U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# Technology Integration: Heat Pump Water Heaters (HPWH)

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All photos of experiment courtesy of BPA

# Project Summary

## Timeline:

Start date: 10/1/2016

Planned end date: 9/30/2020

Key Milestones for this year

1. Commitment from participating utility 9/30/2019
2. Characterization of all homes in Northwest (NW) 9/30/2019
3. PowerPoint of draw profiles 9/30/2019

## Key Partners:

| | |
|---|---|
| Oak Ridge National Laboratory (ORNL) | Portland General Electric (PGE) |
| Bonneville Power Administration (BPA) | Northwest Energy Efficiency Alliance (NEEA) |
| eRadio | Duke Energy |

# Budget:

**Total Project $ to Date:**

- DOE: $615,066
- Cost Share: In kind support from BPA, PGE and Duke Energy Florida

**Total Project $:**

- DOE FY17-19: $615,066
- DOE FY20: $484,934 (to be confirmed)
- Cost Share: In kind support from BPA, PGE and Duke Energy Florida

## Project Outcome:

Supports “Beyond Batteries,” an EERE-wide initiative to develop tools to improve grid reliability through increased flexibility and grid services from renewable generation, load management, and alternative storage technologies. Accomplishes MYPP goal of testing residential water heating for existing homes across climates.

This project tests heat pump water heater energy efficiency and demand response value in most applicable locations. Controllable heat pump water heaters in the NW have the potential to save 1.1 TWh per year and control over 300 MW for peak load reduction. Forecast estimates in the southeast (SE) show energy savings of 1.4 TWh per year in the prospective utility partner’s territory.

# Team Members

**Cheryn Metzger**
PNNL
PI, Tasks 1 and 3

**Josh Butzbaugh**
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**Michael Baechler**
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Analysis

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Analysis

**Walt Hunt**
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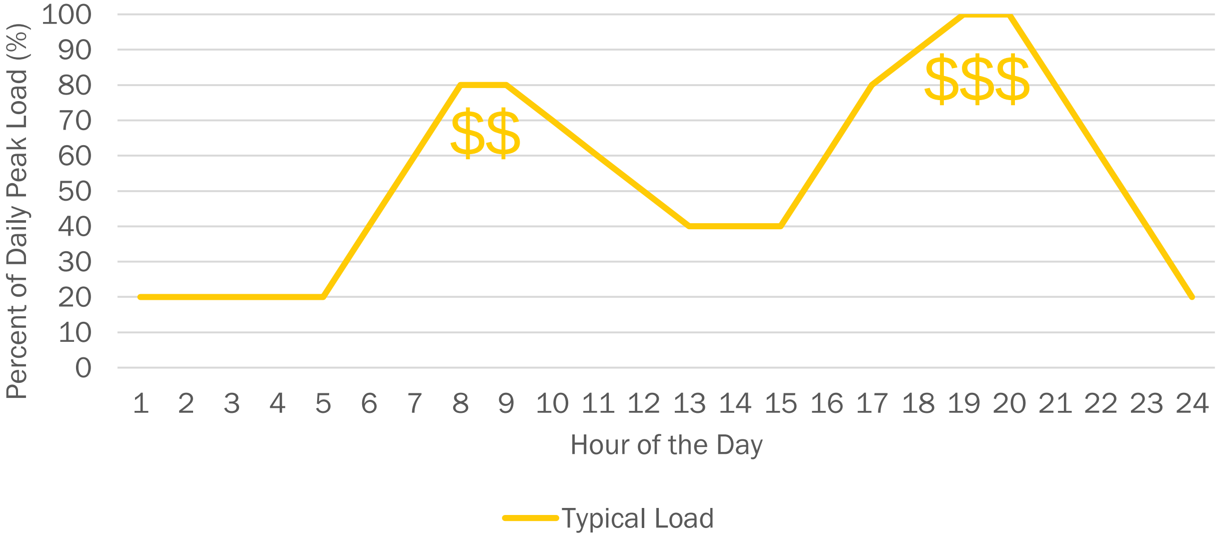
Analysis

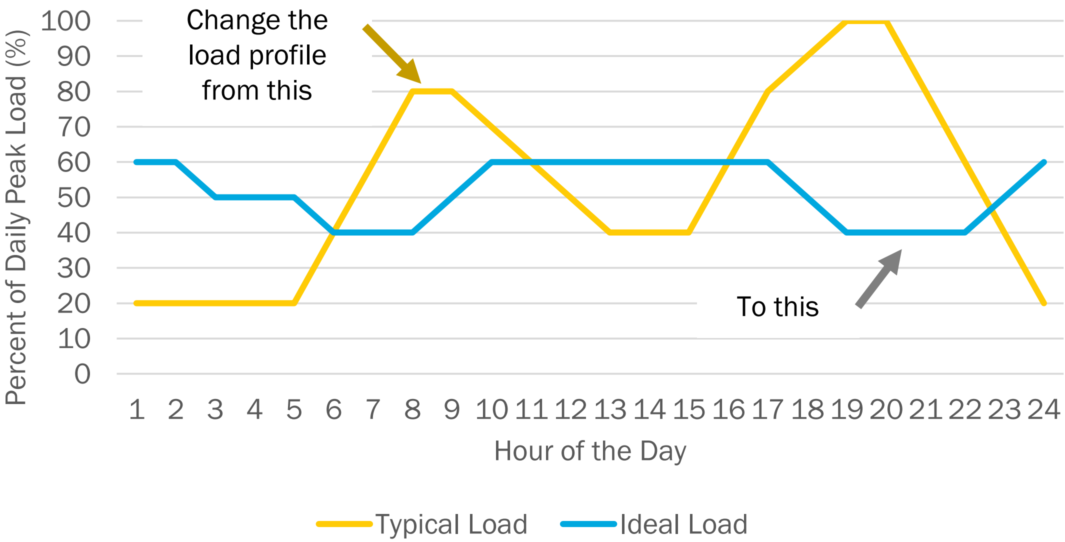
# Challenge

- Water heating is the second largest energy end use in the U.S. residential sector, second only to heating.
- Residential electric loads fluctuate, and peak power costs much more to utilities than baseload power. Utilities are starting to pass those costs on to customers.
- Peak power demand can call for peaking power plants to serve load, or can lead to brown-outs due to peak capacity limitations.
- Thermal characteristics of water heaters provide options to manage peak power requirements.
- HPWH load shifting performance remains to be proven in certain regions (e.g., SE) with large energy efficiency and peak demand reduction potential.



# Approach: High-Level Project Goals

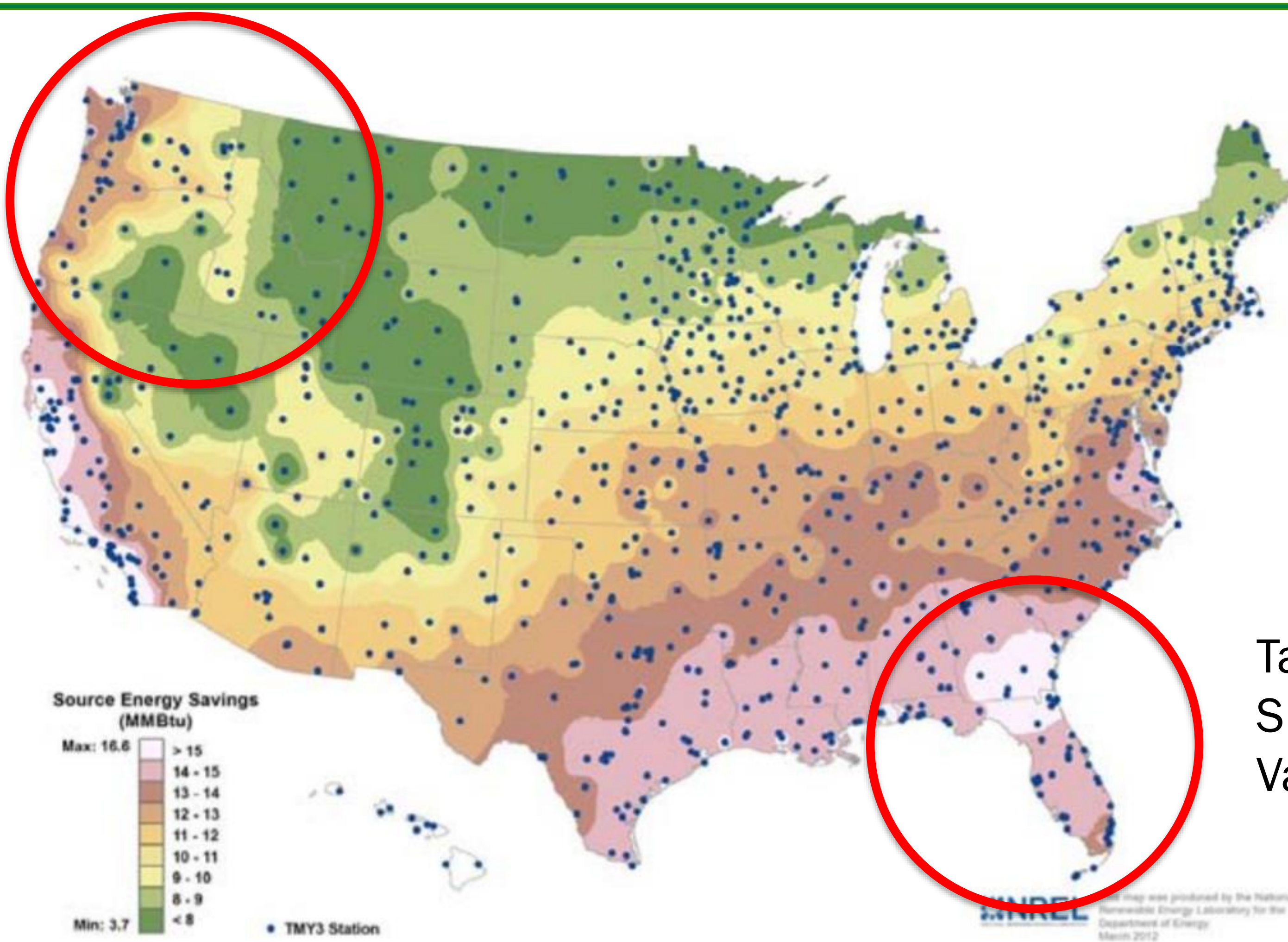
- Support "Beyond Batteries," an EERE-wide initiative to develop new technologies and analytical tools that improve grid reliability through increased flexibility and grid services from renewable generation, load management, and alternative storage technologies;
- Demonstrate a 24x7 control paradigm for **shifting load to align with renewable generation** (e.g., morning load shifting toward mid-day when solar energy would be more prevalent);
- Quantify this value for utilities and consumers using both electric resistance and heat pump water heaters;
- Evaluate customer acceptance of this control paradigm.




Photos Courtesy of NREL PICS Database

# Approach: Research in High-Impact Areas

Task 1:
NW Field
Validation




Task 2:
SE Field
Validation

NREL Highlight, 2012. NREL Develops Heat Pump Water Heater Simulation Model

This map shows the source energy savings potential of heat pump water heaters, including effects from climate and space conditioning interactions. The white areas represent the most savings.

# Approach: Use CTA-2045

- The original manufacturer needs to provide only the standard port (not the additional hardware);
- Any number of stakeholders (e.g., utilities) can pay for the additional “connected” hardware required to turn an unconnected appliance into a connected appliance;
- The modular interface supports every type of communication method at the physical layer (e.g. Wi-Fi, 4G LTE, FM, etc.) and at the command layer (e.g., SEP, OpenADR, etc.); and
- A third party can manufacture the connected hardware.

# Approach: FY19 Project Goals

TASK 1: Continue Field Validation in the NW to shift water heater loads to low-cost periods of the day and quantify energy impacts

- Obtain winter data
- Study energy load shifted through different control strategies
- Milestone: Analysis of winter data from the NW (9/30/19)

TASK 2: Establish a pilot study to monitor, analyze, and document energy savings and peak load reduction of connected HPWHs in the SE

- Forecast load and peak reduction potential for a prospective utility partner in the Southeast (SE) region in the U.S.
- Milestone: Commitment from SE utility to participate in a pilot study (9/30/19)

# Task 1: Unique Approach

- Use of CTA-2045 (GE and AO Smith) to control water heater vs. the use of cloud-based control (Rheem)
- 2 load shifting events per day during peak hours
  - Previous studies focus on seasonal peak days
  - Previous studies focus on large scale load shifting with electric resistance water heaters
- No mixing valves (may use in the future), no changing set-point

Initial Pilot to Ensure CTA-2045 Functionality at Large Scale
FYI8

→

Cold Weather Data and Refined Control Strategy
FY19

→

Optimized Self-Learning Algorithm for Each Water Heater
FY20

# Task 1 Approach for FY19

Scope

- ~75 HPWH using CTA2045
- ~8 Electric Resistance WH using CTA2045
- 10 weeks of winter data (e.g. coldest ground water and coldest semi-conditioned spaces)

Research Questions

- What is the most energy that can be shifted by using heat pump water heaters in the winter months using a single group control strategy?
- What is the most energy that can be shifted and energy and dollars saved for homeowners using a multi-group control strategy?

# Task 1 Progress

## Reduced Risk for Utilities, Reduced Cost to Consumers

| Peak Load Reduction | ER BL (W/Hour of DR Event) | ER BL – ER with DR (W/Hour of DR Event) | ER BL – HPWH Control (W/Hour of DR Event) | ER BL – HPWH with DR (W/Hour of DR Event) | % Savings for Switching to HPWH with DR (W) |
|---|---|---|---|---|---|
| Morning Peak | 623 | 381 | 329 | 540 | 87% |
| 95% CI for Morning Peak | 85 | 79 | 83 | 84 | N/A |
| Evening Peak | 668 | 320 | 442 | 602 | 90% |
| 95% CI for Evening Peak | 57 | 77 | 65 | 58 | N/A |

~90% of evening peak load power can be reduced by switching from uncontrolled ERWHs to Connected HPWHs

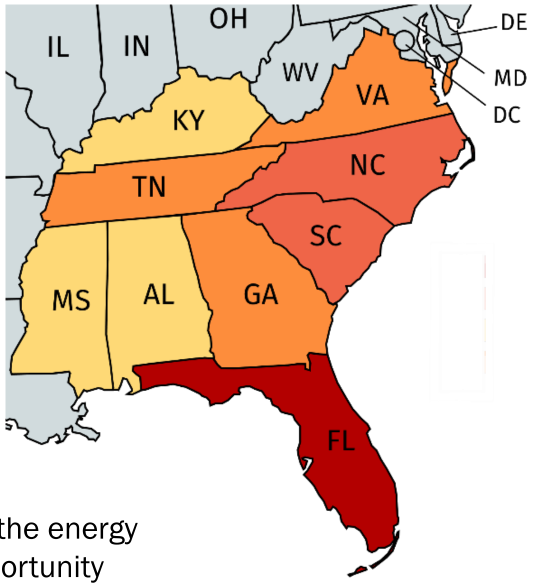
Acronyms: ER = electric resistance, BL= baseline, W = watt, DR = demand response, CI = confidence interval, ERWH = electric resistance water heater, HPWH = heat pump water heater

# Task 1: Remaining Project Work

Smart-learning algorithm to optimize load use for each individual water heater (early phase research)

# Task 2 Approach

- Study the performance of connected HPWHs in a grid-constrained region with high energy efficiency potential
- Identify region offering greatest potential for energy efficiency and peak load shifting through connected HPWHs
  - Prioritize the utility candidates for prospective connected HPWH pilot
  - Conduct preliminary assessment of potential energy efficiency and peak load shifting for priority utility candidate through recalibration of NW study results
- Gain utility commitment to collaborate and launch connected HPWH pilot in the SE
- Analyze results across load up and shed strategies
  - Energy efficiency and peak demand impacts
  - Net cost effectiveness for utility




The darker the red, the greater the energy efficiency & peak reduction opportunity

# Task 2 Progress

- Identified region offering greatest potential for connected HPWHs
- Prioritized and established relationships with viable utility partner candidates for the pilot
- Prepared preliminary assessment (i.e., forecast) of the energy efficiency and peak shifting potential for a prospective utility partner
  - Developed a methodology to calibrate the results of the Pacific Northwest connected HPWH field study to the utility’s service territory, adjusting for climate, loads, and other variables
  - Forecasted energy savings and peak demand shifting by hour for winter morning and summer evening peaks
  - Leveraging results of preliminary assessment to gain commitment to launch a connected HPWH pilot with the potential utility partner

# Task 2 Next Steps

- Solidify commitment from utility partner to move forward with a connected HPWH pilot study
- Assess utility partner's market and technological considerations
  - Leverage lessons learned and best practices from the Pacific Northwest connected HPWH field study
  - Determine communications strategy for pilot connectivity
  - Develop coordination plan for manufacturers and supply chain actors
- Prepare pilot study plan and methodology
  - Prioritize load up and shed strategies
  - Compare 100 connected HPWHs to:
    - Connected ERWHs
    - Uncontrolled ERWHs
    - Uncontrolled HPWHs

# Whole Project Impact

- Converting all ERWHs to HPWHs could save American consumers $7.8 billion annually ($182 per household) in water heating operating costs and cut annual residential source energy consumption for water heating by 0.70 quads[1].
- This project supports the following EERE Goals:
  - "Beyond Batteries," an EERE-wide initiative to develop new technologies and analytical tools that improve grid reliability through increased flexibility and grid services from renewable generation, load management, and alternative storage technologies. (Control over 300 MW for NW utilities alone.)
  - MYPP goal of testing residential water heating for existing homes across climates. This project tests heat pump water heater energy efficiency and demand response value in most applicable locations.
- Substantial energy savings:
  - Potential to save 1.1 TWh per year in the NW.
  - Potential to save 1.4 TWh per year in the prospective utility's territory in the SE.
- Substantial load shifting potential:
  - Average of up to 450 Wh shifted per heat pump water heater for 3-4 hour event[2].
- Customer acceptance of 24x7 control paradigm very good! Only 4% of event hours opted-out (includes planned opt-outs for known parties, etc.)

[1] Building America Case Study: Field Performance of Heat Pump Water Heaters in the Northeast. https://www.energy.gov/sites/prod/files/2014/01/f7/case_study_hpwh_northeast.pdf

[2] Metzger, et al. 2018. Load Shifting Potential Using Storage Water Heaters in the Pacific Northwest https://www.bpa.gov/EE/Technology/demand-response/Documents/Demand%20Response%20-%20FINAL%20REPORT%20110918.pdf

# Stakeholder Engagement

## Early Stage Research

### Past/Current

- Coordinated workshops with regional efficiency organizations (REOs), three major manufacturers, state and local governments, and multiple utilities throughout the U.S. (Task 2)
- Coordinating with related studies with SMUD, NRDC, Ecotope, Duke Energy and ORNL through meetings and conference calls (Tasks 1 and 2)
- Presentation and feedback from the research community (Tasks 1 and 2)
  - ACEEE Summer Study, Better Buildings Residential Network Webinar: We Love Our National Labs, ACEEE Hot Water Forum, CEE

### Future Plan

- Use of Virtual Peaker in the NW using CTA-2045 (this company was previously used in a SMUD study which used the cloud-based control strategy)
- Plan to expand into different climate regions, and potentially testing different approaches side-by-side. Working with national utilities (Orlando Utilities Commission, Duke, Southern Company, National Grid, Xcel Energy, So Cal Edison)

# Thank You

PNNL

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PNNL-SA-142462

# REFERENCE SLIDES

# Project Budget

**Project Budget: See below**
**Variances: No variances**
**Cost to Date: 56% spent to date**
**Additional Funding: $484,934**

| Budget History | | | | | |
|---|---|---|---|---|---|
| FY 2016– FY 2018 (past) | | FY 2019 (current) | | FY 2020 (to be confirmed) | |
| DOE | Cost-share | DOE | Cost-share | DOE | Cost-share |
| $255,927 | In Kind | $359,139 | In Kind | $484,934 | In Kind |

# Project Plan and Schedule

On time and on budget

| | | | |
|---|---|---|---|
| Task 1 | 10/1/2016 Start | 9/30/18 Initial Pilot Complete | 9/30/20 Self-Learning Pilot Complete |
| Task 2 | 10/1/2016 Start | 12/31/2018 Preliminary Assessment | 9/30/20 SE Pilot Complete |

# Task 2 Impact

- Pilot results will quantify energy efficiency and peak shift impact, and validate the methodology of the preliminary assessment
- Successful pilot has the potential to expand into a full-scale program and catalyze other utilities to launch pilots and programs in Florida and throughout the Southeast
- Forecasted energy efficiency and peak reduction potential for prospective utility partner and state of Florida

| | Prospective Utility Partner | Florida |
|---|---|---|
| Target Homes | 700k | 3.2 million |
| Annual Energy Savings | 1.4 TWh | 6.3 TWh |
| Winter Morning Peak Shift | 300 MW | 1,350 MW |
| Summer Evening Peak Shift | 215 MW | 950 MW |

- Peak shift projections are per-hour averages for 6-10 am winter and 5-9 pm summer using forecasted baseline
- Forecasted baseline was compared to metered data for prospective utility partner.
    - Winter morning forecasted baseline was 4% lower than metered baseline as a per-hour average
    - Summer evening forecasted baseline was 17% higher than metered baseline as a per-hour average
- Assumes prospective utility partner's weighted temperature data is representative of Florida