the Energy to Lead

Residential Gas Absorption Heat Pump Water Heaters: Field Trials and Extended Life Testing of Packaged Prototypes

Paul Glanville

ACEEE Hot Water Forum

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Portland, OR

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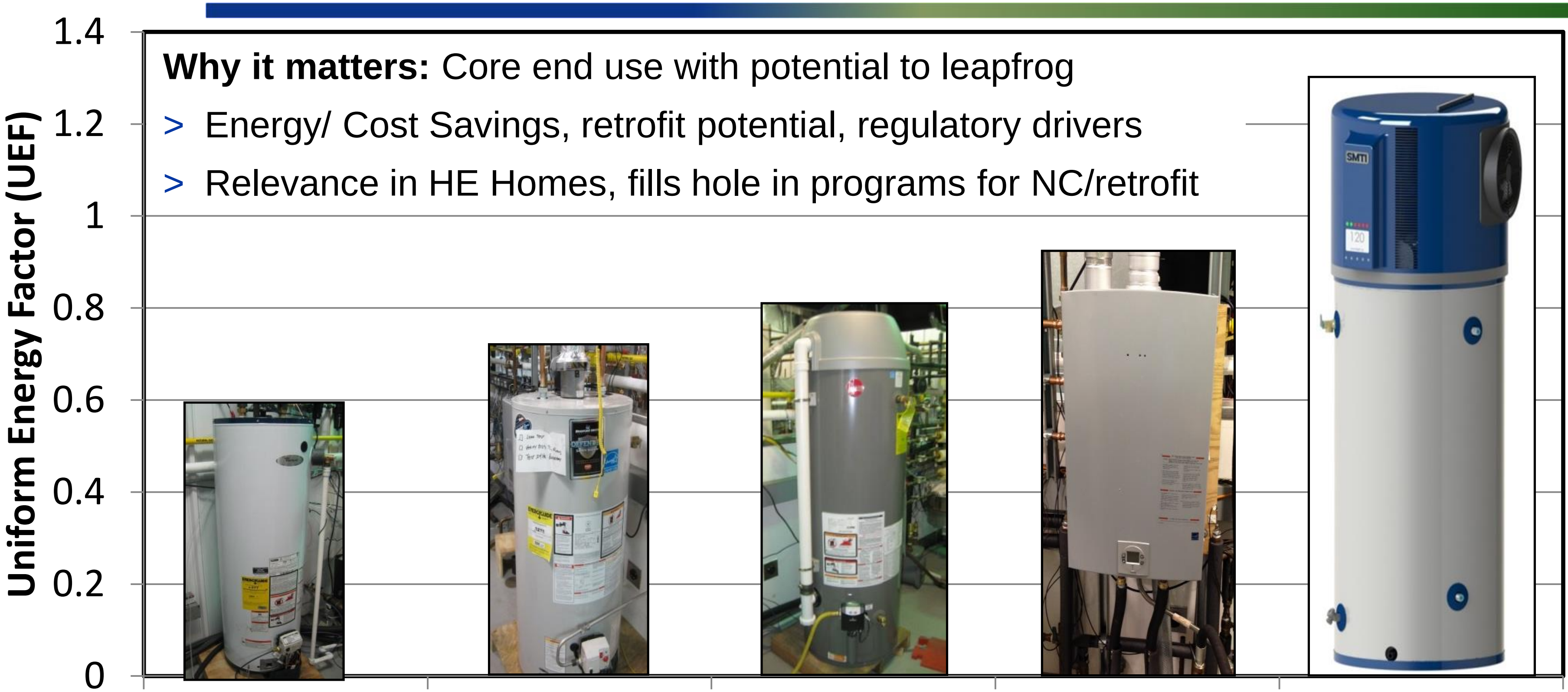
Residential GHPWH – Energy Savings

Why it matters: Core end use with potential to leapfrog

- Energy/ Cost Savings, retrofit potential, regulatory drivers
- Relevance in HE Homes, fills hole in programs for NC/retrofit



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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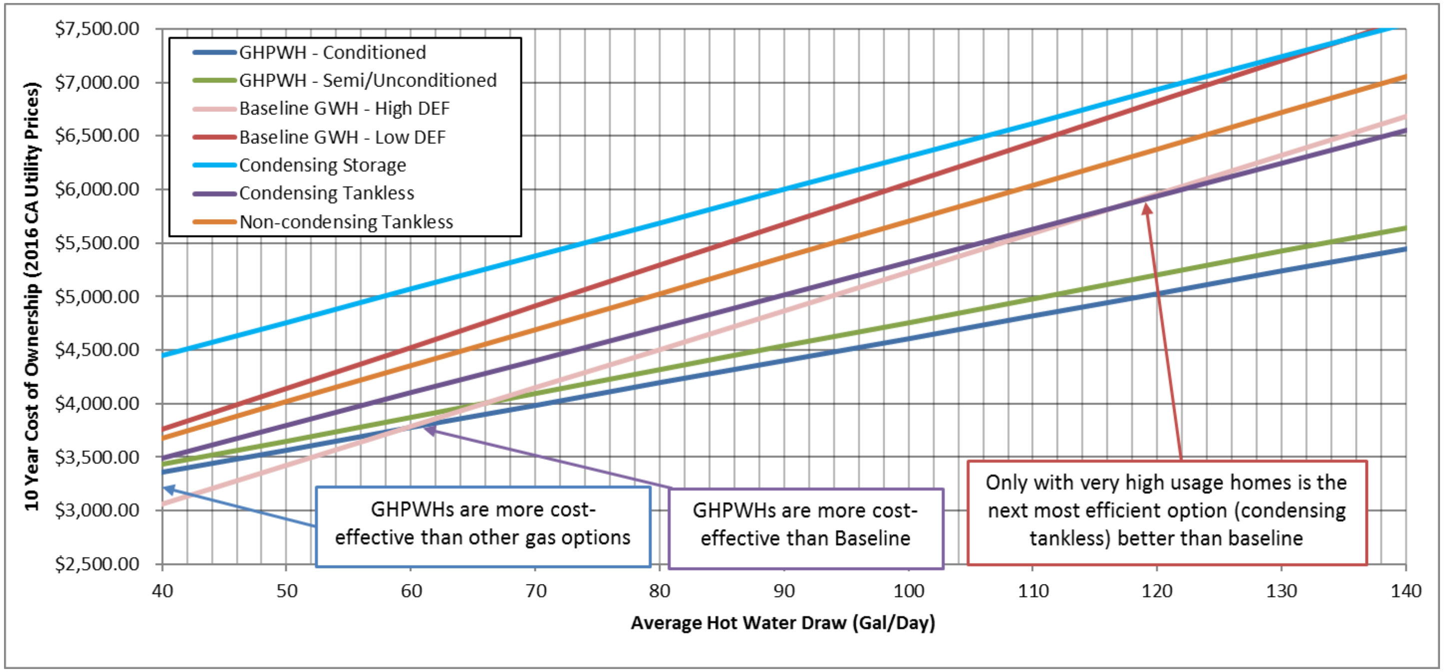
Residential GHPWH – Cost Savings

Energy and Operating Cost Savings

- For standard “High Usage” category (84 gal/day), GHPWHs have projected 1.2 < DEF* < 1.3, > 50% savings versus baseline, can be competitive despite low NG prices**.
- With recent min. eff. guidelines ***GHPWH leapfrogs condensing storage.***

Higher equipment cost than baseline (3-4X), but comparable installation cost:

- Similar form factor.
- No upsize in gas piping.
- 15A / 120 VAC service.
- Small plastic diameter venting



*”Delivered Efficiency Factor” defined as daily energy efficiency as-installed, including standby heat losses.
** Chart assumes 2016 CA average electricity/natural gas rates

Residential GHPWH – System Specs

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	1.3 Energy Factor	Projected
Tank Size	60/80	Gallons
Backup Heating	Experimenting with backup currently – 1.25 kW	
Emissions (projected)	10 ng NO_x/J	Based upon GTI laboratory testing
Installation	Indoors or semi-conditioned space (garage)	Sealed system has NH3 charge < 25% allowed by ASHRAE Standard 15
Venting	½” – 1” PVC	
Gas Piping	½”	¼” feasible, req. codes
Estimated Consumer Cost	<$1,800	

Information and graphic courtesy of Stone Mountain Technologies, Inc.

Residential GHPWH – Overview

GHPWH Development: Brief history shown below.

- Goal to develop scaled-down heat pump for integration atop/aside from standard storage tank, using **easily manufactured design** to assure low-cost.
- Several components not off-the-shelf, due to size and/or NH3 compatibility – several custom components under continuous design improvement following lab/field tests.







2010 — 2013 — 2014 — 2015 — 2016 →

GHPWH R&D* – Two generations of packaged lab. Proof-of-Concept GHPWH Units, then refined design through extended lab testing.

GHPWH Early Field Testing,*** –** Residential sites in TN, OR, WA, and ID, using 2nd/3rd Gen. Prototypes

Extended Life & Field Testing – Improve key component reliability and solicit stakeholder feedback

* 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.

** Glanville, P., Vadnal, H., and Garrabrant, M. (2016), *Field testing of a prototype residential gas-fired heat pump water heater*, Proceedings of the 2016 ASHRAE Winter Conference, Orlando, FL.

*** Glanville, P. and Vadnal, H., (2016) Field Evaluation of Residential Gas-Fired Heat Pump Water Heaters, report prepared for the Northwest Energy Efficiency Alliance.

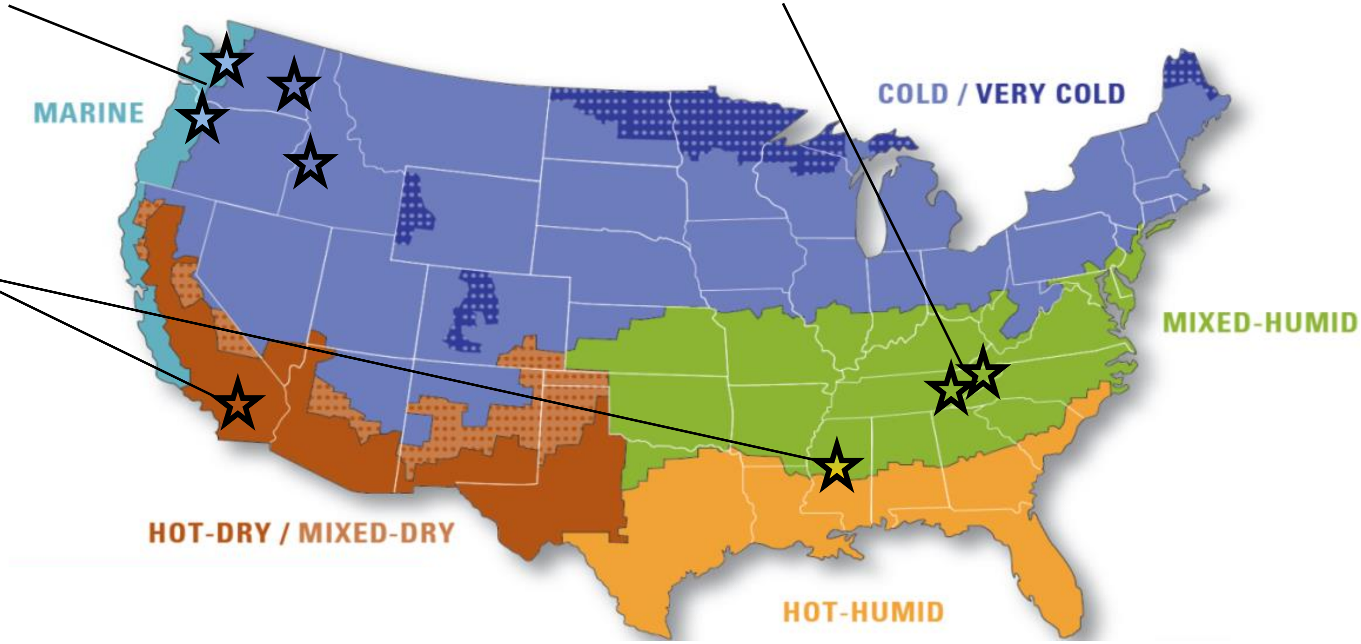
Residential GHPWH – Demonstrations

Location of 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

Residential GHPWH – Demonstrations

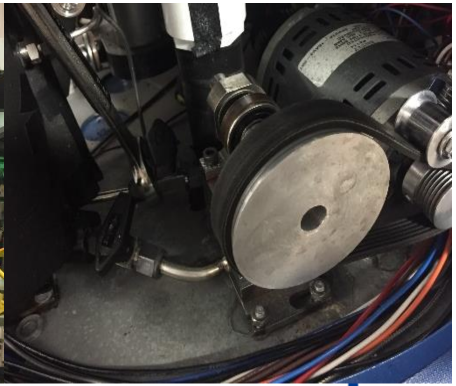
Highlights of 2nd/3rd Gen. Field Testing:

> Heat pumps operated well, at/above target COPs in “real world”
> Site specific therm savings greater than 50% over conventional GWH
> COP impact of water/ambient temperatures characterized
> Cooling effect small, ~3,250 Btu/hr (~1kW)
> EEV/Solution pump reliability challenge for all units tested
> Capacity an issue during infrequent, extreme loading events. Supplemental heat was used 12%-32% of cycles.
> End users noticed noise in some cases, nuisances OK overall
> Installation contractors noted ease of retrofit, except for unit size

Residential GHPWH – 4th Generation

Extended Life and Reliability Testing:

- Support to install and perform extended life testing of Six GHPWH prototypes
  - Five units from prior field testing
  - One purpose-built for reliability/extended testing
- Reliability/Lab testing, including:
  - Practical infrastructure concerns, quantifying condensate production, maintenance issues.
  - Including revision to controls hardware/software to improve startup reliability and hot water capacity, and identifying bugs.
  - Identifying additional failure modes, operational issues through accumulating operating hours on automated test rigs.
  - Incorporation of redesigned/improved components into prototypes and on test stands: electronic expansion valves and solution pumps.



Residential GHPWH – Infrastructure

Evaluating Gas Infrastructure: Venting

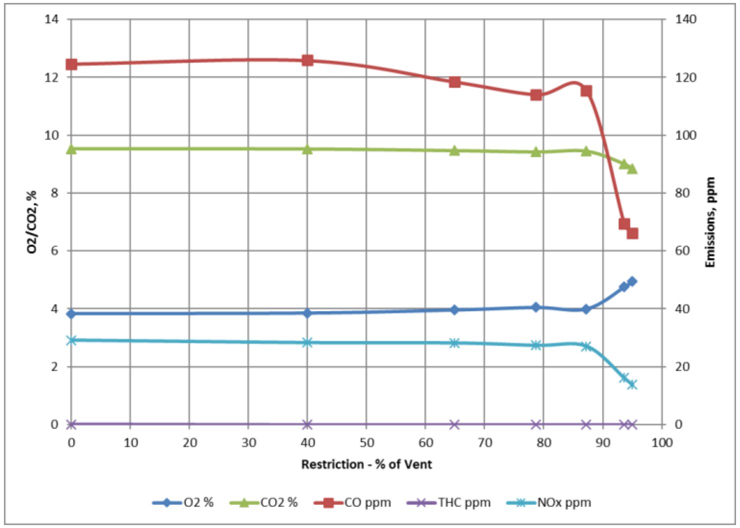
- As-built to date, the GHPWH is a *Power Vent* system. *Direct Vent* is possible but advantage is small:
  - GHPWHs installed in semi/un-conditioned spaces
  - Small impact on ventilation/makeup air - very small combustion air requirement, ~1.4 SCFM*
- With small diameter venting, installation can be straightforward. For PVC, a design 1” W.C. drop is:
  - 43.4 equivalent feet of ¾” Sch 40 venting
  - 177.3 equivalent feet of 1” Sch 40 venting
- GTI experimented with blocked vent and blocked condensate drainage conditions, to evaluate prototype response.
  - For vent, startup with wide open to 95% closed
  - Simulated clogged and “slugging” condensate drain

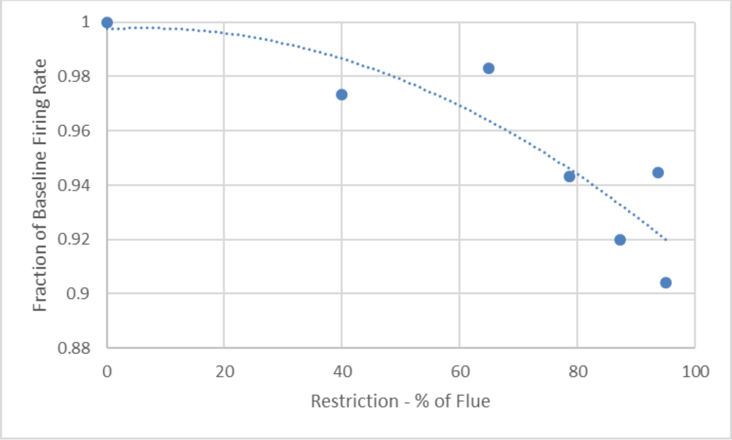
* GHPWH is single stage combustion, generally firing with ~30% excess air.

Residential GHPWH – Infrastructure

Evaluating Gas Infrastructure: Venting

- Vent blockage did not prevent system startup, normal operation up to 95% blocked
  - Near closed, emissions impacted
  - With back pressure, slight de-rating
- Condensate production during normal operation measured at 0.06 GPH (~1 cup)
  - Aligns with *rule of thumb* of 1.0 GPH/100,000 Btu/hr firing rate
  - Sudden condensate blockage does cease operation, backs up within 12.5 min., unit responded with automatic shutdown
  - With partial blockage (2/3 ball valve closed), performance and emissions are not affected. Slight increase in condensate rate (0.006-0.007 GPH) – greater contact with cool condensate

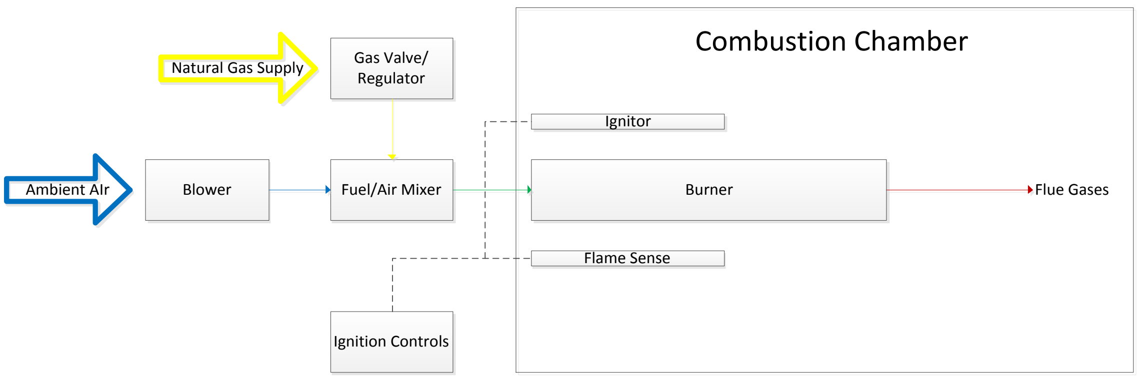


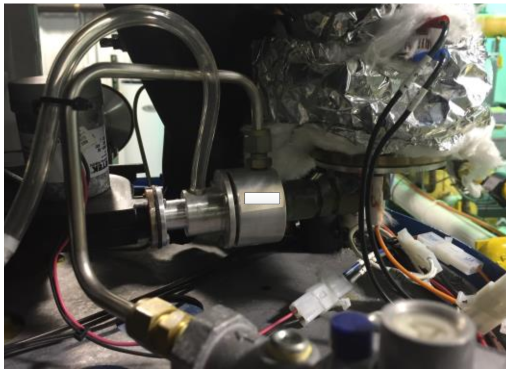


Residential GHPWH – Infrastructure

Evaluating Gas Infrastructure: Gas Line

- Majority of gas water heaters, low-efficiency storage, use ½” gas lines – max capacity* ~95 kBtu/h
- For 6.5 kBtu/h GHPWH, more than adequate. Even ¼” piping would be OK if permitted by code (old muni codes allowed for gas lighting). Sizing ¼” Sch 40 piping:
  - For 545 ft. equivalent length, GHPWH requires only 30% of pipe capacity
- However, small gas flow could be influenced by changes in line pressure from larger equipment cycling on/off
  - Combustion could be susceptible to perturbations communicated through regulator





* Assumes 0.5” W.C. drop over a 30 ft. length per National Fuel Gas Code

Residential GHPWH – Infrastructure

Evaluating Gas Infrastructure: Gas Line

> GTI ran two sets of tests: startups with decreasing line pressure and normal firing with drop in line pressure, repeating to confirm result
  - Startup with nominal 7” W.C. line pressure and decreasing by 1” W.C” increments. Unit ignited for startup down to ~0.1 W.C.” above the manifold setting with a few retries.
  - While firing, line pressure was decreased and unit maintained operation down to 2.25” W.C. *below* manifold setting.

> Results suggest GHPWH could:
  - Operate in region with low pressure distribution (e.g. San Francisco) without issue
  - Sustain operation during drops in line pressure below manifold setting

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Residential GHPWH – Capacity

Balancing Capacity with Efficiency

> As GHPWH technology is adopted, some end users may be acclimated to fast recovery time (or no recovery time, tankless).

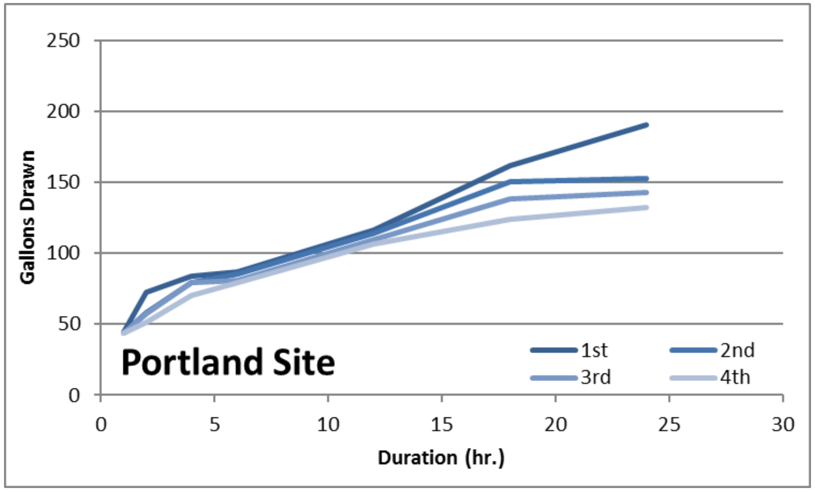
> Integrated HPWHs generally do not load follow, req. more storage.

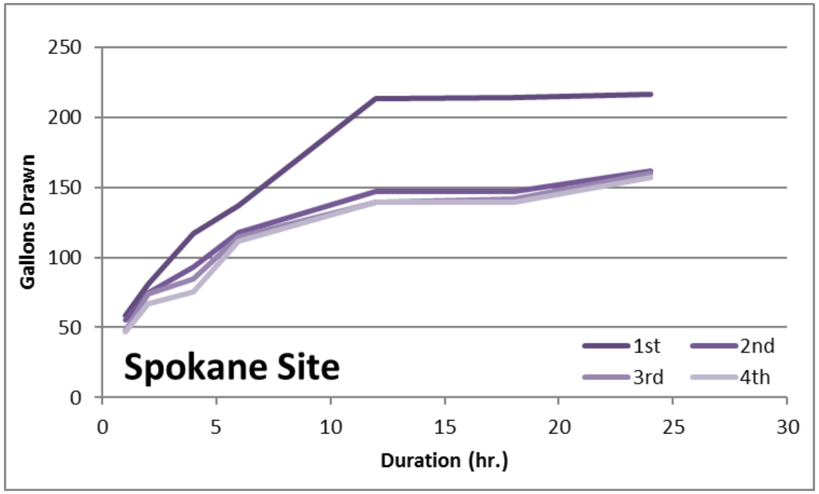
  – Constraint is size of unit, retrofittability concerns

> Using "moving window" method, baseline data can be used for system sizing. Cumulative draw for worst case sequence (and 2nd worst, etc.) are used to infer options for output/storage sizing.

  – Prior studies have looked at both residential and commercial*

  – Sites in Pac. NW had above average consumption, over 10 gal/person-day above regional average, stressed GHPWH at times



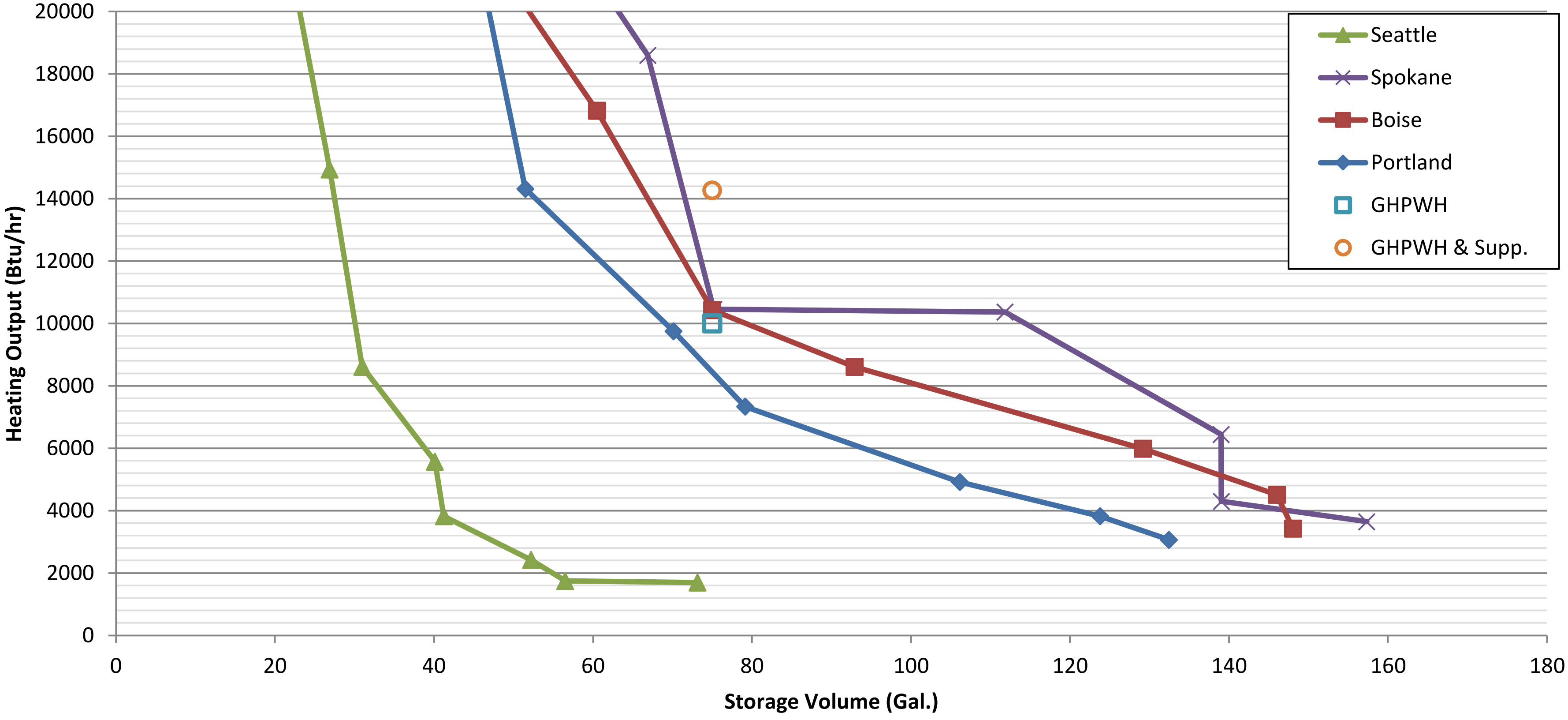


*Hiller, C, and Johnson, R, "Establishing Benchmark Levels and Patterns of Commercial Hot Water Use – Hotels", Results of ASHRAE Research Project RP1544, April

Residential GHPWH – Capacity

Balancing Capacity with Efficiency

> **4th Worst Case:** For a 67 F rise, heating rates are calculated for each increasing interval



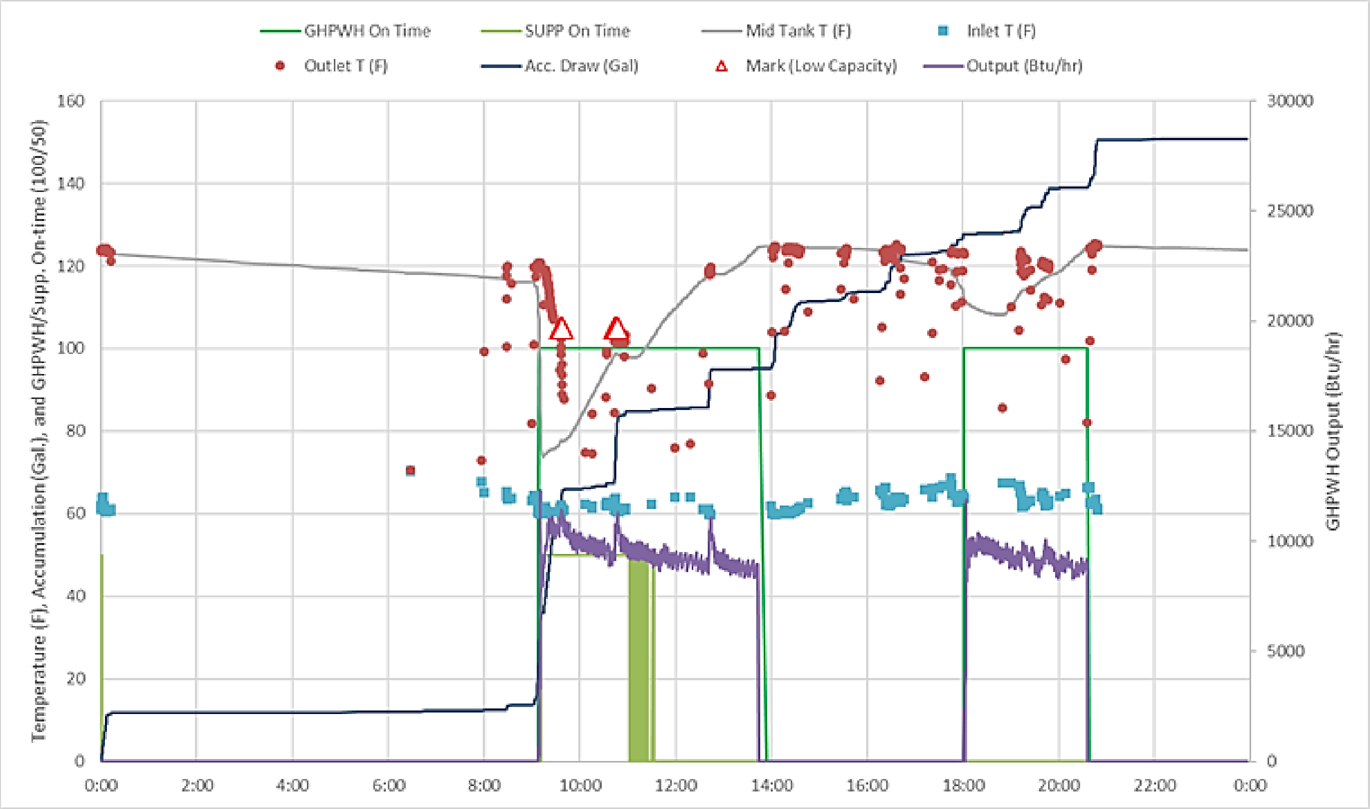
Residential GHPWH – Capacity

Balancing Capacity with Efficiency

Examined field test data to identify ways to avoid loss of capacity (Tout < 105 F) through controls and more judicious use of supplemental heating, tested options in lab and modeling.

Several days at Portland-site had 140+ gal/day, difficult for most storage water heaters to handle.

During field test, unit “ran out” of hot water with aggressive morning loading.



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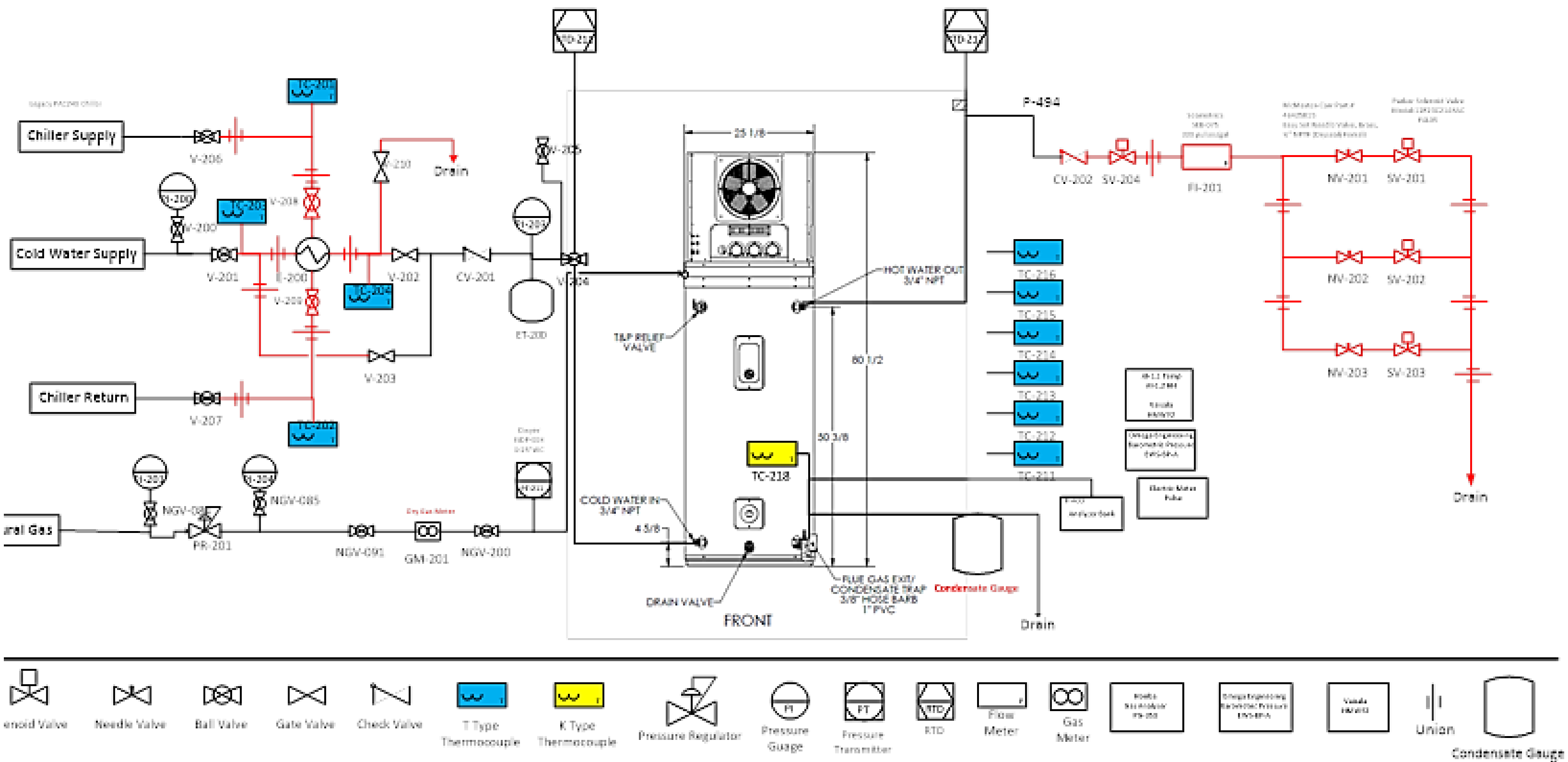
Residential GHPWH – Capacity

Balancing Capacity with Efficiency

Setup one GHPWH prototype on test stand for simulated use testing (DOE and Custom patterns)



Residential GHPWH – Capacity

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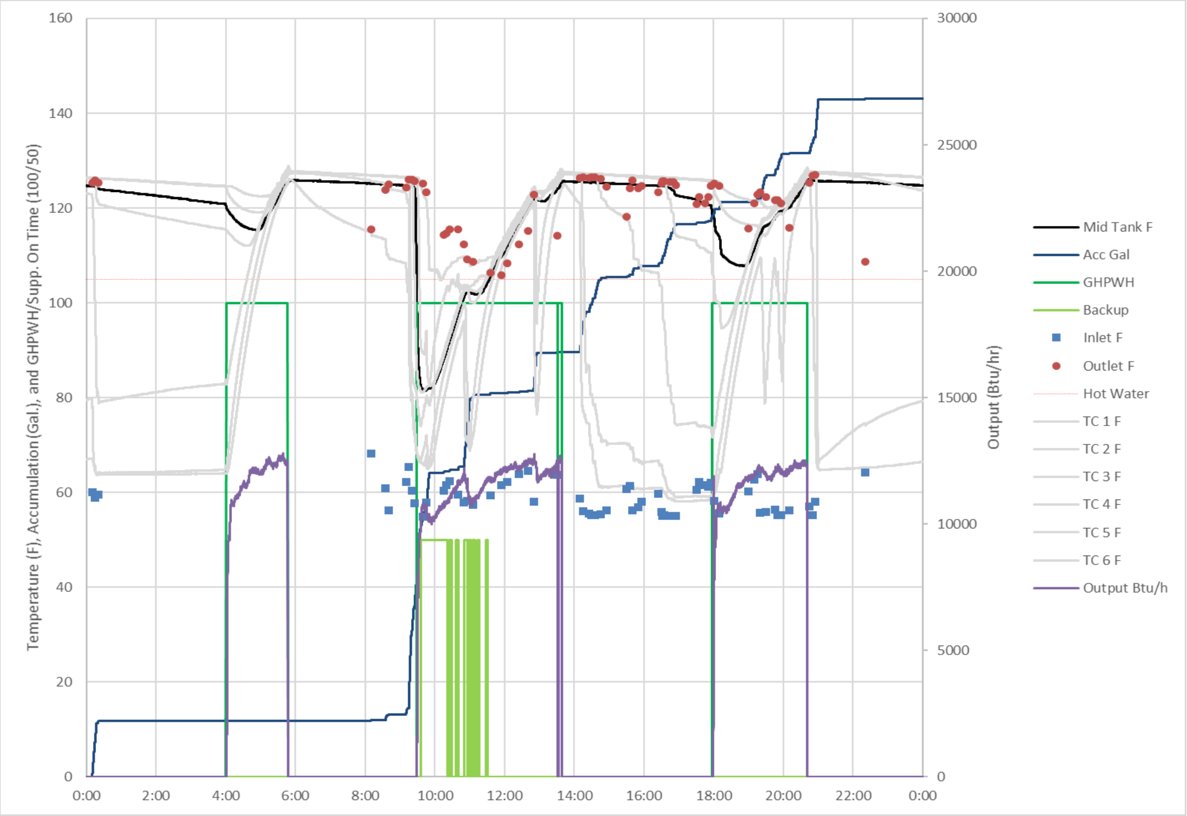

Recreating these patterns in a laboratory setting permitted evaluation of varied control strategies.

A more “pre-emptive” control strategy along with slightly more use of supplemental heating kept temperatures usable despite aggressive morning loading.

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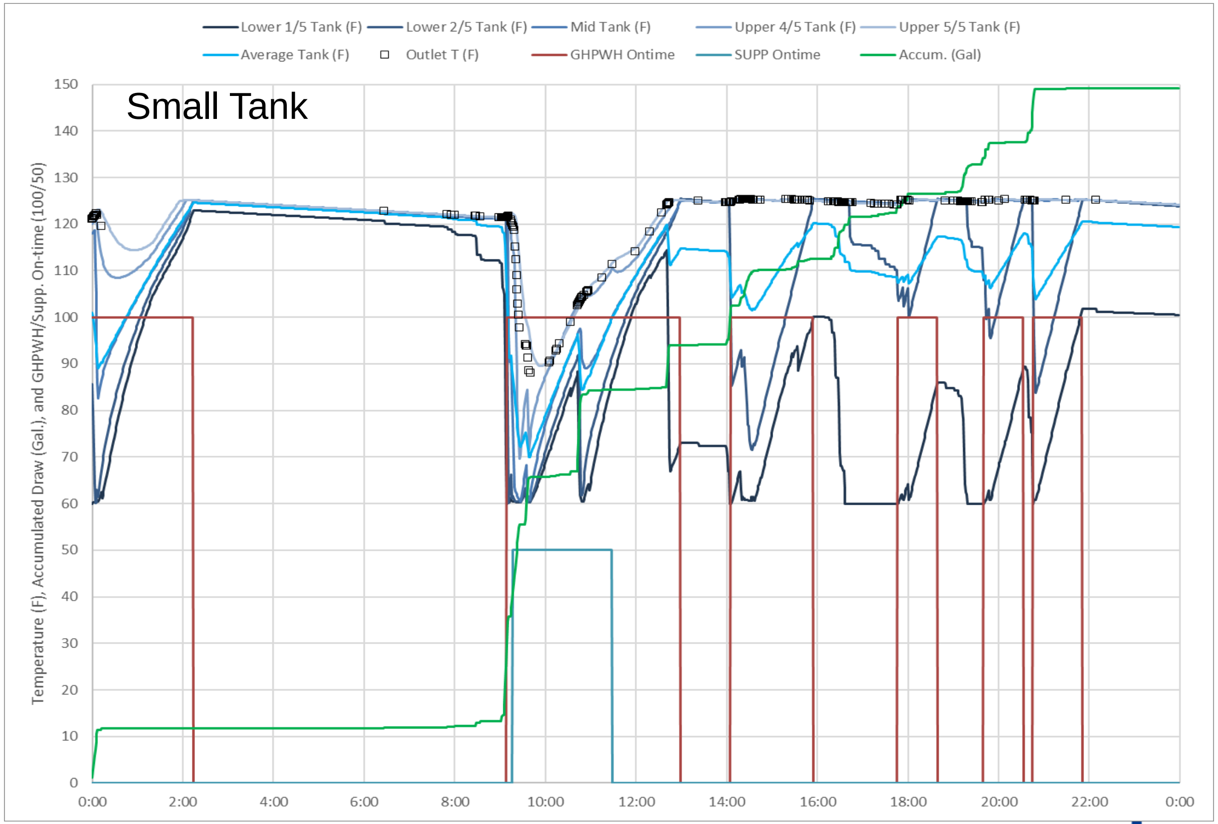
Residential GHPWH – Capacity

Balancing Capacity with Efficiency

Examined field test data to identify ways to avoid loss of capacity (Tout < 105 F) through controls and more judicious use of supplemental heating, tested options in lab and modeling.

Calibrating a dynamic GHPWH model to quickly evaluate numerous loading and, more importantly, varied design features.

Model indicates a reduced size tank, 60 gal from 75, would not be suitable for this loading, despite enhanced controls and more aggressive supplemental heating. Also daily DEF drops from 1.2 to 1.0 and electricity consumption increases by 34%.



Conclusions and Next Steps

Conclusions

- GHPWHs capable of as-installed energy savings of 50% or greater was demonstrated in multiple climate zones, with improvements from generation to generation.
- A GHPWH with these savings could be economically attractive despite low fuel prices and moderate loading.
- Further improvements in reliability and controls have yielded incremental and sustained efficiency improvements.

Next Steps

- Continue monitoring sites into 2017, bringing additional 4th generation demonstrations on with focus on milder climates.
- Solicit additional input on category from stakeholders, including end users, contractors, and industry.

Questions & Answers

Gas Technology Institute

1700 S Mount Prospect Rd,
Des Plaines, IL 60018, USA

www.gastechnology.org

@gastechnology

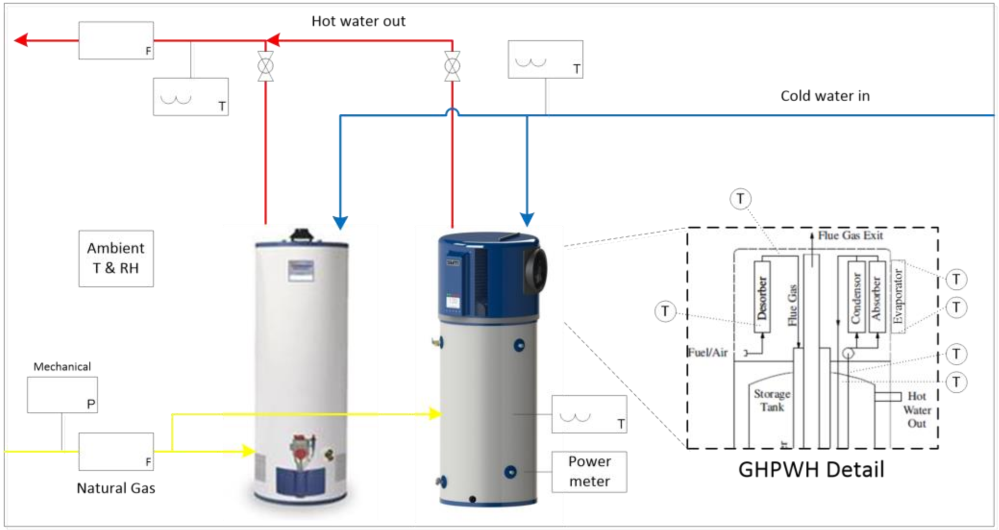
http://www.stonemountaintechnologies.com/

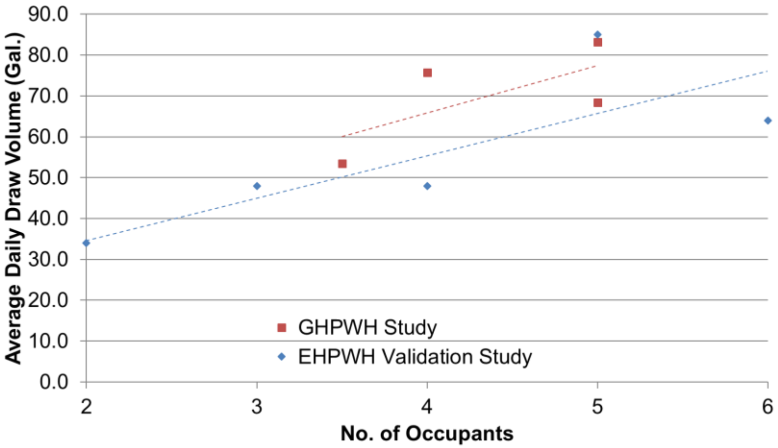
Backup Slides

Residential GHPWH – Demonstrations

Sites and Measurements:

- For Pac. NW study, homes had slightly above average occupancy and usage.
- Sites covered range of characteristics.
- M&V focused on system and absorption cycle.





Existing WH	Seattle	Spokane	Portland	Boise
GHPWH Location	Conditioned Basement	Garage	Garage	Garage
Occupants	3-4, Two adults with one teenager permanently and one college-aged child periodically	4, Two adults and two children under 3 years old	5, Two adults and three children under 6 years old	5, Two adults and three children
Tank Size (Gal.)	40	34	50	40
Firing Rate (Btu/hr)	36,000	100,000	40,000	40,000
Age	14+ Years	18 Years	0 years	13 years
Rated / Avg. Delivered EF/TE	0.59 / 0.56	96% / 0.91	0.62 / 0.47	0.59 / 0.45
Average Inlet T (°F)	53.3	61.2	54.8	58.7
Average Outlet T (°F)	123.8	122.8	115.2	138.0

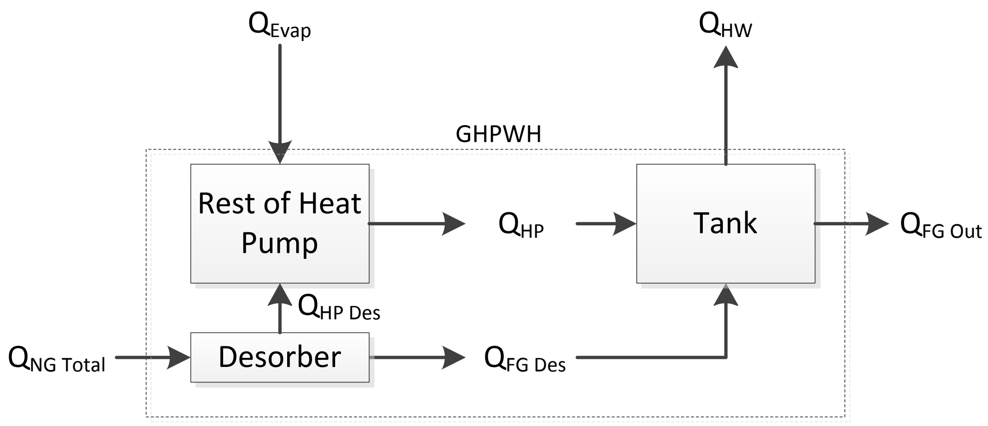
EHPWH Validation: *Heat Pump Water Heater Model Validation Study,* Prepared by Ecotope for NEEA, Report #E15-306 (2015)

Residential GHPWH – Demonstrations

Efficiency Metrics

- **Heat Pump COP** – Efficiency of absorption heat pump based <u>only</u> on heat from combustion.
- **System COP** – Overall efficiency of GHPWH, based on gas/electricity inputs (incl. backup heating).
- **Delivered Energy Factor** – Transient output/input efficiency metric (akin to rating UEF), includes tank heat loss and mixing effects.

$$COP_{HP} \geq COP_{SYS} \geq DEF$$



$$\dot{Q}_{HP} = 60 \cdot \dot{V}_{hyd} C_P \rho (T_{sup} - T_{rtn})$$

$$COP_{HP} = \dot{Q}_{HP} / (\eta_{TH,DES} \dot{Q}_{NG})$$

$$COP_{SYS} = \frac{(\dot{Q}_{HP} + (\dot{Q}_{NG} - \dot{Q}_{HP,DES}) - \dot{Q}_{FG,out})}{\dot{Q}_{NG} + \dot{Q}_{Elec}}$$

$$Input = m \cdot Output + b;$$

$$\frac{Output}{Input} = DEF = \left(m + \frac{b}{Output}\right)^{-1}$$