Thermal heat pumps – The time is now!

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ABSTRACT

Given the significant drive to rapidly decrease greenhouse gas emissions, thermal heat pump (THP) technology represents a crucial opportunity for energy-efficient natural gas products to be part of the solution. THP technology can cut energy use by up to 50% or more and have a similar impact on greenhouse gas (GHG) emissions. The Gas Technology Institute (GTI) and Northwest Energy Efficiency Alliance (NEEA) have partnered to accelerate development and commercialization of multiple THP products. GTI's tenured involvement with efficient gas product development has enabled them to provide technology developers and manufacturers technical solutions to many barriers that afflict heat pump technology – from burner development, to electrical requirements to condensate mitigation. And, NEEA's experience running market transformation programs for both ductless heat pumps (DHP) and electric heat pump water heaters (HPWH) has provided many best practices and lessons learned on the importance of achieving supply-chain advocacy for emerging technology. NEEA's efforts have focused on priming the market for new efficient technology, so that when a broadly adoptable product is launched, the market is ready. Attendees to this session will learn from both GTI and NEEA about stumbling blocks, lessons learned, and opportunities related to the ongoing process of quickly ramping up an entire product category so that it is positioned to transform the market.

Introduction

The North American energy efficiency industry is at a crossroads. With decreasing costs of renewable energy, increased focus on GHG emissions reductions and rapidly evolving technology, both gas and electric powered heating, ventilation and air conditioning (HVAC) and water heating products are appropriate solutions to reduce energy consumption and emissions. This paper will explore how one type of gas technology, thermal heat pumps, can be a part of a balanced solution to achieve efficiency and GHG emissions reduction goals.

GTI is an American non-profit research and development organization which develops, demonstrates, and licenses new energy technologies for private and public clients, with a focus on the natural gas industry. NEEA is a collaboration of 140 utilities and efficiency organizations working together to advance energy efficiency in the Northwest on behalf of more than 13 million consumers. NEEA collaborates with utilities, energy efficiency organizations, industry partners, and other groups to transform markets and pave the way for increased adoption of energy-efficient products and practices. GTI and NEEA have been working to accelerate development and market adoption of THP technologies. Before delving into technical details, it is helpful to set the stage with some historical background and context.

Historically, in North America, natural gas has been a lower-cost option for space and water heating in homes and buildings. In addition, many electric power generation plants were powered by coal, with its associated negative environmental impacts. Electric solutions with efficiency levels greater than 100% (heat pumps) for space heating were new and tended to underperform, especially in colder climates. Electric heat pump water heaters (HPWHs) entered the market as an extremely niche product. Early on in their technical maturity, electric HPWHs suffered product failures that tainted the market's perception of these efficient technologies. Gas, on the other hand, offered a cleaner alternative to expensive coal-derived electricity and had efficiency levels close to 100%. Natural gas HVAC and water heating products were the leading energy efficient choice, with widespread campaigns to get people to switch to gas. In addition, in the early 2000's, tankless gas water heaters enjoyed a significant boost in awareness and sales, likely due to positive consumer reaction to having "endless hot water" (Talbot 2012).

Over the past couple of decades, improving technology has led to product innovations in both electric HVAC and water heating. Electric heat pumps have become increasingly efficient in a wider variety of conditions, leading to greater awareness and acceptance of heat pump-based products. NEEA's work on ductless heat pumps supported Northwest sales of nearly 300,000 units in 10 years. Concurrently with increased adoption, performance has also been enhanced, with new ductless heat pumps performing well down to -15°F (NEEA 2019). Electric heat pump water heaters are seeing a similar trajectory. Successful demonstration of electric heat pump technologies to be highly efficient and market acceptable, combined with \ "greening" of the electric grid (increase in renewable energy and decrease in coal-generated energy), has solidified electric heat pumps as a core pathway for deep GHG emissions reductions.

Over the same period of time, there has been relatively limited market uptake of gas products with significant increases in performance and efficiency over minimally allowable levels. As seen in Figure 1 below, using the residential water heating market as an example, a full spectrum of energy efficient products is available, from baseline storage-based products through "condensing efficiency" level performance with storage (up to 0.88 UEF) and tankless (up to 0.97 UEF). However, despite availability of these higher efficiency options, for ~4 million gas-fired storage water heaters sold each year only 5% sold are at or above the EnergyStar ® level of 0.67 UEF [U.S. Census, 2017 and AHRI, 2019]. While this is like electrically driven water heating, which 98% of U.S. homes with electric water heating are at or below EnergyStar criteria, here the bar is much higher towards a heat pump technology [U.S. Census, 2015]. As a result, gas technologies have not yet demonstrated significant efficiency gains and GHG reduction potential equal to that of their electric counterparts. Low costs of natural gas reduce financial reasons for saving energy; relatedly, gas utilities historically have not been mandated or incented to reduce customer end use energy as electric utilities have been.

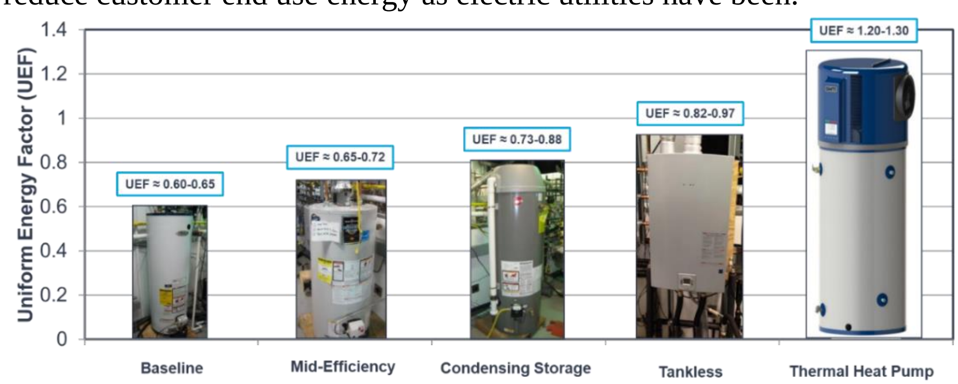

Figure 1: Graphical Representation of Residential Gas-fired Water Heating Efficiency Classes (Source: GTI)

Still, despite the relatively low cost of natural gas and manufacturer focus on the development of efficient electric products, gas technology innovation has continued. Research, Development and Demonstration (RD&D) efforts by academic, government, and industry participants have led to several promising technologies based on a diversity of thermodynamic cycles, including most prominently Sorption-type, Vapor Compression (Engine-Driven), and Thermal Compression-type equipment, that could lead to thermal heat pumps with efficiencies greater than 100% (GTI and Brio 2019). Meanwhile, in the Northwest, five utilities convened in 2014 to develop a strategy for initiating natural gas energy efficiency market transformation efforts (Avista, Cascade Natural Gas Corporation, Energy Trust, NW Natural and Puget Sound Energy). This group initially identified two product categories that could utilize thermal heat pump technology to achieve significant energy savings. A residential water heater using a thermal compressor was estimated to have technical potential to save >200M therms annually in the Northwest, assuming a Uniform Energy Factor (UEF) of ~1.2. A thermal compressor combination space and water heating unit (combi) achieving similar levels of performance was estimated to have the technical potential of saving >500M therms annually in the Northwest. On a national scale, if all residential gas storage water heaters sold in the U.S. were qualified gas heat pump water heaters (GHPWH), those energy cost savings would exceed $4B annually, and 145B lbs. of annual CO2e would be prevented; equal to taking 14M vehicles off the road!

From 2015 onward, these five organizations, through NEEA, have funded development activities to accelerate thermal heat pumps to market. To this end, the alliance has supported vetting of over 10 thermal heat pump technologies, assessing them for technical and market readiness, evaluating their performance for Northwest markets and supporting expedited development. NEEA has partnered closely with GTI in this work and relied on their significant technical expertise. Detailed results from this partnership, and additional GTI work, is covered next in this paper but a key finding is that thermal heat pump technology can deliver a significant energy savings due to performance improvements of 200% or more.

THP Technology Overview

As defined in this paper, thermal heat pumps (THPs) are not a new technology and in numerous cases the underlying technology predates widespread electrification of buildings in the early 20th century, including sorption cycles for ice production using solar energy in 1878 [Butti, 1980] and using fuel-driven compressors to drive air-conditioning & refrigeration equipment before the U.S. Civil War [Univ. of Fl, 2020]. At their core, all heat pumps deliver thermal comfort by moving ambient energy from a low-temperature source to a high-temperature sink, operating against an adverse temperature gradient. In addition to moving heat "uphill," often heat pumps can operate reversibly to provide air conditioning (A/C) and space heating with the same product. If waste heat recovery is employed, the heat pump can also provide service hot water (SHW). Heat pumps generally involve use of a refrigerant and thus based on refrigeration cycles.

Instead of using an electrically driven compressor, THPs use thermal energy and collectively refer to two main classes of heat pumps, 1) those that are *work activated*, or engine-driven and drive a refrigerant compressor with mechanical output of an engine and 2) those that are *heat activated*, which use heat generated by combustion or other source (e.g. solar thermal). The thermally-driven subclass of THPs can be based on a diverse set of cycles and employ a wide range of working fluids. However, as electrically driven heat pumps are far more common than THPs, the term "heat pump" commonly refers to an electrically driven heat pump.

Recently, GTI developed an extensive catalogue of THP equipment design and performance as part of a *Gas Heat Pump Market and Technology Development Roadmap* (GTI and Brio 2019), which focused on residential and light-commercial scale equipment that were commercially available or within three years of commercialization. With these criteria in mind, three major THP product categories emerged reflecting products available and under development: Vapor Compression (Engine-Driven), Sorption-type, and Thermal Compression-type equipment. Building on a portfolio of RD&D efforts (Figure 2), GTI compared across THP categories and product types to identify strengths/weakness, technology maturity, technical and non-technical gaps and barriers, and a regional analysis of energy and GHG gas emission reduction potential. This builds on an emerging portfolio of several excellent reviews of THP technologies issued over the past 10 years, including the following notable examples from the Netherlands, the UK, Canada, and from the U.S. Dept. of Energy (GTI and Brio 2019).

Figure 2: Commercial/Prototype THPs in GTI Demonstrations: Engine-driven VRF, Sorption-type Water Heater, Sorption-type Whole House Combi System, and Thermal Compression-type Heat Pump Boiler (Source: GTI)

GTI grouped THPs into three primary categories described below, which due to their fundamental designs differ significantly such that researchers and companies developing THP technologies commonly select only one THP technology category, described as follows:

Vapor Compression: The majority of conventional electrically-driven heat pumps use the *vapor compression* cycle, electro-mechanically driven or directly driven by an engine. At its core, the compression of a refrigerant creates a pressure difference which, in turn, drives the refrigeration effect moving heat from the cold reservoir to the warm/hot reservoir such that the saturation temperature during phase change favors this direction of heat flow from the evaporator to the condenser. Technically, this is a reversed Rankine cycle, the forward version of which is used in steam engines, nuclear power stations, and other means of generating useful work from heat input over a temperature difference. Electrically driven heat pumps using the vapor compression cycle are a very common form of HVAC, used in 99% of all air-conditioning (cooling) equipment and an increasing share of heating equipment. The most common form of this THP is the internal combustion (IC) engine driven THP. The IC-THP can take advantage of similar components as the more common EHPs, recovery of waste heat otherwise wasted at the power plant as hot water and providing peak load management for the broader electricity grid.

This product category emerged in the 1980s in Japan, with a current market of more than 800,000 installed and approximately 30,000/year (2018)[1], where peak power demand is critical and three-phase power is costly in some retrofits (THPs commonly only require single-phase power), THPs are emerging throughout Asia, with South Korea and China as major secondary markets. Japanese manufacturers Aisin, Yanmar, and Panasonic/Sanyo are joined by emerging Korean manufacturers Samsung and LG to support the growing interest in THP-driven variable refrigerant flow (VRF). In North America the market is small, ~150 units per year, with Aisin/Intellichoice and Yanmar introducing products in the 2010s, and brief introduction of

[1] Data source: Osaka Gas, Tokyo Gas, JARN, GRI/GTI

Panasonic/Sanyo as well. Prior RD&D efforts have driven non-VRF products into the market, most notably the York Triathlon residential-sized product which sold ~3,000 units in the 1990s but suffered from high equipment costs and reliability challenges. Also, a packaged rooftop unit (RTU) version of the Intellichoice/Aisin THP was introduced in 2011 and a THP optimized for water heating was introduced by Tecogen in 2012. Performance tends to be good in both heating and cooling, comparable to electrically driven heat pumps on the cycle itself, with a gas input-based Coefficient of Performance[2] (COP) ranging from 1.40-1.60 in both heating and cooling modes, with recent improvements in both cold-climate and part-load performance. Equipment costs tend to be higher, 2-3 times that of equivalently sized electrically driven equipment, ranging from $2,000/ton to $3,500/ton for residential and commercial sized equipment. Compliance with strict air pollution standards is typically not an issue, however engine exhaust after treatment comes at an added cost.

Sorption: Sorption heat pumps include THPs using vapor absorption and vapor adsorption cycles, where the sorbent is in the liquid and solid phases respectively, which work on the principle that combining refrigerant/working fluid with a sorbent (liquid/solid), significantly less input energy is required to raise refrigerant pressure, however a thermal energy input is necessary to "desorb" the refrigerant/working fluid from the sorbent in order to yield a high-pressure vapor. Sorption heat pumps benefit by the ability to reach smaller scales, more suitable for domestic applications. Common absorption working fluid pairs LiBr/H_2O (chilling) and NH_3/H_2O (heating), while common adsorption working fluids are H_2O, NH_3 and common adsorbents are activated carbon, zeolites, silicon dioxide, and various salts. Use of liquid versus solid sorbents each have their advantages, generally that liquid-based sorption THPs have higher capacity/efficiency by virtue of their continuous nature however solid-based sorption THPs have fewer moving parts (e.g. no solution pumps with dynamic seals) thus a potential for lower cost and greater reliability. In practice, liquid-based sorption THPs are more common in HVAC and SHW applications, with numerous products available domestically and internationally.

One notable advantage is heating performance in *cold climates*, which exceeds that of vapor compression equipment. In the case of a single-effect vapor absorption cycle, the most common cycle deployed in sorption-type THPs, approximately 60% of the heat pump output is from internal heat recovery while 40% of heat delivered to building is from the ambient environment ("refrigeration effect"), based on GTI testing and varying slightly over a range of operating conditions. For this reason, THPs in heating mode are much less sensitive to cold conditions and commonly do not require backup heating, contrasting with EHPs, which often have a lower temperature that the unit switches over to electric-resistance heating. Additionally, ammonia is a common refrigerant for sorption-based GHPs which has superior cold-climate performance when compared with conventional refrigerants (R-134a, R-410a, etc.).

Given the advantages with sorption-based THPs in scaling down and performing well in heating-dominant climates, this class of THPs is favored in European-based developments, including efforts by several major boiler companies including developments (Ariston, Bosch, Robur, Viessmann, Vaillant), branding (Remeha, Buderus), and even startups (SaltX/HeatAmp). Ammonia is the preferred refrigerant for sorption-type THPs, which has advantages as a natural refrigerant with zero Global Warming Potential (GWP) and zero Ozone Depletion Potential (ODP) but also requires care in its use due to toxicity and mild-flammability concerns. This places an upper limit on equipment size due to allowable ammonia charge in the vicinity of occupied residential and commercial buildings.

[2] COP_Gas defined as [Thermal Output] / [Fuel Input, HHV basis]

In North America residential and light commercial products are from Robur, based in Italy, and the US-based SMTI, with distributor-based and OEM-supplier business models respectively (Figure 4). Both companies collectively develop THPs over a wide range of sizes and types, including: 1) integrated residential water heaters, with a projected Uniform Energy Factor (UEF) of 1.20-1.30, a unit cost of approximately $1,800, and Ultra Low NO_x certification, transitioning from demonstration stage to commercialization [Glanville, 2020], 2) whole house heating as a boiler or furnace replacement, with a projected 140% Annual Fuel Utilization Efficiency (AFUE), unit cost of approximately $4,500, also Ultra Low NO_x certified and transitioning from demonstration stage to commercialization [Glanville, 2019], 3) and commercial-sized THPs[3], installed as "hybrid" central plants in conjunction with boilers and commercial water heating systems, often taking advantage of the cooling function.

Figure 3: Commercial Installations of Sorption THP Equipment Including GTI Demonstrations of SMTI THPs in Multifamily Buildings (Left), Full-Service Restaurants (Center), and a Commercial Installation of Robur Equipment (Source: GTI/Robur)

<u>Thermal Compression</u>

Thermal Compression THPs are commonly driven by variations of the Stirling Engine cycle, which can be driven by external combustion or non-combustion sources of heat *and* can use a wide range of working fluids**.** These THPs use power cycles that produce useful work (internal or external) with an *external* source of heat. As these THPs decouple the source of heat from the working fluid's cycling performance, THP developers can increase operating temperature and pressure of the cycle while selecting working fluids well-suited for extreme conditions. THPs are "heat engines", converting a source of high temperature heat (e.g. combustion) into mechanical work, which in turn compresses a refrigerant-like working fluid. Generally speaking, the hotter the "hot end", the better. With these higher temperatures, Thermal Compression-type THPs are theoretically capable of a) high temperature heating (> 160°F), b) low temperature chilling, even cryogenic cooling, and c) non-incremental efficiency increases over other THP types. While multiple types of externally-fired engines exist, Stirling Engine cycles are more favorable to THPs, operating by expanding a specific volume of gas at one temperature and recompressing it at another temperature. Typically, the Stirling cycle utilizes inert gases like air, helium, carbon dioxide or hydrogen as the working gas. The Stirling cycle can be arranged as either a dual cylinder system, referred to as alpha-configured with separate cold/hot cylinders each with their own pistons, or as a one-cylinder system with an internal displacer, referred to as beta-configured. Within a single cylinder system, one end of the cylinder is hot and the other is cold. To realize a heat pump cycle, operating between three temperatures, commonly these simple Stirling cycles are augmented to combine work output and fluid

[3] Note that the well-established class of larger absorption chillers manufactured by major companies (Trane, Carrier, York) and smaller players (Thermax, Broad, Yazaki) were outside the scope of this assessment.

compression/expansions aspects of the THPs. For the two Thermal Compression THPs in this assessment, cycles selected are sorted by technology developer: 1) **Thermolift** uses a modified "Vuilleumier cycle," which combines a Stirling engine and Stirling heat pump, though unlike the duplex Stirling engine the mechanical coupling is through a shared working medium rather than through a shared piston and 2) **boostHEAT** developed a transcritical CO_2 based heat pump wherein only the thermal compressor is replaced by a gamma-type Stirling engine with the power cylinder/piston replaced by inlet/exhaust ports with precise valve timing. Both developments are early stage, with Thermolift in the U.S. performing laboratory testing and boostHEAT currently fulfilling their first set of heat pump boiler orders in Europe. Both efforts have benefited from significant R&D investments from private and public entities and, due to technical challenges overcome and that remain, the path to broad commercialization within 3-5 years is feasible but challenging. Despite the challenges with these more complex THPs, operating with higher temperatures/pressures requiring specialized materials, these THPs have high potential for operating efficiencies and achieving higher heating/lower chilling temperatures than other THP cycles. For example, the boostHEAT BH.20 is certified with a heating rating of "A++", per EU metric, and with an LHV-based Gas Utilization Efficiency (GUE) of 1.81 at A7W35 and a seasonal estimated efficiency of 1.88 on an LHV basis for medium temperature heating, performance that has been confirmed in recent GTI laboratory testing.

Technology Comparisons

Comparing across THP product types, the table below highlights key differences between the aforementioned categories: Vapor Compression (engine-driven), Sorption, and Thermal Compression. While these three THP categories are commonly applicable across product categories, these differences are significant enough such that researchers and companies developing THP technologies commonly select and stick with only one THP technology category. Also grouped by market application, the following key THP developments are examined in the table below, wherein each technology category is rated by applicability (NA = Not Applied, 1 = Least Applicable, 3 = Most Applicable), with the following overall themes:

- Residential water heating, due to integration with storage and common retrofit scenarios, is the smallest THP application, defined by ASHRAE as less than 20 kBtu/hr. input. Sorption is best able to scale down cost-effectively.
- For residential HVAC market segments, results are mixed as: a) in heating-focused applications, sorption-based THP combi systems may be most cost-effective and b) where cooling is important, vapor compression has advantages in technical maturity. In both cases, thermal compression can have incrementally higher performance.
- For commercial SHW applications, vapor compression is an option with one product available, however sorption may again represent the most cost-effective option. Thermal compression may have challenges with cost-effectiveness in this segment.
- For packaged standalone HVAC equipment, vapor compression is a technically mature option as with residential packaged HVAC, however "split" style sorption-based equipment may prove more cost-effective in the near term though installations may be more complex.
- In other commercial applications, hydronic heating/chilling THPs, installed in hybrid arrangements with conventional heating and cooling equipment (baseload/peaking arrangement), have advantages for X-to-water equipment in sorption (near-term) and thermal compression (long-term). For Variable Refrigerant Flow (VRF) installations, currently codes and standards only permit certain refrigerants, only vapor compression applies.

Table 1: Qualitative Comparisons of GHP-Types[4]

	Vapor Compression	Sorption		Thermal Compression
		Vapor Absorption	Vapor Adsorption	
Installation Type	Air-to-Air with hydronic heat recovery & direct-expansion possible	Air-to-water/brine or Water-to-water/brine		Water-to-water/brine, air-source req. coil
Common Working Fluids	R-134a, R-410a	NH_3/H_2O or $LiBr/H_2O$	Zeolite/Water, Ammonia/Carbon, or Ammonia/Salt	Helium, CO_2
Heating Performance	Good (in mild climates)	Very Good	Good	Excellent
Cooling Performance	Very Good	Good	Good	Excellent
Environmental Impact	High-GWP refrigerants are common, after-treatment needed for NO_x	Ultra-Low NO_x certified, low/zero GWP refrigerants	Ultra-Low NO_x capable, low/zero GWP refrigerants	Ultra-Low NO_x capable, low/zero GWP refrigerants
Market Players	Blue Mountain Energy, Yanmar Panasonic, Tecogen, Samsung	Robur, SMTI, Ariston, Bosch, Viessmann	HeatAmp/SaltX, Oxicool, Viessmann	boostHEAT, Thermolift

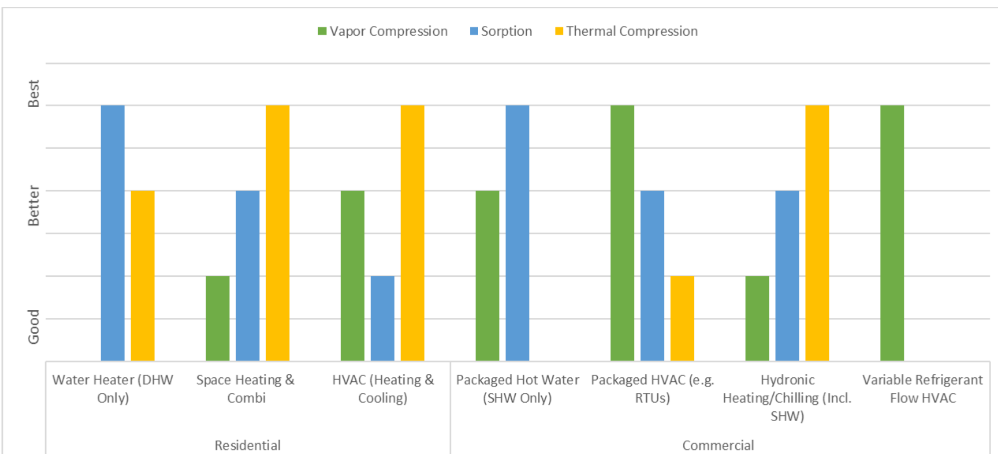

Figure 4: THP Categories Sorted by Market Segment/Application

Focusing on homes in the Pacific Northwest and building on NEEA's *Residential Building Stock Assessment*, there is a great opportunity for this innovative equipment to reduce energy use and GHG emissions by 40% or greater with space and water heating as has been seen in field studies (Glanville, 2019/2020). Of THP products available and under development, the majority of homes are suitable for THP retrofits, including the 50% of homes with a gas/propane fired furnace, and for the 49% of homes with gas/propane fired water heaters, industry is developing product solutions to facilitate retrofits with the 27% of homes without 8' of vertical clearance and 80% of homes without a condensate drain within 4' of the water heater. Also for THP-based water heaters, for the 47% of retrofits of gas-fired water heaters in the (semi) conditioned space (main house or basement), recent research has indicated the impact on the home's HVAC will be small and more than offset by the HVAC system impact of the low-efficiency water heater removed. While the 'heat pump' portion draws some energy from the ambient environment, it is much smaller than that of the natural draft storage-type water heater which increases infiltration for both combustion air and exhaust gas dilution (Glanville, 2020).

[4] Represents GTI's judgment on efforts within the scope of this paper and is not exhaustive

Adoption Barriers and Mitigation Strategies

It is becoming clear that technology developers and manufacturers can, or will be able to, supply a new generation of high efficiency gas products. But what about the demand side of the equation? Manufacturers need a clear business case and market demand at a price point that will be profitable, in order to invest in product development and dedicate manufacturing resources. Several barriers exist in building a viable business case for thermal heat pump products; because of this, manufacturers are cautious when evaluating market potential for this technology.

A significant barrier for manufacturers is the difficulty in justifying the expense of product development without confirmed utility support and rebates (GTI and Brio, 2019). Typically, manufacturers only move to develop a new product when they have high confidence that the new product will enjoy greater uptake than an existing one. With GHPWH, a clear and compelling consumer value proposition is not yet fully defined. Manufacturers seek to partner with utilities to understand market potential and then develop products that are likely to receive utility rebates and with potential for co-developing go-to-market strategies.

Another barrier is a generalized perception that natural gas products are incompatible with achieving GHG emission reductions. Electrification efforts have been well-coordinated and funded by major organizations. A few jurisdictions have banned new residential gas lines and states such as California are exploring broader reductions of natural gas direct use. Because of these highly publicized activities, manufacturers are now deliberating how much to invest in efficient gas technologies. A dialogue has only recently begun highlighting that in some instances, efficient direct use of natural gas may be a low-cost way to achieve deep GHG emission reduction goals. One example is a study performed by Energy and Environmental Economics, Inc. for NW Natural that "(demonstrates) the potential role and impact of natural gas heat pumps, an emerging technology which has not been evaluated in prior deep decarbonization studies, to our knowledge" (Energy and Environmental Economics, Inc. 2018, 20). This study found that natural gas technologies can play a key role in achieving an 80% reduction in Northwest GHG emissions by 2050. Because of long-term cost impacts and timelines needed for electrification, particularly in colder climates reliant on natural gas use for peak heating periods, efficient gas technology can be a critical and immediate step for reducing GHG emissions.

Previous NEEA market transformation successes have harnessed consumer demand for new product features. One example is increased adoption of ductless heat pumps (DHP) in the Northwest. This effort has driven sales of close to 300,000 DHPs, with a consumer satisfaction rate of over 90% (NEEA, 2016). Largely, this success was driven by the fact that the technology provides consumers with multiple benefits, in addition to energy savings. Consumers indicated they benefited from more comfortable/even heating, the addition of efficient cooling and perception of a safer way to heat their home, among other features. Combined with the aforementioned energy savings and a sizable utility rebate, DHP market adoption has accelerated in response to market transformation interventions.

When considering how to transform the market for efficient gas technologies covered in this paper, a new perspective is required because unlike a DHP, with a GHPWH there are minimal product features to attract consumer demand. In a general sense, and certainly at the time products enter the mass market, the primary consumer benefit will be energy savings and associated financial impacts. In the case of the GHPWH, consumers will likely have the same hot water they always had, just at a lower cost (reduced by up to 50% compared with a standard, baseline gas storage water heater). While ancillary benefits such as a larger volume of hot water and faster recovery time than other options are possible, there are no other significant features that would drive consumer demand. With a THP combination space and water heating (combi) system, like the GHPWH, consumers will still have a warm home and hot water as they did with their previous furnace and water heater or boiler, just at a lower operating cost (saving up to 50%). With the combi, there may be some additional benefit due to reduced space that a combi system will take up in comparison to standalone products. Perception of that benefit will vary, however, based on individualized characteristics such as previous system(s), housing characteristics and installation location.

Installers can help drive demand if they benefit from the new product coming to market. Indeed, many of NEEA's successful market interventions involve targeting the supply chain rather than consumer demand. Installer benefit can also be a large driver of a successful business case and market transformation. Key questions that need to be addressed to justify a new product's value to installers were clearly documented in recent NEEA research: Does the new product solve a consumer's problem? How will a new product impact the installer's business? Will the manufacturer support the new product, should issues arise? Installers need positive answers to all three of these questions before they consider adopting a new technology (NEEA 2020). In 2018, NEEA performed quantitative and qualitative research to define which THP combi product capacities and features yield the highest probability of market success. (NEEA 2018) Surveys explored installer and distributor attitudes toward selling high efficiency equipment, including financial, physical, logistical, and other barriers facing a new efficient technology being introduced to the marketplace. Findings indicated installers associate market potential with attributes shown in Figure 7.

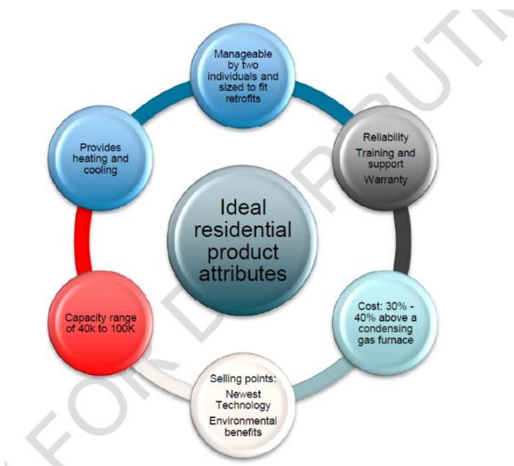

Figure 7: Diagram of Ideal Product Attributes

This research reiterates installers are looking for a product that solves problems for their customers, has minimal impacts to how they work, and is provided by a manufacturer who thoroughly supports their products. It is encouraging to see there is also a value associated to increased performance and functionality, indicated here by a willingness to pay up to 40% more than a current highly efficient gas furnace. Evidence from NEEA's DHP program supports this component of successful adoption: installers of DHPs cited reduced energy bills, ability to provide zonal control and ability to provide heating and cooling as reasons why they recommended the technology to their customers (NEEA 2018). Clearly, when a product provides benefits installers can promote, these benefits translate into demand.

NEEA plans on implementing key intervention strategies to stimulate adoption of THP technology. Because of the early stage of THP product development, much effort has gone to build strong relationships with technology developers and manufacturers. Goals of these relationships include helping accelerate technology maturation and support business case formation. Once viable products are established, NEEA and partners will perform testing to validate performance, monitor quality, and begin to develop the market through education, awareness and training. There are a limited number of products currently available, and NEEA estimates several new entrants in 2022-2025.

As momentum builds, coordinating with and supporting utility programs becomes a core tactic to bolster sustained adoption. Three key elements of this foundation, proven by electric HPWH programs, include generous incentives, a broad array of midstream/instant rebates and robust trade ally programs. Consortium for Energy Efficiency data reinforces that the availability of incentives creates a tipping point for uptake (Rosenberg 2019). Efficiency Maine's instant, high-dollar, midstream rebate similarly instigated a marked increase in sales (Meyer 2019).

These traditional utility programs and NEEA market intervention strategies will help to get THP products "off the ground," however, given the current market landscape and desire for rapid uptake, driving significant demand will require new tactics. Looking at the key market actors who have contributed to successful market transformation in the past, utilities could be pivotal in driving adoption for these products. Utilities would realize the following benefits from commercialization and adoption of thermal heat pump technologies:

- Achieving energy savings targets/requirements;
- Maintaining end uses for renewable natural gas and/or hydrogen blended gas;
- Providing customers with a highly efficient option without switching to electric equipment;
- Providing trade allies with efficient gas HVAC and SHW solutions for their customers; and,
- Meeting internal and/or external GHG emission reduction targets/requirements.

Altogether, these benefits justify exploring non-standard delivery methods that include but go above and beyond traditional utility rebate programs. This "all of the above" approach relies on methods to provide initial momentum and innovative approaches for sustained growth.

Conclusion

The time is now. Highly efficient electric technologies have made significant gains in performance, consumer satisfaction and adoption. Several evolving gas technologies are either available or coming soon, all with potential to be viable partners to their electric counterparts. Utilities can get involved in many ways, either directly working with manufacturers to accelerate development and commercialization or collaborating to help "prime the market" for efficient technologies. As referenced above, traditional utility programs will be a key component to successful adoption – but headwinds are strong and additional solutions will be required. Possible new, innovative strategies to consider:

Buying the market- Providing no-cost equipment to select groups, initially through programs like Energy Savings Assistance Programs, is the cornerstone of a strategy to "buy the market." Increasing throughput of new products in this way will help manufacturers achieve higher volumes and realize economies of scale that can be applied to more traditional sales. Additionally, fully funded installation programs will provide installers a lower-risk environment to gain experience with new technologies. An expansion of this concept would incorporate utilities providing no-cost equipment to all customers. Particularly with a water heater, this model could allow for a replicable and cost-contained way to achieve energy savings, carbon reduction and customer retention goals/requirements.

Capturing the value of GHG emissions reductions– Leveraging the financial value of GHG emissions reductions could help reduce first costs of new technologies. There is proven methodology for determining this value, and a path to use this value to lower costs. A water heater manufacturer (or other entity involved in the purchase path) could potentially retain ownership of carbon credits and sell them to reduce consumer costs.

Changing efficiency metrics – Changing metrics used in calculating cost effectiveness to incorporate the value of GHG emissions reductions could result in favorable results allowing larger incentives than for efficiency alone. Sacramento Municipal Utility District (SMUD) recently did this for their electric energy efficiency programs (SMUD 2020), and a similar approach could be used for gas.

Clearly, there are several emerging gas technologies that can provide significant energy savings and GHG emissions reductions, as outlined in this paper. It will take further innovation and ongoing collaboration to get these technologies over the finish line but once that happens, the market for efficient gas technologies will never be the same.

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