1st Geothermal Energy Machinery and Systems Workshop
Southwest Research Institute
San Antonio, Texas, November 29-30, 2023

Enabling Decarbonization using Geothermal Heat – sCO_2 Brayton Power System & High Temp Heat Pumps

November 30, 2023

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TharEnergy

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Outline

- **Supercritical Carbon Dioxide (sCO_2) Brayton Power Cycle**
  - **Concepts to hardware**
    - **Component Development/Testing**
    - **Power Cycle Analysis/Testing**
  - **Opportunity for Geothermal power production**

- **sCO_2 High Temperature Heat Pump**
  - **Why? What need does it meet?**
  - **How does it work?**
  - **How does it enable new Geothermal markets?**

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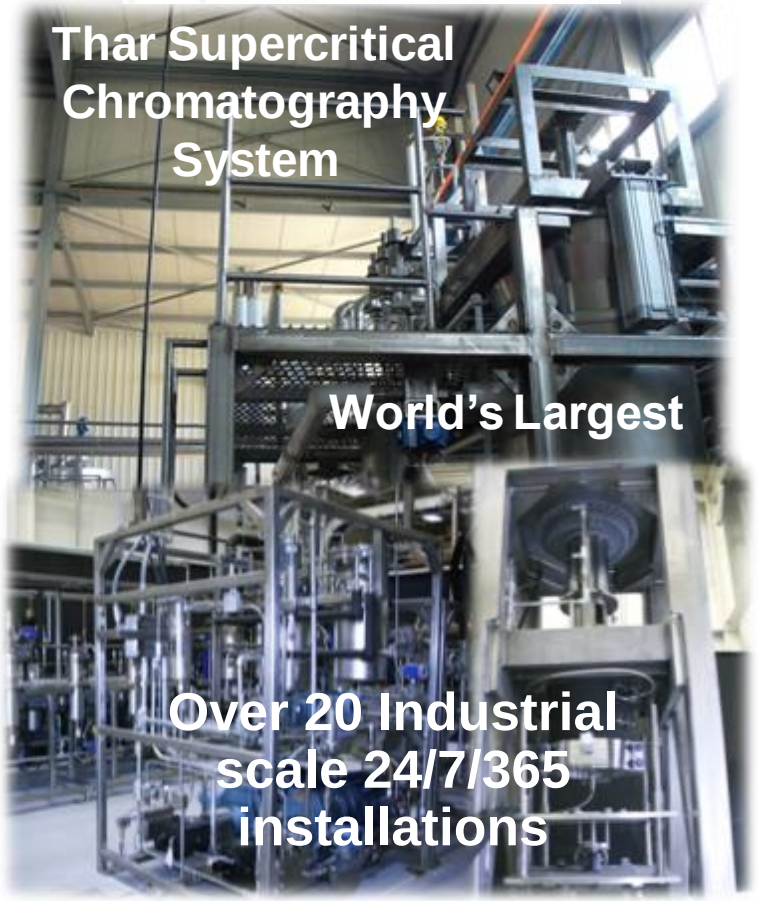
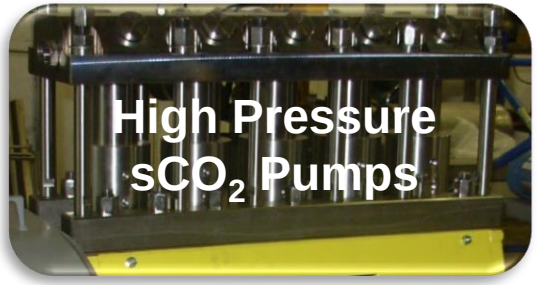
Over 30 years of Innovation with "Green" Supercritical Fluid Technologies

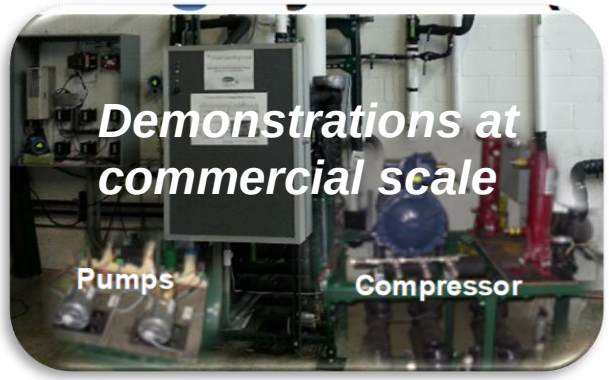
Design and commercialization of supercritical systems & major components





Over 5,000 scientific instruments installed

Direct Exchange, R744 (CO_2) Geothermal Heating & Cooling



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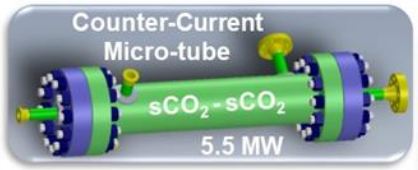
Components & Cycle Development

Turning concepts into hardware

sCO_2 Brayton Power Cycle Development

COMPACT **Heat Exchangers for sCO_2 Power Cycles**



3D Printed, Inconel 718, sCO_2-sCO_2 Recuperator

Design – Construct – Install Primary Heater for Sunshot One MWe sCO_2Test Loop

Design – Construct – Operate sCO_2 Heat Exchanger Test Loop

Superior Thermal Performance Confirmed

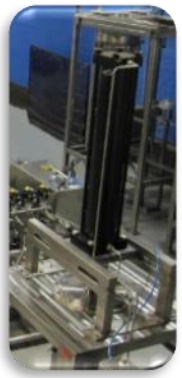
Gas Cooler Air-sCO_2

2014

TharProcess

Design – Construct – Operate Largest GMP sCO_2 Extraction System in USA

2015



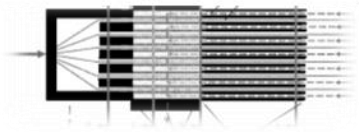
2016

Oxy Combustion Test Facility
Design – Construct – Operate
Demonstrate auto-combustion

2017

UNITED STATES PATENT AND TRADEMARK OFFICE

Patent - Notice of Allowance
Counter Current Heat Exchanger/Reactor



Thar Pharmaceuticals sold to GRUNENTHAL

Expands into Liquid Chromatography

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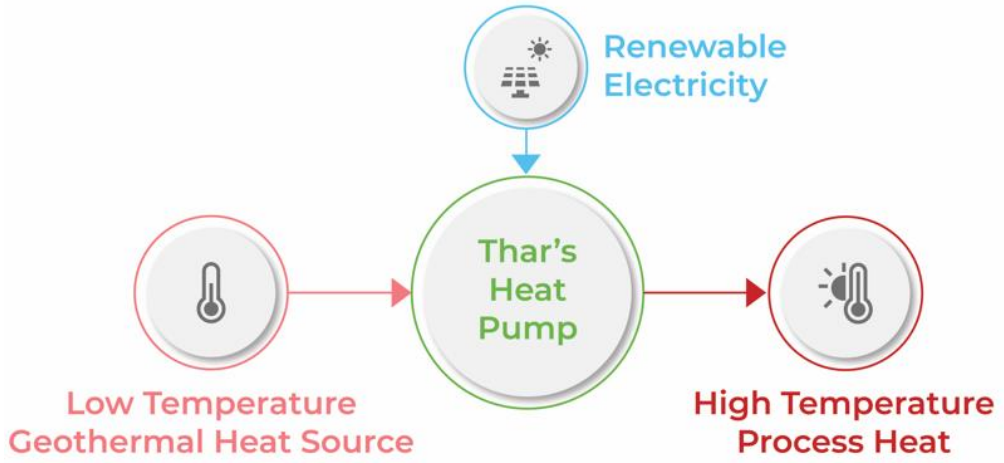
System & Product Development

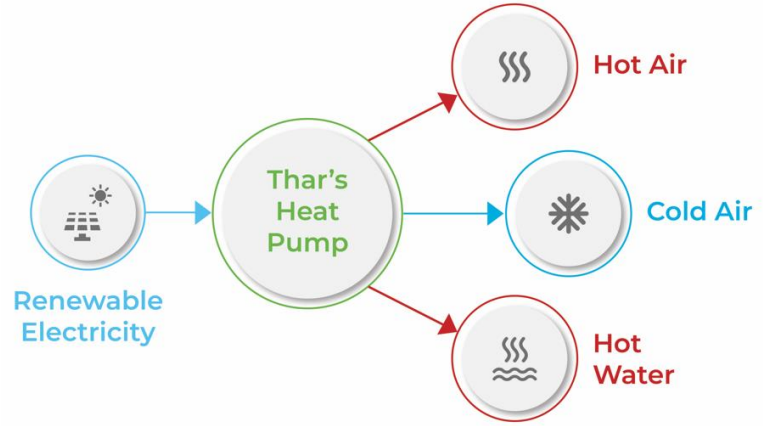
Geothermal Power

Cost Effective - Efficient - Modular

High Temperature Heat Pump



Simultaneous Heating & Cooling



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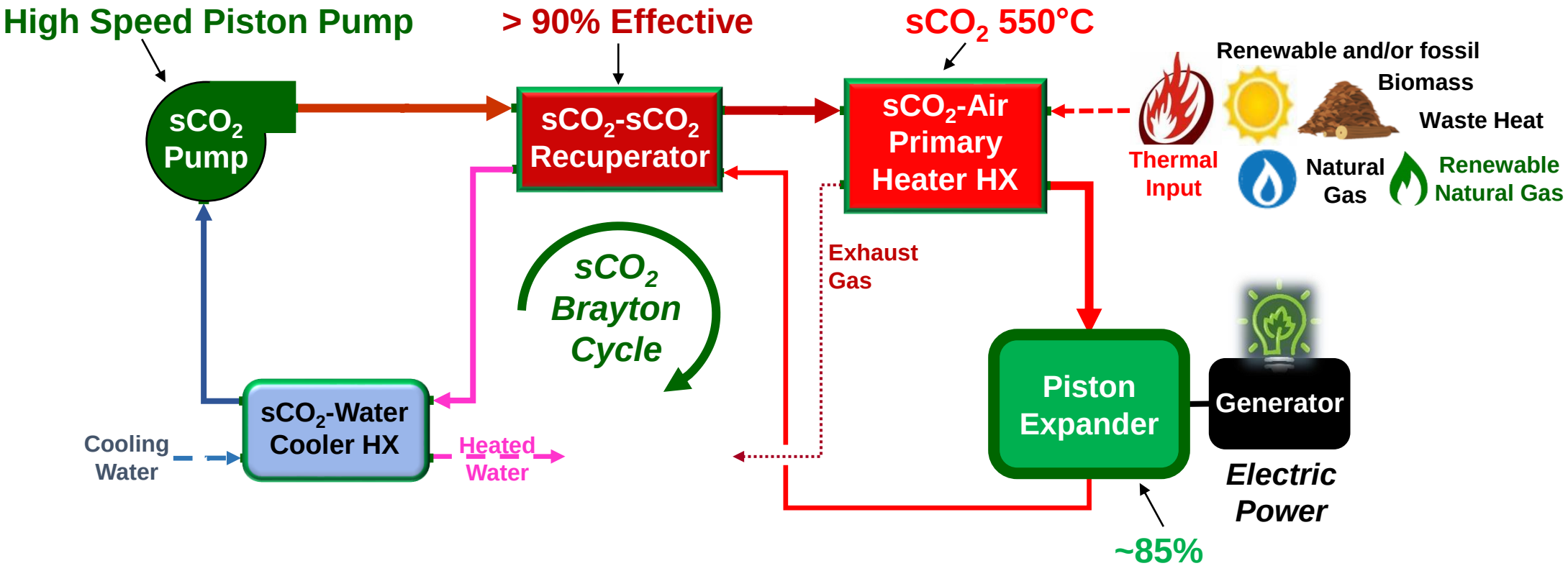
sCO_2 High Temperature Recuperated Brayton Power Cycle System

1-Stage, < 1 MWe



2-Stage System, 800°C EIT

Thermal efficiency > 50%

γ' strengthened Nickel Super-alloys

Haynes 282, Inconel 740H

Work supported by US DOE
ARPA-E HITEMMP DE-AR0001129

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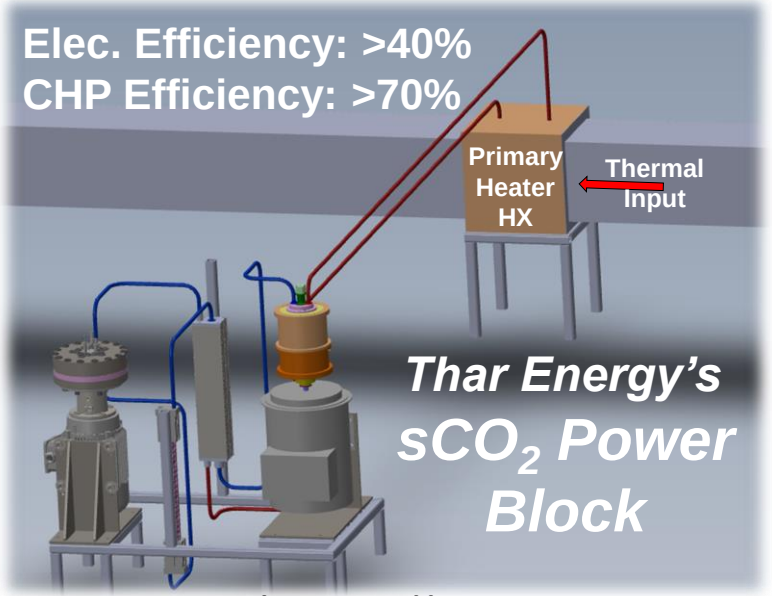
Business Case

1-Stage System, 550°C EIT – Waste Heat Recovery Market

- Electrical cycle efficiency, >40%
- Low operating costs
- Load following
- Reduced carbon footprint
- Payback period under 2 years, assuming constant energy pricing
- Modular, factory fabricated, lower EPC costs
- *200 kWe, 1-stage sCO_2 power block competitive at ~2,100 $/kWe*



Work supported by US DOE
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2-Stage System, 800°C EIT – Commercial viability - limited in near term

- Nickel superalloys, required for higher temperature, operation are too expensive
- Added costs offset higher system efficiency

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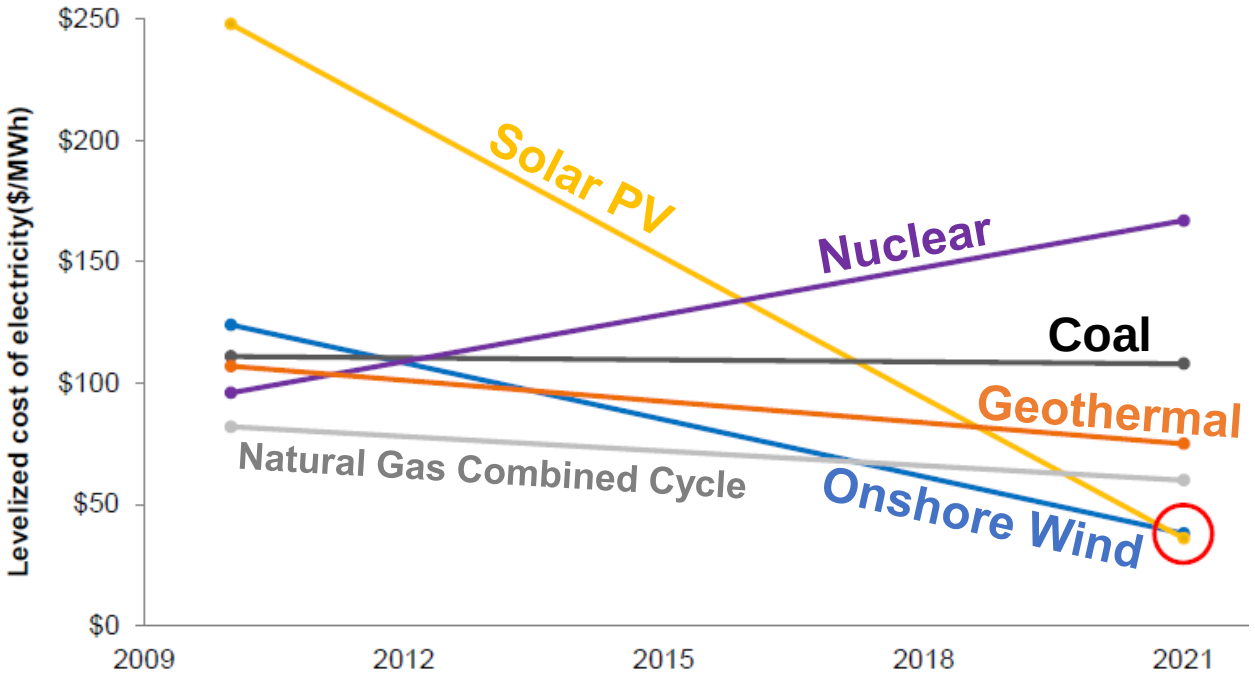
Costs for Wind, Solar Power and Battery have drastically decease



Ricks, Wilson, Geothermal and the Energy System, Geothermal Rising Conference, Workshop: Synergies with other renewable energies to accelerate geothermal project development, Reno, NV, 8/30/2023

Capital Cost Comparison ($/kWe)

Technology	Range ($)		
Solar PV - Utility Scale	825	-	975
Wind (onshore)	1,050	-	1,450
Conventional Geothermal Energy*	4,500	-	6,050
Solar Thermal Tower with Storage*	6,000	-	9,090
Nuclear*	7,675	-	12,500
Natural Gas (Combined Cycle)	700	-	1,250
Coal	2,900	-	6,225

* **Baseload/dispatchable energy resource with CO2 "free" steady state operation**

https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf

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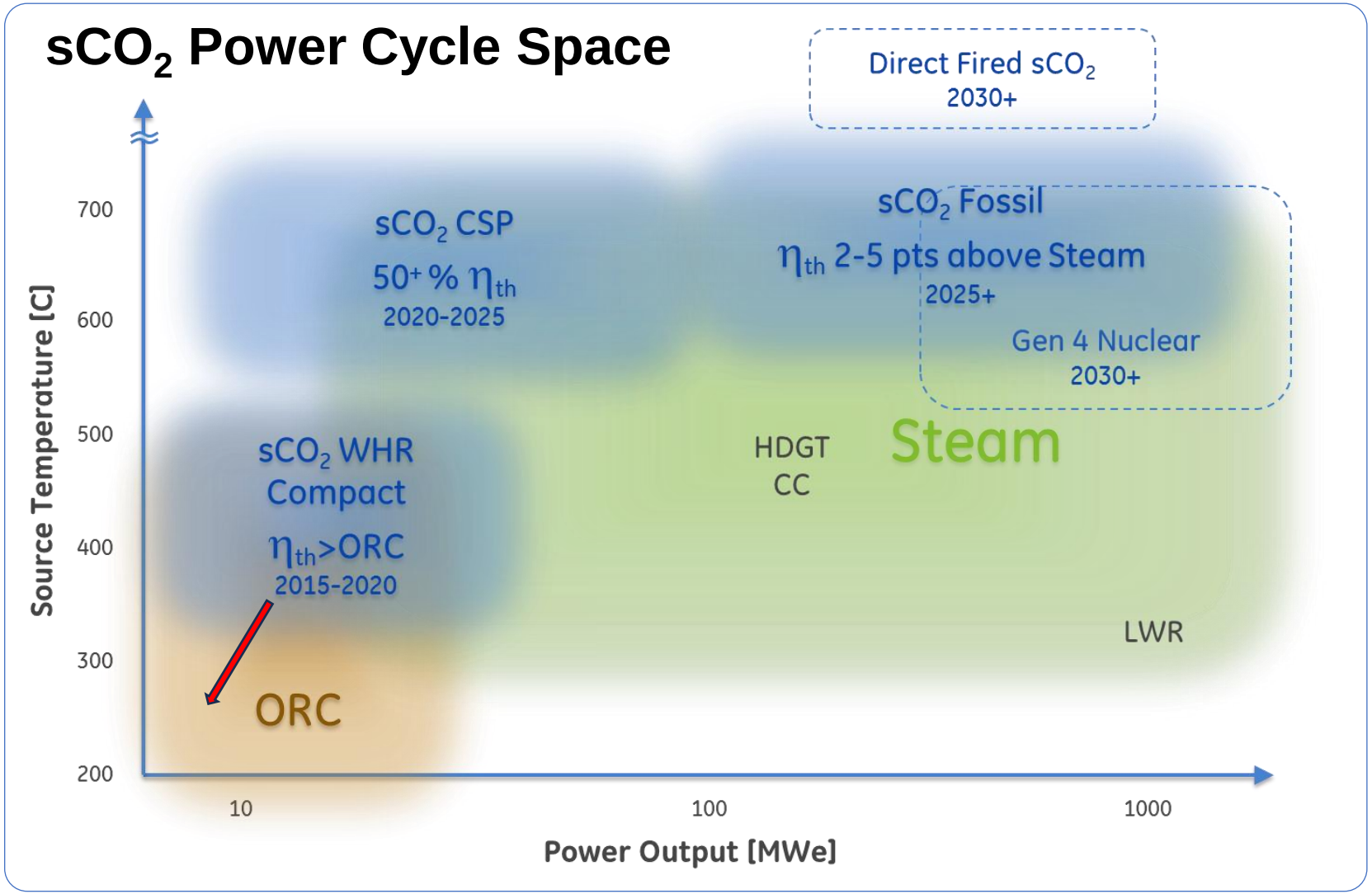
How to use the sCO_2 Power Cycle for Geothermal Base Load Power?



Development of Supercritical CO2 Power Cycle Applications , The Pathway Forward, IGTI Turbo Expo, Dusseldorf, Germany, June,19 2014

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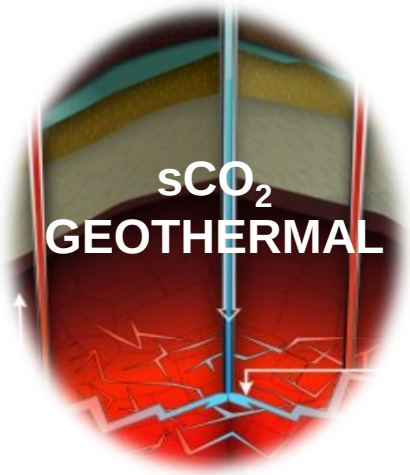
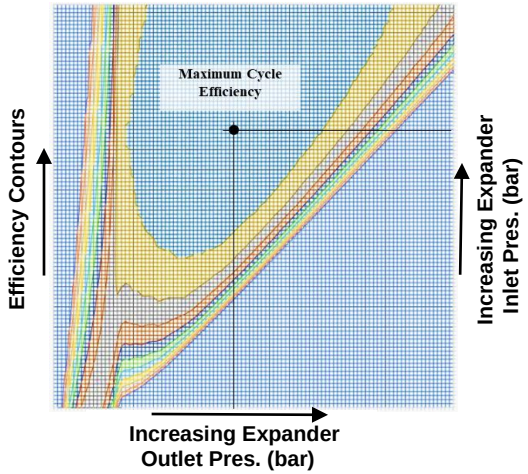
Geothermal - Renewable Base Load Power

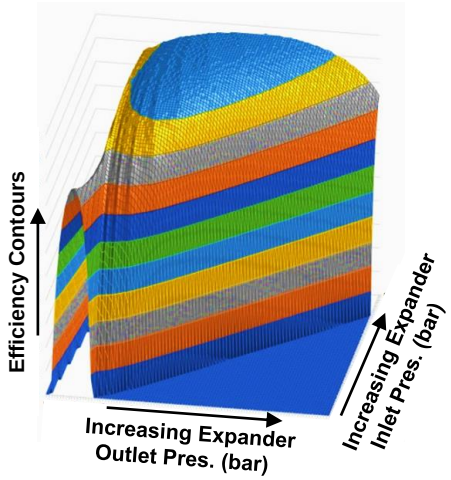
sCO_2 Power Cycle System Analysis



Modeling to optimize performance/cost metrics

- Expander design
- Expander inlet temperature and pressure
- Recuperators designed optimum effectiveness
- Gas Coolers - air or water cooled
- Cycles designed to reduce compression work



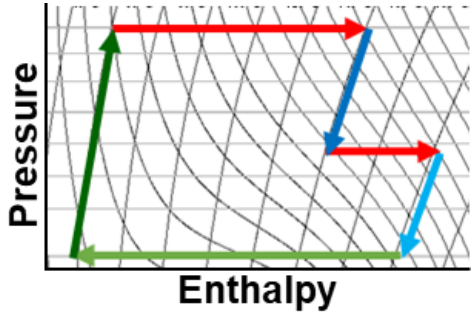


Work supported by US DOE
ARPA-E HITEMMP DE-AR0001129

Competitive vs

Organic & Steam Rankine Cycles

- 2-Stage Expansion
- 150°C - 250°C EIT
- Lower cost materials
  - Heat exchangers
  - Expander
- Module size: 1-6 MWe
- Targeting $2,000/kWe



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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 our nation's energy-related CO_2 emissions.

This creates ~52% of the country's industrial direct greenhouse gas emissions.

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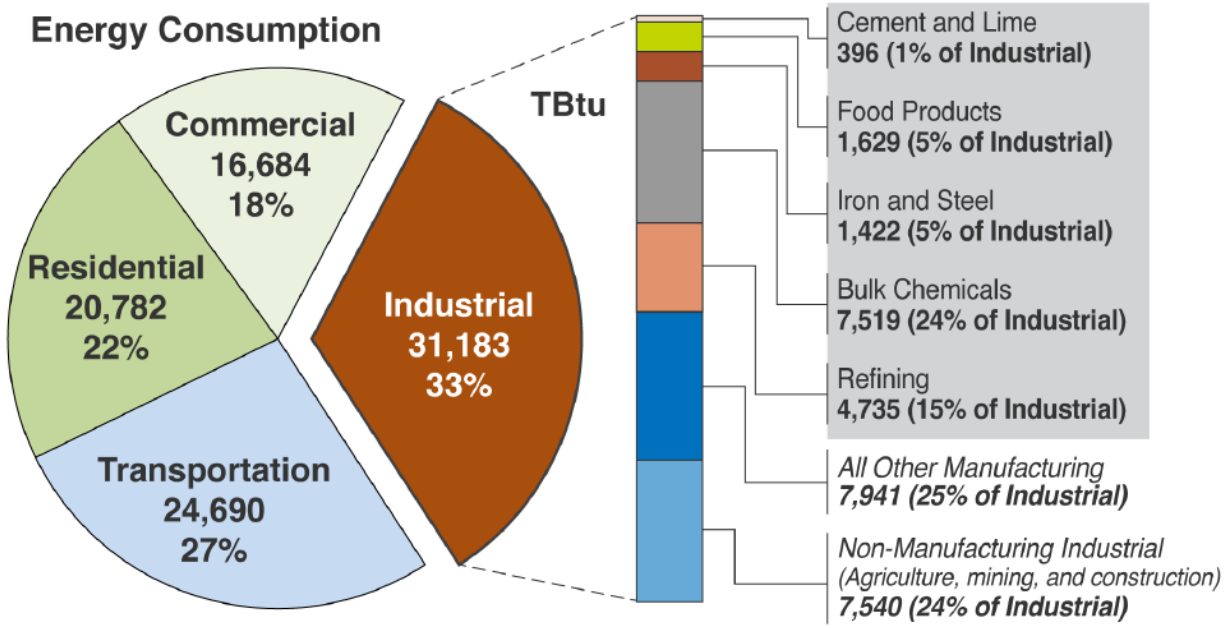
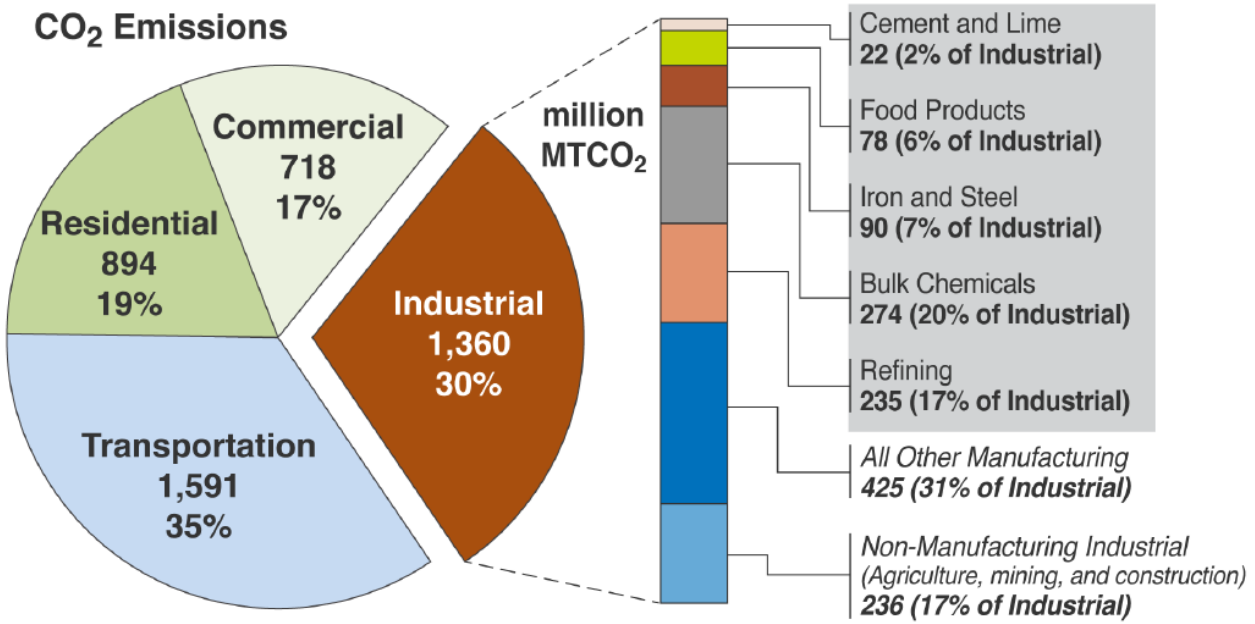
Industry accounts for 33% of energy consumption & 30% of CO_2 emissions



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

Five Sectors to Decarbonize

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



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U.S. DOE Pathways to Decarbonize Industrial Heat

Electrify industry processes

- Cost effective heat pumps for low temps.
- Electric resistance and electric arc furnaces for medium & high temps.

Green the grid

- Heat pumps abate emissions today
- Greener grid needed to unlock electric resistance abatement potential

Deploy renewable combustible fuels

- Clean hydrogen
- Biomass from waste feedstocks

Deploy renewable technologies

- Solar thermal & thermal storage
- Clean tech combinations e.g., heat pumps with geo or solar thermal

Capture & store carbon

- CCS & DAC
- Bio-energy w/ CCS (BECCS)

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

Product/Solution: High Temperature Heat Pump

to improve process economics and decarbonize industrial heat

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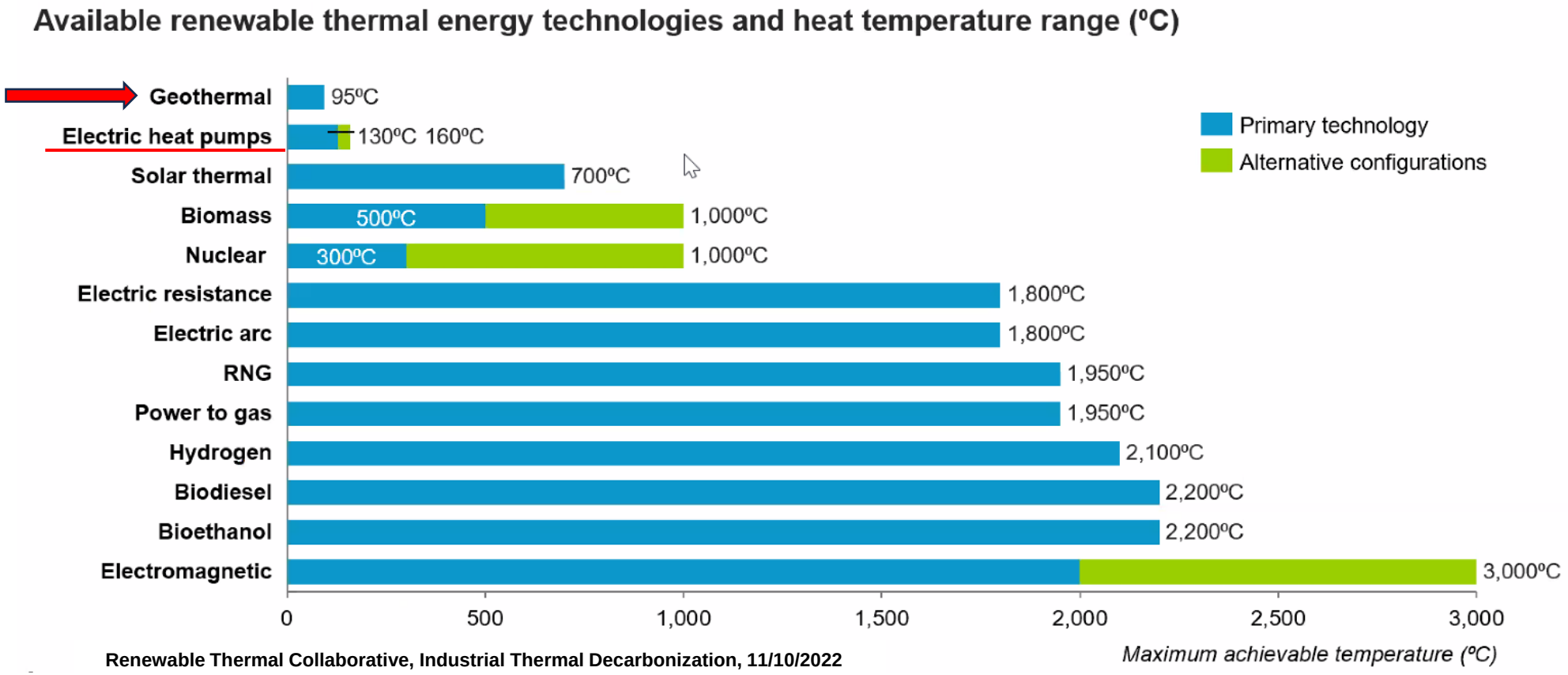
U.S. DOE identified Renewable Thermal Technologies



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

No Geothermal alternative configurations are being considered

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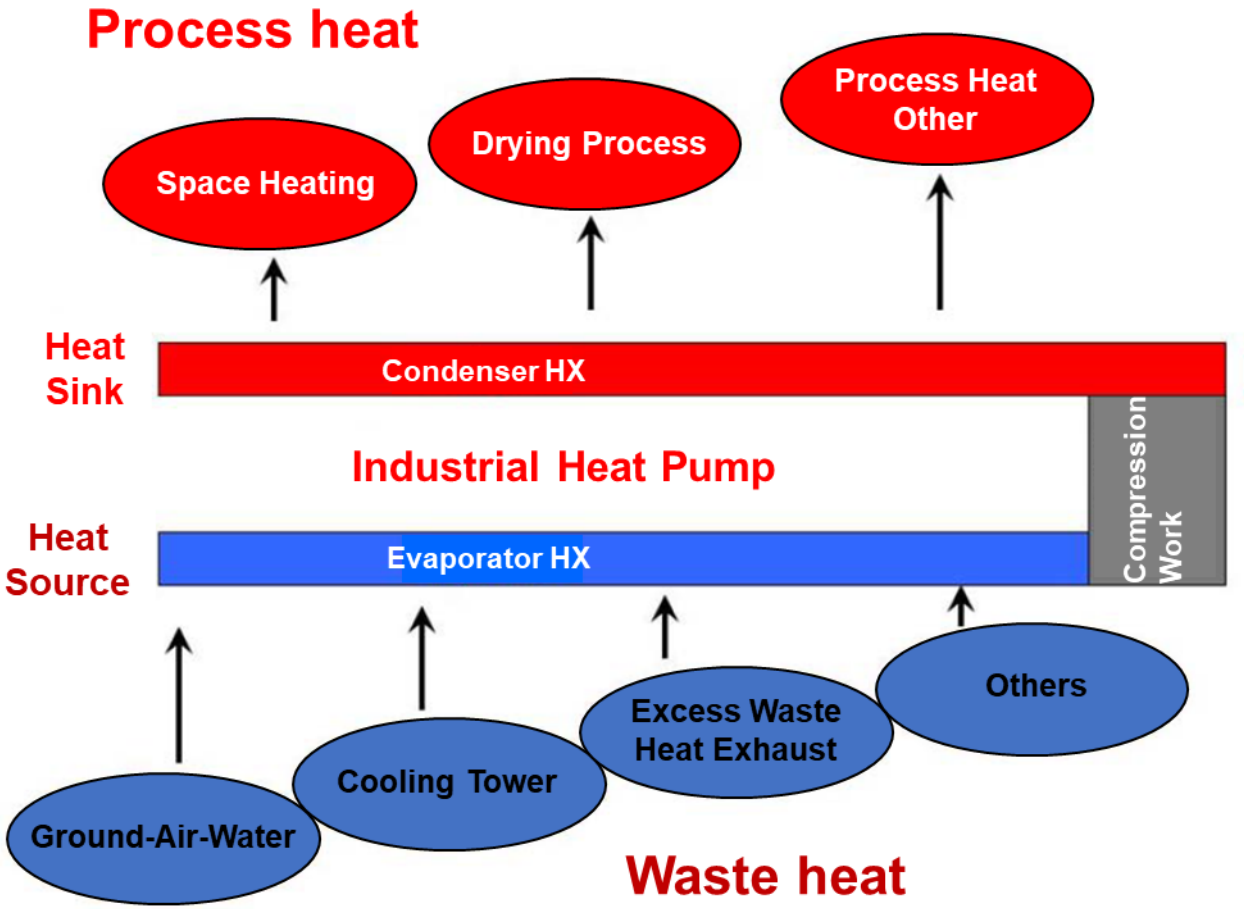
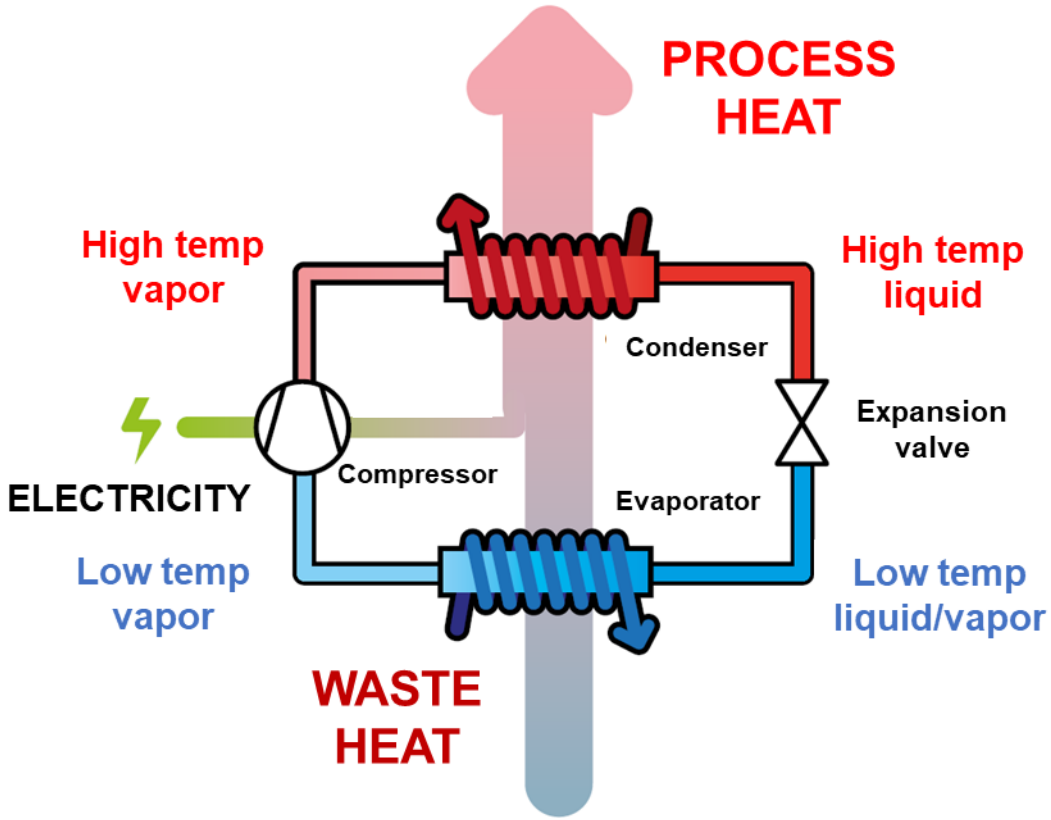
High Temperature Heat Pump
Basics





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

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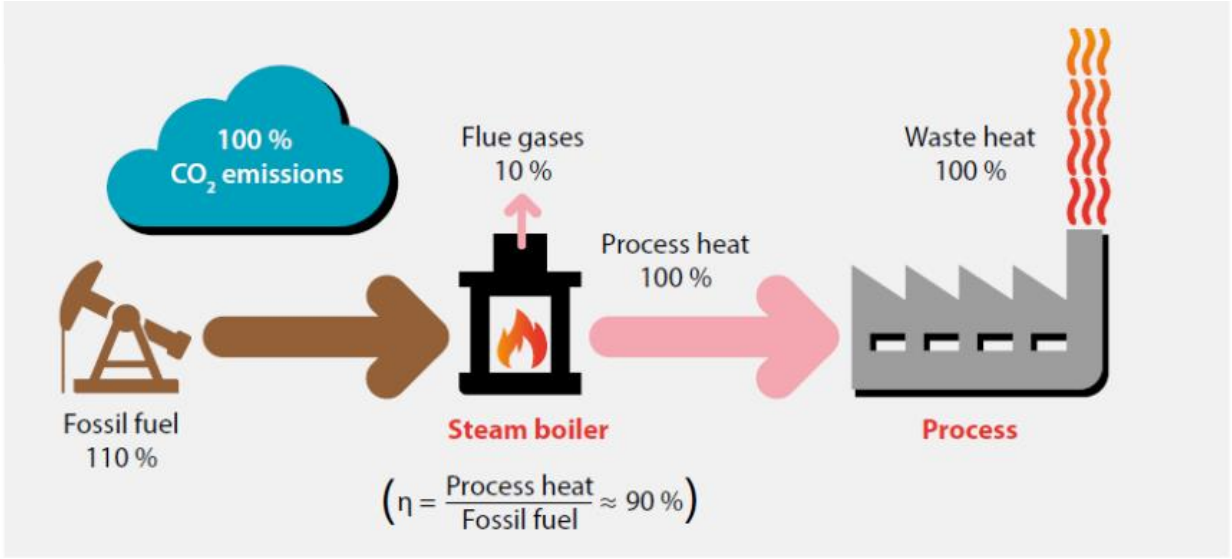
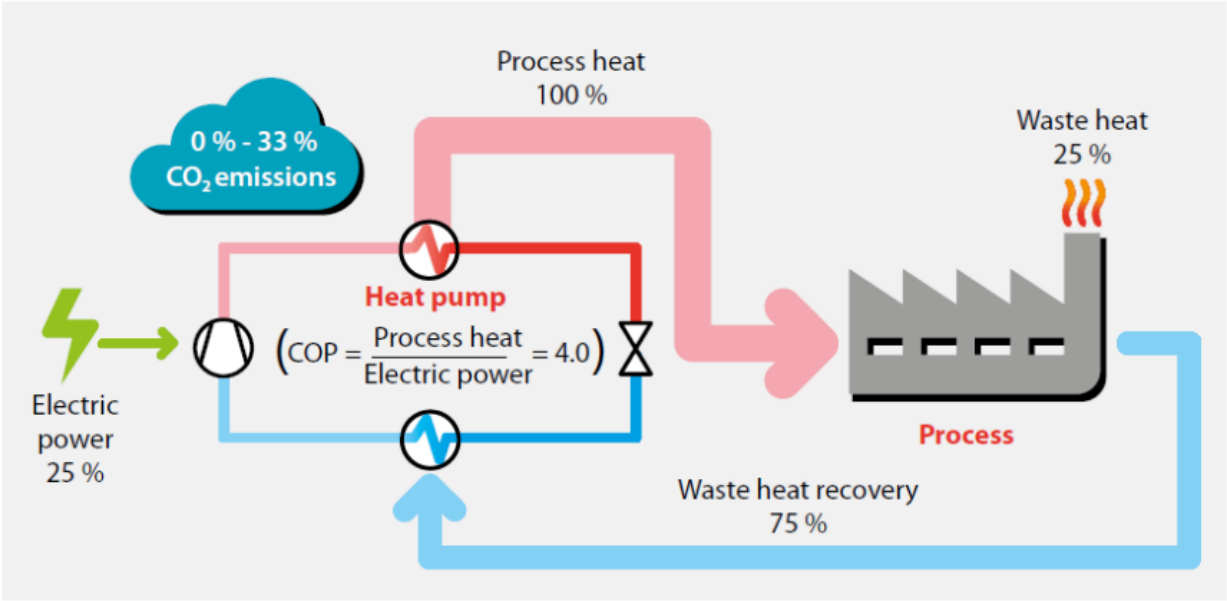
Problem
Fossil Fuel Heating



Solution
Heat Pump Heating



↑ COP

↑ Efficiency

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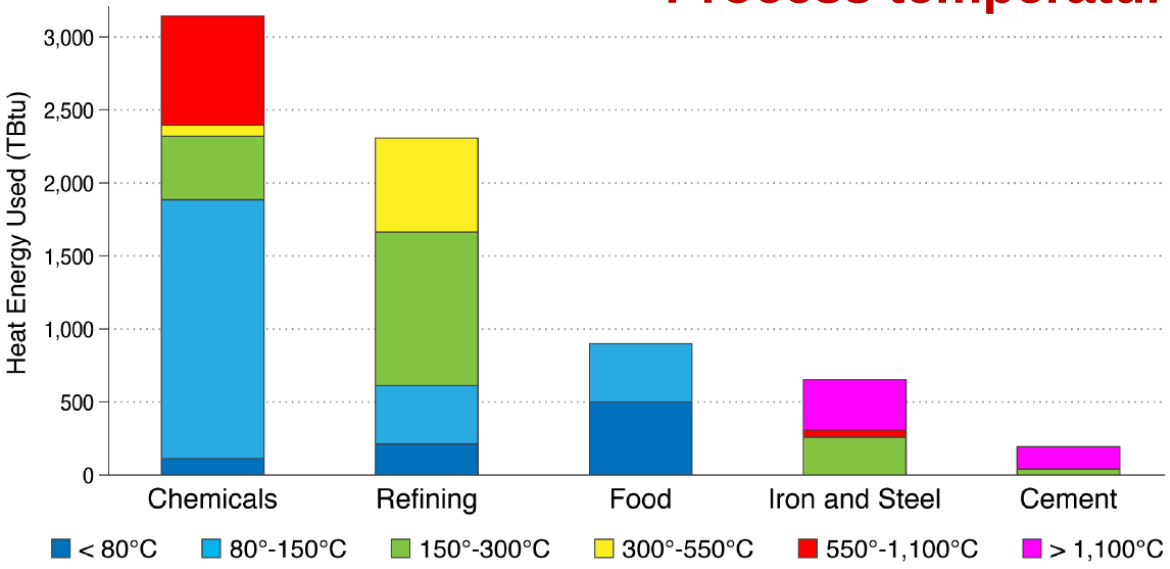
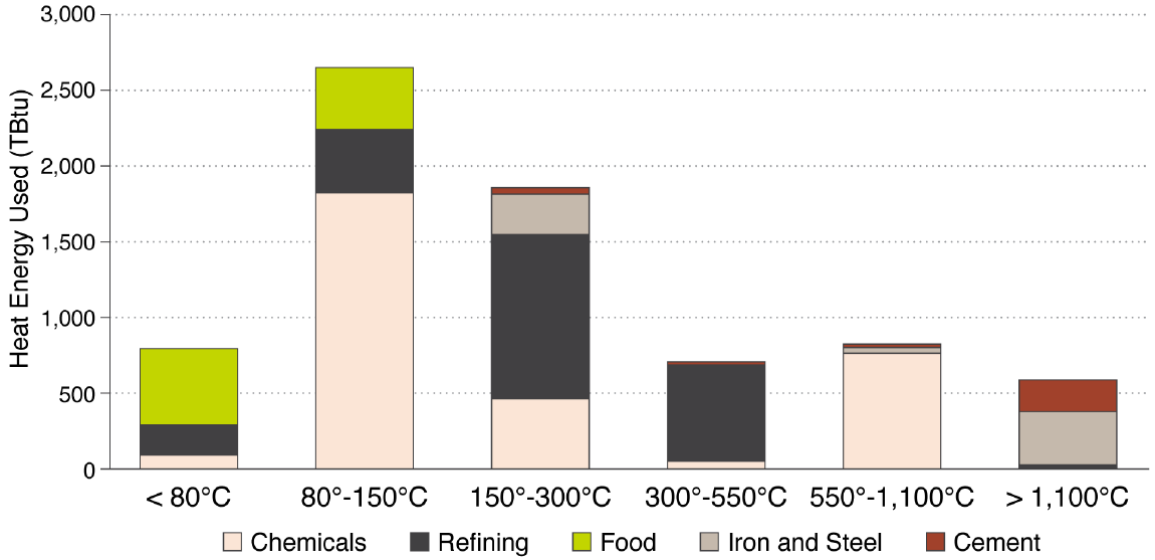
How can the High Temperature Heat Pump open new markets for Geothermal Energy?

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

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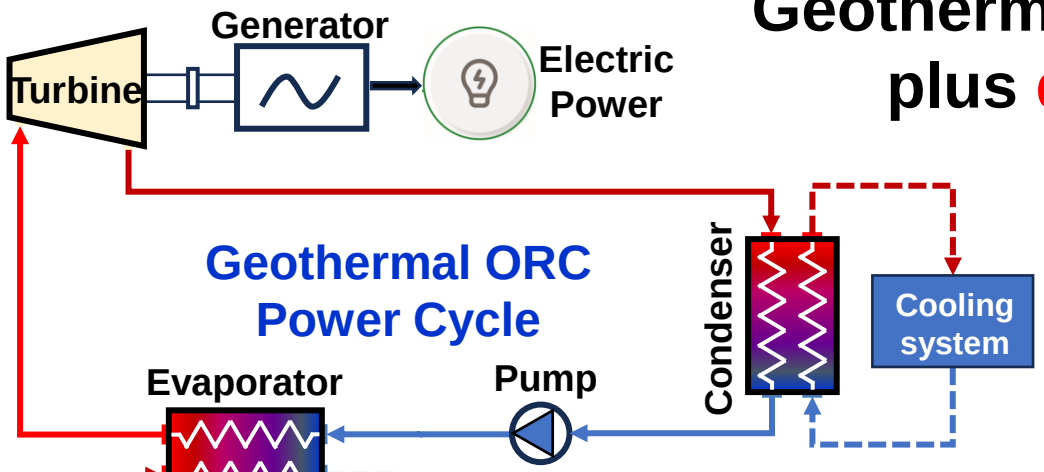
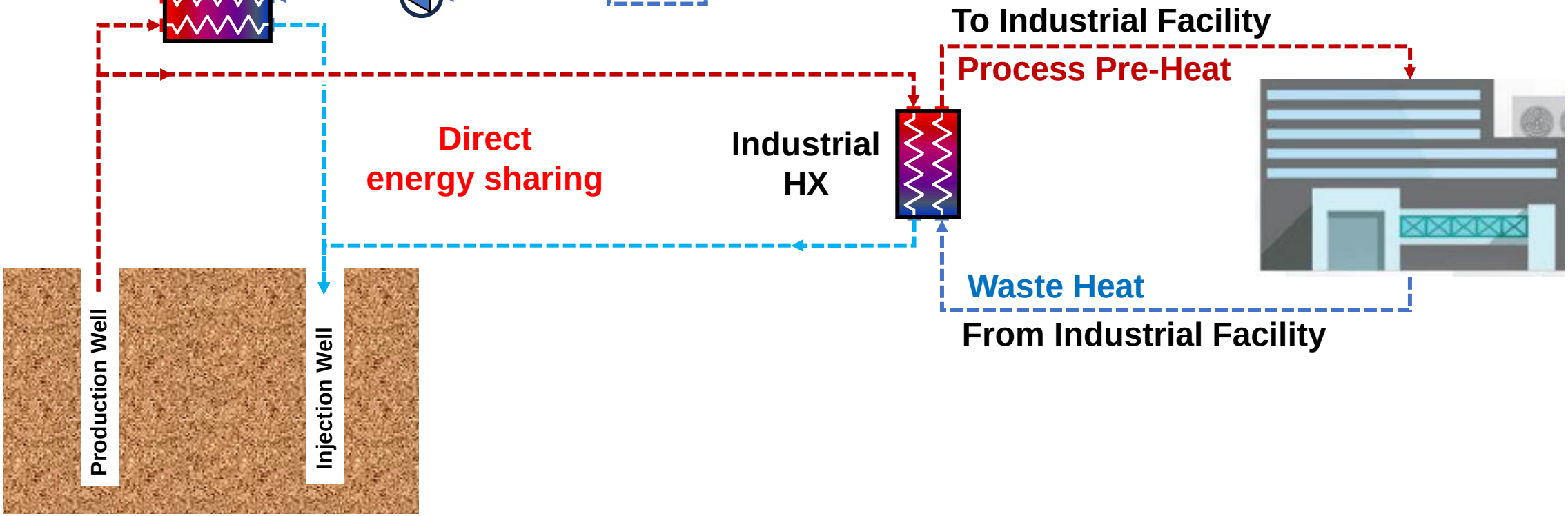
Geothermal Organic Rankine Cycle plus direct energy sharing



Example: Pre-heat water to facility's natural gas boiler



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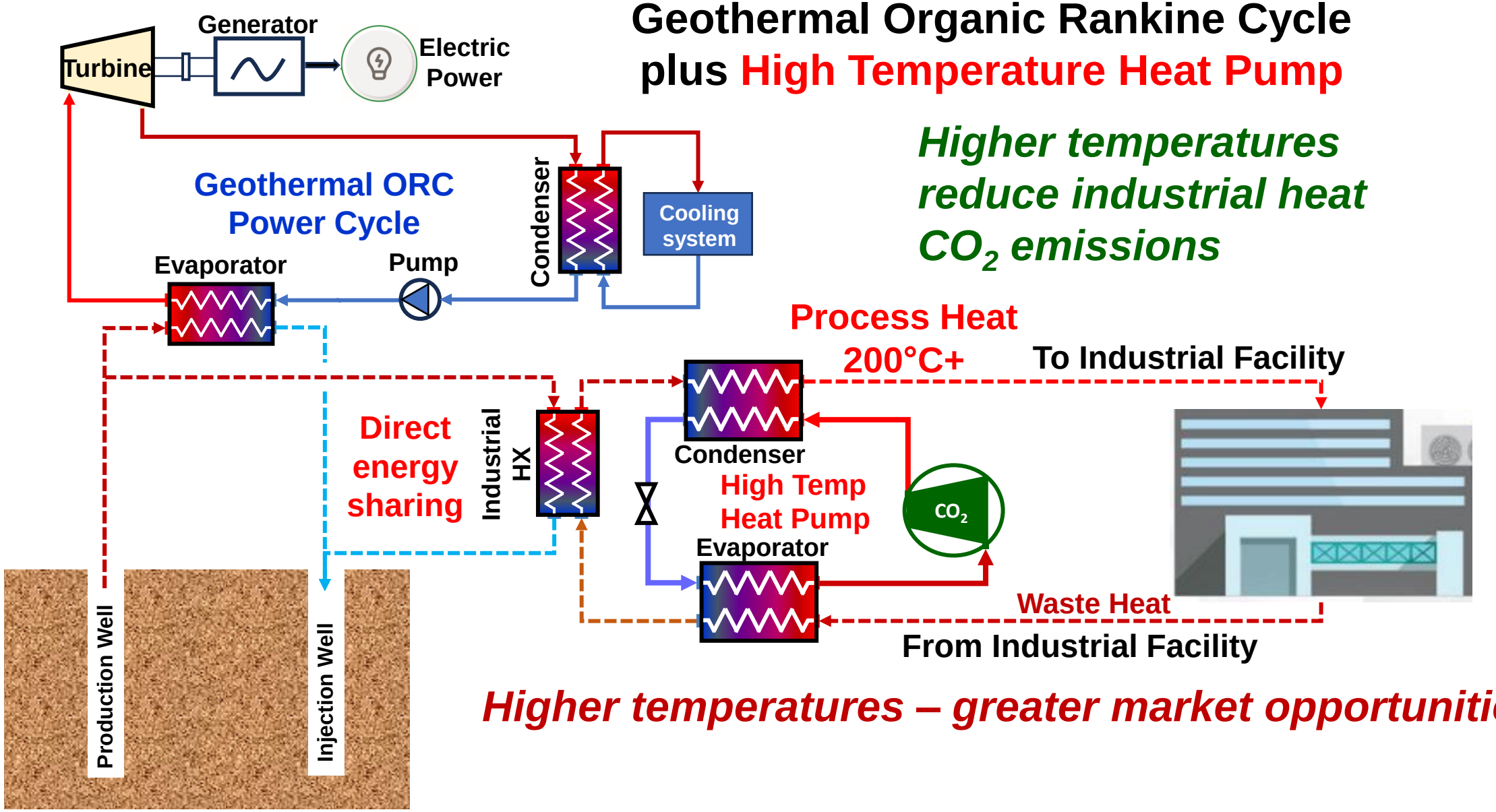
Geothermal Organic Rankine Cycle plus High Temperature Heat Pump



Higher temperatures reduce industrial heat CO_2 emissions

Higher temperatures – greater market opportunities

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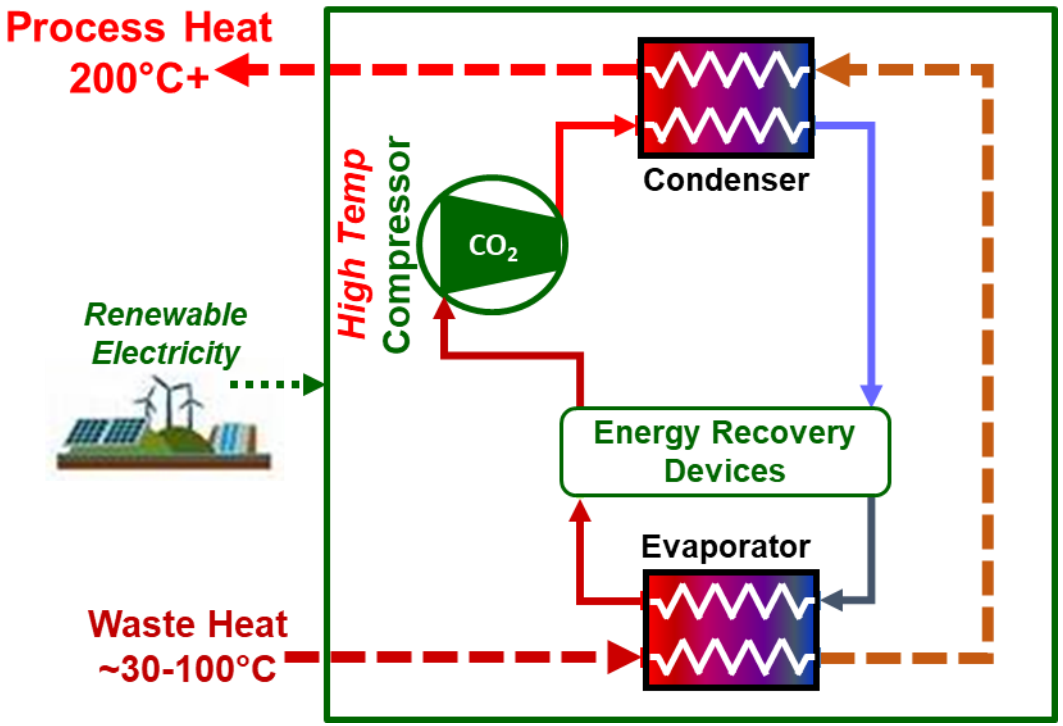
Higher temperatures – Greater market opportunities

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**

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Thank you for your kind attention!

Questions?

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