Preliminary Findings from Next Generation SMTI Residential GHPWH Demonstration

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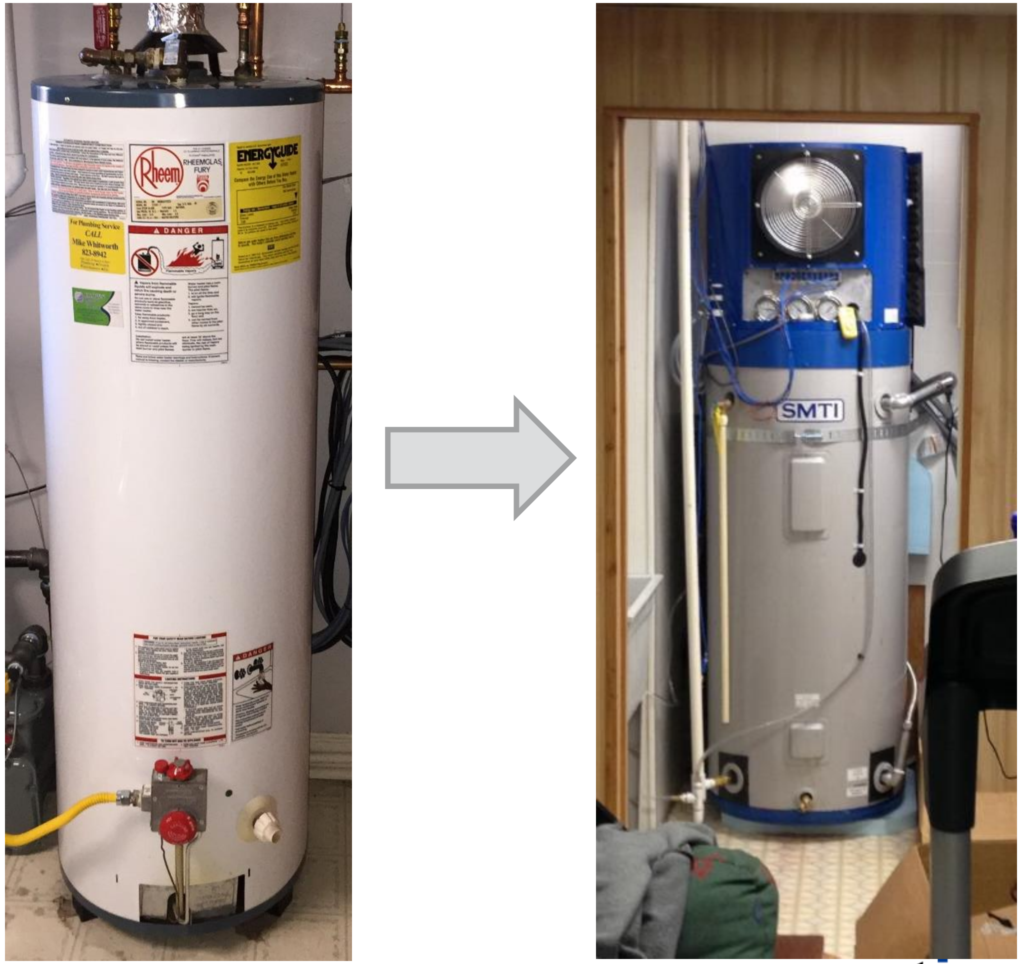
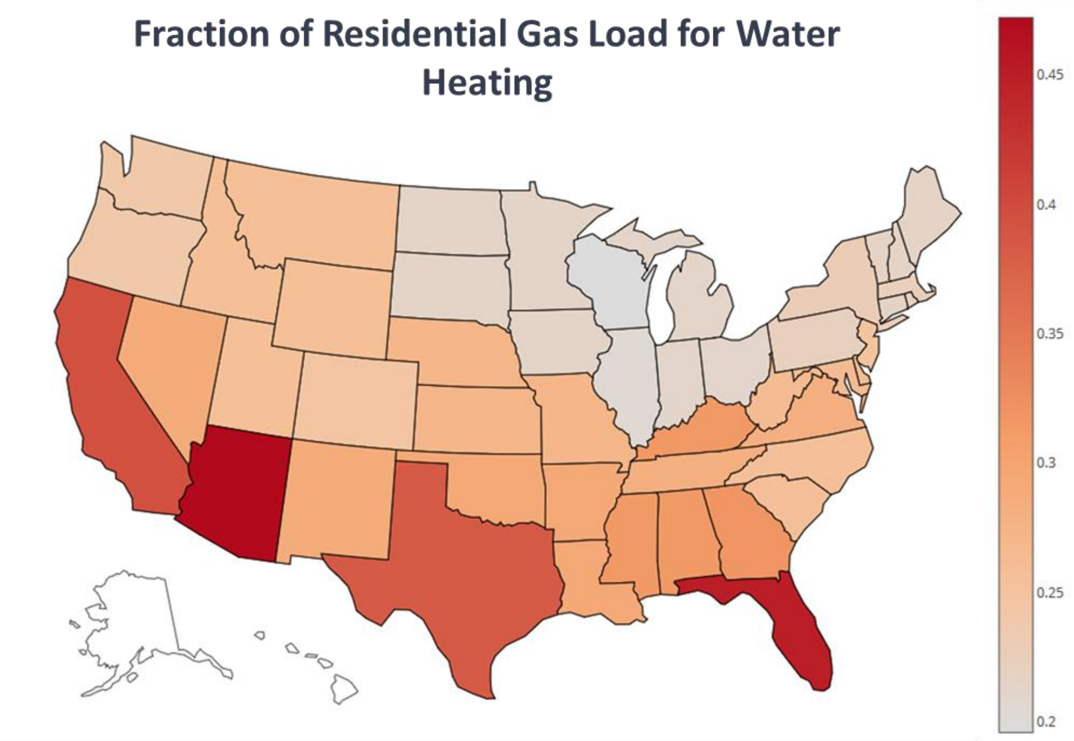
Presentation Outline

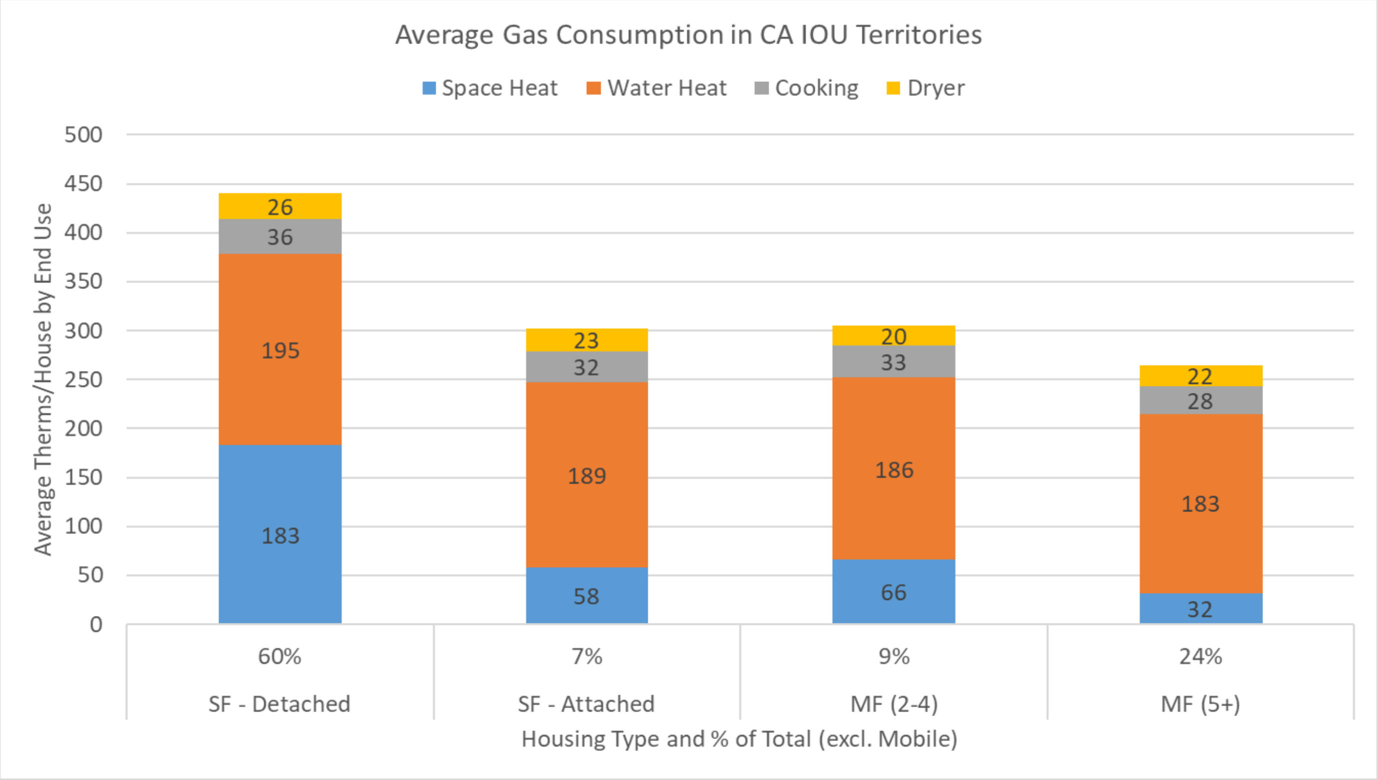
- >Motivation for Gas HPWH
- >Review Gas HPWH Development and Lessons Learned
- >Improvements to Recent Generation
- >Preliminary Results from Field Trial and Next Steps
- >Transforming the Market



Motivation- Why Care About Water Heating?

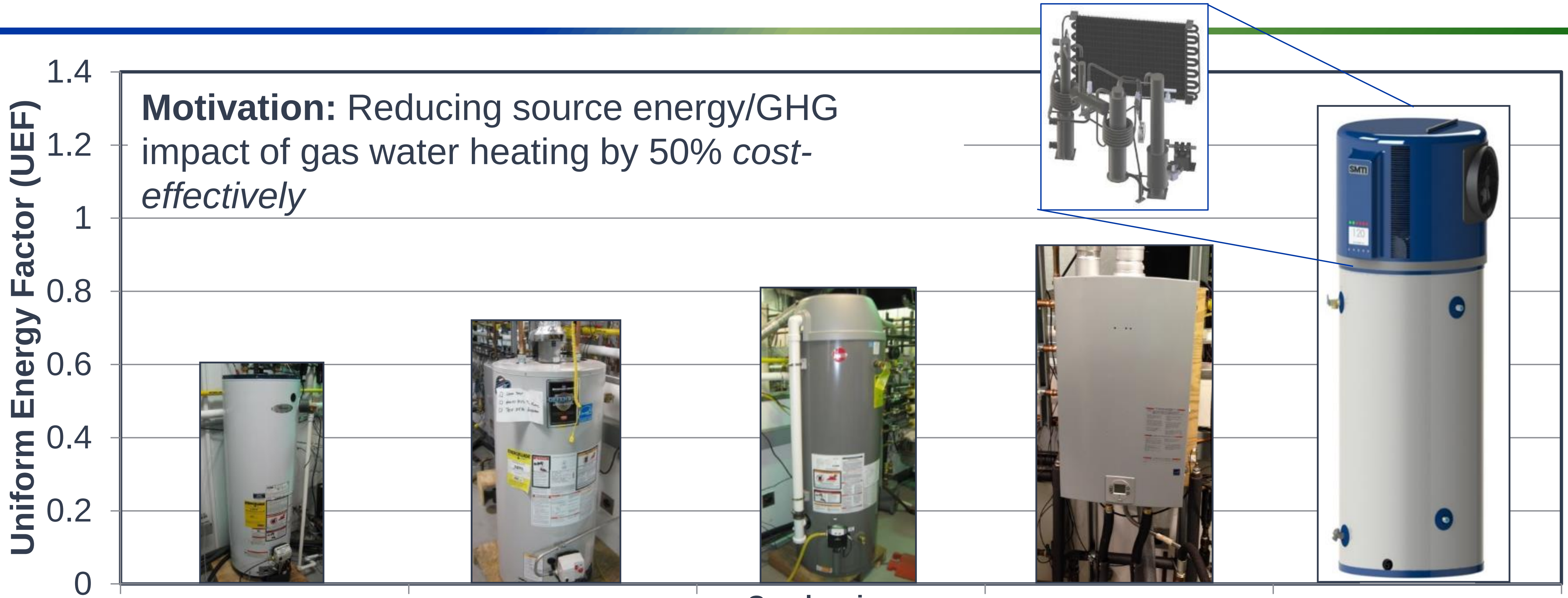
> Nationwide: 12.3 Billion therms consumed in half of all homes
> California: 1.7 Billion therms, in ¾ of homes, **95% by minimum efficiency GWHs**





* Data sources: EIA RECS, 2009 CEC Residential Appliance Saturation Survey and 2010 US Census;

The Challenge in Gas Water Heating



Baseline:
90% of Gas WHs sold.
At risk with advancing efficiency, combustion safety requirements

Mid-Efficiency:
50-100% greater equipment costs, simple paybacks beyond life of product.

Condensing Storage:
~ 20% therm savings with 4-5X equipment cost and retrofit installation costs of $1000 or more.

Tankless and Hybrids:
~ 33% therm savings with 2-3X equipment cost and similar infrastructure req's as condensing storage.

Gas Heat Pump:
> 50% therm savings with comparable installed cost to tankless.

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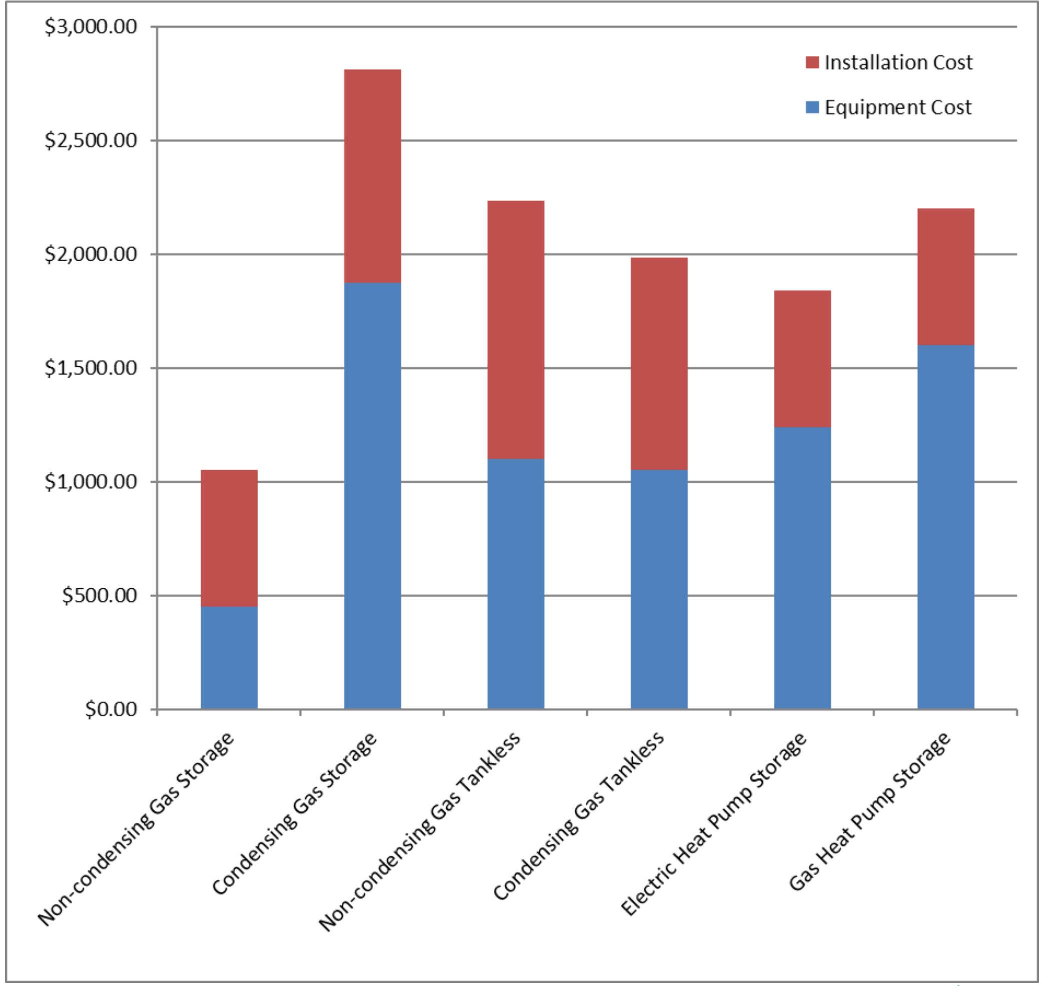
Garrabrant, M., Stout R., Glanville, P., Fitzgerald, J., and Keinath, C. (2013) *Development and Validation of a Gas-Fired Residential Heat Pump Water Heater*. Report DOE/EE0003985-1, prepared under contract EE0003985.

The Challenge in Gas Water Heating

- Economics of higher-efficiency equipment are challenging when average homeowner spends $250-$300/year on hot water
- GHPWH has higher equipment cost over baseline, but comparable installation cost:
  - Similar form factor.
  - No upsize in gas piping.
  - 15A / 120 VAC service.
  - Small plastic diameter venting
  - No special training to install
- For a GHPWH that reduces gas consumption 50% over baseline, has potential to leapfrog condensing storage and be competitive despite low NG prices



Note: GHPWH costs are projected, assuming moderate product volumes.

Residential Gas Heat Pump Water Heater

GHPWH System Specifications: Startup company with OEM/industry support designed and demonstrated prototype GHPWHs, using direct-fired NH3-H2O single-effect absorption cycle integrated with storage tank and heat recovery. Intended as fully retrofittable with most common gas storage water heating, without infrastructure upgrade.

	GHPWH	Units/Notes
Technology Developer	Stone Mountain Technologies	OEM support
Heat Pump Output	10,000	Btu/hr
Firing Rate	6,300	Btu/hr
Efficiency	1.2-1.3 Energy Factor	Projected (Medium - High Usage)
Tank Size	60-80	Gallons
Supplemental Heating	Experimenting with backup currently – 1.25 kW	
Emissions (projected)	<10 ng NO_x/J	Pending Certification
Installation	Indoors or semi-conditioned space (garage)	Sealed system has NH3 charge < 25% allowed by ASHRAE Std. 15
Venting	½” – 1” PVC	
Gas Piping	½”	¼” feasible, req. codes
Estimated Consumer Cost	<$1,600	Moderate initial volumes

Information and photo courtesy of SMTI

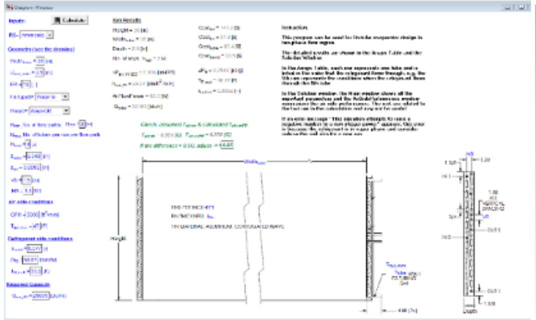
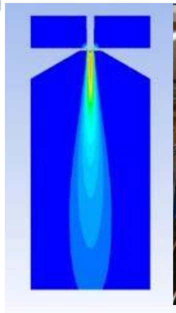
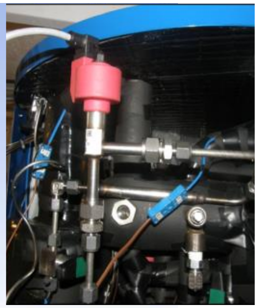
Residential Gas Heat Pump Water Heater

GHPWH – Product Development

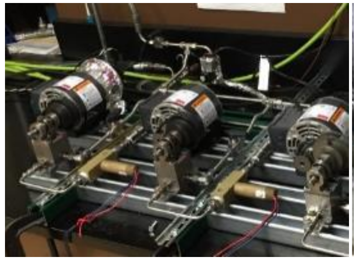
Laboratory & Early Field Development

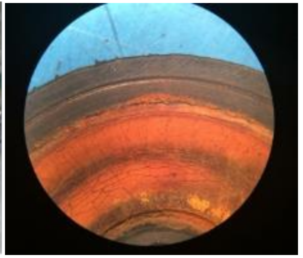


Component Design & Design Tools

Component Reliability Testing





System Reliability Testing

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Gas HPWH – Lessons Learned

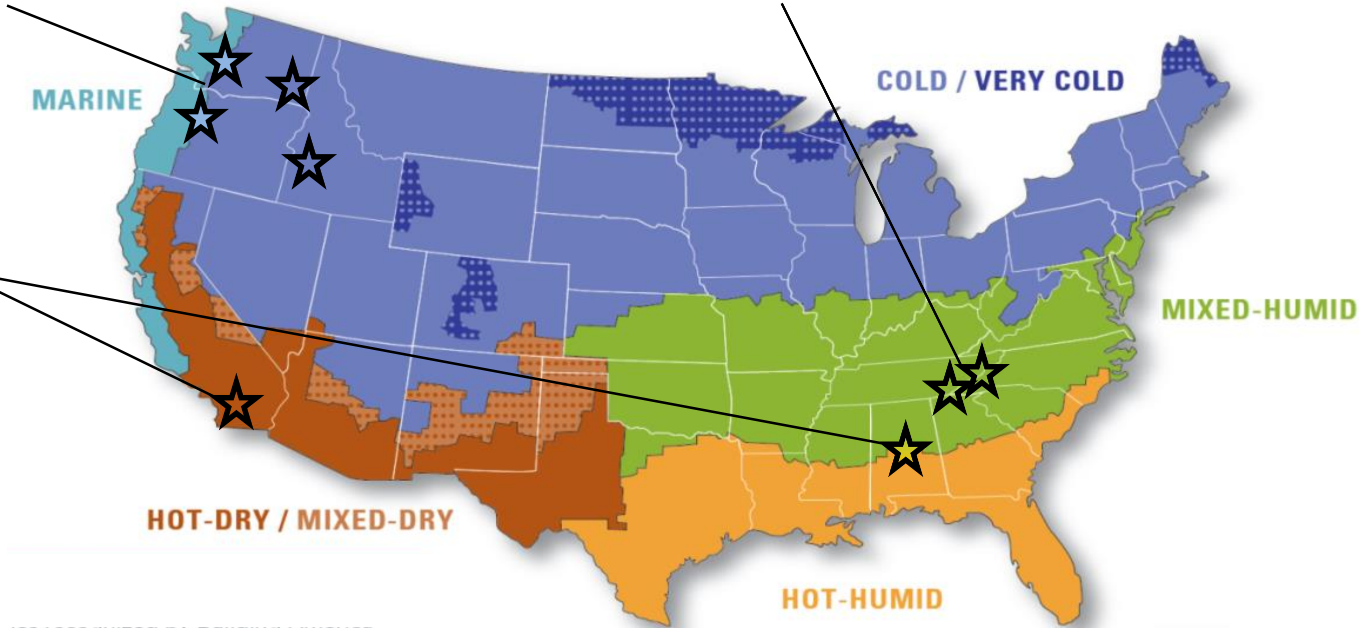
GHPWH – Field Demonstrations

Units deployed in SF homes in garage and semi-conditioned basement installations

Pac. NW Demonstration (WA/OR/ID)
Four 3rd Gen. GHPWHs operated in major NW cities for first 'true' demonstration.

Initial Controlled Demonstration (TN)
Two 1st/2nd Gen. GHPWHs installed near mfr, at homes of mfr/utility employee.

4th Gen. Demos (CA/AL)
Demonstrations of multiple 4th generation GHPWH units are active/planned in Alabama and Southern California.



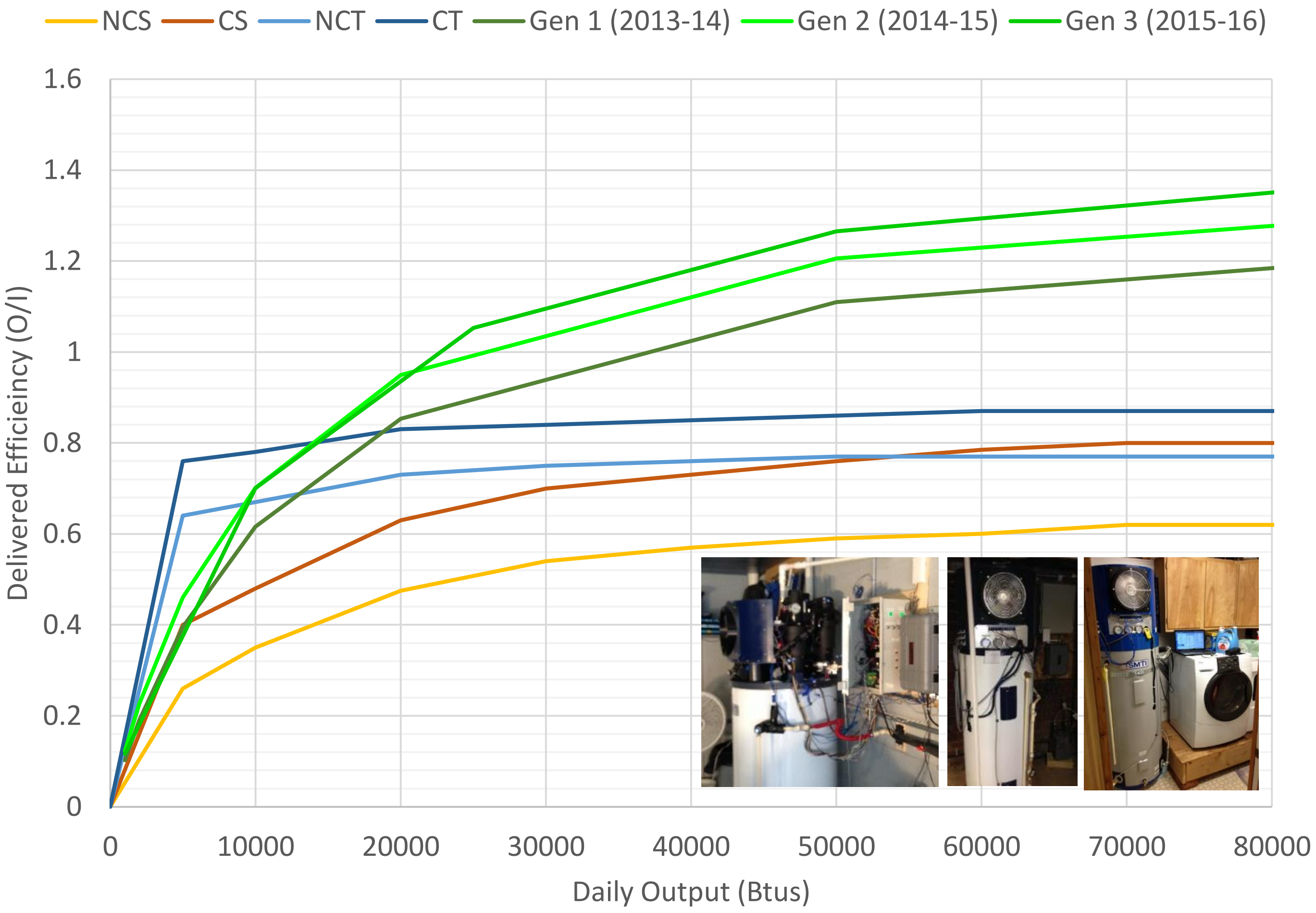
Map from: Baechler, MC, et al. (2010) *Building America Best Practices Series Volume 7.1: Guide to Determining Climate Regions by County*. PNNL-17211

Gas HPWH – Lessons Learned

GHPWH – What Went Well?

Highlights of Prior Gen. Field Testing, gathering ~ 6,000 hrs

- Heat pumps operated well, at/above target COPs in "real world"
- Site specific therm savings greater than 50% over conventional GWH
- Subsequent generations showed improved efficiency and reliability
- COP impact of water/ambient temperatures characterized
- Cooling effect small, ~3,250 Btu/hr (~1kW)



Kosar, D., Glanville, P., and Vadnal, H. "Residential Water Heating Program - Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating - Final Project Report", CEC Contract CEC-500-2013-060, 2013. Link: http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2013-060

Gas HPWH – Lessons Learned

GHPWH – Areas for Improvement in Next Generation

> **Component Reliability**

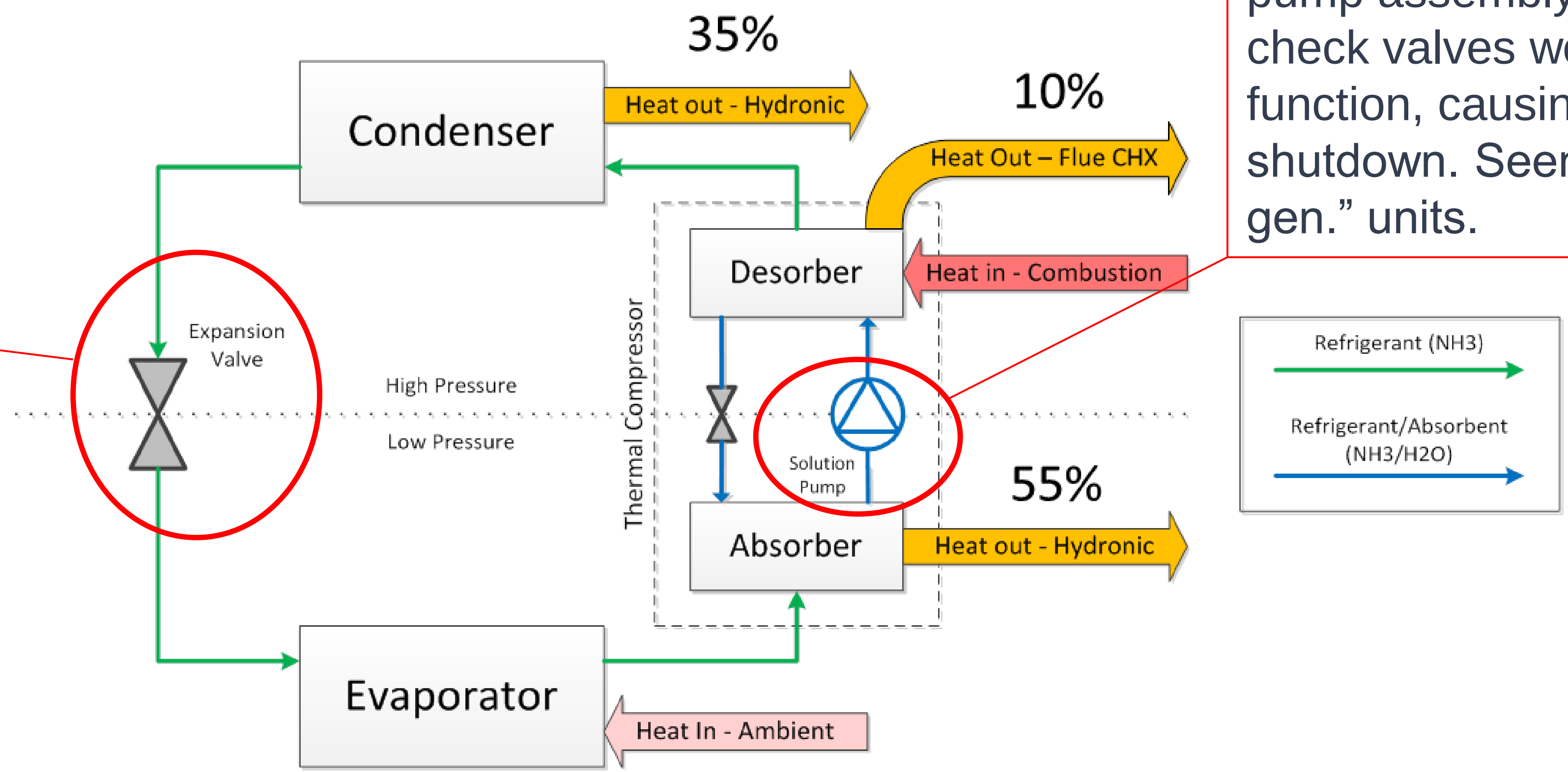
Electronic Exp. Valve:

Initial challenge with EEV selection due to:

- Material compatibility
- Design for temperature glide
- Low NH3 charge/flow
- GHPWH startup control

OTS design selected worked well, however:

- Had long term operational and reliability issues
- Resulted in decreased heat pump performance

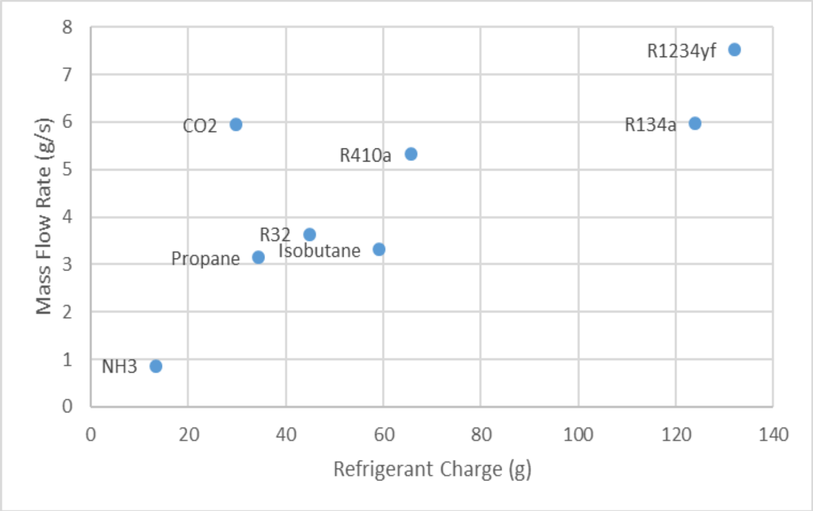


Solution Pump:
With extended operation, pump assembly and check valves would lose function, causing system shutdown. Seen in all "3rd gen." units.

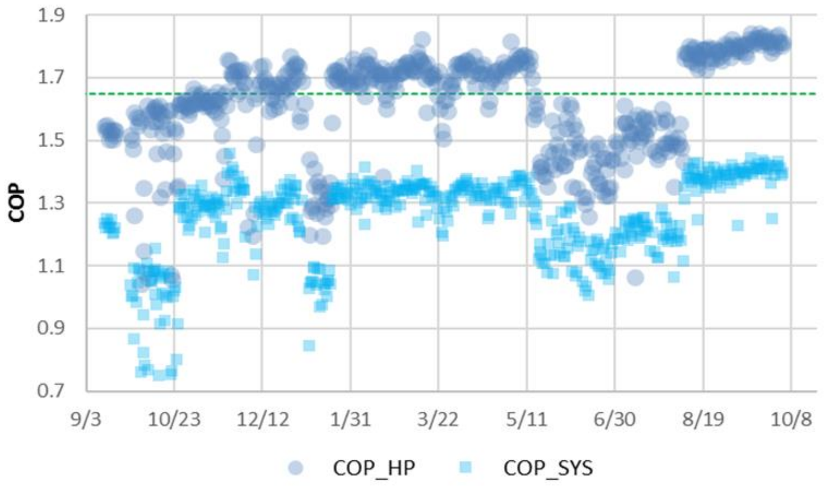
Gas HPWH – Lessons Learned

GHPWH – Areas for Improvement in Next Generation

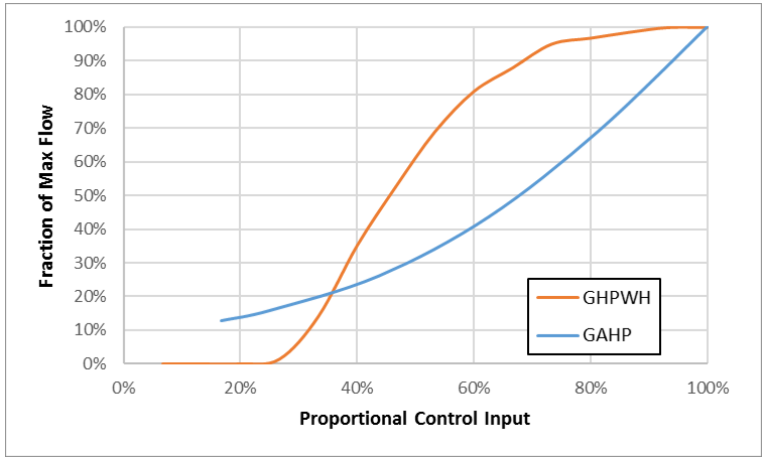
- **Component Reliability – EEV Focus**: New approach was necessary to address pervasive performance issue, novel design developed and proven in extended laboratory testing.



NH3 is inherently low mass/low-flow. Estimated 55-90% lower charge and 73-89% lower MFR in HVAC comparison.



Primary reason for poor performance in extended trials was original EEV after extended operation, despite improvements



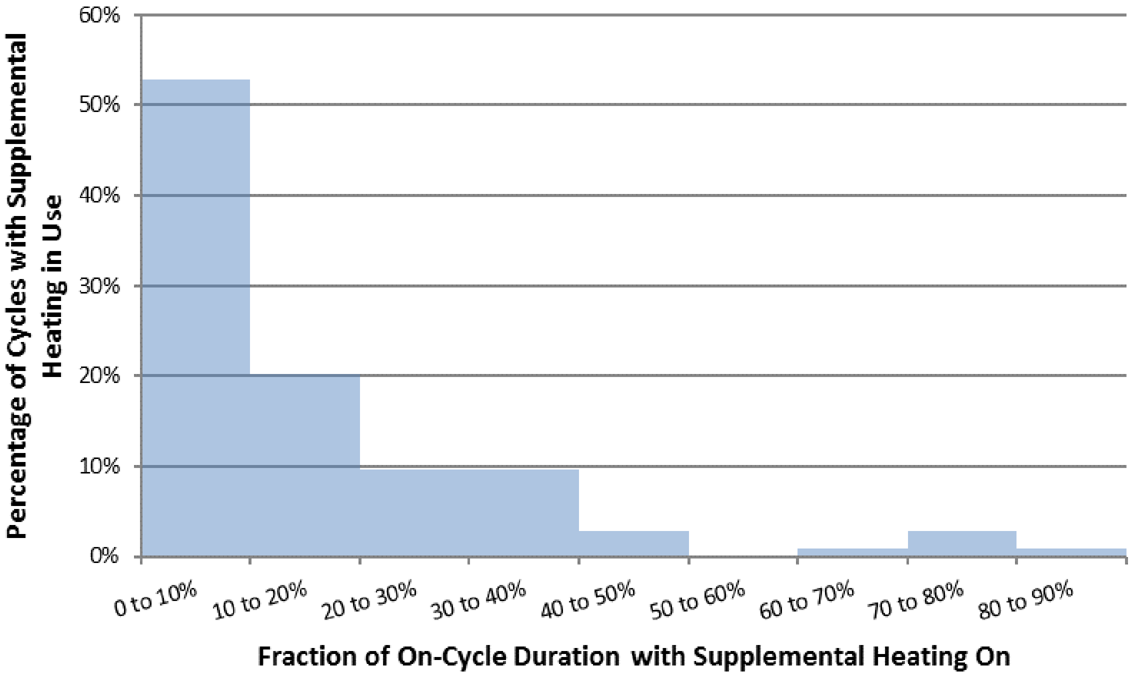
Even when functioning, response was not ideal for process control (non-linear). EEV in companion GAHP development much better

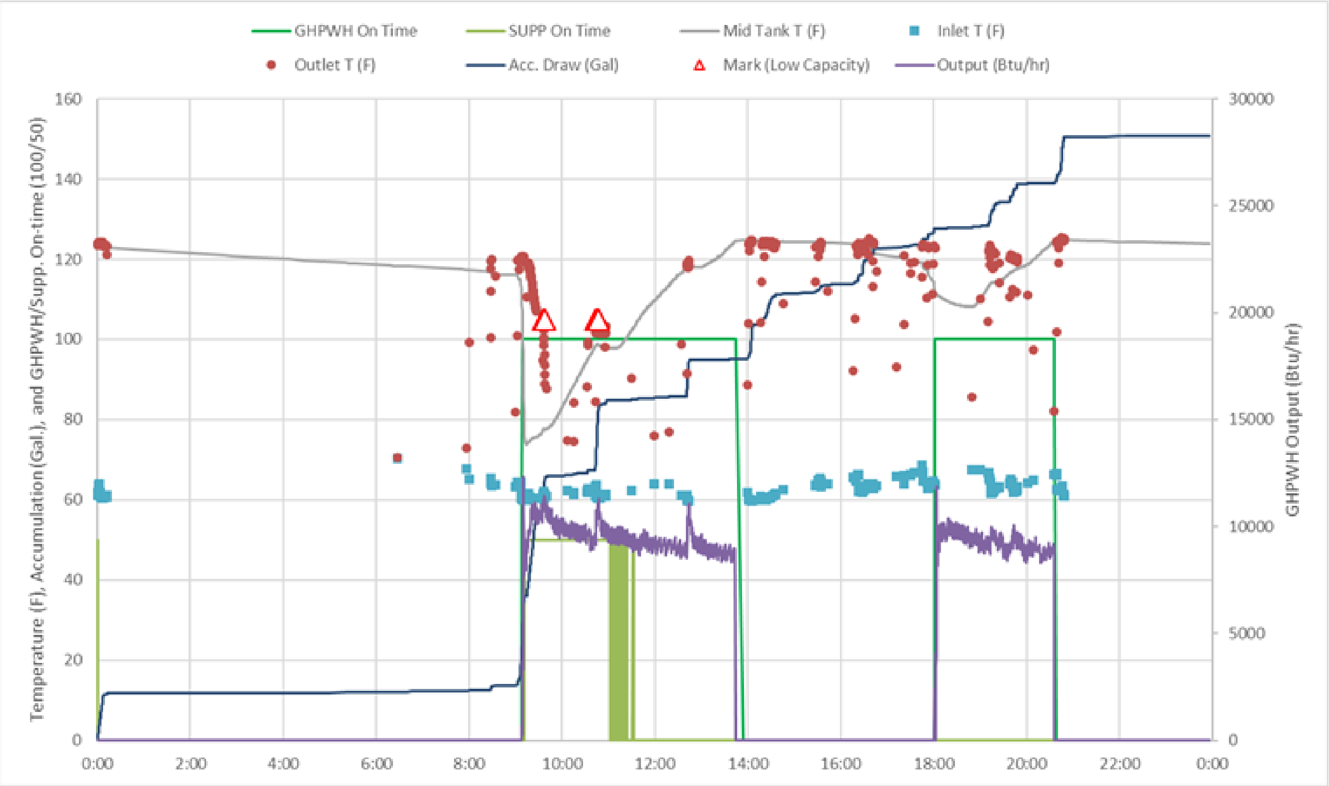
Data source: Hrnjak, P. "Natural Refrigerants in Different Applications", presentation at the ASIA Atmosphere – Natural Refrigerants Conference, Tokyo, Japan, 2014.

Gas HPWH – Lessons Learned

GHPWH – Areas for Improvement in Next Generation

> **Capacity:** With some high usage (> 100 gal/day), several host sites "ran out" of hot water





Next Generation Gas HPWH

Smaller Form Factor:

- Built onto 60-gallon nominal tank, expanding on prior 80-gallon versions.
- Shorter, narrower profile and reduced system weight*
- Designed for lower usage homes and for installation by 1-2 plumbers (not 2-3)

Improved Capacity with Controls:

- “Preemptive” cycling controls improve output capacity, learning from prior testing
- Addition of tank temperature sensors, control algorithms reacting to actual usage and extended standby periods
- Judicious deployment of auxiliary heating
- Further improvements expected within “generation” to balance with UEF

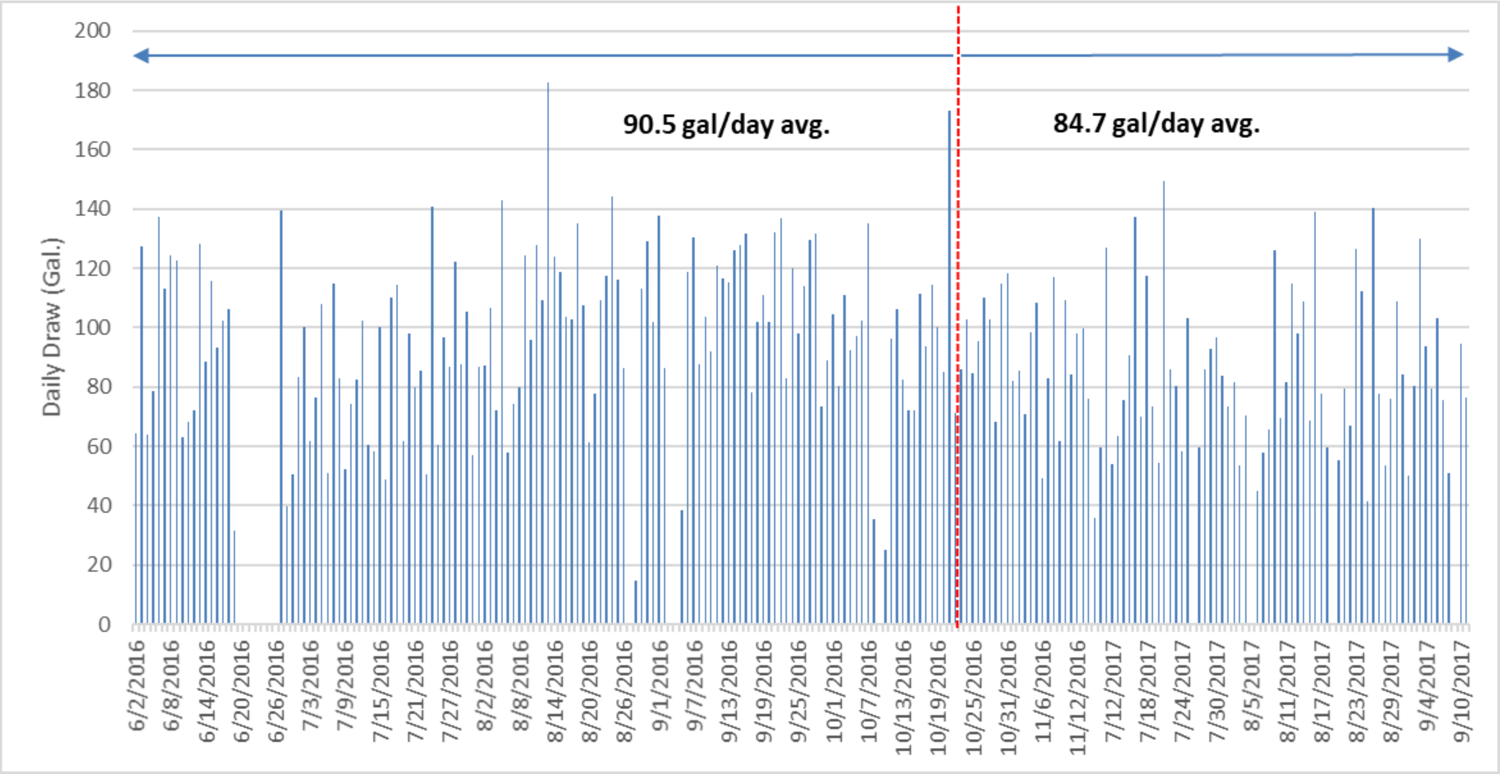
Improved Components, Design:

- *Solution Pump*
    - Improvements in check valve designs, filtration to avoid seating issues after extended operation
    - Other mechanical improvements to pump to improve operation, noise,
    - Move towards standardization of assembly, positioning relative to balance of sealed system
- *Electronic Expansion Valve*
    - New custom EEV implemented in unit, with revision to controls
- *CHX Geometry*
    - In some units, shift away from submerged CHX for reduced cost, system weight.

Height reduced by ~6.5”, diameter by 1.125”, and shipping weight by ~160 lb.

Next Generation Gas HPWH – First Field Trial

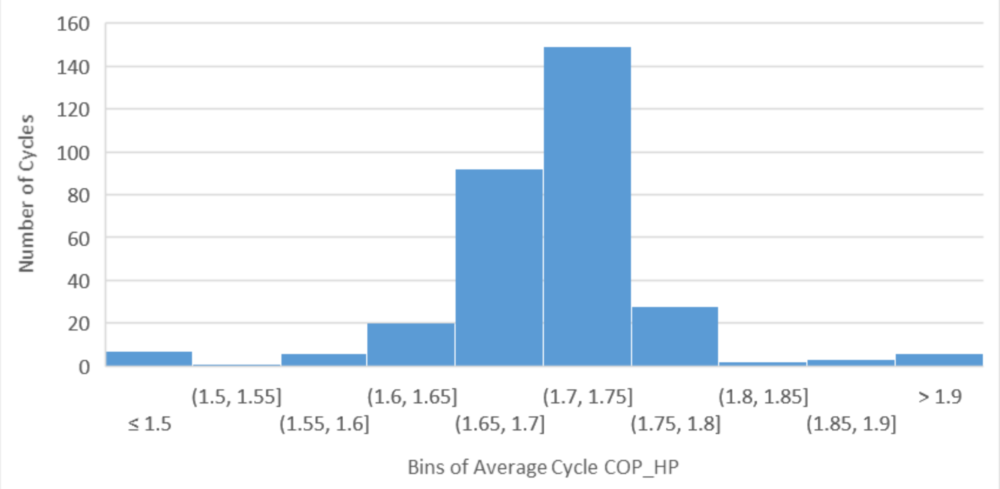
- Birmingham, AL. 1956 Ranch-style home on slab
- Four occupants, two adults, two children
  - Extended stay of relatives
- Baseline monitoring for 5 months, existing equipment 40 gal. / 34 kBtu/h input low-efficiency GSWH.

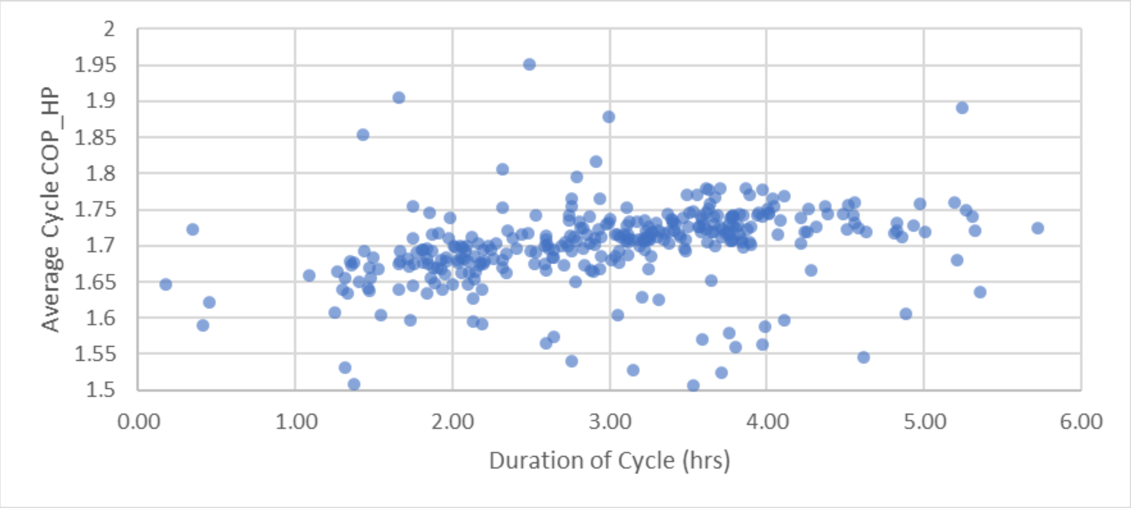


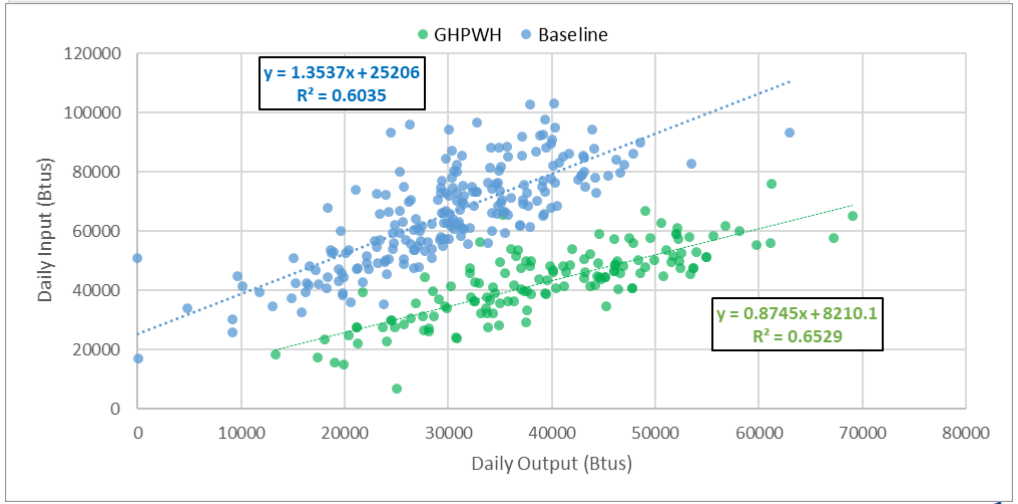
Higher than expected usage measured, LFSHs deployed as add'l measure to limit avoidable capacity issues. Had minor impact for pre/post baseline periods.

Next Generation Gas HPWH – First Field Trial

> **Efficiency:** Operating COP of heat pump has been excellent, 85% of cycles $COP_{HP} > 1.50$. Relatively insensitive to ambient conditions. For mid/high usage homes (per DOE) savings are:
  – 115-145 therms/yr, 45-48% reduction in gas consumption
  – Results are lower than expected, but still good

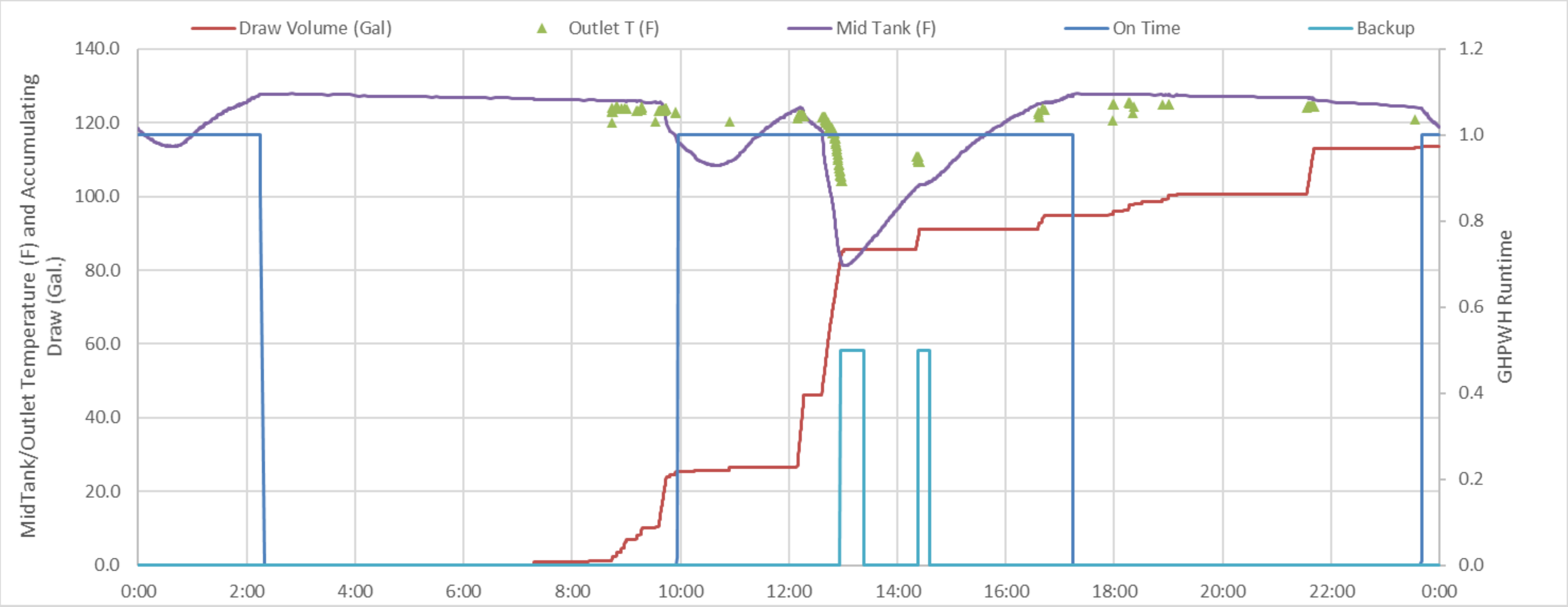






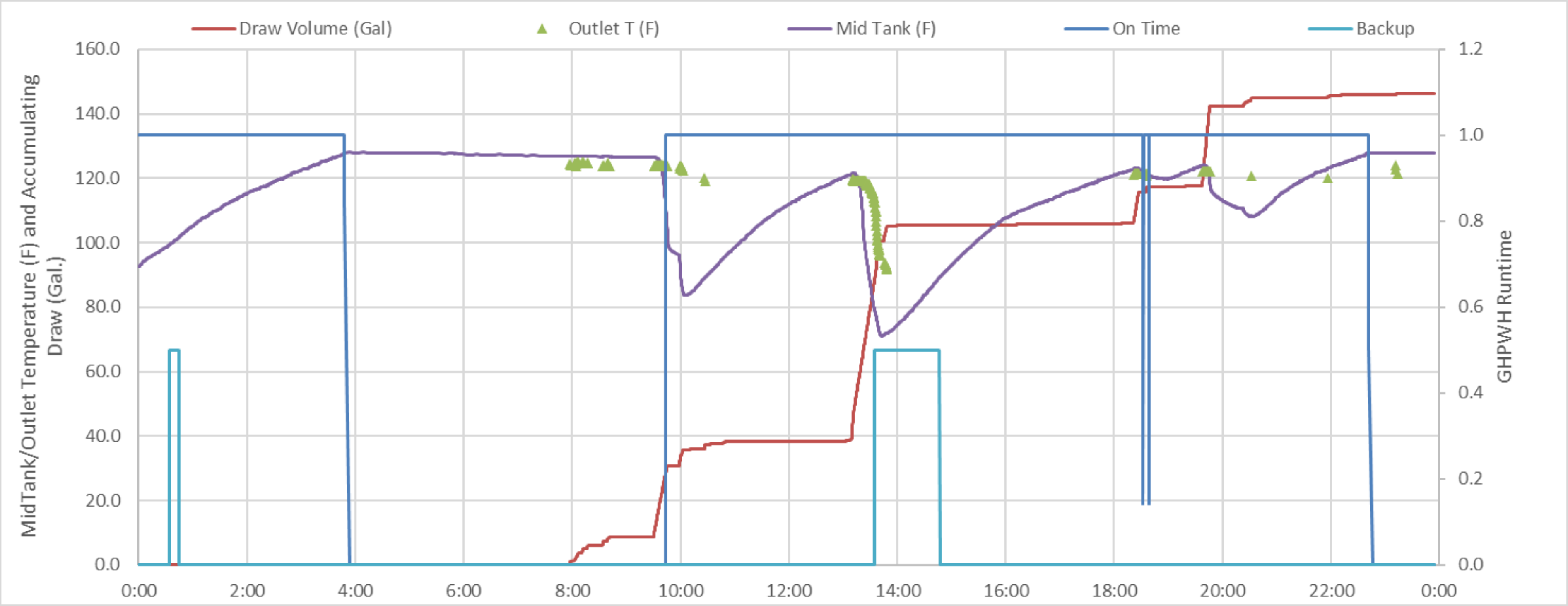
Next Generation Gas HPWH – First Field Trial

- **Improvements:** Improvements in capacity successful, via add'l sensors and new algorithm
  - Host noted in survey regarding satisfaction with capacity: "Very satisfied, we did not run out of hot water when the unit was operating."



Next Generation Gas HPWH – First Field Trial

- **Improvements:** Improvements in capacity successful, via add’l sensors and new algorithm
  - Of course, some extreme events are hard to design for…



Next Generation Gas HPWH – First Field Trial

- **Other Improvements/Issues:**
  - Suppl. heating element is active for ~1h during high demand. Power is 0.8-4.0 kWh/day overall
  - New EEV performed well for > 1,150 hrs., no need for servicing or replacement as with prior trials
  - Solution pump improvements eliminated issues from prior field trials, however new issues arose
    - Unintended consequence of new design/assembly led to belt slippage with time and a vapor lock event
  - Firing rate decreased slightly over trial, de-rating the unit.
    - Gas HPWH was installed in laundry room, could be impact of lint on gas train. Add’l filtration designed as precaution

Next Generation Gas HPWH – Next Steps

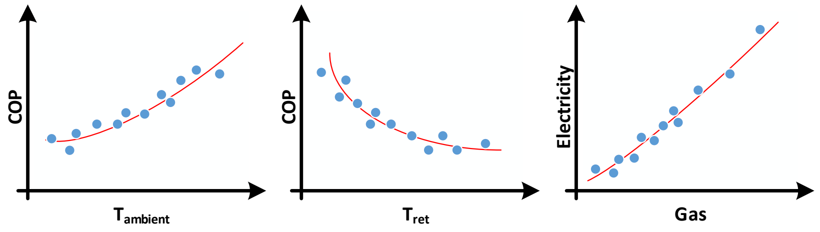
California Next Gen. Gas HPWH Demonstration (Through 2020)

- Demonstrate 50% or greater therm savings over baseline in 5-unit residential demo
  - Baseline monitoring underway, prototype Gas HPWHs built and undergoing AQMD certification for NOx
- Partner with SoCal Gas *Engineering Analysis Center* to perform reliability/emissions testing of add’l prototype
  - Quantify NOx/GHG emissions benefit to South Coast Air Basin
- Develop model/Title 24 Analysis and guidance to reduce codes/standards market barriers, NZEH white paper,
- Perform market research and extensive outreach to key stakeholders – Host at ERC

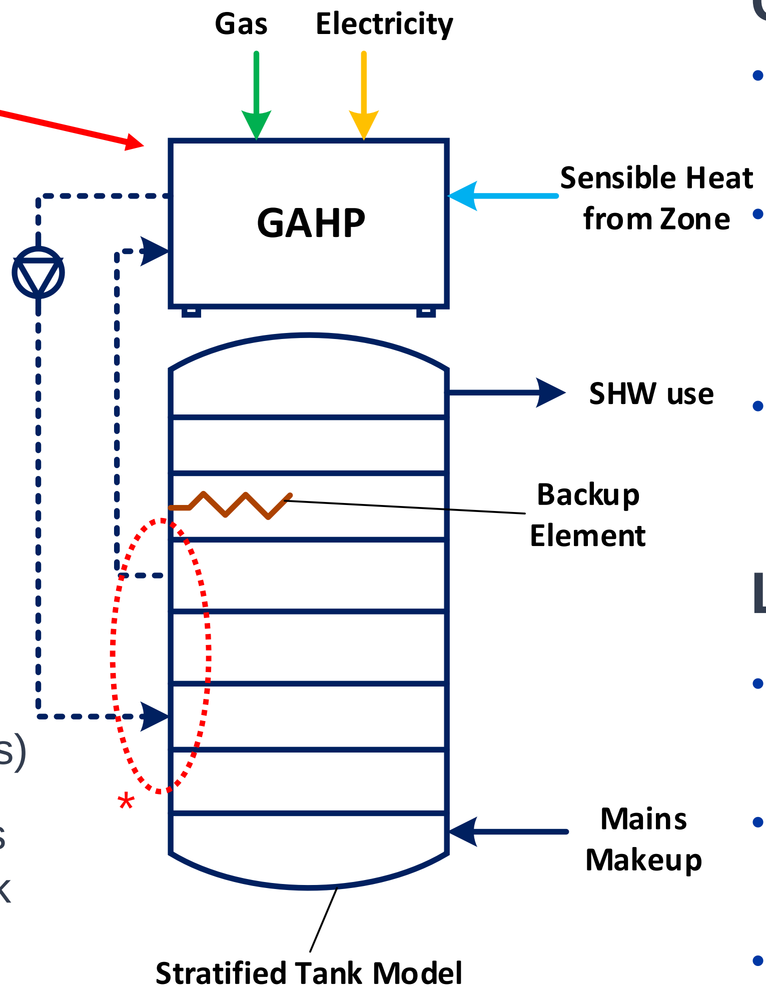
Next Generation Gas HPWH – Standard Models

Custom Plant Object

- Empirical performance model:



- GAHP is a simple water heating device in a plant loop
- GAHP module determines heating and cooling capacities as a function of temperatures for each time step using an EMS/ERL program (script inside EnergyPlus)
- Balance of system are standard EnergyPlus components (indirectly heated stratified tank and plant controls)



Challenges:

- Heat transfer on the tank side is handled crudely (effectiveness model*)
- Controls strategies between backup element and GAHP heater are challenging to implement
- Model is not portable (i.e., not part of EnergyPlus). Compatibility may break with new releases.

Long Term Needs:

- Need a generalized model for heat pump water heaters
- Better handling of immersed heat exchangers in EnergyPlus
- Robust control over water heater behavior

Gas HPWHs – Transforming the Market

With *product turnover* and *limited infrastructure* for low-efficiency models, **opportunity for market transformation**:

- Vast majority of residential water heaters are not maintained and have emergency replacements (82% of sales)
  - Typical life expectancy is 8-12 years
  - 37% are 10+ years old
- EPA estimates that about ½ are sold through distributors, the remaining half through retailers:
  - 34% homeowner for plumber install
  - 52% DIY install
  - 14% to building owners/remodelers
- Opportunity for non-emergency changeouts?
  - Alleviates the "what's on the plumbers' truck" issue

* Source: Data reference from EPA, Image source: Plumber Magazine

Gas HPWHs – Transforming the Market

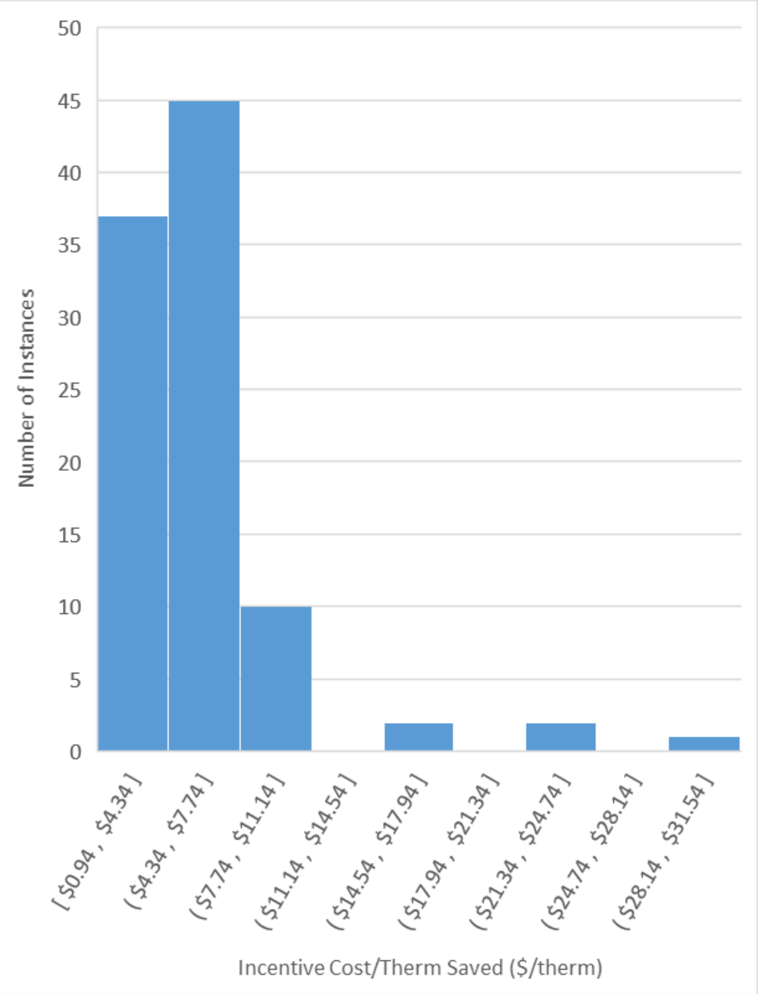
Hope for the Gas HPWH?

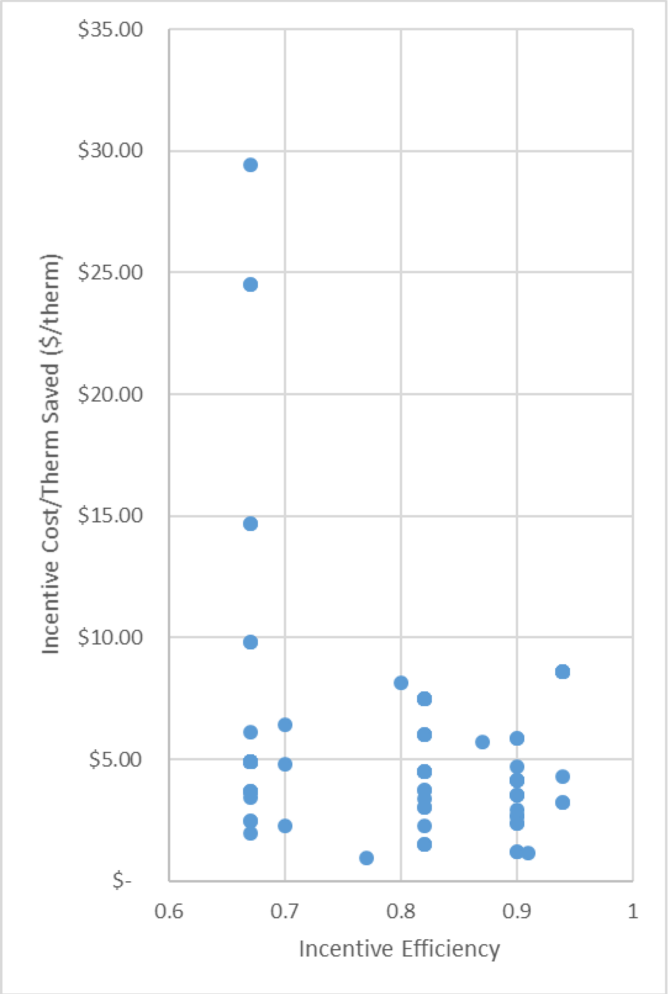
Assume the following for a typical home:

- Homeowner consumes 84 gal/day of hot water, 58 F in and 125 F out (per DOE standard for High Use)
- Original water heater is lowest possible efficiency for new storage products, 0.62 EF
- $1.00/therm

Two tiers of efficiency:

- ~$2/therm and $5/therm
- Vast majority of gas utilities with incentives pay ~$5/therm saved for 0.67



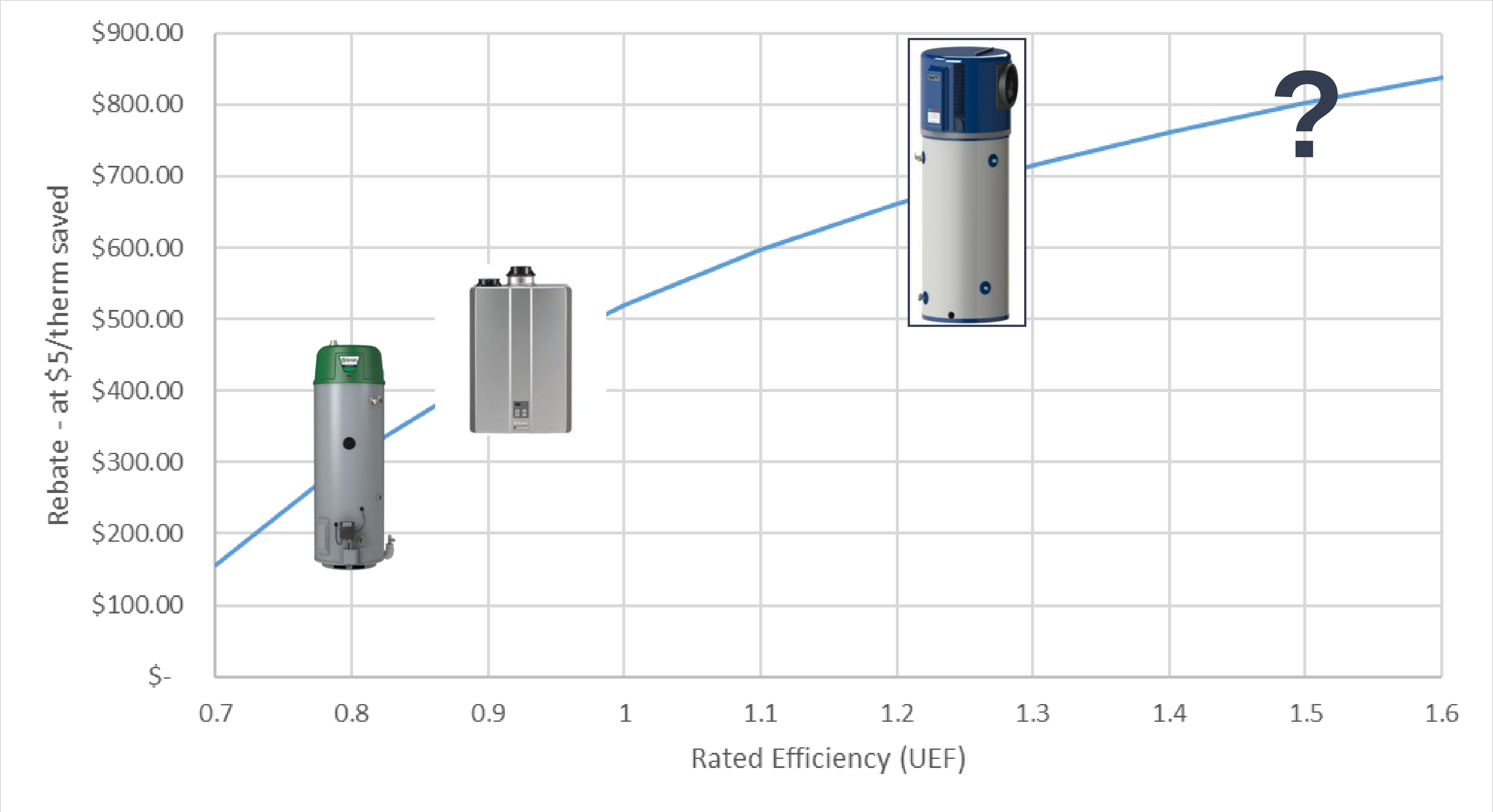


* Statistics on Gas Water Heating Programs from CEE's *2017 CEE Residential Water Heating Program Summary*

Gas HPWHs – Transforming the Market

Using $5.00/therm saved

- Most common incentive, based on $100 for 0.67 (EStar)
  - Estimated 20 therms saved/year with prior analysis
- Lines up with common incentives for condensing storage/non-condensing tankless and condensing tankless
- 1st gen. Gas HPWHs receive ~$650
  - < 3 year consumer payback



References for More Information

Published Materials:

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Questions?

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