APTI Course 427

Combustion Source Evaluation

Chapter 2:
General Types and Characteristics of Combustion

Chapter Overview (outline)

- Introduction to Combustion Systems
- Types of Combustion Systems
- Fuel Storage, Handling and Processing
- Combustion Air Pollution Controls
- Steam System Components
- Ash Handling

Introduction to Combustion Systems

- Introduction
- Knowing the system enables intelligent regulation
- Combustor vs an open fire
  - Completely enclosed
  - Controlled fuel & air flow
  - Controlled air-fuel mixing

Combustion Source Components

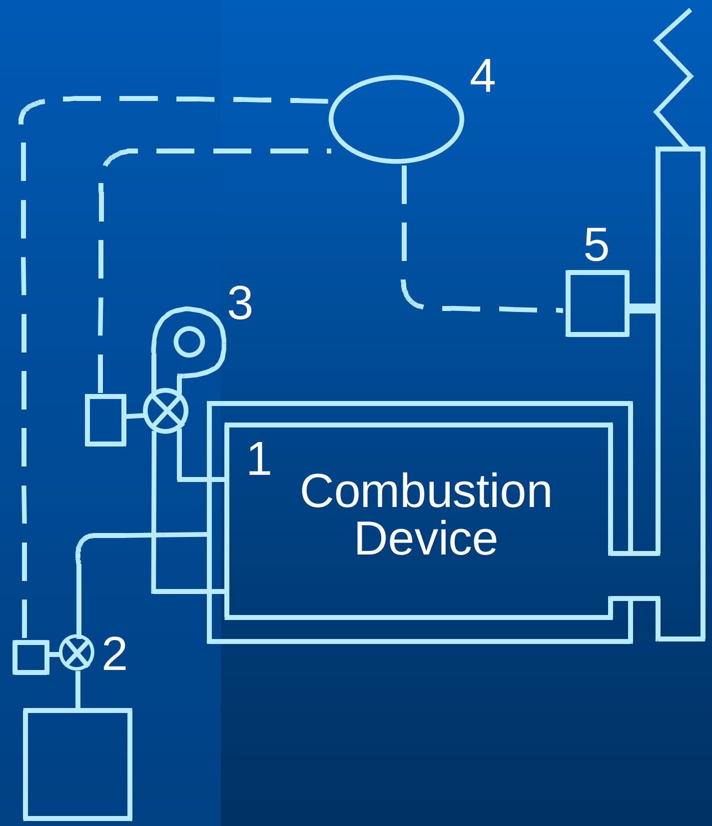


Diagram Key:

1. Burner - Combustion Device
2. Fuel Supply
3. Air Supply (Fan)
4. Control System
5. Combustion or Emissions Monitor (Optional)

Types of Combustion Systems (outline)

- Engines and Turbines
- Boilers
- Thermal Oxidizers
- Other Combustion Systems

Engines and Turbines

- Background
  - Clean fuel use means fewer pollutants
  - Uniform construction means predictable emissions
- Uses and Trends
  - Traditional use: pumping & emergency power
  - Increasing use for electric power generation
  - e.g. More gas used in addition to coal

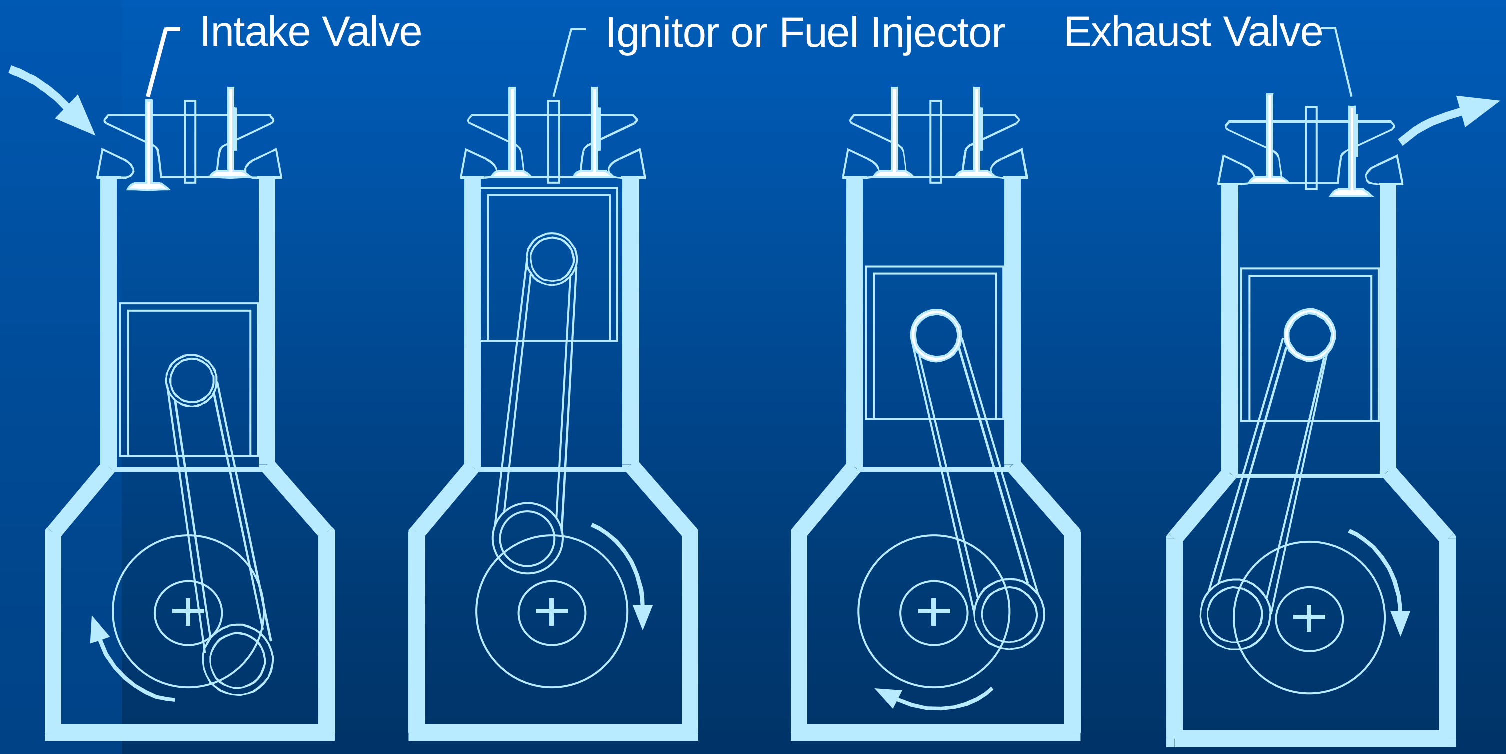
Engines and Turbines (cont.)

Two types of engine

- Reciprocating Engines
- Combustion Turbines

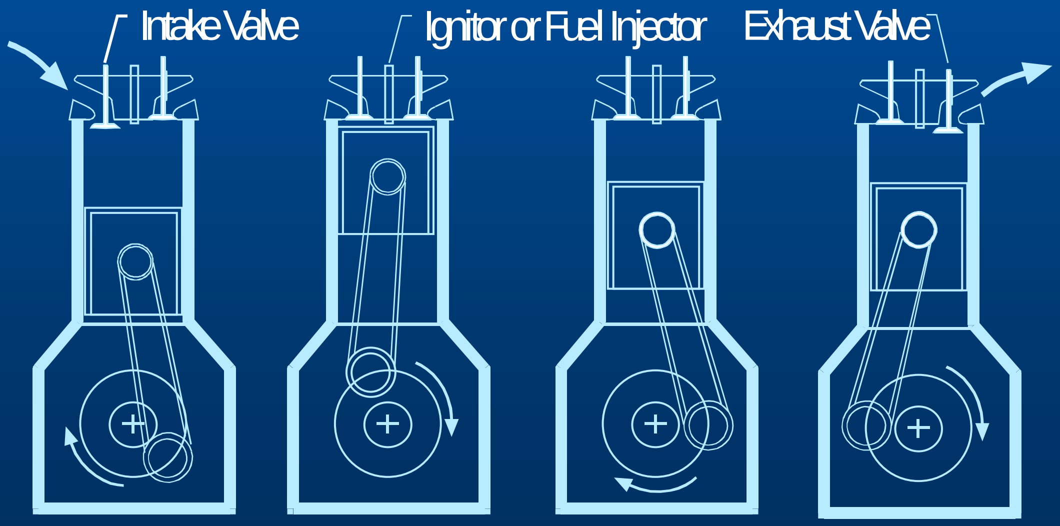
Combined Cycles and Cogeneration

Reciprocating Engines



Reciprocating Engines

- Engine sizes: tiny to10,000 HP
- Diesel vs gasoline or gas fuel
- Four stroke vs two stroke



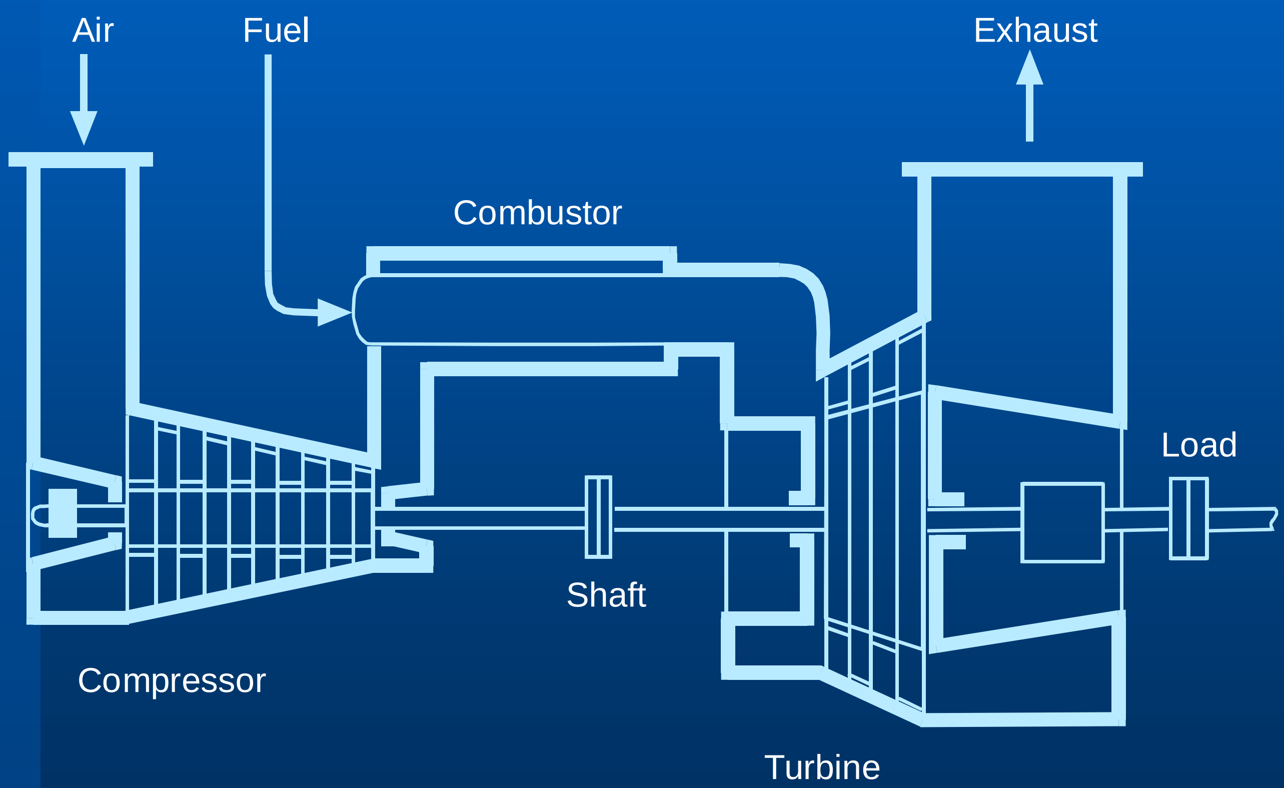
Reciprocating Engines (cont.)

Table 2-1. Types of Reciprocating Engines	
Type	Characteristics
Natural Gas	Gas mixed with the intake air, spark ignited
Diesel Fuel	Diesel oil auto-ignites and burns as it is injected, no spark required.
Dual Fuel	Essentially a gas fired diesel engine. A small amount of diesel fuel is injected to ignite the gas with no spark plug.
Lean Burn	Operates with ***more*** than 5% excess air
Rich Burn	Operates with ***less*** than 5% excess air

Combustion Turbines

- History
  - Evolved from aircraft engines
- Power
  - No upper size limit
- Fuels
  - Short term = no restriction
  - Long term = very finicky
- Efficiency
  - Depends on size, load & sophistication

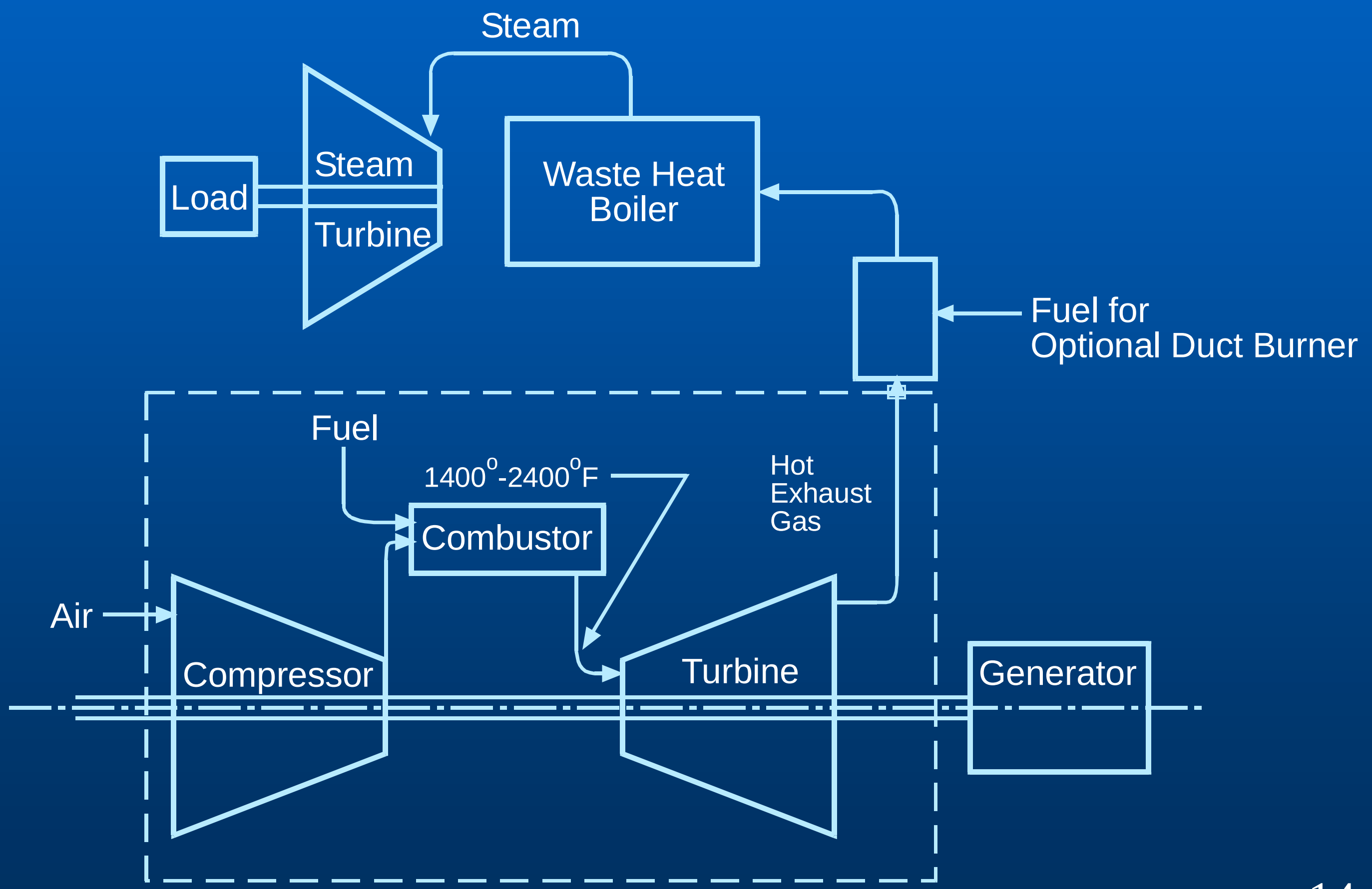
Components of a Turbine



Combined Cycles and Cogeneration

- Engine/turbine efficiency improves if we capture waste heat.
- *Combined cycle* – exhaust heat used for steam to drive a steam turbine.
- *Cogeneration* - exhaust heat used in an industrial process, campus heating, etc.

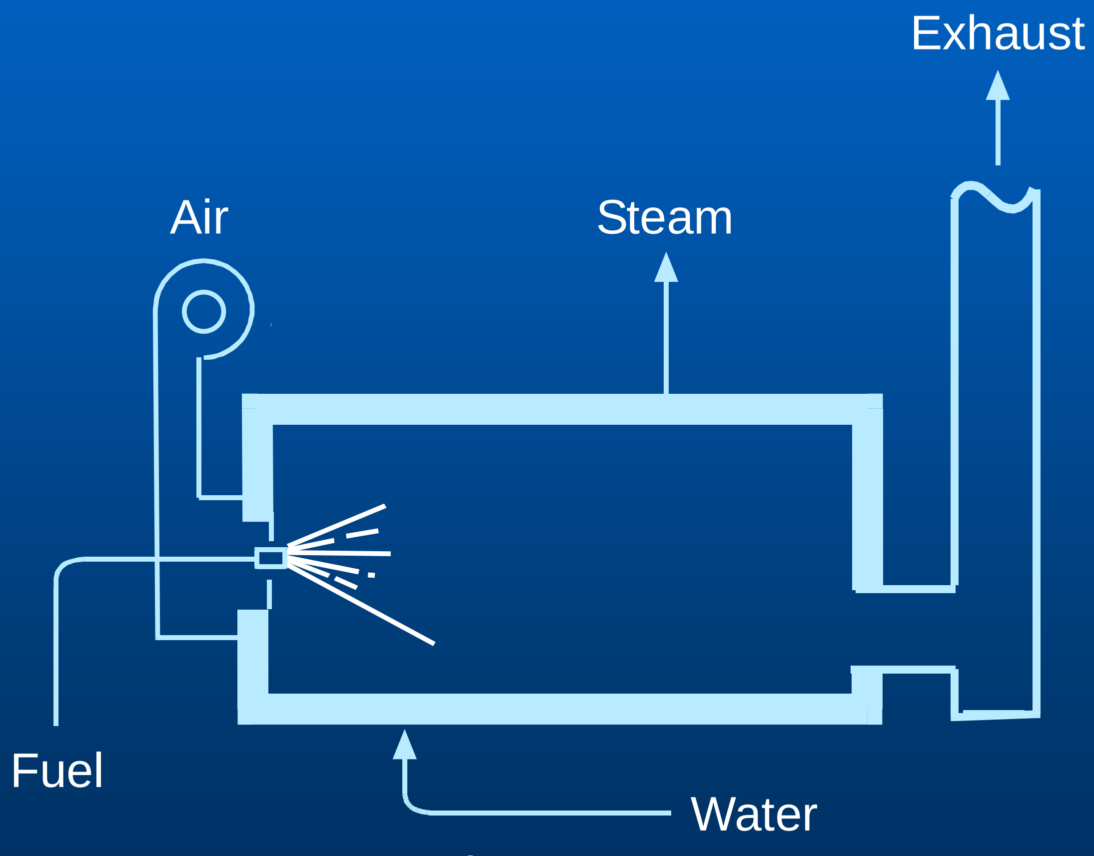
A Combined Cycle System



Types of Combustion Systems
(outline)

- Engines and Turbines
- Boilers
- Thermal Oxidizers
- Other Combustion Systems

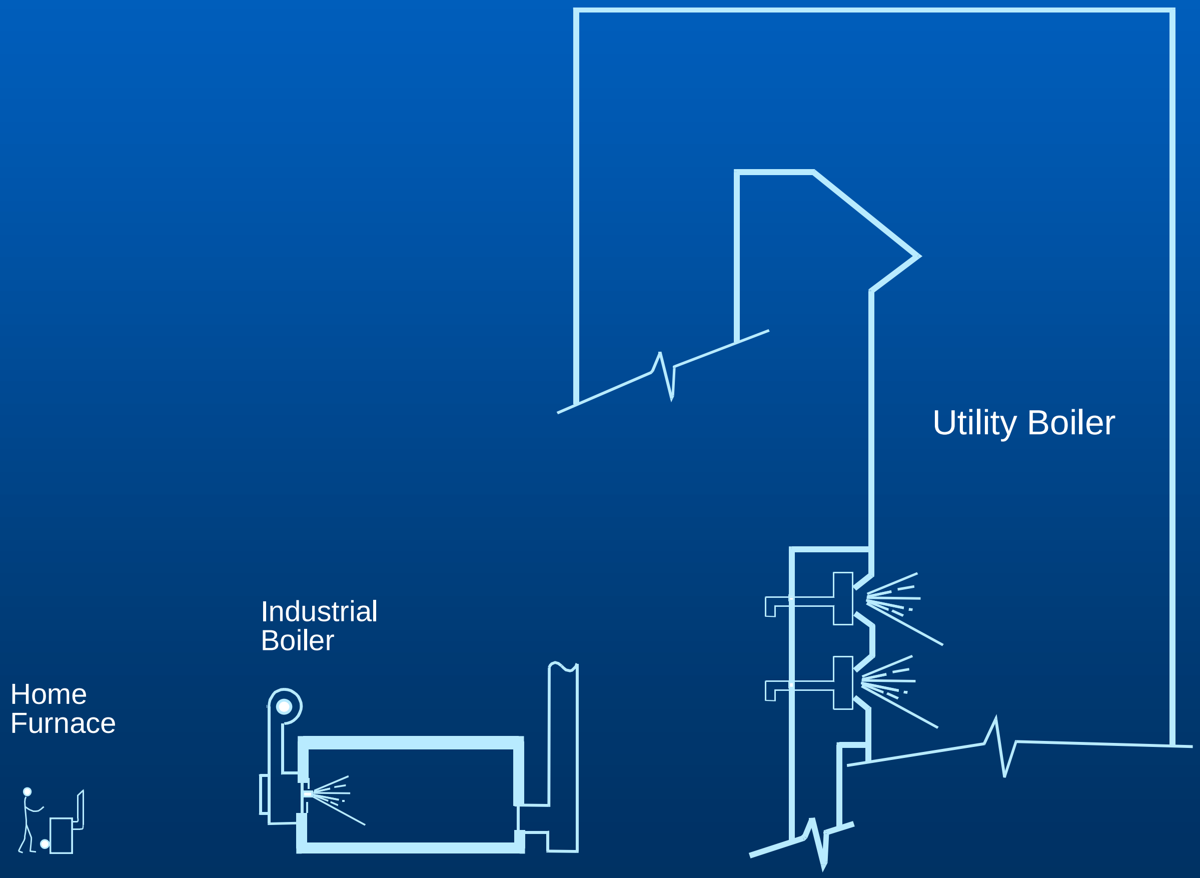
A Basic Boiler



Boilers

- History
  - Energy source for early engines (steam)
  - Fuel = anything combustible
- Types
  - Fire-tube
  - Water-tube

Comparative Sizes of Boilers



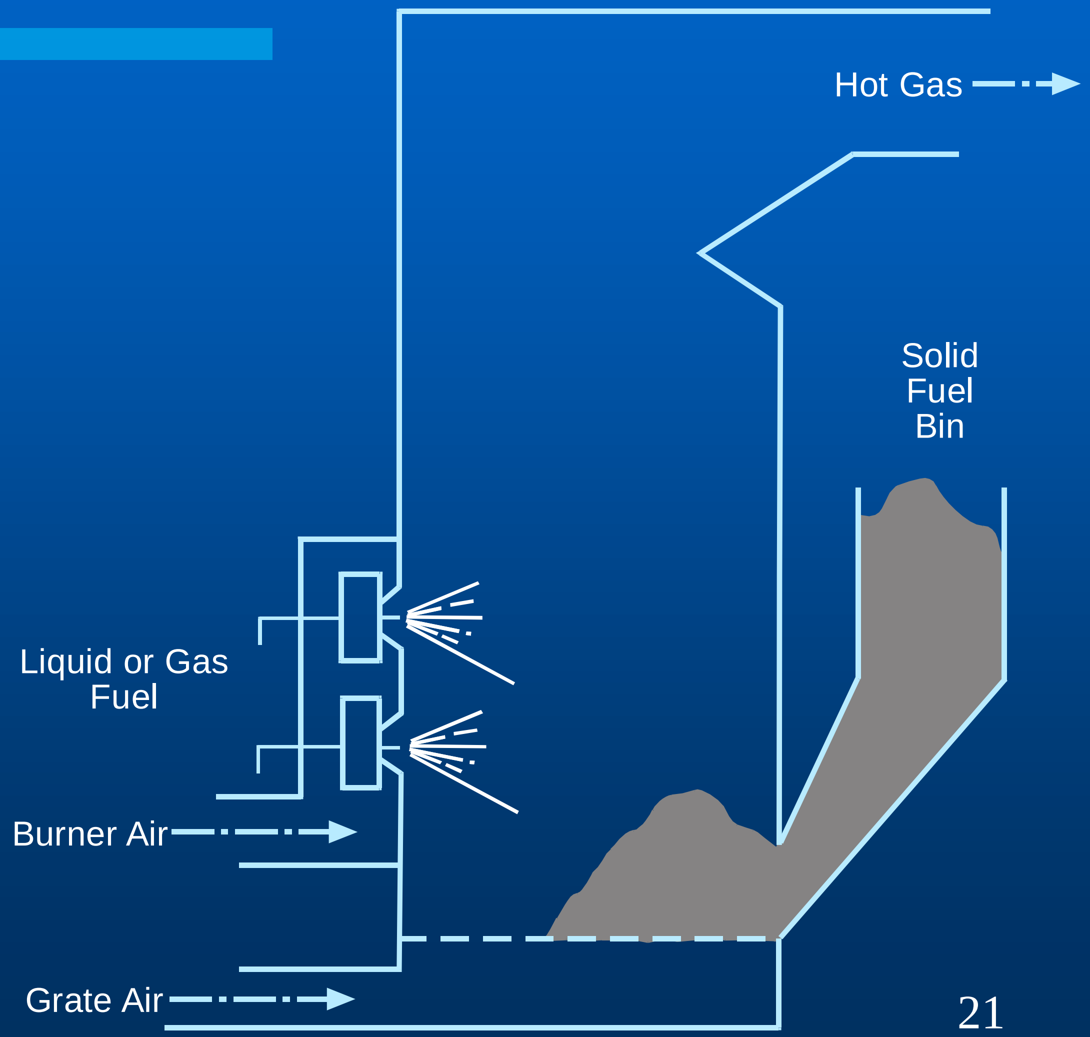
Comparative Sizes of Boilers (cont.)

Table 2-2. Examples of Boiler Size		
Use	*Generic Size*	*mmBTU/hr*
Residential heat	50,000 BTU/hr	0.05
Commercial building heat	100 Horsepower	3.3
Factory – medium size	30,000 lb/hr steam flow	40
Manufacturing - large	200,000 lb/hr steam flow	250
Electric Utility	500 MW (electric)	5,000

Suspension Versus Grate Firing

- *Suspension Fired –*
  - Gas fuel, atomized oil, or powdered coal burns in suspension
  - Residence time is about 1 second
- *Grate Fired –*
  - ‘Chunks’ of solid fuel burn on a metal or refractory grate
  - Residence time is minutes to hours

Suspension and Grate Firing

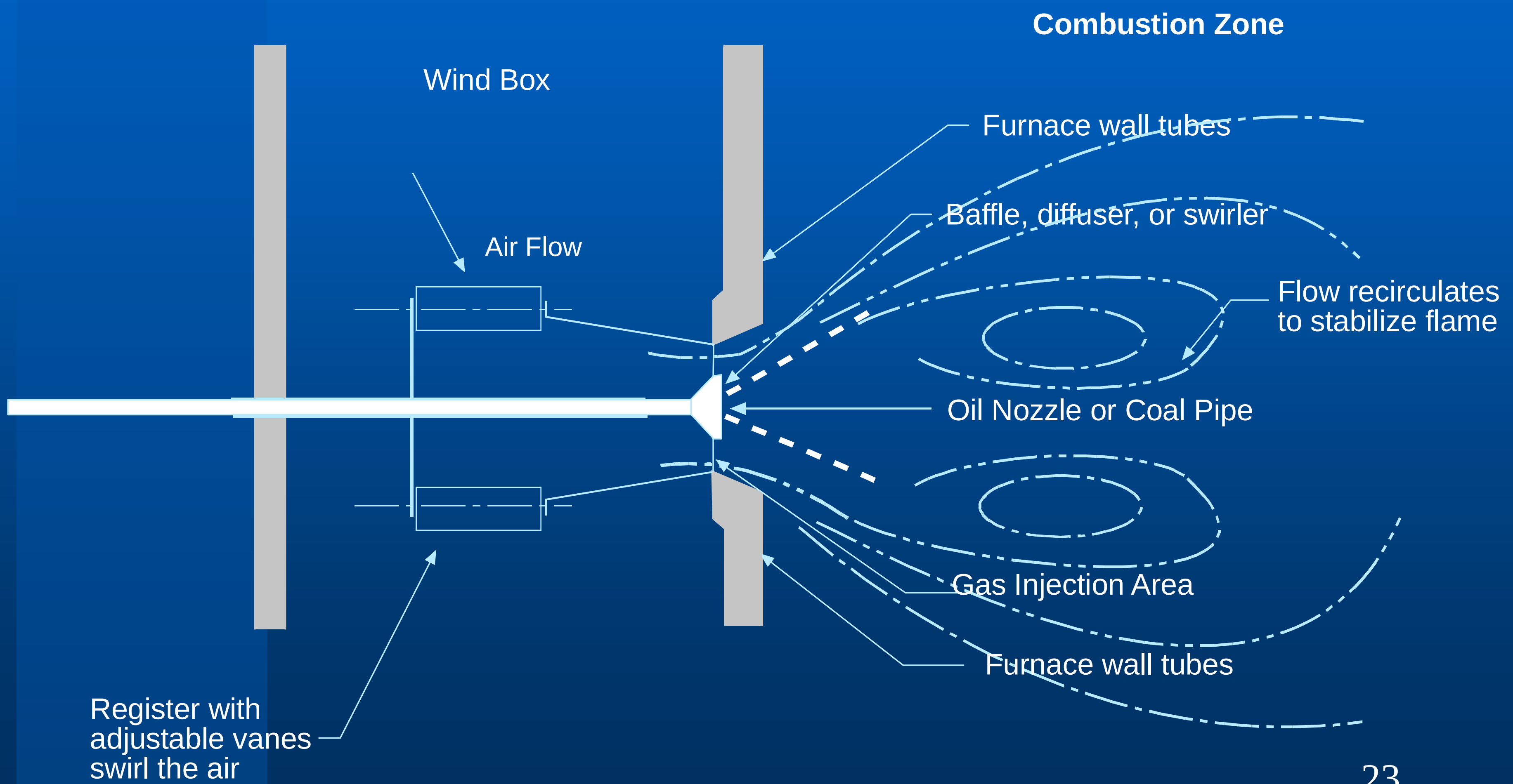


Basic Burner Design

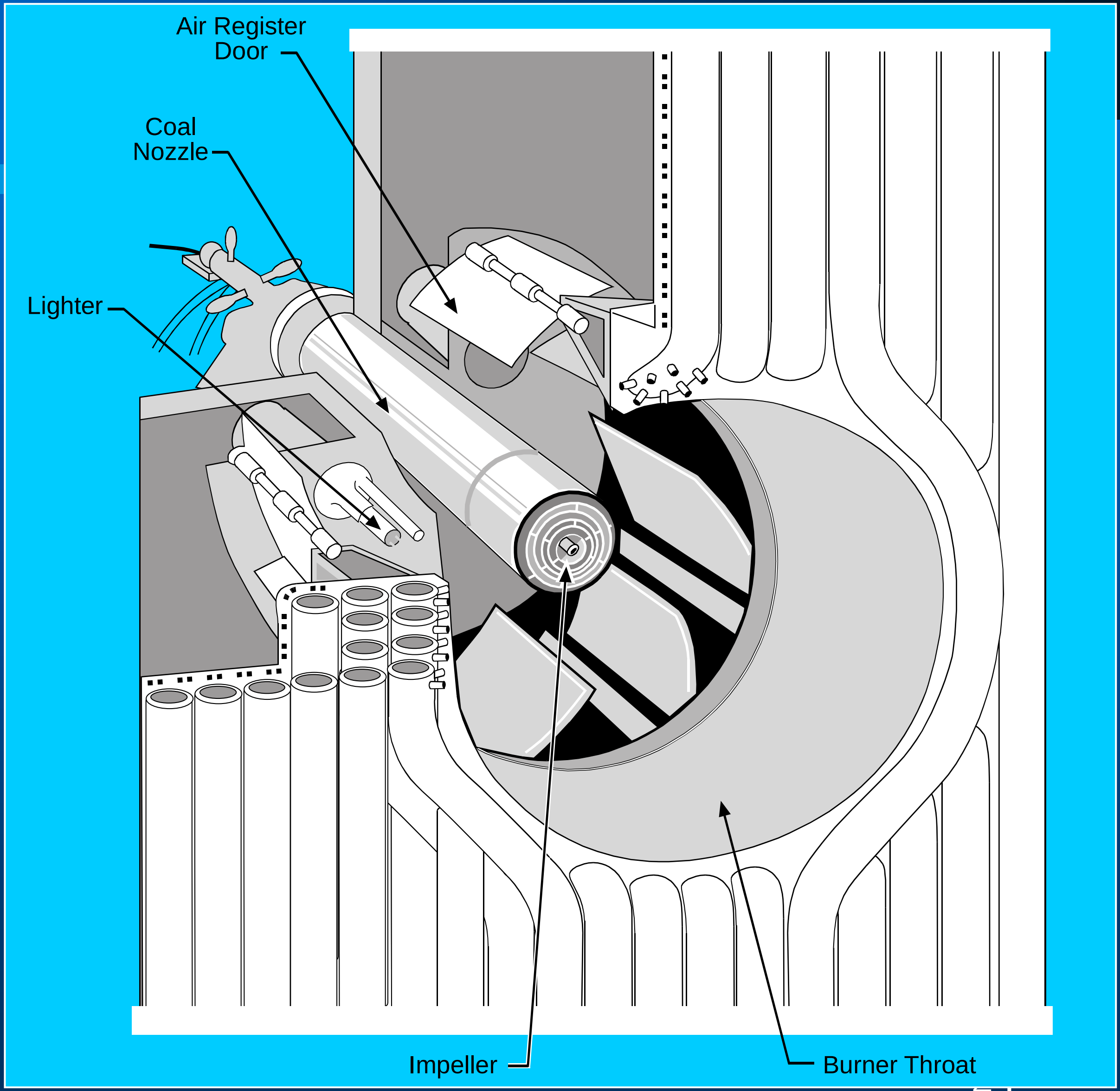
- Goals
  - Flame stability
  - Complete combustion

- Secondary Objectives
  - Emission (NOx) control
  - Flame shape
  - Turn down

Basic Burner Design (cont.)



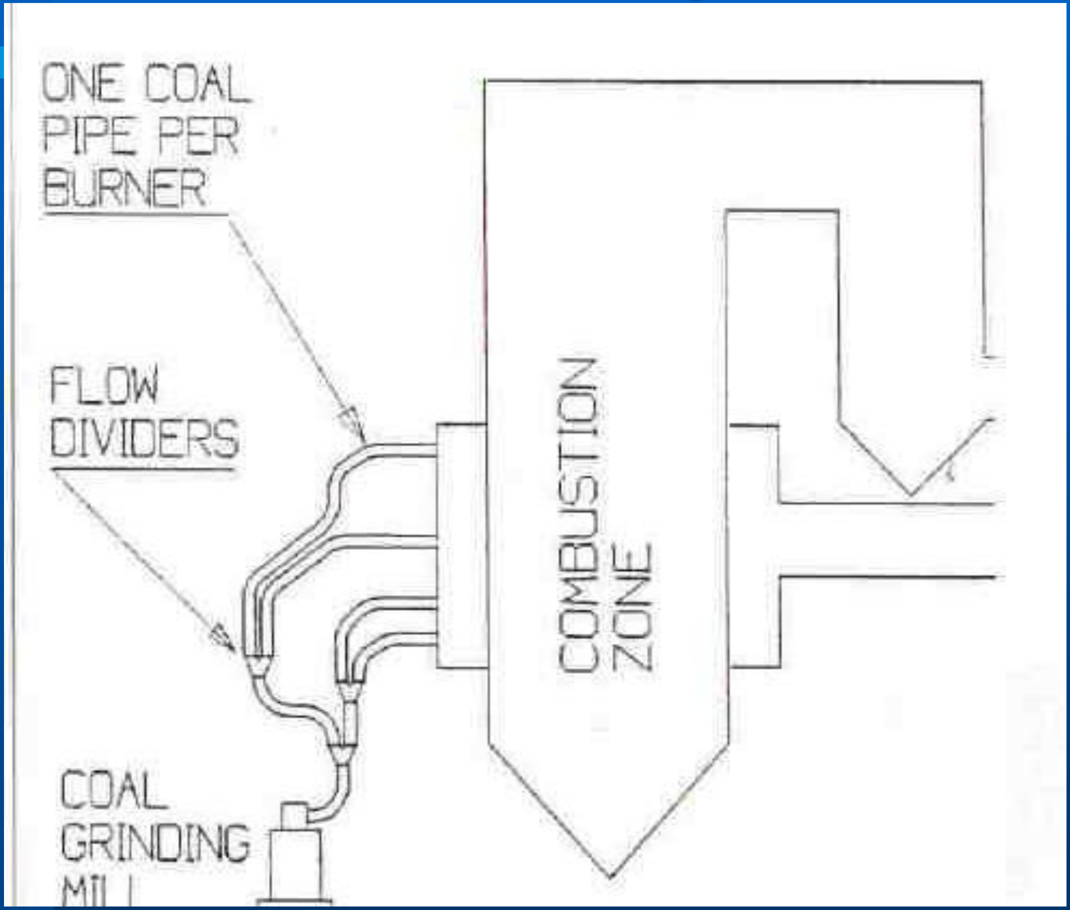
Typical Large Burner



Burner Features

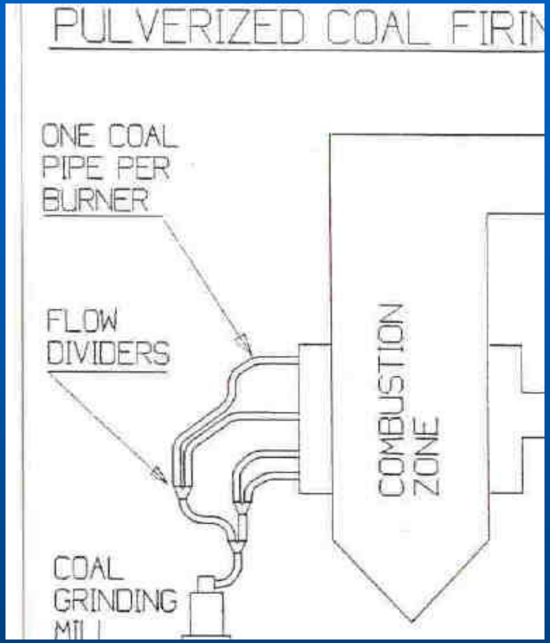
- Air flow rate & pattern control
- Gas fuel injectors
- Atomizer adjustments
- Pulverized coal injection
- Burner can be built for 2 or 3 fuels

Pulverized Coal System



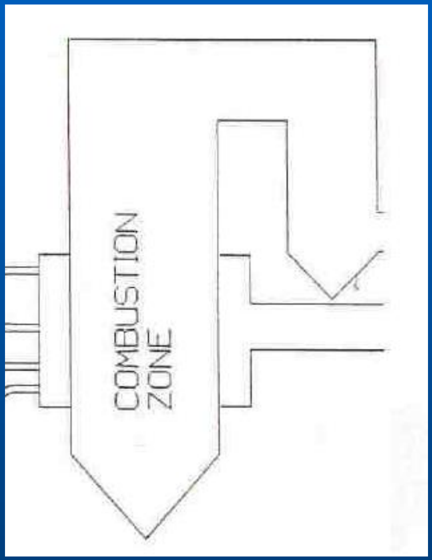
PC Firing

- Grinding mill feeds a set of burners.
- A large boiler has several mills.
- About 20% of the boiler air for pneumatic transport.
- Challenge of uniform coal flows
- Abrasive wear

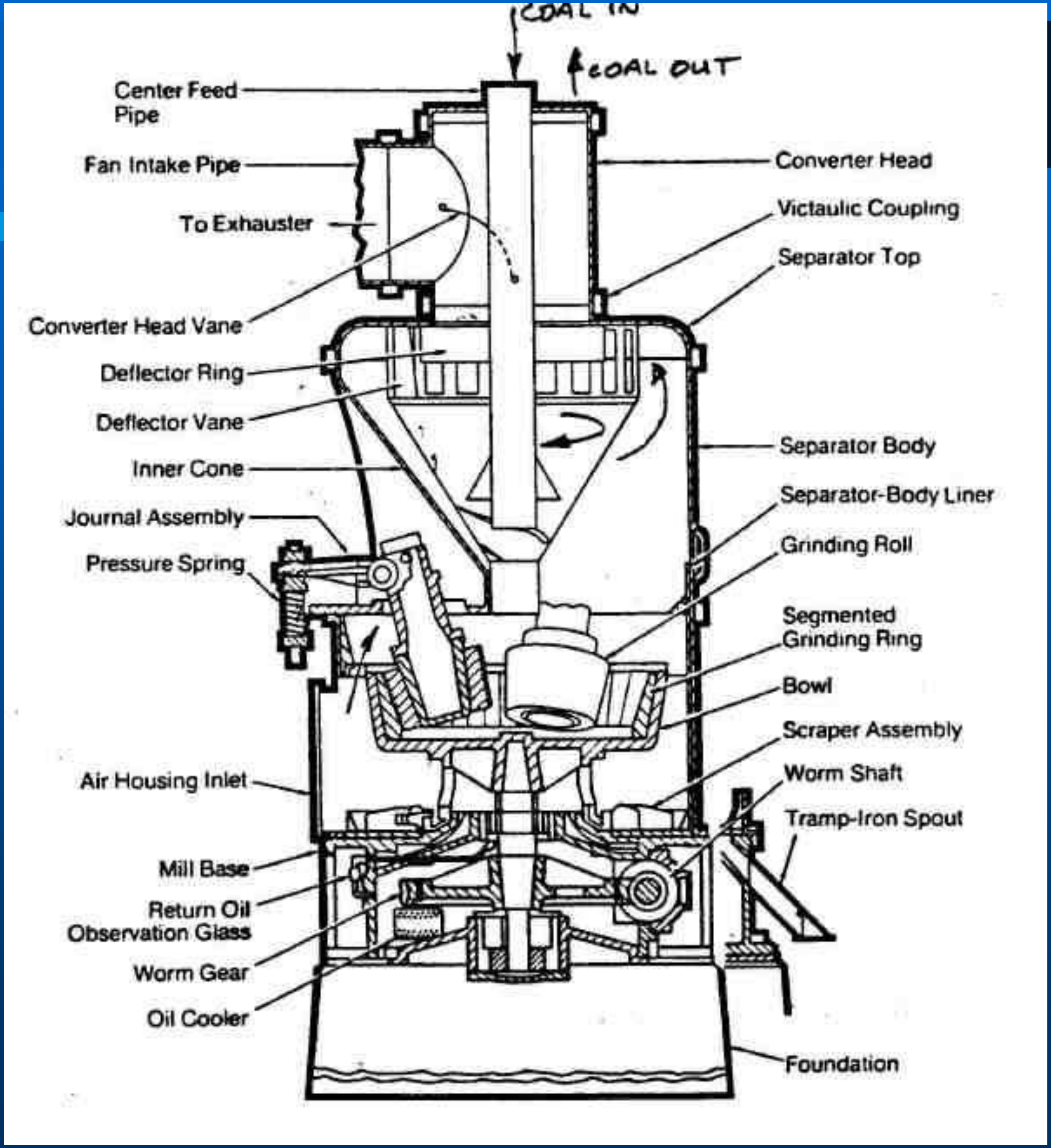


PC Firing (3)

- Molten sticky ash in suspension
- Heat transfer issues
- Soot blowers
- Large ash accumulations
- Use of combustion controls

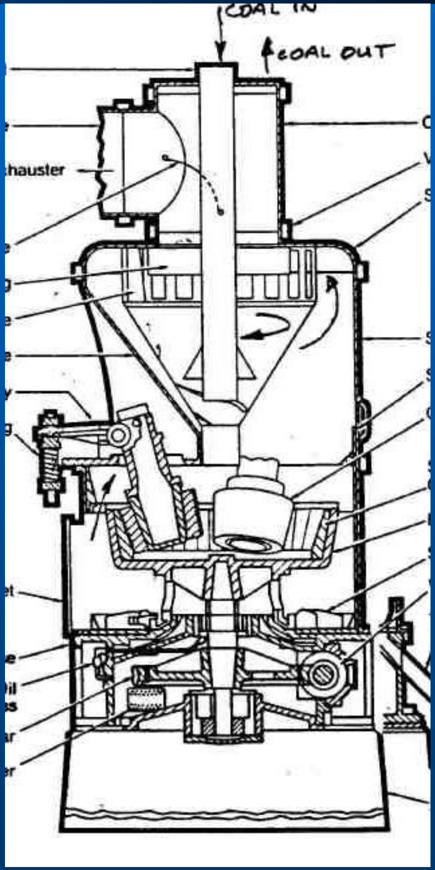


Coal Grinding Mill

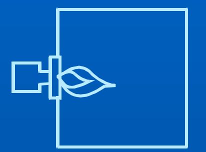


Grinding Mills (2)

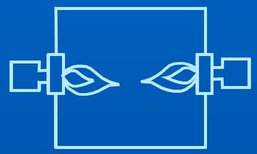
- Drying the coal.
- Classifier
- Hardness vs capacity & finess
- Maintenance is essential



Suspension Firing – Burner Arrangements

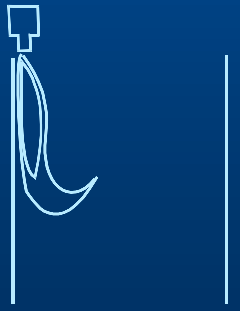


Wall-fired,
Elevation View

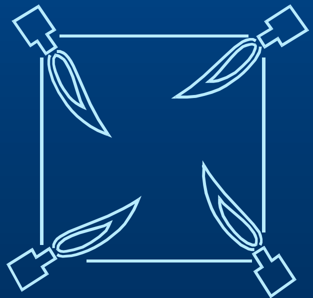


Horizontally Opposed,
Wall-fired, Elevation View

Turbo-fired,
Elevation View

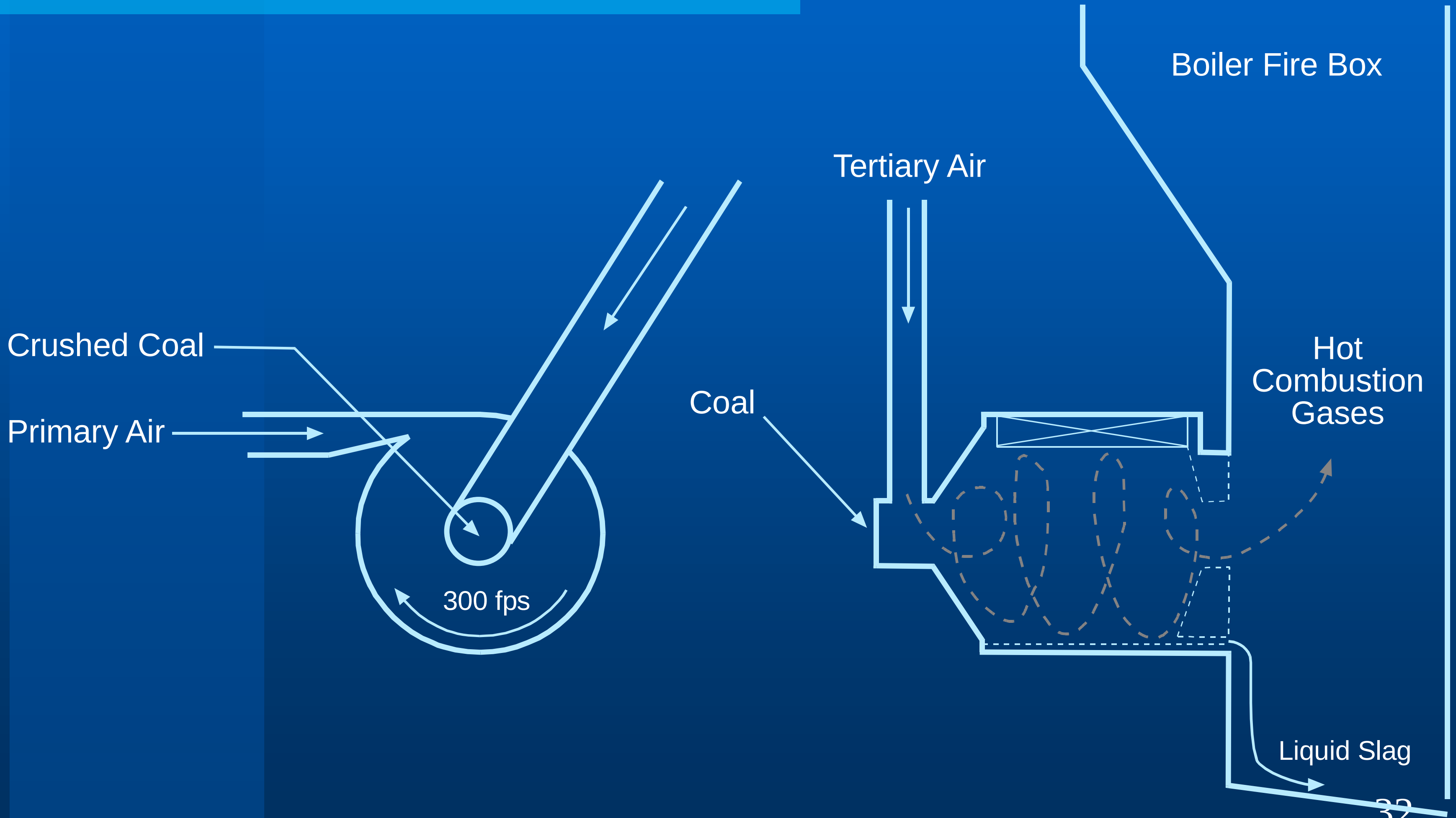


Arch-fired,
Elevation View



Tangential Firing,
Plan View

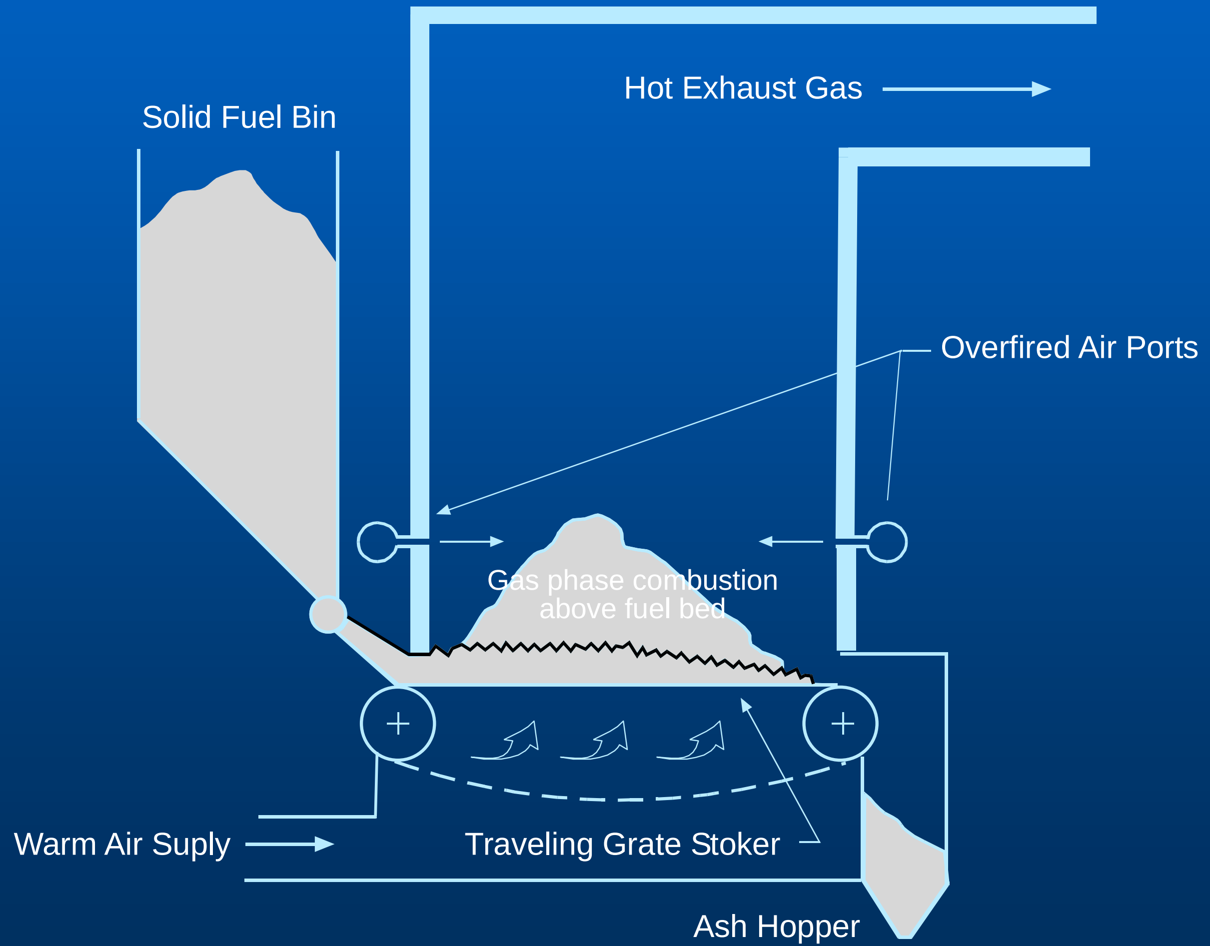
Cyclone Burner



Stoker Firing

- General
  - It's the original furnace combustor
- Fuels
  - Any solid
- Size
  - Limited by grate surface area – 1000 sqft (1000 mmBTU/hr)
- Use and Trends
  - Industrial boilers, wood waste, MSW

Stoker Firing Concept



Stoker Firing Concept (cont.)

- Concepts
  - Residence (grate transport) time – drying, combustion
  - Load following – slow
  - Challenge of automation
- Fuel Feeders
- Air Management
- Grate Concepts

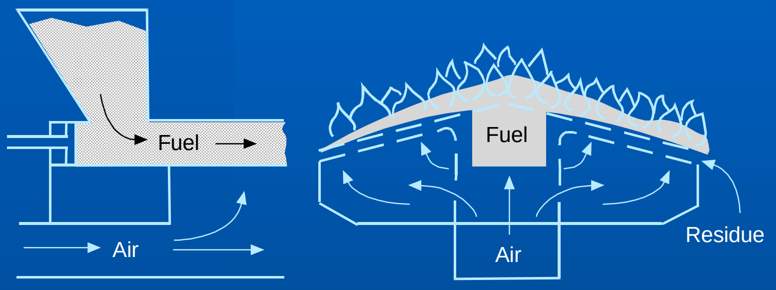
Fuel Burning on a Grate

- Size of fuel particles
  - Burning time is proportional to size
    - So size distribution determines grate speed
  - Furnace air velocity can carry out particles smaller than 2 mm
  - Suspended particles larger than 0.2 mm don’t burn completely
- Type of fuel
  - Wet fuel requires hot air & time to dry

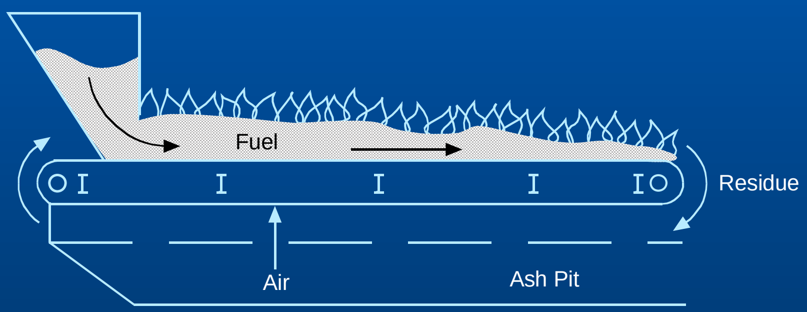
Fuel Feeders

- Objective
  - Get fuel into the furnace without jamming
  - Achieve a uniform distribution on the grate (try to match fuel & air distributions)
- Types
  - Bottom feeders
  - Spreaders
  - MSW mass feed

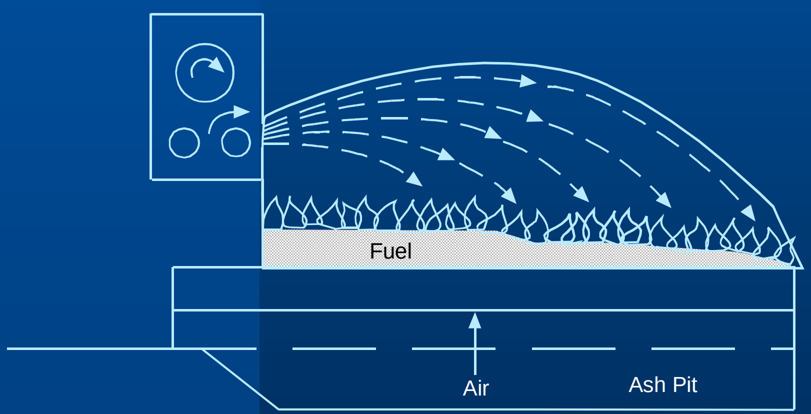
Fuel Feeders (cont.)



(a) Underfeed



(b) Crossfeed Spreader



(c) Overfeed Spreader

Air Flow

- Air is supplied by a Forced Draft fan
  - An Induced Draft fan may draw flue gas from the furnace
- Air is distributed between under grate and over fired
  - Under grate air distribution won't perfectly match the fuel distribution above
  - Enough under grate air is needed for cooling.
    - This limits the minimum air flow = high excess air levels
    - It also limits the amount of over fired air

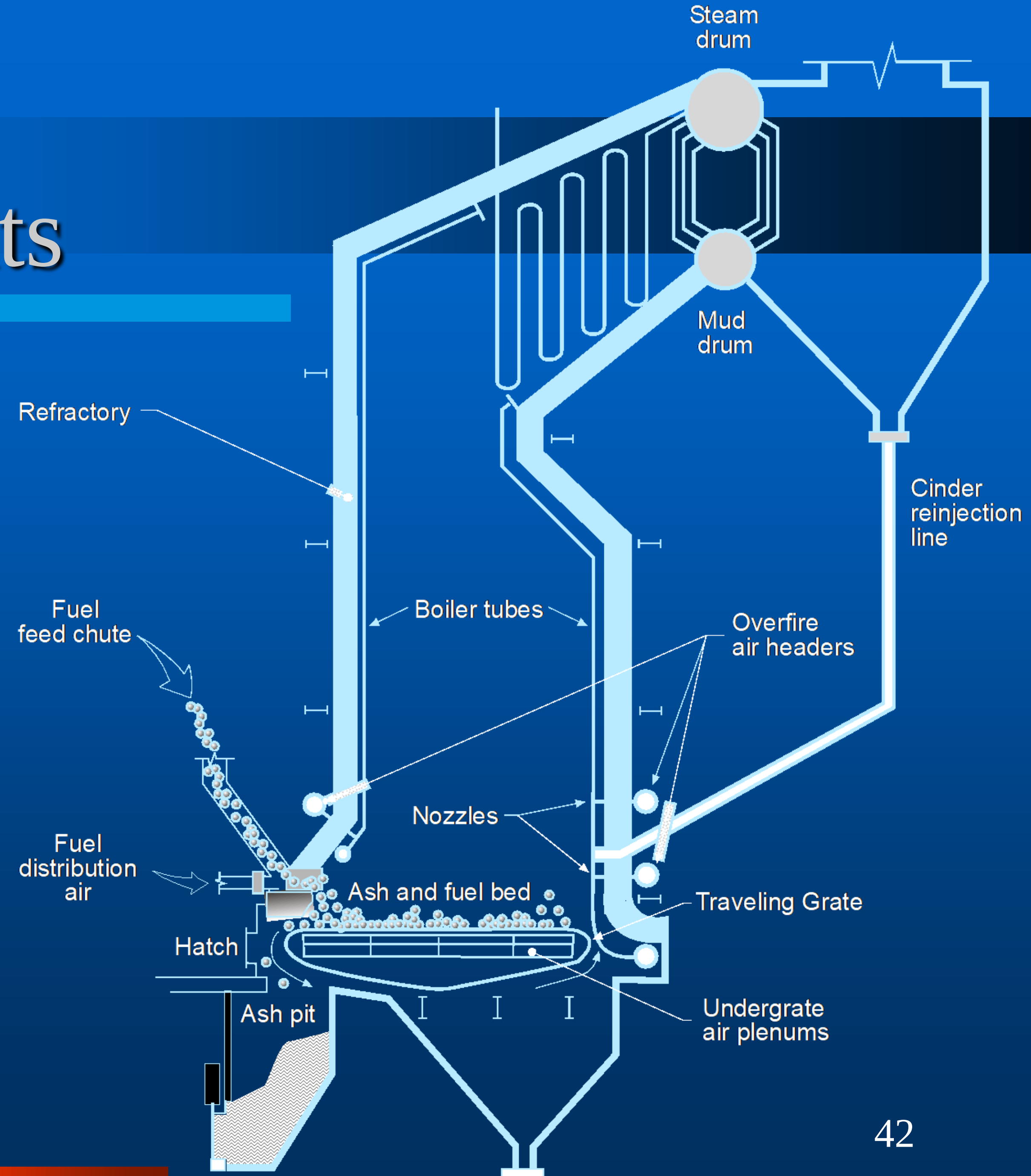
Overfired Air

- Over fired air burns volatile fuel from the bed
  - Over fired controls CO emissions
- Problems
  - The amount of over fired air is usually limited by grate cooling needs
  - Geometry (design) of the over fired air ports is critical to optimum emission performance

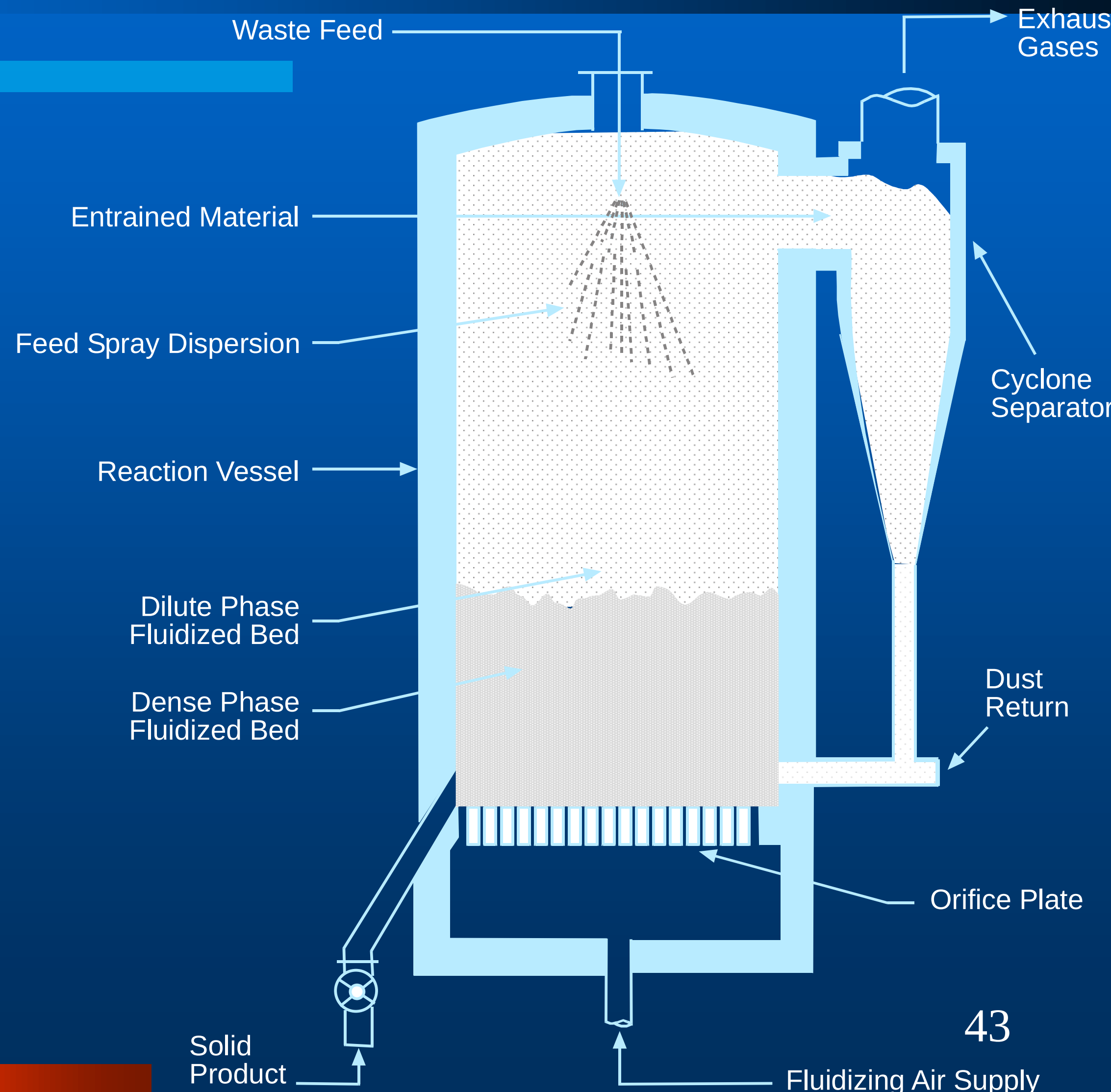
Grate Concepts

- Pressure drop
  - 0.5” or more needed for even distribution
  - Worn grate → poor air distribution
- Types
  - Stationary: simple, allows water cooling
  - Traveling: automatic ash transport
  - Oscillating: stirs the fuel & transports

Stoker Components



Fluidized Bed Combustor



Advantages and Disadvantages

- Advantages
  - Fuel flexibility
  - Low NOx & possible SOx control
- Disadvantages
  - Fan energy is high
  - Bed cooling incurs
    - High excess air OR
    - High erosion rates or
    - Complexity – circulating fluid bed
  - Ash & bed solids management
- If good fuel is cheap why buy a fluid bed?

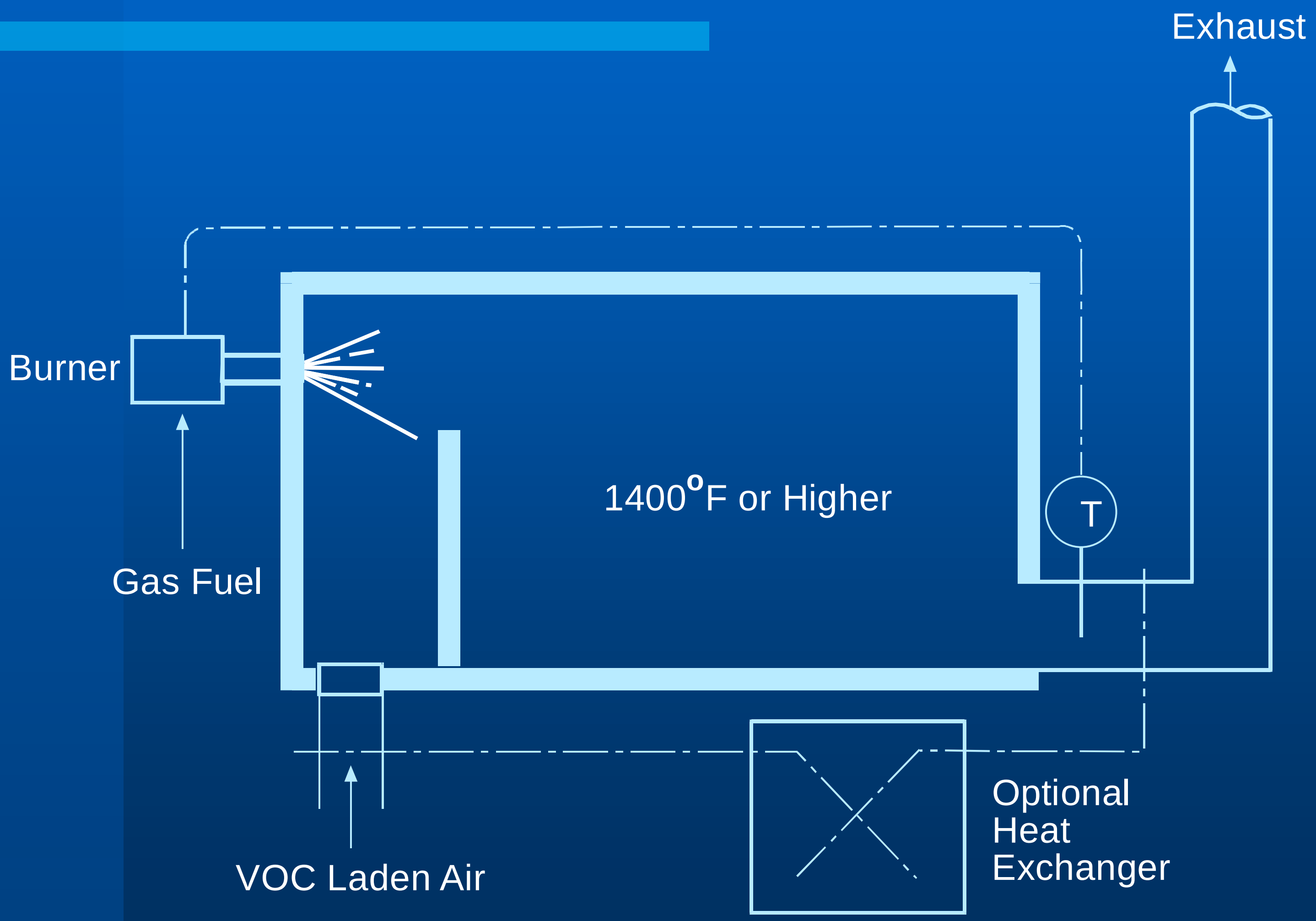
Types of Combustion Systems (outline)

- Engines and Turbines
- Boilers
- Thermal Oxidizers
- Other Combustion Systems

Thermal Oxidizers (outline)

- Gas “incinerators” are pollution control devices
- High Temperature Oxidizers
- Catalytic Oxidizers
- Flares

High Temperature Thermal Oxidizers



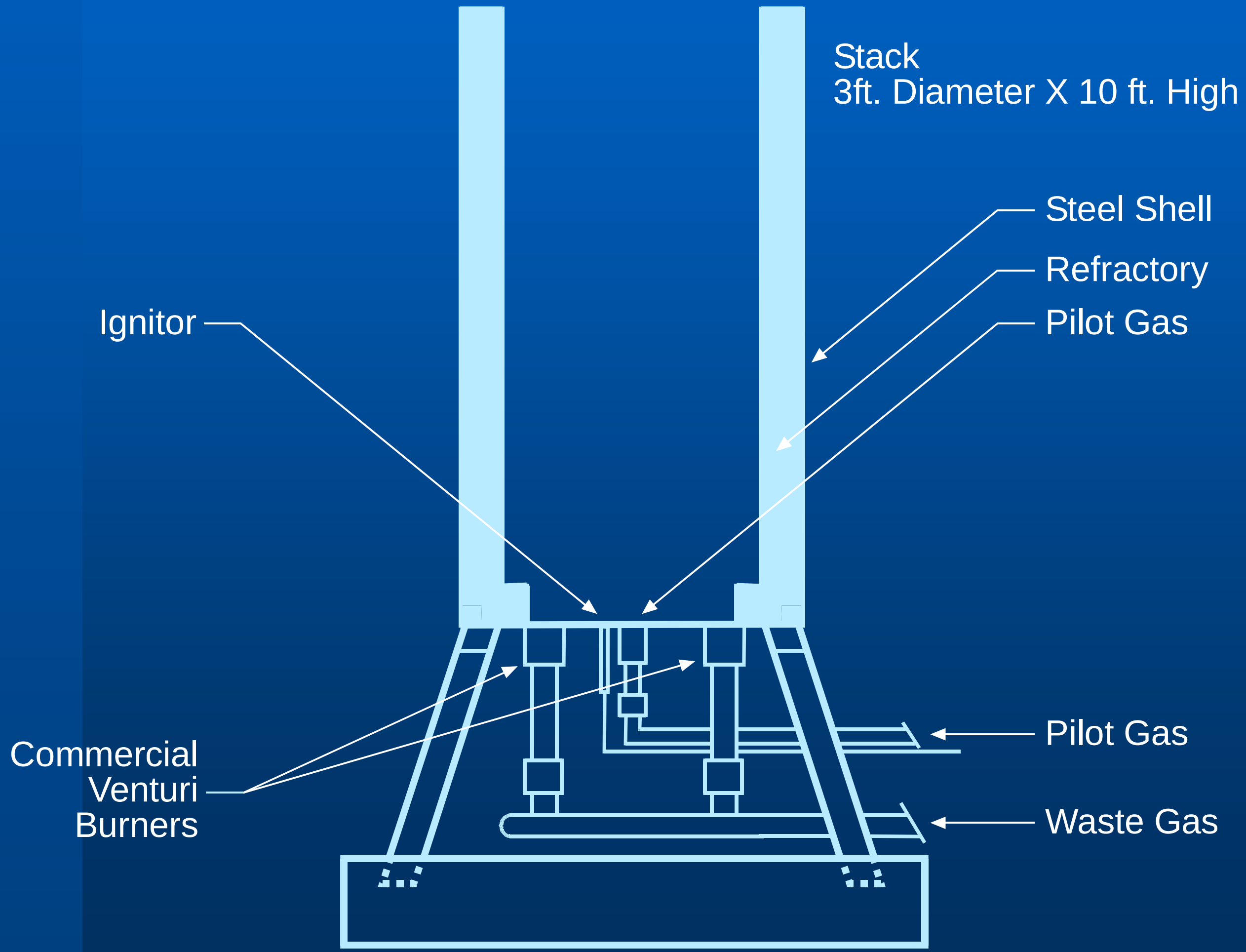
High Temperature Oxidizers

- 1400F should give complete destruction
  - Provided mixing (design) is good
  - A simple oxidizer is very effective
- Oxidizers with 1400F exhausts use a lot of fuel
- Heat exchangers cut fuel use dramatically
  - Heat exchangers can leak → emissions

Catalytic Oxidizers

- Similar to a simple oxidizer except for lower temperature - <700F
  - Same requirement for uniform mixing
- Destruction efficiency varies by chemical
- Catalyst performance can deteriorate → emissions

Flares


Stack
3ft. Diameter X 10 ft. High
Steel Shell
Refractory
Pilot Gas
Ignitor
Commercial
Venturi
Burners
Pilot Gas
Waste Gas

Flares

- Concept: continuously burn waste gas
- Traditional purpose: prevent flammable gas accumulation
- Recent purpose: pollution control
  - Common at landfills
  - Replaced by beneficial use in some cases

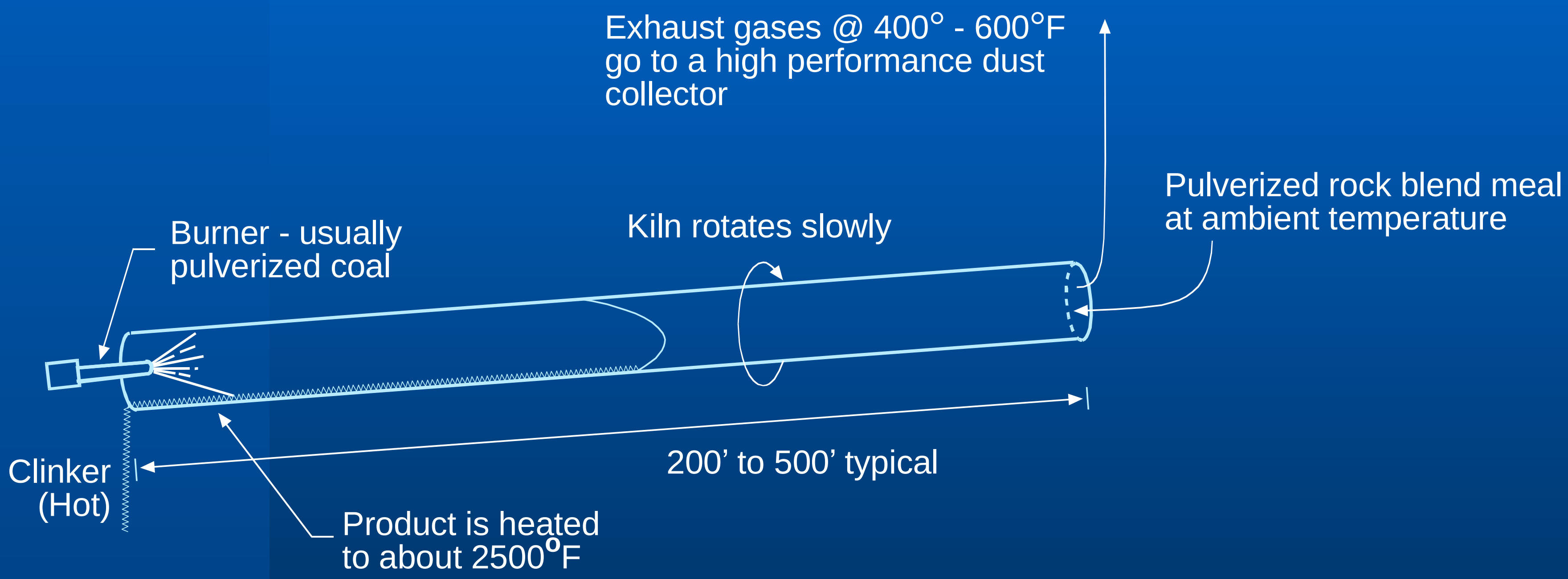
Types of Combustion Systems (outline)

- Engines and Turbines
- Boilers
- Thermal Oxidizers
- Other Combustion Systems

Other Combustion Systems (outline)

- Cement Kilns
- Sludge Burners

Cement Kilns



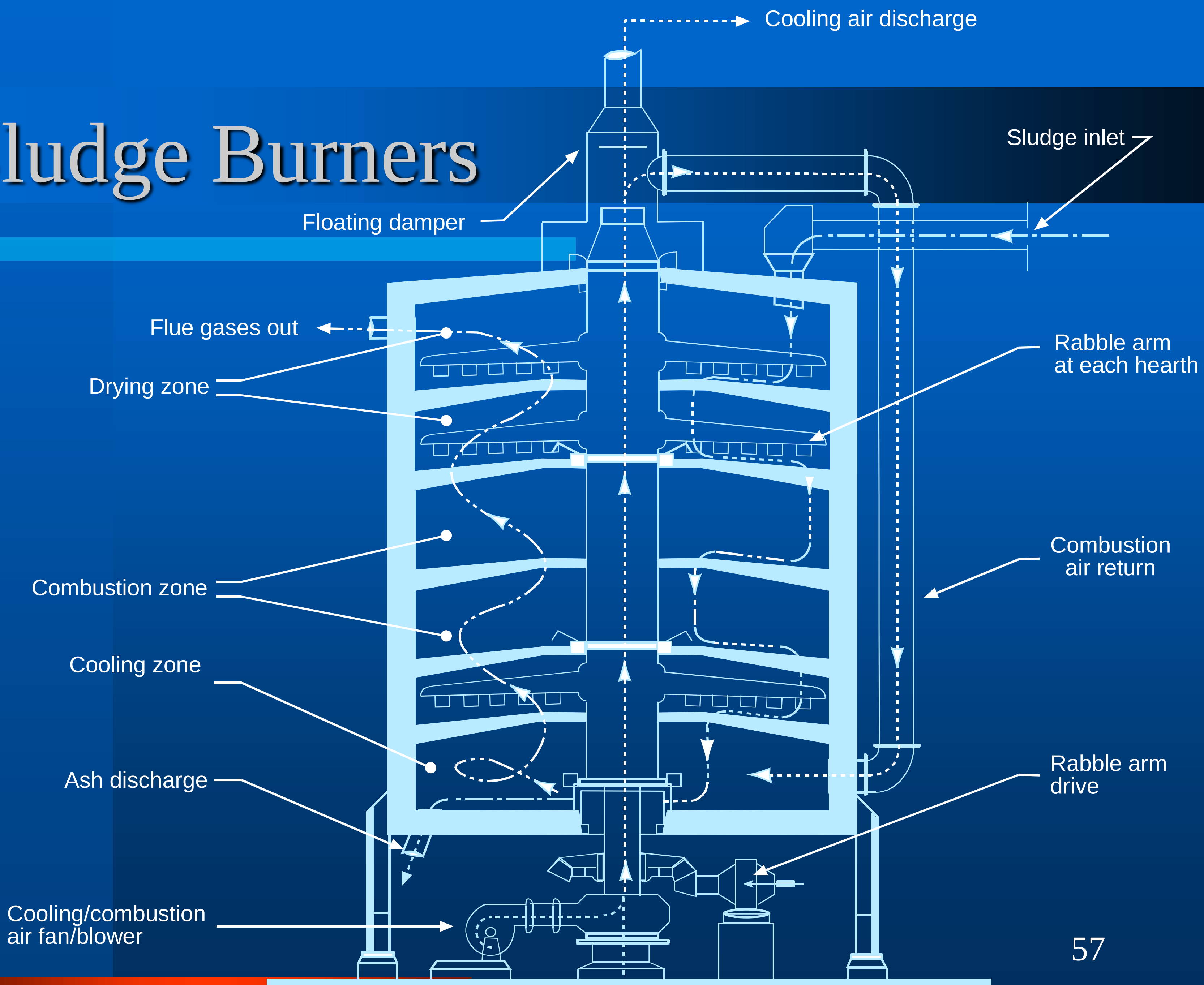
Cement Kilns (cont.)

- High temperature, long residence time
- Fuels – flexibility to burn cheap fuel
  - Coal
  - Liquid & solid hazardous waste
- Emissions
  - NOx
  - Volatiles from process

Rotating Hearth Burner

- Design is obsolete (grandfather cases)
- Counter flow heat exchanger
  - Sludge volatiles are emitted
- New sludge processors use fluid bed combustor or other treatment methods

Sludge Burners



Fuel Storage, Handling and Processing (outline)

- Natural Gas
- Oil
- Solid Fuels
  - Coal
  - Wood and Waste

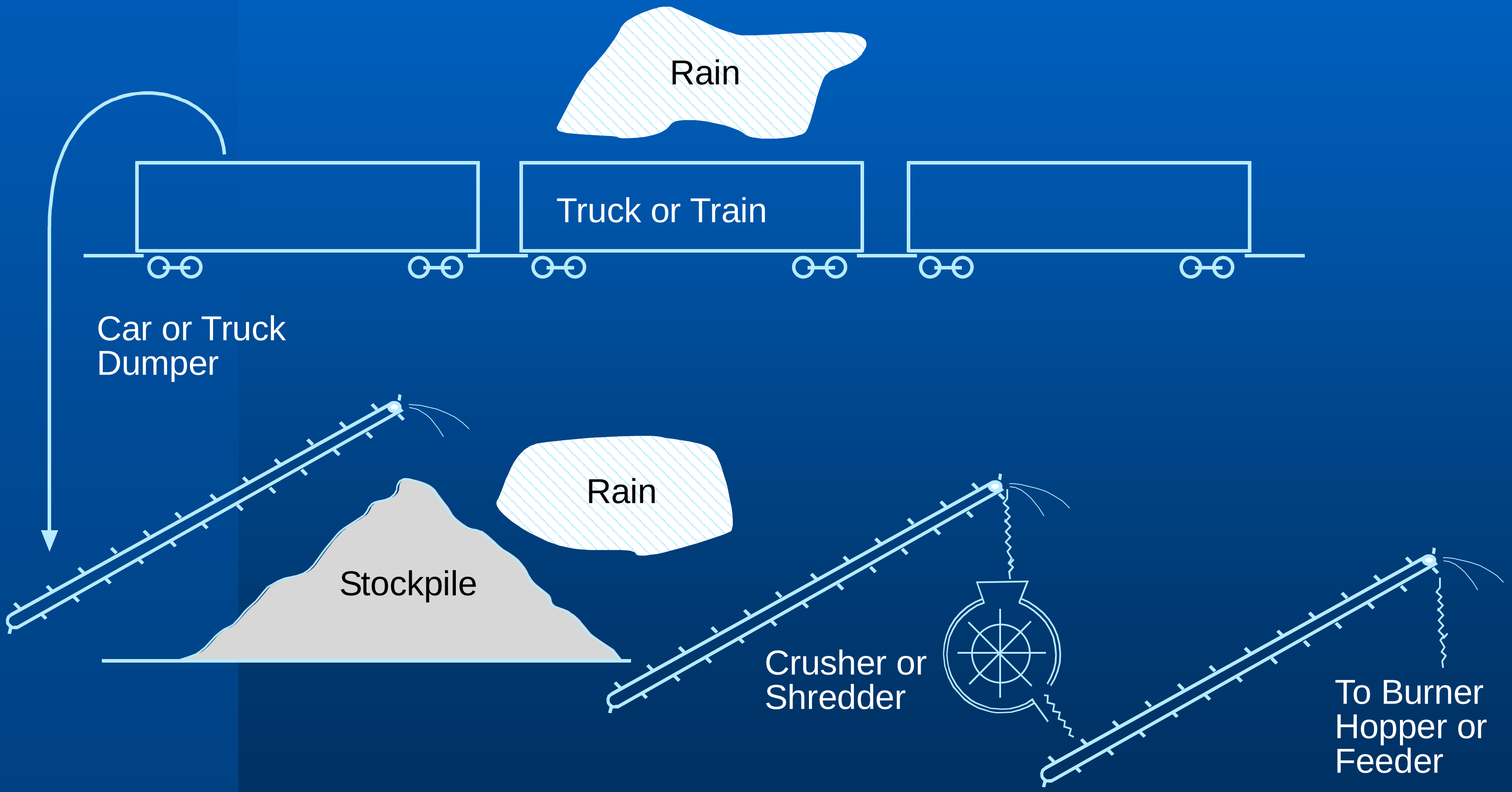
Natural Gas

- Delivery
  - Piped direct to customer
- Storage is in wells
- An interruptible supply is cheaper

Oil

- Delivery
  - Truck, rail, barge or ship
  - Pipeline to large customers & distributors
- Storage capacity is usually weeks or months
  - #6 Oil must be kept hot to pump it
  - Stratification can occur in large tanks

Solid Fuels


Rain
Truck or Train
Car or Truck Dumper
Rain
Stockpile
Crusher or Shredder
To Burner Hopper or Feeder

Coal

- Primary users are electric utilities
- Delivery by unit train
- Storage piles
  - Can accumulate moisture
  - Fire potential

Wood and Waste

- Used on site or delivered by truck
- Moisture
  - Initial high moisture will increase with rain
- Wood deteriorates (rots) → no long term storage

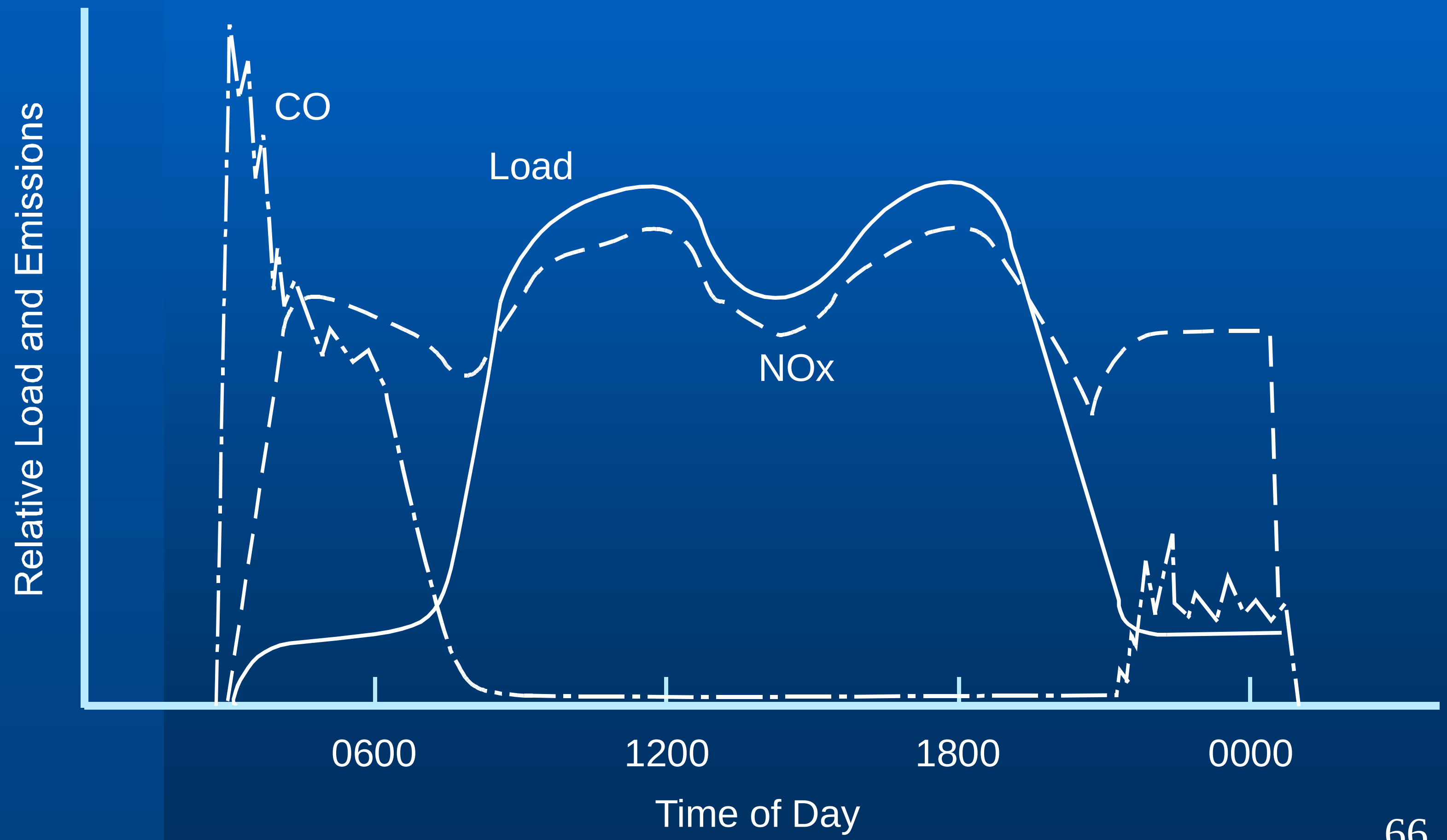
Combustion Air Controls (outline)

- Load Variations
- Control Systems
- Air Moving Components

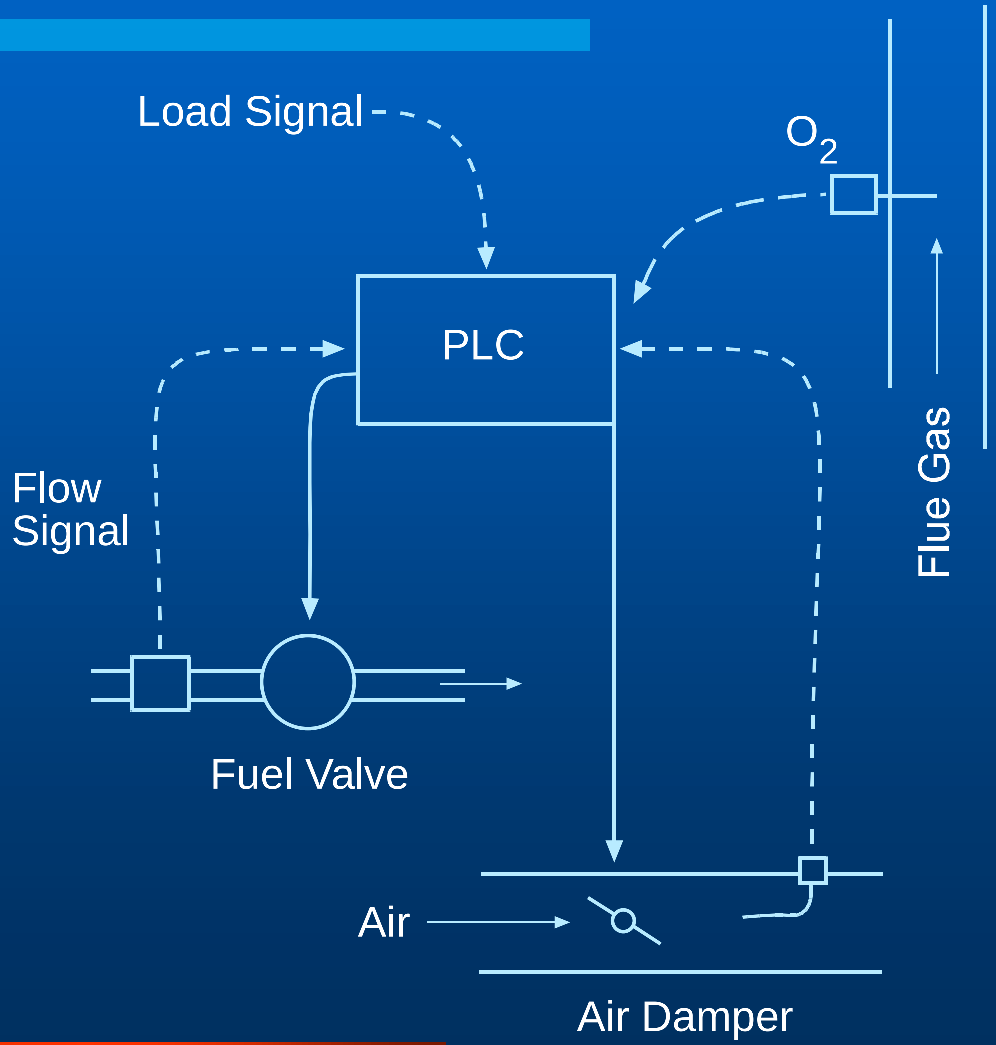
Load Types

- Base load
- Swing load
- Emergency
- Regulated facilities see variable loads – control system required

Control Systems



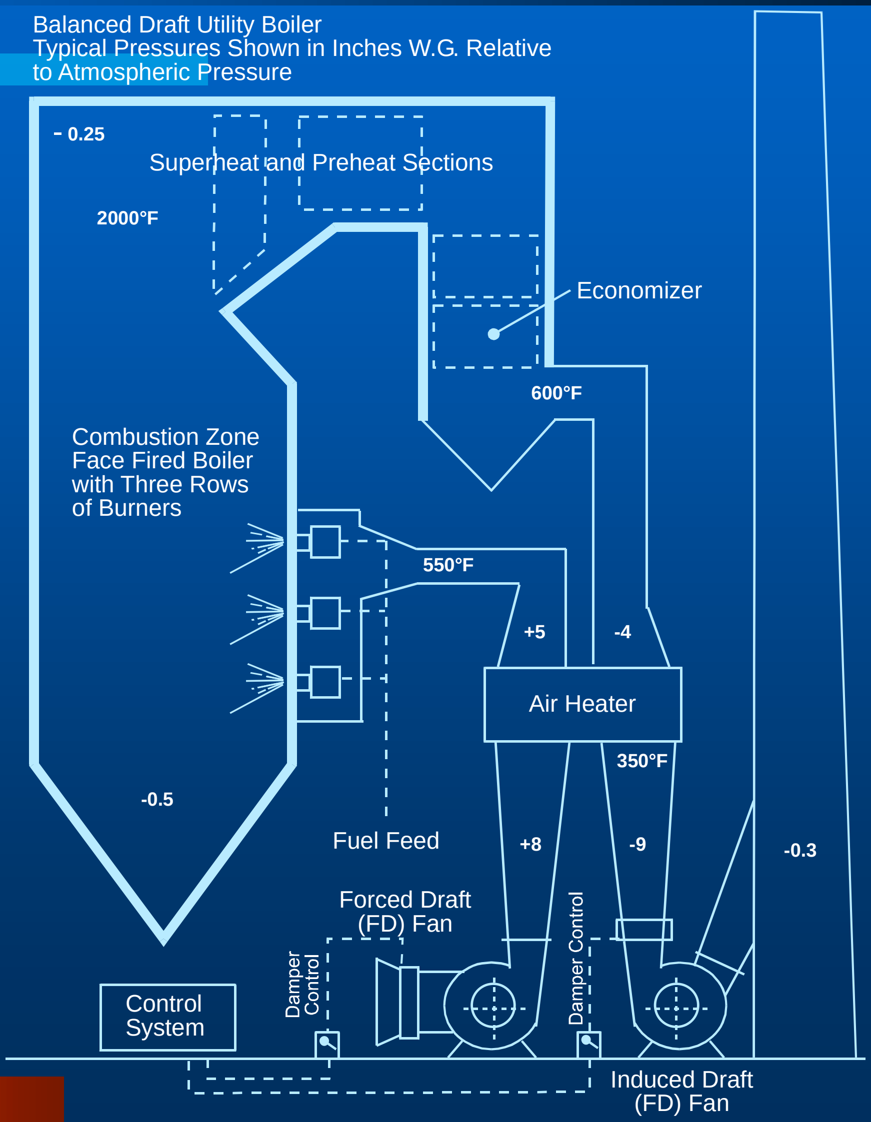
Control Systems (2)



Control Systems (3)

- Fuel flow responds to load demand
- Air Flow must match (follow) fuel flow
  - Keep the air-fuel ratio constant
  - Mechanical coupling devices do a poor job
  - PLC allows sophisticated flow matching
- O_2 meter directly measures air-fuel ratio

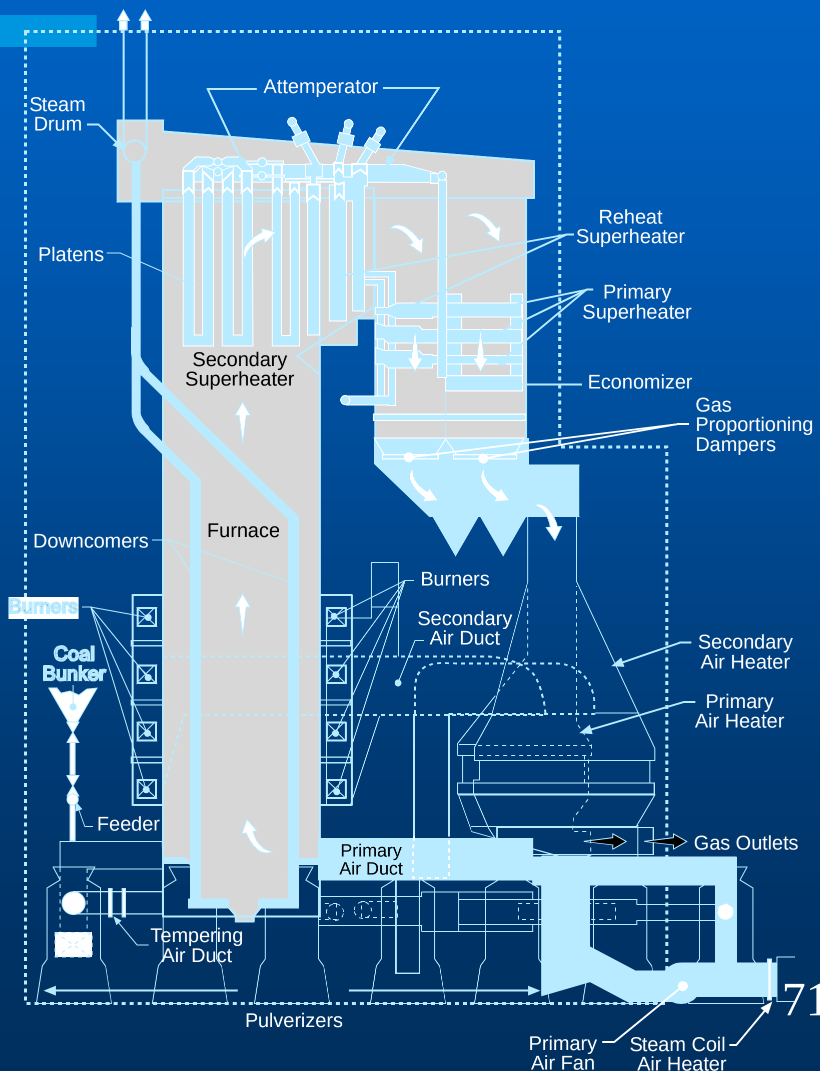
Air Moving Components



Air Moving Components (2)

- FD fan provides/controls combustion air flow
- Optional ID fan
  - Keeps furnace at negative pressure
  - Controls unison with FD fan
- Optional air heater
- Note pressures decrease from FD fan to ID fan or stack

Steam Generator Components



Steam Generator Components (2)

- Boiler feed pump
- Economizer
- Steam drum
- Steam generator
- Downcomers
- Mud drum
- Superheater
- Makeup water
- Attemperator
- Blowdown

Steam Generator (2)

- Boiler feed pump
- Economizer
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Steam Turbines

- Components
  - High pressure turbine
  - Low pressure turbine
  - Reheat superheater
  - Condenser
- Efficiency
  - Sensitive to inlet temperature
  - Deteriorates with wear

Factors Affecting Steam Temperature

- Size of the superheater
- Deposits on HX surfaces
- Type of fuel
- Excess air levels
- Boiler load
- Burners in service

Ash Handling (outline)

- Boiler Surface Deposits
- Bottom and Fly Ash Management
- LOI and Introduction to Ash Chemistry

Boiler Surface Deposits

- Fuels & fuel ash characteristics
- Quantities
  - Collection & management
- Surface deposits
  - Formation, accumulation
  - Sensitivity to chemistry, operating conditions

Deposit Control Methods

- Coal purchase specifications
- Soot blowing
- Limit the load, excess air

Bottom and Fly Ash Management

- Stoker versus suspension firing
- Disposal, beneficial use

LOI and Introduction to Ash Chemistry

- Ash carbon content (LOI)
  - High carbon content (<5%) wastes fuel and prevents beneficial use
- Residence time & particle size vs carbon
- Ash Chemistry
  - Volatile elements concentrate in fine particles

Chapter Summary

- Types of combustion sources
- Conversion to mechanical energy
- Boilers
- Electric Power Plants
- Fuel and Air Flow
- Waste heat
- Emission control
- Fuel Storage, Handling, and Processing
- Fly ash