Gas Heat Pump Water Heaters in CA: Field and Laboratory Results

Paul Glanville, PE
Gas Technology Institute

Presented at 2019 ACEEE Hot Water Forum
Nashville, TN
March 13th, 2019
Agenda

> CA Project Motivation
> Gas HPWH Technology Description
> Preliminary CA Field Results
  - Methods & Baseline Findings
  - Preliminary Gas HPWH Findings
> Parallel Testing and Market Research
> Next Steps
Motivation

> Gas WHs operate in ¾ of CA homes, an installed based of ~9MM units, 1.7 billion therms/yr

- In SCG territory, 95% of homes use gas, **95% are low efficiency**
- Roughly ¼ of all U.S. gas water heaters are in California
- Water heating’s significance grows in mild climates
Motivation

> Ripe for Market Transformation?
  - Majority of residential water heaters are not maintained and are emergency replacements (82% of sales)
  - Life expectancy is 8-12 years; 37% are 10+ years old

> But, Value Proposition is Difficult:
  - Homeowner spends ~$250-$300/year on hot water
  - GHPWH has higher equipment, but lower install cost
  - About 50/50 sales through distributors vs. retailers, how best to promote efficiency?

> And Reliability is Key:
  - Need 10+ years of operation with no/low maintenance
  - For retail sales, ½ are for DIY installs
Motivation

Gas HPWH (Pre-commercial): As-installed COP_{site, average} ≈ 1.5

<table>
<thead>
<tr>
<th></th>
<th>Elec. In (kWh)</th>
<th>NG In (Therm)</th>
<th>GHG Emitted (Lbs. CO2e)</th>
<th>COP_{source}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Plants</td>
<td>Non-Baseload</td>
<td>All Plants</td>
<td>Non-Baseload</td>
</tr>
<tr>
<td>Gas HPWH</td>
<td>0.8</td>
<td>0.3</td>
<td>5.6</td>
<td>1.29</td>
</tr>
<tr>
<td>Electric HPWH</td>
<td>6.6</td>
<td>N/A</td>
<td>4.3</td>
<td>1.16</td>
</tr>
</tbody>
</table>

For 100 Gal of Hot Water Produced (67 F Rise) – in CA

Supplemental Heating (elec. resistance) typically 2-5% of delivered energy

Disclaimer: Estimates are based on field data for gas-fired/electrically-driven HPWHs and do not represent certified performance

Excludes backup/supplemental heating

Gas HPWHs in CA – ACEEE 2019 Hot Water Forum
Gas HPWHs in CA – ACEEE 2019 Hot Water Forum

Technology Description

**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, without infrastructure upgrade.

<table>
<thead>
<tr>
<th>GHPWH</th>
<th>Units/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology Developer</strong></td>
<td>Stone Mountain Technologies</td>
</tr>
<tr>
<td><strong>Heat Pump Output</strong></td>
<td>10,000</td>
</tr>
<tr>
<td><strong>Firing Rate</strong></td>
<td>6,300</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>1.2 – 1.3 UEF</td>
</tr>
<tr>
<td><strong>Tank Size</strong></td>
<td>60-80</td>
</tr>
<tr>
<td><strong>Supplemental Heating</strong></td>
<td>1.25 kW</td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td>≤ 10 ng NOx/J</td>
</tr>
<tr>
<td><strong>Installation</strong></td>
<td>Indoors or semi-conditioned space (garage)</td>
</tr>
<tr>
<td><strong>Venting</strong></td>
<td>½” – 1” PVC</td>
</tr>
<tr>
<td><strong>Gas Piping</strong></td>
<td>½”</td>
</tr>
<tr>
<td><strong>Estimated Consumer Cost</strong></td>
<td>&lt;$1,600</td>
</tr>
</tbody>
</table>

*Information and photo courtesy of SMTI*
Technology Description

> Goal was to develop scaled-down heat pump for integration atop/aside from standard storage tank, using **easily manufactured design** to assure low-cost with < $1600 consumer cost target.

> Absorption cycle development by startup, with support from GTI and multiple water heater OEMs, 20 built to date, >9,000 field operating hours.

---

2011

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

---

2013

**GHPWH Early Field Testing**

---

2015

**Extended Life & Gen 3 Field Testing**

---

2017

**Gen 4 Pilot & ULN Cert.**

---

2019


Gas HPWHs in CA – ACEEE 2019 Hot Water Forum
Technology Description

Absorption Cycle is comprised of:

> **Heat exchangers**: Absorber, Condenser, Desorber, Evaporator, Rectifier, RHX, and SHX

> **Solution pump**

> **Expansion**: EEV & WS Let Down
Technology Description

Summary of Prior Field Demos

Highlights of Prior Gen. Field Testing, gathering ~ 7,200 hrs

> Heat pumps operated well, at/above target COPs in “real world”

> Site specific therm savings generally 50% over conventional GWH

> Subsequent generations showed improved efficiency and reliability
  — Improvements with EEV, soln. pump

> COP impact of water/ambient temperatures characterized

> Cooling effect ~3,250 Btu/hr (~1kW)
California Demonstration Project

California Next Gen. Gas HPWH Demonstration (Through 2020)

> **Demonstration:** Demonstrate 5 “4th generation” GHPWHs in single-family homes, using datasets to estimate annual energy, operating cost, and emissions savings.

> **Lab Assessment:** Quantify GHPWH energy efficiency, emissions, and reliability through performance and extended life laboratory testing.

> **Model Development:** As a new product category, prepare stakeholders and code officials with information sharing, model development, and analysis.

> **Market Research:** Assess and evaluate market barriers to entry for the GHPWH in California.

> **Stakeholder Outreach:** Obtain valuable feedback from end users, installation contractors, and other stakeholders prior to GHPWH commercial introduction.
Demonstration Methods & Baseline

**Measurement Method Accuracy**

- **Natural Gas**
  - Positive displacement diaphragm meter with pulser: ±1%
- **Electricity Input**
  - True rms power transducer with split core current transformers (CT): ±0.5% (Meter), ±0.75% (CT)
- **Water Flow**
  - In-line turbine flow meter with pulse output: ±2.0% for 0.22 to 1.1 GPM, ±1.5% for 1.1 to 20.0 GPM, Resolution of 0.0132 gallons
- **Water Temperature (Hot/Cold); Air Temperature; Integrated GHPWH Temperatures**
  - Type T Thermocouples: ±1.5°F

**M&V**

- Outdoor T
- GHPWH Exhaust T
- NG Flow
- Water Flow
- Power Draw (total)
- Water inlet/outlet temperatures

**Prototype Performance**

- Indoor T
- Gas valve on/off
- Storage tank thermostat temperature

**HP Temperatures**

- Evap in/out
- Hyd. Loop Rtn/Sup.
- Desorber shell
- Flue gas exiting temperature

**Monitoring Phase**

- Independent M&V

---

Gas HPWHs in CA – ACEEE 2019 Hot Water Forum
Demonstration Methods & Baseline
## Demonstration Methods & Baseline

### Site Recruitment:
- 18 sites considered, 17 responded positively post-proposal phase. Online surveys completed and 15 inspections performed
- Criteria for Site Selection:
  - Required: Existing gas water heater; Continuous occupation for > 1.5 yr; necessary space indoors; in LA/OC
  - Preferred: ≥ 3 occupants, garage install, clustered sites
- Issues with finalization/screening
  - Sites outside of target area
  - Outdoor GWHs
  - Limited access for Gas HPWHs
  - Late withdrawals (life event, WH replacement)

### Site Details

<table>
<thead>
<tr>
<th>Site</th>
<th>Heater Location</th>
<th>Existing Equipment</th>
<th>Site Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Garage</td>
<td>Gas Storage Type, 40,000 Btu/hr input, 40 gallons, 0.62 EF</td>
<td>City = North Hills (LA); House Type = Single Family; Occupants = Four (39, 36, 6, 3)</td>
</tr>
<tr>
<td>2</td>
<td>Garage</td>
<td>Gas Storage Type, 40,000 Btu/hr input, 40 gallons, 0.62 EF</td>
<td>City = Stanton; House Type = Single Family; Occupants = Four (30, 30, 3, 1)</td>
</tr>
<tr>
<td>3</td>
<td>Garage</td>
<td>Gas Storage Type, 40,000 Btu/hr input, 40 gallons, 0.54 EF (estimated)</td>
<td>City = Northridge (LA); House Type = Single Family; Occupants = Four (60, 57, 25, 20)</td>
</tr>
<tr>
<td>4</td>
<td>Garage</td>
<td>Gas Storage Type, 40,000 Btu/hr input, 50 gallons, 0.62 EF</td>
<td>City = Studio City (LA); House Type = Single Family; Occupants = Four (60, 49, 19, 14)</td>
</tr>
<tr>
<td>5</td>
<td>Garage</td>
<td>Gas Storage Type (PowerVent), 36,000 Btu/hr input, 40 gallons, 0.67 EF</td>
<td>City = Huntington Beach; House Type = Single Family; Occupants = Two-Three (65, 61, 27)</td>
</tr>
</tbody>
</table>
Demonstration Methods & Baseline

Consumption

<table>
<thead>
<tr>
<th>Site</th>
<th>Average Gal/day</th>
<th>Peak Gal/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.6</td>
<td>116.0</td>
</tr>
<tr>
<td>2</td>
<td>56.9</td>
<td>124.8</td>
</tr>
<tr>
<td>3</td>
<td>50.3</td>
<td>112.3</td>
</tr>
<tr>
<td>4</td>
<td>55.1</td>
<td>163.0</td>
</tr>
<tr>
<td>5</td>
<td>35.6</td>
<td>117.7</td>
</tr>
</tbody>
</table>

Site 5 is Dashed where measurement accuracy is diminished.
“Running Out” of Hot Water

> Site 2, 4, and 5 appear to be well served by existing water heating equipment

> Site 1 and 3 appear to, at times, “run out” of hot water

> Ability of GHPWHs to match baseline equipment capacity will be examined
Initial Gas HPWH Demo Results*

Installation and commissioning was successful in mid-2018, with GTI support from Harrison Plumbing, SMTI, Rinnai, and ADM Associates.

– During commissioning, GHPWHs were validated to perform correctly with spot measurements of noise/combustion ~63 dB using NEEA procedure.

*Data reported for first four months of trial.
Initial Gas HPWH Demo Results

Issues during installations:

Site #2 Venting:
> In 1st week, unit had intermittent ignition issues, detecting ‘blocked vent’
> Condensate drainage issue resolved with secured, sloping vent run

Site #2 Electrical:
> Home had overloaded breaker, wouldn’t cover cost of expanded service
> Disabled 1250 W element, verified DHW loading doesn’t require its use

Site #4/Lab Unit Tank Water Leak:
> Leak discovered between tank/water loop, due to shipment vibrations
> Assembly improved to prevent issue with subsequent units

FVIR: Unlike conventional GWHs, GHPWH does not require >18” stand
Seismic Straps: Required in Los Angeles area
Venting: Ready access to sidewall or vertical penetration at each site
Initial Gas HPWH Demo Results

DHW Capacity:

> Moderate to low usage at sites (40-80 gal/day mostly).
  - No capacity complaints so far

> Supplemental heating is used sparingly, 0.2-2.0% of total DHW output.
  - Recall disabled @ Site 3
  - Site #4 unit excluded

> Power 0.5-1.0 kWh/day (without suppl. heating)
  - Appx. 6 Wh/gal DHW/day above constant 25 W

Supplemental Heating at GHPWH Sites

[Graph showing supplemental heating usage over time and frequency.]
Initial Gas HPWH Demo Results

DHW Capacity:

> Very long standby period, followed by draw cluster in evening

> Unit pre-empts draw cluster, initiates heating during 15 gal draw, followed by 50 gal draw.

> Outlet temperatures remain above 105 F with suppl. heating

Site #1 – 8/28/18
Initial Gas HPWH Demo Results

DHW Capacity:

> Similar situation, long standby with heavy draw cluster in evening.

> Site consumes 55 gal. DHW in 17 minutes (tub fill + machine draws?)

> GHPWH cycles on, suppl. heat on once mid-tank drops below 110°F

> Outlet temp. drops below 100°F at end
Initial Gas HPWH Demo Results

GHPWH Efficiency:

> Comparing to baseline, GHPWHs already show marked savings.
  - Site 4 is skewed due to limited runtime

> Site-specific therm savings for 55 gal/day:

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
<th>Site 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>56.1%</td>
<td>54.6%</td>
<td>64.9%</td>
<td>58.4%</td>
<td>51.9%</td>
</tr>
</tbody>
</table>

> Prototypes differ in this study
  - Smaller tanks
  - CHX design/placement

> Possible that both have altered dynamics of the hydronic HX

> Initial performance good, however
  - Loop temperatures rise faster
  - Peak COPs tend to be later/lower

> Will continue to monitor

Site 5: 12/26
COP_{HP} = 1.49

COP peaks about 30 minutes after startup

Challenge establishing superheat
Parallel Laboratory Assessment

Performance Testing
> **Energy Efficiency** testing per DOE “UEF” method
> **Emissions** CO2, CO, NOx and unburned hydrocarbons (UHC) per SCAQMD methods.

Accelerated Durability Test
> Accelerated operating life test on automated test stand, extrapolate to equipment life
> Spot checks to assess degradation of performance metrics (UEF, First Hour Rating) and emissions levels
Gas HPWH Market Research

Market research was designed with a two-step approach:

- **Qualitative step**: Complete
  - In-depth interviews with 27 plumbing, HVAC, and/or home energy improvement contractors lasting 90 minutes each
  - Followed by four professionally moderated focus groups in California, lasting 2 hours each, 40 participants total, in Sacramento and Irvine

- **Quantitative step**: Underway
  - Two surveys executed nationwide, one targeting contractors (minimum of 500 responses) and one targeting homeowners (minimum 1,000 responses).
Gas HPWH Market Research

Highlight of Qualitative Results ("SWOT" type analysis from MR):

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Primary Strengths</th>
</tr>
</thead>
</table>
| • TWH install cost high, GHPWH could be 'middle priced' alternative  
  • Energy savings are big  
  • Need to lead with total cost of ownership (leasing?) | • Lowest TCO if 10+ year warranty is standard  
  • Well-known brand names critical  
  • Competitive replacement cost with Power Vent |

<table>
<thead>
<tr>
<th>Threats/Weaknesses</th>
<th>Secondary Strengths</th>
</tr>
</thead>
</table>
| • Units are large, no space-saving benefit  
  • Shouldn’t compete directly with TWHs  
  • Slow recovery time | • Install price between storage/TWHs, could draw those who don’t pay “tankless premium”  
  • Environmental benefits  
  • Rebates could accelerate sales |
Next Steps

> **Demonstration**: Continue to service prototypes, monitor/analyze data, decommission in Summer 2019

> **Laboratory Assessment**: Complete experimental test plan, with durability testing complete in Summer 2019

> **Model Development**: Complete model/Title 24 Analysis and guidance to reduce codes/standards market barriers, NZEH white paper

> **Market Research and Outreach**: Complete quantitative MR assessment and perform stakeholder outreach with complete findings
Questions?

Further information:
pghanville@gti.energy

RD&D Discussed Supported by:

Gas Technology Institute
1700 S Mount Prospect Rd, Des Plaines, IL 60018, USA
www.gastechology.org

http://www.stonemountaintechnologies.com/
Technical Appendix
Site 1, 2, and 4 have similar performance with 0.62 EF rated GSWHs. Site 4 runs at higher temperatures, leading to greater standby losses.

Site 3 has est. 0.54 EF heater, with expected performance.

Site 5 0.67 EF (power vent) but low utilization
Initial Gas HPWH Demo Results

GHPWH Efficiency:

> Preliminary estimate of energy savings using Input/Output methodology

> Scatter should be improved with larger dataset and maintenance/repairs to units

\[ \text{Input} = m \cdot \text{Output} + b; \]

\[ \frac{\text{Output}}{\text{Input}} = \text{DEF} = \left( m + \frac{b}{\text{Output}} \right)^{-1} \]
Tackling Installation Barriers

**Electrical Service:**
- Sized for 120 VAC, 15 A line
- Normally consumes ~150 W, 1250 W element used sparingly
- Larger elements possible

**Gas Piping:**
- ½” is most common existing pipe
- GHPWH can be served readily by ½”, even ¼” would work.

**Condensate Drain:**
- Need to drain comb. condensate (~1 cup/hr) and evaporator condensate (variable)
- Run directly to sanitary drain, tie into condensate pump
- May permit disposal outdoors, may also require neutralization before drainage

**Venting:**
- ¾” and 1” PVC venting is feasible, low cost to install
- In some jurisdictions, higher temperature plastics (CPVC, etc.) may be required
- ½” is possible for shorter runs
- For evaporator air, eventual req’s may be in place for ducted GHPWHs

**Gas Piping:**
- ½” is most common existing pipe
- GHPWH can be served readily by ½”, even ¼” would work.
Tackling Installation Barriers

Goals of parallel, multi-faceted effort were to:

- Quantify impact of GHPWH tech. on conditioned space, define need for venting/sourcing evap. air and re-use of existing vent penetrations
- Develop, demonstrate novel methods of condensate neutralization/disposal

Analyzing condensate to determine most cost-effective means of treatment and disposal per req’s
- Avoid costly oversizing!

Investigating novel means of treating/disposing of condensate, using:
- Passive/wicking evaporation
- Ultrasonic-assisted atomizers
- Utilizing existing exhaust streams