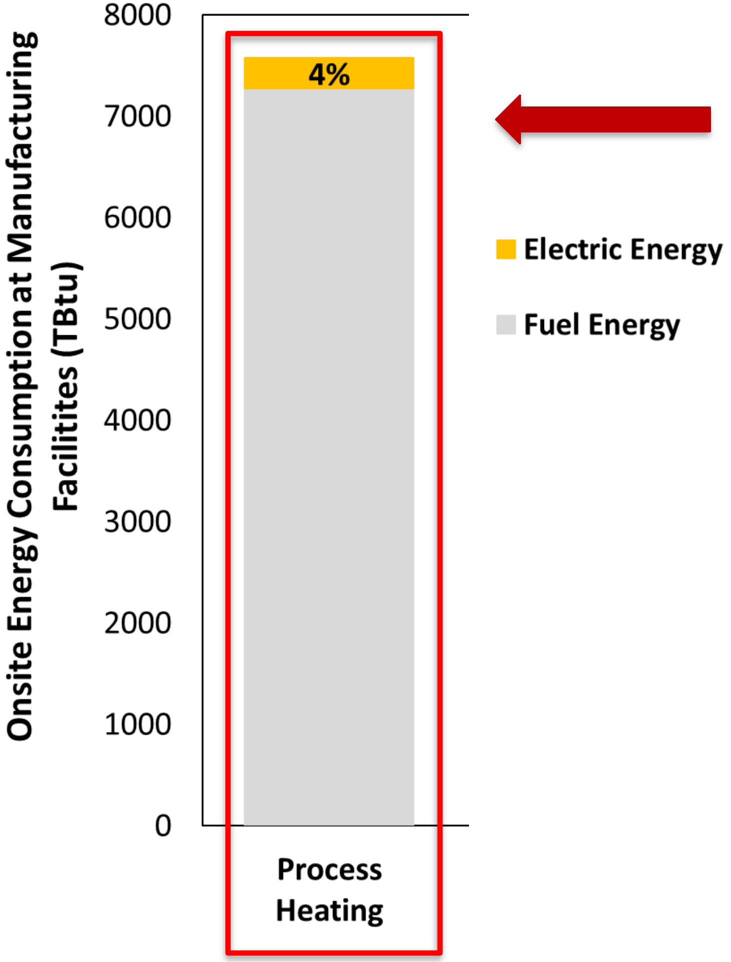
Better Plants
U.S. DEPARTMENT OF ENERGY

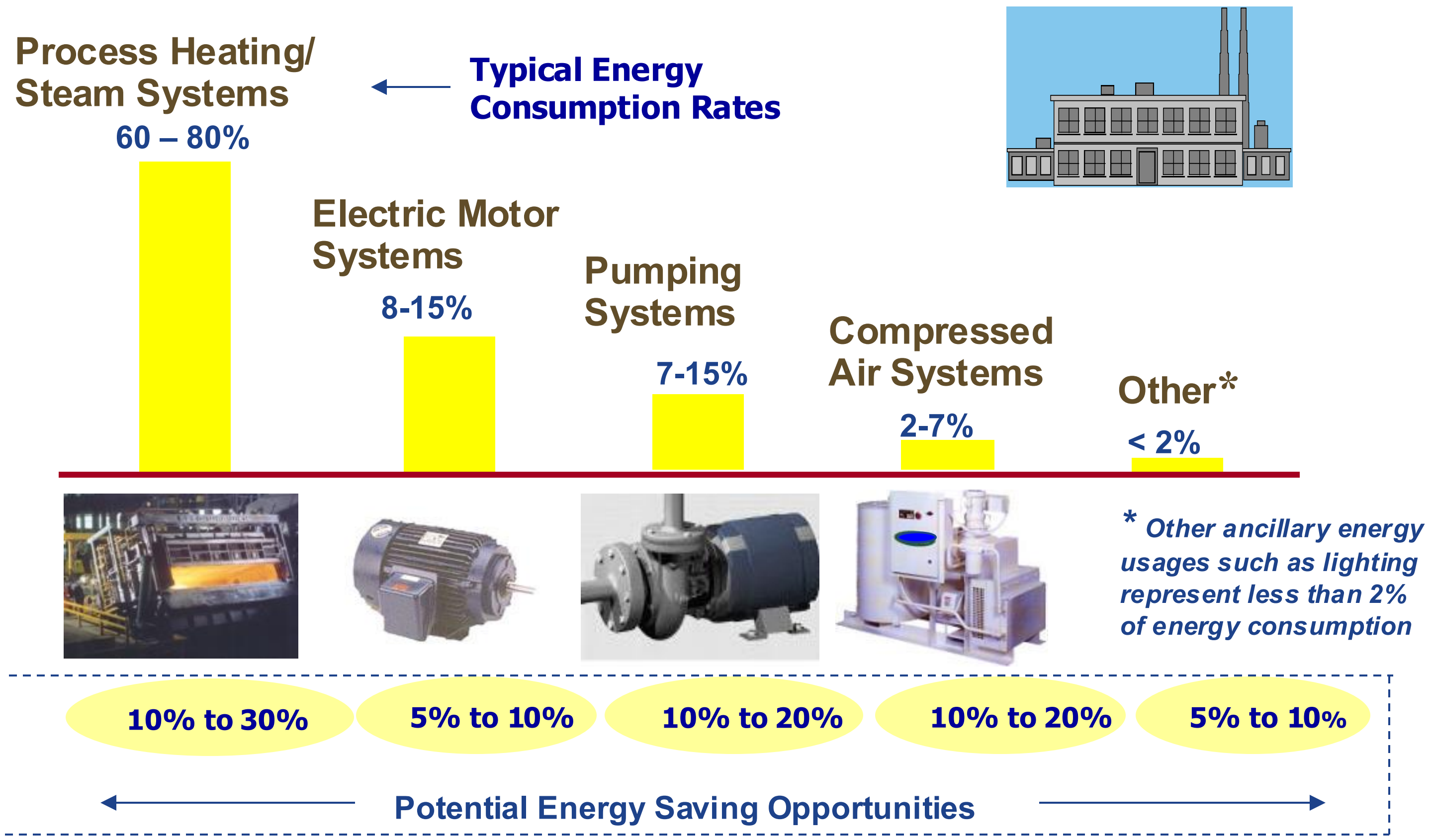
VIRTUAL PROCESS HEATING INPLT
Session 6

Training Module # 6
Energy Efficiency Improvements for Process Heating Equipment

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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

Process Heating Equipment

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)

Poll Questions

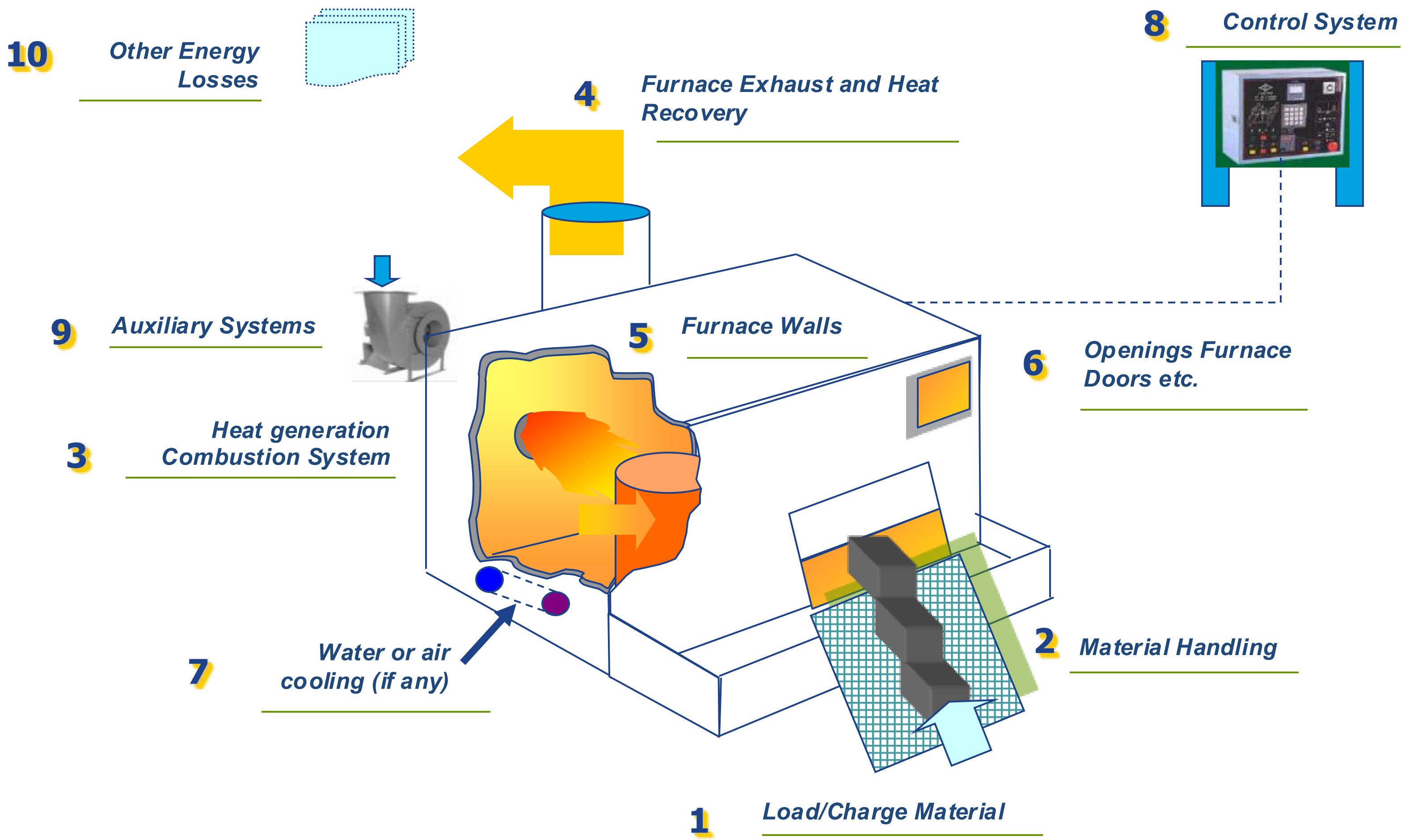
1. What are the primary barriers you face in adopting energy-efficient technologies for industrial thermal processes?
   a) High Capital Costs and Long Payback Periods
   b) Technological Limitations OR Availability
   c) Production Disruption and Downtime Concerns
   d) Lack of Awareness and Technical Knowledge
   e) Energy Efficient Projects Receive Lower Priority

2. In your operations, which specific thermal process do you consider the most challenging to improve? (Open-ended)

3. In your opinion, which area requires the most attention and support to overcome challenges related to energy efficiency in industrial thermal processes?
   a) Hands-on Technical Assistance
   b) Validated Case Studies and Demonstrations
   c) Research and Development of New Technologies
   d) Financial incentives or grants for adoption
   e) Decision-support Tools and Lifecycle Cost Analysis Frameworks

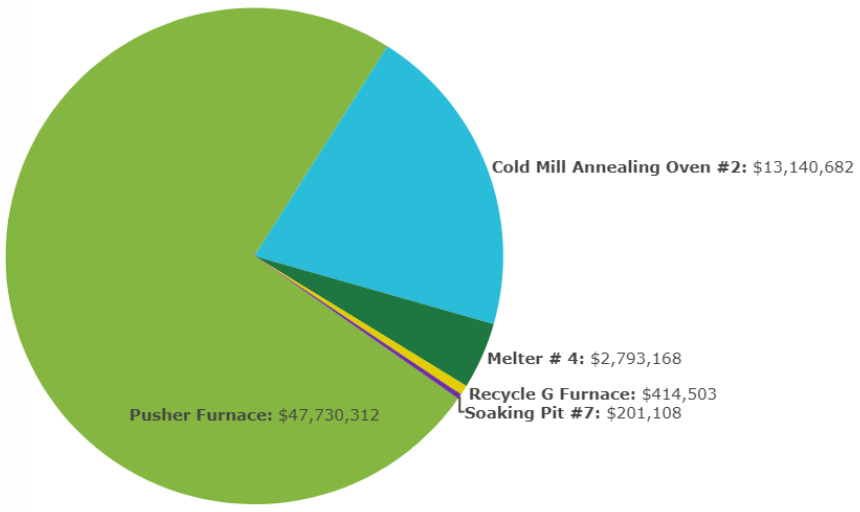
Energy Savings in Process Heating

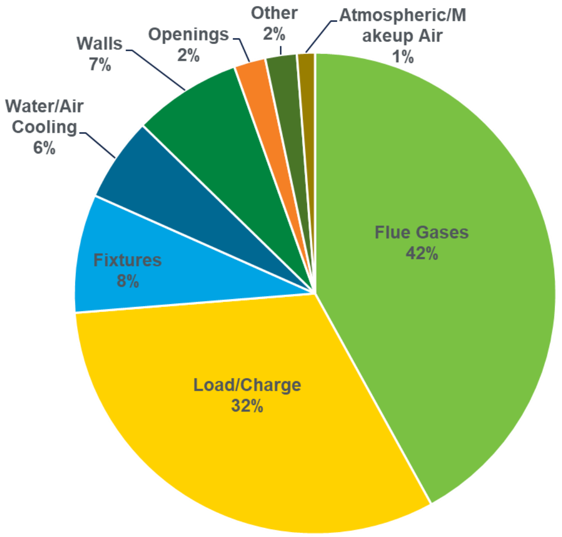
Areas of Energy Use and Possible Improvements



Steps to Improve Thermal Efficiency

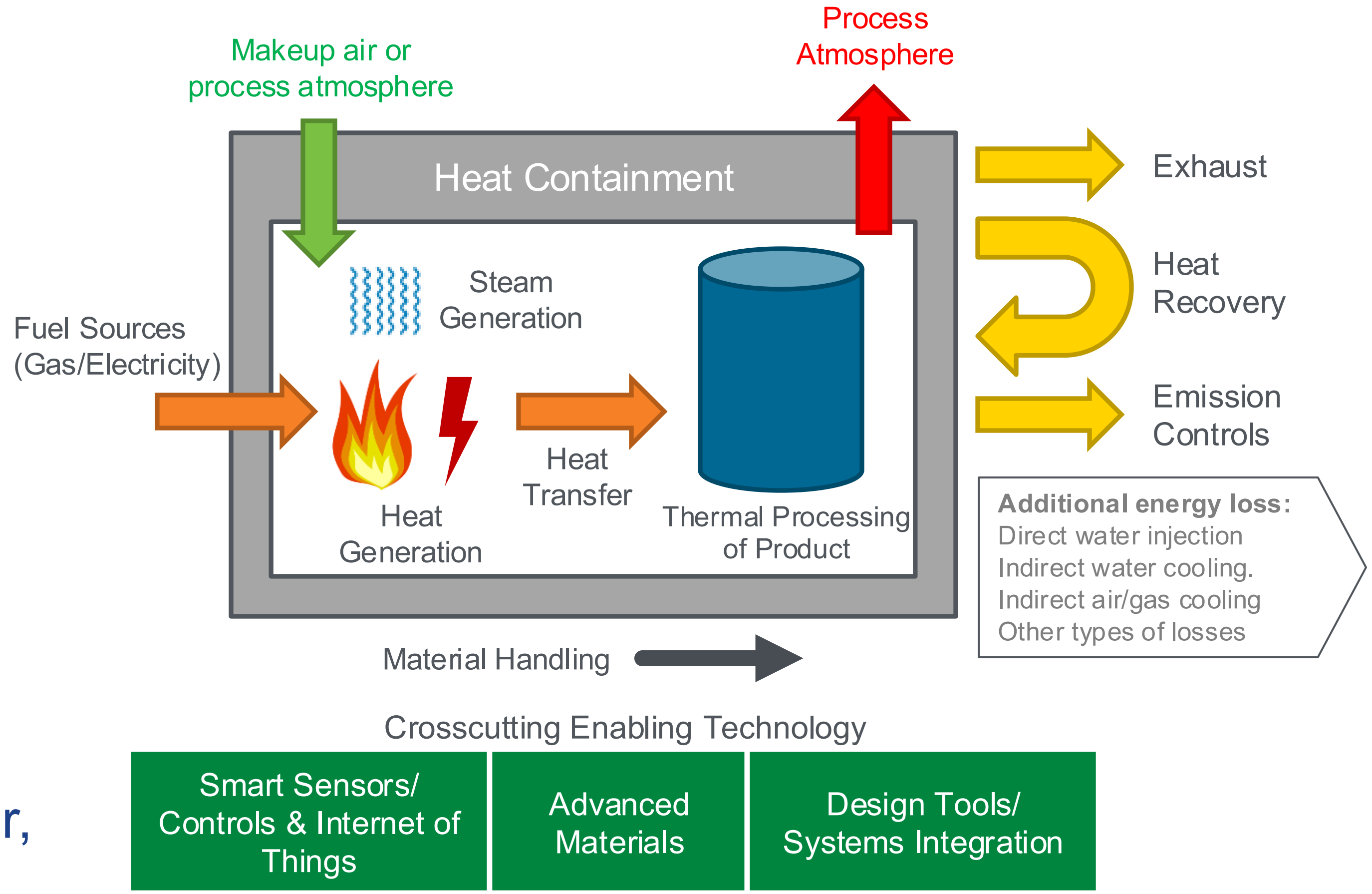
- **Analyze energy use distribution**
  - How much energy is used and where is it going?
- **Identify areas of possible energy savings and measures**
  - Where can we reduce energy loss and save energy
  - What measures/actions can be taken to reduce energy loss and improve energy efficiency?
  - How 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.)

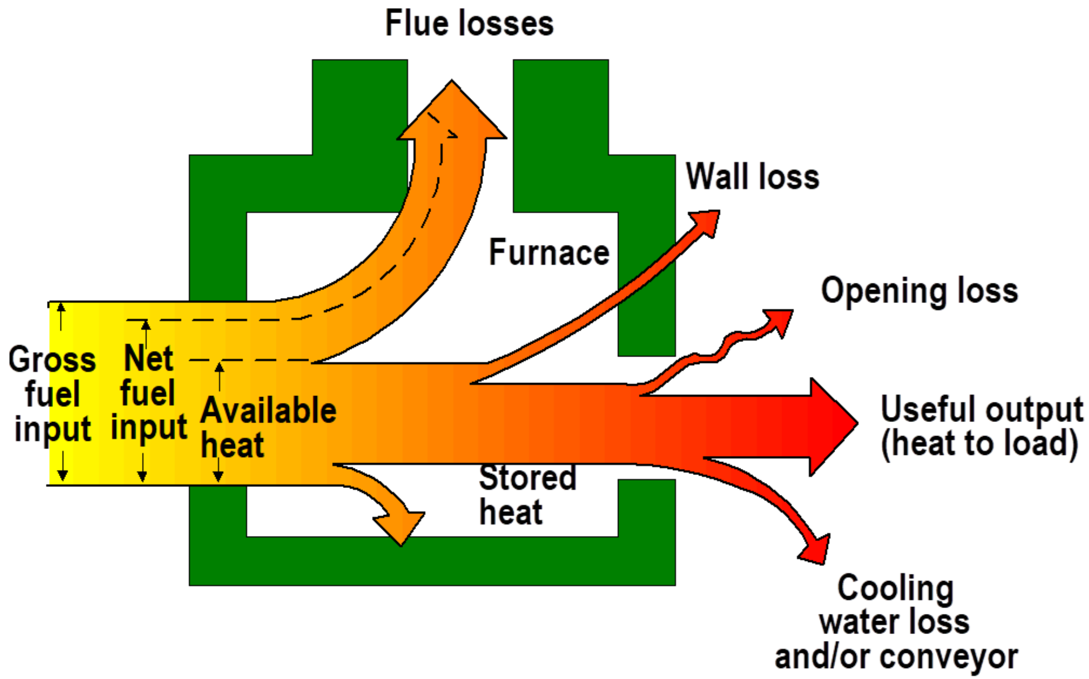


What is Available Heat?

$$Available\ Heat = Heat\ to\ Load + Wall, Opening, Conveyor,$$
$$and\ Cooling\ Losses\ + a\ Portion\ of\ Stored\ Heat$$

$$= Gross\ Heat\ Input\ - Flue\ Gas\ Losses$$

$$\%\ Available\ Heat = \frac{Furnace\ Heat\ Input\ - Heat\ in\ Flue\ Gases}{Furnace\ Heat\ Input}$$



Sankey Diagram Source: North American Combustion Handbook, Second Edition, Courtesy Fives North American Combustion, Inc.

Range of Energy Use and Savings Potential

Area of energy use or loss	Range of energy use as % of the input	Range of energy savings use as % of energy use
Load/charge material	15 to 75	0 to 25
Material handling	0 to 20	0 to 50
Heat supply/heat generation (combustion system, electric, and other)	N/A	0 to 50
Furnace exhaust and heat recovery	10 to 60	0 to 50
Furnace-oven walls	2 to 15	0 to 25
Furnace openings and doors	0 to 20	0 to 100
Water or air cooling (furnace internals – if any)	0 to 15	0 to 50
Control system	N/A	0 to 10
Auxiliary systems	2 to 10	0 to 25
Other losses (i.e., atmosphere, makeup air, ex-filtration of gases, etc.)	0 to 50	0 to 50

Note: Exact values depend on many factors and can be obtained only by conducting a good heat balance analysis. The U.S. DOE MEASUR tool can be used effectively to prepare a heat balance and estimate ranges for values.

TOP TEN FREQUENTLY IDENTIFIED PROCESS HEATING OPPORTUNITIES

SAVE ENERGY NOW ASSESSMENTS - 2006 to 2011

Top Ten Frequently Identified Process Heating Opportunities (ESAs - 2006 to 2011)	No. of Times Identified	Average Energy MMBtu Savings Identified (Source)	Average Source Energy Savings % Identified (%)	Average Energy Cost Savings Identified ($)	Average Energy Cost Savings % Identified (%)	Average of Payback Period Actual (yr)
Reduce O_2 content of flue (exhaust) gases	183	24,500	1.2	$177,500	1.3	0.9
Use of exhaust gas heat for combustion air preheating	123	67,000	3.6	$407,000	2.6	1.9
Proper insulation and maintenance of furnace structure or parts	120	24,500	1.0	$166,500	1.1	1.4
Reduce-eliminate openings and air leakage in the furnace	76	20,400	1.1	$154,500	1.3	1.0
Load or charge preheating using heat from exhaust gas or other source of waste heat	72	30,200	1.5	$245,700	1.8	2.0
Heat cascading - use of exhaust gas heat from higher temp. process to supply heat to lower temperature processes	61	53,700	2.1	$407,000	2.3	1.5
Use of proper heating methods - replace inefficient and uneconomical methods with economical/efficient system	54	83,000	6.5	$407,500	3.6	3.0
Heat recovery from hot products or other heat sources (i.e., from walls) from a furnace - oven	44	83,000	2.8	$558,700	3.3	1.8
Furnace scheduling, loading, shut down, delays, waits, cooling between operations etc.	40	36,000	2.3	$323,900	2.8	0.4
Use of O_2 for combustion	37	86,000	2.6	$598,300	3.2	1.9

* Based on Save Energy Now assessments conducted between 2006 to 2011. Numbers are as of October 1, 2011.

Few Example Projects

- Chemours reduced its GHG emissions by 1,200 MT of CO2e/year by improving boiler control and optimizing fuel/air to improve turndown, eliminate steam venting, and reduce stack losses.
- Charter Steel installed a sustainable scrap preheat system that reduced dust in the facility by 73%, annual electricity consumption by 2.25 million kWh, and annual GHG emissions by 14,000 tons.
- Eastman Chemical Longview, TX facility reduced its process heating demand significantly by splitting production into an ultra-high purity product and a high-purity product – 42% reduction in energy and 11,000 short tons of CO2 emissions reduction annually.
- Nissan Smyrna, TN facility implemented new paint plant that uses a "3-Wet" process that allowed for the removal of a costly high temperature oven bake step – 40% energy savings, 78% reduction in VOCs, and 20% reduction of CO2 emissions.
- 3M implemented a real-time, battery-less steam trap cloud monitoring system that saves 10.6 million pounds of steam per year.

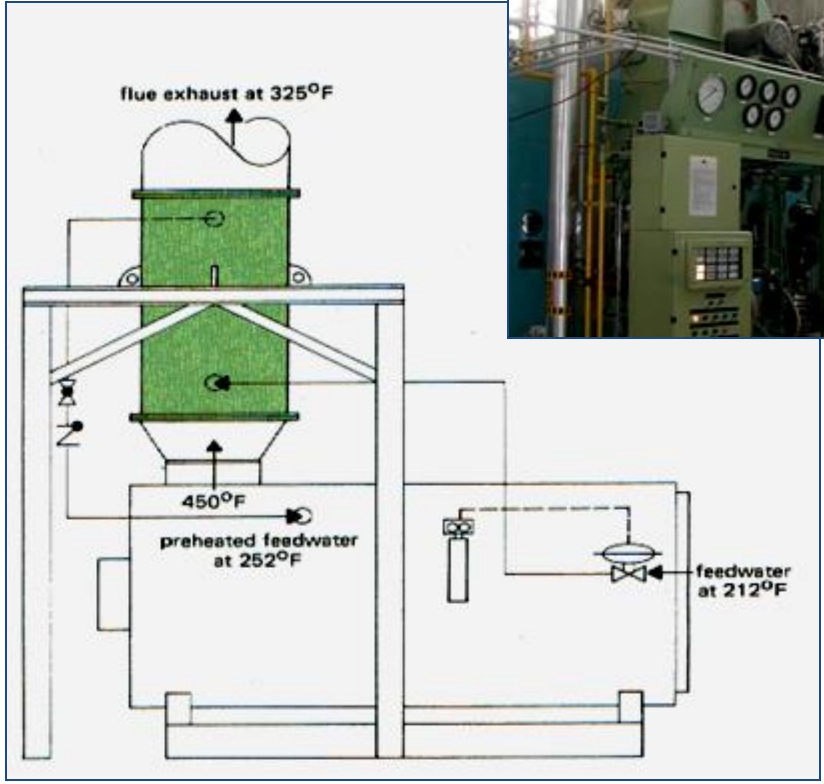
Few Example Projects

- Bridgestone eliminated the use of hot water from the tire curing process and replaced it with a N2 process, resulting in 15,000 MT of CO2 emissions and ~13 million gallons of water per year.
- ThyssenKrupp implemented improvements to a decades-old structural oven, with a 35% reduction in oven gas consumption and 34% reduction in firing rate and oven hours.
- Waupaca installed a blast-air dehumidification system to compensate for high humidity conditions, reducing annual coke usage by 2.5% and representing savings of 16,728 MMBTU and 1,804 MT CO2 per year.
- PepsiCo installed a condensing economizer to recover energy from a boiler stack, reducing site fuel usage by 10%.

Load Charge Material

- Hot charging of the load where possible
- Preheating of the load or charge:
  - External preheating
    - Using heat from furnace flue gases
    - Using auxiliary preheating
  - Internal preheating
- Drying or moisture removal
- Charging at or near design capacity and frequency
- Proper load arrangement for optimum heat transfer
- Use of new processes and technologies

Feed Water Economizers



- Economizers can be used to recover 40% to 60% of the flue gas heat entering the economizer
- Overall energy reduction could be in the range of 3% to 10% of the total heat used for the boiler
- Avoid cooling the flue gases below their dew point
- Flue gas condensation temperature depends on water content and type of fuel (H_2 and S content) used

Recoverable Heat from Boiler Flue Gases

Initial Stack Gas Temperature, °F	Recoverable Heat, MMBtu/hr			
	Boiler Thermal Output, MMBtu/hr			
	25	50	100	200
400	1.3	2.6	5.3	10.6
500	2.3	4.6	9.2	18.4
600	3.3	6.5	13.0	26.1

Based on natural gas fuel, 15% excess air, and a final stack temperature of 250˚F.

Feed Water Economizer Options

Non-condensing economizers

- Typically, a non-condensing economizer will raise the overall efficiency by 2% to 4%.
- They are designed and operate to maintain the flue gas temperature above the flue gas condensing temperature to prevent corrosion of the flue gas ducting.
- For fuels with high sulfur content condensation will lead to the formation of sulfuric acid, which is highly corrosive.

Condensing economizers

- Condensing economizers are designed to accommodate the corrosive fluids generated when condensing the moisture out of the flue gas.
- There are 2 types of condensing economizers: heat exchange and direct contact (spray). They can raise the overall boiler efficiency by 10% to 15%.
- For condensing economizers to be the most effective, low temperature heat sinks are required to bring the flue gas temperature well below the flue gas condensing temperature.

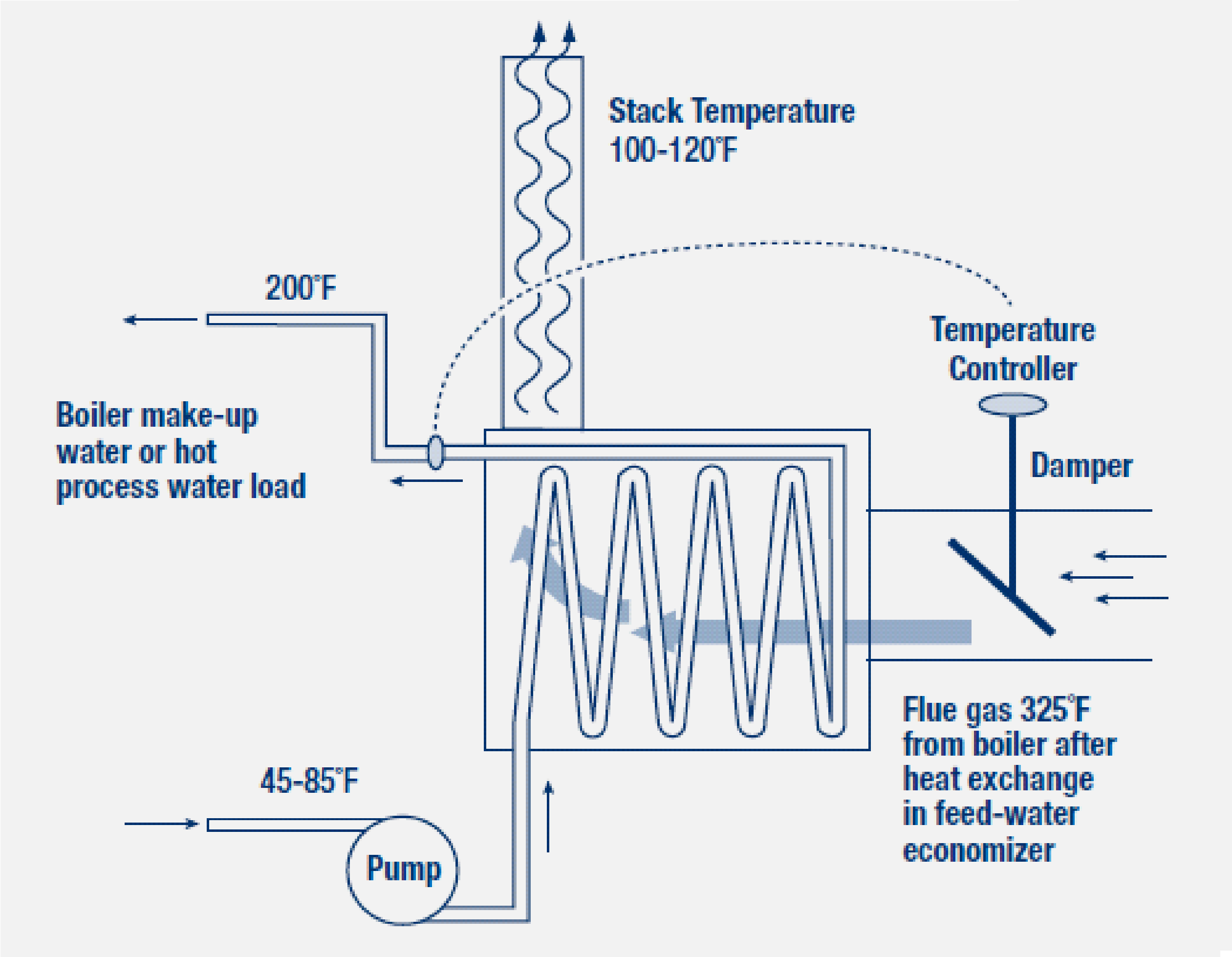
Economizer Examples

Installation of a condensing economizer on a boiler
Courtesy: Clever-Brooks Inc.

Example of use of economizer
Before and after case
(courtesy Cane Industries)

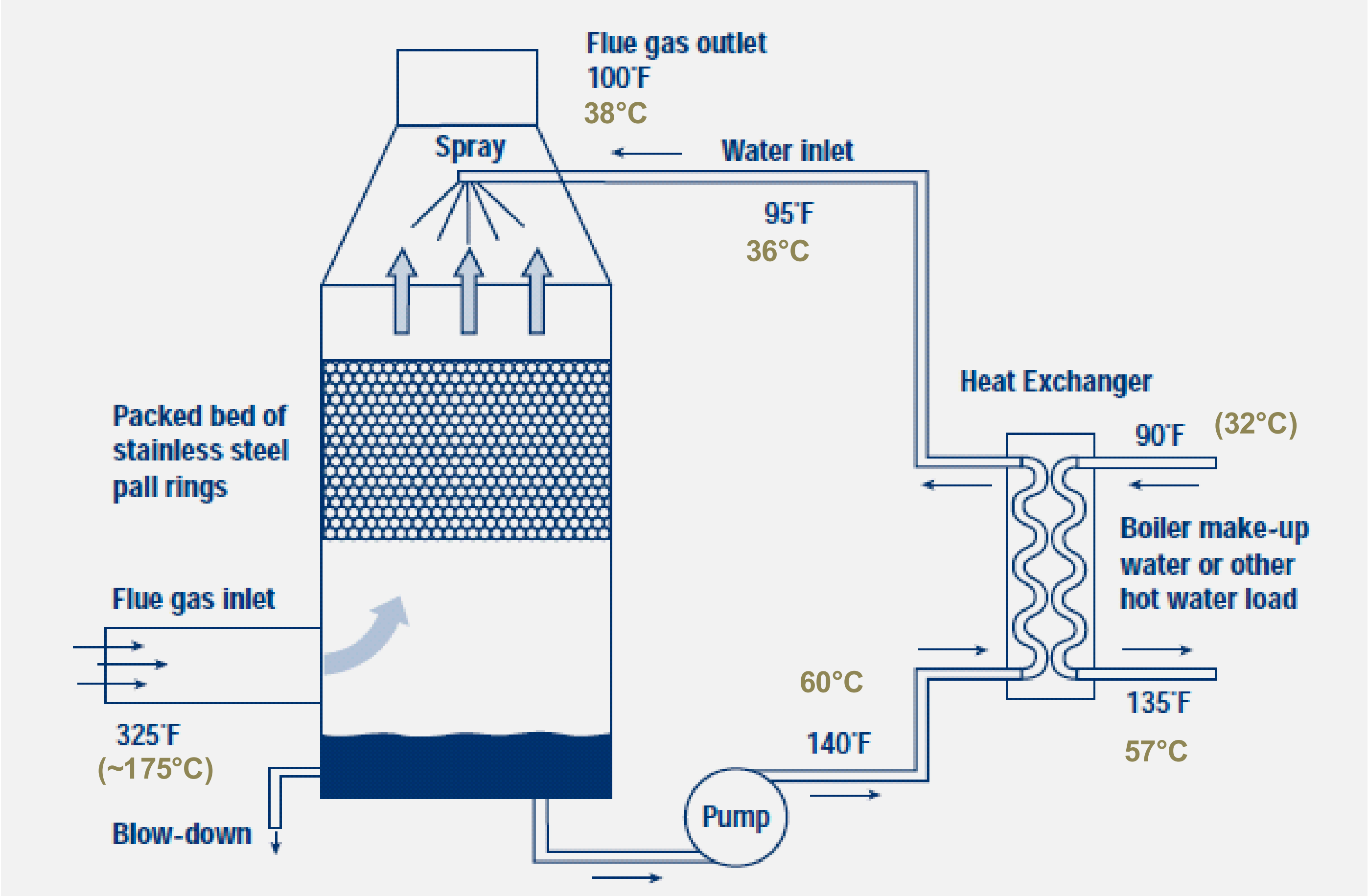
Super boiler that offers ~95% efficiency
Before and after case
(courtesy GTI)

Indirect Condensing Economizer



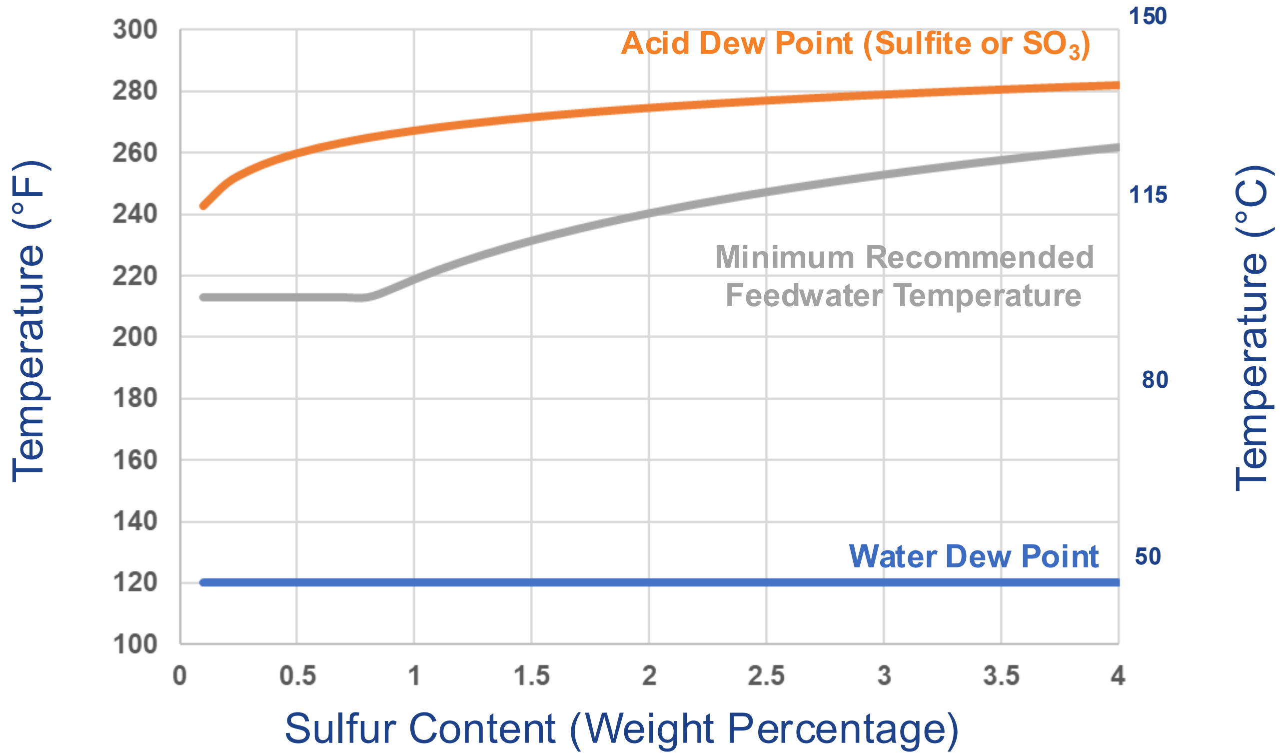
Indirect contact condensing economizer

Direct Contact Condensing Economizer



Direct contact condensing economizer with packed bed and external heat exchanger

Limits on Flue Gas Temperature from an Economizer



- Heat recovery from flue gases depends on the type and sulfur content of the fuel used
- This graph shows the minimum recommended feed water temperature at the inlet (economizer) so that the flue gas temperature does not drop below acid dew point
- For most natural gas applications, maintain a feed water temperature above 220°F so that the flue gas temperature does not drop below approximately 250°F

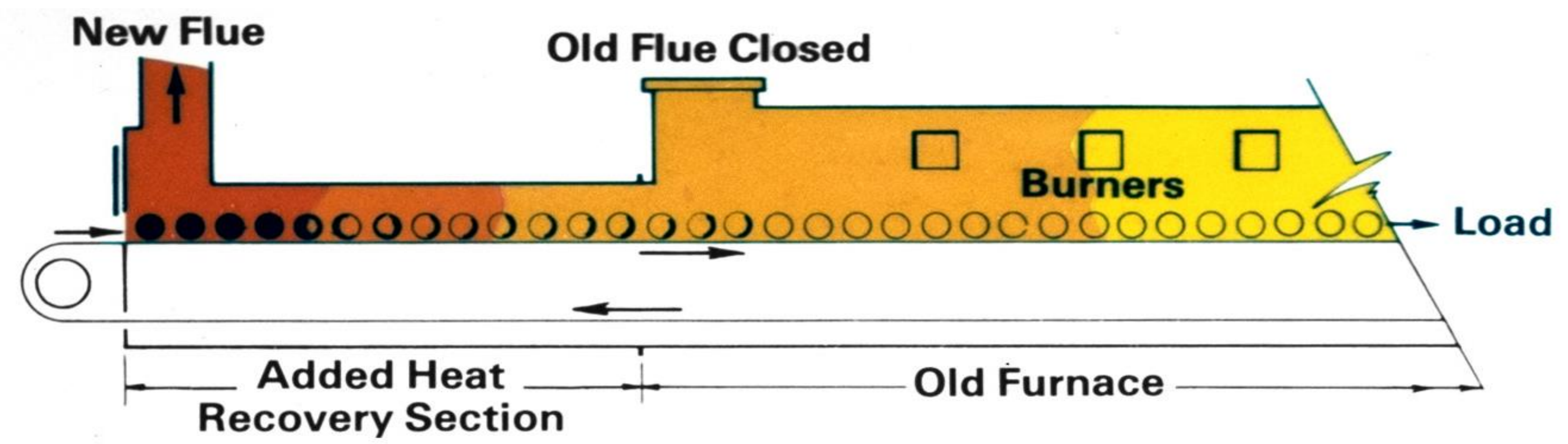
Savings by Using Higher Temperature Feed Water in a Boiler

Equipment type	BOILER
Connected load (MBtuh)	55,000
Operating time (hrs/yr)	8,000
Load factor (%)	90%
Equivalent full load hours (hrs/yr)	7,200
Annual gas use (therms/yr)	3,960,000
Flue gas temperature (hot-side inlet) (F)	600
Oxygen in flue gas (%, dry basis)	5.0%
Excess air (%)	28.0%
Water (cold-side) flow rate (gpm)	60.00
Water (cold-side) pressure (psig)	150
Water (cold-side) inlet temperature (F)	125
Displaced hot water boiler efficiency (%)	72%
Water (cold-side) outlet temperature (F)	305
Heat transferred to cold water (therms/yr)	389,111
Flue gas (hot-side) outlet temperature (F)	251
Gas savings (%)	13.6%
Annual gas savings (therms/yr)	**540,432**
Gas rate ($/therm)	$0.95
Annual cost savings ($/yr)	**$513,410**

Calculation methodology provided by Arvind Thekdi, E3M, Inc.

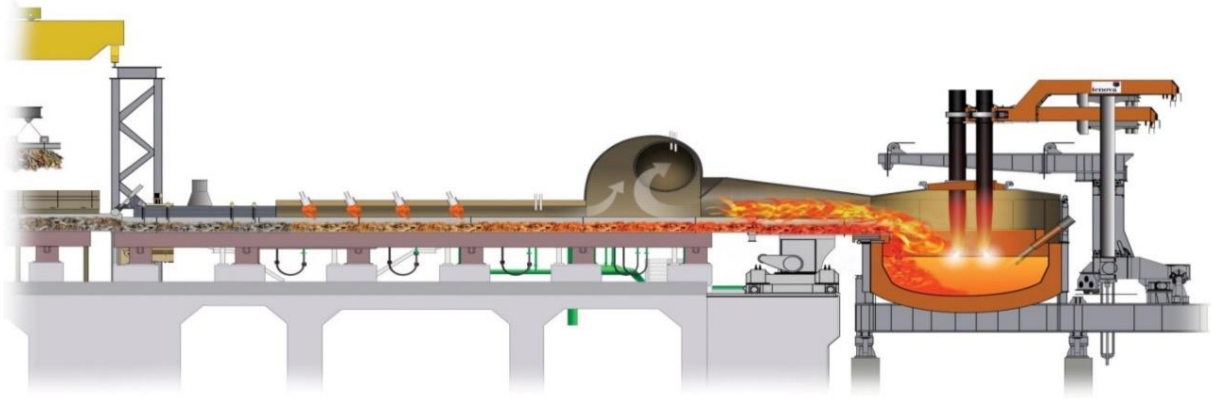
- Use of an economizer to preheat boiler feed water
- Initial conditions:
  - Water inlet temperature to boiler: 125°F
- Final conditions after installation of an economizer
  - Water inlet temperature to boiler: 305°F
- Energy savings: 13.6%
- Energy cost savings
  - $513,400 per year at $9.50/MMBtu
  - 8,000 hours/year operation at 90% load factor
- CO2 reduction: 3,160 tons/year

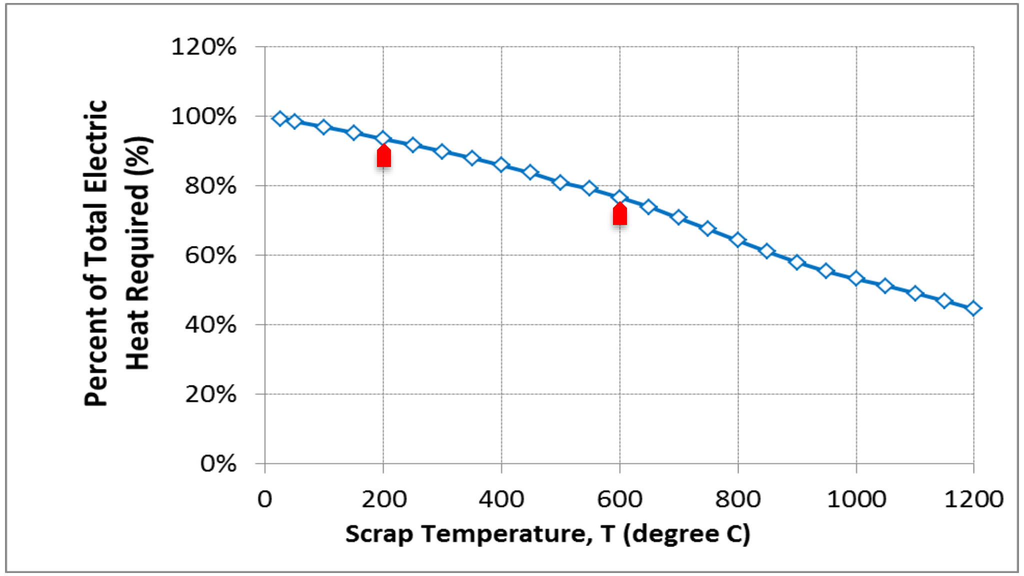
Load Preheating: Steel Reheat Furnace



- Use of the furnace flue gases to preheat the furnace charge material in continuous heating or heat-treating furnaces
- Furnace flue gases are passed “over” the charge material
- Potential energy savings – 15% to 20% for steel reheating furnaces

Steel Scrap: EAF Dryer and Preheater

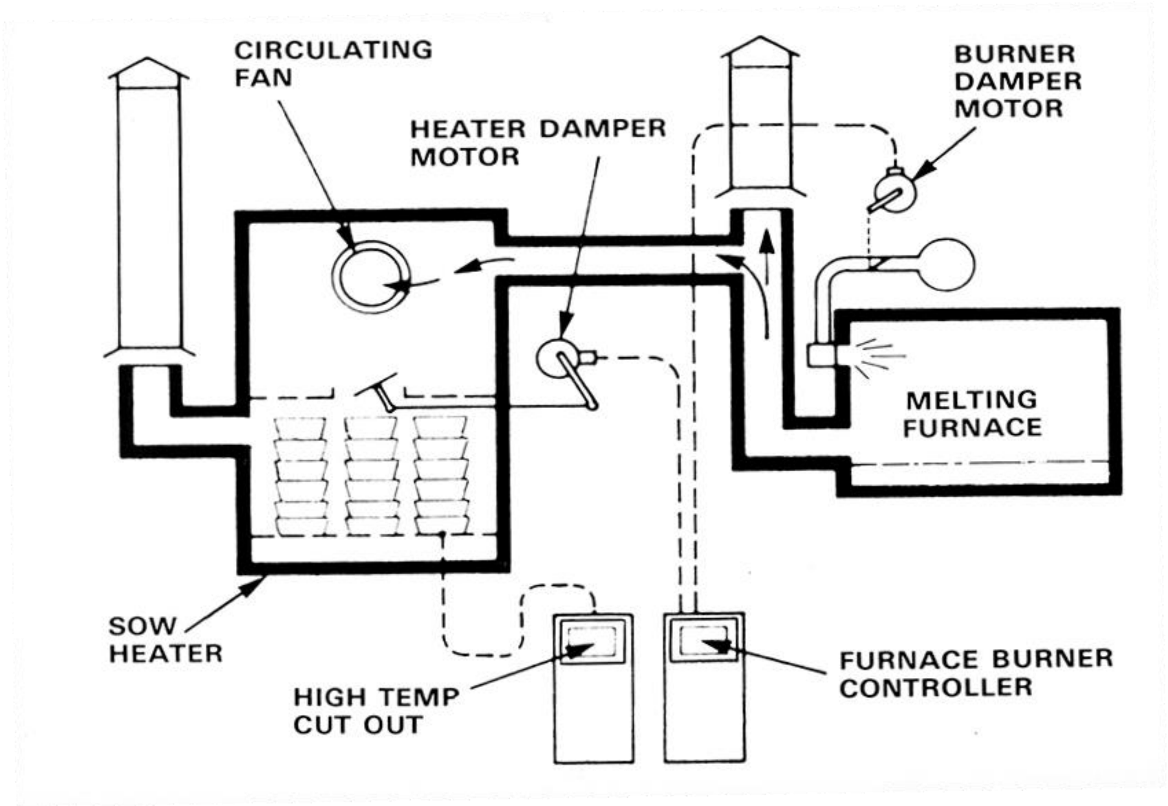




If we increase the scrap temperature from 390°F to 1110°F, the amount of electric energy needed for melting the scrap drops by additional 15%.

- Steel scrap is separated by a magnetic separation system
- Off gases from EAF are diverted to a conveyor carrying a steel scrap charge
- Necessary to use air for combustion of CO, H_2, and other combustible components of off gases
- Temperature control is crucial to avoid unsafe conditions, overheating of the system, or damage to property or personnel

Load Preheating: Aluminum Melting-Holding Furnace



- Use of the furnace flue gases to preheat the furnace charge material in aluminum melting or holding furnaces
- Furnace flue gases are used in a separate unit to preheat the charge material
- Potential energy savings – 15% to 20% for the melting furnaces

Load Preheating: Aluminum Melting-Holding Furnace

- Using hot or warm charged aluminum in a melting furnace can reduce energy use and save money
- Depending on the charge temperature, savings could vary from 10-20% of the total furnace energy used in the furnace
- Energy savings depend on:
  - Preheat temperature
  - Furnace operating conditions (flue gas temperature and percentage of O_2 in flue gases)
  - Final temperature of the charge
  - Heat losses from the furnace
- Additional benefits
  - Possibility of increased productivity

Savings: Load Preheating Aluminum Furnace – Gas Fired

Charge preheating in a typical gas-fired furnace can save up to <u>$30,000/year</u> in energy cost and may help increase production

Calculations for Savings - Furnace Charge Preheating using Exhaust Gases			
		Base	**New**
1	Charge Material	Aluminum	
2	Charging rate (as charged with moisture) (Lbs./hr)	4,000	
3	Base Charge Initial temperature (°F)	82	
4	New Charge Preheat temperature (°F)		400
5	Specific heat of the charge in temp. range of preheat (Btu/lb. F)	0.21	0.21
6	Base % moisture content in the charge (cold)	1.00%	
7	New % moisture content in the charge (preheated)		0.25%
8	Net heat reduction due to preheat (Btu/hr)	300,269	
9	Flue gas temperature from oven/furnace (°F)	1100	1100
10	Air preheat temperature (°F)	80	80
11	Current O2 in flue gases (%)	4.50	4.50
12	Available heat (%)	63.00%	63.00%
13	Savings in gross heat supplied to oven/furnace (Btu/hr.)	Base	476,607
14	Total energy savings (MM Btu/hr)	Base	0.477
15	Energy Cost ($/MM Btu)	$8.00	$8.00
16	Operating Hrs (per year)	8000	8000
17	**Energy savings (MMBtu/year)**	**Base**	**3,813**
18	**Savings - Energy cost ($/year)**		**$30,502.82**
19	**CO_2 savings based on fuel: natural gas (tons/year)**		**223**

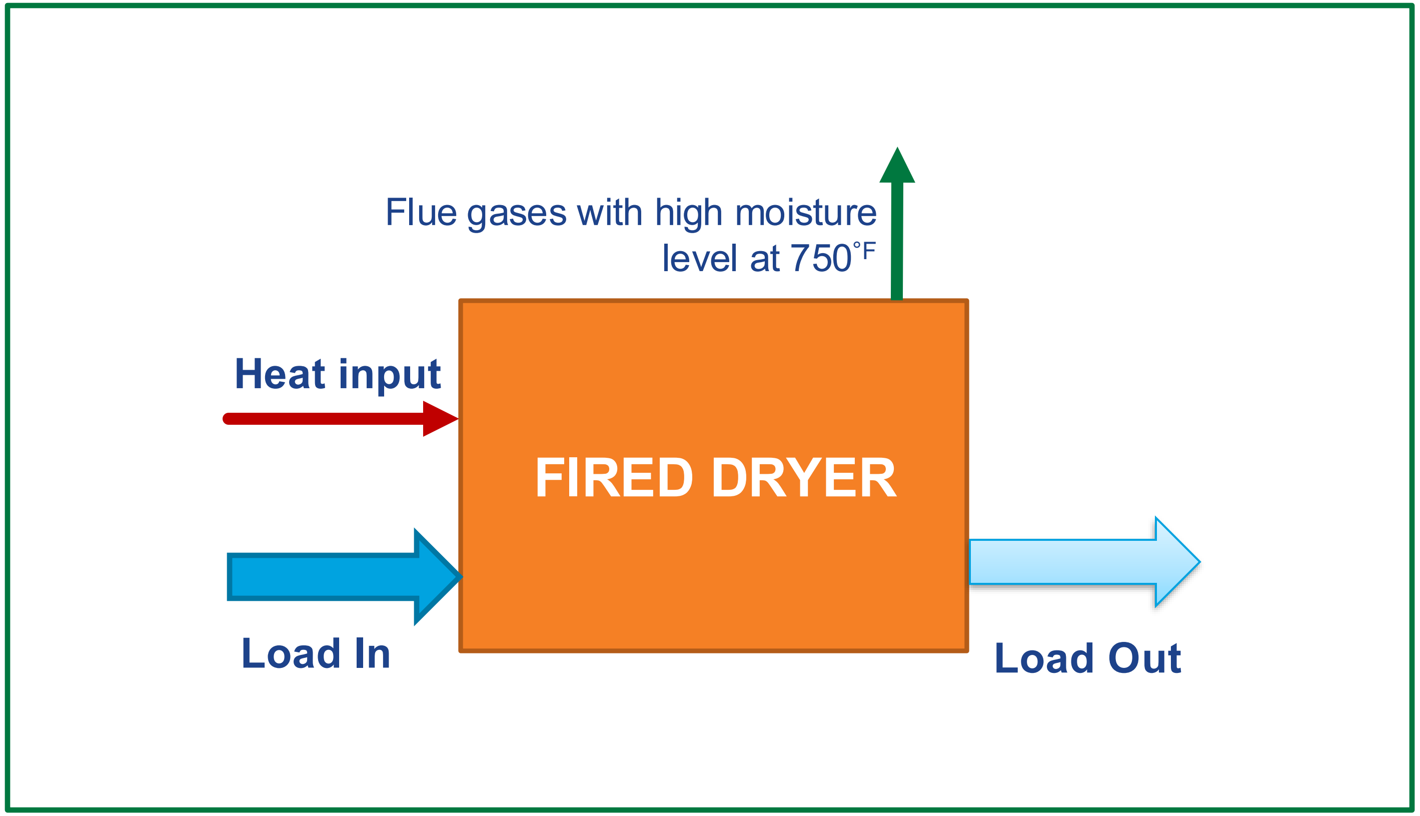
Moisture Removal or Pre-drying

Infrared pre-dryers for textile drying application - Energy reduction – 15% to 20%

Pre-drying of aggregate using heat from exhaust gases – mixed with outside air to reduce air humidity

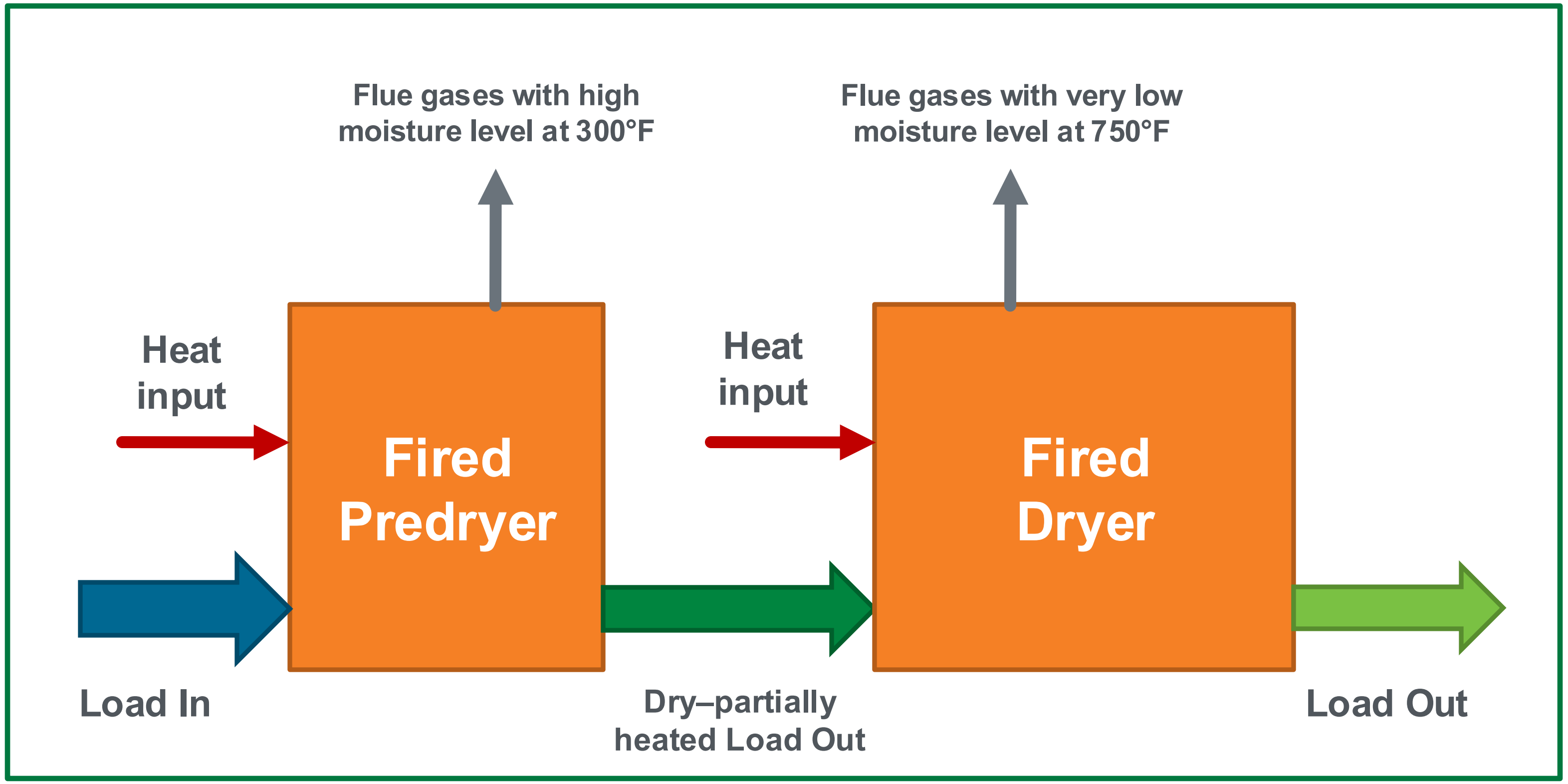
- Moisture removal requires a large amount of heat
- For most drying applications heat of water evaporation is a major heat load for the heating equipment
- Removal of moisture by non-thermal means (mechanical pressing) can be more energy-efficient in many cases
- Pre-drying (thermal moisture removal) can be done by:
  - Forced air drying
  - Using an external heat source
  - Using heat from dryer or oven exhaust gases

Use of Externally Fired pre-dryer



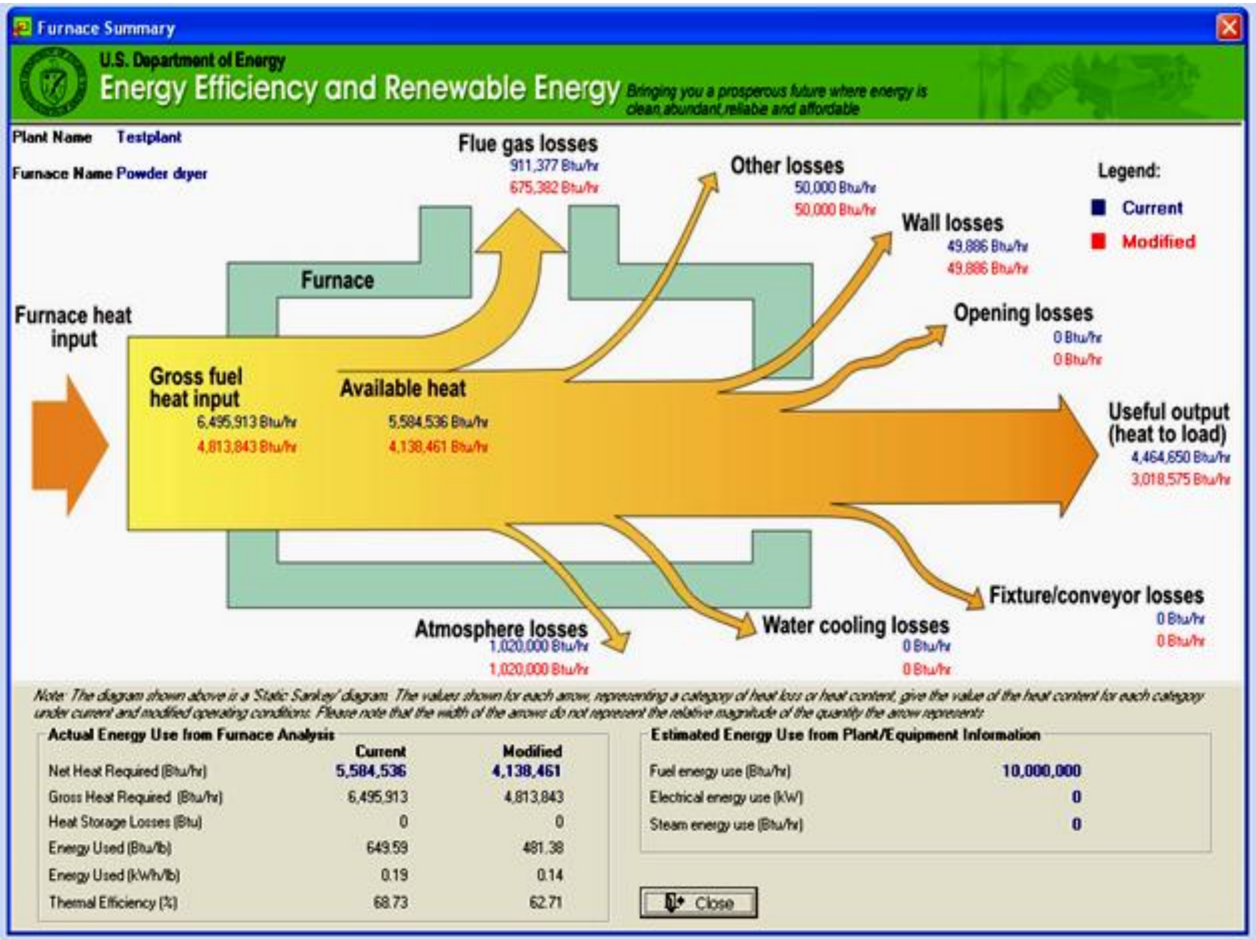
Conventional Dryer System

Use of Externally Fired Pre-dryer



Externally fired preheated – Energy savings approx. 10%

Moisture Reduction



Use Exhaust Gases for Pre-drying

- Moisture reduction from 30% to 15%
- Net heat requirement for drying goes from 5.6 to 4.1 MMBtu/hr.
- Gross heat input from the burner reduces from 6.5 to 4.8 MMBtu/hr.
- Total heat reduction: 1.7 MMBtu/hr or 26% of the heat used.
- Gas cost is $5/MMBtu
- Operating hours: 6,000 hours/year
- Total savings: $51,000 per year

Optimize Water-level In Charge Feed Rate Mixture W/O Impacting the Operation & Product

- **Energy Savings = 24,500 MMBtu/yr**
- **Cost Savings = $87,000/yr**
- **CO2 emissions reduction = 1,300 MT/yr**

Diagram Report Sankey Calculators

Optimize water feed rate
Selected Scenario
View / Add Scenarios

Operations | **Charge Materials** 2 | Flue Gas 1 | Fixture 1 | Wall 6 | Cooling | Atmosphere | Opening 2 | Leakage | Extended Surface 1 | Other

	BASELINE		OPTIMIZE WATER FEED RATE	
	Fiber Glass + Water		Fiber Glass + Water	
Select Type	Solid		Solid	
Name of Material	Custom Material		Custom Material	
Add New Solid Material				
Average Specific Heat of Solid	0.2629	Btu/(lb-°F)	0.2629	Btu/(lb-°F)
Latent Heat of Fusion	0	Btu/lb	0	Btu/lb
Average Specific Heat of Molten Material	0.2629	Btu/(lb-°F)	0.2629	Btu/(lb-°F)
Melting Point	2156	°F	2156	°F
Charge Feed Rate (Wet)	36480	lb/hr	36480	lb/hr
Charge Inlet Temperature	96	°F	96	°F
Charge Outlet Temperature	260	°F	260	°F
Water Content (Charged)	48.85	%	45	%
Water Content (Discharged)	0	%	0	%
Water Vapor Discharge Temperature	545	°F	545	°F
Charge Melted	0	%	0	%
Charge Reacted	0	%	0	%

RESULTS HELP NOTES

Energy Loss/Use	Baseline MMBtu/hr	Optimize water feed rate MMBtu/hr
Charge Materials	23.30	21.61
Fixtures, trays etc.	3.34	3.34
Wall Losses	1.39	1.39
Cooling Losses	——	——
Atmosphere Losses	——	——
Opening Losses	0.05	0.05
Leakage Losses	——	——
Extended Surface Losses	9.31	9.31
Other Losses	——	——
Total Net Heat Required	37.39	35.70
Available Heat (%)	56.6%	56.6%
Flue Gas Losses	28.61	27.32
Exothermic Heat from Process	——	——
Fuel Heat Delivered	——	——
Gross Heat Input	**66.00**	**63.01**
CO_2 Emissions (tonne CO_2/hr)	3.5	3.34
CO_2 Emissions Savings (tonne CO_2/hr)	——	0.16

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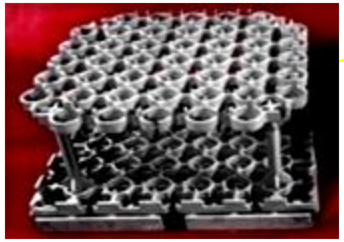
Summary for Load/Charge Related Measures

Actions	Potential energy savings*
Hot charge load wherever possible	5% to 30%
Preheat load or charge material using furnace flue gases or an auxiliary externally fired preheater	5% to 30%
Moisture removal prior to loading in the furnace	10% to 25%
Charge at near design capacity and frequency - minimize hold or idling	2% to 5%
Proper load arrangement for optimum heat transfer	1% to 2%

Material Handling



- Reduce weight of the fixtures, trays, and baskets
  - Redesign to reduce weight: cast vs. fabricated
  - Change material (steel vs. stainless, metal vs. synthetic material, etc.)
  - Alternate material-handling method (belt vs. rollers, trays vs. belt, etc.)
- Maximize loading
  - Proper load arrangement
- Avoid cooling fixtures when reused
- Return belts and conveyors within the furnace rather than outside to avoid heat loss

Reduce Conveyor Weight Aluminum Can Drying Oven

Calculation for Savings - Fixture Heat Loss Reduction		
	Current	New
Conveyor weight (rate lbs./hr)	2,500	1,500
Conveyor initial temperature (Deg. F.)	90	90
Conveyor - final discharge temperature (Deg. F.)	550	550
Oven exhaust gas temp. (Deg. F)	600	600
Percent O2 (dry) in flue gases	12.00	12.00
%Excess air	119.33	119.33
Combustion air temperature (Deg. F)	90	90
Fuel savings (%)	Base	40.00%
No. of operating hours	8000	8000
Therms used per year (Therms/year)*	18,517	11,110
Therms saved per year (Therms/year)*	Base	7,407
Cost of fuel ($/Million Btu)	$ 8.00	$ 8.00
Annual savings ($/year)	Base	$ 5,926
CO2 savings (Tons/year) - natural gas fired systems	Base	43.33

Developed by E3M, Inc.

Note: 1.0 Therm = 0.1 MM Btu

Note:

- The calculator does not allow accounting for other possible changes in the operations.
- The only change considered is conveyor weight reduction by using a different design weave.
- The change results in reduction in heat input cost and savings of almost $6,000 per year.

Summary for Fixture Related Measures

Actions	Potential energy savings*
Minimize the weight of fixture, trays, and baskets used for material handling	1% to 5%
Whenever possible return the conveyor belt within the furnace to maintain its temperature	1% to 2%
Avoid cooling fixtures and trays during reuse	1% to 2%
Maximize loading of trays, fixtures, and baskets	2% to 5%

Combustion System Energy Saving Measures

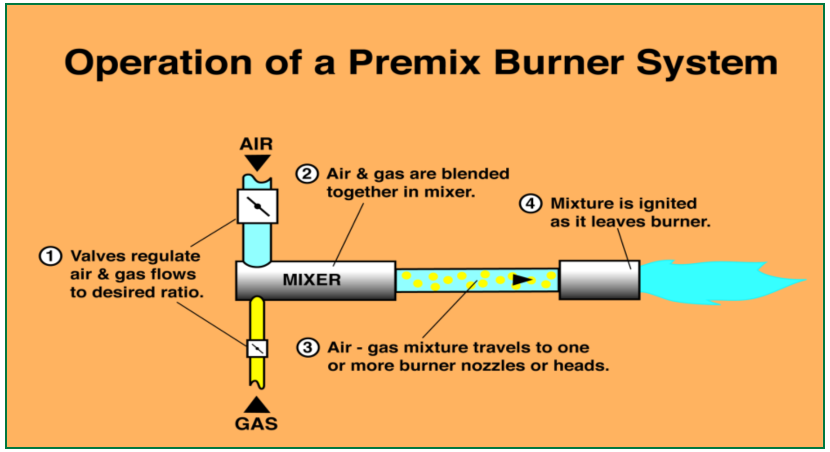
- Use proper burners
- Use proper fuel-to-air ratio control system
  - Eliminate or reduce excess air operation
  - Always maintain proper fuel-to-air ratio
  - Avoid fuel-rich operating conditions
- Use preheated air
- Use preheated fuel where possible
- Use oxygen-enriched combustion air
- Use an alternate burner control system (pulse firing) to extend the operating range (turn-down) for the burners

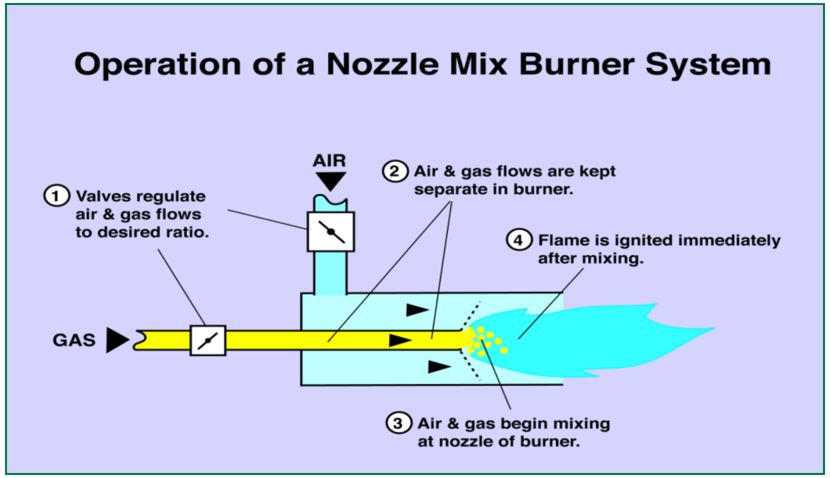
Combustion System Performance

Overall performance of the combustion system depends on the performance of the burner and the air-fuel supply-control system.

- The burner design should offer stable and efficient combustion at all firing rates while using minimum excess combustion air and producing minimum (negligible) amount of unburned hydrocarbons or soot.
- The air-fuel ratio control system should be able to maintain combustion air and fuel ratio to the burners with minimum excess air.
- For liquid fuel burners the atomizing agent (air, steam, etc.) mass flow should be minimum required for stable and efficient combustion of the fuel.

Commonly Used Burner Types

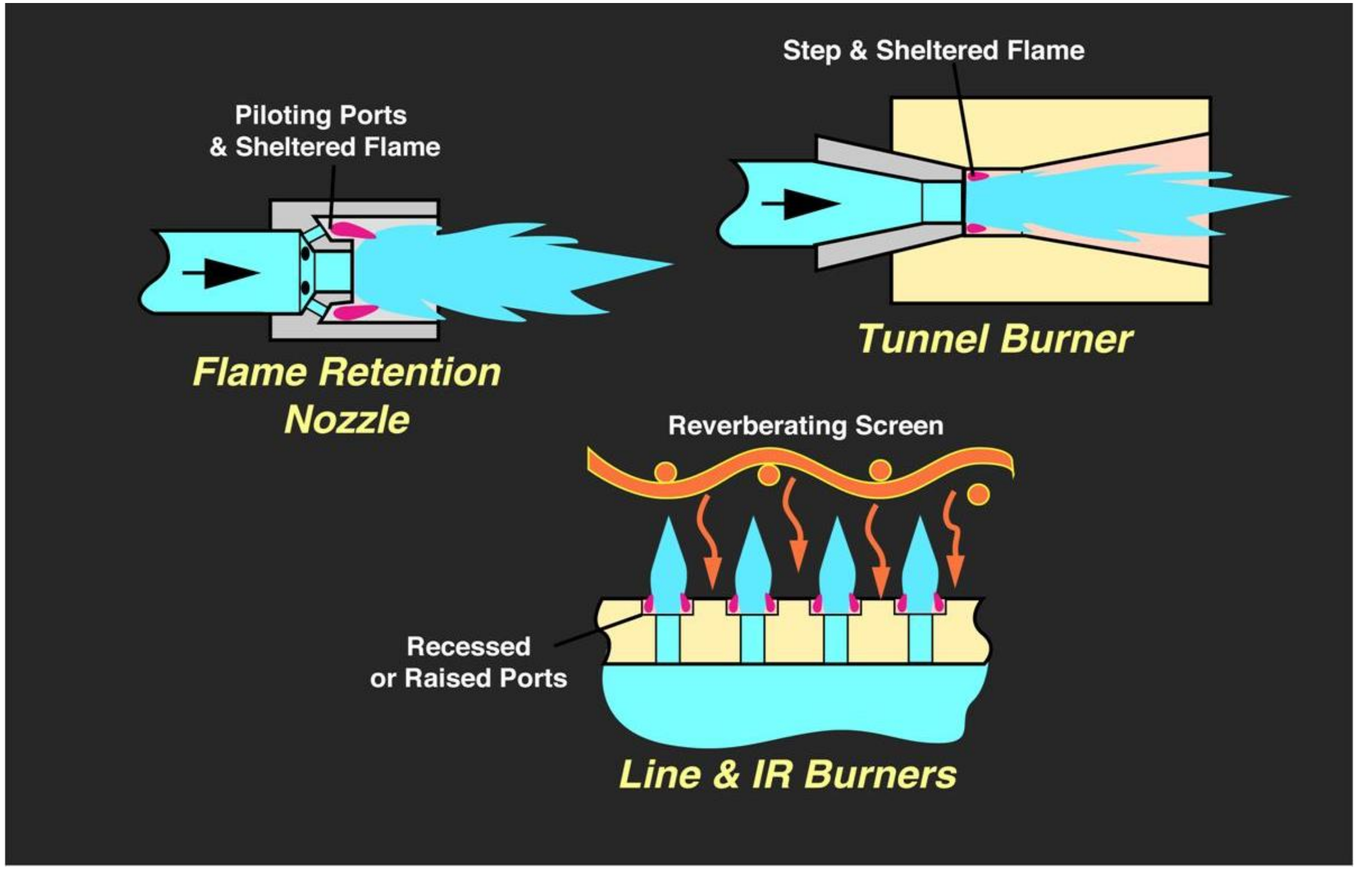




Gas Fuel Burners:

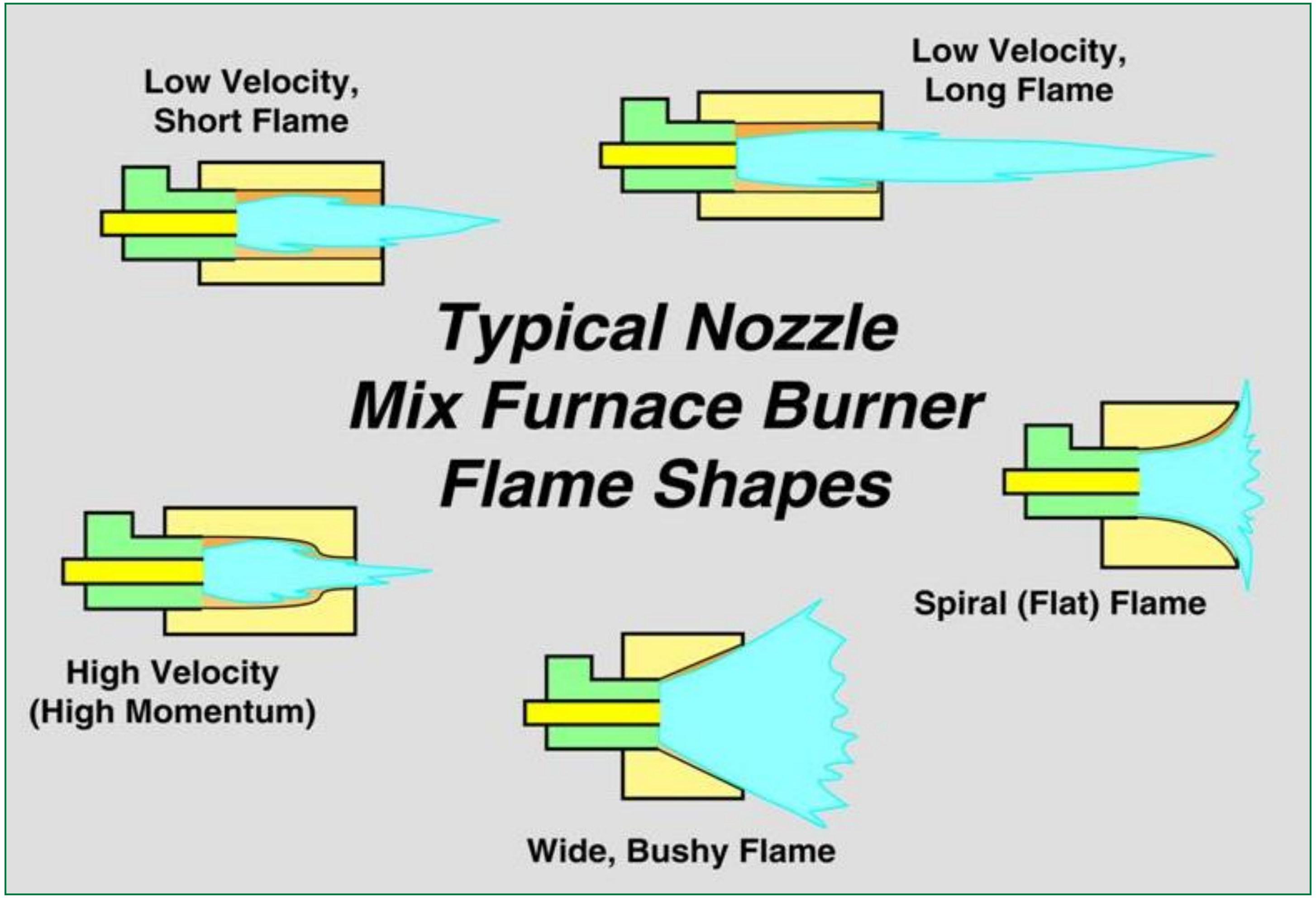
- Premix burners
  - Air and gas are mixed before they enter the burner.
  - There are many variations of this design.
  - Several limitations in its use.
- Nozzle mix burners
  - Air and gas are introduced separately in the burner and are mixed within the burner.
  - There are many variations of this design.
  - Considered preferred design for process heating systems.

Premix Burners



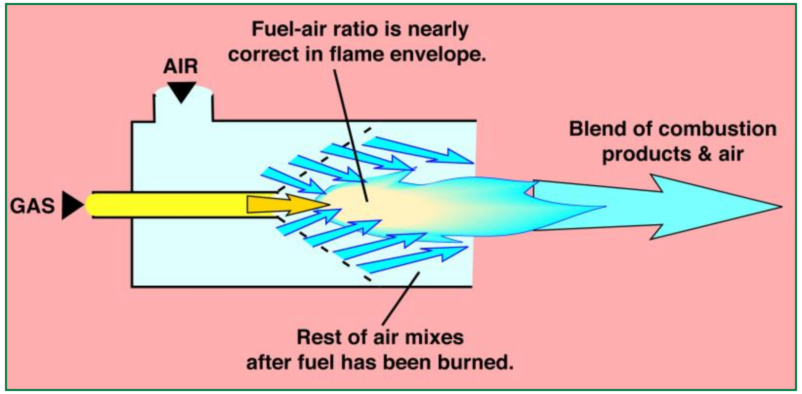
Premix burners can use gas fuels

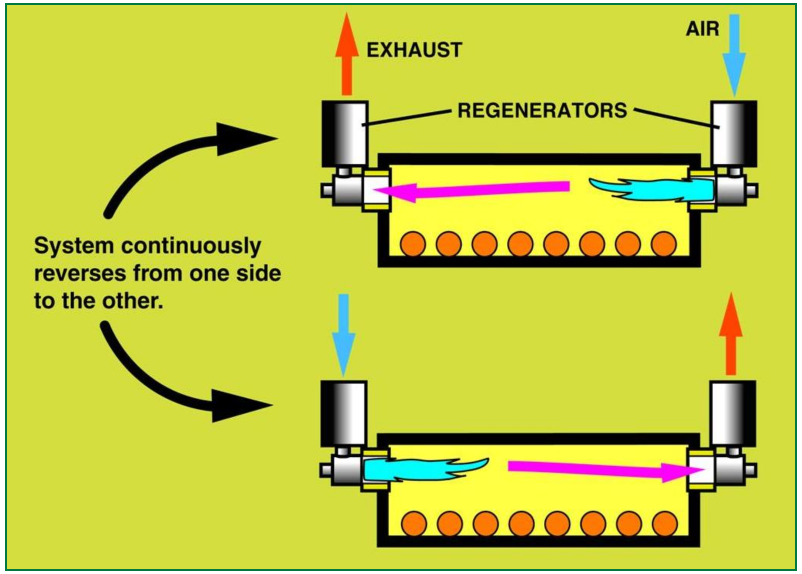
Nozzle Mix Burners



Nozzle mix burners can use gas or liquid fuels

Special Design Burners





Gas Fuel Burners:

- Special design or names
- These are variations of the premix or nozzle mix designs
  - Staged combustion burners designed for emission (primarily NOx) reduction
  - Burners with integral heat recovery (i.e. self recuperative burners, regenerative burners, etc.)
  - Catalytic burners
  - Radiant tube burners
  - Infrared burners
  - Multi-fuel burners
  - Other?

Considerations for Burner Selection

- Fuel flexibility (if required)
- Burner turn-down capability with stable and efficient combustion
- Required excess air for the range of burner operation
- Method of liquid fuel atomization and atomizing medium requirement
- Range or limit on combustion air temperature
- Recommended maximum process temperature for which the burner can be used
- Flue gas emission data (NOx, CO and unburned combustibles, if any) for the range of operation for the desired application
- Maximum allowable combustion air preheat temperature

Considerations for Burner Selection

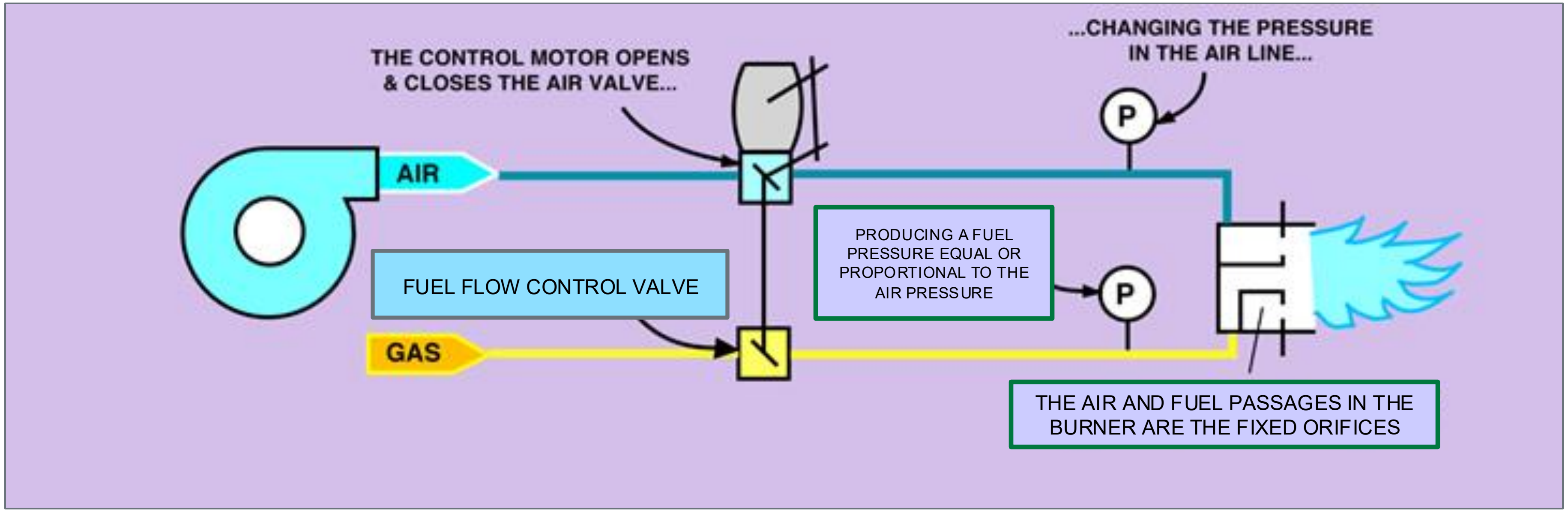
- Method of ignition (constant or interrupted pilot, spark ignition, igniter etc.)
- Method of flame supervision
- Recommended air and gas flows (max. and min.) required for ignition
- Allowable and recommended heat emission rates (not input rates) expressed as Btu/ft^2 of the burner or tube surface for different sink (or furnace) temperature ranging from ambient to 1400^0 F.
- Physical dimensions and recommended-required mounting arrangement
- Flow vs. pressure drop characteristics for air and gas at ambient temperature

Recent Developments and Trends

- Regenerative burners – combustion air preheating
- Regenerative burners – low calorific value gas fuel preheating
- Self-recuperating burners for direct fired and radiant tube applications
- Low NOx burners of various designs and applications
- Oxy-fuel burners for melting applications (glass, steel, aluminum etc.)
- Oxygen enriched air burners (by various names) for medium to high temperature heating applications
- Oxygen enrichment of combustion air for low calorific fuels in boilers and other low to medium temperature applications
- Mass flow control for air and fuel
- Sub-stoichiometric burners for steel reheating applications
- “Radiant” burners of various types and designs for drying applications
- Burners for low calorific value fuels

Air-fuel Ratio Control

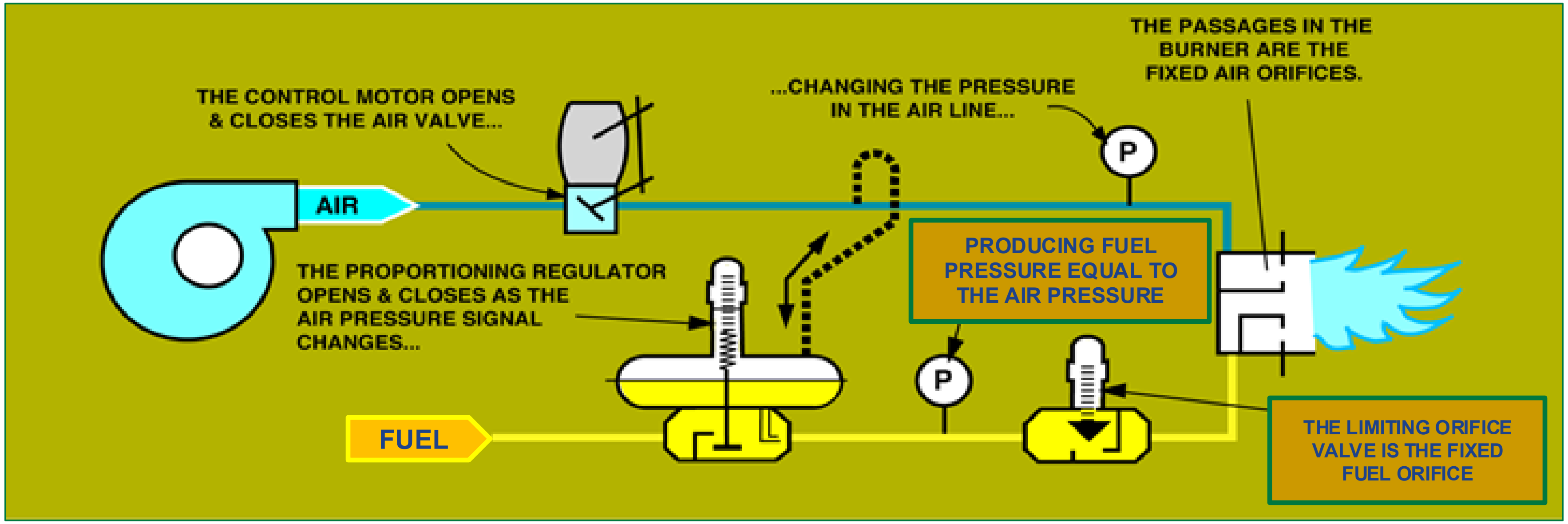
Tandem valve proportionating system – Mechanical linkage



- Commonly used control system for boilers and furnaces using oil or gas as fuel.
- Difficult to adjust the linkages and maintain correct air fuel ratio or excess air for the entire range of burner turn-down or firing rate.
- In most case the ratio tend to give higher excess going from high fire to low fire.

Air-fuel Ratio Control

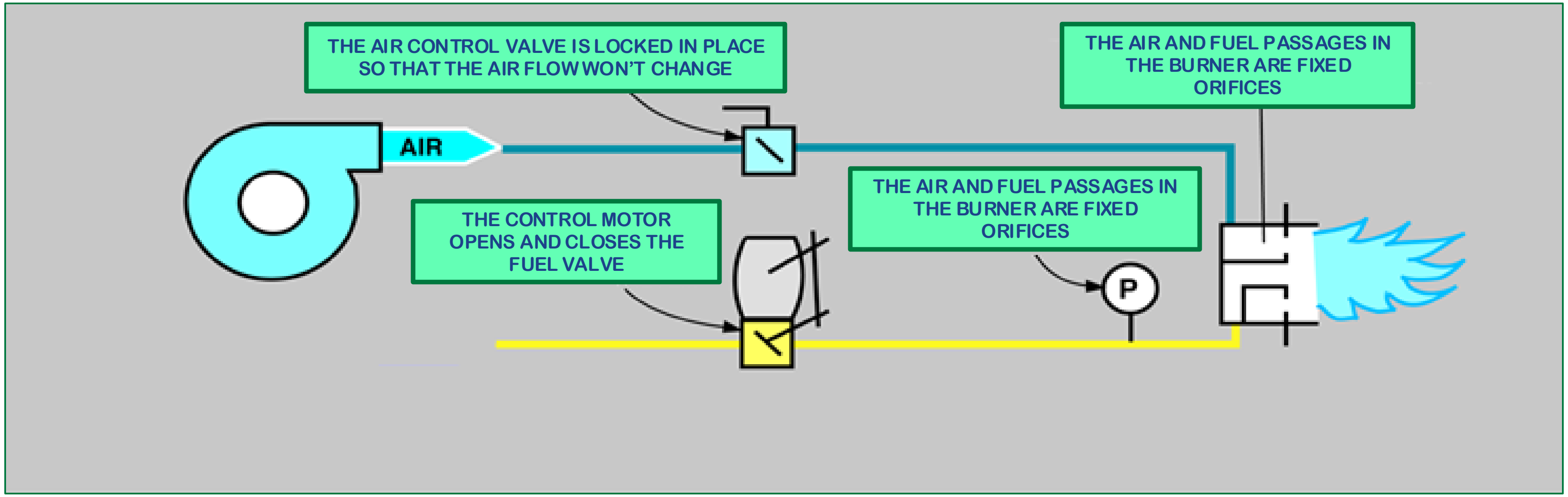
Pressure balanced system using ratio regulator



- Commonly used control system for furnaces, ovens, heaters etc. using oil or gas as fuel. It is more common for gas fired systems. Many different variations of this system are used to meet fuel pressure restriction.
- It provides flexibility to adjust air-fuel ratio (in most cases linearly) as the burner firing rate is changed from high to low conditions.
- Relatively easy-simple to adjust and maintain air fuel ratio.

Air-fuel Ratio Control

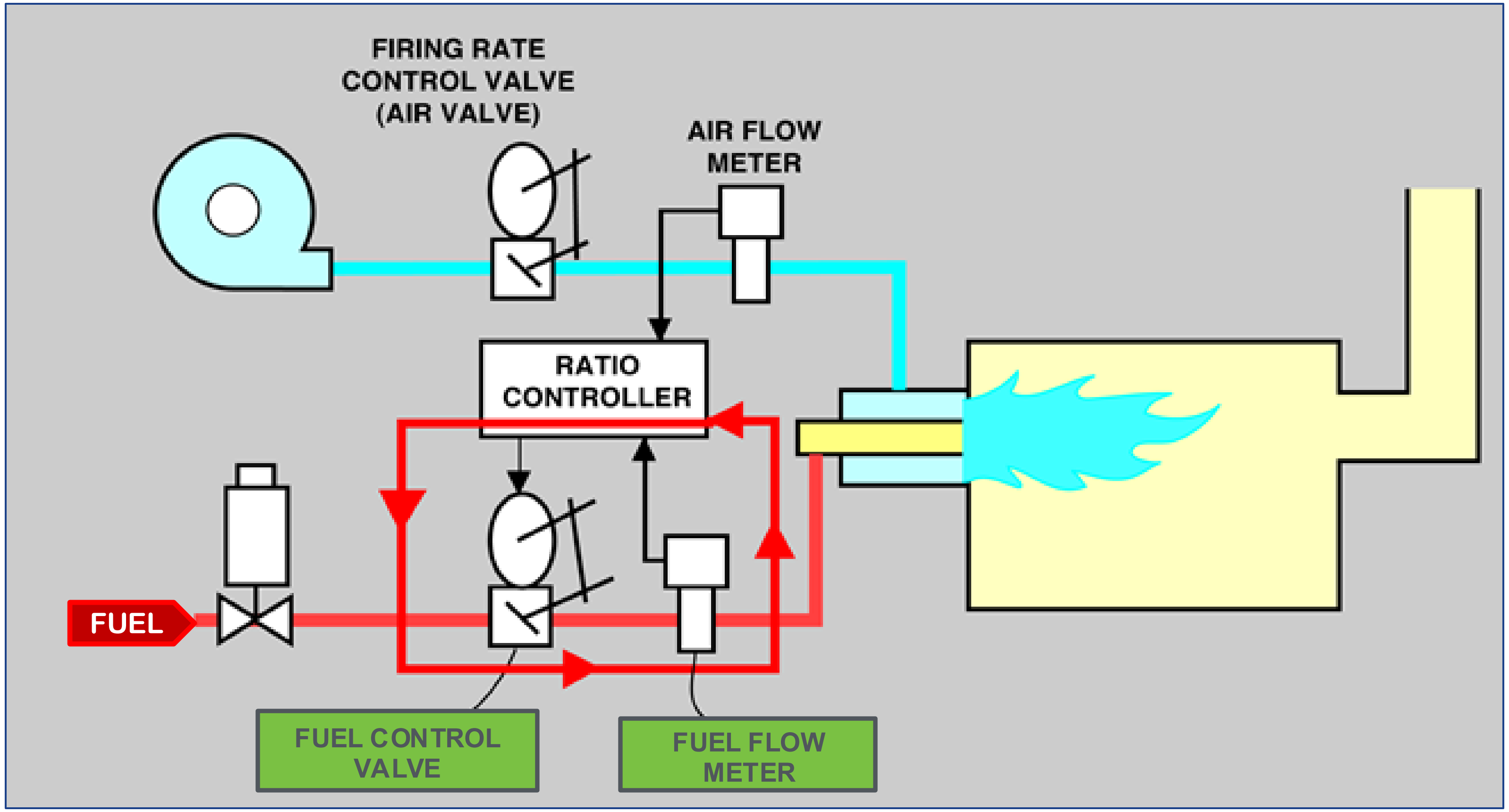
Constant air – fuel flow control system



- Commonly used for low temperature ovens where large amount of excess air is required for safety or product quality reasons.
- Very inefficient if the air flow is not properly adjusted to meet the process requirements.
- Often used for processes where temperature uniformity is required
- Try to avoid it if possible!

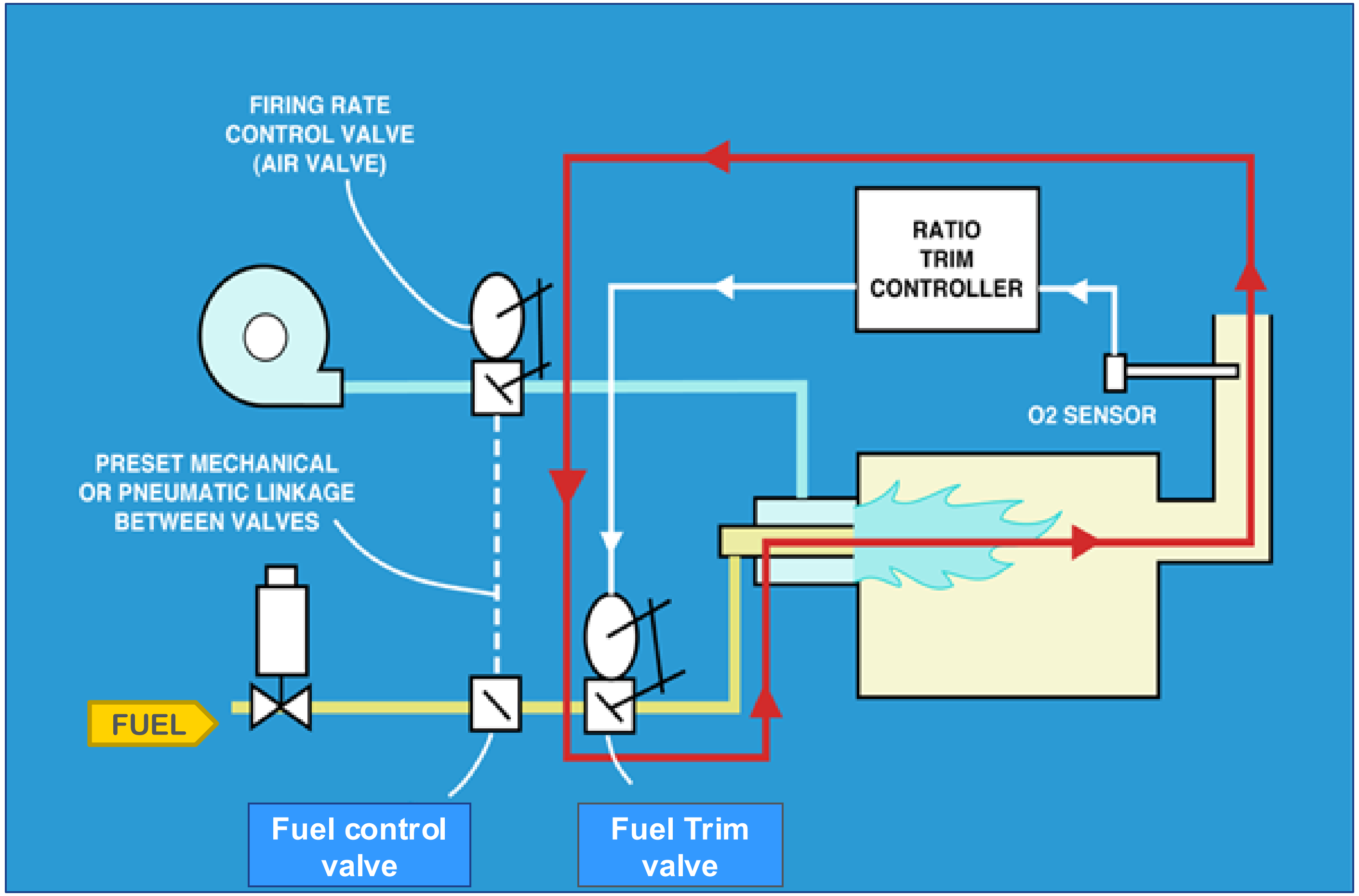
Air-fuel Ratio Control

Mass flow ratio control system



Air-fuel Ratio Control

Fuel – Air ratio control system with fuel trim based on flue gas analysis

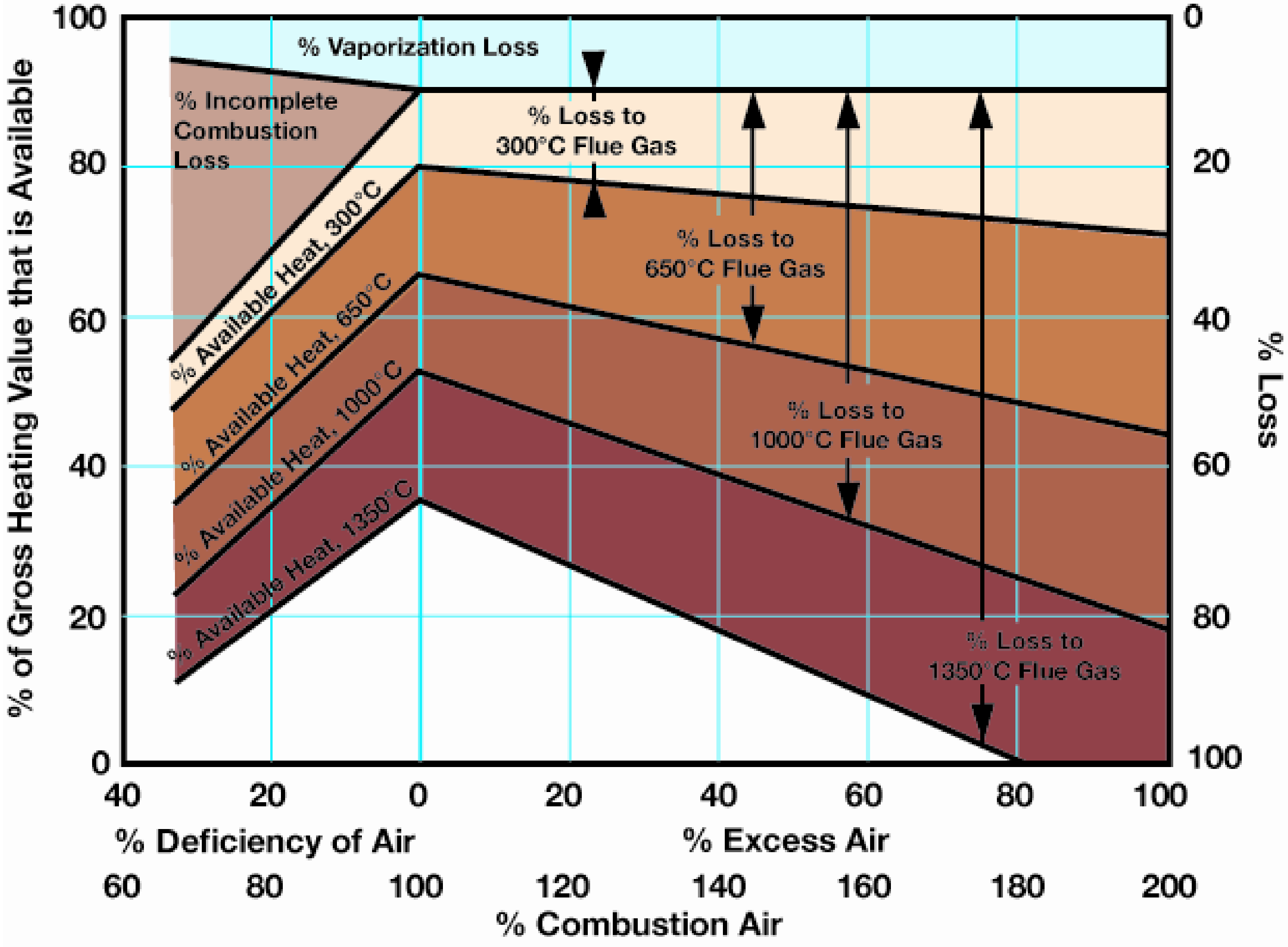


Excess Air Control

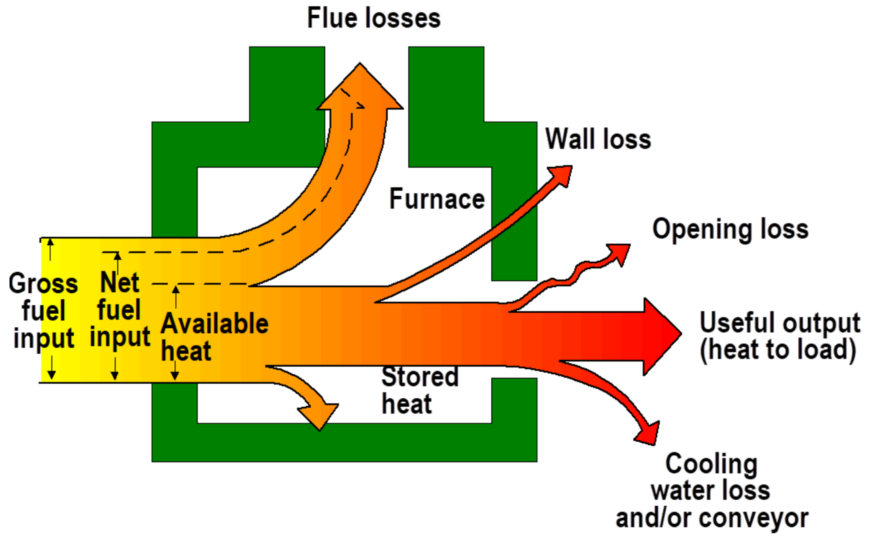
The Most Cost-Effective Methods to Save Energy for Furnaces/Ovens

- Excess air may enter from several sources:
  - Combustion air in burners
  - Air-leakage from openings
  - Make-up air used for ovens and dryers
- Control furnace pressure to eliminate or minimize cold air entering the furnace
- Reduce the size and number of openings
- Control make-up air to the minimum of openings
- Review the burner firing control system to avoid use of high excess air at low fire conditions
- Use sealed burners to avoid cold air “draft” through hot tubes for radiant tubes with and on/off control

Effect of Excess Air on Available Heat and Heat Loss



Adapted from ***North American Combustion Handbook, Second Edition***. Courtesy Fives North American



Courtesy: Fives North American Combustion, Inc.

Note: This information can be used for fuel oil with less than 5% error.

Energy Savings: Reduction of Excess Air

Control Air-Fuel Ratio or Reduction of Excess Air (or O_2) in Flue Gases			
		Current	**New**
11	Furnace flue gas temperature (°F.)	1,200	1,200
12	Percent O2 (dry) in flue gases	8.00	3.00
13	% Excess air	55.08	14.92
14	Combustion air temperature (°F.)	70	70
15	Fuel consumption (MM Btu/hr) - Avg. current	20.00	17.32
16	Available Heat (%)	53.8%	62.2%
17	Fuel savings (%)	Base	13.39%
18	No. of operating hours (hours/year)	8000	8000
19	Heat energy used per year (MM Btu/year)	160,000	138,579
20	**Heat energy saved (MM Btu/year)**	**Base**	**21,421**
21	Cost of fuel ($/Million Btu)	$ 5.00	$ 5.00
22	**Annual savings ($/year)**	**Base**	**$ 107,105**
23	**CO2 savings (Tons/year)**	**Base**	**1,253**

- Firing rate: 20 MMBtu/hr
- Current flue gases
  - O_2 (dry) in flue gas: 8%
  - Flue gas temperature: 1,200°F
- After burner tune-up, leak check, and sealing of the heater:
  - O_2 (dry) in flue gas : 3.00%
  - Flue gas temperature: 1,200°F
- Fuel savings: 13.4%
- Energy cost savings: $107,000/year
- Basis for calculations:
  - Fuel cost – $5/MMBtu
  - Operating hours – 8,000/year

A Few Things to Watch

- In many cases, O_2 measurement in flue gases is used as an indication of excess air used in the furnaces
- However, several factors such as air leakage in the furnace due to negative pressure, leaking in the sampling line, dilution of flue gases before the point of measurement, or air introduced in the oven (where volatiles from the material being heated are released) can contribute to O_2 readings in flue gases
- Check for the above-mentioned conditions or requirements before adjusting the air-to-fuel ratio for the burners
- In some cases, it is not possible or useful to adjust air-to-fuel ratios for the burners to achieve low O_2 in flue gases
- The best method to adjust air-to-fuel ratios for the burners is to measure air and fuel flow (or another parameter such as pressure drop on the air and fuel side within the burner) for each burner

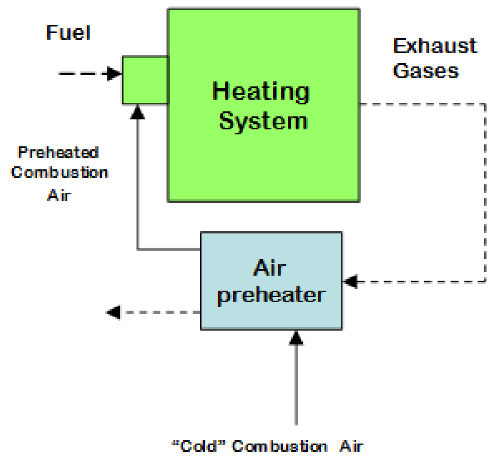
Use of Preheated Air

- Using higher-temperature combustion air preheated by using the heat of the flue gases can save 10% to 40% of the energy used for the heating system
- Using preheated air offers several advantages
  - Improved combustion
  - higher flame temperature
  - higher heat transfer - increased productivity
  - possibility of using lower-grade fuel (such as blast furnace gas or wet solids)
- Concerns about higher NOx generation with the use of preheated air can be alleviated by using the new generation of low-NOx and ultra low-NOx burners

Combustion Air Preheating Savings

Gas fired reheat furnace saves approx. $23,000 per year. This is a preliminary evaluation for possible heat recovery using heat of exhaust gases.

	Use of Preheated Combustion Air Note: The combustion air is heated by using heat from flue or exhaust gases.		
		Current	**New**
11	Furnace flue gas temp. (°F)	1,000	1,000
12	Percent O2 (dry) in flue gases	3.00	3.00
13	% Excess air	14.92	14.92
14	Combustion air temperature (°F)	60	600
15	Fuel consumption (MM Btu/hr) - Avg. current	5.00	4.36
16	Volume of fuel gas scfh - based on fuel heating value	4,945.19	4,308.71
17	Available Heat (%)	66.89	76.77
18	Fuel savings (%)	Base	12.87%
19	No. of operating hours (hours/year)	6000	6000
20	Heat used per year (MM Btu/year)	30,000	26,139
21	**Heat saved per year (MM Btu/year)**	**Base**	**3,861**
22	Cost of fuel ($/Million Btu)	$ 6.00	$ 6.00
23	**Annual savings ($/year)**	**Base**	**$ 23,167**
24	**CO2 savings (tons/year)**	**Base**	**227**

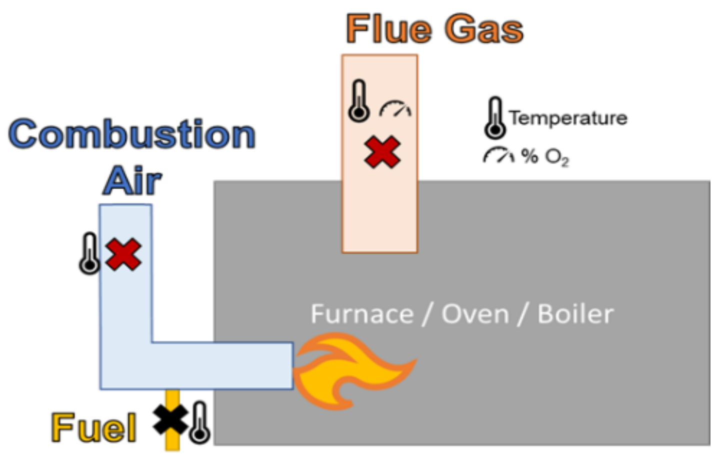


Summary for Combustion System Related Measures

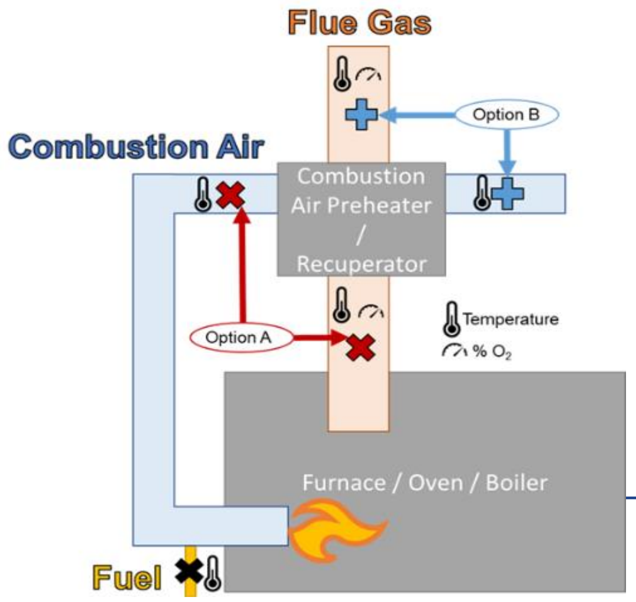
Actions	Potential energy savings*
Use proper burner type	2% to 5%
Use proper air-to-fuel ratio control system	5% to 15%
Use preheated air	5% to 30%
Use oxygen-enriched combustion air or oxy-fuel burners where economically justified or required	5% to 35%
Use alternate burner control system to extend burner turn-down if necessary	1% to 5%

Energy Saving Measures Exhaust Gases or Flue Gases

Measurement location without recuperator



Measurement location with recuperator



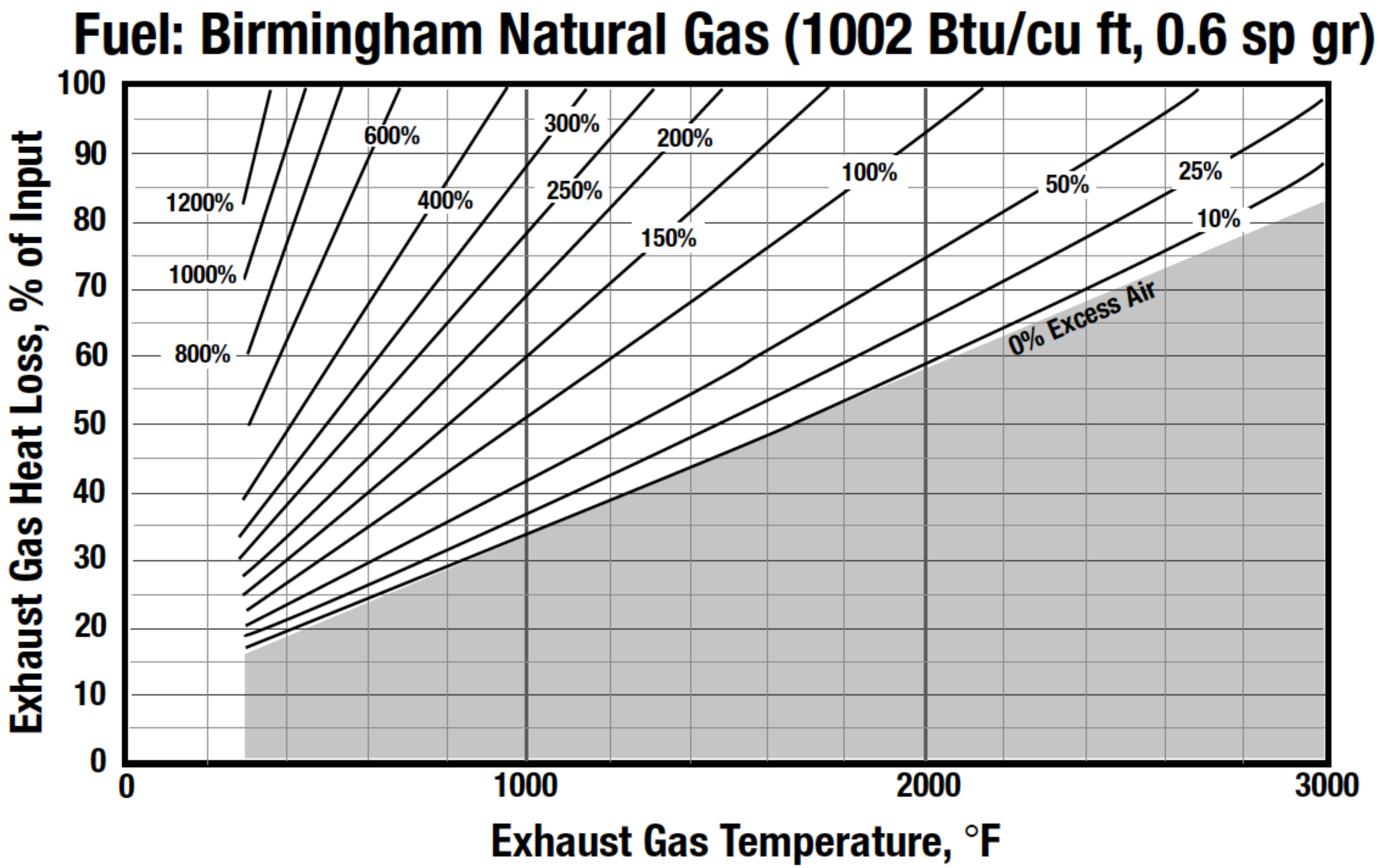
- Flue gases from a furnace may contain:
  - Combustion products
  - Water vapor
  - Liquid vapors
  - Volatiles
  - Condensable solids
  - Non-condensable particles
  - Furnace "atmosphere" or gases
- Flue gas analysis (FGA) such as percentage of O_2 and percentage of CO_2 given by most commonly used analyzers is affected by the presence of non-condensable gases
- Care must be taken to correct the analysis for the presence of these gases, if any, in using FGA results for thermal calculations

Factors Affecting Flue Gas Heat Loss

$$\Delta H = M \times C_p \times \Delta T$$

ΔH	M	C_p	ΔT
Flue Gas Temperature Heat Loss	Mass Flow of Flue Gases	Specific Heat	Temperature Rise
Determined by:	Excess Air (or Oxygen) in Flue Gases	Type of Fuel (Flue Gas Composition)	Flue Gas Temperature / Combustion Air Temperature

Reduce Flue Gas Losses



Flue losses increase with: Temperature of flue gases; O_2 level in flue gases

Options for Exhaust Gas Waste Heat

- Waste heat **Reduction** within the heating system itself
- Waste heat **Recycling** within the heating system itself
- Waste heat **Recovery**:
  - Use of waste heat outside the heating system – utilize heat in (or for) other systems within the plant or outside the plant.
  - Waste heat to power conversion

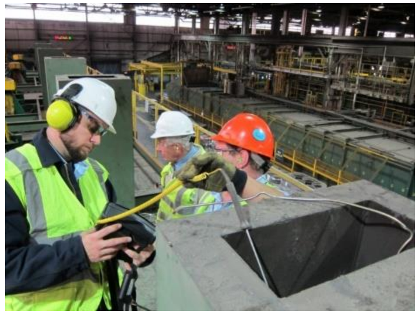
Exhaust Gas Waste Heat Reduction

Reduce mass flow rate

- Reduce/control excess air for burners
- Control make-up air
- Reduce/eliminate air leaks
- Reduce moisture content of exhaust gases where possible
- Process specific actions (i.e. pretreatment of charge material)
- Use of oxygen enriched air
- Use of air and/or fuel preheating

Reduce temperature of exhaust gases

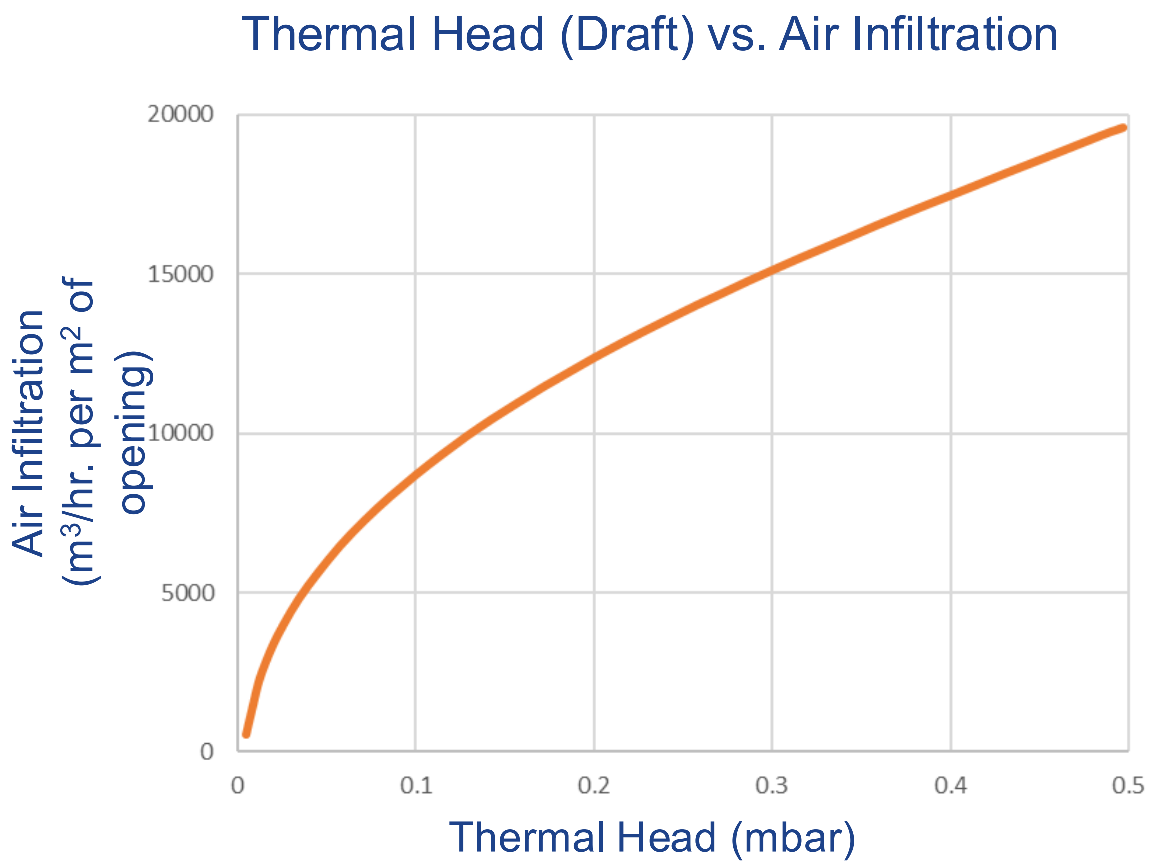
- Use of proper temperature controls Use of advanced controls to optimize zone temperature (i.e. on-line process modeling)
- Avoid over-firing of burners
- Control air-fuel ratio to avoid sub-stoichiometric (rich) combustion



Waste Heat Reduction Air Leakage Control

- Air leaks into the furnace through openings, large and small, visible or invisible, and at unsuspected locations when the furnace pressure is lower than the ambient pressure
- Most common areas of air leaks include gaps at door seals, fully or partially open doors, cracks in furnace walls, and seals at the tubes, burner mounting, and conveyor rollers
- Pressure in the furnace varies from top to bottom and, in some cases, from side to side or at local spots; measurement at one point or level does not mean the same pressure at all levels within the furnace
- Pressure could become negative (with respect to ambient pressure) due to:
  - Draft generated due to “chimney” effect when the exhaust gas temperature is higher than the ambient temperature
  - Use of an induced draft (ID) fan
  - Jet effect of flame or other air jets, if used

Air Leakage vs. Pressure (Draft)



Conversion Factor

0.1 mb = 1 mm of H_2O

Common Areas of Air Leaks for Process Heaters

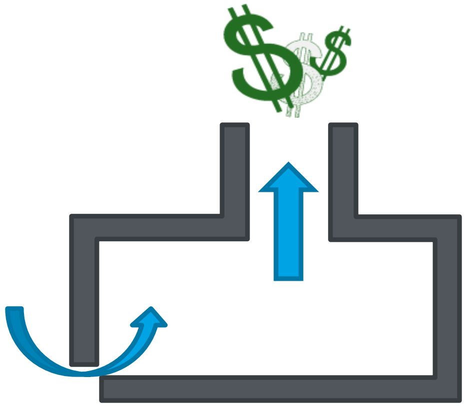
Tube Penetrations

Door Seal

Tired Gasket

Explosion Door

Cost of Air Leakage

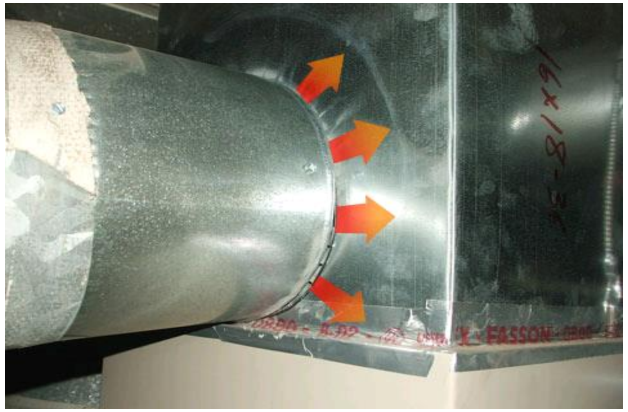


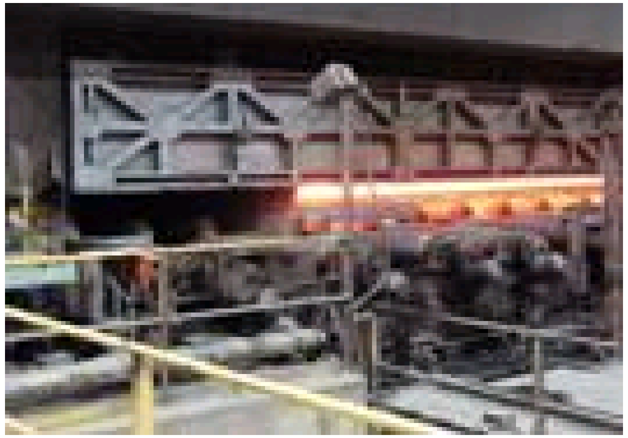
Cost of Air Infiltration in Oven or Furnace	
Furnace draft (neg. pressure) inch. W.C.	0.050
Opening size - area ft^2	1.00
Combustion air temperature (F)	70
Temperature of flue gases (F)	400
Excess air used in burners (%) **	10
Available heat for burners (%)	84.6
Fuel cost $/Million Btu	$ 9.00
Operating hours/year	8000
Heat reqd. (net) to heat air Btu/hr.	273,278
Gross heat reqd. btu/hr	323,072
Air infiltration from the opening (SCFH)	40,188
Cost of fuel wasted per year	$ 23,261

* Note: This is NOT oxygen in stack gases.
It represents how the burners are adjusted for air-fuel ratio
In many cases the users are advised to adjust burners to give
2% to 4% Oxygen (10% to 20% excess air) in combustion products

** Default value for burner excess air is 10%

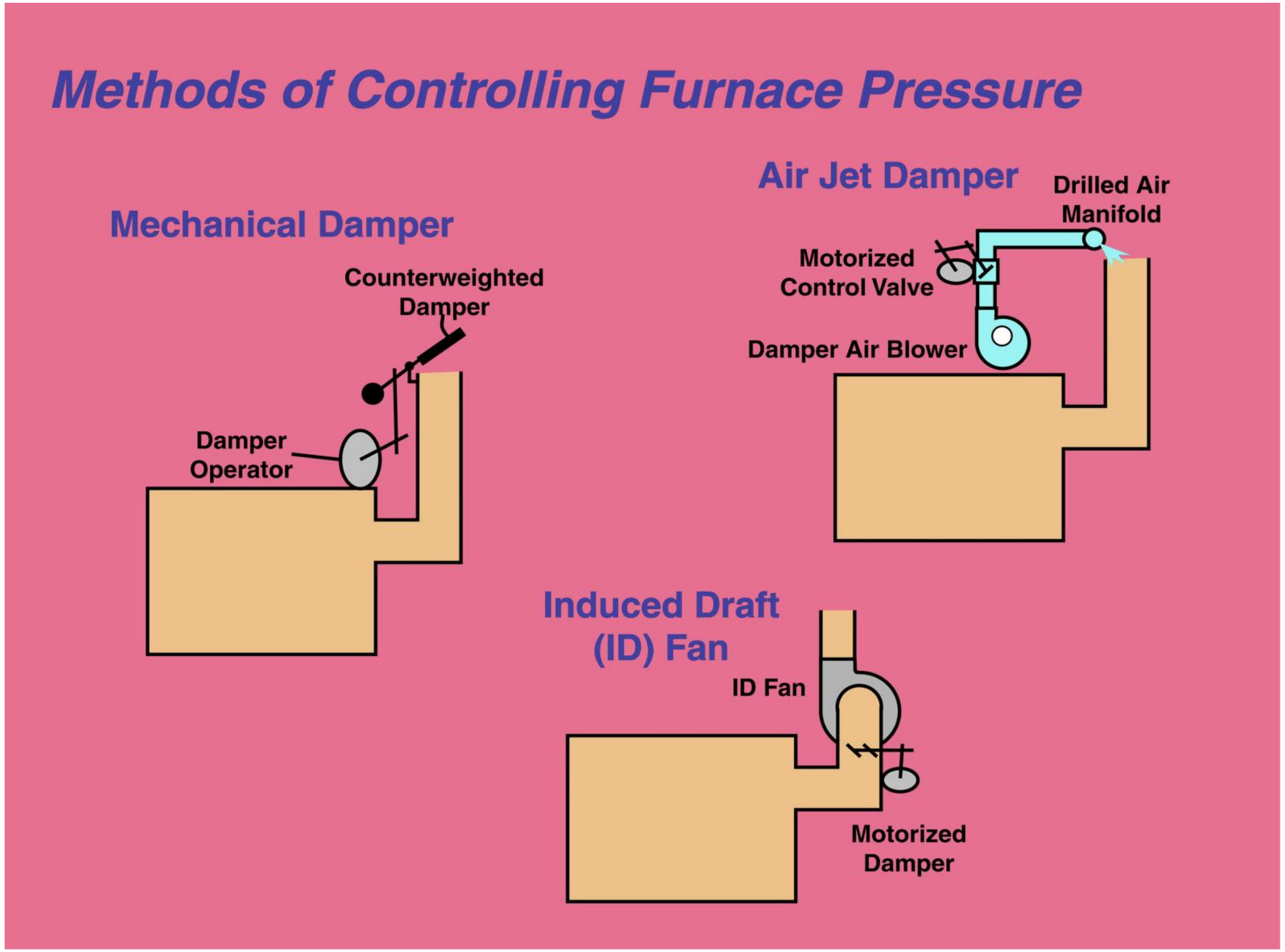
Hot Gas Leakage





Density corrected flow (nm^3/hour)	1,075
Ambient temp (°C)	35
Heat loss in hot gases kJ/hr.	1,102,961
Number of operating hours per year	8,000
Total energy loss GJ/year	8,824
Heat recovery efficiency for the system (if used) - %	55%
Loss in heat recovery GJ/year	4,853
Cost of fuel ($/GJ)	$ 6.00
Potential cost savings $/year	$ 29,118
Potential Annual Cost Savings ($/year)	**$29,120**

Furnace Draft Control



Summary for Exhaust Gas Reduction Related Measures

Actions	Potential energy savings*
Reduce excess air used for fuel combustion in burners	2% to 10%
Control and minimize the amount of make-up air, if used, in ovens and dryers	5% to 20%
Minimize air leakage by reducing the size and number of openings	1% to 5%
Use pressure control to reduce/eliminate air infiltration or hot gases exfiltration	1% to 5%
Use proper controls for zone temperature and furnace firing rate to avoid excessively high exhaust gas temperature	2% to 10%
Avoid discharge of excessive moisture or process gases if possible, by pre-processing the load/charge material	0% to 2%

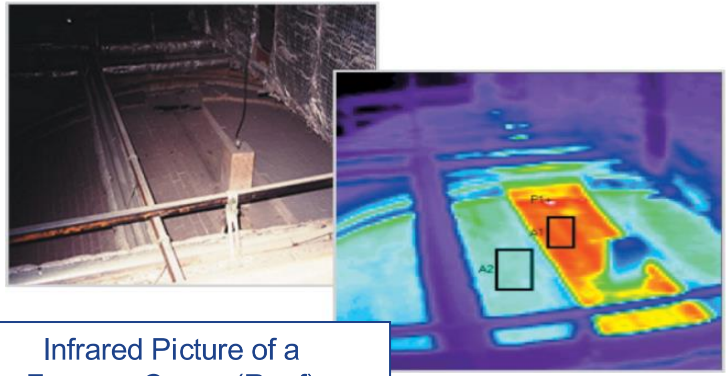
Waste Heat Recycling & Recovery

Waste heat **Recycling** within the heating system itself

Waste heat **Recovery**:

- Use of waste heat outside the heating system – utilize heat in (or for) other systems within the plant or outside the plant.
- Waste heat to power conversion

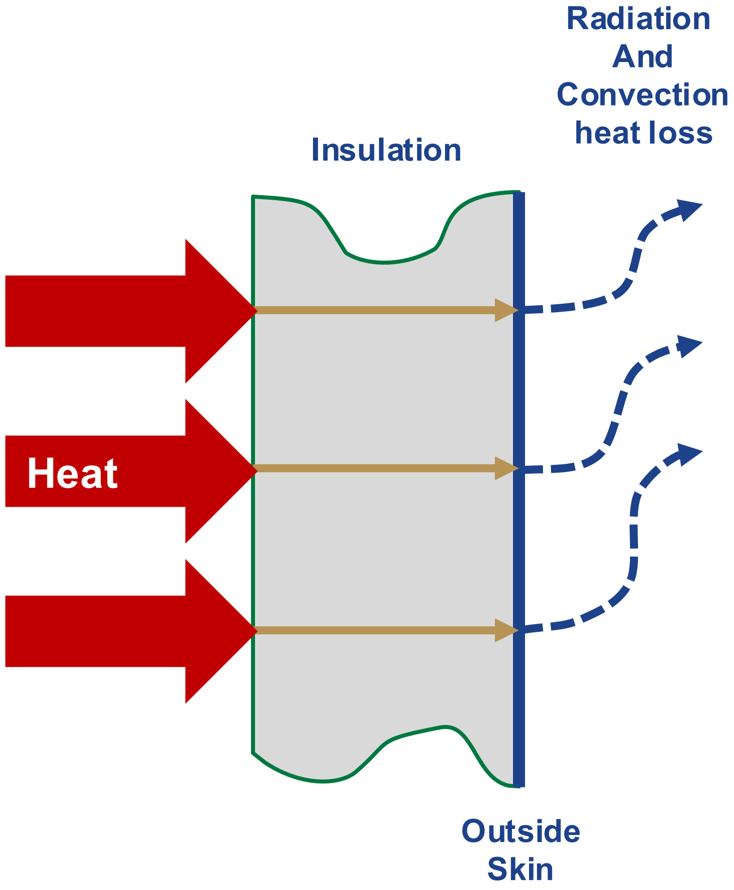
Furnace Wall Heat Loss



Infrared Picture of a Furnace Crown (Roof)

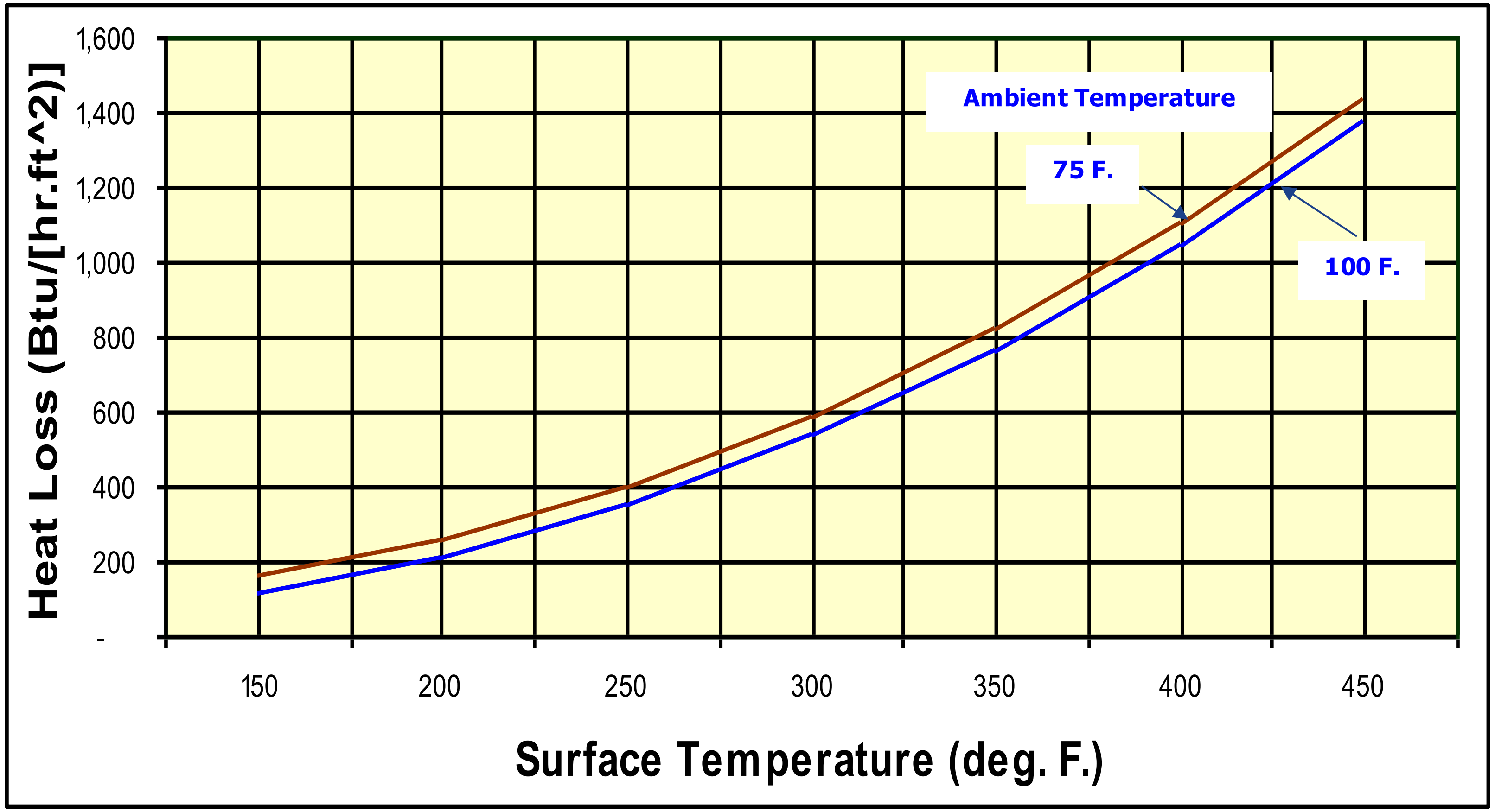
- Furnace walls use insulation or refractory to maintain the required temperature inside the furnace
- The type and size of the insulation used by the furnace suppliers depends on the furnace inside-temperature and economically justifiable type/size of the insulating materials
- The furnace outside-wall temperature varies considerably due to localized damage, cracks, or the location of insulation support members (anchors)
- A good temperature survey or a thermograph should be used to identify areas of large heat loss

Heat Loss from Furnace Walls



- Furnace wall heat loss can be calculated by measuring the wall surface temperature
- It is not necessary to know the details of the wall insulation or construction
- Wall heat loss calculated based on the wall temperature measurement gives heat loss under the operating conditions rather than the design conditions.

Heat Loss from Furnace Walls



- Average values based on vertical surface (sides)
- Wind velocity = 0 mph
- Normal (grey) wall color

Factors Affecting Wall Loss

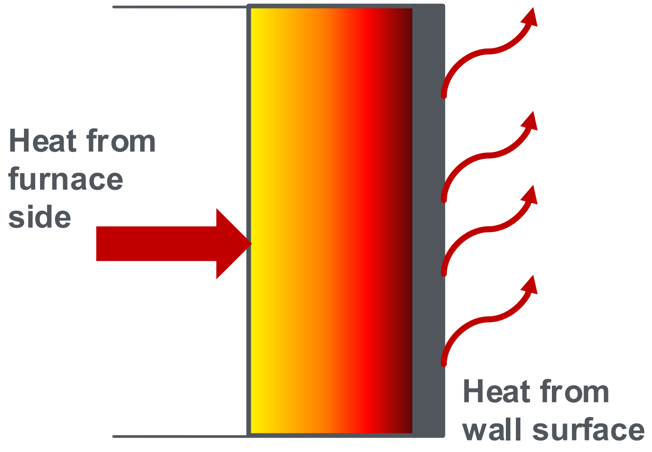
- Wall surface temperature
  - Higher temperature gives higher losses
- Ambient temperature
  - Lower temperature gives higher heat losses
- Surface orientation
  - Vertical surface as base line
  - Bottom horizontal surface – lower heat loss (by about 5% to 10%)
  - Top horizontal surface – lower heat loss (by about 5% to 10%)
- Wind velocity over the surface
  - Higher velocity results in higher loss
- Surface emissivity
  - Higher emissivity results in higher loss at temperature >480°F

Savings: Wall Temperature Reduction

OVEN WALL TEMPERATURE REDUCTION				
	Current		New	
Surface temperature (F)	125		98	
Ambient temperature (F)	80		80	
Heat Loss [Btu/(hr.ft^2)]	106		39	
Surface area (ft^2)	2,500		2,500	
Furnace flue gas temp.(F)	500		500	
% Oxygen in flue gases	10.00		10.00	
Combustion air temp. (F)	70		70	
Cost of fuel ($/Million Btu)	$	9.00	$	9.00
Operating hours/year		8000		8000
Therms used per year		27,690		10,312
Therms saved per year				17,378
Cost of fuel used ($/year)	$	24,921	$	9,281
Savings $/year	Base		$	15,640
Developed by E3M, Inc.				
Protected by U.S. Copyright protection				

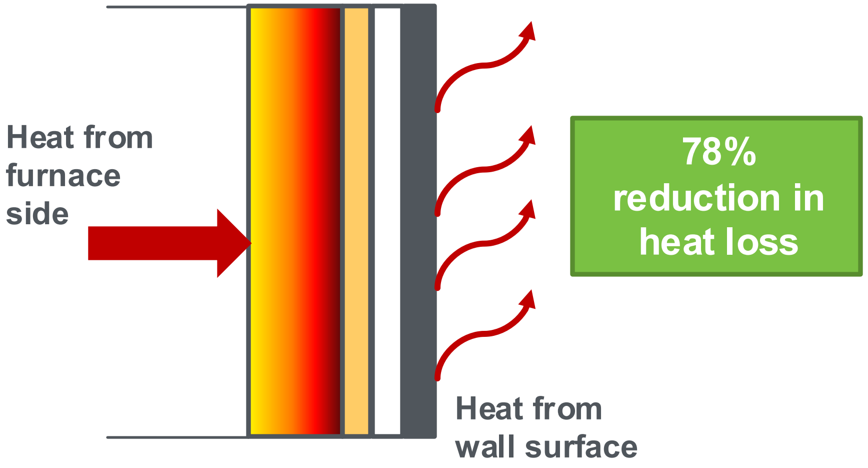
- Wall skin temperature can be reduced by using different types of insulation – refractory material and its thickness
- Use MEASUR to determine effect of different types of insulations in the walls on the furnace skin temperature

Wall Surface Temperature Reduction



14” (355 mm) Castable
0.25” (6 mm) steel plate
$T_{surface}$ = 390^{0} F

Heat loss
~1,125 Btu/(ft^{2}-hr.)



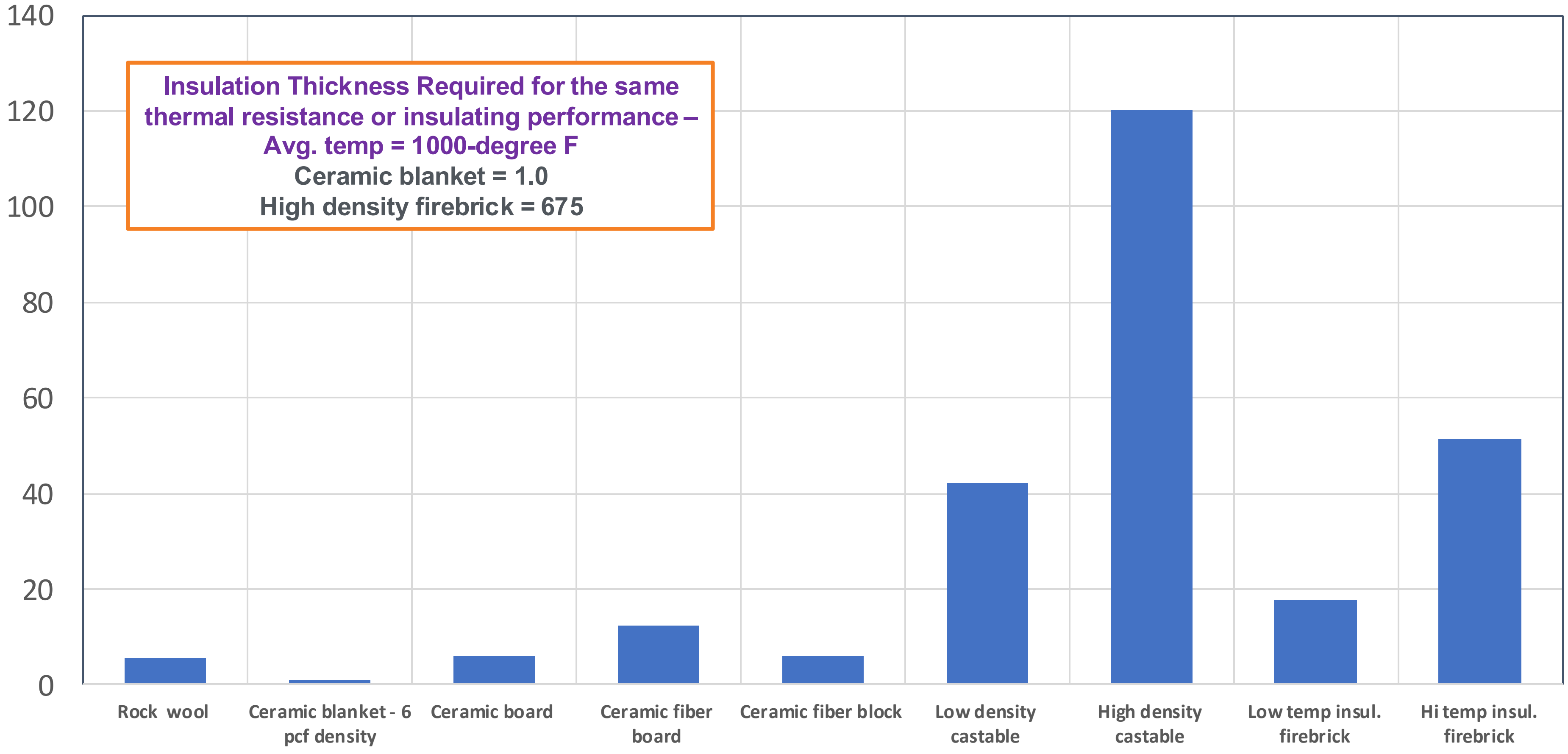
8” (20 mm) Castable
4” (100 mm) insulation board
2” (50 mm) fiber blanket
0.25” (6 mm) steel plate
$T_{surface}$ = 180^{0} F

Heat loss
~253 Btu/(ft^{2}-hr.)

Insulation and Refractory Materials

#	Material	Application Temperature Range (°F)	Application Temperature Range (°C)
1	Carbon steel	0-500	0-260
2	Rock (mineral) wool	0-1200	0-650
3	Ceramic blanket - 6 pcf density	300-2000	150-1100
4	Ceramic board	200-1800	100-990
5	Ceramic fiber board	300-2300	150-1260
6	Ceramic fiber block	300-2400	150-1315
7	Low density castable	300-2200	150-1200
8	High density castable	300-2600	150-1425
9	Low temp insul. firebrick	300-2300	150-1260
10	Hi temp insul. firebrick	300-2800	150-1540
11	High density firebrick	300-3000	150-1650

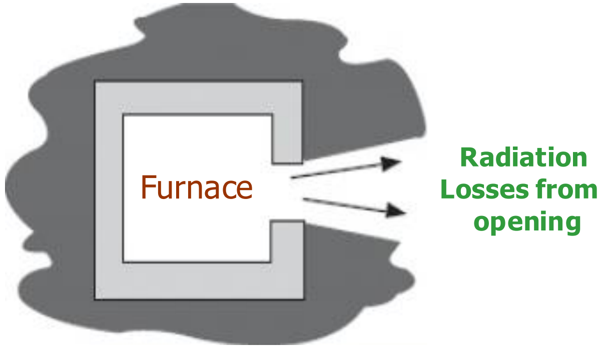
Relative Insulating Values



Summary for Insulation Related Measures

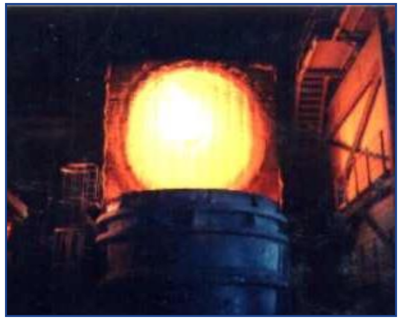
Actions	Potential energy savings*
Use the proper type and thickness of insulation for furnace/oven walls	0.5% to 2%
Repair and maintain insulation or refractories used for the walls and doors	Less than 1%
Whenever possible avoid cooling the walls of ovens and furnaces; use them continuously.	Less than 1% to 2%

Fixed and Variable Opening Loss



- Radiation loss from hot surfaces or openings is a preventable heat loss
- Different types of openings allowing radiation heat loss:
  - Fixed openings, such as a hole or crack in the furnace walls or doors; an open stack facing the sky, etc.
  - Uncovered hot liquid metal ladle with or without metal; crucible furnace with open top
  - Variable openings such as a door opened during charging or discharging of material

How to Reduce Opening Loss?



Reduce opening loss:

- Use a cover for hot metal transport ladles or crucible furnaces whether they contain liquid metal or not
- Plug holes where possible
- Reduce the size of holes
- Use a radiation shield made of metal or ceramic material to reduce heat loss
  - Minimize door opening time or size of the opening
  - Do you need to open the door to fully open position?
  - Can you reduce charging frequency?
- Maintain the doors to allow easy operation and minimize operator efforts

Savings can be estimated by using MEASUR or simple calculators

Savings: Reduce Door Opening

RESULTS | HELP

Baseline Results

Fuel Use	20,563 MMBtu/yr
Fuel Cost	$82,046.10
Gross Loss	2.35 MMBtu/hr

Copy Table

Modification Results

Fuel Use	15,079 MMBtu/yr
Fuel Cost	$60,167.14
Gross Loss	1.72 MMBtu/hr

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Savings

Fuel Savings	5,483 MMBtu/yr
Annual Cost Savings	$21,878.96

BASELINE

+Add Loss

Loss #1 +Remove Loss

Fuel | Electrotechnology | Steam-based

Annual Operating Hours	8760 hrs/yr
Fuel Cost	3.99 $/MMBtu
Available Heat (Calculate)	100 %
Select Type	Rectangular (or Square)
Number of Openings (Same Size and Shape)	1
Furnace Wall Thickness	16 in
Length of Openings	420 in
Height of Openings	60 in
Total Opening Area	175.00 ft ^{2}
View Factor (Calculate)	0.868
Average Inside Temperature	2400 °F
Ambient Temperature	75 °F
Emissivity of the Source (Typical - 0.9)	0.9
Time Open	15 %
Opening Loss	**2.34737 MMBtu/hr**
Gross Loss	**2.34737 MMBtu/hr**

MODIFICATION

Loss #1 (Lower Time Open)

Fuel | Electrotechnology | Steam-based

Annual Operating Hours	8760 hrs/yr
Fuel Cost	3.99 $/MMBtu
Available Heat (Calculate)	100 %
Select Type	Rectangular (or Square)
Number of Openings (Same Size and Shape)	1
Furnace Wall Thickness	16 in
Length of Openings	420 in
Height of Openings	60 in
Total Opening Area	175.00 ft ^{2}
View Factor (Calculate)	0.868
Average Inside Temperature	2400 °F
Ambient Temperature	75 °F
Emissivity of the Source (Typical - 0.9)	0.9
Time Open	11 %
Opening Loss	**1.72140 MMBtu/hr**
Gross Loss	**1.72140 MMBtu/hr**

Summary for Heat Containment Related Measures

Actions	Potential energy savings*
Minimize door openings during charging and discharging the load or charge material	Less than 1% to 2%
Keep the doors closed and adjust the stack damper to avoid "cold air draft" through the stack	Less than 1% to 2%
Open the door to the minimum height as required for load charging	Less than 1% to 2%
Reduce openings, cracks, and holes in the heating equipment walls	Less than 1%
Plug the openings when not used or use a curtain, radiation shield, or other method to reduce exposure to the furnace interior	1% to 2%
Use a cover for hot metal ladles, tundish and crucible furnaces to reduce radiation heat loss	1% to 2%

Control Systems for Energy Savings

- Heat Generation
  - Fuel and air-flow control
  - Fuel gas composition control when appropriate
  - Air-to-fuel ration control
  - Furnace zone temperature control
  - Air and fuel supply system controls
  - Flame monitoring (safety system)
- Draft (pressure) control
- Load (molten metal, slab outlet, fluid) discharge temperature control where possible
- Flue gas temperature control for heat-recovery system
- Flue gas outlet temperature control from heat-recovery system to avoid condensation (or to protect pollution control system)

Control Systems for Energy Savings (continued)

- Furnace inside wall temperature control (high limit)
- Maximum tube temperature monitoring for process heaters
- Stack gas emission monitoring for O_2, CO, and combustibles
- Stack gas emission monitoring for criteria pollutants (NOx, particulates) if required by law
- Make-up air-flow control through use of LEL control or humidity control system
- Use of models and computerized zone temperature control to minimize energy use during part load operations
- Other safety related controls as required by insurance underwriters
- Calibrate and maintain sensors, instruments, and controllers

Energy Savings for Auxiliary Systems

- Clean soot or other deposits from heat transfer surfaces, such as radiant tubes and boiler tubes, or on the furnace inside walls
- Reduce heat loss from:
  - Metal or other components embedded in furnace walls (anchors, refractory support) or extended from the furnace itself (roller shaft, probes)
  - Preheated air piping to burners
  - Recirculation fan casing, flue gas ducts between the furnace, and the flue gas heat recovery device
  - Heat recovery device (recuperators or regenerator) surfaces

Energy Savings for Auxiliary Systems (continued)

- Use variable speed motors for recirculation fans, combustion air blowers, ID fans, pumps, or propellers
- Minimize use of flame curtains, vent pilots, or other types of fuel-consuming auxiliary heating devices; this may require time control when the devices are "on" while following safety guidelines
- Clean or replace filters for combustion air blowers, water pumps, and oil pumps regularly
- Take combustion air and make-up air (if used) from outside the enclosed building, particularly when the outdoor temperature is low and indoor heating is used

Reduction of Other Energy Loss
Thermal Efficiency Improvement

- Furnace operation:
  - Operate at or near design capacity - part load operation or overloading reduces thermal efficiency
  - Monitor energy use – maintain a record of energy intensity (energy use per unit of production) for all products
- Avoid water or other liquid content in combustion and make-up air or fuel used in the burners
- Control cooling-water flow to equipment such as water-cooled fans and other water-cooled components
- Check dampers and valves for unnecessary air leaks where ambient cold air is used to cool control flue gas temperature entering a flue gas heat-recovery device (recuperators or heat wheel)
- Consider using a combined heat and power (CHP) system where applicable and justified

Acknowledgement

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Information used in the presentation is derived from several sources including equipment manufacturers' websites, published literature, and handbooks.

- Fives North American Mfg. Co.
- Bloom Engineering
- Echogen Power
- Thermal Transfer Company
- Eclipse Combustion
- U.S. Department of Energy
- Industrial Heating magazine
- G.C. Broach Company
- Air products and Chemical Inc.

Questions and Answers