the Energy to Lead

Field Testing Results for Residential Gas-Fired Heat Pump Water Heaters

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ACEEE Hot Water Forum

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Nashville, TN

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Overview

- >Why Residential Gas HPWHs?
- >Describing the GHPWH
- >Field Test Plan
- >Preliminary Results
- >What's Next

Why Residential Gas HPWHs?

Residential Water Heating Market has been driven by significant innovation in the past 10 years (well done!).

EnergyStar® and past/future changes in Federally allowable minimum efficiencies have resulted in:

> A proliferation of “mid-efficiency” gas water heating products.

> A gas tankless market at over 10% of the overall gas WH market, and growing.

> More, lower cost options for condensing-efficiency gas storage and “hybrid” products.

> A recent generation of electric HPWHs that are here to stay, and also growing in market share.

Why Residential Gas HPWHs?

But…

While electric water heating customers have product options with a "step-change" in operating efficiency/cost savings, gas customers can go from 0.59/0.62 EF to:

- Non-condensing EnergyStar® water heaters with 0.67-0.70 EF, with higher equipment/installed cost.
- Condensing GSWH/Hybrid, requiring venting/gas piping upgrade, electrical service, delivering a ~0.80 EF.
- Non-condensing or condensing Gas Tankless Water Heater (GTWH), with an EF 0.82 – 0.95, requiring venting upgrade, electrical service, and often larger gas piping.

Need that "step-change" that retrofits with min. EF gas water heaters, the majority of market.

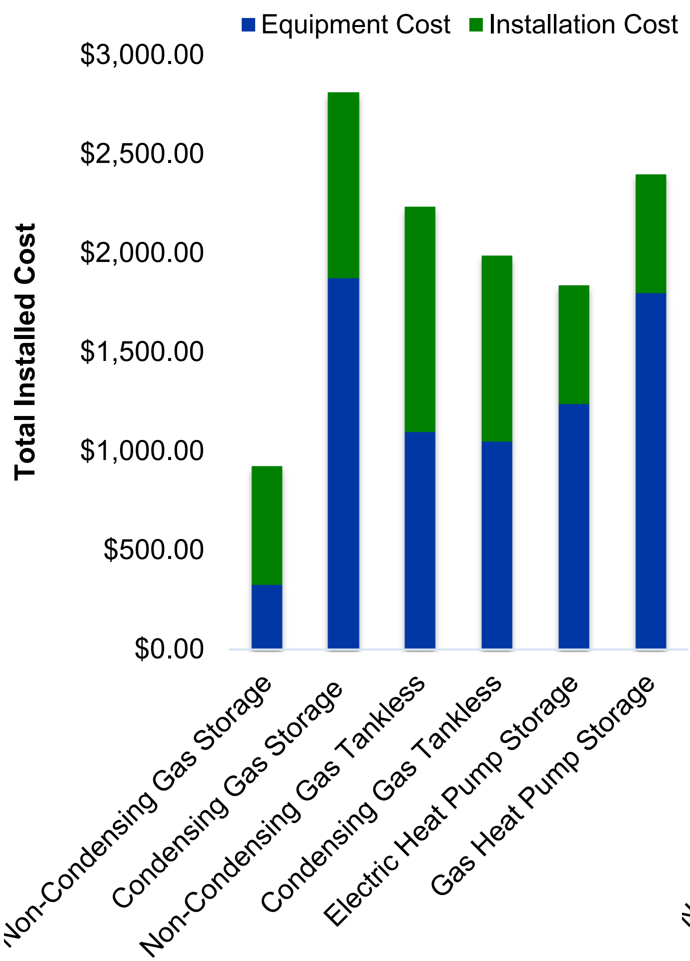
Describing the Gas HPWH

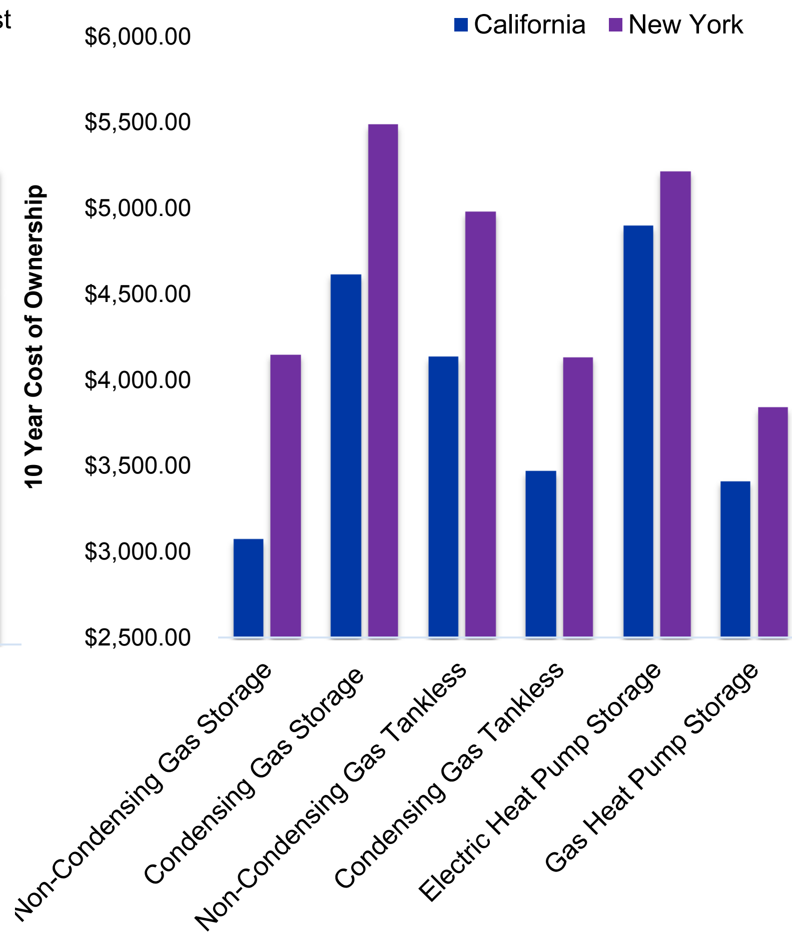
GHPWH System Specifications: Direct-fired NH3-H2O single-effect absorption cycle integrated with storage tank and heat recovery. Intended as fully retrofittable with most common gas storage water heating, *without infrastructure upgrade*.

	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	75	Gallons
Backup Heating	Experimenting with backup currently	
Emissions (projected)	10 ng NO_x/J	Based upon GTI laboratory testing
Commercial Introduction	2016	Projected
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”	
Estimated Consumer Cost	<$1,800	

Information and graphic courtesy of Stone Mountain Technologies, Inc.

Describing the Gas HPWH



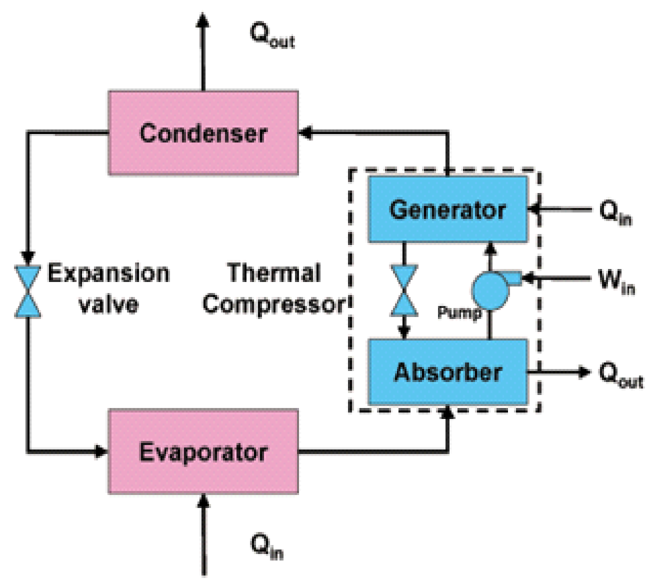


- With low firing rate required, GHPWH installation costs are low
- GHPWH has total cost of ownership close to baseline water heaters, cost-engineering will result in the lowest cost of ownership

Describing the Gas HPWH

How it works - Very similar to EHPWHs, except:

- Compressor is replaced with “thermal compressor”, comprised of several HXs and addition of absorbent.
  - Easier to compress liquid, solution pump requires appx. 1.0% of the compression energy of a standard vapor compression heat pump
- Ammonia is the refrigerant, instead of more common R-134a for EHPWHs, which is:
  - Very efficient thermodynamically, used almost exclusively in industrial refrigeration
  - Has large affinity for water, stable over range of temperature/pressure conditions
  - Non-ozone depleting
  - A natural chemical, with a global warming potential of 0 (R-134a is 1300)
  - An irritant and hazardous, requiring special care. Helpfully, unlike most refrigerants, NH3 is lighter than air.

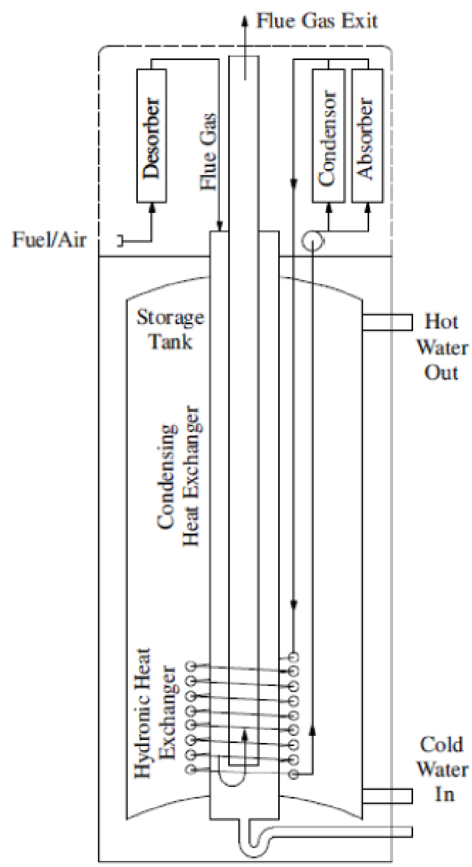


[Source: MW CHP Center]

Describing the Gas HPWH

How it works – SMTI System Design:

- Heat pump absorbs heat from the ambient air and recovers heat from the absorption of NH3 to water (in absorber)
  - Heat transfer to potable water is mediated by a closed hydronic loop
- In addition, useful heat from hot flue gases exiting the heat pump is delivered to storage tank by separate HX
- As the GHPWH only partially heats water from the refrigeration cycle, cooling effect at the evaporator is 1/3-1/2 that of equivalently sized EHPWHs
- GHPWH uses Single Effect absorption cycle, more complex cycles were considered by SMTI but were not cost-effective



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Field Test Plan

Monitoring Goals

1) Pre-commercial GHPWH system reliability and performance, with monitoring of both the heat pump cycle and the water heating system.
2) Quantifying delivered efficiency versus prior laboratory testing
3) Identifying installation issues and other barriers to market entry, including data concerning the space cooling effect
4) Assessing end-user satisfaction with hot water production and potential nuisances (e.g. system noise)

Field Test Plan

<u>Building on prior GTI lab testing of early GHPWHs, estimate the:</u>

- COP of the heat pump as function of ambient T & RH, inlet water mains, and other installation characteristics.
- Delivered efficiency of hot water as function of usage volumes/patterns, compare to similar high-efficiency systems and extrapolate to annual energy savings.
- Disaggregation of electricity and natural gas inputs, tracking backup heating.
- Space cooling effect on interior space
- Robustness of absorption heat pump startup/shutdowns, as function of operating conditions.

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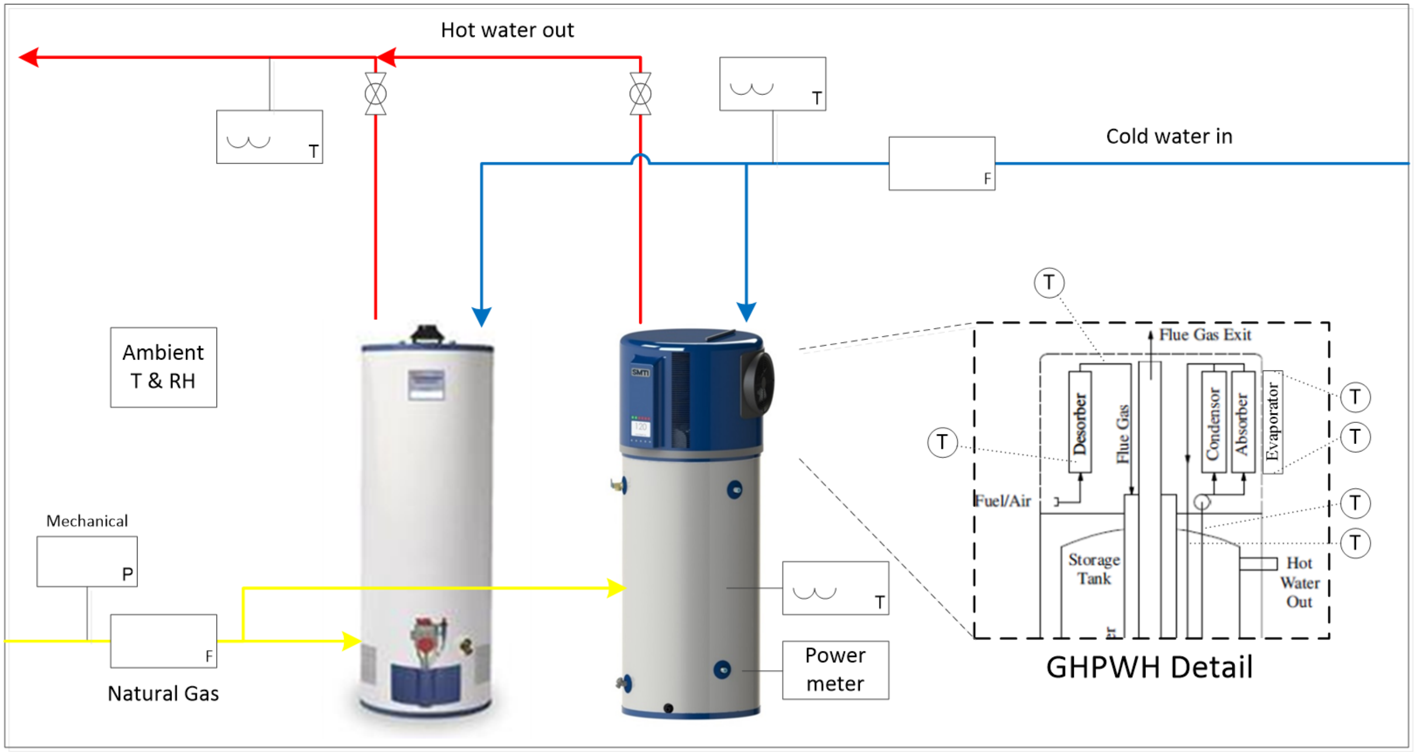
Field Test Plan

Measurement Scheme (Continuous)



Monitoring Phase	Continuous Measurement
Baseline & GHPWH	• Indoor T &RH • NG Flow • Water Flow • Power Draw (total) • Water inlet/outlet temperatures
GHPWH Only	• Gas valve on/off • Storage tank thermostat temperature HP Temperatures • Evap in/out • Hyd. Loop Rtn/Sup. • Desorber shell • Flue gas exiting temperature

Field Test Plan

Initial GHPWH "Controlled" Field Test

- First unit installed at SMTI employee home in late 2013, has been operating ever since. Unit was built by SMTI during initial laboratory prototyping program with GTI/OEM/GIT.
- Second "3rd gen." unit built specifically for field testing, installed at utility employee home 2014.
- Both sites are in Eastern TN:
  - Unit 1 in attached garage, with 2-4 occupants
  - Unit 2 in semi-conditioned basement, with 3-4 occupants
- While performing well unattended, both units have been under close watch and improvements have been implemented as a result, including:
  - Control strategy for cold ambient/water startup
  - Adjustments to when backup element is operating
  - Investigating options for corrosion inhibitors

Field Test Plan

Additional Gas HPWH Field Demo Sites:

Site #3: Seattle, WA
- 3-4 Occupants
- Semi-conditioned

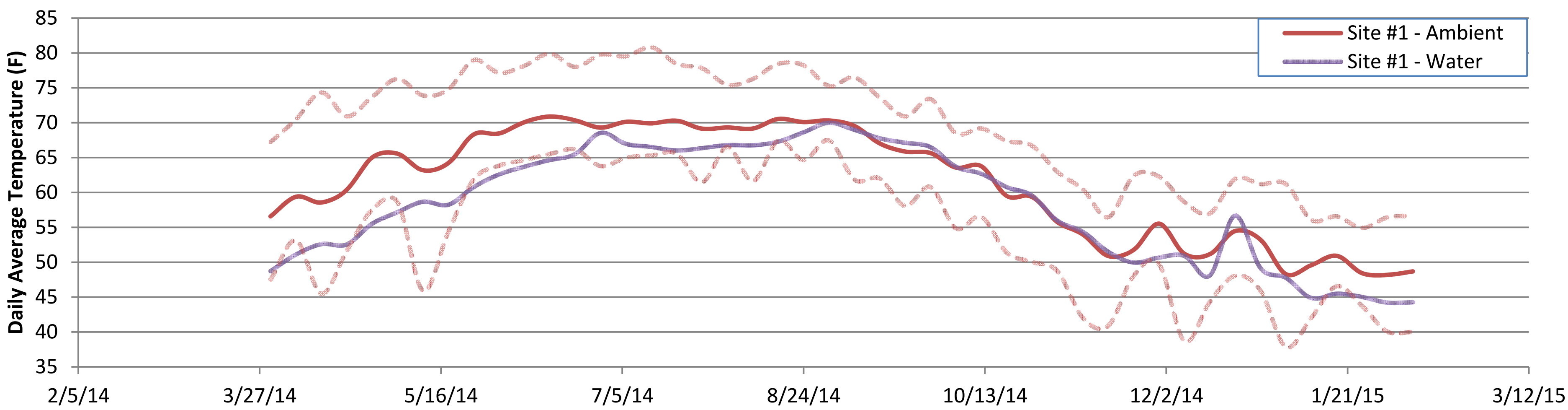
Site #4: Portland, OR
- 5 Occupants
- Garage

Site #5: Spokane, WA
- 4 Occupants
- Garage

Site #6: Boise, ID
- 5 Occupants
- Garage

Preliminary Results from Sites #1 & #2

Operating conditions and hot water consumption – Weekly Averages



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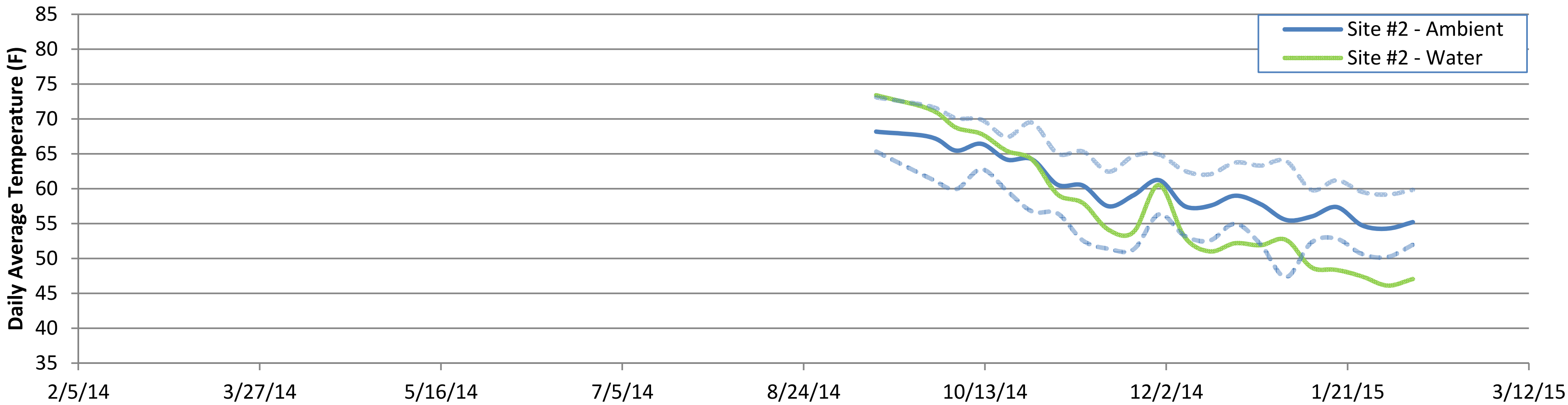

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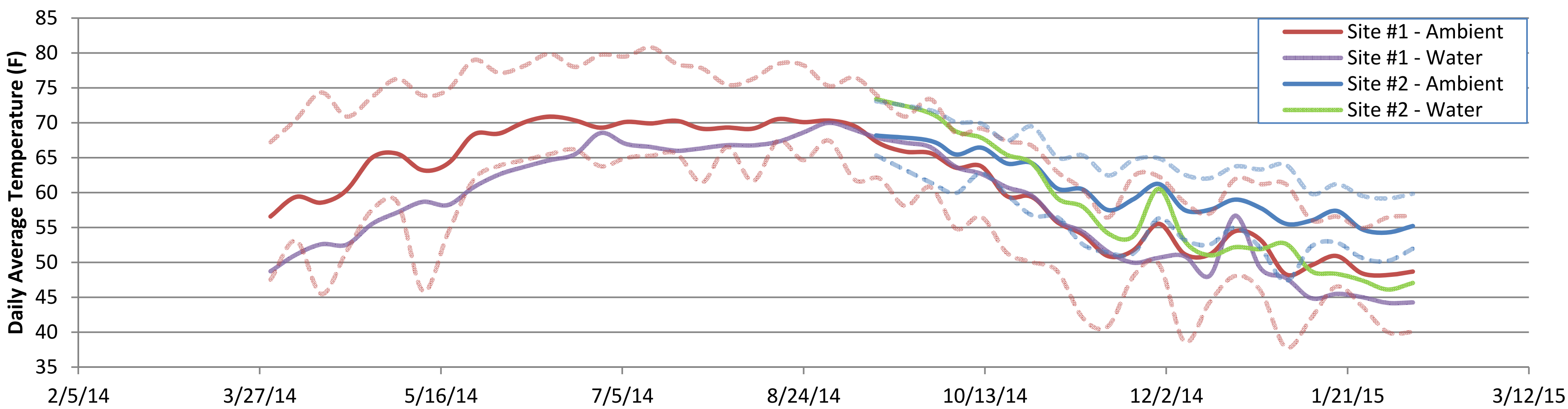
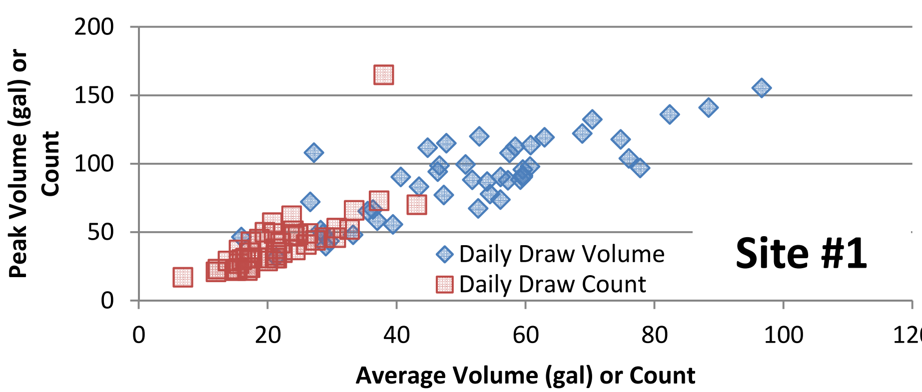
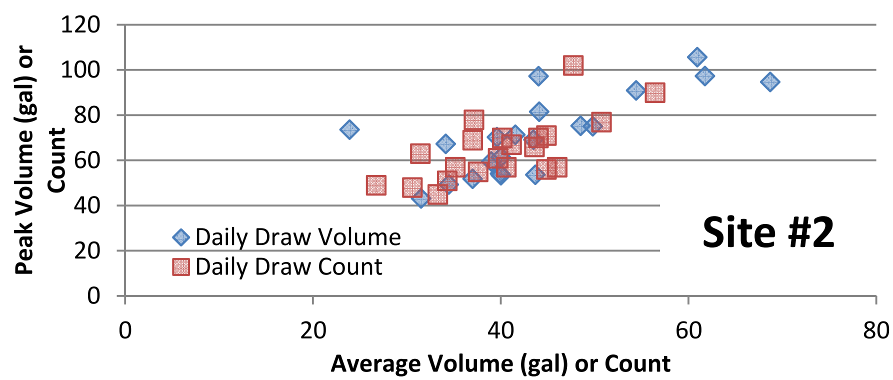






Preliminary Results from Sites #1 & #2

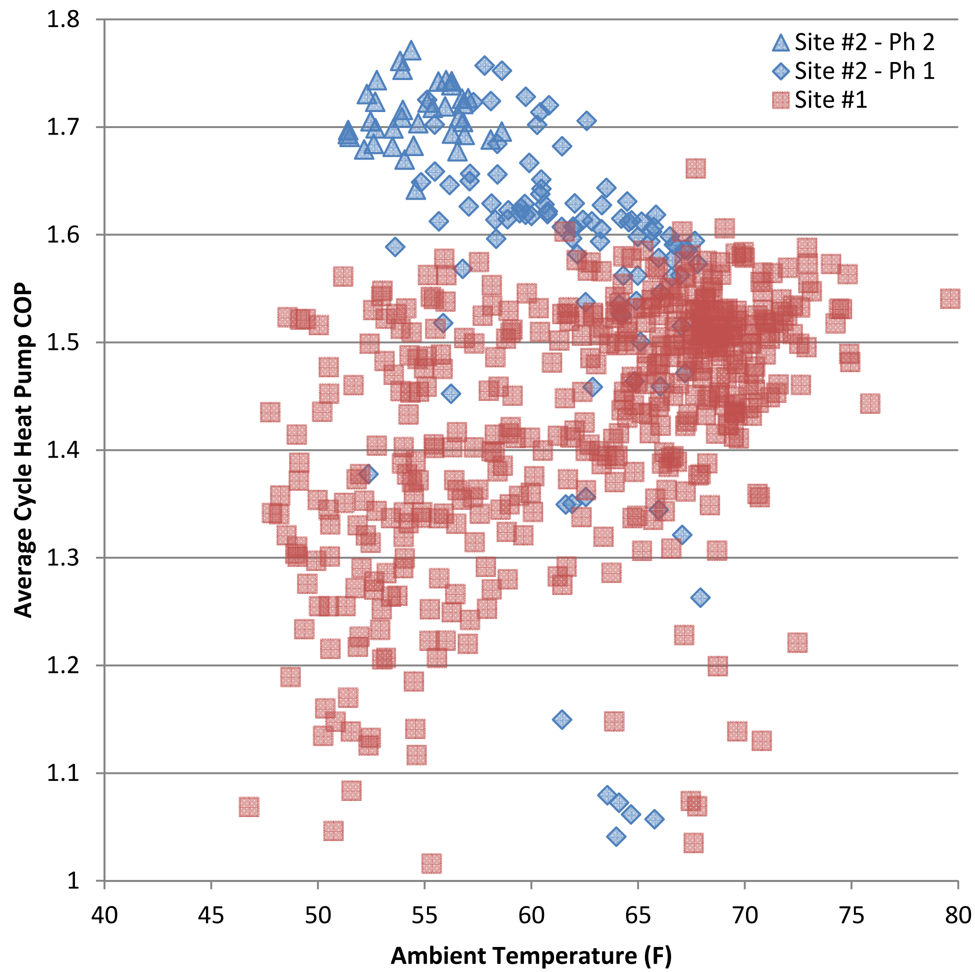
Heat Pump Performance

> Focusing on abs. heat pump operation, COP is often at high levels observed in prior laboratory testing, 1.4 - 1.8

> Aggregated data over all cycles (~800) show influence of lower ambient temperature on performance

> Site #2 had significant modification, phases 1/2 show pre/post mod.

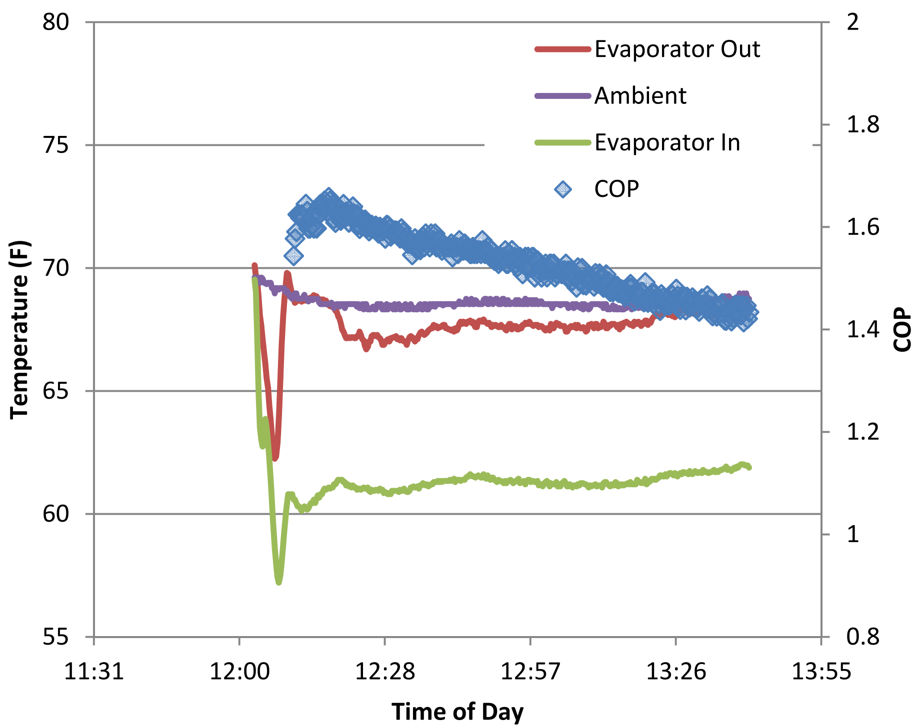
> COP affected by tank temperature, hot water usage, and other factors

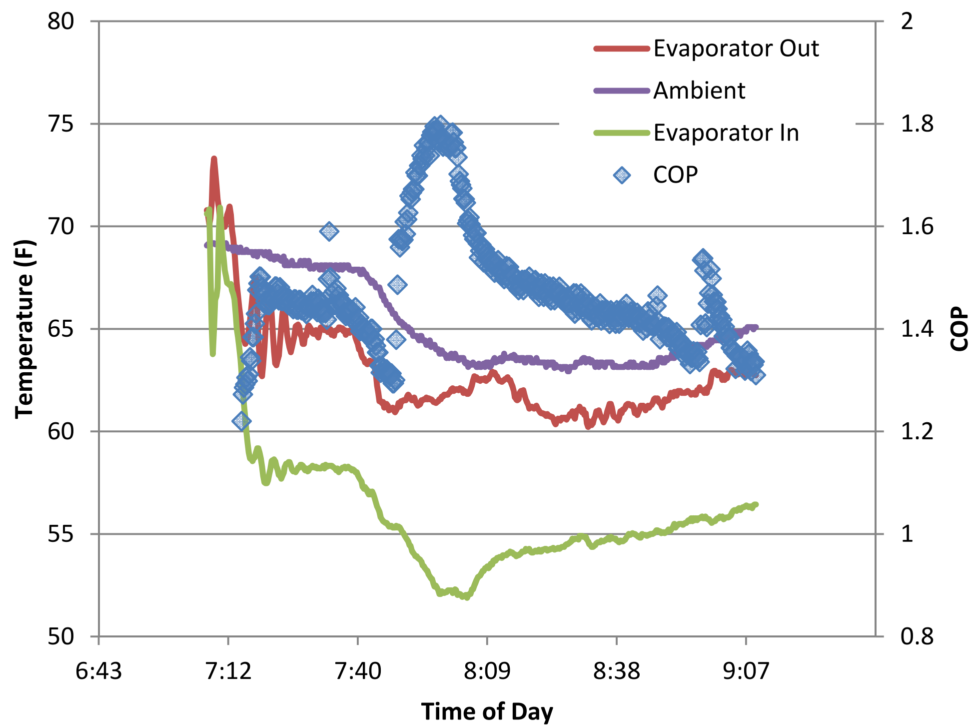


Preliminary Results from Sites #1 & #2

Some slips in startup early on, issues resolved to maximize COP

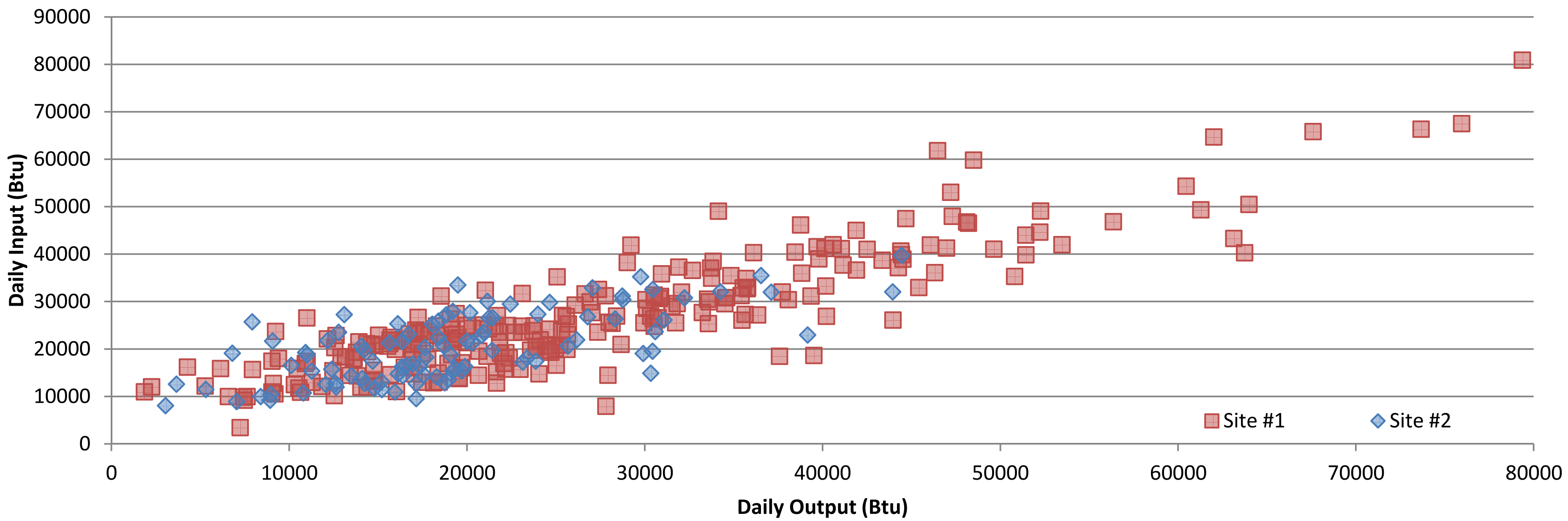
> A smooth start to the heat pump is critical for high performance, with good (left) and bad (right) readily apparent from the data.





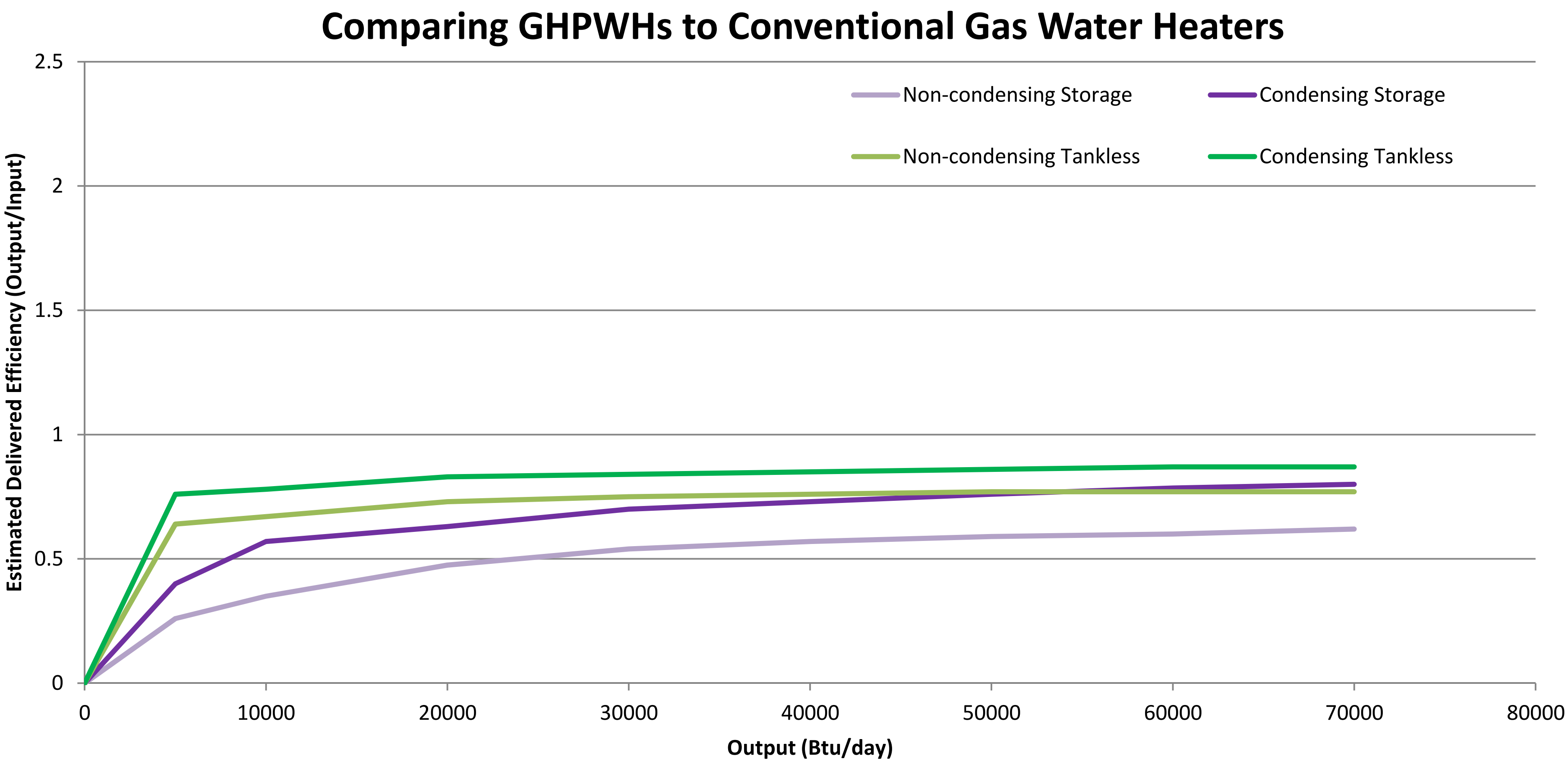
Preliminary Results from Sites #1 & #2

- Aggregating daily input/output data, projected Delivered "EF" is ~ 1.2 and 1.3 respectively for Site #1 and Site #2 units.
- Seeking to reduce impact of standby heat loss to improve results



$$Input = m \cdot Output + b; \frac{Output}{Input} = DEF_{adj} = \left(m + \frac{b}{Output}\right)^{-1}$$

Preliminary Results from Sites #1 & #2



Conventional Gas Water Heater Data from:

Kosar, D. et al. "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)

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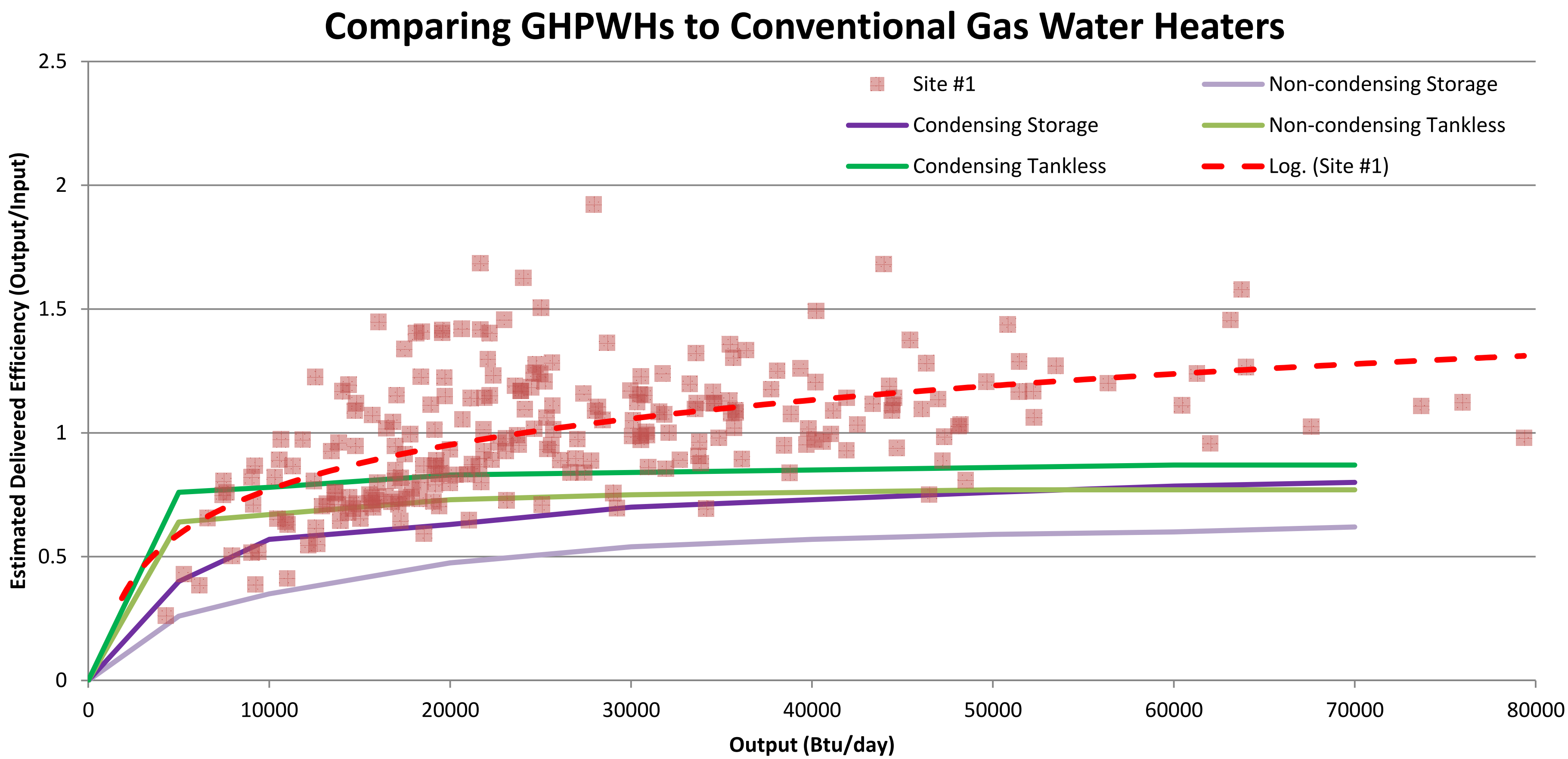

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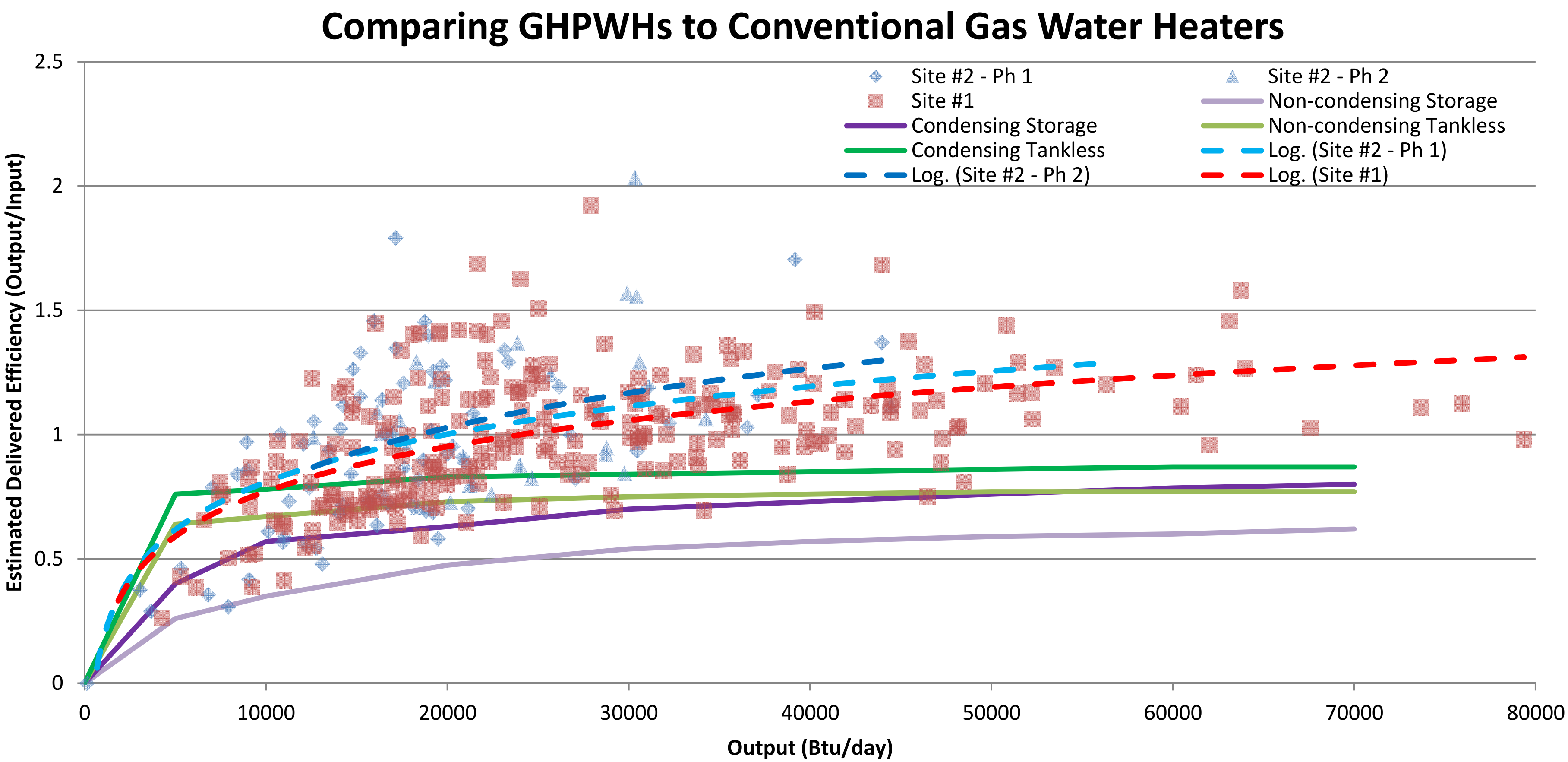

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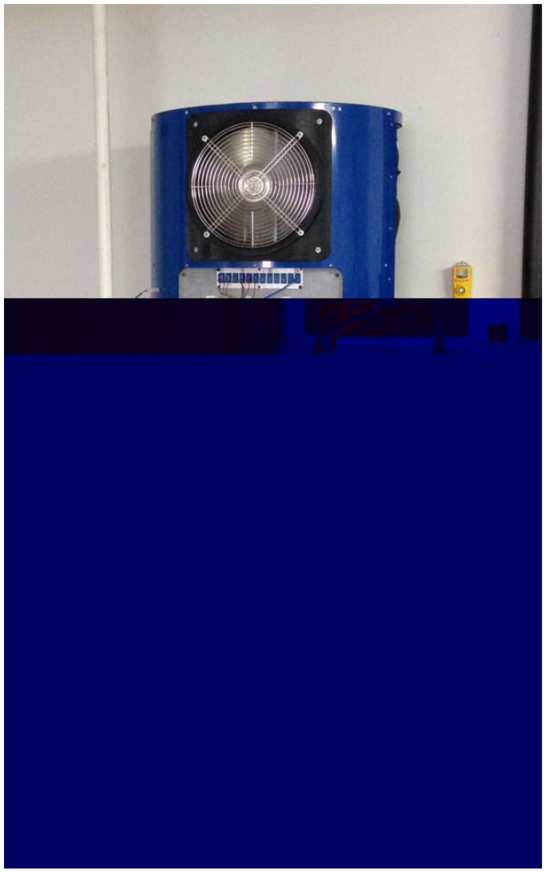
What's Next

GHPWH Field Evaluation

- Collect/analyze data from all units, with add'l installations planned for '15.
- Wrapup in late 2015 monitoring all field units.
- Understand initial challenges/barriers with homeowners, contractors.
- Share findings with stakeholders.
- Support rounding out of product family, size range, "hybrid", etc.

Questions & Answers



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