Decarbonization of Industrial Process Heating Systems

Session 4. Use of Electric Heating technologies

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Prepared for The Energy Solutions Center

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 CO_2 emissions. Description and effectiveness of such actions with comments on economics.
- **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 of electricity – electro technologies for process heating. Available technologies for specific applications (i.e. metal melting, drying, heat treating, calcining, non-metal melting etc.).

Overview of the Presentation Content

1. Electricity sources and associated CO_2 emissions.
2. Electric heating systems (electro-technologies). Description, characteristics and possible process heating applications
3. Application of alternate electric heating systems for process heating in major industries.
4. Issues or factors to consider while selecting an alternate electric heating system.
5. Resources – Additional information on electric heating systems in process heating.

Electrical Heating Terms and Cost

Cost of Electric Heating

Electricity cost Cents/kWh	Equivalent "heat" cost $/MM Btu		
Application efficiency ⇨	100%	90%	75%
3	$ 8.79	$ 9.77	$ 13.02
4	$ 11.72	$ 13.02	$ 17.36
5	$ 14.65	$ 16.28	$ 21.70
6	$ 17.58	$ 19.53	$ 26.04
7	$ 20.51	$ 22.79	$ 30.38
8	$ 23.44	$ 26.04	$ 34.73
9	$ 26.37	$ 29.30	$ 39.07
10	$ 29.30	$ 32.56	$ 43.41
11	$ 32.23	$ 35.81	$ 47.75
12	$ 35.16	$ 39.07	$ 52.09

1 kWh= 3,413 Btu/hr...

* Per the US Energy Information Agency (EIA)

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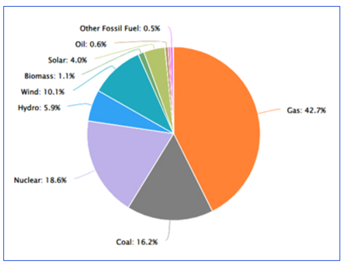
- Electrical energy is measured in terms of Kilowatt-hours (kWh).
- Electricity production at a central power plant is 33% to 40% efficient based on the generation system and type of energy required at the power plant.
- Primary fuel use for electricity is calculated by using 1 kWh = 10,500 Btu*. It can be as low as 6,000 Btu/kWh for combined heat and power (CHP) systems.
- Actual efficiency of application of "electric heat" could be in the range of 65% to 90% depending on the heating system design and operation.
- Indirect CO_2 emission from electric heating system depends on the source of electricity.

Primary Energy Sources for Electricity Generation in USA

- Renewable* source – 21.1%
- Nuclear – 18.6%
- "CO_2 free" energy source – 39.7% of the total

* Includes solar, biomass, wind and hydro.



Source: US EIA -DOE

Electricity Generation in USA CO_2 Emission

- In 2023, the average carbon dioxide (CO_2) emissions per kilowatt-hour (kWh) of electricity generated in the United States was 0.81 pounds (lbs.) per kWh. This includes nuclear and renewables electric "plants" and the efficiency of the fuel fired power plant.
- For natural gas fired power plant CO_2 emission is 0.96 lbs./kWh
- This represents more than double the CO_2 emission from direct natural fired systems.
- For direct natural gas fired systems CO_2 emission is 117 lbs./MM Btu (equivalent to 0.4 lbs./kWh) heat supplied.

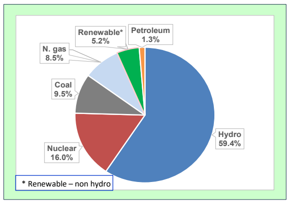
From global climate considerations net CO_2 emission is the lowest for direct natural gas firing compared to use of electricity in USA (2023 data from US EIA) for comparable heat delivered.

Source: US EIA -DOE

Electricity Generation and CO_2 Emission in Canada

- Renewable* source – 64.6%
- Nuclear – 16.0%
- "CO_2 free" energy source – 80.4% of the total

* Includes solar, biomass, wind and hydro.

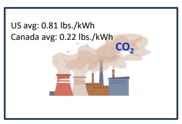


In 2022, Canada's electricity grid had a greenhouse gas intensity of 100 grams (0.22 lbs.) of CO_2 equivalent (CO2e) per kilowatt-hour (kWh) of electricity generated.

Note: These values can be different for different provinces

Source: Greenhouse gas emissions - Canada.ca

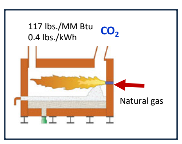
CO_2 Emission – Natural Gas vs. Electric Heating



Note:

CO2 emission for electric heating in Canada based on national average which is significantly lower than that for USA

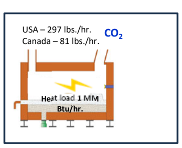
Thermal efficiency for heating system:
Gas heating: 65%
Electric heating 80%

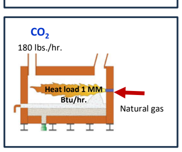


CO_2 emission for electricity depends on the source of electricity

- Above values are based on national averages
- For on-site or off-site generation by gas turbines or reciprocating engines the CO2 emission can be substantially higher - 3 to 5 times the average given above.
- For renewable electricity they can be practically zero.

CO_2 Emission – Natural Gas vs. Electric Heating





CO_2 (lbs.) emission per MM Btu NET HEAT LOAD		
	Type of heating	
	Nat. Gas	Electric
USA	180	297
Canada	180	81

CO_2 emissions for electricity – national average
US avg: 0.81 lbs./kWh., Canada avg: 0.22 lbs./kWh
The marginal rates can be higher

Note:

CO2 emission for electric heating in Canada based on national average which is significantly lower than that for USA

Thermal efficiency for heating system:
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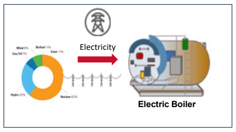
Does Electrification Reduce GHG Emission?



- Depends on how the GHG savings are calculated
- Where the boundary is drawn
  - **Site or source**
- Which electricity grid emission factors are used to calculate GHG savings
  - Average or marginal
  - Current or future emissions

- Electric equipment use electricity generated from various sources including nuclear, hydro, gas – base load plus solar and wind (intermittent)
- Gas plants provide vital role of meeting peak demand, grid resiliency and other services
- New electric equipment will add to incremental demand
- Will add to marginal generation and emissions associated with marginal generation

Courtesy: Aqeel Zaidi, Enbridge Gas

Grid Emission Factors

What are these factors? – Ontario, Canada example

Average grid emission factor =

$$\frac{Annual\ GHG\ emissions}{Total\ Annual\ Generation\ from\ all\ sources\ (Nuclear, Renewable, Fossil)}$$

Average grid emission factor (2024) = $\frac{6.9\ megatonne\ (from\ gas\ power\ plants)}{148\ TWh\ (total\ generation)}$

= 50 gm/kWh or 0.11 lbs./kWh

Gas plant emission factor (2024) = $\frac{6.9\ megatonne\ (from\ gas\ power\ plants)}{17.6\ TWh\ (gas\ plant\ generation)}$

= 390 gm/kWh or 0.86 lbs./kWh

Marginal emission factors (combined cycle power generation)= $\frac{Change\ in\ GHG\ emissions}{Unit\ change\ in\ Demand}$

= (0 – 390 gm/kWh) or 0 – 0.86 lbs./kWh

Courtesy: Aqeel Zaidi, Enbridge Gas

Marginal Emission Factors

Marginal emission factors: More Complex

- Depends on which source of generation is on the margin, imports and exports
- Marginal generation changes based on non-base load generation, imports and exports and consumption
- Change by the hour of day, day of the week and by season:
  - Low during off-peak hours and shoulder season, and high during peak hours and winter and summer
- MEF could be 0 when gas is not the margin and 417 gm/kWh (0.92 lb./kWh) when all marginal demand is supplied by gas plants
- Proper use of appropriate of emission factors is essential to determine realistic GHG emissions

Courtesy: Aqeel Zaidi, Enbridge Gas

Example: Emission Depends on which factors are used

- **Gas Boiler**
  - Rating = 42 MMBtu/hr.
  - Operation = 4,000 hr./yr
    - two x 8 hr. weekday shifts
    - 50 weeks per year
  - Avg. firing rate = 50%
  - Gas consumption = 2.3 million m3/yr
  - Gas emission factor = 1.9 kg/m3
  - **CO_{2e} emissions = 4,360 tonne/yr**

- * Power Advisory Report Prepared for Enbridge Gas "Marginal Greenhouse Gas Emission Factors for Ontario Electricity Generation and Consumption

Tonne – metric ton = 2240 lbs. or 1.12 US tons.

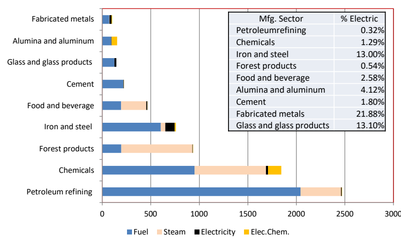
The values used in this example are Ontario, Canada.

- **Electric Boiler**
  - Rating = 10 MW
  - Operation = 4,000 hr./yr
    - two x 8 hr. weekday shifts
    - 50 weeks per year
  - Avg. firing rate = 50%
  - Electricity consumption = 20,000 MWh
  - MEF during operating time = 0.343 tonne/MWh*
    - Average MEF forecast for 20 years (2020 – 2040)
  - Avg EF = 0.05 tonne/MWh
  - **CO_{2e} emissions (MEF) = 6,869 tonne/yr**
  - **CO_{2e} emissions (AEF) = 1.000 tonne/yr**

Courtesy: Aqeel Zaidi, Enbridge Gas

Current Status of Electric Heating in Manufacturing*

Process Heating Energy use (TBtu/year)
By the type of energy used - 2018 MECS Data (USA)



Mfg. Sector	% Electric
Petroleumrefining	0.32%
Chemicals	1.29%
Iron and steel	13.00%
Forest products	0.54%
Food and beverage	2.58%
Alumina and aluminum	4.12%
Cement	1.80%
Fabricated metals	21.88%
Glass and glass products	13.10%

*** Over all, electric heating represents approximately 5% of the total energy used for process heating in the US manufacturing sector.**

Electrical Heating Systems

for Industrial Process Heating Applications

1. Resistance heating (RH)
2. Induction heating (IH)
3. Electric infra-red processing (EIP)
4. Electric arc heating (EAH)
5. Microwave heating (MWH)
6. Radio frequency heating (RFH)
7. Electron beam processing (EBP)
8. Ultra violet processing (UVP)
9. Plasma heating (PH)
10. Laser heating (LH)
11. Industrial heat pumps (IHP)

Use of Electrotechnology for Process Heating - 1

Electrotechnology	Typical applications	Primary industries	Competing technologies
Resistance (direct and indirect) heating	Convection and radiation ovens and furnaces for metal and non-metal heating, glass melting.	Metals, ceramics, glass, food, chemical.	Electric IR processing, microwave and RF heating, arc-plasma heating.
Induction heating and melting	Heating, heat treating, melting	Fabricated metal products, primary metals, transportation equipment, machinery	Resistance heating, infrared processing, electron beam processing, gas furnaces
Electric IR processing	Heating, drying, curing, thermal bonding, sintering, sterilizing	Fabricated metal products, transportation equipment, plastics and rubber	Electron beam processing, ultraviolet curing, resistance heating, induction heating
Arc furnaces	Steel production, melting steel, iron and refractory metals, smelting	Primary metal production, especially steelmaking	Oxygen furnaces (coal), plasma processing
Microwave and radio frequency processing	Heating, tempering, drying, cooking, plasma production	Food/beverage, plastics and rubber, wood products, chemicals	Resistance heating, induction heating, ovens

Source: Arvind Thekdi

Use of Electrotechnology for Process Heating - 2

Electrotechnology	Typical applications	Primary industries	Competing technologies
Electric heat pumps	Low temperature (<300 F) process heating, drying, liquid heating etc.) in selected	Food, beverage, forest products, pulp & paper, and chemicals industries.	Convection heating (resistance), microwave, infrared heating.
Laser processing	Heat treating, hardening, trimming and cutting, welding	Transportation equipment, fabricated metal products, electronics	Electron beam processing, plasma processing, induction heating, arc welding
Electron beam processing	Melting, drying, welding, machining, curing, crosslinking, grafting	Fabricated metal products, machinery, transportation equipment, plastics	Infrared processing, laser processing, ultraviolet curing, induction melting, arc welding
Plasma processing	Melting scrap, remelting for refining, reduction, surface hardening, welding, cutting	Primary metals (titanium, high-alloy steels, tungsten)	Arc furnaces, oxygen furnaces, electron beam processing, laser processing

Source: Arvind Thekdi

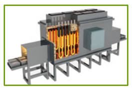
Electrical Heating – Application Options



- Partial replacement or supplemental electrical heating to reduce use of natural gas.
- Complete conversion of the current system (furnace, oven etc.) from gas heating to electric heating.
- Use of alternate heating process and/or equipment. For example, use of induction heating to replace conventional gas heating system.
- Replacement of thermal process with use a non-thermal process for production of materials-components. Example: electro chemical process to produce iron from iron ore.

Figures from Process Heating Sourcebook – US DOE

Options for Existing Equipment


- Direct fired furnace or oven
  - Electrical resistance elements to replace burners.
  - Install electrical infrared panels
- Radiant tube heated furnace
  - Insert electrical resistance heating assembly to replace burners.
- Gas infrared heated ovens
  - Replace with electrical infrared panel
- Recirculating gas ovens or furnaces
  - Replace gas burners/heaters with electrical resistance heaters
- Partial replacement of burners in certain zones of a furnace or oven by electrical heating system to reduce CO_2 emission.

Figures from Process Heating Sourcebook – US DOE

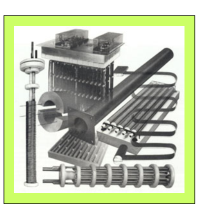
Major Components of a Resistance Electrical Heating System

Resistance Heating

Heat is produced when electric current is passed through a resistor. (E=I²R)

- Heating Elements (various types)
- Power Supply from the grid to the point of use
- Power Control System Connected with the Furnace Temperature Control System
- Water Cooling System (in some cases)

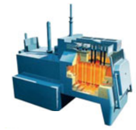
Heating Elements



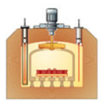
Source: Kanthal Handbook by Kanthal Corporation

- Materials for elements: metallic or ceramic
- Commonly used elements:
  - Cr-Ni alloys
  - Silicone Carbide
  - Molybdenum
  - Graphite
- Mounting arrangements:
  - Mounted on the furnace inside wall
  - Inside a metal or ceramic tube
  - Embedded in molded fiber ceramic insulation
  - Encased or sheathed

Heating Elements Application



Direct exposed ceramet heating elements in a heat treating furnace



Radiant tube replacement heating elements in a heat treating furnace

Source: Kanthal Corporation Electric Elements Handbook

Heating Element Types

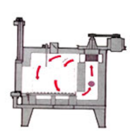
Heating Element Family	Material	Maximum Temperature of Element (°C)	Application - Remarks
Iron-Nickel-Chrome Alloys	Fe-20Ni-25Cr	900	Widely used because of their availability and low cost Wide range of temperatures Used in oxidizing atmospheres
	Fe-45Ni-23Cr	1050	
	Fe-65Ni-15Cr	1100	
	80Ni-2-Cr	1150 to 1200	
Iron-Chrome-Aluminum Alloys	Fe-22Cr-14.5Al	1280	Higher temp. than Ni-Cr at about same cost Embrittlement on first heating Used in oxidizing atmospheres
	Kantal AF	1400	
Non-metallic Alloys	SiC (silicon carbide)	1600	Bars are brittle – susceptible to thermal & mechanical shocks Used in oxidizing or reducing atmospheres
	$Cr_2O_3La_2O_3$ (lanthanum chromite)	1800 to 1900	
	Graphite	2500	Low cost of bars Used in neutral or reducing atmospheres, or under vacuum
Noble metals	Molybdenum	2300	Wire or plates Very high cost Only in neutral or reducing atmospheres, or under vacuum
	Tungsten	2500	
	Tantalum	2500	

Resistance Heating Applications

- Directly exposed heating elements (radiant heating)
  - Low to medium temperature ovens used in drying and heating applications.
  - Metal and non-metal re heating furnaces
  - High temperature metal heating – sintering
- Convection furnaces using air or special atmosphere circulation
  - Low temperature heating applications such as drying ovens, air heaters,
- Enclosed heating elements (radiant tubes or muffle)
  - Heat treating furnaces
- “Shielded” heating elements
  - Vacuum furnaces
- Use of charge (material being heated) as an electric resistor
  - Glass melting

Electrical Resistance Heating Applications

Heat Treating Furnace



High Convection Heat Treating Furnace

Vacuum Furnace

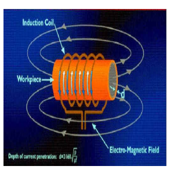
Electric Glass Melting Furnace

Source: Process Heating Source Book – U.S. DOE

Conversion from N. Gas Firing to Electric Resistance Heating

- It is very difficult or practically impossible to match heating capacity of natural gas fired system when electrical resistance heating elements are used to convert a heating system in an existing furnace. In most cases there is not enough space to place the required heating elements.
- The options include:
  - Reduction of production rate
  - Change in process specifications or heat transfer enhancement if possible (i.e. use of high convection to improve heat transfer)
  - Conversion of indirect - radiant tube heating with direct heating
  - Use of auxiliary heating system to preheat or "soak" the product while maintaining the productivity.
- The conversion requires considerations and cost of installation of electric power supply, distribution and control equipment.
- General rule: Conversion of a 3 MM Btu/hr.. heating system may require additional power supply capacity of 1 MW.

Induction Heating



- The power supply sends alternating current through the coil, generating a magnetic field.
- When the work piece (material) is placed within the coil, the magnetic field induces eddy currents in the work piece, generating localized heat without any physical contact between the coil and the work piece. The heat can simply raise the material temperature or even melt the material

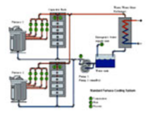
The basic components of an induction heating system
- An AC power supply,
- Induction coil,
- Work piece (material to be heated or treated)
- A method of material handling, and
- Some method of coil/water cooling.

Applications of Induction Heating

- **Induction Heating**
  - Through (entire cross section) heating
    - Metal reheating for forging, rolling etc.
  - Selective length – section heating
    - End heating
  - Surface heating
    - Heat treating (carburizing, nitriding, case hardening)
- **Induction Melting**
  - Crucible (coreless) induction heating
    - Melting of ferrous and non-ferrous metals
  - Channel induction heating

Components of Induction Heating System

Power Supply and Control System



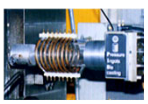
Cooling Water System

Induction Coils

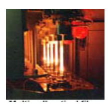
Source: Electroheat Technologies, Royal Oak MI.

Induction Heating Applications

Pipe and Rod Heating



Die Heating



Optical Fiber Drawing

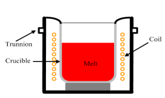
Welding of fins on a pipe

Localized Heating of a Bottle Top

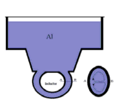
Curing of glue on a car door

Source: Electroheat Technologies, Royal Oak MI.

Induction Melting Furnaces



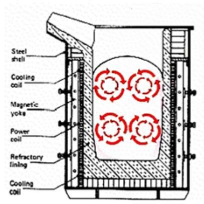
Coreless Induction Melter



Channel Induction Melter

- Coreless furnaces use the entire metal bath as the conductive medium, while channel furnaces have a specific channel loop that concentrates the induction field.
- This difference leads to variations in melting speed, energy efficiency, and suitability for different applications.
- A channel induction furnace is best for metals which have lower melting points, while the coreless furnace is best utilized for metals with higher melting points.

Coreless Induction Melting Furnace



Major Components

- Coreless induction furnaces are used for higher melting point metals
- Coreless induction furnace (steel shell, refractories etc.)
- Medium frequency power supply
- Peripheral equipment such as water-cooling unit
- Hydraulic unit and transformer
- Furnace and process control unit

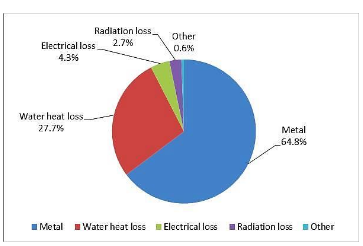
Induction Heating System Efficiency

Power Source	Frequency	Terminal efficiency %	Coil efficiency %	System efficiency %
Supply system	50 to 60 Hz	93 to 97	50 to 90	45 to 85
Frequency multiplier	50 to 180 Hz	85 to 90	50 to 90	40 to 80
	150 to 540 Hz.	93 to 95	60 to 92	55 to 85
Motor generator	1kHz	85 to 90	67 to 93	55 to 80
	3 kHz	83 to 88	70 to 95	55 to 80
	10 kHz	75 to 83	75 to 96	55 to 80
Static inverter	500 Hz	92 to 96	60 to 92	55 to 85
	1 kHz	91 to 95	70 to 93	60 to 85
	3kHz	90 to 93	70 to 95	60 to 85
	10 kHz	87 to 90	76 to 96	60 to 85
Radio-frequency generator	200 to 500 kHz	55 to 65	92 to 96	50 to 60

Induction heating system power supply efficiency can vary from 40% to 85%

Source: **Elements of Induction Heating: Design Control and Applications**
by S. Zinn (Author), S. L. Semiatin (Author)

Heat Balance for a Typical Induction Heating System*



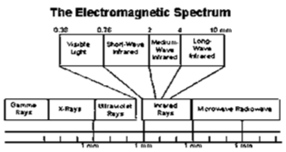
* This is for heating of steel – forging application

Source: **Elements of Induction Heating: Design Control and Applications**
by S. Zinn (Author), S. L. Semiatin (Author)

Infrared heating

What is Infrared?

- Infra-red is part of the electromagnetic spectrum between visible light and radio-waves. It covers the range of the electromagnetic spectrum between 0.78 and 1000 mm.
- It is invisible to the human eye but its heating effect is dramatic. Infra-red heating has the ability to heat people and objects directly, without the need to heat up the air in between

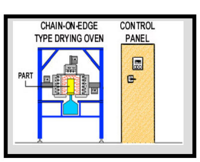


Source: Fostoria Industries

Application of Infrared Heating Systems

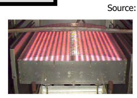
- Drying and curing – polymerization
  - Paints and coatings on metal, wood, glass, paper etc.
- Dehydration and partial drying
  - Paper, cardboards, textiles, inks etc.
- Misc. heating
  - Heating of plastic and glass prior to forming
  - Low temperature melting
  - Thawing of aggregates and frozen materials
  - Sterilization of bottles and components in pharmaceutical industries
  - Bonding adhesives and other materials
  - Food processing

Typical Infrared Heating Systems



Source: Fostoria Industries

Short Wavelength



Medium Wavelength

Long Wavelength

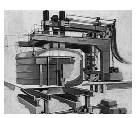
IR Heat Sources

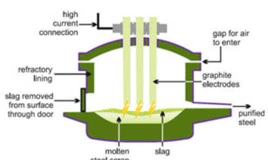
Source: Advanced Energy

Electric Arc Furnace (EAF)

- An Electric Arc Furnace (EAF) uses high-powered electric arcs to melt steel scrap and other iron-rich materials, producing molten steel,
- Electric power supplied from a 3 phase multi voltage tap transformer, a power transformer and associated control system.
- Industrial arc furnaces range in size from small units of approximately one-ton capacity (used in foundries for producing cast iron products) up to about 400-ton units used for secondary steelmaking.
- Main uses of EAF
  - **Steelmaking:** The primary use of EAFs is in the production of steel, especially from recycled scrap materials.
  - **Alloy Steel Production:** EAFs are also used in the production of high-grade alloy steels.
  - **Other Metals:** While primarily used for steel, EAFs can also be used for melting and refining other metals like aluminum, copper, and lead.

Electric Arc Furnace (EAF)



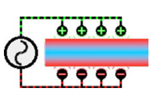


Source: Steel manufacturers Association (SMA)

CO_2 emission from EAF: 0.67 tons per ton of steel melted

This compares to 2.62 tons CO_2 per ton of steel produced by conventional (Blast Furnace route) methods.

Dielectric Heating



- When Dielectric materials such as moist wood are introduced into an alternating electric field, molecules such as water rotate and move literally millions of times per second in an attempt to align with the changing electric field.
- This generates heat within the material in a manner similar to friction. As the wood dries and the water is removed, the alternating field will no longer heat the material
- Most dielectric heating is done at Radio-Frequencies of 10 to 100MHz. A growing number of applications are done at higher microwave frequencies.

Dielectric Heating Application

Wood dryer heated by using Dielectric heating

- The material to be heated is placed in this high-frequency field often between two parallel plates or electrodes where it becomes the dielectric of a capacitor.
- Since the heat is developed directly in the material, excellent uniformity and remarkable speed of heating are possible.
- In drying applications energy is absorbed in relation to the amount of moisture present and becomes self-limiting.
- Practical efficiencies of 50% to 60% (line power to heat in the work) are readily attained.

Source: Penn State

Dielectric Heating Applications

Wood Veneer Dryer

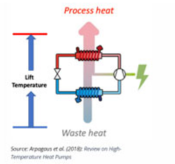
Foam Dryer

Food Dryer

UV/EB Curing

- Ultraviolet radiation can induce chemical and or physical changes in certain materials.
- This ability is used in many applications. These include:
  - hardening clear coatings on wood products,
  - curing powdered coatings on metal products,
  - activating adhesives and inks in the graphics industries and
  - selectively etching circuitry in the electronics industry.

Electric Heat Pumps

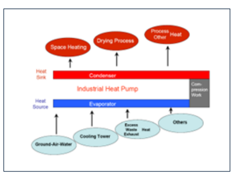


- Heat pumps can be used to replace fuel fired systems to supply heat for many lower temperature processes
- Commercially available electrically powered industrial heat pumps (IHPs) can provide process heat up to 160°C (320°F). More advanced heat pumps, under developments) can supply heat up to 280°C (536°F).

$$\text{COP} = \frac{Power\ (Energy)\ gained\ Btu\ or\ kWh}{Power\ (Energy)\ input\ kWh}$$

- The Coefficient of Performance (COP) represents the ratio of useful heating provided to the energy input.
- Coefficient of Performance (COP) ranging from 2 to 6, with some reaching 7-10 in specific applications..

Applications for Industrial Heat Pumps



Source: Application of Industrial Heat Pumps IEA Industrial Energy-related Systems and Technologies.

1. **Few examples of typical low temperature (<350^{0}F) processes.**
   - Water or other liquid heating.
   - Air or other gas heating
   - Low pressure steam generation
   - Drying of grains, paper, pulp, fruits and vegetables, metal ore, textile, air heating, and
2. **Industries where heat pumps are used.**
   - Dairy industry
   - Canned vegetable and fruit processing Industry
   - Cane and beet sugar Beet sugar industry
   - Corn wet-milling industry
   - Textile industry
   - Pulp and Paper industry
   - Automotive Industry

Heat Pump Installations

Courtesy: SPH Heat Pumps.

Electric heat pump application for water heating

Electric heat pump application in food – powder drying using waste heat.

Courtesy: TLK Energy

Final Comments
Selection of Electric Heating System

It depends on these considerations.

- Availability of the required and reliable power at the point of use
- Process characteristics: drying, melting, heat treating etc. as discussed earlier.
- Range of operating process temperature.
- Type of heating:
  - batch or continuous,
  - direct heating vs. indirect heating,
  - type of process atmosphere (flue gases, air, reactive atmospheres etc.) used,
  - material handling system etc.
- Production rate, heat requirements (in terms of MM Btu/hr... or KW)
- Integration with other plant equipment
- Product quality, safety and governing regulations etc.
- Overall economics including capital and operating cost

References and Resources

- This presentation covers most commonly used methods of electric heating technologies which can be used to achieve CO_2 emission reduction
- There are many other options and they are not covered here due to time limitations.
- References for additional information.

  - *Marks' Standard Handbook for Mechanical Engineers*, Twelfth Edition, Chapter on Electric Heating by Arvind Thekdi, 2017.
  - Industrial Process Heating: Current and Emerging Applications of Electro technologies, 1020133, Technical Update, November 2010
  - Improving Process Heating System Performance: A source book for the industry, Department of Energy, EERE, 2015.
  - Energy Implications of Electro technologies in Industrial Process Heating Systems Kiran Thirumaran, Oak Ridge National Laboratory Sachin Nimbalkar, Oak Ridge National Laboratory Arvind Thekdi, E3M Inc. Joe Cresko, US Department of Energy

For additional information and help regarding emission factors and other related topics, please contact Aqeel Zaidi of Enbridge Gas at Aqeel.Zaidi@enbridge.com

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Thank You