Better Plants
U.S. DEPARTMENT OF ENERGY

Process Heating Virtual Training
Session 1

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What is a Virtual Training?

- In-Plant Trainings (INPLTs) are specialized workshops by BP experts that teach participants to identify, implement, and replicate energy saving projects.
- The aim is to help manufacturing plants enhance efficiency, lower energy usage, and operational cost.
- Before Covid, BP partners conducted 3-day on-site training sessions, inviting others to participate.
- In response to Covid challenges, we shifted to eight 2-hour virtual training sessions but have since returned to in-person sessions while still offering virtual options.
- Through BP, industrial organizations set efficiency targets and receive technical support and national recognition for their efforts.

Poll Question # 1

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

A Reducing operational cost

B Improve energy productivity and achieve goals

C Improving environmental performance

D Gain knowledge

Thank You to Our Participants

Sachin Nimbalkar, PhD, CEM

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 - 2021
- 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

- Certified Energy Manager, Association of Energy Engineers (2025-present)
- 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

Agenda

- Week 1 – Introduction & Process Heating Overview (April 2)
- Week 2 – Process Heating Basics (April 11)
- Week 3 – PH Assessment Methodology & Demo on DOE's MEASUR Tool (April 16)
- Week 4 – PH Diagnostic Equipment and Data Collection Form (April 23)
- Week 5 – Energy Efficiency Opportunities in Process Heating Systems (April 28)
- Week 6 – Assessment & Analysis of MEASUR Data for Finding Opportunities (May 7)
- Week 7 – PH VT Results Discussion and Review of Final Presentations (May 14)
- Week 8 – Process Heating VT Wrap-up Presentations (May 21)

Training Module # 1
Process Heating Systems Overview

Outline

- Major Energy Use Systems
- What is Process Heating?
- Why Industrial Process Heating is Important?
- Overview of Industrial Process Heating
- DOE Resources on Process Heating

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%

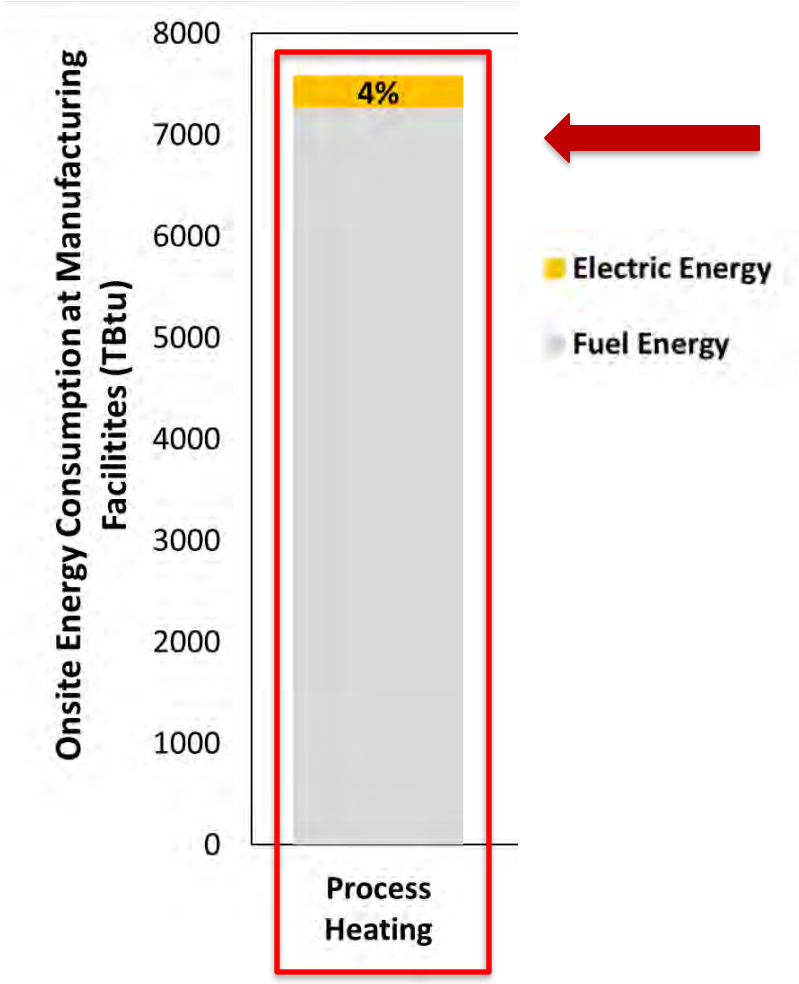
B 50%

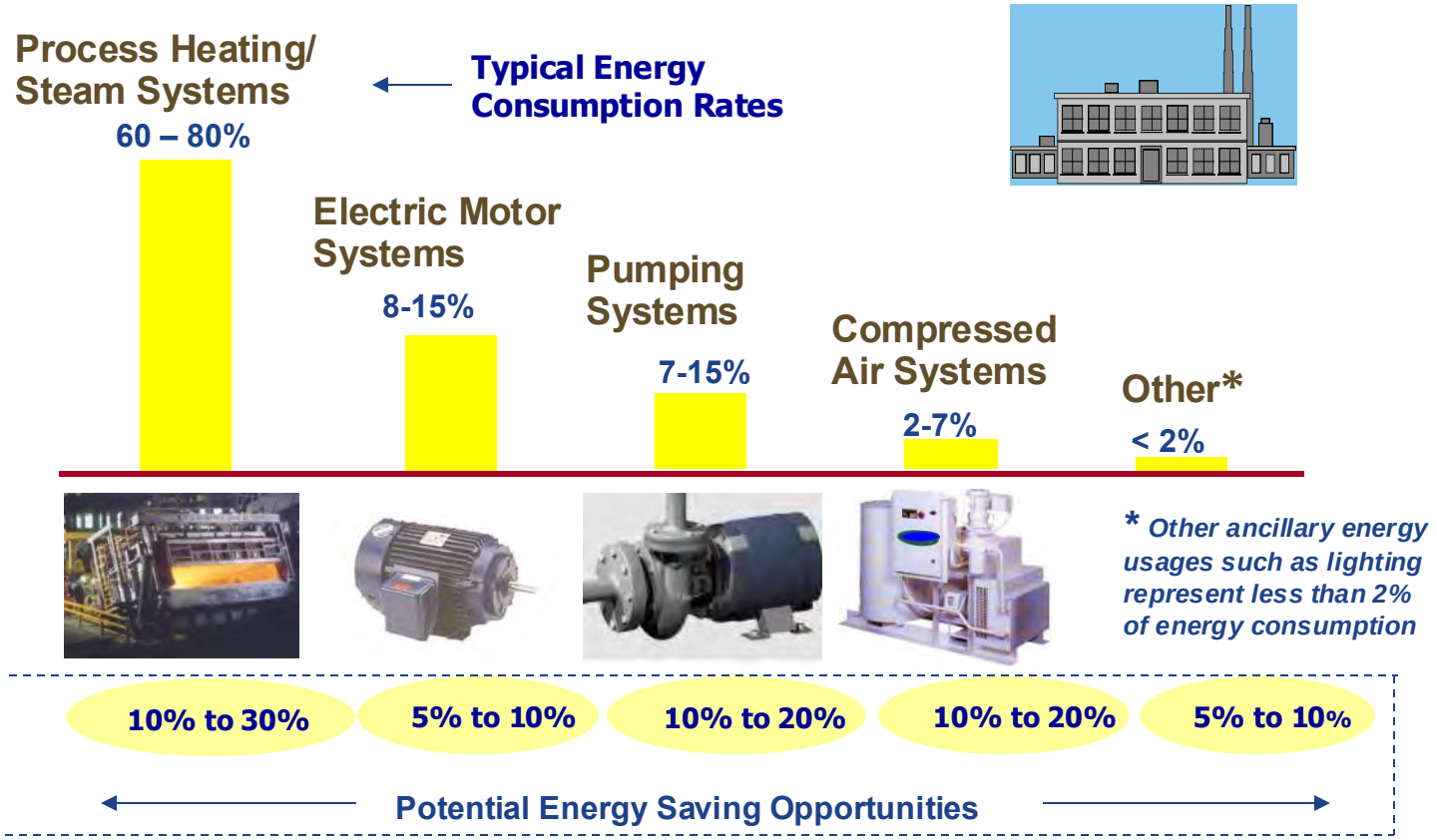
C 60%

D 70%

Yes!

System Focus Targets Major Energy Consumers





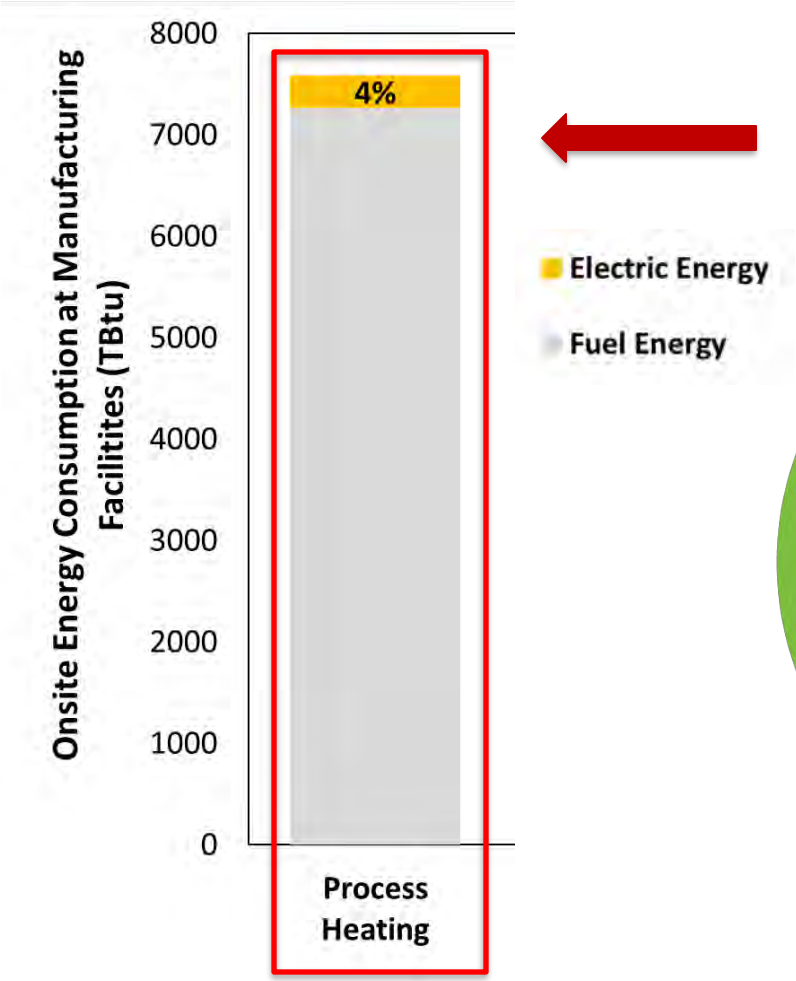
Data sources: DOE *Manufacturing Energy and Carbon Footprints*, based on EIA Manufacturing Energy Consumption Survey (MECS) data for 2018; C. McMillan, Manufacturing Thermal Energy Use in 2014. 2019. National Renewable Energy Laboratory. dx.doi.org/10.7799/1570008; AMO Thermal Process Intensification Workshop Report

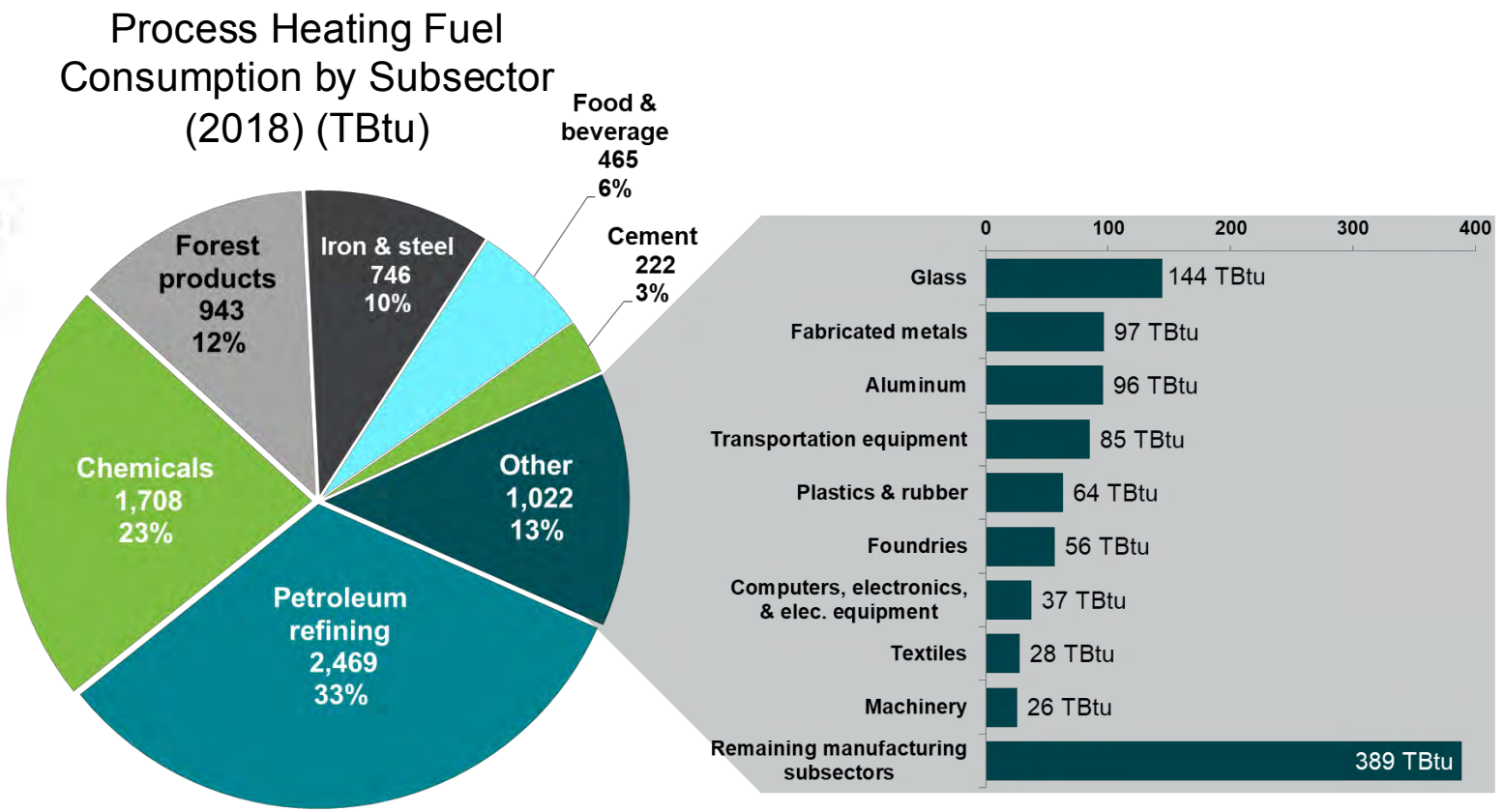
What is Process Heating?

Supplies heat to materials for further processing using:

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

Industrial Heat Demand by Industry





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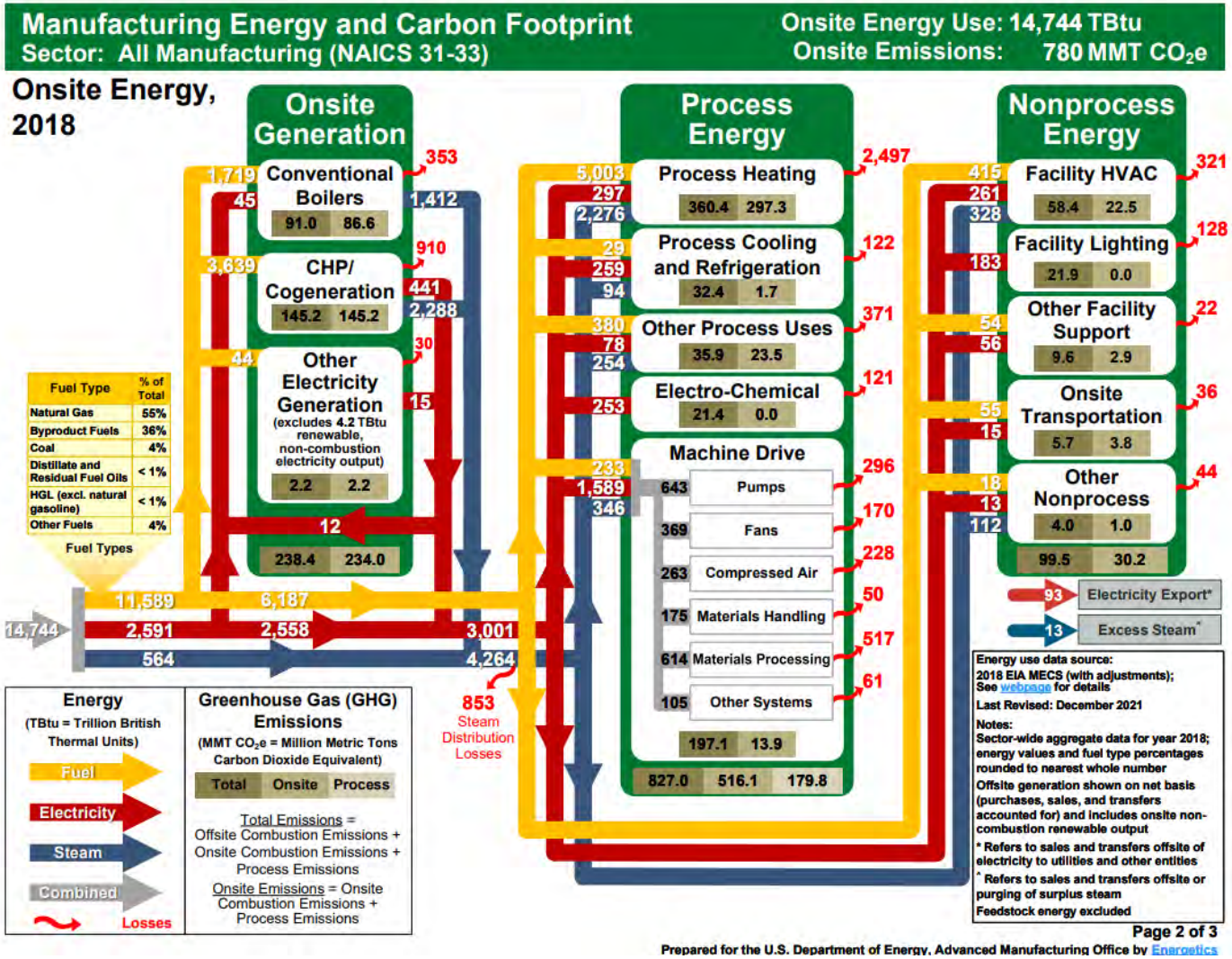
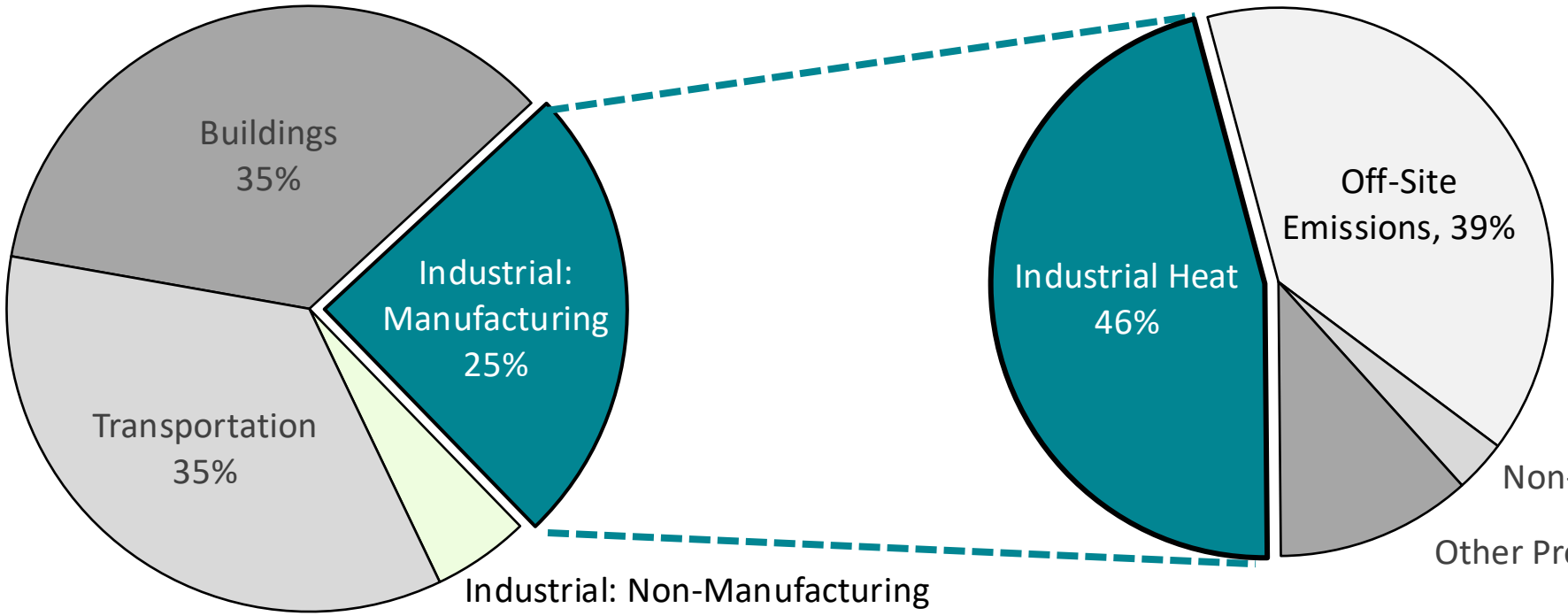
Why Industrial Process Heating is Important?



- Process heat is the application of heat in industry to manufacture materials, goods, and products.
- Every single major industry uses process heat, but the thermal needs are exceptionally heterogeneous and expensive.
- Over 90% of process heat is generated from the unabated burning of fossil fuels.
- One-third of energy consumed for process heating is ultimately lost as waste heat.
- Industrial heat is a large and increasing issue.
- NG, coal, and fuel oil combustion produce criteria air pollutants like NOx, CO, PM that impact health.

U.S. Energy-related Emissions: ~11% is Attributable to Industrial Heat



2020 Energy-Related CO_2 Emissions by U.S. Economic Sector

2020 Estimated Industrial: Manufacturing Energy-Related CO_2 Emissions by Source

To decarbonize industry, we must decarbonize heat

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Sources: EIA Annual Energy Outlook (2021); IEDO 2018 Manufacturing Energy and Carbon Footprints (2022)

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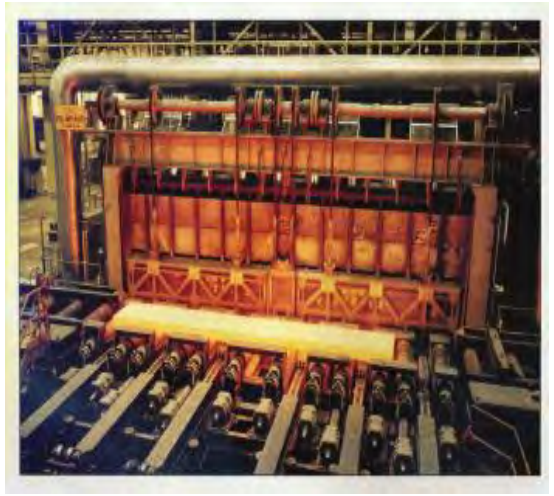
Process Heating Systems are Exceptionally Heterogeneous

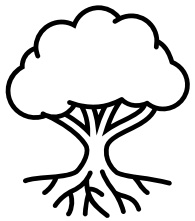


A Cross-Sectoral Approach is Needed

Thermal processes and systems are <u>essential</u> and <u>pervasive</u> in industry, but every major industrial subsector uses heat in <u>different ways</u>…

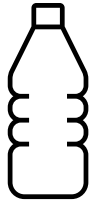
drying
paper, batteries



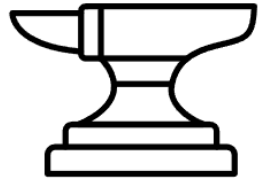
steam
pasteurization of food & beverage

distillation
high purity chemicals

melting
formed plastics, semiconductors



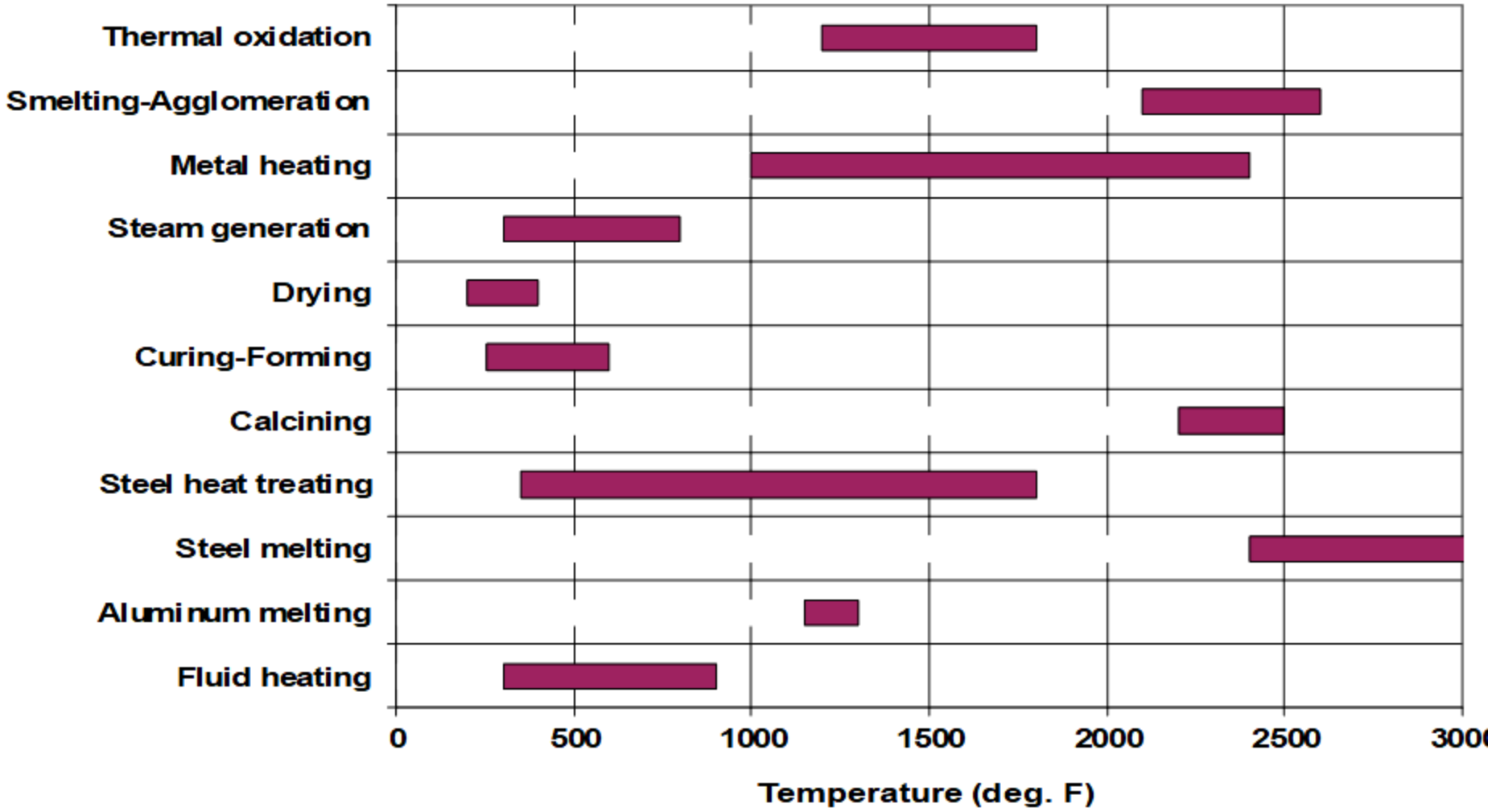
smelting
iron, copper, aluminum



calcining
cement, lime

<100°C — **Process Temperatures Needed** — **>800°C**

Temperature Range for Commonly Used Processes



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

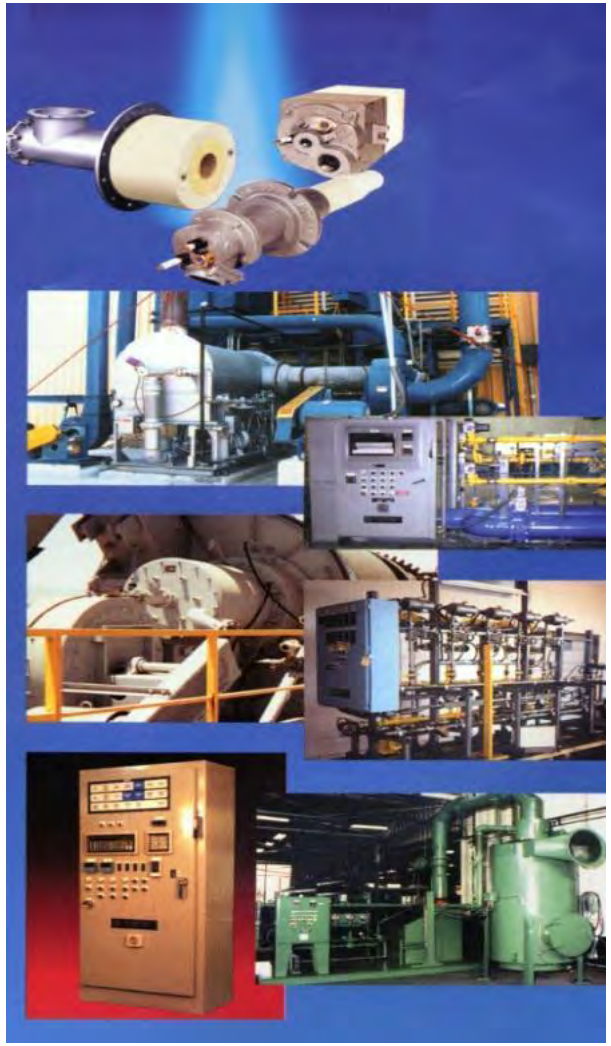
(Source: Process Heating Sourcebook)

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.

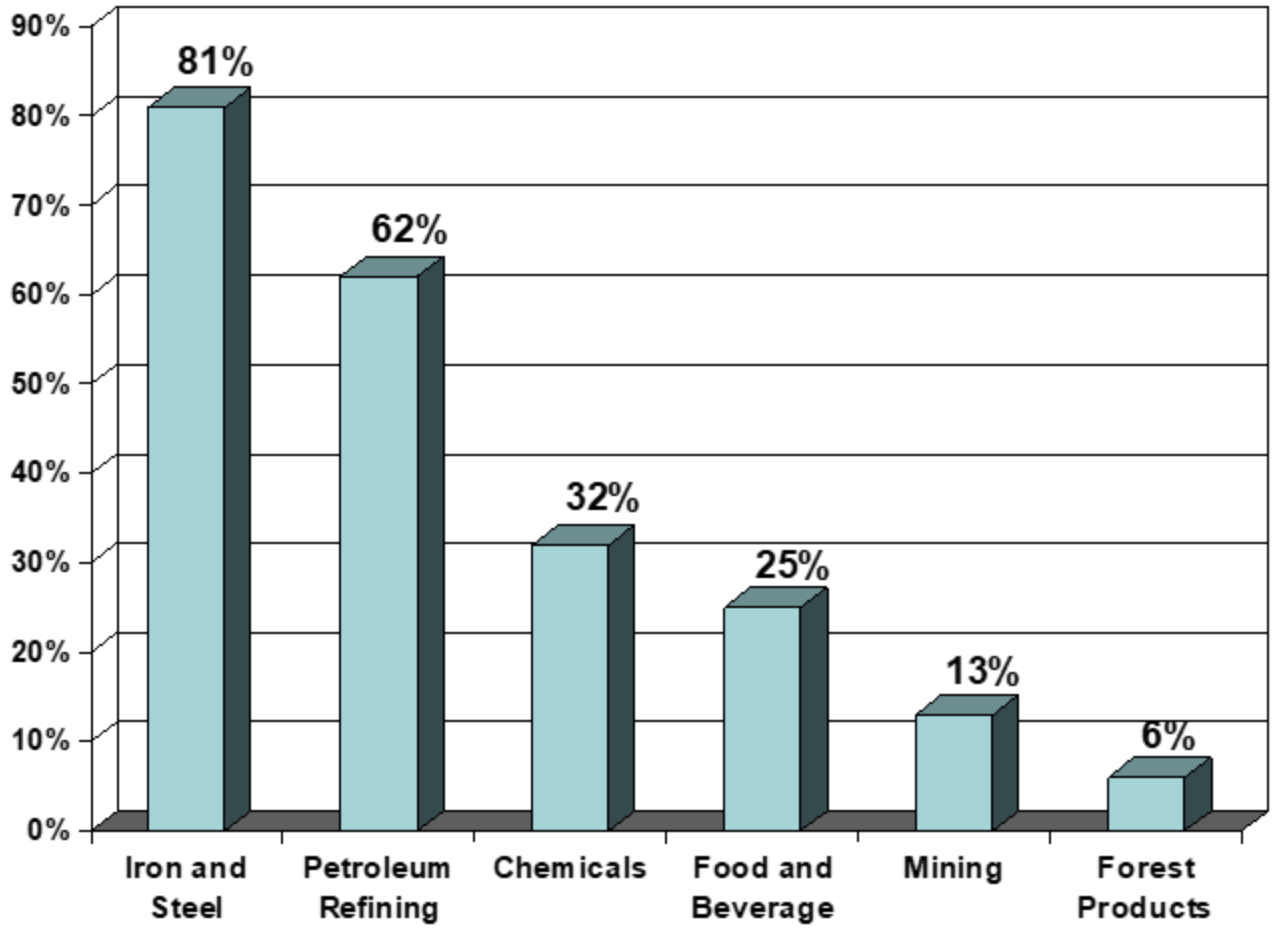
Poll Question # 3

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!

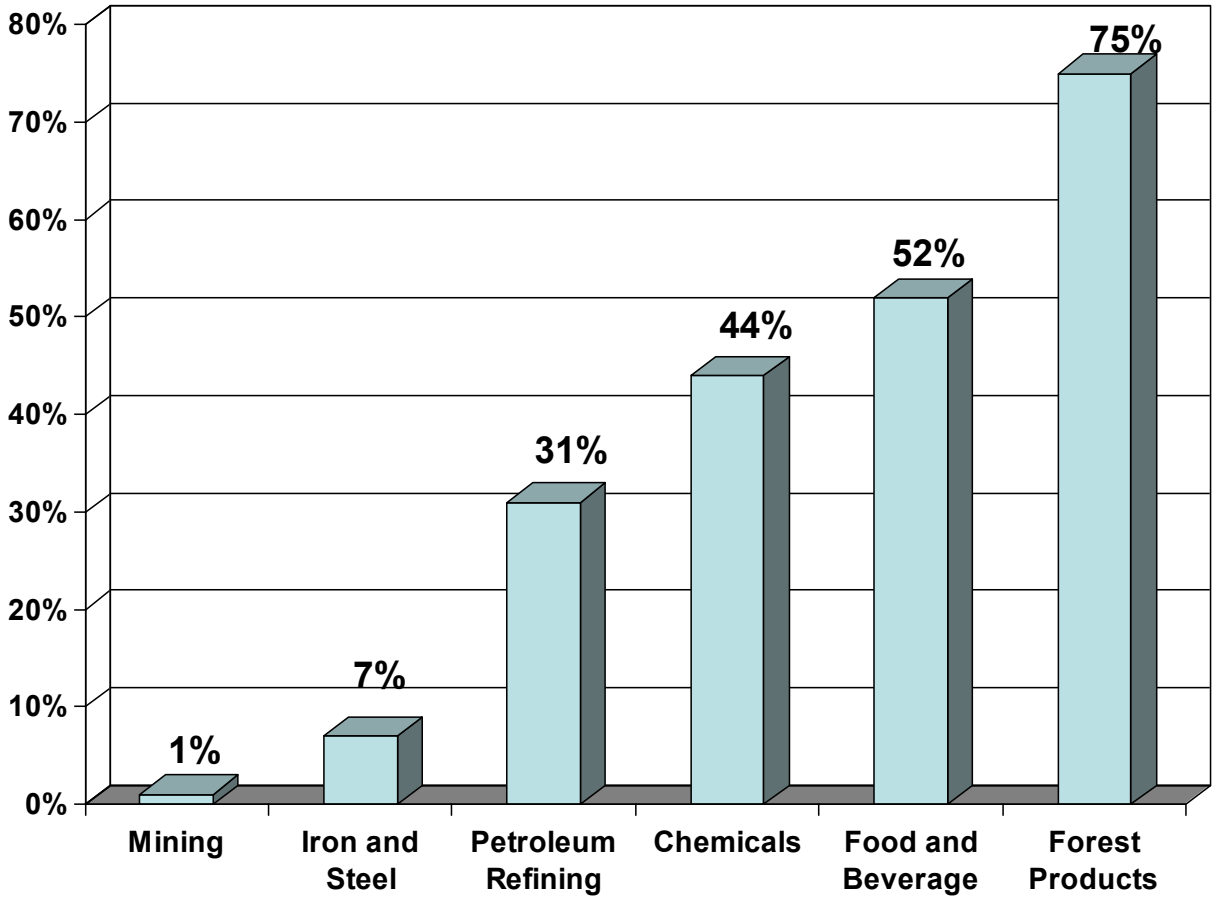
Fired Systems

Energy Use as a Percentage of Total Energy End Use

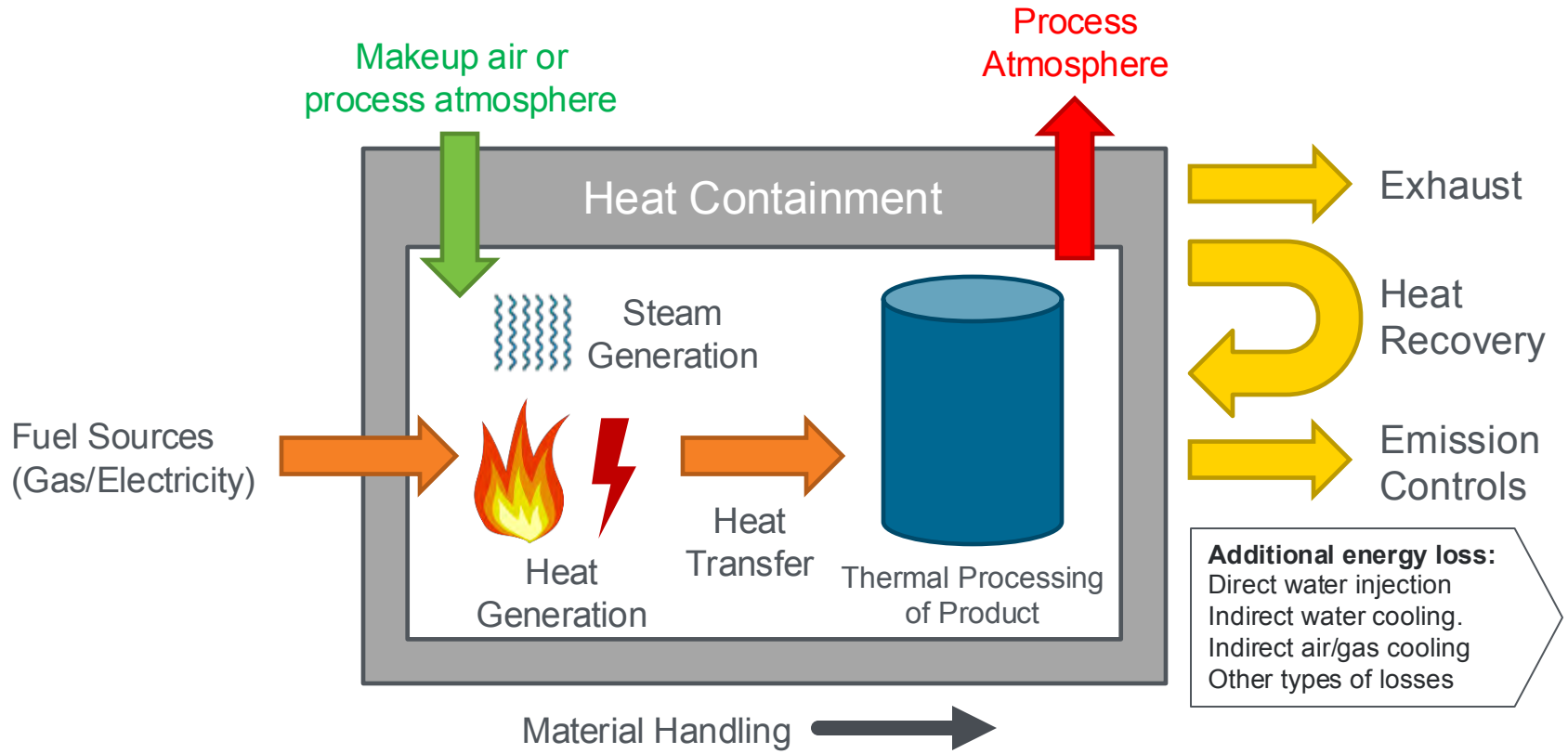


Steam Systems

Energy Use as a Percentage of Total Energy End Use



Process Heating System Components



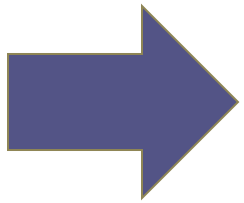
Crosscutting Enabling Technology

Sensors/ Process Controls	Advanced Materials	Design Tools/ Systems Integration

Process Heating Systems and Energy Supply Used by Industry

Energy Sources

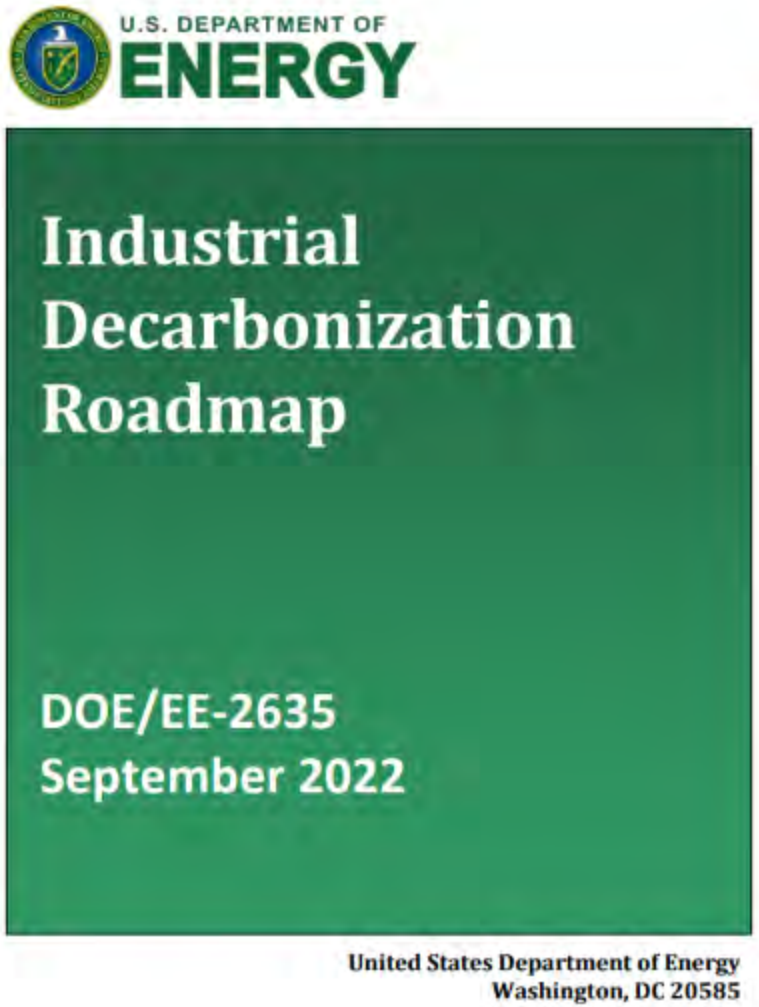
- Fuels (gas, oil, coal etc.)
- Electricity
  - Resistance heating
  - Induction
  - Arc - Plasma
- Steam
- Hot fluids (oil, water etc.)



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

Industrial Decarbonization Pillars
(Source: DOE's Decarbonization Roadmap)



Energy Efficiency	Industrial Electrification	Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)	Carbon Capture, Utilization, and Storage (CCUS)
Energy efficiency advancements minimize industrial energy demand, directly reducing the GHG emissions associated with fossil fuel combustion.	Industrial process technologies that utilize electricity for energy, rather than combusting fossil fuels directly, enable the sector to leverage advancements in low-carbon electricity from both grid and onsite generation sources.	Substitution of low- and no-carbon fuels and feedstocks for fossil fuels can further reduce combustion-associated emissions for industrial processes.	This multi-component strategy for mitigating difficult-to-abate emissions involves capturing generated CO_2 before it can enter the atmosphere; utilizing captured CO_2 whenever possible; and storing captured CO_2 long-term to avoid atmospheric release.
<u>Energy efficiency technology examples:</u> • Energy management approaches • Thermal integration of process heat • Smart manufacturing • Improved technologies and processes; system integration	<u>Industrial electrification technology examples:</u> • Electrification of process heat (e.g., heat pumps) • Electrification of hydrogen production for industrial process use	<u>LCFFES technology examples:</u> • Fuel-flexible processes • Clean hydrogen fuels and feedstocks • Biofuels and biofeedstocks • Concentrating solar power • Nuclear • Geothermal	<u>CCUS technology examples:</u> • Post-combustion chemical absorption of CO_2 • CO_2 pipelines and other CCUS-supportive infrastructure

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https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

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

Poll Question # 5

What type of projects have you already implemented for improving energy efficiency and reducing scope 1 emissions from your process heating systems?

A Energy efficiency technologies

B Waste Heat Recovery

C Electrification of thermal processes

D Biomass utilization

E Energy storage

F Carbon Capture and utilization

G Hydrogen-based technologies

H Smart manufacturing & IOT

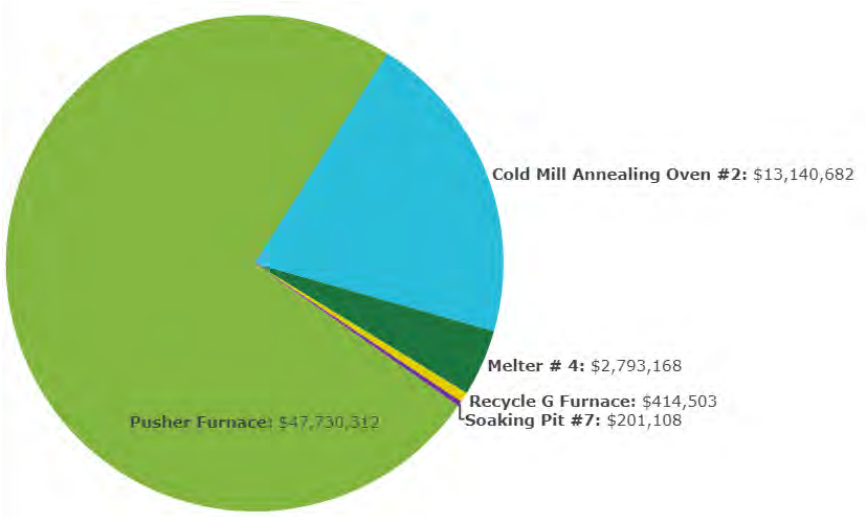
Energy Efficiency of Process Heating Systems

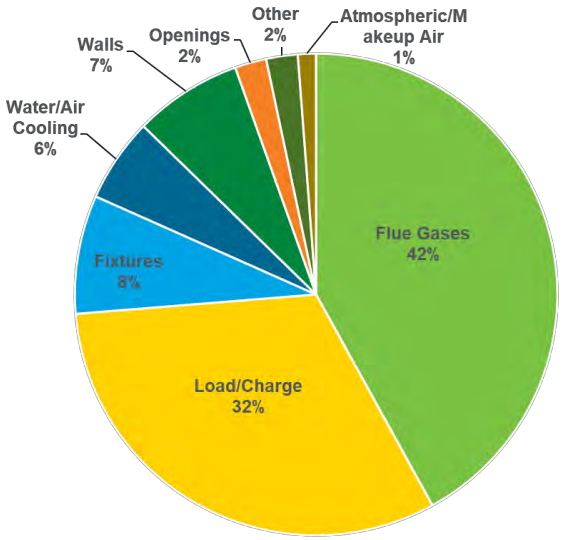
Energy efficiency improvement measures or actions can be implemented through the following categories of actions:

- Operations
- Maintenance
- Retrofits
- Use of new technologies (process or equipment)

Steps to Improve Thermal Efficiency

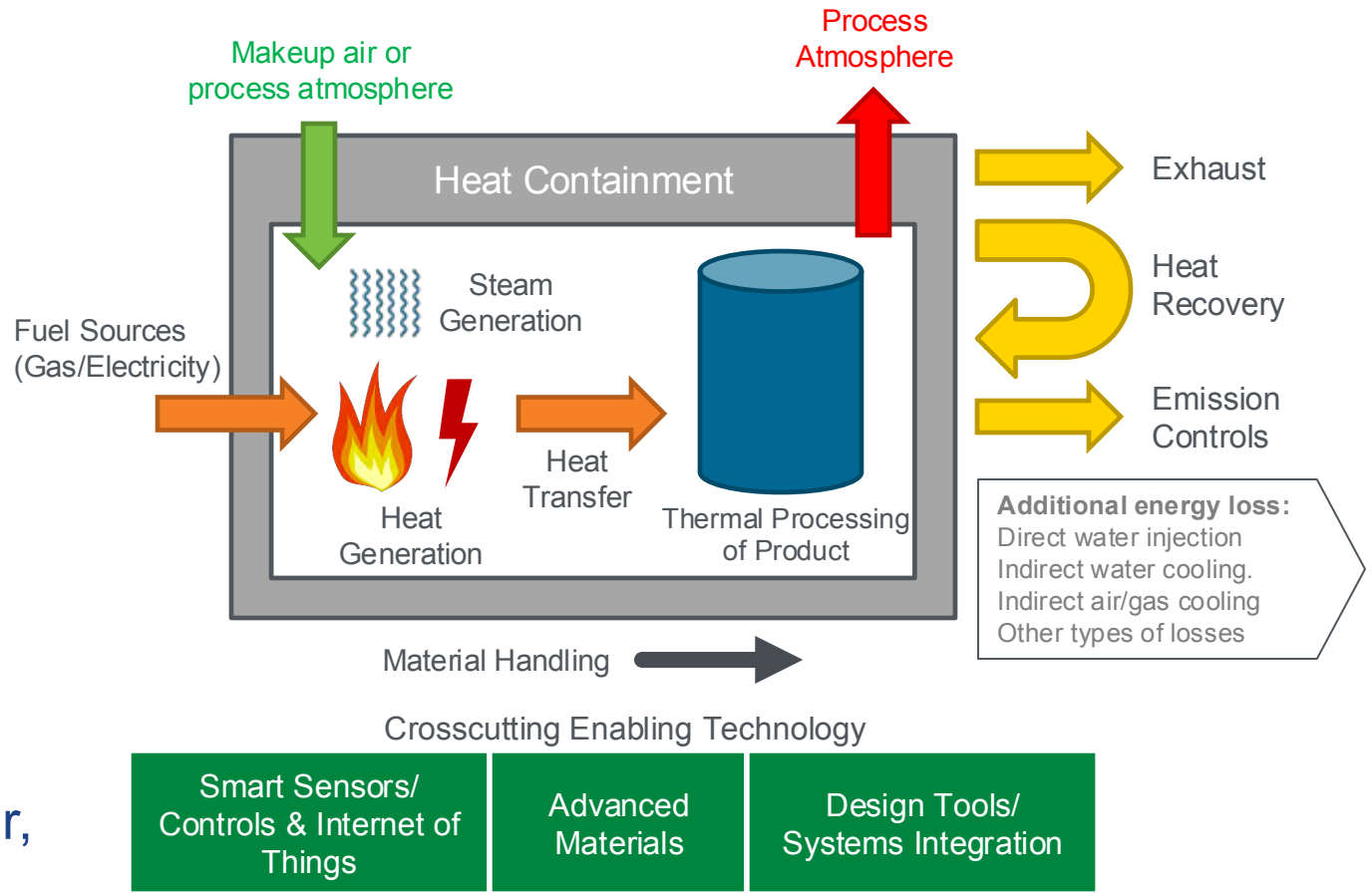
- **Analyze energy use distribution**
  - How much energy is used and where is it going?
- **Identify areas of possible energy savings and measures**
  - Where can we reduce energy loss and save energy
  - What measures/actions can be taken to reduce energy loss and improve energy efficiency?
  - How many of these measures are practical?
- **Estimate effect of energy-saving measures**
  - How much energy is saved?
- **Select appropriate energy measures**
  - What measures give the best energy savings?
- **Develop an action plan**





Major Areas for Energy Savings Potential

1. Load/charge material
2. Material handling
3. Heat supply/heat generation (combustion system, electric, & other)
4. Furnace exhaust and heat recovery
5. Furnace-oven walls
6. Furnace openings and doors
7. Water or air cooling
8. Control system
9. Auxiliary systems
10. Other losses (i.e., atmosphere, makeup air, ex-filtration of gases etc.)



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 (%)

...nt, & power factor

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

Please Submit Pre-Screening Forms by April 9th

ENERGY

Outline

- Major Energy Use Systems
- What is Process Heating?
- Why Industrial Process Heating is Important?
- Overview of Industrial Process Heating
- **DOE Resources on Process Heating**

DOE Resources on Process Heating

https://www.energy.gov/eere/amo/process-heating-systems

- Online Material
  - Process Heating Tip Sheets (11 tip sheets)
  - Sourcebook for Industry
  - Case Studies
  - Cheat Sheets
  - Pre-recorded webinars

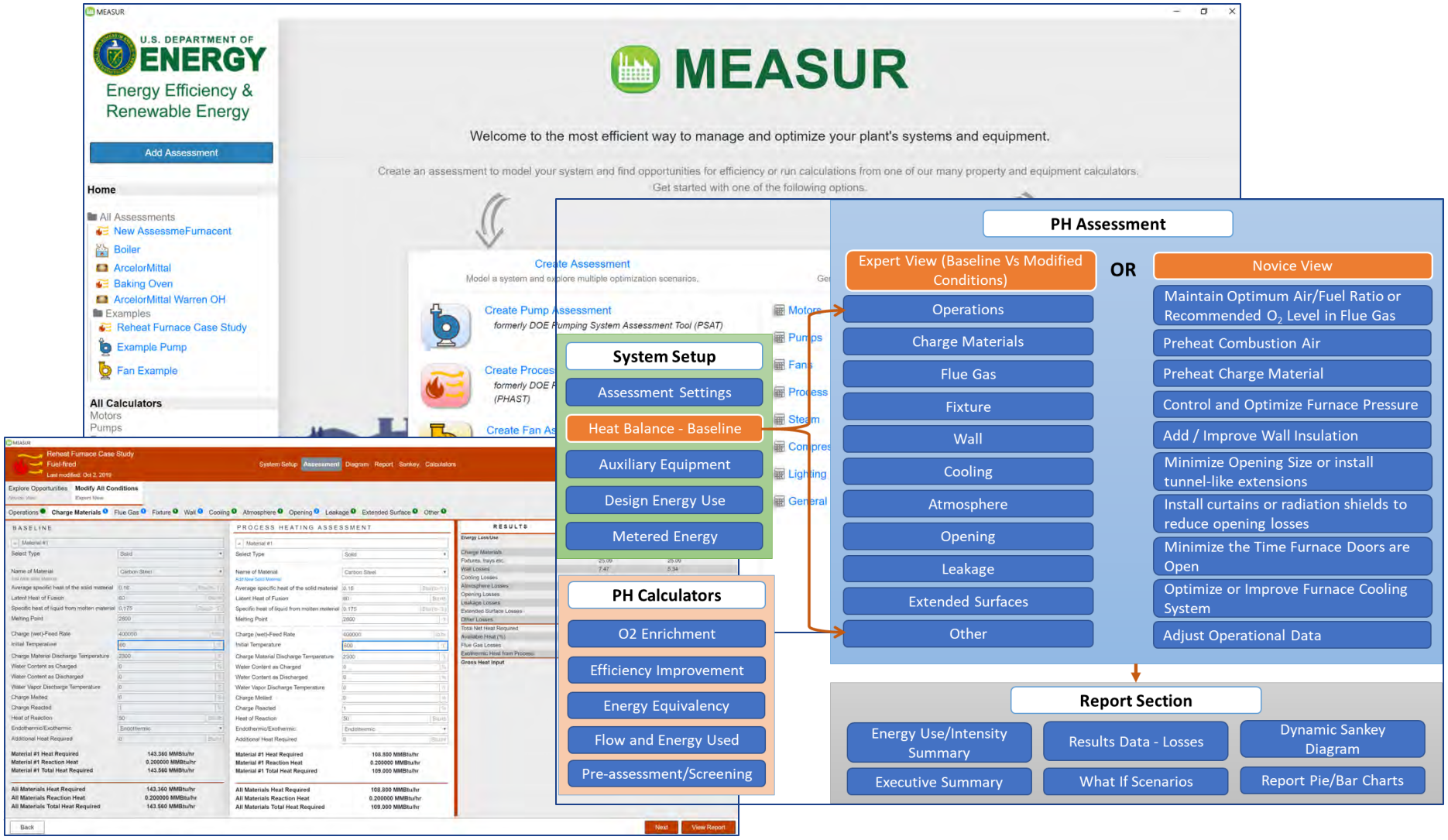
- Software Tools
  - MEASUR – PHAST and PH Calculators
  - PHASTEx – Excel version

Process Heating Tip Sheets & Other Resources

The tip sheets and other resources can be downloaded from the AMO Process Heating site at https://www.energy.gov/eere/iedo/process-heating-systems.

- Preheated Combustion Air (recovery)
- Check Burner Air to Fuel Ratios (generation)
- Oxygen-Enriched Combustion (recovery)
- Check Heat Transfer Surfaces (transfer)
- Reduce Air Infiltration in Furnaces (containment)
- Furnace Pressure Controllers (generation)
- Reduce Radiation Losses from Heating Equipment (containment)
- Install Waste Heat Recovery Systems for Fuel-Fired Furnaces (recovery)
- Load Preheating Using Flue Gases from a Fuel-Fired Heating System (recovery)
- Using Waste Heat for External Processes (recovery)
- Use Lower Flammable Limit Monitoring Equipment to Improve Oven Efficiency

MEASUR – Process Heating Module



Summary

- Major Energy Use Systems
- What is Process Heating?
- Why Industrial Process Heating is Important?
- Overview of Industrial Process Heating
- DOE Resources on Process Heating

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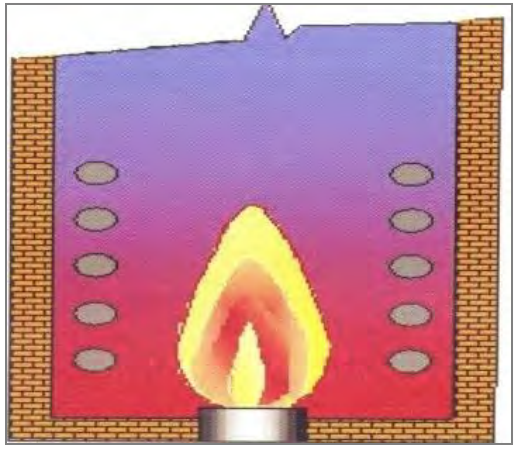
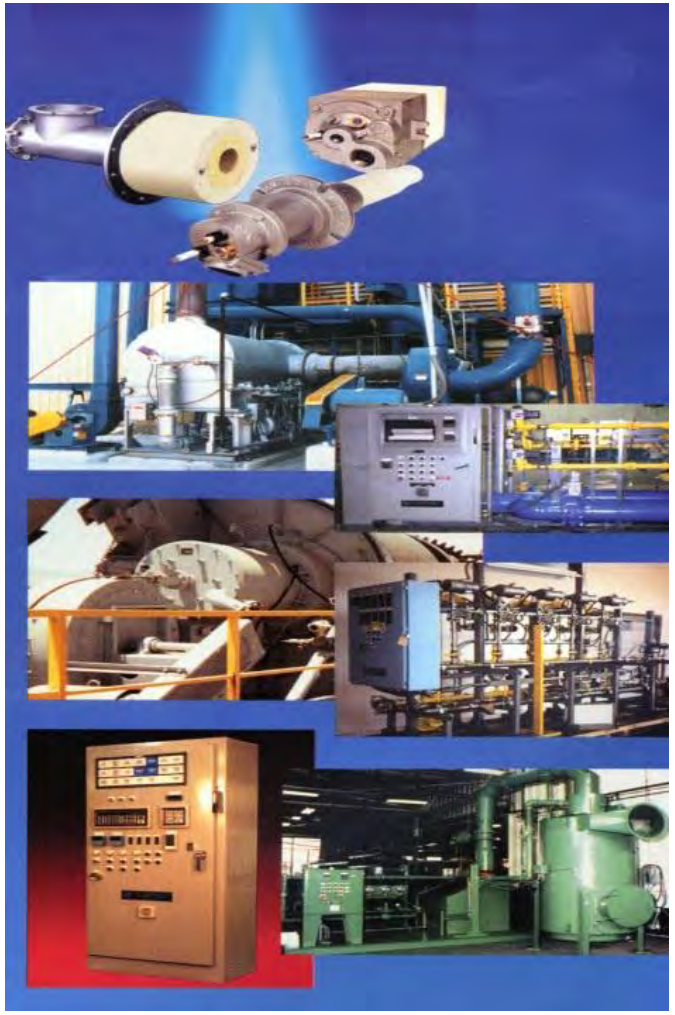
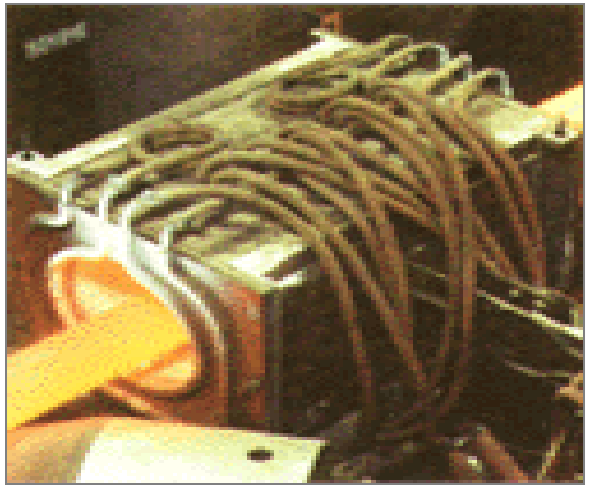
Questions?

Process Heating - Highlights of Equipment used by the Industry





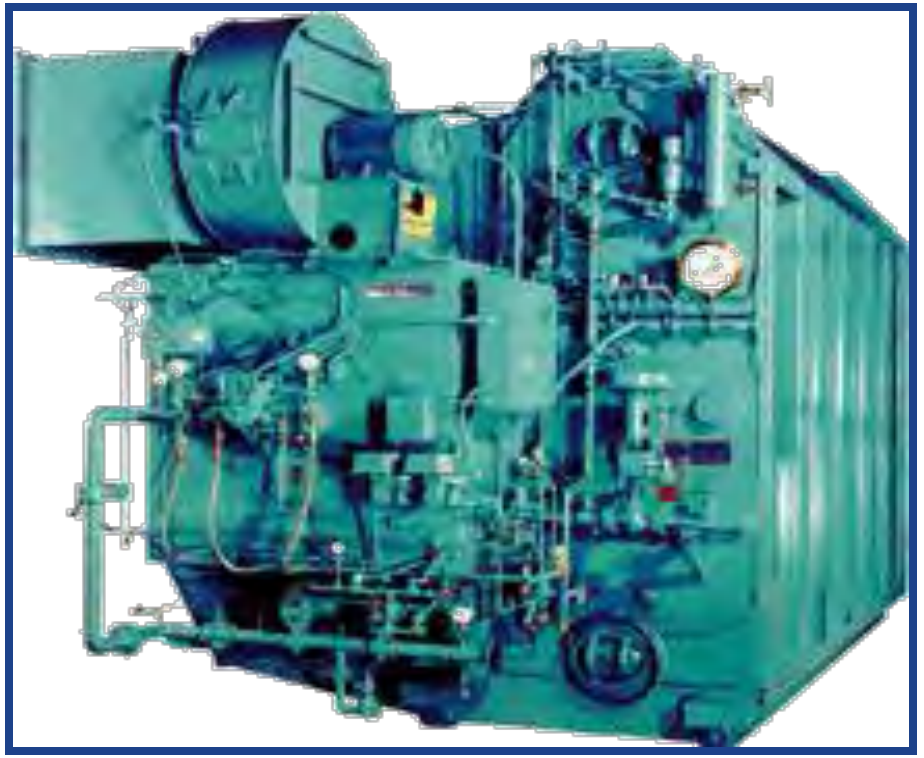


Steam Generation

- 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

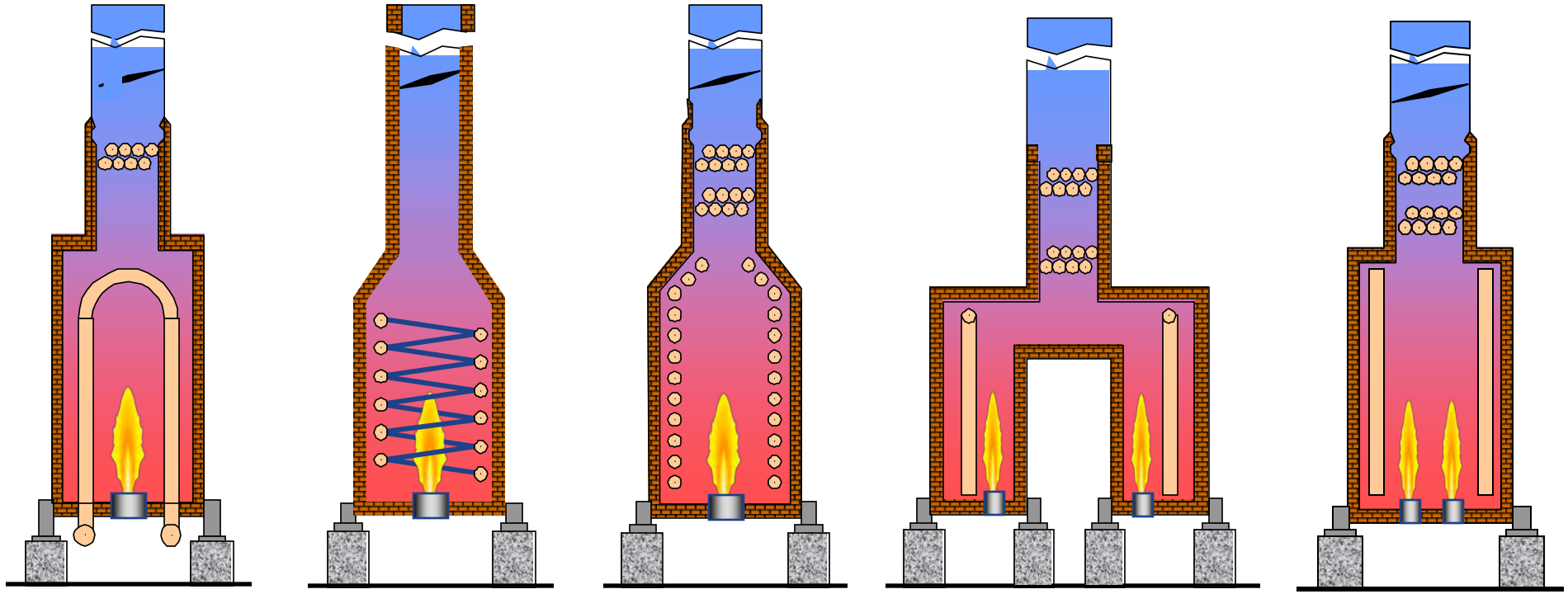


Fuel Fired Boiler for process steam generation

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

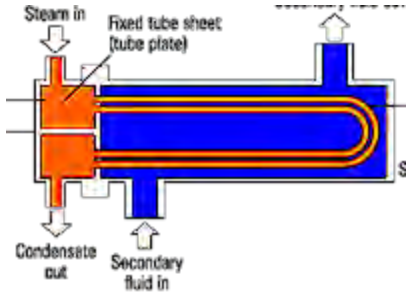
Type B -
Cylindrical heater with helical coil

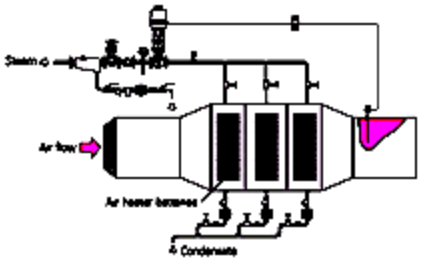
Type C -
Cabin heater with horizontal tube coil

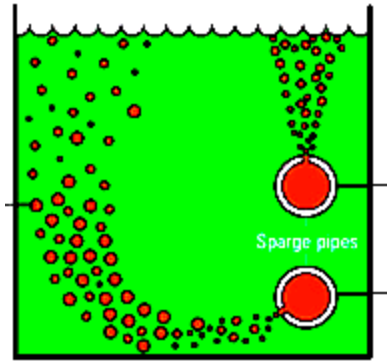
Type D -
Box heater with vertical tube coil

Type E -
Cylindrical heater with vertical coil

Other Type of Fluid Heating Systems







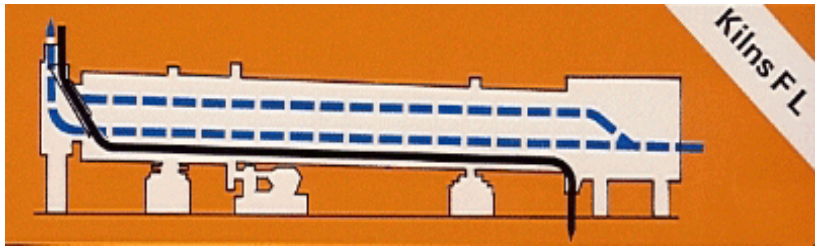
- Fired heaters for water, oil, or other liquid heating
- Air heaters used for drying and other applications
- Liquid or gas heating in heat exchangers using steam or waste heat (gases or liquids)
- Direct steam injection water heaters
- Direct contact water heaters using flue gases
- Immersion tubes

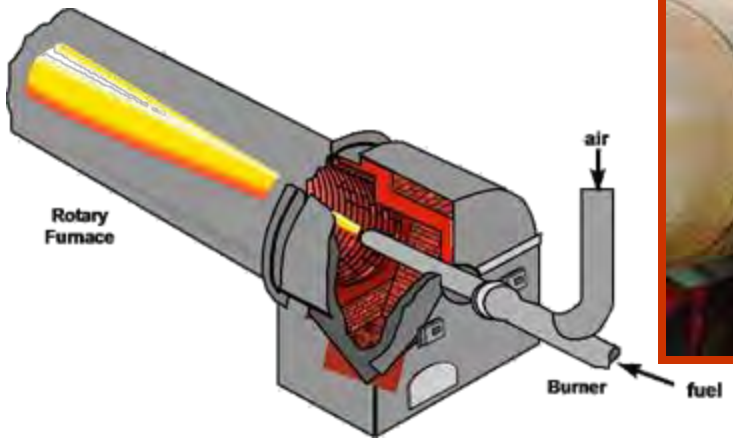
Calcining

- 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

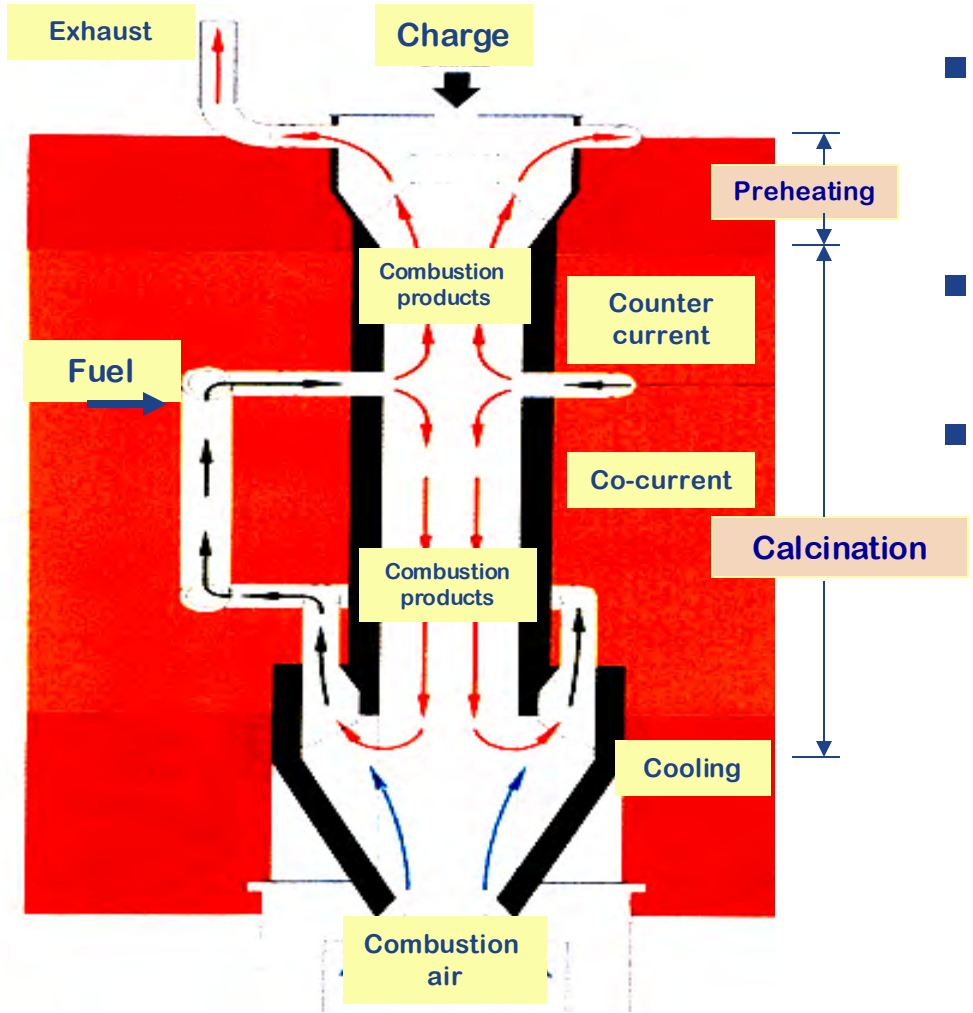
Calcining - Rotary Kilns

- 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%



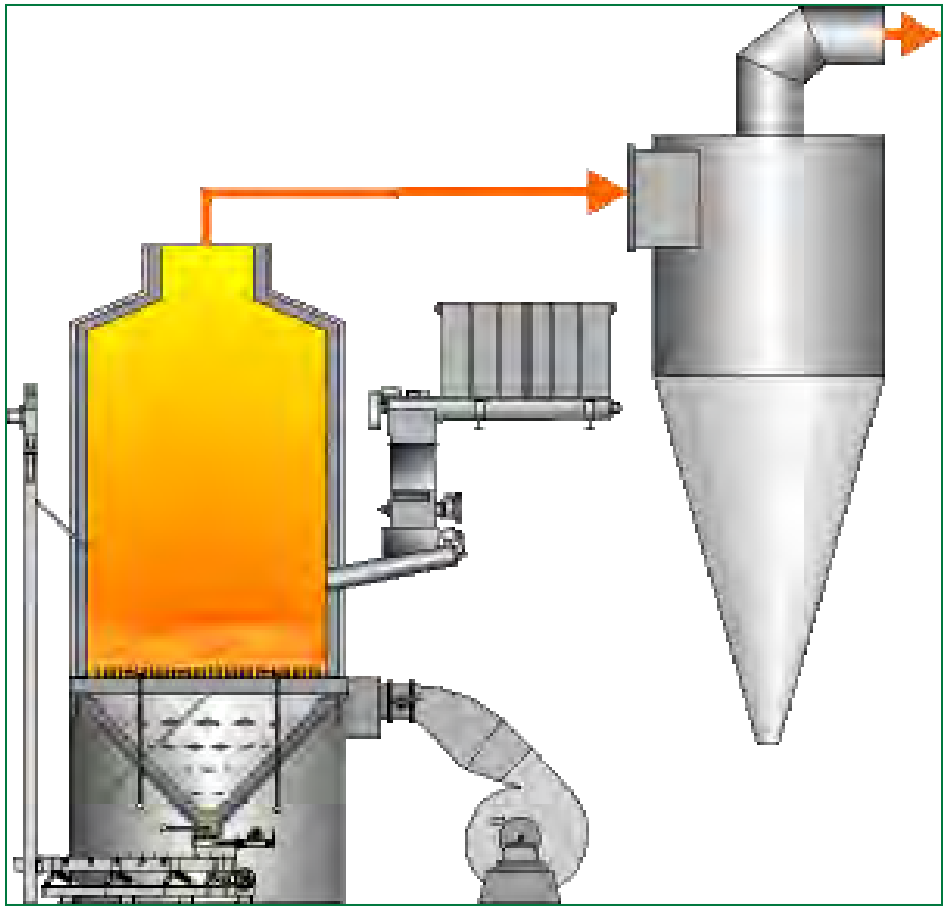


Calcining – Vertical Shaft Calciner

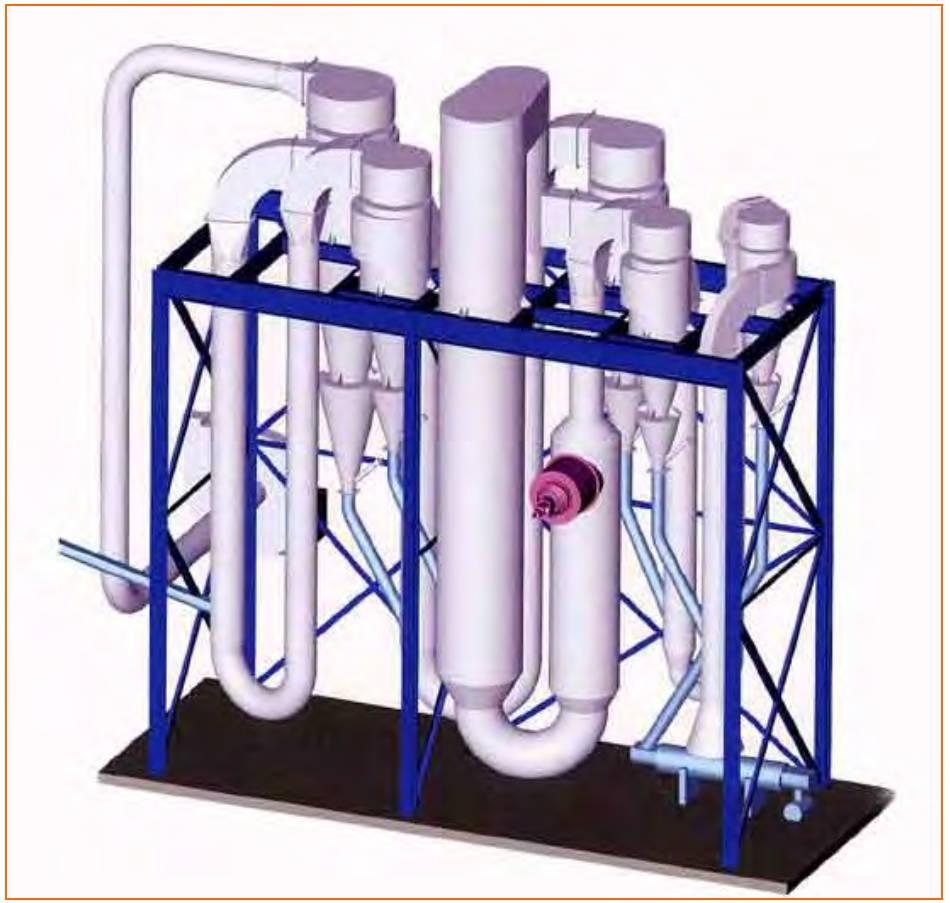


- Upper short counter-current zone where most of heat is distributed resulting in calcination of material.
- Counter current flow results in efficient use of heat.
- Lower, longer co-current zone where lesser amount of heat is distributed, resulting in less intensive reaction with temperatures controlled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

Fluidized Bed and Flash Calciners



Fluidized Bed Calciner



Flash Calciner

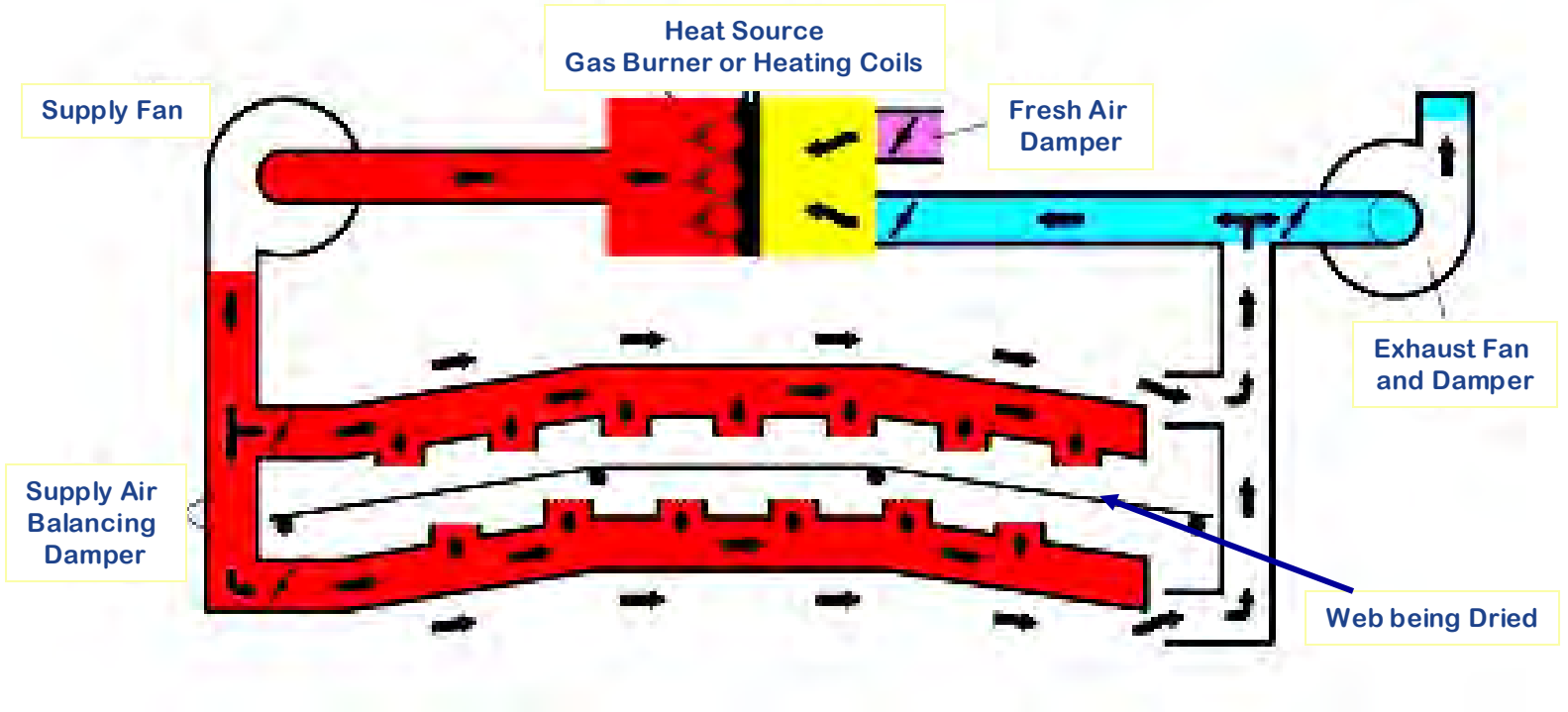
Drying

- 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

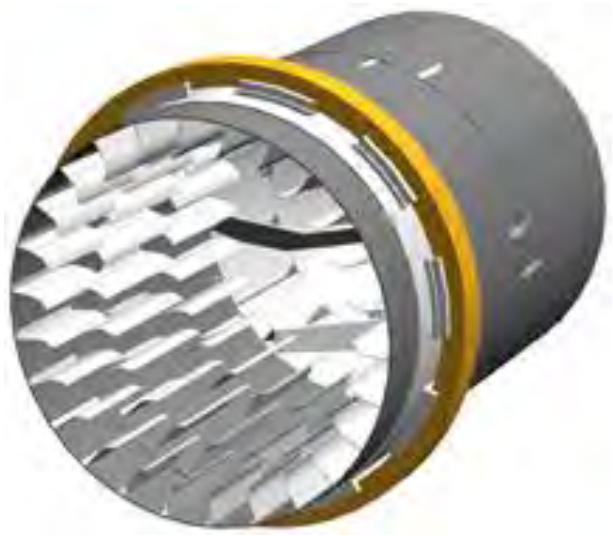
Drying – Jet Impingement Drying



Floatation Drying Ovens with High Convection Jet Impingement Heating and Drying

Drying – Rotary Dryer

Photo courtesy of Drytech Engineering.

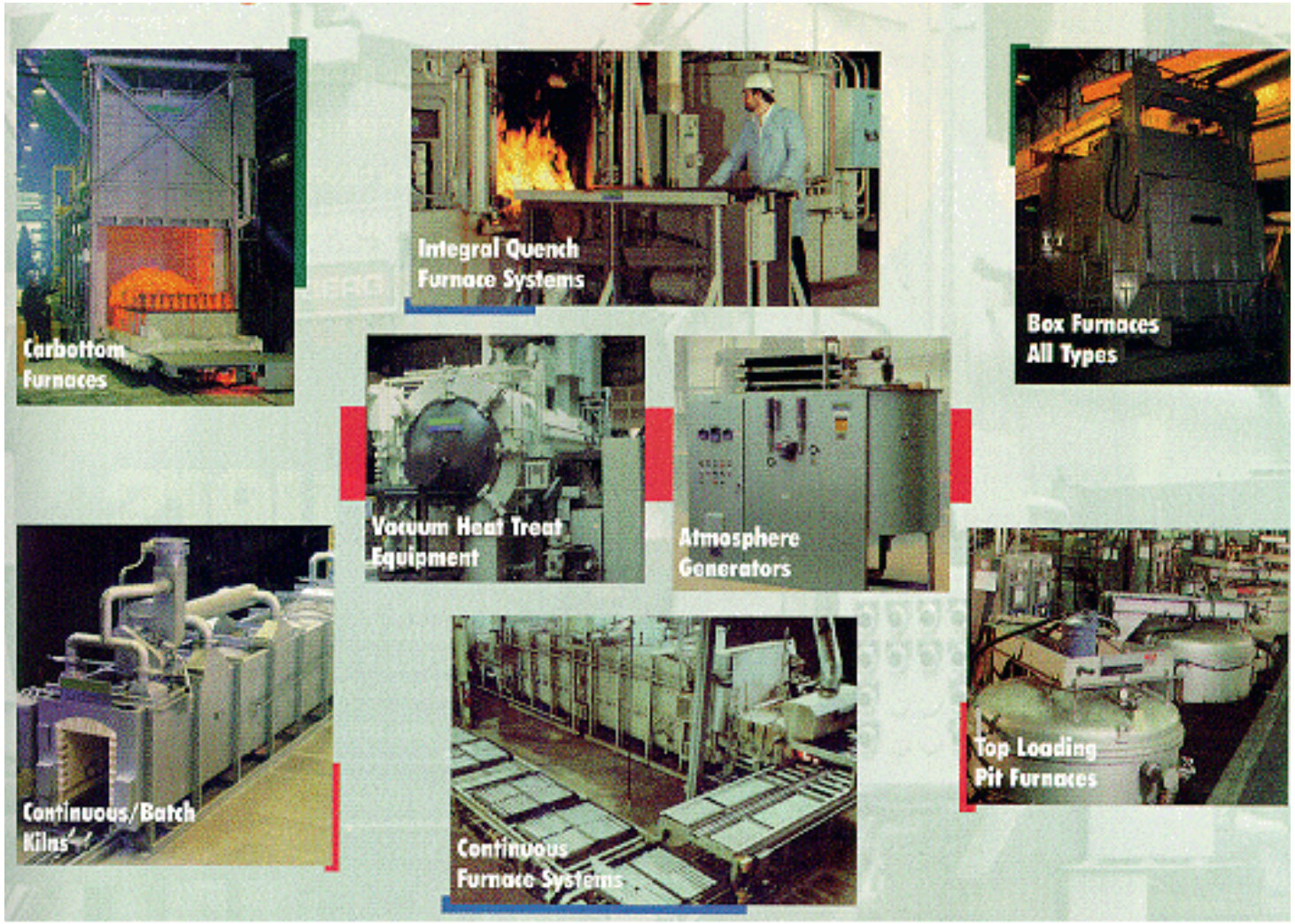


Spiral flights quickly move material out of feed section. Lifting flights elevate material to produce a curtain. Drum is supported by a riding ring.

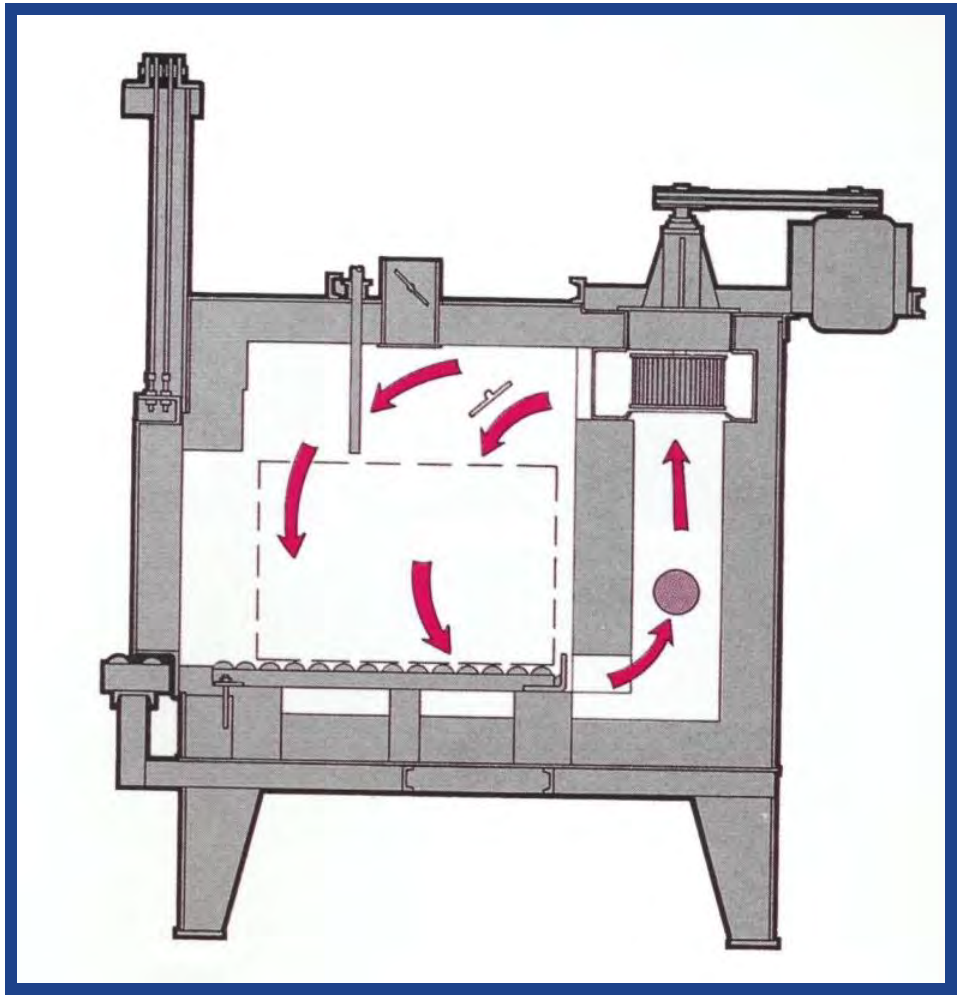
Heat Treating

- 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)

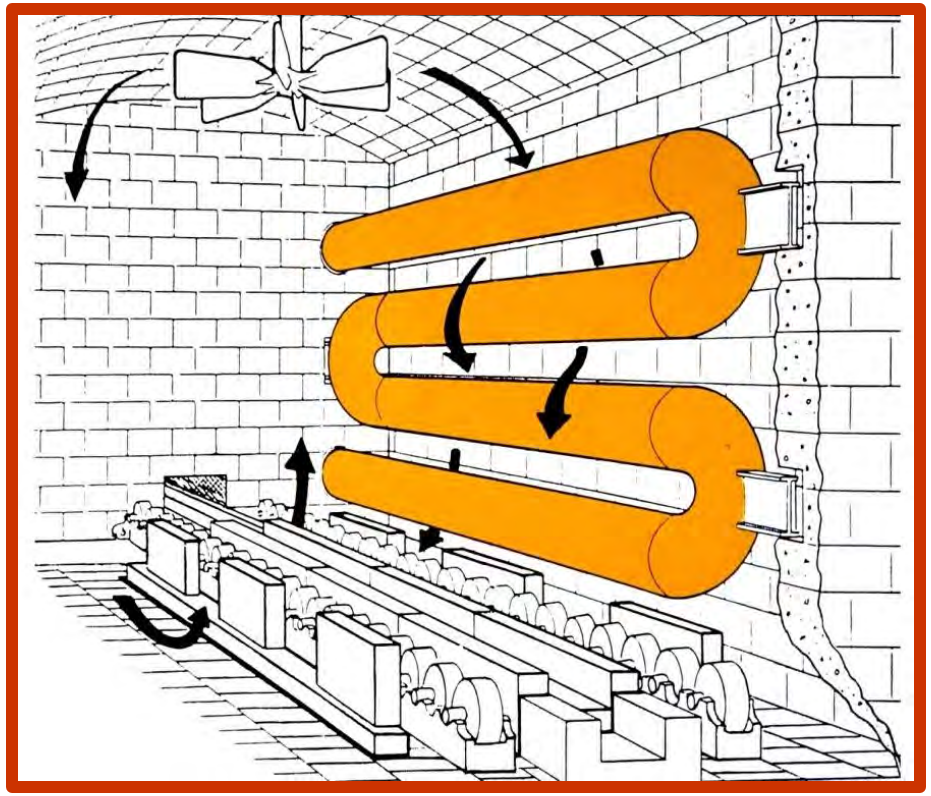
Process Heating Equipment Used by The Heat-Treating Industry



Direct Fired Tempering and Homogenizing Furnaces



Metal Heat Treating - Indirectly heated heat-treating furnaces

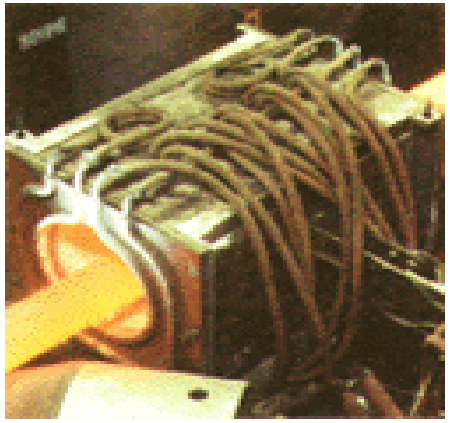


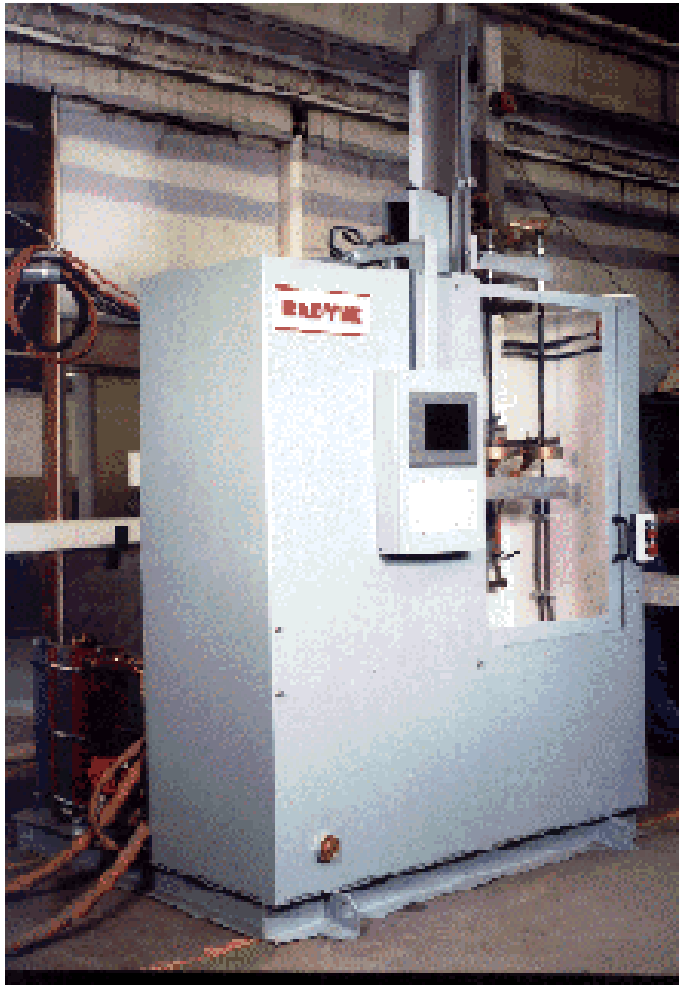
Indirect heating using radiant tubes with a convection fan in a heat-treating furnace

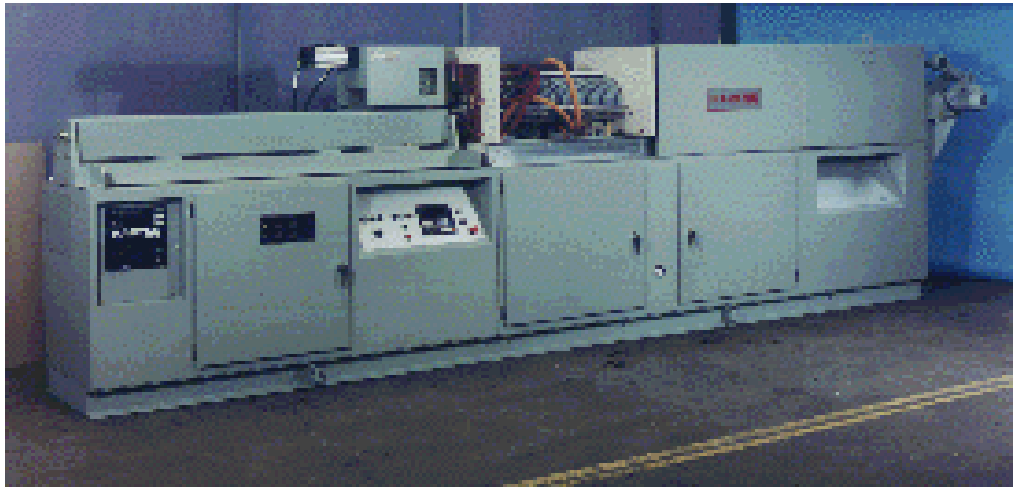
Large pit furnace – direct fired with metal retort to isolate load from flue products

Courtesy: Surface Combustion

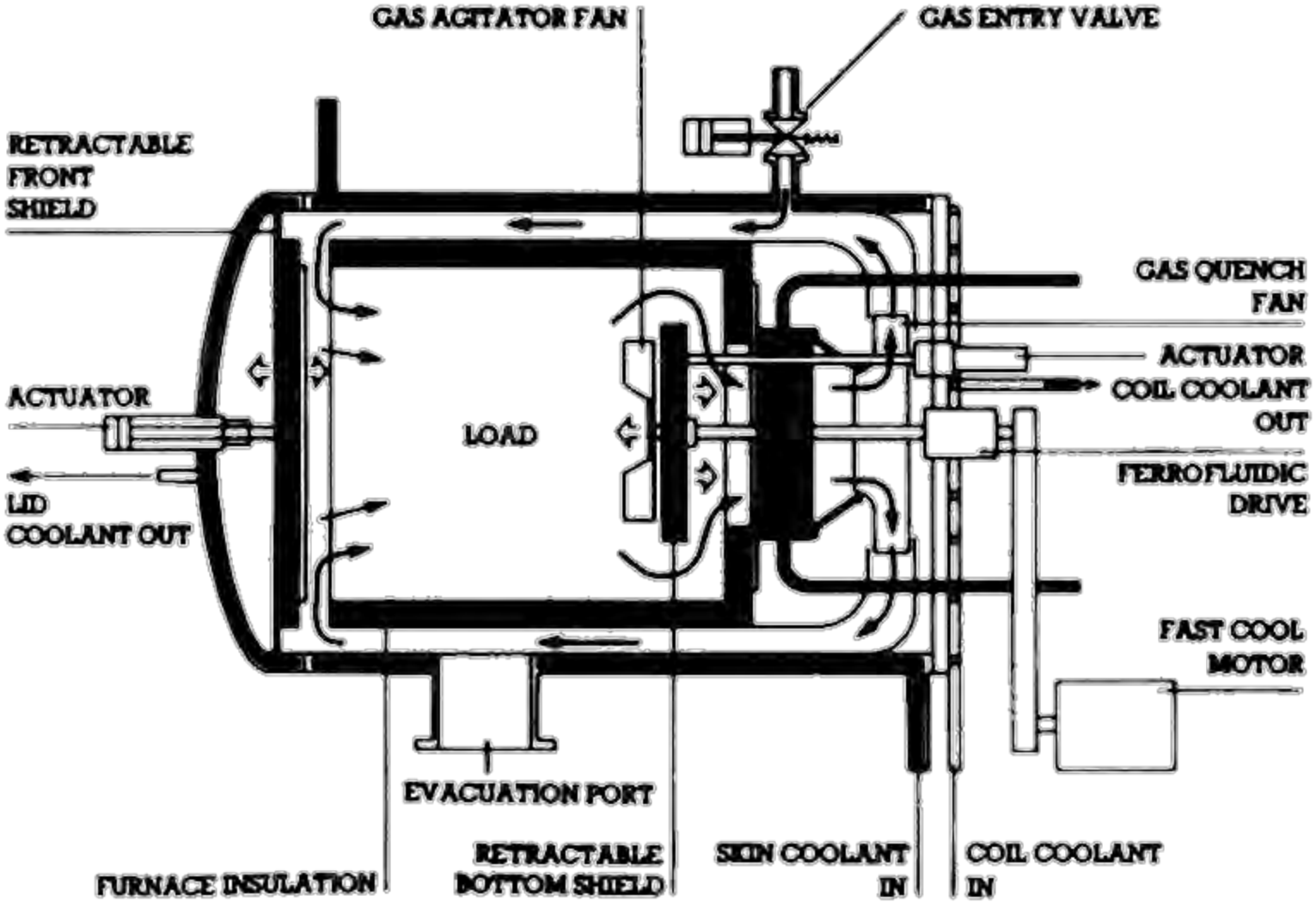
Induction Equipment for Metal Heat Treating and Heating







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

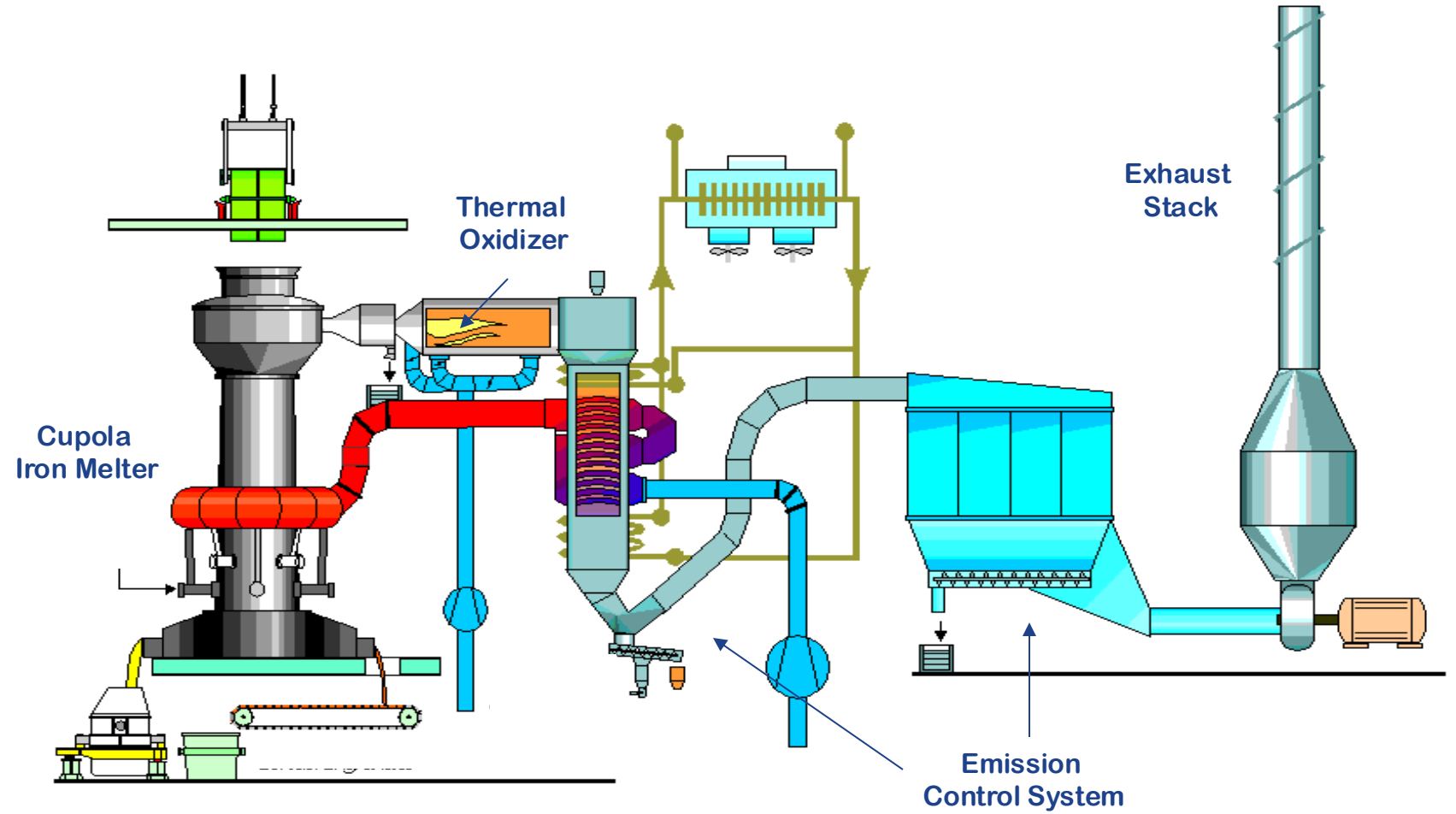
Walking Beam
Walking Hearth

Pusher Furnace

Metal and Non-metal Melting

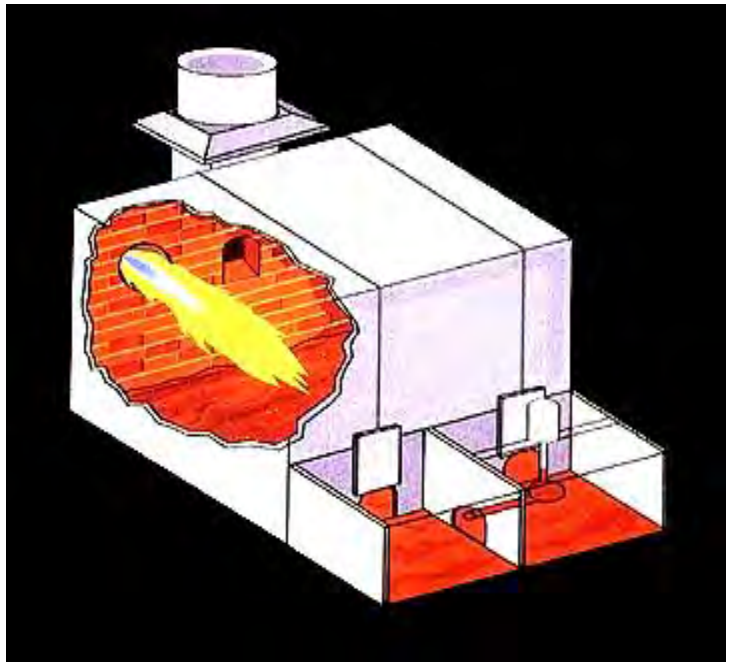
- To raise temperature of metal or non-metal to (or above) its melting temperature.
  - Direct fired furnaces
    - Various configurations
  - Induction heating systems
  - Electric arc furnaces
- Current level of efficiency – 30% to 60%
- Energy Source – Natural gas, coke and electricity
- Major Applications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



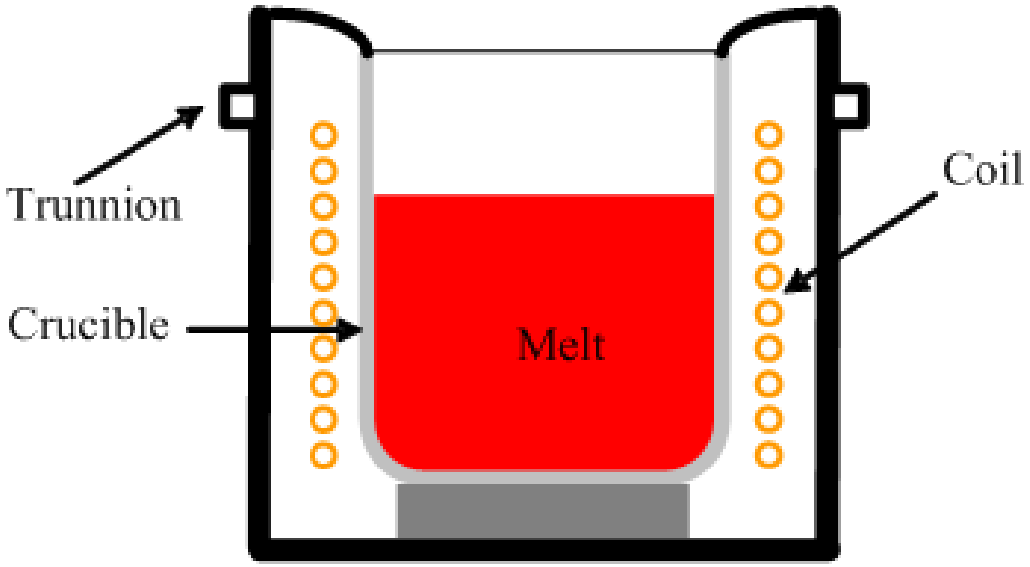
Typical burner firing for Reverberatory Furnace

Types of Induction Melting Furnaces

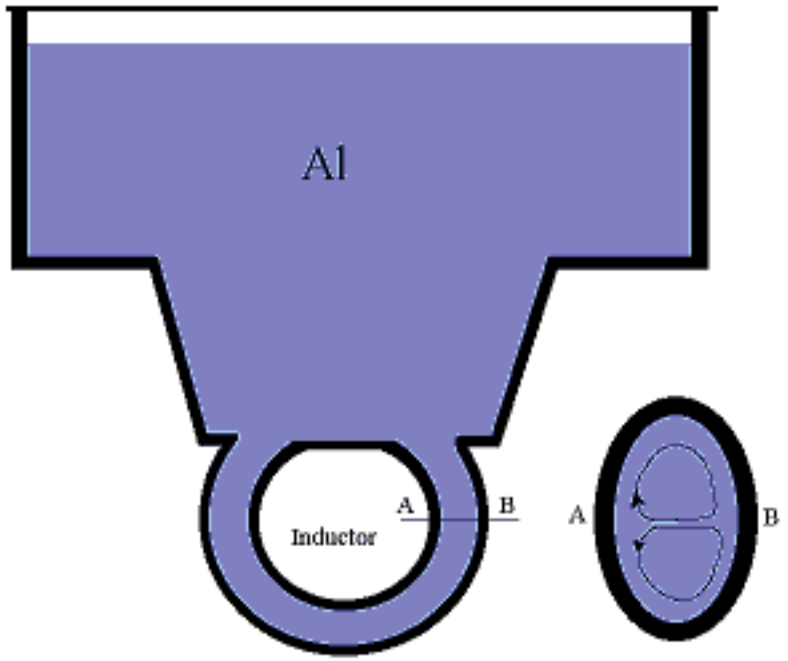
2 most common induction melting furnace designs are coreless & channel furnaces:

- **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

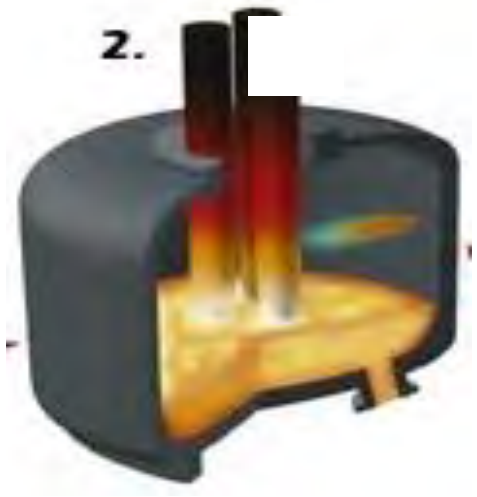


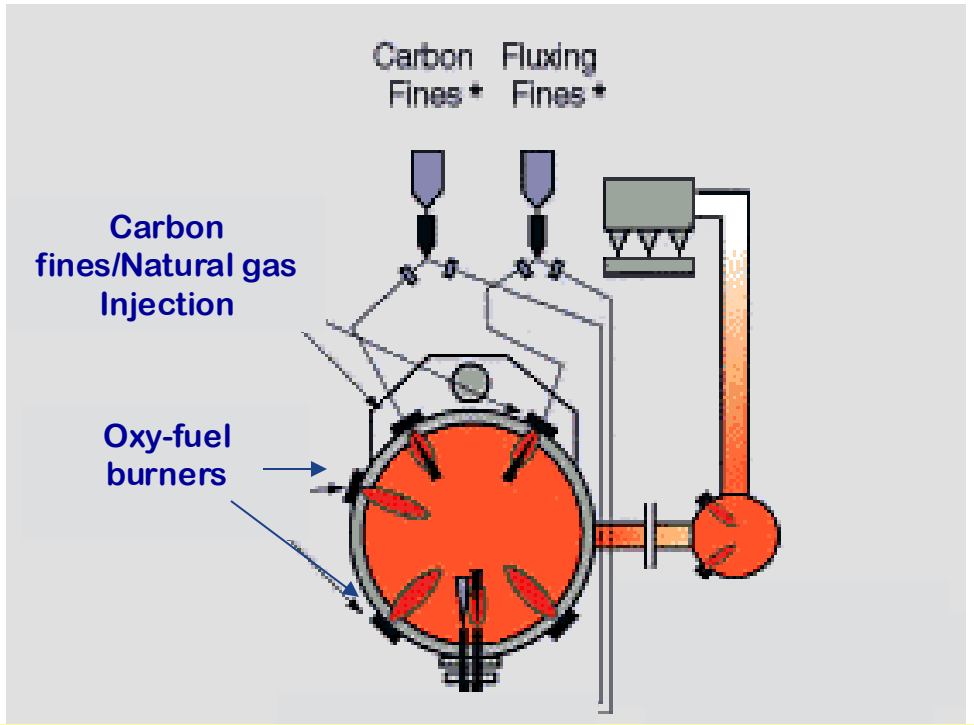
Coreless Induction Melter



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

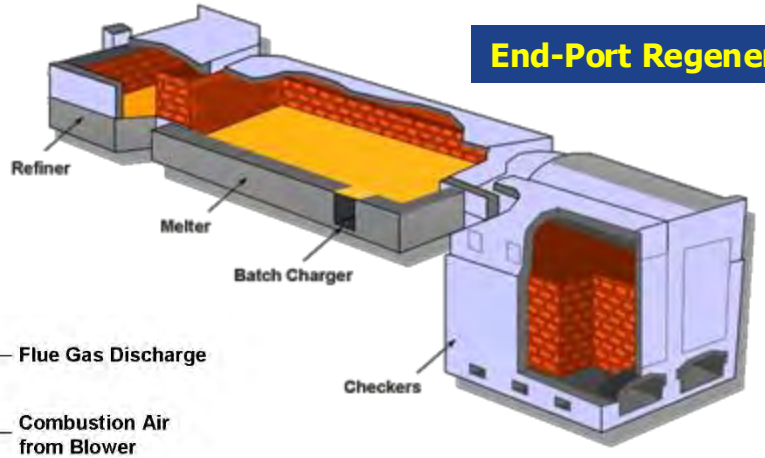
Oxy-Fuel Fired Melter

Recuperative Gas Fired Melter

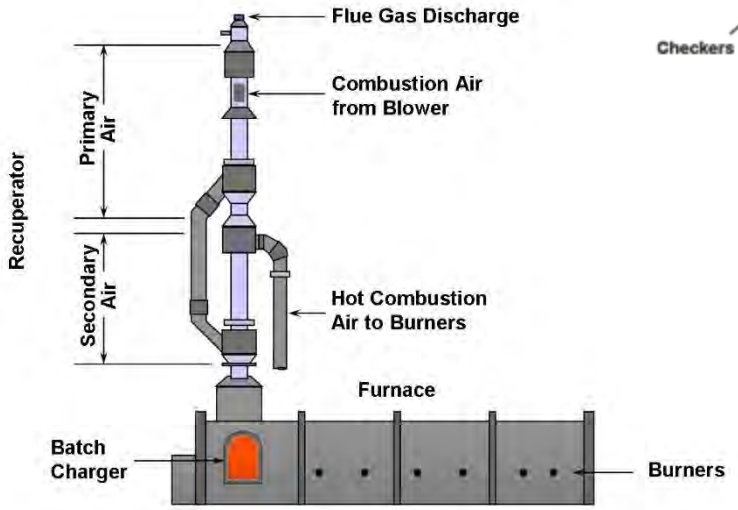
Regenerative Gas Fired Melter

Electric Melting Furnace

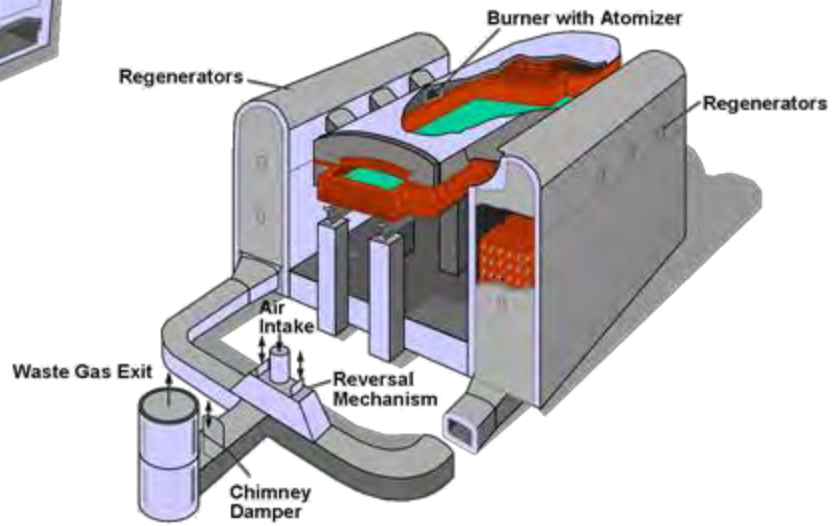
Glass Melting Furnaces



End-Port Regenerative Gas Fired Melter



Regenerative Gas Fired Melter

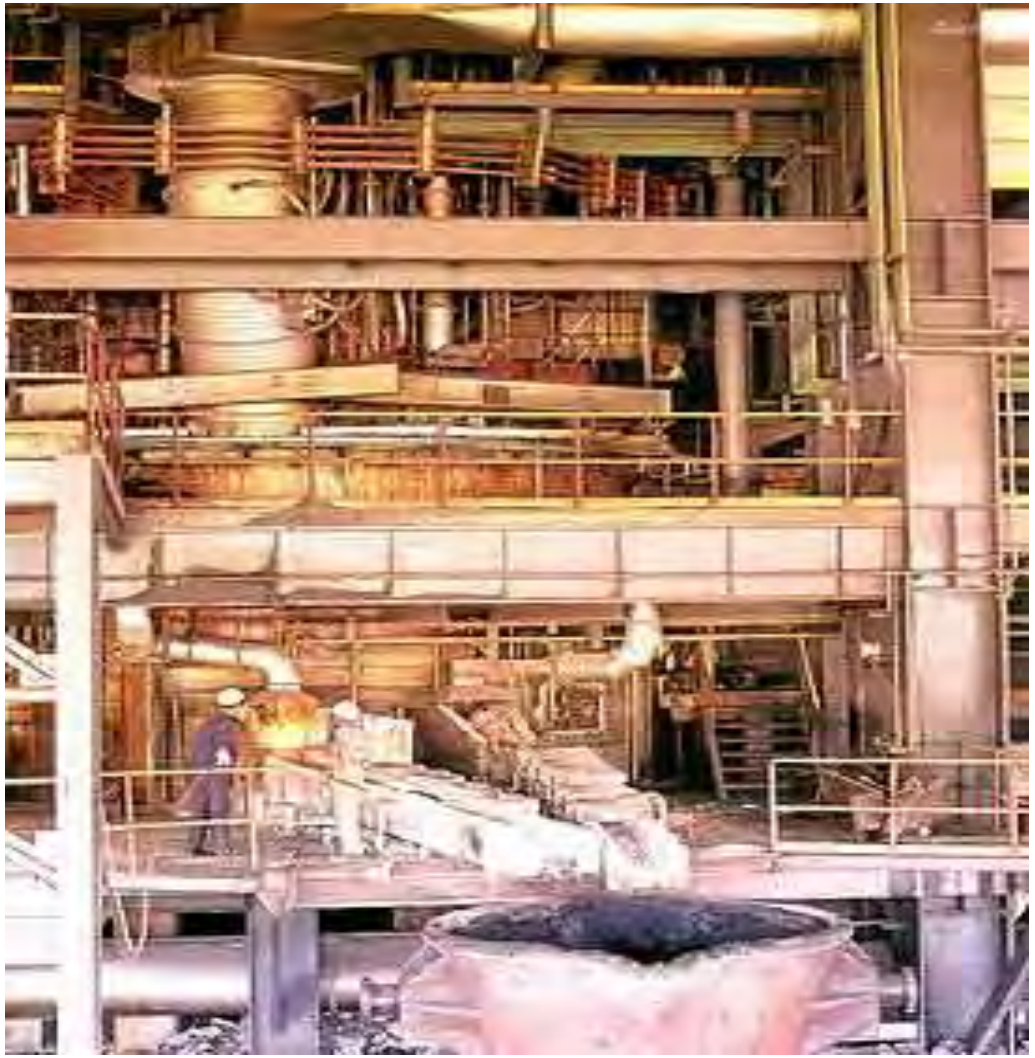


Side-Port Regenerative Gas Fired Melter

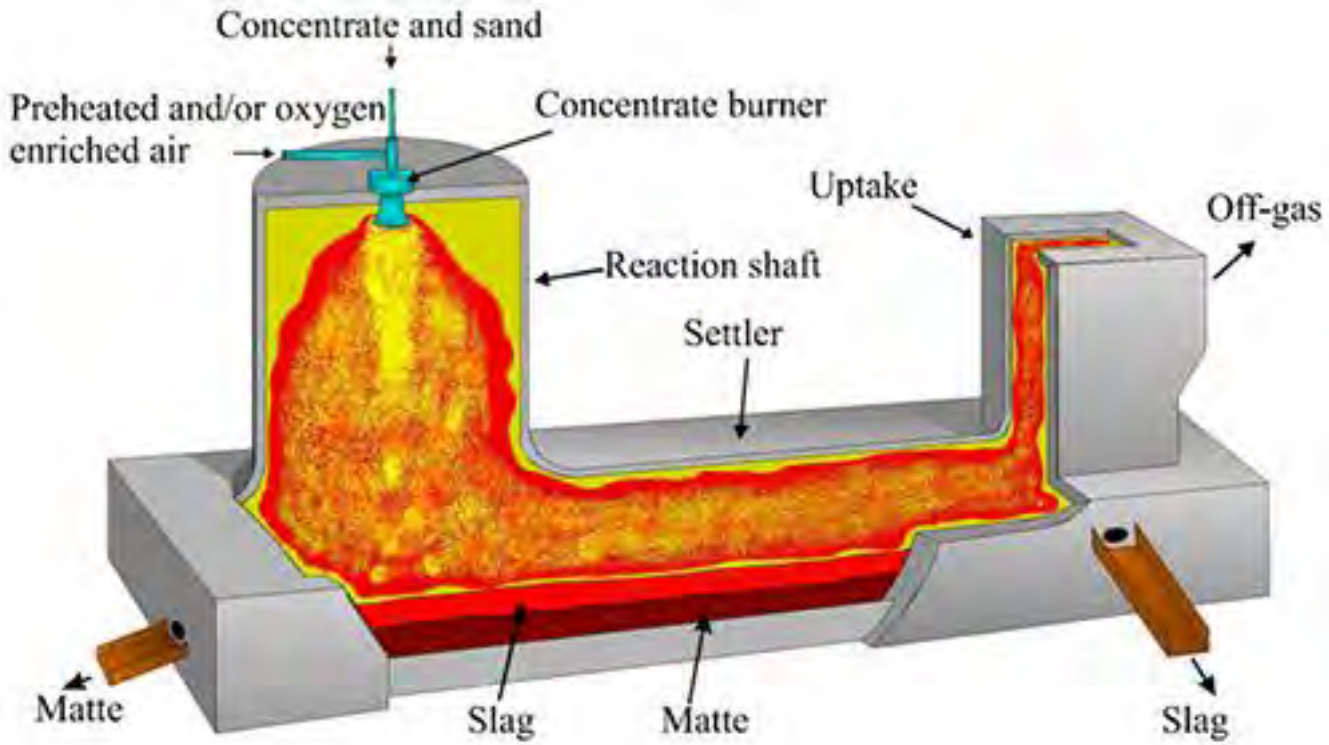
Smelting and Agglomeration

- 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



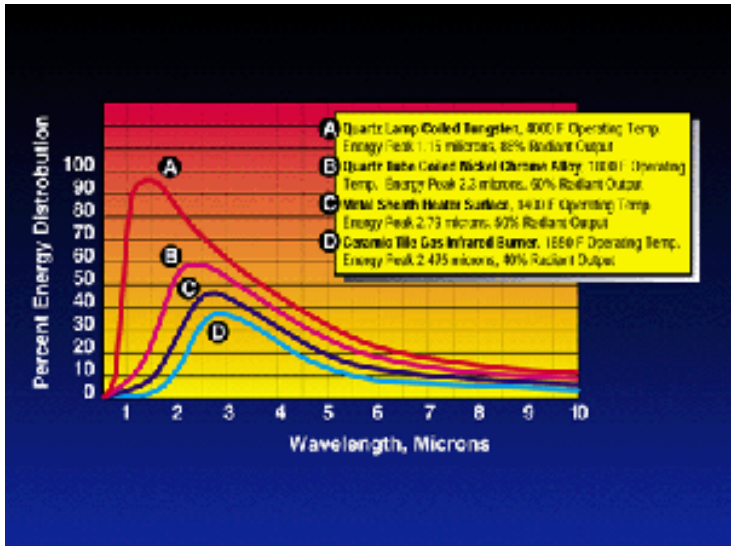
Smelting and Agglomeration - Conventional Smelting Furnace (Copper smelting)

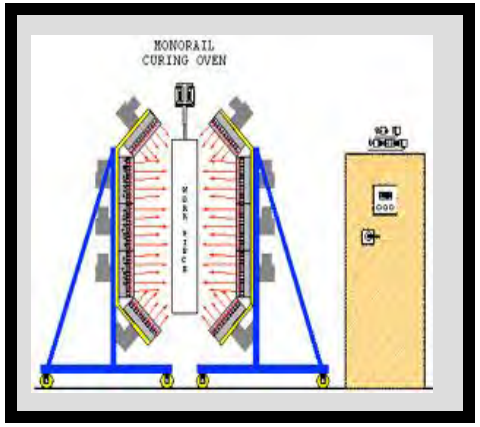


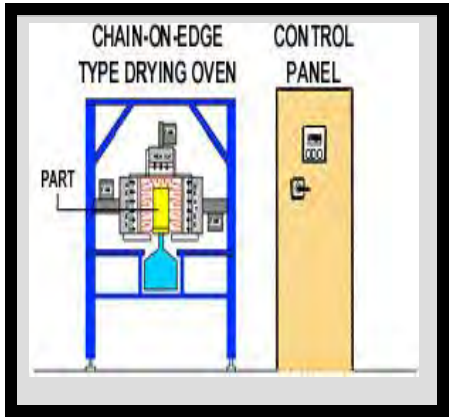
Curing and Forming

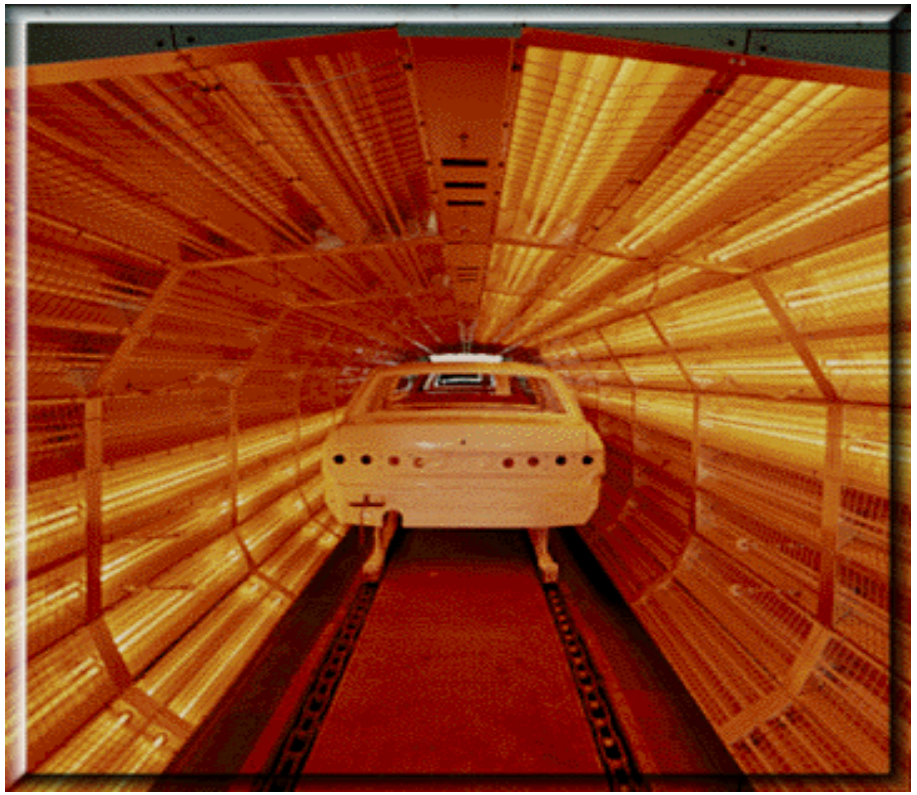
- To heat materials (commonly organics) to promote chemical change, to bond, fuse, to change shape, etc. without melting.
  - Direct fired ovens
    - Various configurations
  - Infra-red heating systems (gas or electric)
  - Hot liquid or steam heated systems
- Current level of efficiency – 50% to 70%
- 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

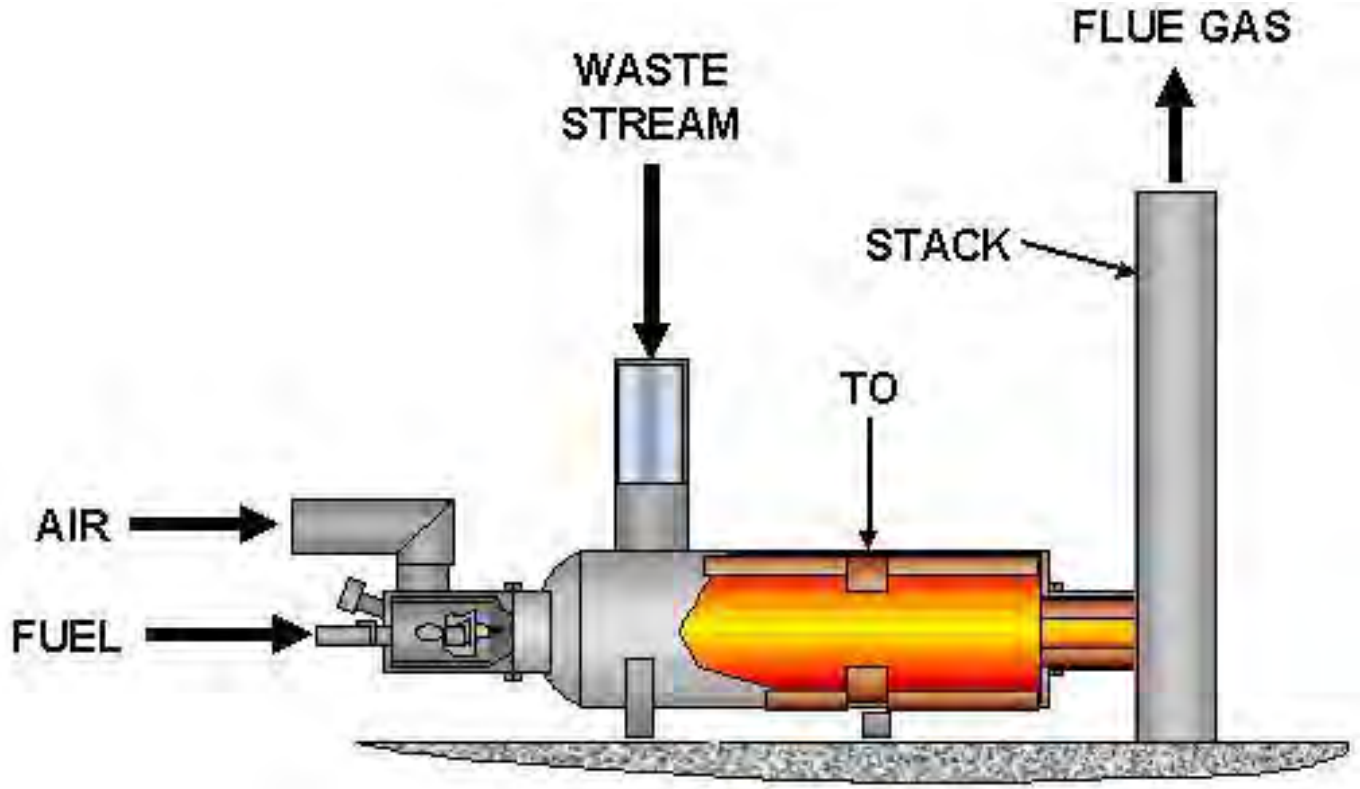
Conveyor Type Drying Ovens with High Convection Recirculating Gases

Coil Coating – Drying Ovens with High Convection Recirculating Gases

Other Heating

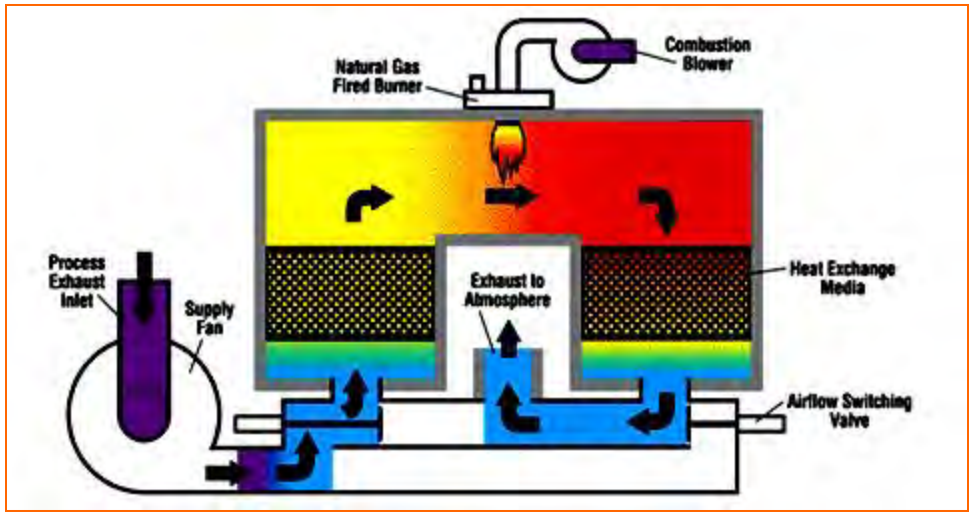
- To heat material or equipment (i.e., Thermal Oxidizers, Ladle Heating, Tundish Heating, etc.)
  - Direct fired ovens
    - Various configurations
  - Infra-red heating systems (gas or electric)
  - Hot liquid or steam heated systems
- Current level of efficiency – 50% to 70%
- Energy Source – Natural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

Thermal Oxidizers

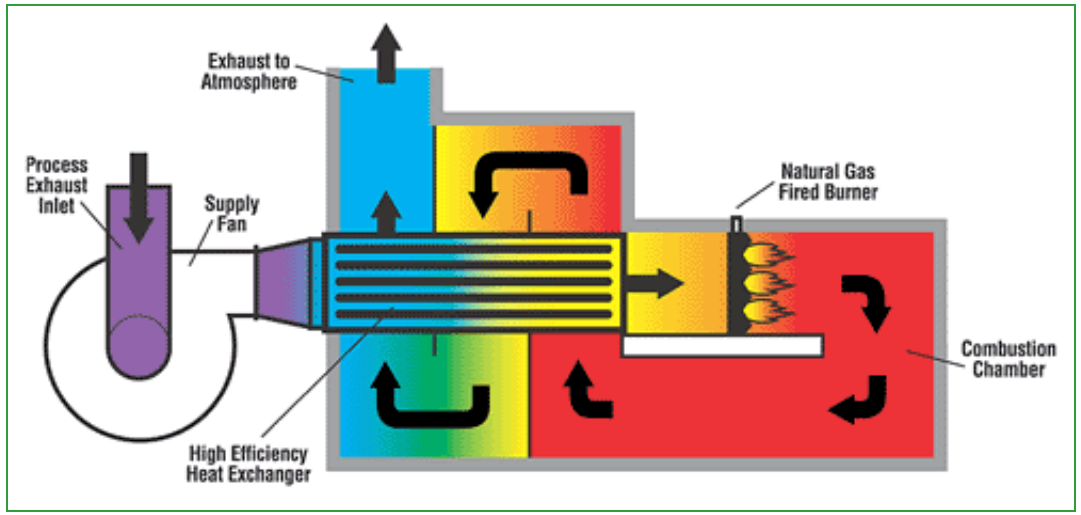


Thermal Oxidizers convert hydrocarbon air pollutants to carbon dioxide & water where time, temperature, & turbulence are important for destruction efficiency.

Thermal Oxidizers



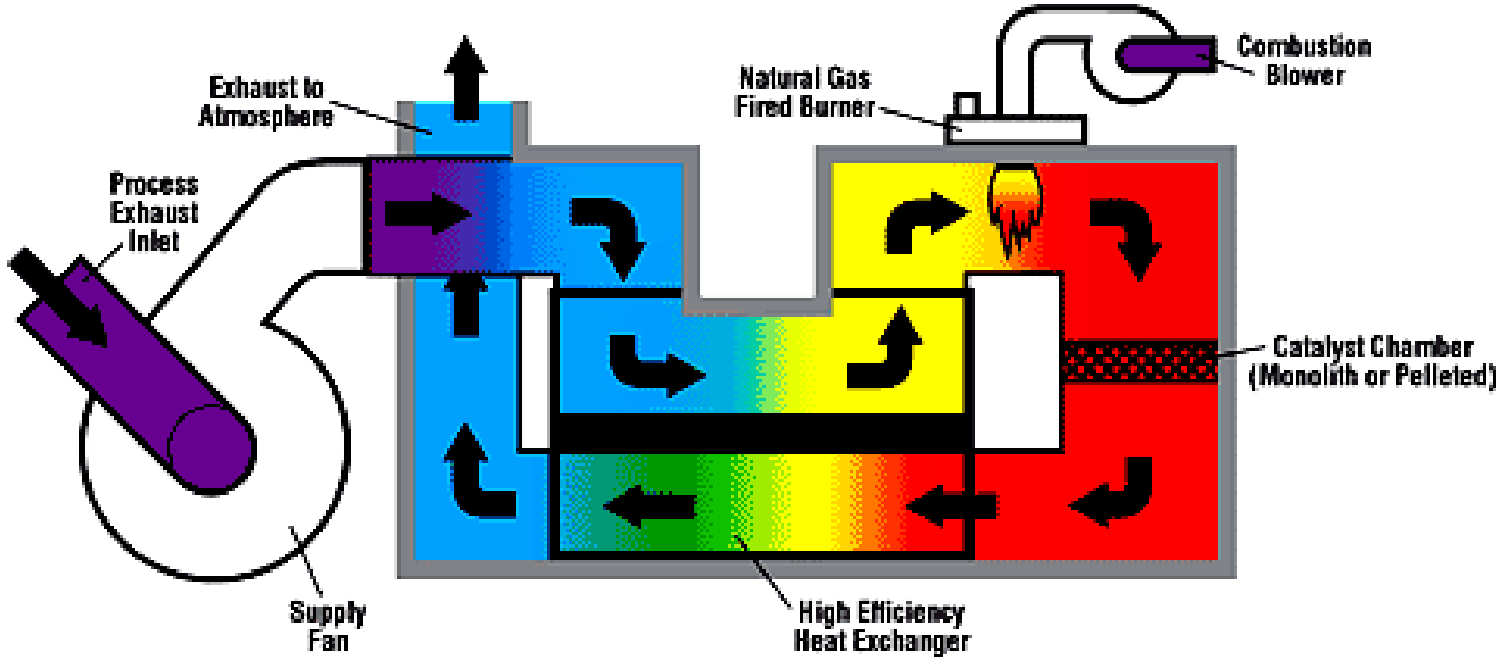
Regenerative Thermal Oxidizer



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