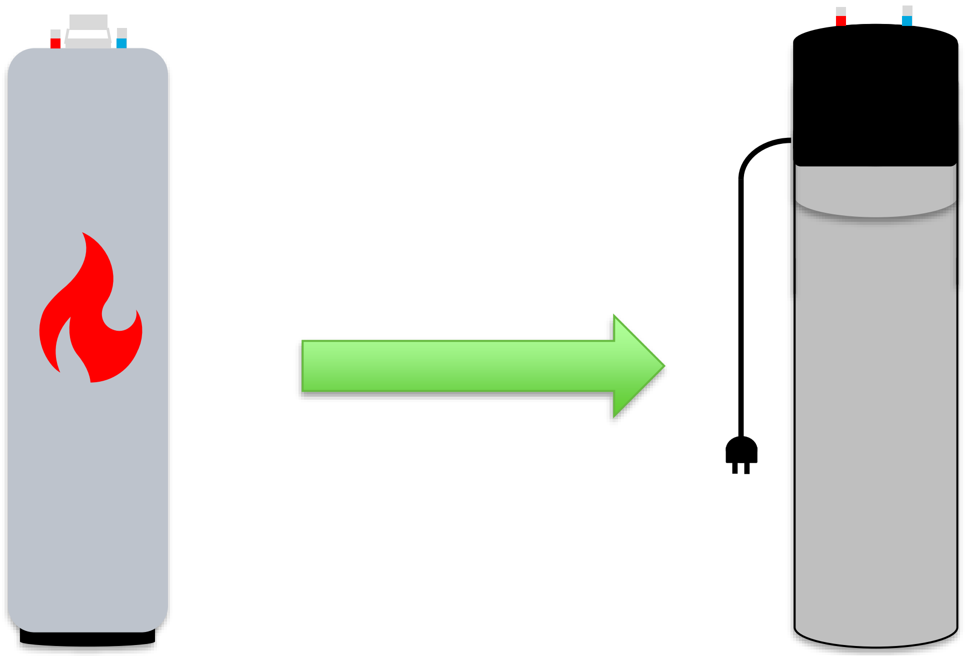
120 V Heat Pump Water Heater Replacement Solution for 30–40-gallon Gas Water Heaters



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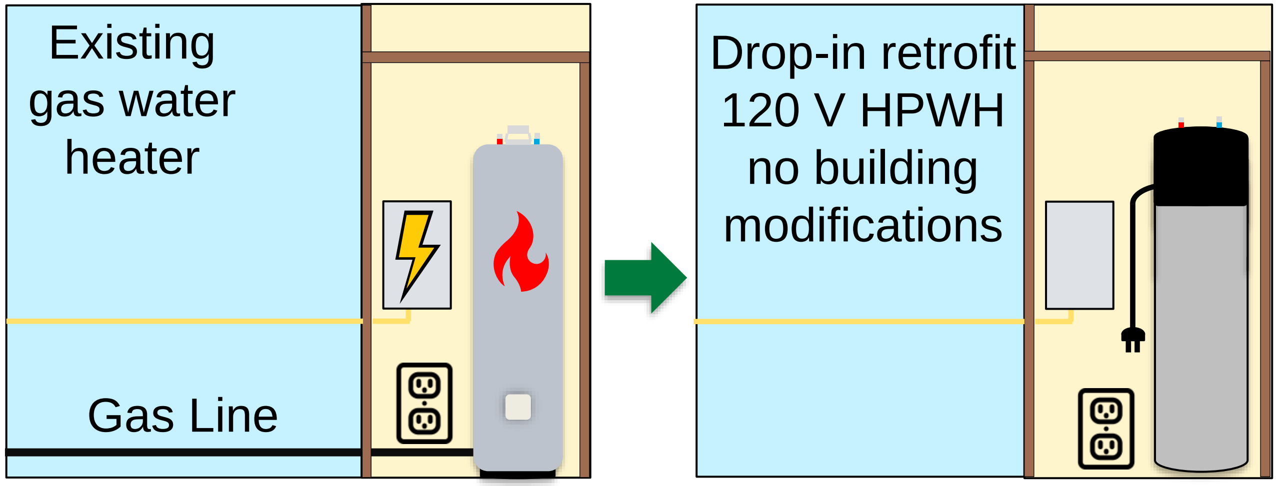
Project Summary – New Project! (Feb. 2023)

Objective

- Develop and evaluate in the laboratory a 120 V-powered electric heat pump water heater (HPWH) as direct replacement for 30-40 gallon tall and slim gas water heaters (<20 inch diameter)
- Maximize FHR within the form factor constraint

Outcome

- Development of a prototype 120 V HPWH diameter 20” and height of 60” with minimum FHR = 65 gal. and UEF ≥ 2.20



Team

- ORNL

Kyle Gluesenkamp (PI)
Bo Shen
Melanie Moses-DeBusk
Ahmed Elatar
Sylas Rehbein
Ed Vineyard
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Stats

Performance Period: FY23-FY24

DOE budget: $450k/yr

Milestone 1: Identify 120V HPWH Consumer Issues (FY23)

Milestone 2: Baseline product characterized (FY23)

Milestone 3: 1st Prototype Design and Assembly (FY23)

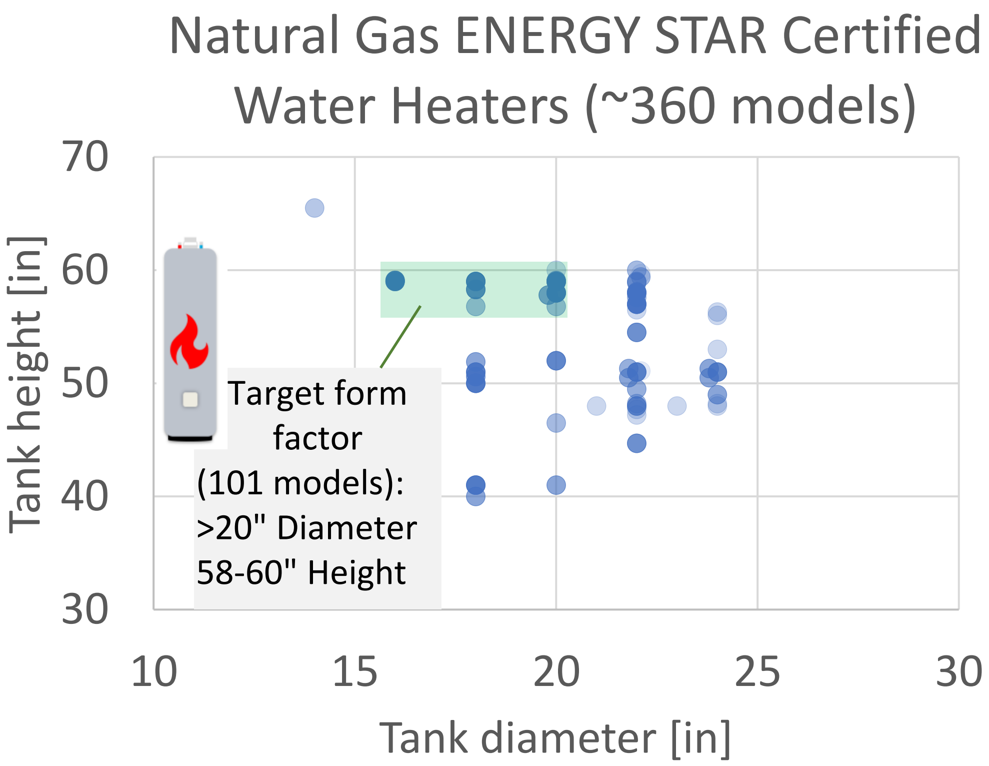
Milestone 4: 1st Prototype Performance Evaluation (FY24)

Milestone 5: 2nd Gen. Prototype Fabrication (FY24)

Milestone 6: 2nd Gen. Performance Evaluation (FY24)

Problem – Decarbonizing the Market

- *60 million[1] US homes have gas-fired water heaters*
  - *93% of water heaters in California alone are gas*
- *Many do not have electrical panels ready to power conventional (240 V) electric water heaters*
- *A common **form factor** is the "tall and slim" (~60" tall and 20" diameter) gas-fired water heater*
- *These have large burners to achieve high water delivery capacity*



[1] U.S. Energy Information Administration, Office of Energy Demand and Integrated Statistics, Form EIA-457A of the 2020 Residential Energy Consumption Survey

Problem – Engineering and Design

Challenges replacing a tall and slim gas unit:

- *New product must meet customer hot water needs*
- *Small electrical power replaces large gas power*
  - *Powered from one dedicated 120 V circuit*
  - *1.44 kW_{elect} vs. 14.6 $kW_{thermal}$*

Water heater type	Power source	Power available	
Tall & slim gas-fired	Gas burner	36 – 50 $kBtu_{thermal}$/hr	10.6 – 14.6 $kW_{thermal}$
120 V HPWH dedicated circuit	120 V x 12 A (80% of 15 A breaker)	4.9 $kBtu_{elec}$/hr	1.44 kW_{elec}

- *Installations are often in tight quarters (e.g., closet). The replacement unit's external dimensions must fit.*

Problem – Cost of Electrifying Tall & Slim Water Heaters

		Baseline 240 V Elec. Resistance	Baseline 240 V HPWH Hybrid	Commercialized 120 V Dedicated Circuit (<12 A)	Commercialized 120 V Shared Circuit (<7.5 A)	**ORNL 120 V Prototype**
Product price (list price)		$0.5k	$1k – 2k	$1.9k – 3.1k[7]		TBD
Installation cost	Electrical Panel upgrade[3]	$0 – 3k	$0 – 3k	$0	$0	$0
	Carpentry modifications to the space to fit larger product[4]	$0 – 3k	$0 – 3k	$0 – 3k	$0 – 3k	$0
	Service Line to House[5]	$0 – 2.5k	$0 – 2.5k	$0	$0	$0
	Water Heater General Installation Costs[6]	$0 – 1.4k	$0 – 1.4k	$0 – 1.4k	$0 – 1.4k	$0 – 1.4k
Total installed cost		$0.5k – 10.4k	$1.7k – 11.9k	$1.9k – 7.5k	$1.9k – 7.5k	***Lowest in most cases***

[3] https://www.thisoldhouse.com/electrical/reviews/cost-to-upgrade-electrical-panel

[4] https://www.homeadvisor.com/cost/additions-and-remodels/mudroom/

[5] https://homeguide.com/costs/cost-to-run-power

[6] DOE BTP Res Htg Prod Final Rule Analytical Tool

[7] depending on options https://www.canarymedia.com/articles/heat-pumps/finally-a-heat-pump-water-heater-that-plugs-into-a-standard-outlet

Alignment – Accelerate Electrification through Cost Reduction

Accelerate Electrification

- *Directly accelerates electrification of US residential sector*

Increase Building Energy Efficiency and Decarbonize Power Systems

- *Developing a HPWH specifically to replace gas-fired water heaters enables decarbonization*

Diversity, Equity, and Inclusion

- *Eliminates high costs from panel upgrades*
- *Reduces professional installation costs*
- *Increases access to state-of-the-art technology for lower income households*

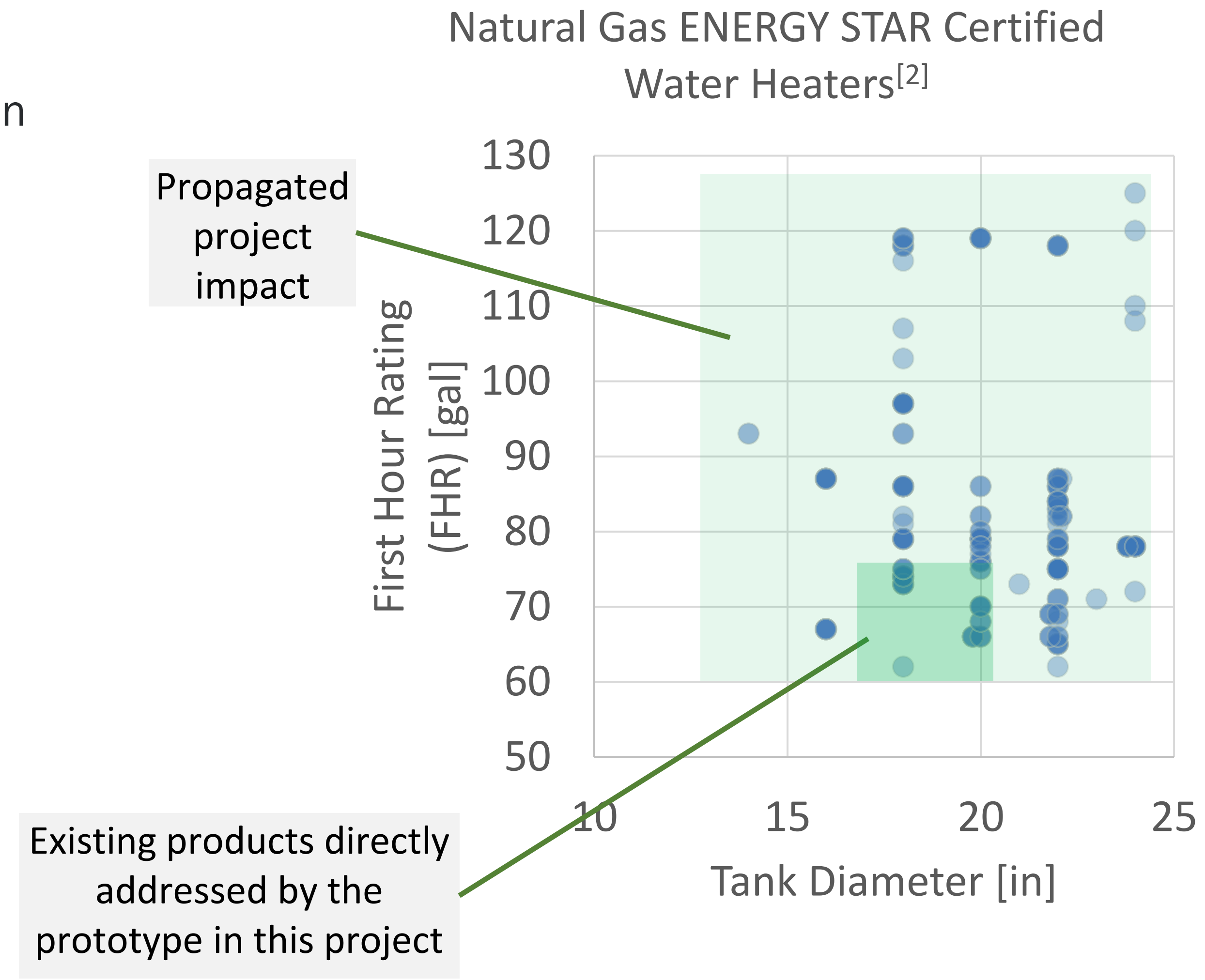
Impact – Success for Tall & Slim and Further

Success in this Project Means:

- A demonstrated path to meeting consumer expectations for water delivery from a direct-drop-in heat-pump electrified water heater

Impact

- Provide an electrified solution drop-in for tall slim gas water heaters
- This solution can also propagate to other product categories for expanded impact
- Reduce costs to consumers by avoiding panel upgrades and carpentry modifications



[2] Data from ENERGY STAR qualified product list
https://www.energystar.gov/productfinder/product/certified-water-heaters/results

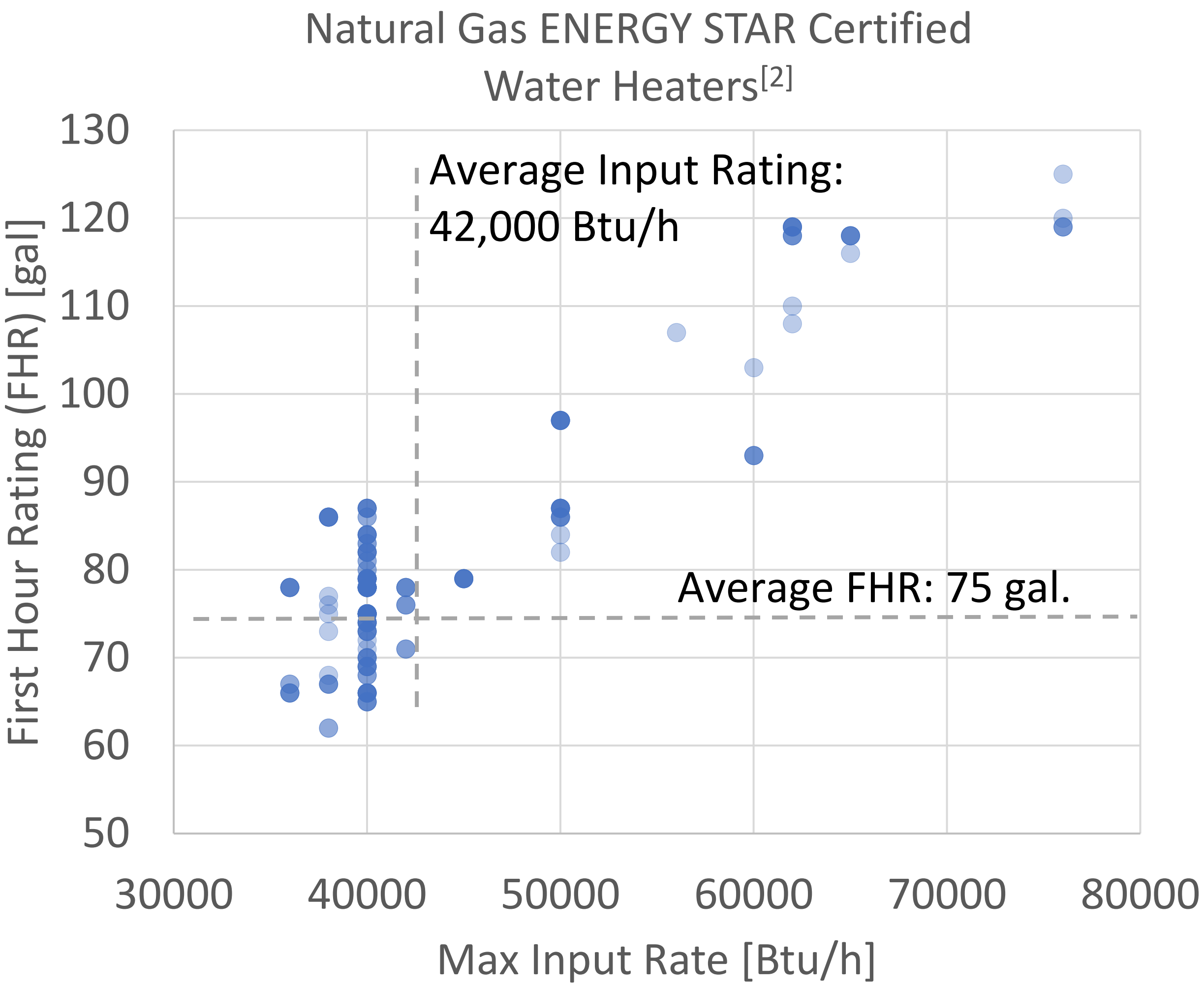
Approach – Current Retrofit Needs

Current Natural Gas Units

- *ENERGY STAR qualification criteria for 120V (15 amp shared circuit) units requires UEF of 2.2 and FHR of 45 gal (no physical size requirement)*

- *Regulations for many retrofits and new homes will prevent gas-fired water heaters from being installed*

- *However, current HPWH products require high-voltage and/or are difficult to physically fit where there used to be a tall & slim gas unit*



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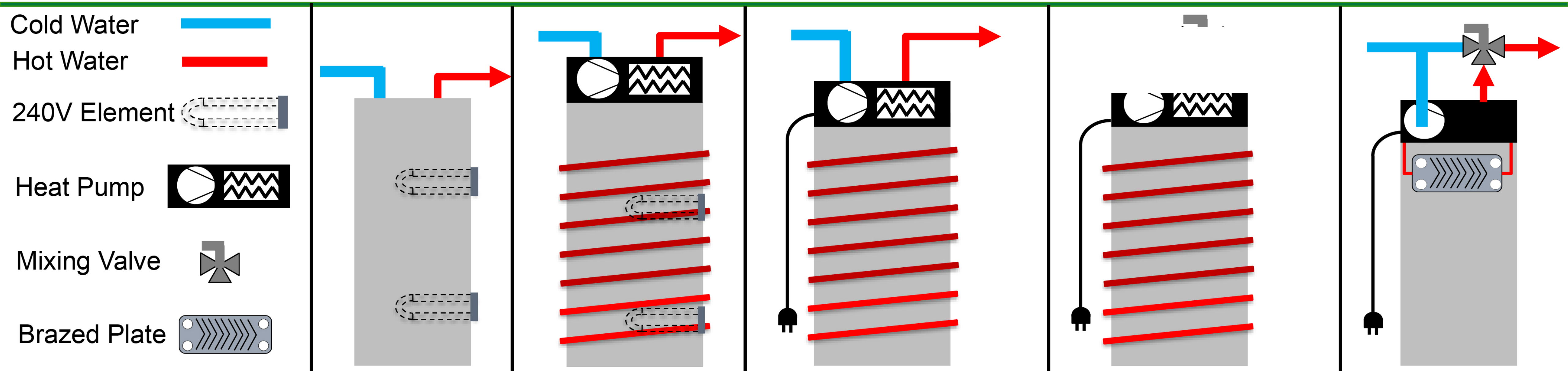
Approach – Electrifying a Tall & Slim Gas Unit: “Max-Tech FHR”

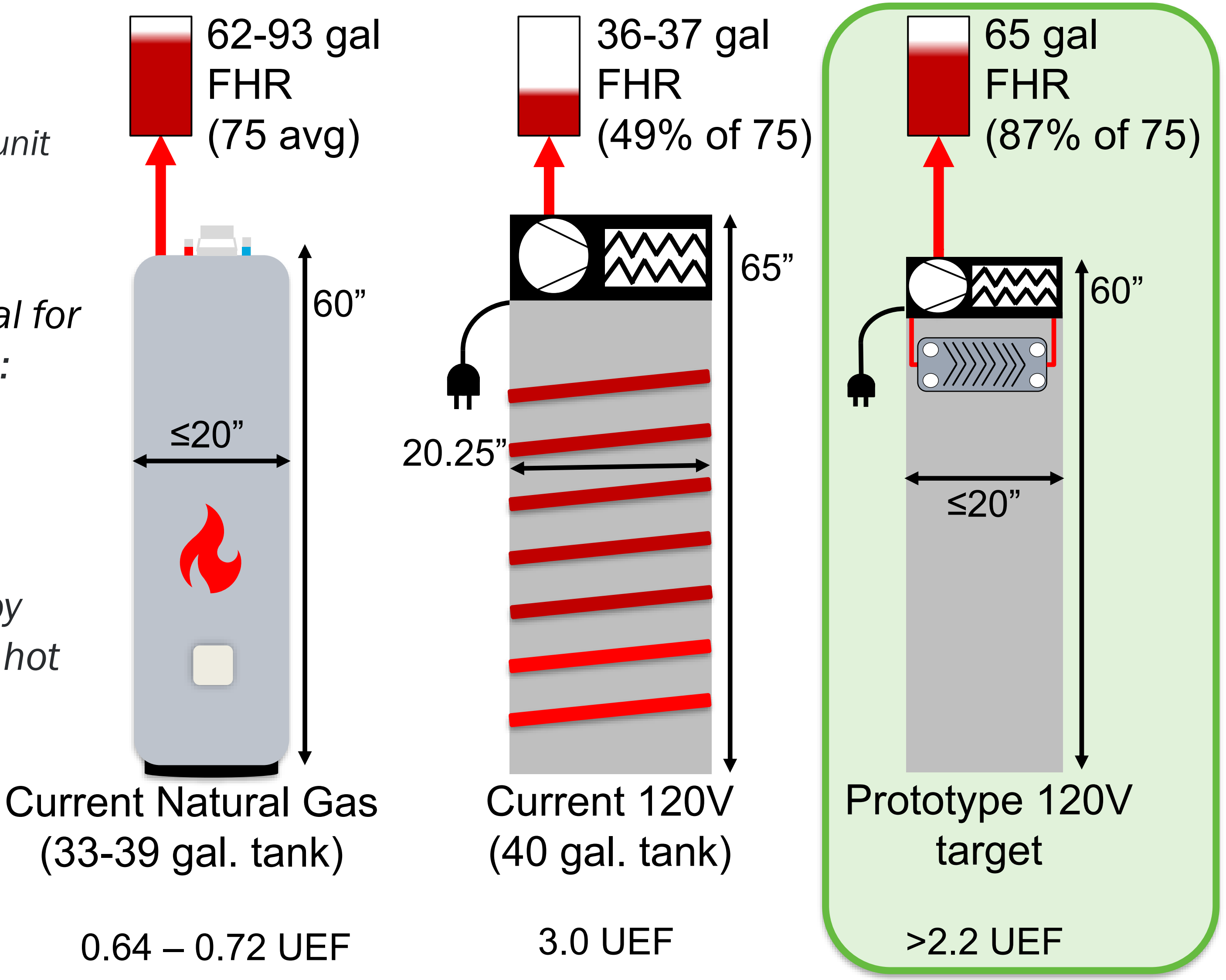


		Baseline 240 V ER	Baseline 240 V HPWH Hybrid	Commercialized 120 V Dedicated Circuit (<12 A)	Commercialized 120 V Shared Circuit (<7.5 A)	ORNL 120 V Prototype
what	Electrical drop-in?	Needs 30 A/240 V	Needs 30 A/240 V	✓	✓	✓
	Physical drop-in?	✓	No, taller	No, taller	No, taller	✓
	Delivery capacity	Comparable	Comparable	low	low	Comparable
how	Heat pump size		normal	larger	normal	larger
	Mixing valve				✓	✓
	Brazed-plate HX					✓

Approach – Novel Size and Performance Combination

Focus on consumer acceptance

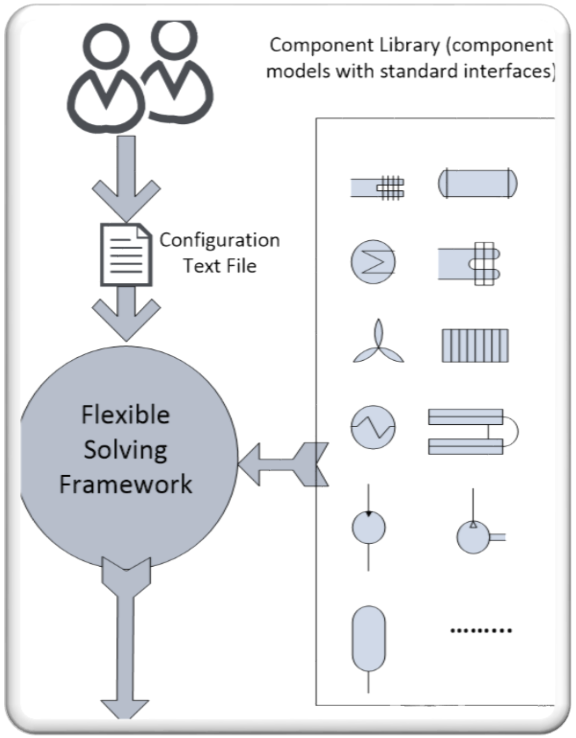
- *Critical parameters for a direct drop-in:*
  - *Physical envelope of current gas-fired tall & slim unit*
  - *First Hour Rating (FHR) water delivery capacity*
- *Commercially available 120V HPWH are not ideal for direct drop-in replacement for tall slim gas units:*
  - *taller (65" vs. 60")*
  - *lower FHR (37 vs 75 gal avg)*
- *This project targets achieving market adoption by meeting the space constraint while maintaining hot water delivery capacity that meets consumer expectations*



Approach –DOE/ORNL Heat Pump Design Model

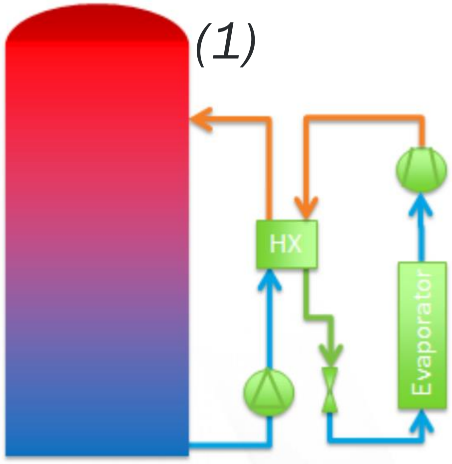
Component-Based

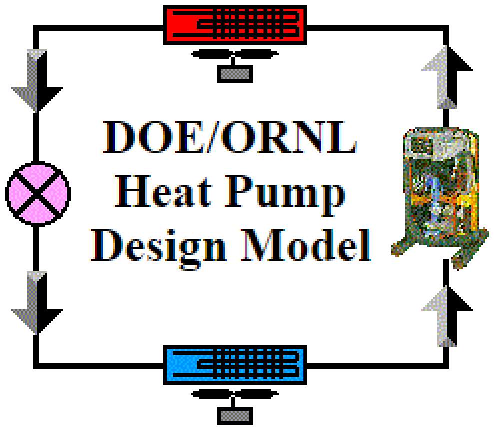
Component models have standard interfaces to the solving framework, and generic connections to each other.



Automatically connect components into required system configuration by user input file.

(1)





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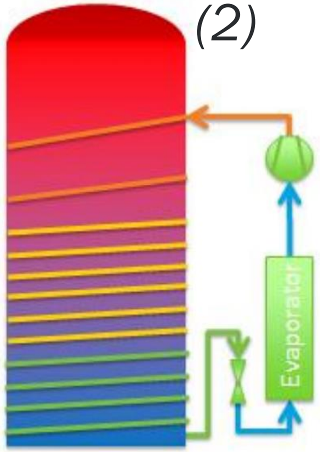

Detailed HPWH system design tool

- *UEF & FHR Simulation*
- *External HX (1) and wrapped condenser (2) modeling*

https://hpdmflex.ornl.gov/hpdm/wizard/welcome.php

Approach – Project Delivery, Challenges, & Mitigation

A New Water Heater Unit

- *Major deliverable will be a 120 V heat pump water heater unit that physically fits within the space for existing tall and slim gas units and delivers comparable hot water*
- *Multiple prototype generations with increasing FHR and UEF performance will be fabricated, tested, and delivered with recorded performance in publications and presentations*

Challenge & Mitigation

- *The largest challenge of this project is the design and fabrication of a HPWH that fits the existing space as well as the FHR performance requirements. There is no currently technology that satisfies both.*
- *Mitigation of this challenge includes: 1) performing extensive modeling to ensure the UEP and FHR are achievable with the space requirements for the tank and heat pump combination; and 2) achieving the Go/No-Go milestone of the first-generation prototype for the intermediate target to confirm confidence that the final requirements can be met.*

Approach – Market Engagement and Stakeholders

Industry Partners

- *Materials procurement for fabricating a realistic prototype will require contact with OEM part suppliers*
- *As the result of previous and ongoing projects within the water heating sector, ORNL has strong existing relationships that can be engaged as necessary as the project progresses in the later stages*

Market Engagement

- *Communication with companies currently in the residential water heater sector enables an understanding of the expectations of consumers to increase the likelihood that this solution will be adopted*
- *Stakeholders specific to this project are water heater manufacturers and owners of gas-fired tall & slim water heaters.*
- *Physical design, performance, and cost of retrofit installation and replacement units will be confirmed with an existing manufacturer prior to market introduction*

Related Work (Other Projects)

This project leverages the findings of other projects

- *Test facility and data processing for other projects gives a head start on testing needs*
- *Water heater tank stratification model developed in other projects with FHR & UEF prediction models will be leveraged*

This project is unique in focusing on the tall-and-slim form factor

- *GEB by ME is a related project developing a smaller size ~20 gallon 120V HPWH*
- *Other HPWH development projects focus on traditional HPWH form factor*

Future Work & End Vision

Project Tasks

1. *Identify key consumer issues with current 120 V HPWHs*
2. *Baseline characterization, prototype design, and procurement of off-the-shelf components*
3. *First-generation prototype design and fabrication*
4. *First-generation prototype shakedown, evaluation, and dissemination of results*
5. *Second-generation prototype design and fabrication*
6. *Second-generation prototype shakedown, evaluation, and dissemination of results*

Project Goals Create Path to Electrification/Decarbonization

- *Gas-fired water heaters in difficult retrofit spaces lack affordable electrified options that meets consumer expectations*
- *A HPWH will be designed, fabricated, and evaluated with water delivery capacity comparable to gas-fired units and meeting physical size constraints*
- *Identifying components of a HPWH critical to meet this goal will be completed during this project through fabrication and testing of the prototypes*

Thank you

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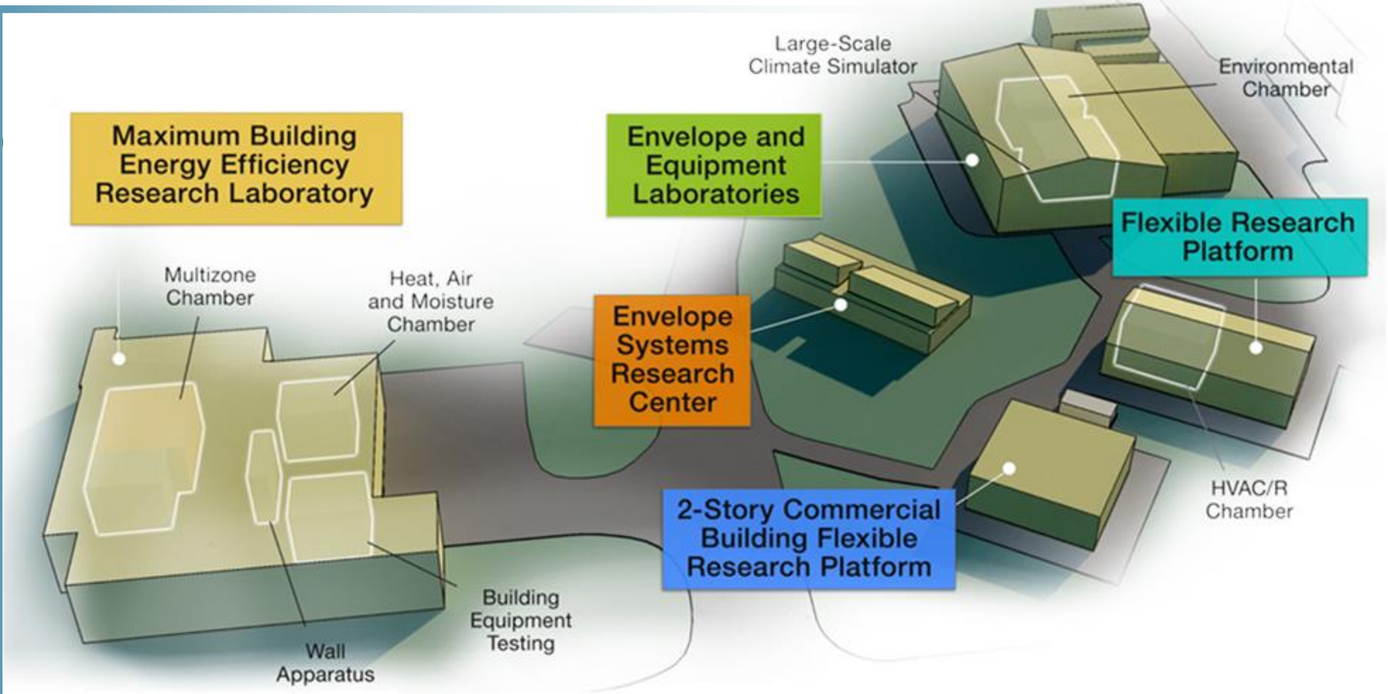

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Scientific and Economic Results

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

Project Start: Feb 2023

	Task	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
1	Set targets & identify relevant load profiles								
2	Baseline characterization								
3	Prototype design								
4	Prototype fabrication								
5	Prototype evaluation in laboratory								
6	Disemmination and reporting activities								
	Milestone	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
1	Identify key consumer issues with 120V HPWHs								
2	Baseline gas unit characterization, 120V prototype design, procurement of off-the-shelf components								
3	Prototype shakedown for FHR & UEF evaluation			Go/No-Go					
4	Second generation prototype shakedown for FHR & UEF evaluation								
5	Final prototype evaluation for FHR > 65 gallons, ENERGY START UEF > 2.20								

Team

Oak Ridge National Laboratory

Kyle Gluesenkamp (PI): conceptualization and design, project management

Bo Shen: prototype design, system modeling

Melanie Moses-DeBusk: prototype fabrication, experimental design & evaluation

Ahmed Elatar: market research, prototype evaluation

Sylas Rehbein: experimental design, data analysis

Ed Vineyard: prototype design

Brian Kolar: experimental evaluation

Zhenning Li: prototype simulation and validation