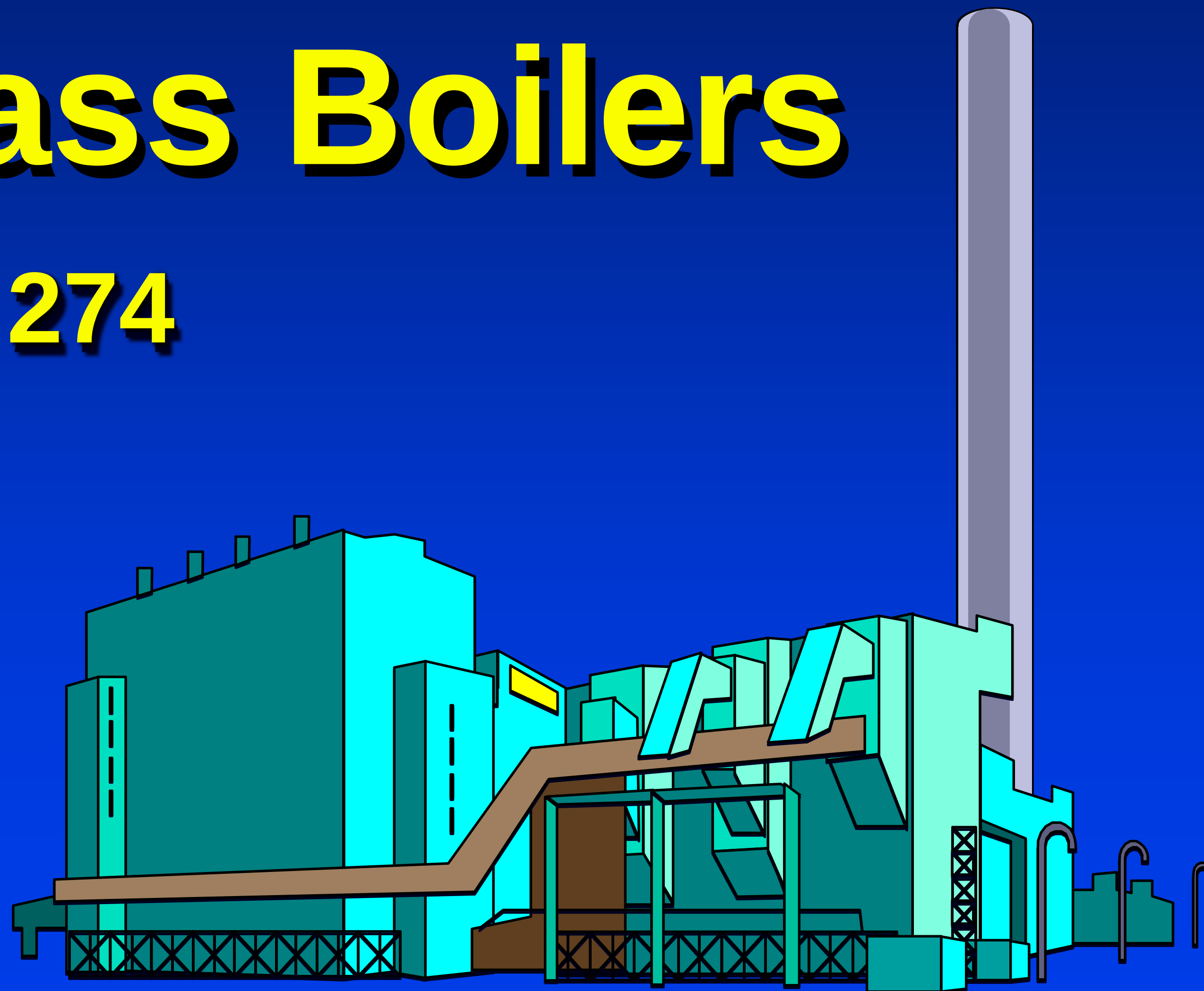
California Environmental Protection Agency

Biomass Boilers

Course # 274

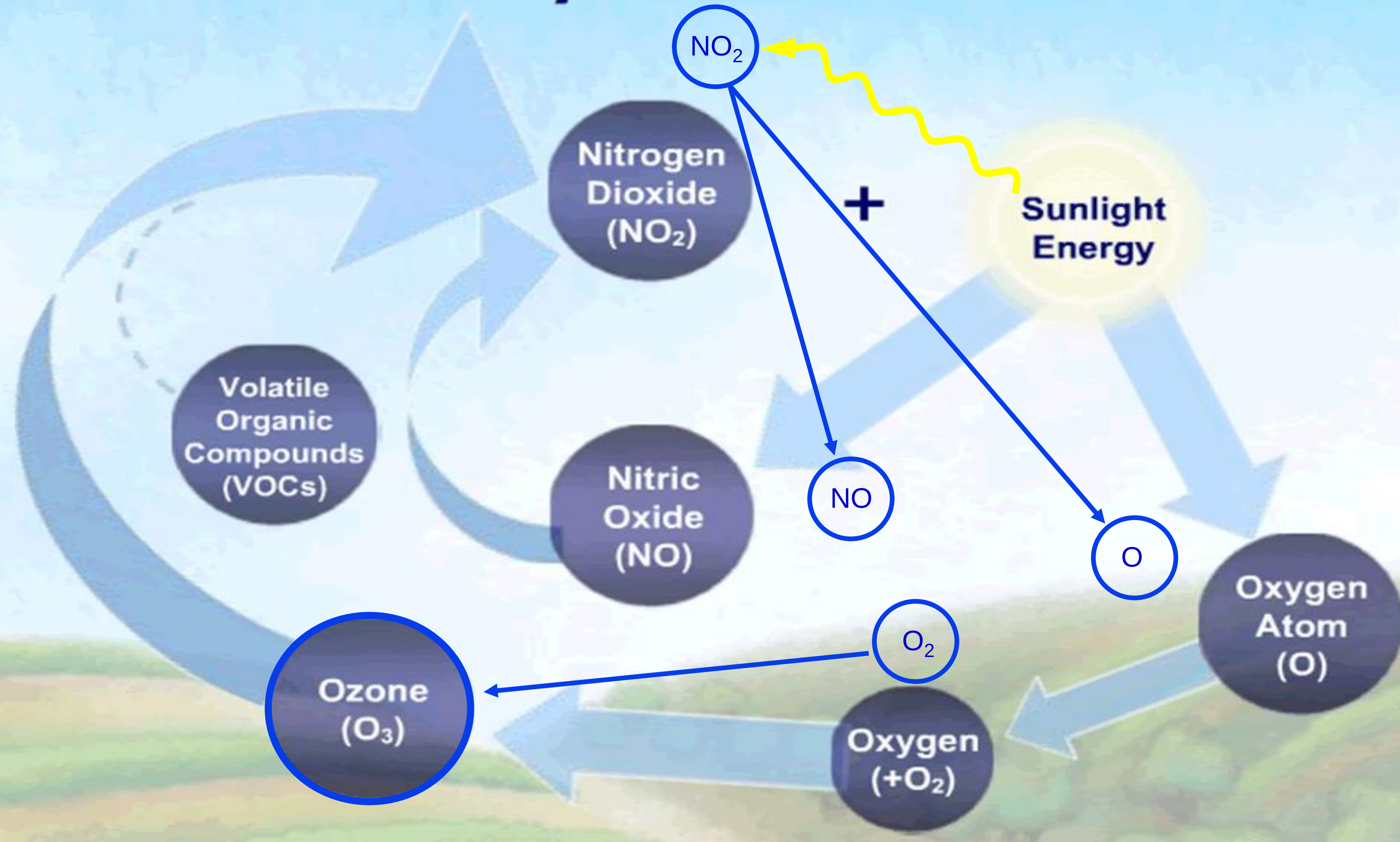


Course Overview

- **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 (1,800 -3,800 psi)

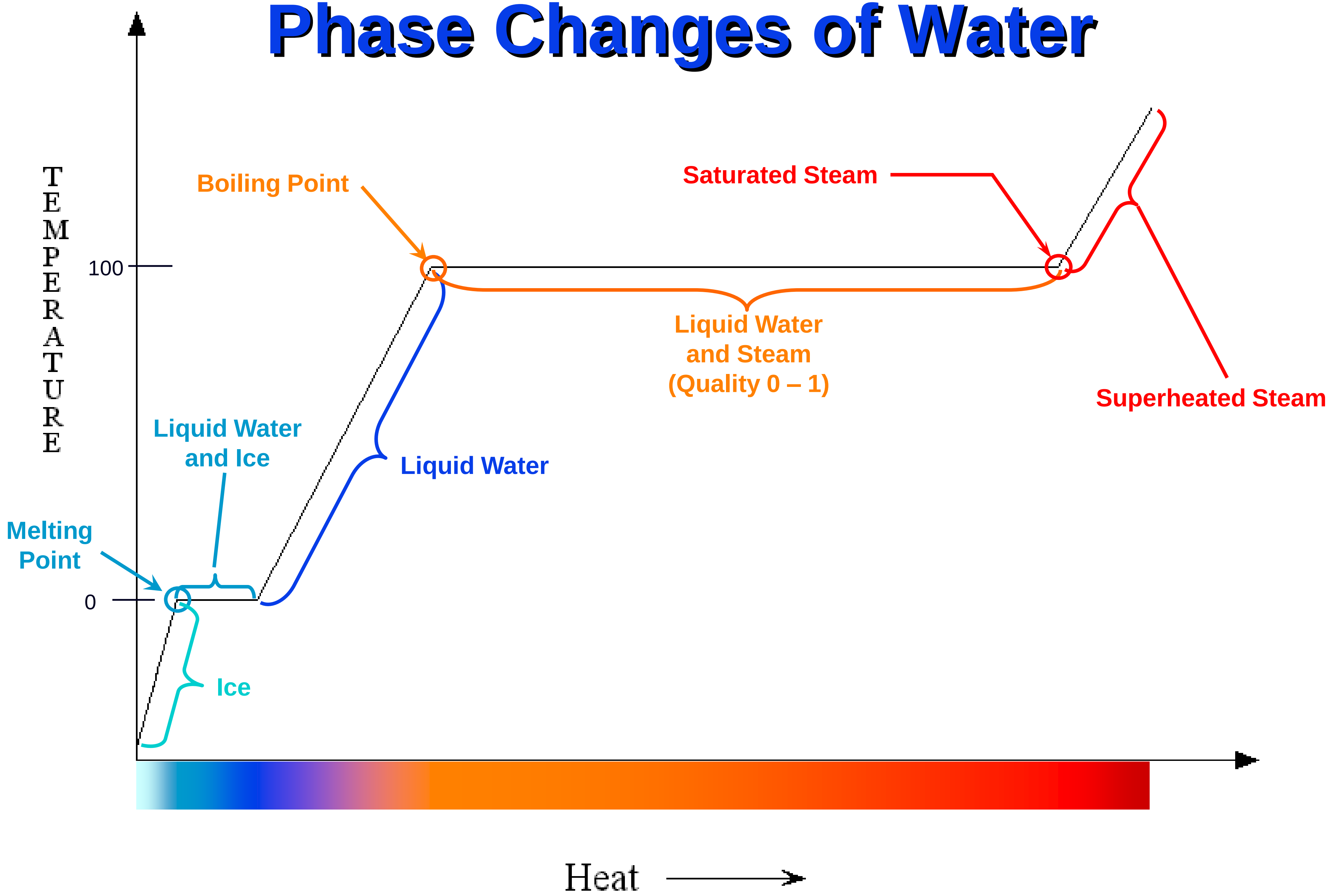
- Space heating — Low Pressure (150 – 1,600 psi)
- Food preparation
- Commercial laundries
- Pulp & paper industry
- Petroleum industry
- Chemical industry

Small Firetube Boiler


Industrial
Boiler

Biomass Utility Boiler

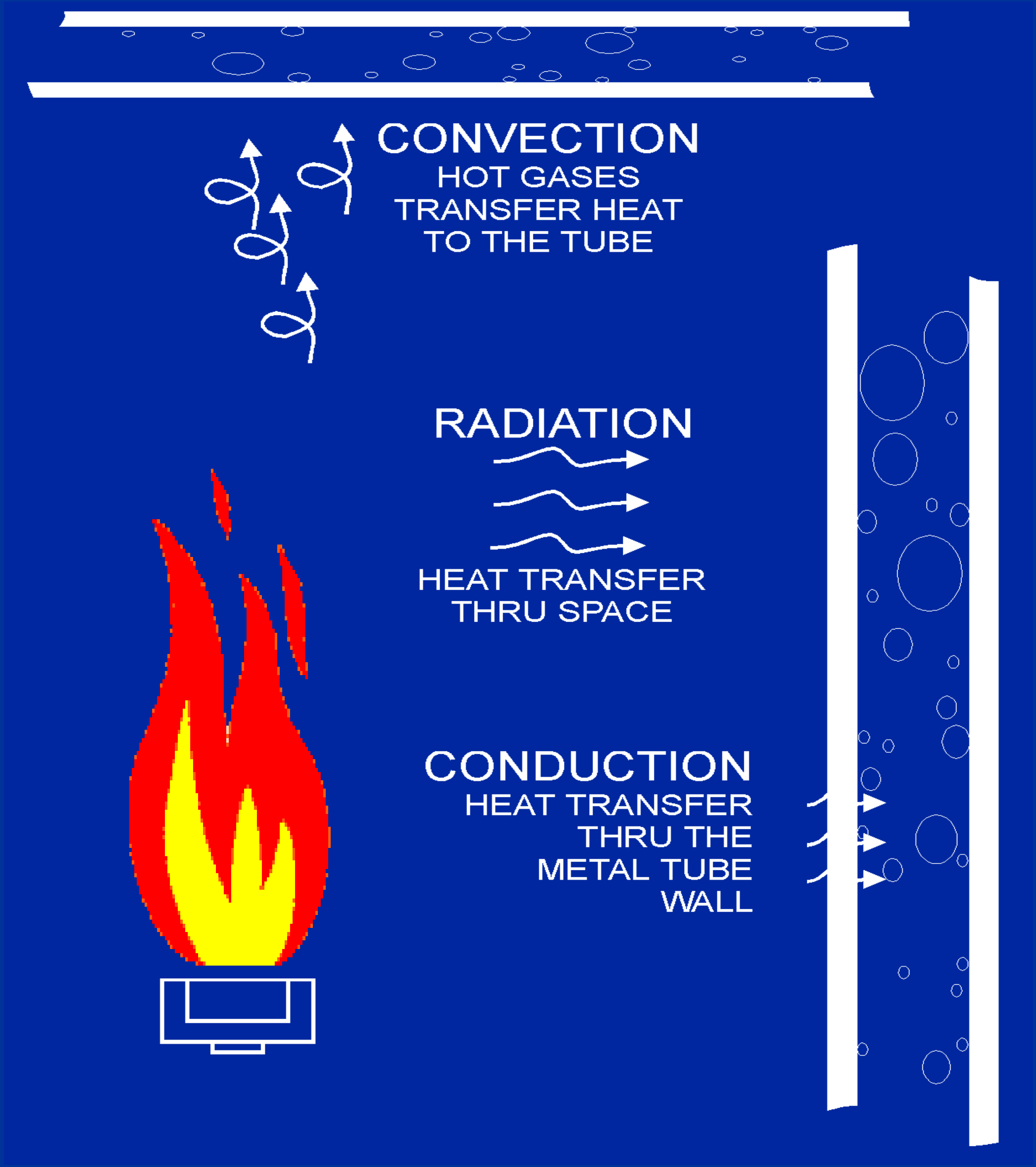
Phase Changes of Water



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

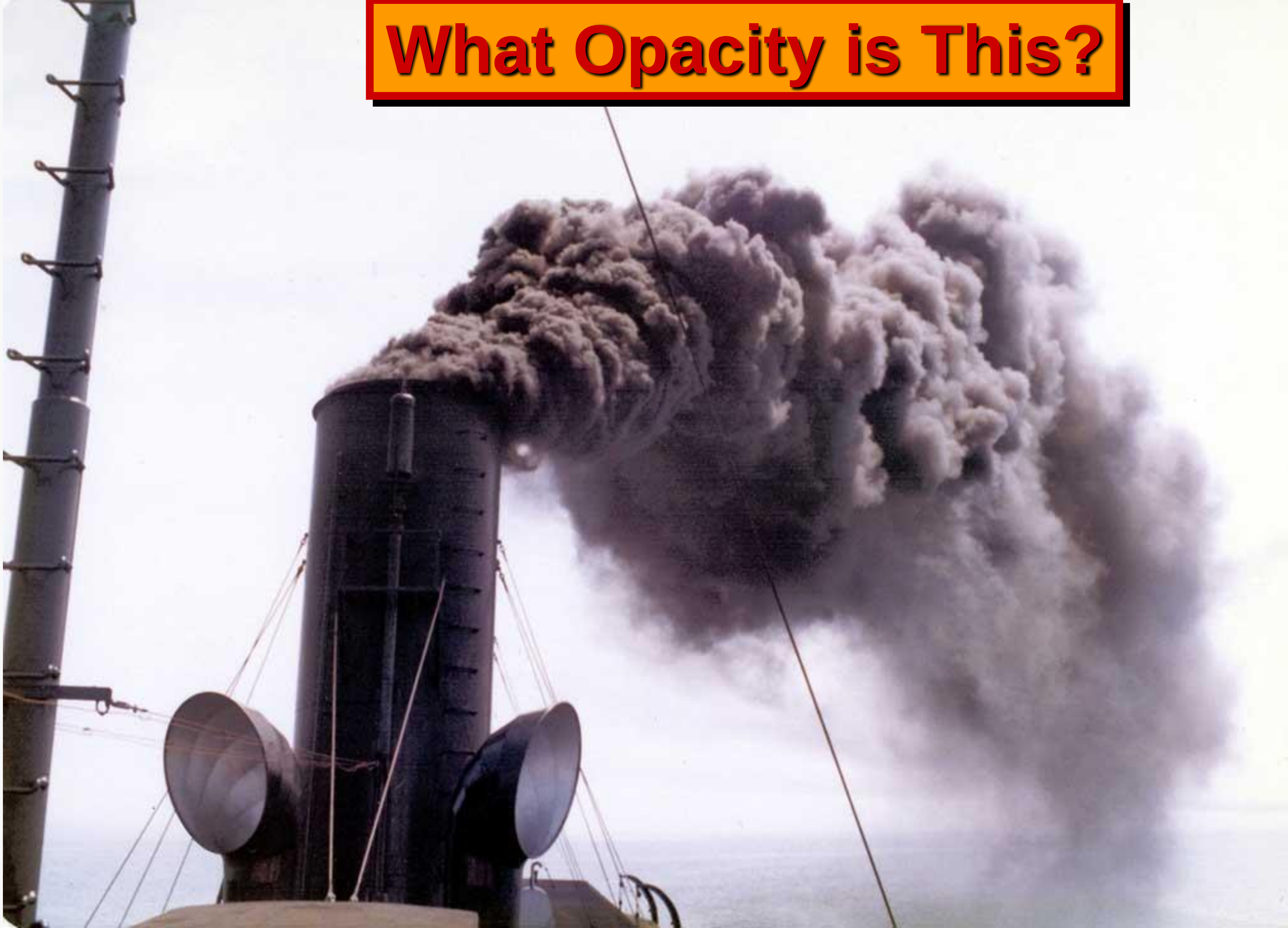
- Lower Heating Value (LHV)
  - Heating value of a fuel not counting heat needed to vaporize water
- Higher Heating Value (HHV)
  - Heating value of a fuel including heat needed to vaporize water



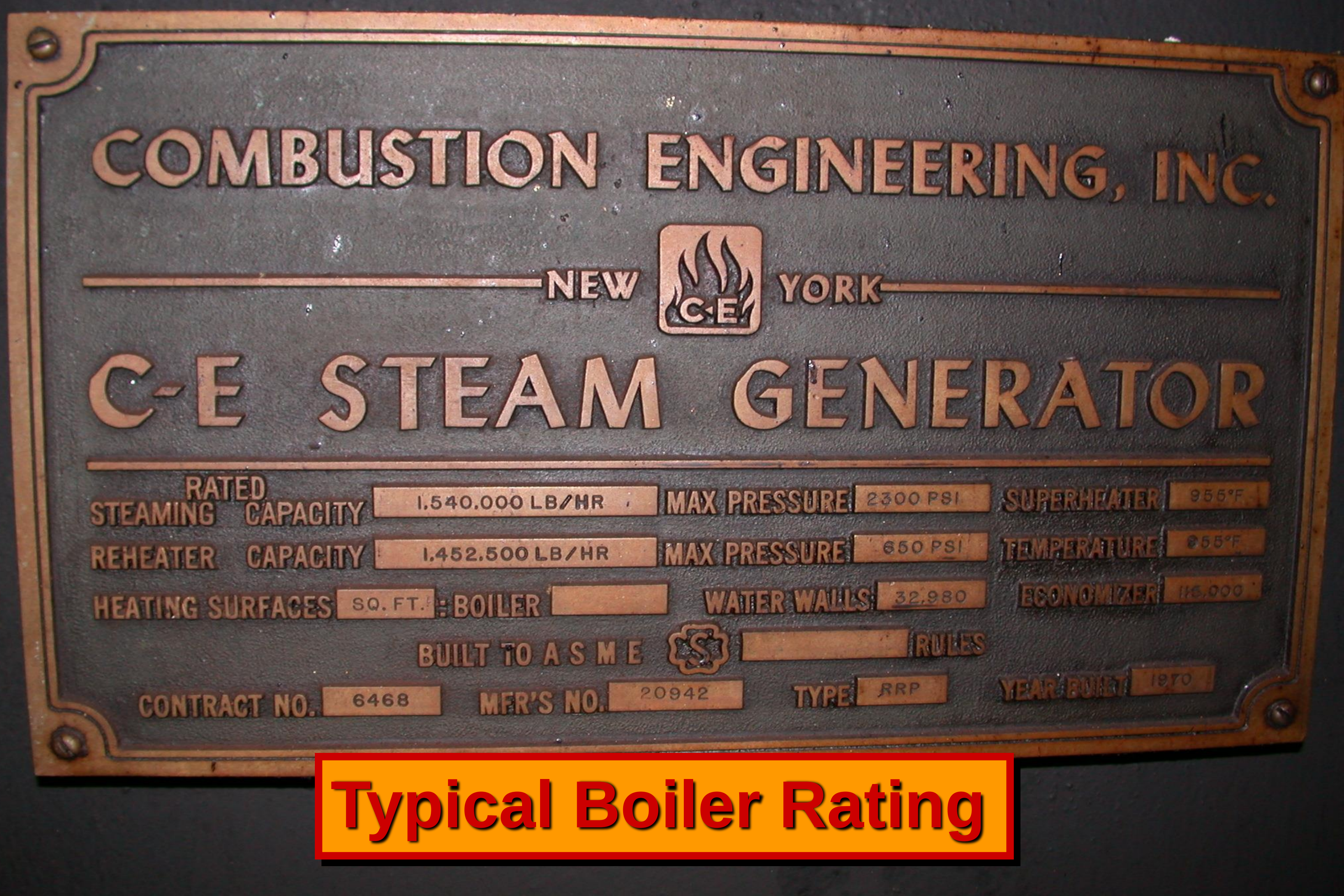
Heat Transfer Methods


Boilers &
Opacity

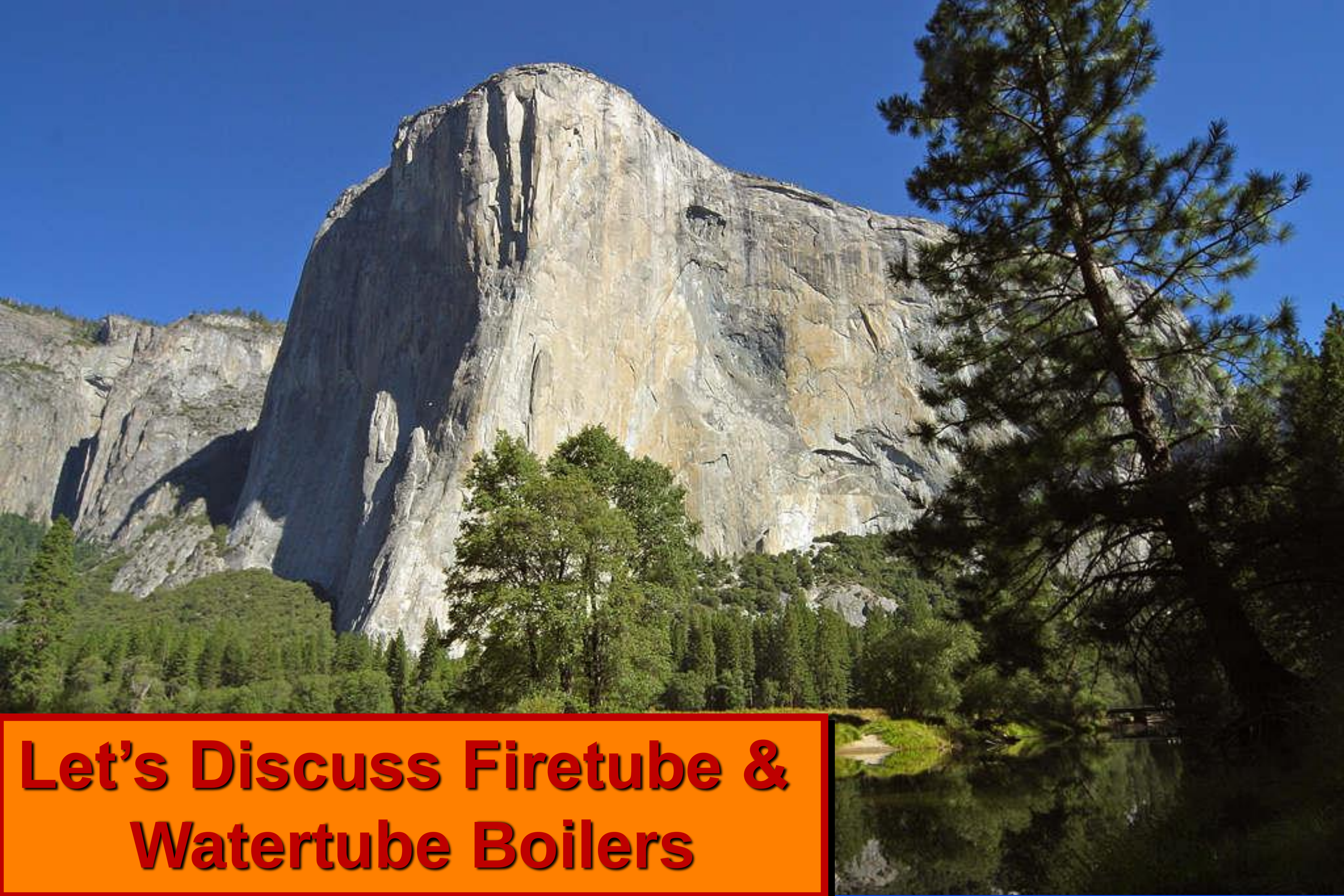
What Opacity is This?



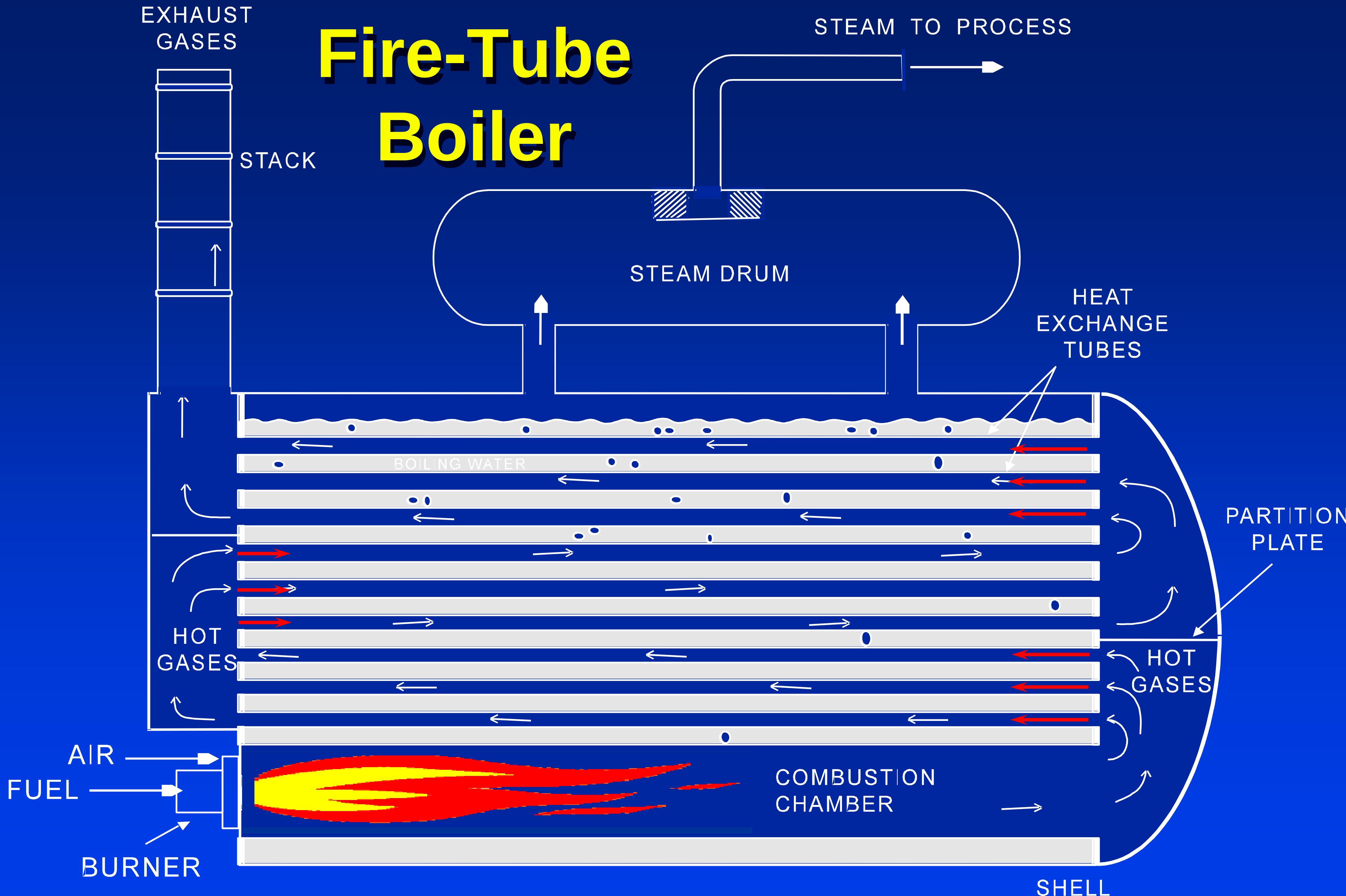

Boiler Ratings
Millions of BTU/hr
Boiler HP
Pounds of Steam/hr
Megawatts
Tons per day

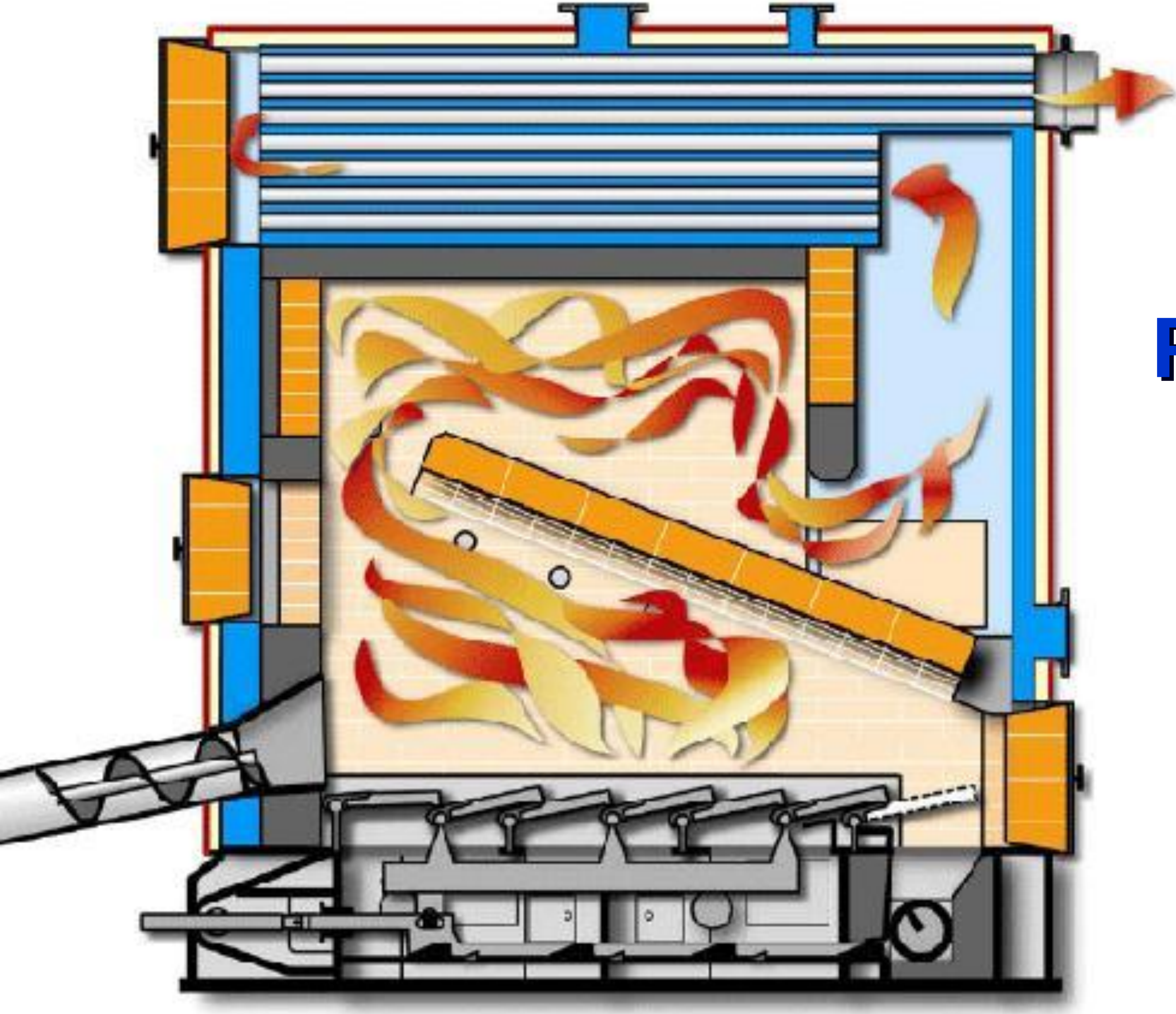


Typical Boiler Rating


Let’s Discuss Firetube &
Watertube Boilers

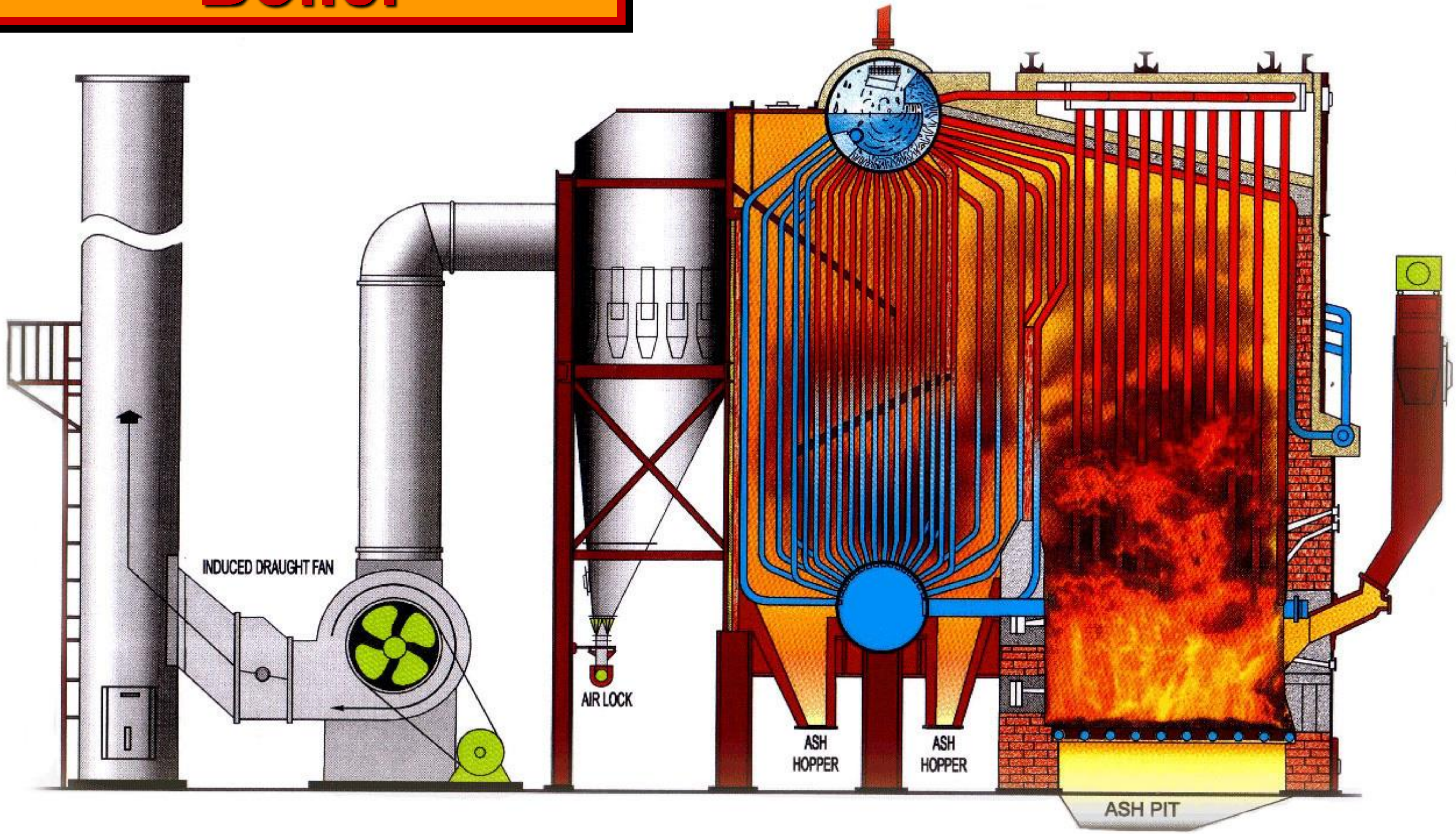
Fire-Tube Boiler





Fire-Tube Boiler

Water-Tube Boiler



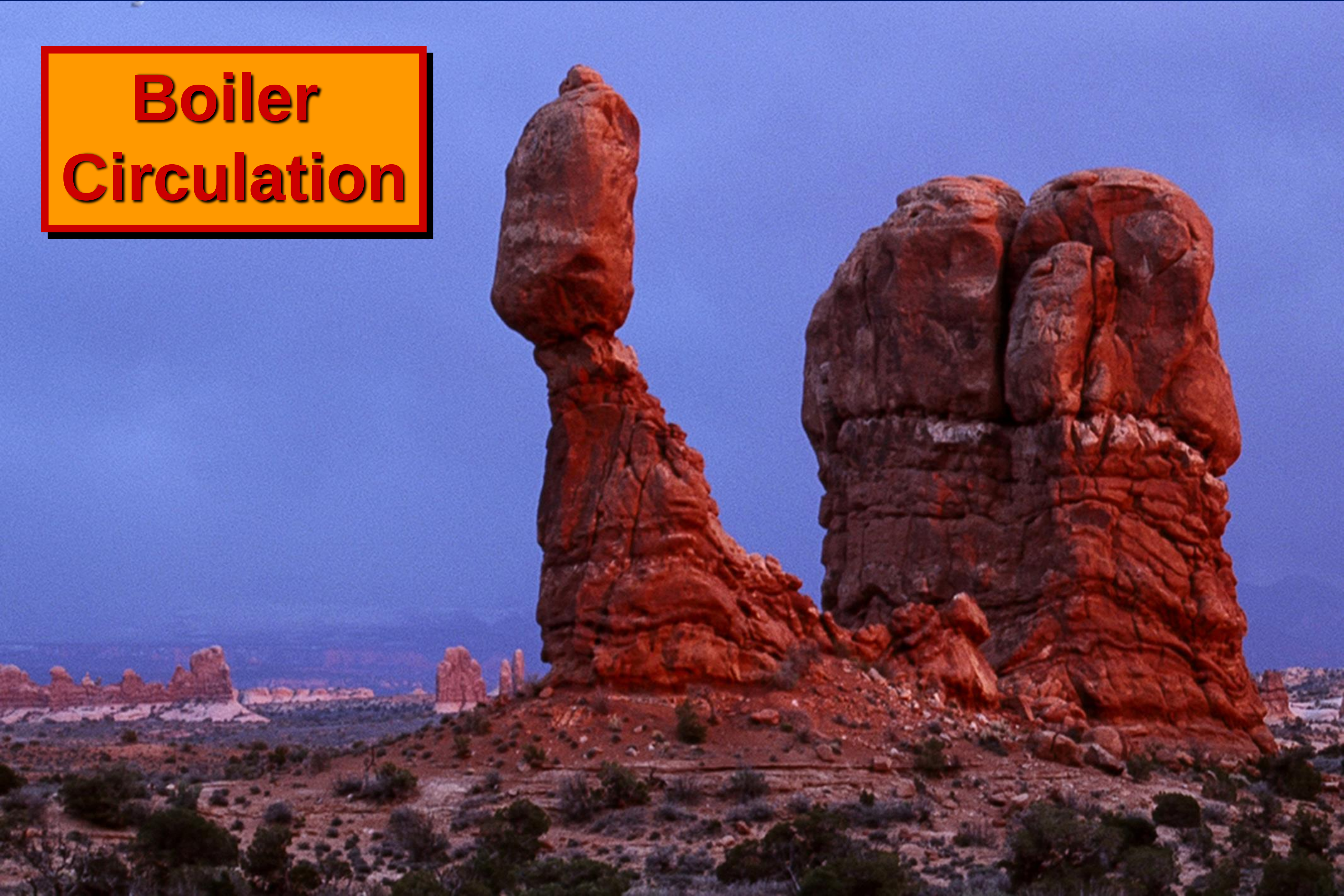
Hybrid Boiler

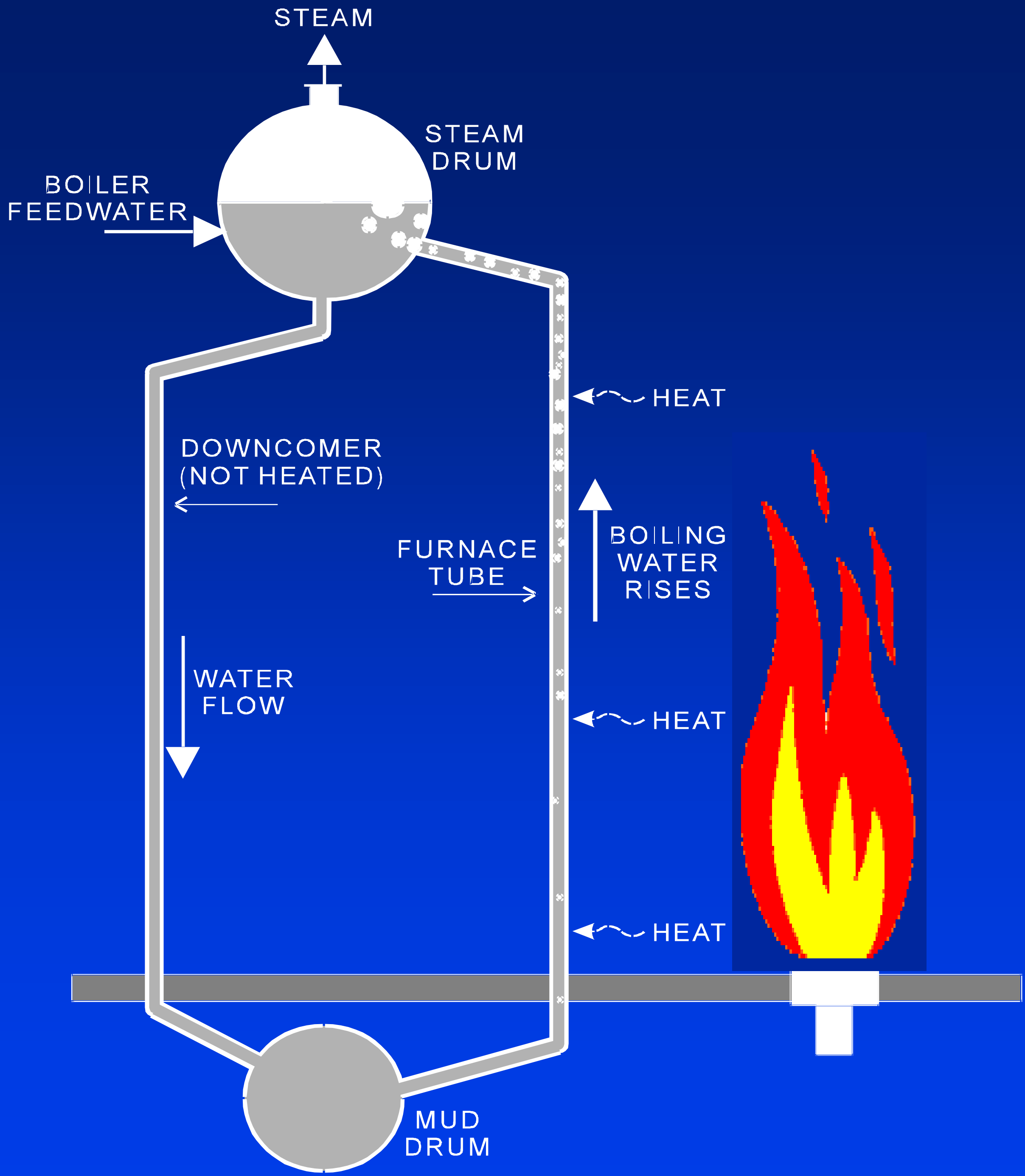

Fire Wall


Boiler Tubes

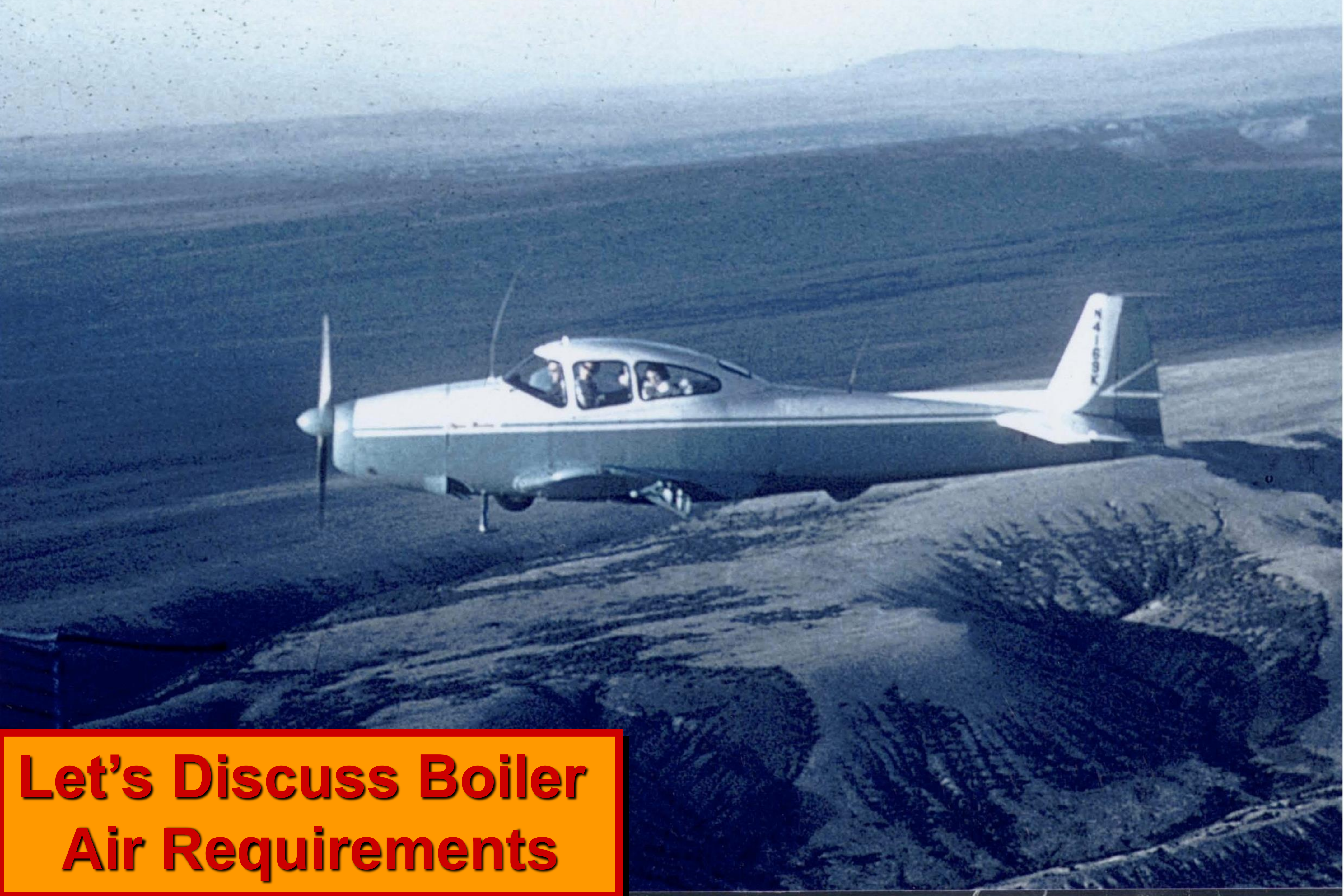

Boiler Tubes with Fins

Boiler Circulation





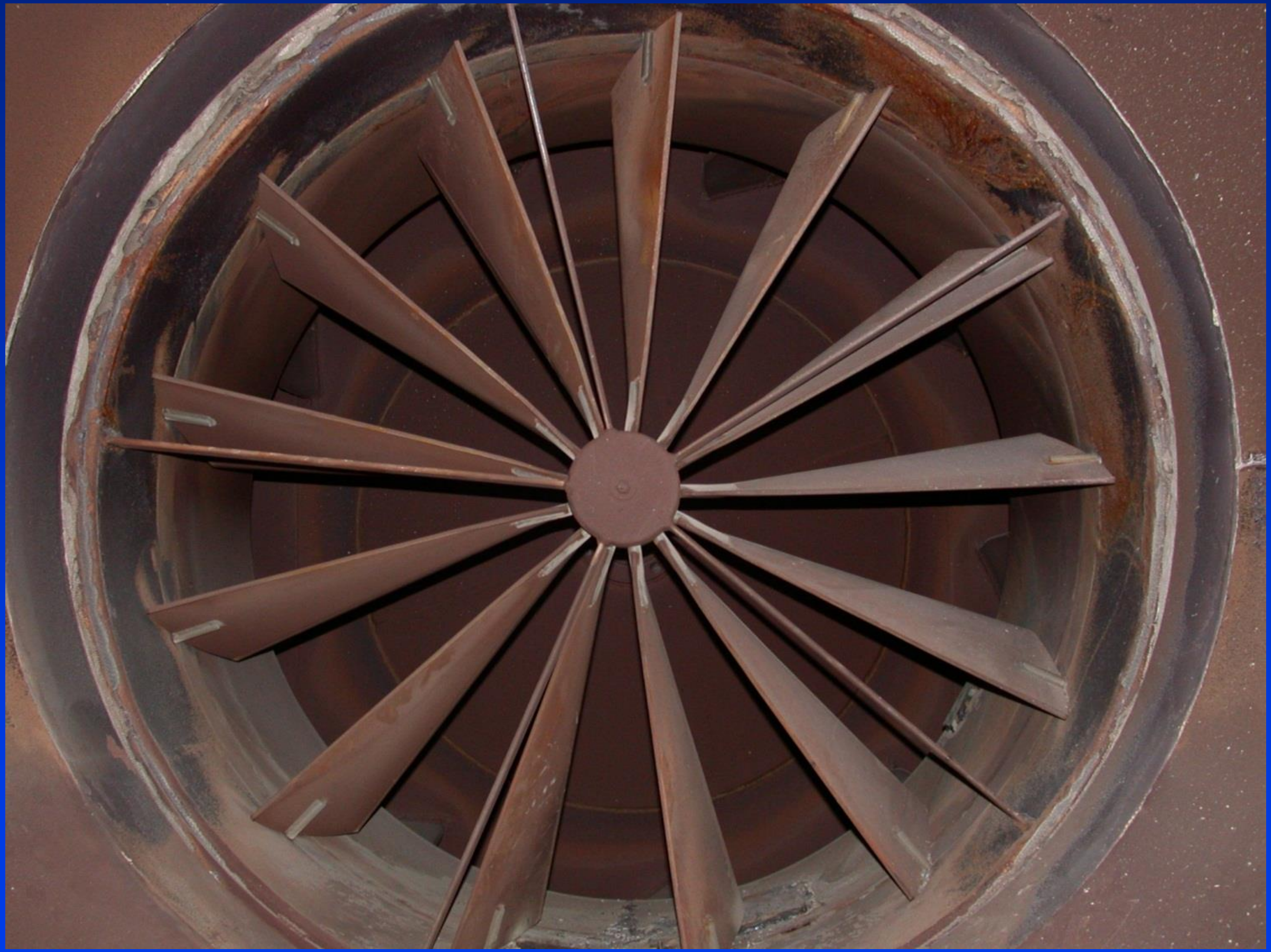
Water to Steam Circulation Loop



Let's Discuss Boiler Air Requirements

Boiler Air Requirements

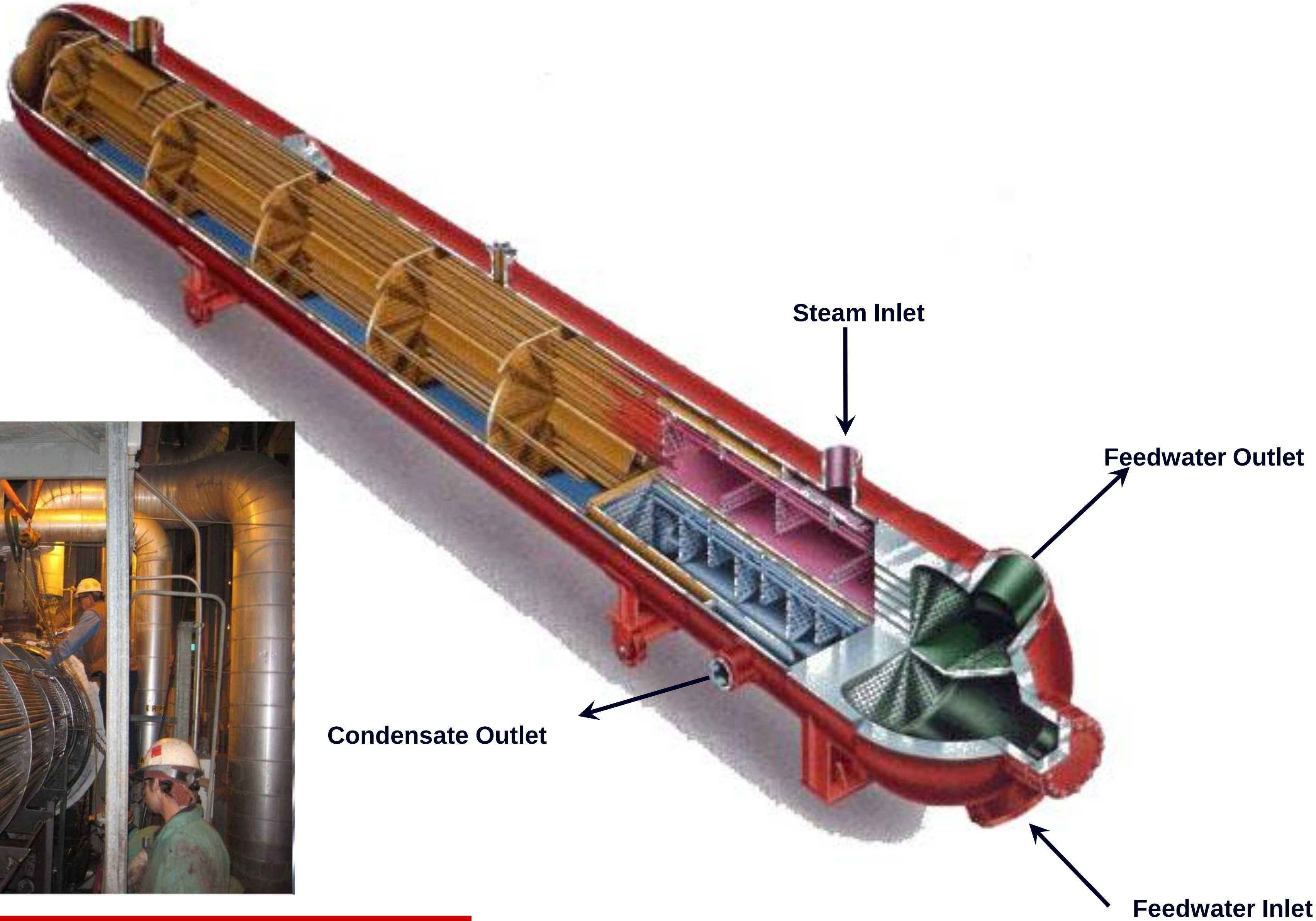
- Draft
  - Natural
  - Forced
  - Induced
- Combustion air
  - Primary
  - Secondary
  - Excess




Forced Draft Fans

Induced Draft Fans

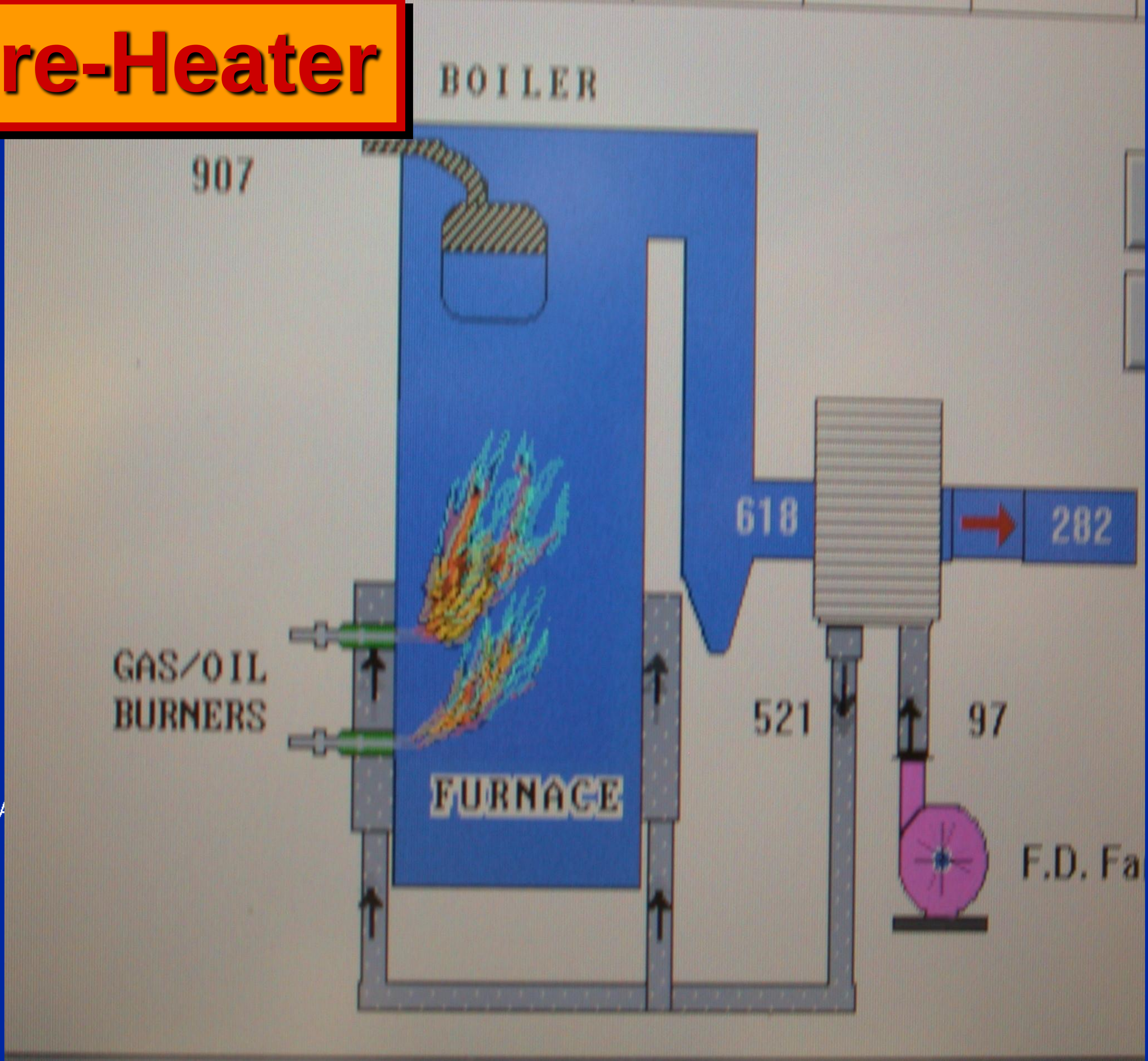
Let’s Discuss Economizers, Feedwater Heaters & Air-Preheaters



Feedwater Heater

Economizer – H_2O Inside Tubes

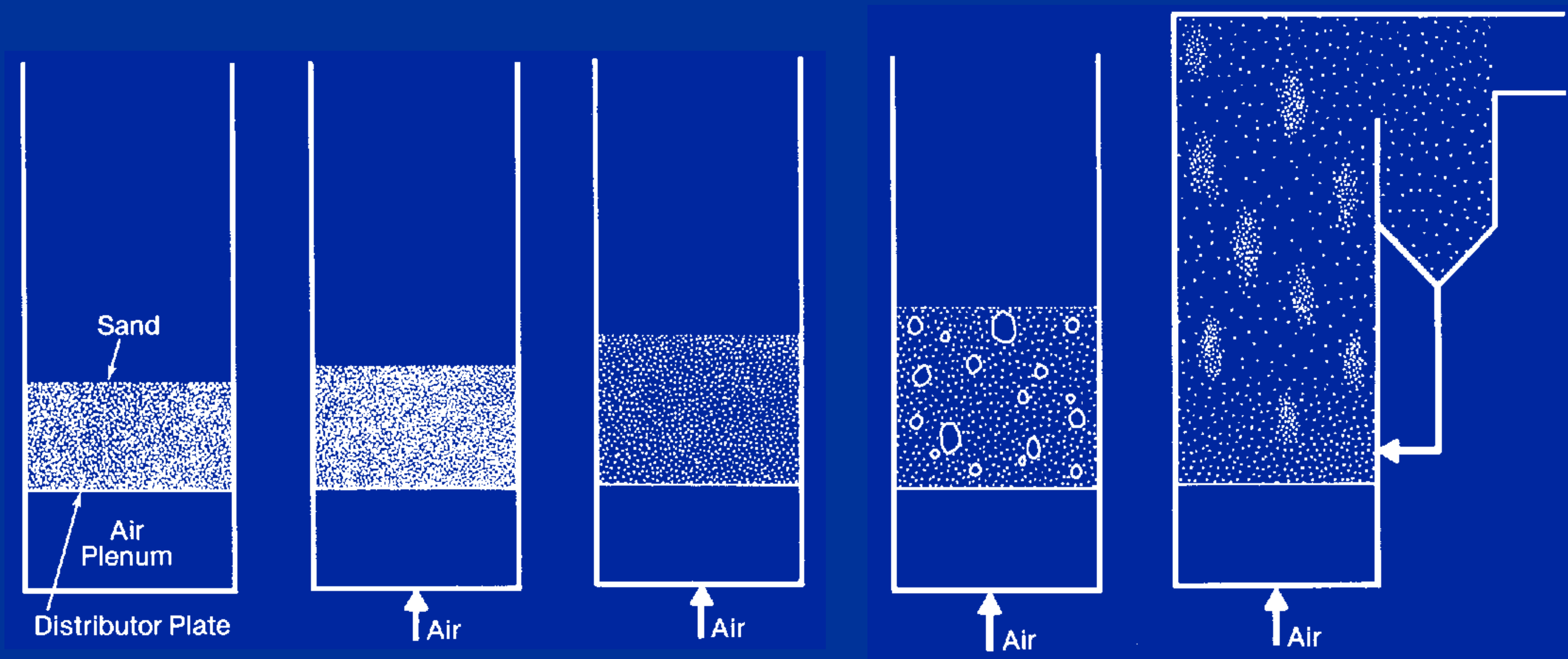
Air Pre-Heater



NA

Let’s Discuss Fluidized Bed Boilers

Fluidized Bed Modes



Start
No Air Flow

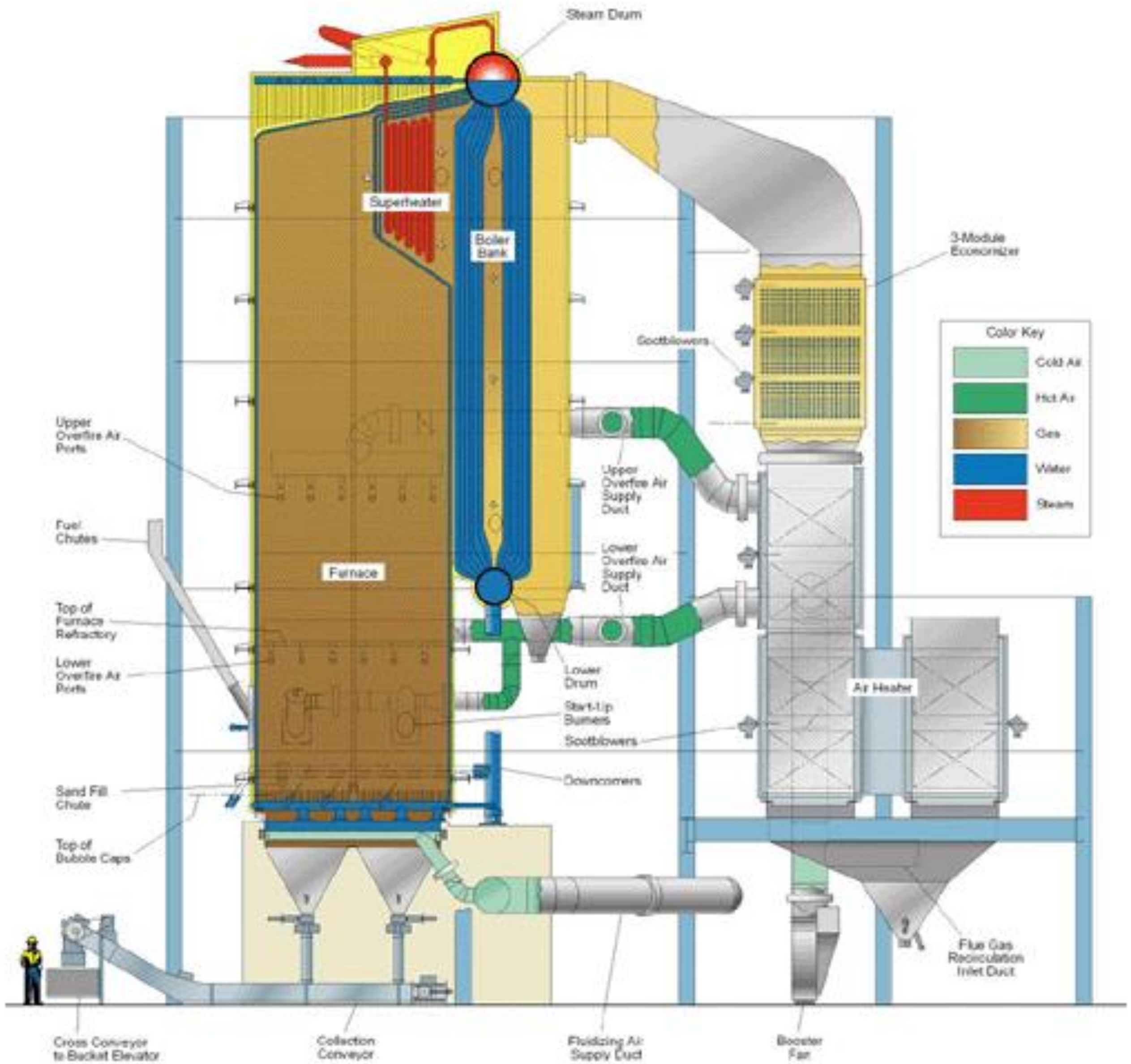
Fixed
Bed

Minimum
Fluidization

Bubbling
Bed

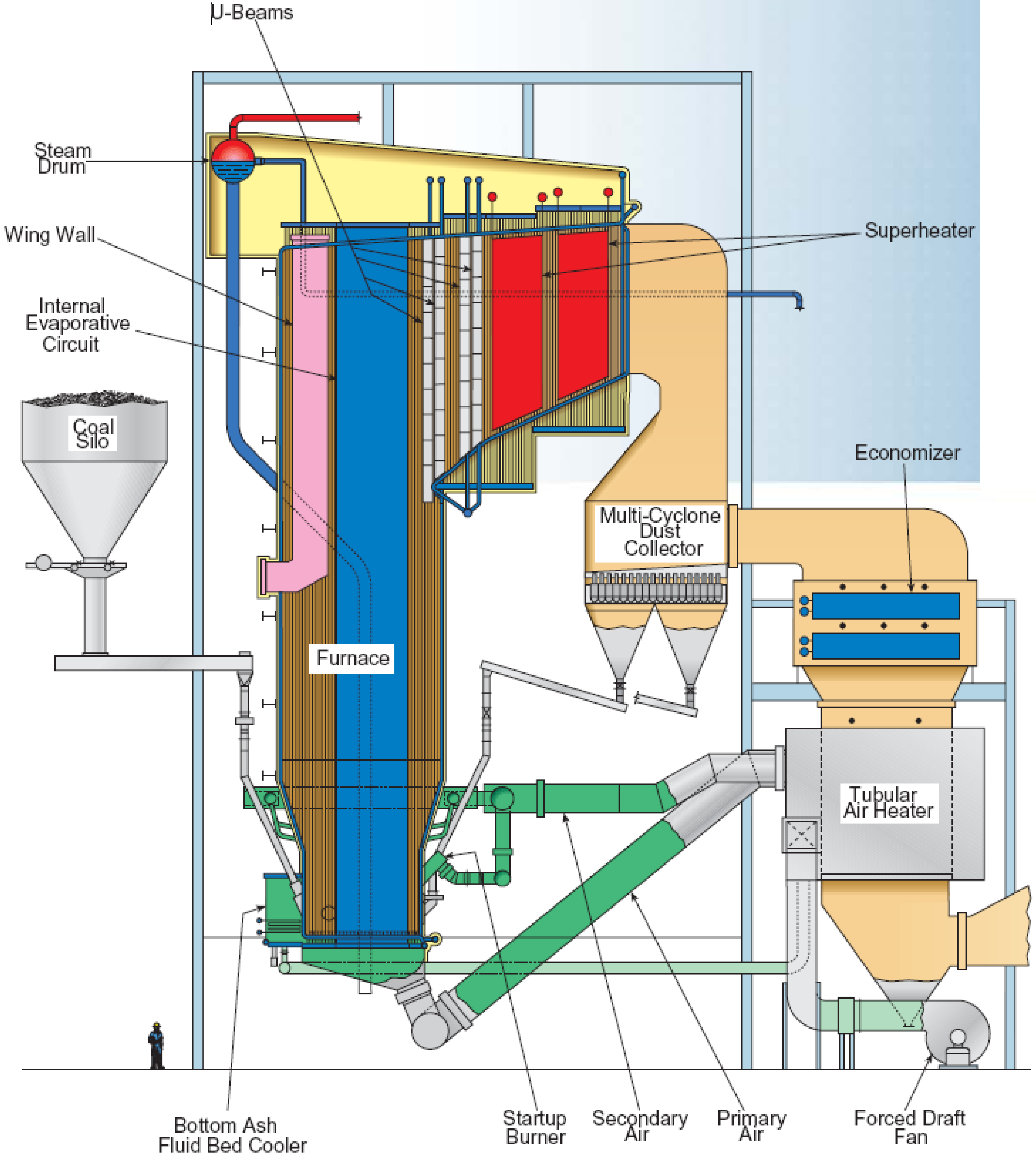
Circulating
Bed

BFB Bottom Supported

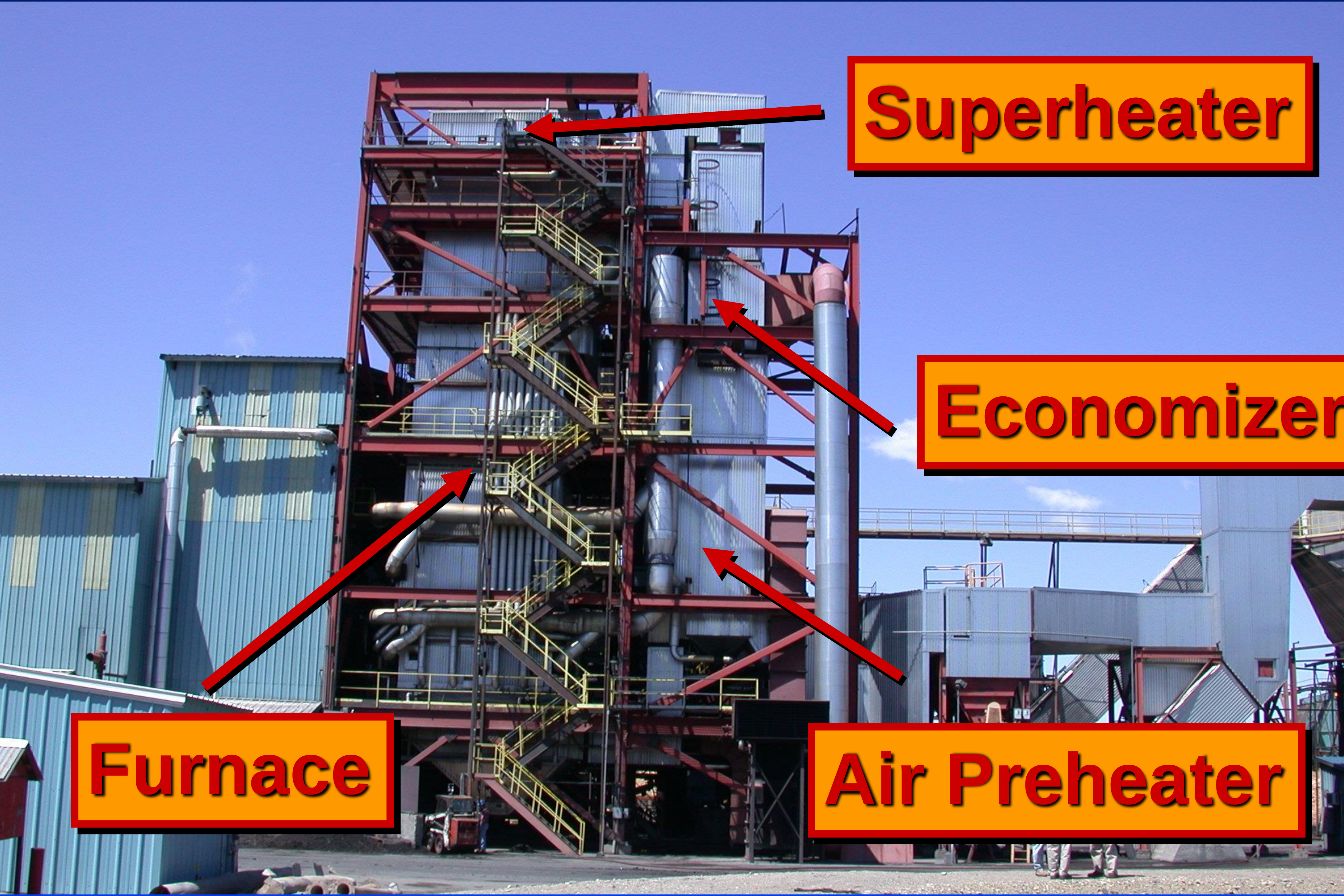


Bubbling Fluidized Bed (BFB)

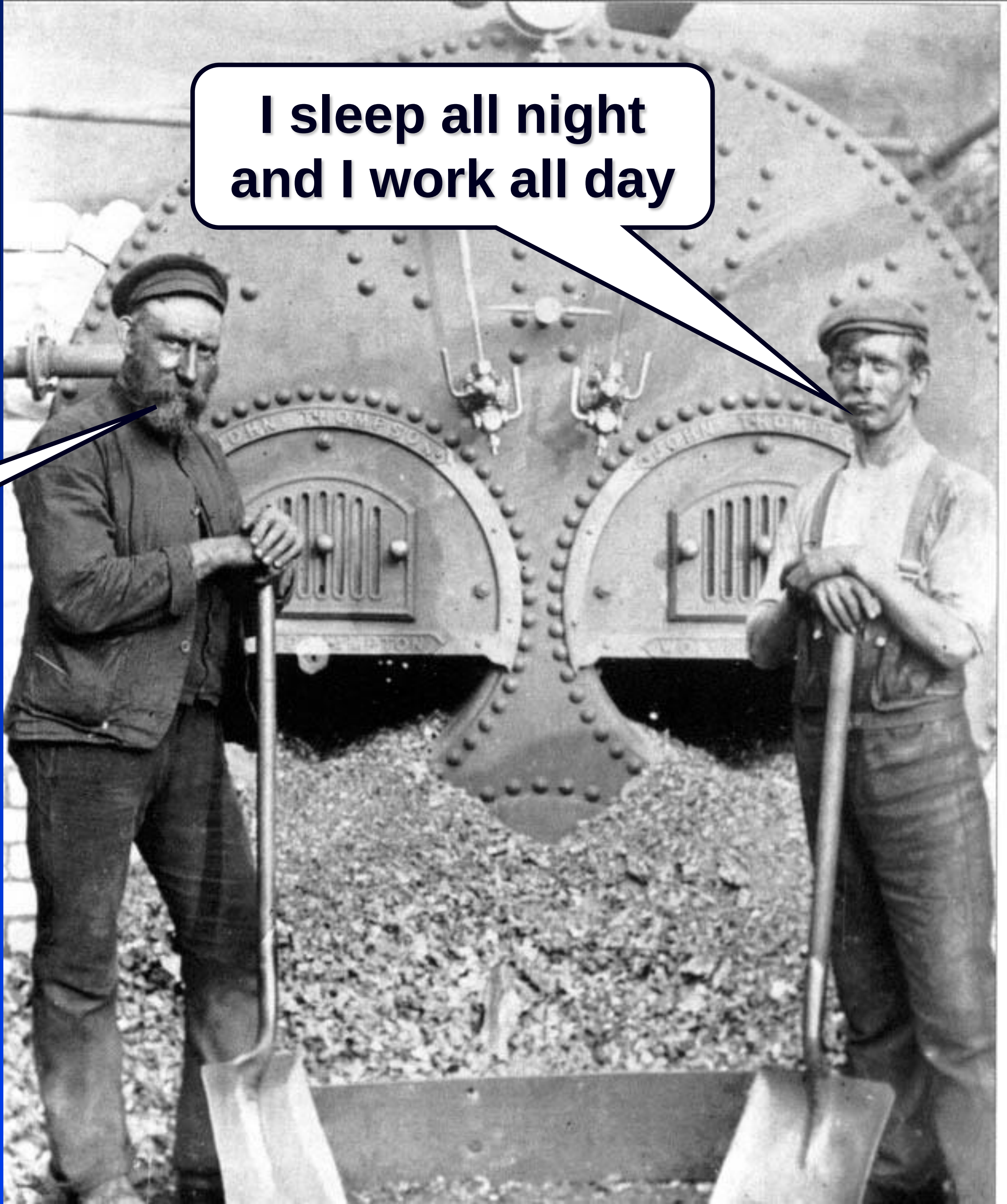
Circulating Fluidized Bed (CFB) Boilers



Circulating Fluidized Bed Boiler


Superheater
Economizer
Furnace
Air Preheater

Let's Discuss Stoker Boilers



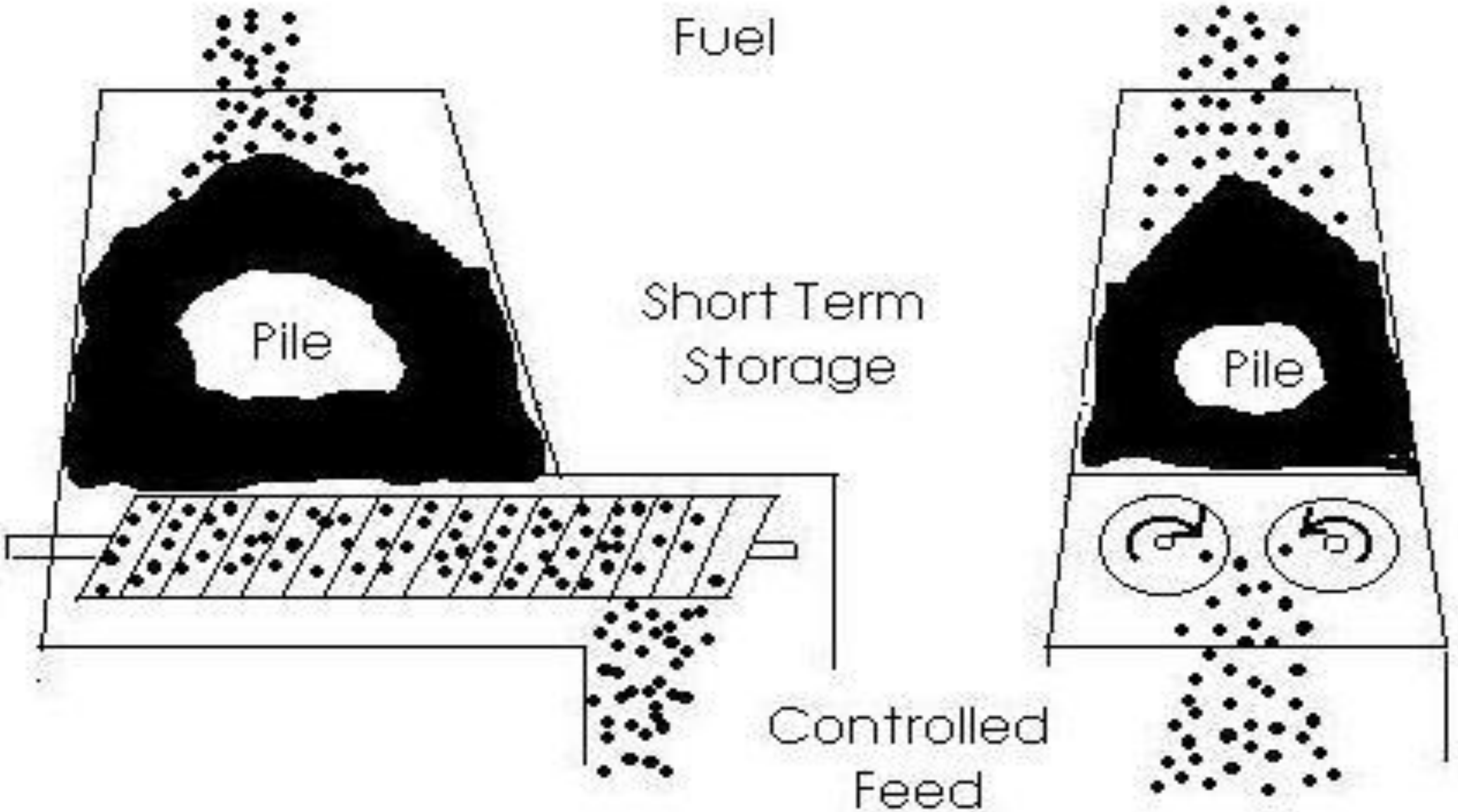
Stoker Boilers

Stoker Boilers

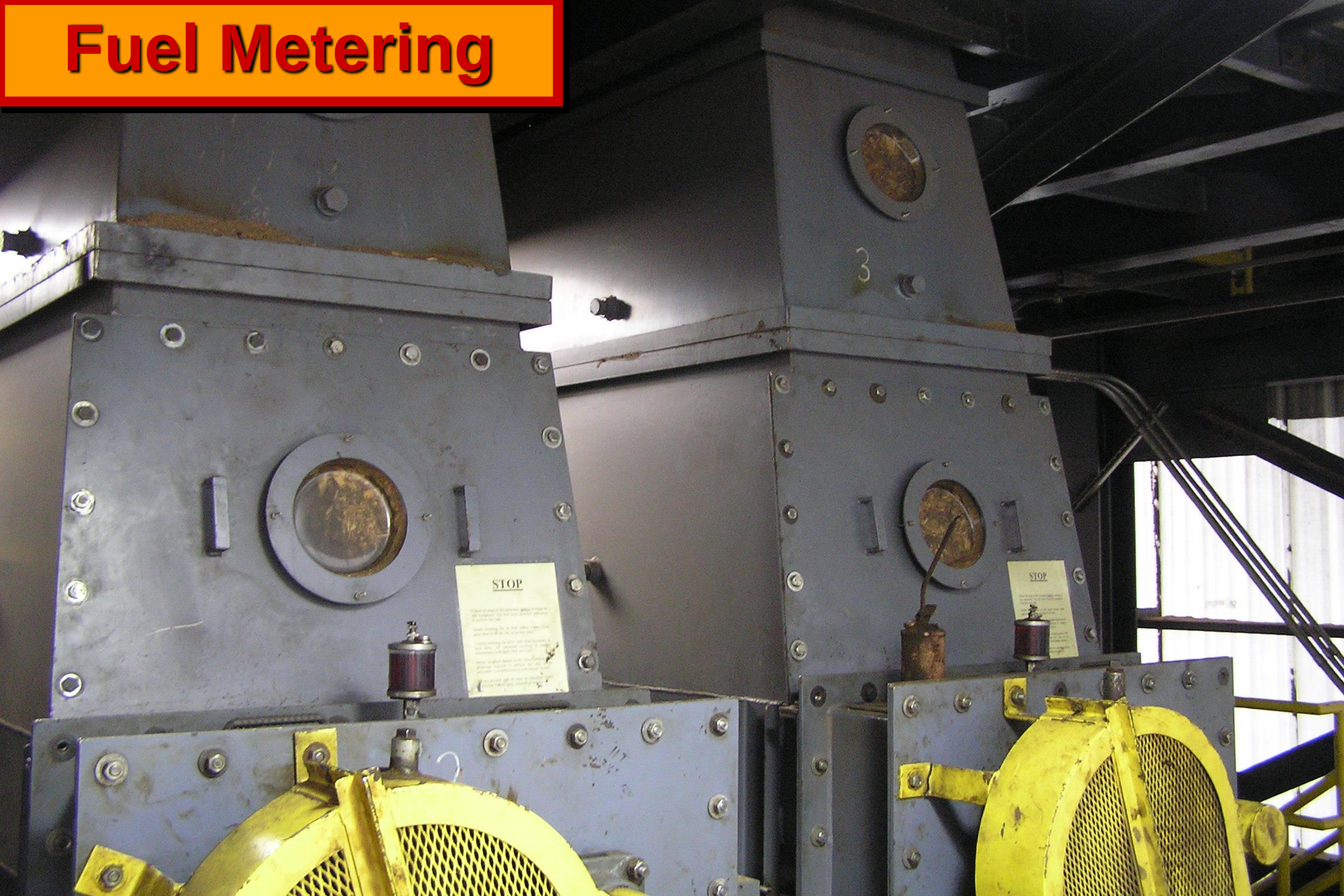
Combustion Using a Stoker Boiler

- "Stoker" involves combustion on a grate
- Fuel Distribution Onto the Grate
- Undergrate or Underfire Air
- Overfire Air
- Three Steps of Biomass Combustion
  - Step 1 - Drying
  - Step 2 - Gasification and Volatile burnout
  - Step 3 - Char Burnout (Step #3) on the grate

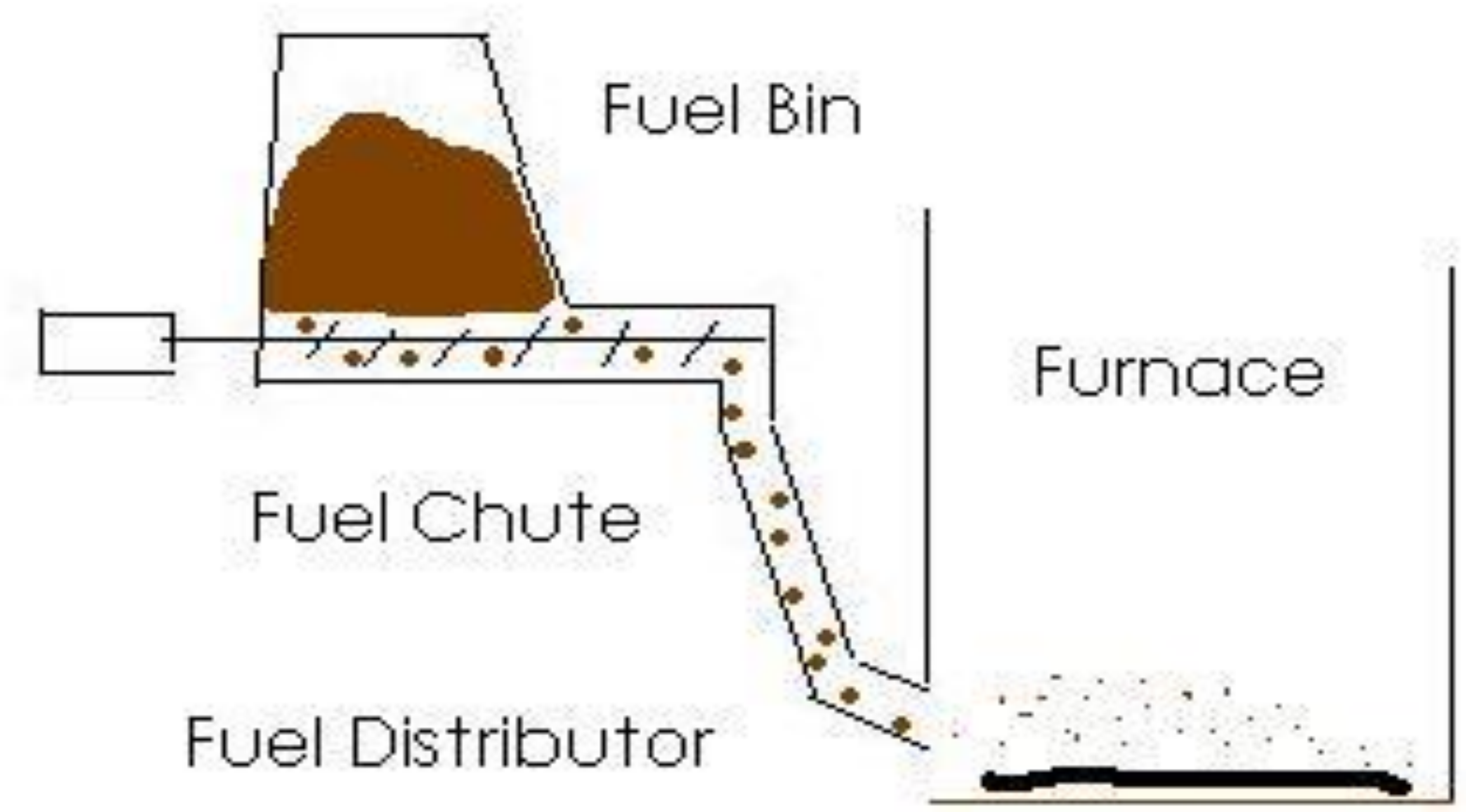
Fuel Metering



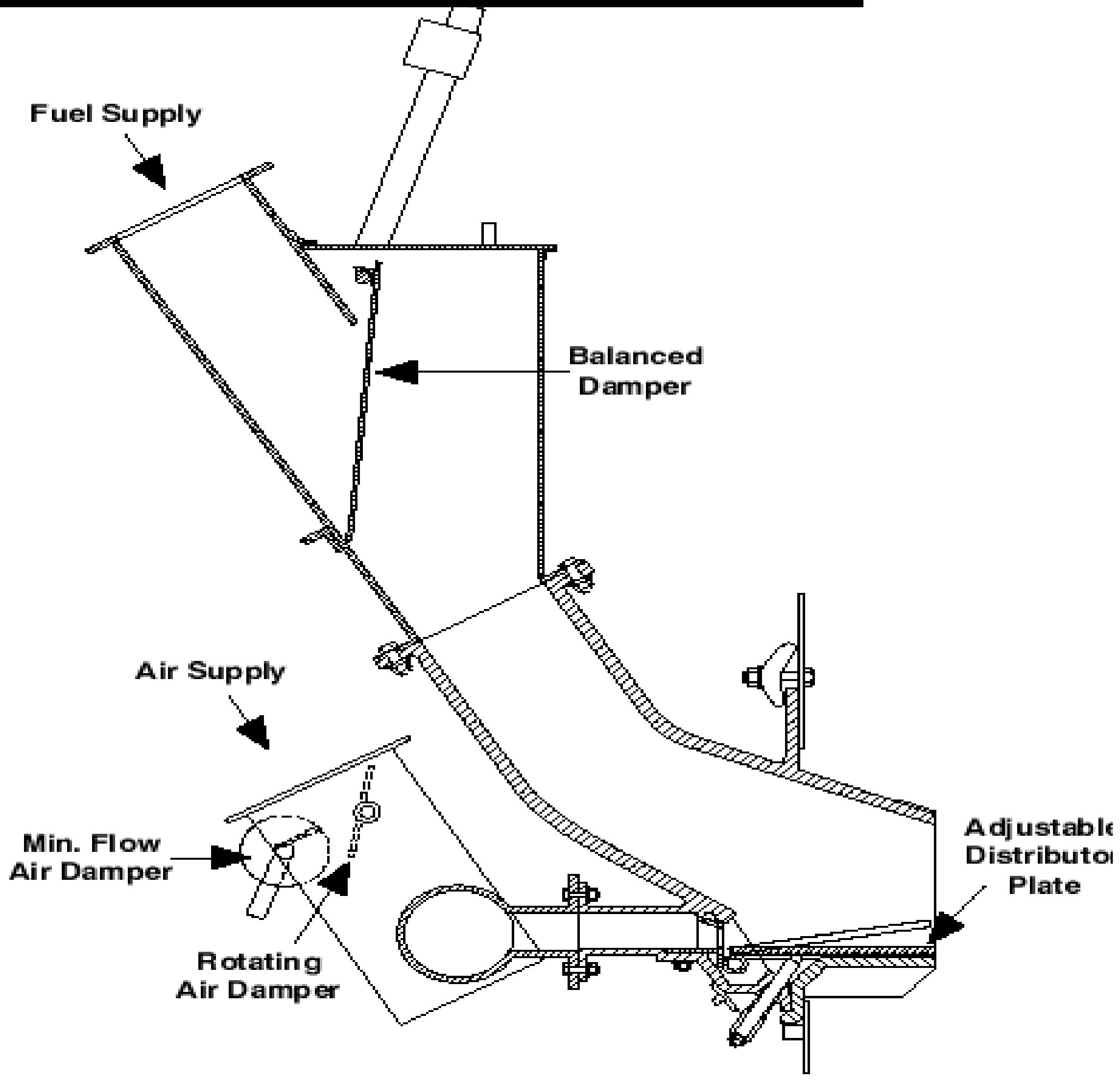
Fuel Metering



Fuel Chute and Simple Distribution



Pneumatic Distribution



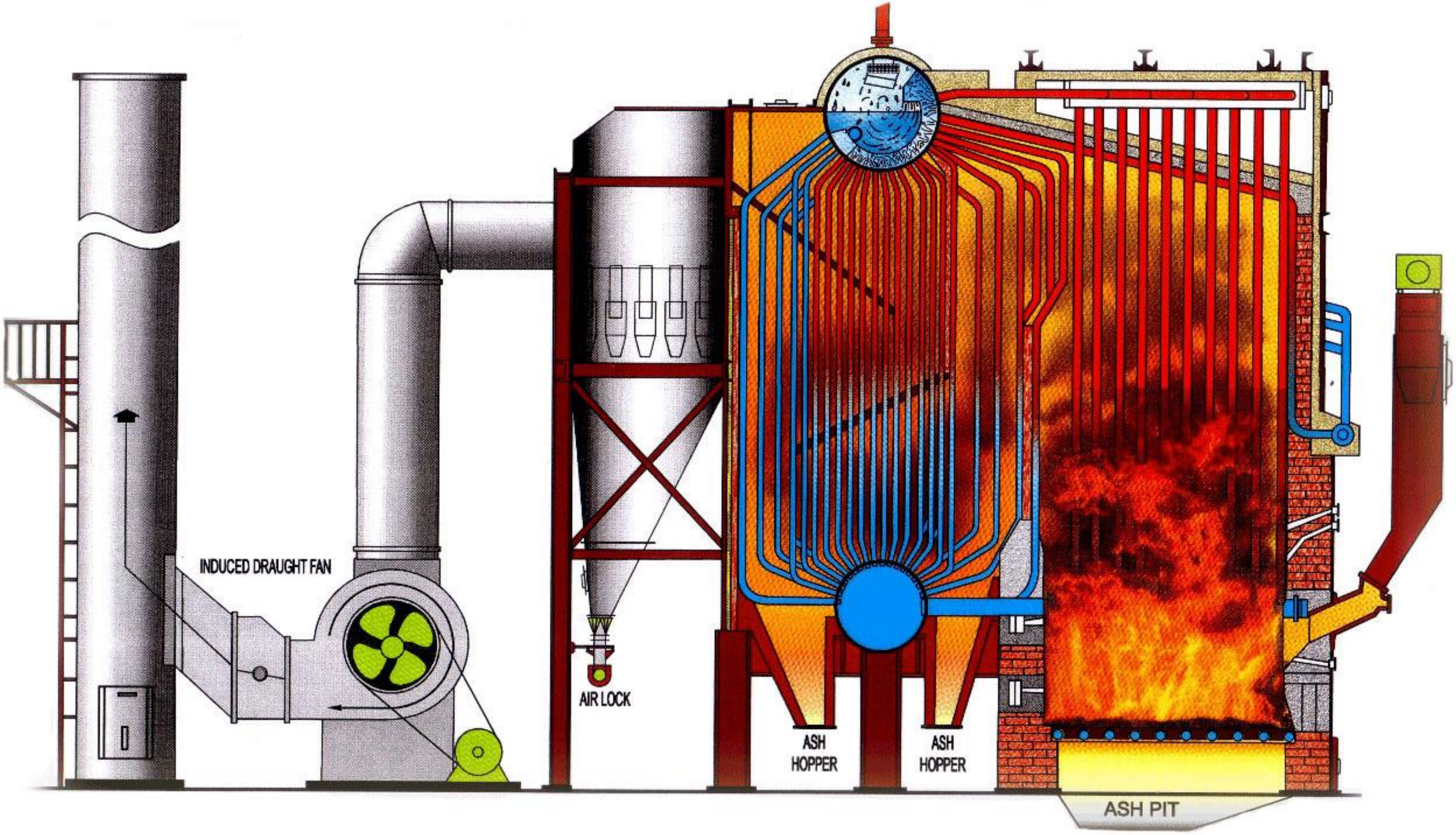
Detroit Air Swept Fuel Distributor
Model AD

Pneumatic Distribution

Classified by Grate Designs

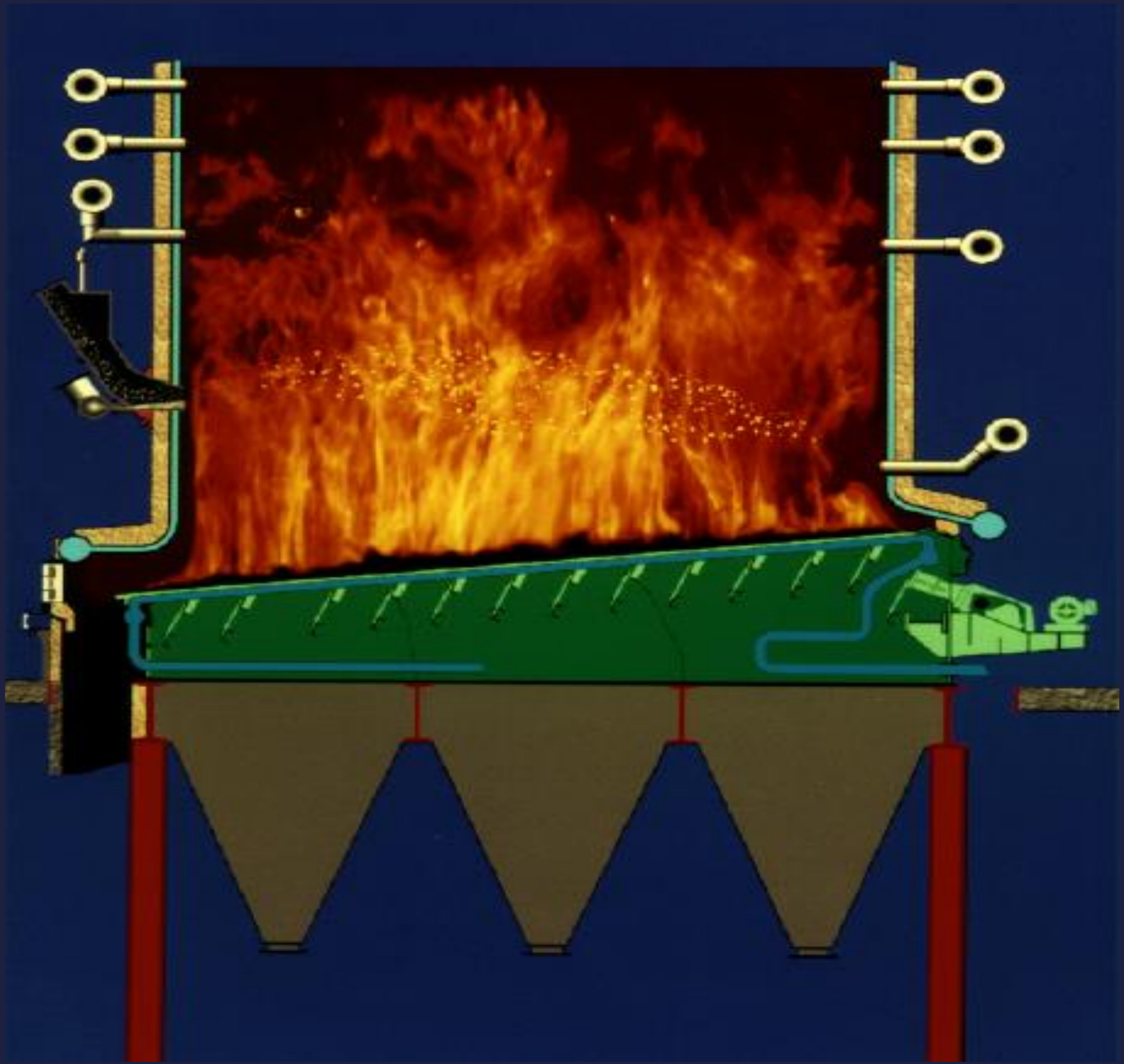
- Fixed Grate (Pinhole)
- Vibrating Grate
- Watercooled Hydrograte
- Reciprocating Grate
- Kablitz Grate
- Traveling Grate

Fixed Grate

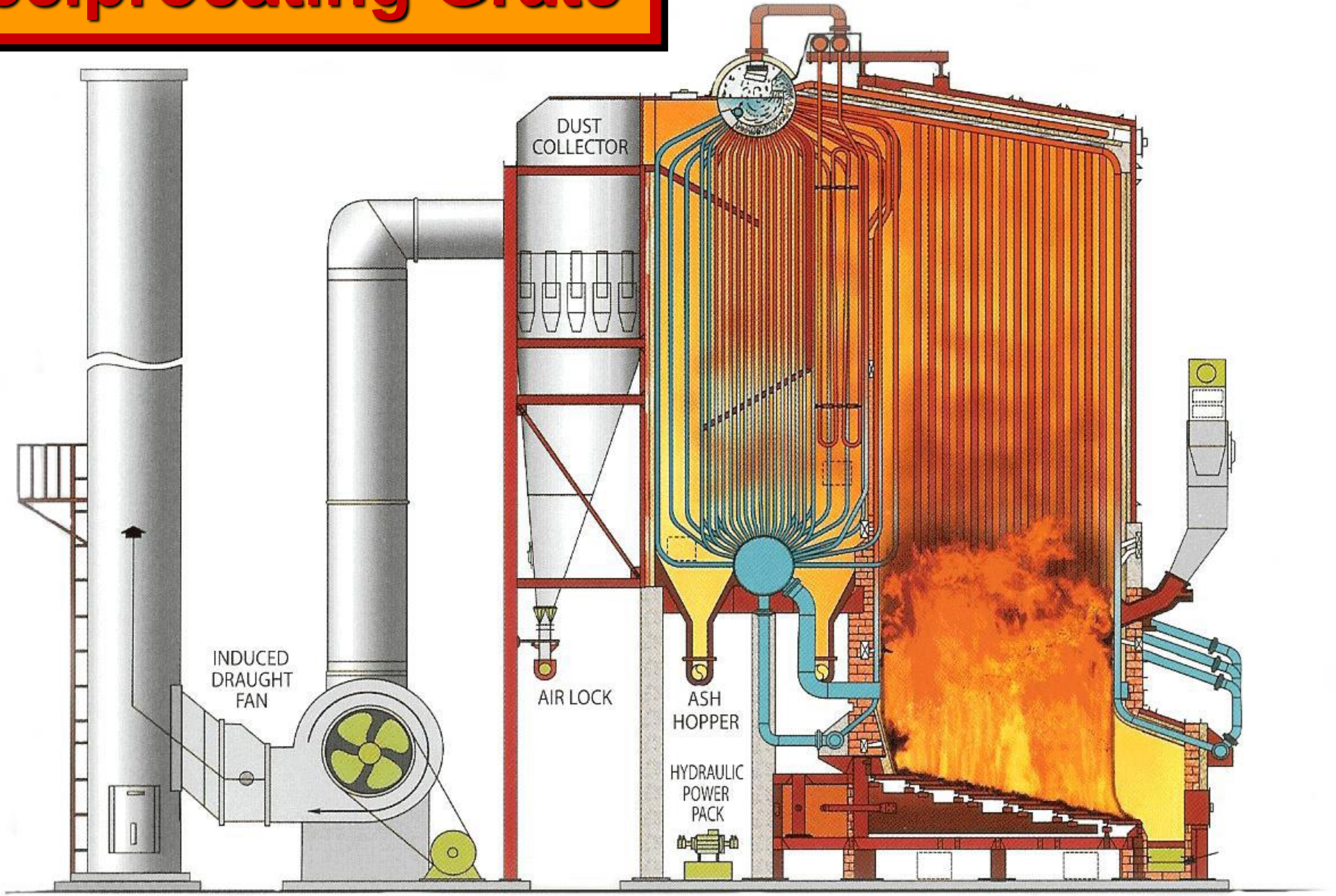


Vibrating Grate

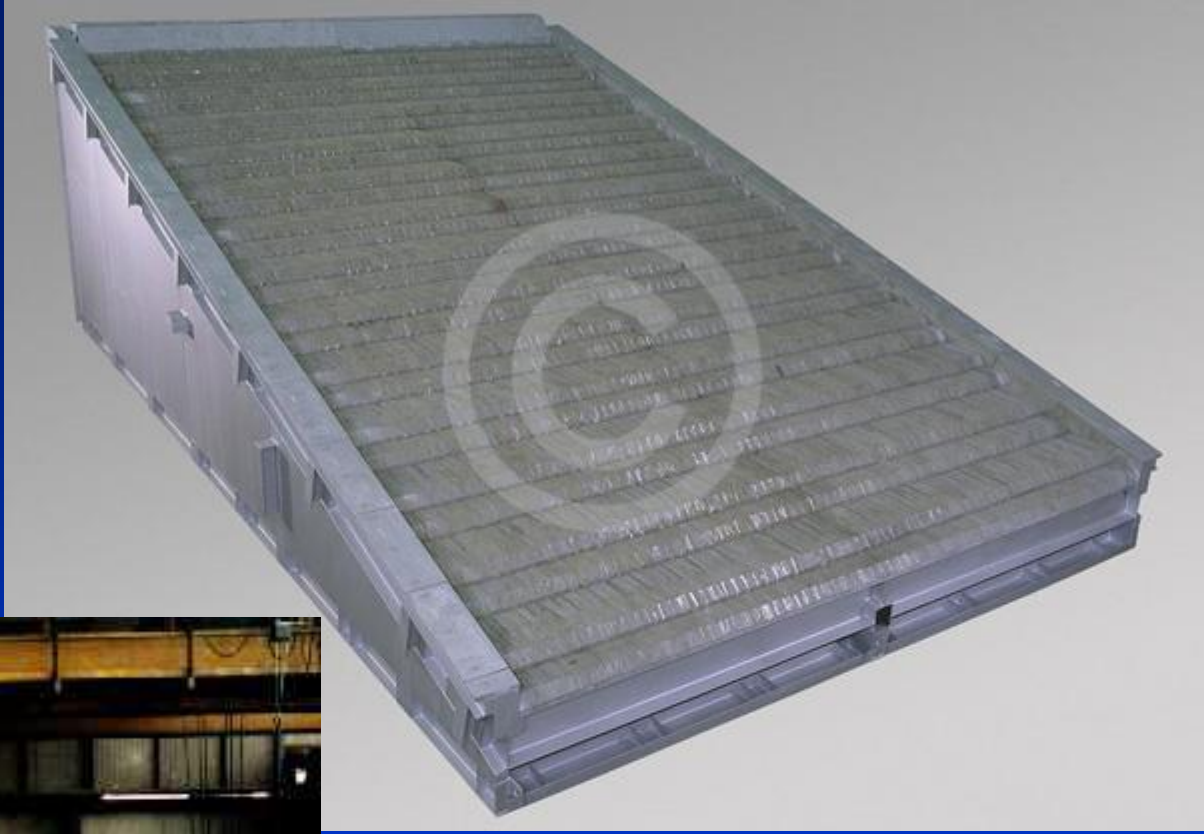
Watercooled Hydrograte



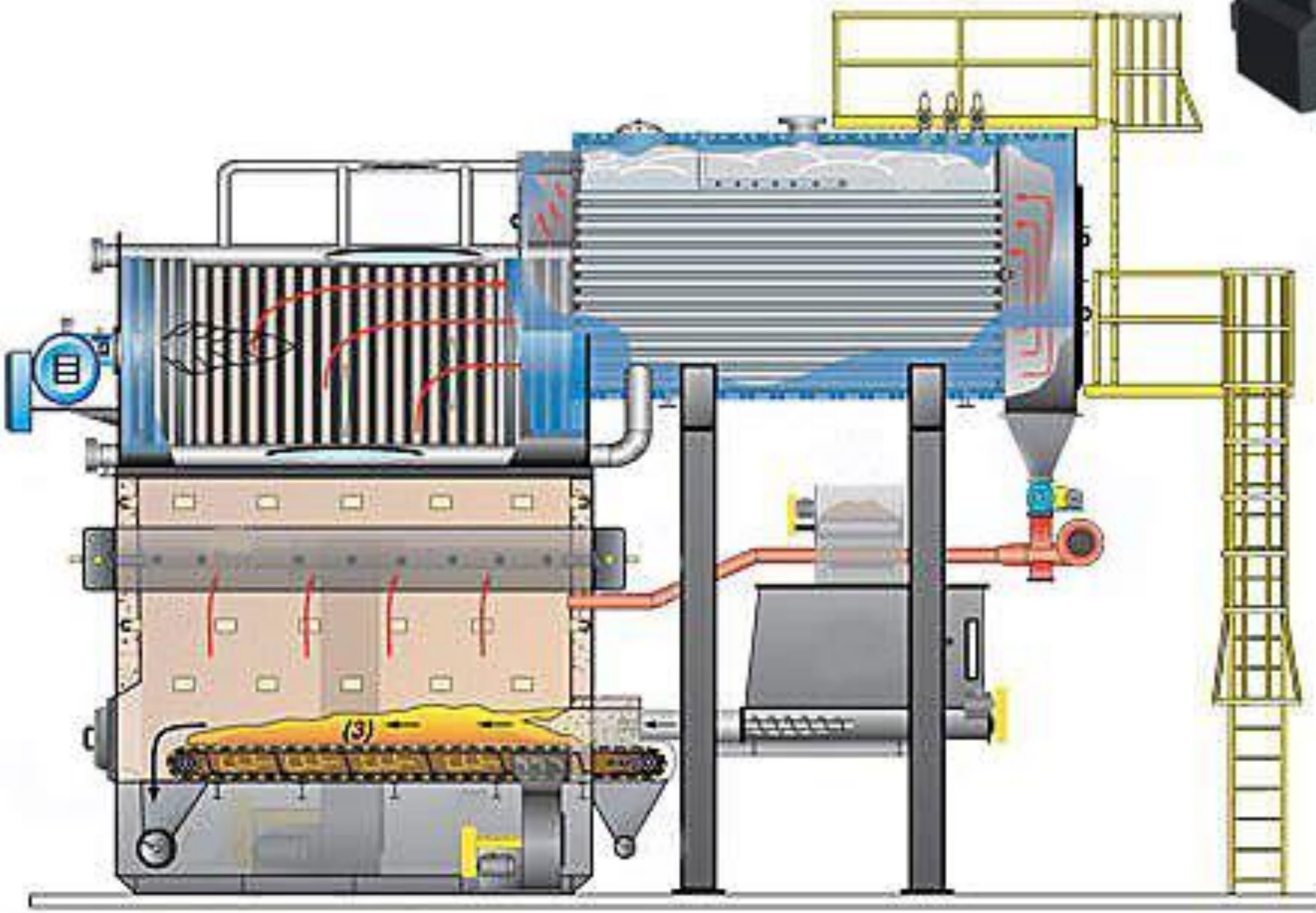
Reciprocating Grate



Kablitz Grate



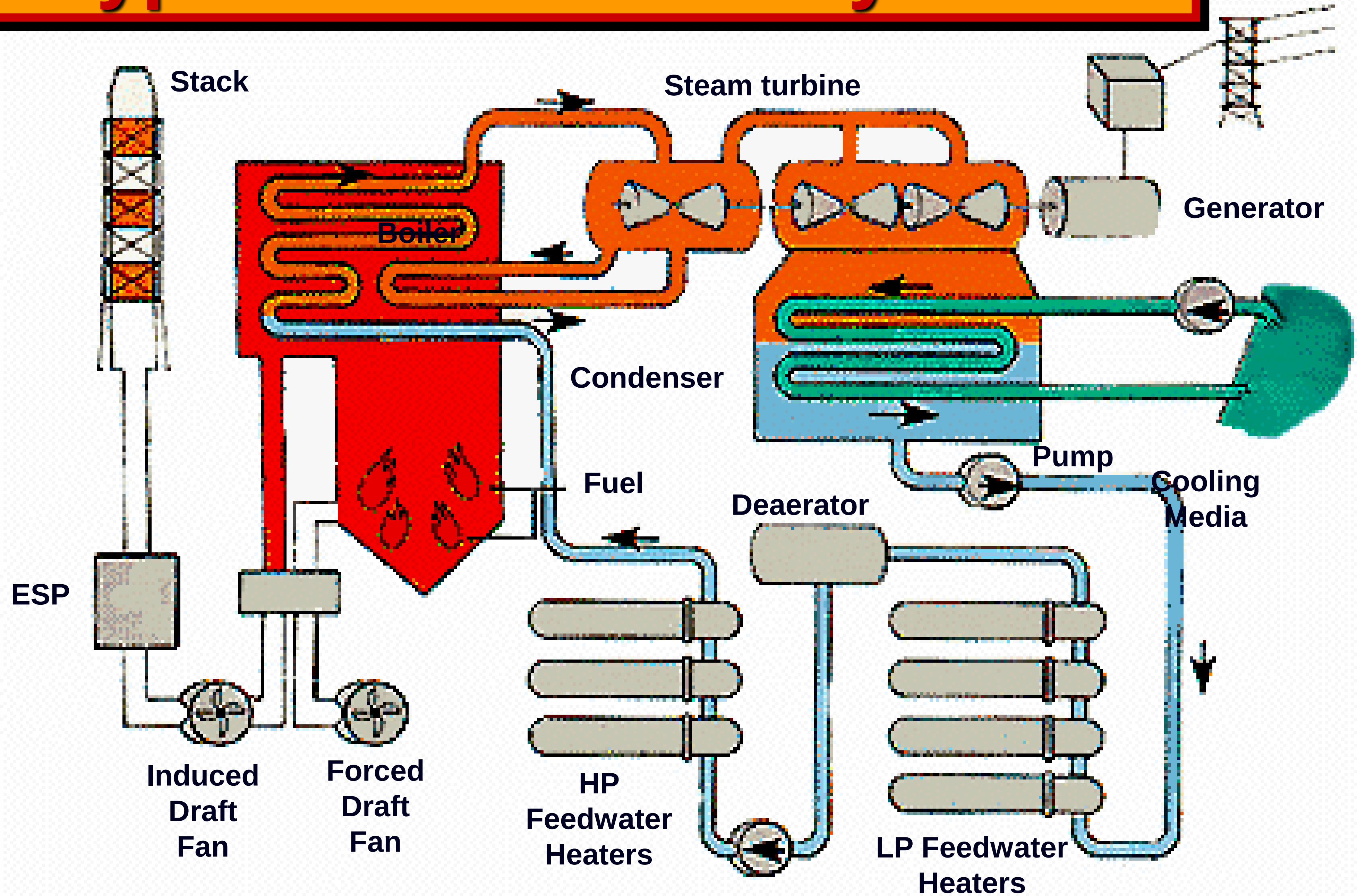
Traveling Grate



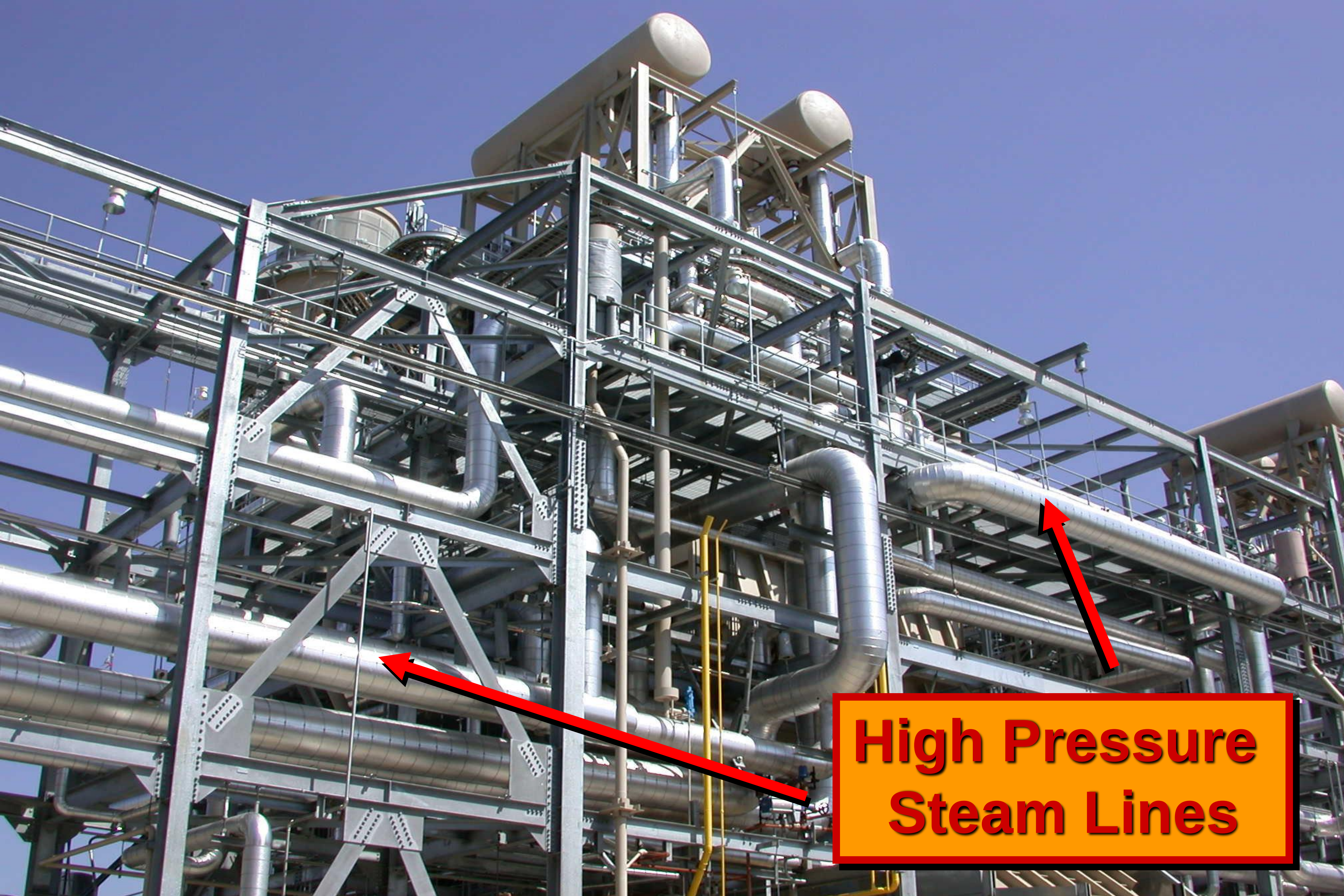
Traveling Grate

Let’s Discuss Power Generation

Typical Electric Utility Plant

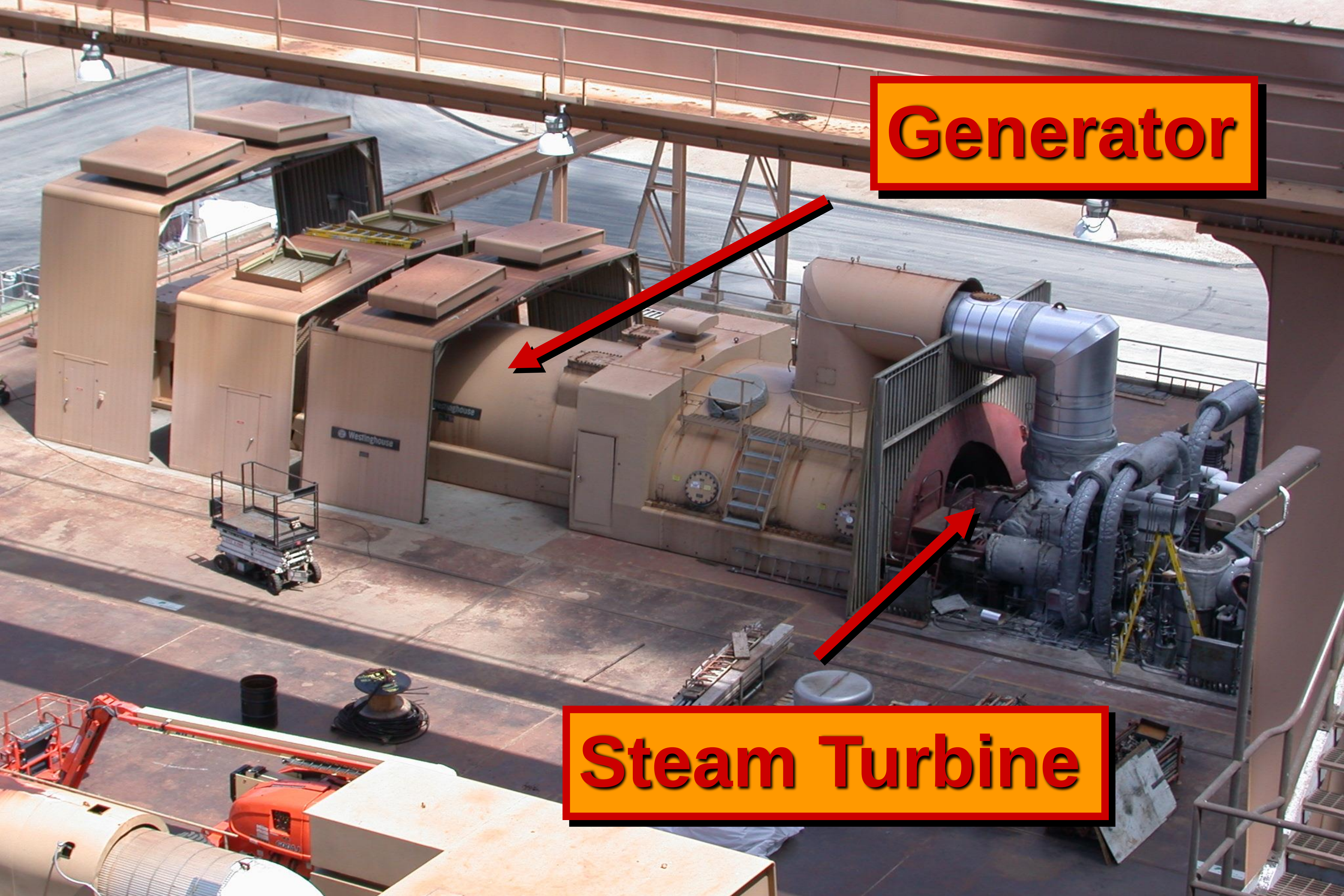


High Pressure Steam Risers


High Pressure
Steam Lines


Steam
Turbine


Steam
Turbine


Generator
Steam Turbine
Westinghouse


Cooling Towers

Typical Control Room

2,600 MW

2 – 750 MW boilers

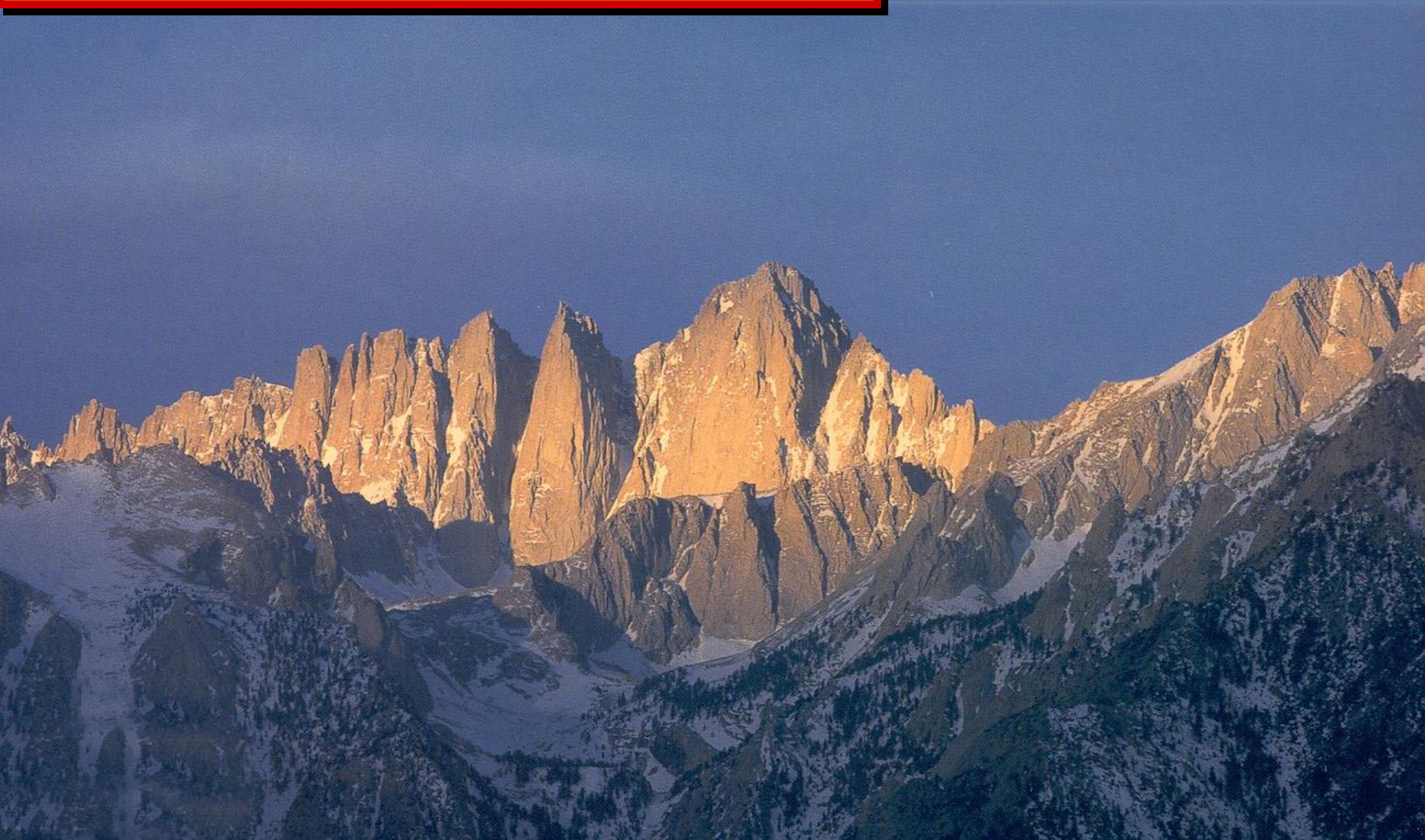
4 – Gas turbines and

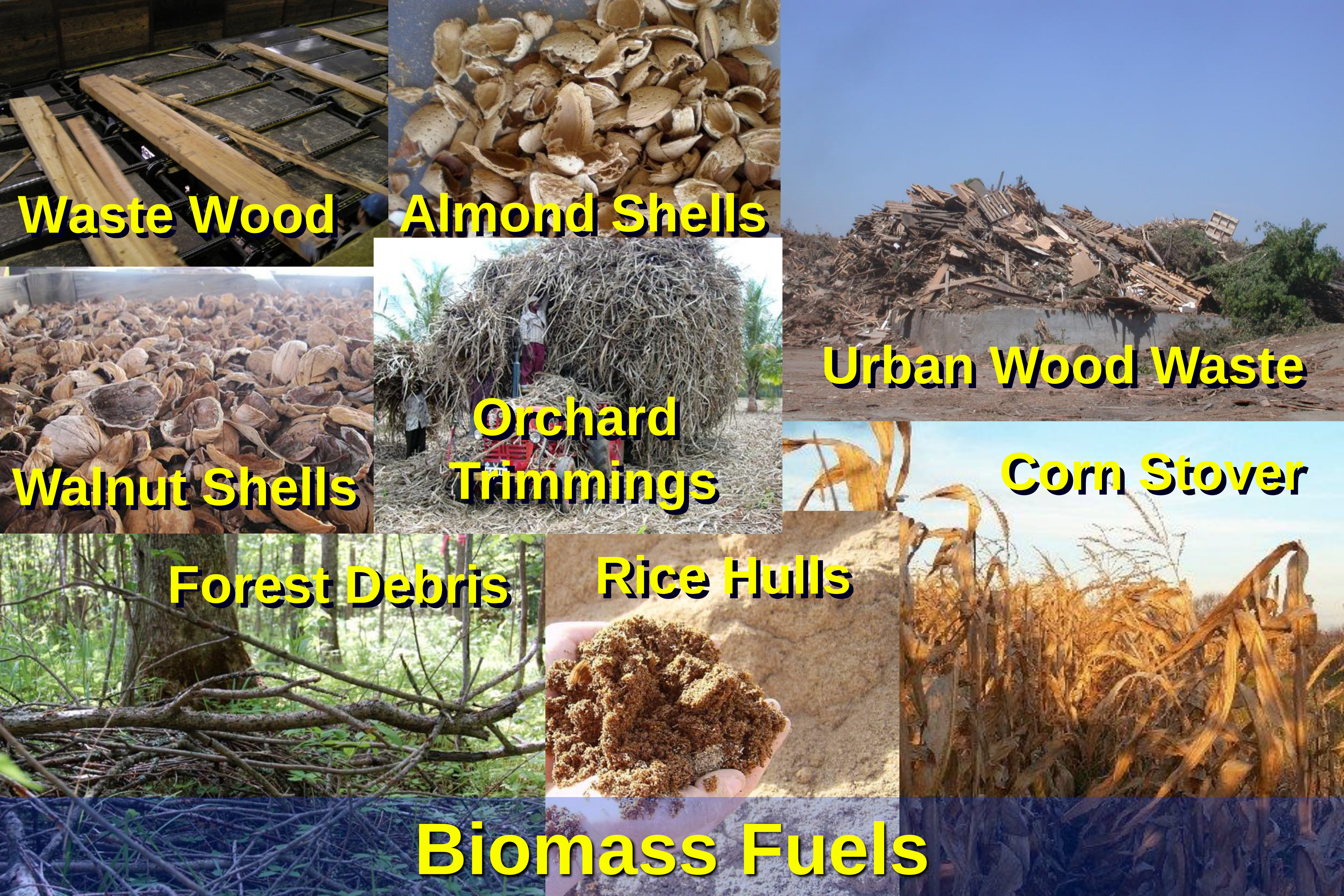
2 steam turbines in a

2 to 1 arrangement

Moss Landing

Let’s Discuss Biomass




Waste Wood
Almond Shells
Urban Wood Waste
Walnut Shells
Orchard Trimmings
Corn Stover
Forest Debris
Rice Hulls
Biomass Fuels

Wood As A Fuel

- Wood is man’s oldest fuel
- Until very recently, wood was considered industrially as a waste material to be disposed of
- Escalating fuel costs and environmental concerns have changed things
- Wood use has opened up other “biofuels”

History

- 200,000 to 300,000 years - Controlled Use of Fire
- 10,000 to 20,000 years – Domesticated (living area)
- 800 years ago - First wood fuel shortages
- 400 years ago - Coal use in Europe
- 250 years ago - Industrial Revolution
- 150 years ago - Oil use
- 130 years ago - Natural gas use and electrification
- 70 years ago - Industrial wood-firing
- 50 years ago - Air pollutant investigations
- 20 years - Biofuels and “space age” investigations

- Wood differs from conventional fossil fuels
  - Physical structure
  - Chemical structure
  - Moisture content
  - "It's alive" when harvested
- Therefore it burns and must be burnt differently
- Commercially viable for other uses
- Relatively scarce resource
- Development of "urban wood wastes"

Wood Fuel Physical Characteristics

- Xylem interior "white wood"
  - Board lumber
  - Chips
- Cambium layer
  - new growth
  - source of nutrients
- Bark

Wood Fuel Physical Characteristics

- Debarking removes the Cambium layer and bark
- Yard wastes
- Processed through a hammermill (“hog”) for size reduction
- White wood
  - Sawdust
  - Sanderdust
  - Chip fines

- Other - plywood trim

Waste Wood at Lumber Mill


Mixed Fuel
Pallets, Urban Wood Waste, Tree Trimmings
Rice Hull Silo
transcon

Wood Fuel Variability

- Random reclaim operations will result in significant variations in fuel quality
- Emphasizes the importance of good fuel management and blending
- Selective fuel purchasing is also very important
- But … generally, you burn what you got

Fuel Quality

- Poor combustion performance and high CO
- Small wood particles
  - Not handled well in the feed and distribution systems
  - Rapidly entrained with insufficient time to complete the 3-Step combustion process within the furnace
- High moisture content
  - Tends to pile on the grate
  - Causes "thick-bed" grate conditions
  - Disrupts undergrate airflow

Fuel Preparation

- Screening
- Metal Removal
- Drying
- Deicing
- Sizing
- Blending

Wood Fuel Sizing

- “Overs” (> 3 inches) => Plug fuel chutes
  - Screen out
  - Mill to a smaller size
- “Fines” (<1/4 in) => Not completely burned
  - Segregate
  - Blend up to 20% with larger materials

Wood Fuel Screening

Tub Grinder for Gross Size Reduction

Hammermill for Fine Size Reduction

Wood Fuel Drying

- Part of another wood processing operation
  - Kiln dried trim
  - Dried planer shavings
  - Sanderdust
- MC > 65% requires some type of drying or blending with drier fuel
- MC < 15% is potentially explosive

Fuel Blending

Importance of Blending

- Control moisture content
- Improve fines burnout
- Implement by:
  - Gross mixing using a front-end loader
  - Separate fuel bins feeding a common feed system

Wood Fuel Characteristics - Moisture Content

- Water needed for life
- Present in the cell structure and on surface
- Moisture content varies with
  - Species
  - Location
  - Season
  - Handling practices
- Nature levels of 30% to 65%+
- Kiln dried to less than 10%

Effect of Moisture

- Decreases combustion temperatures
- Leads to incomplete combustion and the generation of higher levels of CO and ash C
- Decreases boiler efficiency
- Leads to more fuel use, higher energy costs and increased air pollutants

Wood Fuel Characteristics - Volatility

- 70% to 80% of dry wood is “volatile” hydrocarbons
- Released from the wood structure at relatively low temperatures (500 F)
- Volatiles burn “in suspension” away from the wood particles
- Balance is “fixed carbon” or “char”

Wood Chemistry

Hydrocarbons

♦ Methane	CH_4
♦ Ethane	C_2H_6
♦ Propane	C_3H_8
♦ Complex Fuels	C_xH_y
♦ More Complex Fuels	$C_xH_yS_zN_a$

Wood Species

Parameter	Pine	Redwood	Hemlock	Fir
C (%wt,dry)	50.3	53.5	50.4	52.3
H (%wt,dry)	6.2	5.9	5.8	6.3
O (%wt,dry)	43.1	40.3	41.4	40.5
N (%wt,dry)	0.04	0.10	0.10	0.10
S (%wt,dry)	< 0.1	< 0.1	< 0.1	< 0.1
Ash (%wt,dry)	0.3	0.2	2.2	0.8
Moisture (%)	30 - 60	30 - 60	30 - 60	30 - 60
Btu/lb	9,153	9,220	8,620	9,058

3-Step Combustion Process
Step #1 - Drying

- **Fresh wood particles absorb heat by convection and radiation from the ongoing combustion processes**
- **Initially, the heat energy evaporates the water in the cells and on the surface**
- **The evaporated water vapor diffuses away and mixes with the combustion products**

3-Step Combustion Process
Step #2 – Devolatilization

- **The wood fuel particles continue to absorb heat**
- **The energy absorbed releases the volatile combustibles**
- **The volatiles diffuse away, mix with air (oxygen), and burn**
- **The energy released radiates back and helps to sustain combustion**

3-Step Combustion Process
Step #3 - Char Burnout

- The char remains after the volatiles have been released
- Char is primarily pure carbon and requires:
  - An extended time period to burn
  - Air (oxygen) transported to it
- Inert ash remains after the char burnout

Ash

- Intrinsic ash (potassium) can combine with alumina and silica to form a relatively low melting point temperature ash (1600 to 1800 F)
- Potassium also volatilizes at low temperatures (1500 F) and reacts with ash in the boiler flue gas stream contributing to fouling problems
- Ash accumulation causes
  - Airflow problems
  - High draft levels and fan horsepower
  - Reduced superheat temperatures
  - Boiler shutdowns


Ash
Loadout
484A
TANK

Ash Loadout


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
- Cl-

Emissions Control Methods

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

Control of Gaseous Emissions

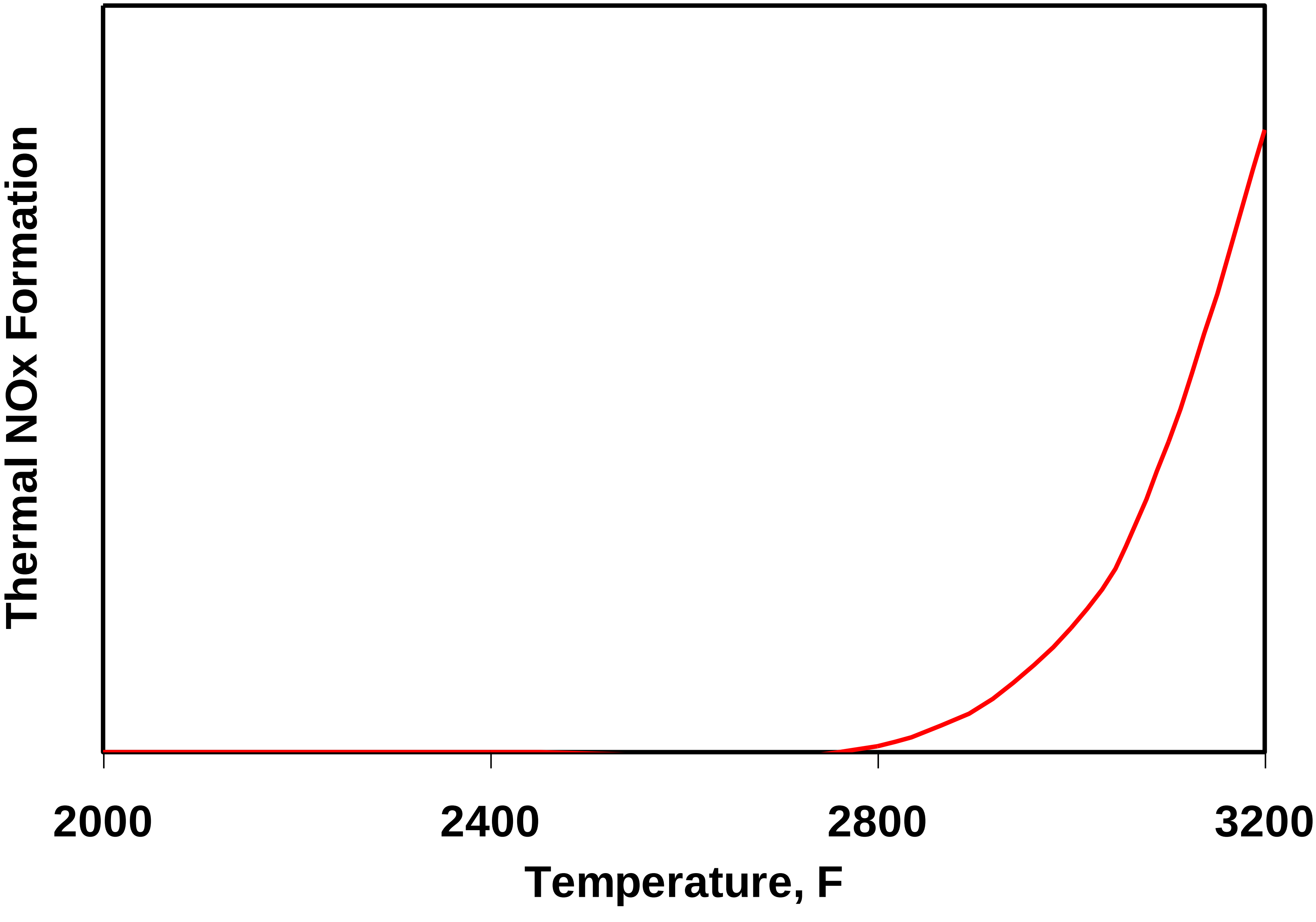
- Low-NOx burners
- OFA
- Ammonia injection (SNCR)
- Catalysts (SCR)
- RSCR
- FGR

Combustion Considerations

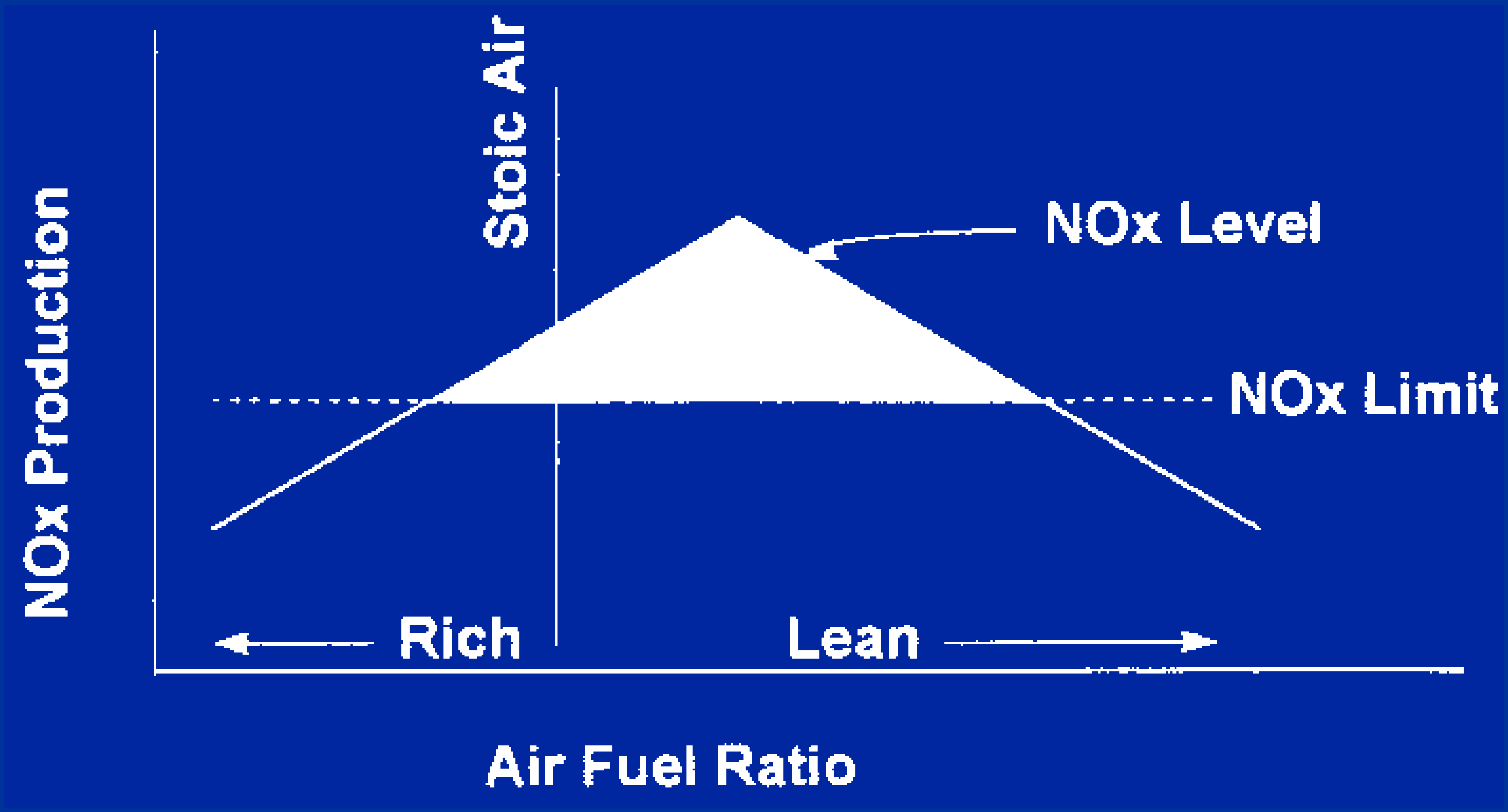
- Time
- Temperature
- Turbulence
- Oxygen
- Nitrogen

♦ Thermal NOx
♦ Fuel-bound NOx
♦ Prompt NOx
NOx Creation

Thermal NOx vs. Temperature

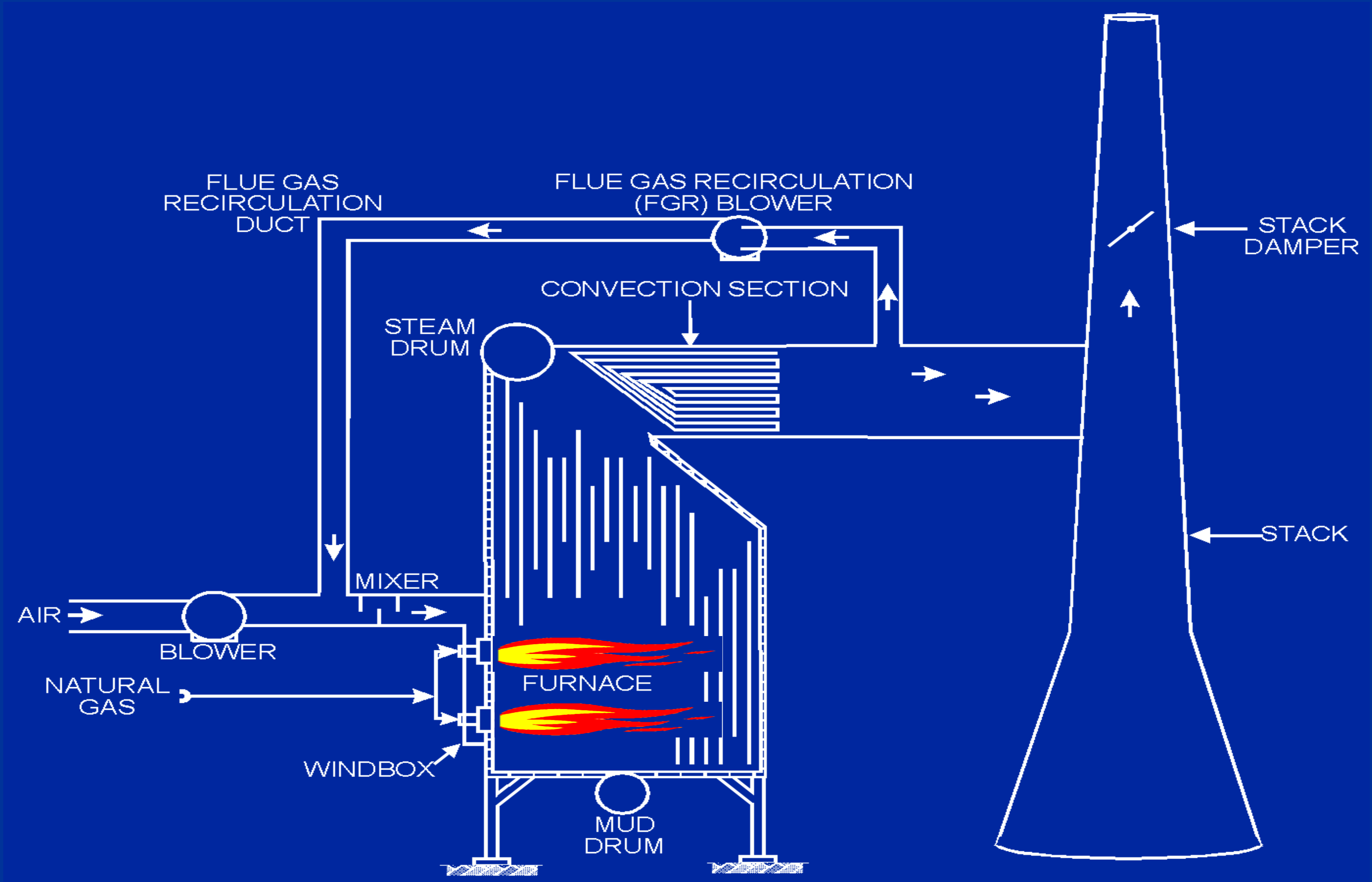


NOx Production vs. Air/Fuel Ratio

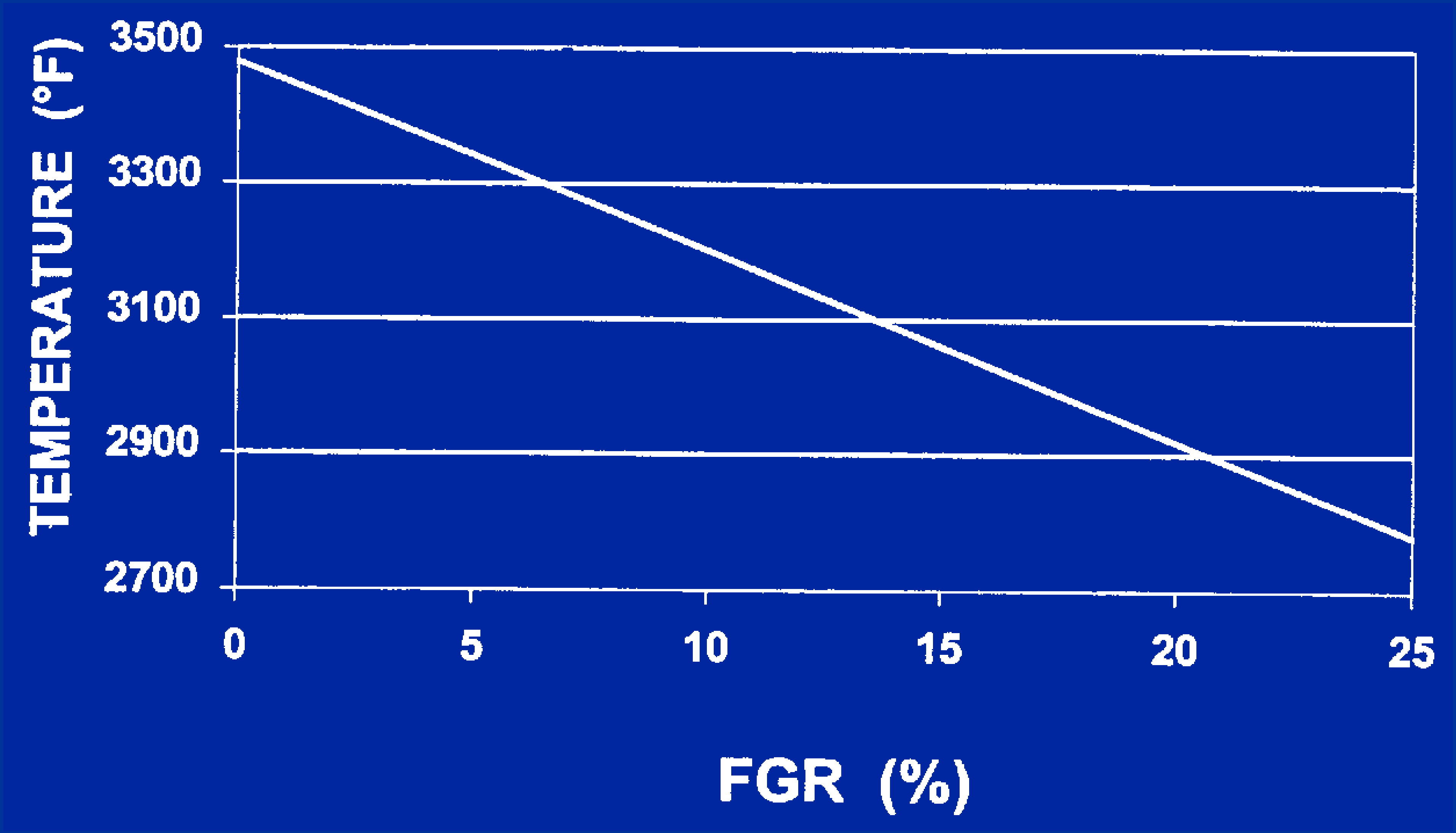


Let’s Discuss FGR

Flue Gas Recirculation (FGR)

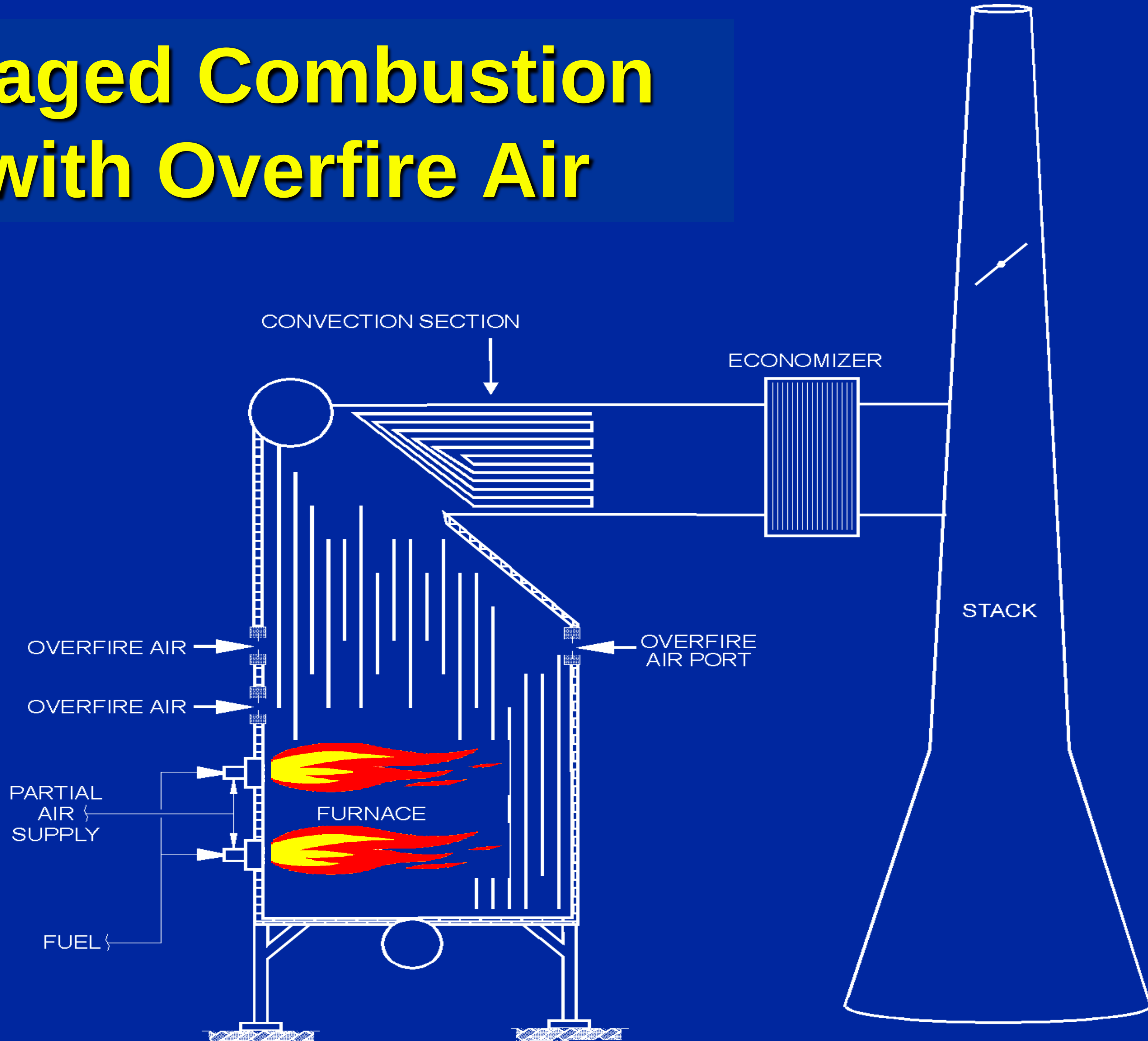


Flame Temperature vs. FGR



Let’s Discuss Staged Combustion

Staged Combustion with Overfire Air



Let's Discuss SCR, SNCR and RSCR

What is SCR?

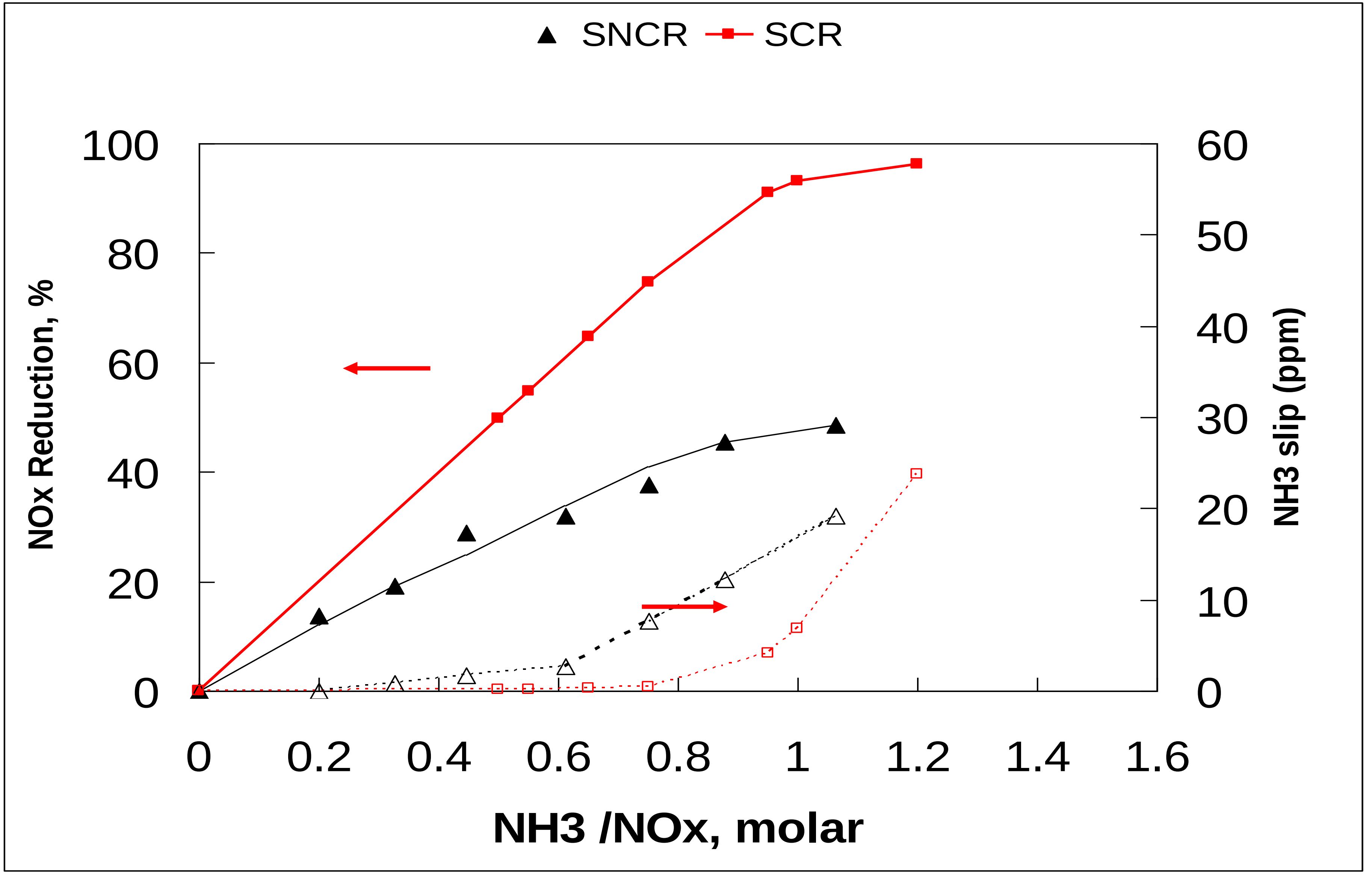
SCR

Selective **C**atalytic **R**eduction

(This means that NO_x will selectively react with NH_3 in the presence of Oxygen, similar to SNCR but a catalyst is needed to help the reaction which takes place at a lower temperature than SNCR)


SCR
Application

SNCR vs. SCR



SNCR
SCR
100
80
60
40
20
0
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
NOx Reduction, %
NH3 slip (ppm)
NH3 /NOx, molar

Where is SCR Used

- Widespread Use
  - Coal and Gas Fired Utility Boilers
  - Gas Turbine Electric Generators (Simple and Combined Cycle)
- More Recently
  - Refinery Combustion Systems
  - Smaller Industrial Boilers (Gas, Biomass Fired)

SCR @ Typical Utility Boiler

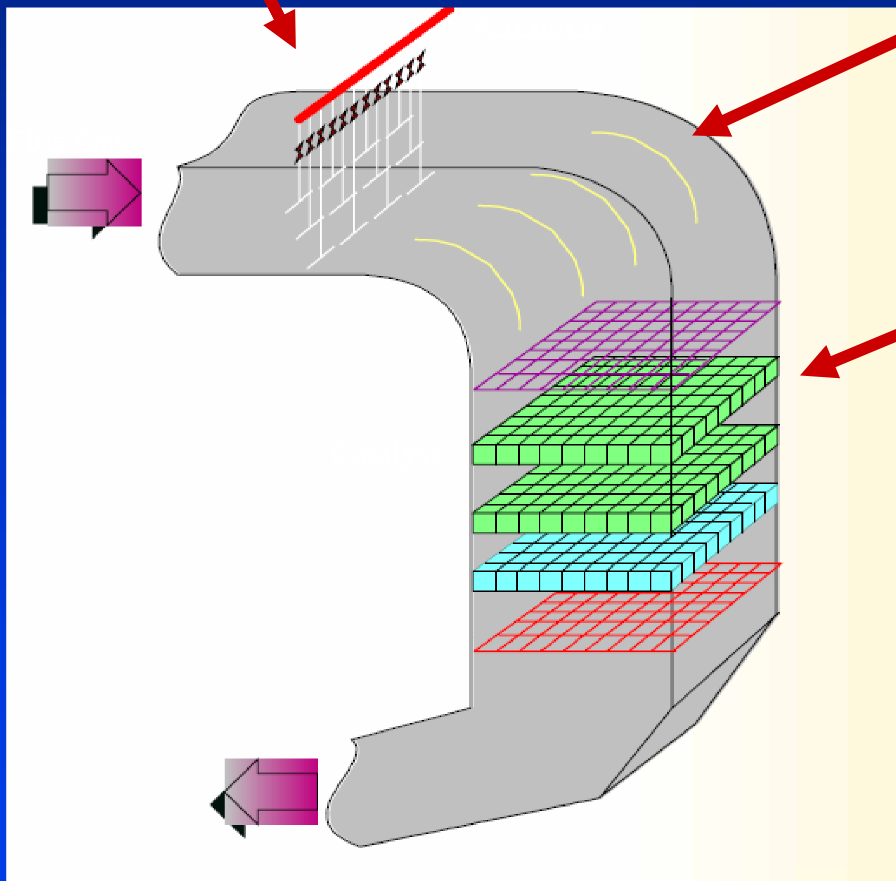
SCR

NH_3 Injection:

(Uniform NH_3/NO_x Critical)

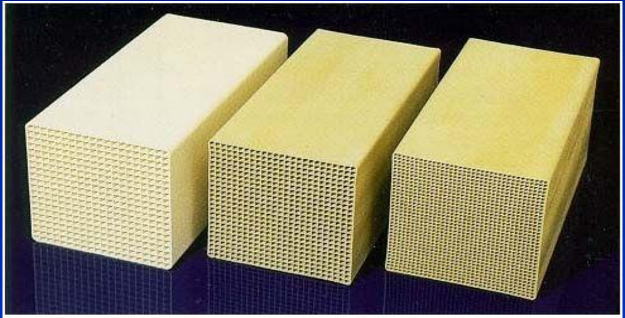
Turning Vanes to give uniform Velocity across the Catalyst

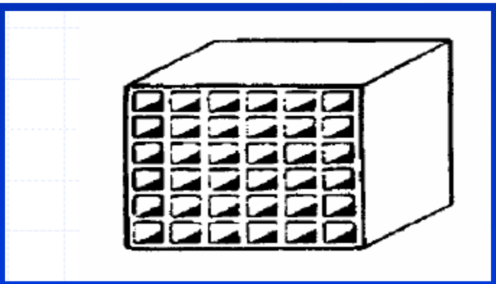
Catalyst Layer(s)



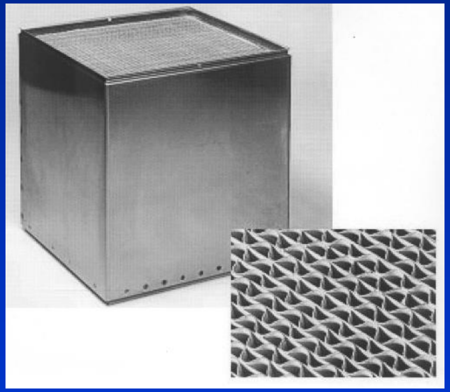
SCR Catalyst Types

Extruded Ceramic Honeycomb

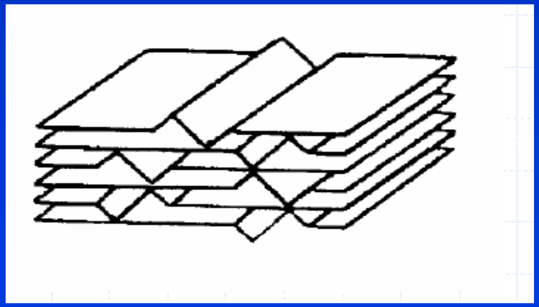




Corrugated (Haldor-Topsoe)



Plate



Composition

- Vanadium Pentoxide (V_2O_5)
- Titanium Dioxide (TiO_2)
- Molybdenum
- Tungsten


SCR Catalyst &
NH_3 Tubes

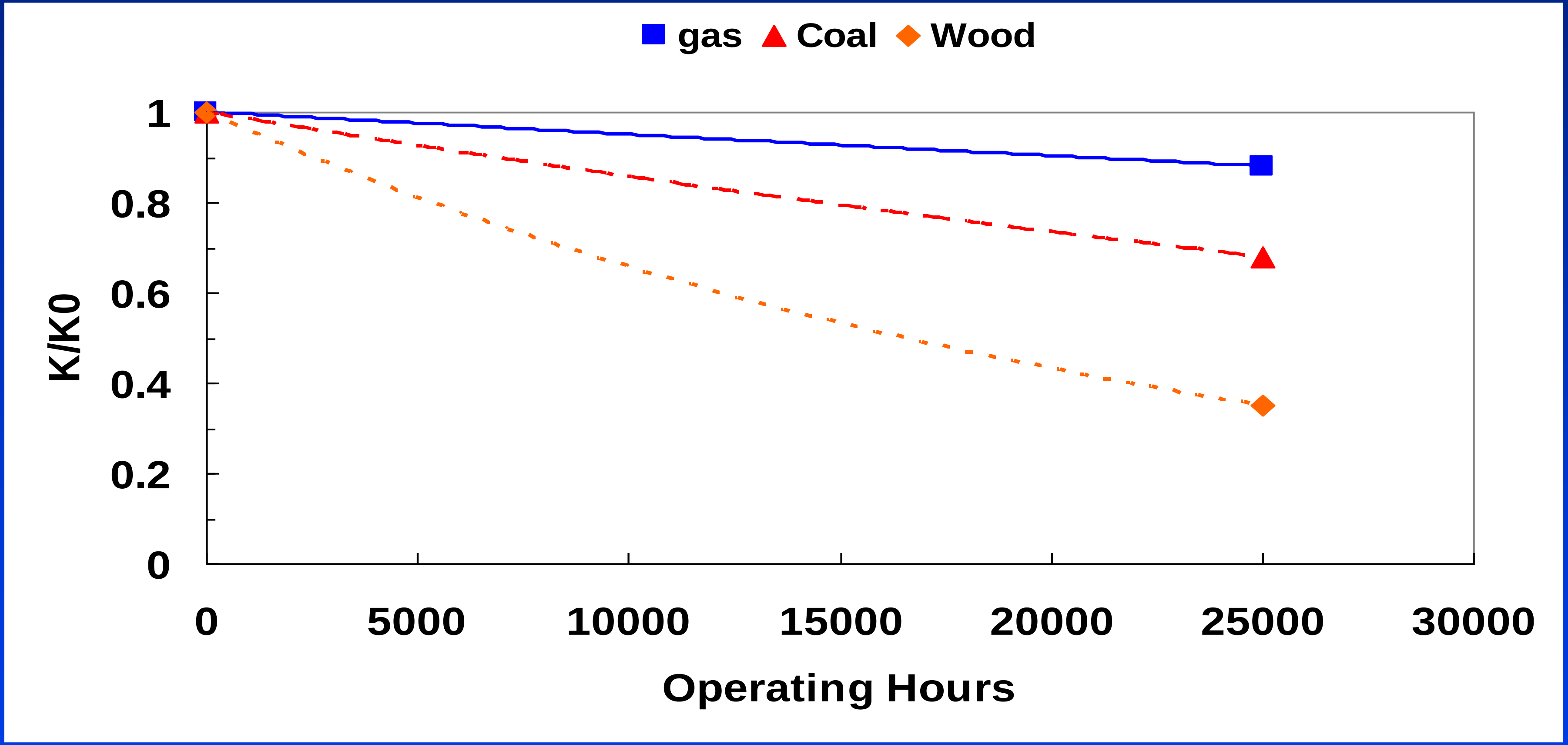

SCR Catalyst

Catalyst Degrades With Time

Reason for Degradation Fuel Dependent

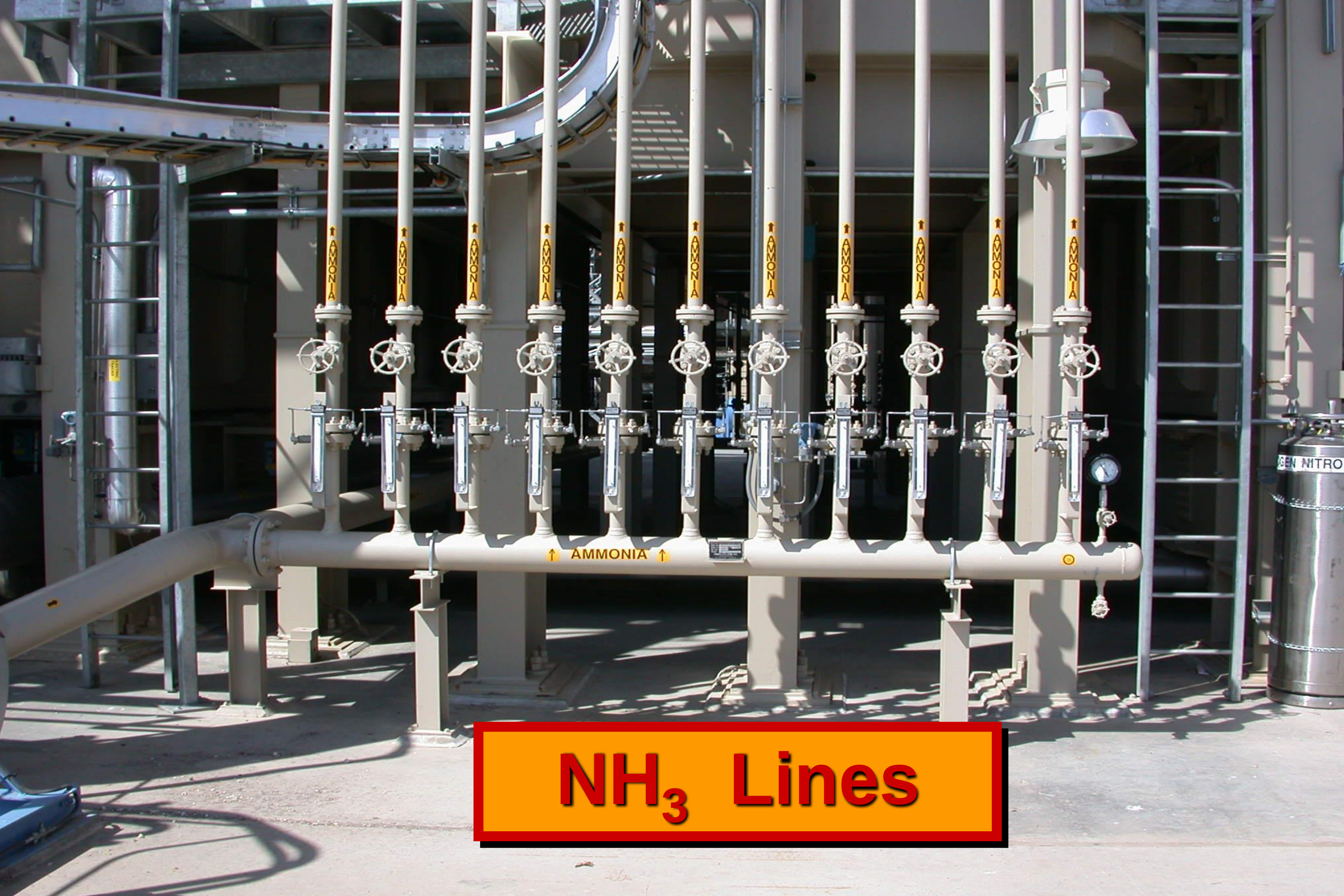
- Bituminous Coal-Arsenic Poisoning
- Other Coal- Calcium sulfate blinding
- Potassium & ChlorinePoisoning

Typical Catalyst Deactivation Rates




Ammonia
Injection
Grid


SCR &
NH_3 Tubes



NH_3 Lines


Small Boiler
with SCR


Utility Boiler with SCR

SNCR vs SCR

	SNCR	SCR
NOx Reductiuon	20-50%	50-95%
Hardware	Simple	More Complex
Capital Cost	Low (1)	High (5-10)
Reagent Utilization	Typ. 30%	Almost 100%
O&M	Reagent	Reagent/Catalyst
Designability	Poor	Good
NH3 slip	5-20 ppm	<10 ppm

Let's Discuss Particulate & NH_3 Controls

What is SNCR?

SNCR

Selective **N**on-**C**atalytic **R**eduction

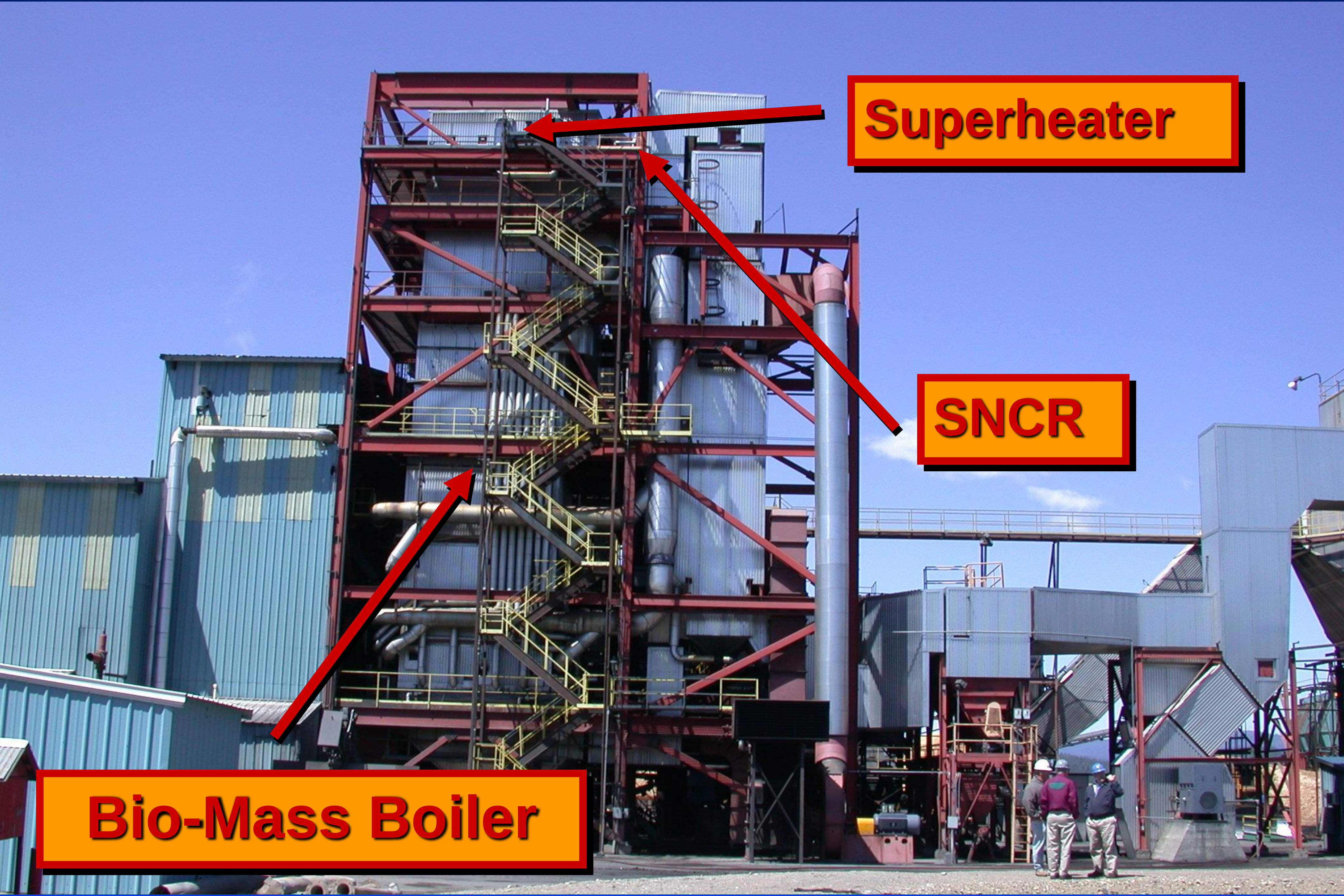
(Means that a chemical will selectively react with NO_x in the presence of Oxygen)

- **Ammonia (NH3)**

Urea (NH2CONH2)


Circulating Fluidized Bed Boiler
w/SNCR

SNCR @ Bio-Mass Plant


Superheater
SNCR
Bio-Mass Boiler

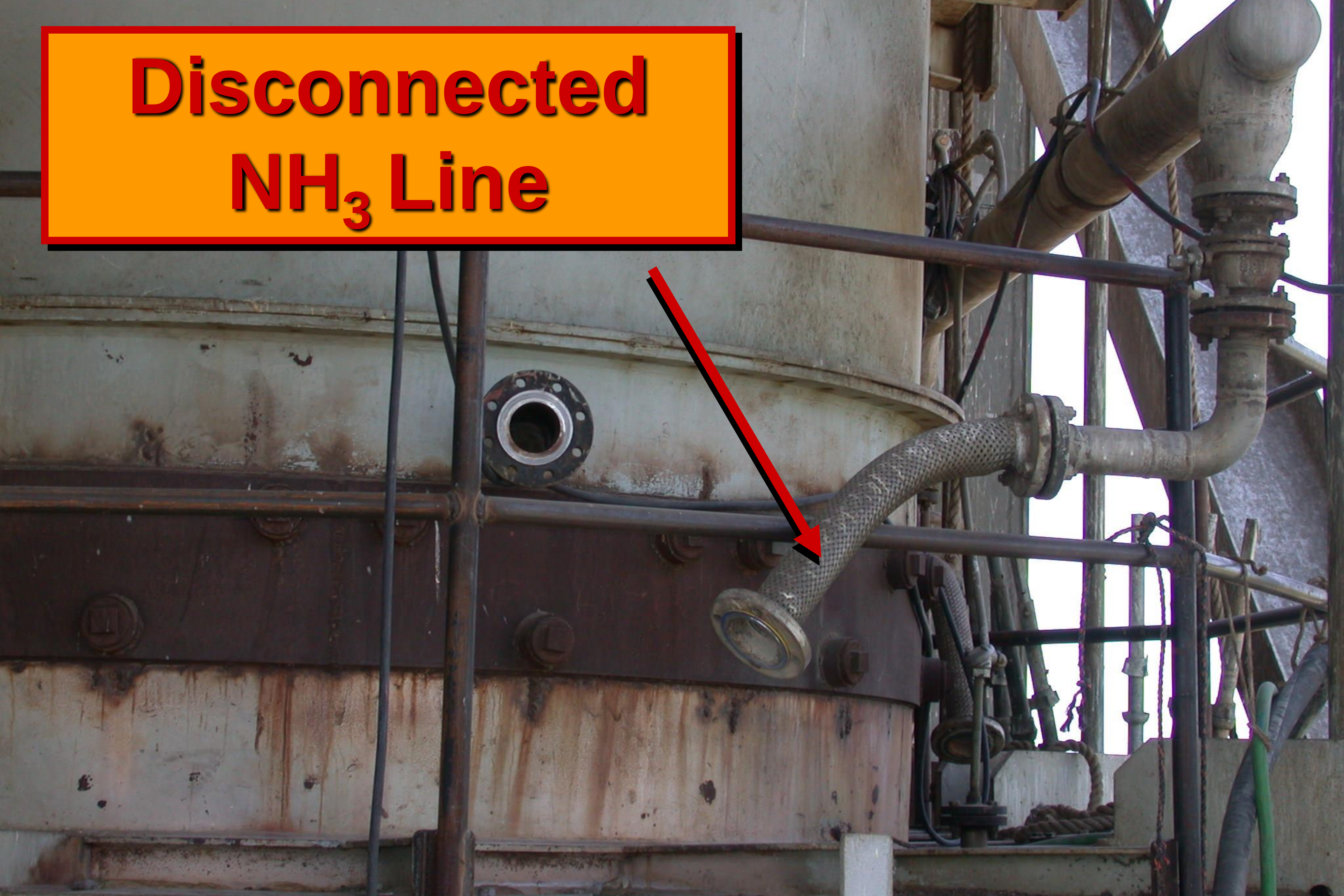
Ammonia Storage Tank

Anhydrous Ammonia Storage Tank

Ammonia vs. Urea

Parameter	Ammonia	Urea
Form	High Vapor Pressure Liquid Ammonia/Water Solution	Liquid Solution
Safety	Anhydrous/29.4% Aqueous- safety iss 19% Aqueous- fewer Safety Issues	No Safety Issues
Storage	Anhydrous-Pressure Vessel Aqueous- Atmospheric Pressure	Atmospheric Pressure Crystalization at Low Temperature
Injectors	Needs Carrier Gas	Atomizers(Pressure or Twin Fluid)
Temperature	Peak Removal @ 1750 F	Peak Removal @ 1850 F Large Dilute Drops Shield Urea
System Complexity	Relatively Simple	Relatively Simple


Bio-Mass Boiler


Disconnected
NH_3 Line

Balance-of-Plant Impacts

- NH_3 Slip
- SO_3/NH_3 Reactions (APH Deposition)
- HCl/NH_3 Reactions (Plume Visibility)
- Ash/NH_3 Absorption (Ash Sales, General Nuisance)
- N_2O Emissions

What is RSCR?

RSCR

Regenerative Selective Catalytic Reduction

(This means that NO_x will selectively react with NH_3 in the presence of Oxygen, similar to SCR with a catalyst to help the reaction and two thermal transfer beds)

Ammonia Slip

- $NH_3 + OH \Rightarrow NH_2 + H_2O$
- $NH_2 + NO \Rightarrow N_2 + H_2O$
- $2NH_3 + OH + NO \Rightarrow 2H_2O + N_2 + NH_3$
- 10 to 25 ppm NH_3 Slip
- Could be higher
- Always have Some NH_3 slip

NH_4Cl Formation

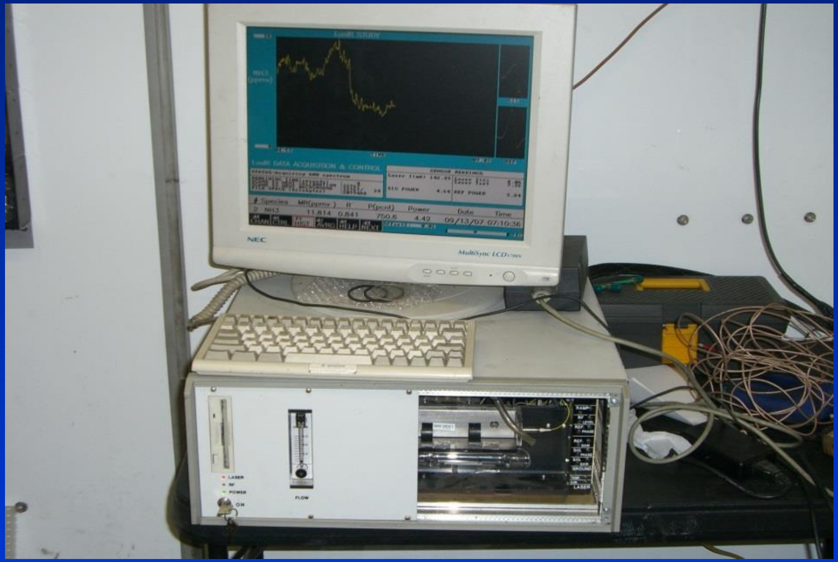
NH_4Cl Formation

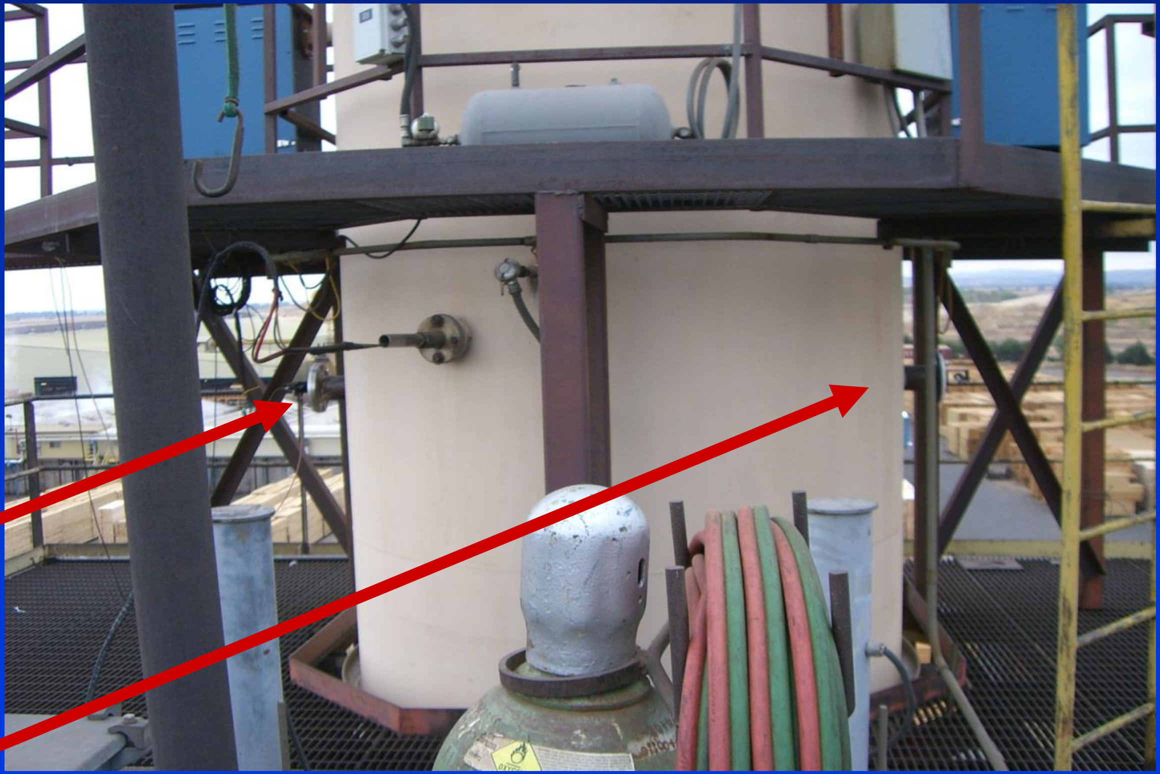
- Function of the concentrations of NH_3 and HCl
- Concentrations decrease as air is mixed into the plume
- Lower concentrations => less NH_4Cl formed
- Therefore: air dilution is good

What Can Be Done??

- Minimize (eliminate Cl) in fuel
- Install acid gas controls
- Minimize NH_3 slip <= monitor
- High stack gas temperatures
- High ambient air temperatures (winter time a problem??)
- Promote rapid gas/air mixing ??
- Install high gas temperature concentric stack annulus ??

Continuous NH3 Analyzer





Laser &
Detector

Retro
Reflector

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 – 1st 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
PM Control

What is Particulate Matter??

- It is what the test measurement says it is
- Meaning:
  - Solid particles that are captured on a filter
  - Condensable matter collected in a set of impingers
- What eventually condenses in the atmosphere is also considered as particulate matter along with “solid” particulate in the gas stream


PM


Circulating Fluidized Bed Boiler
Sources of PM

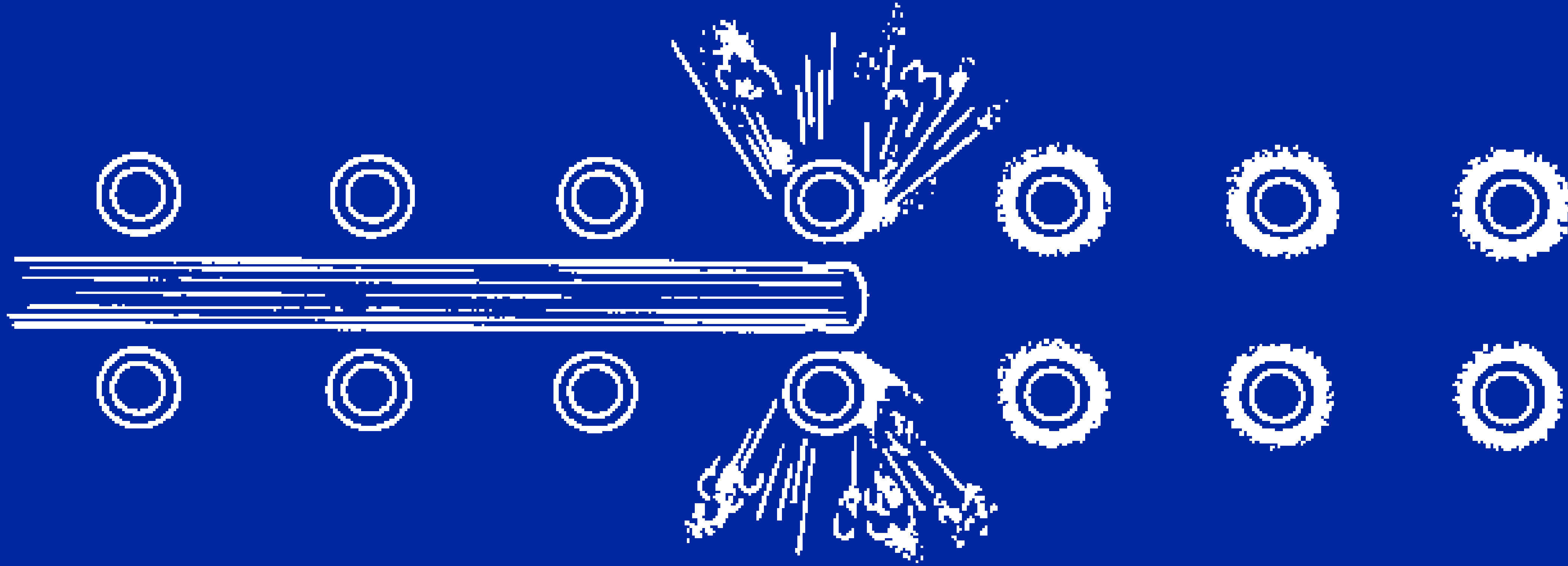
Sources of "Particulate Matter"

- Ash in the fuel
  - Silica and Alumina - generally large particles that are retained or collected in the boiler/precipitator
  - Intrinsic ash - generates the small particles that are more troublesome to control
  - Alkalis - potassium, sodium and calcium
- Condensables (HCl, SO_3, NH_4Cl) which are also considered as "particulates

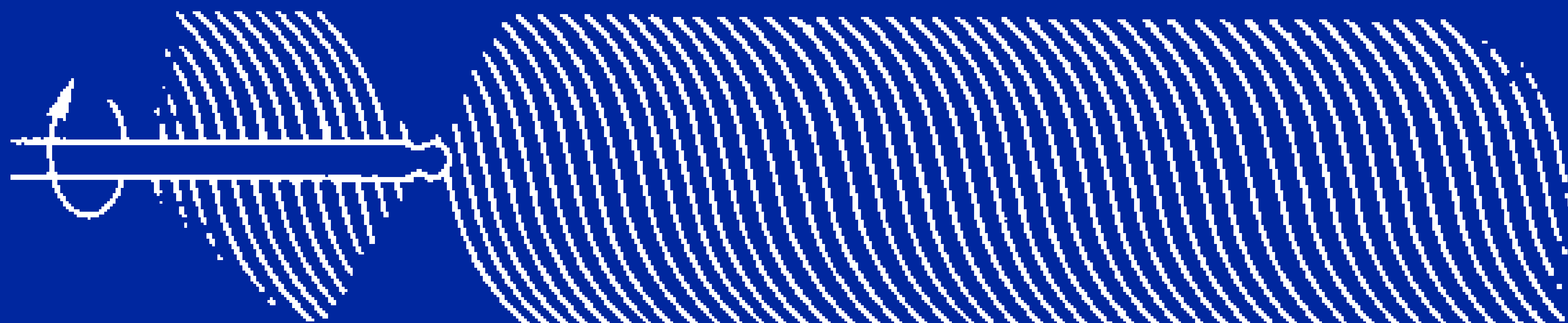
Control of Particulate Emissions

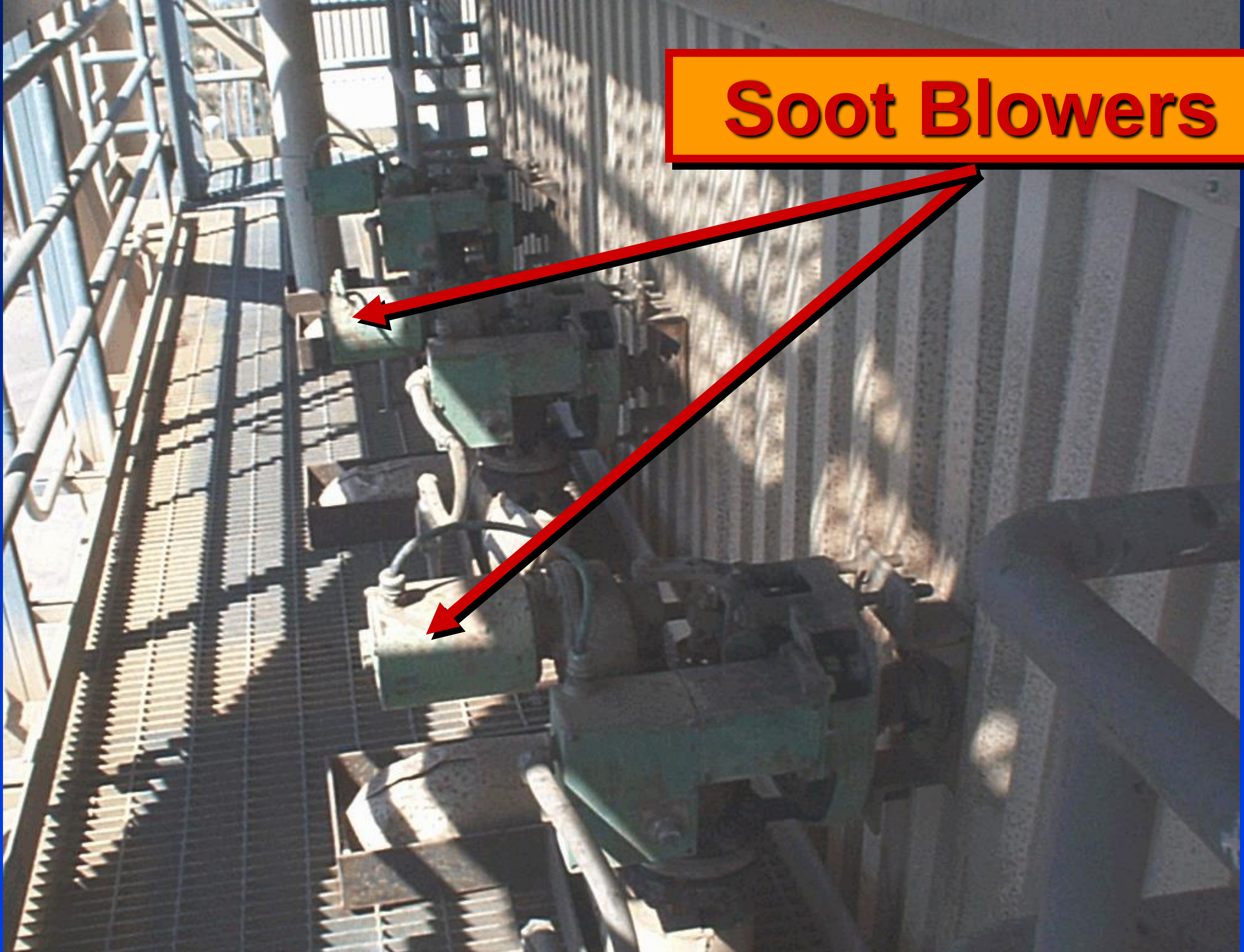
- Settling chambers
- Cyclones
- Baghouses
- ESPs
- Scrubbers


Water Spray



Soot Blowing




Soot Blowers


Cyclone

Multi-Cyclone


Baghouse


ESP

Regulatory Requirements

Regulatory Requirements

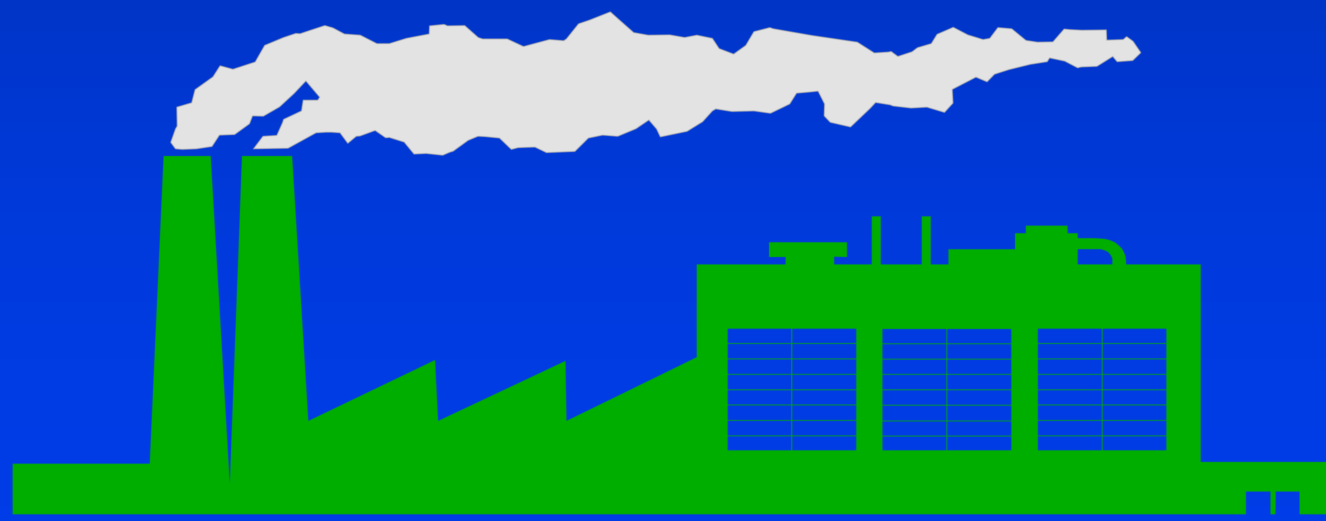
- Federal, state, and local requirements
- Boiler specific limits
- Permit requirements
- Monitoring requirements
- Visible emission limits
- Nuisance regulations
- Breakdowns & variances

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
- MACT DDDDD & JJJJJJ

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

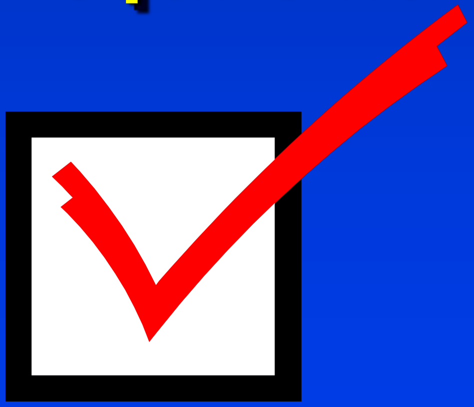


BACT

Type of Control	NOx Limits
Natural Gas Fired with SCR & Low NOx Burner	0.010 lb/MMBTU
Natural Gas Fired Units (< 60 MMBTU/hr)	0.035 lb/MMBTU
Biomass Fuel Fired Boilers (Large), SNCR	0.10 lb/MMBTU
Municipal Solid Waste	110 ppmv @7% O2

Permit Condition Categories

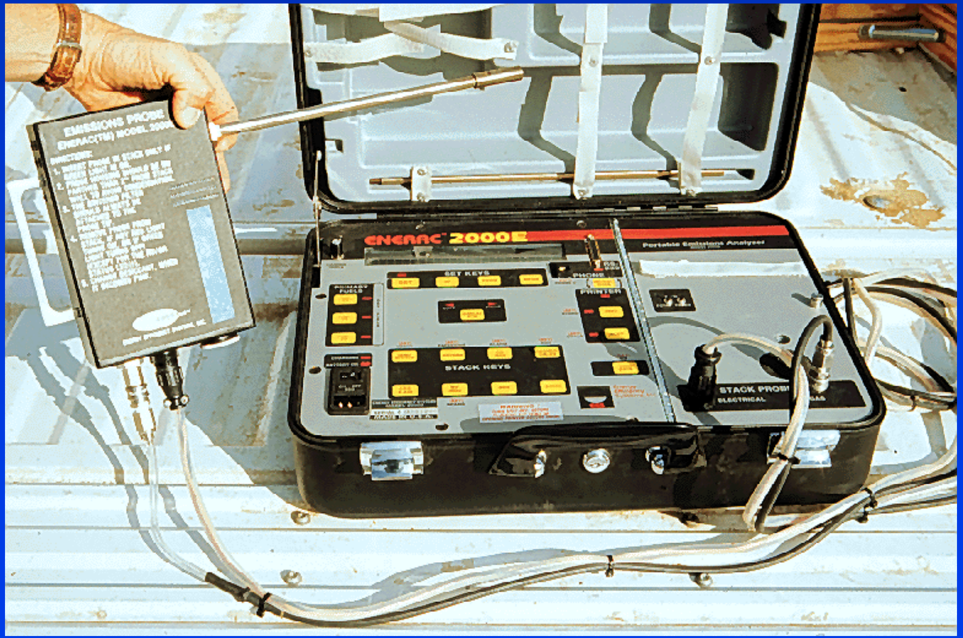
1. Emissions Limitations
2. Equipment Requirements
3. Operating Conditions
4. Monitoring and Recording Requirements
5. Compliance Testing
6. General Requirements



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

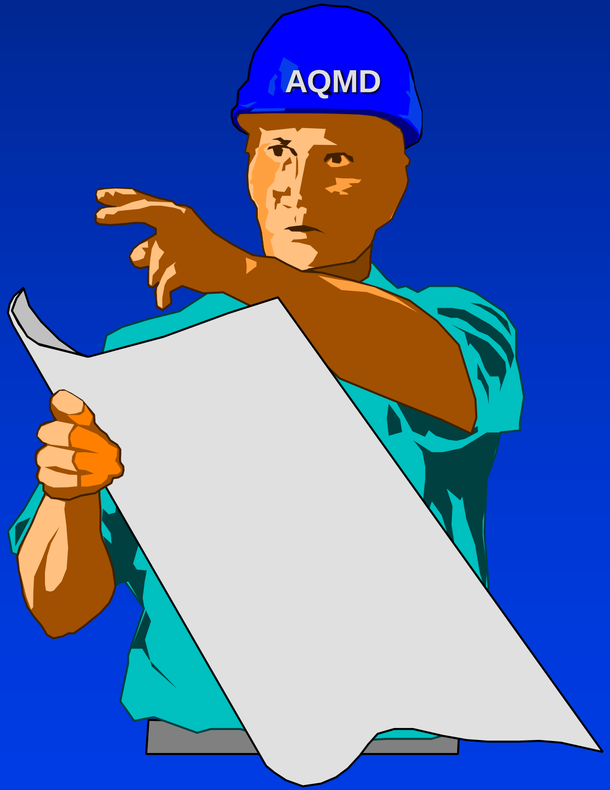

Points of Inspection
♦ Capture
♦ Transport
♦ Air mover
♦ Control device
♦ Instrumentation
♦ Subsystem
♦ Records

Pre-Inspection

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

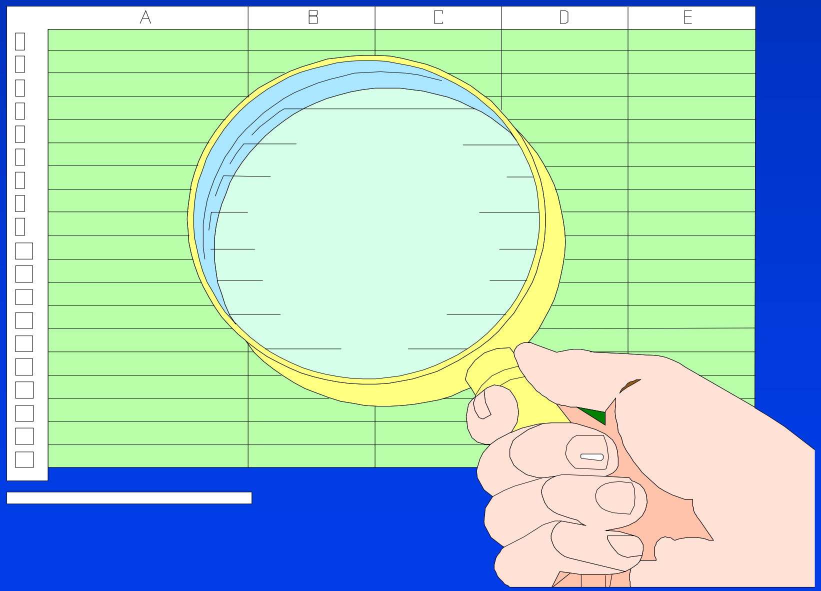
Reasons for Inspections

- 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

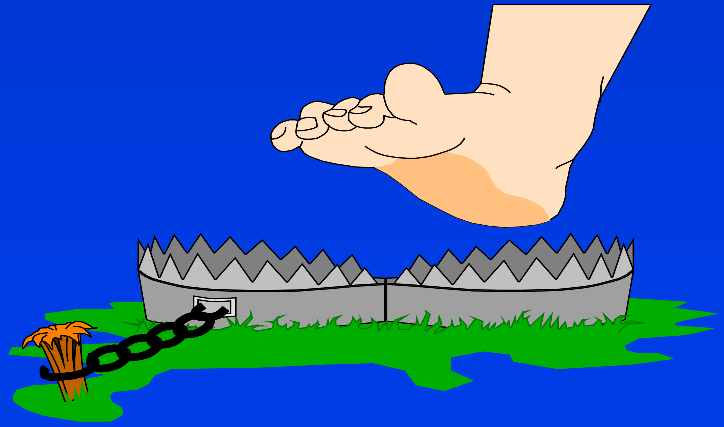



Plant
Safety

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

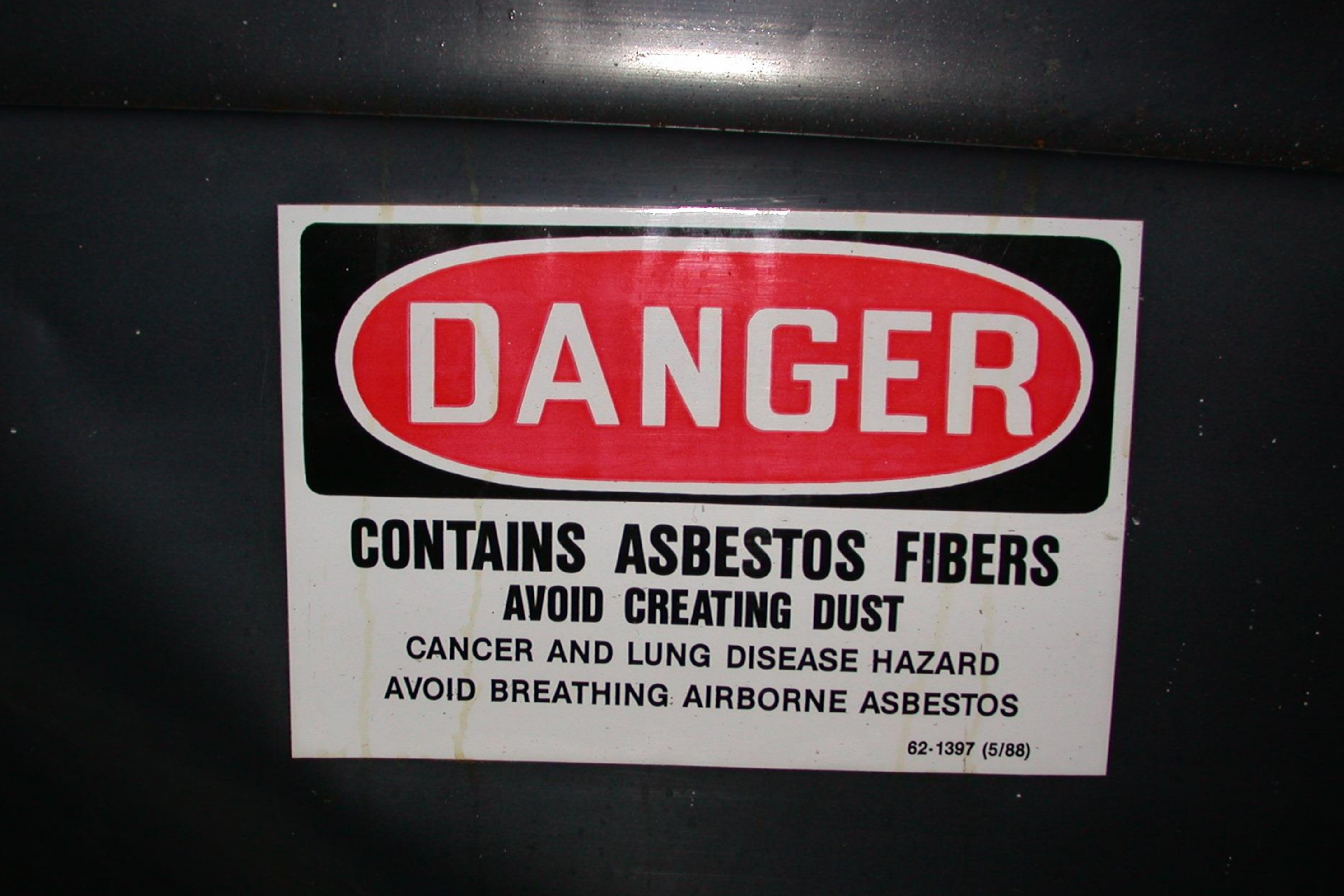


Plant Safety


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)


FUEL GAS
HP Gas Lines


Ruptured
Steam Line


Steam
Exhaust


Access


Access


Thank You!