the Energy to Lead

Development of Economical Gas-fired Ammonia-Water Absorption Heat Pumps for Water Heating and Space Heating Applications

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> International Gas Union Research Conference
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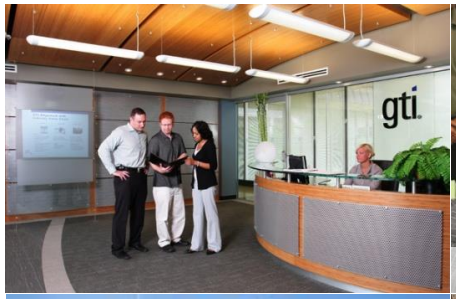
ESTABLISHED 1941

Gas Technology Institute

- Independent, not-for-profit company established by natural gas industry
- Providing natural gas research, development and technology deployment services to industry and government clients
- Facilities
  - 18 acre campus near Chicago
  - 200,000 ft^2 with 28 labs
- Staff of 260
- Wellhead to the burner tip including energy conversion technologies



Training

CHP and Renewable Energy Lab

Pilot-Scale Gasification Campus

Energy & Environmental Technology Center

Outline

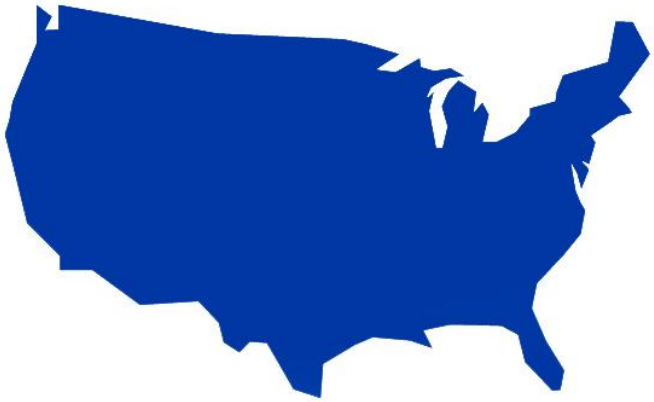
Can Gas Heat Pumps find their place in the U.S.?

> The U.S. market for residential space and water heating

> Overview of residential gas heat pump developments

> Performance comparisons

> Future RD&D Plans

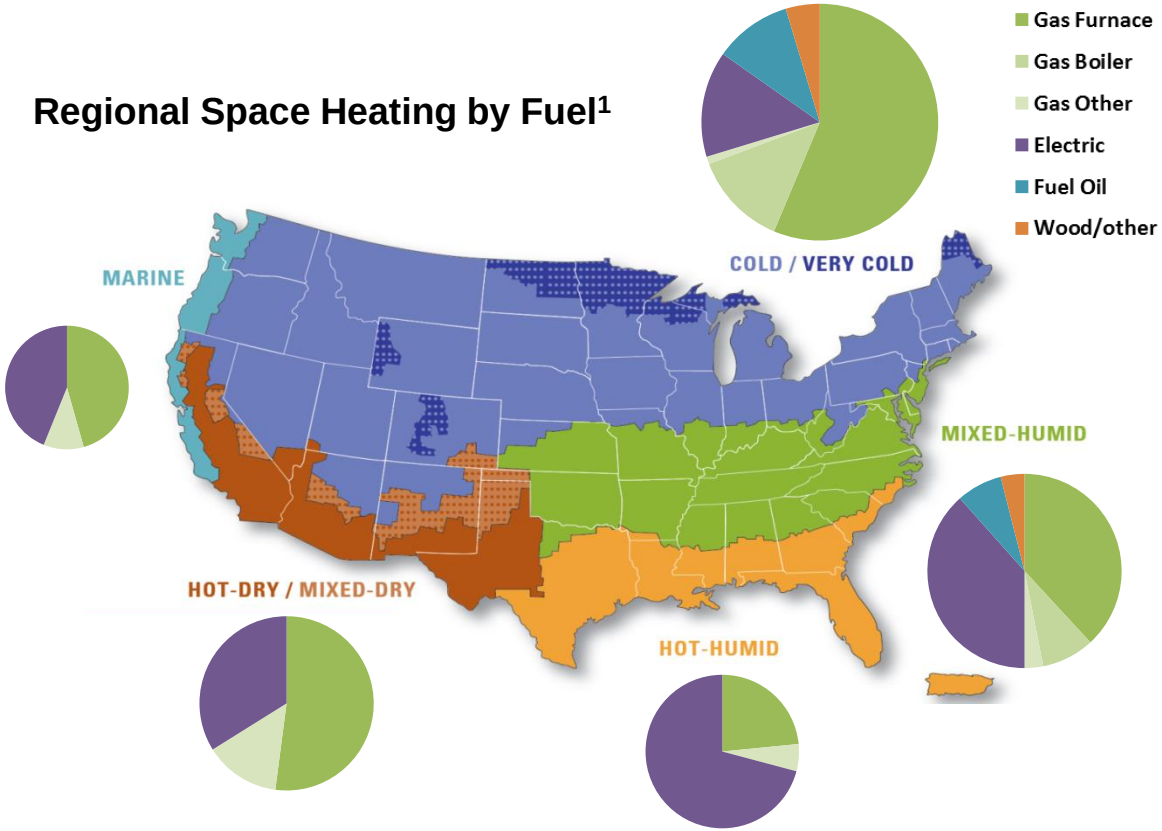


U.S. RESIDENTIAL SPACE HEATING

Space Heating Overview

- Largest residential use of natural Gas in U.S., 63% of the residential load, 29.4 billion therms/yr
- Gas still preferred fuel for space heating, but declining from better envelopes and competition
- Regional variation largely climate driven, but also by spark spread and state regulations
- Cold climate focus

Regional Space Heating by Fuel[1]



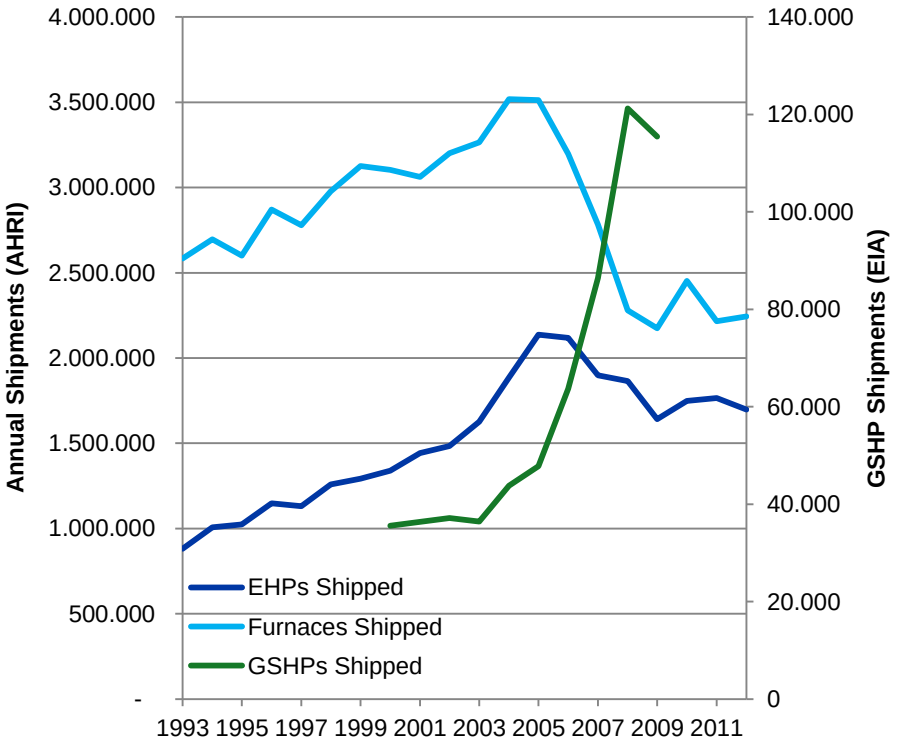
1. Map from "Guide to Determining Climate Region by County", Prepared by PNNL and ORNL, Report No. PNNL-17211, August 2010. Data from US DOE 2009 RECS (2013).

U.S. RESIDENTIAL SPACE HEATING

Trends

Traditional Gas Heating Losing Ground

- Gas is the most common heating fuel in U.S. cold climate regions and some mild climates
  - 80% are central warm-air furnaces, remainder is primarily steam/hydronic system
- Furnace market share is dropping and with it gas consumption, with an 18% drop in use of natural gas as a heating fuel from 1997 to 2009 (incl. envelope improvements, migration, etc.)
- Higher efficiency heating technologies for condensing combustion (~90-96% AFUE) an old technology, represents over half of furnace shipments
  - Stalled regional standards in U.S. seek to require this, already the case in parts of Canada
- Market needs cost-effective, high-efficiency heat pump option for gas customers

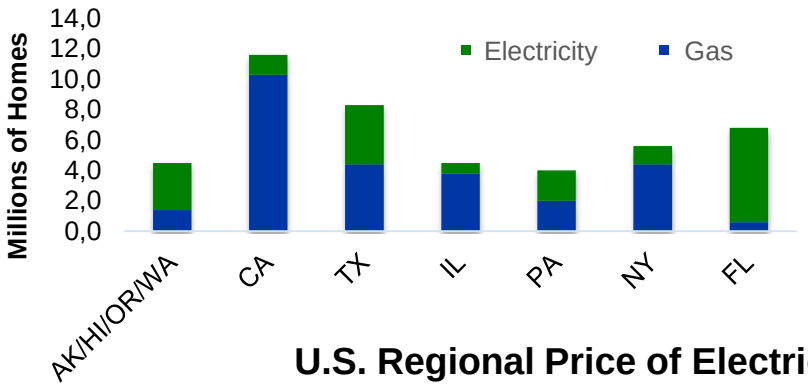


U.S. RESIDENTIAL WATER HEATING

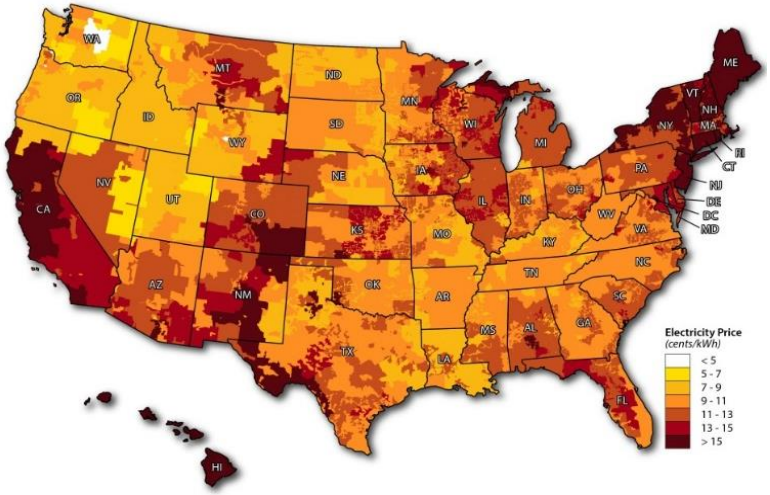
Water Heating Overview

- Water heating is second largest residential use of natural gas in U.S., 26% of the residential load, 12.3 billion therms/yr
- Distribution of water heater types is primarily influenced by spark spread, not climate. Loads also not climate-driven, but occupancy-driven
- Due to state efficiency codes and water heating being the largest residential load (2.5 billion therms/yr), CA is major influence with 10 million gas water heaters
- Nationwide, split is roughly 50/50 electric/gas

Water Heating by Fuel[1]

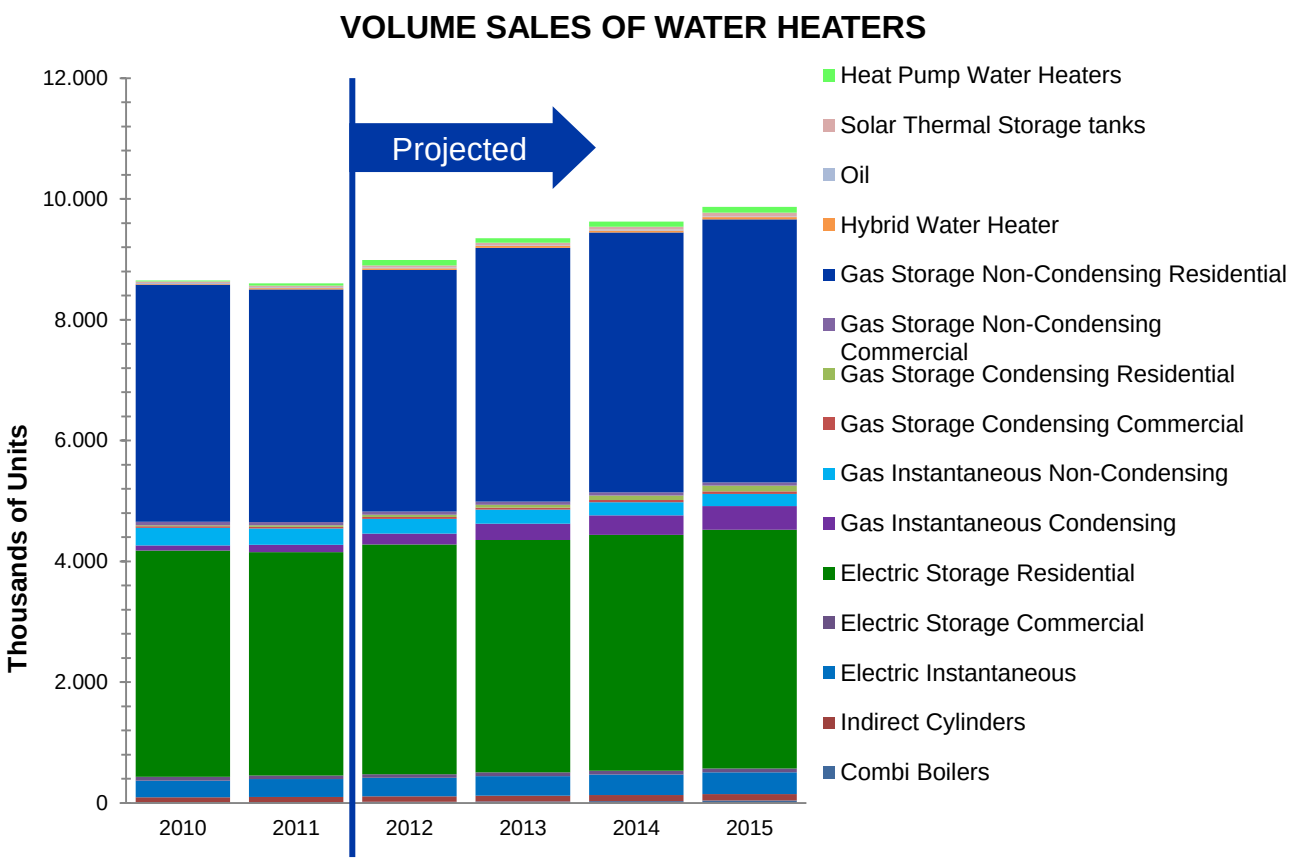


U.S. Regional Price of Electricity



1. Map produced by NREL for the US DOE in 2013 (2010 prices). Data from US DOE 2009 RECS (2013).

U.S. RESIDENTIAL WATER HEATING
Trends



Low-Cost is Still King

> Lion's share of products sold are still low-efficiency gas and electric storage residential water heaters

> Growth in gas condensing tankless water heaters

> Electric heat pump water heaters growing as well, however 2012 shipments were on the order of 50,000/yr

Data Source: Parker, M. "American Water Heating Dynamics: Present and Future", ACEEE HWF (2011).

U.S. RESIDENTIAL WATER HEATING

High-Efficiency Retrofit Options

- Non-condensing EnergyStar® water heater with 0.67-0.70 EF, current models require electrical service
- Condensing gas storage water heaters (GSWH)/Hybrid, requiring venting upgrade and electrical service
  - Most currently rated with thermal efficiency (TE), recent study has found units with TE > 90% have EF of less than 0.80*
- Convert to non-condensing or condensing Gas Tankless Water Heater (GTWH), with an EF 0.82 – 0.95 typically, requiring venting upgrade, electrical service, and often larger gas piping
  - Delivered efficiency of TWHs is in dispute due to cyclic/startup losses not covered by EF, some groups de-rate the EF of TWHs by 9%**

Market is predominantly 0.59 – 0.62 EF residential GSWH

** Davis, R. "Laboratory Testing of Advanced Storage Water Heaters", ACEEE HWF (2012).*
*** RESNET. Results of Electronic Ballot of RESNET Board of Directors on Adopting Proposed Standard Amendment on Adjusting Instantaneous Water Heater Efficiency (2012).*

U.S. RESIDENTIAL WATER HEATING

Why Now?

- After Energy Star (ES) for water heating was enacted and with new Federal req's, strong incentives for high-efficiency
- While Electric Resistance Storage water heaters are exempt, Electric Heat Pump water heaters qualify for ES and financial incentives
  - Large potential in regional markets, Pac NW, SE
- GTI Evaluated a series of EHPWHs in 2010 under standard and stressed conditions
- Interest in a gas-fired option, U.S. DOE and utilities have supported developments of GHPWHs with industry/OEM partners

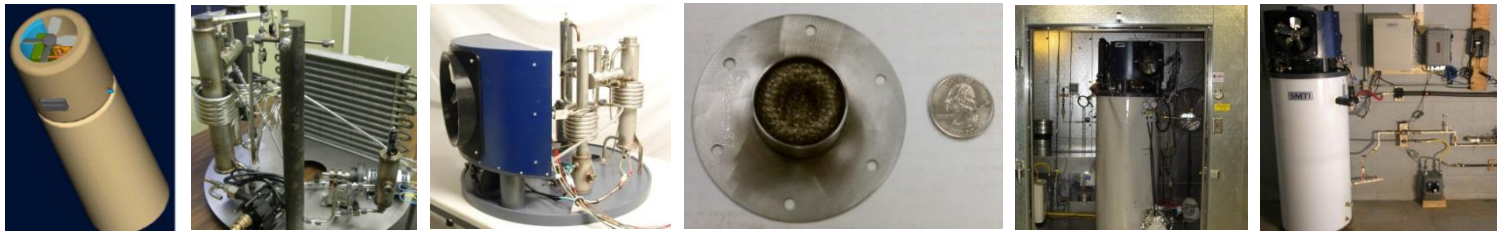
Opportunities for Water and Space Heating in the U.S.

- **Technical:** Numerous heat pump cycles are technically feasible
  - Engine-driven vapor compression
  - Direct-fired absorption cycle: NH3-H2O, Strong Salt-H2O common
  - Solid sorption/adsorption: silica gel-H2O, zeolite-H2O
  - Stirling engine cycles and variants
  - Thermoacoustic cycles
- **Economic:** Problematic in prior commercialization efforts
  - Limited commercially available options, primarily EU/Japan suppliers
  - Installed costs are high, sales volumes are low (1,000s), but growing
  - GHPs are not often designed as dedicated water heating device (e.g. residential absorption chiller).
- Critical for U.S. GHP products to be as low-cost as possible, as compared to other “high-efficiency” options

RESIDENTIAL GAS HEAT PUMP

Technology Development

> Gas Heat Pump Water Heater (GHPWH) and Gas Heat Pump (GHP) for space heating both developed by startup company Stone Mountain Technologies Inc. (SMTI), with OEM, GTI, and University Support with government and utility sponsors



GHPWH R&D Proof-of-Concept – Completed with 3 Packaged Lab. Proof-of-Concept GHPWH Units, then refined controls and design.

GHPWH Field Testing – Currently at two residential sites, five additional sites planned by end of 2014

2010 — 2013 — 2014 — 2015 ▶

GHP R&D Proof-of-Concept – Designing low-cost GHP, in lab testing phase currently.

Field Testing Planned

RESIDENTIAL GAS HEAT PUMP

System Specifications

- Based on low-cost single-effect cycles, these are intended as fully retrofittable with most common gas storage water heating and hydronic heating systems *without infrastructure upgrade*

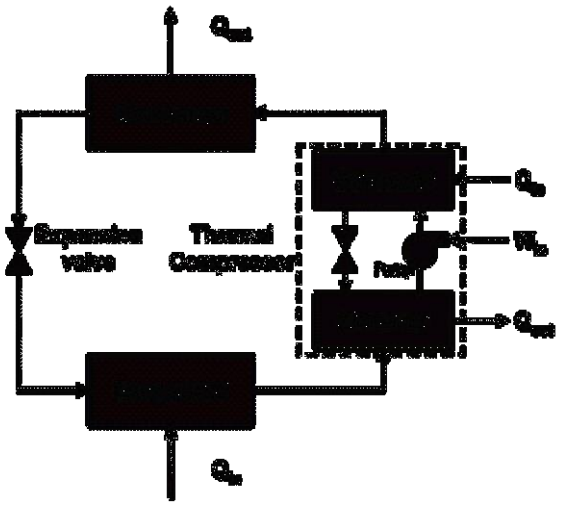
	GHPWH	GHP
Heat Pump Output (kW)	2.9	23.4
Firing Rate (kW)	1.9	16.1
Efficiency	1.3 Energy Factor	COP > 1.4
Storage Size (L)	265	N/A
Emissions (projected)	10 ng NO_x/J	14 ng NO_x/J
Commercial Introduction (projected)	2016	2017
Installation	Indoors/semi-conditioned space (garage), sealed NH3 charge < 25% max allowed by ASHRAE Std 15	Outdoors
Venting	½" – 1" PVC	N/A
Gas Piping	½"	¾"
Estimated Consumer Cost	<$1,800	<$4,500

RESIDENTIAL GAS HEAT PUMP

How It Works

Very similar to vapor compression, 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

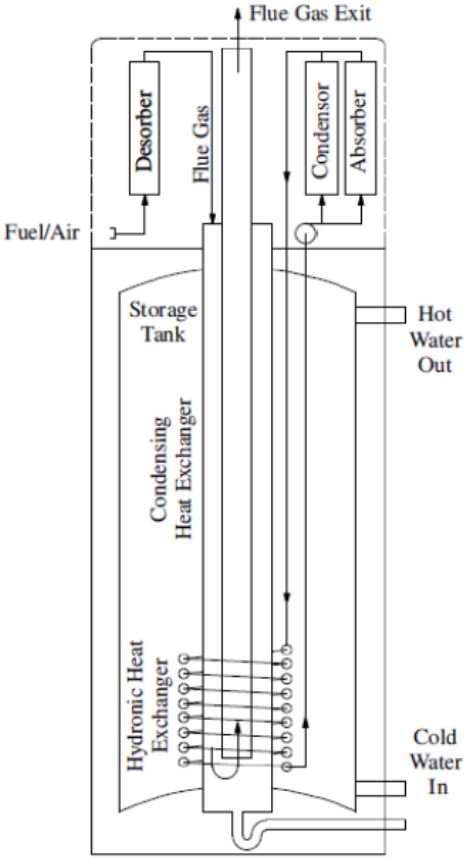


[Source: MW CHP Center]

RESIDENTIAL GAS HEAT PUMP WATER HEATER

How It Works

- 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

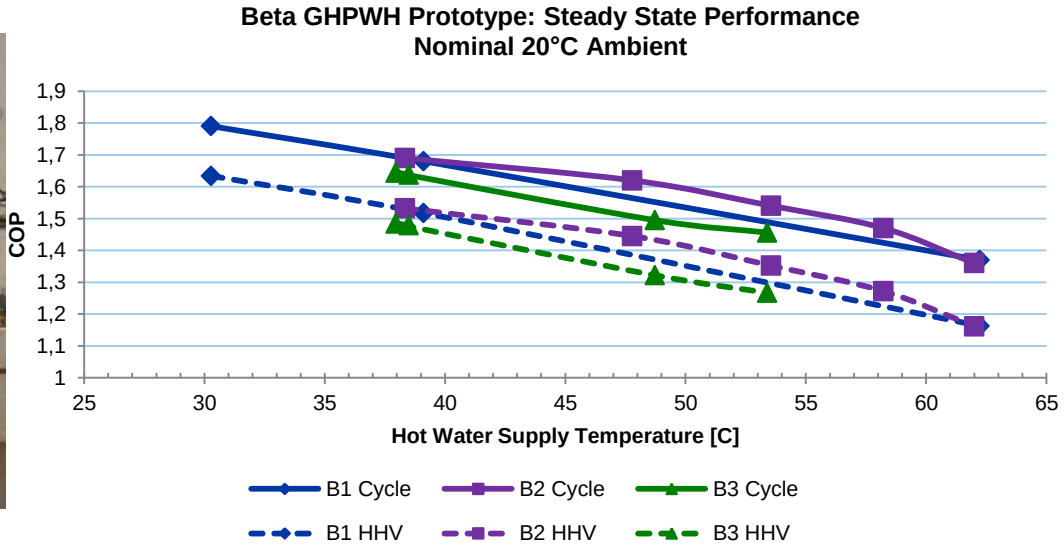


RESIDENTIAL GAS HEAT PUMP WATER HEATER

System Performance

> In environmental chamber, cold/dry to hot/humid conditions, system operates close to theoretical maximum COP

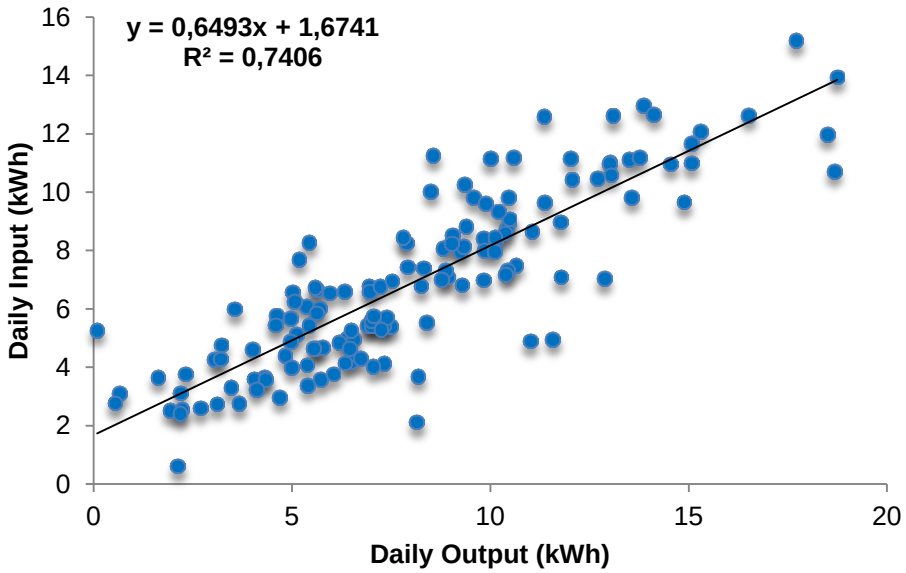
> Performance in field has confirmed results, focus now on controls and system cost



RESIDENTIAL GAS HEAT PUMP WATER HEATER

Field Evaluation

- Team has developed methods to estimate installed energy savings depending on usage, installation characteristics
  - Two-unit assessment active in TN, more planned for West Coast
  - Several improvements in controls, exp. valve implemented



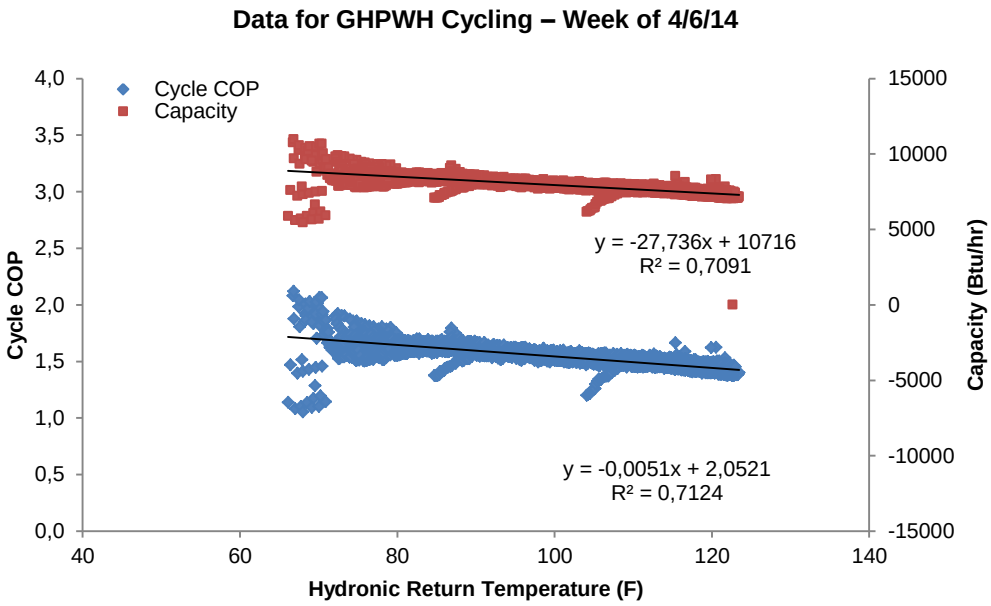
Extrapolating field "Delivered Efficiencies", between 1.1 and 1.4 as measured, unit is showing performance to 1.3 EF target. Tank standby loss can be improved by 50%, using standard methods to surpass this goal

DOE Test Category	Daily Output (L)	Delivered Efficiency (Field Ambient – 19 C avg.)
Medium Usage	208	1.20
High Usage	318	1.30

RESIDENTIAL GAS HEAT PUMP WATER HEATER

Field Evaluation

- Unit has demonstrated successful operation with ambient temperatures below 35 F, with a COP > 1.0, unattainable by EHPWHs that disable HP at T < 45 F typically
- Under standard conditions, unit shows COP near theoretical maximum for single effect cycle, between 1.4 and 1.8



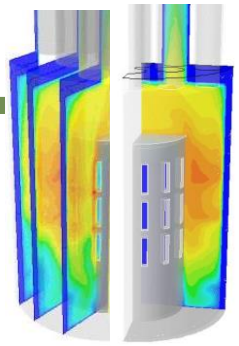
GTI data logging displays real-time cycle COP vs. key metrics, ambient temperature, water temperature, and hydronic return temperature

RESIDENTIAL GAS HEAT PUMP WATER HEATER

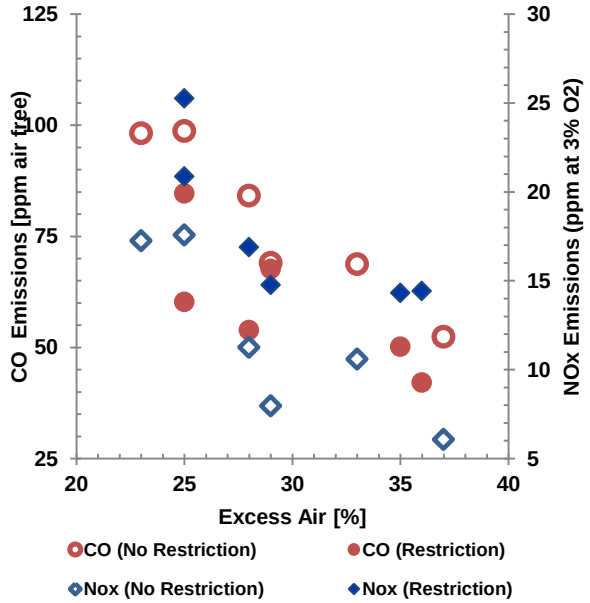
Combustion Design

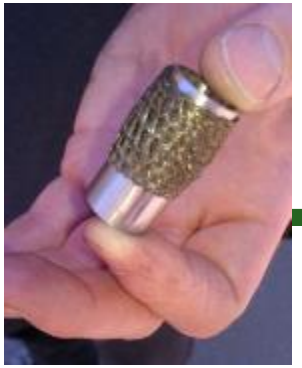
- Firing into desorber at 1.9 kW, designed for efficiency, cost, and size
- Boiler solution at chamber walls has temperature of 120-170°C
- Beyond efficiency, NO_x and CO emission targets are aggressive

Largely using radiant metal mesh designs, several geometries evaluated, results mixed, refined with CFD to meet targets, customized components



Reduce OD





RESIDENTIAL GAS HEAT PUMP WATER HEATER

Technology Comparison

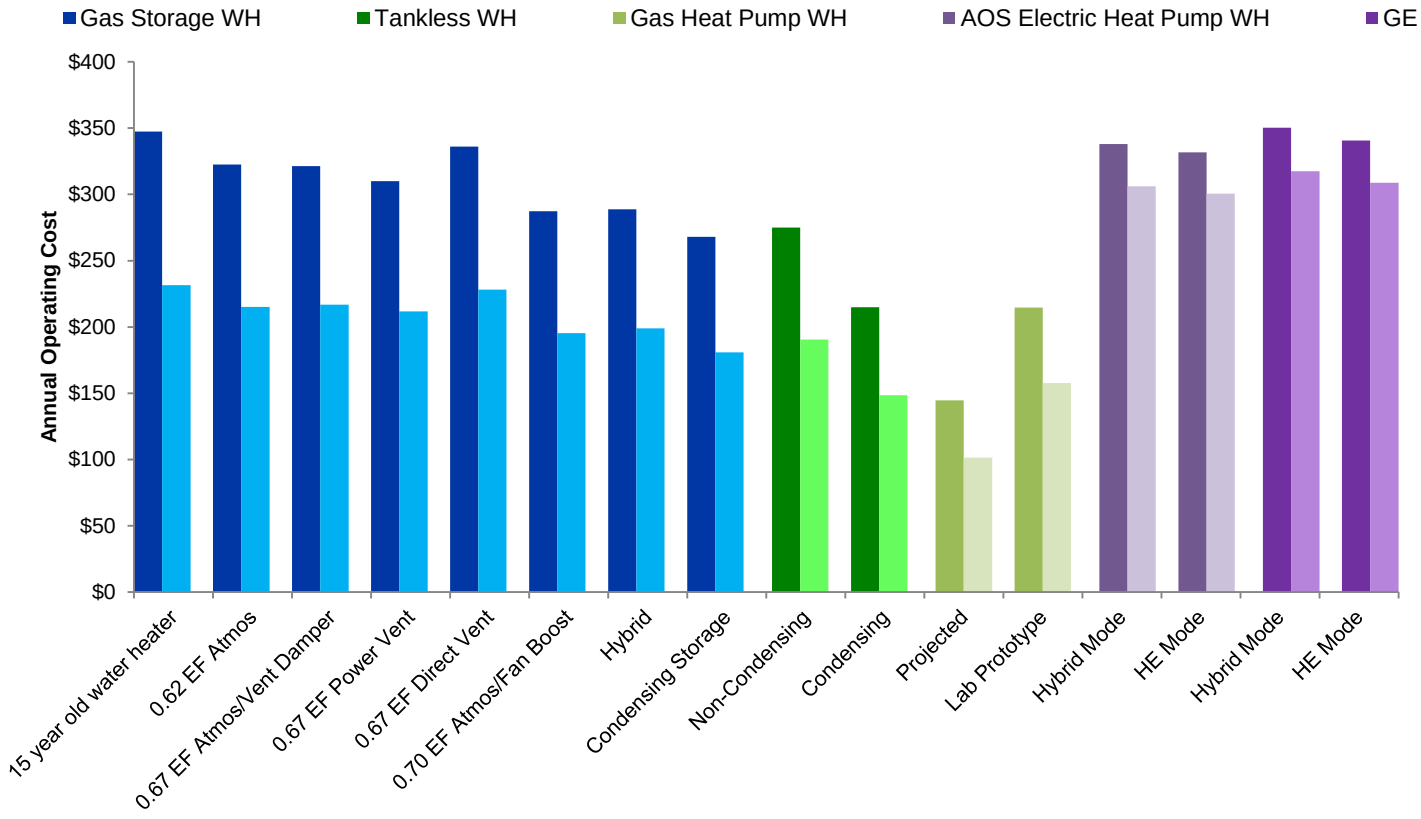
Is there a energy saving opportunity for GHPWHs?

- Comparative Analysis–Assembling laboratory test data with daily electricity & natural gas consumption:
  - CEC Residential Gas Water Heating Program, GTI and PG&E performing laboratory testing on residential gas tankless and gas storage water heaters respectively*
  - Laboratory Characterization of Electric HPWHs, GTI testing three of the major 2009-10 EHPWH products. Results for analysis are for EF of 2.4 – 2.6**
  - Laboratory Testing of Prototype Gas-Fired Residential Absorption HPWH, GTI testing of prototype absorption GHPWH under standard and field conditions. Results for first generation. prototype correspond to EF 1.1 – 1.2***

* 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
** Glanville, P. et al. "Parametric Laboratory Evaluation of Residential Heat Pump Water Heaters", Trans. of ASHRAE v. 118 pt. 1, Chicago, IL. (2012).
Link: http://aceee.org/files/pdf/conferences/hwf/2011/1B%20-%20Paul%20Glanville.pdf
*** Garrabrant, M. et al. "Development and Validation of a Gas-Fired Residential Heat Pump Water Heater - Final Report ". DOE Contract EE0003985 (2012).
Link: http://www.osti.gov/scitech/biblio/1060285

RESIDENTIAL GAS HEAT PUMP WATER HEATER

Technology Comparison

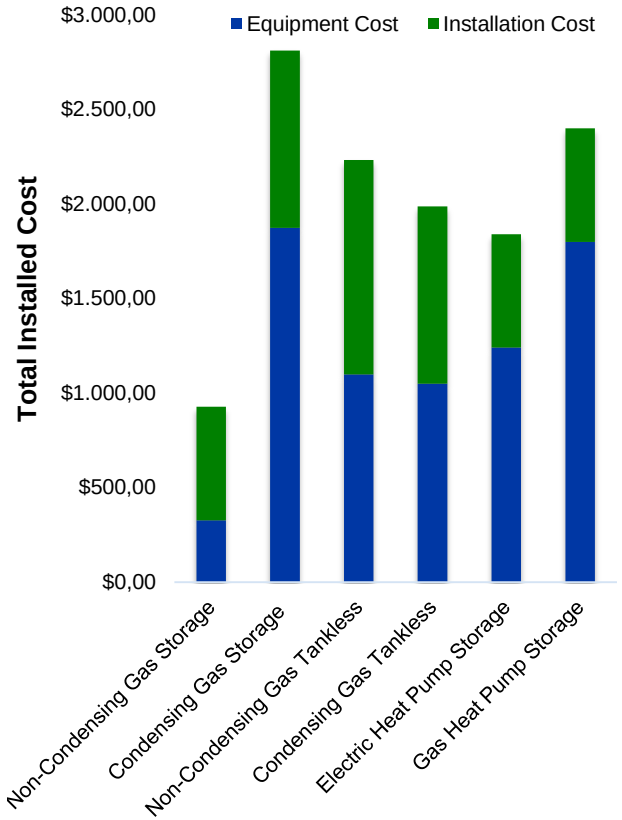


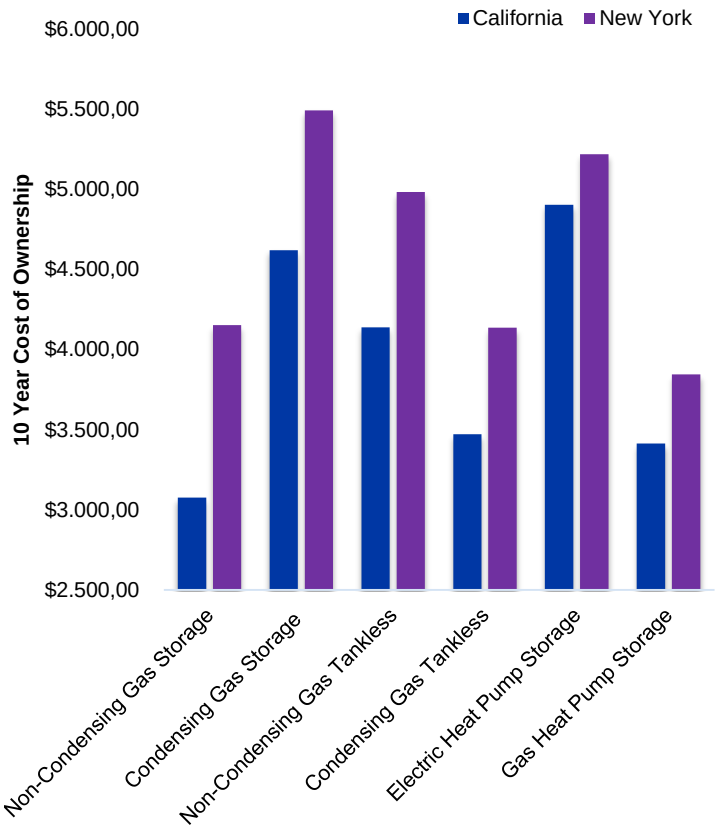
When introduced into the market, GHPWHs will have the only Source Energy Factor > 1.0. Success in large gas WH markets is critical (CA/NY)

NY – Dark Shade; CA – Light Shade; Energy prices are statewide averages for gas/electricity

RESIDENTIAL GAS HEAT PUMP WATER HEATER

Technology Comparison





- 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

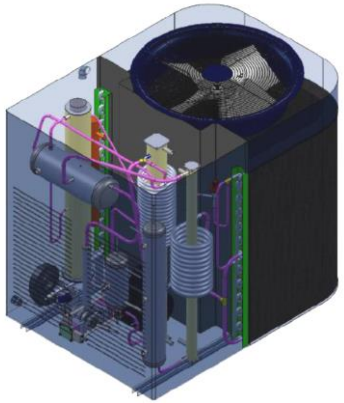
Technology Performance

GHP Space Heater Development:

> Using lessons learned, team is scaling up low-cost, single-effect system to GHP for space heating

> Unit will be equivalent to a 80,000 Btu/hr output hydronic boiler, with 3:1 turndown and outdoor install

> Planned GTI psychrometric chamber testing down to -13°F (-25°C) during coming winter



Future Plans

- **Water Heating**
  - GHPWH on target for near term market introduction, field demonstration in five states underway. OEM and utility support has been critical.
  - U.S. DOE recognized GHPWHs through recent rule change. Parallel development efforts underway led by ORNL.
- **Space Heating**
  - GHP prototype demonstration completed early 2015, field evaluation shortly thereafter
  - Exploring dynamics of combined water/space heating

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