Decarbonization of Industrial Process Heating Systems

AZ0

Session 2. Energy Efficiency

Dr. Arvind C. Thekdi
February 2025
Prepared for The Energy Solutions Center

AZ0

Overview of the Sessions

- Session 1. Introduction to industrial process heating and pathways to decarbonization.
- **Session 2.** Efficiency improvements – low to no cost approaches to reduce CO2 emissions. Description and effectiveness of such actions with comments on economics. AZ1
- Session 3. Use of non-carbon bearing / low carbon fuels. Fuel options and their use. Fuels may include H2, Bio fuels including methanol, ammonia at selected locations etc.
- Session 4. Use electricity – electro technologies. Available technologies for specific applications (i.e. metal melting, drying, heat treating, calcining, non-metal melting etc.).

Overview of the Presentation Content

1. Recap of CO_2 emissions from various systems in a manufacturing plant.
2. Role of process heating as a major source of CO_2 emissions
3. Efficiency improvement steps – onsite generation and non-process systems with focus on process heating systems (furnaces*, boilers and steam systems)
4. Areas of efficiency improvements and CO_2 reduction
5. Specific actions for key areas of opportunities
6. Resources – tools for calculation of energy savings and CO_2 reduction

* The term furnaces is used for a variety of heating equipment such as ovens, melters, dryers, heaters etc.

Slide 1

AZ0 Add "Through Energy Efficiency"
Aqeel Zaidi, 2024-11-14T23:28:09.374

Slide 2

AZ0 Overall comment: focus only on process heating such as furnaces. Information on cogeneration and steam and boiler is available form other sources. Suggesting to remove several slides
Aqeel Zaidi, 2024-11-15T00:00:37.638

AZ1 Slides do no show information on economics. May not be relevant to go into economics since the focus is decarbonization. Otherwise it will become a very long presentation. This could be mentioned at the beginning of the presentation.
Aqeel Zaidi, 2024-11-15T00:03:40.485

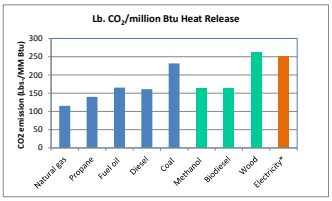
Summary - GHG Emissions from Industrial Sources

- The manufacturing sector released 765 million metric tons (MMT) of $CO_{2\,e}$ in 2021, in CBO's estimation.
- Combustion emissions accounted for 573 MMT (or 75 percent), and industrial process emissions accounted for 192 MMT (or 25 percent).
- Combustion emissions in the United States are more than 99 percent CO_2
- Process emissions are mostly CO_2 but contain a higher proportion of other greenhouse gases.

Source:
Emissions of Greenhouse Gases in the Manufacturing Sector.
Congressional Budget Office, (CBO) - February 2024

CO2 Emission from Various Energy Sources

Reminder



Note: CO_2 produced by complete combustion of fuels.

Carbon neutral
* For reference

Graph by Arvind Thekdi

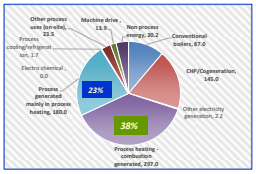
CO2 Emissions from Onsite Energy Systems

Energy use area	CO2 emissions (MM Tons/year)*
Conventional boilers	**87.0**
CHP/Cogeneration	**145.0**
Other electricity generation	2.2
Process heating - combustion generated	**297.0**
Process generated mainly in process heating	***180.0***
Process cooling/refrigeration	1.7
Electro chemical	-
Other process uses (on-site)	23.5
Machine drive	13.9
Non process energy	30.2
Total On site CO2 Emission	**780.5**

*** On-site CO2 emissions (MM Tons/year - 2018 data)**

Note: There is a little difference in CO_2 emission values between data of the year 2018 and 2021 as stated elsewhere.

This presentation does not address process generated CO_2 emission.



CO_2 emissions from process heating – combustion generated and process generated CO_2 represent 61% of the total stated here.

Energy Savings and CO2 Emission Reduction

- In the following slides we have discussed energy saving methods and estimates of energy saving by using several options.
- Each of these would result in reduction of CO_2 emission.
- The value of reduction depends on the type of fuel used.
- All information given here is for commonly supplied natural gas in North America.
- The conversion factor is: 115 lbs. reduction in CO_2 emission per MM Btu saved.
- For other energy sources use information given in an earlier slide.

AZ0

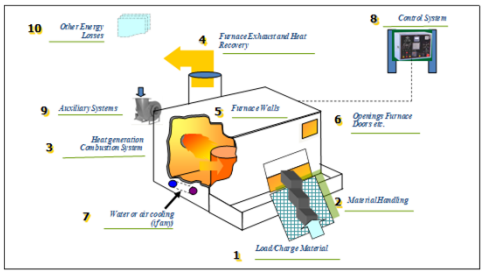
Energy and CO2 Emission Reduction
Low-No Cost Options



1. Personnel training
2. Operating practices.
   - Optimize or change operating practices – measure, monitor and modify process performance.
3. Low or no-cost maintenance.
   - Equipment or system modifications
   - Installation of efficiency Improvement hardware – software.
4. Retrofits or changes.

AZ0

Overview of a Process Heating System
Furnaces, Ovens, Heaters Etc.



Slide 8

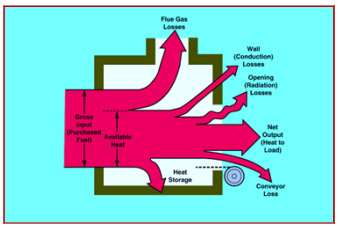
AZ0 Move to the end
Aqeel Zaidi, 2024-10-21T18:58:34.654

Slide 9

AZ0 source
Aqeel Zaidi, 2024-11-15T00:04:51.302

Sankey Diagram – Heat Balance

Visual Presentation For Furnace or Oven

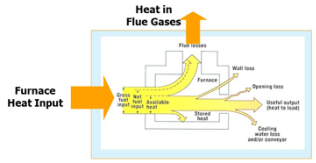


Other areas of heat loss:

Furnace or parts cooling, material handling (trays, fixtures etc.), process control performance, dilution air or process atmosphere.

Concept of Available Heat

AZ0

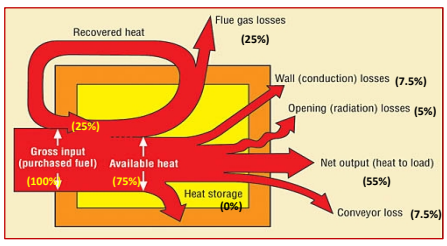


Available Heat = (Furnace Heat Input – Heat in flue gases)

- Concept of available heat states that one Btu saving results in reduction of more than one Btu as heat input.
- For a given fuel (natural gas) , available heat depends on the flue gas temperature, combustion air temperature and oxygen content of flue gases.

AZ0

Sankey Diagram with Typical Heat Losses



Energy use distribution

The actual values vary with the type of application:

Thermal process, temperature, equipment design heat recovery etc.

Slide 11

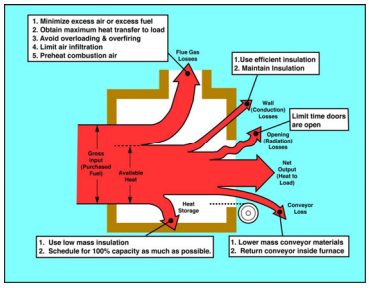
AZ0 Make it bigger to be legible
Aqeel Zaidi, 2024-11-15T00:05:50.901

Slide 12

AZ0 Move it after slide 17
Aqeel Zaidi, 2024-11-15T00:10:11.968

AZ0

Efficiency Improvement Suggestions



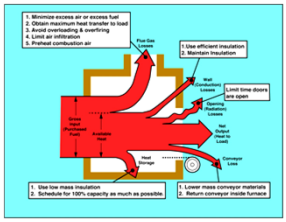
Efficiency improvement for other areas listed in the next slide

AZ0

Efficiency Improvement Suggestions
Additional Areas to Consider

- Material handling
  - Reduce fixture mass (redesign, different material etc.)
- Water or air cooling (furnace internals).
  - Alternate (higher temperature) material
  - Insulation of water cooled components
  - Eliminate water cooling where possible
- Controls
  - Avoid use of on-off control if possible
  - Use of appropriate sensors and monitoring (i.e. O2 sensor, moisture sensor, LEL monitoring, temperature etc.)
- Dilution air or furnace atmosphere
  - Humidity, LEL continuous control
  - Atmosphere flow control to meet process requirements only

Possible Efficiency Improvement Values



Area of heat loss – energy use	Savings (% of current losses)	
Gross heat input	20%	40%
Flue gas losses	10%	25%
Wall losses	5%	20%
Opening losses	10%	75%
Conveyor losses	20%	50%
Heat storage	5%	50%
Material handling	10%	40%
Water-air cooling	20%	60%
Controls	5%	20%
Dilution air or furnace atmosphere	10%	50%

Note: These are typical and possible values

The savings are highly dependent on the type-design of system, application and operating practices.

Slide 13

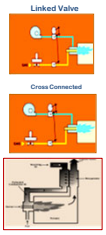
AZ0 Add % saving for each arrow
Aqeel Zaidi, 2024-11-14T23:37:20.148

Slide 14

AZ0 Is this slide needed? Consider deleting or moving to the end
Aqeel Zaidi, 2024-11-14T23:34:39.208

AZ0

Energy Saving – Combustion System



- Use proper burners: premix vs. nozzle mix (preferred)
- Use proper fuel-to-air ratio control system
  - Eliminate or reduce excess air operation
  - Maintain proper fuel-to-air ratio at all times
  - 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

AZ0

Energy Saving - 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 before charging
  - Thermal (flue gas, external heating) drying
  - Mechanical moisture removal if possible
- Charging at or near design capacity and frequency
- Proper load arrangement for optimum heat transfer

Slide 17

AZ0 Since we are deleting lots of slides, consider add a couple of slides to show energy and CO2 saving due to combustion improvement
Aqeel Zaidi, 2024-11-14T23:45:29.202

Slide 18

AZ0 Since we are deleting lots of slides, consider add a couple of slides to show energy and CO2 saving due to combustion improvement
Aqeel Zaidi, 2024-11-14T23:45:29.202

Reduction of Exhaust/Flue Gas Losses

- In most cases reduction of exhaust gas heat losses offers high potential for improving the energy efficiency – CO2 emissions from a heating system.
- The first step to reduce exhaust gas heat losses is take energy efficiency improvement actions discussed earlier.
- Heat recovery from exhaust gases can reduce energy use by 15% to 40%.
- Use of exhaust gas heat recovery requires installation of additional equipment such as a recuperator, burners and control system.
- Heat recovery can be beneficial for even lower temperature (>500^{0}F) furnaces or ovens where the gases contain large amount of excess air or oxygen content.

* The term furnaces is used for a variety of heating equipment such as ovens, melters, dryers, heaters etc.

Sources of Waste Heat

- Furnace exhaust or flue gases
  - high temperature heating systems as fired heaters, melting systems, gas turbines etc..
- Cooling water or air used in furnaces, reactors, product cooling, compressor after coolers etc.
- Heat of exothermic reaction for processes.
- Hot surfaces and other radiation sources (openings)
- Hot products at discharge after heating and/or reactions are completed.
- Steam leaks, boiler blow down water, condensate etc..
- Exhaust stream from thermal oxidizers and emission control systems.

Use of Waste Heat

Options:

- **Recycling: Use the heat within the heating system itself.**
- **Recovery: Use of heat in external applications.**

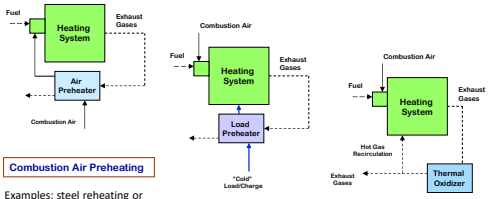
The next few slides give explanation and examples of waste heat recycling and recovery

Options for Exhaust Gas Heat Recycling

For process heating (fired) systems

- Combustion air preheating
- Feed material drying
- Load preheating
- Heat cascading: use of gases from high temperature zones to lower temperature zones.
- Use of chemical heat of reaction products through after burning or within the heating system itself. ,

Waste Heat Recycling Options



Combustion Air Preheating

Examples: steel reheating or forging furnaces, electric arc melting furnaces (EAFs), fired heaters

Load-Charge Preheating

Examples: aluminum melters, ceramic drying kilns, boiler economizers.

Internal heat recycling - cascading

Examples: paint drying ovens, chemical reactors, process heaters.

Illustrations by Arvind Thekdi

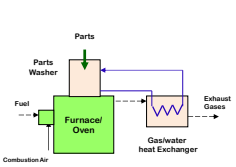
Options for Exhaust Gas Heat Recovery

For process heating (fired) systems

1. Steam generation
2. Hot water (liquid) heating
3. Air (gas) heating
4. Plant or building heating
5. Cascading to lower temperature heating processes
6. Absorption cooling systems
7. Electricity generation

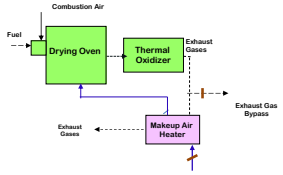
Note: These are the most commonly used methods. There may be additional methods not mentioned here.

Waste Heat Recovery Options



Water heating for an in-line Washer

Examples: heat treating furnaces, pulp and paper industry, food processing ovens etc.



Makeup air heating for an oven

Examples: paint drying ovens in auto industry, food dryers, chemical reactors etc.

Illustrations by Arvind Thekdi

Marching Steps

Actions to Reduce Energy Use and CO2 Emission

- Analyze energy distribution:
  - How much energy is used and where is it going? Use measuring instruments, data loggers etc. and available analytical tools discussed here.
- Identify energy-saving measures:
  - What measures/actions can be taken to reduce energy loss and improve energy efficiency?
  - How many are practical?
- Estimate effect of energy-saving measures:
  - How much energy is saved?
  - What is the CO2 reduction?
- Select appropriate energy measures
  - What measures give the best energy savings?
- Develop an action plan: Energy reduction and associated CO2 reduction.

Data Collection: Tools of the Trade

Measurements and Data Collection

CO2 Emission Reduction through Efficiency Improvements

Available Analysis Tools

- From The US DOE
  - Process Heating Assessment and Survey Tool (PHAST)
  - Steam Assessment tool
  - Other tools for pumps, fans, compressed air and Fan Assessment
- From Energy Solutions Center (ESC)
  - Calculators for process heating and steam systems
- Other
  - Developed for California Energy Commission (CEC)

AZ0

Estimate of Energy Savings and CO2 Reduction

- PHAST* can be used to analyze and estimate:
  - Use of heat (or heat loss)
  - Potential energy savings for commonly-used energy-saving measures identified in each area
- It is necessary to convert energy savings into CO_2 reduction and economic benefits ($ savings) by using the required parameters.
- Simple calculators or calculations should be used for these additional steps.
- *Links to the available tools and calculators are given in a later slide.*

* Process Heating and Assessment Survey Tool developed by E3M Inc. for the US Department of Energy

AZ0

Calculators for Process Heating Equipment
(Energy Solutions Center – ESC)

No.	Calculators - Process Heating
1	Predrying of charge material in a dryer or an oven
2	Preheating of load or charge material using flue gas heat
3	Control of furnace - oven pressure to eliminate or reduce air leaks
4	Use of oxygen enriched combustion air or oxy-fuel firing
5	Use of flue (exhaust) gases for HVAC - air heating
6	Use of hot flue gases to produce steam
7	Heat cascading from high temperature process to lower temperature process
8	Make up air control to control moisture content in exhaust gases
9	Use of waste heat for absorption chiller system
10	Use heat from clean exhaust gases to heat water in a direct contact heater
11	Use of gas heated equipment to replace electrically heated equipment
12	Use of combustion (gas) turbine exhaust gases as combustion air
13	Change weight, material or temperature of fixtures
14	Calculate Thermal Efficiency of a gas fired heating system (a furnace, an oven, a dryer etc.)
15	Direct gas injection for thermal oxidizers or use of duct burners for heat recovery boilers
16	Upgrade to more efficient equipment. (Like to like)
17	Reduce energy loss due to exfiltration (leakage) of gases from a furnace - oven
18	Reduction of product loss and thermal losses for aluminum melting furnaces.

Slide 29

AZ0 Provide links to sites
Aqeel Zaidi, 2024-11-14T23:56:29.322

Slide 30

AZ0 Provide links
Aqeel Zaidi, 2024-11-14T23:56:52.674

Calculators for Steam System
(Energy Solutions Center – ESC)

No.	Calculators - Steam System
19	Calculate Thermal Efficiency of a Steam Generator (Boiler) or a Liquid Boiler - Heater
20	Use of multiple effect evaporators to reduce steam and energy use
21	Use of a pressure reducing steam turbine to replace a pressure reducing valve
22	Use of vent steam to heat water
23	Use of gas heated equipment to replace steam heated equipment
24	Optimize deaerator operation - control pressure and steam vent rate
25	Use of steam for absorption chiller system

Remarks and References

- This presentation covers most commonly used methods of energy efficiency improvements and associated CO2 emission reduction
- There are many other options and they are not covered here due to time limitations
- Some of the references for additional information and training sessions:
  - PHAST program download
  - Process Heating Systems | Department of Energy
  - DOE Steam systems information
  - Steam Systems | Department of Energy
  - Training programs for process heating
  - Comprehensive demo of the Process Heating Module in MEASUR:
  - https://www.dropbox.com/scl/fi/61hhe8n29g2rrifdbd3fp/Process-Heating-VINPLT-Session-3.mp4?rlkey=an3at47ua9e7cqxlqavsp4now&e=1&dl=0
  - virtual process heating training with energy savings methods
  - https://bptraining.ornl.gov/ph-recorded-sessions/

Thank You