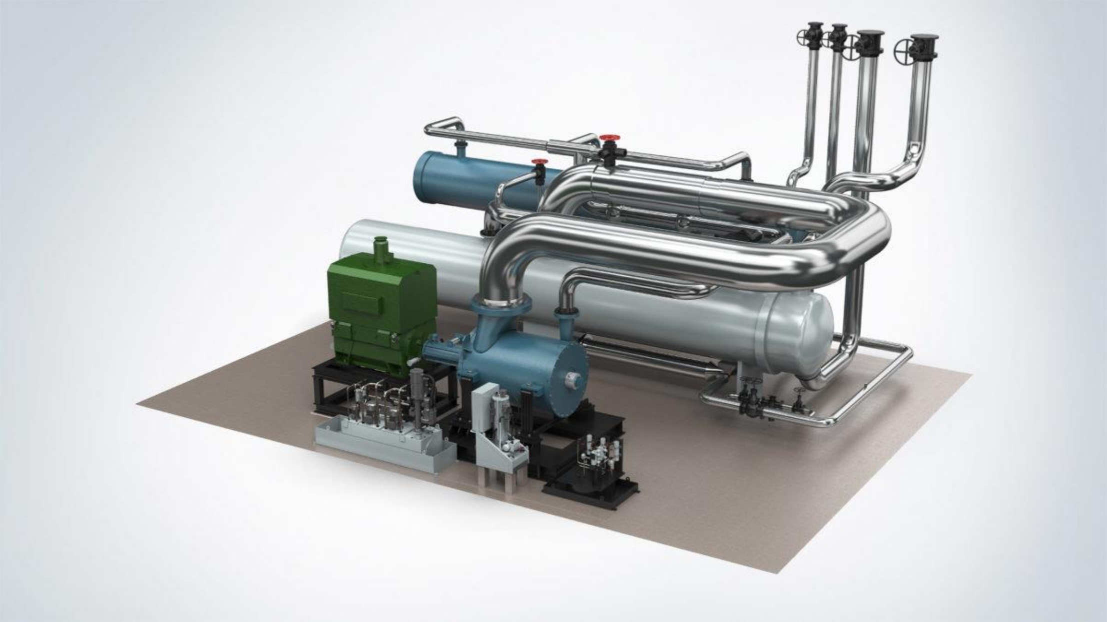
U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

High Temperature Heat Pump for Commercial Space and Water Heating



Oak Ridge National Lab
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WBS 03.02.02.38

Project Summary

Objective and outcome

This project focuses on the development and performance optimization of a high temperature heat pump for space and water heating for commercial buildings. The team intends to design and demonstrate a 30kW or higher capacity heat pump which can provide at least 180^{o}F sink temperature with acceptable COP.

Chemours Southern Company Rheem EMERSON

Team and Partners

Oak Ridge National Lab

Kashif Nawaz, Steve Kowalski, Jian Sun, Pengtao Wang, Zhimming Gao, Cheng-Min Yang

Emerson (Drew Welch), **Chemours** (Kostas Kontomaris), **Rheem** (Ati Manay), **Southern Company** (Pradeep Vitta)

Stats

Performance Period: April 2022- June 2025

DOE budget: $1.5M/year, Cost Share: $500k

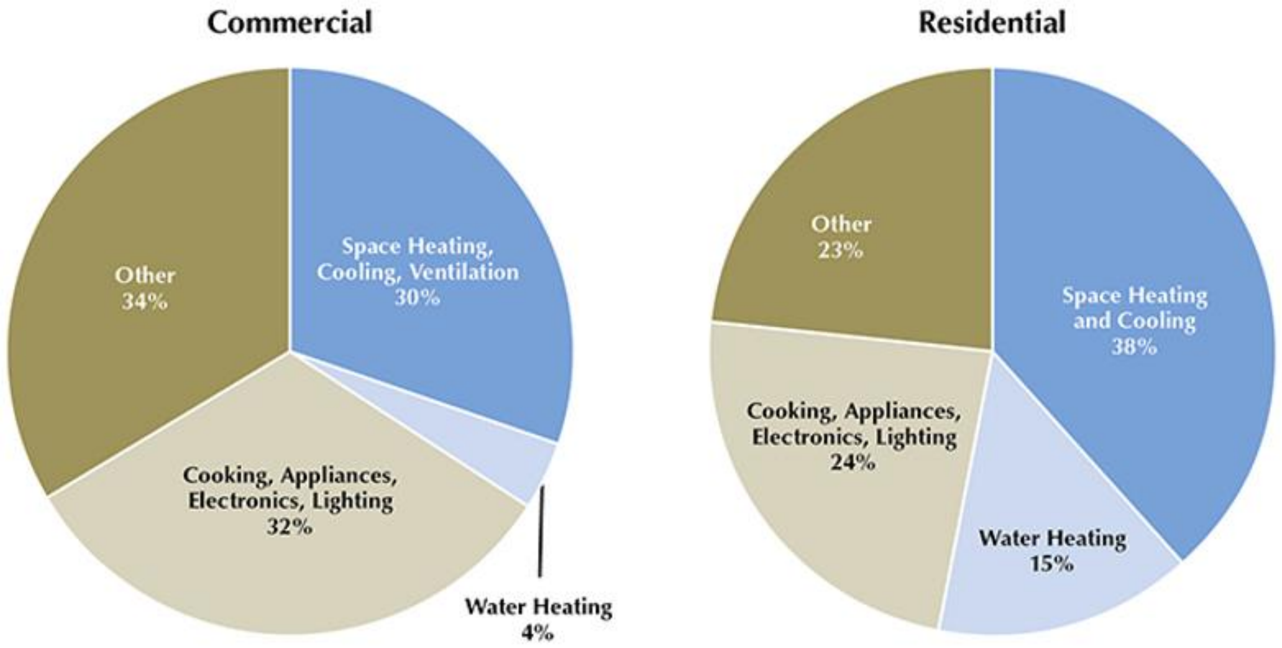
Milestone 1: Analysis of system configuration

Milestone 2: Component acquisition and validation followed by development of prototype

Milestone 3: Lab scale and field validation of performance under realistic operating conditions.

Problem

- Processes in buildings and industrial applications account for 60% of direct and indirect CO_2 emissions.
- More than 1.8 quads of energy are used annually in gas-fired equipment for commercial heating applications, accounting for more than 94 MMT of CO_2 emissions in 2021.



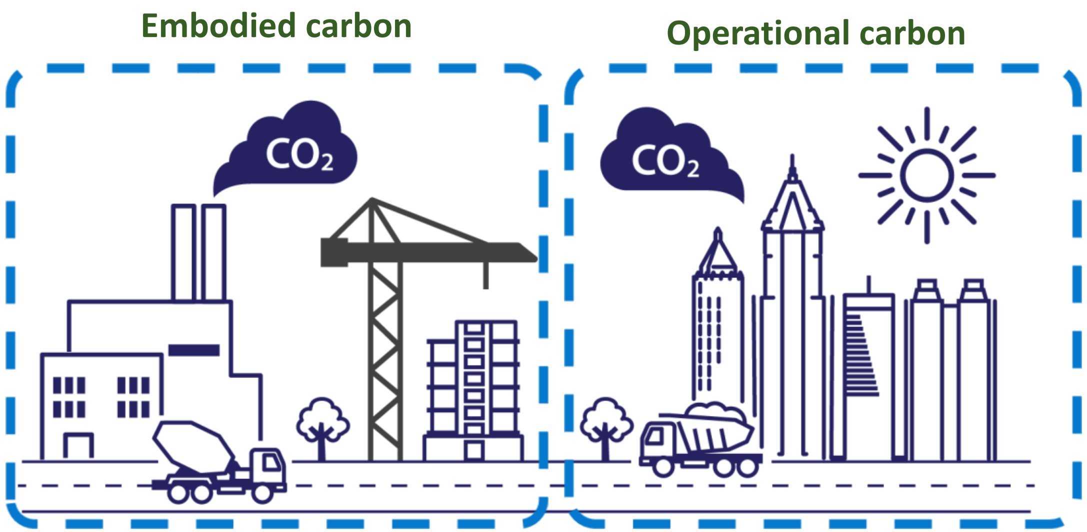
Total CO_2 emissions from commercial and residential sectors

U.S. Energy Information Administration, Annual Energy Outlook (2018)

Direct vs. Indirect decarbonization

Indirect decarbonization

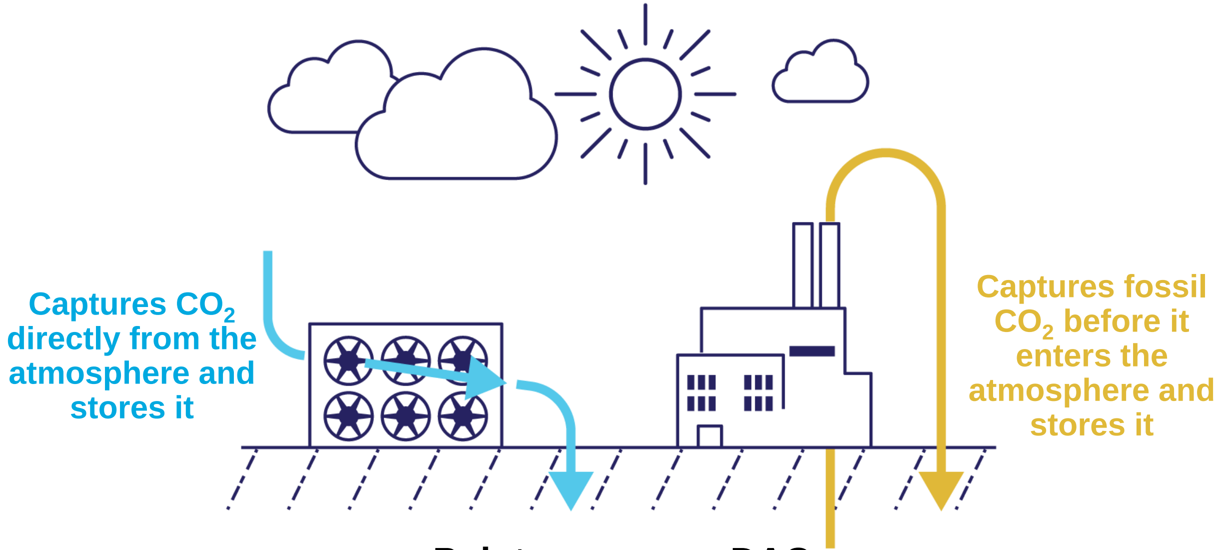
- **Energy-efficient equipment**
- Load shifting – optimum use at grid scale
- Energy storage (materials, systems)
- Embodied carbon



Embodied vs. Operational carbon

Direct decarbonization

- **Elimination of CO_2 emissions**
- Emerging refrigerants with lower GWP
- Non-vapor compression technologies
- Direct carbon removal



Point source vs. DAC

Carbon emissions from gas and heat pump heating systems, UK, 2008
Carob Cure, What is embodied carbon?

Alignment and Impact

A direct replacement for gas-fired technology for commercial buildings' heating

- Electrification of commercial buildings
- At least 50% reduction in direct CO_2 emissions
- Implications for cold climates heating systems

An integrated heat pump concept with unprecedented sink temperature

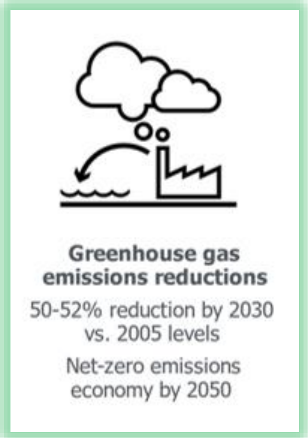
- Optimized process integration for simultaneous air and water heating
- Implications beyond building- Industrial decarbonization

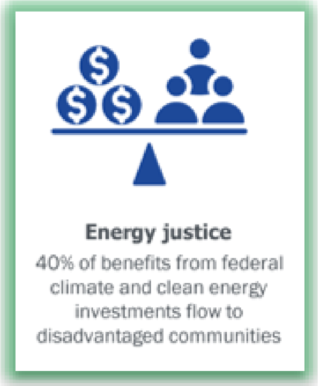
Demonstration of acceptable COP at all operating conditions

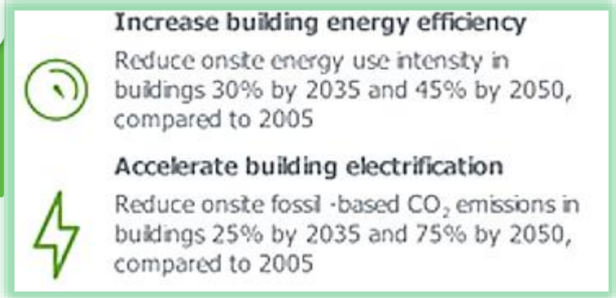
- System design to maximize the performance
- Potential for scaling up for large scale deployments

Positioning US for competitive markets

- An accelerated development plan to assume a leading role.
- Lessons learnt from current/on-going developments (IEA Annex 58)

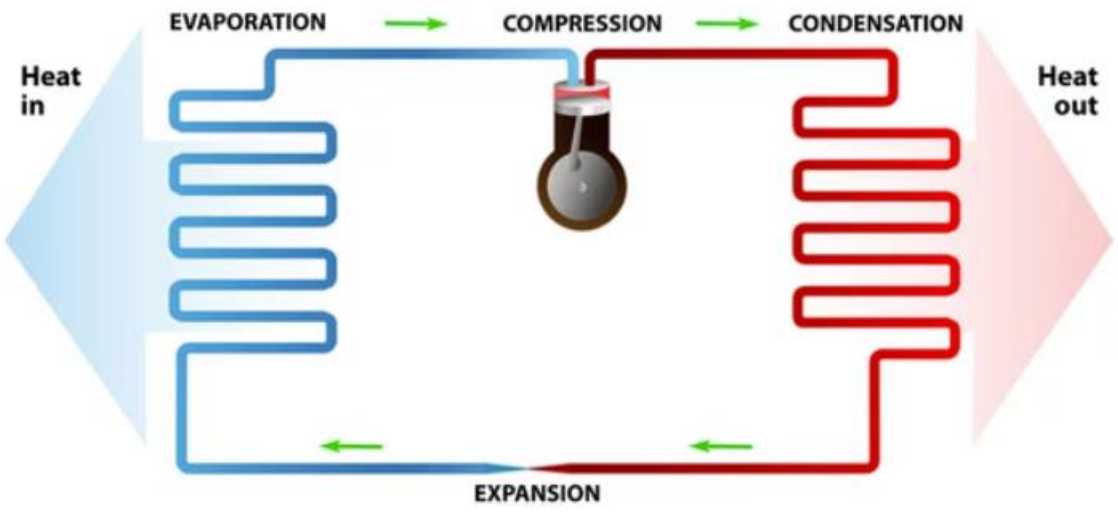


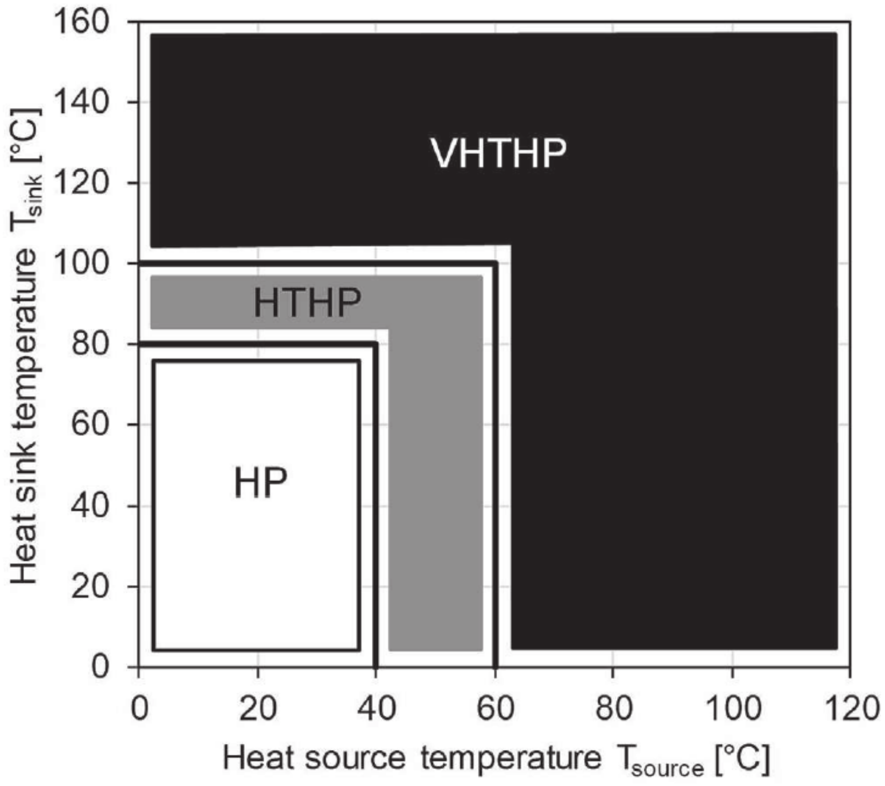




Approach

- Beyond domestic hot water temperatures
- Any heat pump system with sink temperature higher than 160 ºF can be classified as HTHP.
- Heat pump have been used to produce steam (prototype scale development)

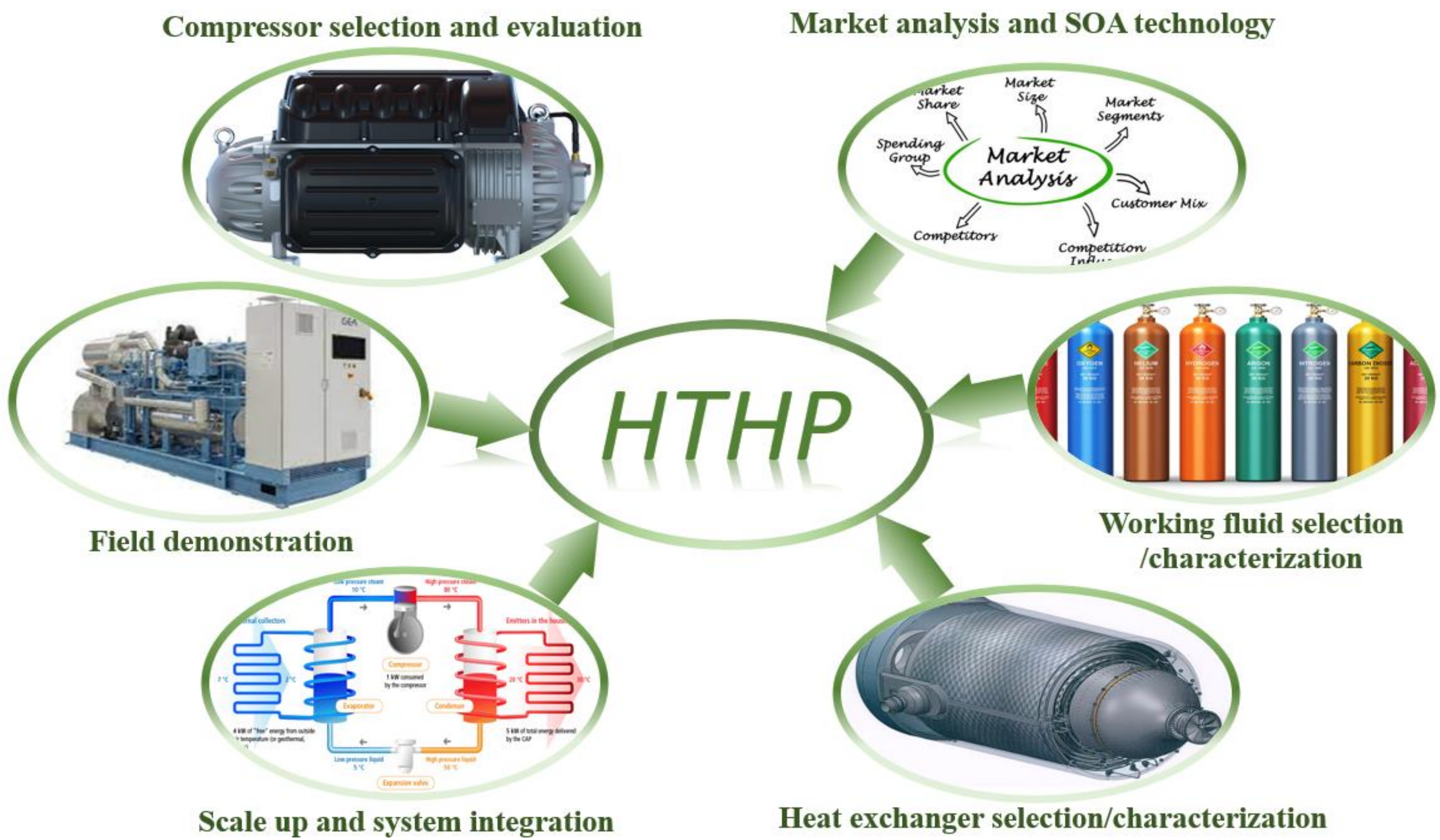




Definition of HTHP

IEA Annex 58

Approach



The ORNL team is developing a comprehensive Research, Development and Demonstration framework for commercial/industrial HTHP.

Working Fluids Selection

Heat source and Heat sink temperature in °C

			-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
Natural		**R718***															X	X	X	X	X	X	X	X	X	X	X	X
		R717			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
		R744**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
High flammability	HC	**R601**											X	X	X	X	X	X	X	X	X	X	X	X	X			
		R601a										X	X	X	X	X	X	X	X	X	X	X	X	X				
		R600								X	X	X	X	X	X	X	X	X	X	X	X	X						
		R600a					X	X	X	X	X	X	X	X	X	X	X	X	X	X								
		R290			X	X	X	X	X	X	X	X	X	X	X													
	HFO	**R1336mzz(Z)**										X	X	X	X	X	X	X	X	X	X	X	X	X				
		R1234ze(Z)								X	X	X	X	X	X	X	X	X	X	X	X	X						
		R1336mzz(E)								X	X	X	X	X	X	X	X	X	X	X								
		R1234ze(E)					X	X	X	X	X	X	X	X	X	X	X											
		R1234yf				X	X	X	X	X	X	X	X	X	X	X												
High GWP	HCFO	**R1233zd(E)**									X	X	X	X	X	X	X	X	X	X	X	X	X					
		R1224yd(Z)								X	X	X	X	X	X	X	X	X	X	X	X	X	X					
	HFC	**R365mfc**											X	X	X	X	X	X	X	X	X	X	X	X	X			
		R245fa									X	X	X	X	X	X	X	X	X	X	X	X						
		R134a				X	X	X	X	X	X	X	X	X	X	X												
			-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200

*R718 Vapor recompression cycle; **R744 Transcritical CO2 cycle

Working Fluids Selection

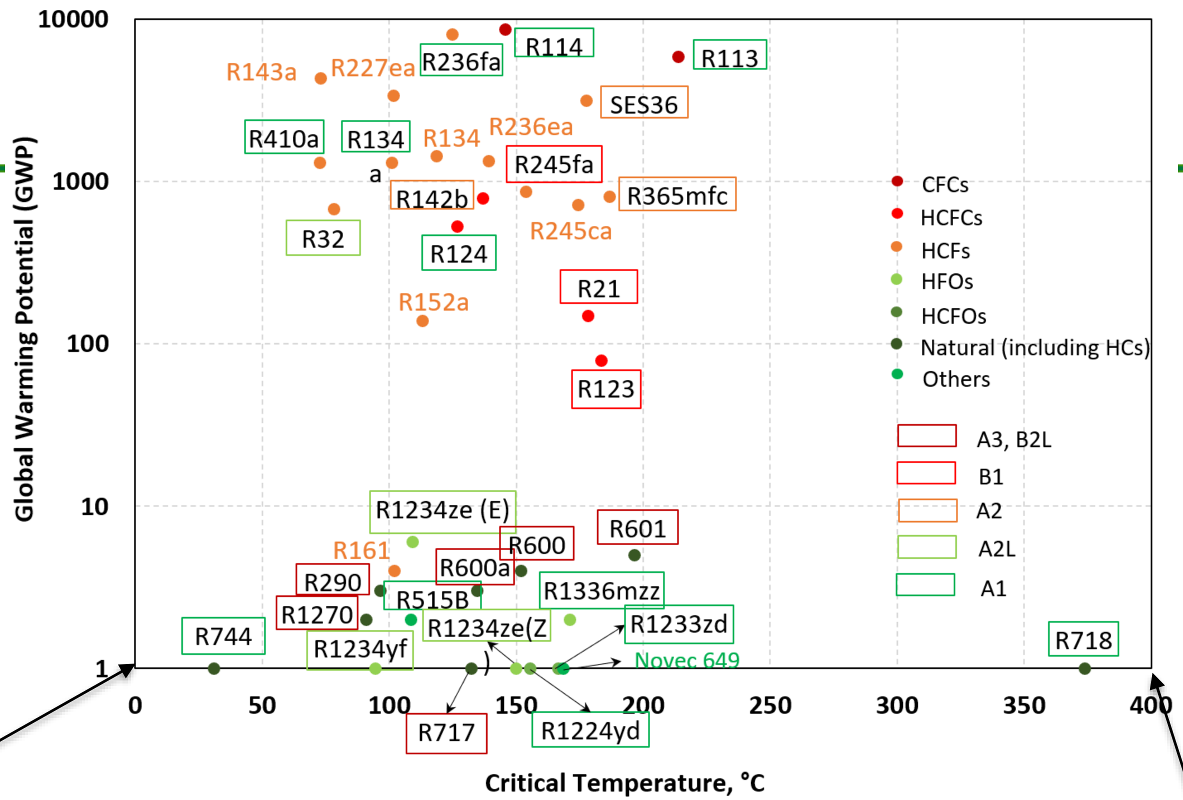
Evaluation Criteria

Environment : ODP, GWP, Atmospheric lifetime (ALT)

Safety: Toxic, Flammable, Explosive

Thermal: Critical temperature, Critical pressure, Latent heat of vaporization, Normal boiling point, Molecular weight

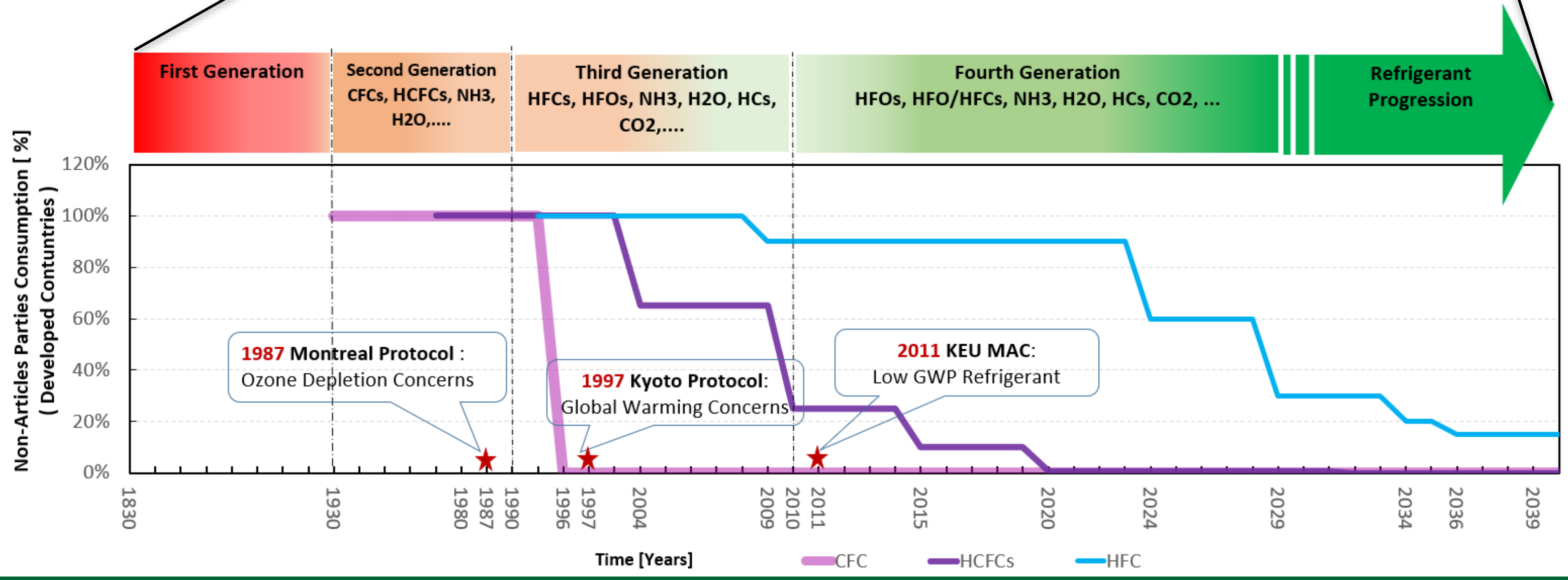
Thermodynamic and physical performance: Coefficient of performance (COP), Specific volumetric heat capacity (VHC), Superheat requirement, Compression ratio



Chemical: Satisfactory oil solubility, Easy leakage detection, High dialectic strength of vapor, Lubricating properties

Compatibility: Compatible with materials of construction, Compatible with lubricant

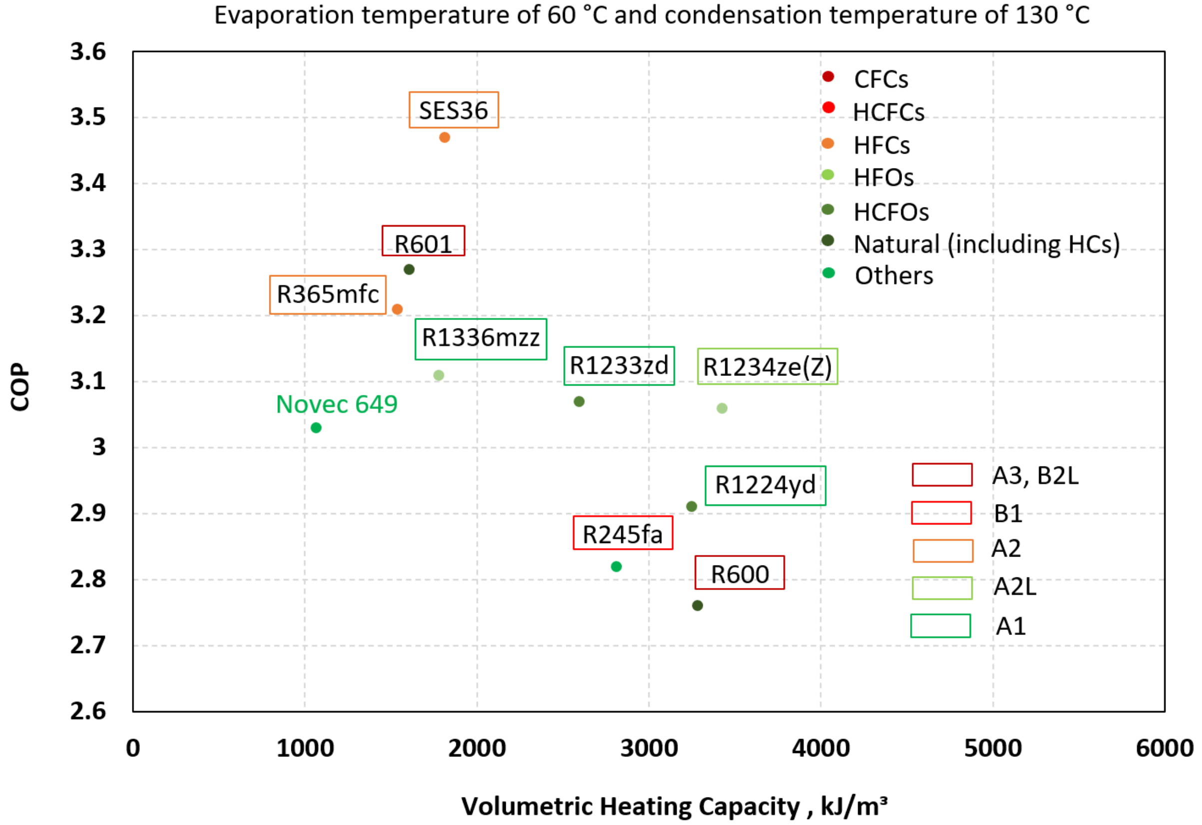
Availability: Cost, Location



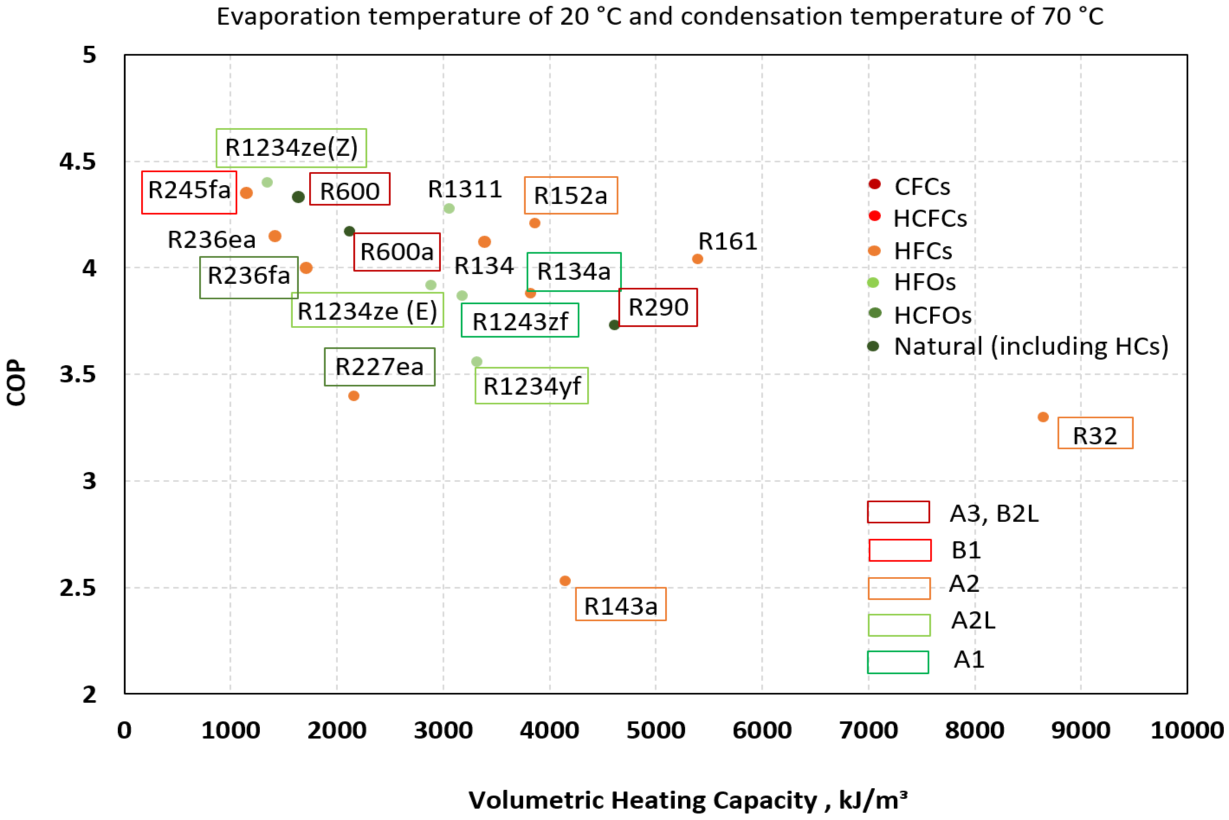
Working Fluids Selection

Thermodynamic and physical performance

High Temperature



Medium Temperature



High temperature heat pump applications: R1336mzz, R1234ze (Z), R1233zd, R1224yd, Novec649, R718

Medium temperature heat pump applications: R1234ze(E),R1234yf. R1234zf, R515B, E170, R744.

Compressor Selection

	Piston	Scroll	Screw	Turbo
Driving force	Displacement	Displacement	Displacement	Flow machine
Compression	static	static	static	dynamic
Swept volume	geometrical	geometrical	geometrical	depending on the counter pressure
Production	pulsing	continuously	continuously	continuously
Volume flow	Up to 1,000 m^3/h	Up to 500 m^3/h	100 to 10,000 m^3/h	100 to 50,000 m^3/h
Heating capacity	Up to 800 kW	Up to 400 kW	80 kW to 8 MW	80 kW to 40 MW
Pressure ratio (single stage)	Up to 10	Up to 10	up to above 20*	Up to 5
Controllable at constant speed	in stages	difficult	continuously	continuously
Speed control	possible	possible	possible	possible
Sensitivity to liquid slugging	high	low	low	low
Causes vibrations	yes	no	no	no

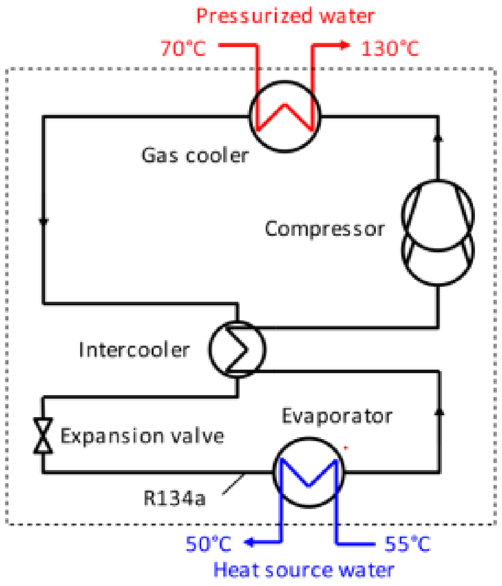
Pressure ratio of screw compressor taken from [ASHRAE, 2020]

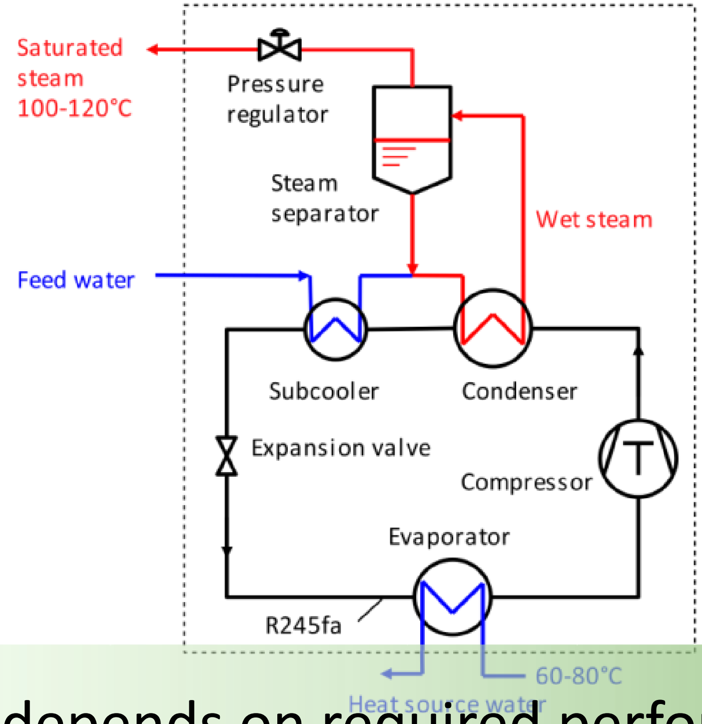
Compressor selection depends on system capacity, desired lift temperature and working fluid.

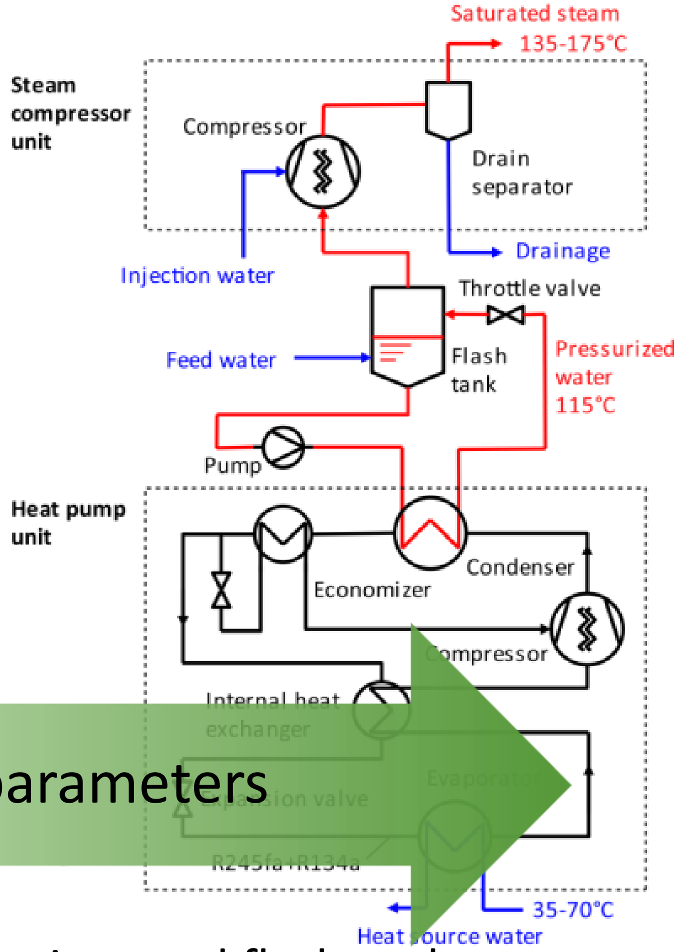
Heat Exchanger Selection

- Gas vs. liquid as cooling/heating fluids
- Compatibility with refrigerants and secondary fluids
- Design consideration for higher lift temperatures
- Resistance to corrosion and fouling
- Compliance with thermal and mechanical stresses

System Configurations





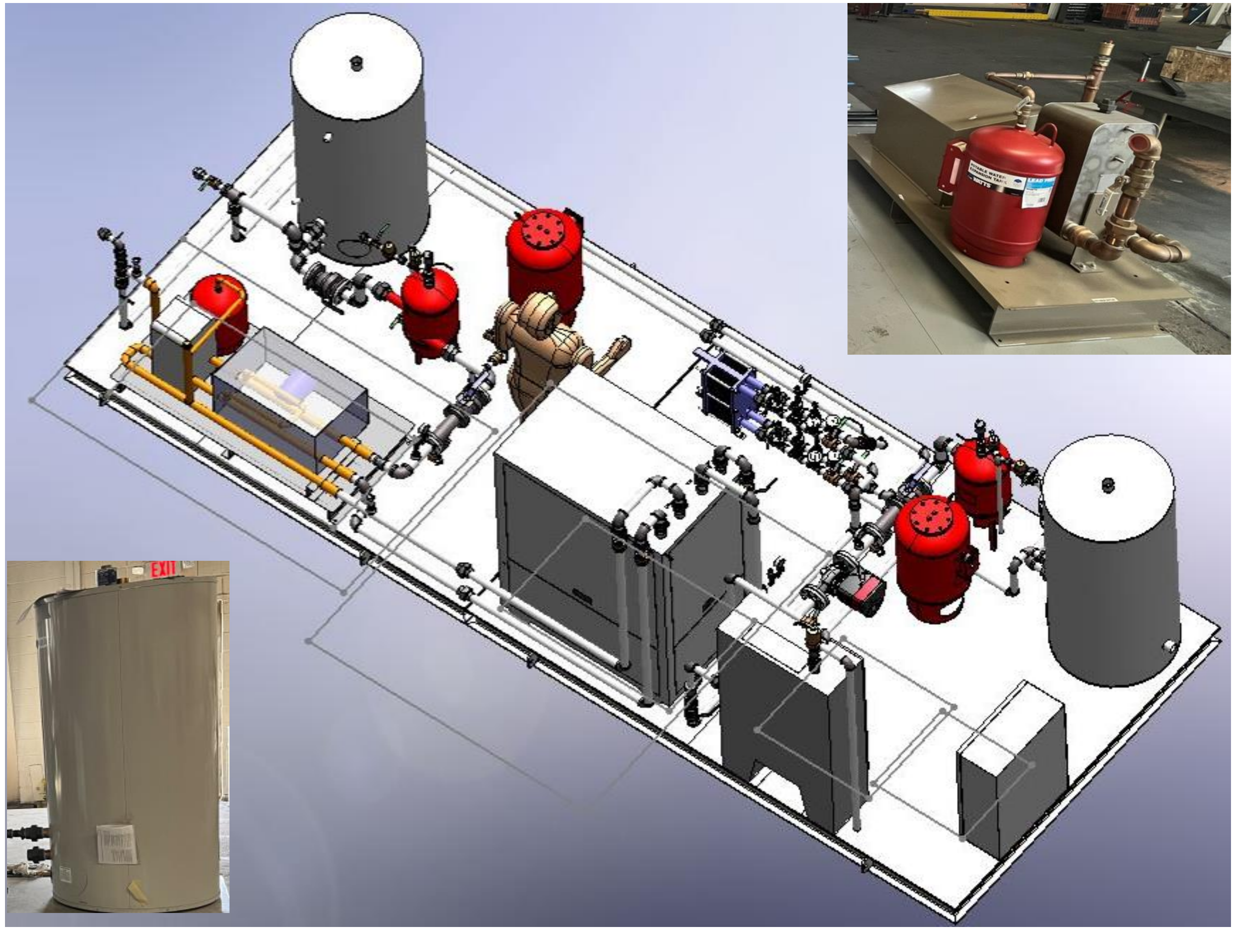


Complexity depends on required performance parameters

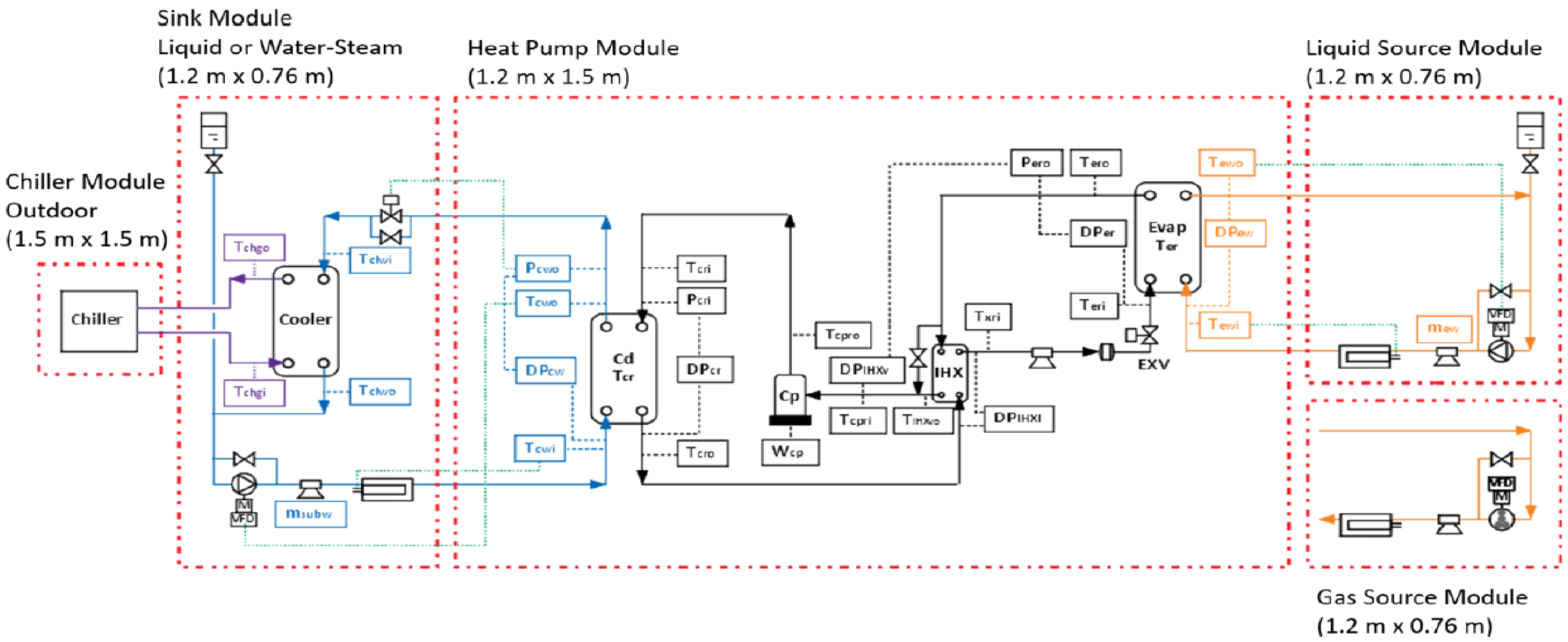
- Additional components for improved system COP, such as ejector, economizer, and flash tank.
- Cascade or Multi-cycle systems have been considered for a desired lift temperature.

Demonstration Facility

- Demonstration facility is under development to establish the performance of any commercial scale heat pump.
- The source and sink conditions will be simulated through controlled heaters and chillers network.



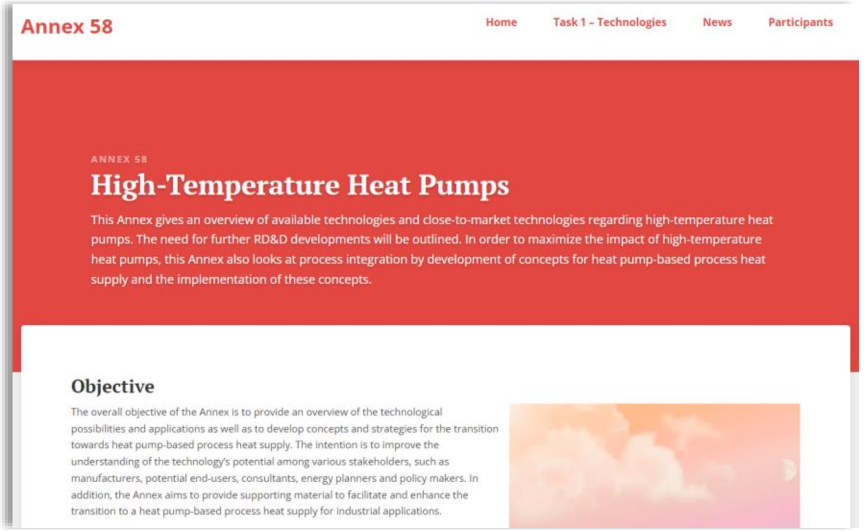
Research and Development Facility



ORNL HTHP testbed can accommodate 30-100 kW capacity with a range of sink temperatures

Stakeholder Engagement

- **Extensive interest from leading OEMs**
  - Water heating OEMs
  - Air heating OEMs
  - Process controls and sustainability
- **Presentations/Conference papers**
  - Planned publications at ASHRAE and beyond
- **Engagement in IEA Annex 58 (ORNL is US Primary Contact)**



Annex 58

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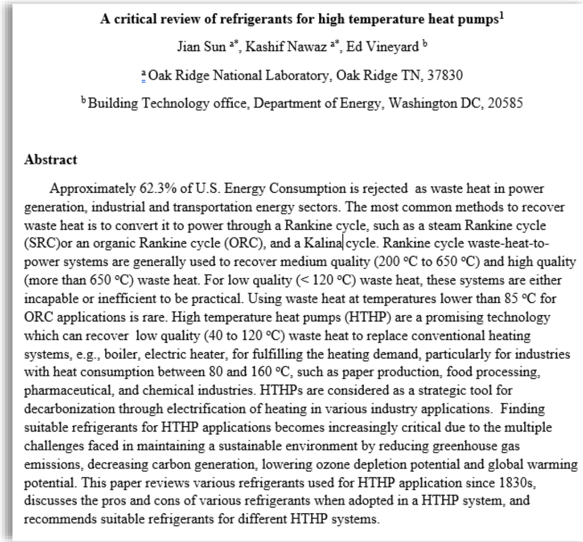
ANNEX 58

High-Temperature Heat Pumps

This Annex gives an overview of available technologies and close-to-market technologies regarding high-temperature heat pumps. The need for further RD&D developments will be outlined. In order to maximize the impact of high-temperature heat pumps, this Annex also looks at process integration by development of concepts for heat pump-based process heat supply and the implementation of these concepts.

Objective

The overall objective of the Annex is to provide an overview of the technological possibilities and applications as well as to develop concepts and strategies for the transition towards heat pump-based process heat supply. The intention is to improve the understanding of the technology's potential among various stakeholders, such as manufacturers, potential end-users, consultants, energy planners and policy makers. In addition, the Annex aims to provide supporting material to facilitate and enhance the transition to a heat pump-based process heat supply for industrial applications.



A critical review of refrigerants for high temperature heat pumps[1]

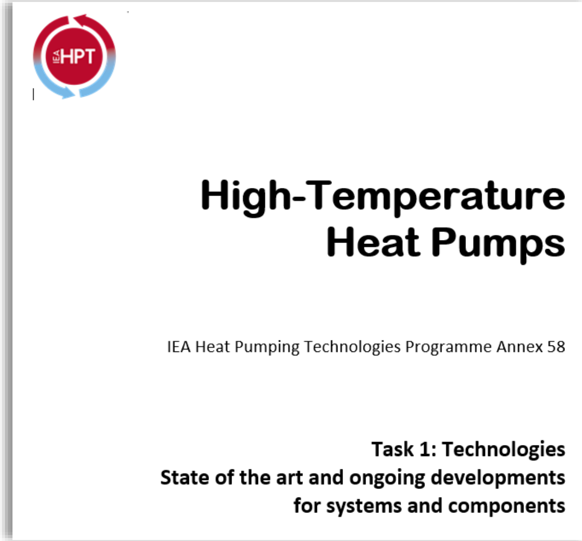
Jian Sun [a*], Kashif Nawaz [a*], Ed Vineyard [b]

[a] Oak Ridge National Laboratory, Oak Ridge TN, 37830

[b] Building Technology office, Department of Energy, Washington DC, 20585

Abstract

Approximately 62.3% of U.S. Energy Consumption is rejected as waste heat in power generation, industrial and transportation energy sectors. The most common methods to recover waste heat is to convert it to power through a Rankine cycle, such as a steam Rankine cycle (SRC)or an organic Rankine cycle (ORC), and a Kalina cycle. Rankine cycle waste-heat-to-power systems are generally used to recover medium quality (200 °C to 650 °C) and high quality (more than 650 °C) waste heat. For low quality (< 120 °C) waste heat, these systems are either incapable or inefficient to be practical. Using waste heat at temperatures lower than 85 °C for ORC applications is rare. High temperature heat pumps (HTHP) are a promising technology which can recover low quality (40 to 120 °C) waste heat to replace conventional heating systems, e.g., boiler, electric heater, for fulfilling the heating demand, particularly for industries with heat consumption between 80 and 160 °C, such as paper production, food processing, pharmaceutical, and chemical industries. HTHPs are considered as a strategic tool for decarbonization through electrification of heating in various industry applications. Finding suitable refrigerants for HTHP applications becomes increasingly critical due to the multiple challenges faced in maintaining a sustainable environment by reducing greenhouse gas emissions, decreasing carbon generation, lowering ozone depletion potential and global warming potential. This paper reviews various refrigerants used for HTHP application since 1830s, discusses the pros and cons of various refrigerants when adopted in a HTHP system, and recommends suitable refrigerants for different HTHP systems.



HPT

High-Temperature Heat Pumps

IEA Heat Pumping Technologies Programme Annex 58

Task 1: Technologies
State of the art and ongoing developments for systems and components

Thank You

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(865) 241-0972

WBS 03.02.02.36, FY 21 AOP Water Heating R&D

REFERENCE SLIDES

Project Execution

	FY2022				FY2023				FY2024			
Planned budget	1500000				1500000				1500000			
Spent budget	750000				200000				1750000			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Stakeholder engagement												
Market assessment												
Design of experimental/demonstartion facility												
Refrigerant selection and analysis												
Compressor selection and performance evaluation												
Heat exchanger design and selection												
Prototype development												
Prototype testing												
Field evaluation												

Team

Kashif Nawaz
Project management
Prototype development

Steve Kowalski
Experimentation
Data analysis

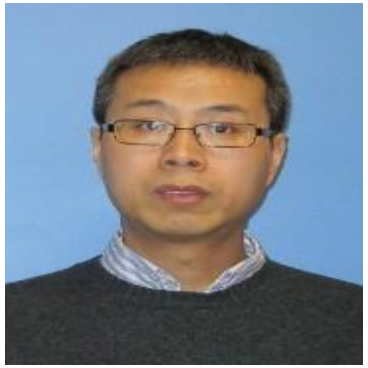
Cheng-Min Yang
Data analysis
Instrumentation

Pradeep Vitta
Advising- Field evaluation

Drew Welch
Advising- Compressor

Pengtao Wang
Performance model
Prototype development

Zhiming Gao
Performance model
Prototype development



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Prototype development
Instrumentation

Ati Manay
Advising- Integration

Kostas Kontomaris
Advising- Refrigerant