Gas Technology Innovations:
Focus on Gas-fired Heat Pumps

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MEEA HQ
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Presentation Outline

- Introduction to GTI
- Emerging Gas-fired HP Technologies
  - – Motivation for Innovation
  - – Survey of Technologies
    - Deployment of Gas Engine-driven HPs
    - Commercialization of Low-cost Gas Absorption HPs
    - Development of Next Generation GHPs
  - – Gas Heat Pump Roadmap
- Discussion

GHPs operating on rooftop of shopping mall

75-year History of Turning Raw Technology into Practical Energy Solutions

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

SUPPLY	CONVERSION	DELIVERY	UTILIZATION

RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

TRAINING

COMMERCIALIZATION

360+ EMPLOYEES

World-class research facilities headquartered in Chicago area

U.S. Office Locations

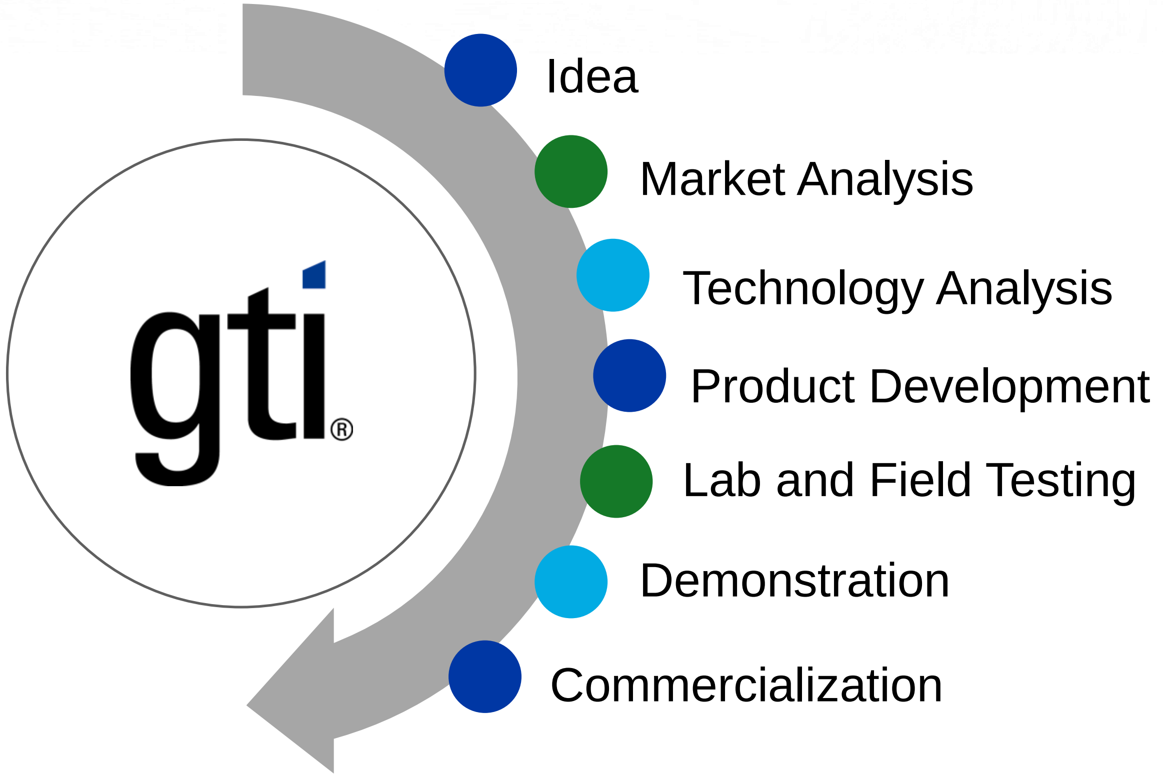
Main Campus in Des Plaines (Just North of ORD)

- 18 acre campus, 200,000 sf with 28 specialized labs
- 250 scientists, engineers, & support staff
- Machine shop, fabrication services on-site
- Pilot Flex-Fuel Gasification (< 6 MWth input) & Biofuel Conversion facilities
- H2 and CNG fueling station
- Analytical labs for gas/solid fuels characterization, material testing, microbiology assessments

GTI – From Concept to Commercialization

Applied RD&D

> Partnering at every phase of the technology development cycle



ENERGY SOLUTIONS… DELIVERED

Energy Delivery and Utilization

Natural Gas Delivery

- Pipeline safety and risk management
- Tools for operations improvement and data automation
- Material testing and evaluation
- Environmental and methane emission minimization

Residential & Commercial

- High-efficiency natural gas appliances and equipment for space conditioning, water heating, commercial foodservice, other uses
- Building systems, codes and standards, and source energy analytics
- Micro CHP, distributed generation, and smart grid systems

Industrial

- Ultra-low NO_x and high efficiency industrial burners, boilers, and process heating systems
- Industrial and large commercial CHP
- Medium-to-high temperature solar thermal systems

Transportation

- Natural gas and hydrogen fuel cell vehicles
- Alternative fuel vehicle fueling infrastructure
- Bio-methane applications
- Hydrogen production and conditioning

Energy Efficiency Program Collaboration
Utilization/Operations Technology Development

Mission

- Identify, select, fund, and oversee research projects resulting in innovative solutions which a) expands the use, cost effectiveness, and efficiency of natural gas utilization equipment and b) improved safety, reliability, and operational efficiency of natural gas systems

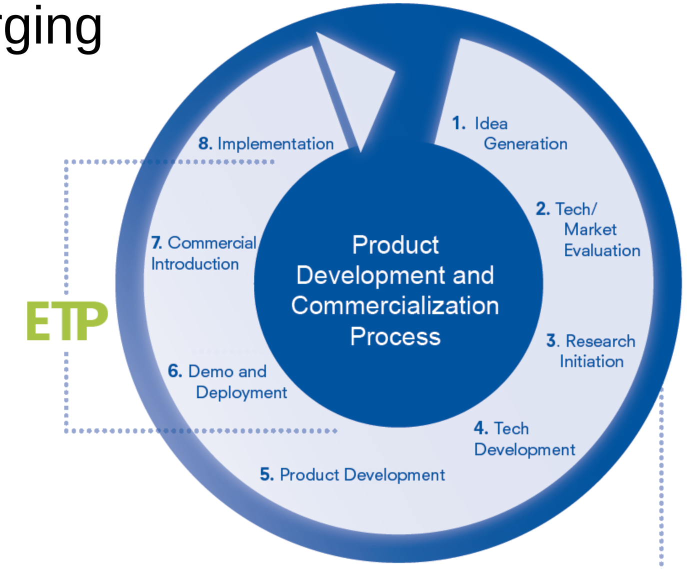
UTD
Utilization Technology Development

OTD
Operations Technology Development

Energy Efficiency Program Collaboration
Emerging Technology Program

> Gas Technology Institute led, utility supported, **North American collaborative** targeting **residential, commercial,** and **industrial** solutions

> ETP's principle goal is to **accelerate** the **market acceptance** of emerging energy efficient technologies



ETP activities are "beyond development" stage: Field Testing, Demonstration, Pilot Programs, and Deployment – a focused effort to ensure market acceptance of next-generation emerging technologies

Emerging Gas Heat Pump Tech.

Primary Takeaways

> Gas Heat Pumps (GHP) are an important emerging technology in the U.S. and Canada for homes and businesses

> GHPs today and tomorrow can:

- Deliver best-in-class **GHG reductions,** 50% or greater
- Integral to **cost-effective** Net/Near-Zero Energy Buildings
- **Maintain thermal comfort**, esp. in cold climates
- Readily utilize **natural refrigerants**

> Many efforts to improve cost-effectiveness of mature GHPs, while pushing envelope on performance and efficiency

Heat Pumps - Motivation

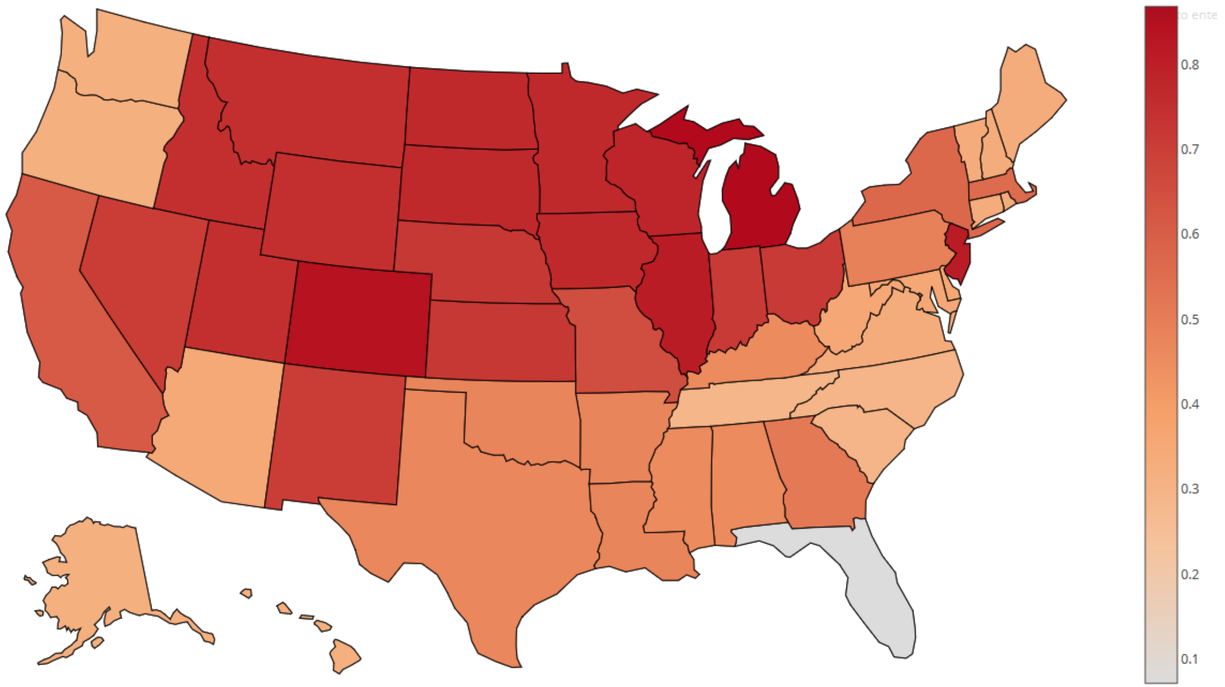
<u>Gas for heating in buildings is widespread and prevalent:</u>

- 84% of gas in buildings for heating and service hot water (SHW)
- Of the ~57% of U.S. homes with gas-fired heating/DHW:
  - For 85% of those with central furnaces, less than half have 90% AFUE or better
  - Only 5% of 4MM gas storage water heaters are 0.67 UEF or better (EnergyStar)

Challenges with gas EE:

- Low, stable utility costs diminish economics
- Declining loads (relative & absolute), migration, occupancy

Fraction of Housing Units Heated with NG/Propane



Data sources: US DOE EIA RECS 2009/2015, EnergyStar, and DOE SNOPR 2016. Technical Support Document: Residential Furnaces, prepared for the DOE by Navigant Consulting, Inc. and Lawrence Berkeley National Laboratory., NRCan.

Heat Pumps - Motivation

In Chicago, winter is coming…

> “Polar Vortex” has hit the upper Midwest again in 2019
  - -23 F recorded at O’hare, after long period below 0 F
  - Frequency impacted by climate change*

> Most homes heated with gas furnaces/boilers (87%)
  - 46% of housing units built before WWII
  - Despite oversize, most could not keep up during Vortex

> If 28% of Chicago’s GHGs are from residences, need to address emissions from home heating, but how?

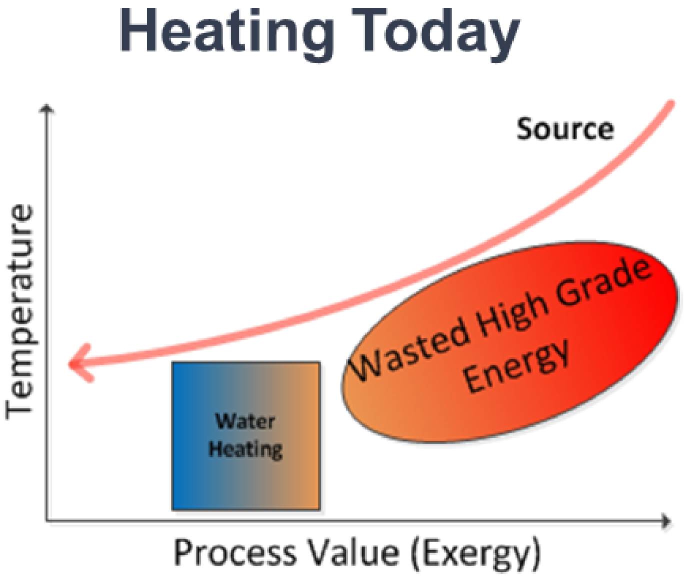
Me, shivering

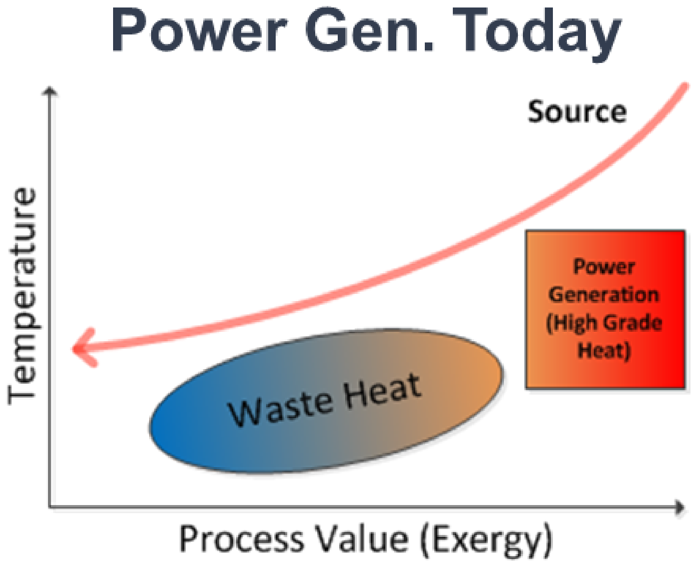
Lake Michigan on Jan. 31st, 2019

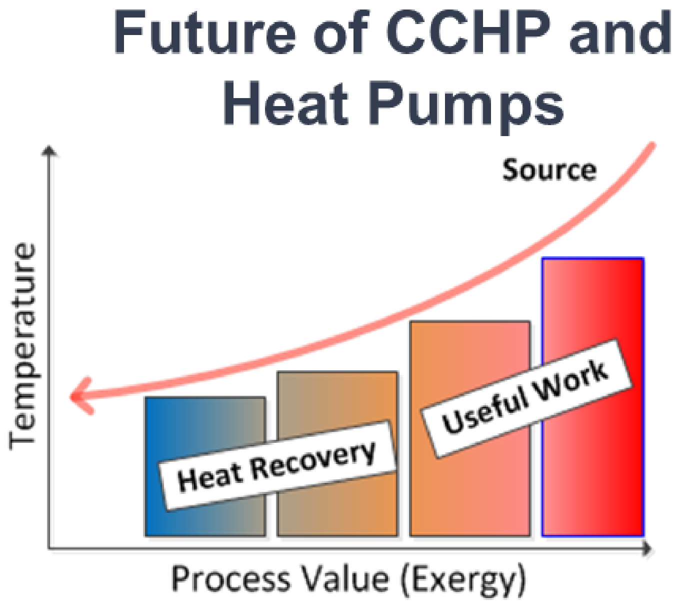
*As reported by the Guardian ; Image Source: Chicago Tribune, Data sources: City of Chicago Greenhouse Gas Inventory Report, 2015, 2010-2012 US Census American Community Survey

Heat Pumps - Motivation

Thermodynamically, it's the right thing to do: Entropy production (exergy destruction) in gas heating process is driven by huge ΔT, $T_{ad,flame}$ ~ 2000°C





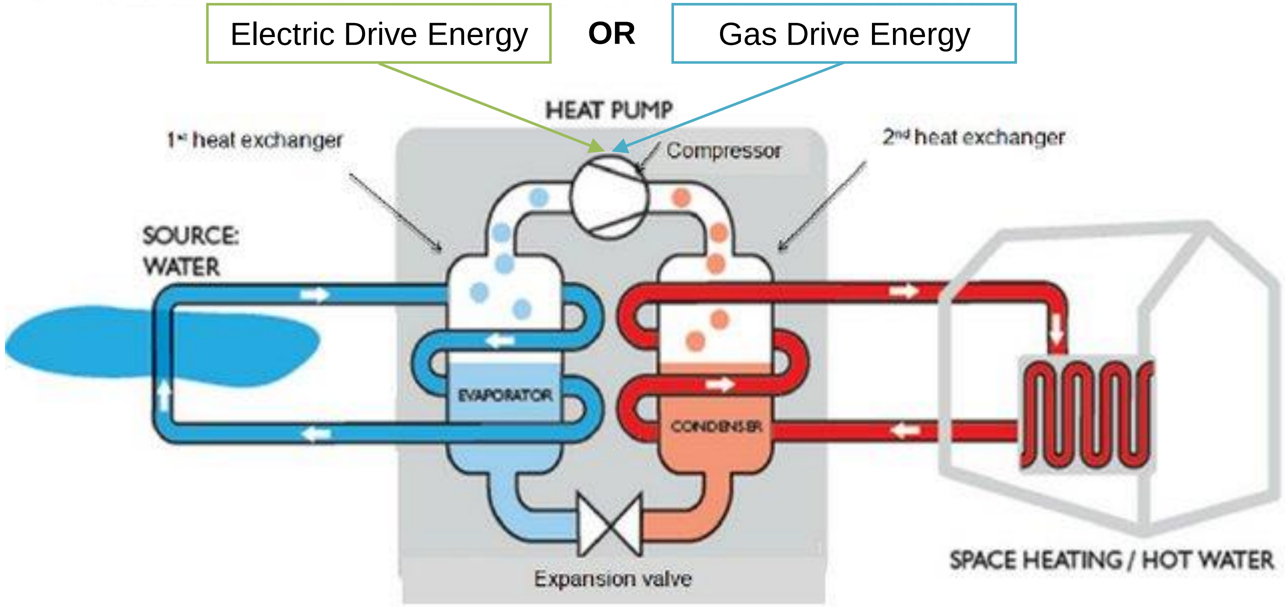


96% of Res. and 75% of Comm. gas heats air or water (incl. steam)

Diagrams adopted from slides produced by Prof. S. Garimella, Mechanical Engineering, Georgia Tech

Heat Pumps - Terminology

- **Heat Pump:** HVAC equipment that moves heat from **cold source** to **warm sink**, moving heat "uphill"
  - Many operate reversibly, providing A/C as well
  - With heat recovery, can provide service hot water (SHW) too
- **Gas Heat Pump (GHP):** Instead of electric compressor, GHPs use gas as drive energy
  - GHPs can be based on several thermodynamic cycles, including vapor compression
  - Cooling feasible but not always economical



Simplified Water-Source Heat Pump

Image Source: Ninikas, Konstantinos & Hytiris, N & Emmanuel, R & Aaen, Bjorn & McMillan, S. (2014). A renewable heat solution for water ingress in the Glasgow subway tunnel system. 161-171. 10.2495/ESUS140141.

Gas-fired Heat Pumps

Small-scale GHPs, available overseas, have many advantages:

> Best-in-class operating efficiency (primary basis)

> Good part-load performance and in cold climates

> Typically do not require backup heating and can continue operation during defrost

> Opportunities for peak load management

> Commonly use natural refrigerants/working fluids with low/no GWP/ODP

> NOx and GHG emissions are decreased by half or greater and combustion ‘sealed’ or occurs outdoors (IAQ & venting)

Image Source: Boostheat, Robur, Viessmann

Gas Heat Pumps – R&D Challenge

- **First Cost:** GHPs are expensive
  - **Heating:** \$100-\$180/MBH output (\$340-\$615/kW); versus \$15-\$35/MBH for conv. gas
  - **Cooling:** 2-4X equipment cost on output basis as current alternatives

RD&D Efforts: Develop/deploy low-cost sorption GHPs, improve economics of engine-driven GHPs

- **Performance/Reliability:** Complexity → Operating Issues?
  - GHPs in the 1980s-90s, primarily for A/C, had notable product failures

RD&D Efforts: Early focus on GHP component/product reliability, failure mode analysis, supporting development of sensible safety/efficiency codes

- **Product Availability:** If you build it…
  - Huge GHP market in Japan, growing in EU, but few imported/adapted options available represent commercialized products to date – follow example of tankless water heaters

RD&D Efforts: Multiple efforts to import/adapt and introduce GHPs to U.S./Canadian markets, emphasis on least-served residential market, incl. market research, roadmapping, & standards

Gas Heat Pumps – Overview

- Summary of GTI GHP Activities
  - Deployment of Gas Engine-driven HPs
  - Commercialization of Low-cost Gas Absorption HPs
  - Development of Next Generation GHPs

<u>Three Major GHP Types</u>

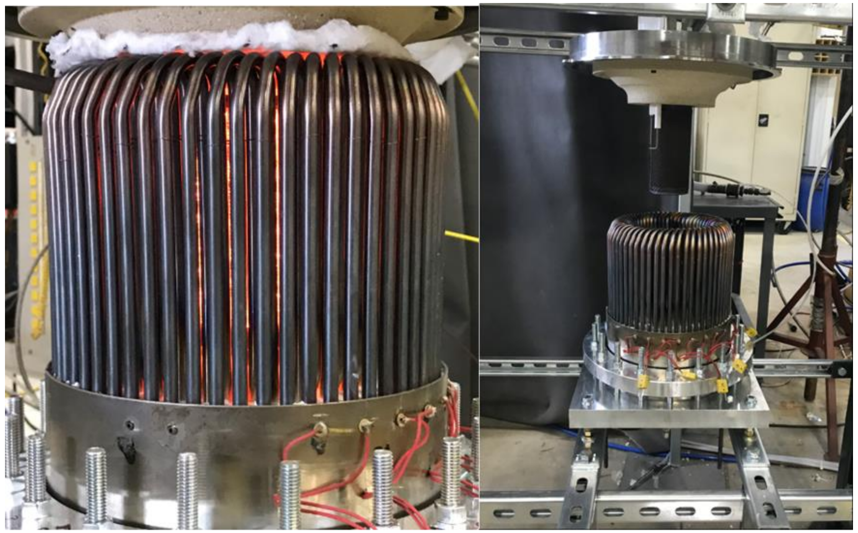
Vapor Compression

Sorption

Thermal Compression

GEHP operating in Boise, ID

Gas HPWH operating in Los Angeles, CA

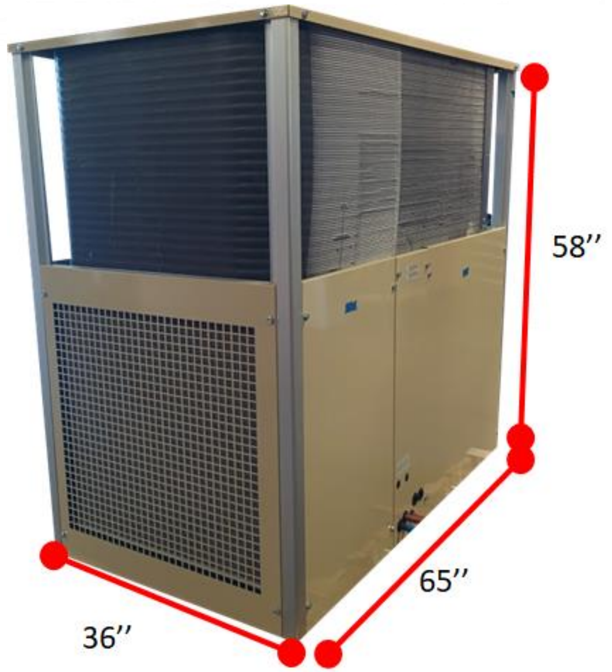


Hot HX Development for Next Generation GHP

Deployment of Gas Engine-Driven Heat Pumps

Vapor Compression Overview:

- **GHP Types:** common air-to-air, internal combustion engine driven VC system (ICE-GHP)
- **Distribution Type:** direct-expansion, multi-speed single zone system
- **Possible Functions:** A/C, forced-air heating, w/ supplemental hot water (engine jacket cooling)
- **Working Fluids:** R-410A (GWP = 2,088)
- **Commercial Status:** Residential = Product Development, Commercial = Multiple Suppliers



Prototype BME *RGHP*

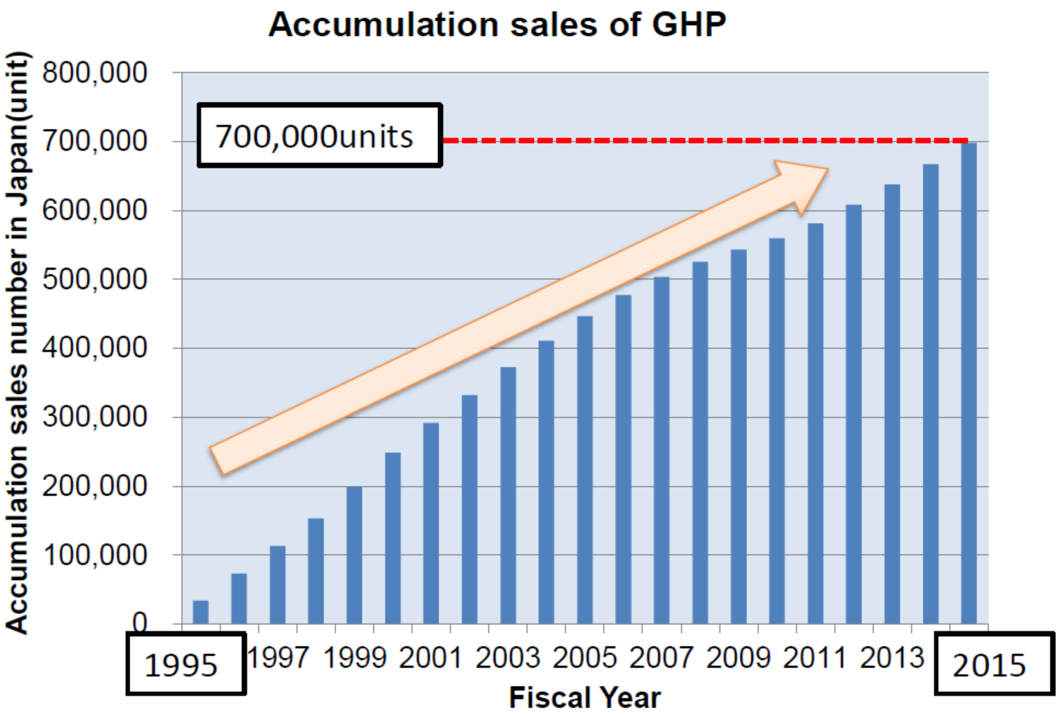
Product Highlight:*

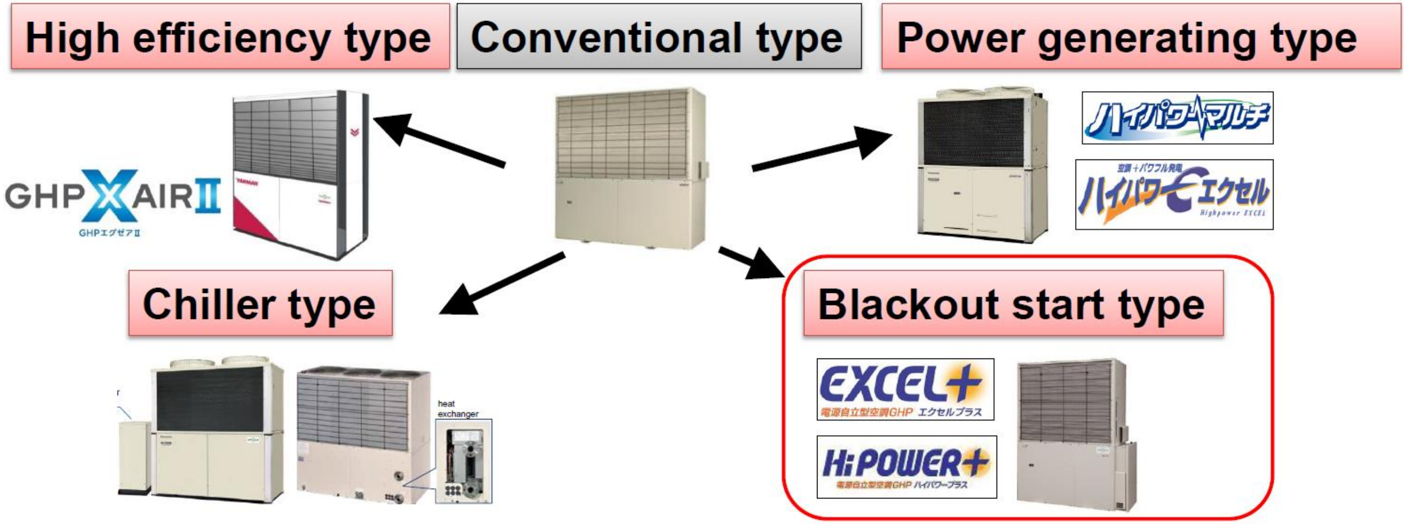
- **Res. GHP (RGHP)** by Intellichoice (BME), Marathon Energy Systems, with major support from US DOE from 2010 on
- **Input:** 75 MBH input, 208/230 VAC, 40%-100% modulation
- **Output:** 5 RT, 75 MBH heat (DX), up to 22 / 34 MBH recoverable as hot water (H/C modes)
- Status is pre-commercial, with multiple pilots complete, 21 units have accumulated more than 23,000 operating hours
- Current focus is cost-engineering, aiming for < $9k from current ~$14k equipment cost, and cold-climate demos in NY State.

*Source: I. Mahderekal, E. Vineyard, "Design and development of a residential gas-fired heat pump" Proceedings of the 2017 IEA Heat Pump Conference, Rotterdam, NL.

Deployment of Gas Engine-Driven Heat Pumps

- Driven primarily by **peak electricity demand reduction with A/C**, Japanese manufacturers have developed mature portfolio of gas-engine driven heat pumps (GEHPs)
- Within past 10 yrs, with support from DOE and gas industry, several “Americanized” products launched



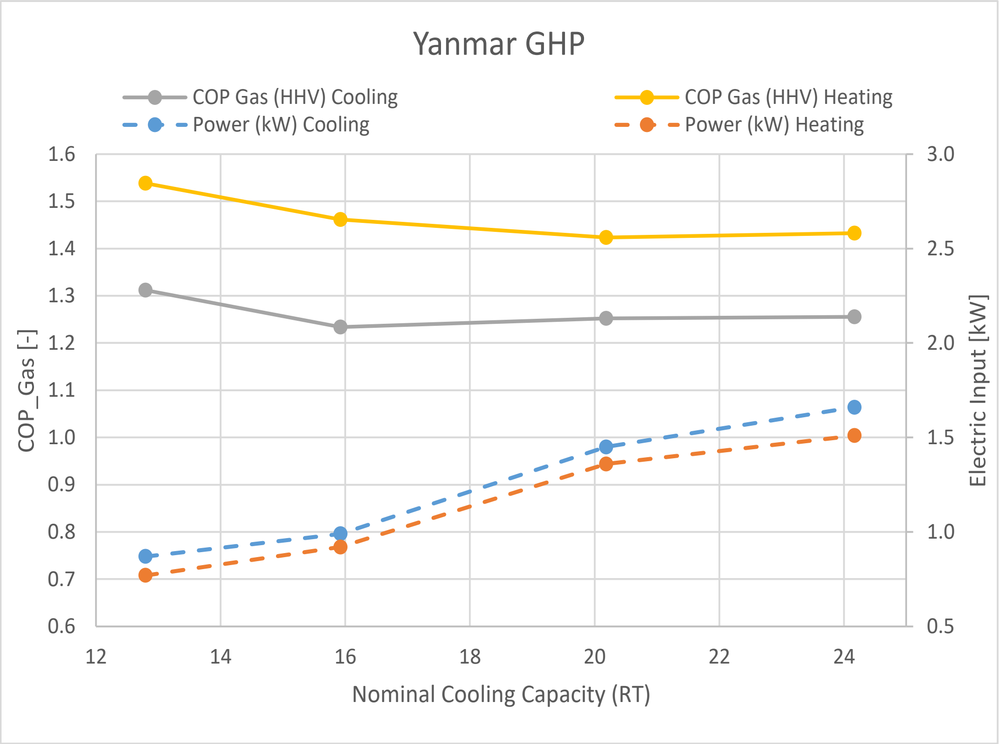


Image/Data source: Osaka Gas

Deployment of Gas Engine-Driven Heat Pumps

- GTI has supported long history of developing GEHPs for buildings, recently proving economics through pilots
- Cold climate performance of 15-ton NextAire™ showed:
  - Capacity reduced by 5% at lowest test temperature (5F); Heating efficiency: 1.20 to 1.30 COP at full load (47F).
  - Efficiency reduced when colder and at part load; VRF air handler design can improve efficiency by up to 20%
- Additional studies on residential-sized GEHP, Yanmar GEHP, RTU GHP and Field Trial of GEHP/EHP at DoD Facility

Yanmar GEHP has high performance with its recent generation products



Deployment of Gas Engine-Driven Heat Pumps

IL Project: Side-by-side comparison of Aisin GEHP and electric cold climate heat pump relative to the baseline conventional HVAC to quantify benefits for DoD applications, incl.: peak electric demand, economics, GHG emissions

- Baseline monitoring complete, GEHP monitoring underway
- Effort will result in case study and best practices for DoD/civilian applications

Low-cost Gas Absorption Heat Pumps

Sorption Overview:

- **GHP Types:** Air-to-water/brine or Water-to-water/brine
- **Distribution Type:** Hydronic Heating and/or Chilled Water/Brine
- **Possible Functions:** A/C and forced-air heating with hydronic air handlers, hydronic/radiant heating, DHW
- **Common Working Fluids/Materials:**
  - GAbHP pairs are $LiBr/H_2O$ (A/C) & NH_3/H_2O (Heating)
  - GAdHP working fluids are H_2O or NH_3 & adsorbents are carbon, zeolites, silicon dioxide, and salts (i.e. MgO)
- **Commercial Status:** Residential = Product Development/Int'l Suppliers, Commercial = Multiple Domestic Suppliers

	Absorption	Adsorption
Pros	As a continuous process, has high efficiency/capacity over wide range (w/ modulation). Best option for cold-climate, generally	Generally fewer moving parts and can be highly reliable GHPs
Cons	Historically, pumps with dynamic seals were failure points and corrosion/non-condensable gas formation must be managed	As a batch process, cycling/seasonal efficiency and capacity is poorer than GAbHPs in general

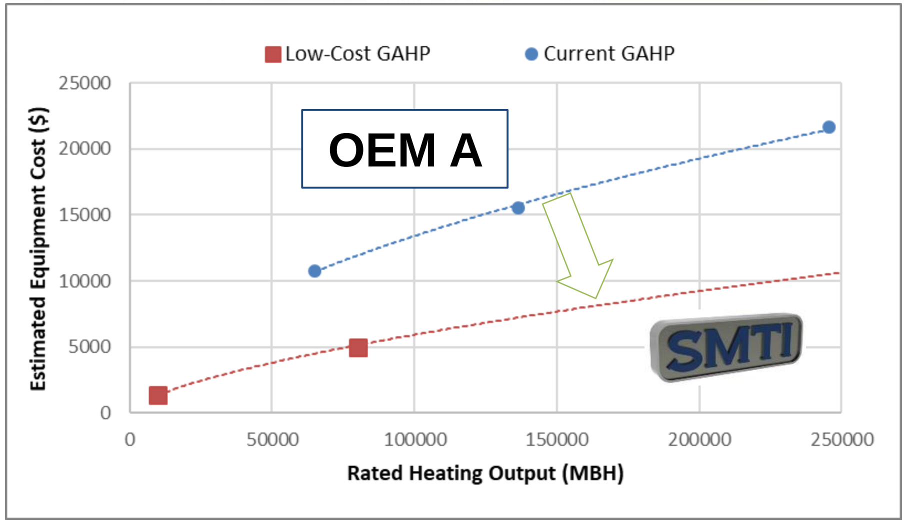
Low-cost Gas Absorption Heat Pumps

> Startup SMTI began in 2008 to commercialize low-cost GAHPs, driving down equipment costs with simplified HX designs.

> GTI, with strong support from gas industry helped move Gas HPWH and GAHP systems from proof-of-concept to field demonstration, >10,000 hours accumulated

  > Best-in-class efficiency, with 1.2-1.3 UEF and 140% AFUE projected

  > Appx. $6MM gov't and $2.5MM gas industry investment to date



Residential Gas HPWH:
- 60-80 gal, 10 kBtu/h output, 1.2-1.3 UEF projected
- Initial development complete in 2013
- Followed by field trials working with 4 different OEMs
- Projected market entry in 2-3 years, with certification for Ultra-Low NOx complete

Res./Comm. GAHP:
- Range from 20 kBtu/h output to 140 kBtu/h output; 4:1 modulation, 140% AFUE proj.
- Initial development complete in 2015
- Followed by Combi and Comm. SHW field trials
- Multiple OEMs engaged, by market segment

Low-load/NZE Res.

Res. Combi

Comm. SHW

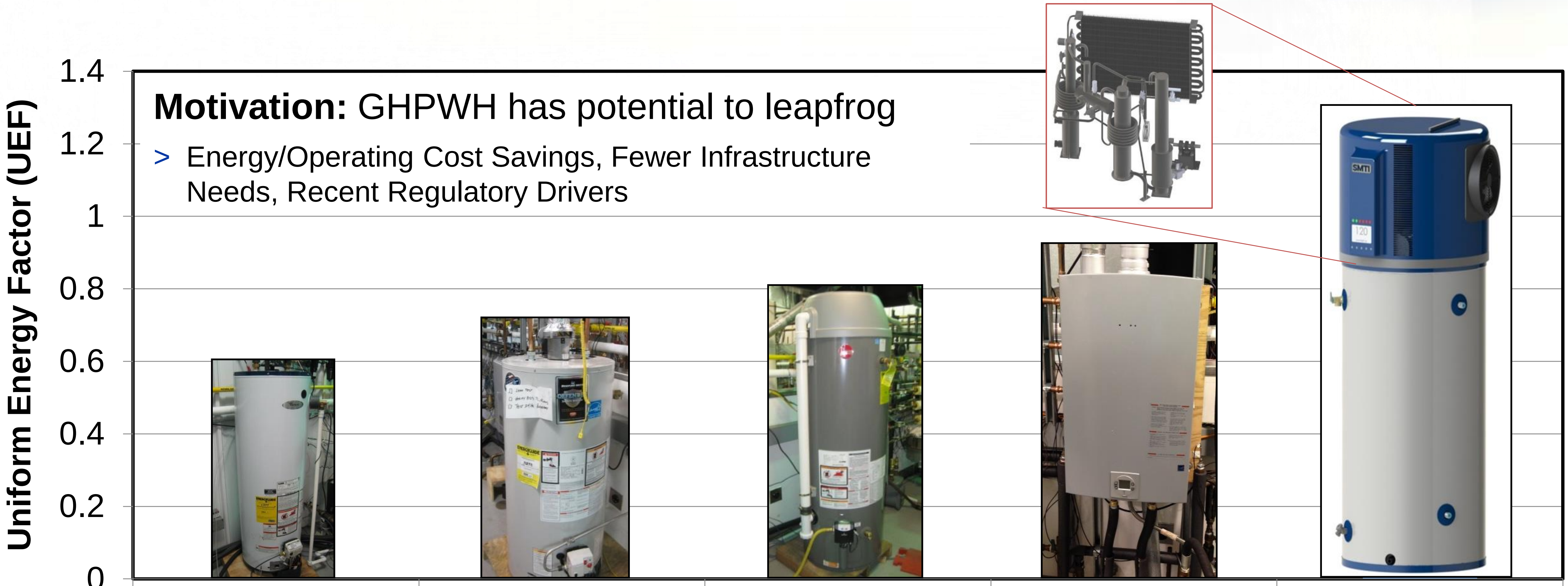
Low-cost Gas Absorption Heat Pumps





	Gas HPWH (~25 built)	Low-Load GAbHP	Whole-House GAbHP (~12 built)
Capacity	10 kBtu/h output	20 kBtu/h output max (nominal 47°F); 4:1 modulation	80 kBtu/h output max (nominal 47°F); 4:1 modulation
Firing Rate	6.5 kBtu/h input	15 kBtu/h input, 4:1 modulation	55 kBtu/h input, 4:1 modulation
Gas Pipe	½”	½”	½”
Venting	¾” or 1” PVC	1” PVC	1 ½” PVC
Emissions	10 ng NOx/J (Certified)	14 ng NOx/J (Projected)	14 ng NOx/J (Certified)
Electrical	~150 W on 120 VAC, 1.25 kW suppl. heat	160-280 W on 120 VAC	300-600 W on 120 VAC
Physical Size	60-80 gallon tank, up to 77” tall 24” diameter	18” W x 24” L x 24” H	34” W x 47” L x 46” H
Ammonia Charge	~1.2 lb	3 lb.	~11 lb

Residential Gas Heat Pump Water Heater



Baseline:
90% of Gas WHs sold, combustion safety concerns

Mid-Efficiency:
50-100% greater equipment costs, similar venting concerns

Condensing Storage:
4-5X equipment cost and retrofit installation costs of $1000 or more.

Tankless and Hybrids:
2-3X equipment cost and retrofit installation costs of $1000 or more.

Gas Heat Pump:
> 50% therm savings with comparable installed cost to tankless.

Residential Gas Heat Pump Water Heater

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

0.35 Units Cooling (Ambient Energy)

0.65 Units Site Energy

1.0 Units Hot Water

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

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

Electric HPWH: As-installed $COP_{site,average}$ ≈ 2.5

0.6 Units Cooling (Ambient Energy)

0.4 Units Site Energy

1.0 Units Hot Water

Backup/Supplemental Heating
(elec. resistance) typically 15-40% of delivered energy

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

	Electricity In	Nat. Gas in	GHG Emitted (Lbs. CO2e)	COP_{source}
Gas HPWH	0.8 kWh	0.3 Therms	5.8	1.20
Electric HPWH	6.6 kWh	N/A	6.4	0.76

Note: Excludes backup/supplemental heating

Site/Source Factors: US National 2016 eGRID Plant Level Database for Illinois, 3.23 Electricity & 1.09 Natural Gas; CO2e Emission Factors (Lb./ MMBtu): 283.84 Electricity & 147.86 Natural Gas

Data References: 1) Glanville, P., Vadnal, H., and Garrabrant, M. (2016), "Field testing of a prototype residential gas-fired heat pump water heater", Proceedings of the 2016 ASHRAE Winter Conference, Orlando, FL., 2) Shapiro, C. and Puttagunta, S. "Field Performance of Heat Pump Water Heaters in the Northeast" Report prepared for U.S. Dept. of Energy under NREL Contract No. DE-AC36-08GO28308, 2016; 3) Ecotope, Inc. 2015. Heat Pump Water Heater Model Validation Study (Report No. E15-306). Portland, OR: Northwest Energy Efficiency Alliance.

Image Sources: GHPWH photo courtesy of SMTI, EHPWH photo from A.O. Smith

Residential Gas Heat Pump Water Heater

- Goal was to develop scaled-down heat pump for integration atop/aside from standard storage tank, using **easily manufactured design** to assure low-cost with < $1600 consumer cost target.
- Absorption cycle development by startup, with support from GTI and multiple water heater OEMs, 20 built to date, >10,000 field operating hours.







2011 — 2013 — 2015 — 2017 — 2019

GHPWH R&D* – Two generations of packaged lab. Proof-of-Concept GHPWH Units, then refined design through extended lab testing.	**GHPWH Early Field Testing**,*** –** Residential sites in TN, OR, WA, and ID, using 2^{nd}/3^{rd} Gen. Prototypes	**Extended Life & Gen 3 Field Testing –** Improve key component reliability and solicit stakeholder feedback	**Gen 4 Pilot & ULN Cert. –** Build/install units in AL & CA with OEM, ULN cert. and MR

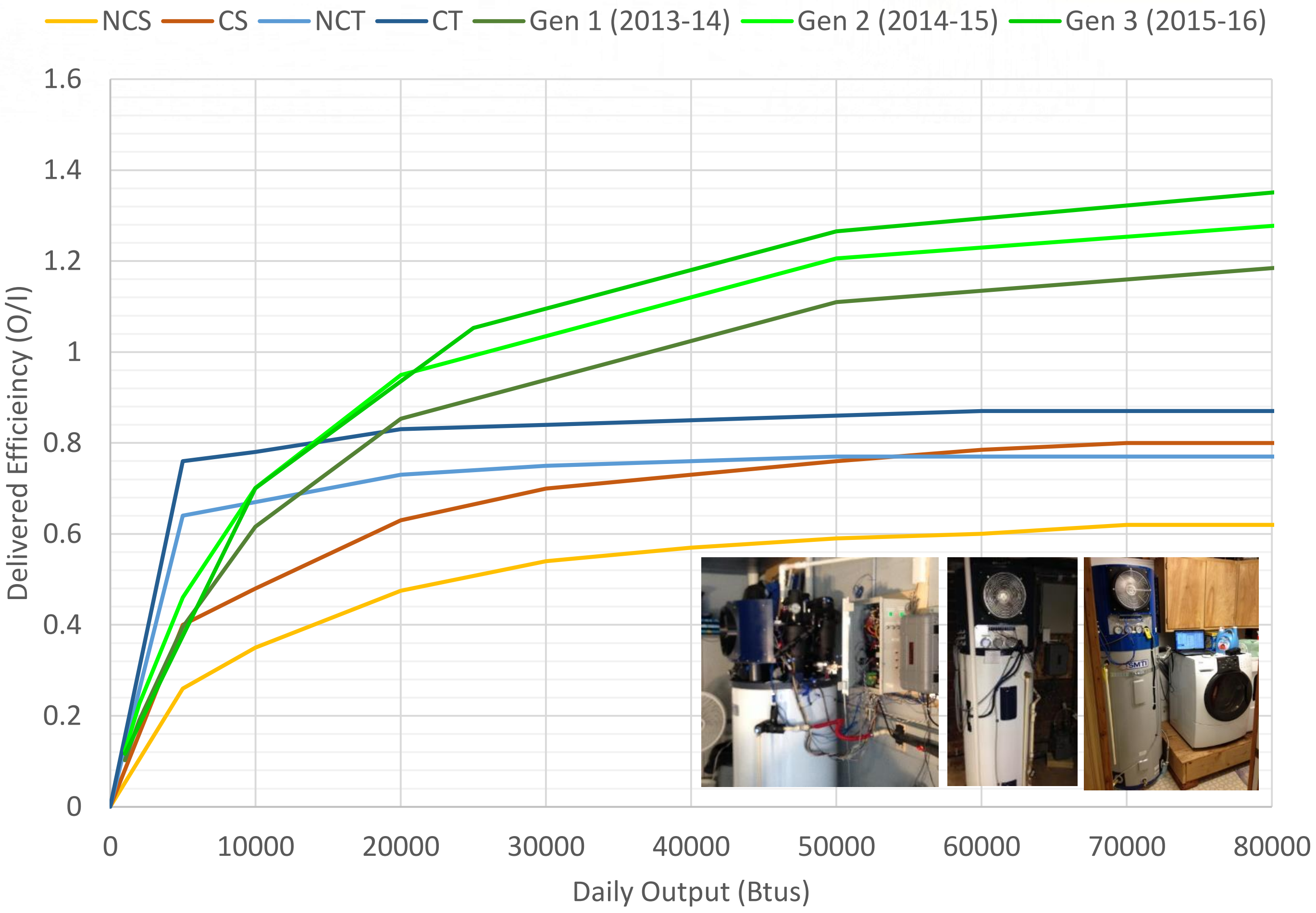
* Garrabrant, M., Stout R., Glanville, P., Fitzgerald, J., and Keinath, C. (2013) *Development and Validation of a Gas-Fired Residential Heat Pump Water Heater*. Report DOE/EE0003985-1, prepared under contract EE0003985.
** Garrabrant, M., Stout, R., Glanville, P., and Fitzgerald, J. (2014), *Residential Gas Absorption Heat Pump Water Heater Prototype Performance Results*, Proceedings of the Int'l Sorption Heat Pump Conference, Washington, DC.
*** Glanville, P., Vadnal, H., and Garrabrant, M. (2016), *Field testing of a prototype residential gas-fired heat pump water heater*, Proceedings of the 2016 ASHRAE Winter Conference, Orlando, FL.

Residential Gas Heat Pump Water Heater

Summary of Prior Field Demos

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

- > Heat pumps operated well, at/above target COPs in “real world”
- > Site specific therm savings generally 50% over conventional GWH
- > Subsequent generations showed improved efficiency and reliability
  - – Improvements with EEV, soln. pump
- > COP impact of water/ambient temperatures characterized
- > Cooling effect ~3,250 Btu/hr (~1kW)



Baseline Data: Kosar, D., Glanville, P., and Vadnal, H. “Residential Water Heating Program - Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating - Final Project Report”, CEC Contract CEC-500-2013-060, 2013.

Residential Gas Heat Pump Water Heater

Next Gen. Gas HPWH Program (Through 2020)

- Demonstrate 50% or greater therm savings over baseline in 5-unit demo
  - Prototype Gas HPWHs completed AQMD certification for NOx, performance monitoring since June ‘18
- Partner with SoCal Gas *Engineering Analysis Center* to perform reliability/emissions testing of add’l prototype
  - Quantified NOx/GHG emissions benefit to South Coast Air Basin
- Develop model/Title 24 Analysis and guidance to reduce codes/standards market barriers, NZEH white paper
- Perform market research and outreach to key stakeholders

State of California Energy Commission | Southern California Gas Company® | UTD. Utilization Technology Development | SMTI | Rinnai®

<u>Transitioning to expanded 100+ unit pilot program</u>

Residential Gas Heat Pump Combi

Previously described the development* and initial demonstration** of a low-cost GHP for whole-house combi heating and light commercial:

> Base tech. is gas-fired single-effect ammonia water absorption cycle and design to be **easily manufactured design** to assure low-cost (30%-50% of existing GHPs)

> Absorption cycle development by startup, tech. support from research institute and OEMs

> Nominal 80 kBtu/h (23 kW) output with 4:1 output modulation, no aux./backup heat, Ultra-low NOx emissions, defrost capable, projected 140% AFUE (Region IV) and 3-5 yr. payback*

Lab Testing (2015-2016)

1st Pilot (2016-Present)

2nd Pilot (2017-Present)

Add'l Pilots (2018-Present)

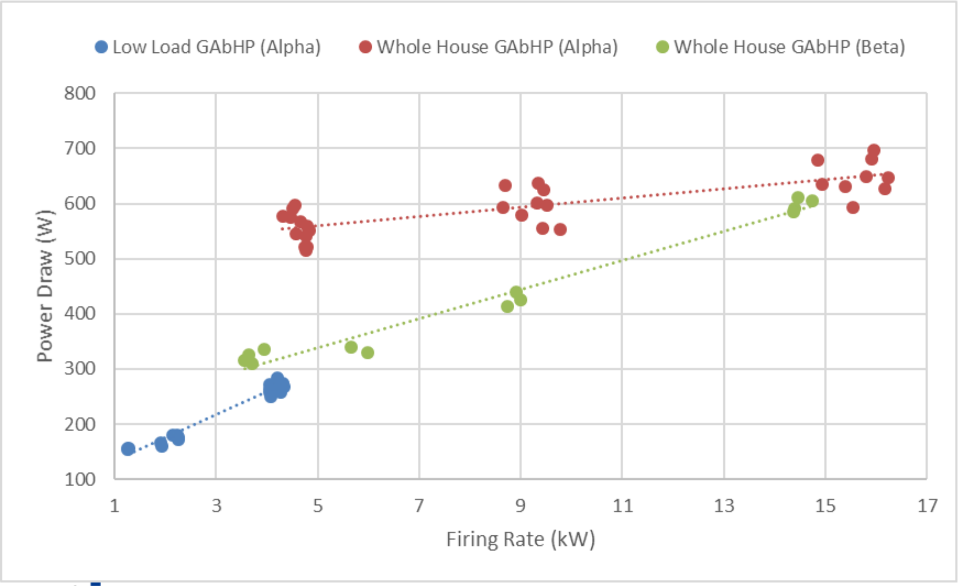
*Glanville, P, Keinath, C., and Garrabrant, M. (2017) *Development and Evaluation of a Low-Cost Gas Absorption Heat Pump*, Proceedings of the ASHRAE Winter Conference, Las Vegas, NV.

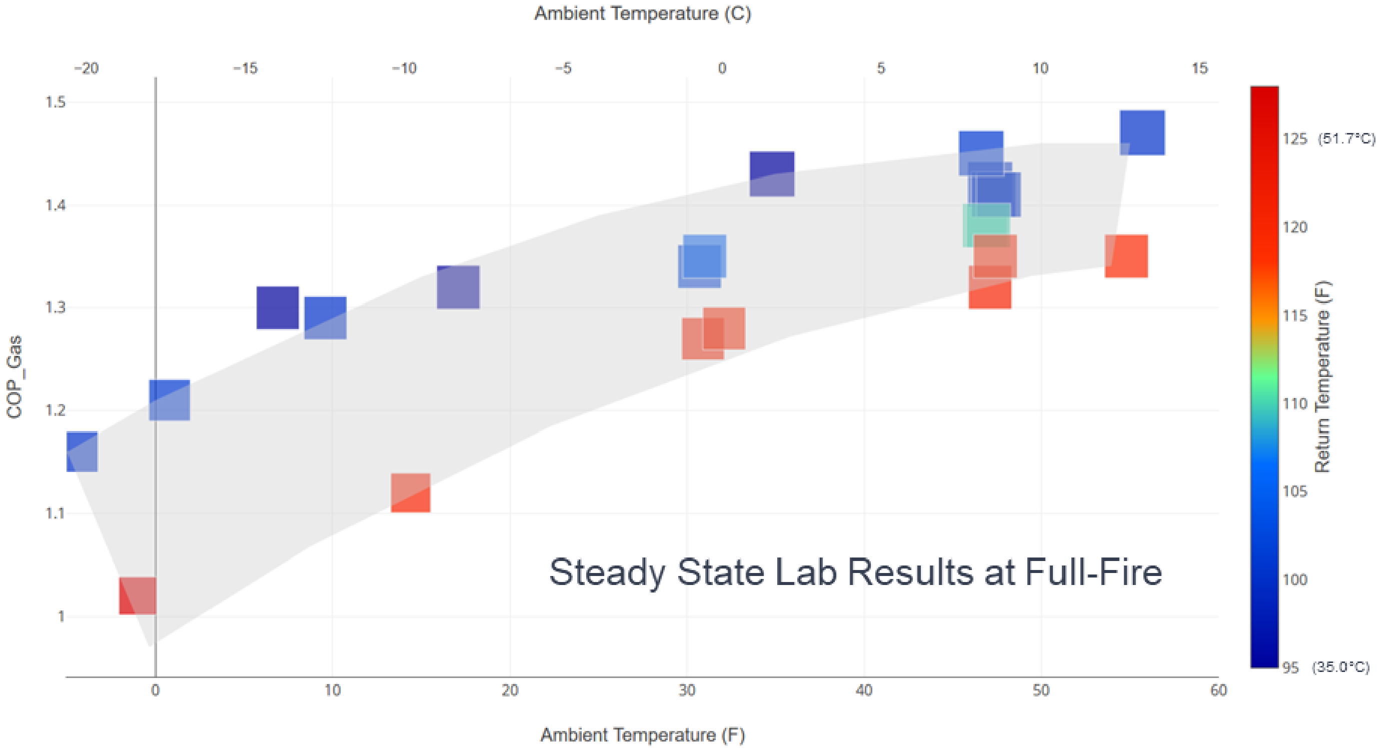
** Glanville, P., Suchorabski, D., Keinath, C., and Garrabrant, M. (2018), *Laboratory and Field Evaluation of a Gas Heat Pump-Driven Residential Combination Space and Water Heating System*, Proceedings of the ASHRAE Winter Conference, Chicago, IL.

Residential Gas Heat Pump Combi

Lab Performance: Evaluated as a combined space/water heating system*, team demonstrated GAHP performance:

- Optimized power consumption, defrost, and combi-system controls





- Whole-house GAbHP evaluated in lab in 2015 (Alpha) and 2017 (Beta); Recent prototype shipped to NRCan
- Low-load GAbHP evaluated in 2018 (Alpha)

*More information: Garrabrant, M., Stout., R., Keinath, C., and Glanville, P. "Experimental Evaluation of Low-Cost Gas Heat Pump Prototypes for Building Space Heating", Proceedings of the 16th Int'l Refrigeration and Air Conditioning Conference at Purdue University, 2016 ***AND*** Glanville, P., Keinath, C., and Garrabrant, M. 2017. "Development and Evaluation of a Low-Cost Gas Absorption Heat Pump", proceedings of the 2017 ASHRAE Winter Conference, Las Vegas, NV.

Residential Gas Heat Pump Combi

Pre-Commercialization Scale-Up Project:

Significant effort from DOE to SMTI (GTI/Trane team members) to support manufacturing/commercialization of low-cost GAHP ($2.7MM overall project)

> Project moves from current state to pre-production
  - Several utilities played critical role in providing gas industry support to the proposal

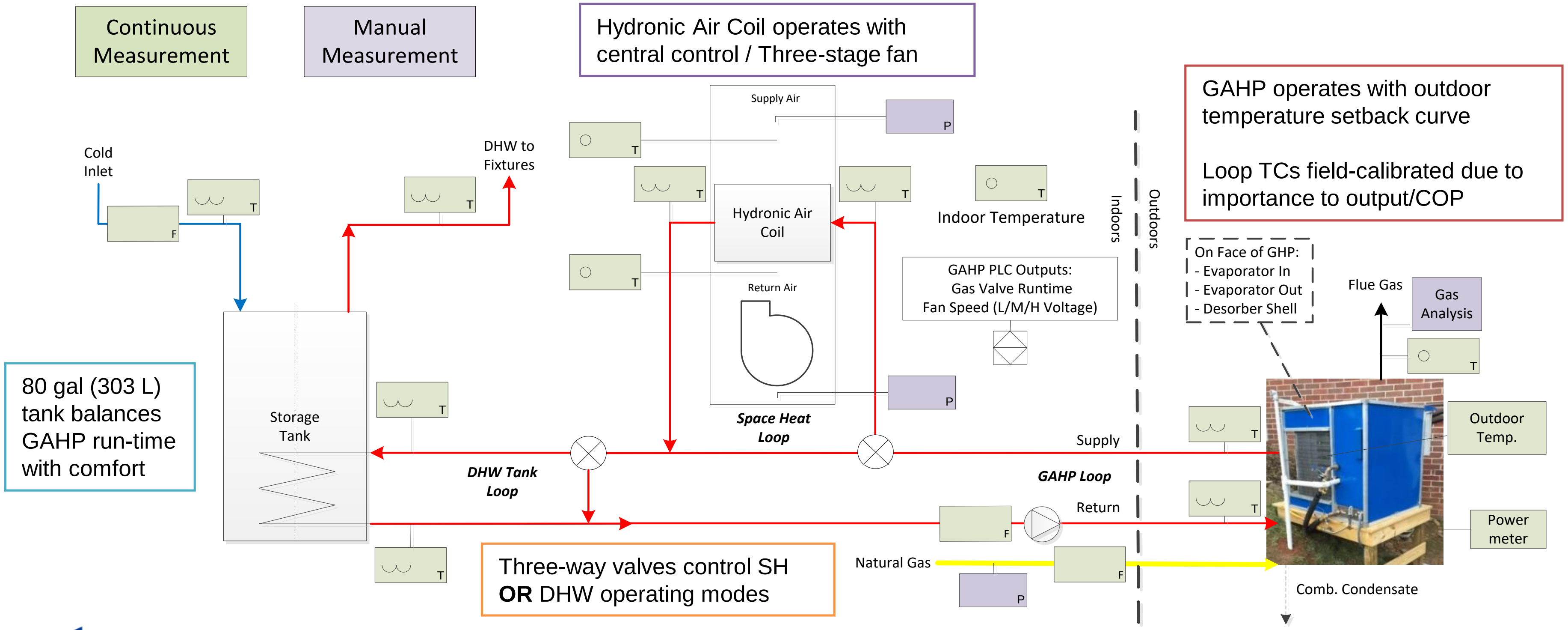
> Highlights from:
  - **GTI:** Demonstration Task, Component Testing, Codes/Stds Analysis, Energy Modeling
  - **SMTI:** DFM, Lab Testing, Market Research
  - **Trane:** Lab Testing, Controls, BoS, Hydronic Air Handler

- Project Complete EOY 2019
- <u>**Expanded demo in planning stages**</u>

Builds on past RD&D from DOE, UTD, NEEA

Residential Gas Heat Pump Combi

- Annualized savings of 45% therm for space/water heat combined over baseline (gas water heater, condensing furnace) at three La Crosse, WI homes estimated
- > 4,000 operating hours during extreme weather (-27 F), with no backup heat/active defrost, unit consumes ~800 kWh/year on standard 120 VAC / 15 A circuit



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Commercial Gas Heat Pump - Hybridization

- Boilers / Gas Water Heaters
  - Capacity is constant
  - Part-load good with Adv. Controls
  - But, limited to condensing eff.
- GHPs
  - Have best-in-class efficiency/GHG emissions
  - But, capacity degrades with very cold T and are 2-3X cost of boiler/water heater

- "Hybridize" System with *retrofit*
  - Std. equipment handles peak loads
  - Analysis suggests sizing GHPs as 30% to 60% of peak load, less for "peakier" loads (restaurant SHW) for stable loads (space heat)

Standard

η_sys = 80%-95%

Hybrid

η_sys = 120%-140%

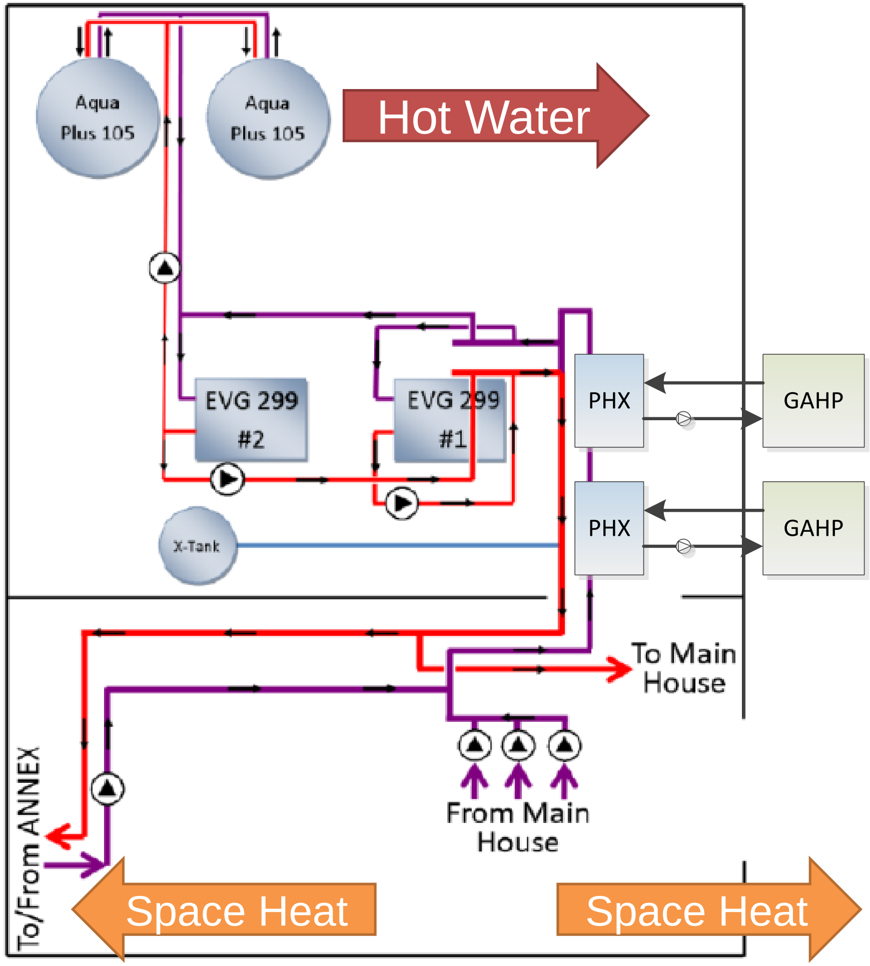
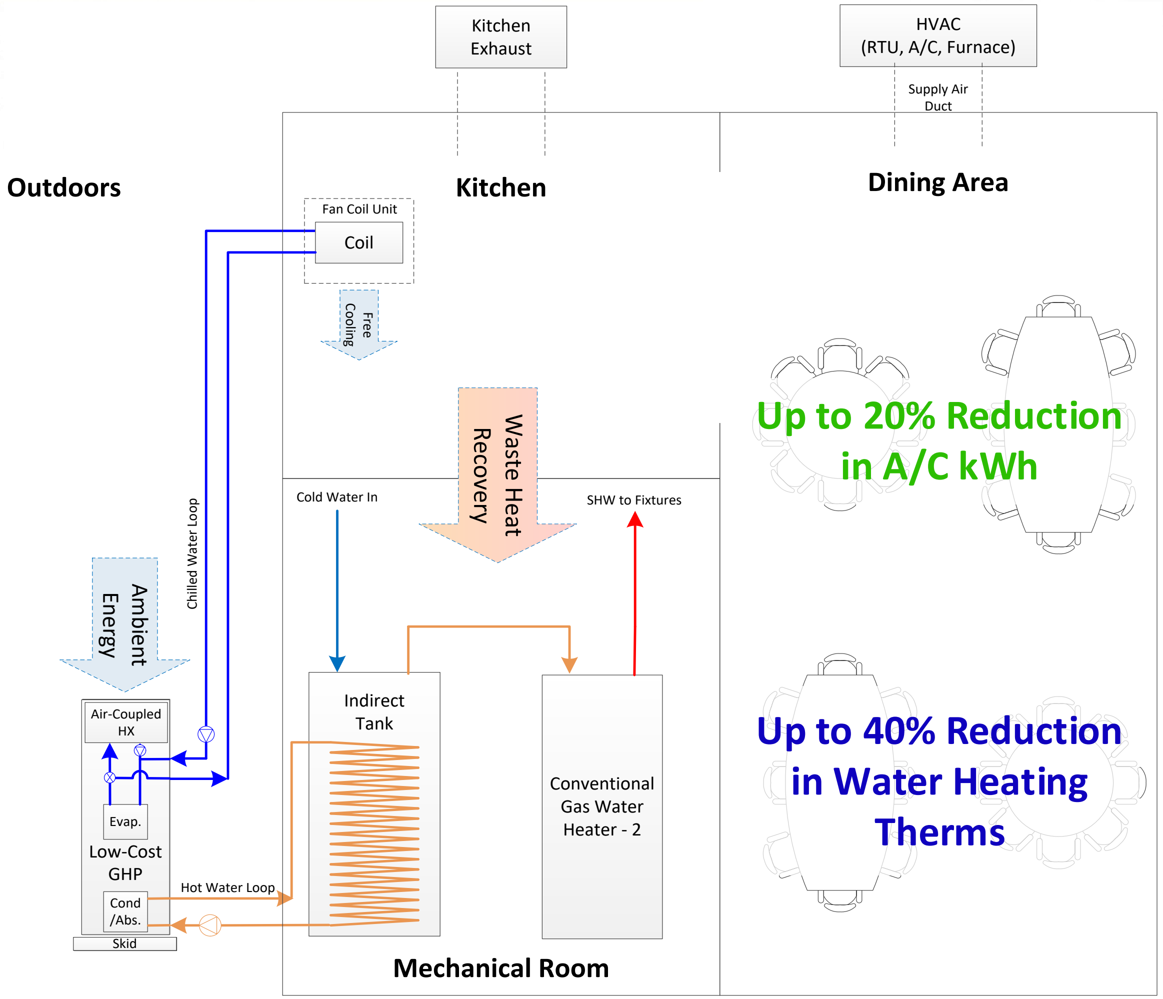


Diagram courtesy of Weil-McLain

Commercial Gas Heat Pump – Hot Water

System Concept:

- Restaurants commonly have large service hot water (SHW) loads, 1,500 gal/day or greater
- With large internal loads from cooking/equipment, A/C load is also significant, year-round
- GHP split of heating output and “free” cooling, 2-2.5:1, can mesh nicely with restaurant loads
- Installed as hybrid system



Commercial Gas Heat Pump – Hot Water

- Goal of demonstration to show 40% or greater therm savings and measurable reduction in displaced A/C (up to 20%)
  - Monitoring of pre/post at two restaurants through early 2020
  - Unit received Ultra Low NOx certification
- In addition to field assessment of Integrated GHP system:
  - Develop sizing tools and design guide
  - Evaluate potential with ZNE Restaurants
  - Market research and outreach events with stakeholders

GAHP photo courtesy of SMTI

Commercial Gas Heat Pump – Multifamily

> Hybrid boiler/GHP system demo operating at multifamily building in NE Illinois
  - Retrofit installation complete in 2019, larger prototype GHP (140 MBH) serving hot water and space heating in parallel to condensing boilers
  - Equipment performance over heating season important, optimizing system controls is critical
  - Critical to understand installation issues, gaps with contractor training

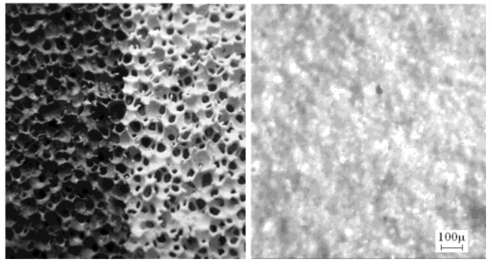
SMTI

UTD Utilization Technology Development

WEIL-McLAIN

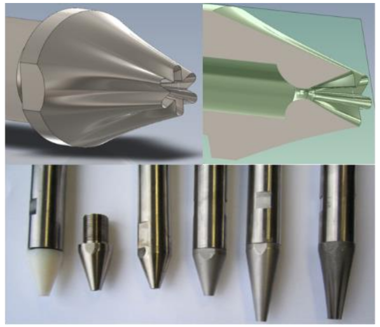
GAHP photo courtesy of SMTI

Developing Next Generation GHPs



- Supporting the design/development of next gen. GHP technologies, with goal of >20% improvement over absorption/vapor compression
  - Require non-traditional working fluids, refrigerants, may also have power generation component
  - GTI generally supporting development of “hot side”, system controls, heat exchangers
    - Generation of simulation tools as is useful to OEMs, industry
  - As TRL increases, GTI sees through to early field trials

Ejector



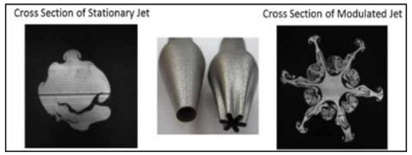
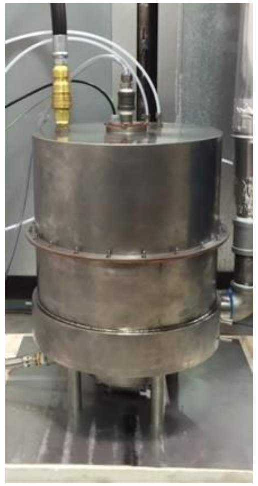
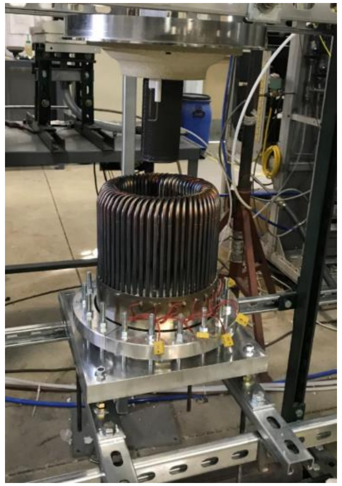


Image Source: MRTS

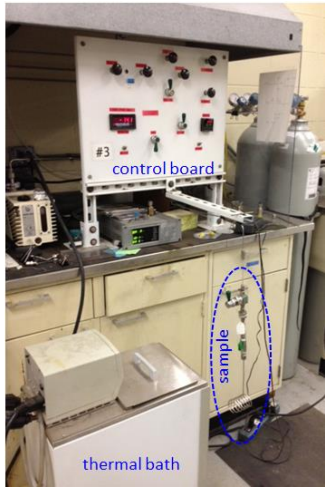
Thermal Compression





Desiccant Cycles

Adsorption



Next Gen. GHPs – Thermal Compression

Thermal Compression Overview:

- **GHP Types:** Air-to-water/brine or Water-to-water/brine
- **Distribution Type:** Hydronic Heating and/or Chilled Water/Brine
- **Possible Functions:** A/C and forced-air heating with hydronic air handlers, hydronic/radiant heating, DHW
- **Working Fluids:** Helium, CO2
- **Commercial Status:** Residential = Product Development, Commercial = Product Development

Source: Boostheat

Product Highlight:*

- **Res. GHP (BH20)** by Boostheat, a French startup with major support from Bosch and ENGIE.
- **Input:** 42 MBH input, 208/230 VAC (50 Hz), backup boiler for high turndown
- **Output:** 68 MBH heat (hydronic), with high temperature heating feasible (200 F)
- **Efficiency:** Cert. with COP_{Gas} of 1.60-1.90 (HHV Est.)
- Status is pre-commercial, with limited pilots underway in EU, ramping up production for wide release
  - Unit shipping to GTI now for evaluation
  - Larger commercial unit and res. product with cooling under development
- Rolling out “Energy as a Service” approach, consumer purchase/finances directly with Boostheat, includes installation and maintenance

*Source: Communications with Boostheat

Next Gen. GHPs – Thermal Compression

Highlight – Thermolift

- Potential for heating COP_{gas} = 2 at 47°F / cold climate heating COP_{gas} > 1.3 at -13°F, early data is promising*
- Simultaneous cooling (COP_{gas} = 1 target)
- 2018 prototype testing showed COP stable at part load and internal power generation feasible
- 3+ years of R&D with GTI on hot-side of cycle, next gen. prototype GTI lab testing and Thermolift demos in planning stages

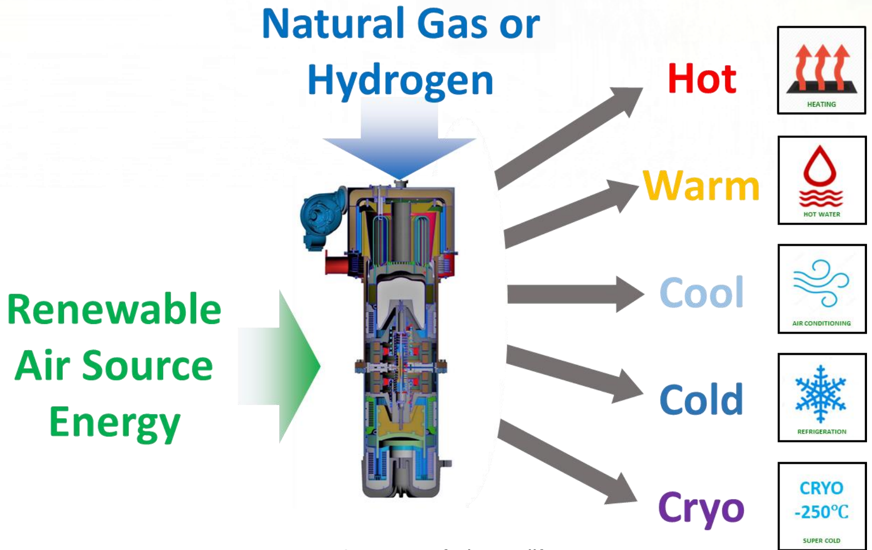


Image Courtesy of Thermolift

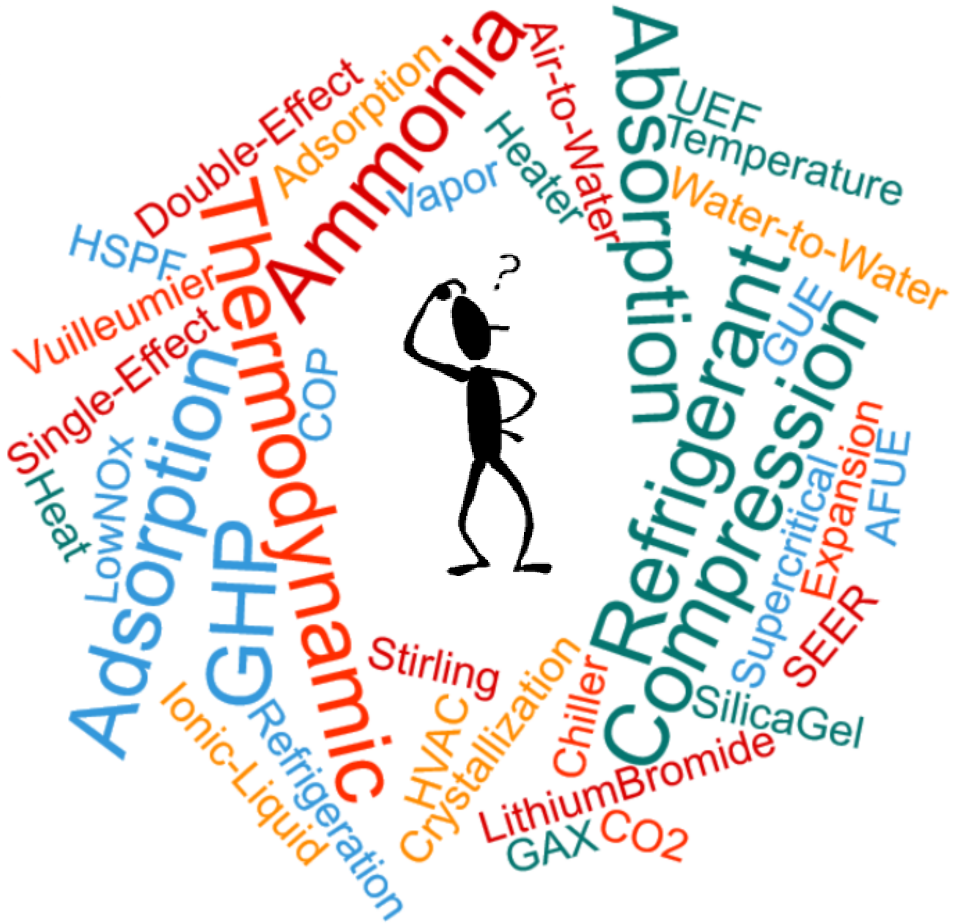
GTI R&D on "Hot Side"

*Source: ORNL, "Test Report of the Thermolift Natural Gas Fired Air-Conditioner and Cold-Climate Heat Pump", prepared by ORNL with support from Thermolift under contract DE-EE0006350

Gas Heat Pumps – Industry Challenge

Need for a roadmap…

- Which GHP technologies are applied best where?
- How do we assure R&D & Demos isn't redundant? What have we learned from recent pilots?
- What's the actual cost-effectiveness of available GHPs?
- Are prototype GHP technologies ready for market introduction?
- What barriers exist to widespread GHP adoption?



Roadmap Overview

- Special-Purpose Collaborative est. 2018 formed by 15 utilities
- Led by team of Brio Consulting + GTI
- Technology and Market Assessment of:
  - Residential and/or Commercial Space/Water Heating & Cooling Only
    - Excludes anything with > 400 MBH input, refrigeration, indirect/waste-fired or custom equipment
  - North American markets, standard supply chains
  - Commercially available now or < 3 years (< 5 for ‘game-changing), domestic and foreign products/tech. considered
  - Air-to-X, Water-to-X considered
- Team finalizing roadmap materials this month (public-facing/confidential)

Image Source: Robur, DOE

Roadmap Overview - Technical

- Overview of Key Players and Technologies
  - GHP fundamentals with 'deep dives' for Sorption, Vapor Compression, and Thermal Compression-types
- Catalogue North American GHP Activity
  - History of GHPs/Gas Cooling with Case Studies
  - Matrix of development/demonstration projects
- Assess and Compare GHP Technologies for Residential/Commercial Applications
  - SWOT-type Analysis per GHP-type
  - Regional Efficiency/Emissions Analysis
- Outline Critical Barriers to Adoption, including Codes & Standards
- Recommend Paths for Impact

GHP Tech. Developers

SaltX Technology, SMTI, ThermoLift, BOOSTHEAT, YANMAR, AISIN, ROBUR caring for the environment, m-trigen Power Generation Systems Solutions, Tecogen Advanced Modular CHP Systems, BLUE MOUNTAIN ENERGY

Manufacturers Interviewed to Gauge GHP Interest

AO Smith, Carrier, DAIKIN, Goodman, TRANE, Rheem The new degree of comfort.™, Rinnai, BRADFORD WHITE WATER HEATERS, VIESSMANN

GE APPLIANCES a Haier company, Johnson Controls, WEIL-McLAIN, And more….

Roadmap Overview - Market

- Overview of Market Participants
  - Supply-side and sponsor participants
  - Extensive interviewing of 40+ organizations
- Defining Market Barriers, Risks, & Opportunities
  - Coalescing themes and major findings from interviews, defining unmet needs of/from gas industry
  - Drawing on experience with similar equipment (electric HPWH, ductless mini-split HPs)
- Review of Possible LDC Collaboration Models
  - Roadmap for collaboration going forward

Image source: Vaillant

Emerging Gas Heat Pump Tech.

Reinforcing Primary Takeaways

> Gas Heat Pumps (GHP) are an important emerging technology in the U.S. and Canada for homes and businesses

> GHPs today and tomorrow can:

- Deliver best-in-class **GHG reductions,** 50% or greater
- Integral to **cost-effective** Net/Near-Zero Energy Buildings
- **Maintain thermal comfort**, esp. in cold climates
- Readily utilize **natural refrigerants**

> Many efforts to improve cost-effectiveness of mature GHPs, while pushing envelope on performance and efficiency

Discussion

Input on direction of GTI's GHP Research, Development, and Deployment?

Further information:

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@gastechnology

Appendix

Building AMERICA
U.S. Department of Energy

GTI Energy

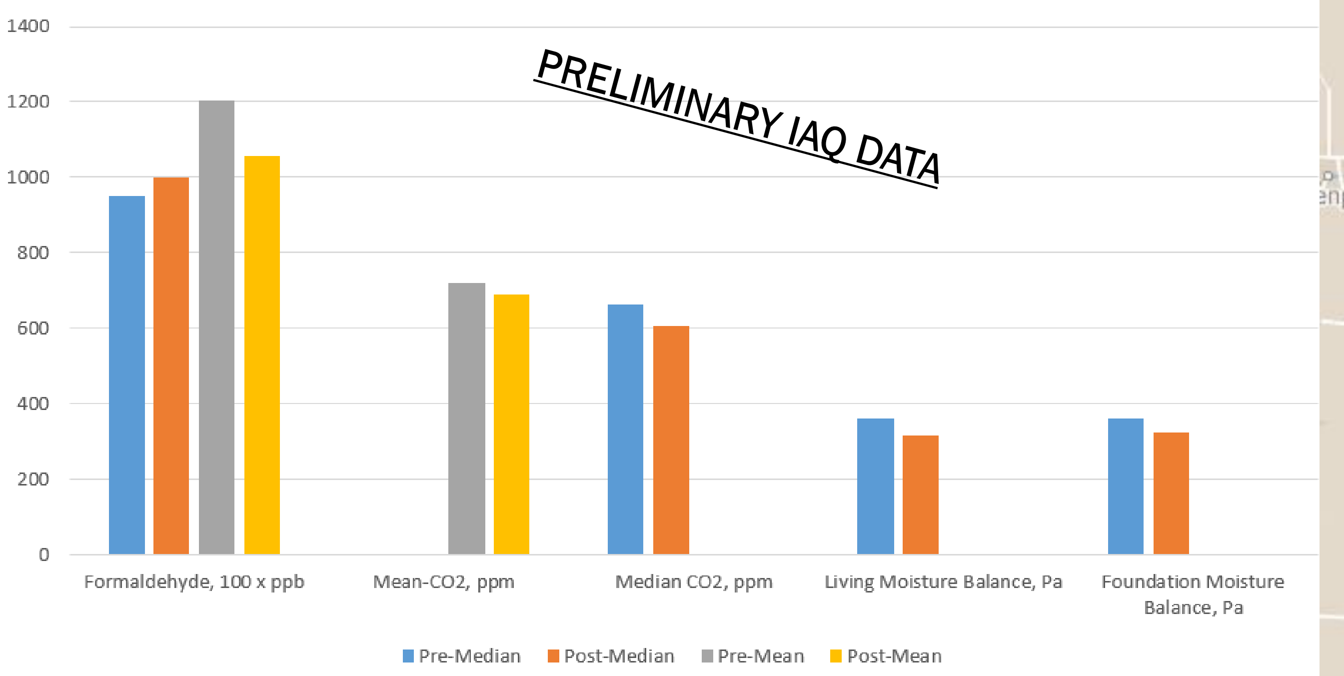
Partnership for Advanced Residential Retrofits
w/ University of Illinois
Midwest Energy Efficiency Alliance
National Center for Healthy Housing

Topic Area

Smarter Indoor Air Quality Solutions

DOE Building America
IAQ in tighter whole-home retrofits

- What happens to IAQ after better energy-efficient retrofits?
- Conducting field tests of 20 control homes and 20 treatment homes in cooperation with field practitioners
- Energy measurements and multiple IAQ measurements including CO_2, radon, formaldehyde, humidity
- Preliminary findings: IAQ is **not** adversely affected when a holistic approach, including ventilation, is used to manage airflows.



DOE Building America Research Sites Needed!

GTI Energy

Partnership for Advanced Residential Retrofits
w/ University of Illinois
Midwest Energy Efficiency Alliance
National Center for Healthy Housing

Topic Area

Smarter Indoor Air Quality Solutions

Success Metrics: : Provide guidance for improved IAQ coupled with energy savings.

What happens to IAQ after energy-efficient retrofits?

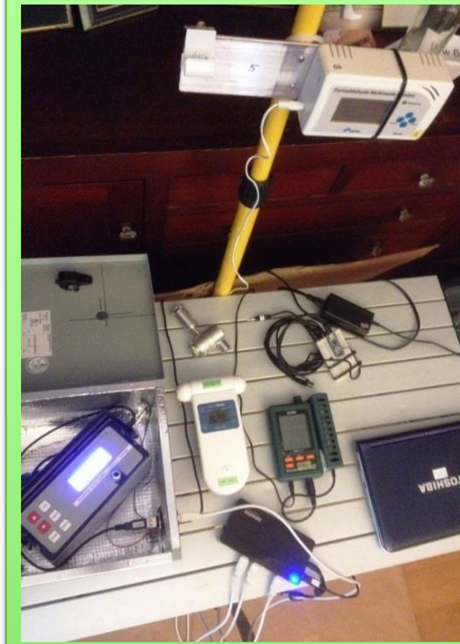
- We are taking energy measurements including blower door and duct leakage tests, and multiple IAQ measurements before/after retrofits.

Homes Wanted:

- Already planned energy improvements (research can not pay, sorry!)
- Single-family detached homes
- Unfinished basement
- Single forced-air heating system
- Non-smokers

Benefits: $Up to 1,500 incentive ($300 homeowner, $300 contractor, $900 for improvements), detailed home IAQ report, free ventilation system

Contact Kara Jonas if interested: **kjonas@mwalliance.org**



Residential Gas Heat Pump Water Heater

Absorption Cycle is comprised of:

- **Heat exchangers:** Absorber, Condenser, Desorber, Evaporator, Rectifier, RHX, and SHX
- **Solution pump**
- **Expansion:** EEV & WS Let Down

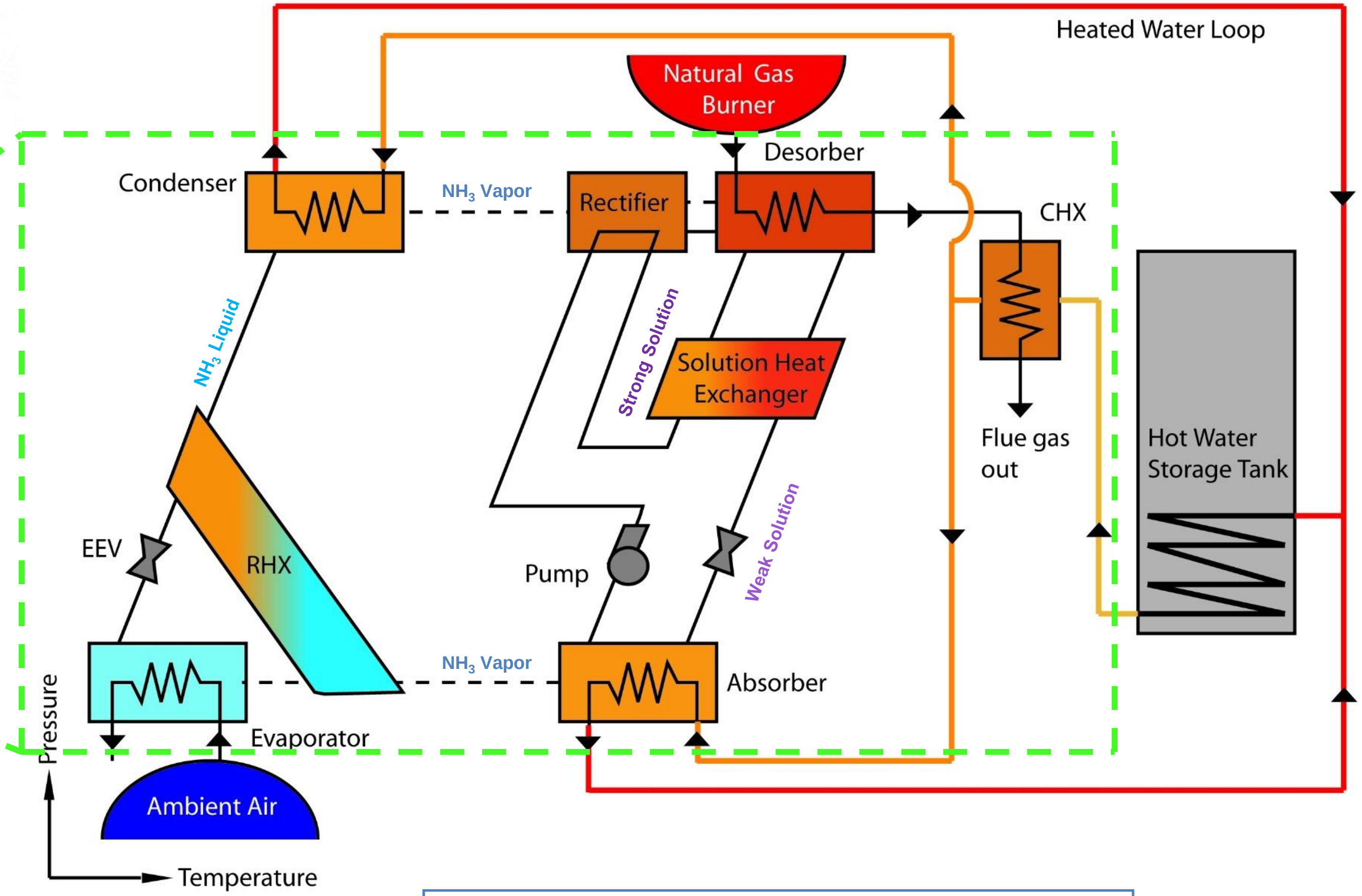
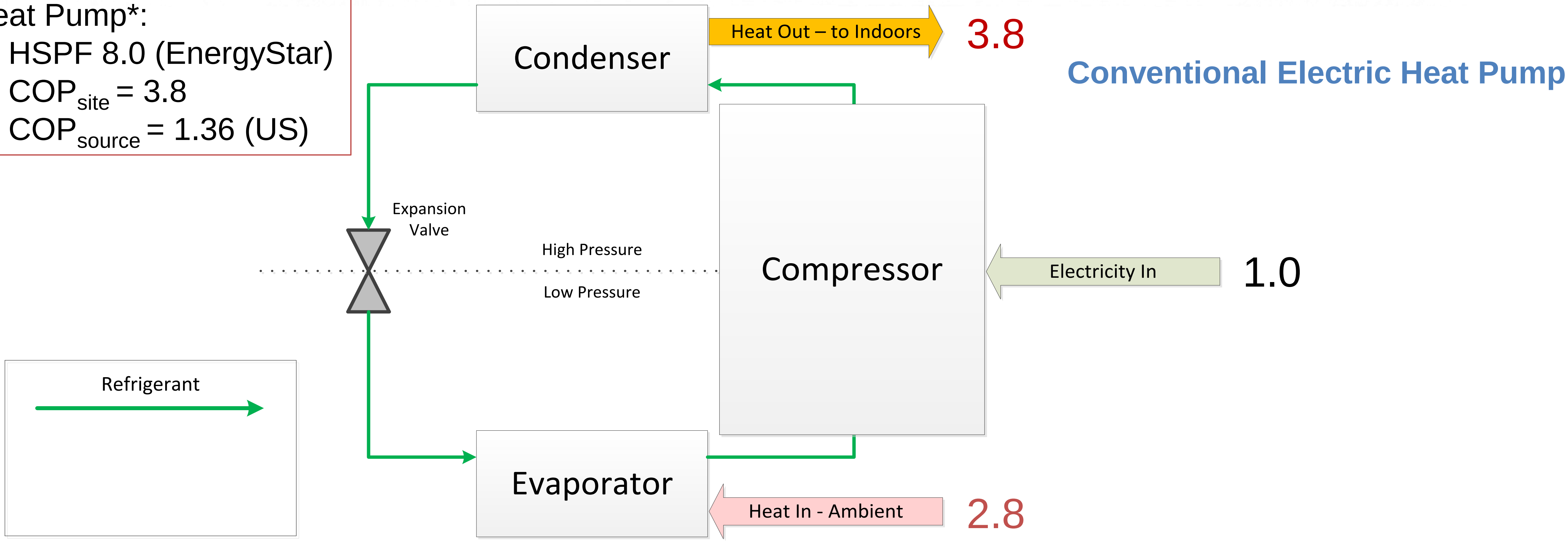


Diagram Courtesy of SMTI

Vapor Compression - Cycle

- Electric Heat Pumps (EHP) are based on the *vapor compression cycle*

Heat Pump*:
- HSPF 8.0 (EnergyStar)
- COP_{site} = 3.8
- COP_{source} = 1.36 (US)



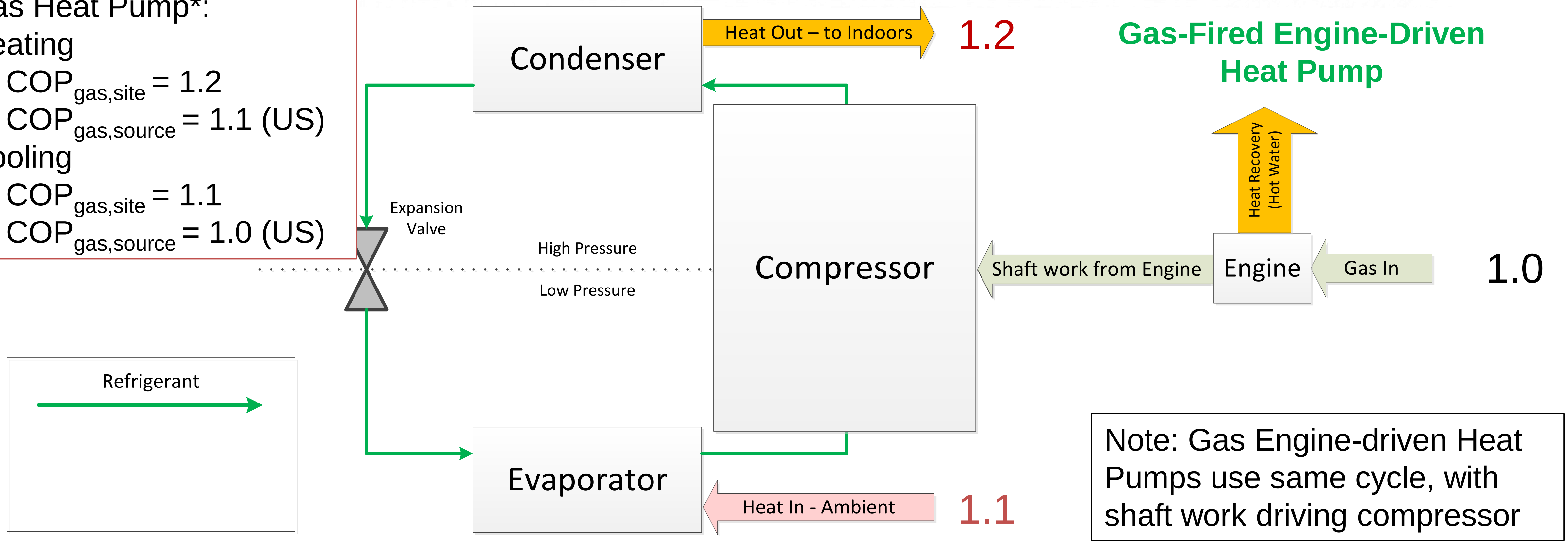
*Simplified estimates of energy flows are for a 47 F outdoor temperature. Site/source conversation factors are 1.09 for natural gas, 2.79 for electricity (US).

Vapor Compression - Cycle

- Gas Engine-driven Heat Pumps (GEHP) are also *vapor compression cycles*

Gas Heat Pump*:
Heating
- $COP_{gas,site}$ = 1.2
- $COP_{gas,source}$ = 1.1 (US)

Cooling
- $COP_{gas,site}$ = 1.1
- $COP_{gas,source}$ = 1.0 (US)



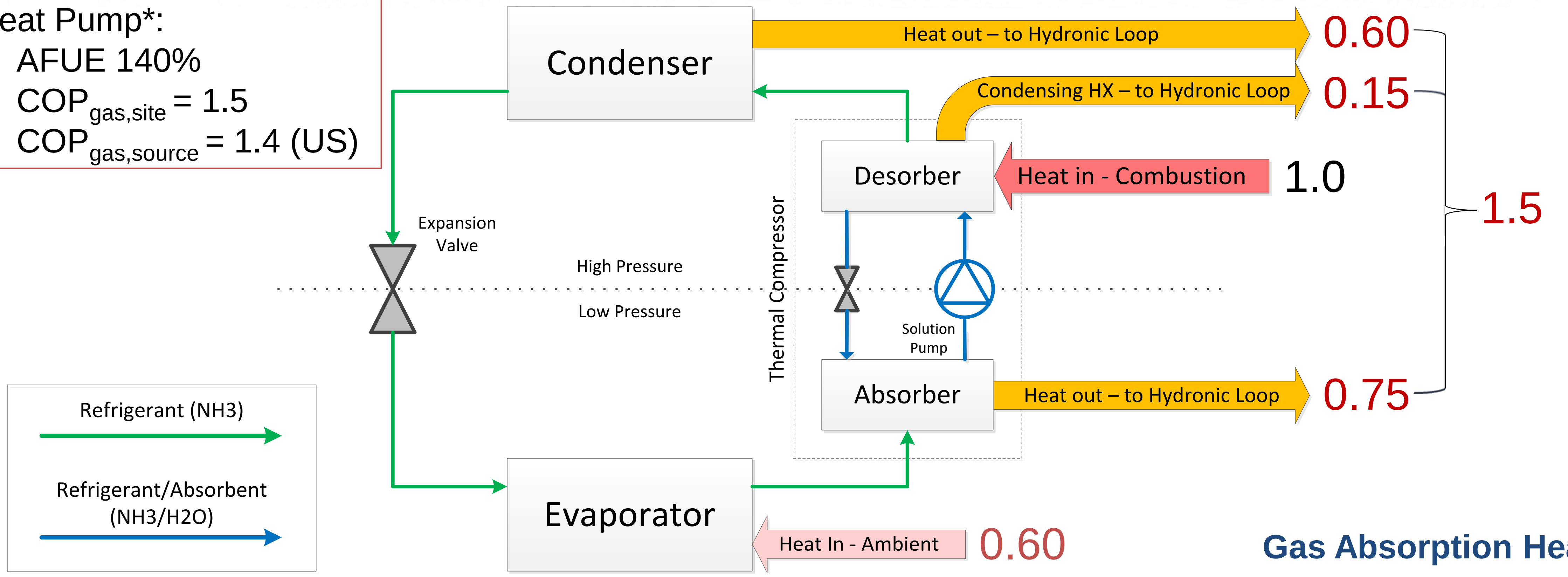
Note: Gas Engine-driven Heat Pumps use same cycle, with shaft work driving compressor

*Simplified estimates of energy flows are for a 47 F outdoor temperature. Site/source conversation factors are 1.09 for natural gas, 2.79 for electricity (US).

Vapor Absorption - Cycle

- Gas Absorption Heat Pumps (GAbHP) are based on the *vapor absorption cycle*

Heat Pump*:
- AFUE 140%
- $COP_{gas,site} = 1.5$
- $COP_{gas,source} = 1.4$ (US)



Gas Absorption Heat Pump

*Simplified estimates of energy flows are for a 47 F outdoor temperature. Site/source conversation factors are 1.09 for natural gas, 2.79 for electricity (US).