ETP
Emerging Technology Program

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TECHNOLOGY SNAPSHOT

Gas Heat Pump Hot Water Heater

Gas Heat Pump Water Heaters (GHPWH) use the mature vapor absorption cycle technology to maximize energy savings from hot water in residential and light commercial applications. In addition to the step-change in efficiency, the GHPWH is better suited for retrofit than other gas water heating products.

MARKET SITUATION

Baseline

- Traditional non-condensing domestic hot water technologies, representing the majority of the gas water heating market.

Opportunity

- Energy efficiency
- Consumer savings
- Trade ally support

Segment

- Residential and light commercial
- New construction and retrofits

Status

- Pre-commercial technology currently being deployed
- Expected 2018 commercialization

Next Steps

- Continued field verification, technology enhancements, market development

The Technology

In the U.S. and Canada, gas-fired residential water heating predominantly consists of minimum-efficiency storage water heaters with Uniform Energy Factors (UEFs) in the range of 0.60 to 0.65. Higher efficiency and higher cost ($700 - $2,000) options serve about 15% of the market (primarily tankless), but still have EFs below 1.0, ranging from 0.65 to 0.95. An R&D project team has developed a new class of water heating products exceeding the traditional limit of thermal efficiency. The team, led by Stone Mountain Technologies Inc. (SMTI) and supported by GTI, A.O. Smith and Georgia Tech, designed and demonstrated a packaged water heater driven by a gas-fired ammonia-water absorption heat pump. This gas-fired heat pump water heater (GHPWH) can achieve UEFs of 1.3 or higher, at a consumer cost of $1,800 or less. The technology is expected to become commercially available in 2018.

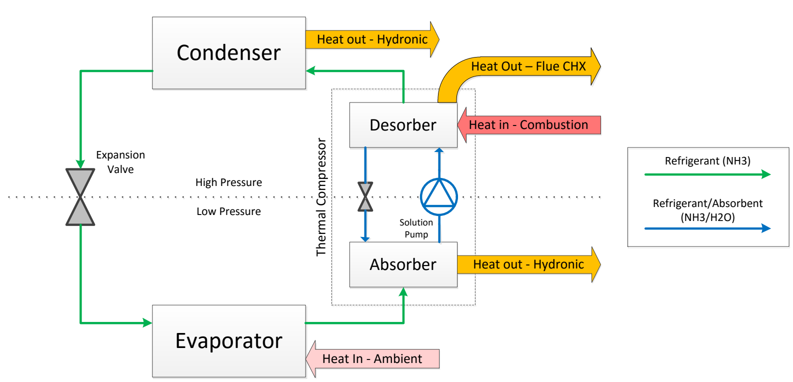

Figure 1: Diagram of GHPWH Vapor Absorption Cycle

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These residential absorption heat pumps use an ammonia-water absorption cycle to provide domestic hot water heating. As in a standard heat pump, the refrigerant (in this case, ammonia) is condensed in one coil to release its heat; its pressure is then reduced and the refrigerant is evaporated to absorb heat. Utilizing this refrigeration process allows for UEFs greater than 1.0.

Market Analysis

According to the U.S. Energy Information Administration's 2005 Residential Energy Consumption Survey (RECS), annual residential water heating totals 1.80 quads of energy annually, or 18% of the energy delivered to residential buildings. These numbers translate to 17% of household consumption in the Northeast to 27% in the Western states.

Heat pump technology has entered the domestic hot water industry through the deployment of electric heat pump water heaters (EHPWHs). While market penetration is still small, with less than 100,000 units sold per year, deployment efforts by manufacturers and energy efficiency programs has raised awareness in the market and stimulated sales. Because the operation of an electric heat pump is similar to gas, regions with successful EHPHWs are well positioned to adopt GHPWHs as many common market barriers are being addressed and lessons learned can be leveraged. Additionally, through the implementation of its new method of test for rating residential water heaters in 2015, the Department of Energy (DOE) has created a new "gas heat pump water heater" product category in advance of the technology's commercialization, signaling their priority to push gas water heating products to have UEFs above 1.0 as they have with EHPWHs.

Costs + Benefits

The value proposition of the GHPWH is its step-change in operating efficiency, yielding 50% or greater therm savings over baseline equipment as demonstrated in a recent field evaluation. With a projected UEF of 1.3, this yields the highest *source energy-based* operating efficiency of all gas and electric products, including Energy-Star-level EHPWHs. Despite that the projected equipment cost exceeds that of the baseline, due to the technical complexity and with an estimated equipment cost of $1,600-$1,800, the GHPWH is uniquely capable of a lower cost retrofit with the predominant minimum-efficiency gas storage water heaters, representing 87% of gas water heating sales. Due to the small GHPWH combustion system and sizing of the backup heating, a retrofit can use existing ½" gas piping, requires only a ½"-1" PVC vent, and requires 120 VAC. Most mid-efficiency gas water heating options require larger diameter special venting, larger diameter gas pipes, and as a result have costlier installation.

To illustrate this, Figure 2 compares the ten-year cost of ownership (installed cost + operating cost) for the GHPWH versus baseline and other gas water heating options. For a wide range of daily hot water draws, 60 gal/day and greater, the GHPWH is the lowest cost option including baseline.

Looking at DHW Technologies: GHPWH Value Proposition

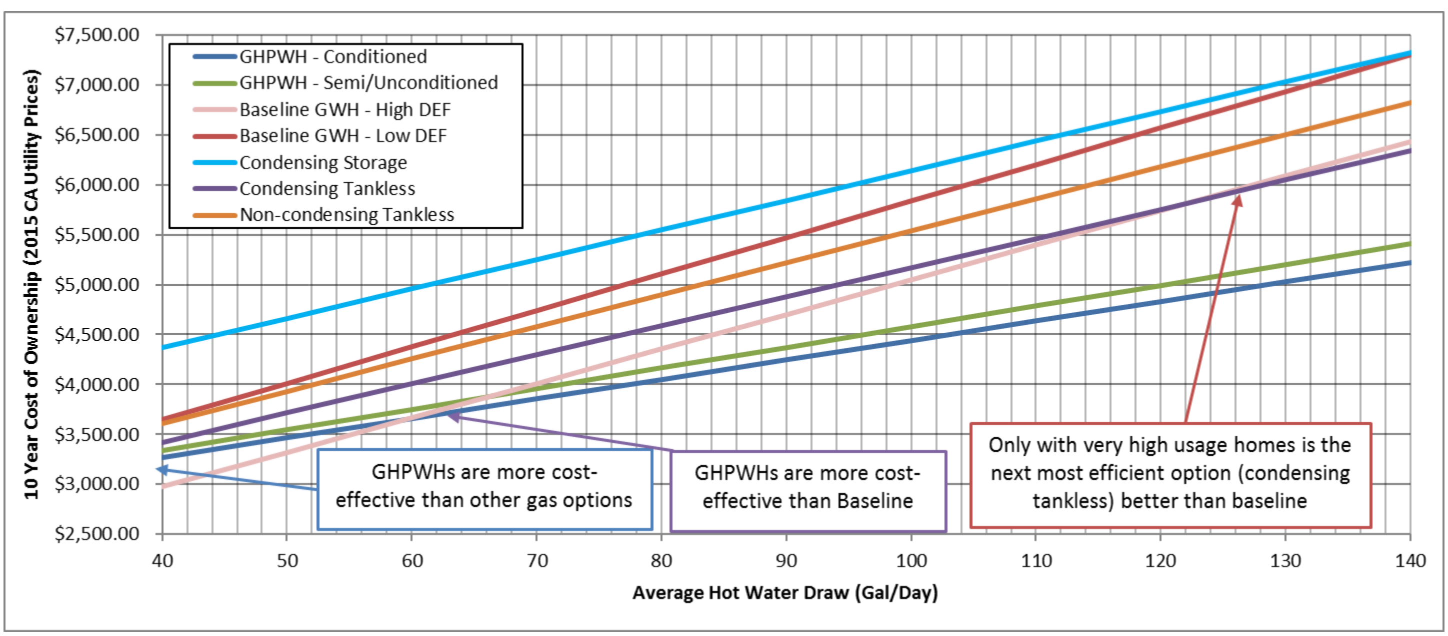

Figure 2: Ten-year cost of ownership for GHPWH versus other Gas Water Heating Technologies
Energy Rates from Energy Information Admnistration (EIA)

Barriers

GHPWHs use existing technology in a new application. Gas heat pump systems have been available in the market for many years, yet the technology has not been utilized for domestic hot water heating until now. Even with a significant investment in laboratory and field testing, the product has not been certified as it remains pre-commercial.

Another potential barrier is the use of ammonia as a refrigerant. Though ammonia is considered to be hazardous and an irritant, the GHPHW is a sealed system with ammonia levels well within the allowable limit found in the relevant mechanical code.

A few installation considerations include:

1. The heat pump itself is a sealed system, not intended for servicing, so the entire heat pump needs to be replaced at end of life.
2. Installers need education as the GHPWH installation, similar to the EHPWH, can include elements related to both plumbing and HVAC.
3. Due to lower recharge timing, heat pump systems require a larger storage tank. Therefore, the 60-80 gallon tank may require a two person install.

Product Potential

The target markets for this new technology are in the light commercial and residential sectors, specifically single-family housing. This market currently represents ~500,000 units, or approximately 10% of residential gas water heater shipments. As the technology develops, multi-family applications may expand the market further.

Figure 3: Residential Heat Pump Water Heater (Patent Pending) Source: Stone Mountain Technologies Inc.

Like the electric version, the GHPHW will likely require incentives to spur market adoption. The significant improvement in efficiency, even over best-in-class condensing systems, justifies energy efficiency program support. As costs decline due to increased production volume, the GHPWH will become the natural choice for all gas tank water heater installations.

Laboratory Testing

Supported by the U.S. Department of Energy and Utilization Technology Development (UTD), Stone Mountain Technologies Inc. (SMTI) led the initial R&D effort with GTI, AO Smith and Georgia Tech. From 2010-2013, prototypes were designed, built, and evaluated at several laboratories to support validation of analysis tools, including:

- A potentially new method of test and rating procedures
- Examination of protocols for field studies
- Evaluation of venting materials and systems.

Goal

1. Market-ready UEF of 1.3+
2. Installed cost competitive with electric heat pump water heaters (<$1,800) with clear value proposition

Key R&D Finding – Efficiency Benefit of Advanced Cycle not Cost-Effective

In seeking to optimize system performance through cycle modeling and breadboard testing, the team evaluated the opportunity for single-effect vs. generator-absorber heat exchange (GAX) cycle. The results showed that while GAX performance was higher overall compared to single effect (by 41%), reaching performance just 5-10% higher would require the GAX to be at least 10 cm taller and costlier than single effect model. This led the team to determine that the single effect model suffices to reach the target goal of an EF at 1.3 while maintaining practical footprint and cost effectiveness.

Field Tests

Since late 2013, with support from UTD, a "2nd" generation GHPWH prototype was installed for field testing at an SMTI employee home. A year later, built with lessons learned from this early field evaluation, a "3rd" generation GHPWH prototype was built and installed at a utility-employee home within a short drive of the SMTI facility in Johnson City, TN. Shortly thereafter, four additional "3rd" generation GHPWH units were installed in the Pacific Northwest in early 2015 with support from NEEA and Intermountain Gas. Through these initial field tests, critical information has been used to improve the GHPWH control strategies and future design improvements. Over the greater than 4,500 cumulative operating hours for these six GHPWH prototypes in the field, GTI documented and has since published these key findings (next page):

SMTI Georgia Institute of Technology College of Engineering AO Smith Innovation has a name.

- **Efficiency:** Heat pumps operated well, at/above target Coefficients of Performance (COP) in "real world". COP impact of water/ambient temperatures were characterized (including sub-freezing) and the cooling effect was measured to be small, ~3,250 Btu/hr. Site specific therm savings greater than 50% over conventional GWH were observed.
- **System Reliability:** Major components (EEV/Solution pump) had reliability challenge for all units tested, leading to important findings to improve design and delivered efficiency. The opportunity to more effectively use "boost" heating was also examined.
- **End User/Contractor Feedback:** Capacity was an issue during infrequent, extreme loading events – leading to methods for improving performance and capacity outlined for future development. End users noticed noise in some cases, however operational nuisances were not a major issue. Installation contractors noted ease of retrofit, except for large unit size (80-gallon form factor).

Reliability Testing

With findings from the aforementioned field trials of "3rd" generation GHPWHs, GTI and SMTI performed an accelerated commercialization program to begin to resolve outstanding technical issues through extended reliability testing of six GHPWH prototypes and a focused development program concerning the key "moving parts" within the GHPWH. Additionally, the team sought to: identify new failure modes for the GHPWH technology, evaluate new component designs for greater reliability, investigate adjustments to GHPWH controls for increased hot water capacity, and investigate potential future operational issues associated with residential infrastructure. This program, wrapping up in Q3-16, led to the development and design of a "4th" generation GHPWH unit.

Future Test Sites

Whereas prior 2nd/3rd generation GHPWH prototyping engaged two water heater OEMs, the deployment of a new 4th generation GHPWH that (a) is located within the hot/humid climate of Alabama and (b) investigates a smaller, 60-gallon form factor, was developed in partnership with a third water heater OEM, continuing to engage the industry with this new technology. Additionally, the team plans to deploy more "4th" generation GHPWHs in an expanded study in the Los Angeles-area.

Alagasco UTD. Utilization Technology Development INTERMOUNTAIN GAS COMPANY A Subsidiary of MDU Resources Group, Inc.

Successful Product Launch: Case Study

Together with utilities and energy efficiency partners, the Northwest Energy Efficiency Alliance (NEEA) supported rapid product development and market launch of electric air-source heat pump water heaters. Since 2012, year-over-year sales of this product in the Northwest have consistently grown by nearly 50%.

Tactics include:

- Development of the Advanced Water Heater Specification, providing manufacturers a single source capturing product needs of the energy efficiency community
- Incentives to accelerate product developments and market launch
- Regional technical training, ensuring knowledgeable, skilled and engaged installers
- Utility programs increasing availability of incentives (over 300 national programs to date)
- Manufacturer partnerships – working together to create customer messaging and grow sales
- Marketing to ensure consistent consumer language and increasing product awareness
- Market research to understand customer and supply chain experiences and refine program strategy

Lessons learned can be used **to support a dynamic launch** of gas absorption heat pump water heaters:

- Manufacturer partnership is crucial and open communication on goals and advancements increases uptake
- Scale accelerates results, national alignment and support from the energy efficiency and utility communities provides market stability
- Demonstrating Return on Investment (ROI) is instrumental in achieving supply chain commitment
- Utility programs across major markets are critical to long-term product success
- Throughout the supply chain, widespread buy-in and constant reinforcement is required
- Upstream/midstream incentives move the most units

neea For more information, visit www.neea.org

Gas Heat Pump Hot Water Heater

Figure 4: 3rd Generation Prototypes Undergoing Reliability Testing at GTI

Figure 5: 2nd and 3rd Generation Prototypes (Left, Right Respectively) in Field Demonstrations

Market Investment

To date, supporting the development, demonstration, and deployment of the GHPWH technology, GTI has coordinated or played a supporting role in the investment of nearly $5 million, with $2.4 million from utilities and the balance from federal/state governments (includes pending California Energy Commission Program).

Resources

For additional information on the development, validation, and demonstration of the gas-fired residential heat pump water heater, please see the following document: http://www.osti.gov/scitech/biblio/1060285

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Emerging Technology Program (ETP) is a collaborative program managed by Gas Technology Institute (GTI) focused on accelerating the commercialization and adoption of the latest end use and energy efficiency technologies. The program is designed to help companies assess the benefits of new energy efficiency products and integrated solutions for use in near- to mid-term energy efficiency program implementation.

To learn more about ETP and the program's initiatives, visit www.gastechnology.org/ETP.

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