



# Natural Refrigerant, Industrial High Temperature Heat Pump

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## MOTIVATION:

The U.S. DOE identified electrification of industrial process heat as one of the four key pathways to reduce industrial emissions. **In the U.S.A., fossil fuel combustion produces heat and steam used for:**

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

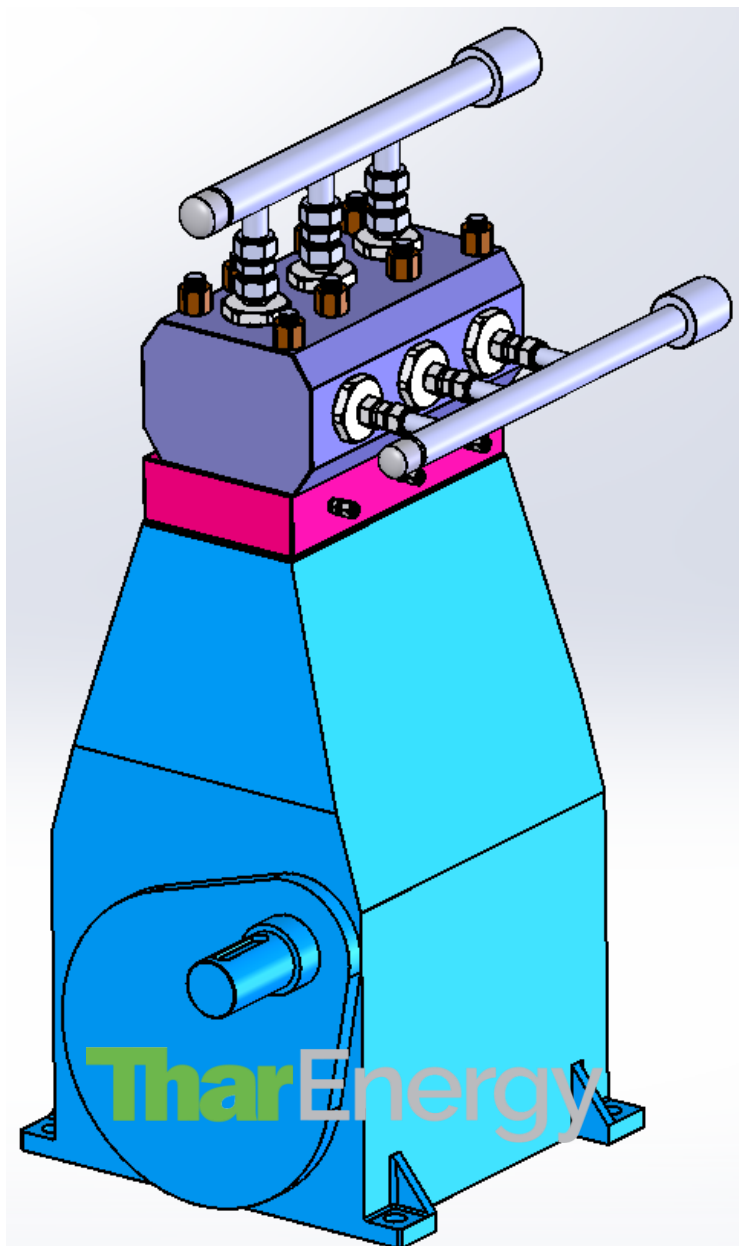
**This creates ~52% of the country's industrial direct greenhouse gas emissions.**

The Steam Industrial High Temperature Heat Pump is being designed as a drop-in replacement for gas fired steam boilers, to lower costs and decarbonize industrial process heat.

1. Industrial Decarbonization Roadmap, DOE/EE-2635, United States Department of Energy, September 2022
2. Renewable Thermal Collaborative, Report in Brief, 02/2021

**sCO<sub>2</sub> - a Natural Refrigerant**  
**Ubiquitous:** Safe, non-toxic, & available worldwide  
**Eco-Friendly:** Global Warming Potential of 1  
 Zero Ozone Depletion Potential  
**Lowest Cost:** 90% cheaper than the latest refrigerants

## High Temp sCO<sub>2</sub> Compressor



**sCO<sub>2</sub>**  
**170°C @**  
**140 bar**



## Steam Heat Pump Stack-sheet Recuperator

Design T / P: 300°C / 300 bar **Effectiveness: ~95%**



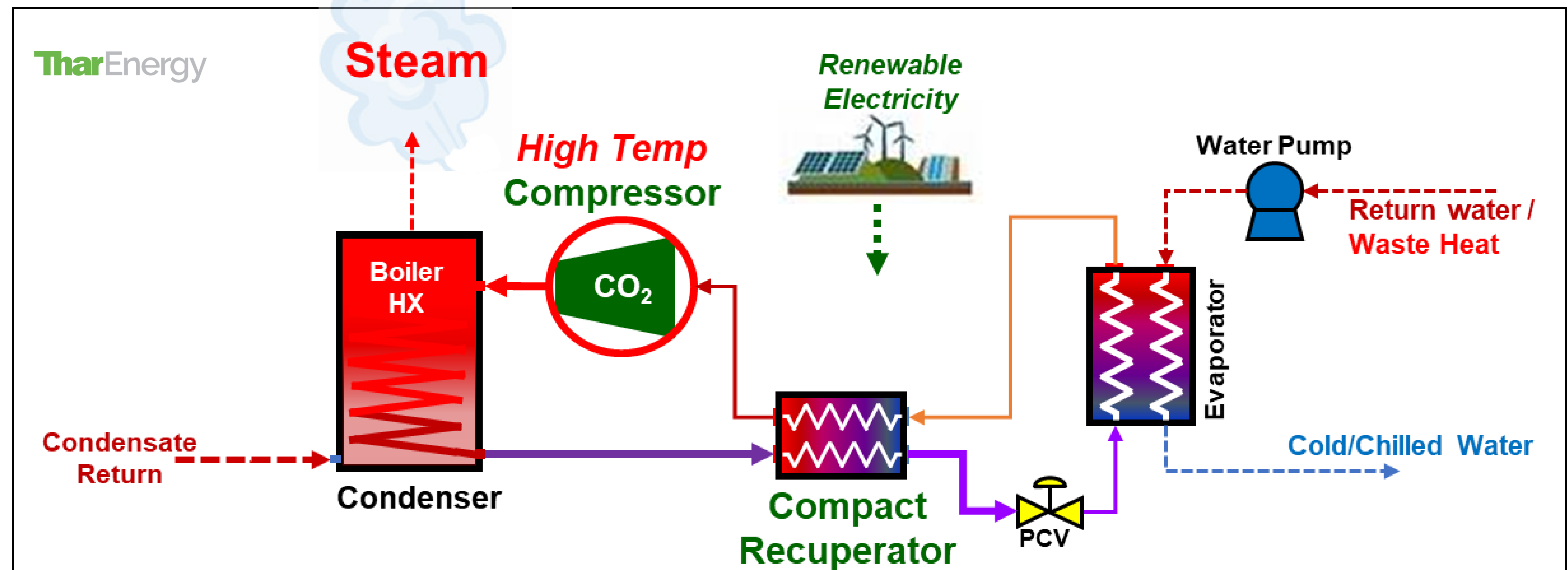
## RESULTS:

**Validated novel iHTHP High Temperature Steam cycle (104°C - 200°C)**

- **High Carnot Efficiency** (65% of Carnot COP (50°C heat source and 200°C heat sink))

## Demonstrated:

- **sCO<sub>2</sub> Recuperated Steam Heat Pump System**
- **170°C High Temp Heat sCO<sub>2</sub> Compressor**
- **Novel Compact sCO<sub>2</sub> - sCO<sub>2</sub> Recuperator**



## Demo sCO<sub>2</sub> Steam Heat Pump System

