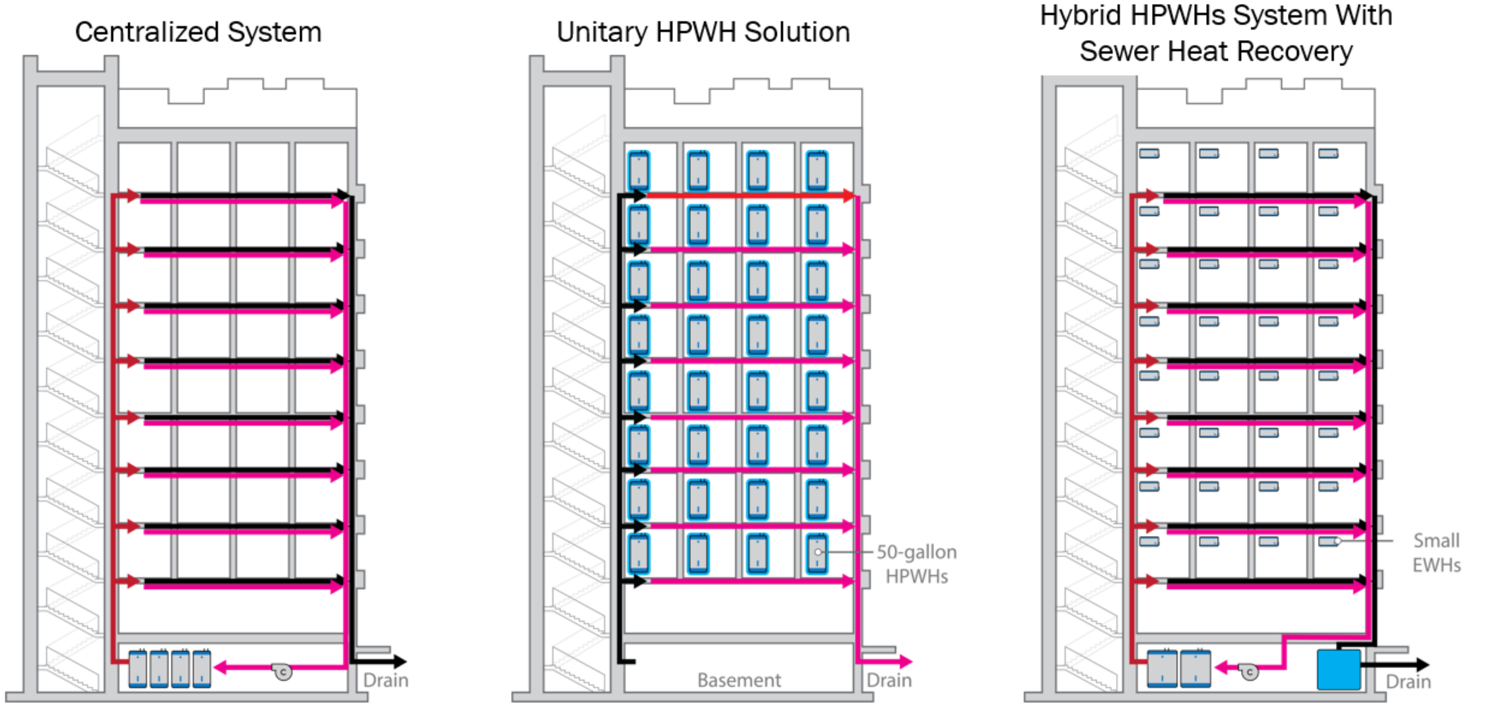
Cost Compression of Heat Pump Water Heaters for Multifamily Housing in Cold Climates (CC HPWH MH CC)



Oak Ridge National Lab
Kashif Nawaz (Senior R&D Staff)
(865) 241-0972 nawazk@ornl.gov
Joseph Rendall (Associate R&D Staff)
(865) 341-0422 rendalljd@ornl.gov

WBS 03.02.02.60, FY 22 ET Lab Call

Oak Ridge National Laboratory | Argonne National Laboratory | A.O. Smith – Innovation has a name | Gary Klein and Associates, Inc. "Where water and energy connect"

Project Summary

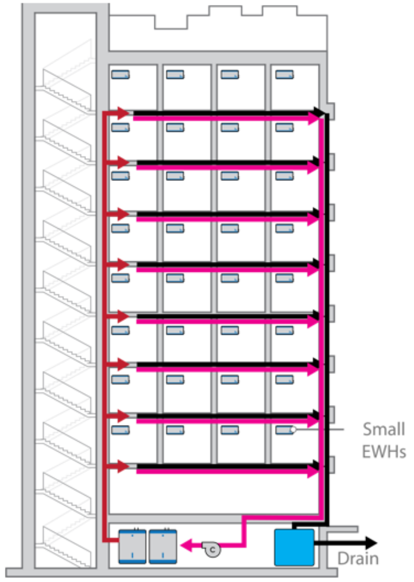
Objective and outcome

Design and pilot-demonstration of an equitable HPWH solution for low-income multifamily housing in cold climates to:

- achieve 30% cost reduction, with
- 25% available hot water increase
- up to 1,000 times reduction in EOL CO_2 compared state-of-the-art HPWHs using R134a.

New Project

Hybrid HPWHs System With Sewer Heat Recovery



Team and Partners

Oak Ridge National Laboratory

Argonne National Laboratory

A.O. Smith – Innovation has a name

Gary Klein and Associates, Inc. "Where water and energy connect"

Stats

Performance Period: 01/2023 – 01/2026

DOE budget: $2,400k Cost Share: Confidential

Milestone 1 (Y23): Cost effective system design for low-income multifamily units modeled

Milestone 2 (Y24): Experimentally validate design for low-income multifamily units

Milestone 3 (Y25): Demonstrate design in pilot study

Problem Statement

Current technologies for energy-efficient water heating in multifamily housing in cold climates have challenges:

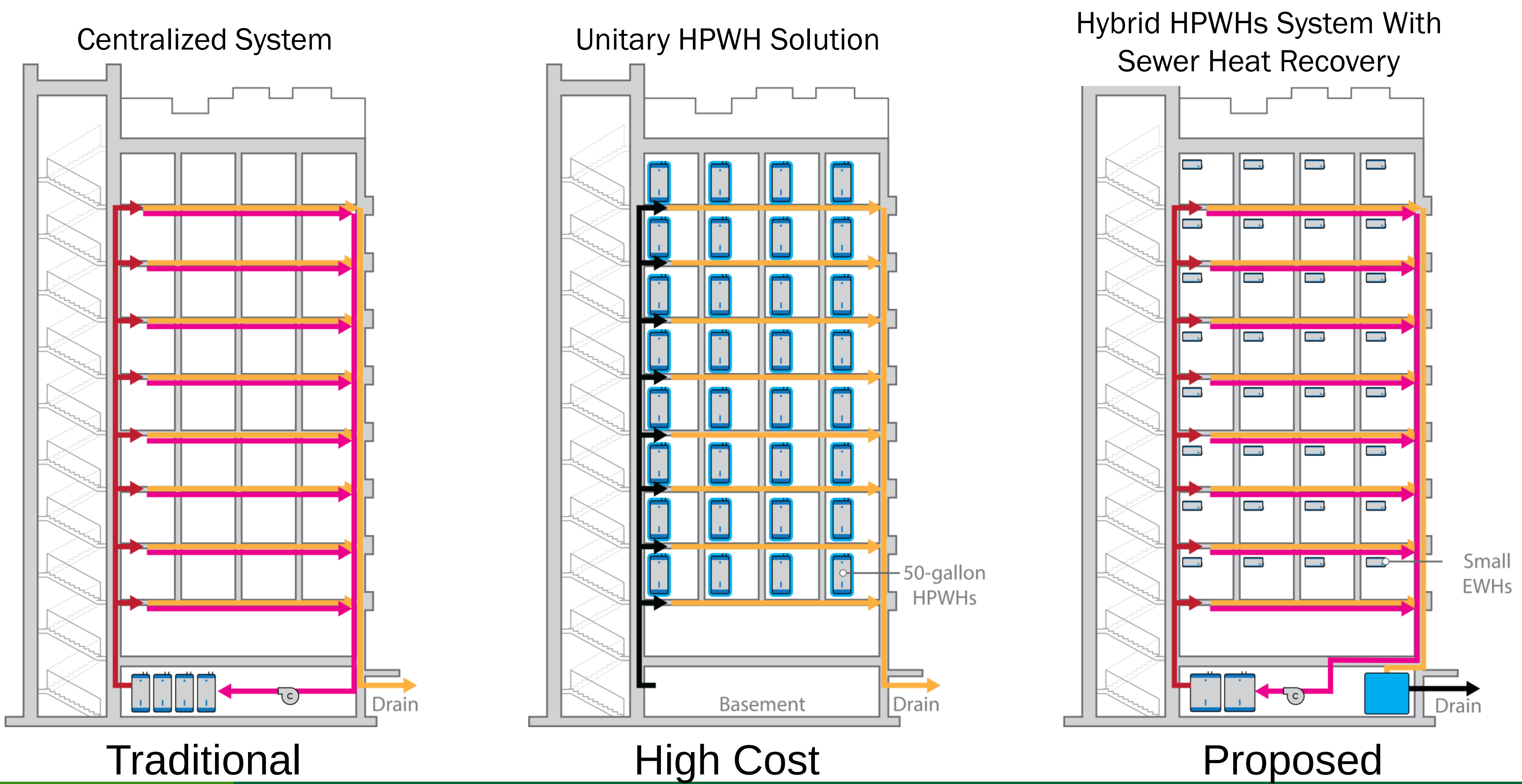
- High Initial cost: Unitary Air Source-HPWH premium costs over unitary electric resistance water heater (ERWH) is $1,300
- Space restriction: Venting a water heater closet in an existing multifamily unit to prevent the AS-HPWH additional space heating load is costly
- Lower Energy Performance: When vented with ambient, COP of Air Source-HPWH reduces to < 2 at colder air temperatures

Proposed Solution

Water Source-HPWH Hybrid Centralized & Distributed with Drain Water Heat Recovery

- Total cost reductions
- Total space requirements smaller
- Higher performance and lower life cycle costs

Approach: System Integration



Alignment and Impact: Project Goals

Project Goals:
- 30% cost reduction (product, installation, and user costs)
- WS-HPWH COP > 5
- 25% available hot water increase
- 1,000 times reduction in end-of-life CO_2 emissions reduction compared to Refrigerant-134a

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

DOE BTO Goals

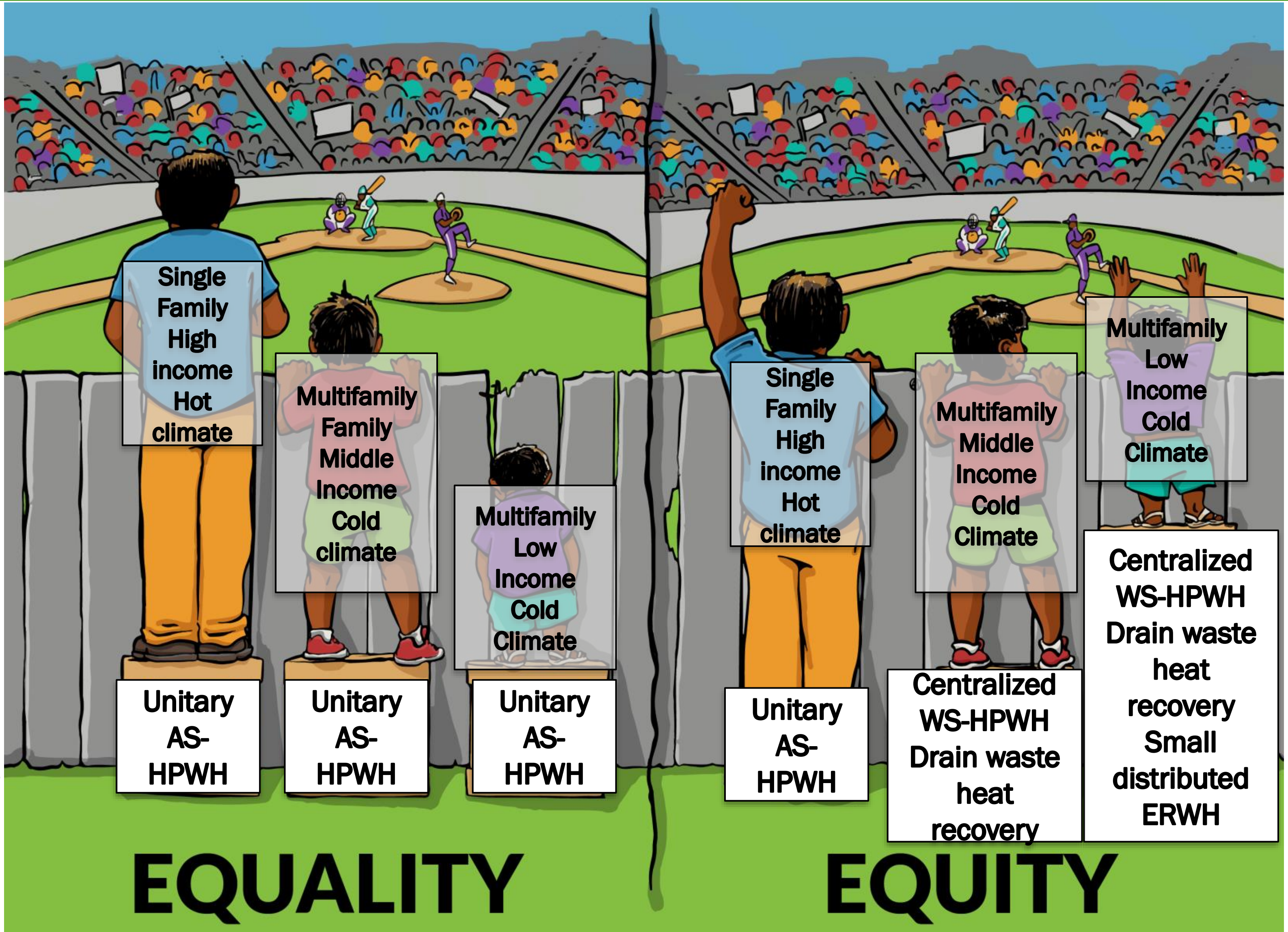
Alignment and Impact: Energy Justice

Energy justice

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

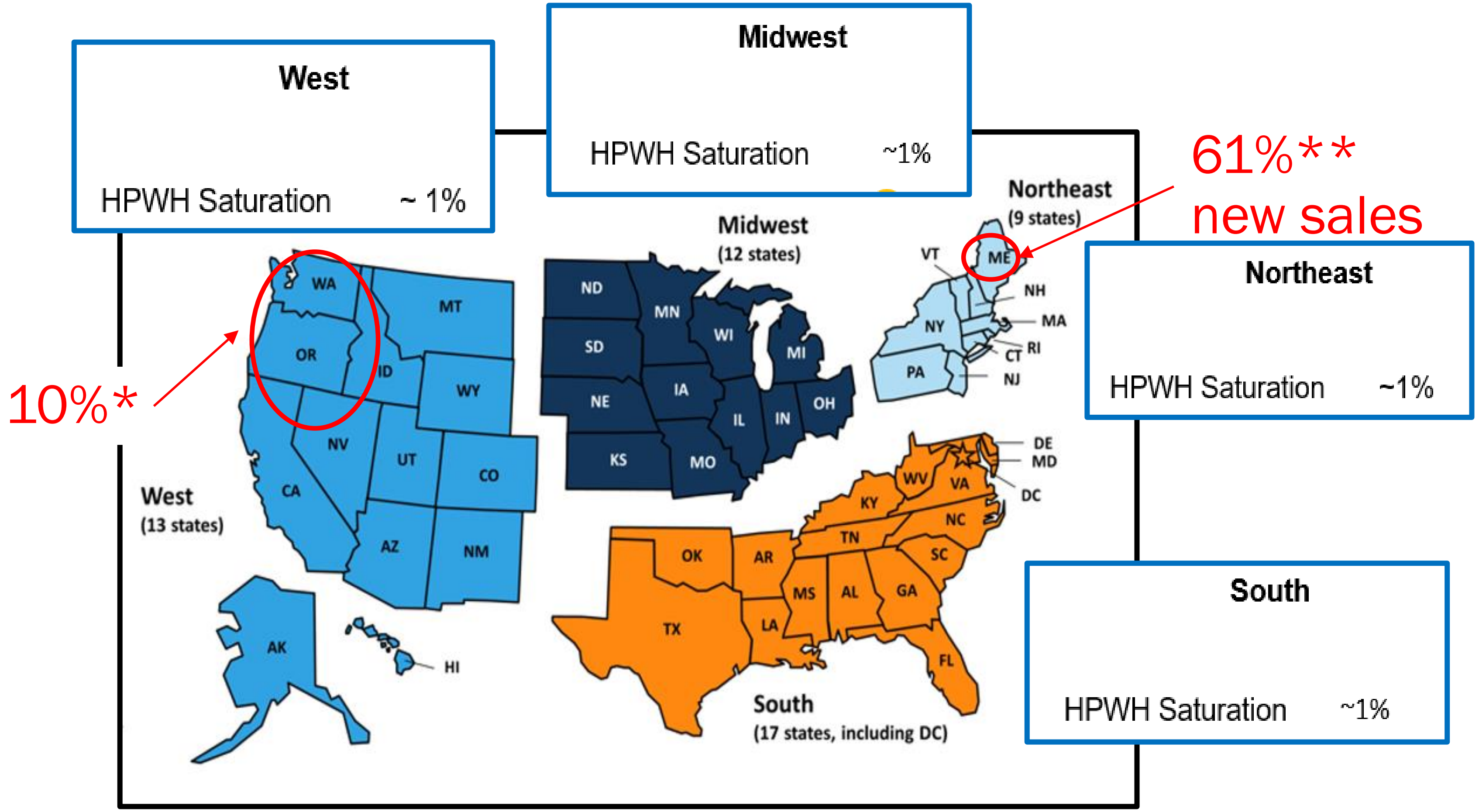
Equity

- **Family sets small ERWH to desired temperature**
- **Reduction of energy burden on disadvantaged households in cold climates**
- **All residences are guaranteed hot water**
  - 10%+ redundancy addition to centralized systems



Adapted Graphic (Interaction Institute for Social Change | Artist: Angus Maguire)

Background: National Market AS-HPWH water heating



Guidehouse Survey 2019

The combined high installation cost and first price of heat pump water heaters (HPWH) is the major reason the market share of HPWHs is only ~1% in the US

*Geoff Wickes
** Andy Meyer

Background: Multifamily Household Characteristics

Multifamily households: 18% of US households live in 5+ unit multifamily housing.

- **Low-income population**: Over 43% of households in multifamily buildings belong to low-income group, compared with 30% across all housing types.

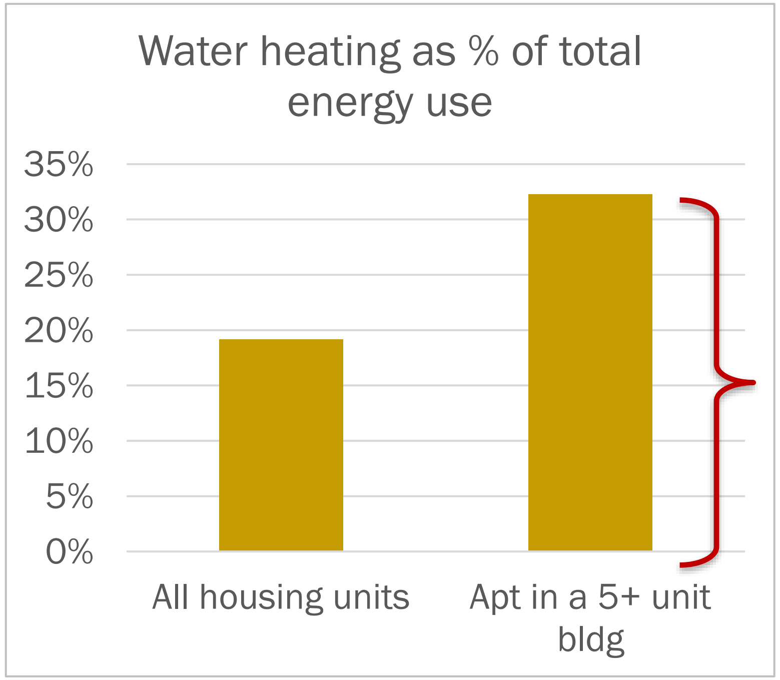
  - **Energy burden:**

    - The median energy burden of low-income multifamily households is 5.4%, which is 2.3 times higher than that of other multifamily households.

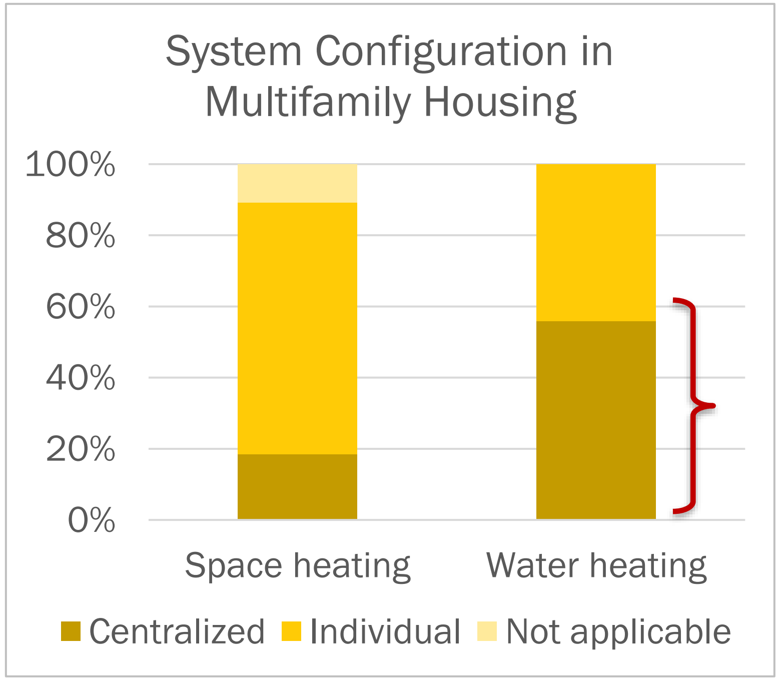
    - 25% of low-income multifamily households are severely burdened, spending more than 10% of their income on energy costs.

Source:
2019 American Housing Survey
A. Drehobl, L. Ross, and R. Ayala, "How high are household energy burdens?," Washington, DC, 2006.

Background: Multifamily Market



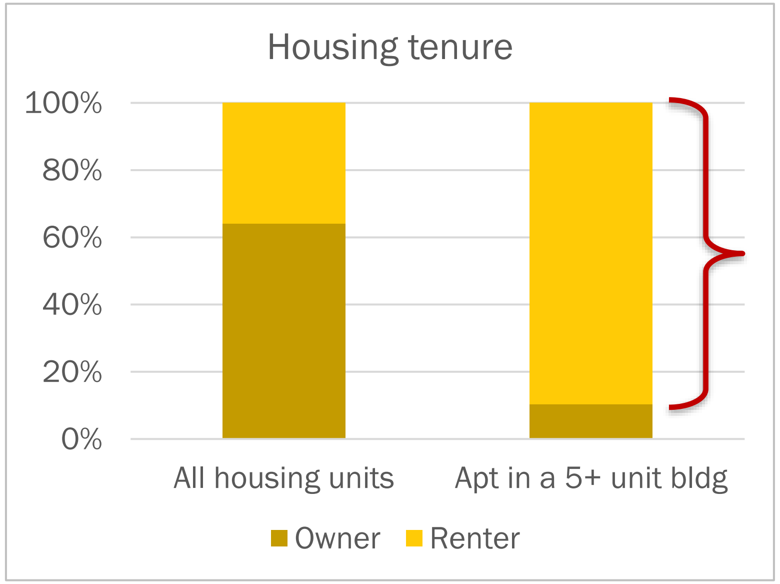
Water heating in multifamily buildings contributes to **32.3% of total energy use**, compared with 19.2% of energy use across all housing types



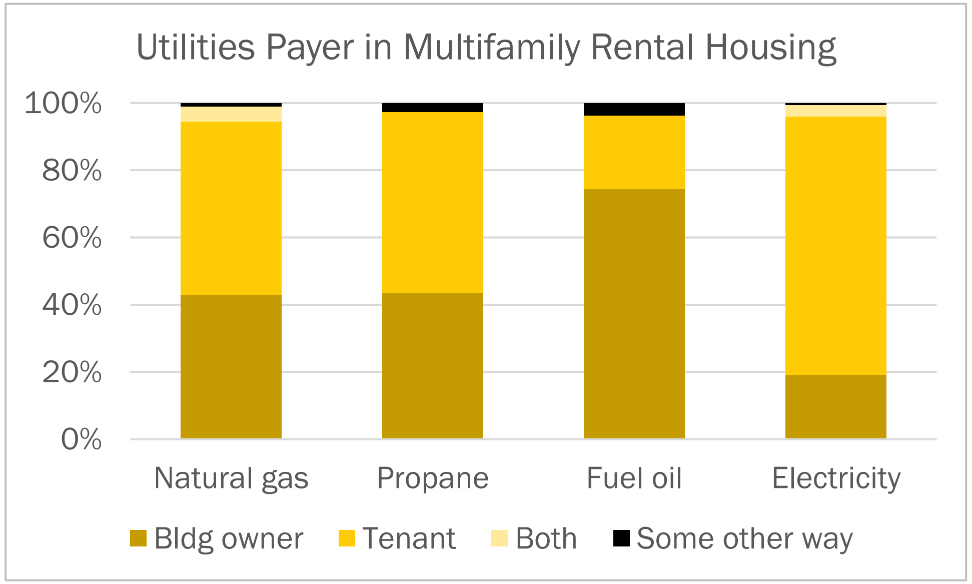
About 56% of multifamily households are served by central water heating systems.

Source: 2015 Residential Energy Consumption Survey (RECS)

Background: Multifamily Market (cont.)



About 90% of multifamily households are **renters**, compared with 36% across all housing types



In a significant portion of multifamily rental housing utilities are paid by building owner

This offers incentives to the building owners to adopt a centralized scheme with HPWHs, as the payback of HPWH is much shorter (~3-4 years) than its life.

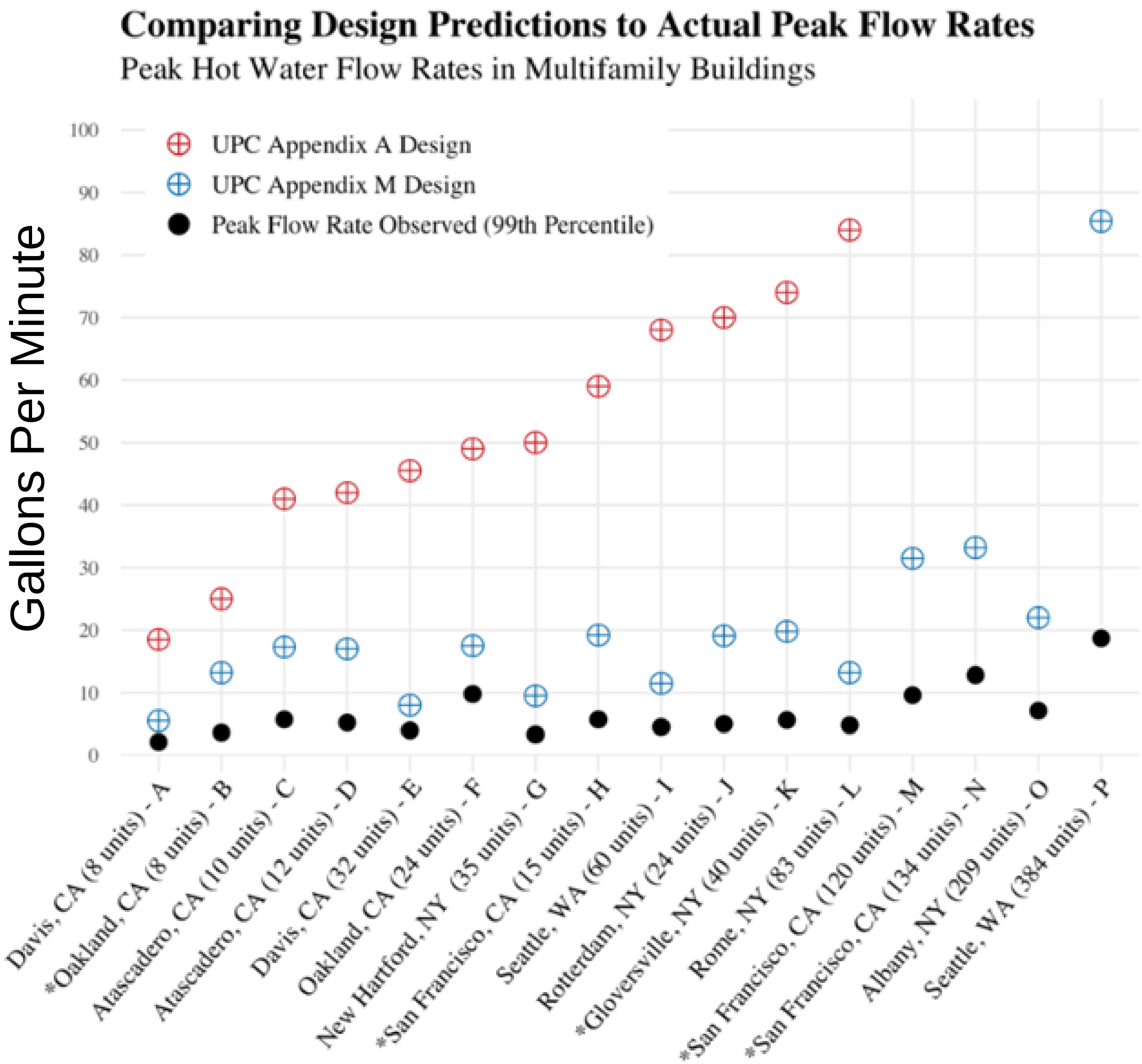
Source: 2019 American Housing Survey; 2015 Residential Energy Consumption Survey; EnergyStar.gov

Approach: HPWH improvements

The project team will realize following improvements in HPWH deployments

- Costs
  - Systems approach taken to analyze initial, installed and <u>life cycle costs</u>
- Footprint
  - Centralized allows for few square feet of water storage
  - Inexpensive low GWP refrigerants can be used in a properly configured utility room
- <u>Efficiency</u>
  - WS-HPWH will have higher COP than AS-HPWH
    - heat source is warmer
    - less resistance to heat transfer in evaporator (liquid/liquid) instead of (liquid/air)
  - Splitting the evaporator away from the tank reduces heat leaks from the tank to the evaporator in unitary systems
  - SWHR allows for upgrading of waste heat lost in the drain to hot water temperatures
    - Better than preheating water when a moderate storage tank is used to collect more energy
  - Utility room installation allows for tight control of heat source

Approach: Plumbing Cost

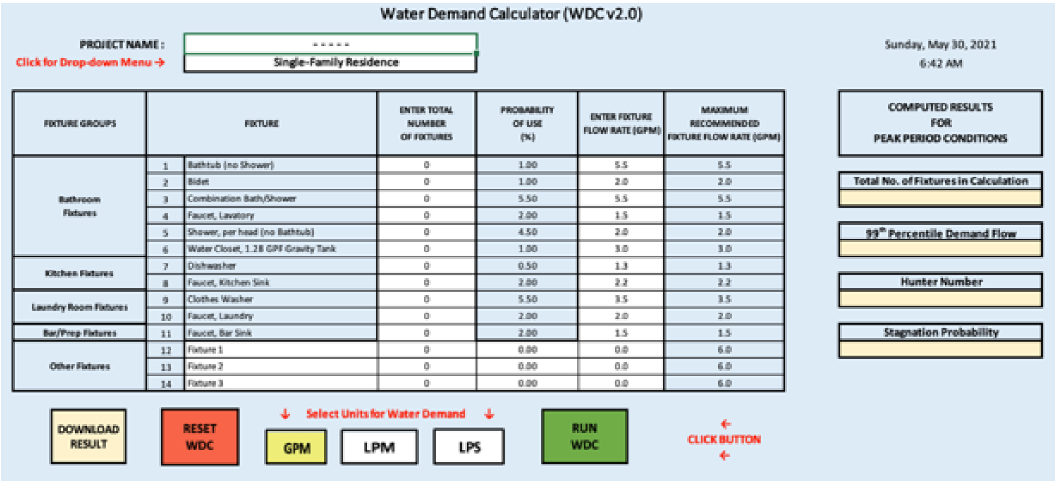


“The rules for sizing hot and cold-water distribution piping in buildings were published in the early 1940s and became part of the plumbing code”

Hot water systems are oversized for today’s fixtures!

Gary Klein

Gary Klein and Associates, Inc.
“Where water and energy connect”



Water Demand Calculator (WDC v2.0)

PROJECT NAME : - - - - -
Click for Drop-down Menu → Single-Family Residence

Sunday, May 30, 2021
6:42 AM

FIXTURE GROUPS		FIXTURE	ENTER TOTAL NUMBER OF FIXTURES	PROBABILITY OF USE (%)	ENTER FIXTURE FLOW RATE (GPM)	MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
Bathroom Fixtures	1	Bathtub (no Shower)	0	1.00	5.5	5.5
	2	Bidet	0	1.00	2.0	2.0
	3	Combination Bath/Shower	0	5.50	5.5	5.5
	4	Faucet, Lavatory	0	2.00	1.5	1.5
	5	Shower, per head (no Bathtub)	0	4.50	2.0	2.0
	6	Water Closet, 1.28 GPF Gravity Tank	0	1.00	3.0	3.0
Kitchen Fixtures	7	Dishwasher	0	0.50	1.3	1.3
	8	Faucet, Kitchen Sink	0	2.00	2.2	2.2
Laundry Room Fixtures	9	Clothes Washer	0	5.50	3.5	3.5
	10	Faucet, Laundry	0	2.00	2.0	2.0
Bar/Prep Fixtures	11	Faucet, Bar Sink	0	2.00	1.5	1.5
Other Fixtures	12	Fixture 1	0	0.00	0.0	6.0
	13	Fixture 2	0	0.00	0.0	6.0
	14	Fixture 3	0	0.00	0.0	6.0

COMPUTED RESULTS FOR PEAK PERIOD CONDITIONS

Total No. of Fixtures in Calculation

99th Percentile Demand Flow

Hunter Number

Stagnation Probability

DOWNLOAD RESULT | RESET WDC | Select Units for Water Demand: GPM | LPM | LPS | RUN WDC | CLICK BUTTON

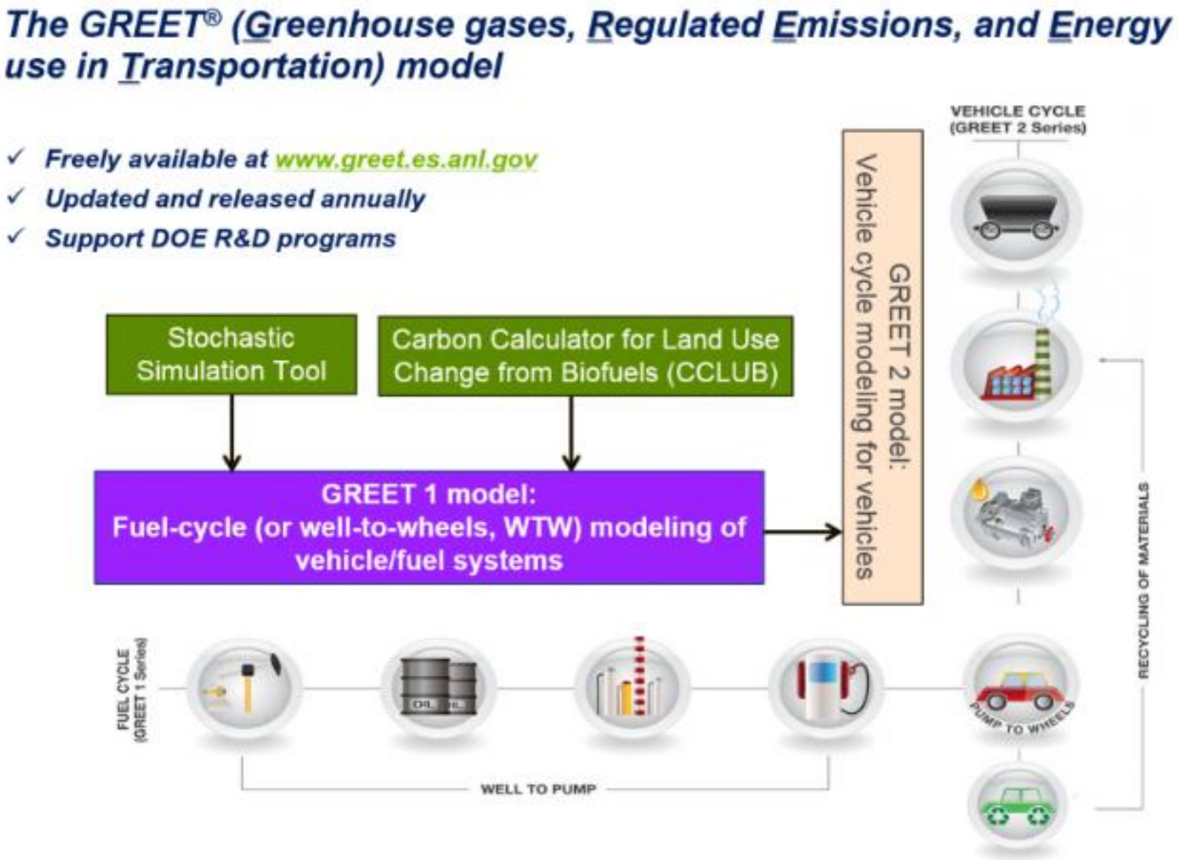
https://www.iapmo.org/water-demand-calculator/

Approach: Component, system lifecycle and heat exchanger design

William Worek

Argonne NATIONAL LABORATORY

- Investigating adapting the Argonne **GREET Model** to evaluate the energy and emissions impact of different Heat Pump Water Heater configurations to an Advanced Building Construction tool.



- Review and design methods to reclaim energy for preheating from wastewater using low-fouling heat exchanger devices.
- RSMeans Guides 2022, an industry standard, are being utilized to determine a “first cut” Heat Pump Water Heater component and installation costs.

Approach: Risk Mitigation

Year 1: Modeling

- G/NG: At least 1 system identified with 30% cost savings
- Technical risks: high item costs due to supply chain issues
  - Mitigation: estimate costs at high product volume

Year 2: Scaled experimentation

- G/NG: At least 1 system experimental performance projects 30% cost savings
- Technical risks: expensive heat exchangers
  - Mitigation: analyze lower cost, lower performance heat exchangers

Year 3: Field deployment pilot

- Technical risks: low space availability for technology
  - Mitigation: consider compact heat exchangers or partial supply heat from air

Progress: Systems to be Analyzed in Detail

Construction types
- New build
- Retrofit

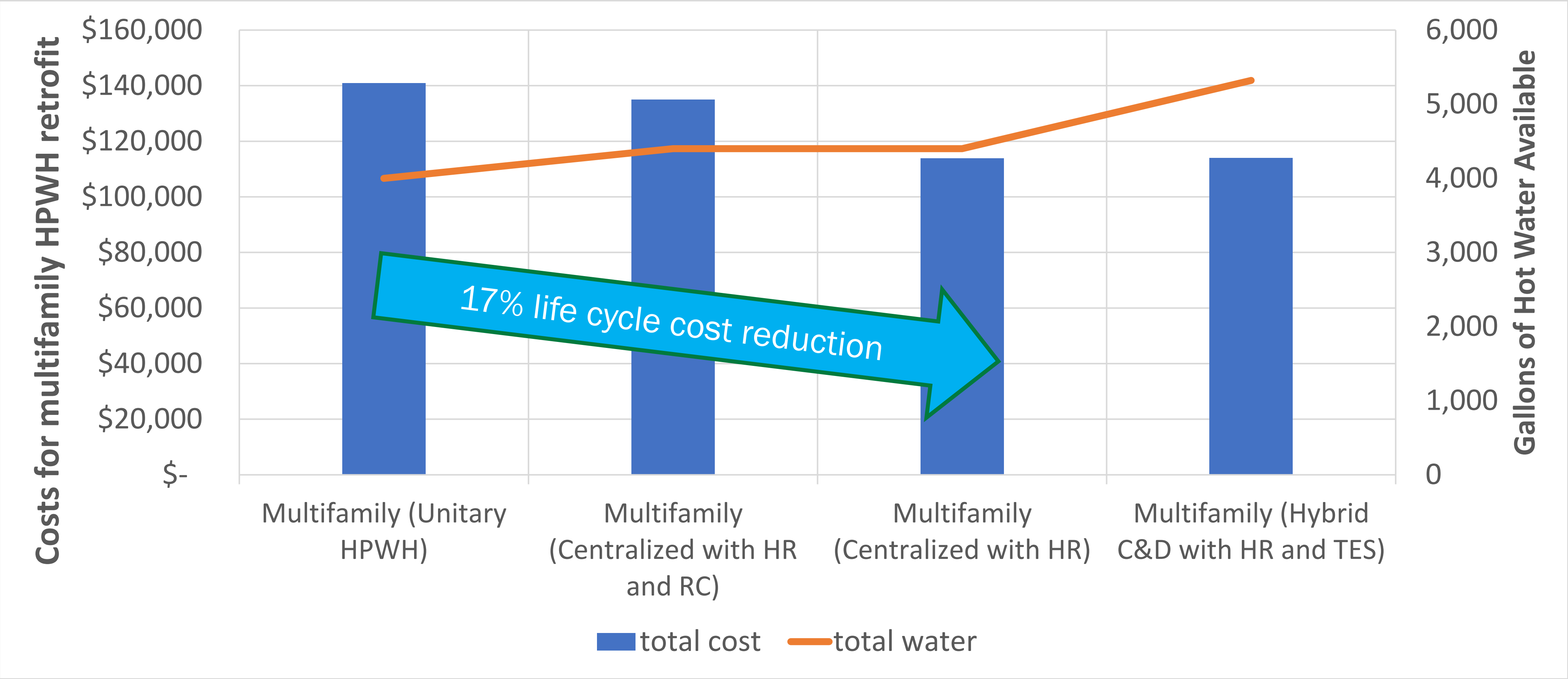
Multifamily Configurations
- Unitary
- Centralized
- Hybrid (C&D)

Water Heating Options
- Gas (GWH)
- Electric Resistance (ERWH)
- Heat Pump (HPWH)
- Heat Recovery (HR)
- Thermal energy storage (TES)

Multifamily Water Heating Solution	Costs Initial	Performance Cold Climate	Emission	**Costs Lifecycle**
Unitary ERWH	Low	Medium	High	**High**
Unitary GWH	Medium	Low	High	**Medium**
Unitary AS-HPWH	High	Medium	Low	**Medium**
Centralized AS-HPWH	Medium	Medium	Low	**Medium**
Hybrid C&D WS-HPWH	*Medium*	*Medium*	*Low*	***Medium***
Hybrid C&D WS-HPWH with HR	*Medium*	*High*	*Low*	***Low***
Hybrid C&D WS-HPWH with HR and TES	*Medium*	*High*	*Low*	***Low***

Retrofit of centralized systems to hybrid centralized systems is the most cost effective and robust solution.

Progress: Initial analysis (Retrofit of centralized systems)



Major assumptions lead to conservative initial analysis

1) same COP across technologies → conservative up to 250%
2) replacing BTU for BTU between systems → conservative up to 300%
3) larger HPWH 75% cost per BTU than smaller unitary → component cost driven

Thank you

Oak Ridge National Lab
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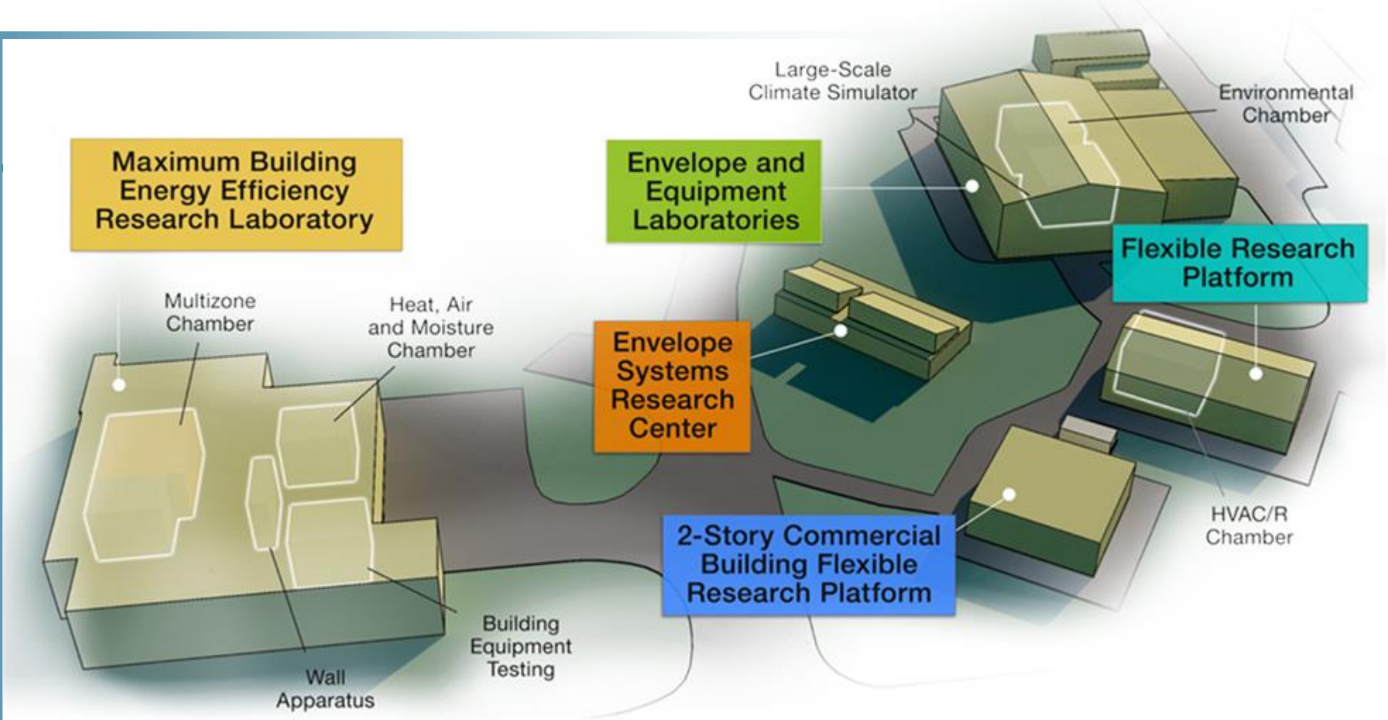


ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

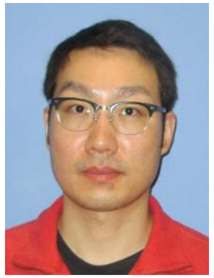
	2023				2024				2025				
Planned Budget	$800K				$800K				$800K				
Spent Budget	$40K												
Milestone Descriptions	M1-3	M4-6	M7-9	M10-12	M1-3	M4-6	M7-9	M10-12	M1-3	M4-6	M7-9	M10-12	
Year 1													
Milestone 1: All components modeled		MS1											
Milestone 2: All systems modeled				MS2									
Milestone 3: Models interact in co-simulation environment			MS3										
Milestone 4: All costs (capital, installed, user) identified in Re-Review				MS4									
Milestone 5: Selection of multifamily configuration with technologies					MS5								
Year 2													
Milestone 1: Components identified and ordered					MS6								
Milestone 2: Test bench commissioned							MS7						
Milestone 3: Manuscripts prepared on test bench and results of system test								MS8					
Milestone 4: System tested									MS9				
Milestone 5: Selection of multifamily configuration with technologies									MS10				
Year 3													
Milestone 1: Pilot facilities identified and onboarded										MS11			
Milestone 2: System installed and commissioned in facility										MS12			
Milestone 3: Data compiled and reduced for 6 months of operation												MS13	
Milestone 4: Performance of system calculated												MS14	
Milestone 5: Final report manuscript prepared													MS15

Go/no-go decision points (MS5 and MS10)

Team

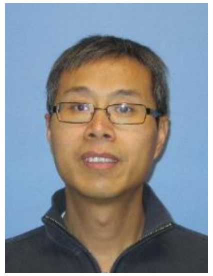
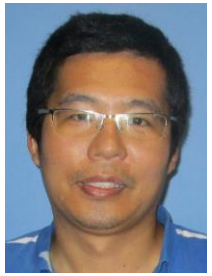
Kashif Nawaz

Principal Investigator

Mini Malhotra Keju An

System cost analysis & Equity champions


Jian Sun Yangfei Li Ahmed Elatar

Modeling and controls


Joe Rendall Jamieson Brechtl

System design and experimentation

William Worek

Argonne NATIONAL LABORATORY

System design
Component cost analysis
Heat recovery



Steve Memory Tim Rooney Jiamin Yin

AO Smith. Innovation has a name

HPWH design

Gary Klein

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System design
Piping optimization

Finnian Casey

U.S. DEPARTMENT OF ENERGY Office of Science

2023 Science Undergraduate Laboratory Intern