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'Heating up the Market'
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GEOTHERMAL 2024

Natural Refrigerant, High Temperature Heat Pump: Enabling a New Geothermal Market – Decarbonizing Industrial Heat

February 21, 2024

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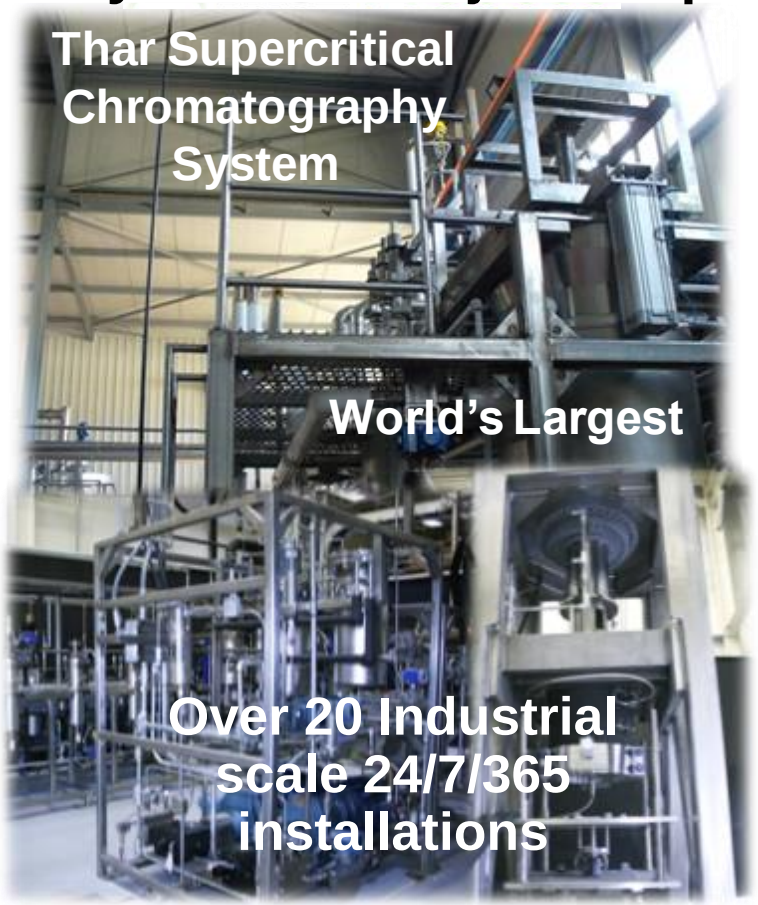
TharEnergy

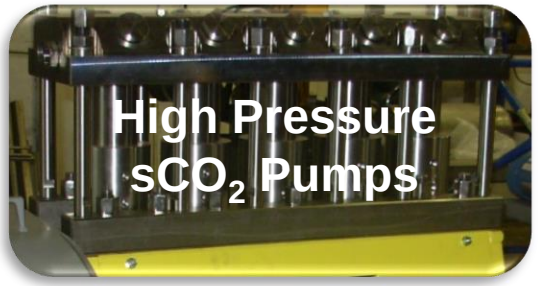
Outline

- **Natural Refrigerant, High Temperature Heat Pumps**
  - **Why? What need does it meet?**
  - **How does it work?**
  - **How does it enable new Geothermal markets?**
  - **Advantages of a natural refrigerant, CO_2/R744**

Over 30 years of Innovation with "Green" Supercritical Fluid Technologies

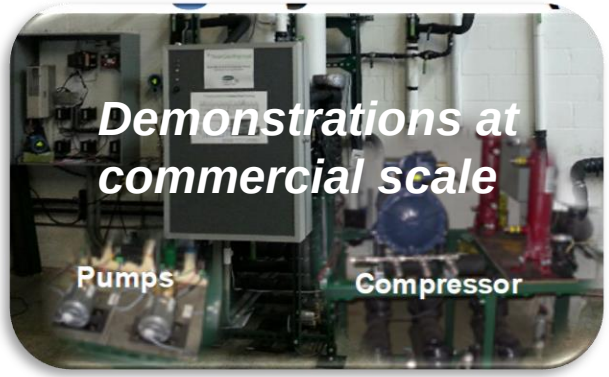
Design and commercialization of supercritical systems & major components





Over 5,000 scientific instruments installed

Direct Exchange, R744 (CO_2) Geothermal Heating & Cooling

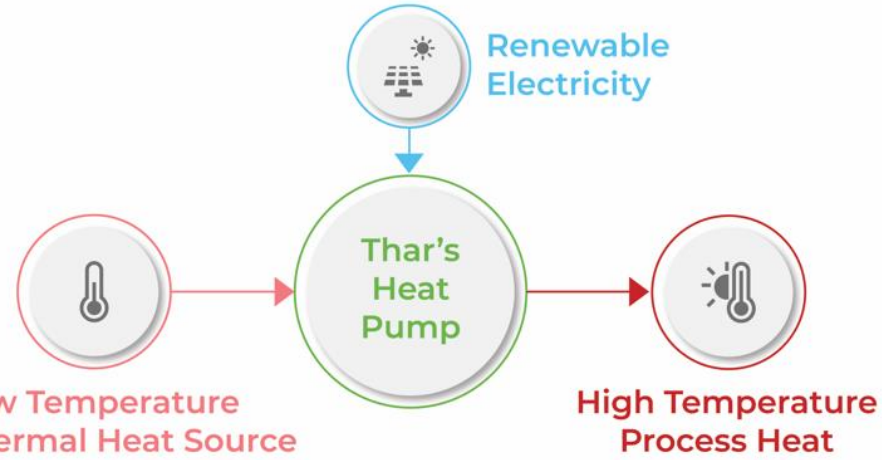


System & Product Development

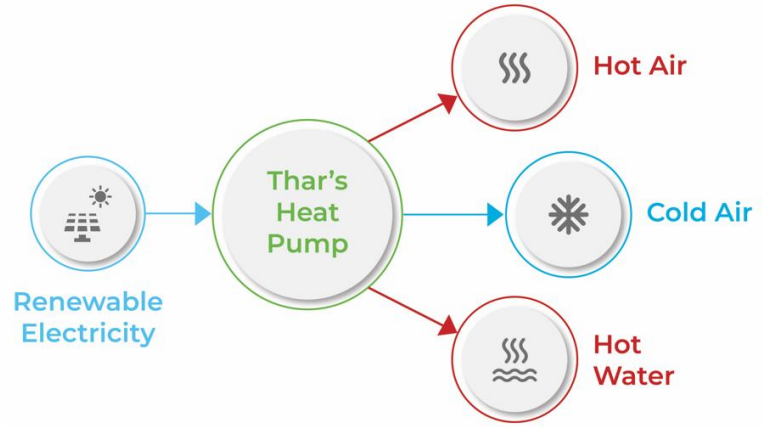
Geothermal Power

Cost Effective - Efficient - Modular

High Temperature Heat Pump



Simultaneous Heating & Cooling



Market Opportunity: Decarbonize industrial process heating


Renewable Thermal Collaborative, Report in Brief, 02/2021

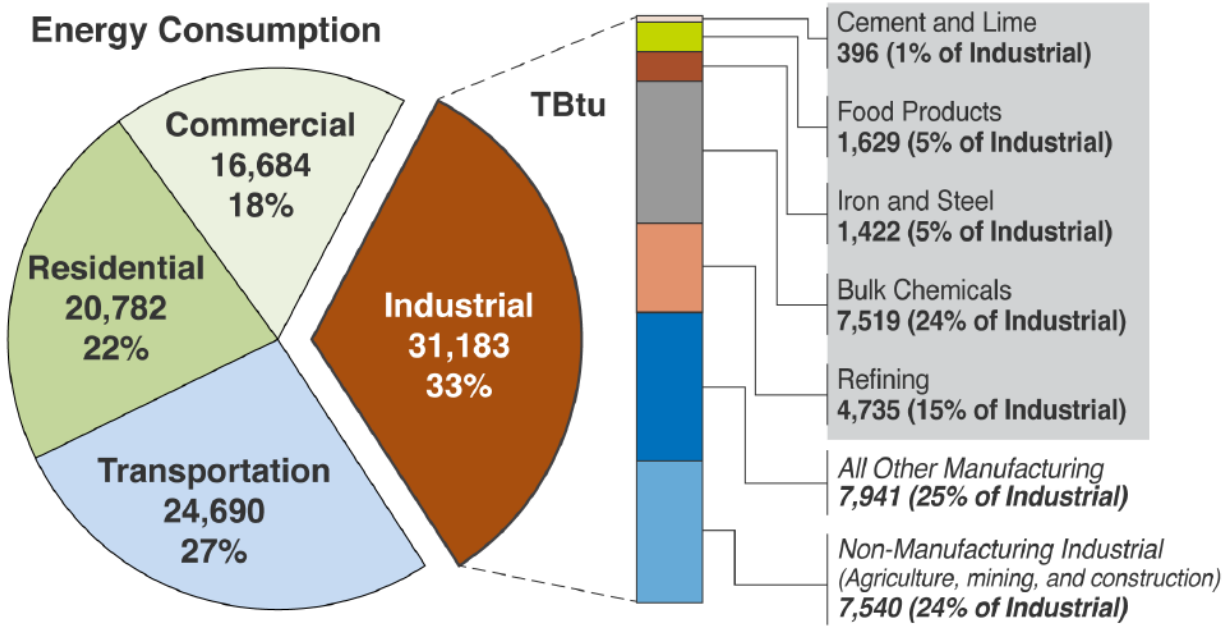
In the U.S.A., fossil fuel combustion produces heat and steam used for example:

- ***Process heating***
- ***Process reactions***
- ***Process evaporation, concentration, & drying***

Industrial sector currently accounts for ~1/3 of U.S.A. energy-related CO_2 emissions.

This creates ~52% of the U.S.A.'s industrial direct greenhouse gas emissions.

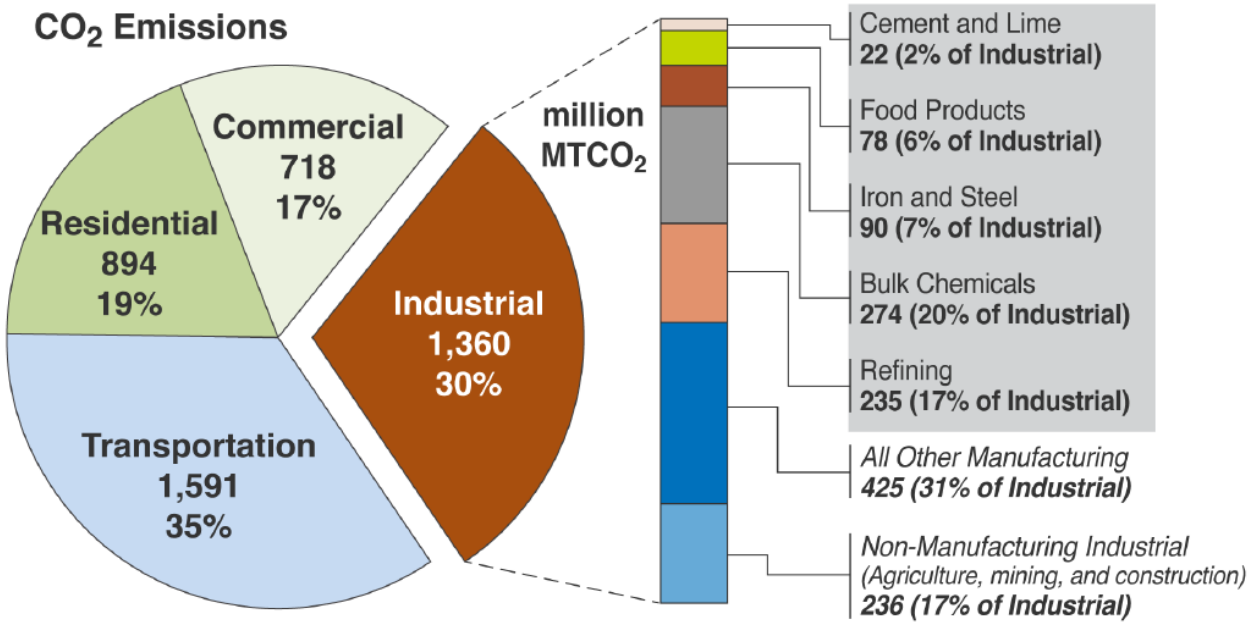
Industry accounts for 33% of energy consumption & 30% of CO_2 emissions



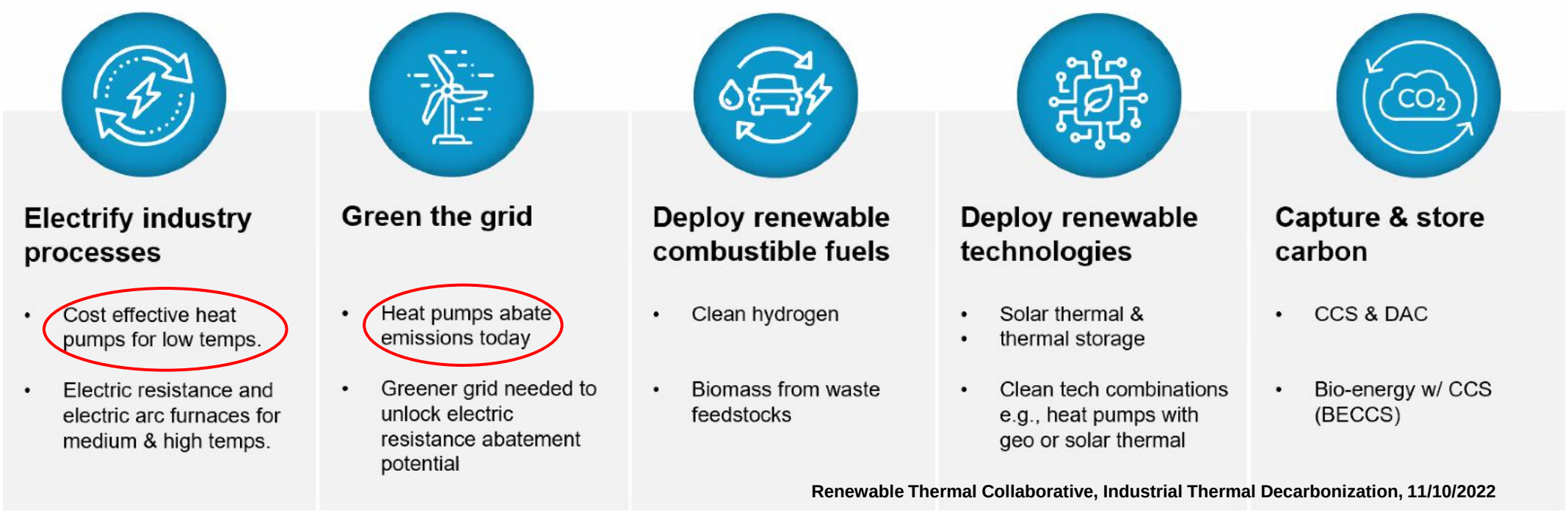
Industrial Decarbonization Roadmap, DOE/EE-2635, US DOE, 9/2022

Five Sectors to Decarbonize

- **Chemicals**
- **Refining**
- **Food**
- **Iron & Steel**
- **Cement & Lime**



U.S. DOE Pathways to Decarbonize Industrial Heat

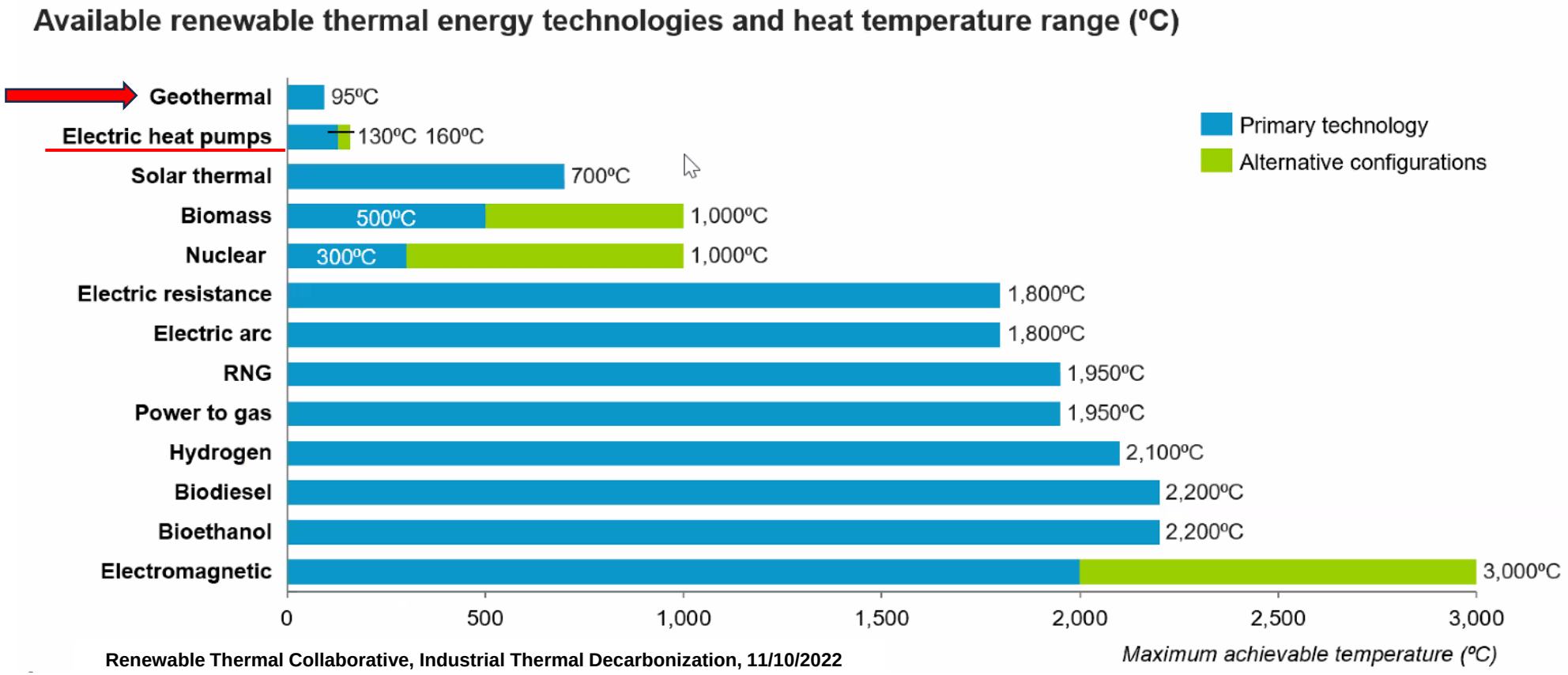


Renewable Thermal Collaborative, Industrial Thermal Decarbonization, 11/10/2022

Product/Solution: High Temperature Heat Pump

to improve process economics and decarbonize industrial heat

U.S. DOE identified Renewable Thermal Technologies



Renewable Thermal Collaborative, Industrial Thermal Decarbonization, 11/10/2022

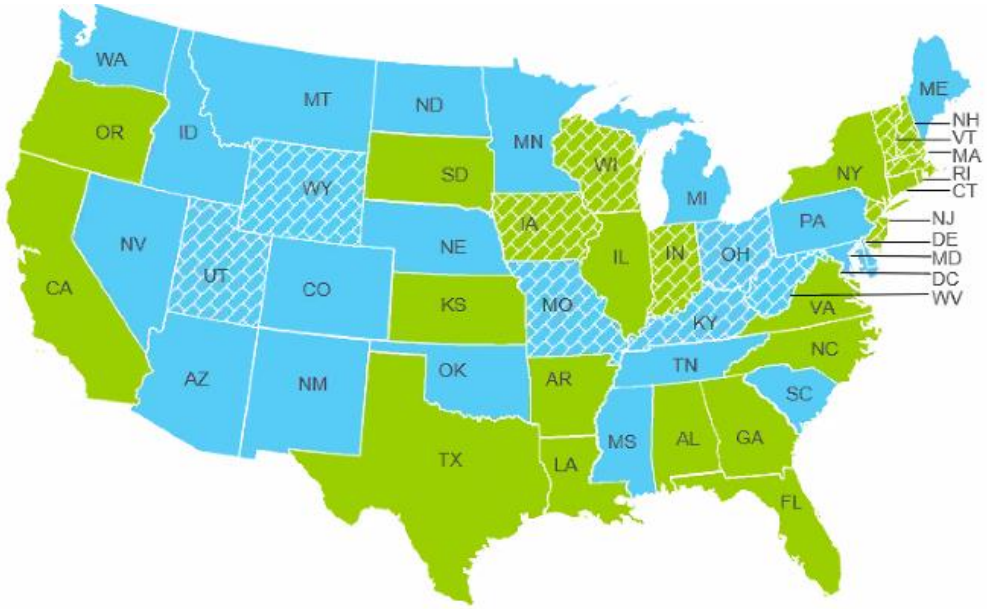
No Geothermal alternative configurations are being considered

Electrification of Industrial Heat

A primary pathway in the short, medium and long-term

Heat pumps

Cost effective & reduce emissions, even with existing grid electricity



LCOH for heat pump vs. natural gas

Heat Pumps Cheaper

Natural Gas Cheaper

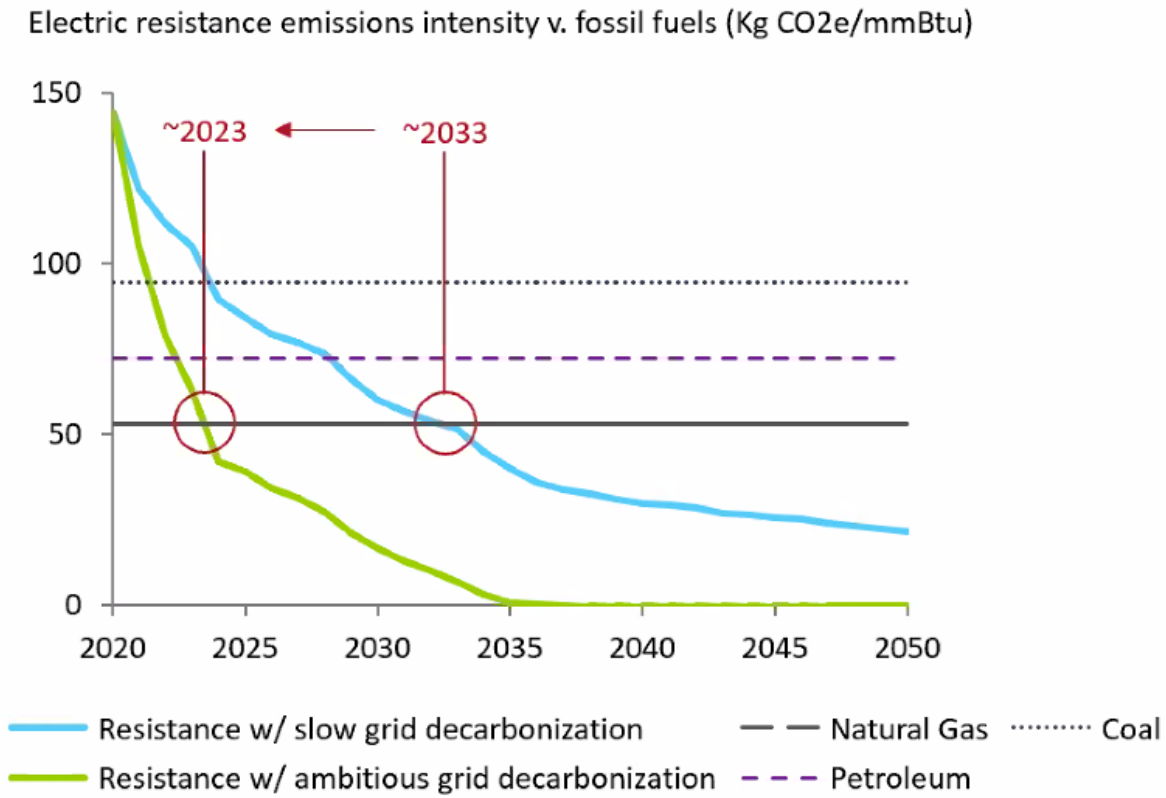
Emissions savings converting natural gas combustion to electric heat pumps:

Today (2022)

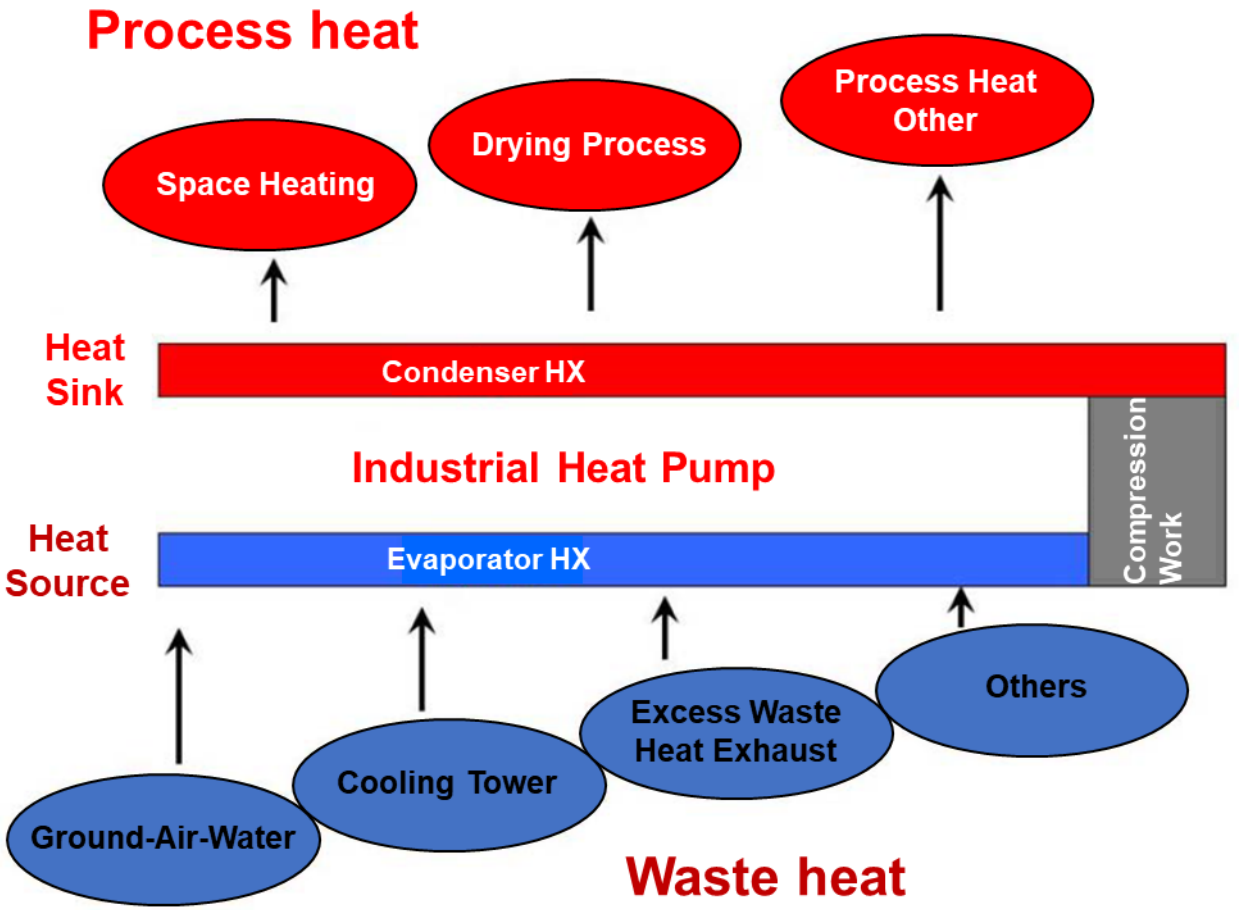
By 2035 or sooner

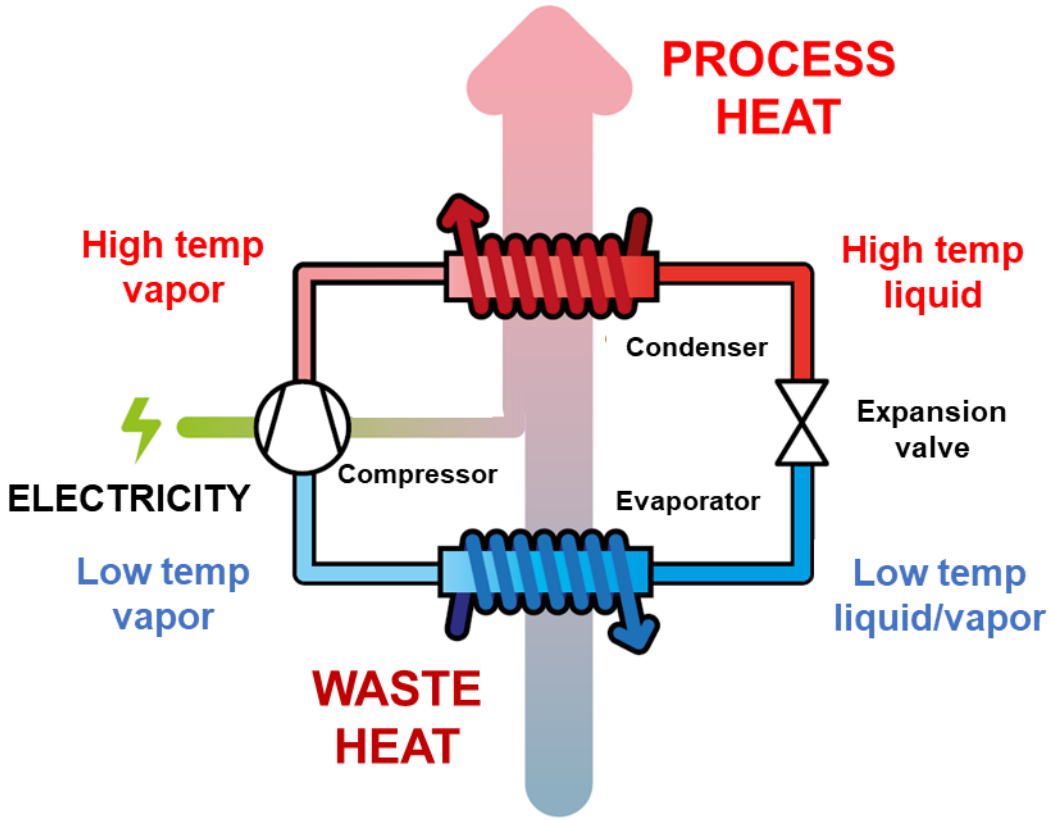
A Greener Grid

Greatly improves decarbonization



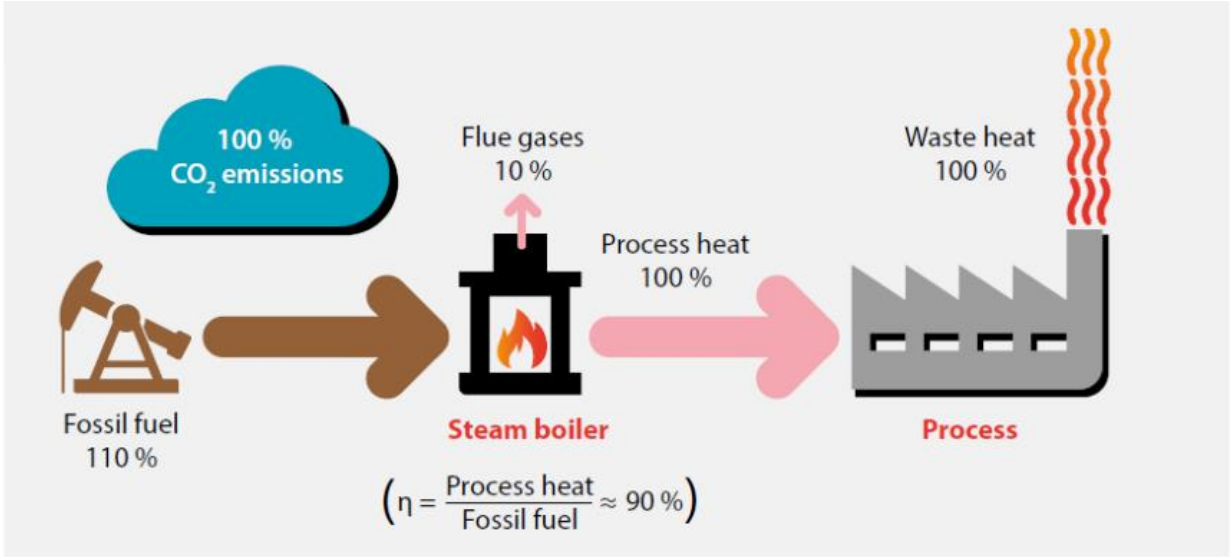
High Temperature Heat Pump
Basics



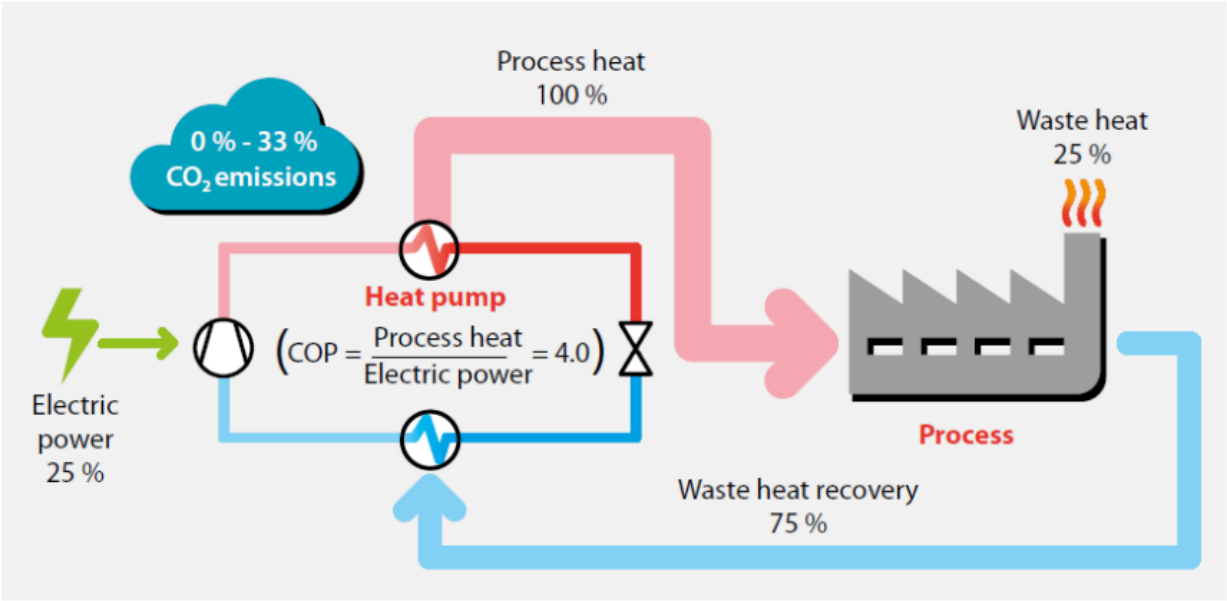


Industrial Heat Pumps, Second Phase, Annex 48, IEA HPT, Report no. HPT-AN48-1, 10/2020

Problem
Fossil Fuel Heating



Solution
Heat Pump Heating



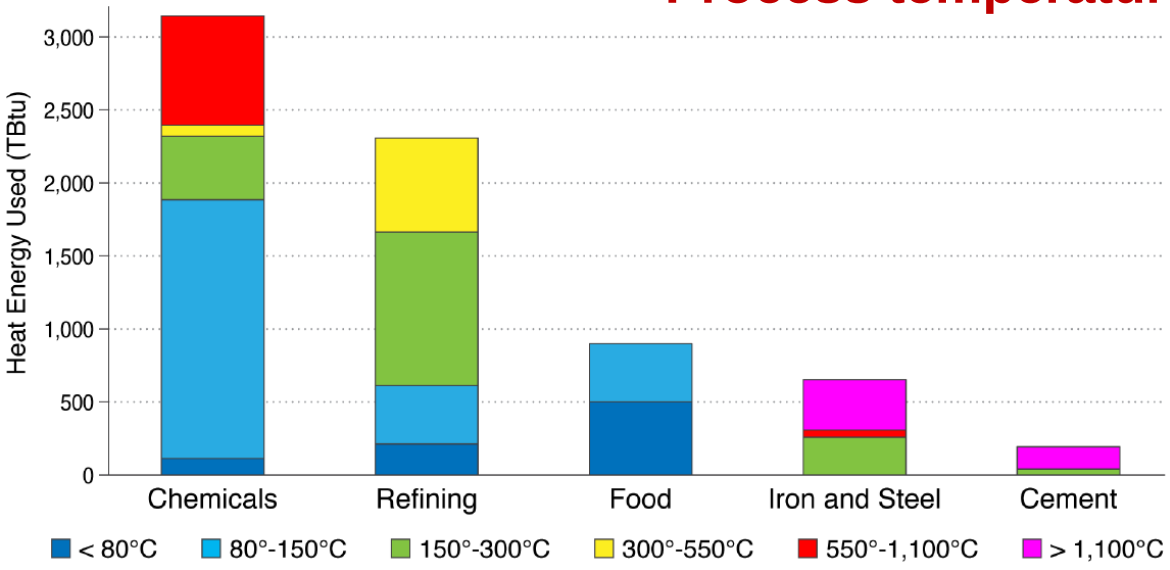
↑ **COP**

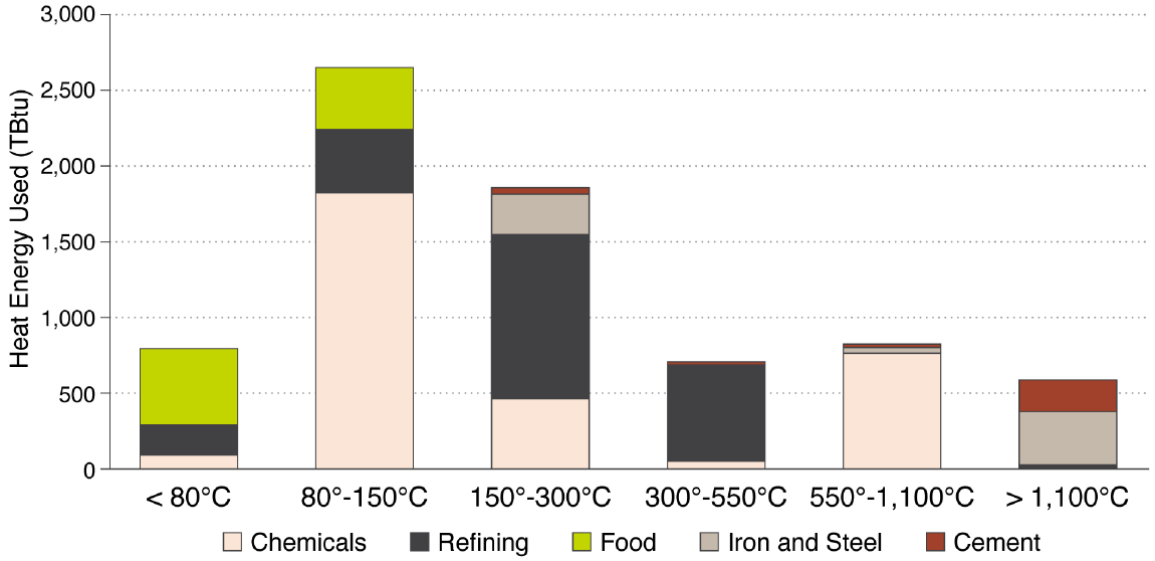
↑ **Efficiency**

How can the High Temperature Heat Pump open new markets for Geothermal Energy?

Supply renewable power & high temperature heat to the chemical, refining and food industries

Process temperature - Industry Distribution

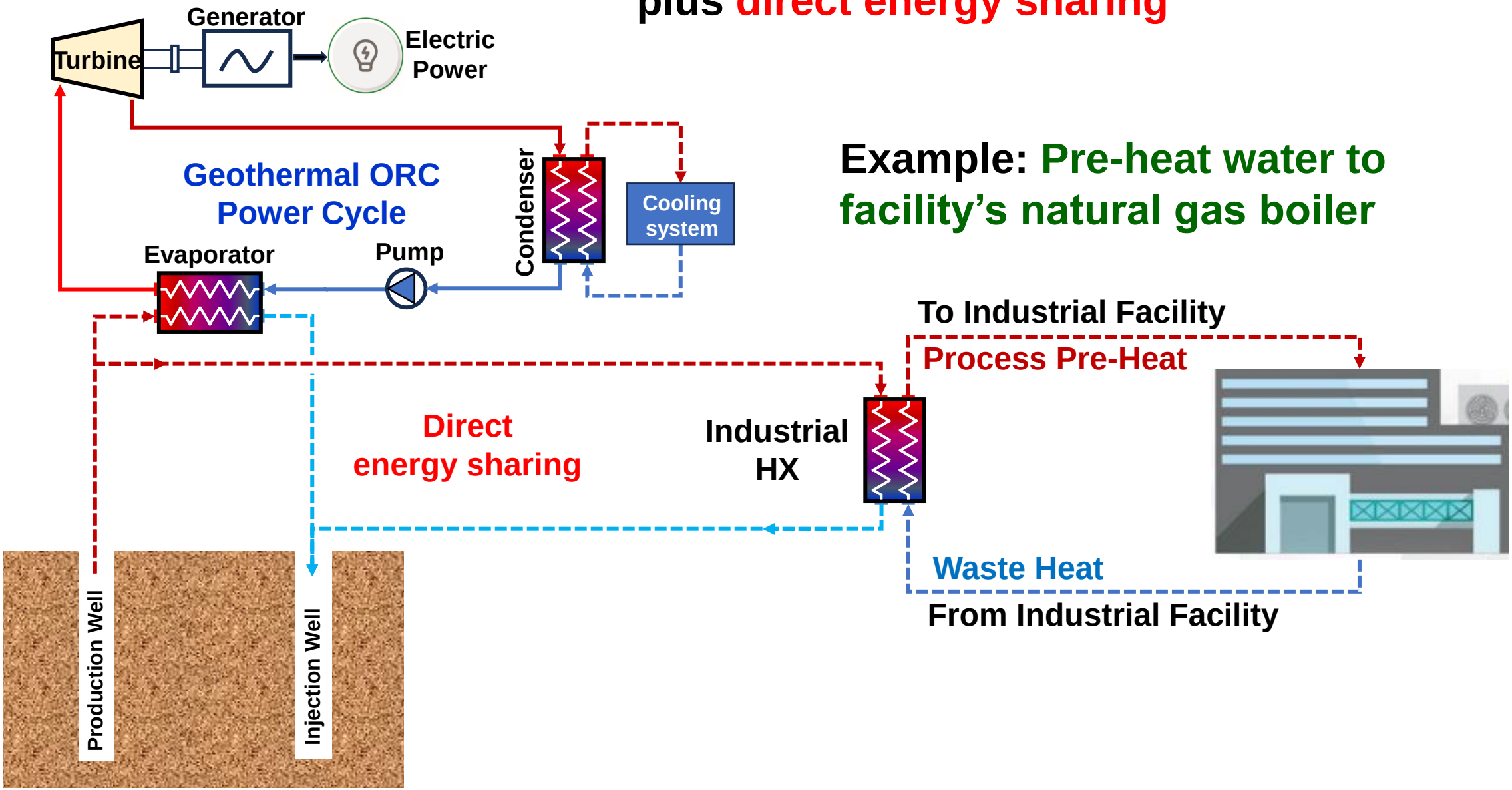




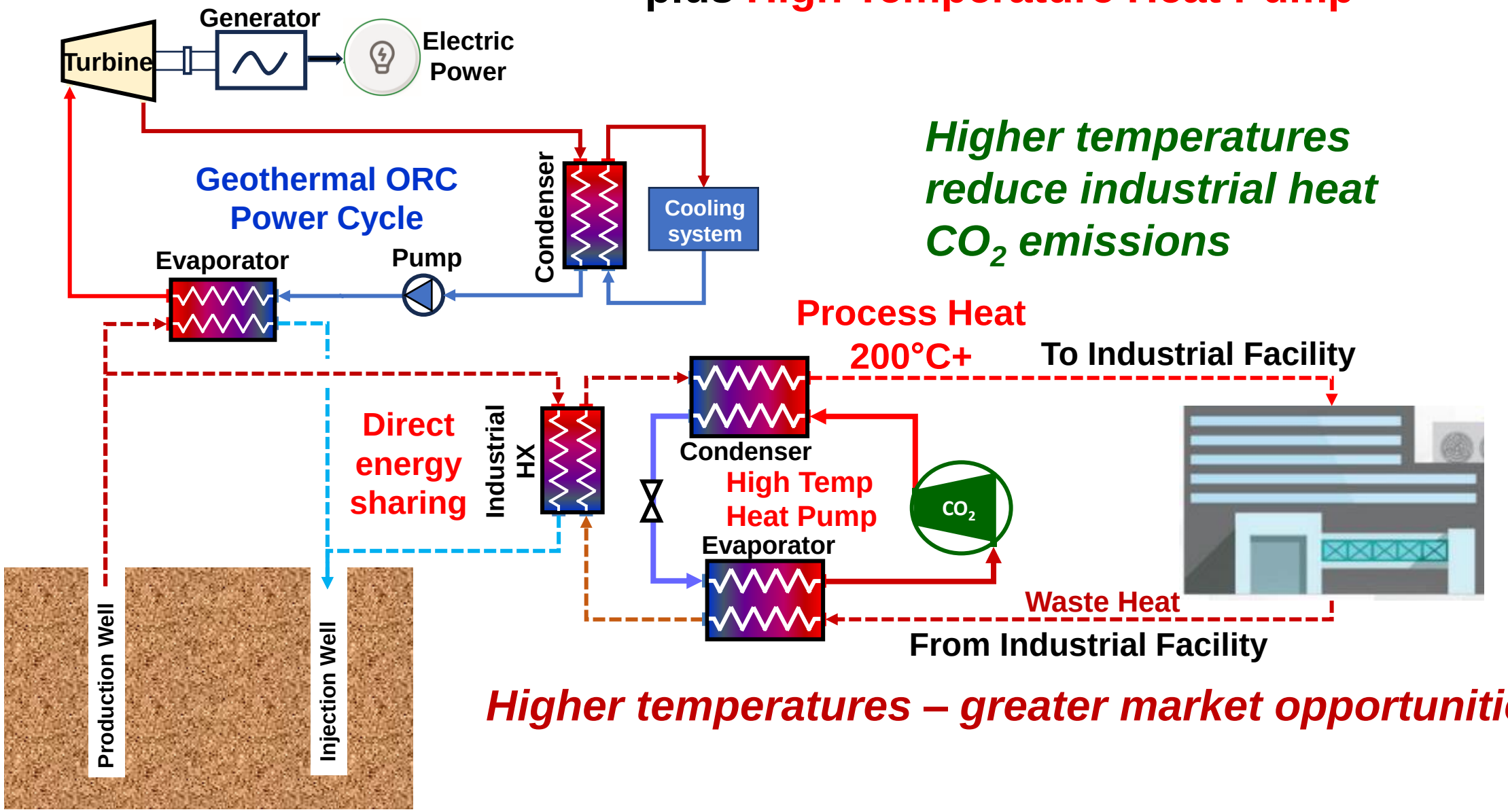
130°C accounts for ~42% of industrial thermal emissions
200°C accounts for ~60% of industrial thermal emissions

McMillian 2019
Thermal Process Intensification: Transforming the Way Industry Uses Thermal Process Energy, Advanced Manufacturing Office, May 2022

Geothermal Organic Rankine Cycle plus direct energy sharing



Geothermal Organic Rankine Cycle plus High Temperature Heat Pump

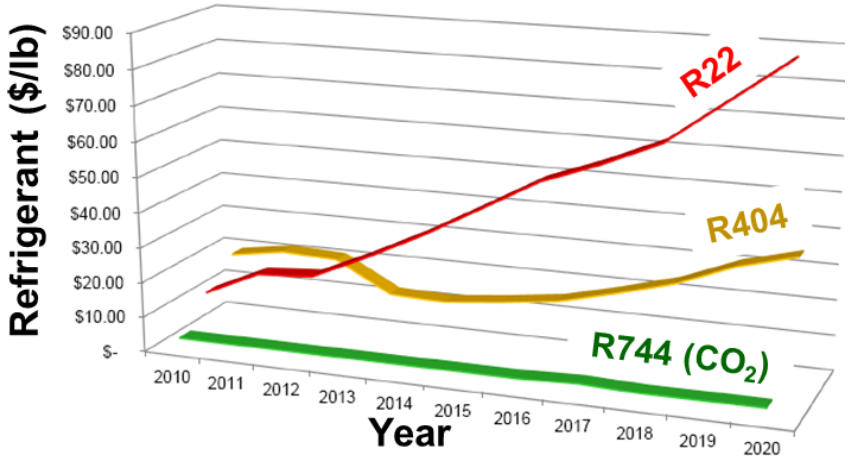


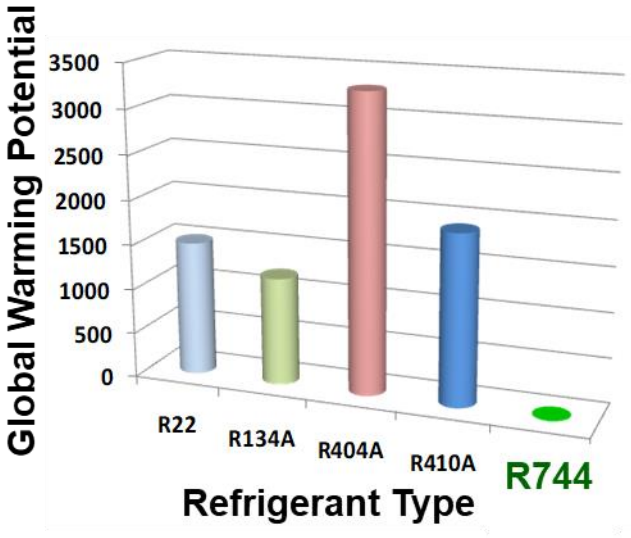
Higher temperatures reduce industrial heat CO_2 emissions

Higher temperatures – greater market opportunities

Recycled Carbon Dioxide CO_2
R744 the *Environmentally Exceptional* Refrigerant

- **Safe: Nontoxic, Nonflammable & Noncorrosive**
- **Significantly less expensive**
- **Does not affect the ozone layer**
- **Least impact on global warming**
- **Large carbon footprint reductions**
  (>30% for refrigeration applications)
- **No phase-out potential**
- **Unaffected by future legislation & taxation**
- **Beneficial Refrigerant Properties**





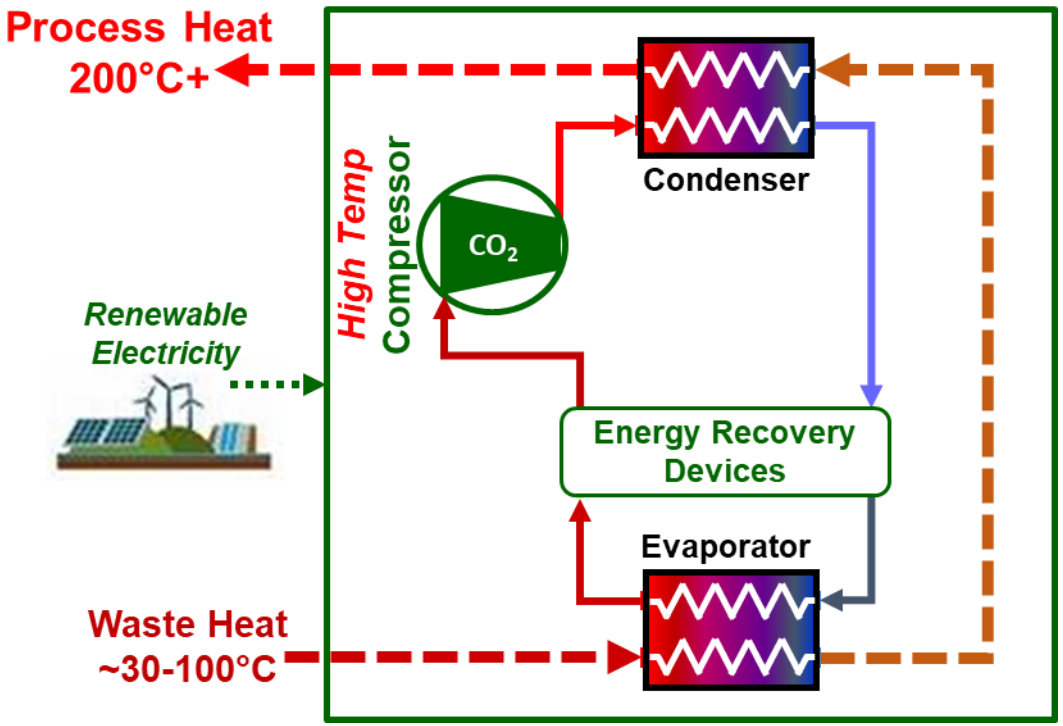
LMP, CO2 – A World of Evolution, Atmosphere America, 2022

Brown, Christopher, Exploring CO2: The Natural Choice for Sustainable, Efficient Refrigeration Systems, Danfoss, January 2013, www.danfoss.com/co2

Higher temperatures – Greater market opportunities

Chemical, Refining and Food Industries

Natural Refrigerant, CO_2, High Temperature Heat Pump



Designed to reduce the cost and environmental impact of process heat.

Options:

- **Hot Air**
- **Hot Water**
- **Steam**
- **w/wo Chilled Water**

Thank you for your kind attention!

Questions?

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