ETCC

WEBINAR SERIES

EMERGING TECHNOLOGIES COORDINATING COUNCIL

Integrated Gas-Fired Heat Pumps for Homes and Businesses:

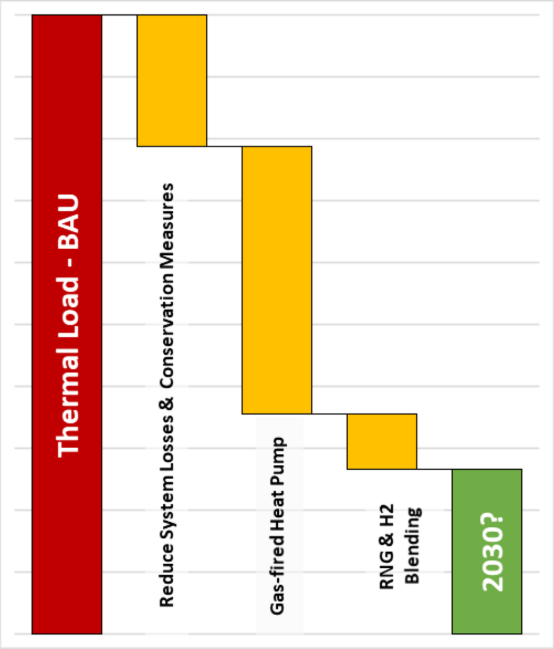
Results from Field Demonstrations and Modeling

Merry Sweeney and Paul Glanville
Project Manager and Principal Investigator
GTI

Introduction – Why Gas-fired Heat Pumps?

- GHPs offer >40% reduction in gas use over baseline
  - Studies indicate >1.20 UEF, >140% AFUE feasible*
  - Better retain capacity, efficiency in cold climates**
- No IAQ concerns, climate-friendly natural refrigerants, multi-function appliance w/ heat recovery
- Key piece in thermal load decarbonization puzzle:
  - Efficiency + next-generation technologies + low-carbon fuels = lots of progress toward GHG reduction goals

Reducing GHG Impact

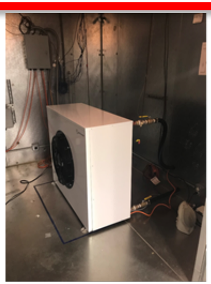
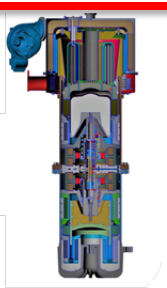


*Glanville, P. et al. *Integrated Gas-fired Heat Pump Water Heaters for Homes: Results of Field Demonstrations and System Modeling,* ASHRAE Transactions . 2020, Vol. 126 Issue 1, p325-332

** Glanville, P. et al. *Demonstration and Simulation of Gas Heat Pump-Driven Residential Combination Space and Water Heating System Performance,* ASHRAE Transactions . 2019, Vol. 125 Issue 1, p264-272

Taxonomy of GHPs – Technologies in Context

GHP

GHP Type	Installation Photos/Images (GTI)			Market Players
Vapor Compression				Aisin / Yanmar Blue Mountain Energy Tecogen Panasonic M-Trigen LG / Daikin / Samsung
Sorption				Robur Stone Mountain Tech. Vicot Ariston Fahrenheit Oxicool HeatAmp
Thermal Compression/ Thermoacoustic				Thermolift boostHEAT Etalim

Residential GHPWH Primary Project Goal

Support the commercialization and deployment of the GHPWH with a focus on the critical California residential water heating market, where approximately one million gas water heaters are sold each year.

CALIFORNIA ENERGY COMMISSION

SoCalGas

A Sempra Energy utility

gti

Objectives

- **Demonstrate 5 GHPWHs in single-family homes**, using datasets to estimate annual energy, cost, and emissions savings.
- Quantify efficiency, emissions, and reliability through performance and **extended life laboratory testing**.
- As a new product category, prepare stakeholders and code officials with information sharing, model development, and analysis.
- Assess and **evaluate market barriers** to entry in California by obtaining feedback from end users, installation contractors, and other stakeholders prior to commercial introduction.

Southern California Gas Company
ADM
FRONTIER energy
SMTI
GE APPLIANCES a Haier company
Rinnai
UTD. Utilization Technology Development
SCOTT HARRISON PLUMBING ORANGE COUNTY PLUMBING DONE RIGHT
APPLIED RESEARCH - WEST, INC. Los Angeles • Chicago • New York

Ripe for Market Transformation?

Low-efficiency Gas-Storage Dominates

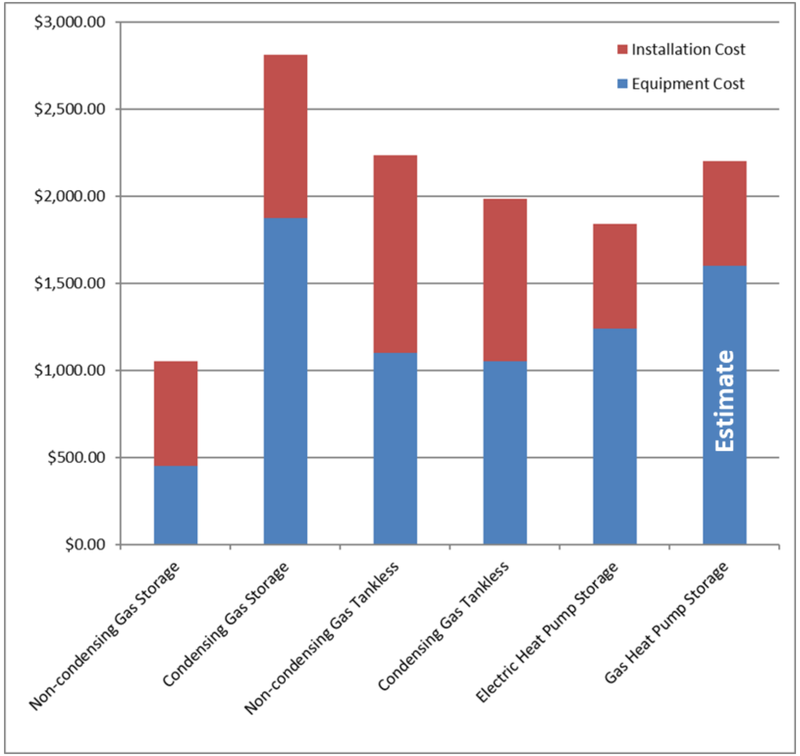
- In ¾ of homes, 95% by minimum efficiency units
- 82% of sales are emergency replacements

Value Proposition is Difficult:

- Homeowner only spends ~$250-$300/year on hot water
- Efficiency premium difficult
- Sales split distributors vs. retailers, how best to promote efficiency?

Reliability is Key:

- Need 10+ years of operation with no/low maintenance
- For retail sales, ½ are for DIY installs

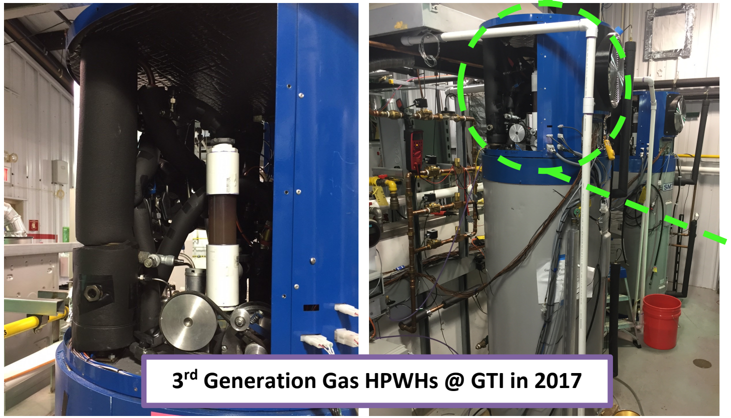


Data sources: EPA EnergyStar, Equipment/Installation costs based on average prices from www.supplyhouse.com and Technical Support Document from DOE NAECA III ruling

Technology – How it Works

Absorption Cycle is comprised of:

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



3rd Generation Gas HPWHs @ GTI in 2017

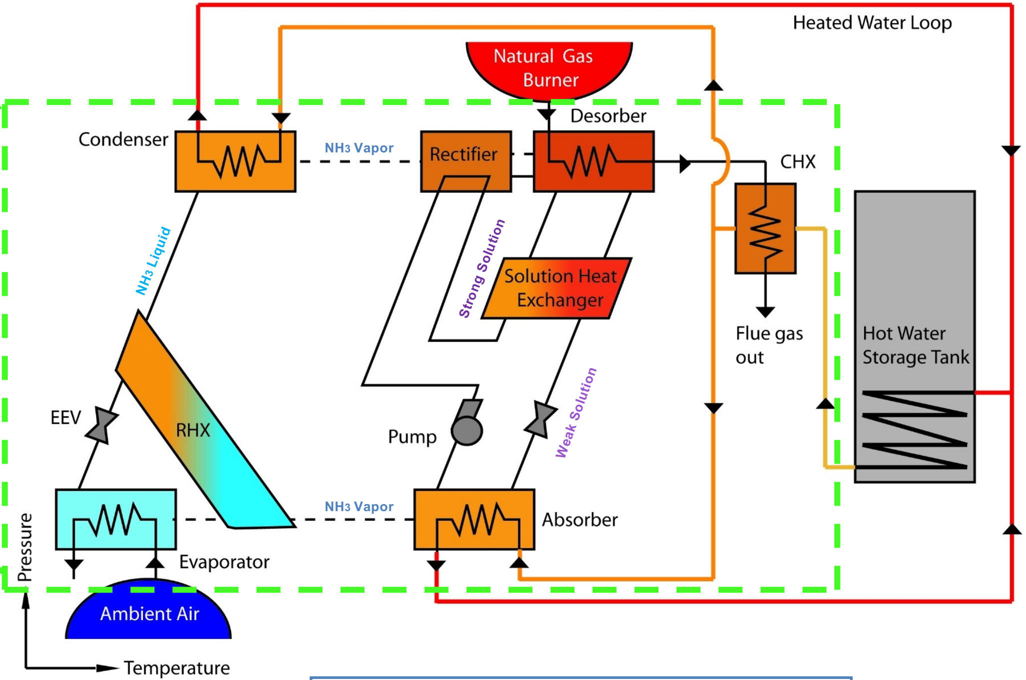


Diagram Courtesy of SMTI

Technology Description





	Gas HPWH (~30 built)	Low-Load GAbHP	Whole-House GAbHP (~20 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 (140 kBtu/h version too)
Firing Rate	6.5 kBtu/h input	15 kBtu/h input, 4:1 modulation	55 kBtu/h input, 4:1 modulation
Projected Efficiency	1.2 - 1.3 UEF	140% AFUE	140% AFUE
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 supplemental heat	160-280 W on 120 VAC	300-600 W on 120 VAC
Physical Size	60-80 gal. tank, 77” tall 24” dia.	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

Field Demo Approach

FVIR: GHPWH does not require > 18” stand / **NOx:** Units were Ultra Low NOx certified

Seismic Straps: Required in Los Angeles area / **Noise:** ~63 dB using NEEA procedure

Venting: Ready access to sidewall or vertical penetration at each site

Nuances of CA Installations vs. Prior Installs

<u>**Field Evaluation - Beyond Therms Saved**</u>

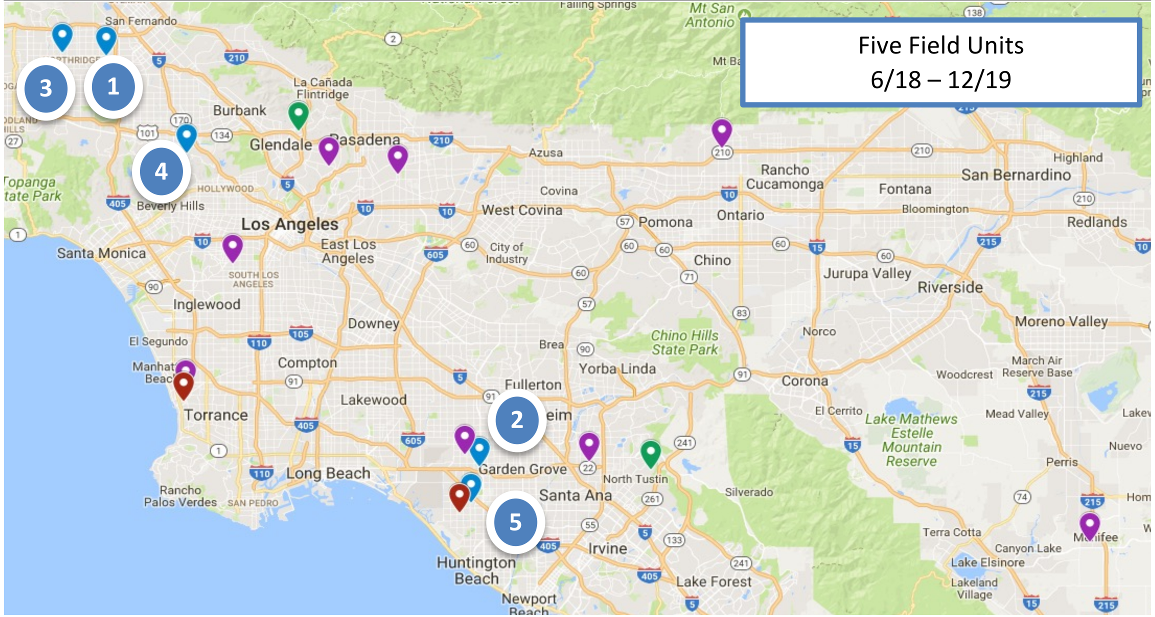
- Detailed performance characterization, **site-specific savings** of gas/electricity
- Assess **reliability issues**, identify pathways for predictive maintenance
- Normalize energy/emission savings based on local (weather, home-type) and behavioral conditions to **general case**
- Impact of **installation barriers**, retrofit ease, plumber experience
  - Spin-off effort to utilize or dispose of condensate w/o drain [pat. pending]
- Quantify **host comfort**, “running out of hot water”, opportunities for innovative controls and judicious suppl. heating

Field and Lab Evaluation

One Lab Unit @ SoCal Gas

Photo of SCG Testing (Courtesy: SoCal Gas)

Blue = Confirmed Sites 1-5; **Green** = Backup Sites; **Red** = Late Withdrawals; **Purple** = Screened Out



Five Field Units
6/18 – 12/19

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Field and Lab Evaluation

Site	Existing Equipment (All Storage-type)	Site Characteristics (All Single-Family Homes, Garage Installation)
1	40 kBtu/h input, 40 gal., 0.62 EF	City = LA; Occupants = Four (39, 36, 6, 3)
2	40 kBtu/h input, 40 gal., 0.62 EF	City = Stanton; Occupants = Four (30, 30, 3, 1)
3	40 kBtu/h input, 40 gal., 0.54 EF (est.)	City = LA; Occupants = Four (60, 57, 25, 20)
4	40 kBtu/h input, 50 gal., 0.62 EF	City = LA; Occupants = Four (60, 49, 19, 14)
5	36 kBtu/h input, 40 gal., 0.67 EF (PowerVent)	City = Huntington Beach; Occupants = Two-Three (65, 61, 27)





During 12+ mo. GHPWH Phase

20,870 gallons DHW Delivered

4,650 hours operation

2,230 GHPWH Cycles

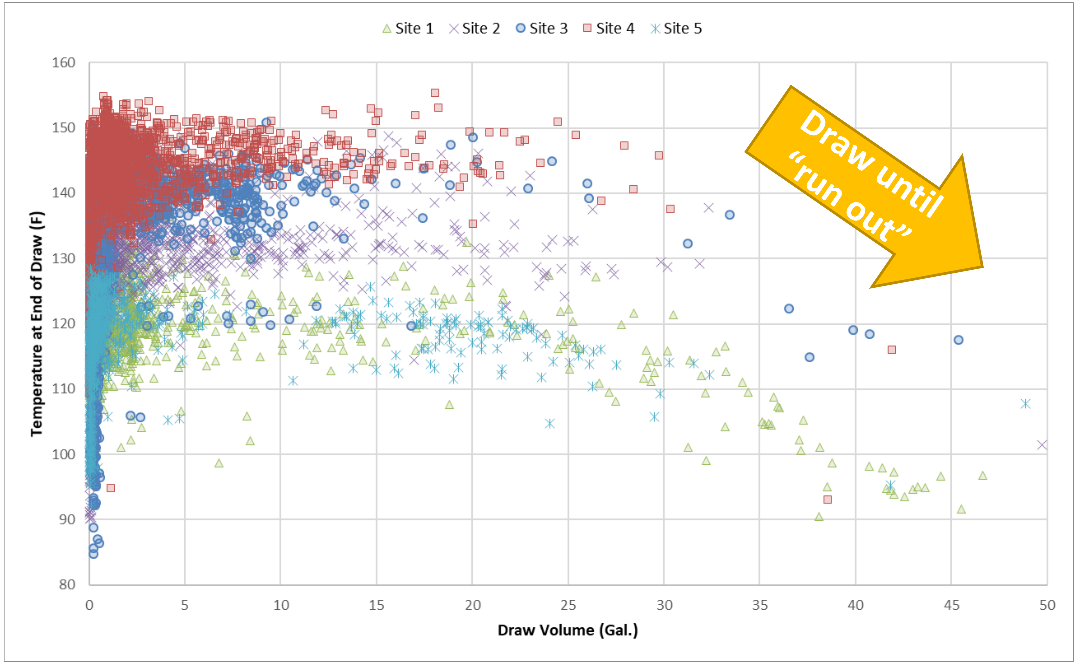
217.5 gal/day maximum draw

67 F avg. temp. rise

Baseline Results

- Concern was projecting GHPWH capacity limitations
- Large discrepancy between average and peak consumption
- Some sites (#1, #3) appear accustomed to “running out” of DHW

Site	Avg. Gal/day	Peak Gal/day
1	58.6	116.0
2	56.9	124.8
3	50.3	112.3
4	55.1	163.0
5	35.6	117.7



All results presented are preliminary pending publication of the final CEC report

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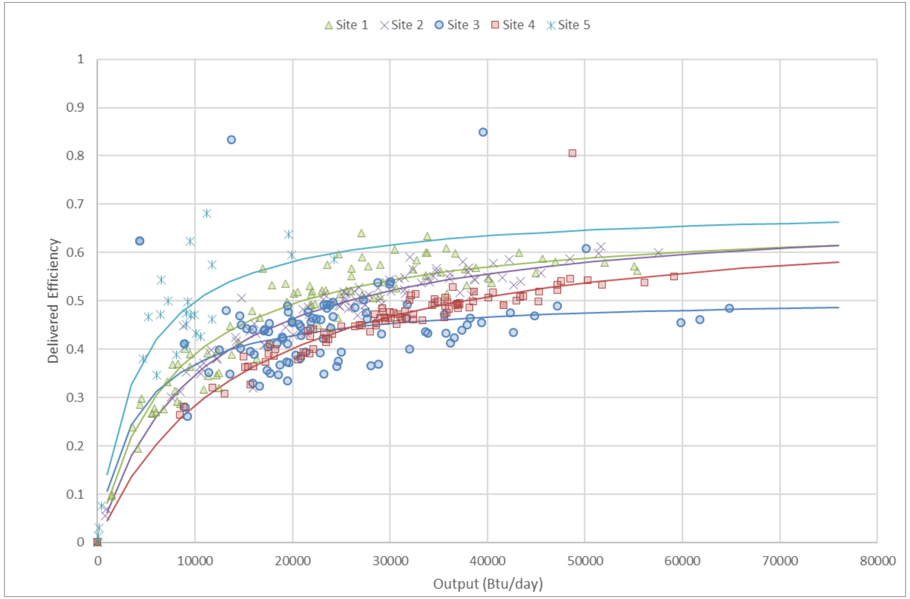
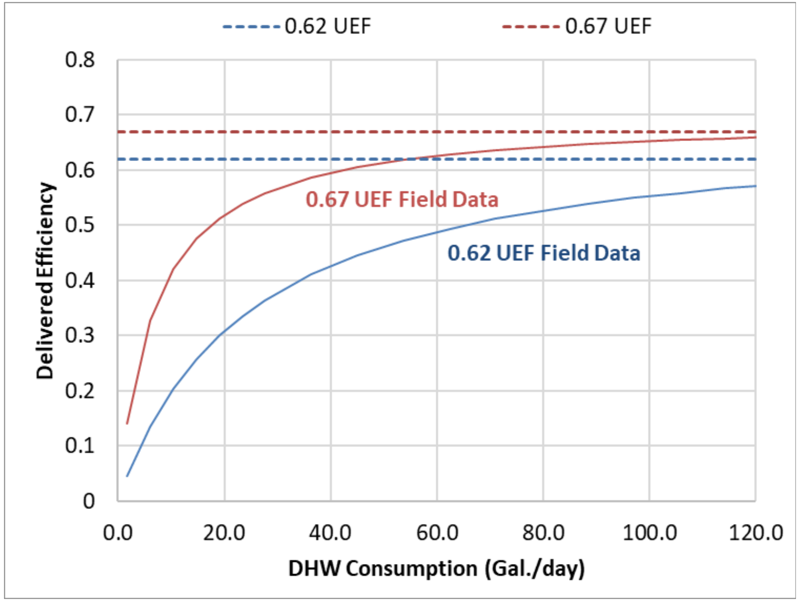
Baseline Results

$$Input = m \cdot Output + b;$$

$$\frac{Output}{Input} = Del.\ Eff. = \left(m + \frac{b}{Output}\right)^{-1}$$

- Established the *Delivered Efficiency* of original water heaters as function of demand





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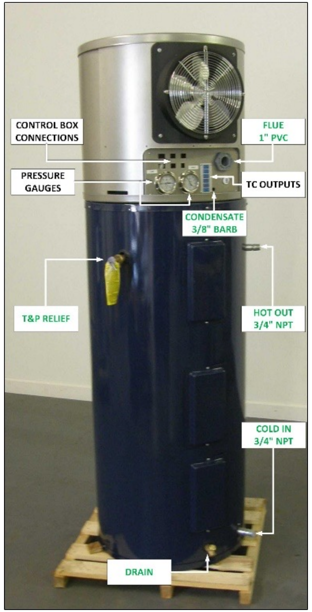
GHPWH Results – Installations



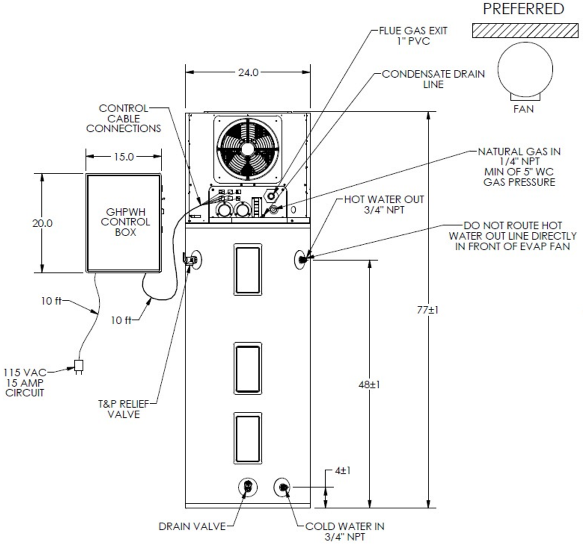
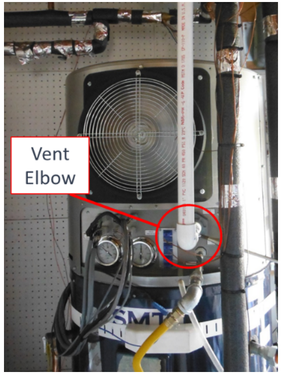


Image Source: SMTI



Items Resolved/Noted During Pilots

Installations:

- Blocked vent/drainage issue at Site #1
- Site #3 electrical service insufficient, element disabled
- System losses led to higher T_del setting at Site #4

GHPWH Units:

- Leak due to shipment @ submerged HX resolved for Site #4 and Lab GHPWH
- Solution pump issue identified, addressed with all GHPWH units
- Internal HXs have been redesigned to avoid issues with vapor lock & ΔP

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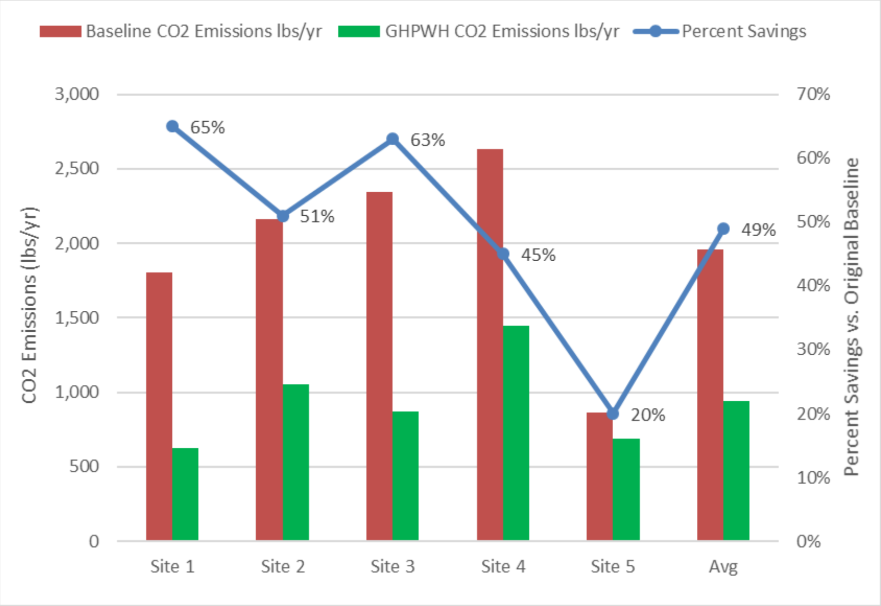
GHPWH Results – Energy & Emissions

- All show savings, though variation:
  - Site #3 has low EF baseline
  - Site #5 has power vent baseline

Site #	GHPWH Gas Use (therms/yr.)	GHPWH Electric Use (kWh/yr.)	Percent Site Savings
1	44	299	67%
2	77	433	53%
3	65	325	64%
4	103	664	47%
5	50	299	23%
Avg	**68**	**404**	**54%**



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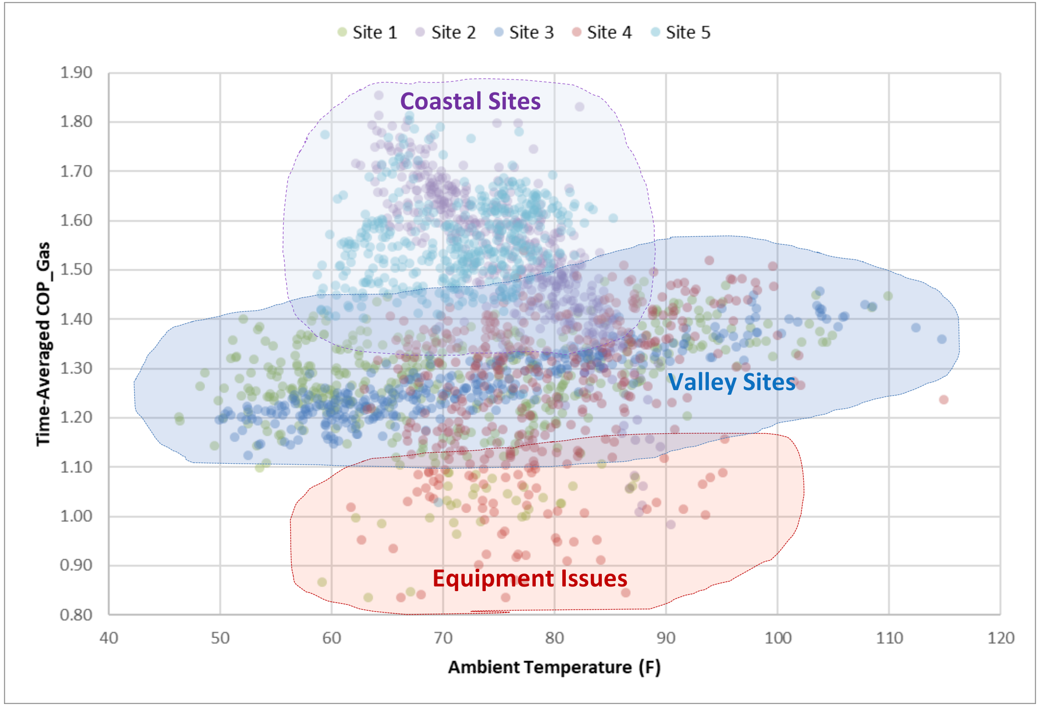
GHPWH Results - Efficiency

Cycle COPs:

- Sites #1 and #3 lower than expected COPs, but consistent with ambient
- Sites #2 and #5 show higher performance in milder climate
  - Inverse relationship at #2 due to decreasing firing rate over time
- **<u>Heavily dependent on internal TCs</u>**
- Site #4 scatter in colder conditions due to timing of replacement

Time Averaged COP_{Gas}



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Market Impact Assessment

- **Qualitative step**:
  - 27 in-depth interviews with plumbing, HVAC, and/or home energy improvement contractors.
  - 4 focus groups in CA, with 40 participants.
- **Quantitative step**:
  - Two nationwide surveys, one targeting contractors (500+ responses) and one homeowners (1,000+ responses).

Opportunities
- TWH install cost high, GHPWH could be 'middle priced' alternative
- Energy savings are big
- Need to lead with total cost of ownership (leasing?)

Threats/Weaknesses
- Units are large, no space-saving benefit
- Shouldn't compete directly with TWHs
- Slow recovery time

Primary Strengths
- Lowest TCO if 10+ year warranty is standard
- Well-known brand names critical
- Competitive replacement cost with Power Vent

Secondary Strengths
- Install price between storage/TWHs, could draw those who don't pay "tankless premium"
- Environmental benefits
- Rebates could accelerate sales

Market Research – Key Findings

- Majority of contractors thought they could sell this new product and the initial cost would be the primary obstacle for consumer acceptance.
- Approximately 1/3 of single-family households with gas or propane were likely to be prime customers for GHPWHs. That audience is predominately:
  - College educated
  - 46-64 years old
  - Earns $75,000+
  - Has 3 or more members in their household
  - Lives in the suburbs
  - Plans to remain in the home for more than 10 years
- **Target audience is more likely to purchase a GHPWH over the standard tank <u>provided</u> the purchase price difference is $1,000 or less.**

Conclusions

- 6 pre-commercial GHPWHs commissioned at 5 homes and a research laboratory
  - SCAQMD Ultra Low NOx certification
  - Average yearly gas savings 54% (110 therms) compared to baseline
  - Average yearly gas savings 57% compared to 2nd high efficiency baseline
- Key accomplishments:
  - In-field operations 12+ months
  - 20,870+ gallons of hot water
  - Median time averaged cycle efficiency of COP_{gas} 1.25-1.60
  - 80% of surveyed participants indicated they never ran out of hot water
  - Lab testing confirms feasibility of achieving 1.20 UEF target

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Future Research Needs

- Improve reliability of GHPWH units
  - Design changes necessary to avoid damages related to shipment. Drop and other vibration testing assured during production, this should be addressed.
  - Large variation in performance between sites, partially explained by site and usage variations, but also variance in prototyping quality.
- Rigorous installation requirements
  - Potential site challenges regarding venting (proper sloping, issues with long runs), electrical service, and space requirements. Cementing technician commissioning procedure would improve this.
- DHW capacity concerns
  - Further product development needed to address supplemental heating, predictive/learning controls, and customer interaction to prevent loss of hot water.

Milestones & Targets

- Multi-sponsor effort
- Targeting 56 sites across 5 regions
- California essential market
- Field demonstration targeted 2022

North American GHPWH Demonstration Collaborative

Project Objectives

Demonstrate commitment to GHWPH commercialization and launch

Evaluate product readiness across various climates and housing stocks with emphasis on reliability, efficacy, efficiency, installation experience, customer satisfaction and manufacturer/technology developer business capabilities

Support program development with savings, cost, and installation information needed to quickly develop and deploy programs upon product launch

Support timely product launch by communicating in situ performance information to manufacturer with a goal of product launch by 2023

Prime the market by providing hands-on experience to local distribution and installation companies

Characterize GHPWH's performance to generate performance curves/modules for rating software, standard metrics, and provide technical support towards certification.

SoCalGas A Sempra Energy utility

spire

ENBRIDGE

Nicor Gas

BRIO

FORTIS BC

Research Foundation

neea

gti

Rinnai

CenterPoint Energy

Integrated GHP in Restaurants Primary Goal

Evaluate and demonstrate an innovative technology at two restaurant sites, the low-cost gas heat pump (GHP) for integrated commercial hot water and air-conditioning.

Project Objectives

- **Assess the energy, water, and operating cost savings** of a novel integrated gas heat pump system through a technology demonstration, providing hot water and space cooling to two restaurants in the Los Angeles Basin.
- **Expand results through modeling and simulation** from these restaurants to other restaurant types and sizes, light commercial businesses, California climate zones, and system configurations to determine total market impact potential of the technology.
- As a novel integrated system, **prepare stakeholders and code officials** with information sharing, model development, and analysis.
- **Understand barriers to market entry** through outreach with stakeholder surveys and obtain feedback from industry workshops.

Commercial Hot Water – Ripe for Transformation

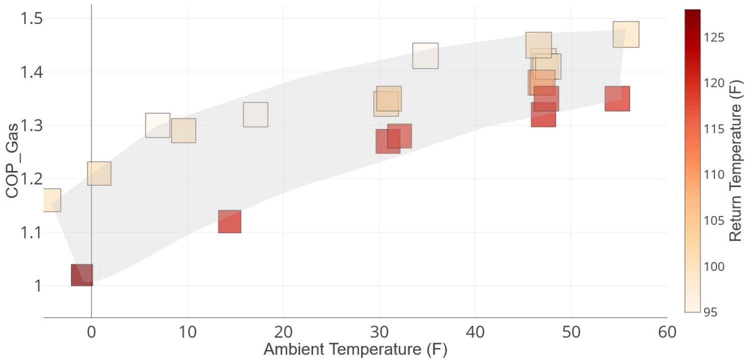
- Service hot water (SHW) remains an important efficiency target in multifamily (MF) and restaurants*
  - 1st gas load in MF (50%), 2nd in restaurants (23%)
  - In CA, restaurants use > 340 million therms/yr**
- Typically boiler + IST (dedicated/zone) or storage-type
  - Racked tankless products evaluated in parallel GTI demos
  - Industry push to >90% eff., >2X over '09-'19 to ~50%***
- Beyond condensing, leverage innovations in thermal heat pumps (THPs)
  - Air/water-to-water THPs available, more under development****
  - Retrofit-ready, raise net eff. > 100% of SHW system
  - Optional 'free cooling'

*Delagah, A. and Fisher, D. (2013) Energy Efficiency Potential of Gas-Fired Commercial Water Heating Equipment in Foodservice Facilities, Report prepared by FNI for the CEC, CEC-500-2013-050.
**Data Source: EIA RECS (2015), DNV Kema, "California Energy Commission Energy Efficient Natural Gas Use in Buildings Roadmap", public presentation (2013).
***Data Source: AO Smith (2020) / ****GTI & Brio *Gas Heat Pump Technology and Market Roadmap* (2019)

Technology Description

Absorption Cycle is comprised of:

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



140% AFUE for HVAC Applications per GTI Testing*

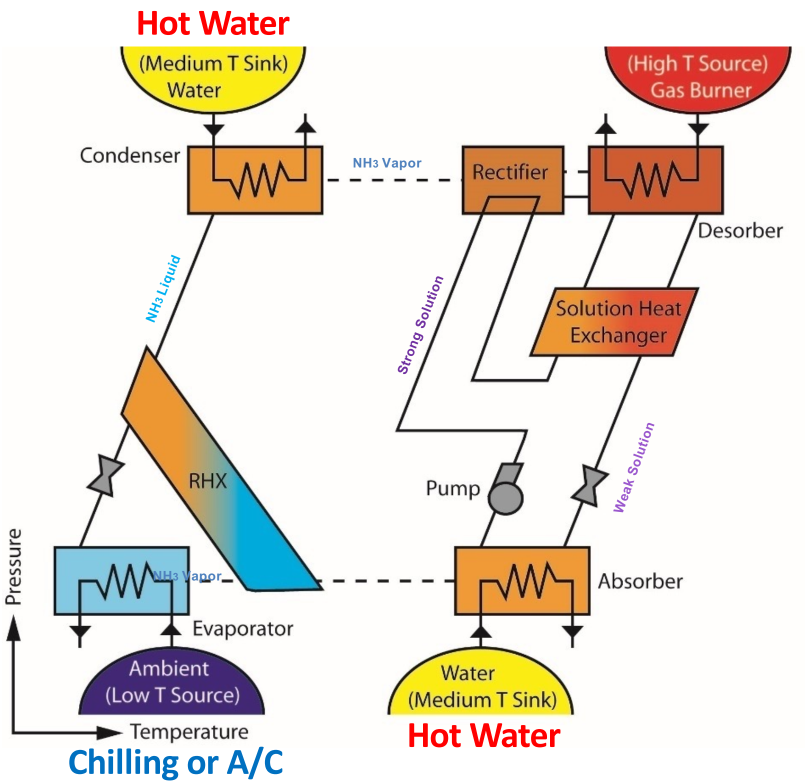


Diagram Courtesy of SMTI

* Glanville, P., Suchorabski, D., Keinath, C., & 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.

Technology Description

SMTI





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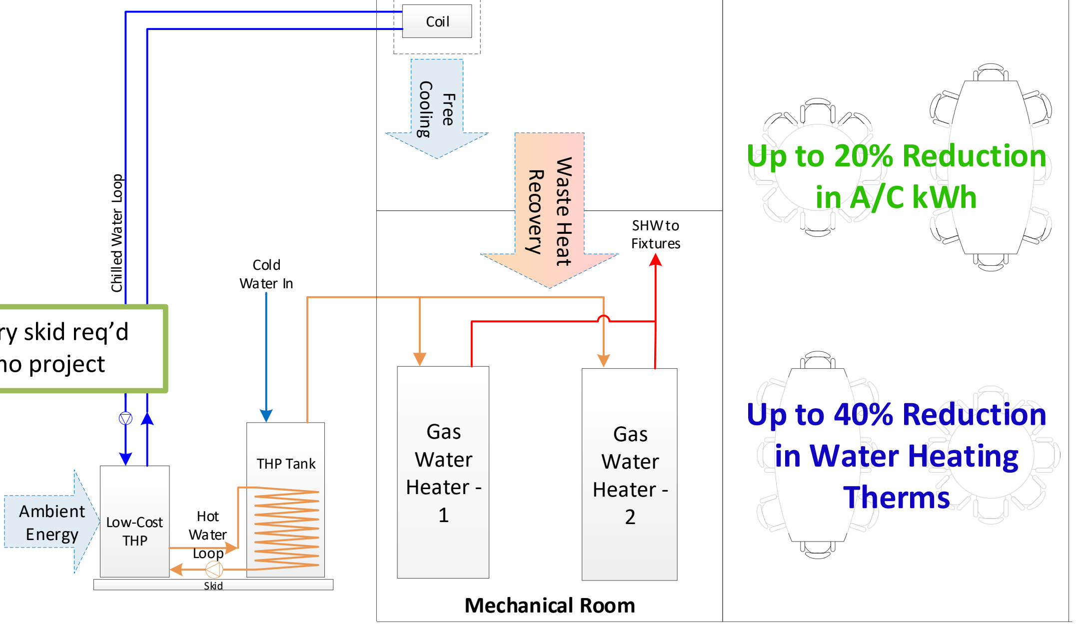
Integrated GHP System Design



Integrated GHP System Design

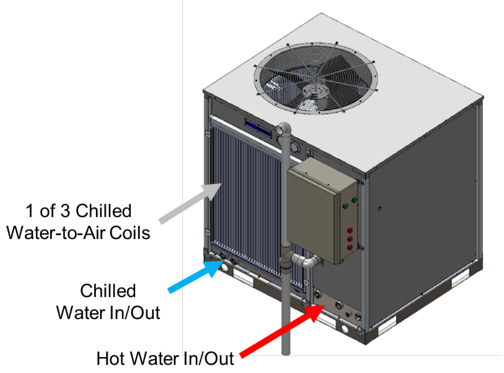
"Skidding" the GHP System

- Factory assembled, plumbed
- 80 kBtu/hr GAHP with chilled water-to-air coils replacing ref.-to-air evaporator coil
- 113-gallon indirect storage tank
- Skid dimensions:

  48" x 96" x 74" (W x L x H)
- Outdoor installation, ease of install/removal

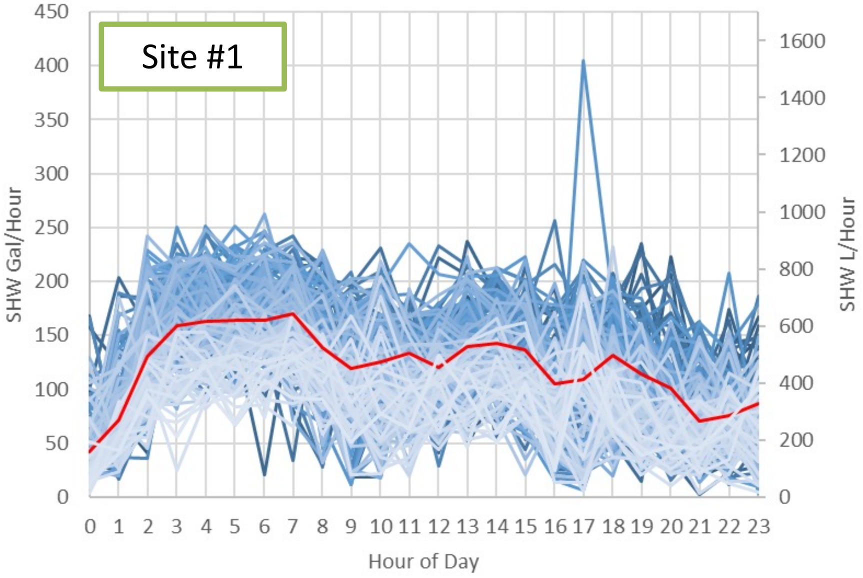
Indoors/Balance of System

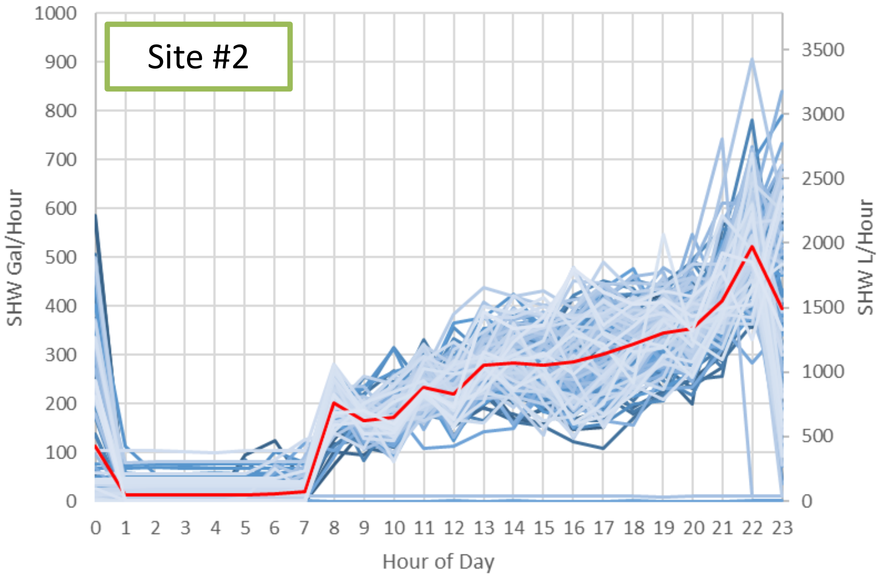
- Chilled Water Fan Coil, water heaters, controls



Baseline Data Collection (Over 7 mo.)

	Average SHW: Gal/day	Peak SHW: Gal/day	Peak SHW: GPM	SHW Inputs: Therms/kWh	Delivered Est. SHW Efficiency	Annual A/C Demand: MWh
Site #1: 24-hr Diner	2,722	3,736	11.9	8,300 / 716	70.0%	79.0
Site #2: FSR	4,821	6,995	19.7	13,100 / 966	79.1%	71.0





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Integrated GHP System - Installation

Siting:

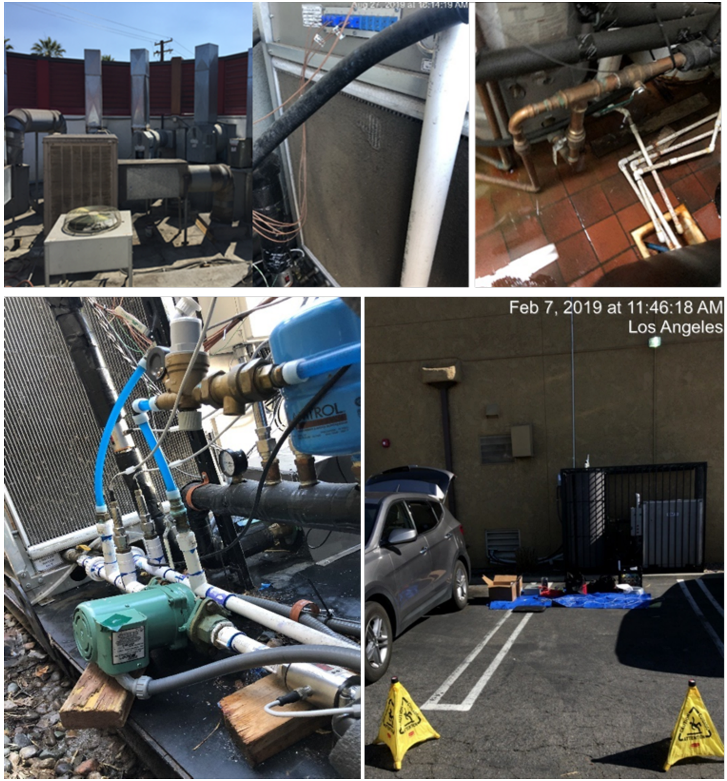
- Neither site met req's on spacing for THP, evaporator coil was closer than recommended to adjacent wall
- Indoor FCU was in suboptimal location at both sites, concerns of existing MEP in drop ceiling dictated placement
  - OTS FCU performance sub-par, high ΔP, had internal damage

Closed Loops

- Air removal challenging (ChW loops), after commissioning & servicing.
- ChW pumps undersized for fittings & instrumentation, below target flow rate for both sites – mainly Site #2

Calibration

- Calibration applied to critical hydronic loop temperatures (sup/rtn X 2)



Integrated GHP System - Operation

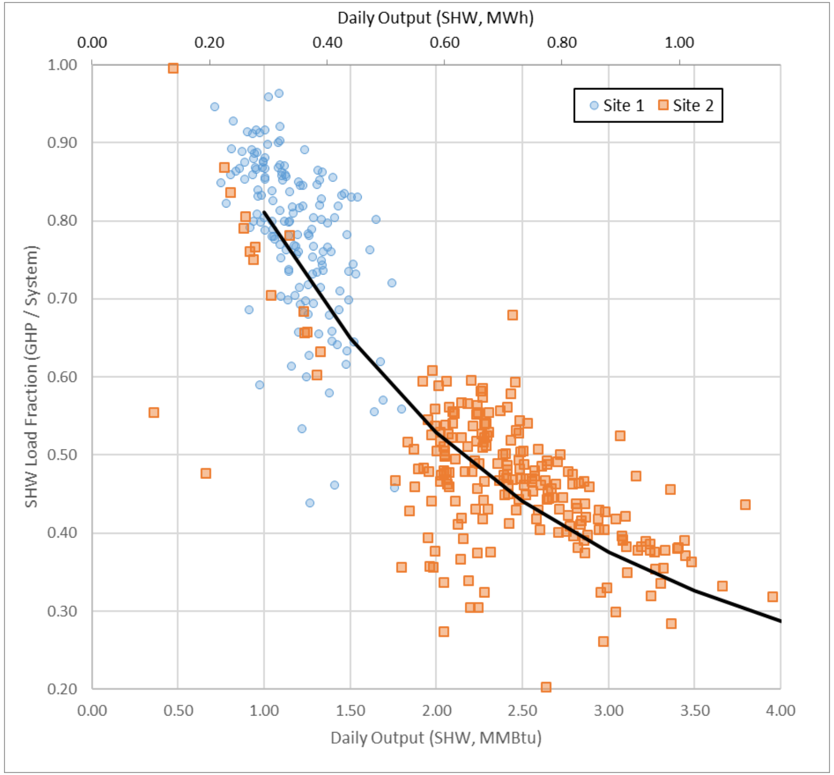
Near constant GHP operation over 12 months

- Calls for cooling observed year-round

Wide range of conditions observed

- Outdoors 35°F-111°F / THP return 100°F-125°F

	Site #1: 24 h Diner	Site #2: FSR
THP Cycles	1157	597
THP Hours	4792	4224
Average COP_{Gas} SHW (SHW + A/C)	1.10 – 1.30 (1.30 – 1.70)	1.25 – 1.45 (1.40 – 1.90)
Average SHW Gal/day	2,226	4,396
Avg. T Rise °F	66.1	70.7
Average THP Load Fraction	73.7%	43.2%



Integrated GHP System - Efficiency

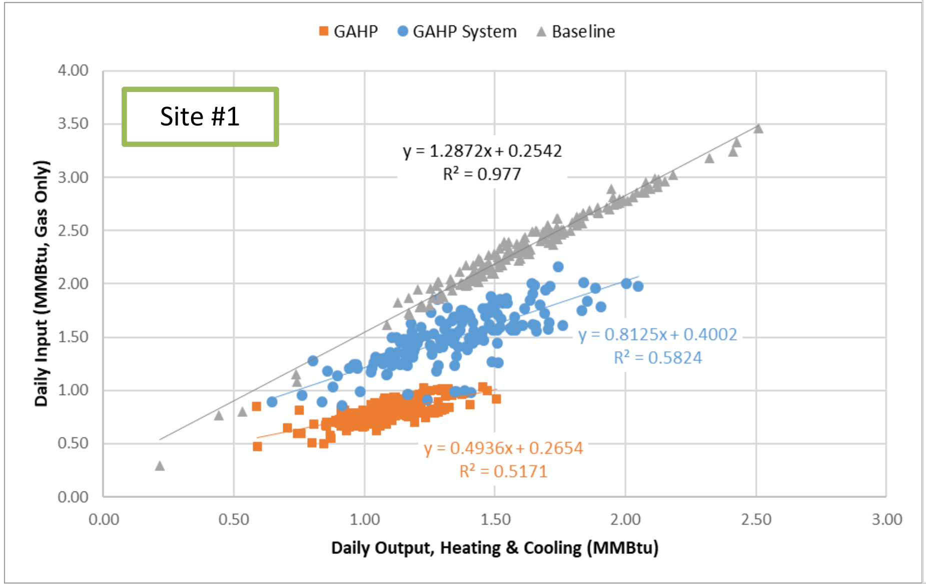
“Input/Output” approach used (Site #1 Highlighted)

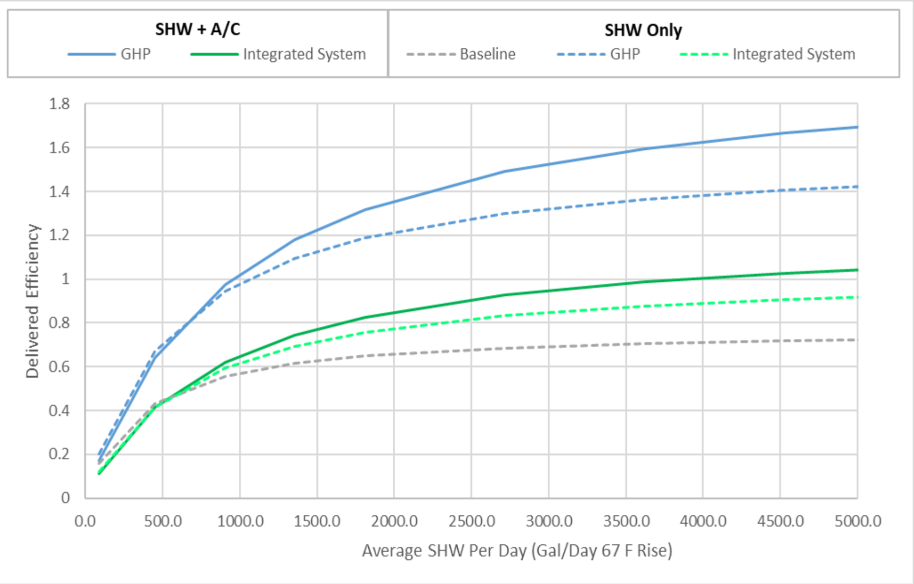
- Site #1 therm savings = 16% (system); 52% (GHP only)
- Site #2 therm savings = 26% (system); 53% (GHP only)

$$Input = m \cdot Output + b;$$
$$\frac{Output}{Input} = DEF = \left(m + \frac{b}{Output}\right)^{-1}$$

For Site #2, typical demand translates to COP of 1.65 (GHP), 1.10 (Overall System), and 0.75 (Baseline)

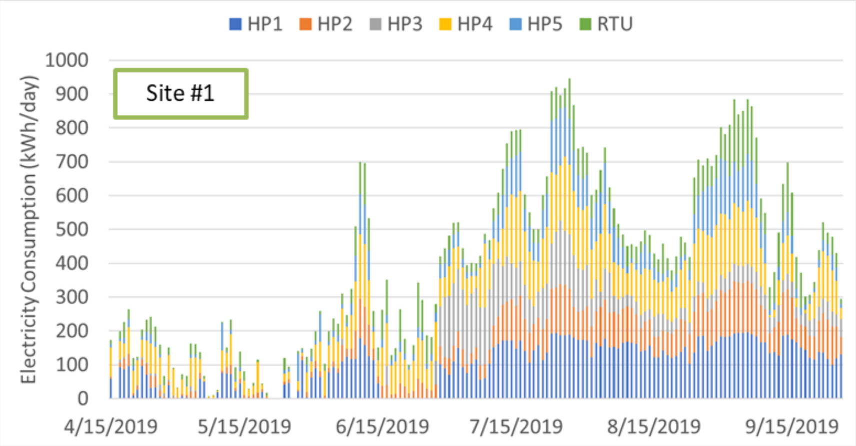
Note: 2.0 MMBtu/day output ≈ 3,500 gal/day

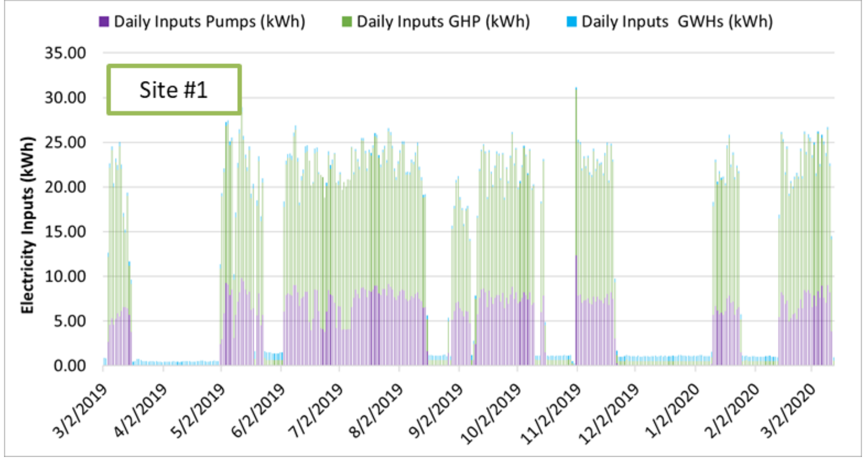




System Power Demand

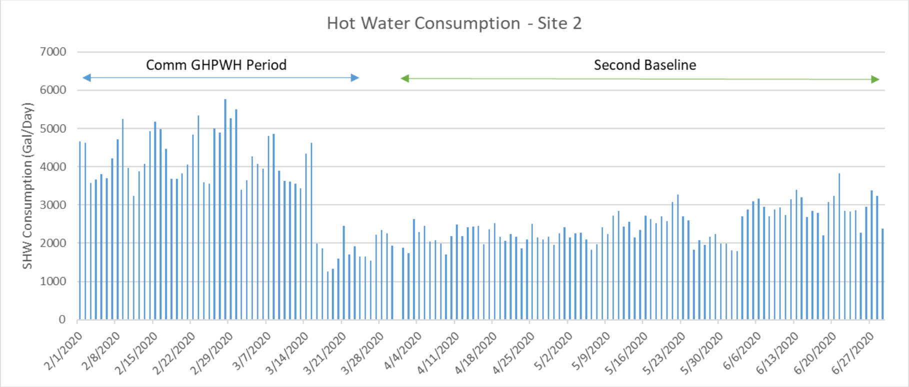
- GHP power 10-15 kWh/day
- Gas water heaters (small contribution)
- Pumps important (≈ 50% GHP*), FCU ≈ 550 W
  - Higher ΔP led to low flow (lower A/C perf.) and higher power draw
- For supplemental A/C, ~5,500 ton-hrs delivered across sites (at coil)
- Weather-adjusted reduction in annualized monitored HVAC
  - Savings at Site #1 = 10,820 kWh; Site #2 = 9,660 kWh
  - 13.7% and 13.6% respectively





Integrated GHP System – Economics

- Large impact of GHP sizing
  - As-is, payback is attractive for high-usage Site #2
- Net elec. increase assumes all cooling is useful
- Assumes $0.91/therm; $0.15/kWh
  - GHG - 1,178.7 lb/MWh elec.; 144.2 lb/MMbtu gas
- Assessment was based on pre-COVID demand



	Site #1 24 h Diner	Site #2 FSR
Average SHW Gal/day (Avg. T Rise °F)	2,226 (66.1)	4,396 (70.7)
Average GHP Load Fraction	73.7%	43.2%
Fuel Savings – System As-Is	16%	26%
Fuel Savings – GHP Right-size	52%	53%
Net Power Demand (kWh/day)	8.3	6.9
Operating Cost Savings – Gas (Net)	$967 ($617)	$2,775 ($2,527)
Simple Payback – Fuel Basis	2.0 – 6.4	1.1 – 2.2
GHG Reduction – GHP Right-size Lbs/yr (%)	44,610 (46%)	82,330 (48%)

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Market Research – Needs Vary, Except Efficiency

Restaurants

Price, dependability, efficiency of hot water is most important due to demand for hot water and tight margins

*“**Nobody wants to touch it until it's broken**. But when you understand that you can take a proactive stance, and you're getting the **benefit of technology and cost efficiency, then to me, it makes perfect sense**”*
Emad, Restaurants; Secaucus, New Jersey

Apartments/Senior Living

Energy efficiency, life expectancy, and warranty is the most important – followed by brand/reputation

*“Of course, we're looking at life expectancy, but also energy efficiency. And **if it's going to pay for itself through energy efficiency, then we'll go ahead and make that investment** on the front end”*
Randy, Senior Living; Fort Worth, Texas

Laundromats

Reliability, efficiency, and ability to support their business (multiple washers / dryers) is the most important – a bonus is anything that would help keep customers indoors

*“Well, I know **first thing I'm looking for is reliability** you know, I'm trying to get the most useful life out of it. Because these are an investment. So you're trying to get your maximum return on investment.”*
Eric, Laundromats; Fullerton, California

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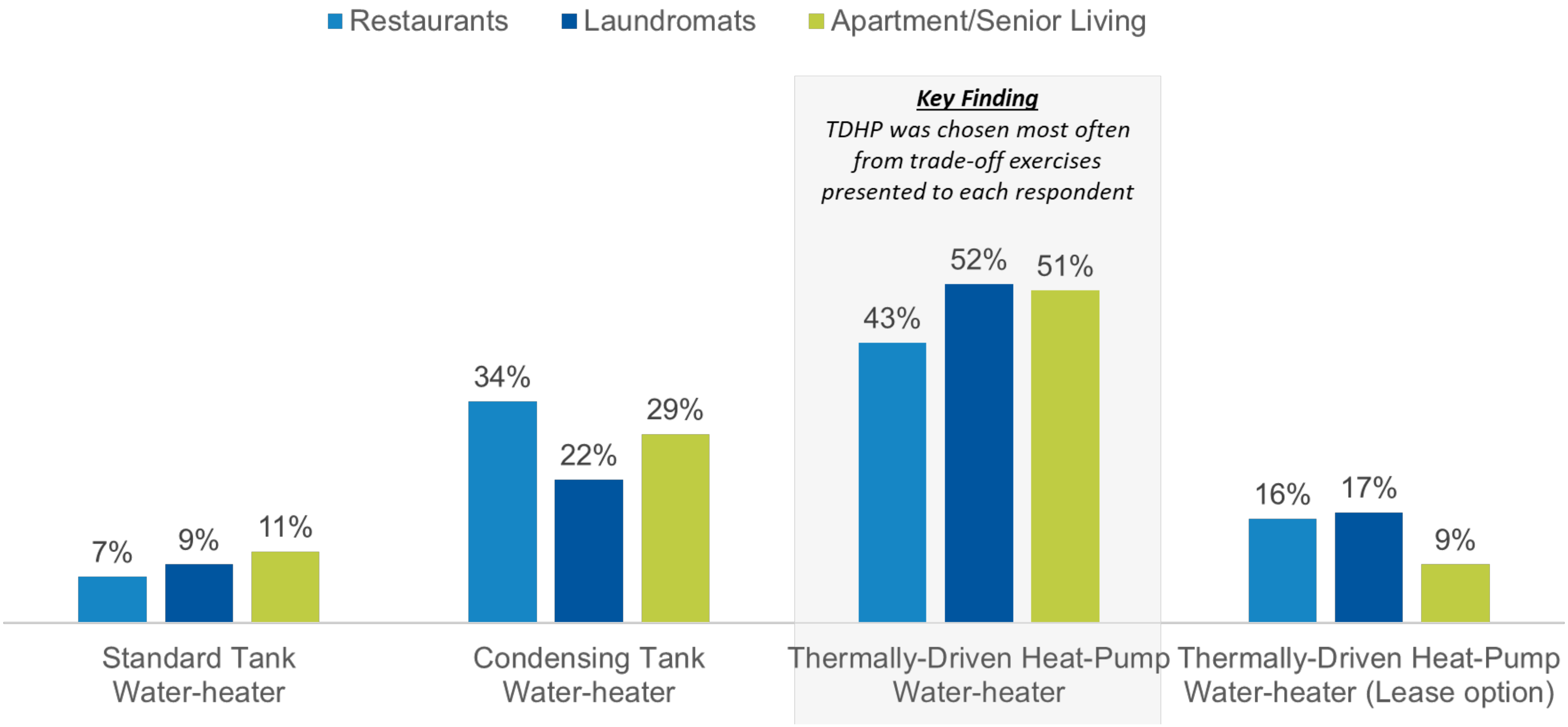
Market Research – Preference in Trade-offs



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Integrated GHP System – Key Results

- Baseline indicated that both sites were **good candidates** for *Integrated GHP System,* significant usage
  - Operating 500+ days at the host sites, **9,000+ operational hours**
  - Staff at both restaurants provided positive feedback about the system, indicating it performed well and one characterized the cooling functionality as "quite amazing"
- GHP installation and operation was hands-on, challenging due to multiple factors & **installation barriers**
- Data show clear gas savings of GHP System/GHP (26%/53%) and displaced electricity (14% kWh savings)
- Operating cost savings of up to $2,500, line-of-sight to **<2.0 year simple payback,** GHG savings of up to 82,000 lbs/yr (57%)

Key Results and Noted Challenges (cont.)

- Market assessment validated that stakeholders in foodservice, laundries, and multifamily/senior living value GHP's higher efficiency and **lower lifecycle costs**.
- Successful demonstration of integrated A/C option with **first-of-its kind GHP package** - generating more than 1.4 million gallons of hot water and providing more than 5,490 ton-hours of supplemental cooling simultaneously.
- Greatest challenges to the integrated GHP system is how best to address **site-specific installation complexities** to currently typical equipment.
- Highlighted the challenges with system controls while **identifying a 30%-60% "sweet spot" for GHP sizing** relative to the estimated peak load.
  - Surprisingly, covered a wide operational envelope, with GHP covering 30% to 95% of load on avg.

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