Better Plants
U.S. DEPARTMENT OF ENERGY

VIRTUAL PROCESS HEATING INPLT
Session 1

U.S. DEPARTMENT OF ENERGY

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Poll Question # 1

What's your main driver for wanting to attend PH Virtual In-Plant Training? (select one or more):

A Reducing process heating energy cost

B Improving environmental performance

C Improving energy productivity

D Gain knowledge

Thank You to Our Participants!

Sachin Nimbalkar, PhD

Group Leader, MEERA Group (ORNL)

Education

- Rutgers, The State University of New Jersey – PhD (Mech. Eng.), 2009
- Rutgers, The State University of New Jersey – M.S. (Mech. Eng.), 2005
- Government College of Engineering Pune, India – B.E. (Mech. Eng.), 2001

Professional Experience

- Group Leader, Manufacturing Energy Efficiency Research & Analysis, 2020 - present
- Group Leader, Energy Efficiency Research & Analysis, 2017 - 2020
- Technical Account Manager, DOE's Better Plants Program, 2010 - present
- UT-ORNL Joint Assistant Professor in the Department of Industrial and Systems Engineering (ISE), University of Tennessee, Knoxville, 2015 - present
- R&D Staff in Energy and Transportation Science Division (ETSD), ORNL, 2008 – 2017
- Graduate Research Assistant, Center for Advanced Energy Systems, Rutgers University, 2003 –2008

Other Qualifications & Affiliations

- DOE's Industrial Qualified Specialist in Process Heating, Steam, and Pumping systems
- Member, DOE's Process Heating Steering Committee, 2009 – 2012
- Member, DOE's Steam Steering Committee, 2010 – 2012
- Member, Sigma Xi (Oak Ridge, Tennessee Chapter), 2010–present
- Member of the American Society of Mechanical Engineers (ASME), 2010–present
- Member of the Society of Manufacturing Engineers (SME), 2018–present

Training Module # 1
Process Heating Systems Overview

Outline

- What is Process Heating?
- Major Energy Use Systems
- Overview of Industrial Process Heating
- Process Heating Systems

Poll Question # 2

Process heating accounts for **what %** of all process energy (energy applied to convert material into products) used in the U.S. manufacturing sector? (select only one):

A 40%

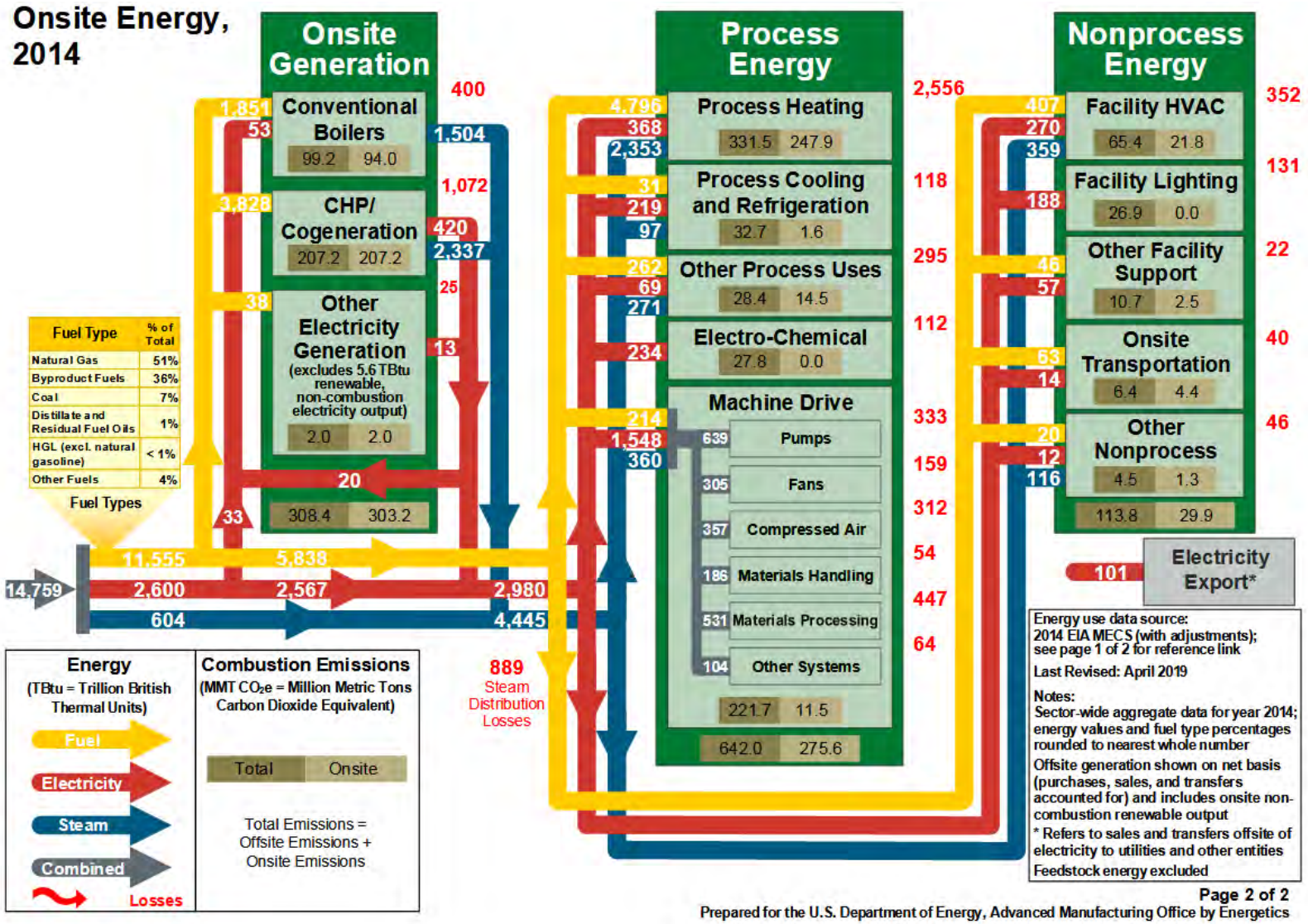
B 50%

C 60%

D 70%

Yes!

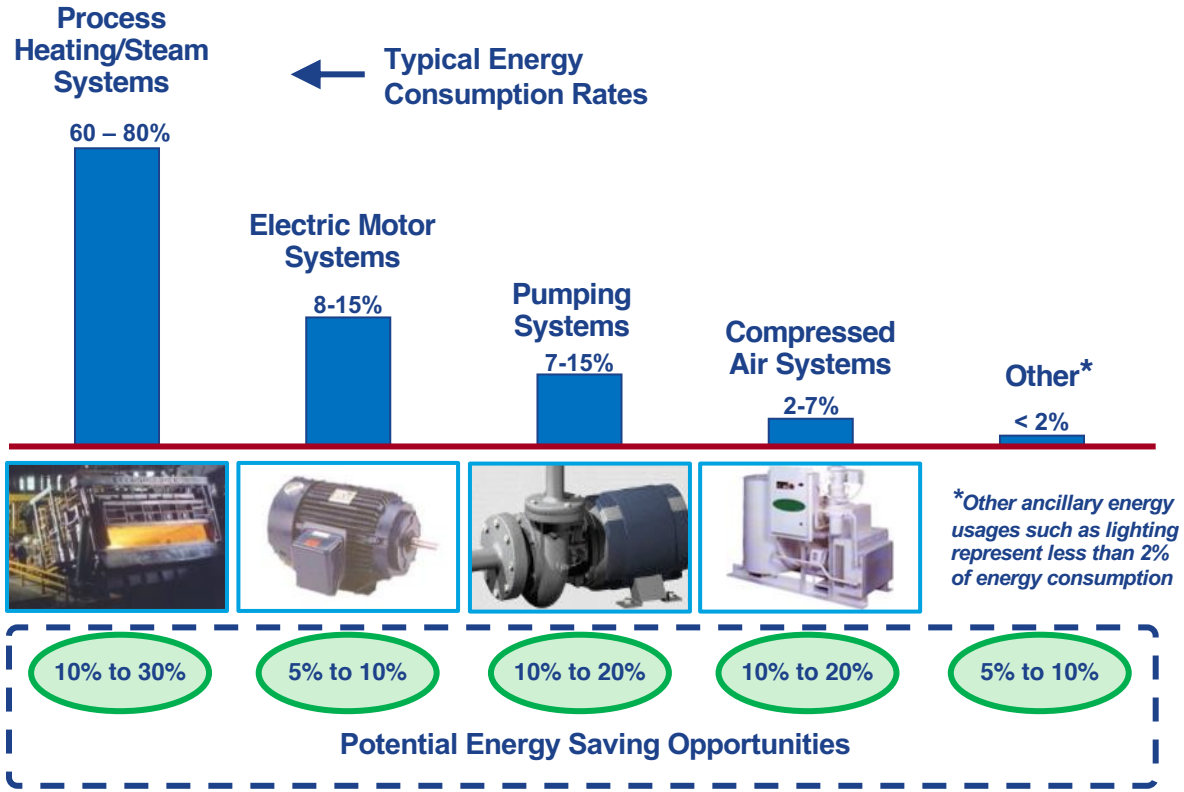
Major Energy Consumers for All Manufacturing Industries



Prepared for the U.S. Department of Energy, Advanced Manufacturing Office by Energetics

System Focus Targets Major Energy Consumers

High-level Plant Energy Consumption & Savings Profile



What is Process Heating?

Supplies heat to materials for further processing using:

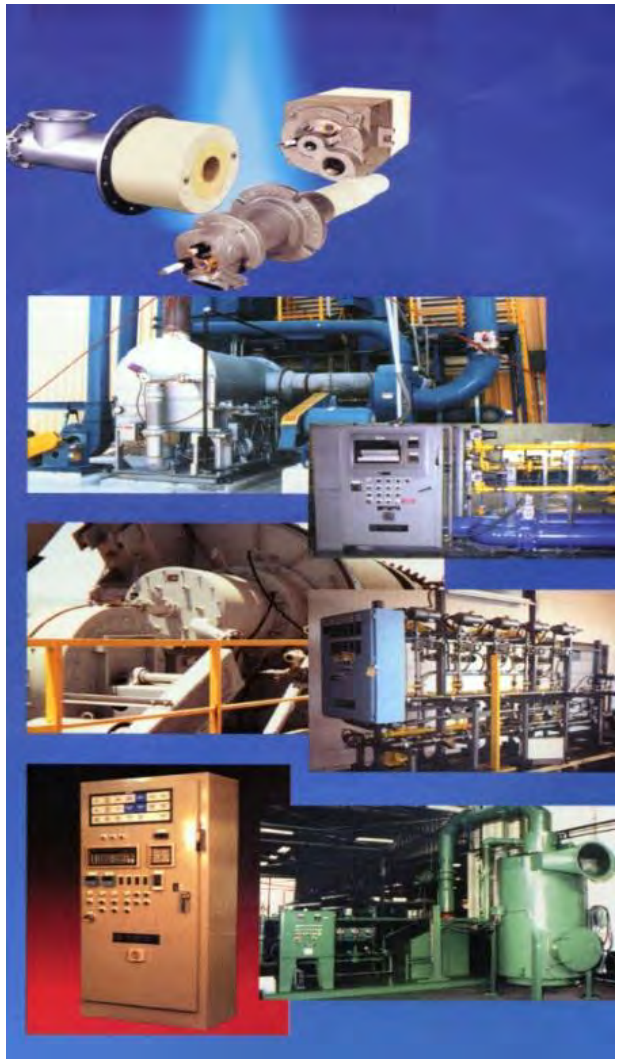
- Furnaces
- Ovens
- Heaters
- Thermal oxidizers
- Dryers
- Kilns
- Boilers
- Other heating equipment

Major Process Heating Operations

Process	Application	Equipment	Industry
Agglomeration - Sintering	Metals Production	Various Furnace Types, Kilns Microwave	Primary Metals
Calcining	Lime Calcining	Various Furnace Types	Cement, Wallboard, Pulp and Paper Manufacturing, Primary Metals
Curing and Forming	Coating, Polymer Production, Enameling	Various Furnace Types, Ovens, Kilns, Lehrs, Infrared, UV, Electron Beam, Induction	Ceramics, Stone, Glass, Primary Metals, Chemicals, Plastics, Rubber
Drying	Water and Organic Compound Removal	Fuel-Based Dryers, Infrared, Resistance, Microwave, Radio-Frequency	Stone, Clay, Petroleum Refining, Agricultural and Food, Pulp and Paper, Textiles
Forming	Extrusion, Molding	Various Ovens and Furnaces	Rubber, Plastics, Glass
Fluid Heating	Food Preparation, Chemical Production, Reforming, Distillation, Cracking, Hydrotreating, Visbreaking	Various Furnace Types, Reactors, Resistance Heaters, Microwave, Infrared, Fuel-based Fluid Heaters, Immersion Heaters	Agricultural and Food, Chemical Manufacturing, Petroleum Refining
Heating and Melting – High-Temperature	Casting, Steelmaking, Glass Production	Fuel-Based Furnaces, Kilns, Reactors, Direct Arc, Induction, Plasma, Resistance	Primary Metals, Glass
Heating and Melting – Low-Temperature	Softening, Liquefying, Warming	Ovens, Infrared, Microwave, Resistance	Plastics, Rubber, Food, Chemicals
Heat Treating	Hardening, Annealing, Tempering	Various Fuel-Based Furnace Types, Ovens, Kilns, Lehrs, Laser, Resistance, Induction, Electron Beam	Primary Metals, Fabricated Metal Products, Transportation Equipment, Glass, Ceramics
Incineration/Thermal Oxidation	Waste Handling/Disposal	Incinerators, Thermal Oxidizers, Resistance, Plasma	Fabricated Metals, Food, Plastics and Rubber, Chemicals
Metals Reheating	Forging, Rolling, Extruding, Annealing, Galvanizing, Coating, Joining	Various Furnace Types, Ovens, Kilns, Heaters, Reactors, Induction, Infrared	Primary Metals, Fabricated Metal Products, Transportation Equipment
Separating	Air Separation, Refining, Chemical Cracking	Distillation, Membranes, Filter Presses	Chemicals
Smelting	Steelmaking and Other Metals (e.g., Silver)	Various Furnace Types	Primary Metals
Other Heating Processes	Food Production (including Baking, Roasting, and Frying), Sterilization, Chemical Production	Various Furnace Types, Ovens, Reactors, Resistance Heaters, Microwave, Steam, Induction, Infrared	Agricultural and Food, Glass, Ceramics, Plastics, Rubber, Chemicals

(Source: Process Heating Sourcebook)

Process Heating Systems



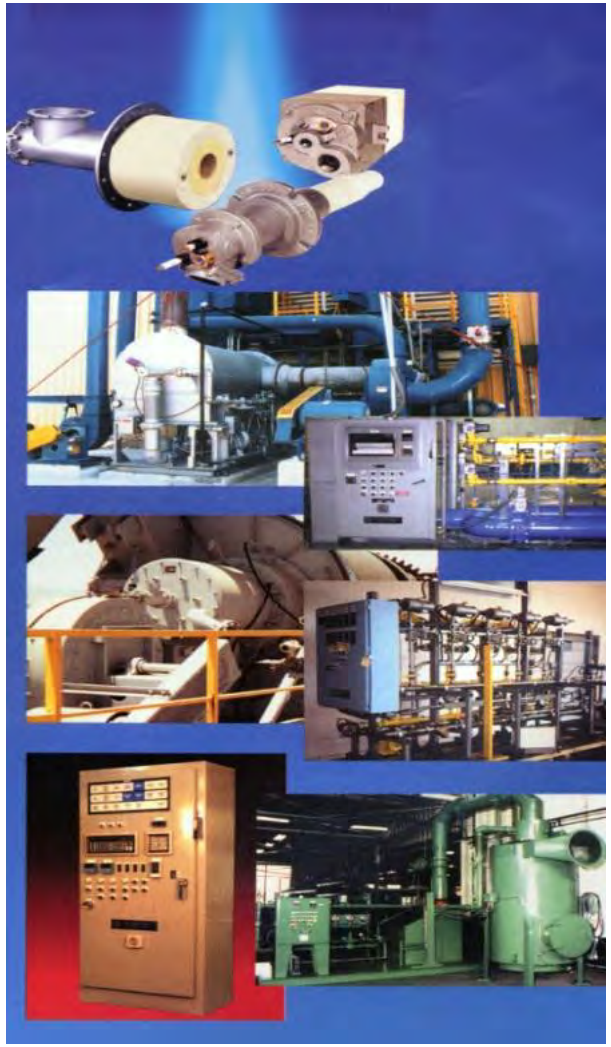
- Process heating includes many different types of heating processes used by industry.
- Heating is carried out at temperatures ranging from as low as 200°F to as high as 3000°F.
- A wide variety of heating equipment (furnaces, ovens, heaters, kilns, etc.) are used for process heating.
- Heating equipment uses many different sources of heat such as fuels (i.e., natural gas, fuel oil, coal), electricity, steam, hot water, etc.

Characteristics of Common Industrial Processes that Require Process Heating and Estimated Energy Use

Process heating operation	Description/example applications[12]	Typical temperature range (F)[13]	Estimated (2010) U.S. energy use (TBtu)[14]
Fluid heating, boiling, and distillation	Distillation, reforming, cracking, hydrotreating; chemicals production, food preparation	150–1000°	3,015
Drying	Water and organic compound removal	200–700°	1,178
Metal smelting and melting	Ore smelting, steelmaking, and other metals production	800–3000°	968
Calcining	Lime calcining	1500–2000°	395
Metal heat treating and reheating	Hardening, annealing, tempering	200–2500°	203
Non-metal melting	Glass, ceramics, and inorganics manufacturing	1500–3000°	199
Curing and forming	Polymer production, molding, extrusion	300–2500°	109
Coking	Cokemaking for iron and steel production	700–2000°	88
Other	Preheating; catalysis, thermal oxidation, incineration, softening, and warming	200–3000°	1,049
Total			**7,204**

Source: Process Heating Technology Assessment, Quadrennial Technology Review 2015

Process Heating Systems



- Majority (more than 70%) of all heat supplied to heating equipment is through controlled combustion of fuels.
- Heating system efficiency is governed by process parameters, selection of proper combustion system, design of the furnaces or ovens and use of waste heat recovery system.
- Emissions from combustion and interaction of combustion products with the load (charge) are major considerations in equipment design and operation.

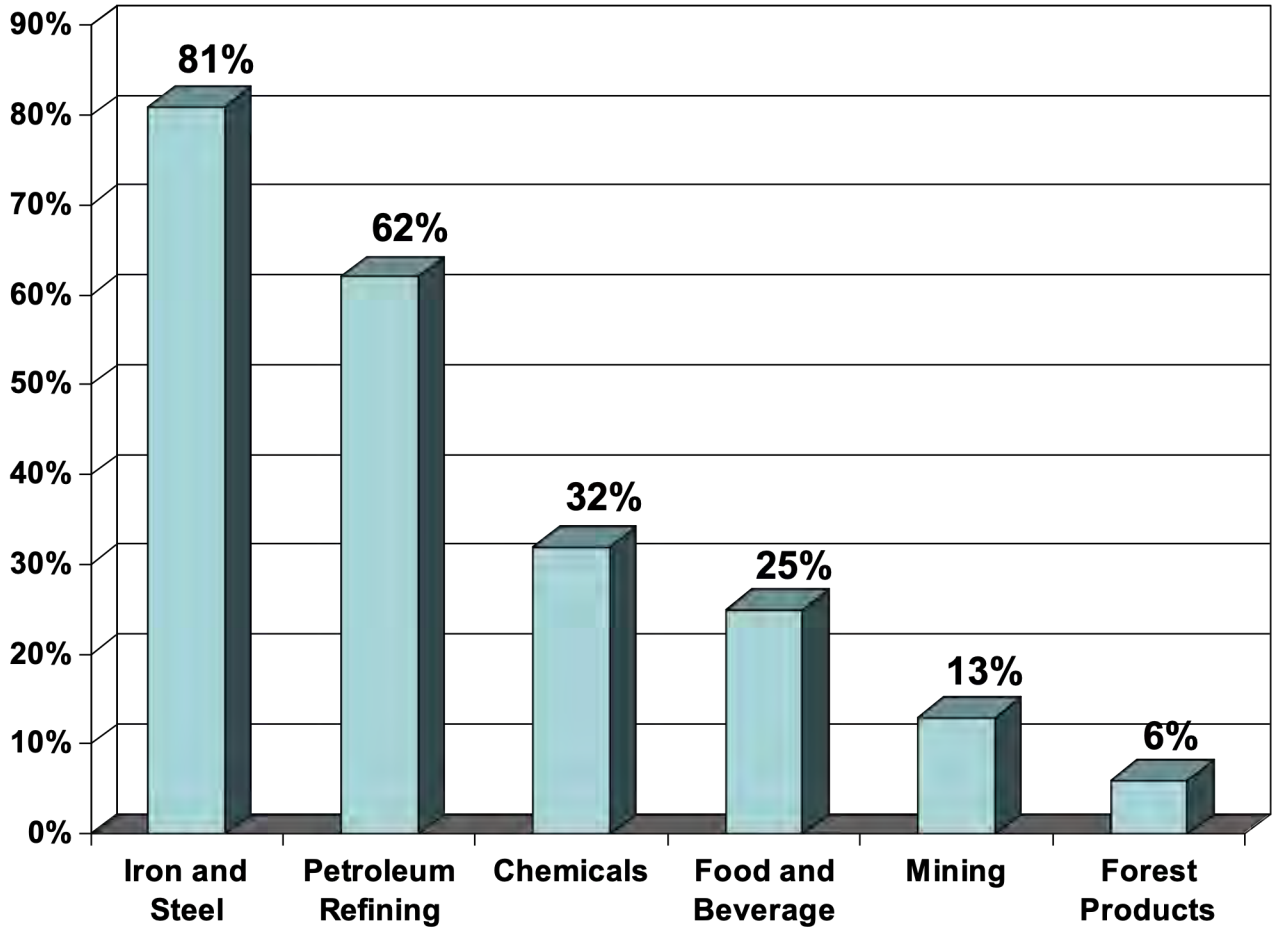
Poll Question # 3

The following industries use steam as a major source of process heat (select two):

A	Iron and steel	
B	Petroleum Refining	
C	Forest products	Yes!
D	Food and beverages	Yes!

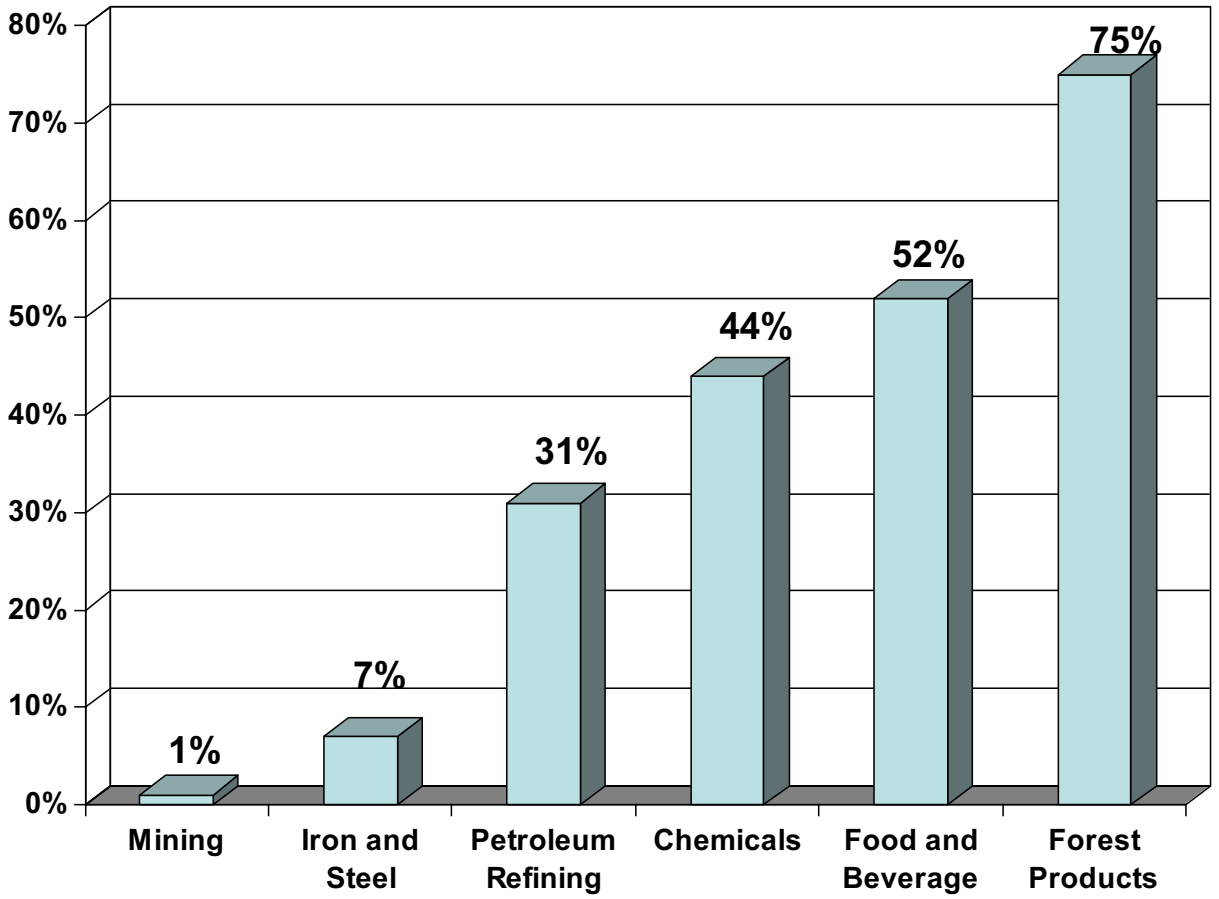
Fired Systems

Energy Use as a Percentage of Total Energy End Use

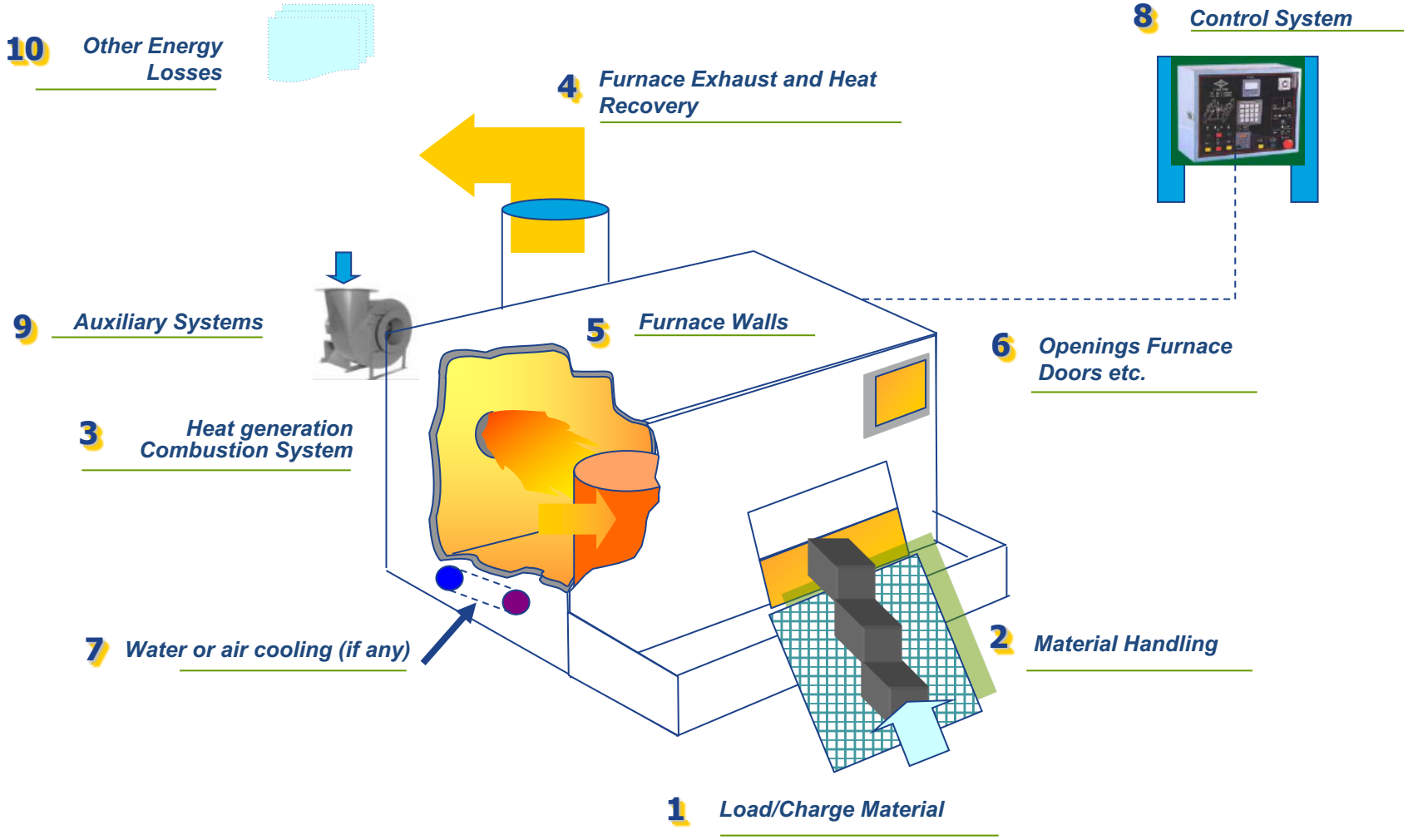


Steam Systems

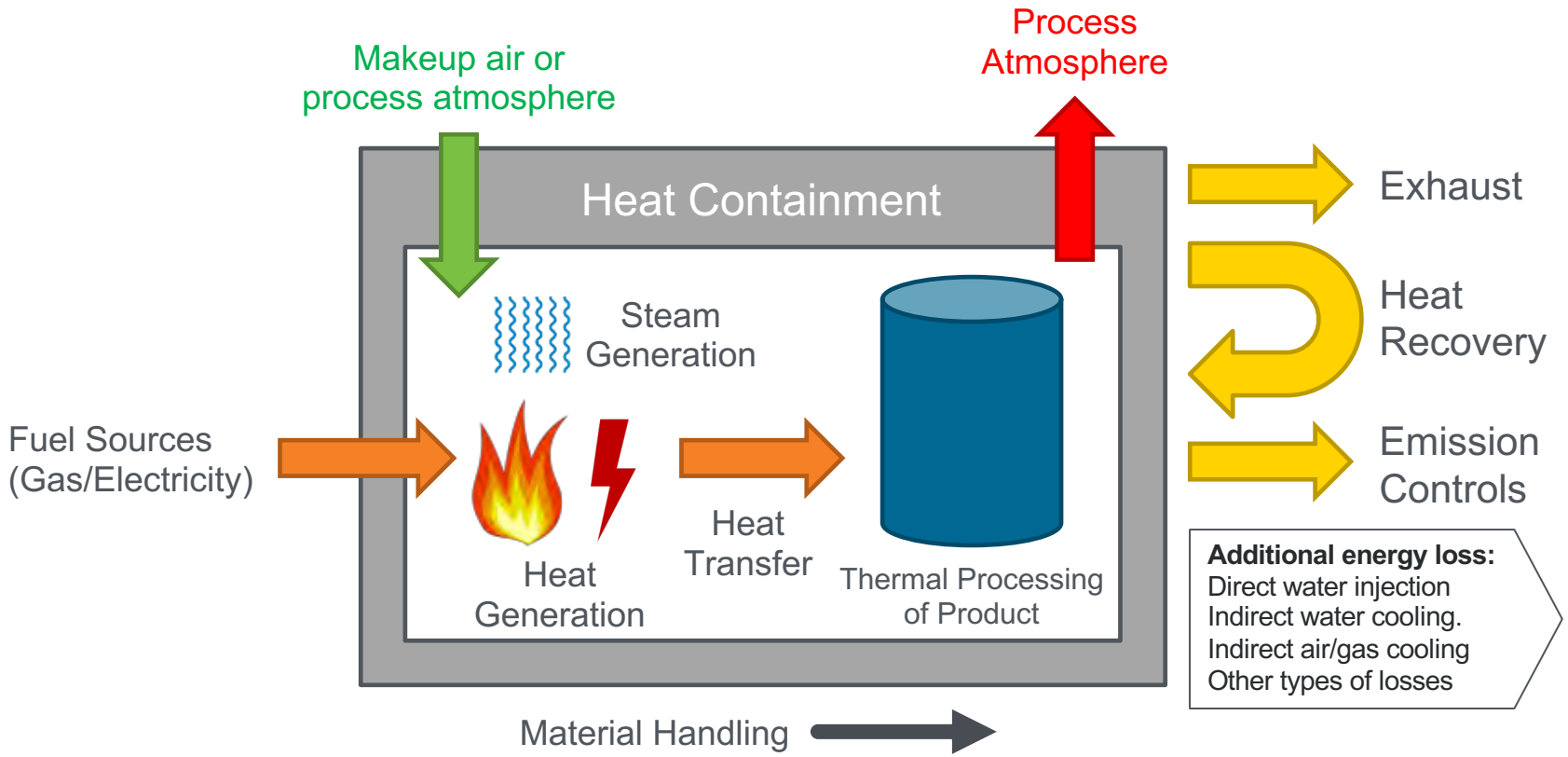
Energy Use as a Percentage of Total Energy End Use



Process Heating Systems



Process Heating System Components



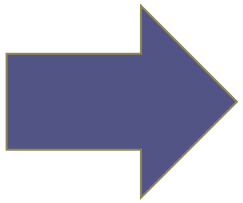
Crosscutting Enabling Technology

Sensors/ Process Controls	Advanced Materials	Design Tools/ Systems Integration

Process Heating Systems and Energy Supply Used by Industry

Energy Sources

- Fuels (gas, oil, coal etc.)
- Electricity
  - Resistance heating
  - Induction
  - Arc - Plasma
- Steam
- Hot fluids (oil, water etc.)



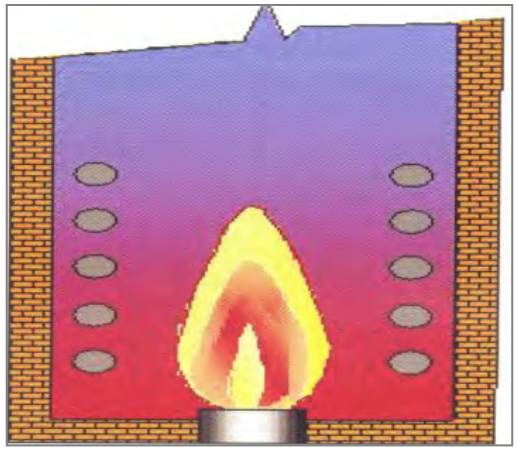
Thermal Processes used in Manufacturing

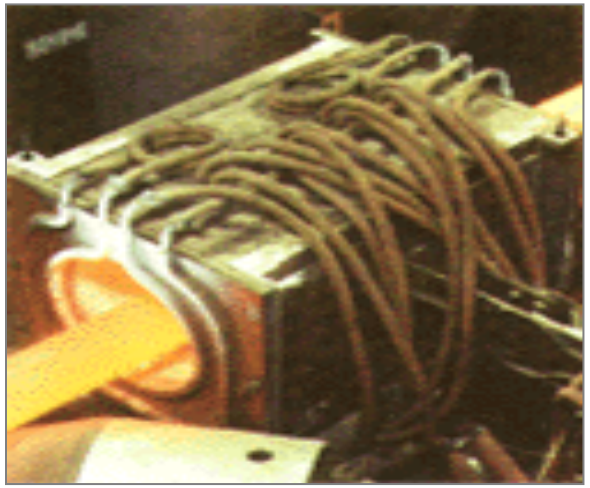
1. Steam Generation
2. Fluid Heating
3. Calcining
4. Drying
5. Heat Treating
6. Metal Heating
7. Metal and Non-metal Melting
8. Smelting, Agglomeration, etc.
9. Curing and Forming
10. Other Heating

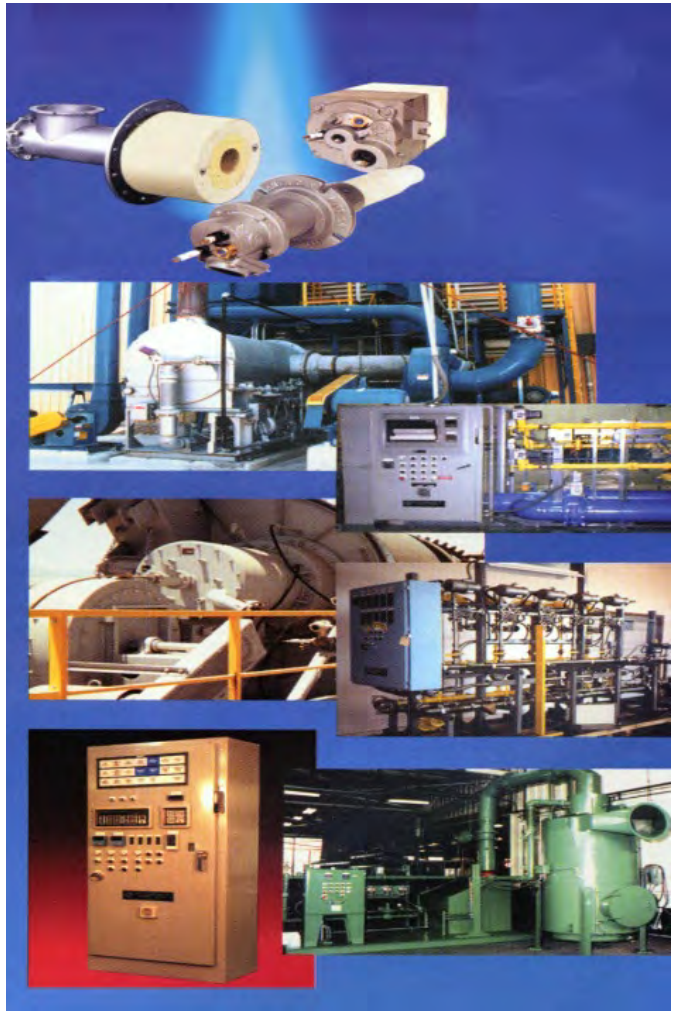
Outline

- What is Process Heating?
- Major Energy Use Systems
- Overview of Industrial Process Heating
- **Process Heating Systems**

Process Heating - Highlights of Equipment used by the Industry







Poll Question # 4

What type of thermal processes your facility hosts (select multiple):

A Metal or non-metal melting

B Thermal oxidation of VOCs, etc.

C Drying

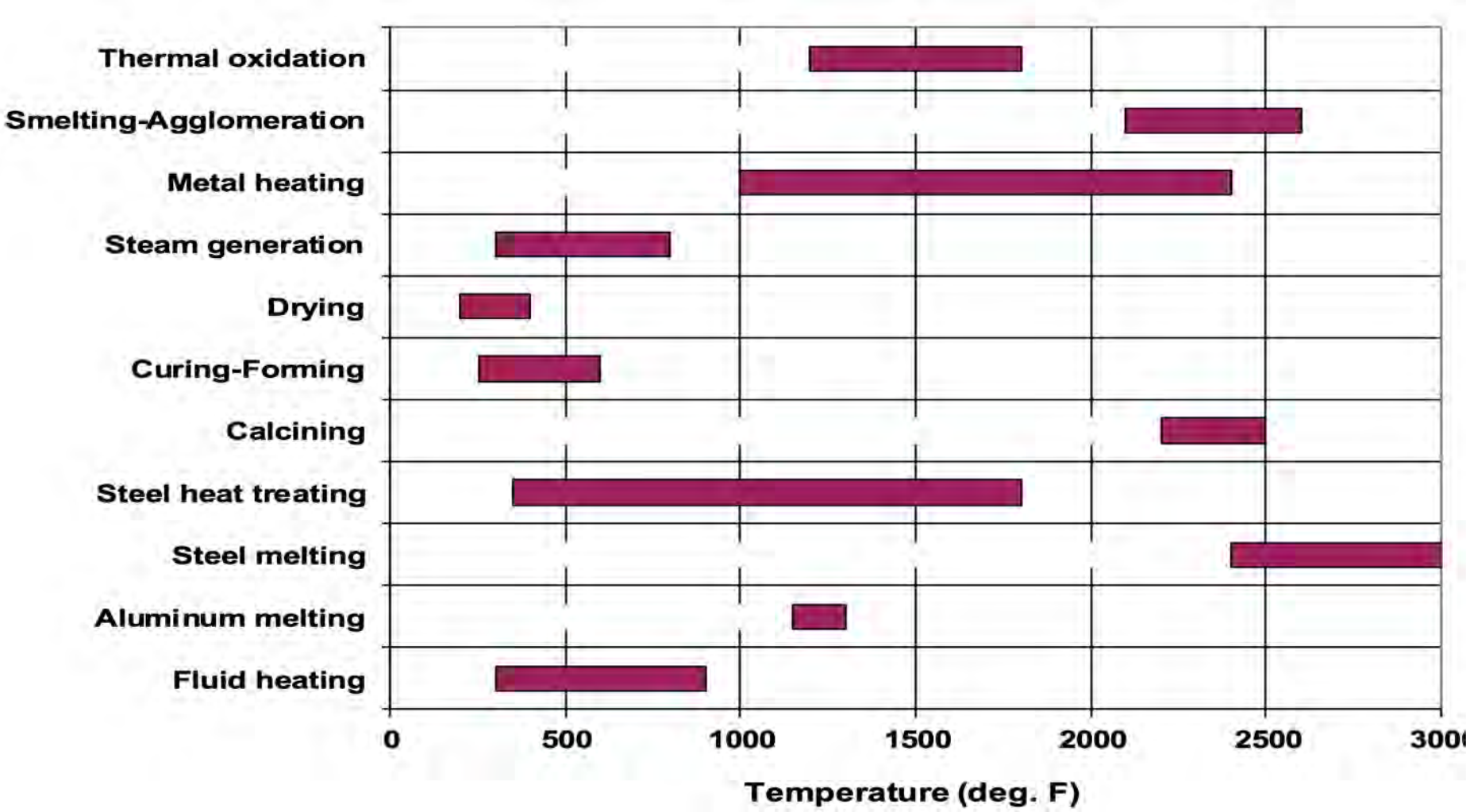
D Calcining

E Steam production

F Curing-forming, etc.

G Metal heat-treating

Temperature Range for Commonly Used Processes



Homework # 1 – Complete the Pre-Screening Form

Plant Info & Energy Sources

Plant - General Information

Company Name	
Plant Name	
Product	

Plant - Contact Information

Contact Name					
Contact Phone		Contact Email			
Facility Address					
State		Zip		Country	

Preferred Units? Imperial Cost Units Energy

	Energy Source	Type
#1		
#2		
#3		
#4		
#5		
#6		
#7		
#8		

Equipment Notes

Operating Condition Notes

Furnace Rated Capacity

Plant - General Information

Company Name	
Plant Name	

Furnace - Pre-Assessment

Furnace	
Furnace Description	
Data Collection	
Furnace Type	
Type of Operation	
Heat Cycle Time	hrs
Rated capacity used	%
Fuel Energy Source	
Electricity Energy Source	
Electricity used during collecti	kWh
Fuel Flow Rate	
Fuel Heating Value	
Fuel Energy Rate	MMBtu/hr
Heat Content of steam	Btu/lb
Steam Flow Rate	lb/hr
Data Collection time	hr
Operating Hours	hr

Electrical Auxiliary Equipment

Plant - General Information

Company Name	
Plant Name	
Furnace	

Furnace - Pre-Assessment (Auxiliary Equipment)

Electrical Equipment with known rated power & load

Equipment	Duty Cycle (%)	Total Connected Power (hp)	Rated Capacity (%)

& power factor

Equipment	Duty Cycle (%)	Supply Voltage (V)	Average Current (A)	Power Factor (%)

Please Submit Pre-Screening Forms by February 17th

ENERGY

Summary

- What is Process Heating?
- Major Energy Use Systems
- Overview of Industrial Process Heating
- Process Heating Systems

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Questions?

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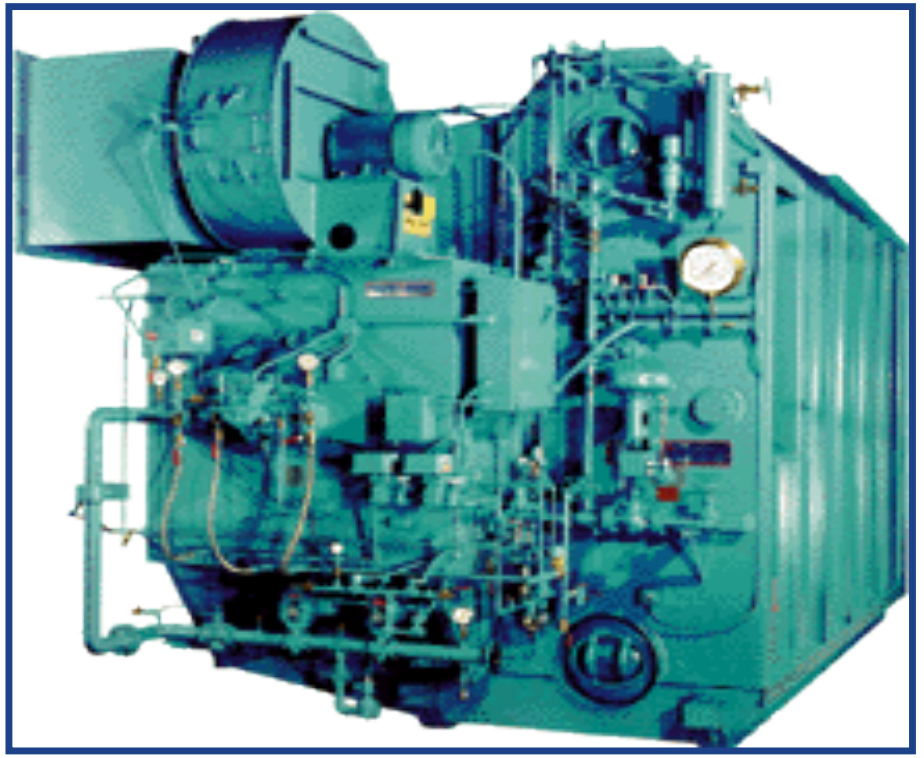
Steam Generation

- Water heating to produce steam at desired temperature & pressure:
  - Water Tube Boilers
  - Fire Tube Boilers
- Current level of efficiency – 60% to 80%
- Fuels used – Natural gas, by-product gas or liquids, fuel oil, coal
- Major industries using Steam Generation
  - Chemical, Food, Petroleum Refining, Pulp and Paper

Steam Generation – Commonly Used Boilers

Waste heat recovery boiler connected to a process heater or gas turbine for recovery of heat

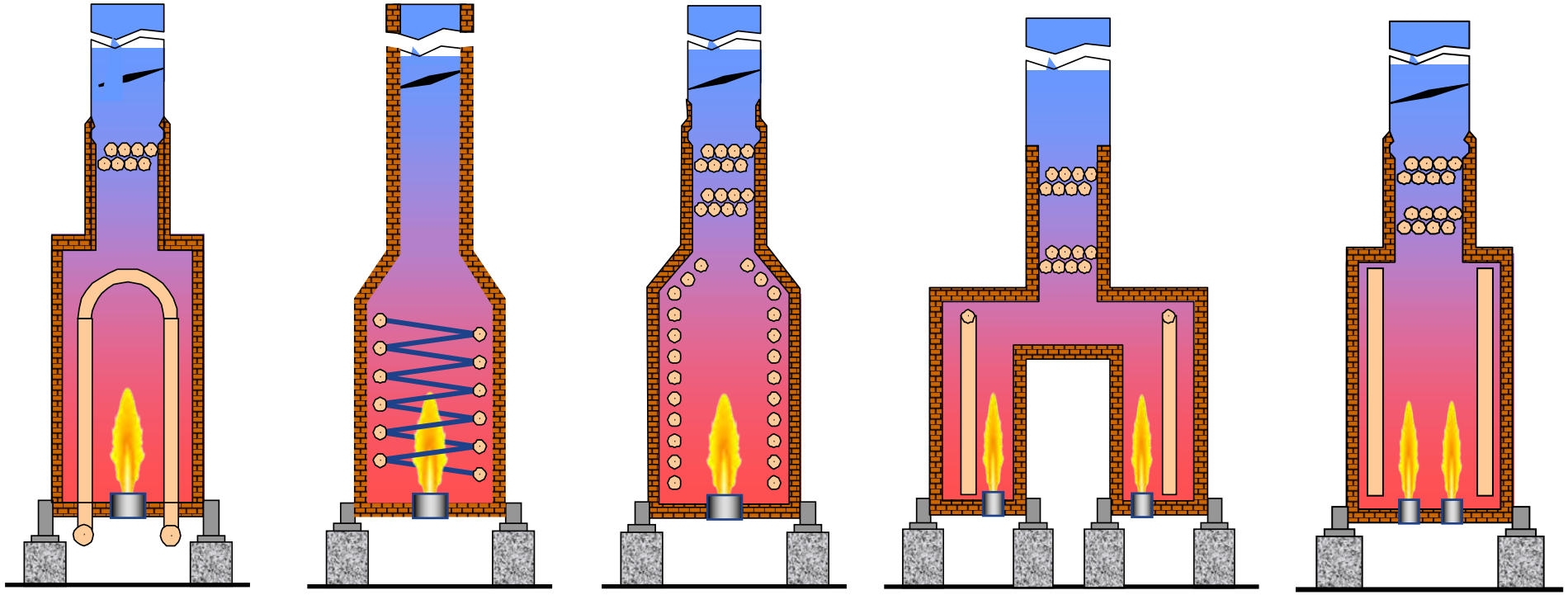


Fuel Fired Boiler for process steam generation

Fluid Heating

- Heating of liquids using fired or unfired heating systems for raising their temperature & promoting chemical reactions or phase changes.
  - Fuel fired heaters
  - Steam heated systems
- Current level of efficiency – 60% to 85%
- Fuels used – Natural gas, by-product gas or liquids
- Major industries using Fluid Heating
  - Chemical, Food, Petroleum Refining, Pulp and Paper, Metals

Commonly Used Direct Fired Furnace Configurations



Type A -
Box heater with arbor coil

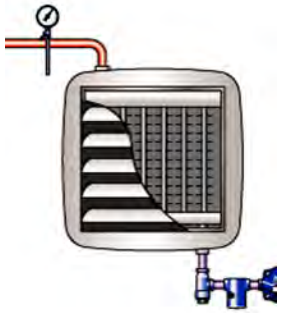
Type B -
Cylindrical heater with helical coil

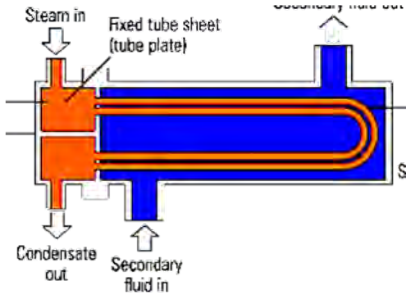
Type C -
Cabin heater with horizontal tube coil

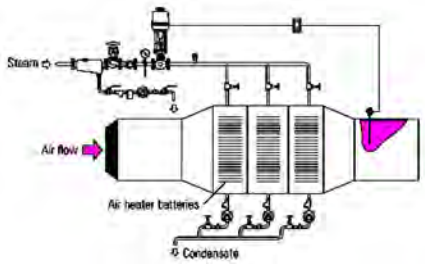
Type D -
Box heater with vertical tube coil

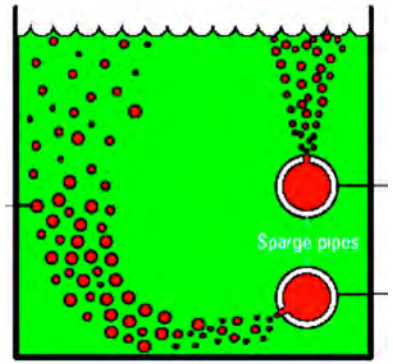
Type E -
Cylindrical heater with vertical coil

Other Type of Fluid Heating Systems









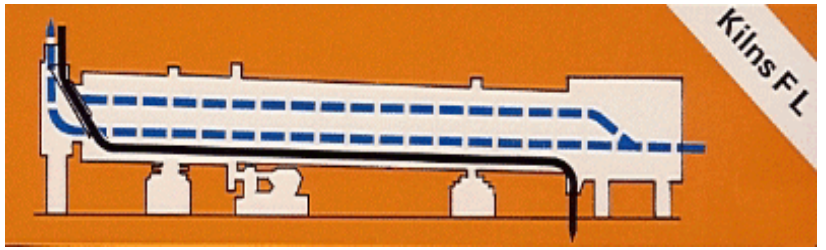
- Fired heaters for water, oil, or other liquid heating
- Air heaters used for drying and other applications
- Liquid or gas heating in heat exchangers using steam or waste heat (gases or liquids)
- Direct steam injection water heaters
- Direct contact water heaters using flue gases
- Immersion tubes

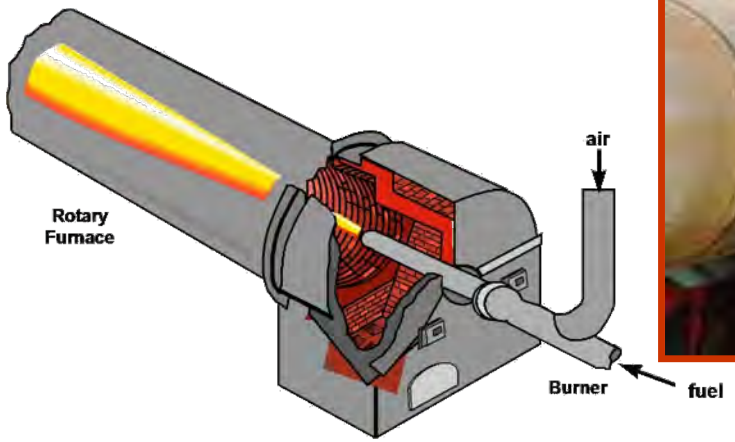
Calcining

- To heat material to high temperature, below melting or fusing temperature, causing loss of moisture, chemical reaction or oxidation:
  - Fuel fired rotary kilns
  - Vertical shaft calciners
  - Fluidized bed calciners
- Current level of efficiency – 40% to 70%
- Fuels used – Natural gas, by-product gas, liquids or solids, fuel oils or coal
- Method of Heating – Direct fired
- Major industries using calcining:
  - Aluminum, Steel, Pulp and Paper, Chemical

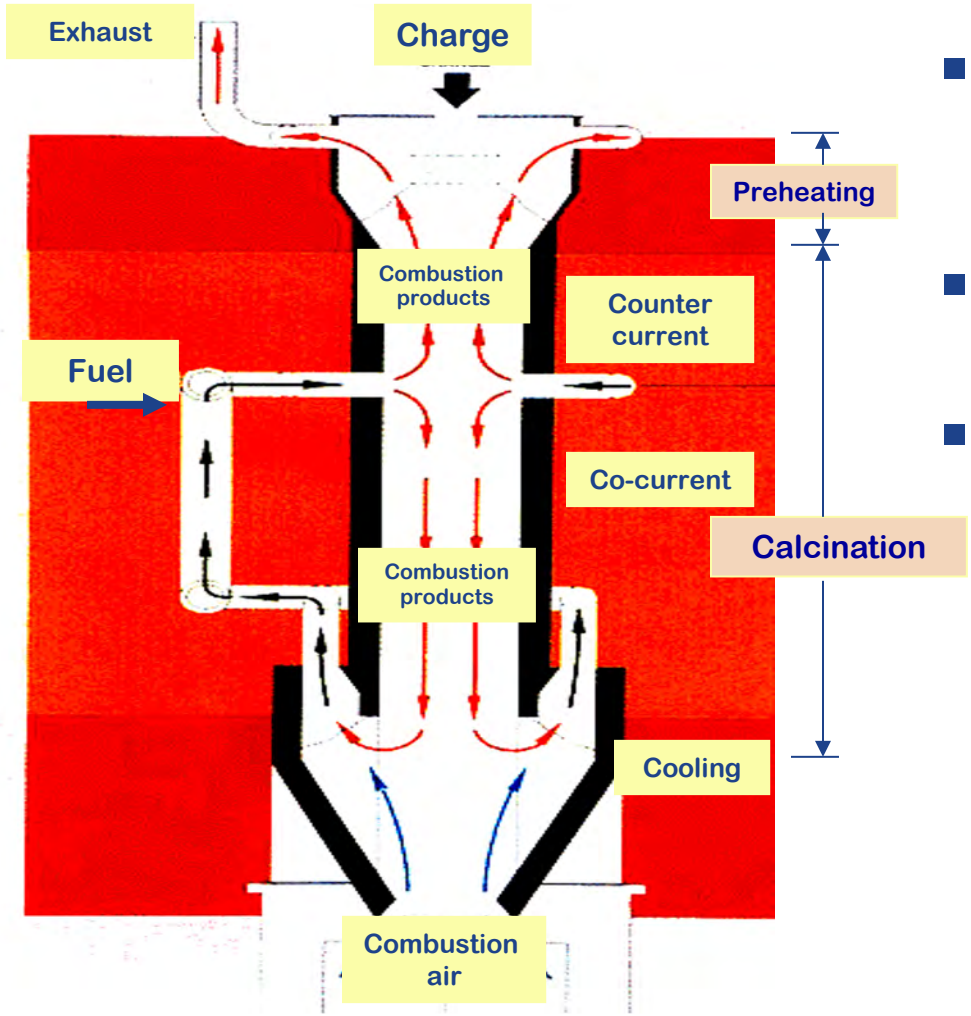
Calcining - Rotary Kilns

- Rotary Kilns
  - Used for drying & calcining raw material.
  - Material flow can be counter-current or co-current to heating gases.
  - Heating system uses a variety of fuels such as natural gas, heavy oil, coal, by-product fuels, tires, etc. System includes exhaust gas clean-up step for emission control.
- Operating temperature
  - 2200°F to 2500°F
- Average efficiency
  - 30% to 50%



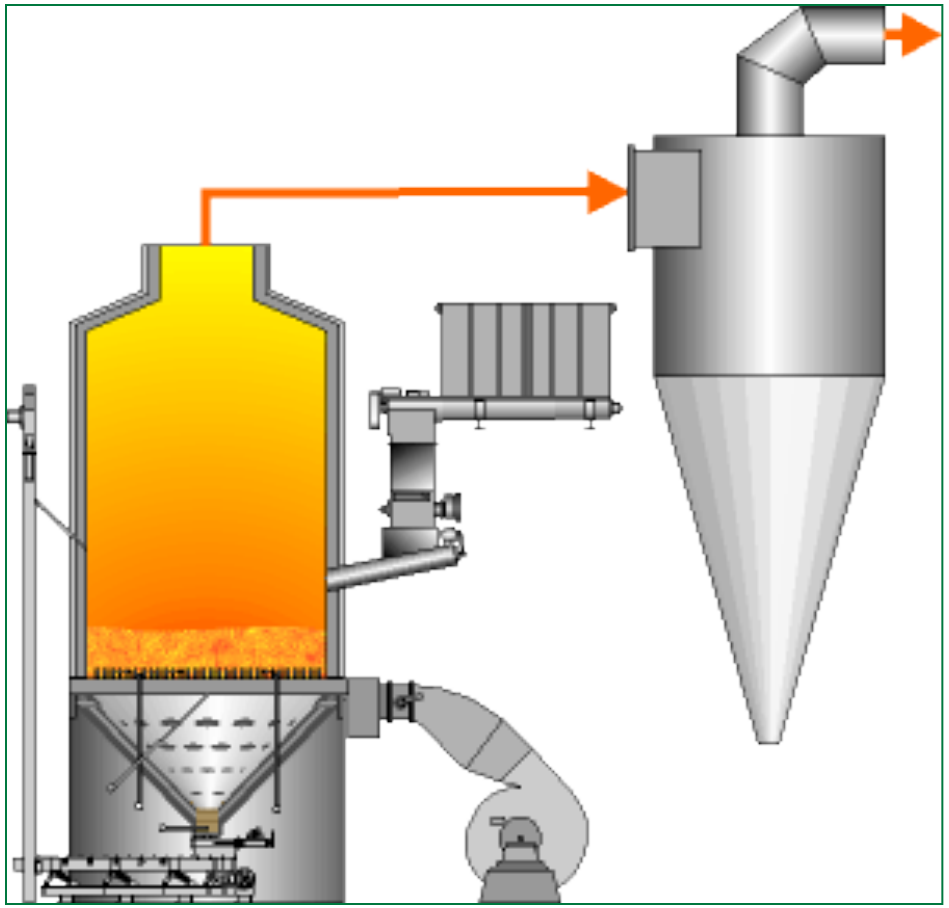


Calcining – Vertical Shaft Calciner

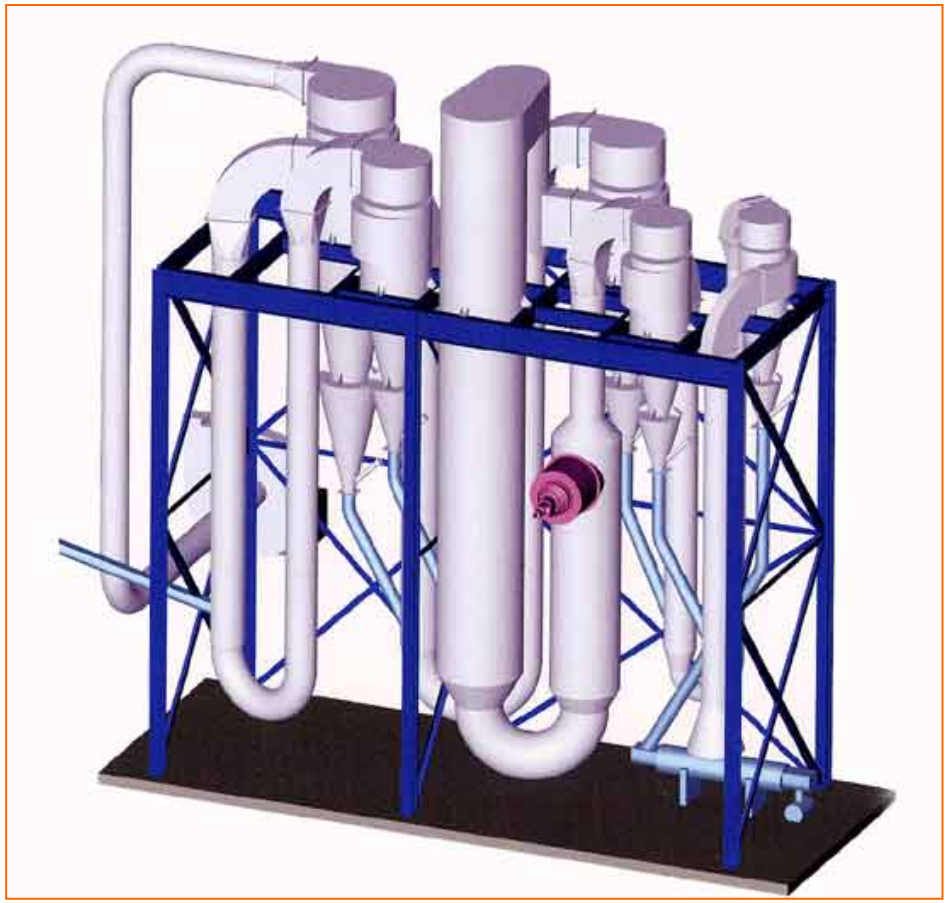


- Upper short counter-current zone where most of heat is distributed resulting in calcination of material.
- Counter current flow results in efficient use of heat.
- Lower, longer co-current zone where lesser amount of heat is distributed, resulting in less intensive reaction with temperatures controlled to complete calcination of larger, unfinished pieces, but avoiding over-burning of smaller pieces.

Fluidized Bed and Flash Calciners



Fluidized Bed Calciner



Flash Calciner

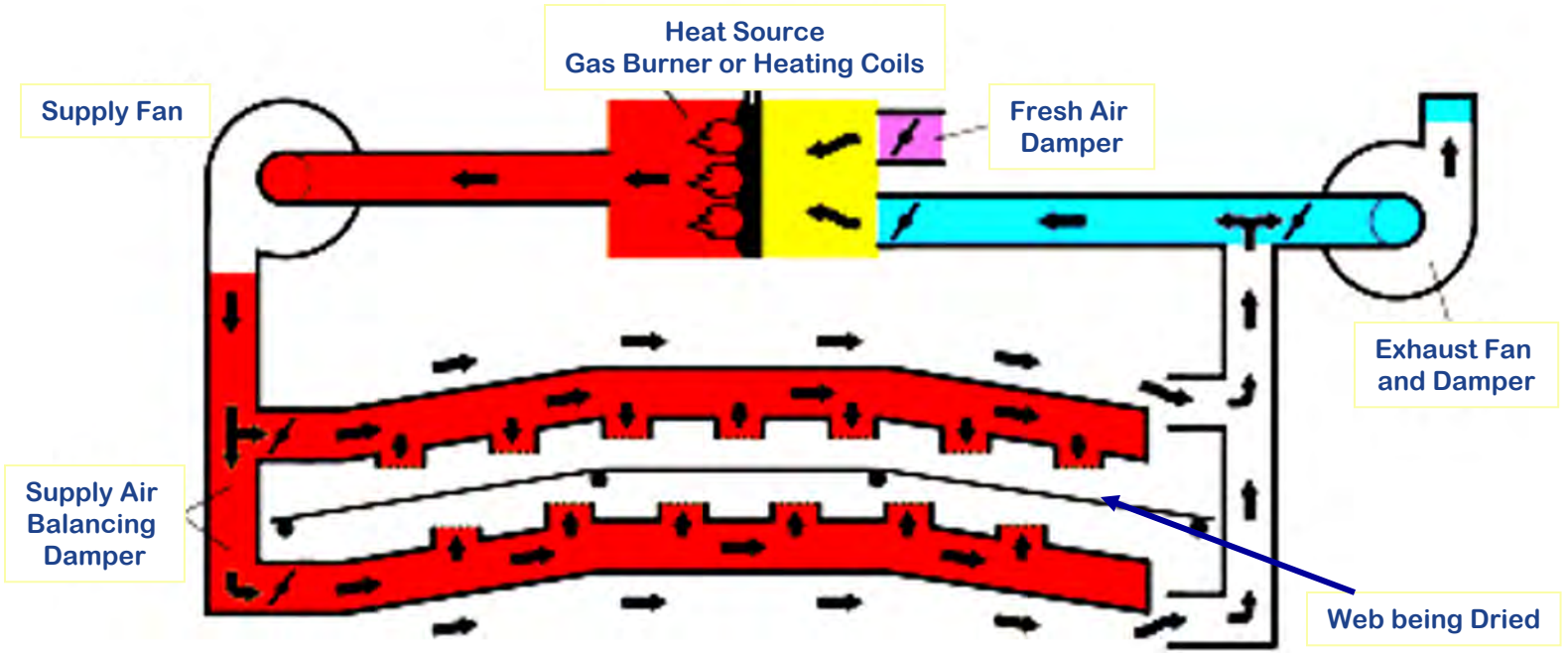
Drying

- To remove moisture or liquid from materials:
  - Fuel fired rotary kilns
  - Fluidized bed dryers
  - Steam heated dryer drums
  - Direct air impingement dryers
  - Infrared dryers
- Current level of efficiency – 60% to 90%
- Fuels used – Natural gas, by-product gas, liquids or solids, fuel oils or coal
- Major industries using Drying
  - Mining, chemical, pulp and paper, metal finishing, food industry

Drying - Drum Dryer

Steam-heated drum dryer for paper drying

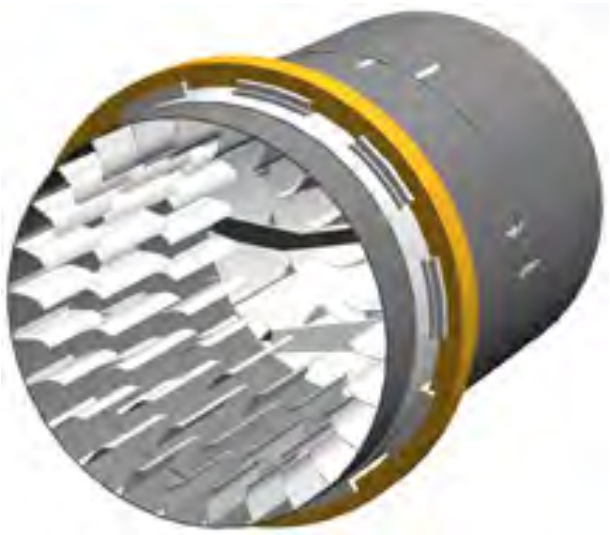
Drying – Jet Impingement Drying



Floatation Drying Ovens with High Convection Jet Impingement Heating and Drying

Drying – Rotary Dryer

Photo courtesy of Drytech Engineering.

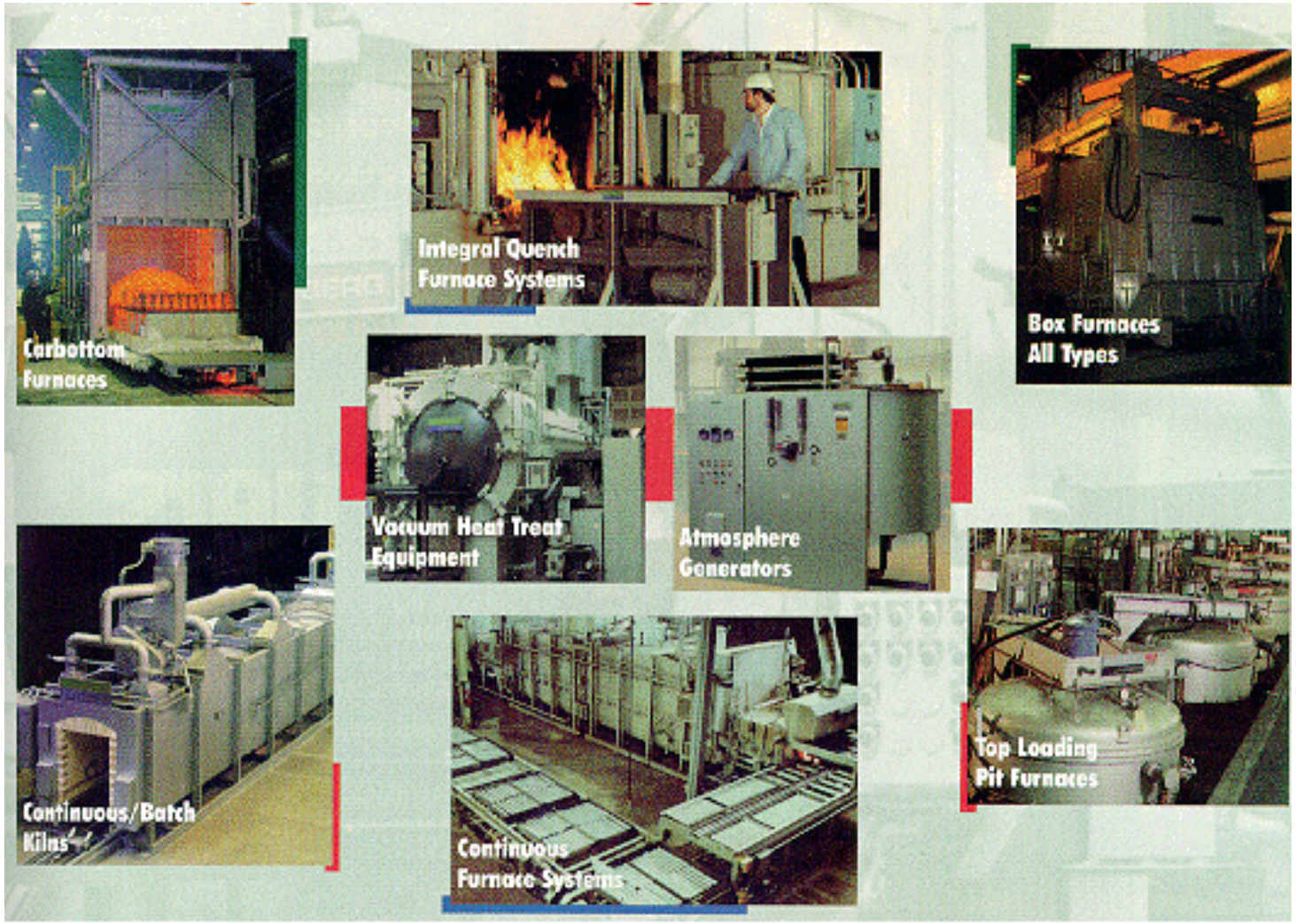


Spiral flights quickly move material out of feed section. Lifting flights elevate material to produce a curtain. Drum is supported by a riding ring.

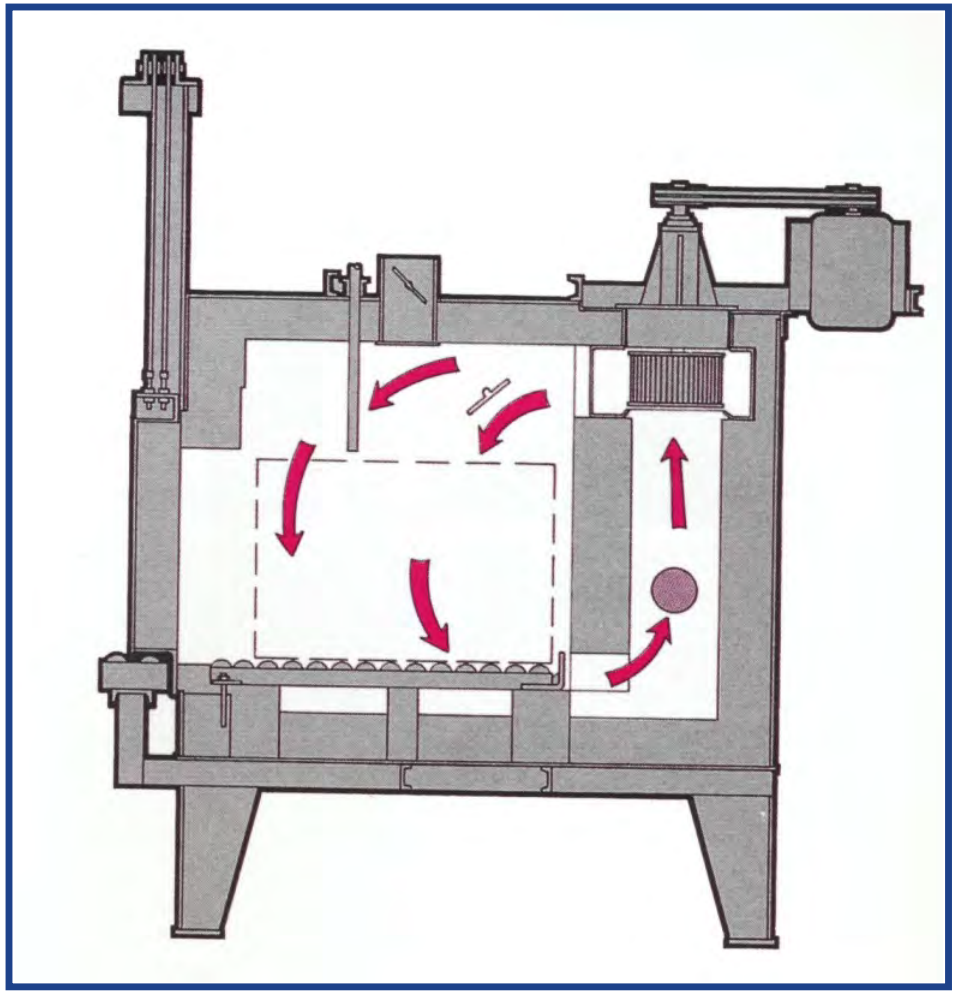
Heat Treating

- To produce desired characteristics, such as hardness or softness in a material (metal) by controlled heating & cooling:
  - Indirectly heated furnaces (radiant tubes, muffle etc.)
  - Various configurations
  - Direct fired furnaces
  - Vacuum furnaces
  - Induction or other type of “spot” heating systems
- Current level of efficiency – 30% to 50%
- Method of heating – Direct or indirect heating, sometimes using prepared atmosphere
- Energy Source – Natural gas & electricity
- Major industries using Heat Treating
  - Metals (Ferrous and non-ferrous)

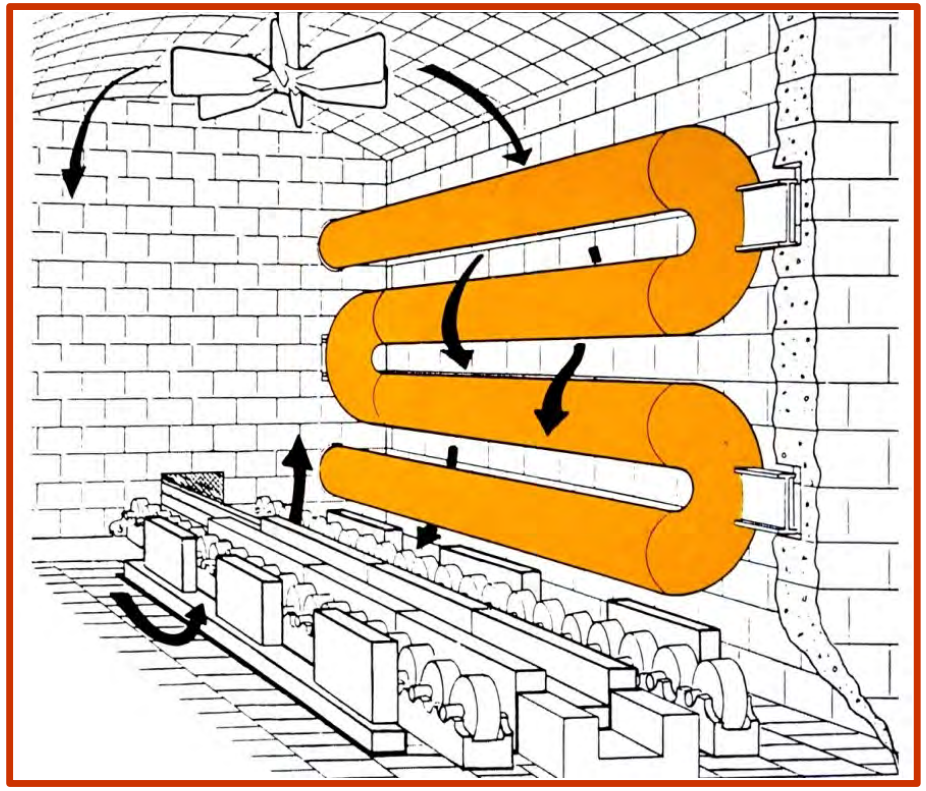
Process Heating Equipment Used by The Heat-Treating Industry



Direct Fired Tempering and Homogenizing Furnaces



Metal Heat Treating - Indirectly heated heat-treating furnaces

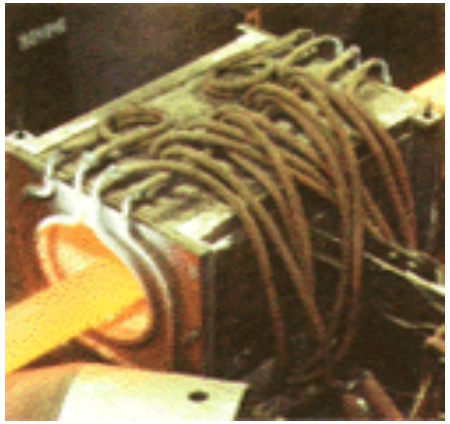


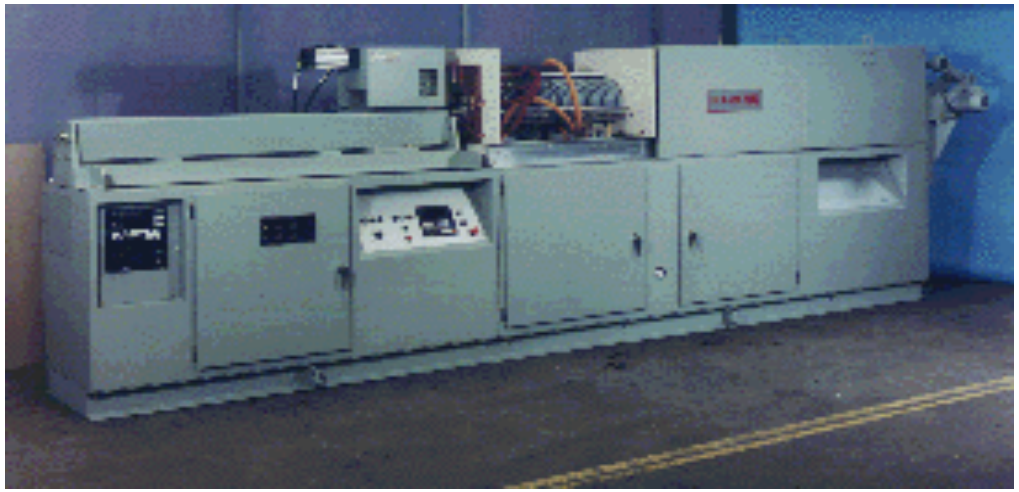
Indirect heating using radiant tubes with a convection fan in a heat-treating furnace

Large pit furnace – direct fired with metal retort to isolate load from flue products

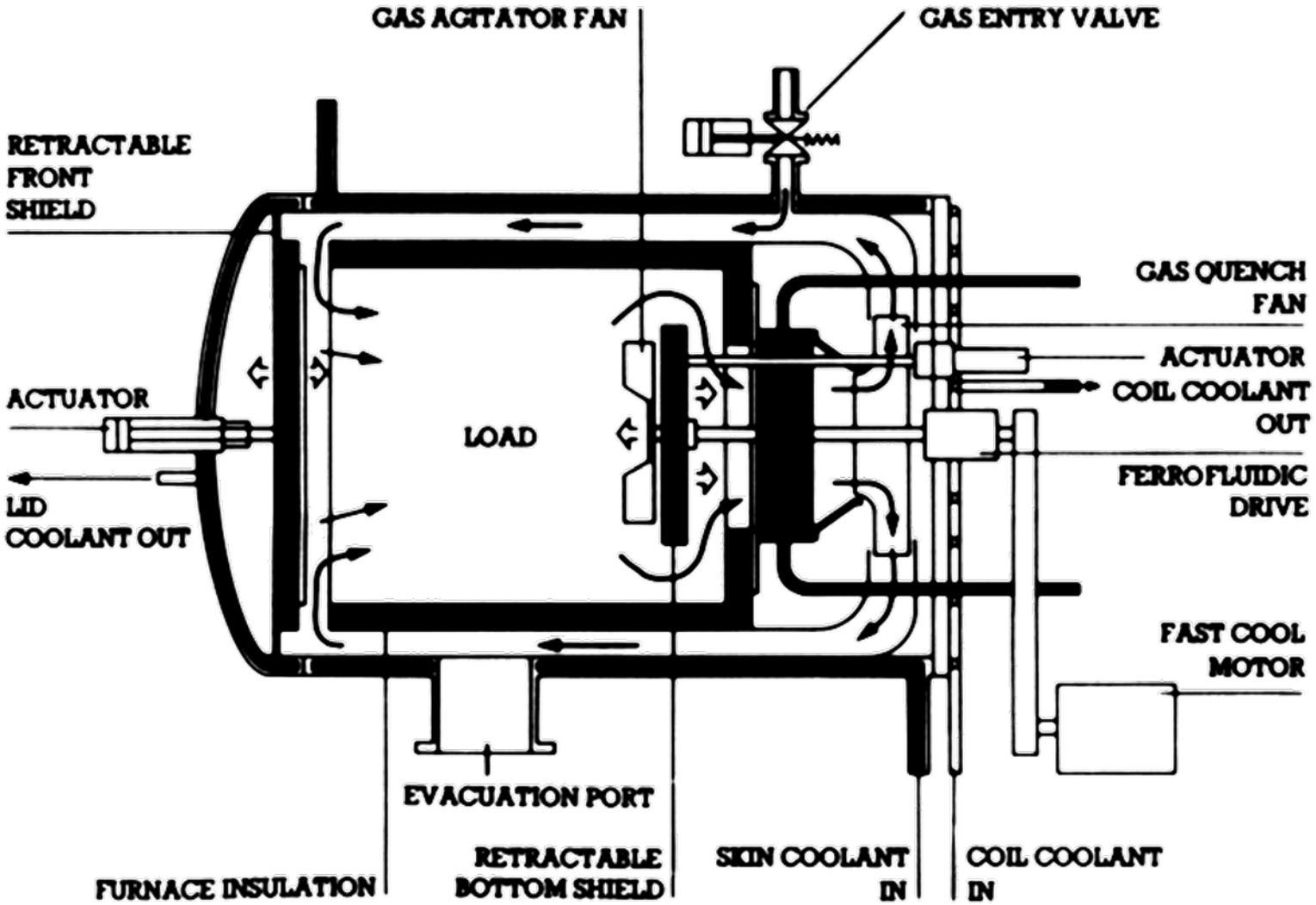
Courtesy: Surface Combustion

Induction Equipment for Metal Heat Treating and Heating

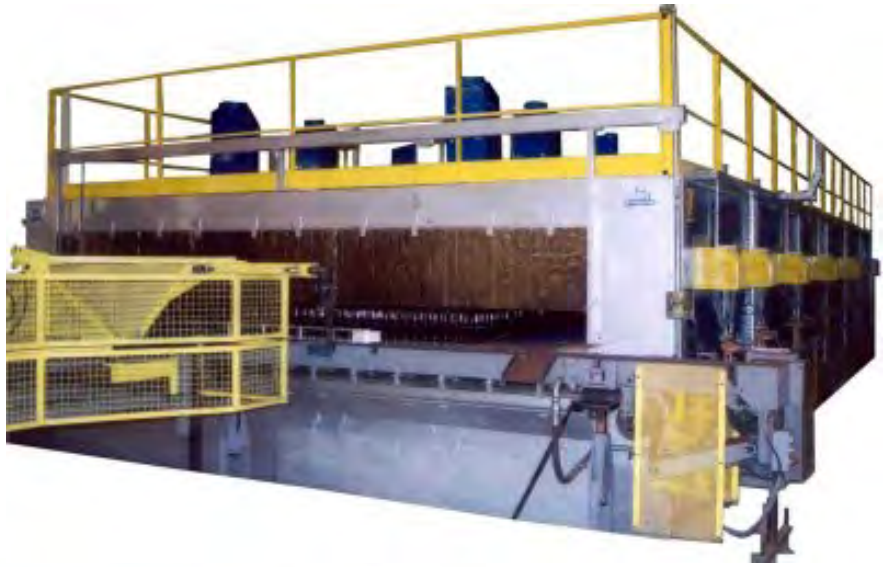




Horizontal Vacuum Furnace



Glass Annealing Systems



Metal Heating

- To raise temperature of metal without melting, fusing or changing chemical properties:
  - Direct fired furnaces
    - Various configurations
  - Induction heating systems
- Current level of efficiency – 40% to 60%
- Energy Source – Natural gas and electricity
- Major industries using - Metal Heating
  - Steel, aluminum, other non-ferrous metals

Electrically-Heated Furnace

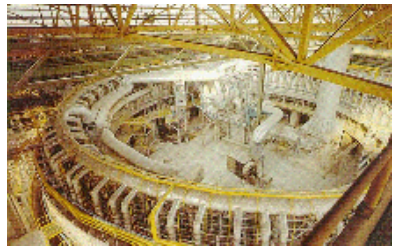
Notice:
- **Electric heating element connections**
- **Lack of burners, vents, air-gas piping or flue gas vents or ducts**

Reheating Furnaces

- Walking Beam - Hearth
- Pusher
- Roller Hearth
- Rotary

Slab Reheating Furnace

Roller Hearth



Rotary Hearth

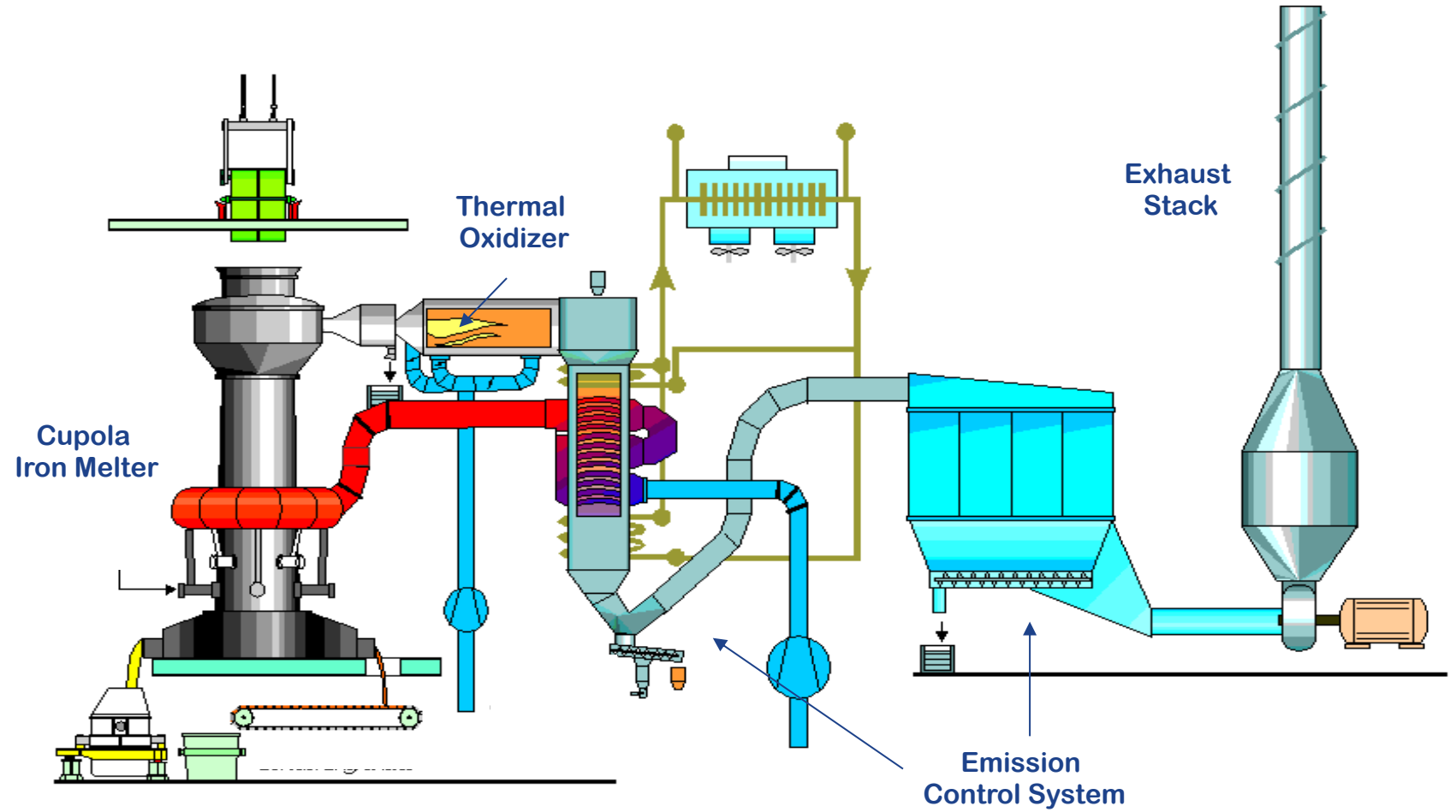
Walking Beam
Walking Hearth

Pusher Furnace

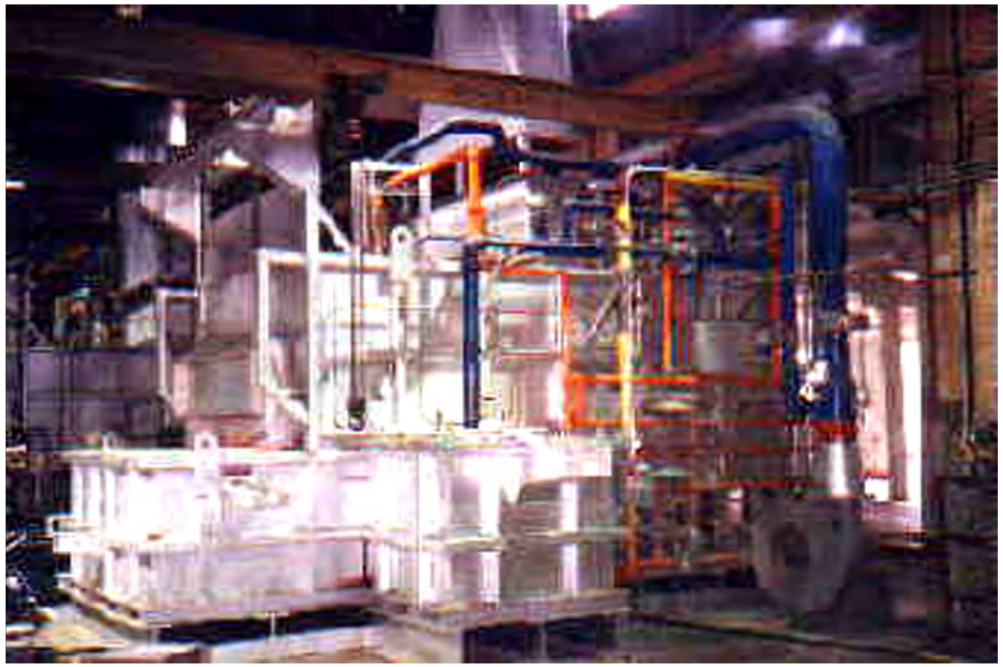
Metal and Non-metal Melting

- To raise temperature of metal or non-metal to (or above) its melting temperature.
  - Direct fired furnaces
    - Various configurations
  - Induction heating systems
  - Electric arc furnaces
- Current level of efficiency – 30% to 60%
- Energy Source – Natural gas, coke and electricity
- Major Applications
- Metal Melting: Iron and steel, aluminum, other metals
- Non-Metal Melting: Glass

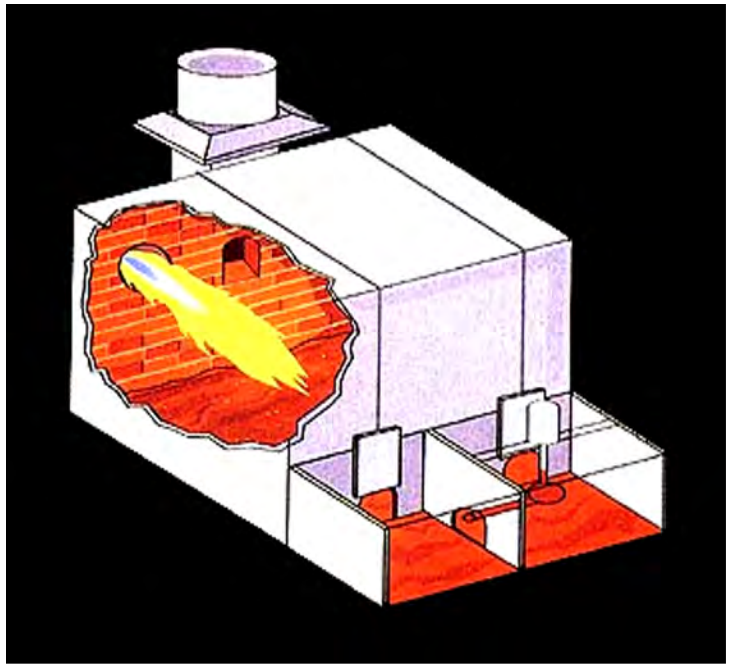
Cupola Furnaces for Iron Melting



Metal Melting - Fuel Fired furnace for Aluminum Melting



Conventional Reverberatory Furnace Used for Aluminum Melting. Usually fuel (natural gas or fuel oil) fired with a holding zone



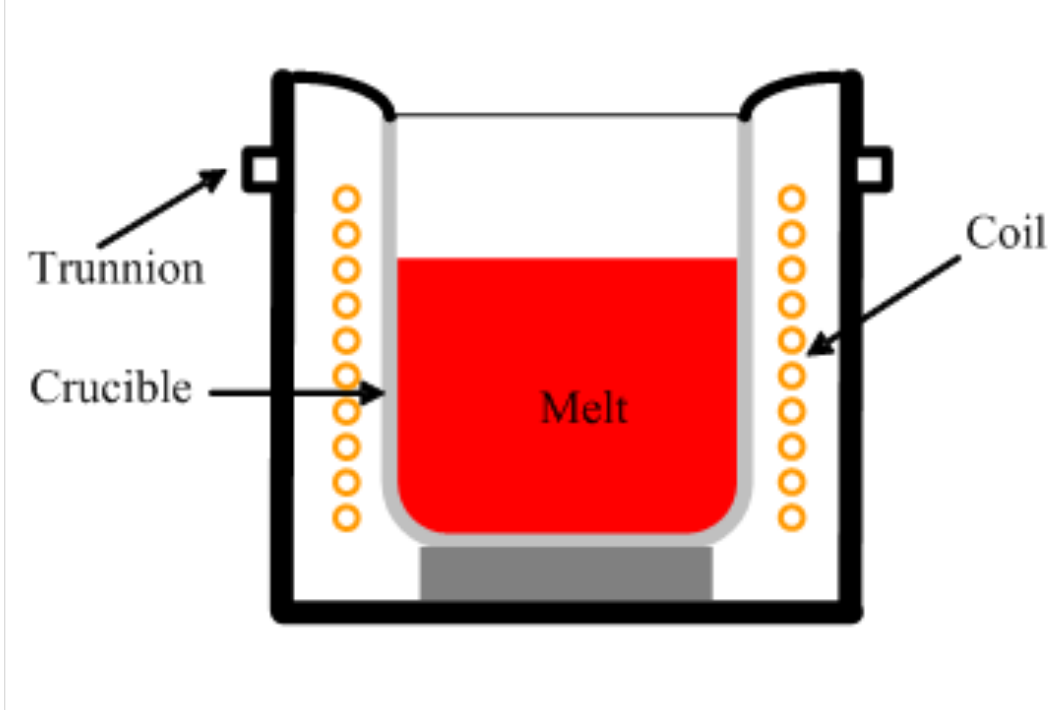
Typical burner firing for Reverberatory Furnace

Types of Induction Melting Furnaces

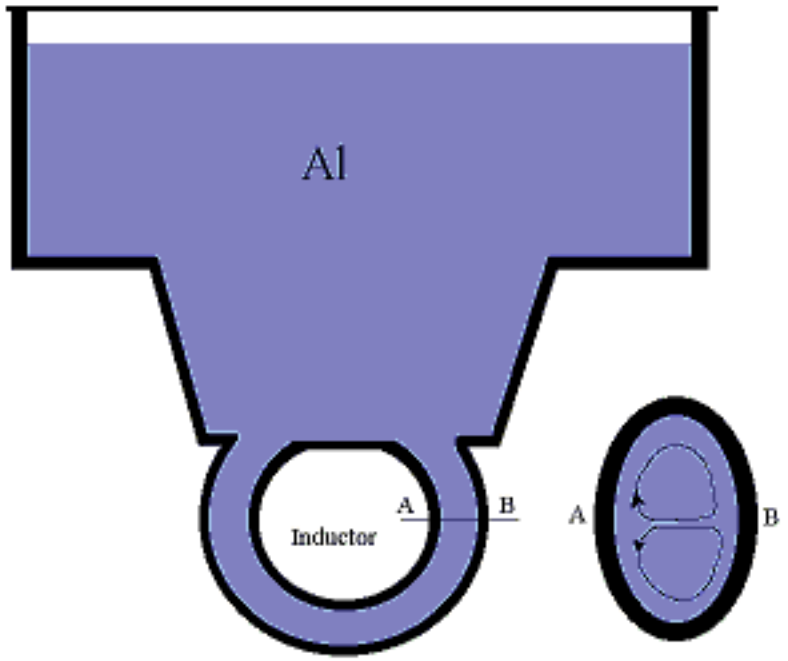
2 most common induction melting furnace designs are coreless & channel furnaces:

- **Coreless melting furnaces**
  - Use a refractory envelope to contain metal, & surround that by coil.
  - Charge acts as single secondary turn, thereby producing heat through eddy current flow when power is applied to multi-turn primary coil.
  - When metal melts, these electromagnetic forces also produce a stirring action.
  - Mixing & melting rates can be controlled by carefully selecting frequency & power.
- **Induction channel furnaces**
  - Use an inductor, comprised of water-cooled coil as energy source.
  - Channel is formed in refractory through coil & forms a continuous loop with metal in main part of furnace.
  - Hot metal in channel circulates into main body of metal in furnace envelope & is replaced by colder metal.
  - Unlike coreless induction furnace, a source of primary molten metal is required for startup of channel furnace.
  - These furnaces do have lower surface turbulence within main metal bath.

Metal Melting - Induction Melting Furnaces

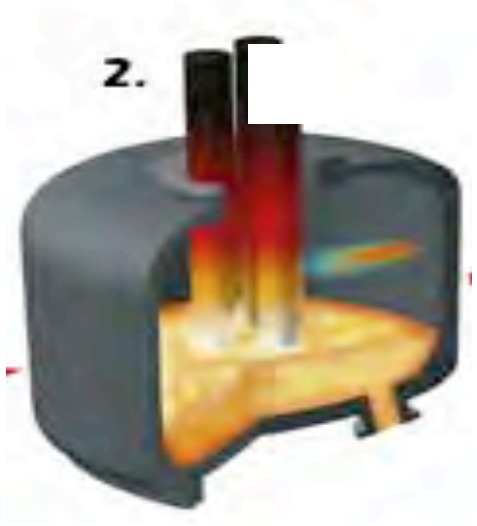


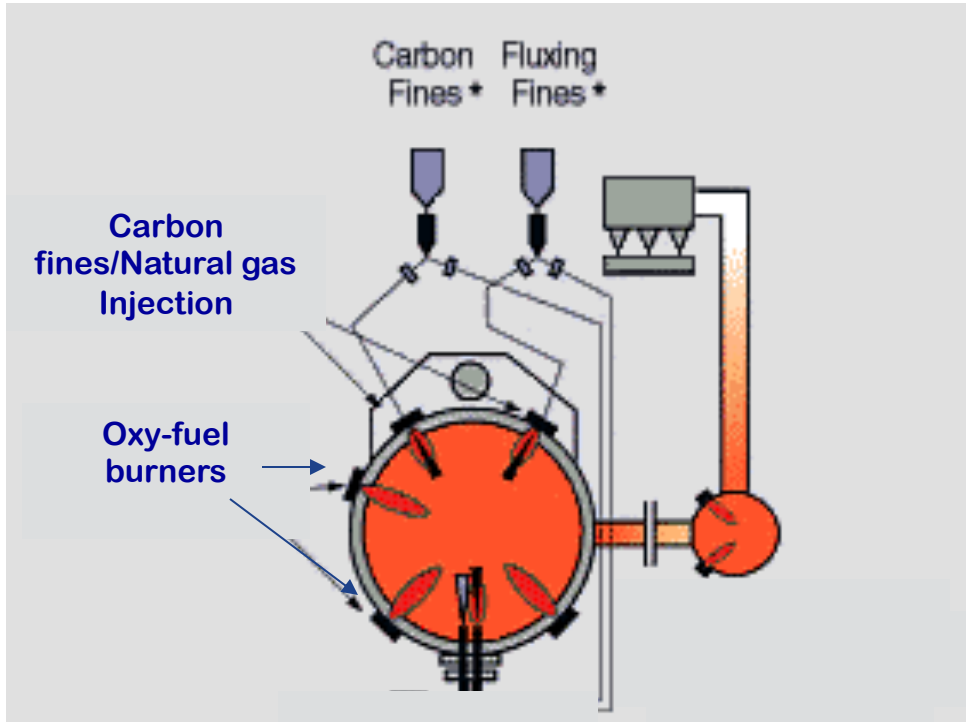
Coreless Induction Melter



Channel Induction Melter

Metal Melting - Electric Arc Furnace





Electric arc melting furnace with oxy-fuel burners and carbon injection to reduce electricity usage

Glass Melting Furnaces

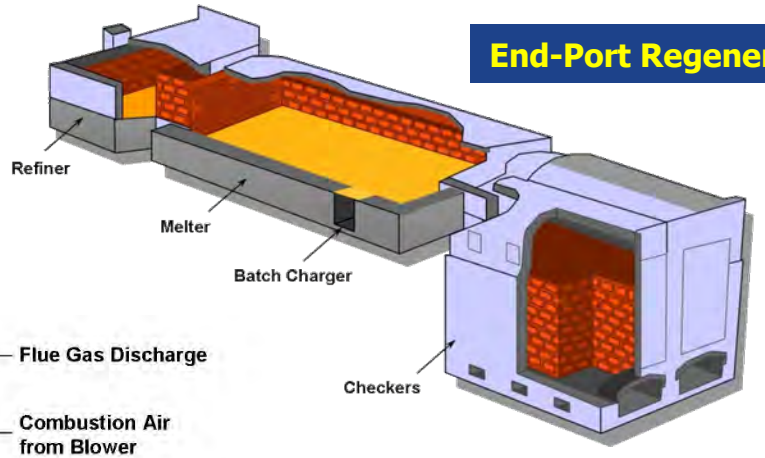
Oxy-Fuel Fired Melter

Recuperative Gas Fired Melter

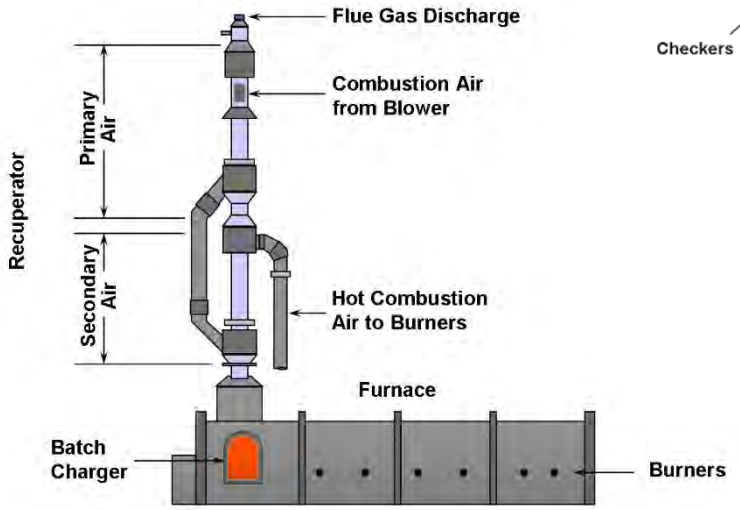
Regenerative Gas Fired Melter

Electric Melting Furnace

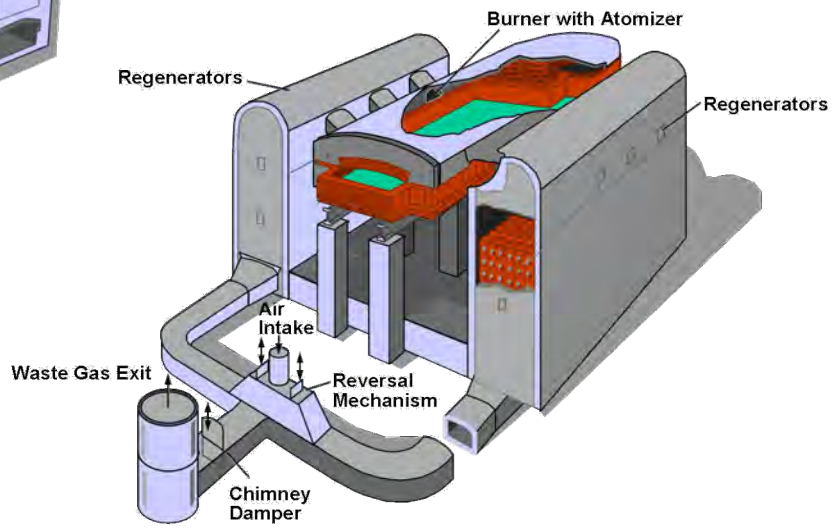
Glass Melting Furnaces



End-Port Regenerative Gas Fired Melter



Regenerative Gas Fired Melter

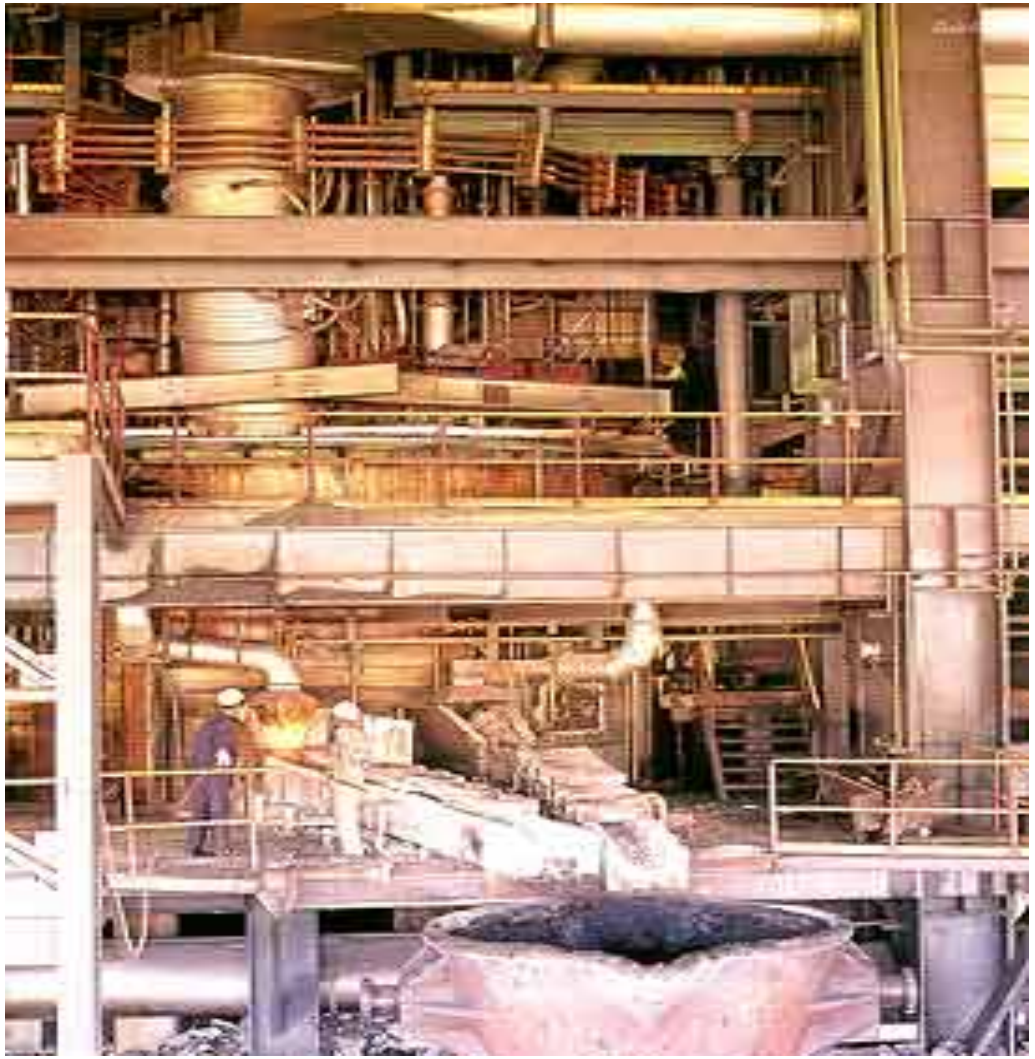


Side-Port Regenerative Gas Fired Melter

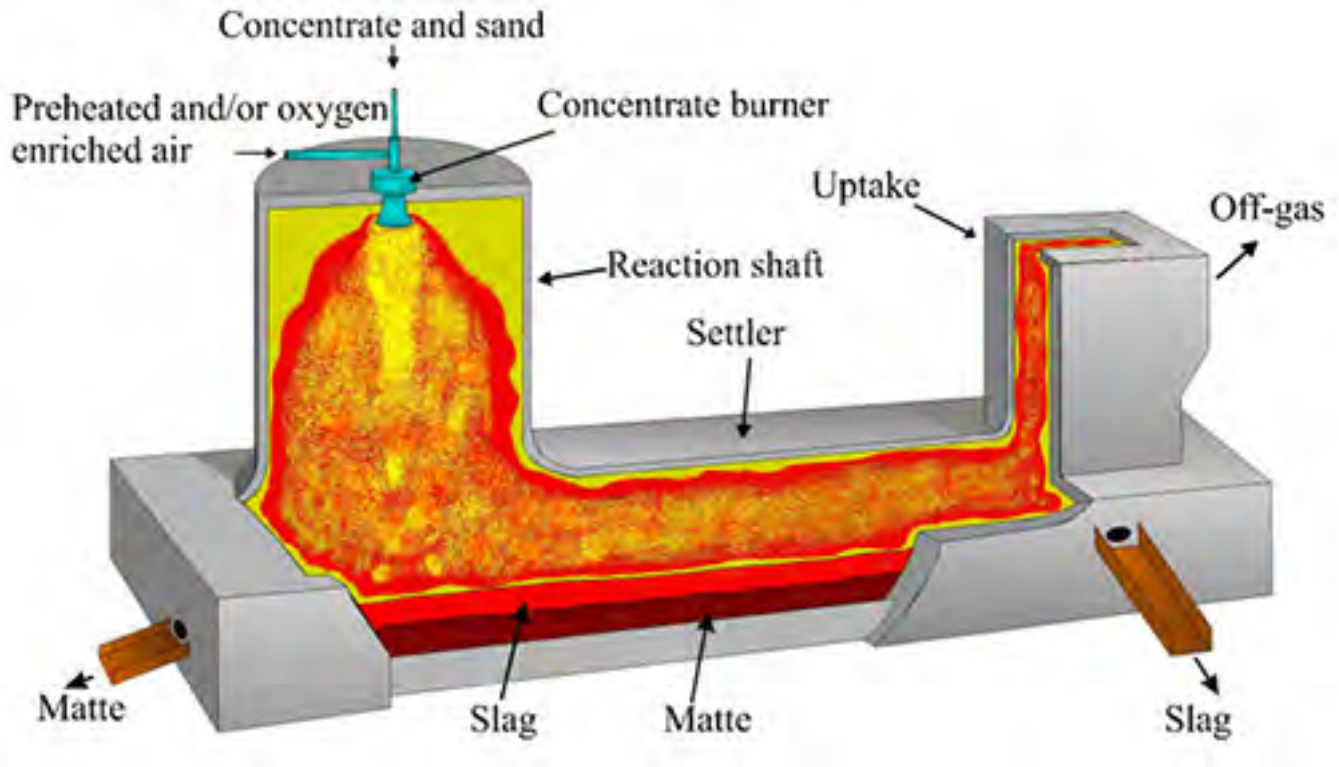
Smelting and Agglomeration

- To fuse or melt materials to separate their metallic or non-metallic constituents (as in ore reduction).
  - Direct fired furnaces
    - Various configurations
- Current level of efficiency – 30% to 50%
- Energy Source – Natural gas, coke or by-product fuels
- Major industries using – Smelting and Agglomeration
  - Iron and steel, aluminum, copper, mining

Smelting and Agglomeration
Flash Smelting of Copper



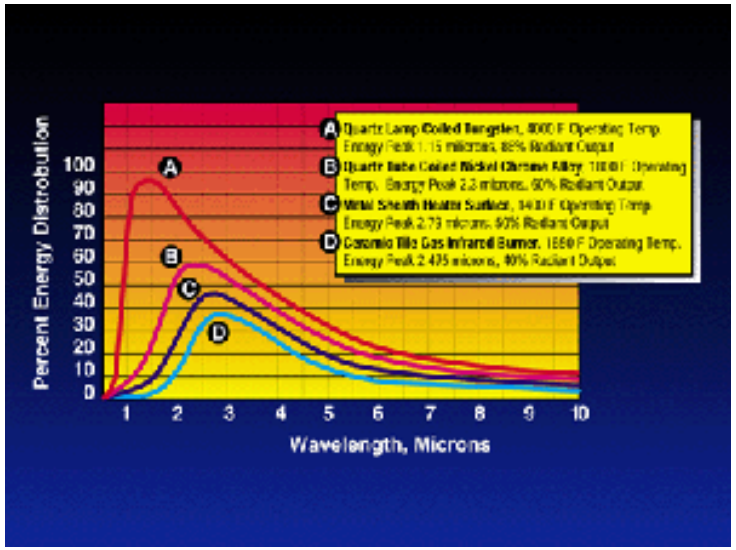
Smelting and Agglomeration - Conventional Smelting Furnace (Copper smelting)

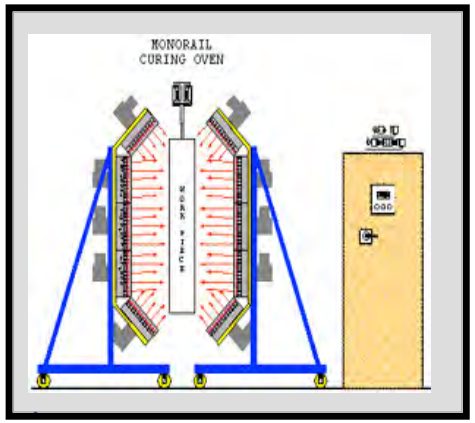


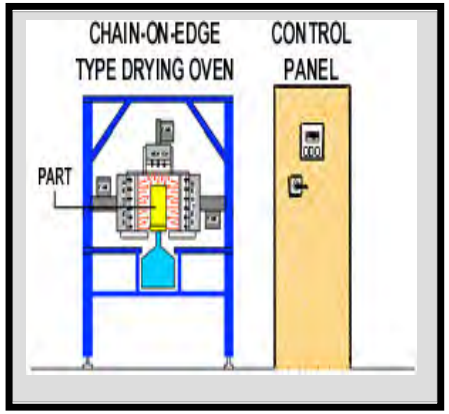
Curing and Forming

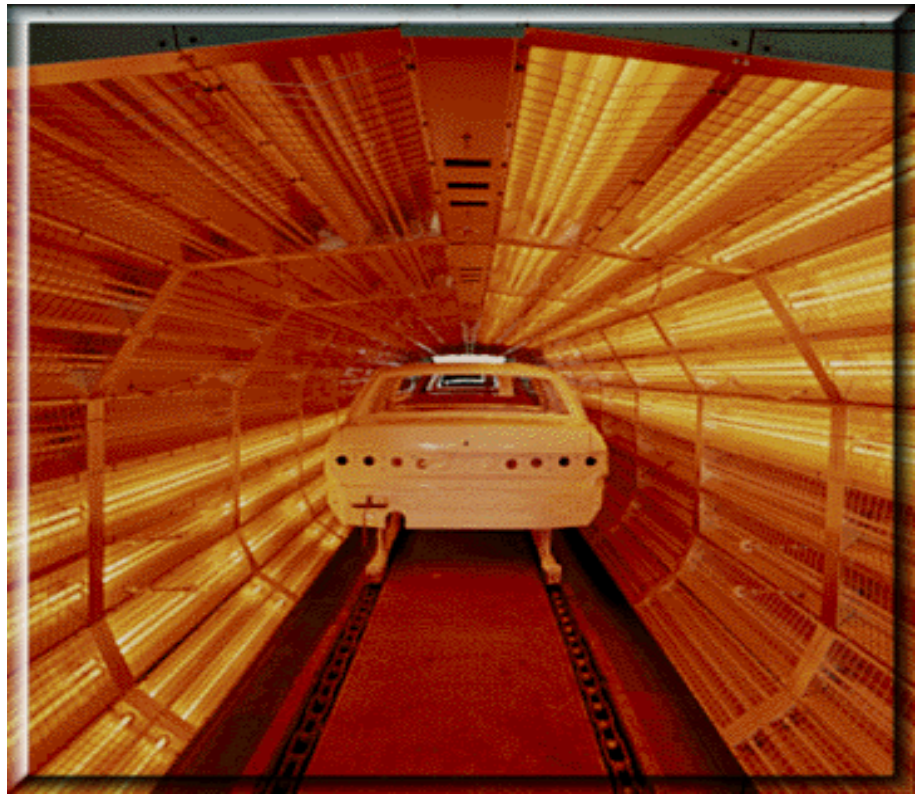
- To heat materials (commonly organics) to promote chemical change, to bond, fuse, to change shape, etc. without melting.
  - Direct fired ovens
    - Various configurations
  - Infra-red heating systems (gas or electric)
  - Hot liquid or steam heated systems
- Current level of efficiency – 50% to 70%
- Energy Source – Natural gas and electricity
- Major industries using – Curing and Forming
  - Chemical (Plastic, polymers, paints etc.)
  - Iron and steel, aluminum coating and lamination

Curing and Forming - Infrared heating









Curing and Forming - Convection Ovens

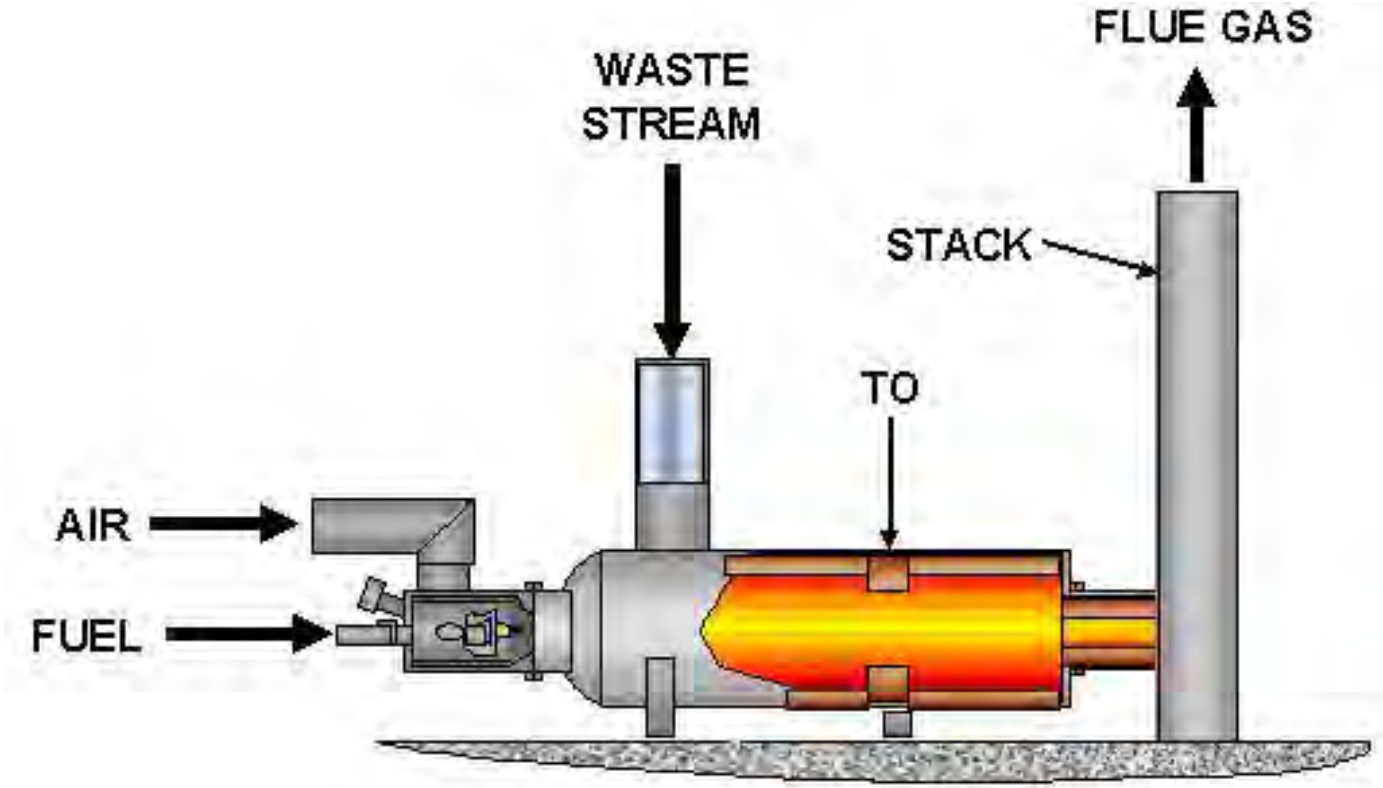
Conveyor Type Drying Ovens with High Convection Recirculating Gases

Coil Coating – Drying Ovens with High Convection Recirculating Gases

Other Heating

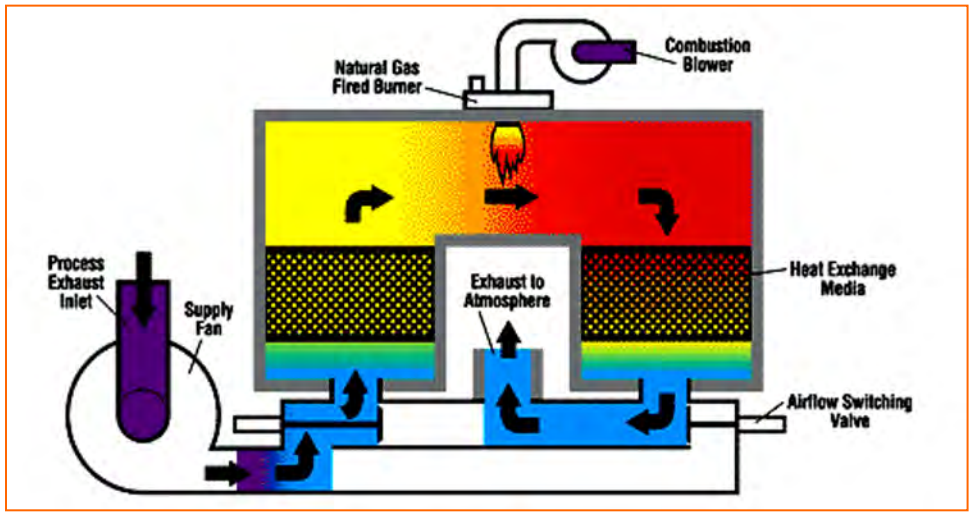
- To heat material or equipment (i.e., Thermal Oxidizers, Ladle Heating, Tundish Heating, etc.)
  - Direct fired ovens
    - Various configurations
  - Infra-red heating systems (gas or electric)
  - Hot liquid or steam heated systems
- Current level of efficiency – 50% to 70%
- Energy Source – Natural gas, electricity or other
- Major industries using Other Heating
  - Various

Thermal Oxidizers

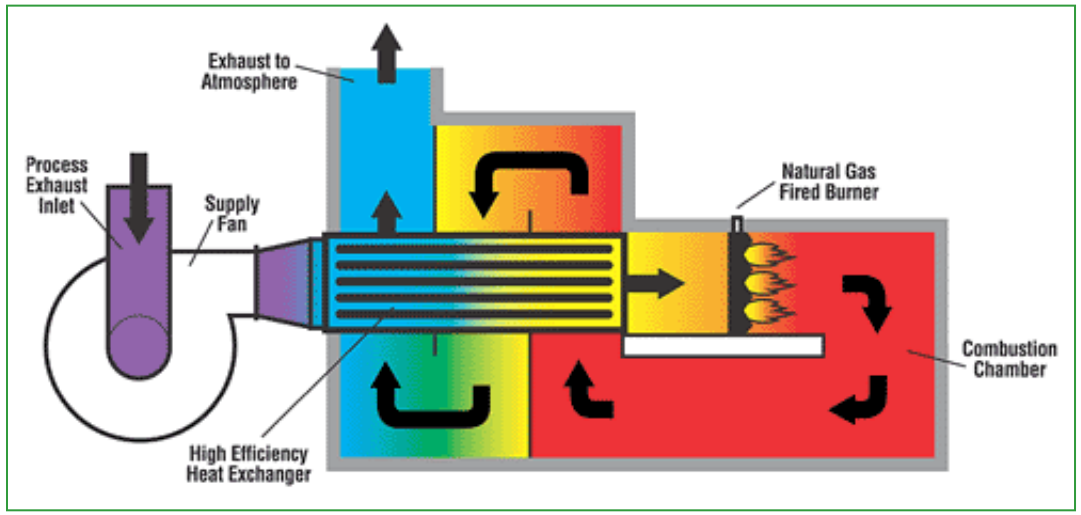


Thermal Oxidizers convert hydrocarbon air pollutants to carbon dioxide & water where time, temperature, & turbulence are important for destruction efficiency.

Thermal Oxidizers



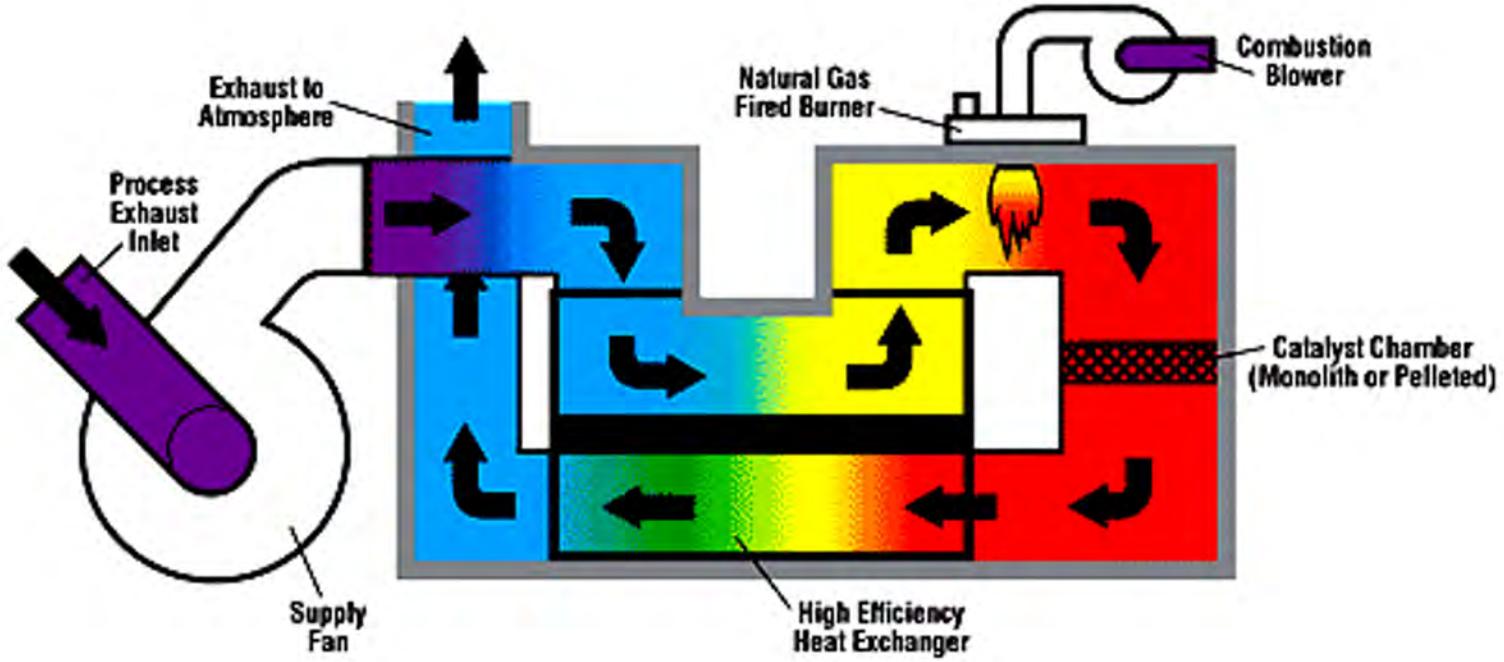
Regenerative Thermal Oxidizer



Recuperative Thermal Oxidizer

Thermal Oxidizers convert air pollutants (Volatile Organic Compounds – VOCs) to carbon dioxide & water at temperatures ranging from 1,350 to 1,500 degree F.

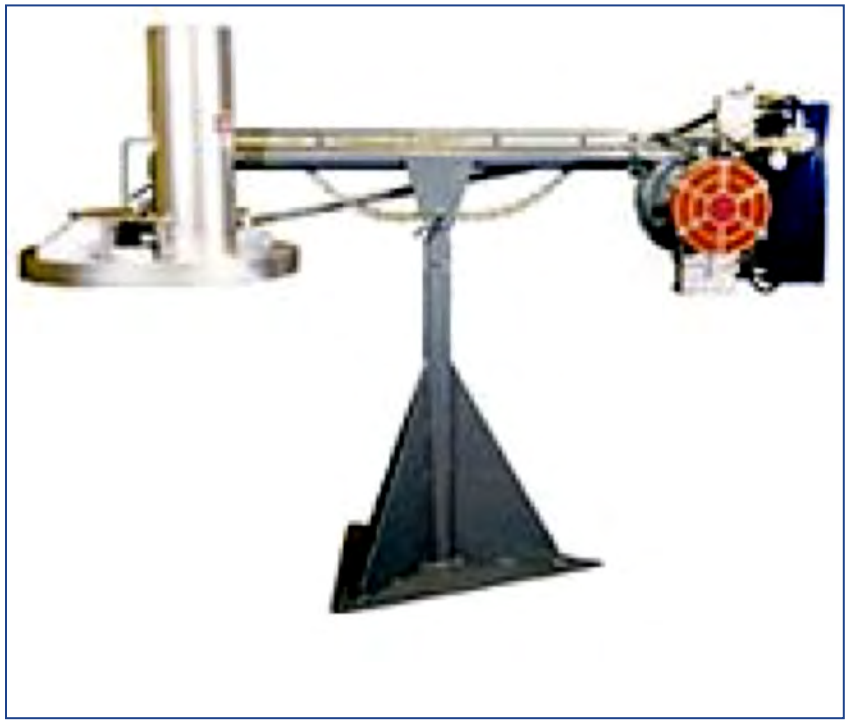
Catalytic Oxidizers



Catalytic Oxidizers convert air pollutants (VOCs) to carbon dioxide & water at temperatures ranging from 500 to 650 degree F. Catalyst used is composed of precious metal deposited on either a monolith or pelleted substrate. Under normal operating conditions, catalyst life expectancy exceeds 10 years.

Other Heating - Ladle Heaters

Conventional ladle heating practice using open flame burner



Efficient ladle heater using forced air burners and, in some cases, recuperator to preheat combustion air