COMMERCIAL GAS HEAT PUMPS FOR HOT WATER AND A/C

DEMONSTRATION IN RESTAURANT APPLICATIONS

Technical Summary of CEC PIR-16-001

PROJECT OVERVIEW

- **Technology Demonstration:** Monitor performance of prototype fuel-fired heat pump water heaters (HPWHs) at two restaurants in the Los Angeles basin.
- **Market Transformation:** Develop stakeholder-facing literature, code analysis, and simulation tools. Quantify product barriers through market research and outreach.
- **Project Team:** GTI (Lead), SMTI, A.O. Smith, ADM Associates, Frontier Energy, ARW Inc., JC Mechanical Inc., BR Laboratories.

KEY FINDINGS

- **Energy Efficiency:** HPWHs achieved 52%-53% therm savings and with "free cooling" an added 14% kWh savings for building A/C measured.
- **Operating Cost:** Projected savings of >$2,500/year, < 2.0 year simple payback estimated. On sizing GHP, 30%-60% of peak demand is optimal range.
- **Emissions:** Up to 48% GHG reduction projected, with pre-commercial HPWHs certified as Ultra Low NO_x and using natural refrigerant with no ozone or climate impact (ODP = GWP = 0).
- **Reliability:** Over 12 mo. period, 9,000+ GHP operating hours for both sites, with HPWHs frequently operating 24/7, meeting 3,000+ gal/day demand.
- **Barriers:** Complex retrofits at both sites requires innovation in installation approaches, but no major barriers per code analysis or market research.

THE TECHNOLOGY

In this project, the team demonstrated the potential of an innovative technology at two restaurant sites in the Los Angeles basin, a low-cost gas-fired heat pump (GHP) for integrated commercial water heating and air-conditioning (A/C). The GHP is a direct-fired, single-effect, absorption heat pump using an ammonia/water working pair, with an operating heating Coefficient of Performance (COP) of 1.40-1.90 (fuel HHV basis). In prior laboratory testing and field applications for space heating, it has an estimated Annual Fuel Utilization Efficiency of >140% and is anticipated to have an equipment cost approximately half that of comparable GHP equipment[1]. To offset A/C energy consumption, this GHP was modified to deliver hot water and supplemental A/C, sized to provide 80 kBtu/h of hot water and 2.5 tons of cooling simultaneously, with 4:1 modulation. This GHP is designed by a startup company specializing in gas-fired heat pumps, Stone Mountain Technologies, Inc. (SMTI), with technical support from GTI and A.O. Smith.

At each site, the GHP was installed as an *Integrated GHP System*, with the GHP component providing hot water in series with indoor conventional storage-type water heaters, while supplementing building A/C in parallel to existing rooftop HVAC equipment. While standard installations place only the GHP outdoors (rooftop or concrete pad), for this project the GHP was coupled with its buffer tank and the associated controls and instrumentation on a removable skid with added anti-vandalism caging. This "skidding" approach was convenient due to the temporary nature of this project but is not common practice.

Figure 1: Commercial Gas Heat Pump Skid Package Installed at Host Site

MARKET OPPORTUNITY

There's a lot of recent innovation in the residential water heating industry, with tankless, heat pump, and grid-connected technologies flourishing. Receiving less attention, innovations in commercial-sized equipment are emerging too, where commercial buildings a) consume 10-100x the hot water as a typical home and b) are commonly served by multiple heaters as a system. For gas-fired commercial water heaters, which represent the majority of the non-"residential-duty" commercial water heating market, approximately 77% of shipments are storage type, 14% are boilers coupled with indirect storage tanks (IST), and 9% are tankless type[2].

As a population, commercial water heaters are efficient. From 2009-19, high-efficiency commercial gas-fired water heaters (thermal efficiency ≥ 90%) have increased from 29% of shipments to 47%, a shift not seen for residential products[3]. As a result, stakeholders are looking to heat pumps for the next step beyond 'condensing efficiency'. For electric options in 2019, a manufacturer introduced a commercial integrated electric HPWH, with a rated COP of 4.2 (site basis) and a heat pump output capacity of 40 kBtu/h. For fuel-fired options, serving larger loads, several active demonstrations of heat pump systems have been performed, in schools, senior care facilities, hospitality, and other commercial buildings, in Oregon, Michigan, British Columbia, and Ontario[4]. These studies commonly involve one or multiple GHPs with an output capacity of 124 kBtu/h each and show therm savings vs. baseline equipment ranging from 18% to 50%, when serving commercial water heating loads[5,6].

This project focused on **the restaurant industry** which as a market sector consumes the most natural gas per square foot, with water heating representing the second highest thermal load after cooking. In California over 340 million therms are consumed for hot water in ~90,000 restaurants, representing more natural gas use than a million homes[7]. With an estimated efficiency of 140%, deployment of gas-fired HPWHs could yield therm savings of >40%[1] in restaurants, while displacing up to 20% of electricity demand for A/C, further enhancing energy and operating cost reductions. This potential was assessed in a year-long demonstration of pre-commercial GHP systems at two restaurants in the Los Angeles basin, summarizing system design and optimization, energy savings over a broad range of operating conditions, retrofit installation barriers, and interactive effects with building systems.

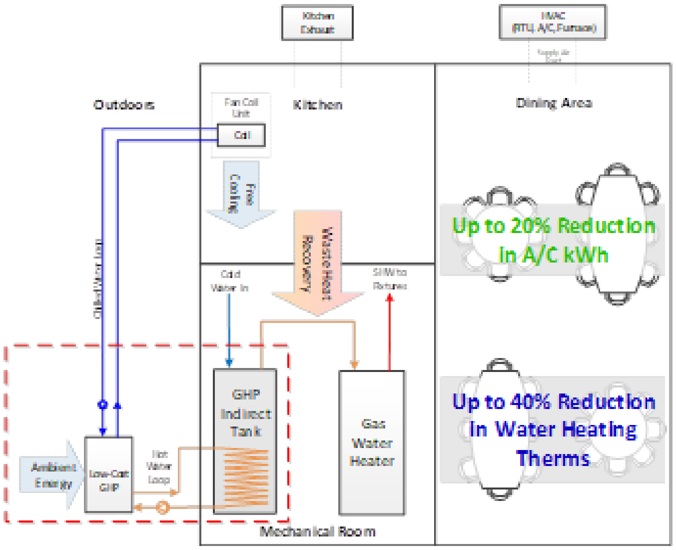

Figure 2: Simplified Diagram of Integrated GHP System

DEMONSTRATION RESULTS

With support from utility and manufacturing partners two restaurant sites were recruited, a national casual dining chain specializing in Italian-American cuisine and a regional Southern California 24/7 diner chain. After an extended monitoring period of existing water heating and HVAC equipment and certifying the GHP as *Ultra Low NOx* per the Air Quality Management District (AQMD) in late 2018, the team finalized the installation and commissioning plans. From late January to late February 2019, the project team completed the *Integrated GHP System* and data collection system commissioning, initiating the 12-month monitoring period.

Per the monitoring plan, 9,000+ hours of GHP operation with high hot water demand was measured at both sites, often exceeding 3,000 gallons/day. Measurements included the thermal output of the GHP unit, the indoor water heaters, rooftop HVAC, and other system components. Upon de-commissioning of the *Integrated GHP System* in March 2020 for both sites, high-efficiency "condensing" storage-type water heaters were installed for a "second baseline period". However, the impact of COVID-19 on normal restaurant operations limited the utility of this added dataset.

GHP system operation was marked by near constant operation, commonly for several days at a time for Site #1 (24-hr diner). Similarly, calls for cooling were observed throughout the monitoring period, both in winter and summer.

Table 1: GHP Operation Summary at Both Restaurant Sites

Location	GHP Operation	COP_{SHW} [$COP_{SHW+A/C}$]	Avg. SHW Load Fraction
Site #1: 24-Hr Diner	4,790 hrs. 1,150 cycles	1.10-1.30 [1.30-1.70]	74%
Site #2: Casual Dining	4,220 hrs. 600 cycles	1.25-1.45 [1.40-1.90]	43%

As shown in Table 1, the significant *Integrated GHP System* runtime provided an ample dataset, with operational COPs shown[A] for service hot water-only (SHW) and service hot water plus space cooling (SHW+A/C) modes, over the range of return water (100-125°F) and ambient temperatures measured (35-111°F). The *SHW load fraction* as shown is defined as the fraction of SHW generated by the GHP vs. the overall *Integrated GHP System*. This varies across sites, due to a) differences in daily demand – 2,225 gal/day (Site #1) vs. 4,400 gal/day (Site #2) and b) the demand profile, with Site #1 spreading SHW demand over a 24-hour period while Site #2 has a ramp to an evening peak followed by little demand overnight. As the GHP system at Site #1 is covering the majority of the SHW load most days (74% load fraction), the GHP is nearly always on and modulating in a "load following" mode. This satisfies demand, but the GHP does not often reach a steady state efficiency, reflected in slightly reduced COPs. By contrast Site #2 is more commonly cycling on/off and operating more efficiently at full capacity when on.

To compare measured baseline data to the *Integrated GHP System,* the linearized "Input/Output" method is used[9] and delivered efficiency curves are generated for the GHP itself and the overall *Integrated GHP System*, for SHW and SHW+A/C modes (see Figure 3). On the rooftop HVAC monitoring during this period, the weather-normalized analysis showed a reduction of 14% at both sites, saving a projected 10-11 MWh/year.

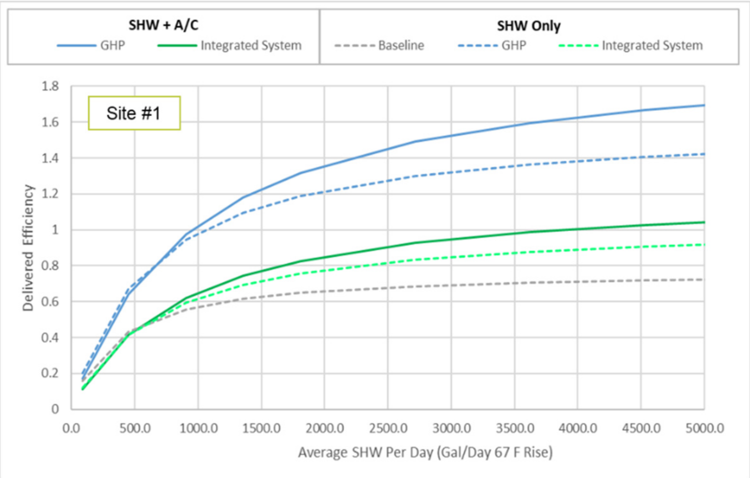

Figure 3: Delivered Efficiency Curves from Site #1 Dataset

INTEGRATED SYSTEM DESIGN

The ***Integrated GHP System*** has three primary components (see Figure 2): the outdoor **GHP** heats a hot water loop and cools a chilled water loop, the hot water loop delivers service hot water (SHW) from an **indirect storage tank (IST)**, and the chilled water loop delivers A/C from a **fan coil unit (FCU)**. In practice, the IST is used as a) a buffer between the SHW demand and GHP operation to prevent short-cycling and b) meeting the required "double-wall" HX requirement for potable water. The indoor FCU can be in-duct or separate, allowing installation flexibility. By using with pumped water loops for heating/cooling, the refrigerant is wholly contained within the GHP device outdoors.

On **system controls**, the *Integrated GHP System* was sized and controlled to be *hot water-led*, with the GHP only cycling on to meet a SHW demand. If when delivering SHW there is also a demand for A/C at the indoor cooling coil, the GHP will direct chilled water to this coil. Absent A/C demand, the GHP will use the outdoor-coupled HX within its cabinet, drawing ambient energy outdoors instead of to the indoor FCU.

On **GHP sizing**, the GHP is not sized to meet 100% of the peak demand, which a) can vary by factors of two or greater from day-to-day and b) large portions of a restaurant's 2,000+ gal/day can occur within a few hours (e.g., kitchen clean-up)[7]. So it is most cost-effective for the GHP to act as "baseload" SHW generation while conventional water heater(s) carry "peak" demand. Balance is key, as GHP under-sizing limits overall savings while GHP over-sizing causes inefficient part-load operation.

On **supplemental cooling,** the team assumed that the 0.5-2.2 tons of cooling are useful in all instances (range depends on modulation) due to internal kitchen heat gain. This is based on prior studies of thermal comfort in commercial kitchens, in which cooking staff were equally uncomfortable during winter and summer months[8]. Also, supplemental A/C is an optional system feature, hot water-only versions use air-source versions of the GHP.

When extrapolating results and including the net power savings (the difference of avoided A/C power consumption versus incremental power consumption from the GHP, pumps, and fans), both sites show attractive economics. Using typical California utility rates, $0.91/therm and $0.15/kWh (ignoring time-of-use or demand charges), the team estimated the following:

- **Energy Consumption**: Therm savings at both sites were 16%-26% for the *Integrated GHP System* and 52%-53% for the heat pump itself. The daily net electricity increase for both sites (as-is) is 7-8 kWh.
- **Operating Cost**: Therm savings translate to $970-$2,780/year, or $620-$2,530 when including elec.
- **Simple Payback**: Using mature quantity production estimates of GHP and other standard equipment costs, simple paybacks for the *Integrated GHP System* range from 1.1 to 6.4 years (fuel savings basis).
- **Climate Impact**: Net greenhouse gas reductions are 46-48% using 2018 CA-statewide emission factors.

BARRIERS & OPPORTUNITIES

Through additional project tasks and stakeholder outreach, the team also outlined that:

- Through **market research**, contractors and owner/operators in food-service, laundries, and multifamily (incl. senior living) cited higher energy efficiency and lower lifetime operating costs as compelling features.
- In documenting **installation and commissioning challenges**, the team outlined how best to address *Integrated GHP System* site-specific complexities in retrofit and new construction scenarios. Concerns with codes & standards were also reviewed in detail.
- Through **system modeling**, the team highlighted the challenges with system controls while identifying a 30%-60% "sweet spot" for GHP sizing relative to the estimated peak SHW load. The demo surprisingly covered a wide operational envelope, with the GHP covering 30%-95% of the daily load on average.

FOR MORE DETAIL

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Full project report and other deliverables to the California Energy Commission are expected to be posted online in early 2021 here: https://www.energy.ca.gov/energy-rd-reports-n-publications

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[A] On a high heating value (HHV) basis.