APTI Course 427

Combustion Source Evaluation

Chapter 6:
Air Pollution Control Systems

Chapter Overview (outline)

- Introduction
- Particulate Matter & Metal Emissions Control
- Sulfur Oxides and Hydrogen Chloride Controls
- Nitrogen Oxide Control
- Carbon Monoxide & Organic Emissions

Introduction

- Pollutant formation
  - Combustion zone formation, direct emission
  - Secondary – H_2SO_4 and dioxins
- Emissions control
  - Combustion zone &/or back end
- Control device combinations & synergy
  - Bag house gas capture
  - Ash sale/reuse
- Factors affecting emissions

Introduction (cont.)

Factors affecting emissions
  - Fuel choices: NOx & SO_2

- Fuel properties
  - Catalyst & precipitator performance
  - Boiler slag

- Emissions control → choices, trade-offs

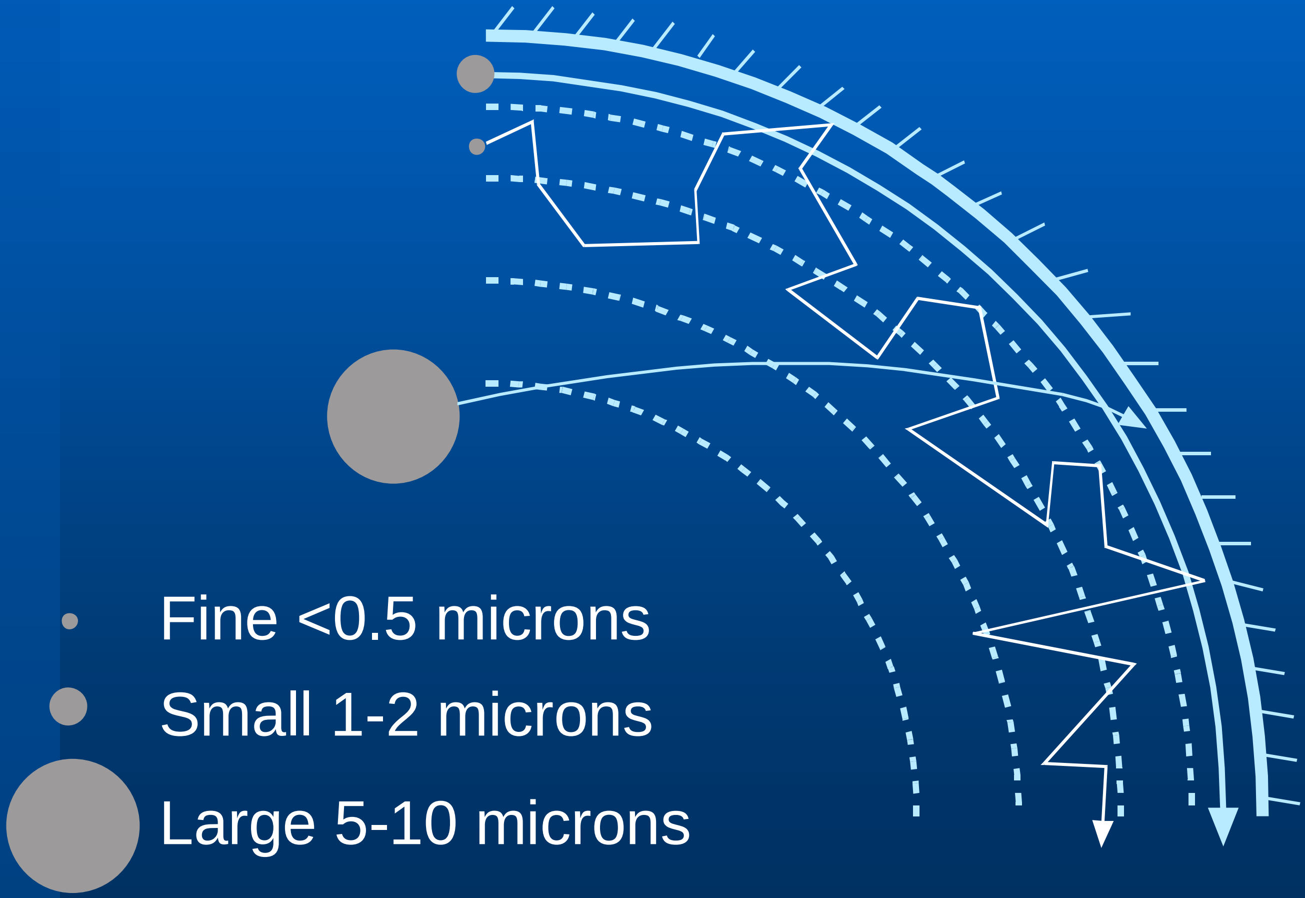
Particulate Matter & Metal Emissions Control (outline)

- Basic Concepts
- Particle Collectors
  - Inertial Collectors
  - Particulate Scrubbers
  - Fabric Filters
  - Electrostatic Precipitators
  - Collector Combinations
- Dust Collector Fires
- Oil Fired Particulate

Types of Particle Collectors

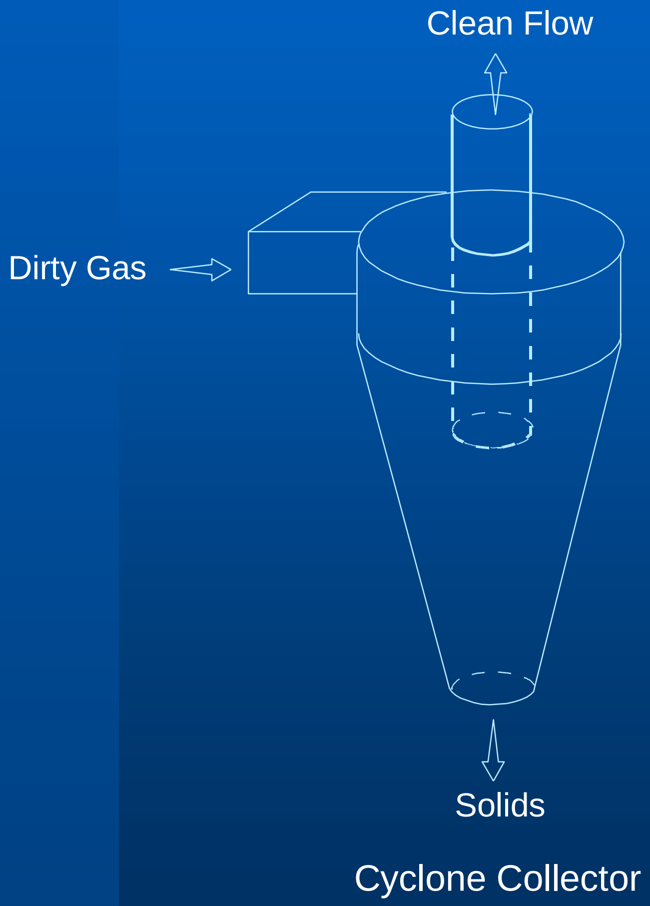
- Collector choice depends on conditions, requirements.
- Three basic mechanisms
  - Inertial Collectors
    - Particulate Scrubbers
  - Filters
  - Electrostatic Collectors
- Particle size

Particle Motion vs.Gas Streamlines

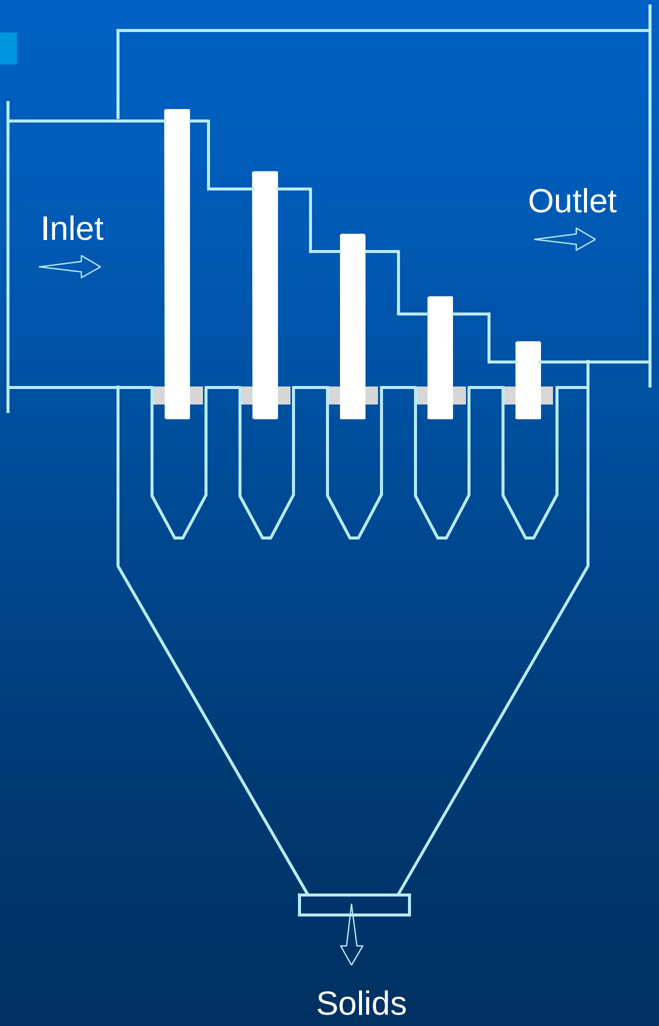


- ● Fine <0.5 microns
- ● Small 1-2 microns
- ● Large 5-10 microns

Inertial Collectors



Cyclone Collector



Multiclone Collector

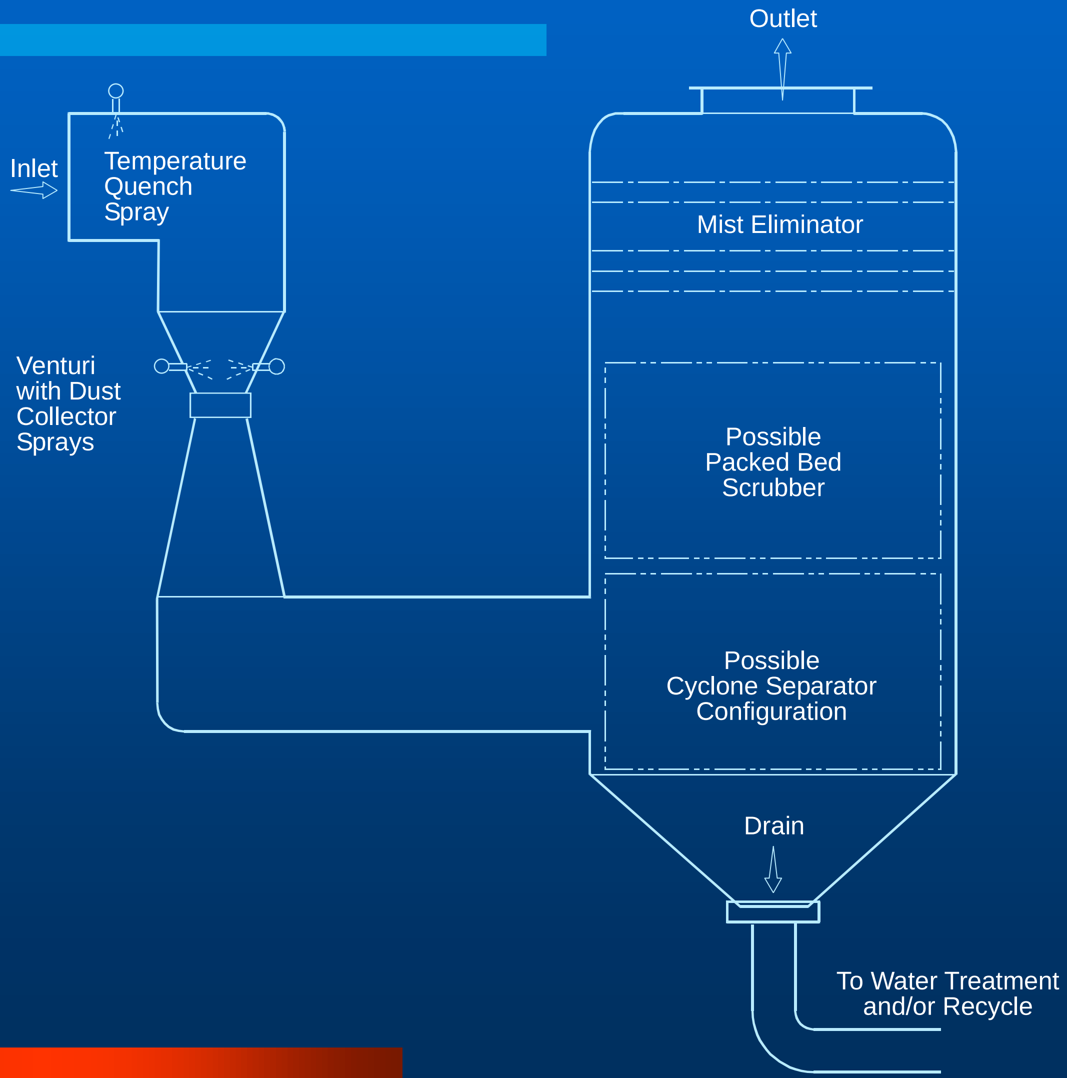
Inertial Collectors (cont.)

- Applications
  - Industrial particle transport
  - Simple emissions control
- Collection efficiency
- Limitation – poor opacity control
- Factors affecting performance

Particulate Scrubber

- Comparative features
  - Collection performance
  - Size
  - Cost
  - Low flammability
  - Waste water management

Particulate Scrubber (cont.)



Example 6-1. Scrubber water

A scrubber requires about 15 gal/min of water per 1000 cfm inlet flow rate. The stack flow is 22,000 acfm @ 155°F. The scrubber inlet is 435°F and +25 inches w.g. How much water is required?

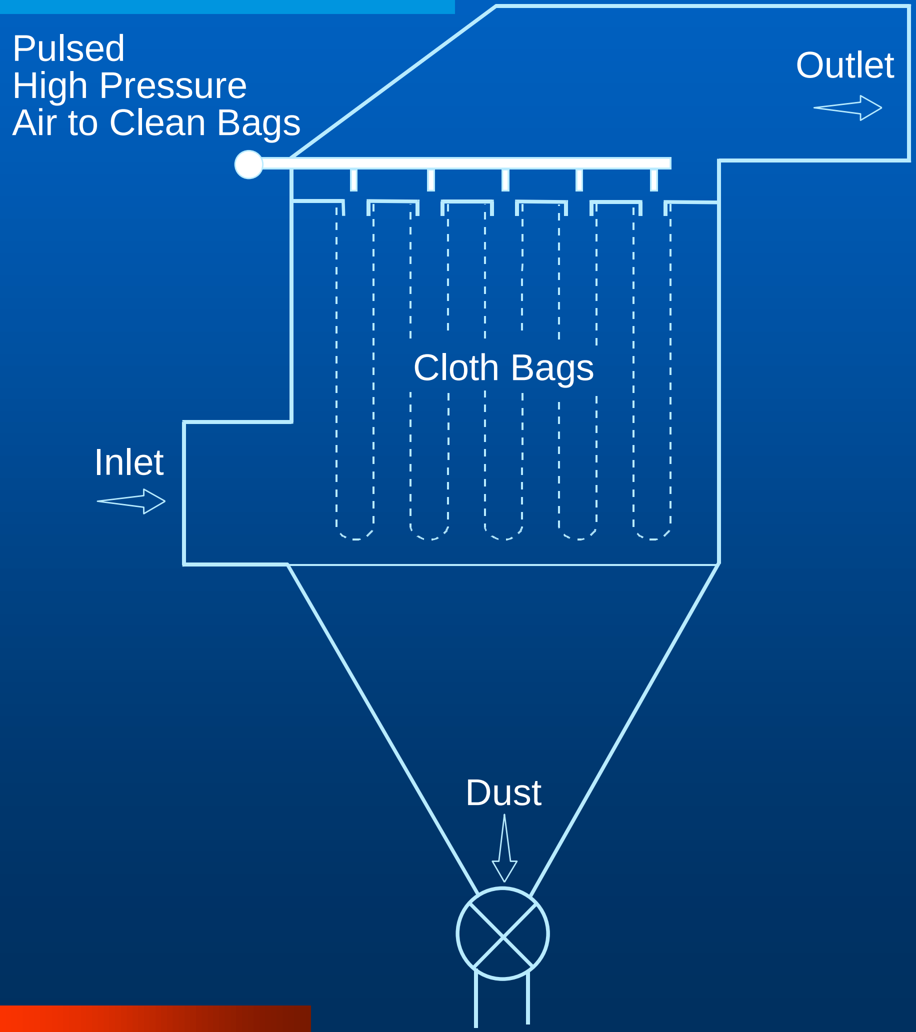
Solution: (a) Determine gas flow

$$22{,}000 \text{ acfm} \times \frac{435 + 460}{155 + 460} \times \frac{29.92}{29.92 + {}^{25}\!/_{13.6}} = 30{,}163 \text{ acfm inlet}$$

(b) Calculate water required

$$15\left(\frac{{}^{\text{gal}}\!/_{\text{min}}}{1000 \text{ cfm}}\right) \times 30{,}163\ (\text{cfm}) = 452\left(\frac{\text{gal}}{\text{min}}\right)$$

Fabric Filter



Fabric Filter Operation

- Collection efficiency approaches 100%
- Similar to a vacuum cleaner
- Cleaning
  - Pulse jet
  - Reverse flow
  - Fluctuating pressure drop

Baghouse Filter Mechanism

- Filter cake collection
  - Filtration & impaction

- Filter materials
  - Matching the dust
  - Temperature limits

Fabric Filter Failure Modes

- Bag life
- Dust accumulation
  - Temporary
  - Blinding

Baghouse Monitoring

- Detect failure
- Tribo electric probe – very sensitive
- Opacity monitor – not sensitive
- Pressure drop – long term indicator

Baghouse Pressure Drop

- Variation over time
- Indicative of flow rate

- Example
  - If 1% flow leaks thru holes
  - Delta P drops 2% (not detectable)
  - Particulate bypass →1% (efficiency <99%)
- Pressure drop will show blinding

Example 6-2. Bag house delta P

A new baghouse has a collection efficiency of 99.95%. The bags develop leaks where 0.7% of the gas bypasses the fabric. Determine the emissions increase and the Δp decrease?

Solution:

The amount of particulate getting through the fabric increases from 0.05% to 0.7 + 0.05 = 0.75% of the inlet particulate. Emissions increase by a factor of 0.75/0.05 = 15.

The gas flow through the baghouse is constant, but now 99.3% = 100% - 0.7% of the gas passes thru the fabric. The pressure drop will decrease by $0.993^2 = 0.986$ or 1.4% less than the original

Baghouse Gas Temperature

- Not direct indicator of emissions
- Low temperature
  - Blinding
- Severe high excursions
  - Complete failure

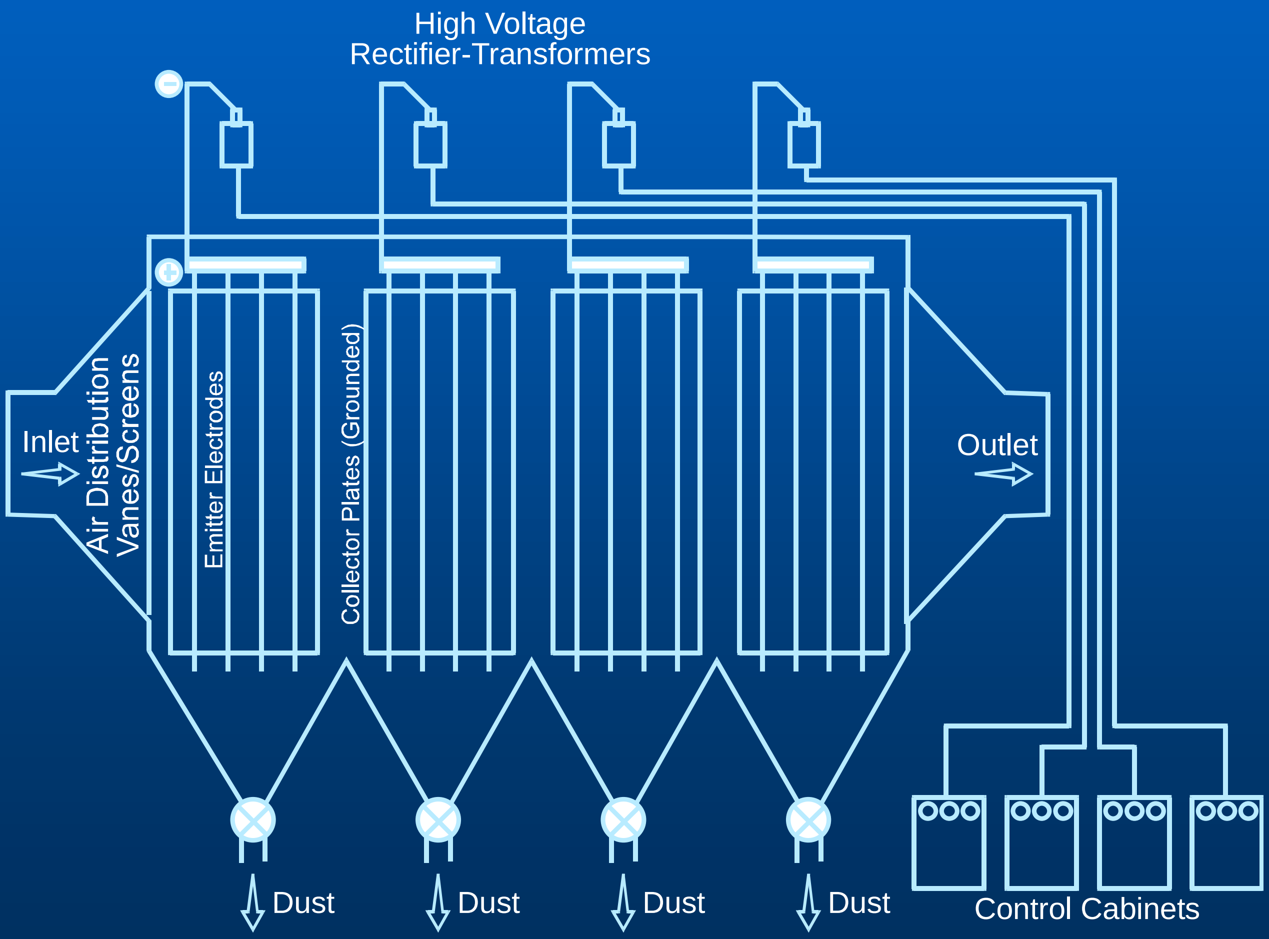
Electrostatic Precipitator

- Collection efficiency
- Advantages – low delta P, rugged
- Operation
- Internal components
- Sensitive to
  -- Dust & gas chemistry
  -- Temperature

Types of ESPs

- Wet precipitators
- Dry precipitators
  - Hot side
  - Cold side

Electrostatic Precipitator



Electrostatic Precipitator (2)

- Electrical control function
- ESP performance margins
- Flow velocity & distribution

Precipitator Monitoring

- Opacity

- Collection performance
  - Flow geometry
  - Reduced power levels

Collector Combinations

- Charging particles
- Particulates and gaseous systems

Dust Collector Fires

- Potential damage
- Prevention (fuel, air, ignition)
- Scenarios
  - Start up & upsets
  - Hopper, bag & plate fires

Oil Fired Particulate

- Emission levels
  - Usually no dust collector
  - 0.05 to 0.1 lb/mmBTU

- Dust collector problems

Sulfur Oxides and Hydrogen Chloride Controls

- Approaches to SO_x Control
  - Fuel Switching and 1990 CAAA
  - Flue gas desulfurization

- SO_3 and HCl Control
  - Troublesome pollutants in small quantities

Fuel Switching

- Emission limit versus cap
  - Sulfur limit vs fuel switch

- Emission allowances & markets

- Boiler limitations on fuel switching
  - Coal vs oil vs gas
  - Coal 1 vs coal 2

Flue Gas Desulfurization

- Dealing with solid waste or by product

- Types of scrubber
  - Wet
  - Semi- Dry
  - Dry

Wet Scrubbers

- Principle (gas washing)
- Components
  - Contactor
  - Water management
- Side effects
  - Mist carries out PM2.5 and H_2SO_4

Semi-Dry Scrubbers

- All water evaporates
- Dry exhaust
- Integral dust collector
  - No mist or fine particulate
- Efficiency
- Typical applications

Dry Scrubbers

- Dry chemistry – integral dust collector

- Reagent
  - Proprietary powders
  - Surface area

- Performance
  - Good for SO_3

SO_3 and HCl Control

- SO_3 issues
  - Wet scrubbers don’t work
  - Visible plume
  - Corrosive
  - Impact of downwash plumes
- Acid condensation
- Dry scrubbing reagent efficiency

- HCl

Nitrogen Oxide Control (outline)

- NOx controls – 2 categories
  - Both still evolving
  - Very low NOx linked to natural gas

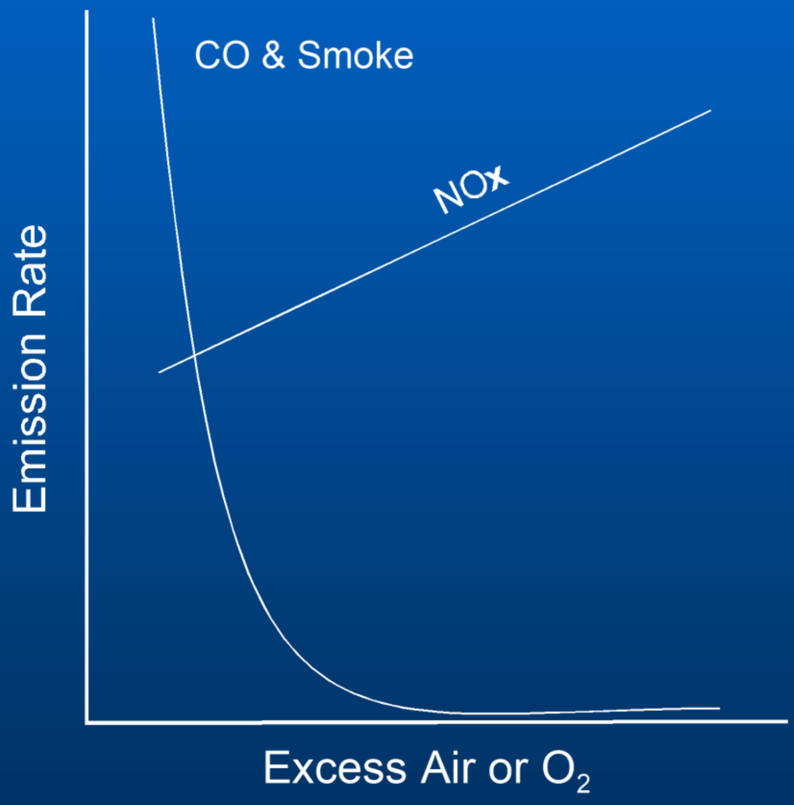
- Combustion Modifications
- Premixed vs. Diffusion Flames
- Add-On or Back End Systems
- Combinations

Combustion Modifications (outline)

- Excess Air Control
- Flame Temperature Reduction
- Staged Combustion
  - Low NO_x Burners

Excess Air Control

- NOx dependence on excess air
- Trade off with CO & PIC
- Air flow control requirements
- Always the 1st step



NSCR

- Non Selective Catalytic Reduction

$$NO_x + CO \rightarrow N_2 + CO_2$$

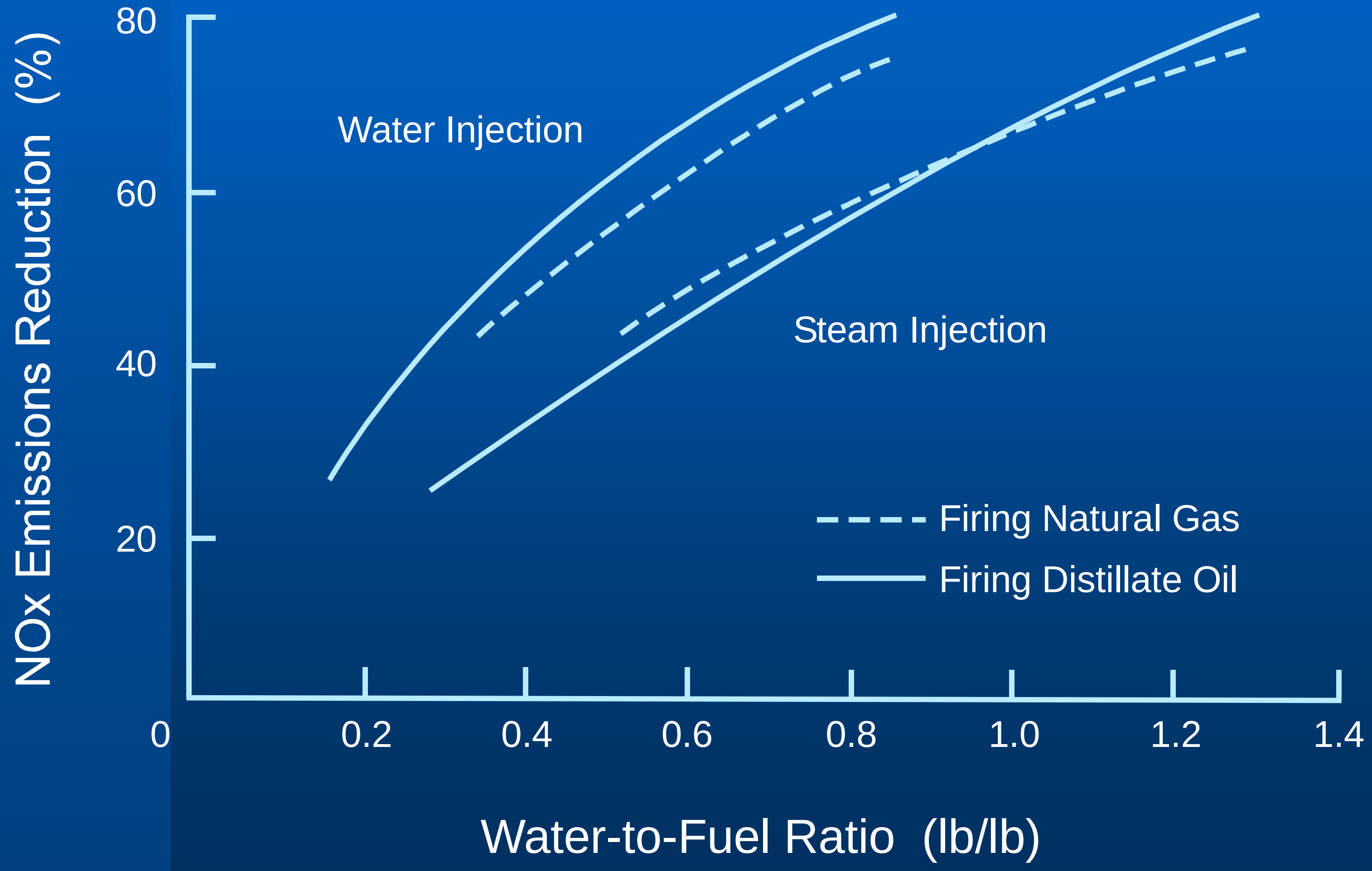
$$NO_x + HC \rightarrow N_2 + H_2O + CO_2$$

- Precise air flow required

Temperature Reduction

- Formation at peak temperatures
- Once formed, NOx is “frozen”
- Cooling methods
  - Water
  - Cool air supply
  - Gas recirculation
  - Ignition retard
  - Premixed flame – raise excess air

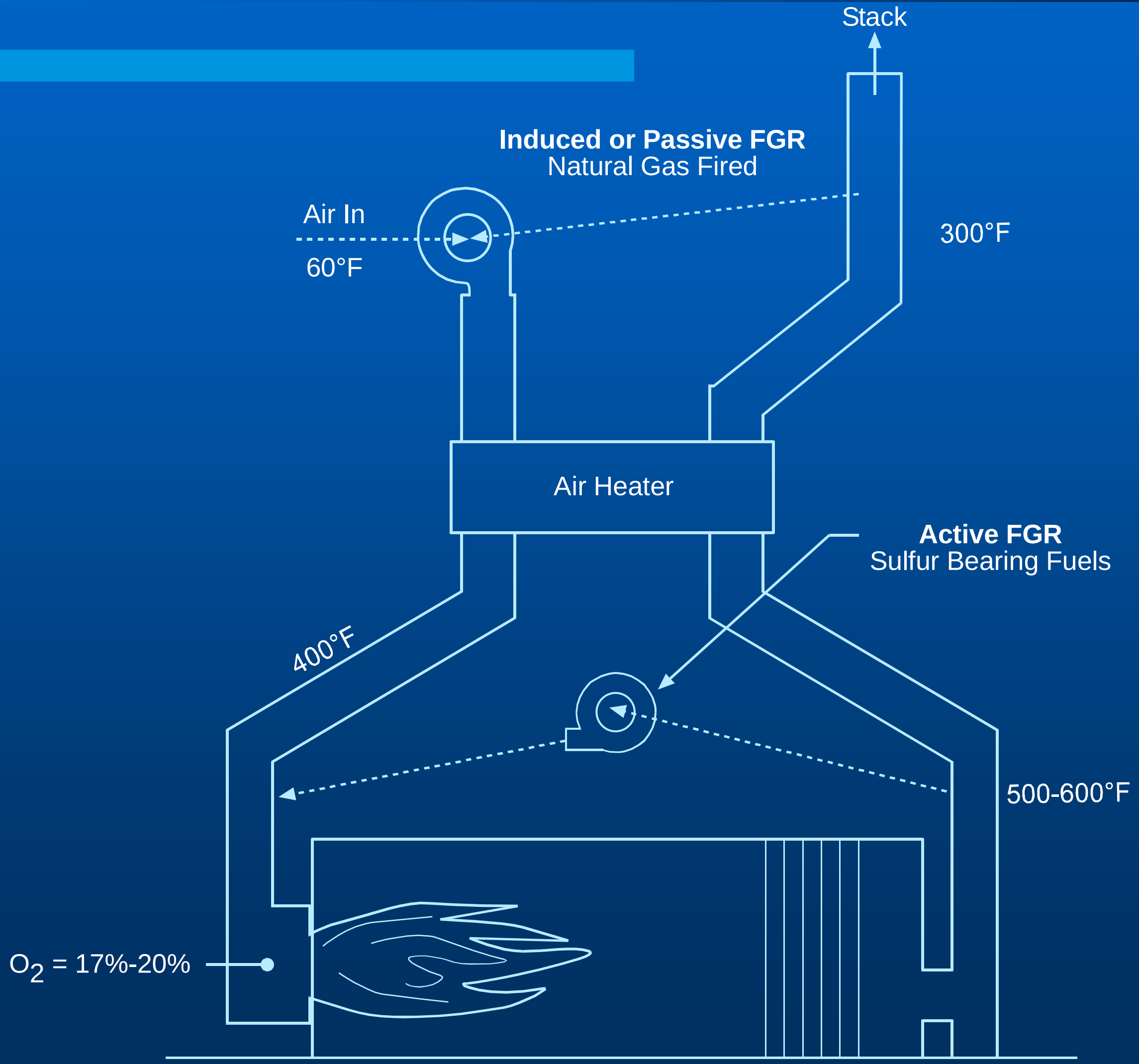
Water Injection



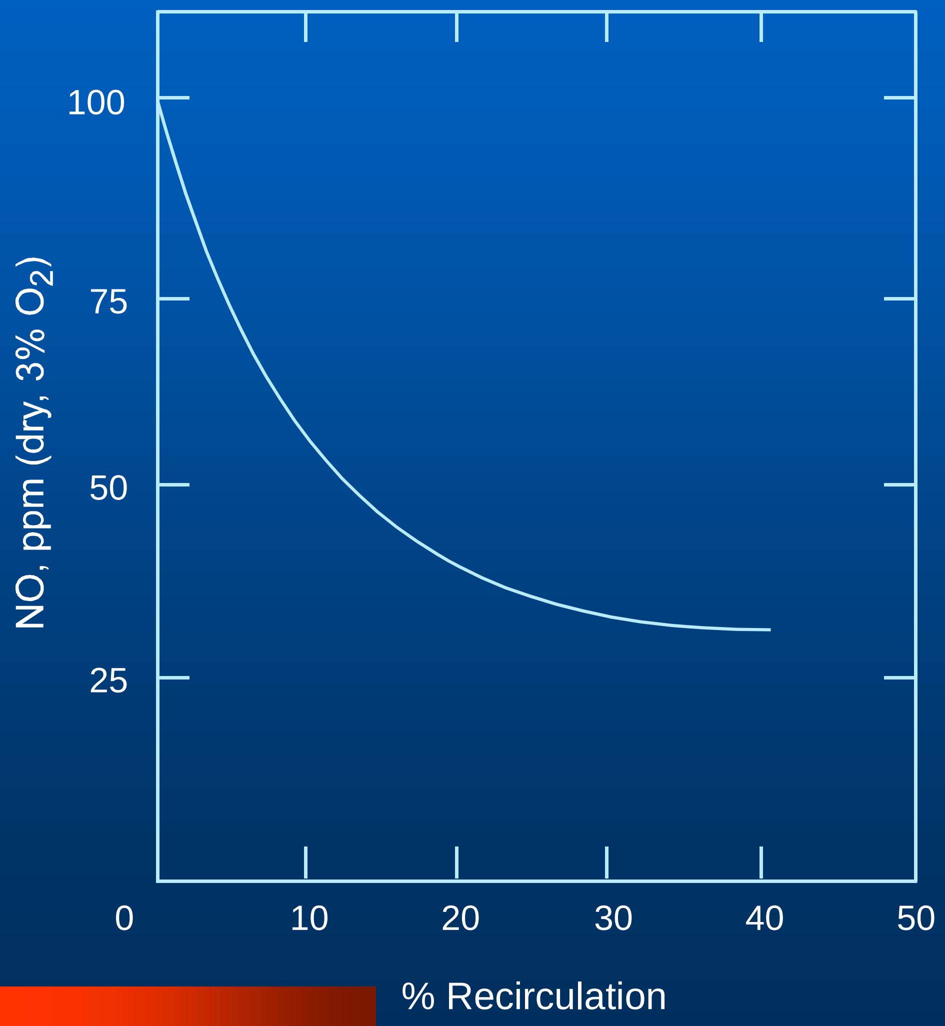
Water Injection (2)

- Exclusive to turbines
  - Small efficiency cost
  - Practical
- Clean water required

Flue Gas Recirculation



Flue Gas Recirculation (2)



FGR (3)

- Induced FGR limited to low S fuel
- Injection point design variations
- Very effective with low nitrogen fuel
- Always part of a “low NOx” package

Ignition Retard

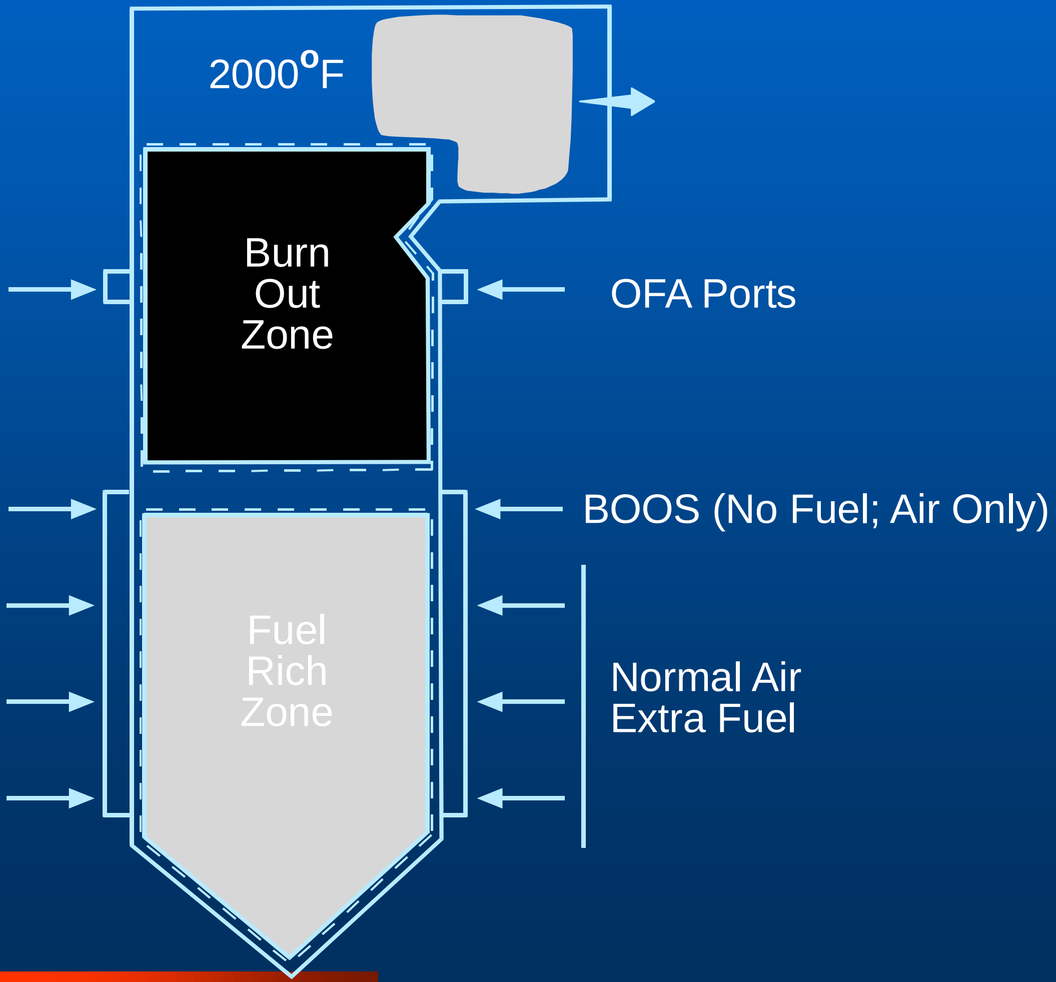
- Ignition timing
- Power & NOx are reduced
- Net emission reduction of 20%-25%

Staged Furnace Combustion

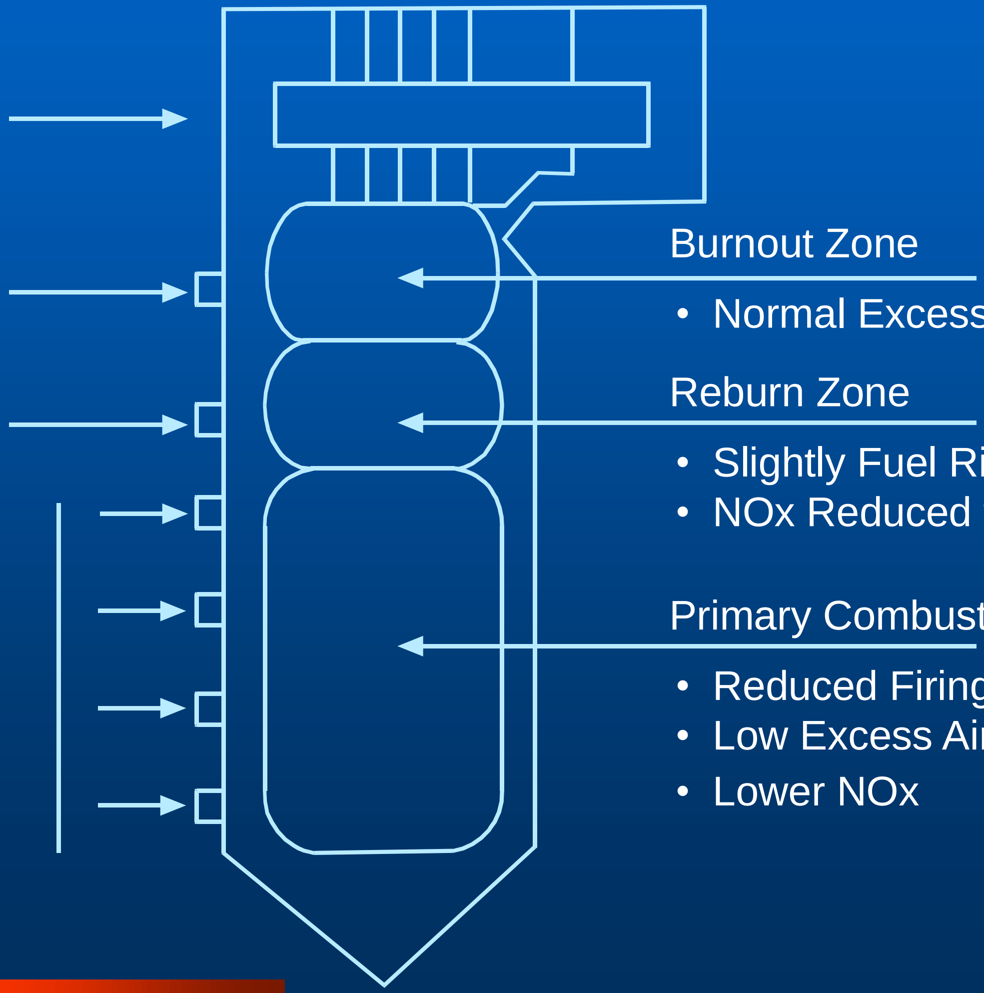
- Stratified combustion & Reburning

- Staged combustion
  - Fuel rich primary zone
  - Fuel N → N_2; Temperature drops
  - Add air to finish combustion
  - Success depends on uniformity, mixing

Stratified Combustion



Reburning



Reheater/Superheater

Overfire Air

Reburn Fuel - Gas
~20%

Primary Fuel - Coal
~80%

Burnout Zone

- Normal Excess Air

Reburn Zone

- Slightly Fuel Rich
- NOx Reduced to N_2

Primary Combustion Zone

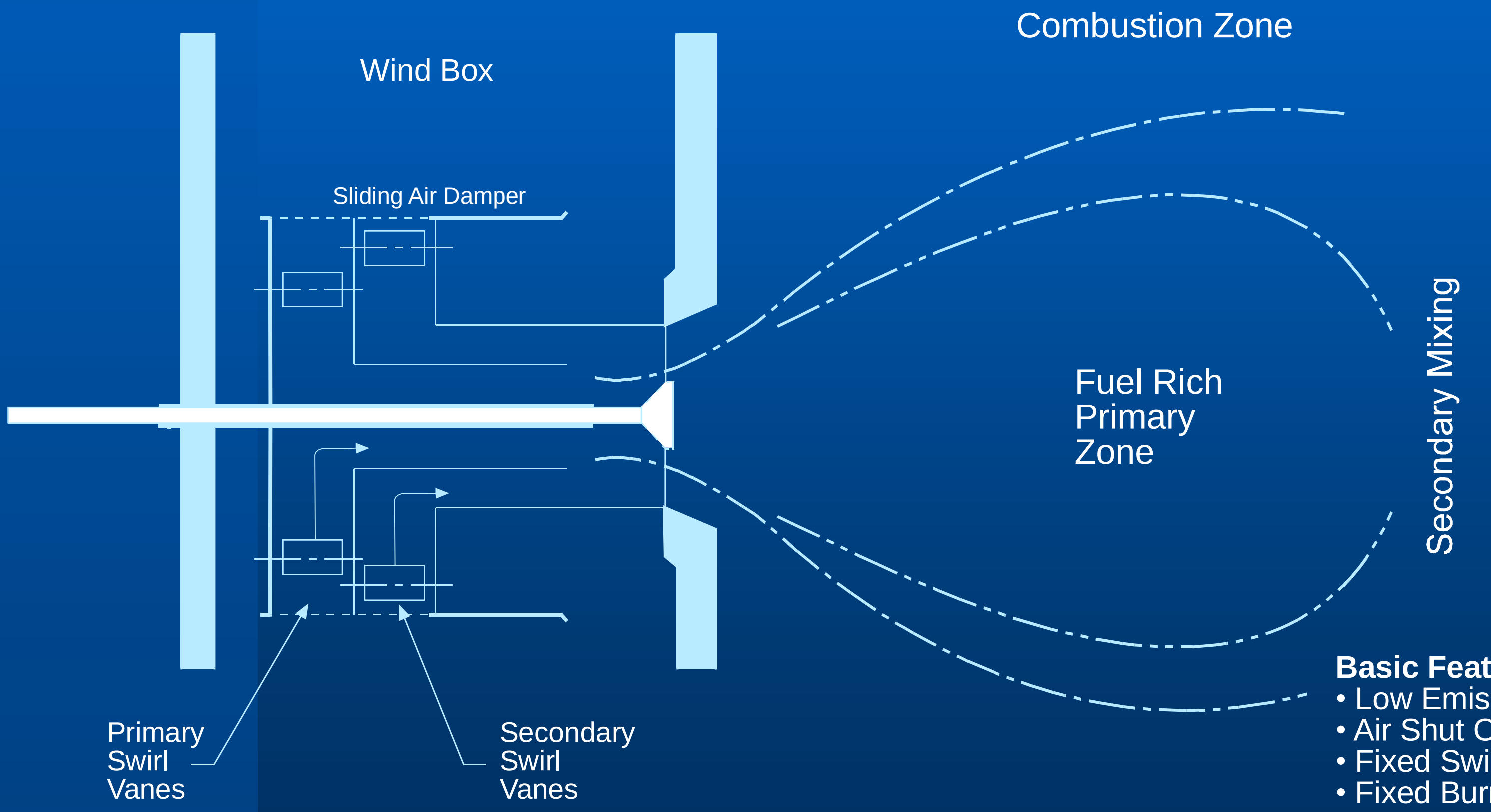
- Reduced Firing Rate
- Low Excess Air
- Lower NOx

Reburning (2)

- Concept
  - Normal combustion zone (reduced load)
  - Reburn fuel above (remaining load)
  - Fuel takes oxygen from NOx
  - Over fired air to complete combustion

- Low NOx means
  - Longer, cooler flames
  - Tendency to smoke

Low NOx Burners



Basic Features
- Low Emissions
- Air Shut Off Damper
- Fixed Swirl Vanes
- Fixed Burner Geometry

Low NOx Burners (2)

- Staging can be axial, radial, circumferential
- Translating lab results into the field
- Achieving uniform fuel & air distribution

Low NOx Burner Features

- Low NOx
- Manufacturer Presets
- Separate Air Flow and Direction Dampers
- Precise Air Flow Control.

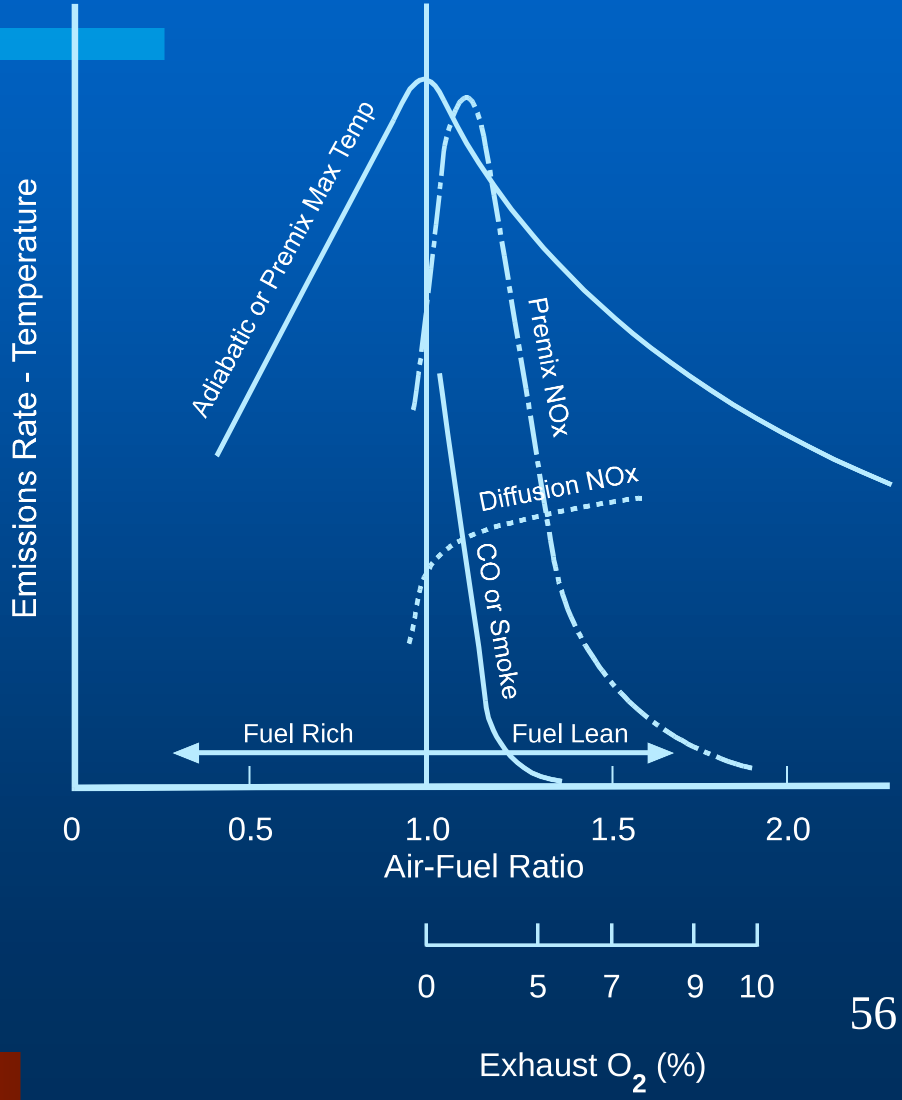
Nitrogen Oxide Control (outline)

- Combustion Modifications
- Premixed vs. Diffusion Flames
- Add-On or Back End Systems
- Combinations

Premixed vs. Diffusion Flames

- Most burners are diffusion
- Premix requires gas fuel
  - No fuel N
- Premix allows lean, cool combustion
  - Turbine combustor
  - Catalytic turbine combustion
  - Reciprocating engine

Theoretical Differences

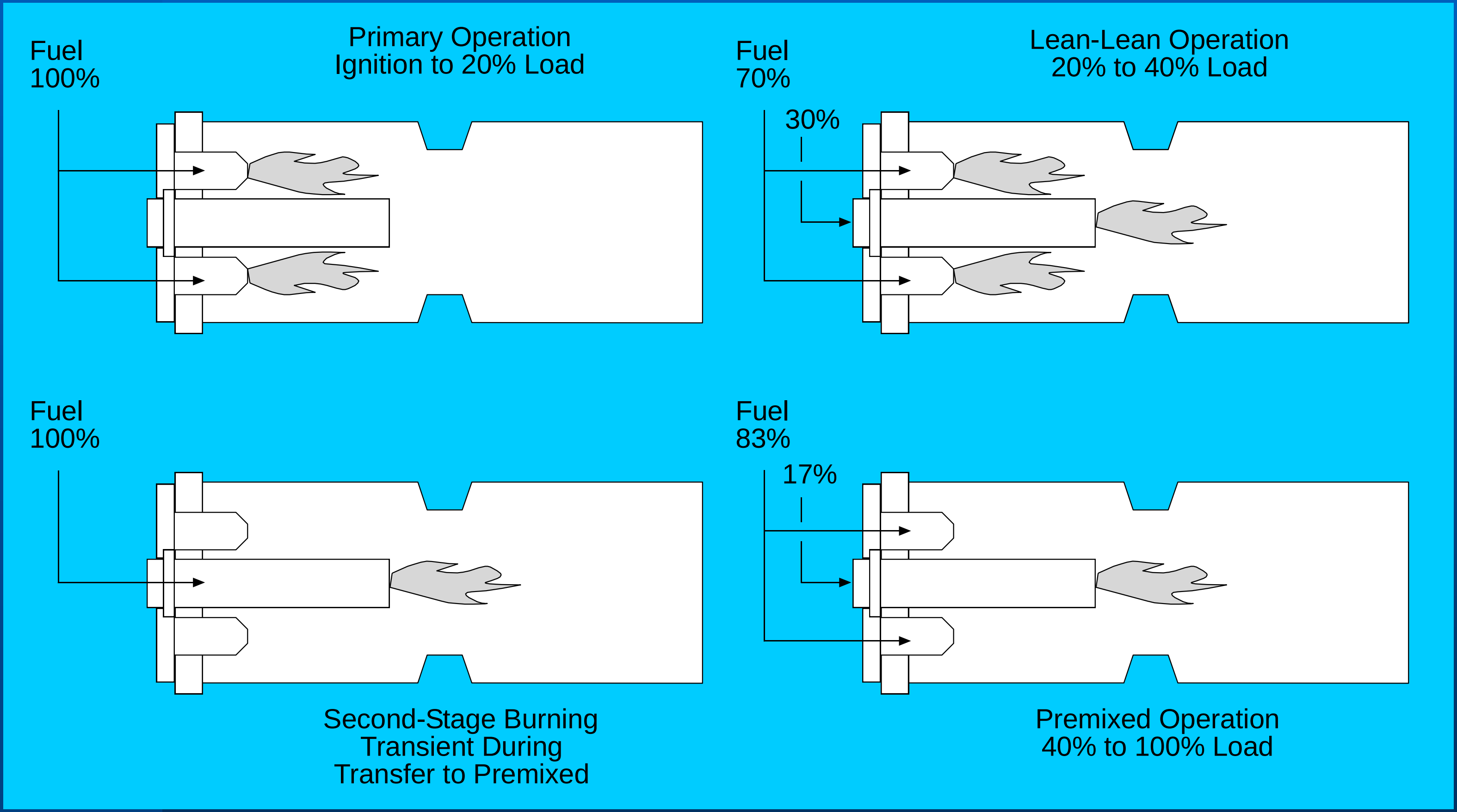


Combustion Turbine Burner

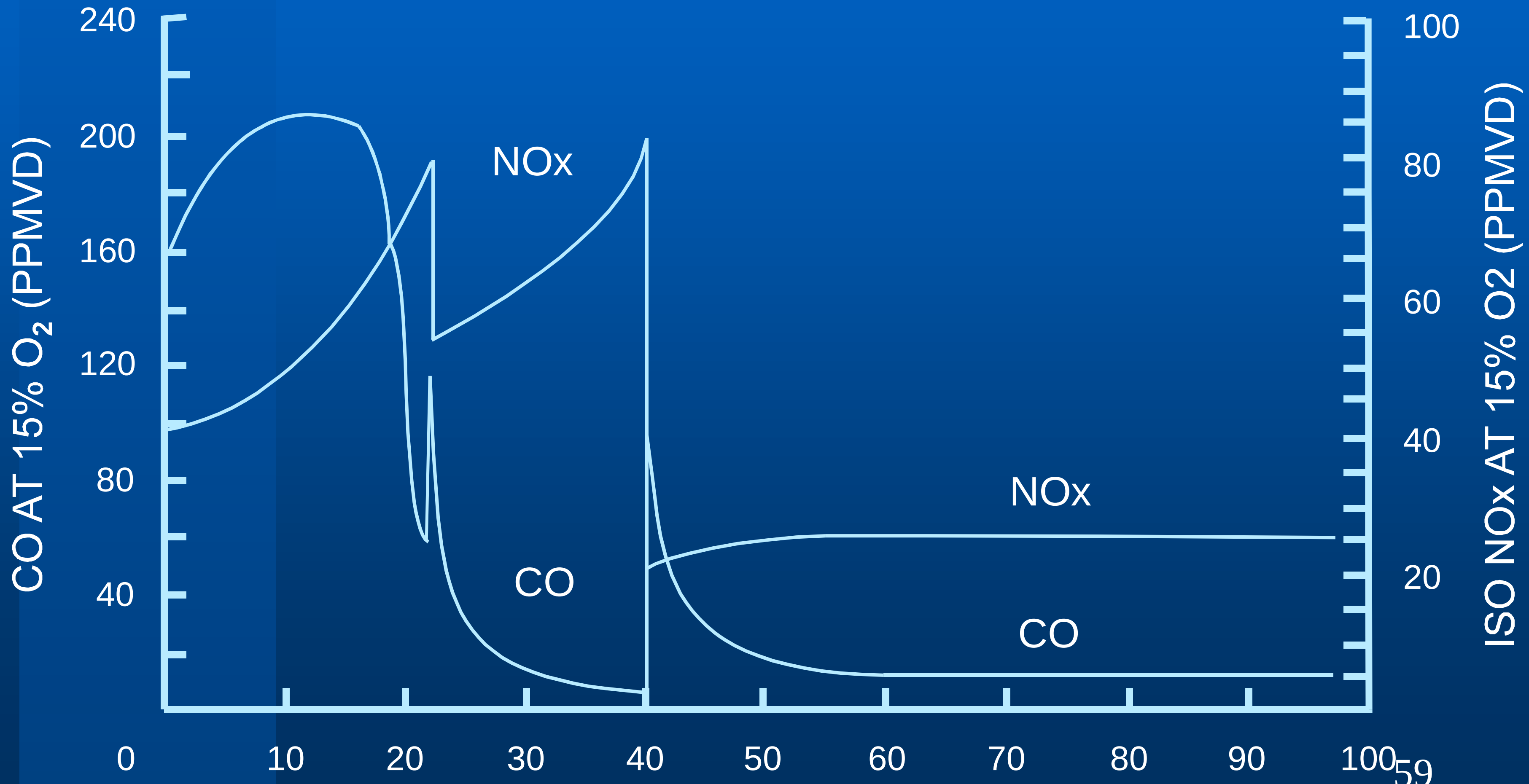
- Water injection

- Dry-low NOx (lean premix) combustor
  - Startup challenge

Dry Low NOx Combustion



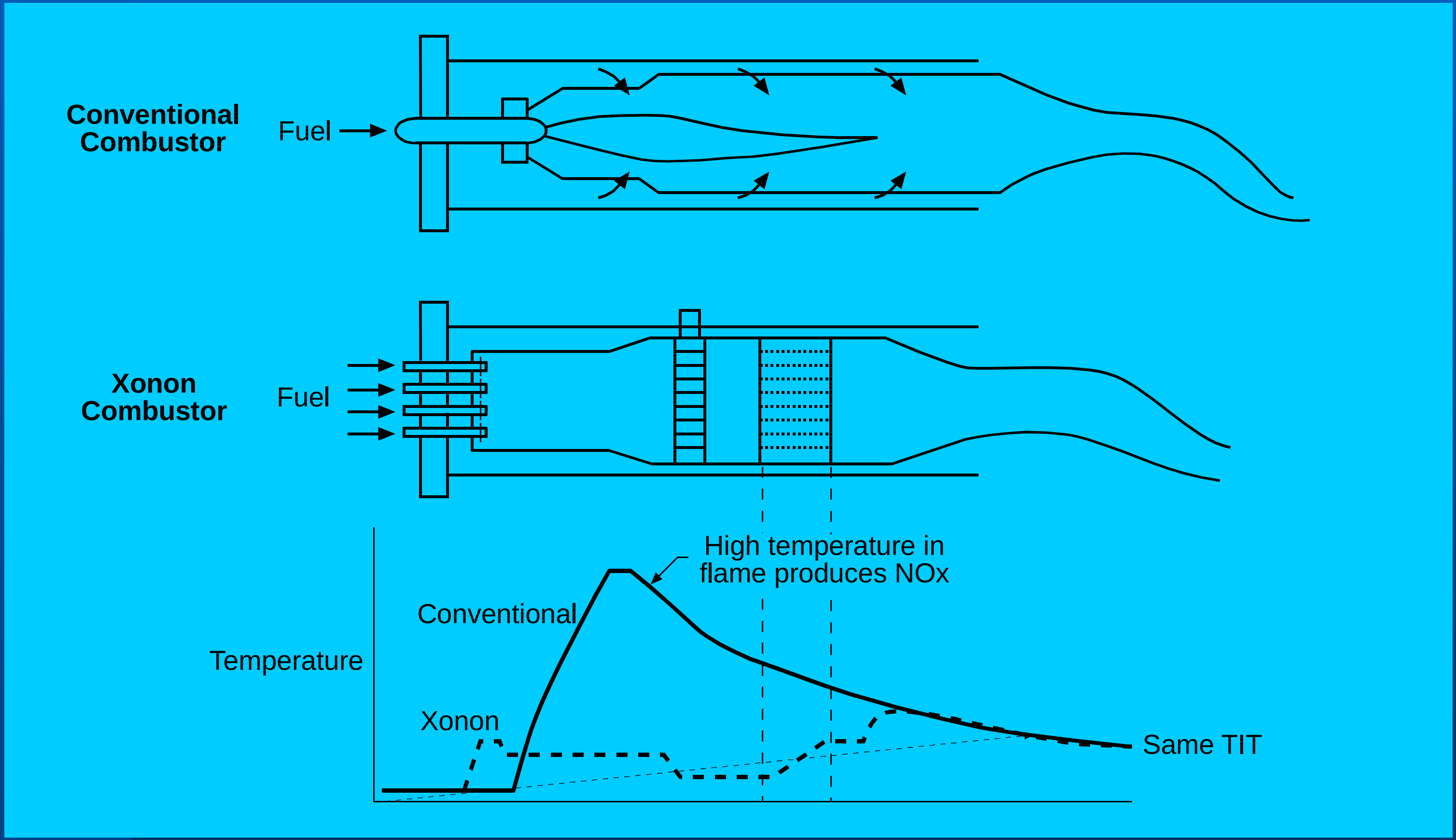
Dry Low NOx CT Emissions



Dry Low NOx Emissions (2)

- Startup emissions
  - Simple cycle
  - Combined cycle
- Ambient conditions & corrections
- Inlet fogging
- Engine fuel (emissions) control

Catalytic Turbine Combustor



Catalytic Turbine Combustor (2)

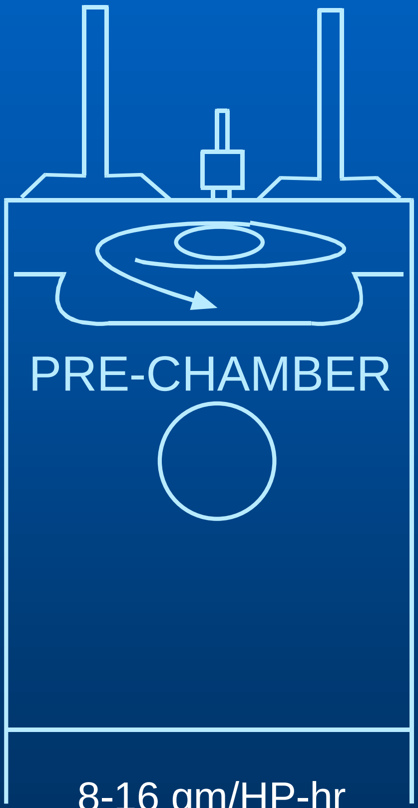
- XONON Combustor by Catalytica
- Engine specific – not generic
- Startup challenge
- No liquid fuel backup

Reciprocating Engines

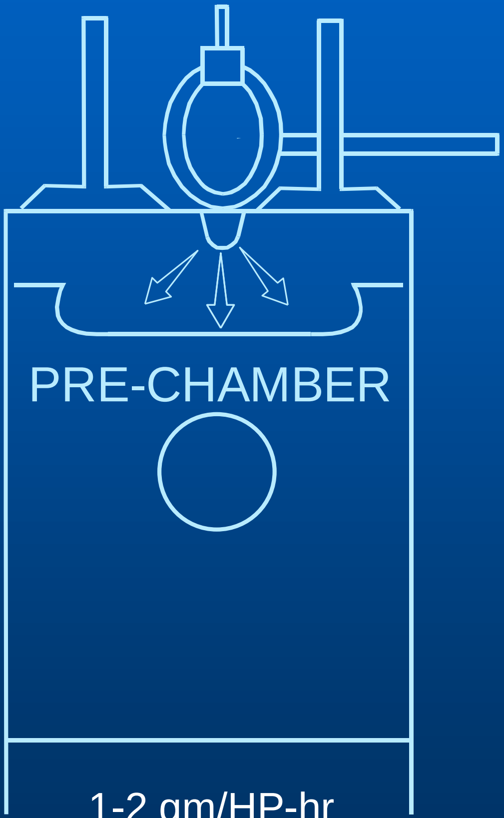
- NOx Control Methods
  - ignition retard
  - modifying the air-fuel ratio
  - exhaust gas recirculation
  - combustion chamber modifications (gas fuel)

- Feasibility of lean operation

Low NOx Combustion Chamber



8-16 gm/HP-hr
(2.5-5 lb/mmBTU)



1-2 gm/HP-hr
(0.3-0.6 lb/mmBTU)

Reciprocating Engine NOx

Table 6-1. Reciprocating Engine NOx - lb/mmBTU

Concept	*Uncontrolled*	*Adjustments*	*Low Emission*
Rich Burn, Spark Ignition	4.64	3.5±	0.6
Lean Burn, Spark Ignition	5.13	No Change	0.6
Diesel	3.95	2.7	NA
Dual Fuel	2.72	1.9	0.6

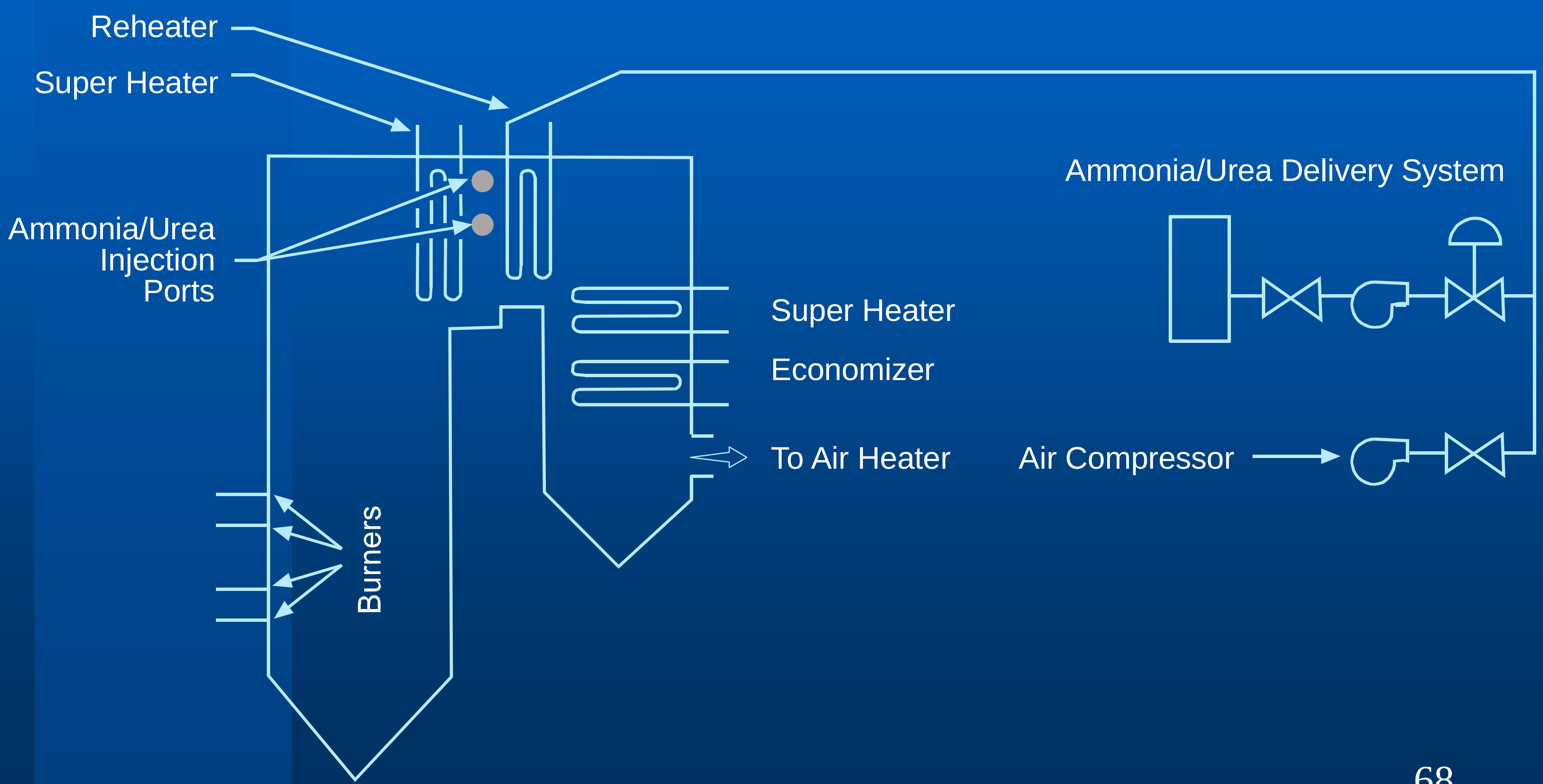
Nitrogen Oxide Control (outline)

- Combustion Modifications
- Premixed vs. Diffusion Flames
- Add-On or Back End Systems
- Combinations

Add-On or Back End Systems

- Broad application
  - Large NOx reductions
  - Expensive
- $NOx + NH_3 \rightarrow N_2 + H_2O$
  - Flow control required
- Ammonia vs. Urea
- Reagent methods
  - SNCR
  - SCR
- NSCR with Rich Burning

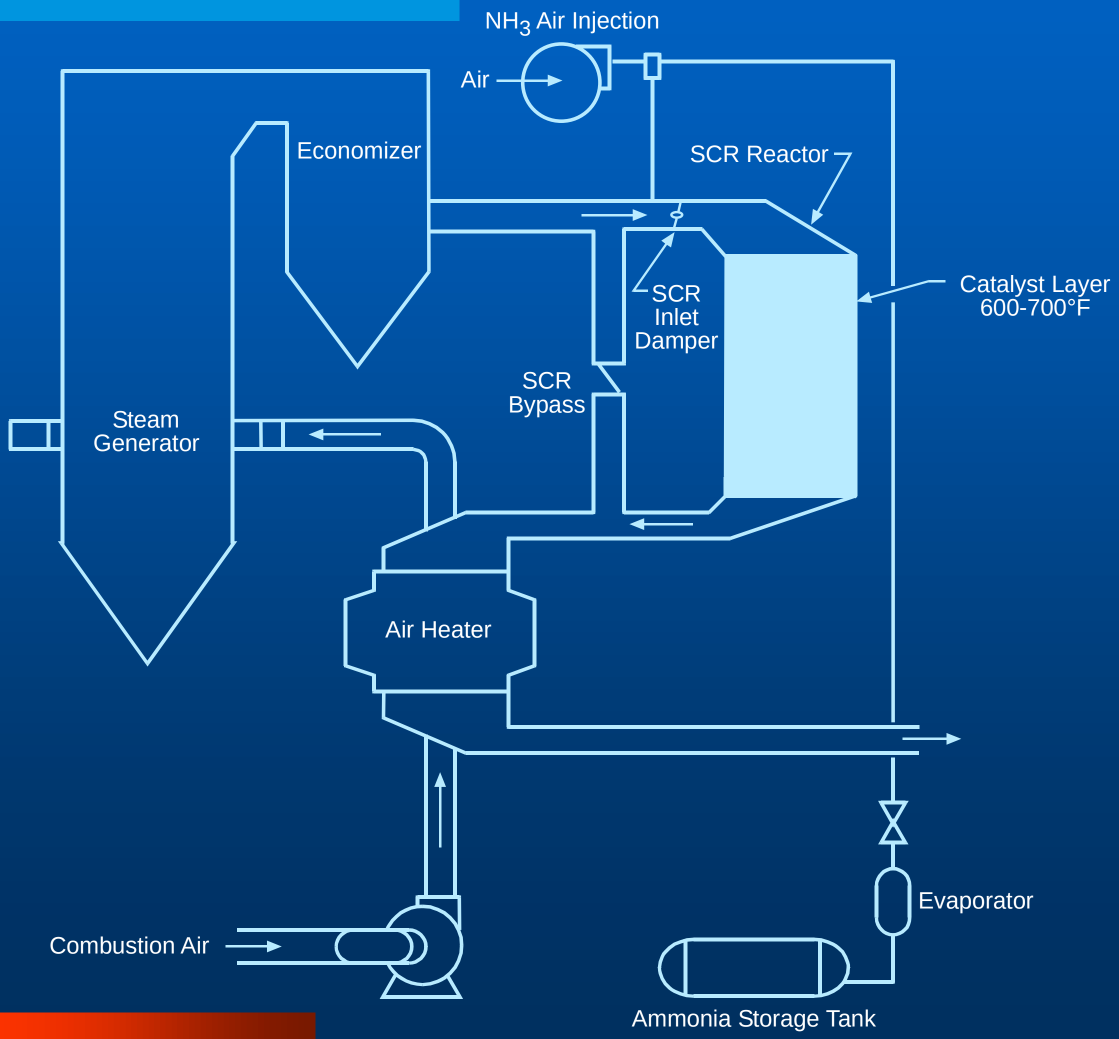
Selective Non-Catalytic Reduction



SNCR (2)

- Narrow temperature window
  - Boiler applications
  - Load following challenge
- Mixing space
  - Complex injection grid
  - Limits retrofits
  - Urea in water
- 50%-70% reduction

Selective Catalytic Reduction



SCR (2)

- Temperature window relaxed
  - Broad application (engines)
  - No “load following”
- Catalysts
  - Compatibility & lifetime
  - Size
- NOx reductions

SCR Catalysts

Precious metal (platinum)	450° – 550°F
Vanadium/titanium catalysts	550° – 800°F
Iron-Zeolite catalysts	800° – 1000°F

NSCR with Rich Burning

- Approach
- Air flow control challenge
- Applications
- Control Efficiency

Nitrogen Oxide Control

- Combustion Modifications
- Premixed vs. Diffusion Flames
- Add-On or Back End Systems
- Combinations

Combined NOx Controls

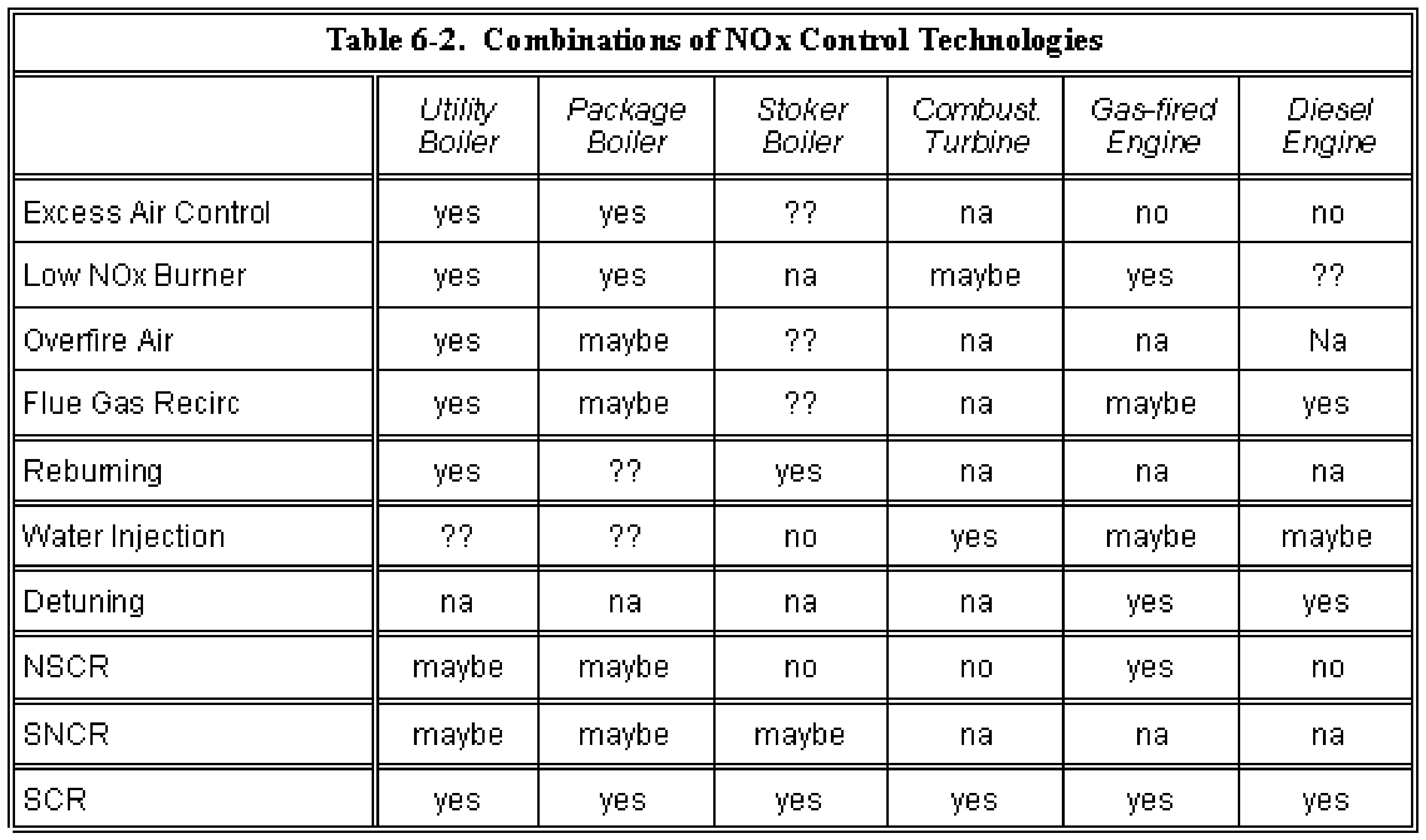


Table 6-2. Combinations of NOx Control Technologies

	Utility Boiler	*Package Boiler*	*Stoker Boiler*	*Combust. Turbine*	*Gas-fired Engine*	*Diesel Engine*
Excess Air Control	yes	yes	??	na	no	no
Low NOx Burner	yes	yes	na	maybe	yes	??
Overfire Air	yes	maybe	??	na	na	Na
Flue Gas Recirc	yes	maybe	??	na	maybe	yes
Reburning	yes	??	yes	na	na	na
Water Injection	??	??	no	yes	maybe	maybe
Detuning	na	na	na	na	yes	yes
NSCR	maybe	maybe	no	no	yes	no
SNCR	maybe	maybe	maybe	na	na	na
SCR	yes	yes	yes	yes	yes	yes

Carbon Monoxide & Organic Emissions

- Section focuses on non combustion control
- Trade-offs with NO_x
- Catalytic Control Systems
- Hydrocarbon Capture

Trade-offs with NO_x

- Most low NOx combustors increase PIC
- NOx limits can trigger CO limits

Catalytic Control Systems

- Oxidation catalysts
  - Turbines & engines
  - Combined cycle systems

- Temperature range

- Destruction efficiency

Hydrocarbon Capture

- Unusual on combustion systems
- Dioxins/Furans
- Using (activated) carbon

Conclusions

- Combustion & fuel based controls
- Combining with post-combustion controls

Chapter Summary

- Particulate Matter & Metal Emissions Control
- Sulfur Oxides and Hydrogen Chloride Controls
- Nitrogen Oxide Control
- Carbon Monoxide & Organic Emissions