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-Efficiency:**
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*.

<table>
<thead>
<tr>
<th><strong>Technology Developer</strong></th>
<th>GHPWH</th>
<th>Units/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mountain Technologies</td>
<td></td>
<td>OEM support</td>
</tr>
<tr>
<td><strong>Heat Pump Output</strong></td>
<td>10,000</td>
<td>Btu/hr</td>
</tr>
<tr>
<td><strong>Firing Rate</strong></td>
<td>6,300</td>
<td>Btu/hr</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>1.3 Energy Factor</td>
<td>Projected</td>
</tr>
<tr>
<td><strong>Tank Size</strong></td>
<td>75</td>
<td>Gallons</td>
</tr>
<tr>
<td><strong>Backup Heating</strong></td>
<td></td>
<td>Experimenting with backup currently</td>
</tr>
<tr>
<td><strong>Emissions (projected)</strong></td>
<td>10 ng NO&lt;sub&gt;x&lt;/sub&gt;/J</td>
<td>Based upon GTI laboratory testing</td>
</tr>
<tr>
<td><strong>Commercial Introduction</strong></td>
<td>2017</td>
<td>Projected</td>
</tr>
<tr>
<td><strong>Installation</strong></td>
<td>Indoors or semi-conditioned space (garage)</td>
<td>Sealed system has NH3 charge &lt; 25% allowed by ASHRAE Standard 15</td>
</tr>
<tr>
<td><strong>Venting</strong></td>
<td>½” – 1” PVC</td>
<td></td>
</tr>
<tr>
<td><strong>Gas Piping</strong></td>
<td>½”</td>
<td></td>
</tr>
<tr>
<td><strong>Estimated Consumer Cost</strong></td>
<td>&lt;$1,800</td>
<td></td>
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</table>

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.

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.

<table>
<thead>
<tr>
<th></th>
<th>Existing WH</th>
<th>Seattle</th>
<th>Spokane</th>
<th>Portland</th>
<th>Boise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank Size (Gal.)</td>
<td></td>
<td>40</td>
<td>34</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Firing Rate (Btu/hr)</td>
<td></td>
<td>36,000</td>
<td>100,000</td>
<td>40,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td>14+ Years</td>
<td>18 Years</td>
<td>0 years</td>
<td>13 years</td>
</tr>
<tr>
<td>Rated / Avg. Delivered EF/TE</td>
<td></td>
<td>0.59 / 0.56</td>
<td>96% / 0.91</td>
<td>0.62 / 0.47</td>
<td>0.59 / 0.45</td>
</tr>
<tr>
<td>Average Inlet T (°F)</td>
<td></td>
<td>53.3</td>
<td>61.2</td>
<td>54.8</td>
<td>58.7</td>
</tr>
<tr>
<td>Average Outlet T (°F)</td>
<td></td>
<td>123.8</td>
<td>122.8</td>
<td>115.2</td>
<td>138.0</td>
</tr>
</tbody>
</table>

Pilot Project Overview - Measurements

Measurement Scheme (Continuous)

<table>
<thead>
<tr>
<th>Monitoring Phase</th>
<th>Continuous Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline &amp; GHPWH</td>
<td>• Indoor T &amp;RH</td>
</tr>
<tr>
<td></td>
<td>• NG Flow</td>
</tr>
<tr>
<td></td>
<td>• Water Flow</td>
</tr>
<tr>
<td></td>
<td>• Power Draw (total)</td>
</tr>
<tr>
<td></td>
<td>• Water inlet/outlet temperatures</td>
</tr>
<tr>
<td>GHPWH Only</td>
<td>• Gas valve on/off</td>
</tr>
<tr>
<td></td>
<td>• Storage tank thermostat temperature</td>
</tr>
<tr>
<td></td>
<td>• HP Temperatures</td>
</tr>
<tr>
<td></td>
<td>• Evap in/out</td>
</tr>
<tr>
<td></td>
<td>• Hyd. Loop Rtn/Sup.</td>
</tr>
<tr>
<td></td>
<td>• Desorber shell</td>
</tr>
<tr>
<td></td>
<td>• Flue gas exiting</td>
</tr>
<tr>
<td></td>
<td>temperature</td>
</tr>
</tbody>
</table>
Pilot Project Overview – Metrics

Efficiency Metrics

> **Heat Pump COP** – Efficiency of absorption heat pump based only 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.

\[ COP_{HP} \geq COP_{SYS} \geq DEF \]
**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
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
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.

<table>
<thead>
<tr>
<th></th>
<th>Output</th>
<th>Low Usage (Seattle)</th>
<th>High Usage (Portland)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily DHW Draw (gal)</td>
<td></td>
<td>41</td>
<td>96</td>
</tr>
<tr>
<td>Baseline</td>
<td></td>
<td>64 gal/day</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>84 gal/day</td>
<td>0.60</td>
</tr>
<tr>
<td>GHPWH</td>
<td></td>
<td>64 gal/day</td>
<td>1.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>84 gal/day</td>
<td>1.25</td>
</tr>
</tbody>
</table>
GHPWH Predicted Savings

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

Delivered Efficiency vs. Output (Btu/day)

- Portland
- Seattle
- Spokane
- Spokane wo Feb.
- Boise
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.

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 $T_{\text{outlet}} < 105$ F. Case below shows high loading managed with cycling and backup heat.

Morning draws are kept above 110 F with backup heating.
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.

Timing and magnitude of draws partially drain tank during morning period, drawing over 50 gallons in a short period of time.
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.

<table>
<thead>
<tr>
<th></th>
<th>Seattle</th>
<th>Spokane</th>
<th>Portland</th>
<th>Boise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise, dB</td>
<td>67.5</td>
<td>64.8</td>
<td>66.4</td>
<td>64.6</td>
</tr>
<tr>
<td>(Average per NEEA Spec.)</td>
<td></td>
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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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