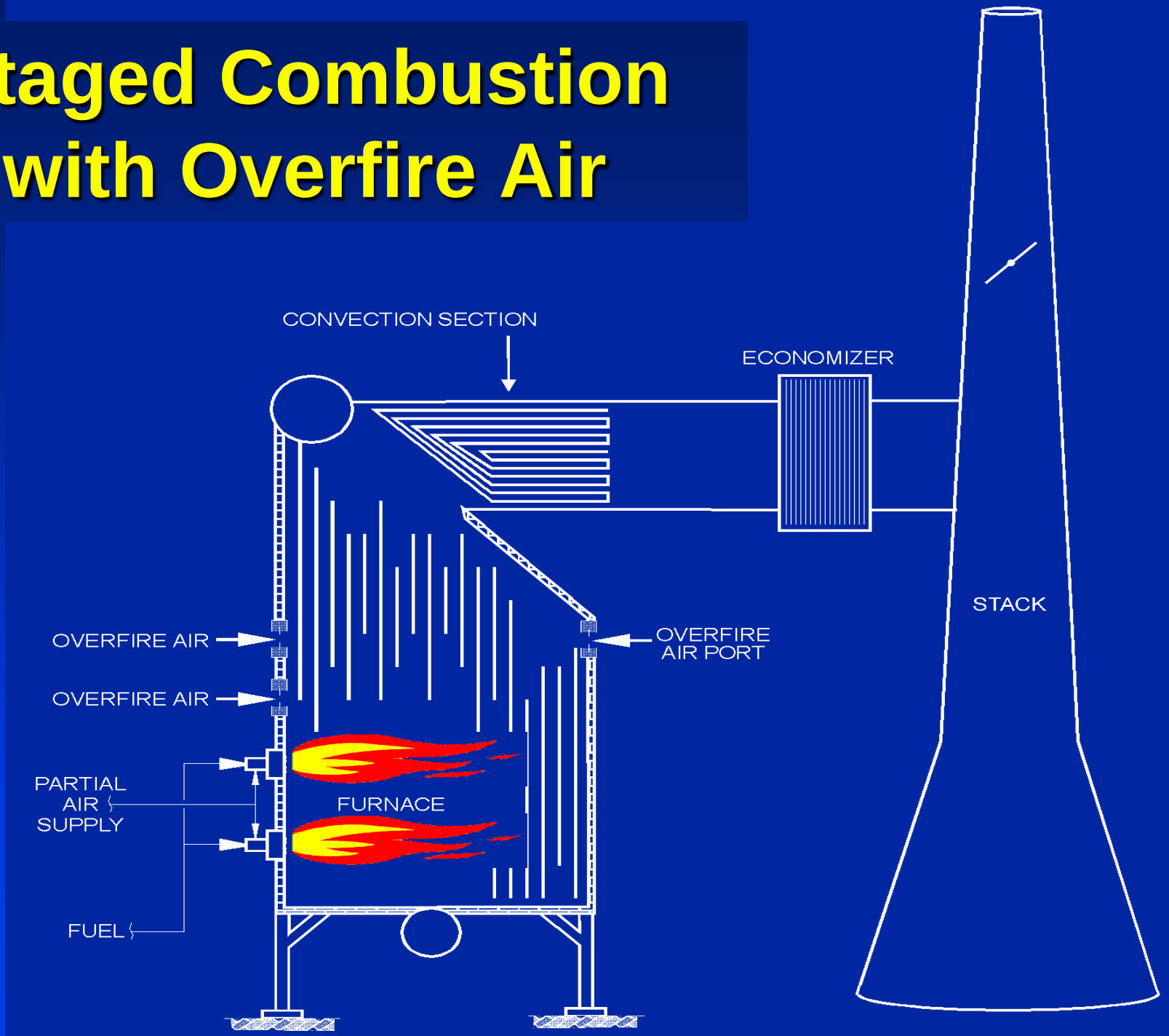
TYPICAL COMPONENTS



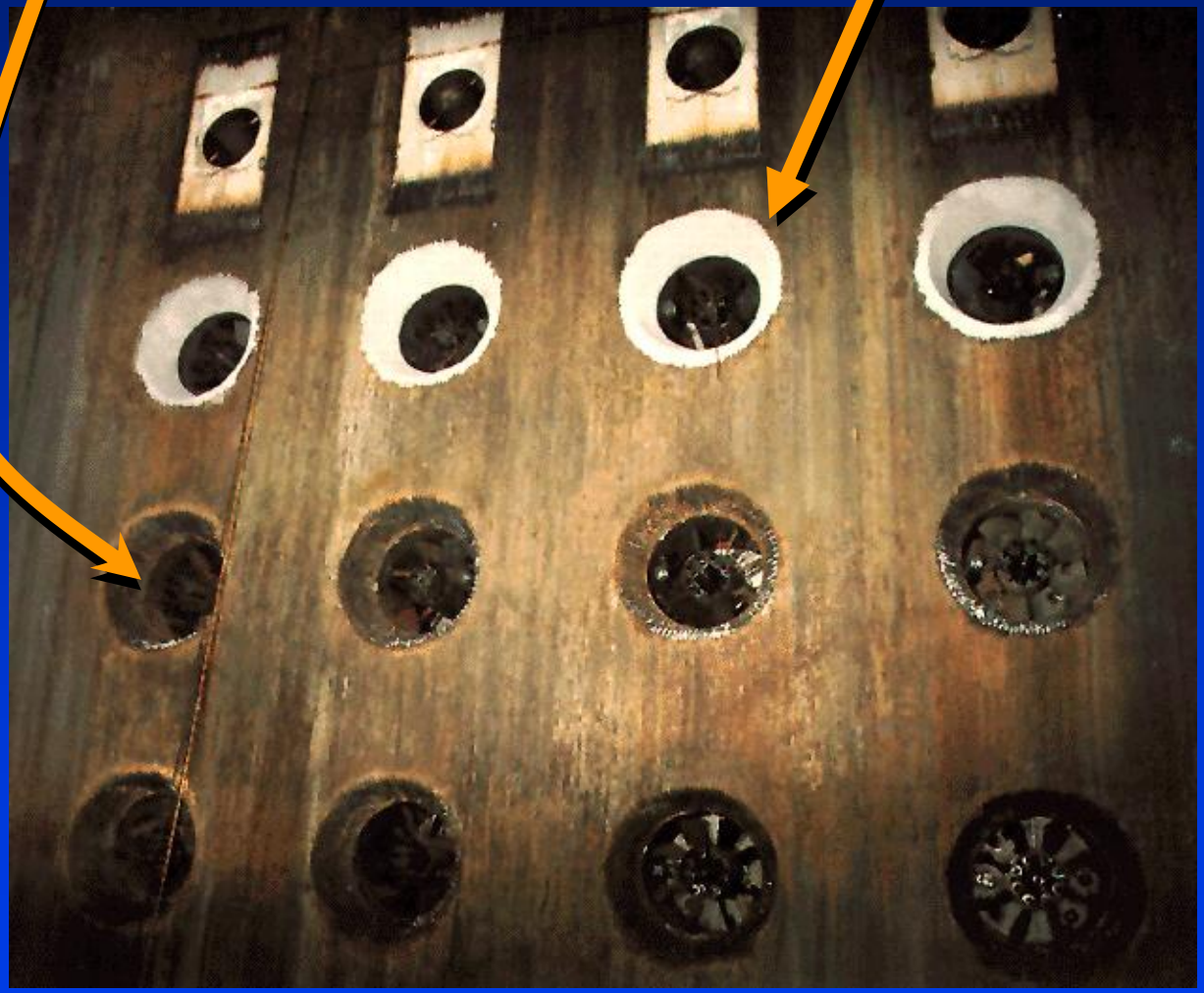
A Look Down the Furnace



Staged Combustion with Overfire Air

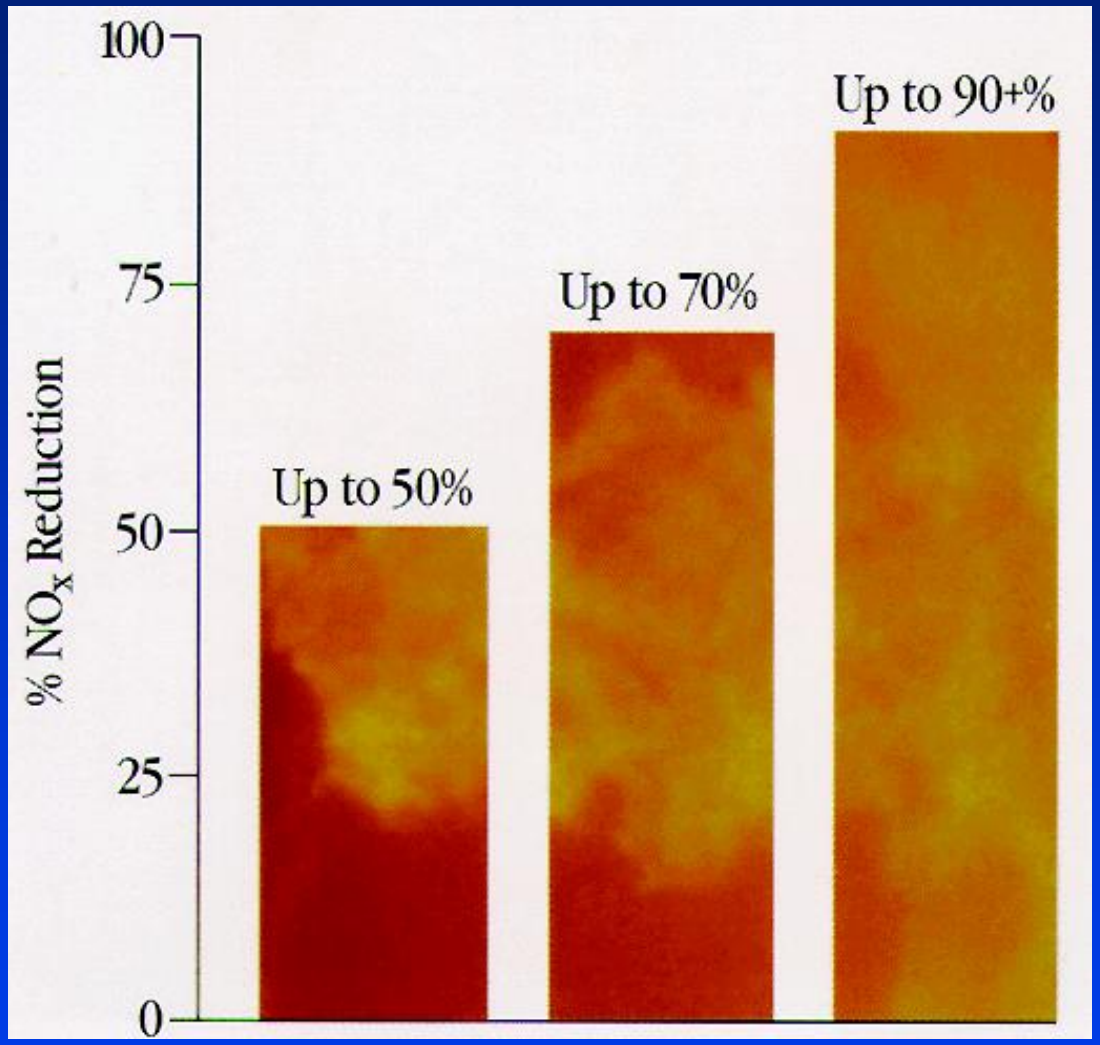


Burners with Overfire Air



Graphic Courtesy of B&W

NOx Reduction by Boiler Configuration



A: Low-NOx burner only, no overfire air (OFA)

B: Low-NOx burner with OFA

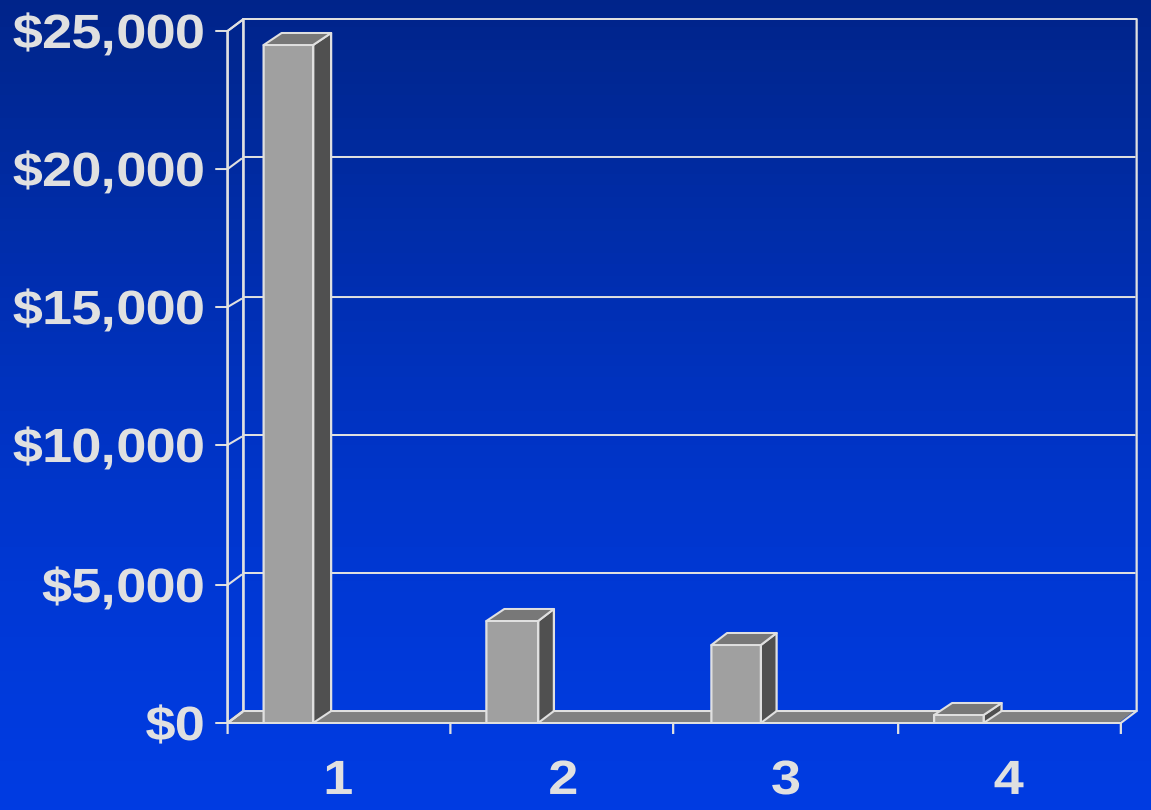
C: Low-NOx burner with OFA and FGR

Graphic Courtesy of B&W

COST $/ TON NOx REMOVED

NEW BOILER SYSTEMS

1. POST COMBUSTION
   $ 24500 (SCR)
2. MASSIVE FGR
   $ 3676
3. POROUS MATRIX
   $ 2787
4. ULTRA LOW NOX TECHNOLOGY
   $258



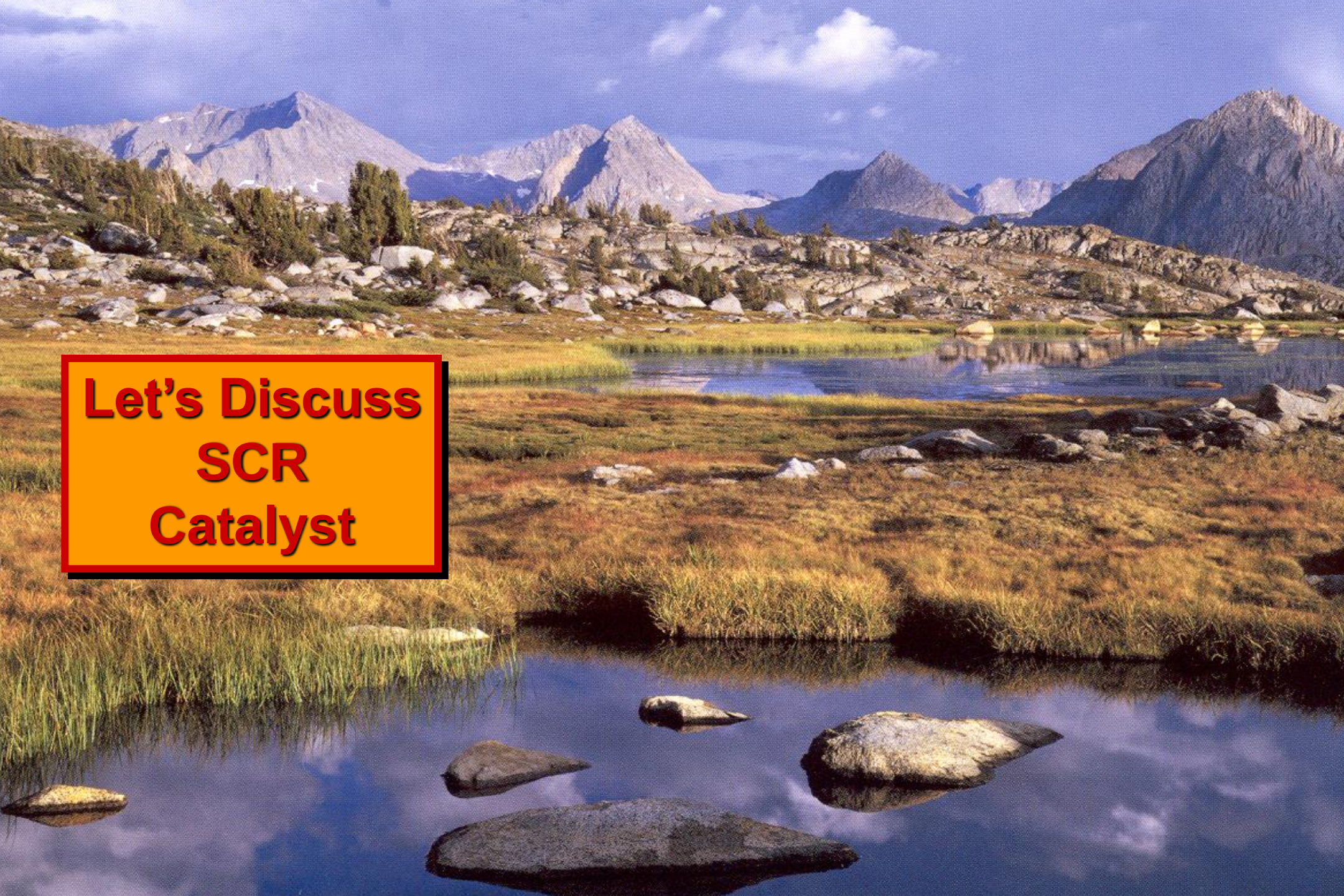
Existing Emissions & Goals

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%

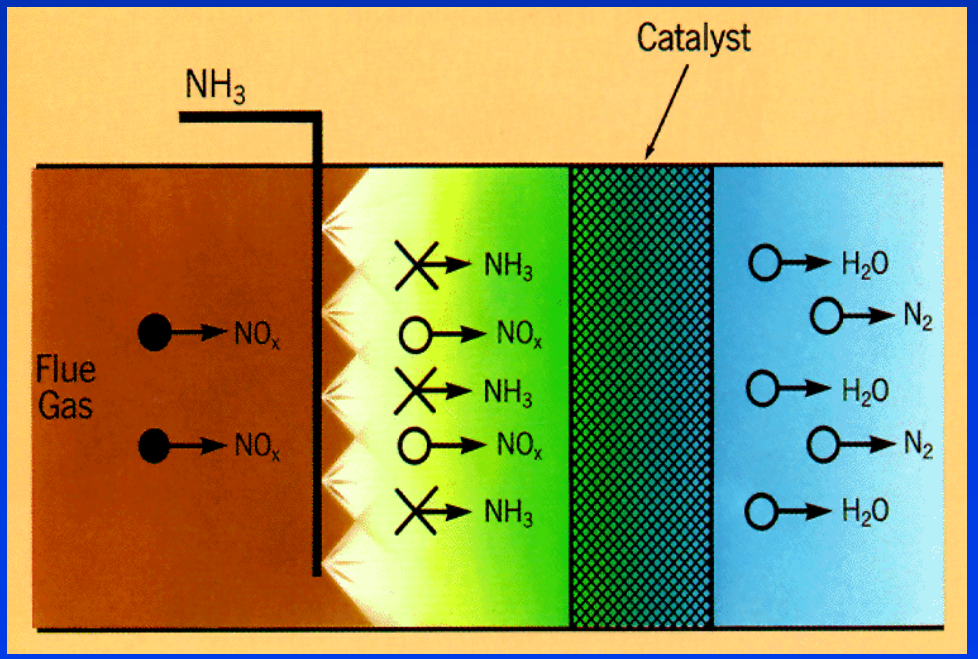
Reduce O2 by 48 - 60%

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

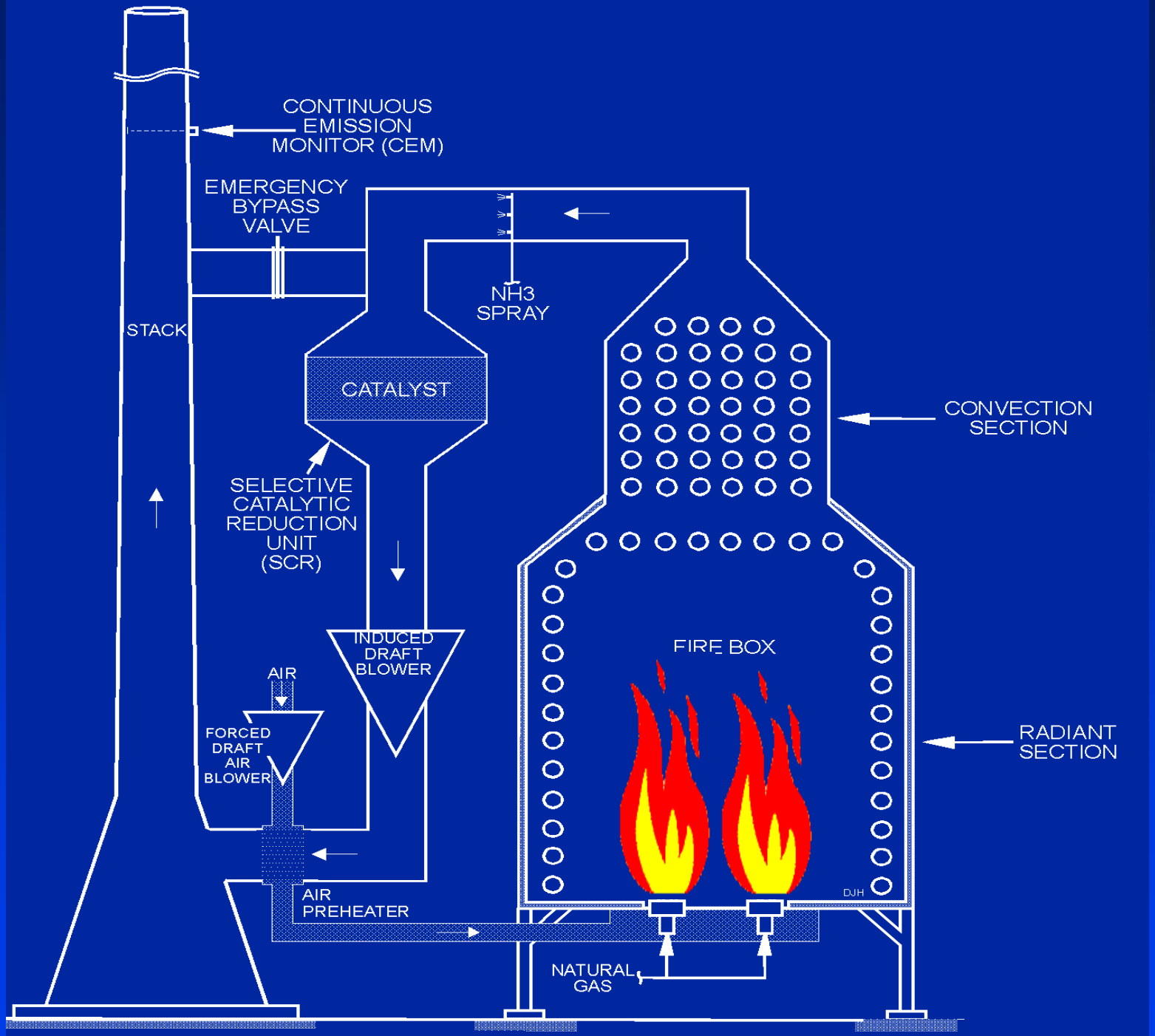

Let's Discuss
SCR
Catalyst

Selective Catalytic Reduction (SCR)

- NOx control thru ammonia (NH_3) injection
- $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
- $2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$
- 90-95% control
- Problems
  - Expensive
  - High maintenance
  - Ammonia "slip"
  - Catalyst replacement & disposal




Small Boiler
with SCR

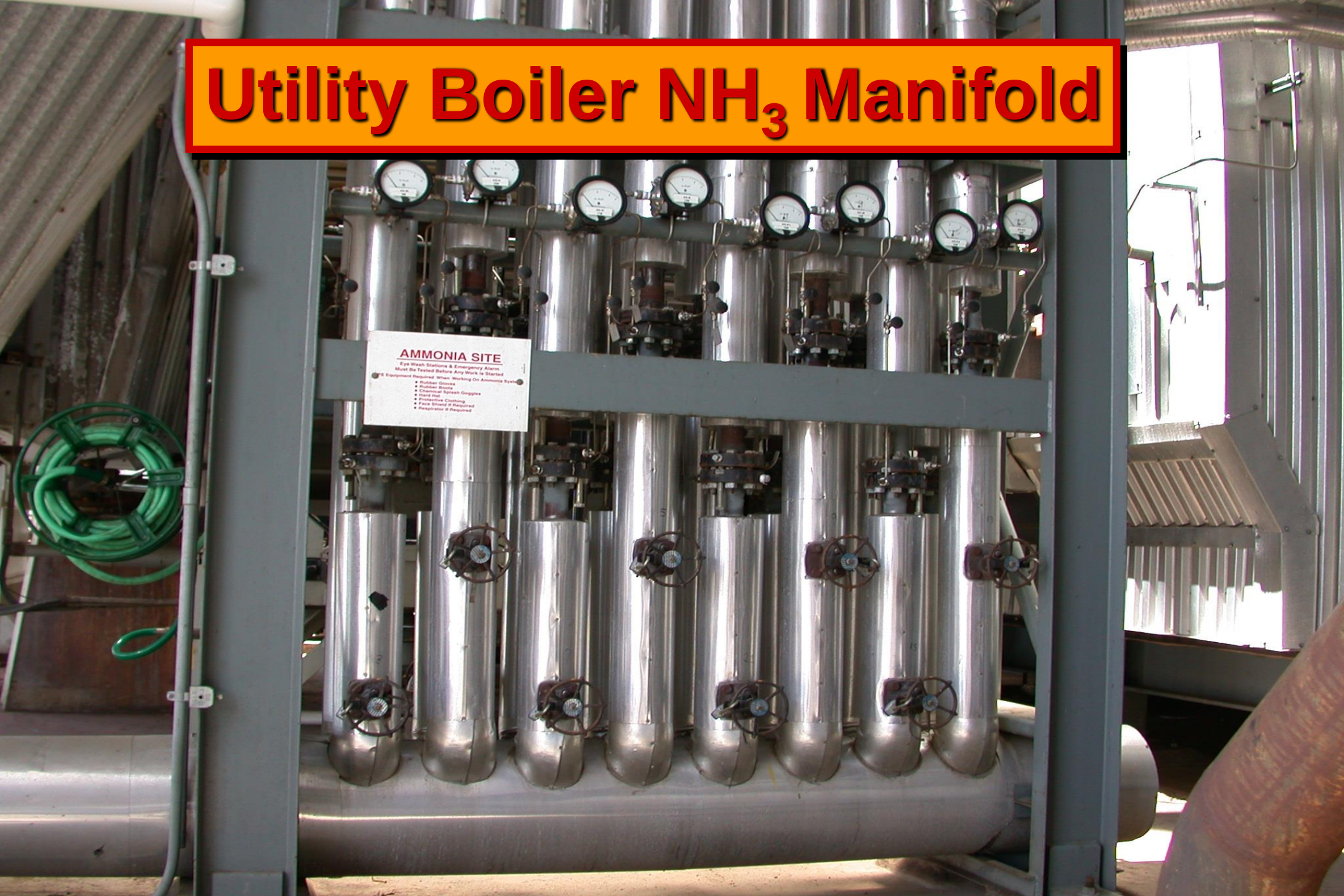


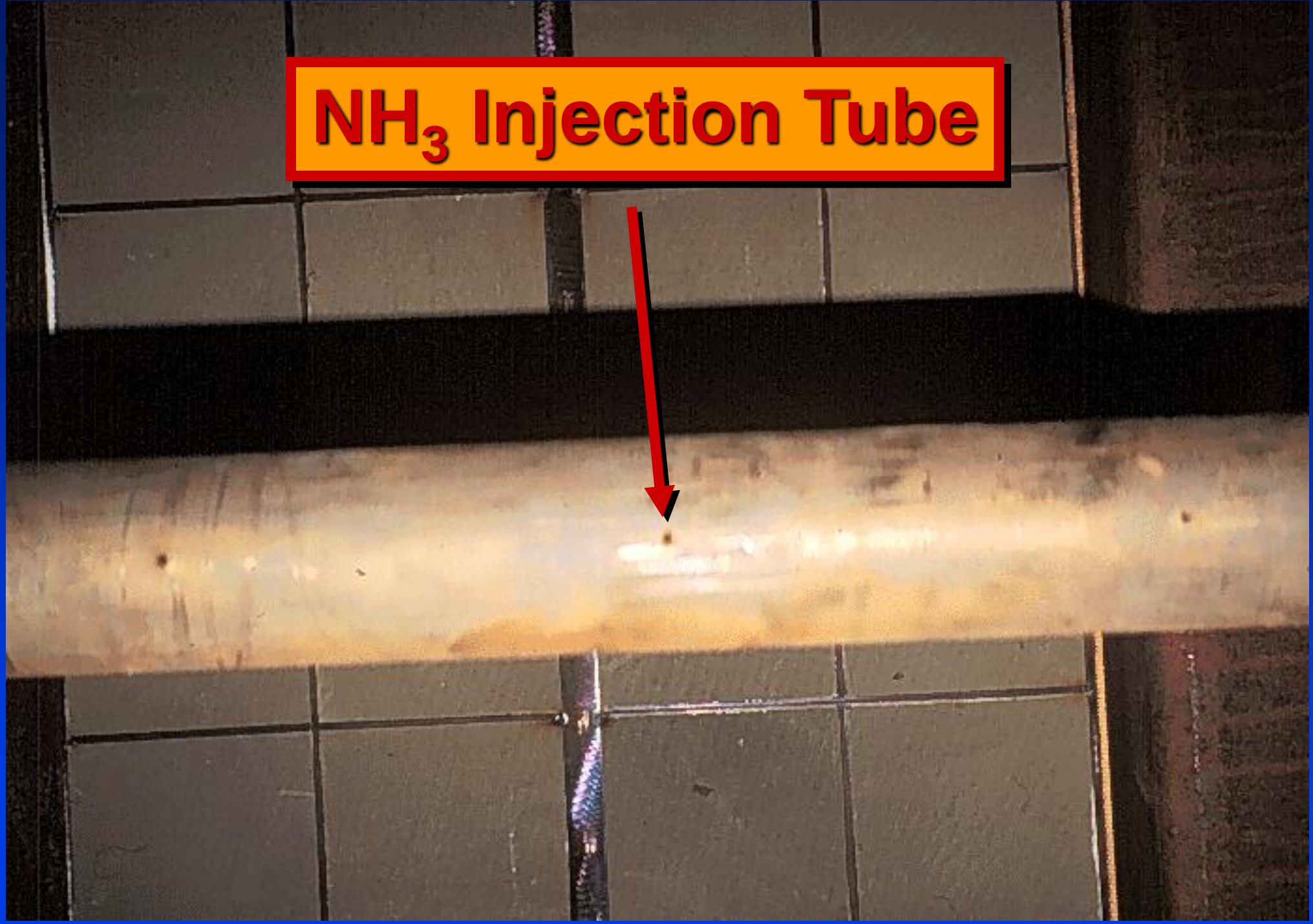
Boiler with Retrofit SCR

Ammonia Storage Tank

Anhydrous Ammonia Storage Tank

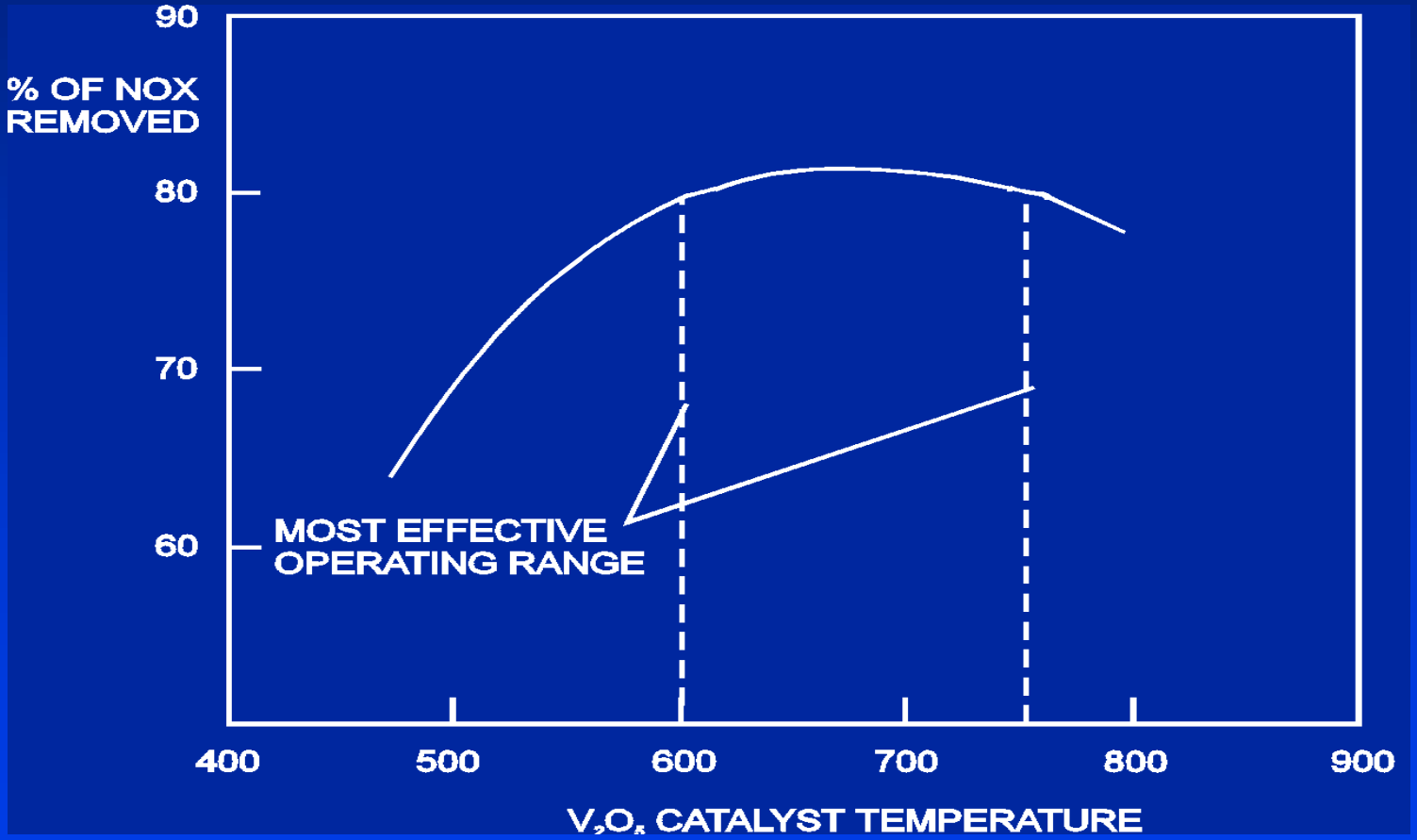
Utility Boiler NH_3 Manifold




NH_3 Injection Tube

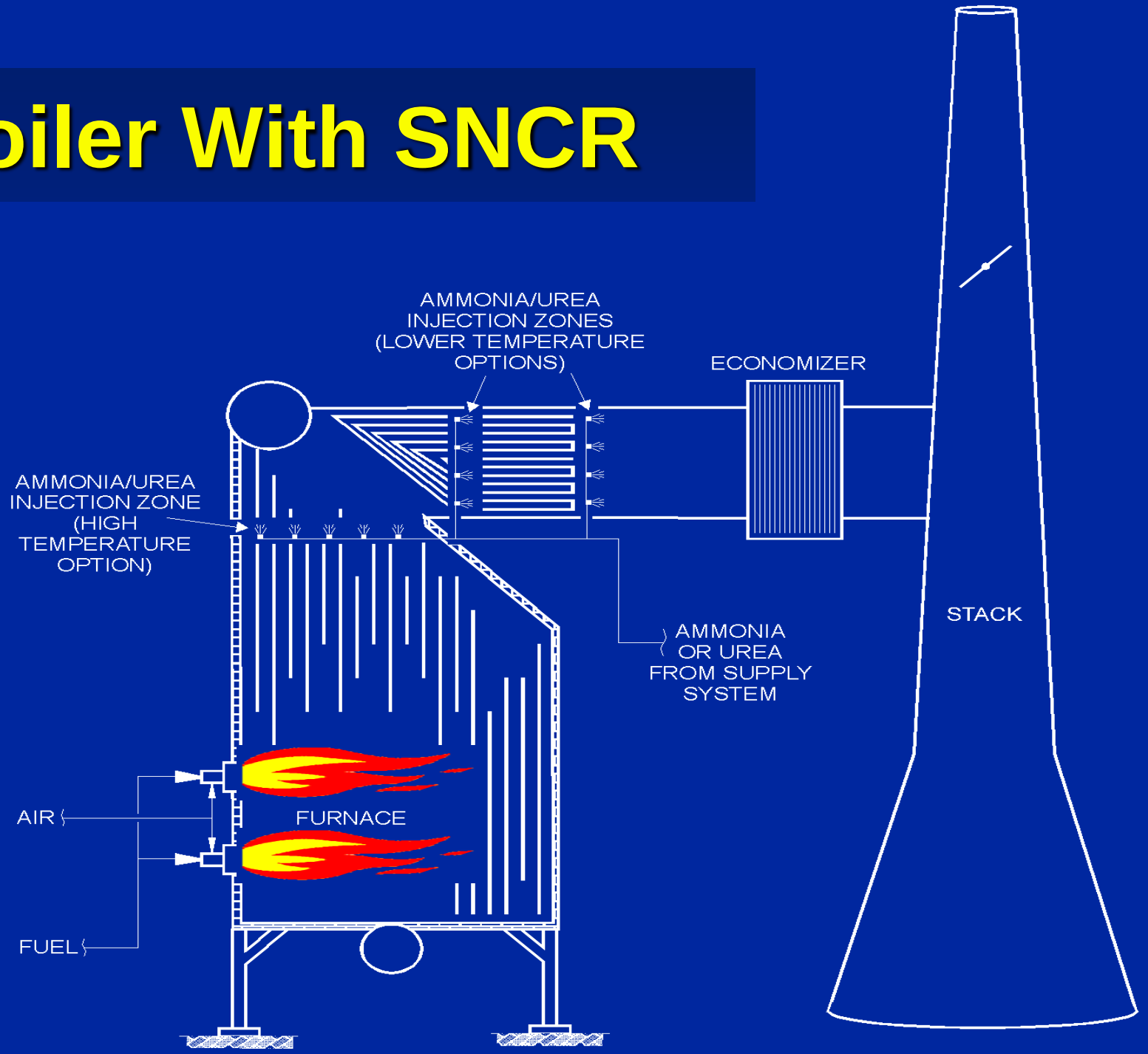

SCR Catalyst

% NOx Removed vs. Vanadium Pentoxide Catalyst Temperature




Boilers
& SNCR
TRUDY S
617342

Boiler With SNCR



Selective Non-Catalytic Reduction

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

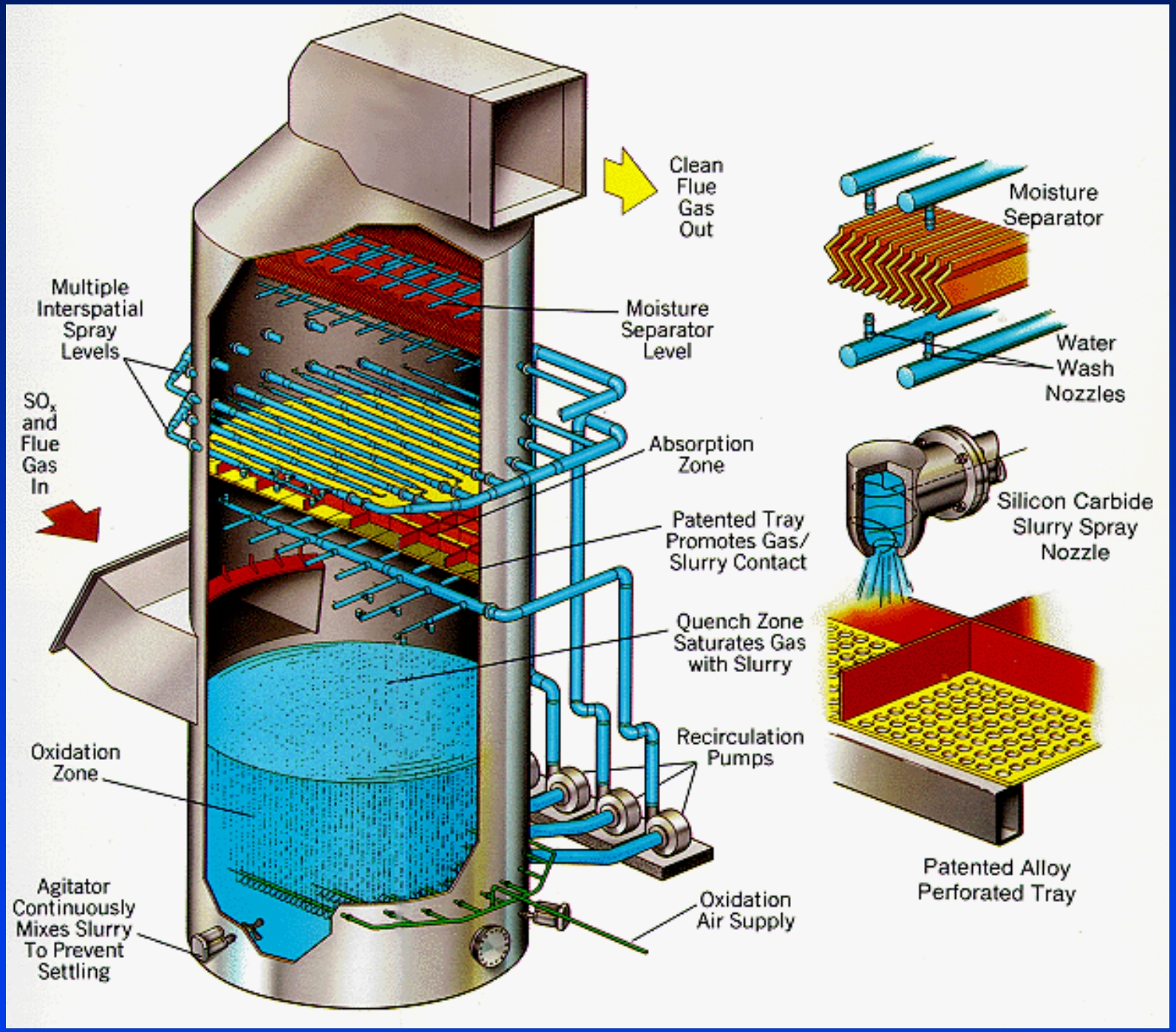
Comparison of NOx Reduction Technologies

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 – Ist gen.	80%	0.03	25 - 30
Ultra Low NOx burners – 2nd 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


Let's Discuss
SOx Control

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

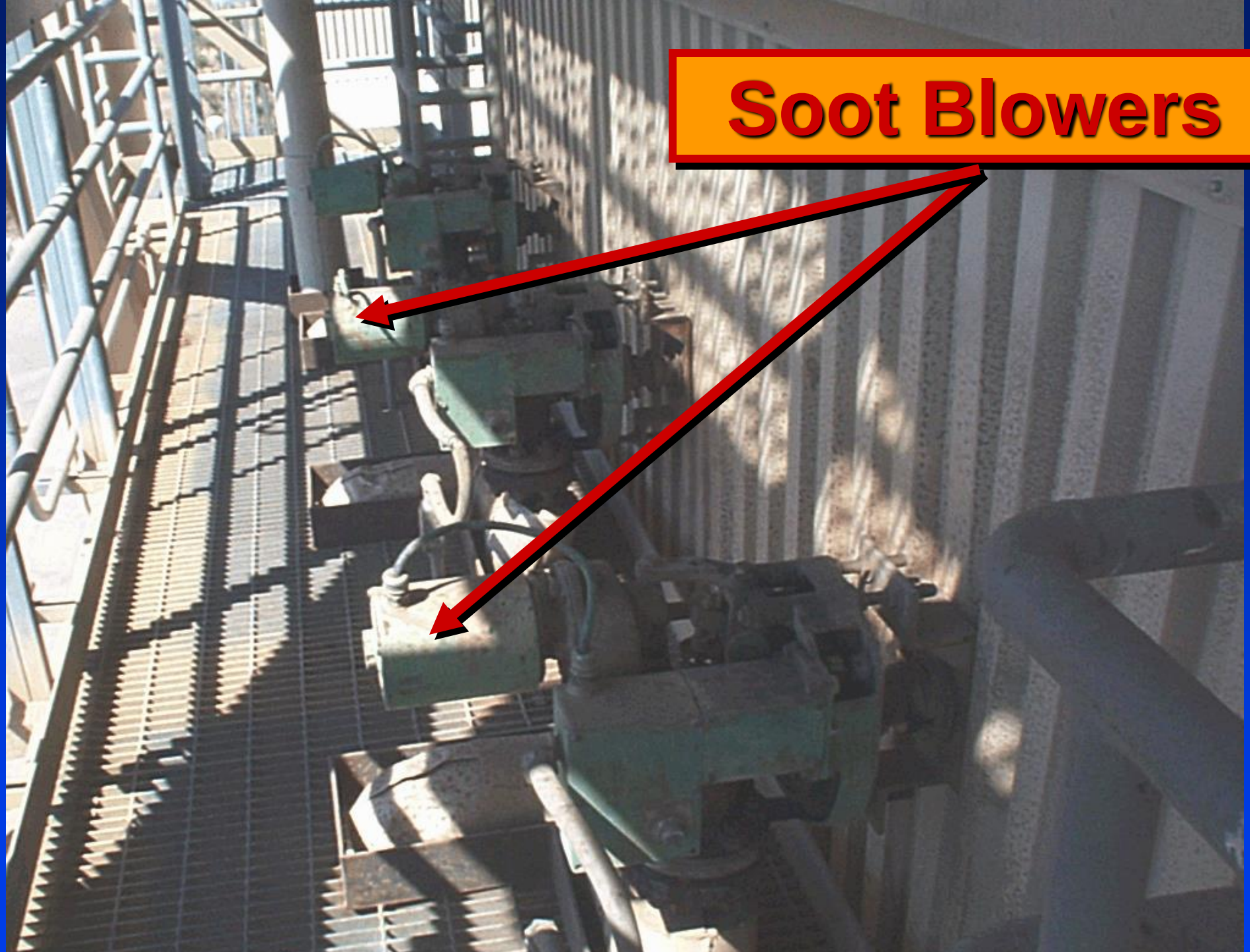

Let's Discuss
PM Control

Control of Particulate Emissions

- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers


Water Spray

Soot Blowing


Soot Blowers


Soot
Blowing/
Rapping


Cyclone

Multi-Cyclone

Graphic Courtesy of B&W


Baghouse


Baghouse
Dirty
Clean


ESP

Regulatory Requirements

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

- NOx, 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

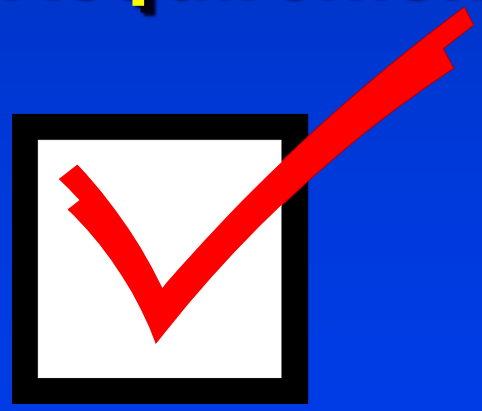
Type of Control	NOx Limits
Natural Gas Fired with SCR or equal	6 - 9 ppmvd @3% O_2 (0.011 lb/MMBTU
Natural Gas Fired with Ultra Low NOx Burner	15 ppmvd @3% O_2 (0.018 lb/MMBTU
Natural Gas Fired with Low NOx Burner	20 ppmvd @3% O_2 (0.024 lb/MMBTU

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
- SO_2
- CO
- O_2 and/or CO_2
- Ammonia
- Mercury Semi-Continuous

Source Testing

- Particulate Matter (PM, PM10, PM2.5)
- NOx, 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 NOx, CO, O_2
- Determination of FGR rate
- Burner mechanical adjustments
- O_2 Trim concentration
- FGR valve(s) setting

Portable Combustion Analyzer


Boiler Inspections

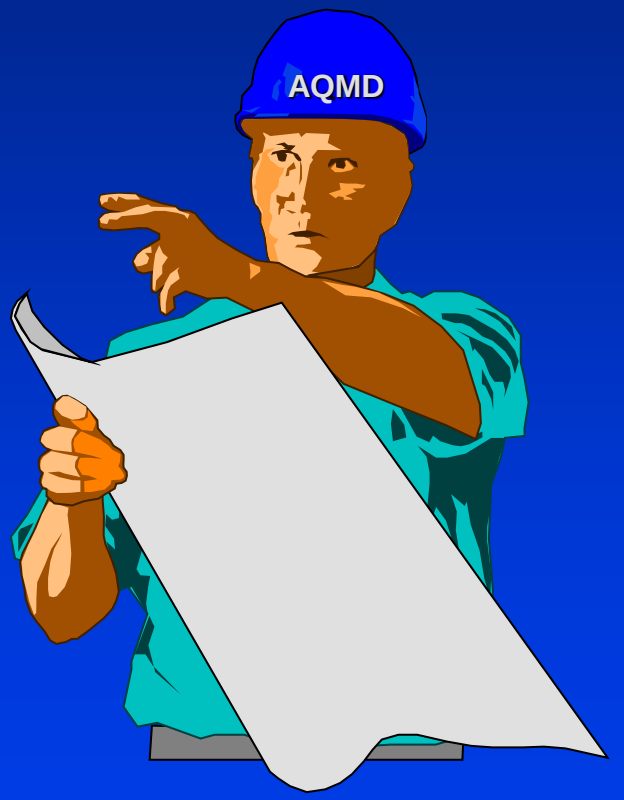

Points of Inspection
♦ Capture
♦ Transport
♦ Air mover
♦ Control device
♦ Instrumentation
♦ Subsystem
♦ Records

Pre-Inspection

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

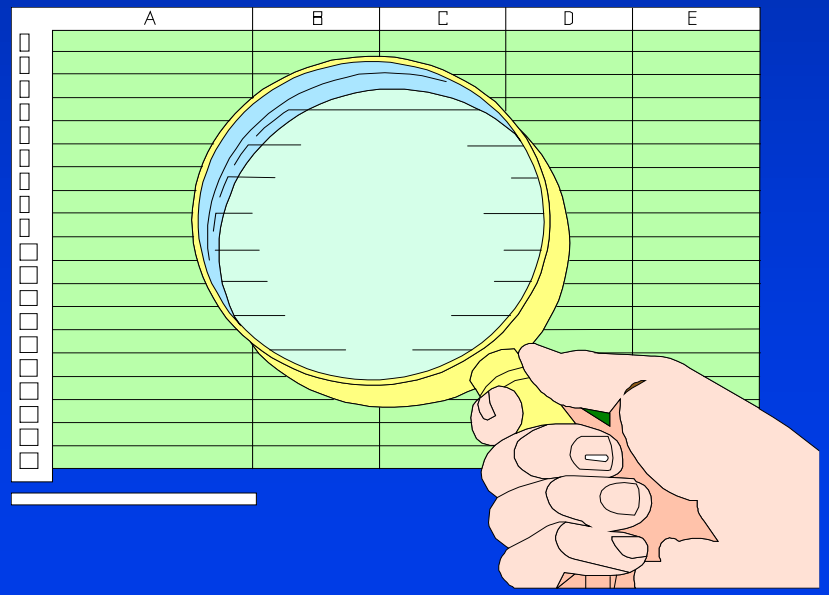
Reasons for Inspections

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



Inspection

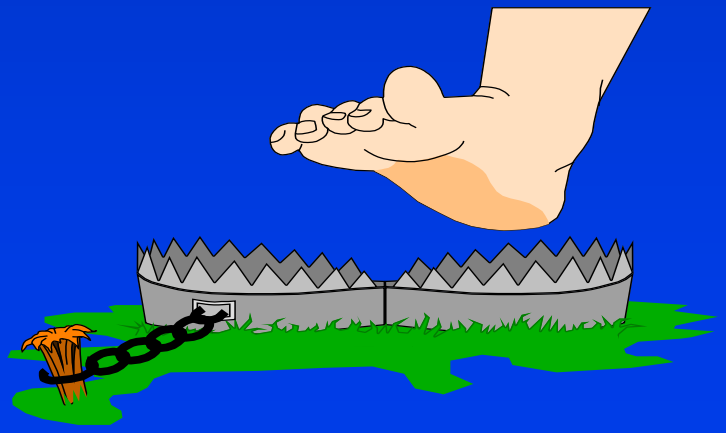
- Visible emission evaluation
- General upkeep & maintenance
- Monitoring instruments & records
- Fuel type and quality
- Maintenance records
- Operational records
- Source tests




Plant
Safety

Inspector Safety

- Proper equipment
- Plant warnings
- Heat
- High pressure steam
- Electrical hazards



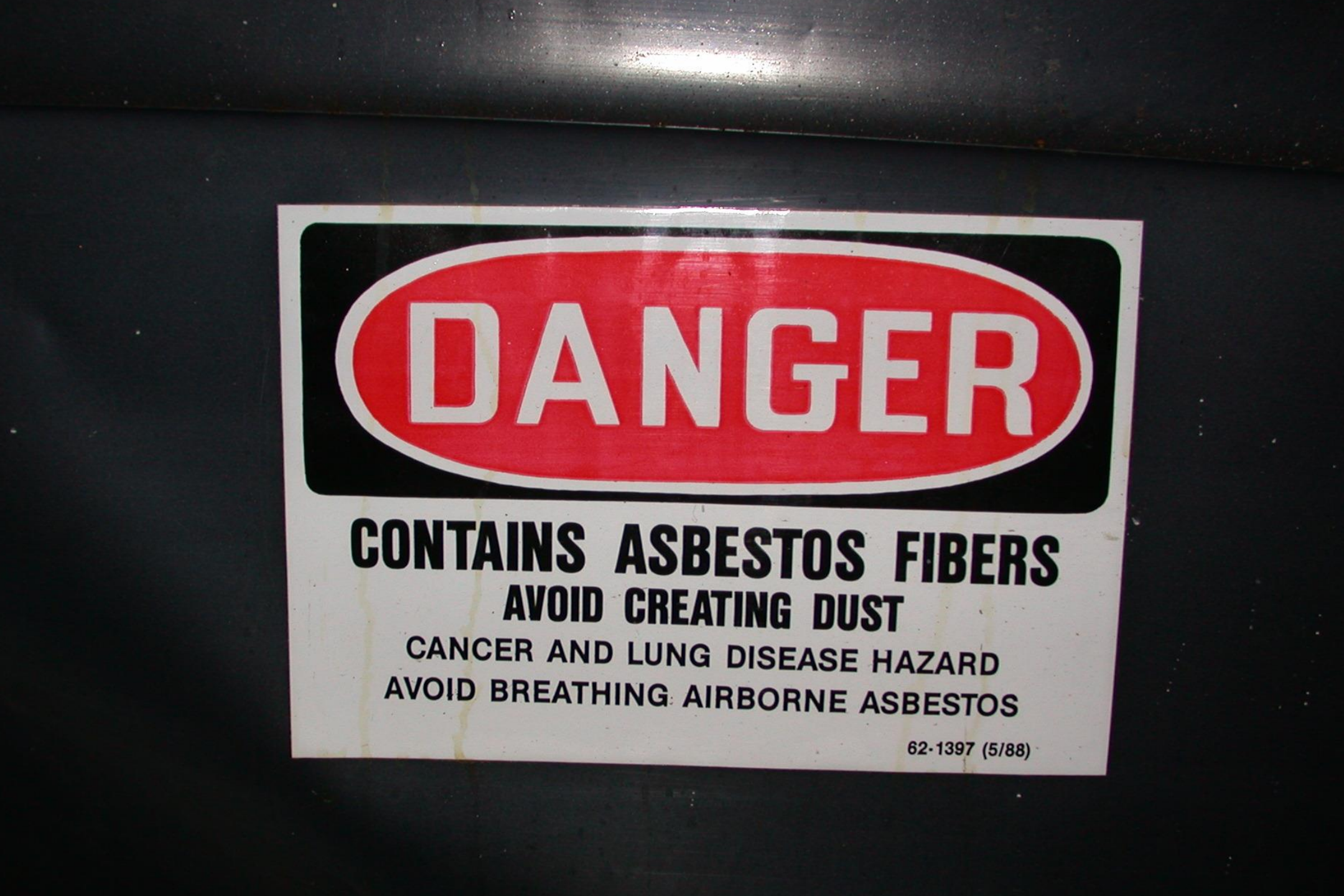
- Noise
- Moving parts
- Inhalation hazards
- Hazardous materials
- Machine disintegration
- Fires
- Other hazards & traps


Plant Safety


Plant Hazards


Confined
Space

Confined Space


DANGER
CONTAINS ASBESTOS FIBERS
AVOID CREATING DUST
CANCER AND LUNG DISEASE HAZARD
AVOID BREATHING AIRBORNE ASBESTOS
62-1397 (5/88)

HP Gas Lines


Ruptured
Steam Line


Steam
Exhaust


Access


Access


Thank You!