THE GAS HEAT PUMP TECHNOLOGY AND MARKET ROADMAP

Presented by:
GTI
Brio

Industry White Paper

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BACKGROUND

Sponsored by 14 U.S. and Canadian local distribution companies (LDCs), the Gas Heat Pump Roadmap (GHP Roadmap) identifies opportunities, information gaps, impediments and strategies to accelerate the commercialization and market acceptance of gas heat pumps (GHPs) in North America.

To create the GHP Roadmap on behalf of the LDCs, GTI compiled a team including Brio, a strategy and project management firm specializing in creating market transformation to accelerate adoption of emerging technologies and practices, and Energy Solution Center (ESC), a nonprofit organization of energy LDCs and equipment manufacturers that promotes energy-efficient natural gas solutions and systems.

The project launched in October 2018 with the following sponsor-determined boundary conditions created to guide the team's exploration:

- U.S. and Canada market applications
- Heat pump technologies including vapor compression (e.g. engine driven), absorption, adsorption, and thermal compression
- Commercially available, or within 3-5 years of commercialization
- Residential and commercial equipment (less than 400 kBtu/hr input)[1]

GHP ROADMAP GOALS

- Gather and share high-level stakeholder input from manufacturers, market partners and LDCs to understand drivers and goals for accelerating GHP technology
- Develop a technical assessment summary overview of domestic and international GHP products and technologies
- Deliver a market assessment summary overview of domestic and international GHP market conditions, prospects and barriers
- Develop technology and market development priorities by synthesizing the information and data gathered through the technical and market assessments
- Recommend next steps to support the following near- and long-term gas industry goals:
    - Near-term (less than 5 years): Market viable GHP product(s) for HVAC and/or water heating, in residential and/or commercial applications, available for purchase in North American markets through standard supply chains.
    - Long-term (more than 5 years): Mature and cost-effective portfolio of GHP products for HVAC and/or water heating, in residential and commercial applications, sold and supported by multiple manufacturers readily available and adopted throughout standard supply chains.

Note: The following Industry White paper is intended for use by LDC organizations, technology developers, OEMS and other interested industry parties. It includes a summary of the sponsoring organizations' approach, key findings and recommendations—all in an effort to accelerate the development and adoption of viable gas heat pump technologies.

[1]Residential cutoffs are typically 200 kBtu/hr. input for heating (incl. furnace, boiler, tankless), 5 tons output for cooling, 120-gallon storage, and 75 kBtu/hr. input for water heating (storage)

PROJECT SPONSORS

In addition to these funding organizations, the GHP Roadmap effort engaged several industry influencers to capture learnings and understand influencers' GHP activities. Influencers included American Gas Association (AGA), Consortium for Energy Efficiency (CEE), ESC, Natural Resources Canada (NRCan), Northwest Energy Efficiency Alliance (NEEA) and Utilization Technology Development (UTD).

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EXECUTIVE SUMMARY

Gas Heat Pumps (GHPs) have substantial potential to reduce energy use and greenhouse gas (GHG) emissions across various climates for both the residential and commercial markets in North America. Local Distribution Companies (LDCs) are eager to accelerate the advancement and commercialization of GHP technologies for heating, ventilation and air conditioning (HVAC) and water-heating applications. LDC motivations include increasing customers' high efficiency product choices, policy drivers, meeting energy efficiency targets, and reducing GHG emissions.

Technology developers and manufacturers represent the majority of supply-side actors interested in GHPs. Their motivations for backing GHPS are similar to the reasons expressed by LDCs. These include the desire to reduce GHG emissions, construct Path to Zero Net Energy (ZNE) buildings and low-load homes, unlock grid balance opportunities, meet regulatory standards with gas products in the future, and, for some, provide resiliency and redundancy. In addition, these developers and manufacturers understand that LDC intervention and collaboration will play a critical key role in transforming the market.

TECHNOLOGY OVERVIEW

In North America, natural gas is the predominant fuel for providing heat and hot water to residential and commercial buildings. In the U.S., the majority of homes and businesses use natural gas for heating, collectively consuming 65 billion therms for space heating and hot water—totaling 23% of the nation's overall natural gas consumption. In Canada, half of all homes use natural gas for heating. 65% of Canadian homes use natural gas to generate hot water, slightly lower than the 80% of Canadian businesses.

The predominance of natural gas aligns with consumer surveys indicating that natural gas is the preferred fuel for thermal comfort. Despite the predominance of and preference for natural gas, developers and manufacturers are met with two major challenges: 1) the gaining market momentum of electric heat pumps, 2) and the difficulty in meeting the increasing efficiency rulings and standards with existing gas technologies.

Despite these challenges, there is a strong opportunity for developers, manufacturers and LDCs to accelerate the market entrance of efficient low carbon GHP technologies, thereby expanding customers' natural gas product choices and demonstrating the role of natural gas in a low carbon future.

As part of this GHP Roadmap effort, a conservative, qualitative analysis was performed to represent GHP applications in residential single-family homes—the broadest GHP application with readily available simulated modeling best practices. Across a variety of diverse sponsor regions, the analysis compared the consumer cost and energy-use emissions for residential-sized GHP equipment versus conventional gas-fired and electrically driven equipment (see Technology Assessment, page 18).

Simulated modeling results revealed:

- GHPs maintain a GHG and cost advantage over the gas baseline scenario in all sponsor regions for heating, and most regions in scenarios where gas-driven cooling (e.g., the gas engine heat pump/ advanced GHP scenario) is also included. The cost-effectiveness of gas-cooling is viable in all but one of the markets considered.
- GHPs consistently have a cost advantage over electrically-driven heat pumps in all but one of the markets. They also have a GHG advantage in heating-dominant climates and in sectors where grid GHG-content is high.
- GHPs may have a more challenging value proposition in sectors where the cost of electricity is low compared to gas, and where the electricity grid has a relatively low GHG content. However, GHPs may still have a compelling customer case in these sectors with their ability to help avoid demand-based charges and electrical infrastructure upgrades, and by offering improved comfort—all aspects not considered in this conservative analysis.

There are multiple GHP products at various stages of development and availability. Although there is a relatively small number of commercialized products currently available in North America, opportunity exists with products in the pre-commercial phase and in the European market.

Table 1: GHP Product Overview

Company	Technology	Application	Status	Type
COMMERCIALIZED				
Blue Mountain Energy/Mestex	HVAC	Commercial	Commercially available: domestic	☀ ❄ 💧
Yanmar	HVAC	Commercial	Commercially available: domestic	☀ ❄
Tecogen	HVAC / Water Heat	Commercial	Commercially available: domestic	☀ 💧
Tedom	HVAC	Commercial	Commercially available: International	☀ ❄
Panasonic / Sanyo	HVAC	Commercial	Commercially available: International	☀ ❄
Robur	Air-to-water GHP	Commercial/ Large residential	Commercially available: domestic	☀
boostHEAT	Air-to-water GHP (Air source w/ outdoor coil)	Residential	Commercialization and pilot stage in Europe; international	☀
PRE-COMMERCIALIZED				
Blue Mountain Energy	HVAC	Residential	Pre-commercial: demo/pilot stage	☀ ❄
SaltX	Air-to-water GHP	Residential	Laboratory prototyping stage	☀ 💧
Thermolift	Water-to-water GHP (Air source w/ outdoor coil)	Residential	Laboratory prototyping stage	☀ ❄
SMTI	Heat Pump Water Heater	Residential	Pre-commercial: pilot stage (2-3-year projected market entry)	💧
	Air-to-water GHP	Residential	Pre-commercial (2-3-year projected market entry)	☀ 💧
	Air-to-water GHP with opt. cooling	Commercial/ Large Residential	Pre-commercial: Pilot stage (3-year projected market entry)	☀ ❄ 💧

KEY: ☀ heating ❄ cooling 💧 water heating

Note: This chart does not reflect products that have been discontinued.

RECOMMENDATIONS

The supply-side interviews conducted for the GHP Roadmap revealed the following key findings:

- building the business case remains the biggest challenge
- the supply side is resource constrained
- technology developers and manufacturers fear that the "electrify everything" consumer and policy trends will negatively impact the role of natural gas products in the future
- there is low product uptake for commercialized products and very limited support from LDCs
- the supply side is focused on building the minimal viable product

LDC Supply-Side Support Recommendations

The supply side requires LDC support to showcase a commitment to the technology and thereby prove the business case for GHPs. This can be demonstrated through executive-level letters of support delivered to manufacturers and technology developers, and by providing market data, such as economic analysis, market characteristics, penetration rates and LDC characteristics so they understand the market opportunity.

Further, LDCs can showcase their dedication to accelerating the GHP market by investing human and/or financial resources to assist the supply side in overcoming resource constraints. This support may come in the form of performing market research, advocacy, tracking policy and regulatory affairs, supporting research and development (R&D), and/or conducting product testing and demonstration projects.

Demonstration project opportunities

There are several immediate demonstration project opportunities currently in the planning stages including 1) an expansive residential Gas Heat Pump Water Heater (GHPWH) demonstration and product assessment project with SMTI; and 2) a scaled-up demonstration of a residential combined space and water heating system with SMTI involving multiple sponsors.

Additional recommended opportunities for targeted R&D projects and product demonstrations include:

- Developing and demonstrating emerging thermal-compression-based GHPs, including those under development by Thermolift in the U.S. and boostHEAT in the EU
- Advancing sorption-based GHP cost-effectiveness and product maturity, focusing on residential space- and water-heating applications (Robur K18, Ariston, SaltX and other EU-based suppliers) and commercial water-heating applications where hybrid installations and utilization of "free cooling" is economical (Robur, SMTI)
- In the realm of vapor compression (engine-drive) GHPs, establishing a viable value proposition for commercial VRF products available domestically and internationally, and emerging packaged HVAC products (e.g., RTUs) that are based on higher volume products in Asia.
    - These activities would include undergoing targeted demonstrations in traditional and emerging (e.g. indoor agriculture) markets; socializing commercial-sized GHP technologies with the architectural, design, and engineering communities; and developing simulation-ready GHP modeling tools. Additionally, these activities would require increasing overall coordination with GHP manufacturers, specifically Asian vendors.

> Given their ability to scale down in size cost-effectively, sorption technologies, such as those developed by SMTI, are the most suitable for residential water heating. Sorption technologies applied as combi-systems are also likely the most cost-effective option, while thermal compression technologies, such as those developed by Thermolift and boostHEAT, can have incrementally higher performance in all aspects.

Successfully introducing GHPs into the market

It's imperative to foster a friendly environment for introducing GHPs and other natural gas emerging technologies into the market. To do so, LDCs must develop and share a collaborative vision of the role of natural gas in the future to demonstrate their understanding that electrification of building thermal loads is not the only path to decarbonization. These efforts will be further supported by generating public awareness of the low carbon benefits of natural gas and its future role to consumers, trades and policy makers.

Providing support to commercialized products is key, even though they currently have limited backing from LDCs and efficiency organizations. LDCs can support existing commercialized products in a variety of ways, including engaging and aiding technology developers to advance commercially available products; educating trades on commercialized and pre-commercialized GHP products, installation practices and how they differ from other technologies; and encouraging LDC customer representatives and strategic teams to provide product education, and engage and support trades and customers.

Facilitating updated codes and standards and product category development efforts is another critical activity to ensure GHP market entrance is smooth. This can happen through collaboration with DOE and NRCan; sharing test data; and influencing test procedures and methodologies. Primarily for commercial-sized applications, it's important to educate regulators to continue allowing non-GHP equipment (e.g., condensing boilers) as part of cost-effective central plants with efficiencies greater than 100%, rather than prohibiting non-GHP equipment, as these "hybrid" systems with GHP and conventional gas-fired equipment are more cost effective in handling peak thermal loads.

LDC ACTIVITIES & COLLABORATION

The supply side is focused on building a minimal viable product—a product with just enough features to satisfy early customers—knowing over time the product will advance to include additional features. LDCs would be wise to work collaboratively to develop and release product specifications for GHP technologies and support an emerging technology awards program for GHP technologies. LDCs should provide guidance on GHP performance expectations, along with features and benefits through product specifications while stopping short of prescribing how manufacturers and technology developers develop products. In other words: LDCs offer supply-side actors a common set of product specifications, allowing supply-side actors to choose the best approach to meeting product specs.

It is recommended to include tiers in the specifications to push for higher feasible performance. For example, NEEA provides tiers in their Advanced Water Heating Specification, including:

- **Tiered efficiency requirements, with a modified method of testing to reflect local climatic conditions**
- **Minimum acceptable product features that aggregate with each tier (e.g., ENERGY STAR compliance)**
- **Installation types permitted**
- **Sound levels and other potential nuisances**
- **Grid-interactive responsiveness**

Further areas of collaboration

Additionally, LDCs should consider these approaches to collaboration:

- Continually tracking research, lab testing, demonstration and pilot activities across North America
- Developing pilot plans with LDC partners and sharing results across GHP categories and regions
- Establishing common programs requirements, expectations, and market and incentive strategies (where possible)
- Creating common trade workforce development plans
- Sharing evaluation results and lessons learned to inform planning and refinement activities

MARKET PARTICIPANTS

TECHNOLOGY DEVELOPERS

Technology developers have a high level of interest and confidence in GHP technology. They are actively working to build the value proposition and business case for manufacturers and investors to accelerate market entry. They are focused on securing funding, refining products and product prototypes, identifying opportunities to reduce product cost, understanding the market potential, and understanding contractor and consumer barriers to product adoption. Technology developers are challenged by policy cases for GHG reductions—as in, designing equipment to meet policy case directives slows time to market and introduces internal resource constraints. In addition, most technology developers lack access to gas HVAC and hot water penetration rates in the U.S. and Canada, and they lack access to research to help understand customer performance and price point acceptance. As a result, some developers are unclear on the ideal application, size category, and price point to best suit customers.

Technology developers highlighted that LDCs, energy efficiency organizations and the industry can provide support to commercialize and drive acceptance of GHPs. Specific support requests included:

- Help building the value proposition, with market actors and commercializing partners
- Demonstration that natural gas LDCs are committed to GHP technology to help developers build the business case
- Investment in research and product development
- Support in the development of sound regulations and testing methodologies
- Participation in funding product reliability testing and demonstration projects
- Provision of market data, research and strategic marketing
- Definition of tangible, long-term incentive commitments
- Support for installer workforce development, training and education

MANUFACTURERS

Manufacturers are apprehensive about the market potential and lack the data to clearly define the opportunity. Similar to technology developers, manufacturers highlighted that they leverage a six-to-seven product stage gate process during product development, launch and refinement. These stages include, for example, discovery, scoping, building and developing the business case, testing and validation, launching the product and post-launch evaluation.

Nearly every manufacturer interviewed indicated that a key barrier is getting past the business case and development stage. In absence of a strong business case (without incentives), manufacturers indicated that limited resources can be focused on GHP technologies, as immediate revenue opportunities take priority. Other barriers of note include lack of research regarding consumers, installer and dealers; material cost; and lack of performance specifications to meet the varying international and regional trends and requirements surrounding emissions limits (GHG, Oxides of Nitrogen (NOx), and building codes (ZNE)).

Manufacturers, like technology developers, are interested in support and knowledge from LDCs, energy efficiency organizations and the natural gas industry. They specifically requested:

- Support developing the consumer value proposition and market for GHP products
- Assistance with field testing
- Guidance in understanding performance expectations
- Provision of supply chain and consumer research
- Multi-year commitments from LDC pilots and programs, including incentives, financing, and product leasing offers
- Help showcasing to consumers and policymakers the portfolio of solutions to reduce GHG emissions

MARKET INFLUENCERS

While demonstrating a great deal of interest and activity in GHPs, market influencer work is mostly siloed into specific focus areas including policy, advocacy, marketing, research and design, convening the industry, market transformation and emerging technologies.

Market influencers expressed interest in leveraging collaboration opportunities. Further, they identified upcoming research and or industry activities aimed at accelerating the design, acceptance and excitement for GHP technology.

Another noted opportunity for collaboration is NRCan's work as part of the Pan-Canadian Framework on Clean Growth and Climate Change. This opportunity would involve testing and development, thereby leveraging the shared interest in advancing gas technologies that exists across borders. Additionally, NEEA's work with GTI to coordinate and design a residential GHPWH demonstration project provides an opportunity to advance GHPWHs and inform future advancement activities. Both of these efforts appear to leverage product testing and in-field research with activities geared toward increasing market understanding and readying the market for ultimate acceptance.
Most market influencers highlighted the importance of the natural gas industry's consistent presence in the policy and industry discussion. With a shared focus on a low-carbon pathway, GHPs provide an opportunity to reduce energy consumption and reduce GHG emissions. Market influencers expressed that additional work stemming from the GHP Roadmap may offer an opportunity for deeper collaboration. Market influencers are eager to review the GHP Roadmap results and believe the efforts are necessary, timely and worthwhile.

LDCs

While LDCs share the same fundamental reasons for prioritizing GHPs, there is variance in the specifics based on local market, customers, regulation and climate. Factors include: LDCs following Integrated Resource Plans (IRPs) that define GHPs as a solution for site-and-source GHG reductions; policy pressure on direct gas usage; the desire to demonstrate innovation; and, in specific sectors with diminishing efficiency solutions for customers, the desire to seize the opportunity to catapult gas technologies into the future with a product differentiator. Almost every LDC highlighted the need for new products, like GHPs, in light of increasing federal standards.

Regardless of each LDCs specific reasons for their GHP interest and commitment, it is clear that all LDCs are eager to accelerate GHPs market entry and adoption by working collaboratively with each other and the market. For the most part, LDCs are focused on the technology without sector and end-use being a driver. Unlike the market, LDCs see market potential for GHPs and are concerned about product performance and reliability. Three LDCs have funding to support pre-commercialized product activity related to concept design, prototype development, and testing analysis, while many others can only support with energy efficiency program budgets that require proven deemed savings. The majority of LDCs have access to some data sets that can benefit technology developers and manufacturers.

Many LDCs identified the need to develop collective strategies and tactics to reduce duplicate efforts and cost. They also highlighted the need for deeper collaboration tracking all GHP activities across the U.S. and Canada including lab testing, field testing, and codes and standards across state, province, federal, regional, and local government jurisdictions.

DEFINITION OF TERMS

Air-source heat pump (ASHP): ASHPs, electrically or gas-driven, absorb heat from the ambient environment when operating in heating mode and reject heat to the ambient environment when operating in cooling mode. The ambient environment in which the heat pump is wholly or partially placed is most commonly outdoors, but in some cases can be indoors (e.g., heat pump water heaters). As refrigerants permit, air-to-air or direct expansion (DX) is possible, wherein the refrigerant directly transfers heat with a supply air stream. Otherwise heat from the refrigerant/working fluid is transferred with an intermediate fluid, which in turn provides space heating/cooling and/or S/DHW, as an air-to-water/brine heat pump.

Annual Fuel Utilization Efficiency (AFUE): An annual efficiency for space heating that is on a gas-input basis only (i.e., neglects electricity inputs and HHV), using a method defined for gas heat pumps by ANSI/CSA.

Buying block: The aligning of a variety of organizations/states to create market leverage and influence procurement, distribution and the supply channel.

CCHP: Combined Cooling Heating and Power

CEE: U.S. and Canadian consortium of gas and electric efficiency program administrators working together to accelerate the development and availability of energy-efficient products and services for lasting public benefit.[2]

Code: A code is enforceable by law or contract, written by a government or a government-approved body (e.g., the National Fuel Gas Code, NFPA 54). Often "model codes", like NFPA 54, are referenced by authorities having jurisdiction (AHJ) and thus, enforceable by law.

Coefficient of Performance (COP_{Gas}): A ratio of useful heating or cooling provided to gas input required.

Commercial equipment: Equipment with less than 400 kBtu/hr input.

Decoupled: Disassociate or "decouple" LDC profits from total electric or gas sales; a mechanism often used in the U.S. for LDCs to remove financial barriers to energy efficiency programs.

Domestic/service hot water: Often abbreviated as "DHW" or "SHW", this refers to heating potable water, with "domestic" and "service" referring to residential and commercial applications, respectively. Equipment providing S/DHW must meet specific design requirements for potable water safety in addition to withstanding operating issues associated with operating as an open system (e.g., scale, corrosion, etc.).

Emerging technology: A term used to describe a new technology entering the market, but can also refer to the continuing development of an existing technology.

EU: European Union

Executive level: C-suite-level executive in an organization or a representative who can speak to the overarching business drivers, goals, vision and strategies for natural gas in a low carbon future.

First cost: Equipment cost

Gas combustion process: A chemical process in which a gaseous fuel reacts with oxygen to give off heat.

Gas heat pumps (GHPs): A subset of heat pumps whose primary input drive energy is a gaseous fuel, instead of an electrically-driven compressor.

Gas Utilization Efficiency (GUE): More commonly used in Europe, GUE inputs are handled on a Lower Heating Value (LHV) basis, resulting in a ~10% higher rating than the COP_{Gas} on a Higher Heating Value (HHV) basis.

Heating Value: Maximum potential heat release during combustion of a fuel, on a mass or volumetric basis (e.g., kJ/kg or Btu/ft^3), where products of combustion are brought down to standard temperature and pressure.

Heat pump: A class of HVAC equipment that moves heat from cold source to warm sink, moving heat "uphill". Often heat pumps can operate reversibly, using a reversing valve or other means, to provide air conditioning (A/C) and space heating with the same product. If heat recovery is employed (using a desuperheater to cool the refrigerant, for example), the heat pump can also provide S/DHW. Heat pumps generally involve the use of a refrigerant and, hence, are based on refrigeration cycles.

[2]Source: https://www.cee1.org

GHPs collectively refer to two main classes of heat pumps, 1) those that are engine-driven and drive a refrigerant compressor with the mechanical output of an engine, and 2) those that are thermally-driven heat pumps which use heat generated by combustion or other source (e.g., solar thermal) to drive a thermodynamic cycle. The thermally-driven subclass of GHPs can be based on a diverse set of cycles and employ a wide-range of working fluids. For reasons explained in depth later in this overview, GHPs used for A/C are technically feasible but are not often economical. Finally, as electrically-driven heat pumps are far more common than GHPs, the term "heat pump" commonly refers to an electrically-driven heat pump.

Higher Heating Value (HHV): This heating value assumes the water in products of combustion condenses, releasing its latent heat of vaporization. In practice, the LHV of natural gas is approximately 10% lower than the HHV, thus an efficiency calculated on an LHV basis will be approximately 10% higher than the same efficiency on an HHV basis.

HVAC—heating, ventilation and air conditioning: Refers to the different systems, machines and technologies used in indoor settings such as homes, offices and hallways, and transportation systems, that need environmental regulation to improve comfort.[3]

Local distribution companies (LDCs): Sometimes referred to as utilities.

Lower Heating Value (LHV): This heating value assumes the water in products of combustion remain in vapor form.

Natural Gas Technology Center (NGTC): Based in Quebec, Canada, the Natural Gas Technologies Centre (NGTC) was established in 1992 as a nonprofit organization operating in the field of technological development.[4]

Northwest Energy Efficiency Alliance (NEEA): A collaboration of 140 utilities and efficiency organizations working together to advance energy efficiency in the U.S. Northwest (Washington, Oregon, Idaho and Montana).[5]

NOx: Oxides of Nitrogen.

Manufacturers: In the context of this study, "manufacturer" refers to companies that license or source gas-fired heat pump technologies from technology developers and package GHP products for sale directly to market or through a distribution chain. This relationship between technology developers and manufacturers can include licensing/acquiring intellectual property, sourcing components (e.g., "thermal compressors"), and branding or "white-labeling".

- **Active manufacturer**: Manufacturers that are currently serving the HVAC and water-heating market that either have a GHP product in the market or are directly participating in efforts and partnerships to demonstrate emerging GHP technologies through field and/or laboratory testing.
- **Non-active manufacturer**: Manufacturers that are currently serving the HVAC and water-heating market that may be performing GHP technology due diligence but are not defined as "active" per above definition.

Market partners: Organizations or individuals working in a given market that can help an organization/program meets its goals and targets (e.g., distributor, contractor, code official, LDC, etc.).

Minimal viable product (MVP): A product with just enough features to satisfy early customers, and to provide feedback for future product development.[6]

Natural Resources Canada (NRCan): Ministry of the Canadian government responsible for natural resources, energy, minerals and metals, forests, earth sciences, mapping and remote sensing.[7]

Parasitic load: Represents the electric energy consumed even when an appliance is shut off.

Refrigerant terminology: When refrigerants are used by GHPs.

[3]Source: https://hvactraining101.com/what-does-hvac-mean/.

[4]Source: http://www.ctgn.qc.ca/en/.

[5]Source: http://neea.org.

[6]Source: https://en.wikipedia.org/wiki/Minimum_viable_product.

[7]Source: https://en.wikipedia.org/wiki/Natural_Resources_Canada.

Residential gas heat pump: Residential gas heat pumps are a class of HVAC equipment that provide heating and cooling and are driven primarily by a gas-fired combustion process. Residential gas heat pumps leverage several unique cycles to produce heat. These include vapor compression (i.e., internal combustion engine-driven), vapor absorption, vapor adsorption, thermal compression (i.e., Stirling-type engine-driven.)

Resource constraints: The limitations of time, budget and/or staffing.

Seasonal/Daily Efficiencies: These transient efficiencies, representing performance over a defined period of time (e.g., year, day, etc.), are based on specific test procedures defined by the U.S. Department of Energy, NRCan, ASHRAE, ANSI and other standards organizations.

Seasonal Energy Efficiency Ratio (SEER): An electric-only A/C seasonal efficiency; a ratio of useful space cooling (Btus) to electrical inputs (Wh). Note that unlike the other metrics, SEER is not unitless.

Site energy: Amount of energy (i.e., gas, electricity) delivered to a building, commonly reflected in utility bills.[8]

Source energy: Amount of energy (i.e., gas, electricity) delivered to a building, including processing raw fuel, conversion/generation processes, and all transmission, delivery and product losses.[9]

Sponsors: Funding LDCs of the GHP Roadmap Project.

Standard: A set of definitions and guidelines, written by an organization or government body. These may be used by industry or by government in the development of regulations.

Steady-State Efficiencies: These values represent the efficiency at a specific operating point, including outside air temperature, delivered/return fluid temperature, and modulation point (e.g., 50% capacity). These are only comparable to other ratings at the same operating points. In Europe, it is common to denote rating points as A#/W##, where "A" denotes ambient air temperature and "W" denotes delivered water temperature. For example, A7/W35 is a rating at a 7°C ambient and 35°C delivered water temperature.

Strategic Energy Management (SEM): Strategic energy management is a long-term approach to energy efficiency that includes setting goals, tracking progress, and reporting results. A successful strategic energy management plan builds long-term relationships with energy users and targets persistent energy savings.[10]

Supply chain: A supply chain is a network between a manufacturer and its suppliers to produce and distribute a specific product to the final customer.

Technology developers: Designs, develops, demonstrates and licenses gas-fired heat pump technologies to Manufacturers. Technology developers may also directly sell product.

Uniform Energy Factor (UEF): A daily delivered efficiency for water heating; defined by the U.S. Department of Energy and NRCan as a ratio of useful hot water delivered over a 24-hour period to the natural gas and electricity site inputs.

Water-source heat pumps: Water-source heat pumps, including ground-source and geothermal heat pumps (GSHP) absorb or reject heat from the earth or a body of water using a heat exchanger. This is commonly an indirect heat exchanger, but direct heat exchangers are feasible with bodies of water. These can be referred to as water-to-brine or brine-to-water HPs.

Delineating between codes and standards:

- A **code** is enforceable by law or contract, written by a government or a government approved body. An example is the National Fuel Gas Code (NFPA 54). Often "model codes", like NFPA 54, are referenced by authorities having jurisdiction (AHJ) and thus, enforceable by law.
    - For example, the state of Louisiana (an AHJ), adopted the International Fuel Gas Code (2015 version) without amendments and, thus, it is enforceable by Louisiana state law.
- A **standard** is a set of definitions and guidelines, written by an organization or government body. These may be used by industry or by government in the development of regulations.

[8]Source: https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/difference.

[9]Source: https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/difference.

[10]Source: https://www.energy.gov/eere/slsc/data-driven-strategic-energy-management.

Additional organizations referenced throughout this analysis include:

- **ANSI**: American National Standards Institute
- **AQMD**: Air Quality Management District
- **ASHRAE**: American Society of Heating Refrigeration and Air-Conditioning Engineers
- **CARB**: California Air Resources Board
- **CGA**: Canadian Gas Association
- **CSA**: Canadian Standards Association
- **DOE**: U.S. Department of Energy
- **DOT**: U.S. Department of Transportation
- **EPA**: U.S. Environmental Protection Agency
- **IAPMO**: International Association of Plumbing and Mechanical Officials
- **ICC**: International Code Council
- **I/NFGC**: International/National Fuel Gas Code
- **IIAR**: International Institute of Ammonia Refrigeration
- **IMC/UMC**: International/Uniform Mechanical Code
- **IPC/UPC**: International/Uniform Plumbing Code
- **IRC**: International Residential Code
- **NFPA**: National Fire Protection Association example, A7/W35 is a rating at a 7°C ambient and 35°C delivered water temperature.

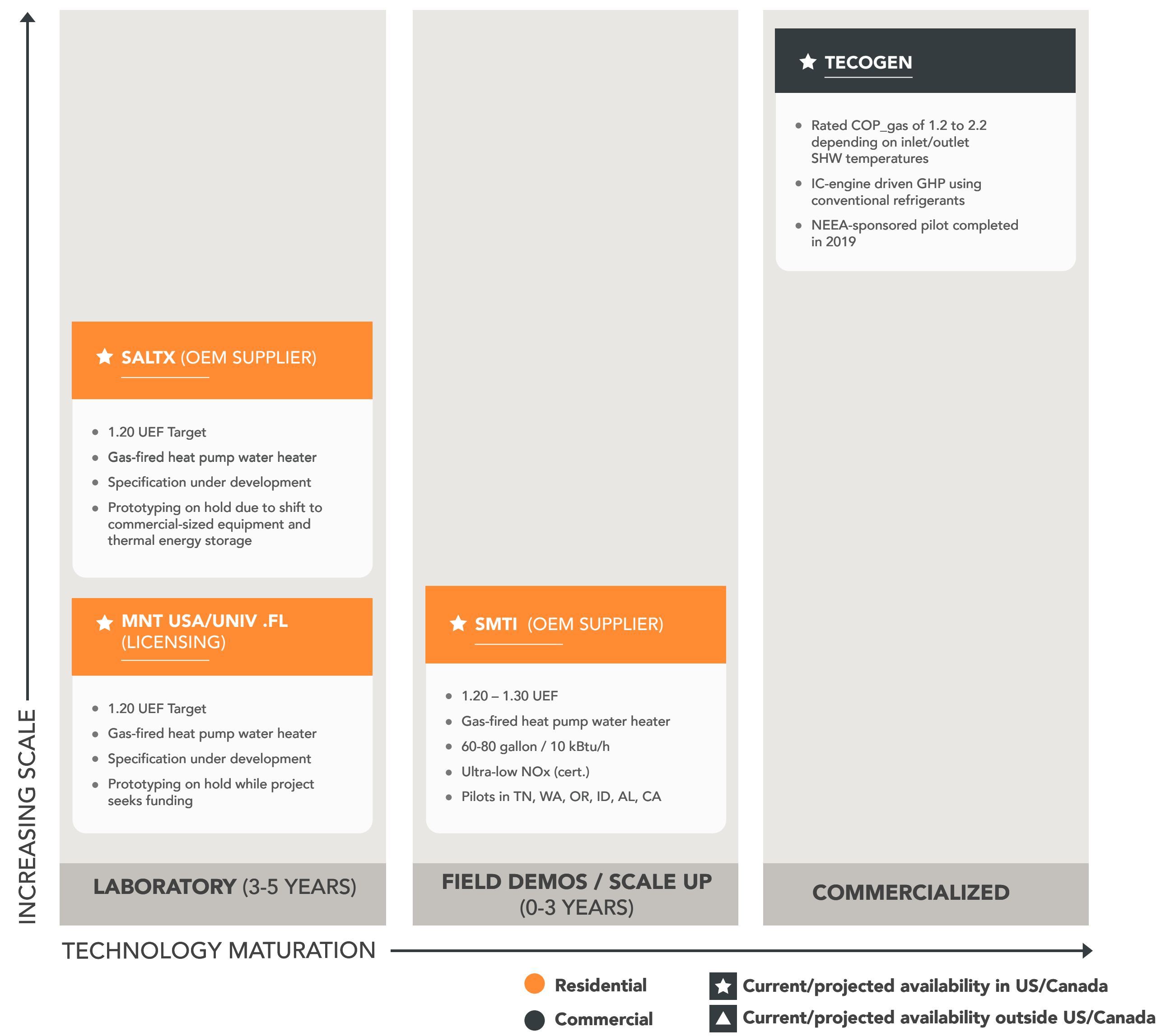
TECHNOLOGY OVERVIEW

The following LDC-determined boundary conditions guided the GHP Roadmap's technology exploration and assessment:

- U.S. and Canada market applications
- Heat pump technologies including vapor compression (e.g., engine driven), absorption, adsorption, and thermal compression
- Commercially available, or within 3 years of commercialization
- Residential and commercial equipment (less than 400 kBtu/hr input)[11]

The charts below include assumptions about energy efficiency, commercialization stage, applicable sector and features, and first-cost.

Figure 1: WATER HEATING



[11]Residential cutoffs are typically 200 kBtu/hr input for heating (including furnace, boiler, tankless), five tons output for cooling, 120-gallon storage, and 75 kBtu/hr input for water heating (storage) .

Figure 2: SPACE HEATING/COOLING

INCREASING SCALE ↑ / TECHNOLOGY MATURATION →

LABORATORY (3-5 YEARS)

★ SMTI (OEM SUPPLIER)

- 140% AFUE and 16 SEER Target
- Whole-house (heating/cooling/DHW)
- Low-load (20 kBtu/h)
- Cold-climate (80 kBtu/h0; 4:1 modulation; ratio of H/C output ~2.5:1

FIELD DEMOS / SCALE UP (0-3 YEARS)

★ INTELLICHOICE/BME/ MARATHON (DIRECT TO MARKET)

- Whole-house HVAC, optional heat recovery (DHW)
- Nominal 5 tons A/C
- 75 kBtu/hr with 60-100% modulation
- COP_Gas = 1.1 (heating) at A8.3 / COP_Gas = 1.04 (cooling) at A35
- Expansive field trial in SW, plans for NY

COMMERCIALIZED

▲ TECOGEN

- R-134a
- Commercial chilled/hot water; 27 tons
- Heat: 467 MBH; cool: ~27 RT
- Appx. 40%-100% modulation

▲ PANASONIC/ SANYO

- R-410A
- VRF
- Commercial gas 13-ton 2 or 3-pipe
- Heat: 171 MBH; cool: 13 RT
- Appx. 40%-100% modulation

★ YANMAR

- Unit rated with COP_gas of 1.4 for heating and 1.3 for cooling
- IC-engine driven gas heat pump using conventional refrigerants; direct to market
  Several equipment pilots in U.S.

★ INTELLICHOICE/ BME

- COP_gas of 1.3 for heating and cooling conventional refrigerants; direct to market
- Numerous pilot activities of current and prior generations

★ ROBUR (DIRECT TO MARKET)

- 129% AFUE (cert.)
- Large whole-house HVAC Heating/Cooling
- (125 / 95 kBtu/h)
- Pilots in ON, pending OR, BC

★ M-TRIGEN (DIRECT TO MARKET)

- Whole-house HVAC, optional heat recovery, backup-generator
- Otherwise off-grid
- Nominal 5 tons A/C
- 50 kBtu/hr heating
- COP heating/cooling < 1.0
- Pilots of CCHP product in MI, NV, TX

● Residential (orange)
● Commercial (dark)
★ Current/projected availability in US/Canada
▲ Current/projected availability outside US/Canada

Figure 3: COMBINATION SYSTEMS

LABORATORY (3-5 YEARS)

★ THERMOLIFT (LICENSING)

- 140% AFUE Target
- Whole-house (heating/cooling/DHW)
- Potential sizing ~60 kBtu/hr with 3:1 modulation
- Recent lab test suggests COP_Gas = 1.52 at A8.3
- Building alpha prototypes for expanded testing in 2019

★ SALTX (OEM SUPPLIER)

- 135% AFUE Target
- Partner with DOE
- Whole-house (heating/DHW)
- Potential sizing 50 kBtu/hr with 4:1 modulation
- Alpha prototype projected Q1 2020

▲ VIESSMAN (DIRECT TO MARKET)

- ~130% AFUE (projected in EU)
- Whole-house Combi (Heating/DHW)
- Heating (48 kBtu/h) w/boiler backup
- Recently discontinued in EU

FIELD DEMOS / SCALE UP (0-3 YEARS)

★ SMTI (OEM Supplier)

- Installed as hybrid system with multiple outputs, heating, hot water, A/C all feasible
- 140% AFUE expected and 20% electricity savings for A/C estimated (where applied)
- Up to 140 kBtu/hr output
- 4:1 modulation
- Pilots in CA, IL

▲ BOSCH/JUNKERS (DIRECT TO MARKET)

- >130% AFUE (projected in EU)
- Whole-house combi (Heating/DHW)
- Heating (61 kBtu/h) w/ boiler backup
- 4:1 modulation
- Commercialization effort halted in 2018

▲ BOOSTHEAT (DIRECT TO MARKET IN EU)

- ~160% AFUE (estimate)
- Whole-house Combi (Heating/DHW)
- Heating (68 kBtu/h) with boiler backup
- Certified with 1.65 COP_Gas at A7/W35
- Recent industrialization in partnership

★ SMTI (OEM SUPPLIER)

- 140% AFUE
- Whole-house combi (heating/DHW)
- Low-load (20 kBtu/h)
- Cold-climate (80 kBtu/h); 4:1 modulation; ultra-low NOx (cert.)
- Pilots in TN, WI

▲ ARISTON (DIRECT TO MARKET)

- ~140% AFUE (projected in EU)
- Whole-house combi (heating / DHW)
- Heating (34 kBtu/h) with boiler backup
- Currently exploring expansion with alternative suppliers

COMMERCIALIZED

▲ ROBUR (DIRECT TO MARKET)

- 130% AFUE (cert. in EU)
- Large whole-house Combi (Heating/DHW)
- Heating (64 kBtu/h)
- Available in EU only

▲ VALLIANT (DIRECT TO MARKET)

- ~128% AFUE (cert. in EU)
- Whole-house Combi (Heating/DHW)
- Heating (51 kBtu/h) with boiler backup
- Recently discontinued in EU, likely due to limited product offerings, high equipment costs and low market adoption

▲ VIESSMAN (DIRECT TO MARKET)

- ~125% AFUE (cert. in EU)
- Whole-house Combi (Heating/DHW)
- Heating (51 kBtu/h) w/boiler backup
- Recently discontinued in EU, likely due to limited product offerings, high equipment costs and low market adoption

INCREASING SCALE

TECHNOLOGY MATURATION

● Residential
● Commercial
★ Current/projected availability in US/Canada
▲ Current/projected availability outside US/Canada

TECHNOLOGY ASSESSMENT

TECHNOLOGY INTRODUCTION

The following technical assessment builds upon existing and similar surveys and reports with an added emphasis on 1) near-term and commercialized developments, and 2) the emerging residential-sized GHP market.

The technology overviews are grouped by three gas heat pump types: vapor compression (engine-driven), sorption (vapor absorption/vapor adsorption), and thermal compression. While these three GHP types are commonly applicable across product categories, there are also sufficient differences between categories resulting in them being treated separately in this assessment. These differences are significant enough that researchers and companies developing GHP technologies commonly select and stick with only one GHP technology category.

Table 2: Qualitative Comparisons of GHP-Types[12]

	Vapor Compression	Sorption		Thermal Compression
		Vapor Absorption	Vapor Adsorption	
Examples	M-Trigen, Blue Mountain Energy	Robur, SMTI	SaltX, Viessmann	Boostheat, Thermolift
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 requires additional coil
Common Working Fluids	R-134a, R-410A	NH3/H2O or LiBr/H2O	Zeolite/Water, Ammonia/Carbon, or Ammonia/Salt	Helium, CO2
Heating/Cold Climate	Good (in mild climates)	Very Good	Good	Excellent
Cooling/Hot Climate Performance	Very Good	Good	Good	Excellent
Environmental Impact	High-GWP refrigerants are common, after-treatment needed for NOx	Ultra-Low NOx certified, low/zero GWP refrigerants	Ultra-Low NOx capable, low/zero GWP refrigerants	Ultra-Low NOx capable, low/zero GWP refrigerants

Note: For climate zone definitions, visit: https://www.energy.gov/eere/buildings/climate-zones.

[12]The information presented represents GTI's engineering judgment on efforts within the scope of this assessment and is not an exhaustive assessment of each GHP type

SUMMARY OF TECHNOLOGY ASSESSMENTS

Residential versus commercial-sized equipment and applications are defined as follows:

- **Residential**: Heating by furnace, boiler, or tankless water heater with less than 200 kBtu/hr. input; Cooling of ≤ 5 tons, and storage water heating with less than 75 kBtu/hr. input and less than 120 gallons of storage.
- **Commercial**: Heating (hydronic or forced-air) greater than 200 kBtu/hr. input; Cooling with more than 5 tons, and storage water heaters with more than 75 kBtu/hr. input and 120 gallons of storage.
    - Too large: Products/developments with greater than 400 kBtu/hr. are excluded.
    - Out of scope: Refrigeration applications (non-comfort chilling), indirect/steam-fired equipment, and custom/ site-engineered equipment that are otherwise not intended for mass-market.

Grouped by market application, the following key GHP developments were examined and themes identified:

- Residential water heating, due to the integration with storage and common retrofit scenarios, is the smallest GHP application, defined by ASHRAE as less than 20 kBtu/hr. input. This application is best served by cycles that can scale down well, which sorption is best able to do cost-effectively.
- For residential HVAC market segments, the results are mixed as:
    - Heating-focused applications, particularly in cold-climates, sorption-based GHP combi systems may be the most cost-effective GHP option while thermal compression offers incrementally higher performance
    - Where cooling is more important than heating modes, vapor compression has advantages in technical maturity and again, thermal compression can have incrementally higher performance
- For commercial SHW applications, with a larger scale, vapor compression is an option with one product available, however sorption may again represent the most cost-effective option. Thermal compression, with high performance, 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.
- Hydronic heating and chilling GHPs, often as installed as systems wherein conventional heating and cooling equipment are installed in a baseload/ peaking arrangement, have advantages for air -to-water/brine equipment like sorption (near-term) and thermal compression (long-term).
- For Variable Refrigerant Flow (VRF) installations, currently codes and standards only permit certain refrigerants for use in this application, thus leaving vapor compression as the only option.

Table 3: GHP Product Developments Sorted/Ranked by Market Application

Market Application		Vapor Compression	Sorption	Thermal Compression
Residential	Water Heater (DHW Only)	N/A	Most Applicable	Applicable
	Space Heating & Combi	Least Applicable	Applicable	Most Applicable
	HVAC (Heating & Cooling)	Applicable	Least Applicable	Most Applicable
Commercial	Packaged Hot Water (SHW Only)	Applicable	Most Applicable	N/A
	Packaged HVAC (e.g. RTUs)	Most Applicable	Applicable	Least Applicable
	Hydronic Heating/Chilling (Incl. SHW)	Least Applicable	Applicable	Most Applicable
	Variable Refrigerant Flow HVAC	Most Applicable	N/A	N/A

MARKET PARTICIPANTS

SUPPLY-SIDE MARKET PARTICIPANTS

GHP Roadmap sponsors identified the need for exploring opportunities to accelerate the development of GHP technologies. To support that effort, the GHP Roadmap team conducted semi-structured supply-side market participant interviews and leveraged current and past experience with emerging technologies. Interviews aimed to uncover the market opportunities, barriers, risks and constraints to advancing GHP technologies. Interview topics included organizational interests, perceptions, product interests, product lifecycle and industry trends.

MARKET PARTICIPANTS

- **Technology developers**: Design, develop, demonstrate and license gas-fired heat pump technologies to manufacturers. They may also directly sell product.
- **Manufacturers**: In the context of this study, "manufacturer" refers to companies that license or sources gas-fired heat pump technologies from technology developers, and package GHP products for sale directly to market or through a distribution chain. This relationship between technology developers and manufacturers can include licensing/acquiring intellectual property, sourcing components (e.g., thermal compressors), and branding or "white-labeling".
    - **Active manufacturer**: Manufacturers that are currently serving the HVAC and water-heating market that either have a GHP product in the market or are directly participating in efforts and partnerships to demonstrate emerging GHP technologies through field and/or laboratory testing.
    - **Non-active manufacturer**: Manufacturers that are currently serving the HVAC and water-heating market that may be performing GHP technology due diligence but are not defined as "active" per above definition.

INTERVIEWS

The purpose of the supply-side market participant interviews was to collect information and highlight key findings to develop and recommend intervention strategies for market acceleration of GHP technology, while also exploring for past experiences and lessons learned.

Organizations Interviewed:

8 Manufacturers

- ***4**—residential, pre-commercialization products (Trane/Ingersoll Rand, Rinnai, Viessman, Rheem)*
- ***1**—commercial, pre-commercialization products (A.O. Smith)*
- ***3**—non-active (Bradford White, Carrier, Daikin/Goodman)*

9 Technology Developers

- ***5**—existing commercialized products (Robur, M-Trigen, Blue Mountain Energy, Yanmar, Tecogen).*
    - ***2**—commercial-products only (Yanmar, Tecogen)*
    - ***3**—both residential and commercial products (Robur, M-Trigen, Blue Mountain Energy)*
- ***4**—pre-commercialization products (boostHEAT, SMTI, SaltX and Thermolift)*

Supply-Side Interview Objectives:

- Understand supply-side organizational perceptions of and commitment to GHP technology
- Understand product development plans
- Gain insight into product and market barriers and risks
- Identify the supply-side product lifecycle, and expectations for moving through it
- Understand supply-side market and policy trends and decision-making process
- Uncover supply-side ideas on how the natural gas industry and Sponsors can support the supply side in advancing GHP products

To meet these interview objectives, the GHP Roadmap team developed a set of questions to guide market participant interviews.

INTERVIEW FINDINGS

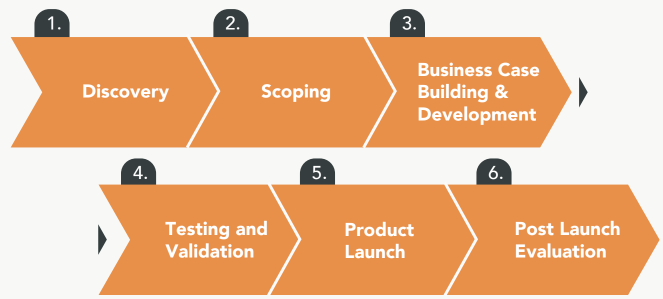
Manufacturer Findings

Manufacturers are apprehensive about the market potential and lack the data to clearly define the opportunity. Therefore, they lack the business case to move to the development stage and have insufficient resources to move forward in a timely manner. Manufacturers are eager to know how LDCs and the efficiency community will show up throughout the product lifecycle to support their business case development, ongoing refinements to the business case and overall market acceleration. Based on past experience with LDCs, they stated their desire to have robust field testing and pilots followed up with large-scale implementation efforts. LDCs entry into deeper supply-side engagement offers an opportunity to overcome this concern. Manufacturers are unaware what LDC support will exist and how long the support will be around, which leaves large holes in their business case. As of now, the supply side does not feel engaged by LDCs, but would welcome their committed involvement.

Interview findings include:

- **Technology perceptions and commitment reported by manufacturers**:
  - While understanding the technical potential of gas heat pumps, they have concerns about the future market potential and lack the business case to clearly define the opportunity.
  - Manufacturers that also offer electrically-driven equipment are fuel agnostic and motivated by finances and customer choice—not by fuel mix.
  - When asked to rate their commitment to bringing GHPs to market on a scale of 1 to 6, with 6 being very committed and 1 being not at all committed, they responded:
    - Half of the active manufacturers respondents reported 3 or below and half reported 6. One respondent abstained, stating the question was unfair as it would require them to reveal something they could not reveal.
    - Non-active manufacturers reported a low commitment to developing the technology with the majority of them rating their commitment a 1.
  - The majority of non-active manufacturers perceive GHPs as being in the very early stages of commercialization.

- **Product lifecycle process and expectations by manufacturers**:
  - Manufacturers highlighted their utilization of a six-to-seven product stage gate process during product development, launch and refinement. These stages include:



  - Manufacturers are struggling to move through the third stage—business case development—of the product stage gate process. They are particularly challenged by defining market size, geographic acceptance, willingness to pay, pay-back period and customer value drivers. They need to be convinced there is a market that will accept GHP technologies.
    - Several water-heating manufacturers cited the slow uptake of the electric HPWH as a "lesson learned" regarding product launches.
  - Internal financial and human resource constraints exist—public companies have to focus on areas that produce shareholder returns and revenues.
  - They were hesitant to share cost-break sales targets, but they showed signs of willingness.

- **Product development plans by manufacturers:**
  - European manufacturers are not actively pursuing the North American market, but they are interested.
  - As product development requires continued investment, projects can become stalled when funding is diverted to products that have clear signs of profitability.
  - Commercialized products sales volumes are low, which may impact future development plans.
  - Manufacturers do not think that electric HPWHs have been successful to date.

Non-active manufacturers highlighted that development plans are generally heavily informed by, 1) scanning and monitoring new technologies, 2) comparing the new technologies to other products within the market, and 3) overlaying those technologies with long-term regulatory requirements.

- **Product and market barriers and risks by manufacturers:**
  - Carbon policy
  - Product development cost
  - Determining specifications to build to the given and/or pending plethora or regulations across states and countries (e.g., Low NOx, ZNE, etc.)
  - Concern exists that builders could move to all-electric HVAC and water-heating technologies
  - Development costs and first-cost
  - As manufacturers make multi-year commitments to bring products to market, the annual planning cycles of LDCs cause concern. As of now, there is a perceived lack of LDC commitment to emerging technologies, which limits manufacturer willingness to invest in new products.

One common manufacturer barrier was the identification of qualified installers, as well as an overall shortage of trade labor.

- **Trends and decision-making process by manufacturers**:
  - They are paying attention to and influenced by "electrification" messaging that's currently driving the market to automatically turn to electric solutions—and away from gas—in pursuit of achieving a low-carbon future
  - Committed to return on investment and maintaining market share
  - Refrigerant regulations
  - Desires for connected devices
  - Several Non-active manufacturers highlighted that regulatory and policy requirements are burdensome and require substantial human and financial recourses—these requirements often drive decisions about committing resources to developing new innovative products
- **How natural gas industry and Sponsors can support the supply side in advancing products by manufacturers**:
  - Reduce the number of program technical specifications so that manufacturers don't have to abide specifications in multiple territories
    - While manufacturers want to be informed on the efficiency and performance expectations through specifications, they do not want LDCs to tell them how to develop products.
  - In early phases of product development and product launch, manufacturers are focused on building the minimal viable product.
  - Manufacturers want and need help with consumer, trade and system nomenclature research to build their initial and ongoing business case
  - Manufacturers need partners to provide financial and human resources to help conduct lab and field testing. They would require help securing test sites and, in some cases, would want partners to keep results confidential.
  - Manufacturers need help generating awareness among consumers, trades and policymakers that natural gas solutions exist in general (e.g., products, renewable natural gas, etc.) and that these solutions can reduce GHG emissions.
  - They also require help exposing installers to GHP commercialized and pre-commercialized product(s), and promoting commercialized products with and/or without incentives.
- **Miscellaneous manufacturer responses worth highlighting**:
  - Renewal isn't guaranteed for annual utility programs, so manufacturers seek a longer term commitment. They would prefer at least three-to-five year incentive commitments (and LDC assistance with incentive design).
  - As rebates change every year and often change quickly, so manufacturers are wary of investing and then seeing the incentives disappear. (One manufacturer stated, "Two year of rebates isn't enough—we need to know that utilities have skin in the game.")

  - They would like to see utilities provide insight into future state to avoid surprises down the road.
  - They lack the time and resources to keep track of a plethora of programs.
  - They find 0% financing, utility financing and leasing to be essential to breaking down first-cost barriers to adoption.
  - They seek quick transition from pilot to full-scale program—ideally within one year.

- **Based on the specific responses above, LDCs should consider communicating pilot and program plans to the market. Specific areas of communication may include**:
  - How much will incentives be, and for how long?
  - Are the incentive models going to be mail-in rebates or are LDCs open to new incentive models? How different will these be across North America?
  - Will GHPs be in a multi-year pilot phase before full-scale implementation?
  - Are programs going to be custom or prescriptive?
  - Will LDCs be equipped to offer on-bill financing/leasing programs/products-as-a-service programs?
  - What efficiency and/or program requirements and requirement changes will there be and across how many territories?

Technology Developer Findings

To accelerate market entry, technology developers are working to build the value proposition and business case for manufacturers and investors. They are focused on securing funding, refining products and product prototypes, identifying opportunities to reduce product cost, understanding the market potential, and understanding contractor and consumer barriers to product adoption. Technology developers are challenged by policy cases for GHG reductions—designing equipment to meet policy case directives slows the time-to-market and introduces internal resource constraints.

Interview findings include:

- **Technology perceptions and commitment**:
  - The majority of technology developers are highly committed to GHP technology and are confident in the technology's potential.
  - Many believe HVAC professionals may be the most qualified install base for both space- and water-heating (a.k.a., combi) GHP technologies

- **Product lifecycle process and expectations reported by technology developers:**
  - Like manufacturers, technology developers also highlighted their utilization of a six-to-seven step product stage gate process during product development, launch and refinement. These stages include Ideation/Discovery, Scoping, Business Case Development, Testing and Validation, Product Launch and Post-Launch Evaluation.
  - Technology developers are also struggling to move through the Business Case Development stage. They are challenged by defining market size, geographic acceptance, willingness to pay, pay-back period and customer value drivers. The majority of technology developers need help convincing manufacturers there is a market that will accept GHP technologies.
  - Internal financial and human resource constraints exist—many technology developer organizations are small nimble innovative organizations with limited human and financial resources.
  - Many haven't and/or are hesitant to share sales targets that will propel the business case for both pre- and post-commercialization.

Most commercialized products at this point are considered to be in the Testing and Validation phase of the product stage gate process.

- **Product development plans reported by technology developers**:
  - Some technology developers with commercialized products wonder if they should continue investing in product development given the holes in the product's business case.
  - Many struggle to find markets where the technology and cost suit the market.

- **Product and market barriers and risks reported by technology developers**:
  - Cost of product development
  - Fuel cost
  - Equipment and component cost
  - Installer awareness and knowledge of installation, application and service
  - Installer onboarding
  - Lack of incentives and incentive commitment

- Consumer access to financing for commercialized product
- Developing and accessing a product maintenance infrastructure
- Lack of awareness by manufacturers, end users/customers, and LDCs
- Low sales for commercialized products
    - Internal and LDC gas-growth sales teams do not push the product due to lack of product understanding
- Lack of internal financial and staffing resources
- Lack of market information

- **Trends and decision-making process reported by technology developers:**
    - Tracking electrification trends
    - They recognize the grid lacks the capacity to run the full space- and water-heating load
    - They struggle to track all the policy case directives and regulations—especially down to component levels
    - There's a lack of industry unification on technology policy
    - Cost of natural gas can drive climate focuses for GHPs
- **How natural gas industry and Sponsors can support the supply side in advancing products**:
    - Provide access to the qualified human resources and consultants if they are going to accelerate products to market
    - Identify customers based on usage
    - Connect customers with the technology
    - Provide incentives for LDC gas growth sales staff for reaching GHP sales goals for commercialized product
    - Support and market commercialized product
    - Streamline collaborative and integrated LDC research, testing, white papers and validation across North America
    - Provide market characteristics and research to inform business case
    - Reduce time to market by accelerating development activities with funding and human resources
    - Showcase commitment to making manufacturers aware of LDC and industry support

Note: As the technology matures, the LDC relationship will shift from LDC-to-technology developer to LDC-to-manufacturer.

Drivers for Gas Heat Pumps

Manufacturers and technology developers expressed similar reasons for their interest in GHPs. Some reported positive environmental impacts such as: GHG reduction, Path to ZNE and low-load homes, grid-balance opportunities, the inability of gas furnaces to meet regulatory standards of the future, and the opportunity to provide resiliency and redundancy to the grid using examples of GHP applications for backup generation in natural disaster areas. Much of supply side sees GHPs as an asset, not a threat, to electric utilities meeting their goals.

KEY FINDINGS & SPONSOR RECOMMENDATIONS

The key findings across the supply side were consistent among manufacturers and technology developers. Our findings include:

- building the business case remains the biggest challenge
- the supply side is resource constrained
- technology developers and manufacturers fear that the "electrify everything" consumer and policy trends will negatively impact the role of natural gas products in the future
- there is low product uptake for commercialized products and very limited support from LDCs
- the supply side is focused on building the minimal viable product

Note: The GHP Roadmap team focused on GHP technology as a whole. Therefore, the findings within are not specific to individual technologies.

Key barriers include defining how go to market, identifying markets, educating trades, establishing distribution and service networks, affording equipment cost and identifying customers.

MARKET BARRIERS & OPPORTUNITIES

The following charts summarize the broad, high-level GHP category barriers and intervention strategies to support both pre-commercialized and commercialized products. Additionally, the charts highlight expected outcomes and associated efforts to the supply chain's stage gate process.

BARRIERS TO ACCEPTANCE

Relating to perceived acceptability of form, fit, and function of the technology

<table>
<tr><th>BARRIER</th><th>INTERVENTION STRATEGY</th><th>EXPECTED OUTCOME</th><th>OEM STAGE GATE</th></tr>
<tr><td rowspan="2">PRODUCT READINESS
(i.e., product and market needs are not aligned, performance varies across climates, emissions and/or refrigerant constraints, no product category exist with EPA, NRCan, DOE, ASHARE)</td><td>PRE-COMMERCIALIZED
• Collaborate with developers/manufacturers on specifications to align performance with customer needs
• Develop lab and field performance testing protocol to support product development and product catagory development
• Conduct lab and field testing across varying climate zones and applications to quantify energy and technology performance, installation best practices, and occupant perceptions
• Share findings of testing with product category development organizations, and supply chain</td><td>PRE-COMMERCIALIZED
• New product specifications meet consumer and performance needs
• Initial lab and field performance testing protocols are defined
• Testing protocols are used to inform government test procedures
• Performance, savings and GHG reduction estimates are validated
• Installation best practices and installer training protocols are established</td><td rowspan="2">0-2
0 = Discovery
1 = Scoping
2 = Build business case</td></tr>
<tr><td>COMMERCIALIZED
• Monitor and continuously refine specification and performance testing protocols, share results stakeholders
• Perform lab and field tests on new product iterations
• Establish QA/QC program to verify install quality
• Provide feedback to developers/manufacturers to influence further improvements and training</td><td>COMMERCIALIZED
• Gas heat pumps meet specification requirements, product category exists, products meet emission and refrigeration requirements
• Products achieve acceptance with consumers and trade
• Installers utilize best practices for installation</td></tr>
</table>

BARRIERS TO AVAILABILITY

Relating to policy and market intelligence challenges to product existence

BARRIER	INTERVENTION STRATEGY	EXPECTED OUTCOME	OEM STAGE GATE
WEAK BUSINESS CASE (i.e., evidence is lacking to build a business case to support investment rationale to implement GHPs)	**COMMERCIALIZED** • Motivate utility executives to sign a letter expressing commitment to bring product to market and then present said letter (along with updated research and evaluation reports) to annual collective GHP North American LDC and efficiency commuity • Incentivize product development and advancement	**COMMERCIALIZED** • New technology developers/manufacturers invest in gas heat pumps • Supply chain continues to invest in product development and investment	0-2 0 = Discovery 1 = Scoping
	PRE-COMMERCIALIZED & COMMERCIALIZED • In partnership with manufacturers and technology developers, establish research objectives for pilots to address and investigate business case questions early and often	**PRE-COMMERCIALIZED & COMMERCIALIZED** • Market partners gather information to inform their business case in partnership with the LDCs and pass their business case stagegate milestone	
BIASED POLICY (i.e., decarbonization policy fails to consider or include upside of natural gas technologies, thereby influencing supply- and demand-side decisions)	**PRE-COMMERCIALIZED** • Develop and share with developers/manufacturers a collaborative sponsors vision of the future role of natural gas • Conduct research, if needed, and/or provide education and outreach to supply chain promoting gas heat pumps as a pathway to reduce GHG emissions • Generate public awareness of the low carbon benefits of natural gas and its future role to consumers, trades, and policymakers in a consistent manner across North America	**PRE-COMMERCIALIZED** • Developers/manufacturers are motivated to develop gas heat pump technologies	0-6 0 = Discovery 1 = Scoping 2 = Build business case 3 = Development 4 = Testing and validation 5 = Launch 6 = Evaluate and refine
	COMMERCIALIZED • Provide education and outreach to supply chain promoting gas heat pumps as a pathway to reduce GHG emissions • Identify and implement initiatives to support natural gas as a part of a solution to help cities and governments meet climate goals, and identify opportunities to support commercialized GHPs in these efforts.	**COMMERCIALIZED** • Developers/manufacturers are motivated to develop gas heat pump technologies	

BARRIERS TO AFFORDABILITY

Relating to equipment and installation costs, and willingness to pay

BARRIER	INTERVENTION STRATEGY	EXPECTED OUTCOME	OEM STAGE GATE
HIGH FIRST COST (i.e., high first costs prohibit investments from developers/ manufacturers)	**PRE-COMMERCIALIZED** • Fund developers/manufacturers during startup • Explore and support manufacturer staffing needs • Identify pathways to rent, lease, loan or offer product as a service • Support trade workforce development, educate installers, leading to more efficient installations and decreased install fees	**PRE-COMMERCIALIZED** • Infrastructure support from efficiency community helps offset risk of investment	0-6 0 = Discovery 1 = Scoping 2 = Build business case 3 = Development 4 = Testing and validation 5 = Launch 6 = Evaluate and refine
	COMMERCIALIZED • Provide incentives, product as a service programs, access to capital • Develop startup cost-share plan	**COMMERCIALIZED** • Price parity with electric heat pumps	
LIMITED INVESTMENT IN TESTING (i.e., developer/ manufacturer budgets limit theirability to refine prototypes)	**PRE-COMMERCIALIZED** • Support confidential prototype testing (in millions) with funding, lab access and field test site recruitment • Incentivize product development	**COMMERCIALIZED** • Developers/manufacturers have resources to build and launch prototype(s)	0-6 0 = Discovery 1 = Scoping 2 = Build business case 3 = Development 4 = Testing and validation 5 = Launch 6 = Evaluate and refine
	COMMERCIALIZED • Support new and existing advanced prototypes with funding, lab access and field test site recruitment • Explore and support manufacturer staffing needs	**COMMERCIALIZED** • Developers/manufacturers have resources (e.g., staff and budget) to continue advancing products	

BARRIERS TO AWARENESS

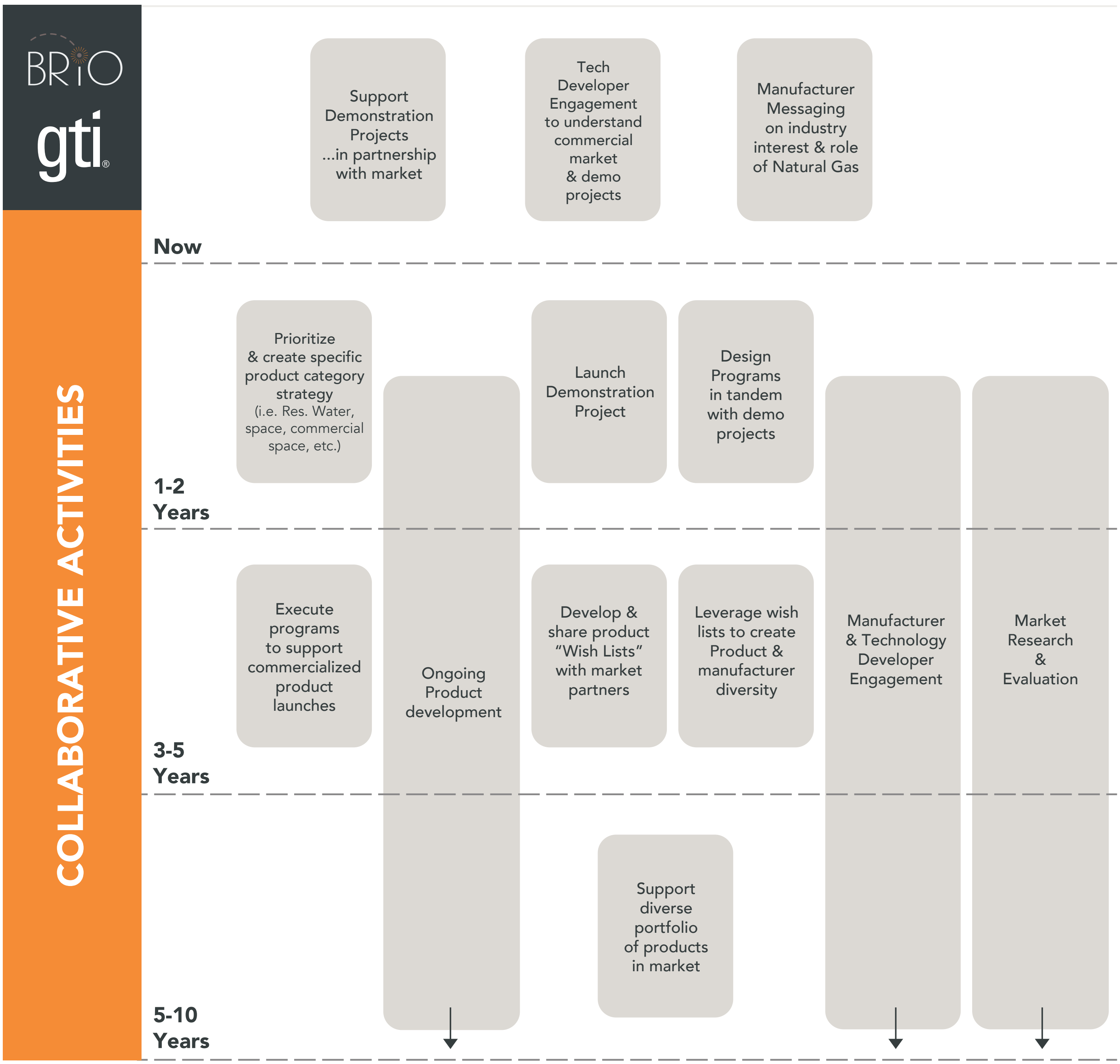
Relating to product awareness among market actors and end customers

BARRIER	INTERVENTION STRATEGY	EXPECTED OUTCOME	OEM STAGE GATE
LACK OF AWARENESS FROM SUPPLY CHAIN (i.e., supply chain is unfamiliar with technology resulting in low or no stocking and inexperienced installer network)	**PRE-COMMERCIALIZED** • Conduct supply chain audience research to understand perceptions and barriers • Educate supply chain on business case • Host educational technology workshops with working units • Educate trades on commercialized and pre-commercialized GHP products • Explore sponsor paths to increase support through efficiency program funding via education and outreach, pilot and program delivery	**COMMERCIALIZED** • Developers have resources (e.g., staff and budget) to continue advancing products	0-6 0 = Discovery 1 = Scoping 2 = Build business case 3 = Development 4 = Testing and validation 5 = Launch
	COMMERCIALIZED • Conduct pre-launch roundtables with supply chain • Develop research-based marketing and education tools that use consistent, effective messaging throughout supply chain and the energy/utility community • Provide training and sales support and tools, including providing installers with educational resources and lead generation opportunities • Host technology workshops to align industry on best practices and insights • Support distributors with display units, home shows and open houses • Develop cooperative marketing opportunities across supply chain to cost-effectively maximize reach • Offer stocking incentives and negotiate stocking commitments with distributors	**COMMERCIALIZED** • Developers/ manufacturers offer installation training • Developers/manufacturers offer cooperative marketing opportunities using unified messaging • Gas heat pumps are stocked and readily available • LDCs offer financial incentive programs	
LACK OF CONSUMER AWARENESS, DEMAND (i.e., consumers are unfamiliar with gas heat pump technology and rely on supply chain to inform them of options)	**PRE-COMMERCIALIZED** • Assess existing product messaging landscape • Conduct product-naming and positioning research with consumers • Develop recommendation report for optimal product name and messaging for use across the market/industry • Implement product messaging across industry and supply chain	**PRE-COMMERCIALIZED** • GHP industry determines go-forward approach to product naming and messaging • Product name and messaging resonates with consumers and increases adoption	4-6 4 = Testing and validation 5 = Launch 6 = Evaluate and refine

ACTIVITY ROADMAP

To help sponsors prioritize activities, leverage their collaborative power and take advantage of real-time opportunities, the following activity roadmap is intended to showcase immediate recommended steps and provide an overview of hows today's activities can lead to tomorrows advancements and growth of the gas heat pump market.

The activities outlined below require large scale participation to be successful and meet the estimated timelines. This model is not intended to be implemented by one organization alone and sticking together is key to its success. This model was built to support GHPs as a whole and individual models should be created for each individual product or program and be tied to its individual strategic market goal.



UTILITY CHARACTERISTICS

ORGANIZATION	CLIMATE ZONES			TOTAL CUSTOMER COUNT	TOTAL RESIDENTIAL CUSTOMER	PRIMARY LOAD
	PRIMARY	SECONDARY	TERTIARY			
Dominion	5	6	3		950,000	SPACE HEAT
DTE Energy	5	6	7	1,300,000	1,200,000	SPACE HEAT
Enbridge Gas Inc. (Enbrige)	6	7				SPACE HEAT
Enbridge Gas Inc. (Union Gas)	5				3,400,000	SPACE HEAT
Intermountain Gas Co.	5	6			350,000	SPACE HEAT
Fortis BC (Gas)	4	5	6	1,200,000	930,142	SPACE HEAT
Fortis BC (Electric)	5				120,921	SPACE HEAT/ COOLING
National Fuel	5A			750,000	720,000	SPACE HEAT
New Jersey Natural Gas	4	5		535,000		SPACE HEAT
Nicor Gas	5				2,237,40	SPACE HEAT
NW Natural	4C			2,000,000	684,000	SPACE HEAT
New York State Electric and Gas Corporation (NYSEG)	5A			266,000		SPACE HEAT
Oklahoma Natural Gas	6	7			811,206	SPACE HEAT
San Diego Gas & Electric	7	10			1,300,000	SPACE HEAT
Southern California Gas (SoCalGas)	4	5	6	21,800,000		WATER HEAT