Field Evaluation of Pre-Commercial Residential Gas Heat Pump Water Heaters

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ACEEE Hot Water Forum

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Portland, OR

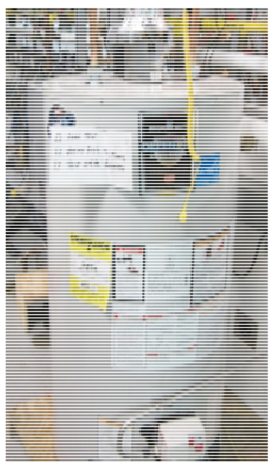
Gas Heat Pump Water Heater – Why?

Motivation: Despite low natural gas prices, GHPWH has potential to leapfrog

> Energy/Operating Cost Savings, Fewer Infrastructure Needs, Recent Regulatory Drivers

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

Mid-Effiency:
UEF approx. 0.67 – 0.72, 50-100% greater equipment costs, simple paybacks beyond life of product.



Condensing Storage:
UEF approx. 0.74 – 0.82, ~ 20% therm savings with 4-5X equipment cost and retrofit installation costs of $1000 or more.

Tankless and Hybrids:
UEF approx. 0.82 – 0.95, ~ 33% therm savings with 2-3X equipment cost and similar infrastructure req's as condensing storage.

Gas Heat Pump:
UEF approx. 1.3, > 50% therm savings with comparable installed cost to tankless.

Technology Leapfrog through Direct Retrofit

Gas Heat Pump Water Heater – What?

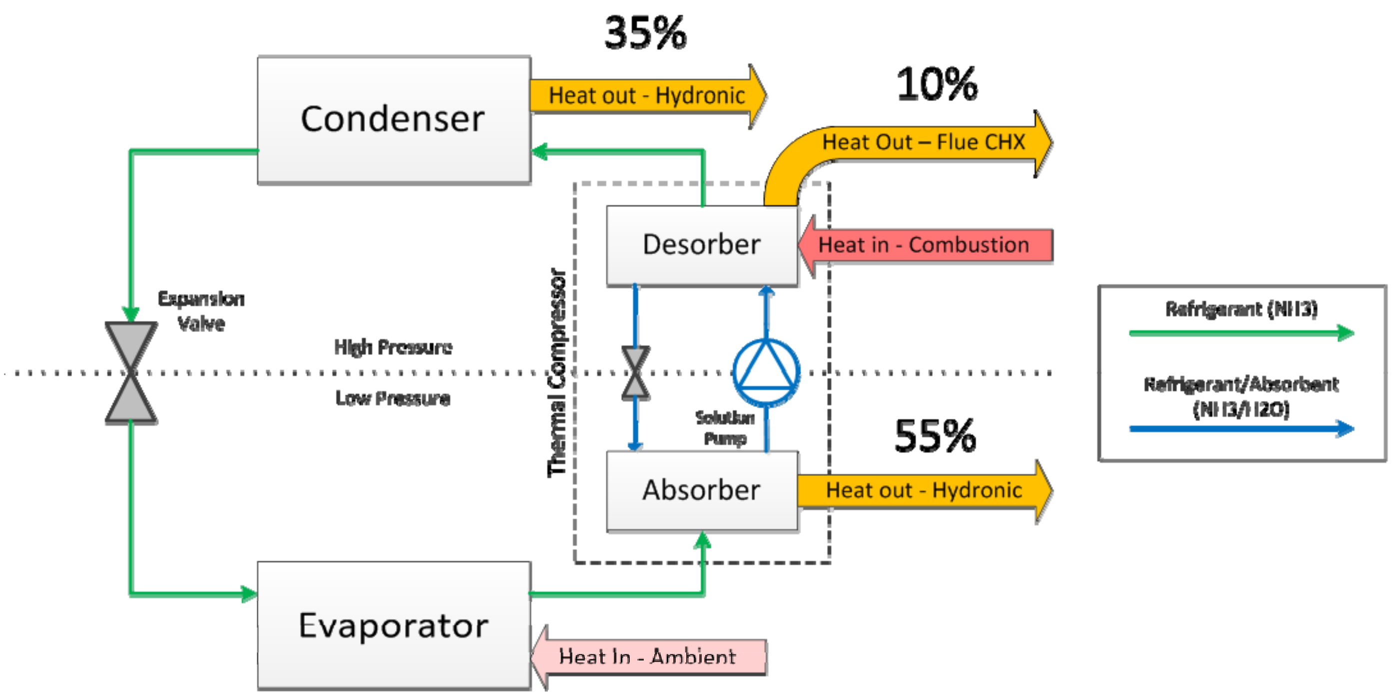
GHPWH System Specifications: Direct-fired NH3-H2O single-effect absorption cycle integrated with storage tank and heat recovery. Intended as fully retrofittable with most common gas storage water heating, *without infrastructure upgrade*.

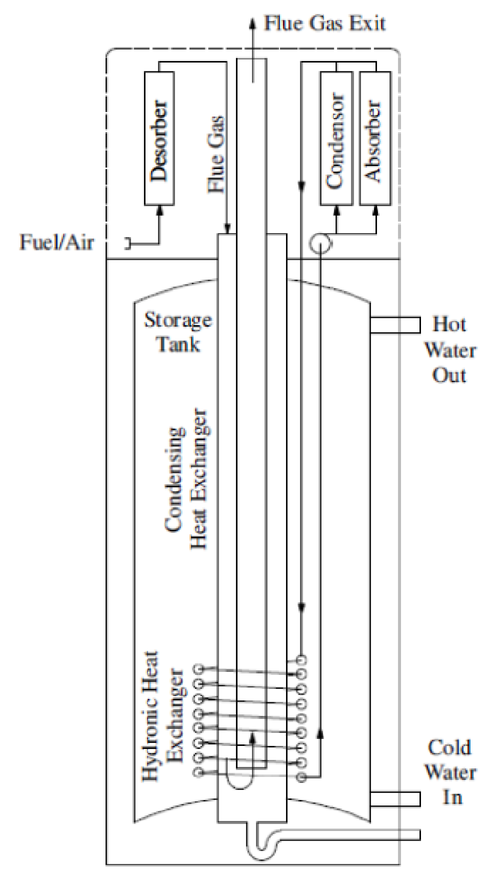
	GHPWH	Units/Notes
Technology Developer	Stone Mountain Technologies	OEM support
Heat Pump Output	10,000	Btu/hr
Firing Rate	6,300	Btu/hr
Efficiency	1.3 Energy Factor	Projected
Tank Size	75	Gallons
Backup Heating	Experimenting with backup currently	
Emissions (projected)	10 ng NO_x/J	Based upon GTI laboratory testing
Commercial Introduction	2017	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.

Gas Heat Pump Water Heater – How?

How it works





- Cooling effect at evaporator is 1/3-1/2 that of electric HPWHs.
- Uses single-effect absorption cycle, more complex cycles were considered by manufacturer but were not cost-effective.
- Features discussed likely to apply to GHPWH product category.

Gas Heat Pump Water Heater – Where?

Pac. NW Demonstration (WA/OR/ID)
Four GHPWHs are operating in major NW cities, focusing on seasonal performance, heating system interaction, end user satisfaction, and contractor education.

Initial Controlled Demonstration (TN)
Two GHPWHs installed near manufacturer, at homes of employee and employee of local utility. Focus on refining system controls and assessing reliability.

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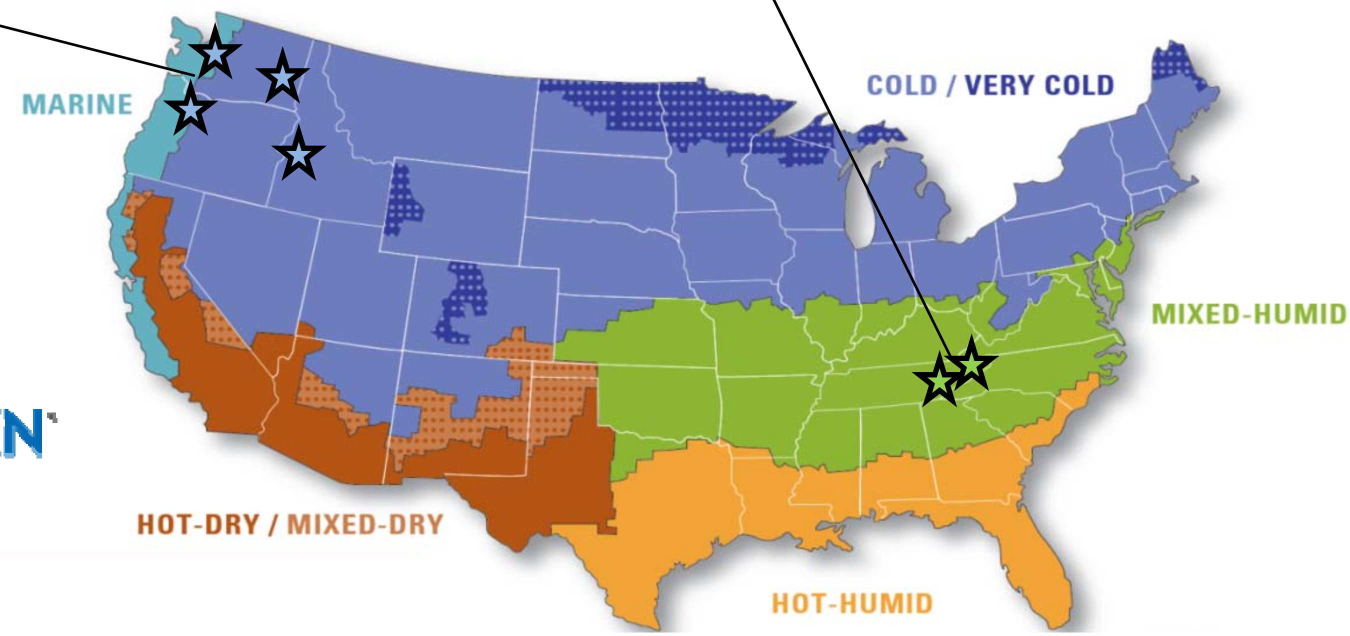
INTERMOUNTAIN GAS COMPANY



Map reference: Baechler, M. et al. "Guide to Determining Climate Regions by County", PNNL-17211, 2010.

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Gas Heat Pump Water Heater – Where?

Four "3rd Gen." installations focus of this study

> Three of four installed in semi-conditioned garages, Seattle-area unit installed in conditioned basement.

> Units installed in parallel to baseline gas water heaters to switch over during periods of prototype servicing.

> Monitoring period over 9 months, beginning in January 2015.

Boise, ID

Spokane, WA

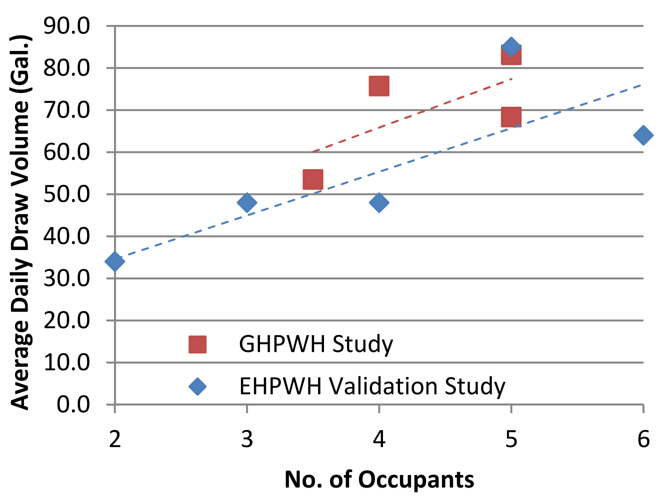
Portland, OR

Seattle, WA

Pilot Project Overview - Sites

Baseline Site Characteristics and Summary:

Compared to typical Pac. NW homes, GHPWH sites have higher than average occupancy (> 2.5) and hot water usage.

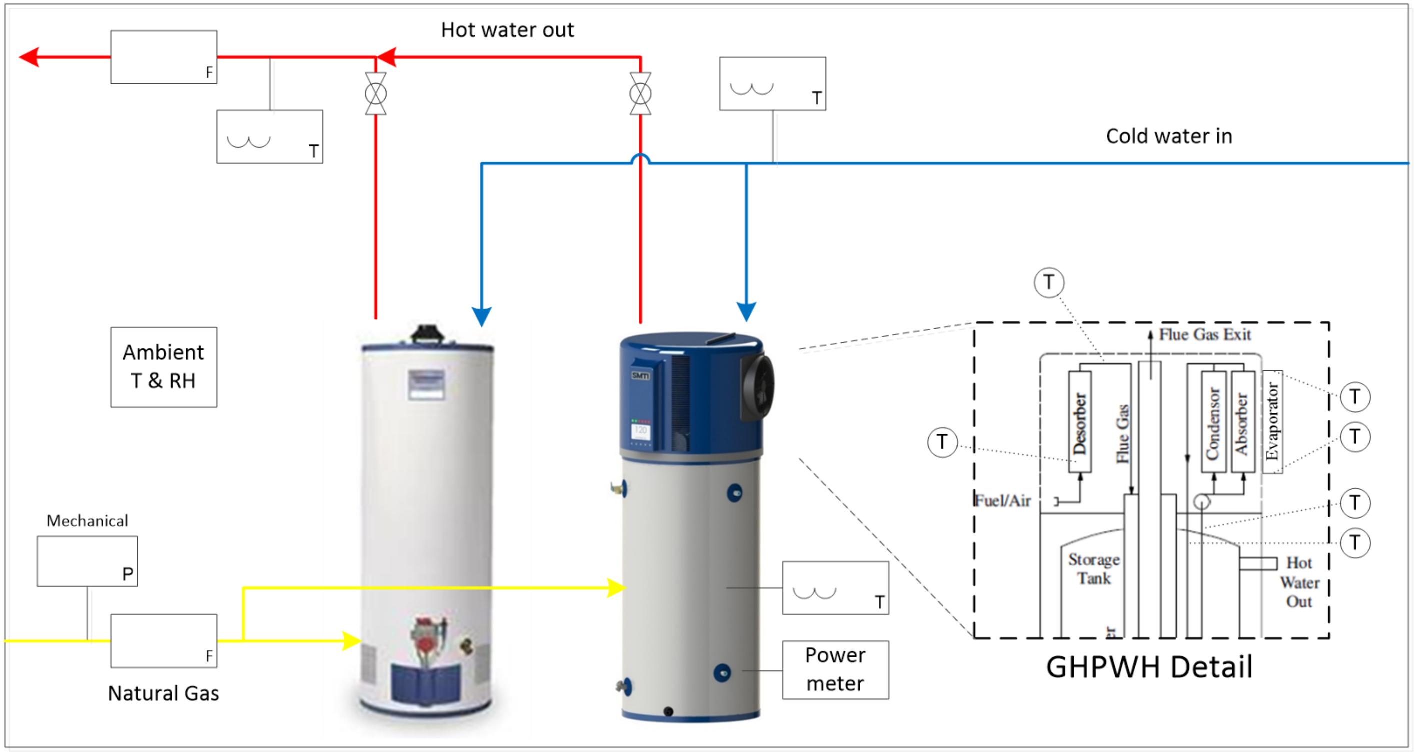


Existing WH	Seattle	Spokane	Portland	Boise
Tank Size (Gal.)	40	34	50	40
Firing Rate (Btu/hr)	36,000	100,000	40,000	40,000
Age	14+ Years	18 Years	0 years	13 years
Rated / Avg. Delivered EF/TE	0.59 / 0.56	96% / 0.91	0.62 / 0.47	0.59 / 0.45
Average Inlet T (°F)	53.3	61.2	54.8	58.7
Average Outlet T (°F)	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)

Pilot Project Overview - Measurements

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

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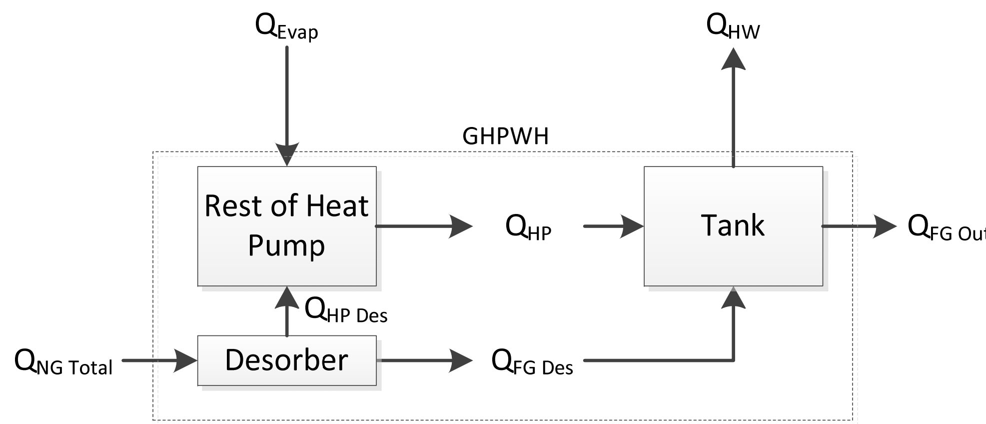
Pilot Project Overview – Metrics

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.

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



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

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

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

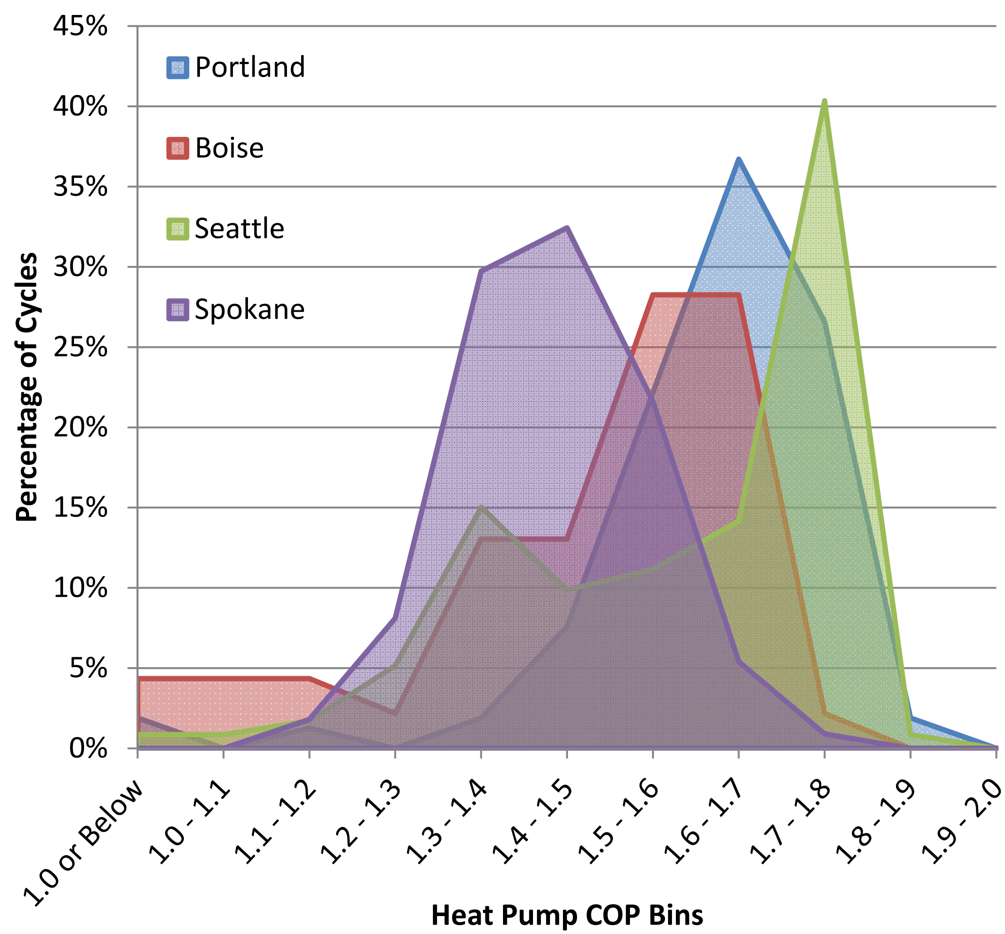
$$Input = m \cdot Output + b;$$

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

GHPWH Performance and Reliability

Heat Pump Performance

- COP_{HP} at lab test targets (1.4-1.8), near theoretical limits.
- Generally, low COPs from EEV
- With reliable heat recovery, steady power consumption (~150W), and minimal backup heating COP_{SYS}/COP_{HP} has correlation coeff. of 0.83.
- For all cycles:
  - 75% COP_{HP} > 1.4
  - 45% COP_{HP} > 1.6
  - 68% COP_{SYS} > 1.3
  - 42% COP_{SYS} > 1.4



GHPWH Performance and Reliability

COP less affected by ambient

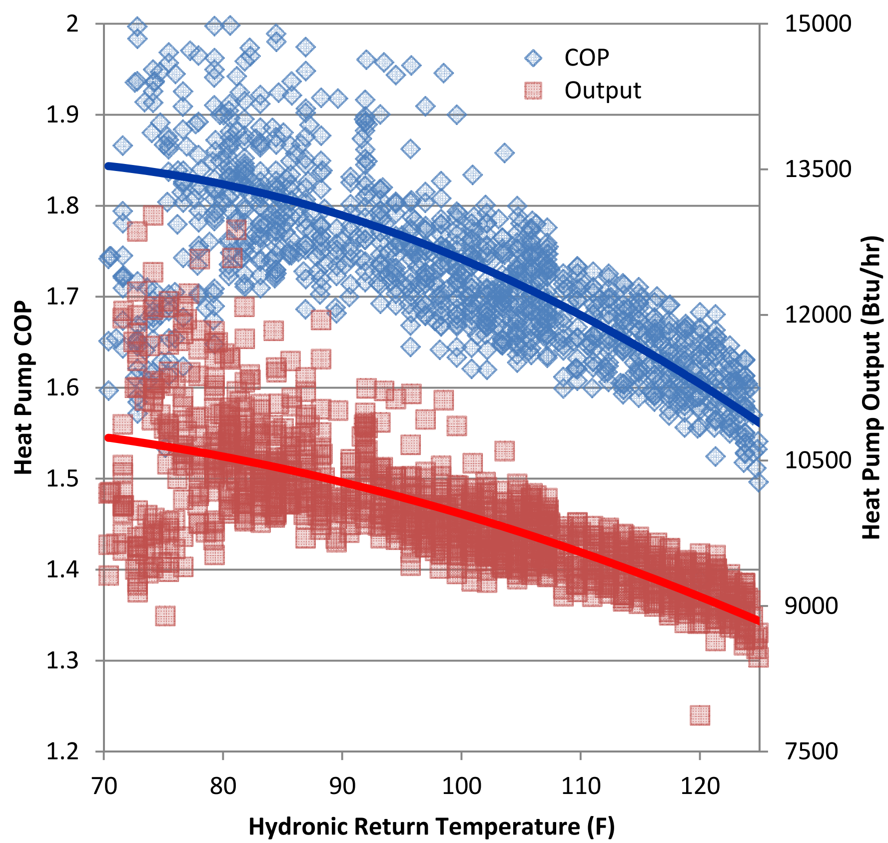
> Known from prior lab testing, GHPWH efficiency is affected more by storage tank temperature than ambient air.
  > Over one cycle, COP and heat pump output drop as tank warms
  > Over range of ambient air temperatures observed, COP nearly flat for GHPWHs

Evaporator cooling effect is small

> Function of cycle COP, higher efficiency – greater cooling effect (same as EHPWHs).

> Observed range from 2,500-4,000 Btu/hr

Portland GHPWH Recovery 2/2



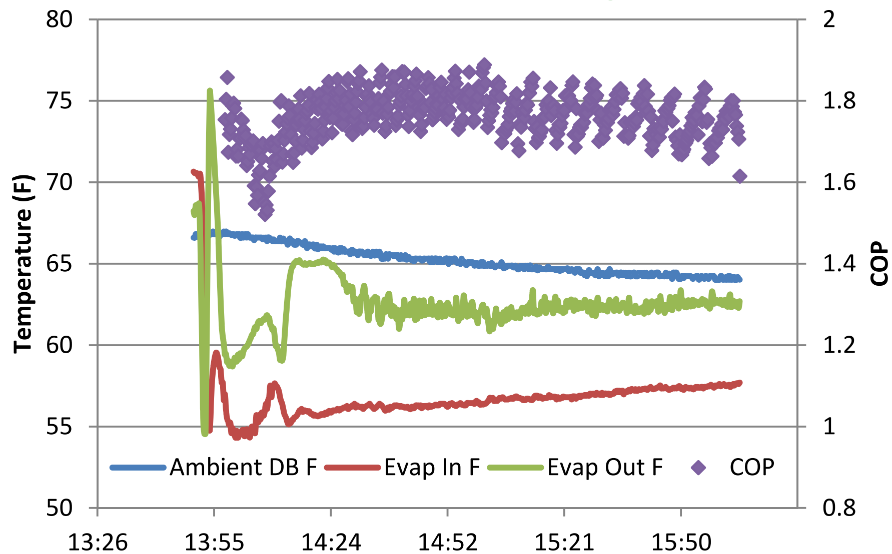
GHPWH Performance and Reliability

Reliability: Electronic Expansion Valve

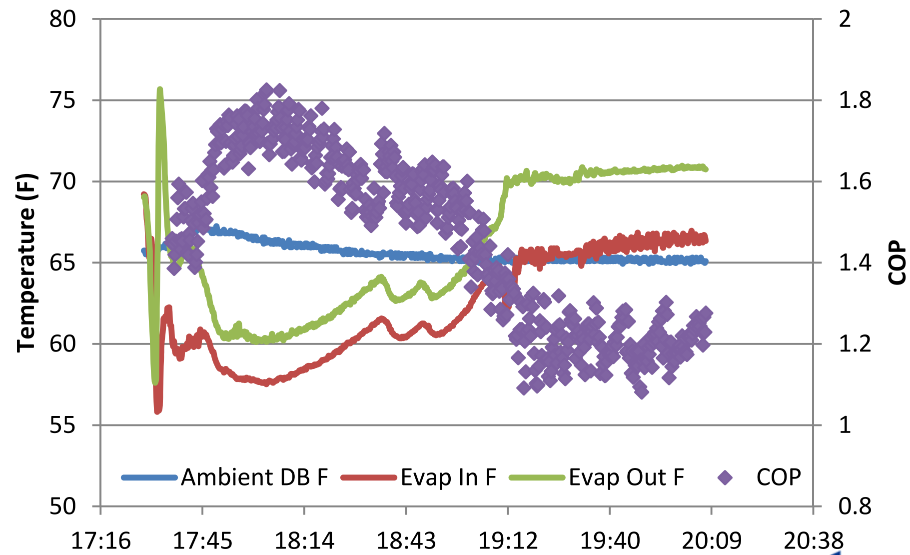
> With reliable EEV performance, GHPWH can take advantage of colder tank temperatures during beginning of on-cycle, increasing efficiency/output capacity.

> Component affected all sites, off-design operation, required servicing

Seattle – EEV Working Well



Seattle – EEV Not Working Well

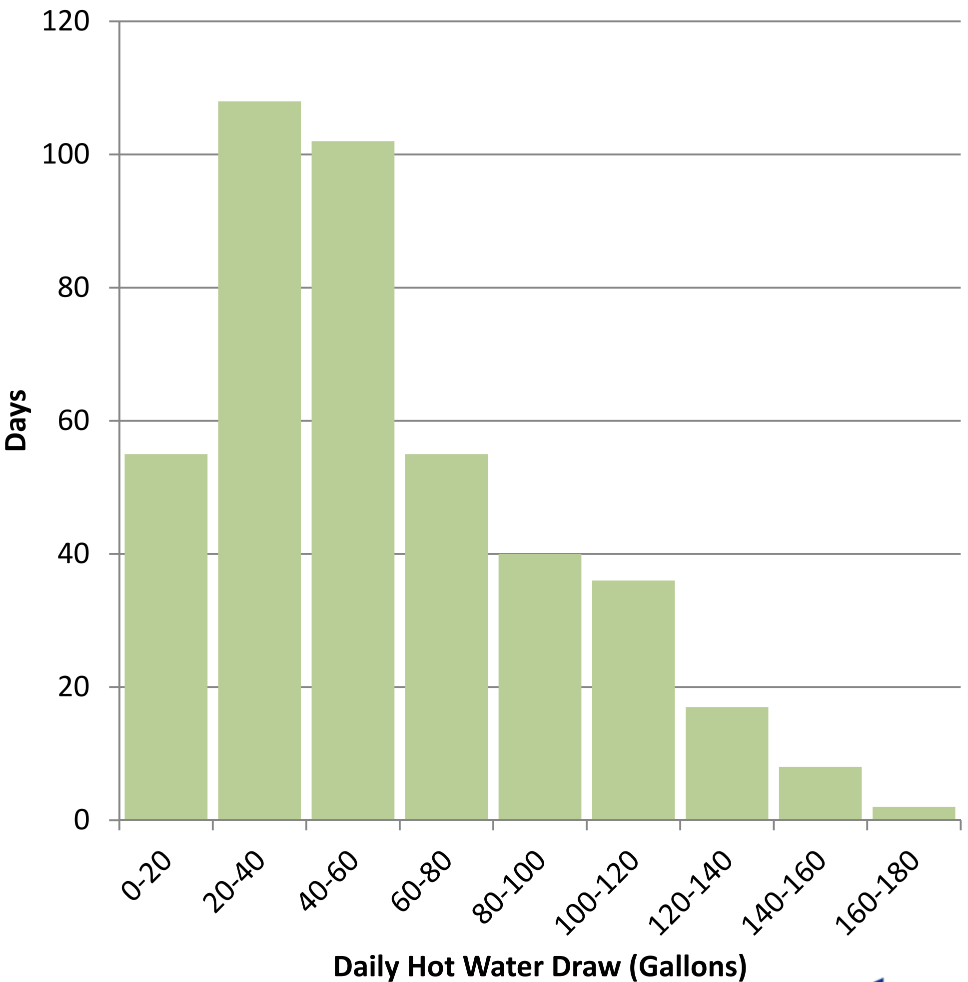


GHPWH Predicted Savings

Therm Savings of 50% or more

- Charting daily input/output creates linear "input/output" relationship, **for gas input only**.
- In comparison to baseline, all sites showed greater than 50% savings except for Spokane with Polaris.
- Sites had large range of daily hot water usage, average from 41 – 96 gal/day.

	Output	Low Usage (Seattle)	High Usage (Portland)
Daily DHW Draw (gal)		41	96
Baseline	64 gal/day	0.59	0.48
	84 gal/day	0.60	0.50
GHPWH	64 gal/day	1.21	1.15
	84 gal/day	1.25	1.18



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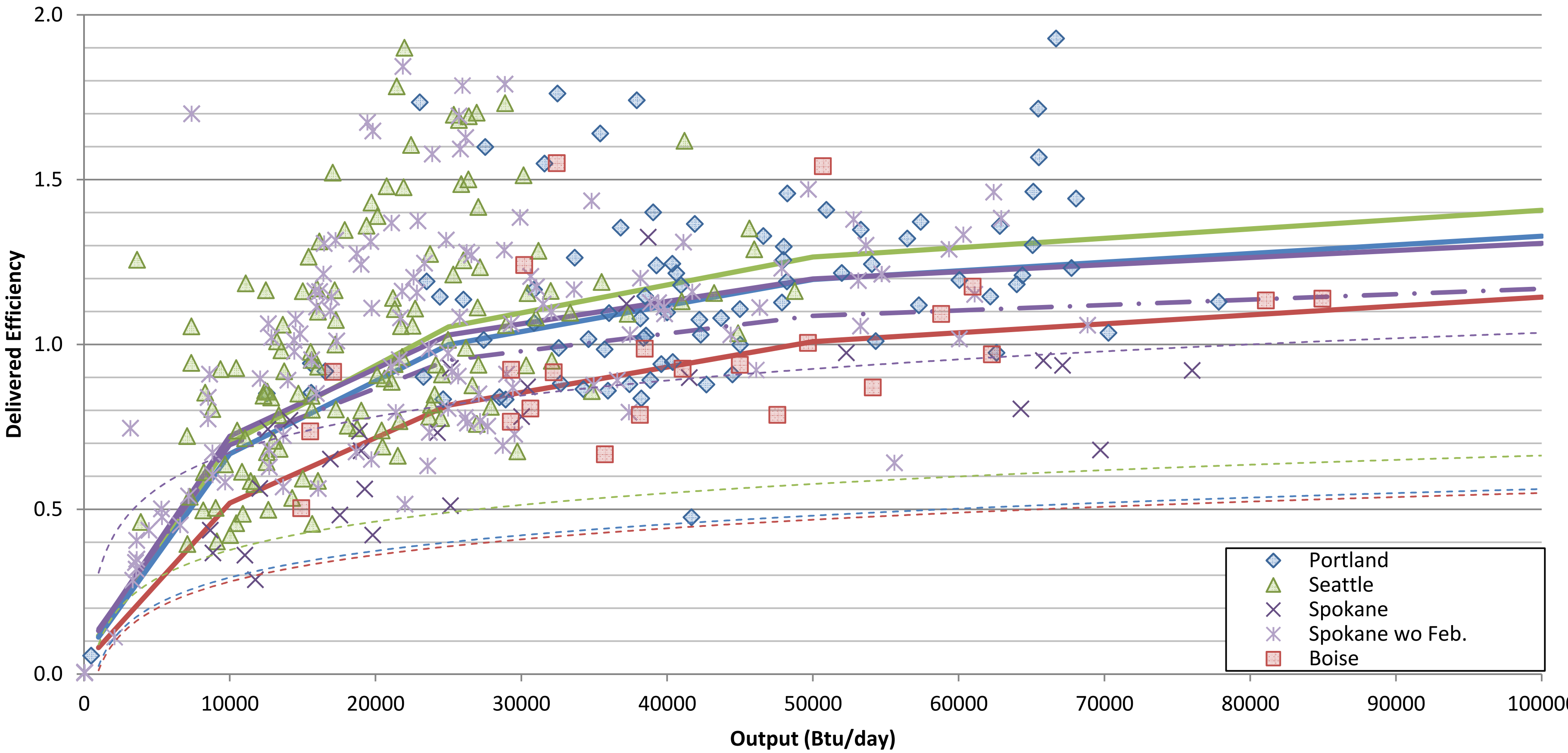
GHPWH Predicted Savings

Delivered Efficiency by Site: Solid = GHPWH, Dashed = Baseline



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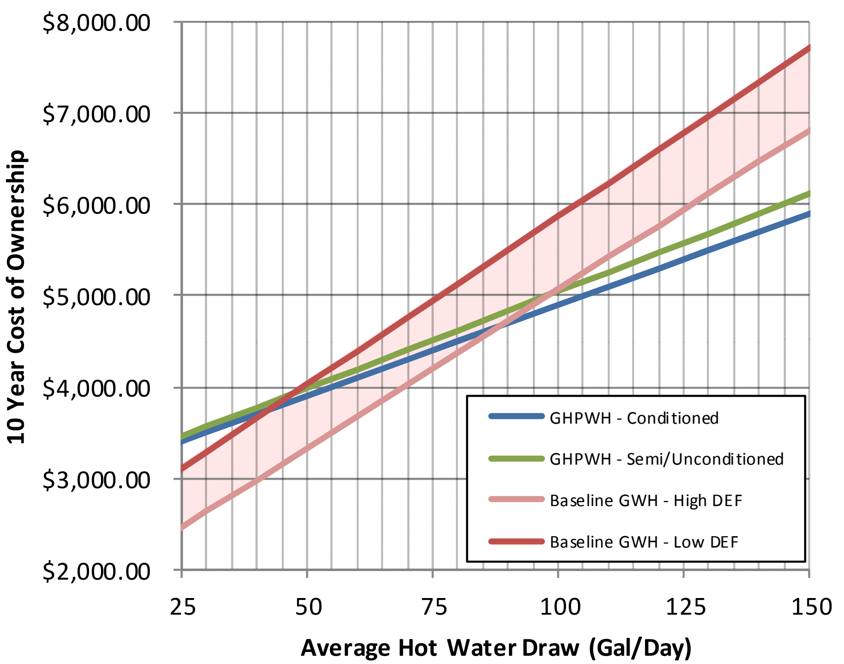
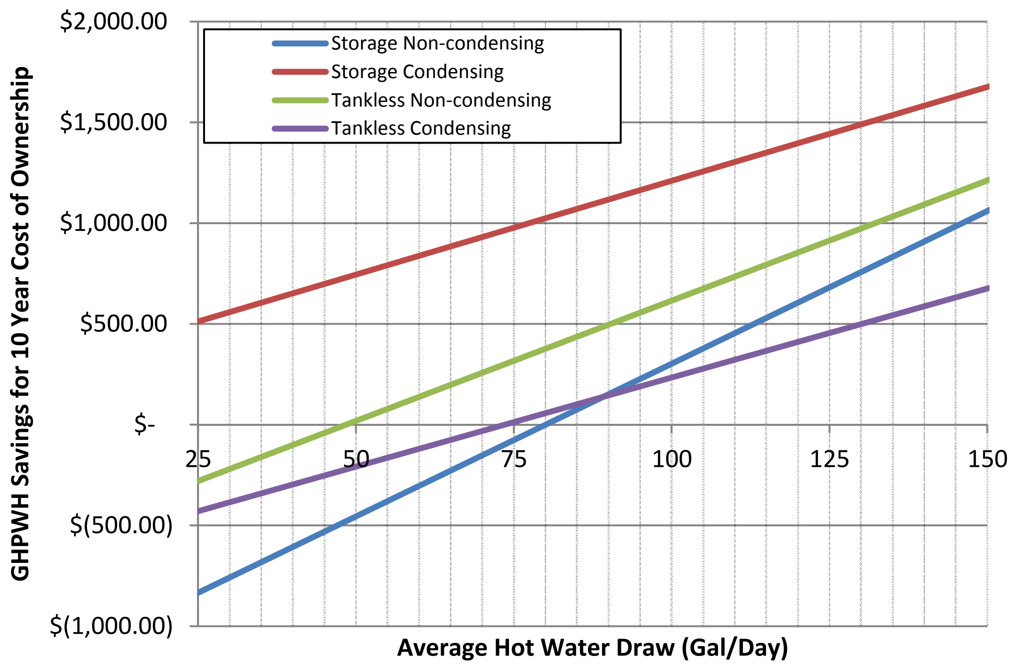
GHPWH Predicted Savings

Projected GHPWH Economics

For DOE "High Usage" category, GHPWHs have projected 1.2 < DEF < 1.3, > 50% savings versus baseline (except Spokane), can be competitive for moderate/high usage homes despite low NG prices. With new min. eff. guidelines ***GHPWH leapfrogs condensing storage.***



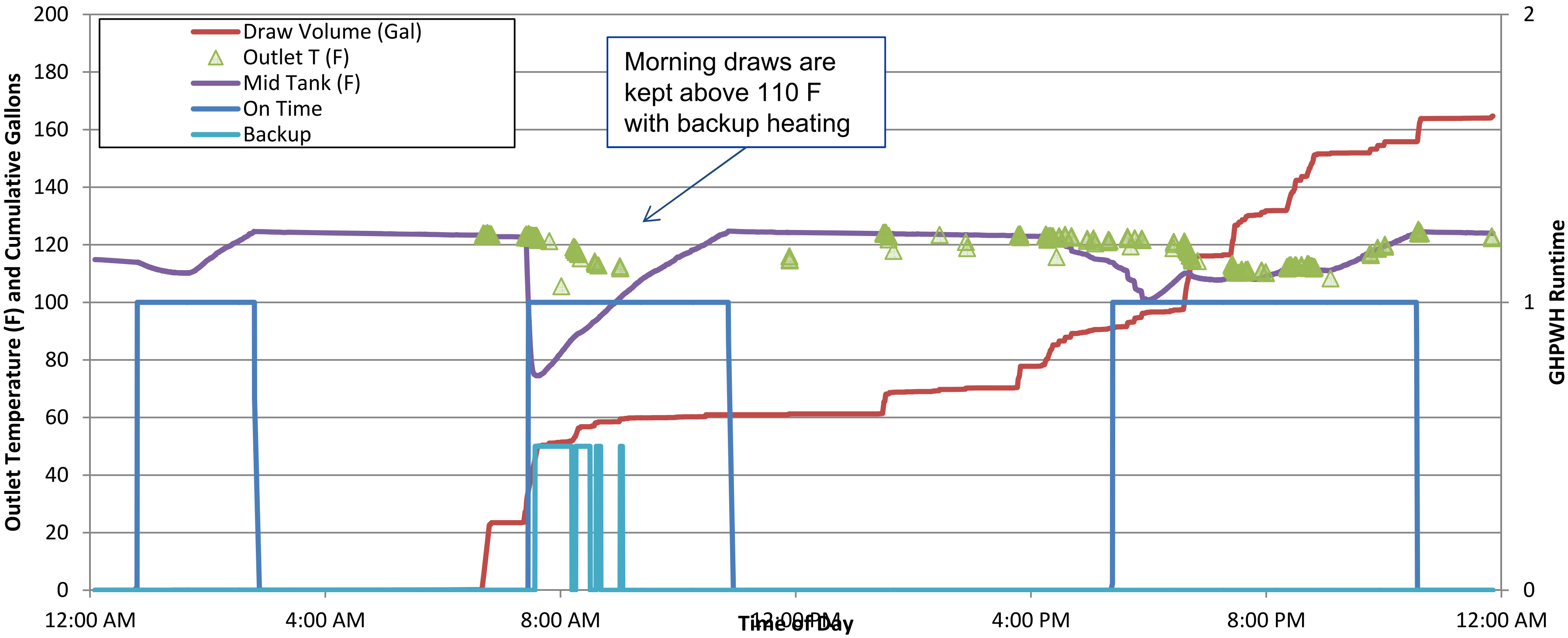


Utility Costs: Assumes OR averages of 11.72 ¢/kWh, $1.11/therm with 1.9% and 1.2% utility escalation rates per EIA 2015 Annual Energy Outlook through 2027.
Conventional Gas Water Heater Data from: Kosar, D. et al. "Residential Water Heating Program - Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating - Final Project Report". CEC Contract CEC-500-2013-060. (2013) Link: http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2013-060

End User/Contractor Feedback

Feedback on Hot Water Capacity

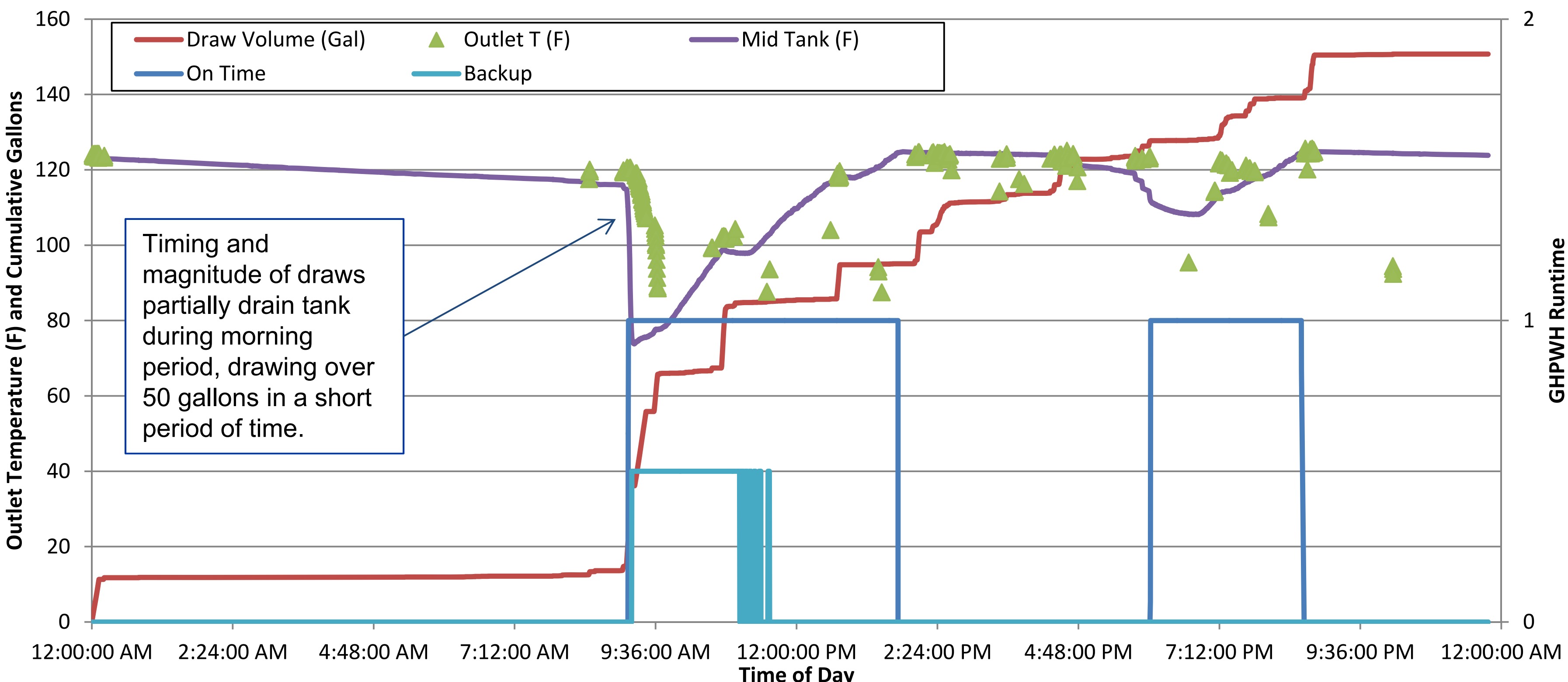
> For three sites, each with 4+ occupants, hosts noted periods of low capacity. Upon inspection, high loading events did result T_{outlet} < 105 F. Case below shows high loading managed with cycling and backup heat.



End User/Contractor Feedback

Feedback on Hot Water Capacity

> Same site, shows impact of cycle timing, tank heat loss, and controls for backup heating. Opportunities for improvement in addition to right-sizing storage.



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End User/Contractor Feedback

End user nuisances minimal

- No complaints drafts or excessive cooling. Non-garage installation noted noise levels. Units noise observed to be near Tier I.

	Seattle	Spokane	Portland	Boise
Noise, dB (Average per NEEA Spec.)	67.5	64.8	66.4	64.6

Installations straightforward, though unit size noted as challenge

- Venting through external wall using new penetration (B, P, Se) or existing vent (Sp).
- Condensate drained to accessible drain (B) or with other condensing equipment (P, Se, Sp). Gas line access OK.

Photos of Boise site highlight:

- Gas/Water connections
- ¾" PVC flue pipe
- Condensate lines

Questions & Answers

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