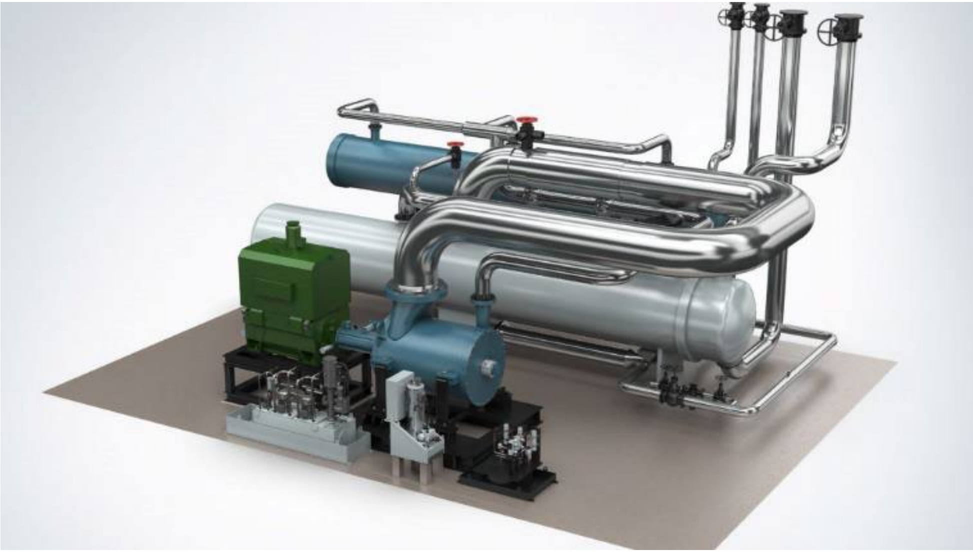
2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

High-Temperature Heat Pump for Commercial Space and Water Heating

High-Temperature Heat Pump for Commercial Space and Water Heating



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WBS 03.02.02.36.NS02

Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

This project is focused on the development and performance optimization of a high-temperature heat pump for space and water heating for commercial buildings. The team wil design and demonstrate a heat pump with a 30 kW or higher capacity that can provide at least a 180°F sink temperature with an acceptable coefficient of performance (COP).

COPELAND

Rheem

TEAM AND PARTNERS

Oak Ridge National Laboratory (ORNL): Kashif Nawaz, Lei Gao, Zhiming Gao, Steve Kowalski, Jubair Shamim, Jian Sun, Pengtao Wang, Cheng-Min Yang

Copeland: Drew Welch

Rheem: Ati Manay, Vishwanath Ardha, Baojie Mu, John Tidwell, Saman Beyhaghi

STATS

Performance Period: April 2022–June 2026

DOE Budget: $1.5M/year, Cost Share: $500K

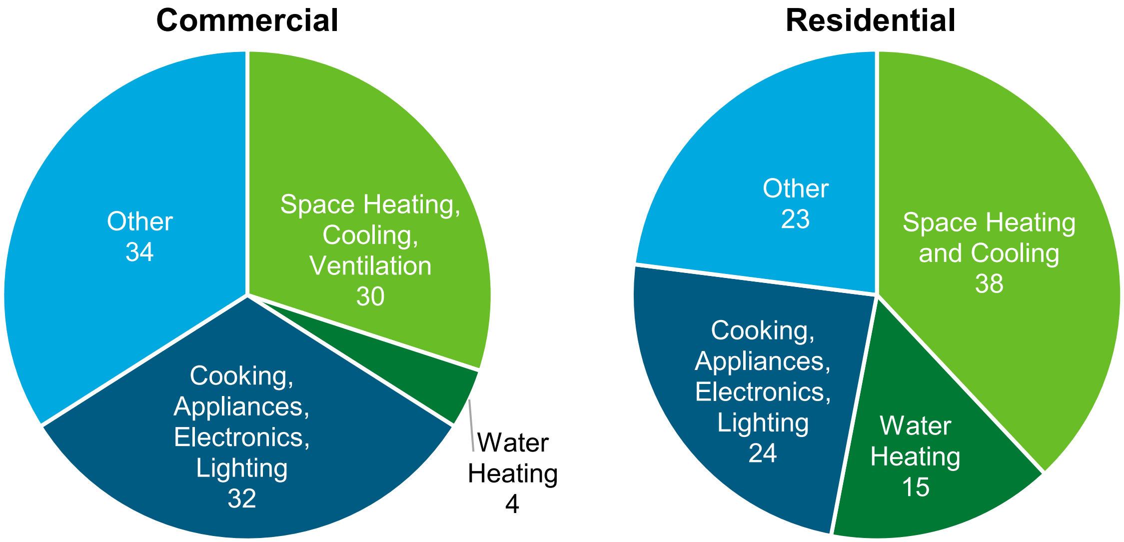
Milestone 1: Analysis of system configuration

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

Alignment and Impact

A direct replacement for gas-fired technology for commercial-building heating

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

An integrated heat pump concept with unprecedented sink temperature

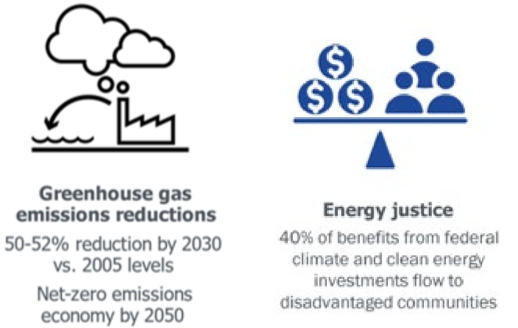
- Optimized process integration for simultaneous air and water heating
- Implications beyond buildings (industrial decarbonization)

Demonstration of an acceptable COP at all operating conditions

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

Positioning the United States for competitive markets

- An accelerated development plan to assume a leading role
- Lessons learned from current/ongoing developments (IEA Annex 58)



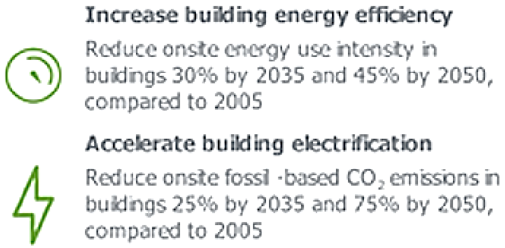
Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities



Increase building energy efficiency

Reduce onsite energy use intensity in buildings 30% by 2035 and 45% by 2050, compared to 2005

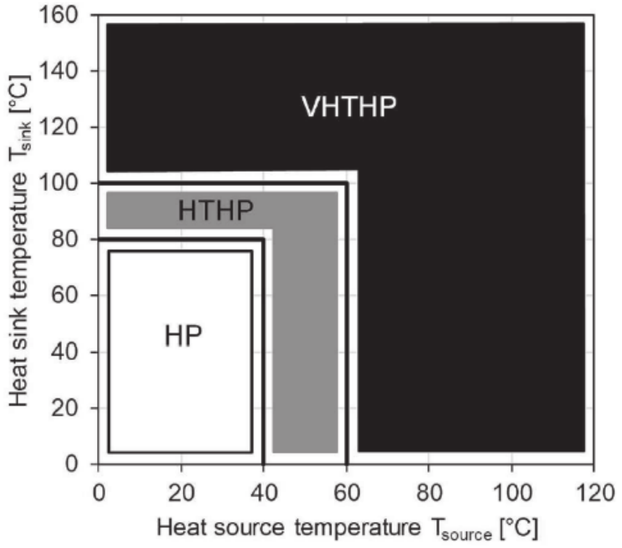
Accelerate building electrification

Reduce onsite fossil-based CO_2 emissions in buildings 25% by 2035 and 75% by 2050, compared to 2005

Approach

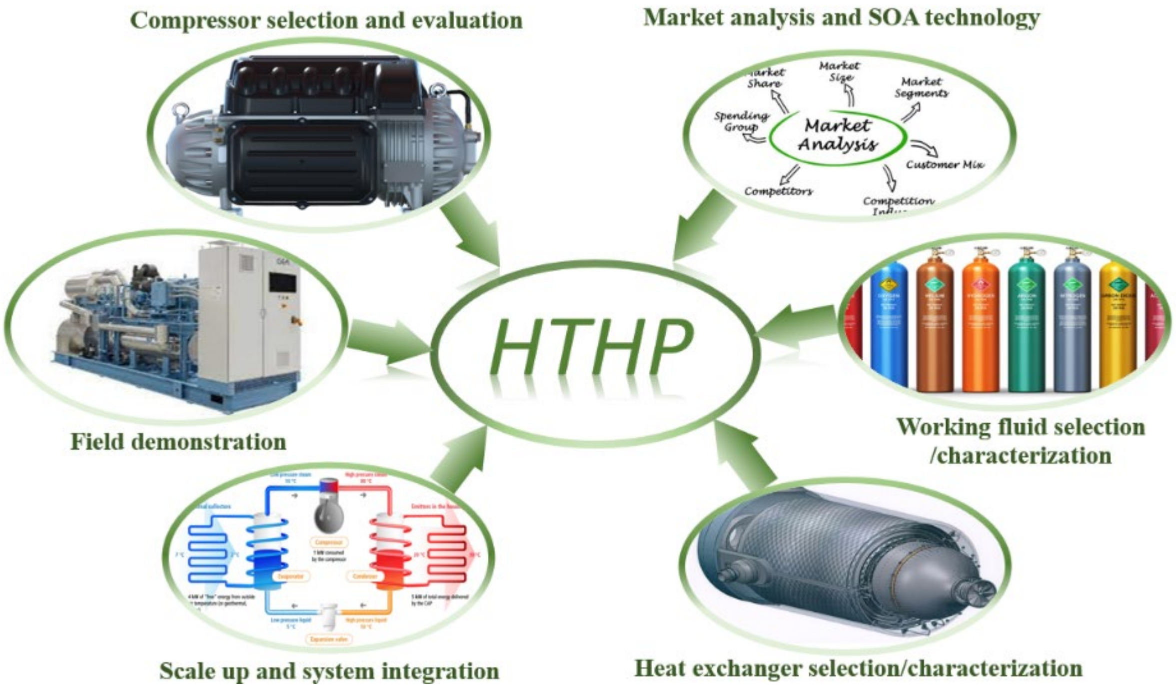
- For heating and domestic hot water in urban multifamily applications, today's solution is often a combustion-fueled boiler
- High water temperatures supplied by boilers are difficult to obtain with today's heat pump technology
- High temperature heat pumps (HTHPs) or very high temperature heat pumps (VHTHPs) are being developed around the world and may meet these application needs

Accepted definitions of high and very high temperature heat pumps



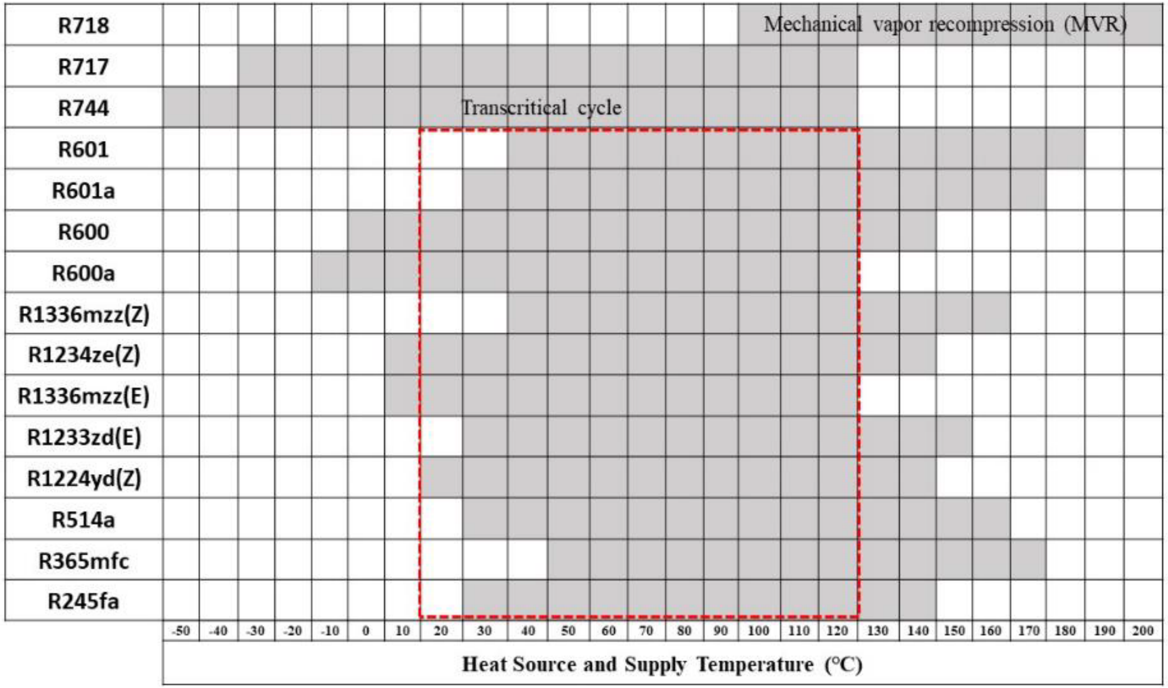
From: Arpagaus, C., Bless, F., Uhlmann, M., Schiffmann, J., & Bertsch, S. S. (2018). High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. *Energy (Oxford)*, *152*, 985-1010. https://doi.org/10.1016/j.energy.2018.03.166

Approach



The ORNL team is developing a comprehensive research, development, and demonstration framework for commercial/industrial HTHPs.

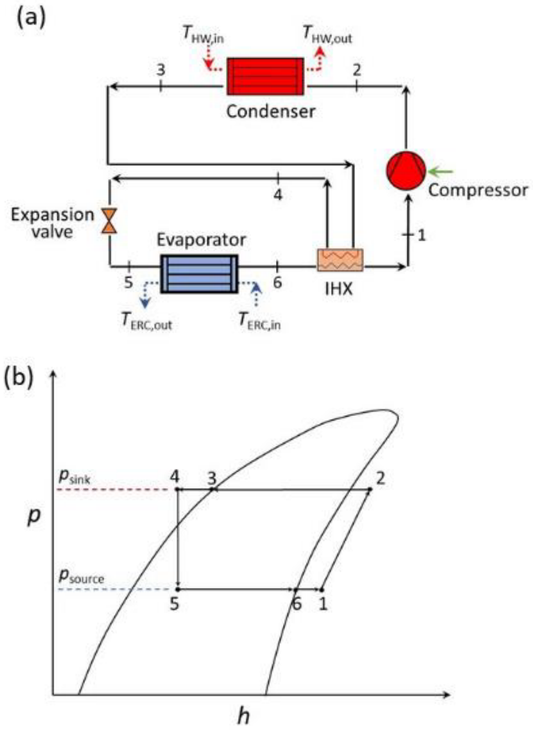
Refrigerant Selection Process



	-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																Mechanical vapor recompression (MVR)	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
R717			▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								
R744	▨	▨	▨	▨	▨	▨	▨	▨	Transcritical cycle	▨	▨	▨	▨	▨	▨	▨	▨	▨								
R601										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
R601a									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
R600						▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
R600a					▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								
R1336mzz(Z)										▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
R1234ze(Z)							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
R1336mzz(E)							▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨								
R1233zd(E)									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨					
R1224yd(Z)								▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						
R514a									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨				
R365mfc											▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨			
R245fa									▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨						

Heat Source and Supply Temperature (°C)

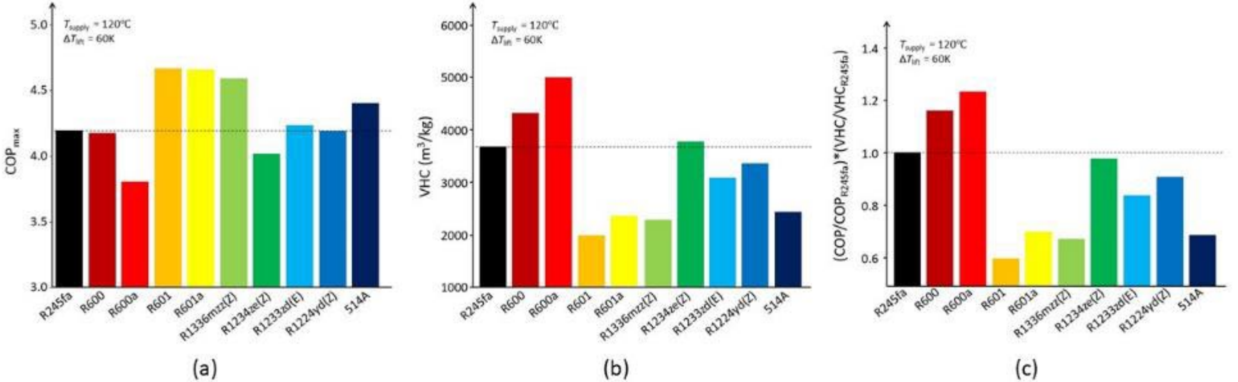
Temperature application ranges of refrigerants in HTHPs (T_{supply} ≥ 100℃)



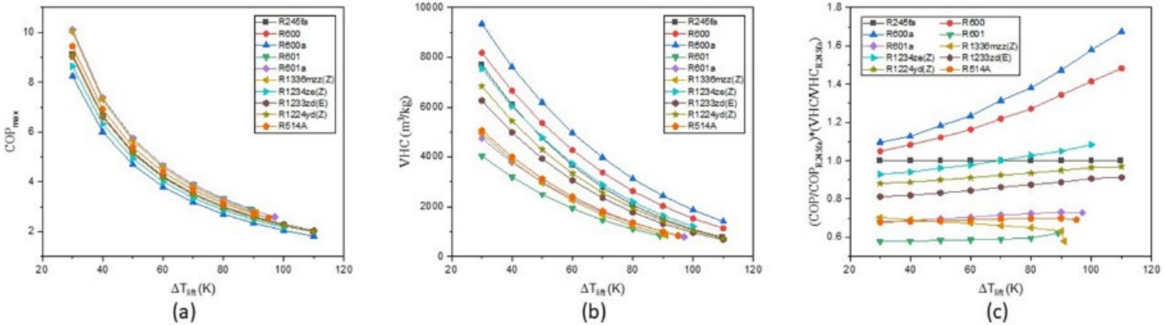
Schematic of an HTHP

Refrigerant Selection Process

- No perfect low-GWP refrigerant exists; a trade-off between the COP and volumetric heating capacity (VHC) must be considered.
- R600 and R600a are appropriate for the balanced COP and VHC scenarios, but A3 flammability requires specific safety measurements.
- R601, R601a, and R1336mzz(Z) are appropriate for the highest COP, but R601 and R601a require very large compressors.

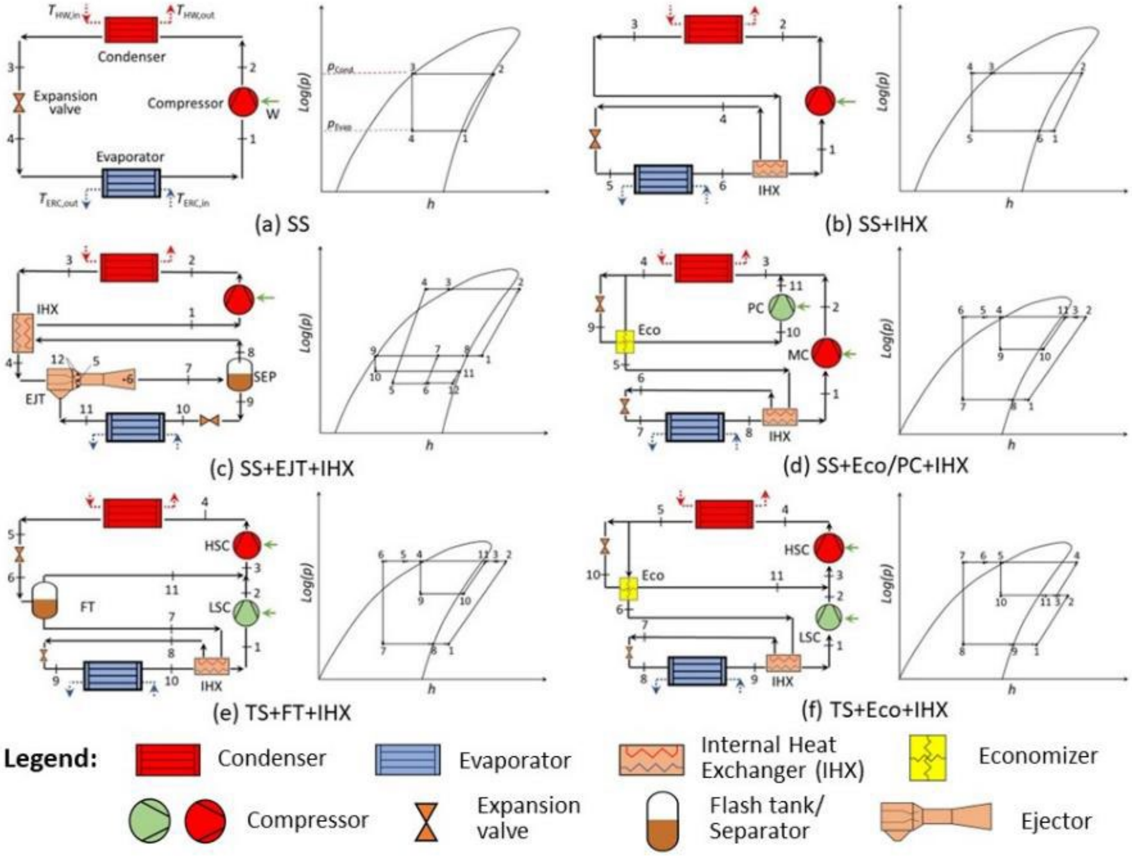


Performance of HTHPs using low-GWPs WFs at T_{supply} = 120℃ and ΔT_{lift} = 60 K.



Performance of HTHPs using low-GWP WFs under T_{supply} = 120℃ and different ΔT_{lift}.

System Configuration Analysis



(a) SS

(b) SS+IHX

(c) SS+EJT+IHX

(d) SS+Eco/PC+IHX

(e) TS+FT+IHX

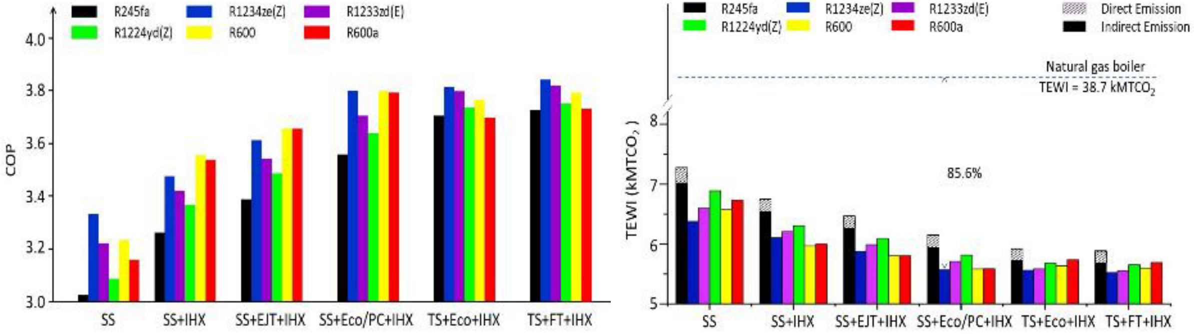
(f) TS+Eco+IHX

System Configuration Analysis

Waste heat: 32°C → 27°C, 2–14 MW

Supply heat: 75°C → 85°C for space and water heating

Maximum COP = 3.78 ± 0.04

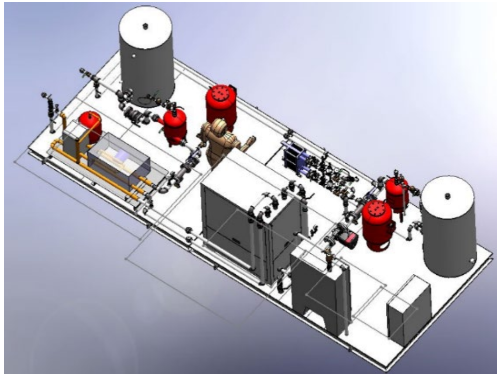


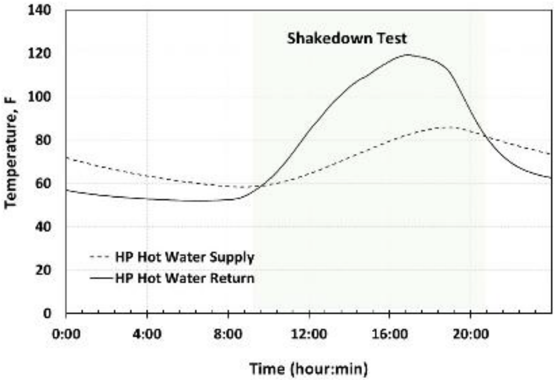
Performance of HTHPs with various configurations and low-GWP WFs: (a) COP and (b) TEWI.

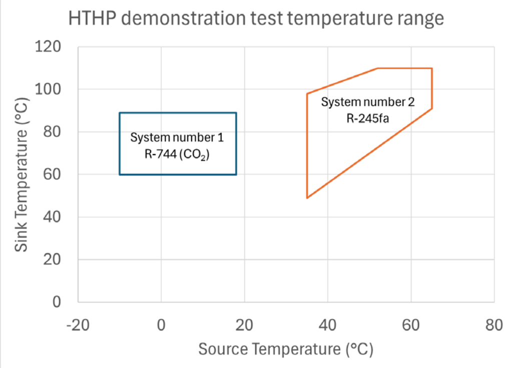
In this analysis of replacing boilers at the ORNL campus with HTHPs that use the supercomputer waste heat as a heat source, a 1 MW HTHP reduces the total equivalent warming impact (TEWI) by 33,000 MMT CO_2 (85.6%).

Demonstration Test Facility

- The facility is complete and ready to demonstrate the operation of commercial-scale heat pumps.
- The source and sink are demonstrated through controlled heater and chiller networks.
- The first demonstration 58 kW system uses CO_2 as a refrigerant.
- The second system to be demonstrated with the facility will have 41 kW capacity and use R-245fa.

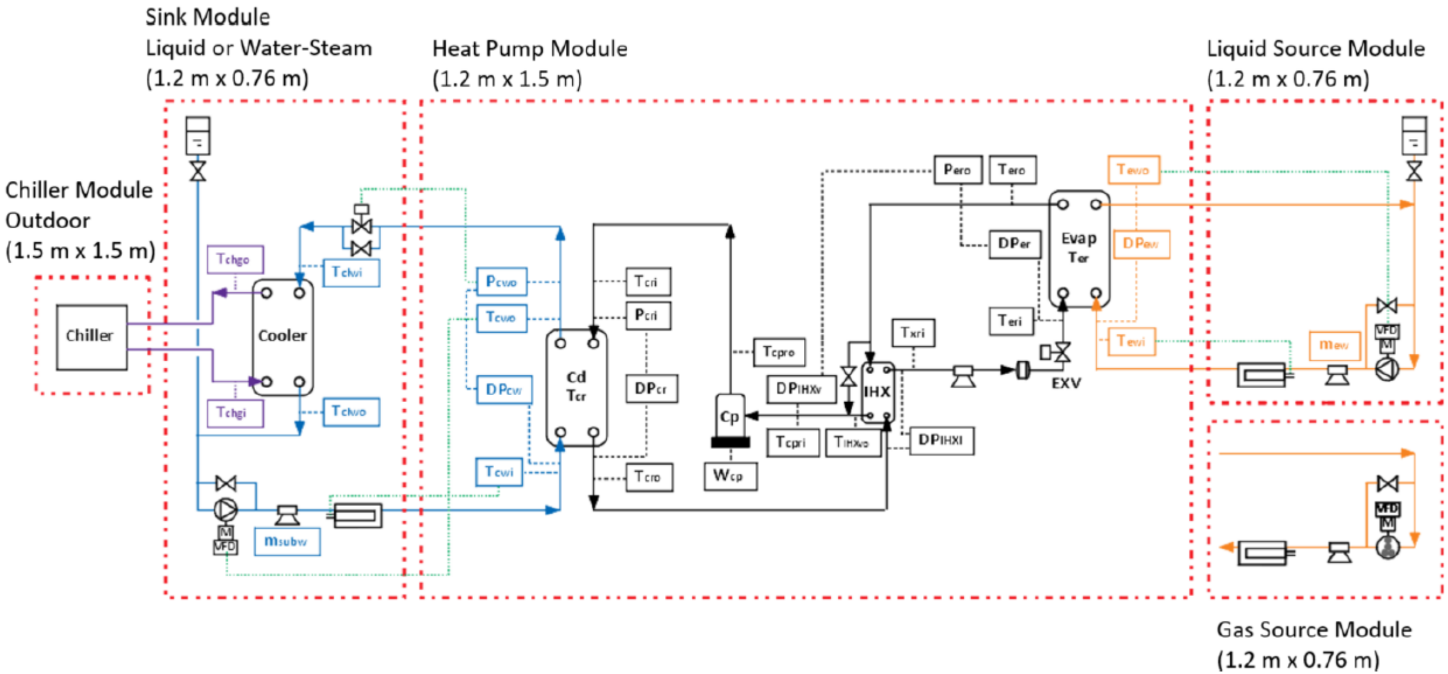




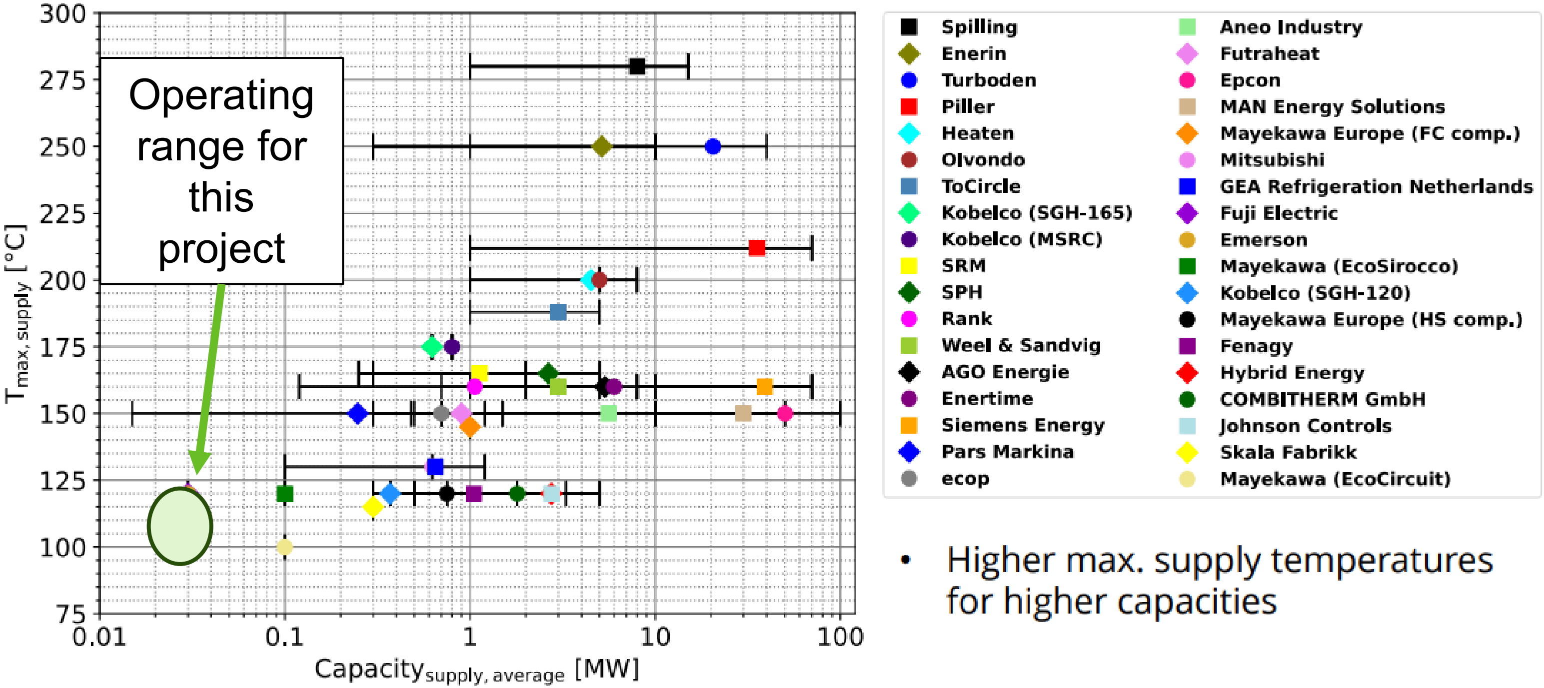


Research Test Facility

- The ORNL HTHP research test bed can accommodate 30–100 kW capacity with a range of gas and liquid sink temperatures



Market Review and Assessment



Operating range for this project

- Higher max. supply temperatures for higher capacities

Benjamin Zühlsdorf, IEA HPT Annex 58 High Temperature Heat Pumps Final Webinar, 23 April 2024.

Partner Engagement

- We are working on the approval for a CRADA with an HVAC OEM and a compressor supplier to develop a product with these characteristics:
  - Heat sink temperature goal = 180° F (stretch goal heat sink temperature = 230° F)
  - Minimum heat source temperature goal = 0° F (stretch goal heat source temperature = −15° F)
  - Heating capacity ≥50 kW (170,600 Btu/h)
  - Target application = replacement of a combustion boiler in multifamily housing
  - COP ≥2
- The prototype will be tested at ORNL, and test results over a range of conditions will feed a life cycle cost analysis to demonstrate the viability of this technology in the application

Thank you

Oak Ridge National Laboratory

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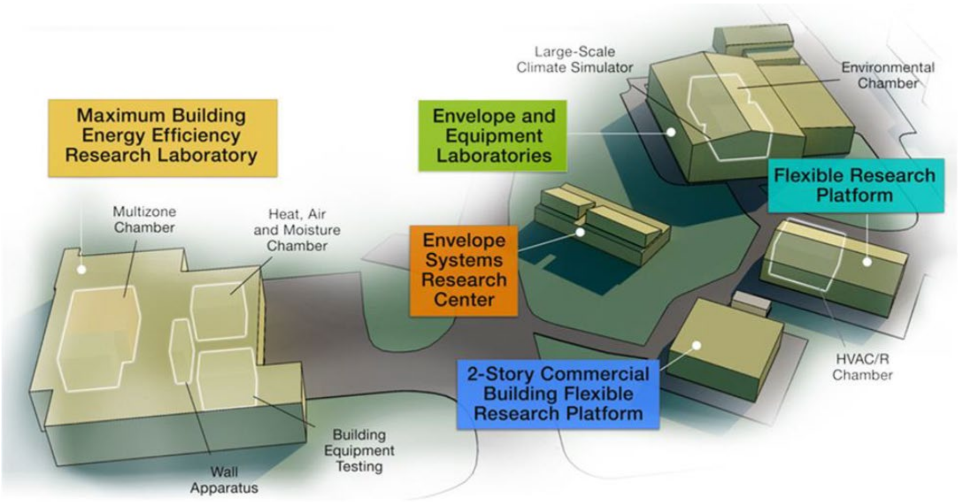


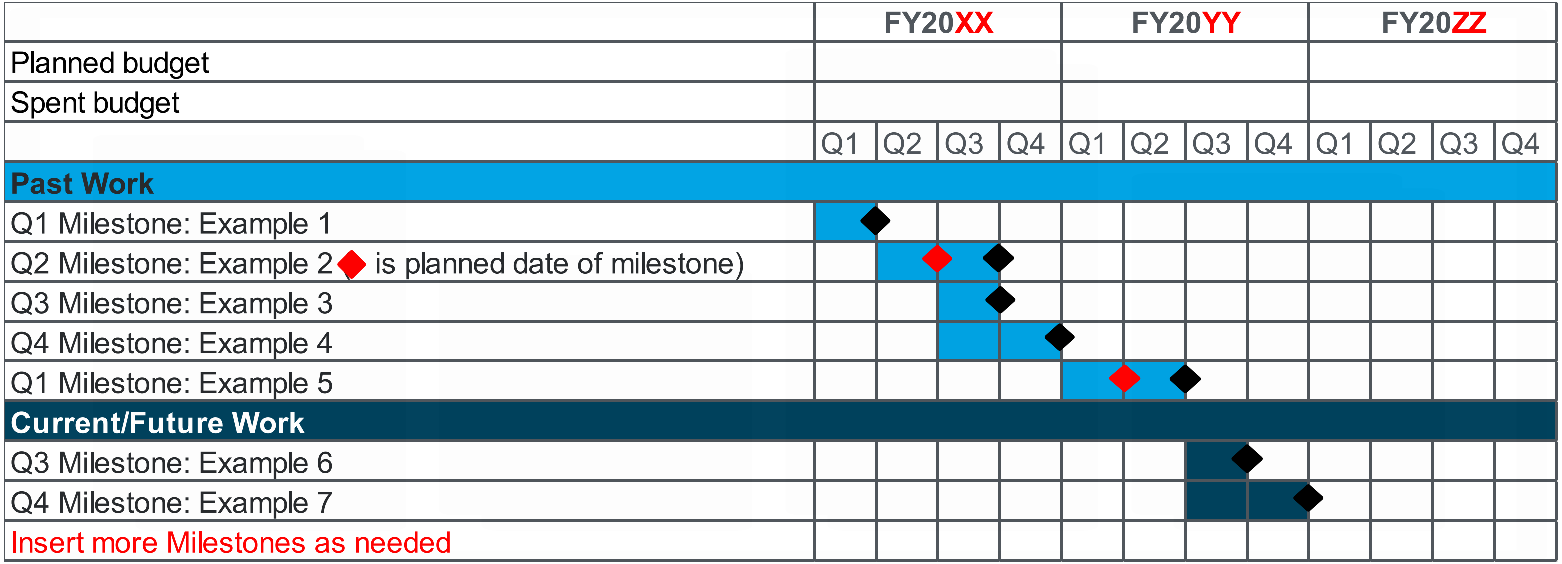
The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

Project Execution



	FY20XX				FY20YY				FY20ZZ			
Planned budget												
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Example 1	🟦◆											
Q2 Milestone: Example 2 ♦ is planned date of milestone)		🟦♦	🟦◆									
Q3 Milestone: Example 3			🟦◆									
Q4 Milestone: Example 4			🟦	🟦◆								
Q1 Milestone: Example 5					🟦♦	🟦◆						
Current/Future Work												
Q3 Milestone: Example 6							🟦◆					
Q4 Milestone: Example 7							🟦	🟦◆				
Insert more Milestones as needed												

- Go/no-go decision points
- Explanation for slipped milestones and slips in schedule

Team

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