Evaluation of Emerging Water Heating Technologies

Project Number ET22SWG0002

Prepared by ICF for submission to Southern California Gas Company

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Abbreviations and Acronyms

Name	Abbreviation
Air Pollution Control District	APCD
Air Quality Management District	AQMD
Cost Effectiveness Tool	CET
Database for Energy Efficiency Resources	DEER
DEER Water Heater Calculator	DWHC
Disadvantaged Community	DAC
Domestic Hot Water	DHW
Domestic Hot Water	DHW
Emerging Technology	ET
Energy Efficiency	EE
Hard to Reach	HTR
Heating Hot Water	HHW
Net to Gross	NTG
Program Administrator	PA
South Coast Air Quality Management District	SCAQMD
Total Resource Cost	TRC
Total System Benefits	TSB
Water Heating Technology Table	WHTT
Zero Net Energy	ZNE

Executive Summary

This emerging technology (ET) study project is aimed to research emerging gas-fired water heating technologies to provide actionable recommendations of technologies and gaps for further study by the Statewide Gas Emerging Technologies (GET) program. Typical gas water heaters, gas furnaces, and gas boilers are well understood and incentive programs have already been developed for many of them. However, there has been accelerated advancement in gas-fired water heating technology types in recent years. Many organizations have been involved in research and development (R&D), field testing, and reliability testing of these emerging technologies. As a result, there are now many new technologies on the horizon that range from being in R&D to being commercially available with varying amounts of publicly available third-party performance testing data. More information is needed for emerging water heating technologies so the GET program will focus efforts on the most promising technologies for California energy efficiency (EE) programs. A water heating technology table (WHTT) was created as part of a parallel project ET22SWG0001, which found seventeen (17) emerging gas water heating technologies. This study narrowed down that list to six (6) high-priority technologies based on several factors. In-depth analysis was conducted on each high-priority technology to examine factors that can affect market adoption and their readiness to be offered in the California Investor-Owned Utilities Energy Efficiency programs. Codes and standards, applicability to zero net energy (ZNE), applicability to disadvantaged communities (DAC) and hard to reach (HTR) customers, and cost-effectiveness were studied for each high-priority technology because those factors can affect adoption and EE program participation. Lastly, subject matter expert (SME) interviews were conducted to gain further insights in the California water heating market.

Project Goal: The goal of this study is to research emerging gas-fired water heating technologies through the lens of California market status and EE program policies to guide GET investments within those technologies.

Technology Description: Emerging technologies in the WHTT that was created for project ET22SWG001 were examined. From that list, six (6) high-priority technologies were selected for in-depth analysis. They are:

- Gas Engine Heat Pump Water Heater (commercial application)
- Absorption Gas Heat Pump Water Heater (commercial application)
- Adsorption Gas Heat Pump Water Heater (residential application)
- Gas Engine Heat Pump Combi (commercial application)
- Absorption Gas Heat Pump Combi (commercial application)

- Thermal Compression Gas Heat Pump Combi (residential and commercial application)

Project Findings:

- The number of manufacturers offering these high-priority technologies varies from one (1) manufacturer for thermal compression gas heat pump combi to several for absorption gas heat pump combi.
- All technologies are impacted by air quality management district (AQMD) rules and regulations and some also need to comply with the California Title 24/Title 20 building energy efficiency standards. However, a gap was found in Title 24 and Title 20 standards specific to the definitions/requirements for gas-fired heat pumps.
- Estimated therm savings for typical use varies from 26% to 49% of the baseline consumption along with estimated total resource cost (TRC) range of 0.21 to 3.17.
- Main barriers for adoption of these technologies are high initial costs, lack of awareness, lack of trained installer and maintenance personnel, and general adverse regulatory environment for gas technologies.
- Existing savings calculation tools for domestic hot water and space heating end-uses are not currently equipped to model gas-fired heat pumps. Accurate energy savings calculation tools/methodology are prerequisite to offer these technologies under California EE incentive programs.
- Publicly available and standardized third-party performance data is lacking for many technologies which also makes energy savings analysis challenging.
- Four (4) out of these six (6) high-priority technologies were recommended for follow-up field and/or lab testing/studies under the GET program to address the gaps identified above.

Project Recommendations: The study team offers the following recommendations based on the findings:

- Perform follow-up lab and field studies/testing to develop performance curve data and generate CO_2 load shapes, determine installation configuration options, and obtain cost data for the: 1) absorption gas heat pump water heater, 2) absorption gas heat pump combi, 3) adsorption gas heat pump water heater, and 4) thermal compression gas heat pump combi.
- Follow-up coordination with codes & standards group to address regulatory gaps
- Follow-up coordination with workforce education and training to close gaps in professional installation and maintenance training

- Follow-up coordination with EE program marketing/outreach teams to educate customers on the advantages of gas-fired heat pump water heating and combi systems
- Coordination with and support of other organizations in the development of appropriate modeling tools.

Introduction

This ET study project aimed to research emerging gas-fired water heating technologies to provide actionable recommendations of technologies and gaps for further study by the GET program. This project covers both residential (single-family and multi-family) and commercial sector water heating systems and includes gas storage water heaters, tankless water heaters, dual-fuel water heaters, combination space and water heating systems, and water heating controls specific to emerging technologies. Research focused on emerging technologies that are ready for lab or field studies, but other technologies that are more nascent were included based on feedback from project stakeholders and the Technology Advisory Group (TAG). A list of current water heating technologies was developed in a parallel project ET22SWG0001. Through surveying and researching market availability, drivers, barriers, and several more technology adoption characteristics, a list of high-priority emerging technologies was determined in this project. Attributes of each high-priority technology were thoroughly investigated, including cost-effectiveness and high-level energy savings. Incremental barriers were also evaluated as a forward-looking analysis to ensure that the technologies are a good fit for CA programs.

Table 1 shows the technologies that were selected for further analysis after prioritization was done. Publicly available data was used for energy savings calculations.

Table 1: Emerging Water Heating Technologies and Manufacturer Data Used

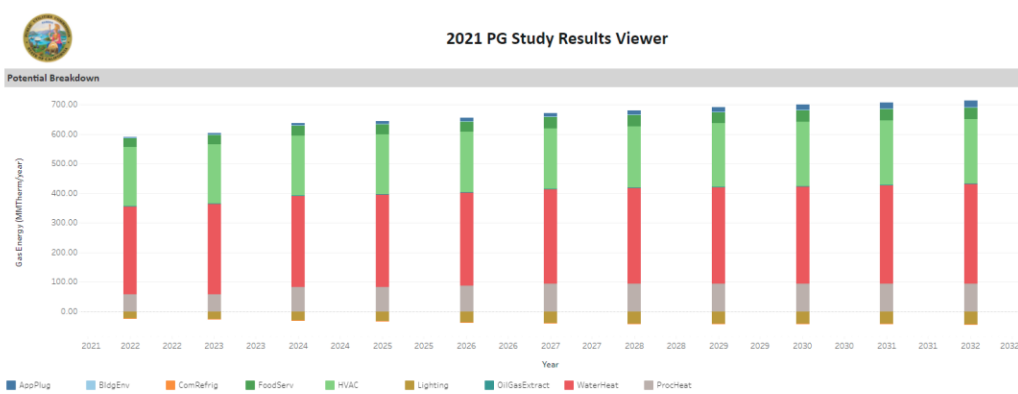
Technology Name & Sector	Description
Commercial Gas Engine Heat Pump Water Heater-Com	Heat pump water heater utilizing **mechanical** output of a gas-driven internal combustion engine to drive a vapor compression cycle (Multifamily & Commercial)
Commercial Vapor Absorption Gas Heat Pump Water Heater-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Multifamily & Commercial)
Residential Vapor Adsorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. (Single Family)
Commercial Gas Engine Heat Pump Combi System-Com	Heat pump utilizing **mechanical output** of a gas-driven internal combustion engine to drive a vapor compression cycle to provide 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating

Technology Name & Sector	Description
Commercial Vapor Absorption Gas Heat Pump Combi System-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating
Thermal Compression Gas Heat Pump Combi System-Res&Com	Thermal energy provided by the combustion of natural gas powers a thermodynamic compression cycle. Helium is the working fluid. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating

Background

According to the 2021 EE Potential and Goals Study Results Viewer, water heating has the highest technical and economic potential within the gas energy sector (298–339 MMtherm/year) when all sectors and end uses are considered (Guidehouse, 2021).

Figure 1: 2021 Potential and Goals Results Viewer for Economic Potential of Gas Energy Savings in Scenario 2: TRC Reference



Typical gas water heaters, gas furnaces, and gas boilers are well-understood and incentive programs have already been developed for many of them. However, the accelerated advancement in this area has led to many different technology types including utilizing different types of thermodynamic cycles to heat water, improved heat exchange between hot and cold mediums, improved heat recovery, combination of water and space heating, better controls, and even electricity generation to make a self-contained water heater (i.e., a water heater that does not rely on external power to operate). Many organizations inside and outside California have been involved in research & development, field testing, and reliability testing of these emerging technologies resulting in a wide variety of reports and case studies. As a result, there are now many new technologies on the scene in gas-fired water heating that range from being in R&D to being commercially available with varying amounts of publicly available third-party performance testing data.

Emerging Technologies

A parallel project (ET22SWG0001) created a WHTT that has available energy efficient water heating technologies including those that are already commercially available and in energy efficiency programs as well as those which are considered to be emerging technologies. This project (ET22SWG002) looked further into those technologies which were emerging technologies. Table 2 includes the list of emerging technologies examined in this study.

Table 2: Emerging Water Heating Technologies

Technology Name & Sector	Description
Machine Learning Water Heating Controls-Res	Machine learning controls that save water heating energy by reducing temperature setpoint of hot water during low-demand times. (Single Family)
Commercial Gas Engine Heat Pump Water Heater-Com	Heat pump water heater utilizing **mechanical** output of a gas-driven internal combustion engine to drive a vapor compression cycle (Multifamily & Commercial)
Residential Vapor Absorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Single Family)
Commercial Vapor Absorption Gas Heat Pump Water Heater-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Multifamily & Commercial)
Residential Vapor Adsorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. (Single Family)
Ejector Sorption Assisted Gas Heat Pump Water Heater-Res	Thermal energy provided by the combustion of natural gas drives an ejector heat pump system assisted by sorption to increase COP. Ejector replaces the compressor in a vapor-compression cycle[18].
Self-Powered High Two-Phase Thermo-Syphoning Residential Storage Gas Water Heaters-Res	Competitive cost higher efficiency (non-condensing) tank water heater utilizing Two-Phase Thermo-Syphoning Technology
Non-Powered Damper Commercial Storage Gas Water Heaters-Res	Competitive cost higher efficiency tank water heater with non-powered damper

Technology Name & Sector	Description
Residential Wastewater Heat Recovery HX (Water Pre Heat)-Res	Utilizing a heat exchanger to use waste hot drain water to pre heat water going into a water heater (Single Family)
Commercial or Multifamily Wastewater Heat Recovery HX (Water Pre Heat)-Com	Utilizing a heat exchanger to use waste heat to pre heat water going into a water heater (Multifamily & Commercial)
Equipment Specific Greywater Recycling with Heat Recovery-Res	Means to collect grey water and recover heat from it for pre-heating hot water for an individual piece of equipment or sink/shower
Commercial Gas Engine Heat Pump Combi System-Com	Heat pump utilizing **mechanical output** of a gas-driven internal combustion engine to drive a vapor compression cycle to provide 2+ of the following 1. Space heating 2. Space cooling 3. DHW heating
Residential Vapor Absorption Gas Heat Pump Combi System-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating
Commercial Vapor Absorption Gas Heat Pump Combi System-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating
Residential Vapor Adsorption Gas Heat Pump Combi System-Res	Heat pump utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating
Thermal Compression Gas Heat Pump Combi System-Res&Com	Thermal energy provided by the combustion of natural gas powers a thermodynamic compression cycle. Helium is the working fluid. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating
Combination Space and Water Gas Heating System Controls - Res&Com	Controls for equipment that provides heating and hot water using gas-burner.

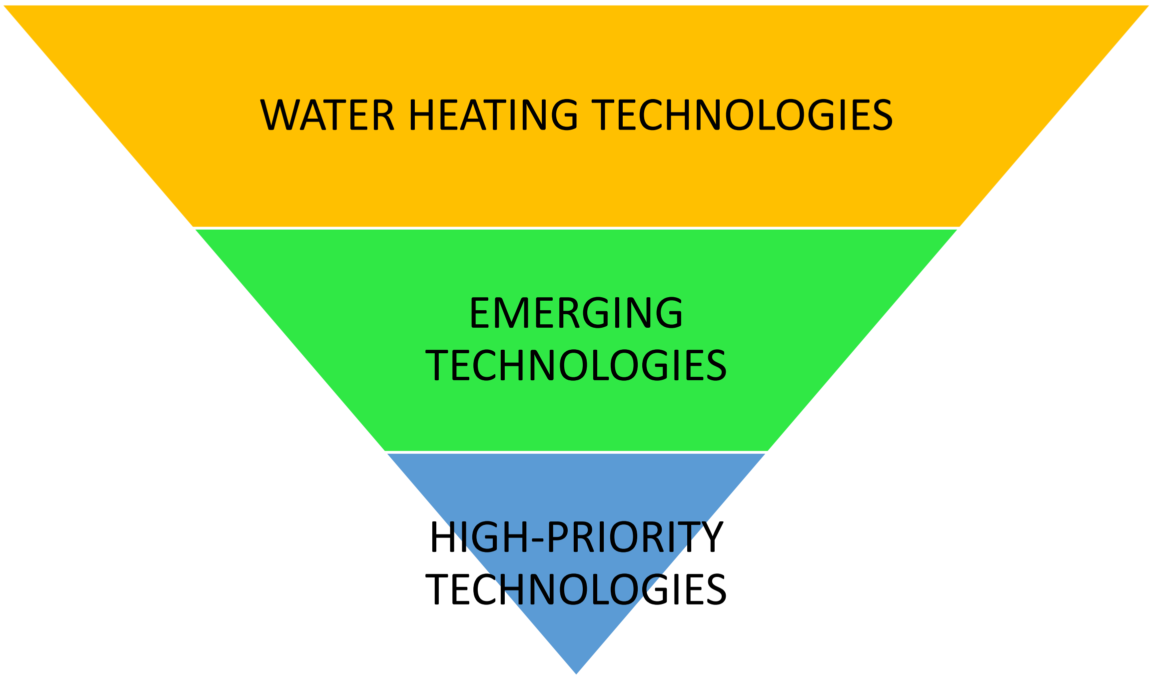
Assessment Objectives

The goal of this study was to research emerging gas-fired water heating technologies through the lens of California climate zones and EE program policies to guide GET investment in those technologies. The objectives of this study were:

1. Provide detailed emerging technology information including
    a. Potential annual energy (gas) savings and energy savings approach(es)
    b. Applicable energy codes and standards
    c. Potential installation cost
    d. Applicability to Zero Net Energy (ZNE) buildings
    e. Applicability to DACs and HTR markets
    f. Other costs and benefits
    g. Technology-specific barriers
2. Determine if and where there are gaps to calculate energy savings for specific high-priority technologies
3. Determine potential cost-effectiveness of high-priority technologies
4. Provide recommendations for further evaluations of emerging gas-fired water heating technologies

Technology Prioritization

Figure 2: Prioritization Funnel



A WHTT was created in a parallel project (ET22SWG0001) that includes water heating technologies that are currently commercially available and those that are not currently commercially available. Emerging technologies ranged from being in early research and development to being commercially available. There were seventeen (17) technologies classified as "emerging." An emerging technology was generally one that was not commercially available yet, had been commercially available less than three (3) years, or had no measure package. The absorption gas heat pump water heater was an exception that had been commercially available for 3+ years and had a measure package (SWWH033), but it had seen very little traction in the California market in the last three (3) years so it was still classified as emerging. The first task completed in this study was prioritizing the technologies so more time would be spent on the most promising emerging technologies that fit within the purview of the GET program. Emerging water heating technologies were prioritized into "High," "Medium," and "Low." High-priority technologies were limited to a maximum of six (6). Prioritization was done by scoring each technology based on the following considerations:

- Program
  - TRC/Simple Payback
  - Market Size
  - Potential to Complete Field/Lab Study Within 3 Years

  - Potential for a Joint Project with Cooperation from Other Internal IOU Programs
  - Product Performance
  - Time to Commercialization
- Customer
  - Added Functionality
  - Material Cost
  - Installation Cost/Complexity
- Market
  - Market Readiness
  - Technology Brand Awareness/Brand Equity
  - Confidence in Technology
- Regulatory
  - Testing Standards
  - Software Tools
  - Risk Technology will be prohibited/made obsolete by state/local codes

Specific scoring standards and the final priority of each technology after scoring can be found in Appendix I. Information and data to score technologies was taken from various publicly available sources as well as some sources acquired directly from certain organizations. Energy savings for each technology were *estimated* at this early stage of the study to prioritize the technologies. Later in this study, more detailed energy savings calculations were done, but the technologies were not re-prioritized. Some technologies that scored high were not ranked as high priority because they were not yet commercially available and did not have a defined commercial availability date that was within 3 years.

High-Priority Technologies

The condensed list of six (6) high-priority water heating technologies is shown in Table 3. In the following sections of this report, the high-priority technologies will be known as:

- Gas Engine Heat Pump Water Heater
- Absorption Gas Heat Pump Water Heater
- Adsorption Gas Heat Pump Water Heater
- Gas Engine Heat Pump Combi
- Absorption Gas Heat Pump Combi
- Thermal Compression Gas Heat Pump Combi

Table 3: High Priority Water Heating Technologies

Technology Name & Sector	Description	Status
Commercial Gas Engine Heat Pump Water Heater-Com	Heat pump water heater utilizing **mechanical** output of a gas-driven internal combustion engine to drive a vapor compression cycle (Multifamily & Commercial)	One (1) product commercially available in U.S.
Commercial Vapor Absorption Gas Heat Pump Water Heater-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Multifamily & Commercial)	(1) Product commercially available in U.S. (2) Products planned to launch in 2023 in U.S. (1) Product commercially available outside U.S.
Residential Vapor Adsorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. (Single-Family)	(1) Prototype will be ready for field testing 2023
Commercial Gas Engine Heat Pump Combi System-Com	Heat pump utilizing **mechanical output** of a gas-driven internal combustion engine to drive a vapor compression cycle to provide 2+ of the following 1. Space heating 2. Space cooling 3. DHW heating	One (1) product commercially available in U.S.
Commercial Vapor Absorption Gas Heat Pump Combi System-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	(1) Product commercially available in U.S. (1) Product planned to launch in 2023 in U.S. (1) Product commercially available outside U.S.
Thermal Compression Gas Heat Pump Combi System-Res & Com	Thermal energy provided by the combustion of natural gas powers a thermodynamic compression cycle. Helium is the working fluid. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	(1) Product undergoing field testing (1) Product was commercially available outside U.S. but had reliability issues, so it is not currently being manufactured

Additional Info: Codes & Standards, ZNE, and DAC/HTR

The first step after initial prioritization was to gather additional information about each technology regarding:

- Relevant Title 20 and Title 24 and other California EE program codes
- Applicability to ZNE buildings
- Applicability to DACs and HTR markets

Information in each category was gained through primary and secondary research and Table 4 shows the summary. A discussion of each category follows. More information on codes and standards is available in Appendices III and IV.

Table 4: High Priority Technology Additional Information

Technology Name/Sector	Codes & Standards	Applicability to ZNE	Applicability to DAC/HTR*
Gas Engine Heat Pump Water Heater	1. AQMD requirements – None 2. Title 24: a. Space Heating: Section 110.2, Table 110.2-C Air Cooled Gas-Engine Heat Pumps - COP for cooling mode = 0.6, COP for heating mode = 0.72 GAP Title 24 COP based on test procedure ANSI Z21.40.4A, this unit is certified by ANSI Z21.40.2. b. Water Heating: GAP Does not apply based on definitions in Title 20 Section 1602	Consumption of baseline system (Boiler) would require solar on 16% of building footprint to offset. Consumption of commercial gas engine heat pump water heater would require 10% of building footprint to offset.	Inconclusive
Absorption Gas Heat Pump Water Heater	1. AQMD requirements – SCAQMD Rule 1146.2 – Paragraph (c),Subdivision (2) – NOx emission limit of 40 nanograms NOx per joule of heat output or 55ppm NOx emissions 2. Title 24: a. Space Heating: GAP Title 24 does not have a standard for absorption heat pumps, so no standards apply. b. Water Heating: GAP Does not apply based on definitions in Title 20 Section 1602	Consumption of baseline system (Boiler) would require solar on 39% of building footprint to offset. Consumption of vapor absorption gas heat pump water heater would require 25% of building footprint to offset.	Inconclusive
Adsorption Gas Heat Pump Water Heater	1. AQMD: SCAQMD - Rule 1121 - Control of Nitrogen Oxides from Residential Type, Natural Gas-Fired Water Heaters, Paragraph (c), Subdivision (3) - NOx emission limit of 10 ng/J (15 ppm) 2. Title 24: references Title 20 for appliances 3. Title 20 - Section 1605.1(f)(1) Table F-2 minimum UEFs for Gas-Fired Storage Water Heaters Apply	Consumption of baseline system (.58 UEF water heater) would require solar on 10% of building footprint to offset. Consumption of residential vapor adsorption gas heat pump water heater would require 7% of building footprint to offset.	May be able to participate in DAC/HTR.

Technology Name/Sector	Codes & Standards	Applicability to ZNE	Applicability to DAC/HTR*
Gas-Engine Heat Pump Combi System	1. AQMD requirements – None 2. Title 24: a. Space Heating: Section 110.2, Table 110.2-C Air Cooled Gas-Engine Heat Pumps - COP for cooling mode = 0.6, COP for heating mode = 0.72 GAP Title 24 COP based on test procedure ANSI Z21.40.4A, this unit is certified by ANSI Z21.40.2. b. Water Heating: GAP Does not apply based on definitions in Title 20 Section 1602	Consumption of baseline system (Boiler) would require solar on 16% of building footprint to offset. Consumption of commercial gas engine heat pump water heater would require 10% of building footprint to offset.	Inconclusive
Absorption Gas Heat Pump Combi System	1. AQMD requirements - SCAQMD Rule 1146.2 – Paragraph (c),Subdivision (2) – NOx emission limit of 40 nanograms NOx per joule of heat output or 55 ppm NOx emissions 2. Title 24: a. Space Heating: GAP Title 24 does not have a standard for absorption heat pumps, so no standards apply. b. Water Heating: GAP Does not apply based on definitions in Title 20 Section 1602	Consumption of baseline system (Boiler) would require solar on 39% of building footprint to offset. Consumption of vapor absorption gas heat pump water heater would require 25% of building footprint to offset.	Inconclusive
Thermal Compression Gas Heat Pump Combi System	1. AQMD requirements - SCAQMD Rule 1146.2 – Paragraph (c),Subdivision (2) – NOx emission limit of 40 nanograms NOx per joule of heat output or 55 ppm NOx emissions 2. Title 24: a. Space Heating: GAP Title 24 does not have a standard for thermal compression gas heat pumps, so no standards apply. b. Water Heating: GAP Does not apply based on definitions in Title 20 Section 1602	Consumption of baseline system (.58 UEF water heater) would require solar on 10% of building footprint to offset. Consumption of thermal compression gas heat pump combi system would require 5% of building footprint to offset.	Inconclusive

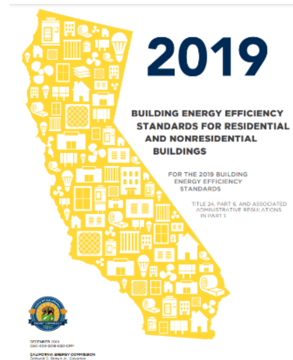
* See HTR Section for information on HTR

Codes and Standards

Relevant Codes and Standards affect what can be offered through EE programs. For example, it was found during a parallel project that Ultra-Low NOx standards for many Air Quality Management Districts (AQMDs) appears to limit adoption of gas fired storage water heaters even when those water heaters meet the minimum efficiency requirements for incentives.

Figure 3: SCAQMD Logo (South Coast Air Quality Management District, 2022)

Figure 4: Title 24 2019 Standards Front Page (California Energy Commission, 2019)



The following codes and standards apply to one (1) or more high priority technologies:

- Title 24
- Title 20
- ANSI Z21.40.4A
- South Coast Air Quality Management District (SCAQMD) Rule 1146.2
- SCAQMD Rule 1121

SCAQMD rules 1146.2 and 1121 require ultra-low NOx emissions from some of these emerge g gas heat pump technologies. Other AQMDs and Air Pollution Control Districts (APCDs) in California also require ultra-low NOx emissions. For the sake of simplicity, only the SCAQMD regulations are discussed in this report because, according to one subject matter expert interviewed, SCAQMD usually adopts these rules first and other AQMDs/APCDs follow suit. However, additional AQMDs/APCDs that require ultra-low NOx burners in certain situations are listed below (HD Supply Solutions, 2022):

- Bay Area AQMD (Reg 9, Rule 6)
- Sacramento Metropolitan AQMD (Rule 411)
- San Joaquin Valley APCD (Rule 4902)
- Santa Barbara County APCD (Rule 352)
- South Coast AQMD (Rule 1146 & 1121)

- Ventura County AQMD (Rule 74-11)
- Yolo-Solano AQMD (Rule 2.37)

Table 4 has a summary of applicable Codes & Standards for each technology. See Appendix II for more detailed information.

Applicability to Zero Net Energy

The most recent version of the California Energy Efficiency Strategic Plan includes goals that (Engage 360, 2011):

- All new residential construction in California will be zero net energy by 2020
- All new commercial construction in California will be zero net energy by 2030

Although these emerging technologies are most likely to be installed in an existing building, the policies for new construction flow down to existing buildings later on. Therefore, in order to be forward-looking in investments in emerging technologies, the GET program wants to consider how these technologies would impact a site's zero net energy status.

The definition of a Zero Net Energy building from the California Department of General Services is:

> "An energy-efficient building where, on a source energy basis, the actual annual consumed energy is less than or equal to the on-site renewable generated energy" (California Public Utilities Commission, 2022)

The GET water heating measures consume gas energy so they would require on-site renewable generated energy for a customer using these technologies to meet a Zero Net Energy definition.

Baseline and measure case therms/year were estimated for all six (6) high priority technologies. These estimates come from the prioritization stage of this project and were not updated based upon the more detailed energy savings calculations that were done later in the study. The estimated baseline and measure case therms come from the following sources:

Table 5: ZNE: Energy Use Data Sources

Technology Name	Estimated Energy Use Data Source
Gas Engine Heat Pump Water Heater and Combi	NEEA Report "Natural Gas Internal Combustion Engine Heat Pump Field Trial Final Report" (Northwest Energy Efficiency Alliance, 2019)
Absorption Gas Heat Pump Water Heater and Combi	California Public Utilities Commission Measure Package for "Gas Heat Pump Water Heater, Multifamily" – SWWH033 (Southern California Gas, 2022)
Adsorption Gas Heat Pump Water Heater, Thermal Compression Gas Heat Pump Water Heater and Combi	DEER Water Heater Calculator (DNVGL, 2020)

Therm use estimates were multiplied by a factor of 1.09 to account for the source energy based upon DOE report "A Common Definition for Zero Energy Buildings" (US Department of Energy, 2015) Page 8. The source therms were converted to an equivalent annual kWh of on-site generation using PV Watts (National Renewable Energy Laboratory, 2022) and three (3) solar panel specifications sheets.

PV Watts was used to determine the average kWh/rated solar system wattage in California. Information was entered into PV Watts for areas in each of California's sixteen (16) climate zones to get the average kWh/rated solar system wattage. Three (3) solar panel specifications sheets were used to determine the average ft^2 area per rated solar system wattage. The source therms were converted into a square footage of total solar array required to offset the therm usage of the baseline and measure cases for each technology. This array area was then compared to the building footprint in the baseline and post to determine the percentage of total footprint required.

Table 6 gives an example of calculated values for the adsorption gas heat pump water heater. Table 7 lists the constants used in the calculation.

Table 6: Example Adsorption Gas Heat Pump Water Heater ZNE Calculation

Case	Consumption at site [therm]	Consumption at Source [therm]	Equivalent source electric consumption [kWh]	Required Array Area [ft^2]	Percentage of building footprint
Baseline	198	216	6,325	209	10%
Measure	133	145	4,249	140	7%

Table 7: Constants used in Adsorption Gas Heat Pump Water Heater ZNE Calculation

Constant	Value	Notes
Site to Source Conversion Factor	1.09	From DOE Study (US Department of Energy, 2015)
Average ft2/kWh	0.033	From PV Watts and Solar Panel Spec Sheets (National Renewable Energy Laboratory, 2022)
Building Footprint [ft2]	2,083	Average floor area for Single Family Home from

In some cases, baseline and measure therms had to be normalized based on the square footage. Floor areas come from MAS Control models or measure packages. Table 8 below lists the source of the building areas for each calculation

Table 8: Building Footprint Source

Technology Name	Building Footprint Source	Notes
Gas Engine Heat Pump Water Heater and Combi	DEER Nursing Home	NEEA Study done in retirement community. Savings taken from that study.
Absorption Gas Heat Pump Water Heater and Combi	Measure Package SWWH033; (84) units with 1000 sqft each. Assumed 2-story building.	Savings taken from measure package SWWH033
Adsorption Gas Heat Pump Water Heater,	DEER floor areas for Single Family Homes; average of all vintages and climate zones	Savings estimated with DWHC for Single Family Home
Thermal Compression Gas Heat Pump Water Heater and Combi	DEER floor areas for Single Family Homes; average of all vintages and climate zones	Savings estimated with DWHC for Single Family Home

Since this is a high-level calculation, only one calculation was done for gas engine heat pump water heater and combi together and one calculation was done for vapor absorption gas heat pump water heater and combi together. One calculation was done for thermal compression gas heat pump water heater and combi at this stage (in a single-family home). However, when more detailed high-level energy savings calculations were done, an additional calculation of the thermal compression gas heat pump water heater in a fast-food restaurant was added.

Applicability to DAC/HTR

California Senate Bill 350 (SB 350) directs the California Public Utilities Commission to “include specific strategies for, and an update on, progress toward maximizing the contribution of energy efficiency savings in disadvantaged communities” (Clean Energy and Pollution Reduction Act of 2015, 2015). The goal of GET is to transfer emerging technologies into EE programs, so the GET program also wanted to consider how these technologies might affect disadvantaged communities.

Disadvantages Communities (DAC) are determined by Cal EPA based on “geographic, socioeconomic, public heath, and environmental hazard criteria” (California State Senate, 2022). To determine if a customer is located in a DAC their address must be available and it must be checked on CalEnviroScreen 4.0 (as of the date of this report) (California EPA, 2022). The California Public Utilities Commission (CPUC) clarified in Decision 18-05-041 that being in a DAC area meets the geographic criteria for a hard-to-reach customer (California Public Utilities Commission, 2022). Therefore, only HTR will be discussed further since DAC designation is one of the qualifiers for the HTR NTG ID

Projects whose customers meet the HTR criteria may use the HTR net-to-gross (HTR NTG) IDs. Customer address is required to determine if a customer is in a DAC area but that is considered private data, and addresses are not available in any public facing documents. However, NTG IDs are available in the California Energy Data and Reporting System (CEDARS). Therefore, to determine if high priority technologies were applicable to HTR customers, CEDARS data that had a NTG ID of ‘Com-Default-HTR-DI’ or “Res-Default-HTR-DI” were analyzed to see if any similar technologies have previous participation with HTR NTG IDs. CEDARS data from 2019 – 2021 was sorted to examine those measures across all programs and Project Administrators (PAs) that had those NTD IDs and that were also water heating measures. Analysis was split up between residential (single-family, mobile home), residential (multi-family), and commercial.

HTR Summary

Residential

Water heating measures with the NTG ID “Res-Default-HTR-DI” from 2019-2022 were:

Table 9: Water Heating Measures with NTG ID "Res-Default-HTR-DR" in 2019-2022

Measure	Single-Family/Mobile Home	Multi-Family
Demand Control for Centralized Water Heater Recirculation Pump		X
Diverting tub spout with Thermostatic Expansion Valve (TSV)	X	X
Faucet aerator	X	X
Hot water pipe insulation		X
Hot water tank insulation		X
Low flow showerhead	X	X
Residential storage water heater, non-condensing efficiency	X	
Thermostatic Expansion Valve (TSV)	X	
Thermostatic Expansion Valve (TSV) and low flow showerhead	X	X

The only measure that has historically been installed with an HTR NTG ID that is comparable to any of the gas heat pump water heaters is "residential storage water heater, non-condensing efficiency." This indicates that the vapor adsorption gas heat pump water heater may be able to be installed in HTR customer homes because it is being designed as a drop-in replacement for typical gas-fired storage water heaters. There may be opportunity to expand the measures offered using the HTR NTG ID. However, the offering of these gas heat pump water heater technologies to HTR customers is determined by each program's design.

Commercial

Water heating measures with the NTD ID of "Com-Default-HTR-DI" from 2019-2021 were:

- Faucet aerator
- Hot water pipe insulation
- Hot water tank insulation
- Laminar flow restrictor
- Low flow showerhead

None of these measures was comparable to the gas heat pump water heating technologies. There may also be opportunities in commercial programs to expand the water heating measures that are offered using the HTR NTG ID. Again, this is determined by program design.

High-Level Energy Savings and Gaps

After technologies were prioritized and additional information was gathered, high level energy savings were calculated for each technology and gaps for calculations were documented. At least one (1) energy savings calculation was done for each technology. Each energy savings calculation was done using one (1) building type/building vintage combination in one (1) California climate zone. Two (2) energy savings calculations were done for the following technologies:

- Absorption Gas Heat Pump Combi
- Thermal Compression Gas Heat Pump Combi

Energy savings were calculated using publicly available calculation methodologies, tools, models, and assumptions. Wherever specific data was not available, engineering judgement was used. These energy savings values are more detailed than what was used for prioritization but are still only meant to give a ball-park energy savings value for each technology for the purpose of selecting technologies for further study. These savings values by no means represent the best- or worst-case energy savings and may change based upon more exact calculation methodologies, assumptions, and data. A summary of the energy savings is presented first in Table 10 followed by a discussion of the gaps and then information on how the building types and climate zones were selected for each technology. Detailed explanations of the methodologies used for each technology and the resulting energy consumption and saving values are in the Appendices.

Table 10: Technology Savings Summary

Technology/Building Type/Climate Zone	Baseline [therms/yr]	Measure [therms/yr]	Savings [therms/yr]	Savings %	Savings/ Normalizing Unit	Savings Methodology
Gas Engine Heat Pump Water Heater– Hotel Guest Room (HGR), CZ08	25,229.3	14,094.5	11,134.8	44%	21.01/Cap-kBtuh	Appendix IV
Absorption Gas Heat Pump Water Heater– Assembly (ASM), CZ08	6,611.2	4,571.2	2,040.0	31%	10.54/Cap-kBtuh	Appendix IV
Adsorption Gas Heat Pump Water Heater – Single Family Home (SFM). CZ10	196.3	132.7	63.6	32%	63.6/Household	Appendix V
Gas Engine Heat Pump Combi– Nursing Home (NRS). CZ08	29,383.1	17,440.2	11,942.9	41%	11.10/Cap-kBtuh	Appendix VII
Absorption Gas Heat Pump Combi– Office-Small (OFS). CZ08	1,269.2	874.6	394.6	31%	2.36/Cap-kBtuh	Appendix VII
Absorption Gas Heat Pump Combi– Nursing Home (NRS), CZ08	28,979.1	21,576.8	7,402.3	26%	7.99/Cap-kBtuh	Appendix VII
Thermal Compression Gas Heat Pump Combi– Restaurant Fast Food (RFF), CZ08	1,337.9	726.10.3	611.80	46%	4.71/Cap-kBtuh	Appendix VII
Thermal Compression Gas Heat Pump Combi– Single Family Home (SFM). CZ10	313.7	160.0	153.7	49%	2.37/Cap-kBtuh	Appendix VII

Gaps

Here is an overall summary of gaps for energy savings calculations for these technologies:

1. Neither eQuest nor Energy Plus can model a gas-fired heat pump water heater. A workaround is required.
2. The DEER Water Heater Calculator (DWHC) does not model a gas-fired heat pump water heater. A workaround is required, and the workaround requires assumptions about Tank UA and an additional calculation of heat losses in water-to-water heat exchangers.
3. The DWHC ambient air temperatures appear to be ambient air temperatures inside a boiler/water heater room. Some of these technologies must be installed outside so the DWHC would need to be updated to include outside ambient air temperatures.
4. DEER measures split up water heater and space heating into separate measures. Water heating is calculated using the DWHC and space heating using hot water is modeled with DEER eQuest models. The DEER eQuest models do not include DHW in them. In order to properly model a combi system, eQuest or Energy Plus models would need to include DHW systems.
5. The available field studies for the gas heat pump absorption and gas engine systems indicate that the baseline water heater/boilers still exist to supply peak hot water demands in the measure case system.
    a. It is unknown if this would be the case for most installations so further information gathering is needed to establish what the typical measure-case installation looks like. Conversations with one (1) manufacturer indicate that there are three (3) typical measure-case configurations. The configuration selected for energy savings calculations is the gas heat pump water heater/combi alongside new condensing efficiency storage water heater(s)/boiler(s). See Appendix IV for more information.
    b. In this calculation, an assumption is made that the storage water heater(s)/boiler(s) must always be on standby which decreases the overall energy savings. More data is needed to determine if this is the case in actual installations, or if there are controls that can turn off this equipment during times of low demand.
    c. Assumptions had to be made about how the water heater(s)/boiler(s) operate in the measure case. More data is needed to properly model the energy consumption of this equipment when the emerging technologies are installed.
    d. Another possible measure-case installation is the gas heat pump water heater/combi operating alongside the existing water heater(s)/boiler(s). This presents issues when the rules of a program (for example custom EE program) stipulate that the baseline equipment must be decommissioned or removed. Investigation needs to be done to determine how this barrier could be overcome.

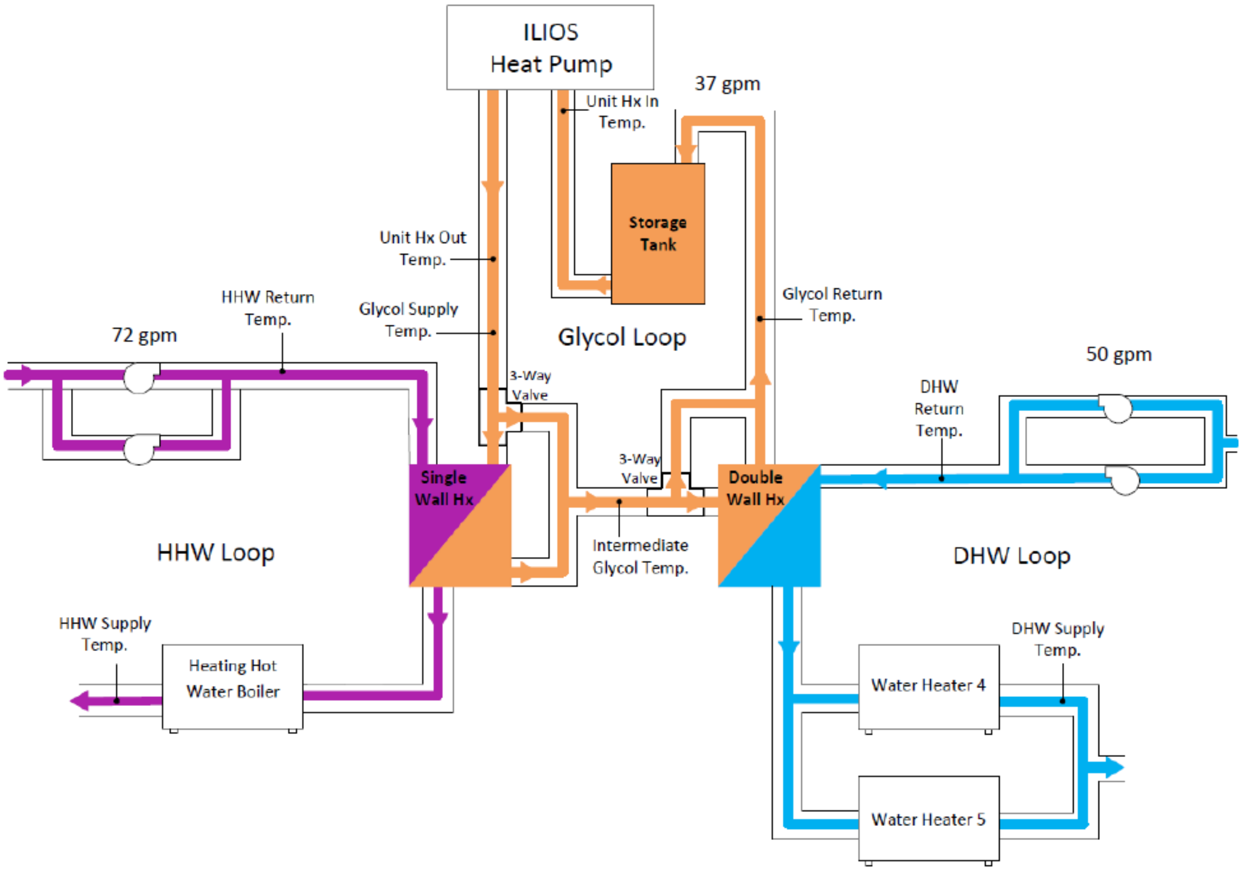
6. California is switching over to EnergyPlus models for DEER measures. Residential prototypes are expected in October 2022 and commercial prototypes are expected in 2023 (DNV, 2022). Once the prototypes are released, measure package development will require an updated MAS Control tool as well.
7. There is limited information on the performance curves of these technologies. Where data is available, it is usually from manufacturers. Third party information on performance curves is needed especially for vapor adsorption gas heat pump water heater, thermal compression gas heat pump combi, one of the upcoming absorption gas heat pump combi systems in a commercial setting, the water-source gas engine heat pump water heater and combi and water-source absorption gas heat pump water heater and combi.
8. Not all of the performance curves for the emerging technology water heaters reflect the parasitic electric loads to run equipment. More data is needed to understand what the parasitic loads are. All technologies in this analysis are air-cooled or assumed to be air-cooled.
9. Performance curves are based upon the ambient air temperature, but that temperature can vary based upon where the unit is installed (if outside the ambient air temperatures will fluctuate more than if installed inside an existing boiler room). More data is needed to determine where units are commonly installed (inside/outside). These calculations assume gas heat pump water heaters are installed outside and new condensing water heater(s)/boiler(s) are inside a mechanical room.
10. GTI's study "Pathways to Decarbonization" on a gas-fired heat pump absorption system indicates that capacity is a function of ambient air temperature, supply water temperature and return water temperature (Alex Fridlyand, 2021). Differing return water temperatures were not used with the methodology used in this study.
11. There are no testing standards for this equipment when it is at part-load conditions, so manufacturers are not required to test their equipment at part-loads to get those performance curves. One organization verbally told the GET team they had tested one of these emerging technology water heaters at part load conditions but did not share that testing information. This part-load testing data by a third-party will be key to advancing these technologies in the California EE programs.

Building Type & Climate Zone Selection

Gas Engine Heat Pump Water Heater

Below is a diagram of a typical system set up from "Natural Gas Internal Combustion Engine Heat Pump Field Trial Final Report" (Northwest Energy Efficiency Alliance, 2019).

Figure 5: Gas Engine Heat Pump Water Heater System © (Northwest Energy Efficiency Alliance, 2019)



The gas engine heat pump combi in the NEEA study was installed with it being the baseload equipment and the existing boiler and water heaters remaining to handle the peak load. The manufacturer rep indicated they don't size the equipment to a certain percentage of the total building water heating load, rather they want to make sure it runs a certain minimum hours per year to ensure the energy savings of the system is enough to offset the additional first cost and yearly maintenance costs of the unit. Also, the equipment can modulate so it can be sized to meet 100% of the load and still modulate down when hot water load is not at its peak. In the water heating only mode, building types where (1) unit could meet between 50-100% of the total DHW load were found. Then the building type with the largest yearly hot water volume required was determined. The capacity of the gas engine heat pump water heater varies and a range of 400,000-600,000 btu/hr is given on the specifications sheet. Therefore, an average capacity of 500,000 btu/hour was used to determine the percentage capacity met by the gas engine heat pump water heater. The DWHC provides the "Required Capacity for Peak Volume" and "Hourly Water Volume" for each building type. These values are independent of climate zone. The "Required Capacity for Peak Volume" was pulled out of the DWHC and a sum of the "Hourly Water Volume" to get yearly water volume for all commercial building types available in the tool were pulled out. The building types where the gas engine heat pump water heater serves 50%-100% of the load are shown in Table 11.

Table 11: Required Capacity and % Capacity met by Gas Engine Heat Pump Water Heater

Building type	Required Capacity [btu/h]	% Capacity met by (1) Gas Engine Heat Pump Water Heater	Yearly Water Volume (Gallons)
Secondary School	632,122	79%	1,277,811
Community College	924,370	54%	2,608,391
University Dormitory	610,929	82%	2,084,086
Hotel Guest Room	985,090	51%	5,200,897

The building type where the gas engine heat pump water heater can meet the required capacity with the largest yearly water volume is Hotel Guest Room (HGR).

Table 12: DEER Weights for Hotel Guest Room by Climate Zone

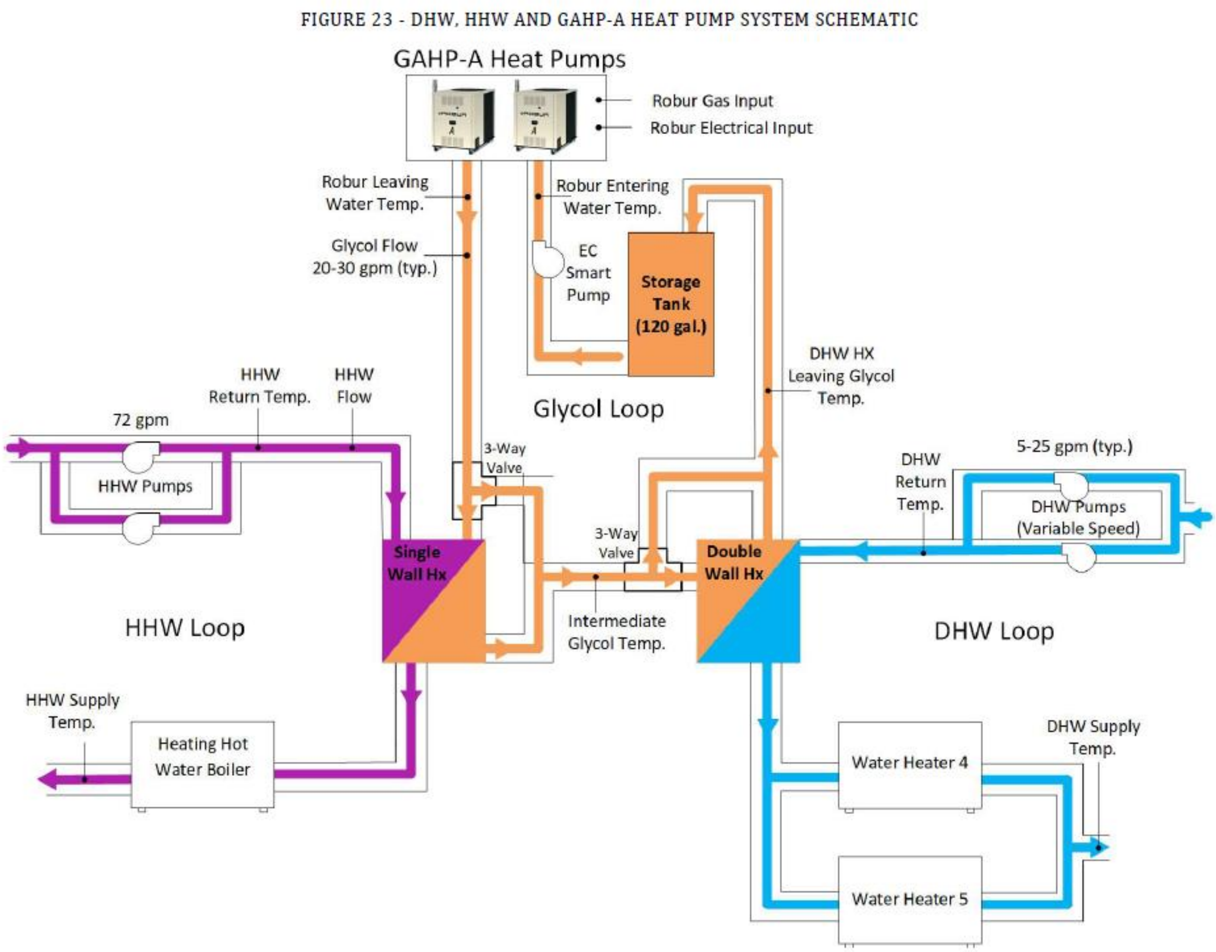
Climate Zone	DEER Weight – Hotel Guest Room
1	0.98
2	4.52
3	27.11
4	9.55
5	4.32
6	41.31
7	20.68
8	28.59
9	32.47
10	9.21
11	2.57
12	8.88
13	6.84
14	3.56
15	17.82
16	5.51

Hotel Guest Room in Climate Zone 9 has the highest DEER weight. However, for all other commercial building types, climate zone 8 had the highest DEER weight. So, Hotel Guest Room in climate zone 8 was selected for savings analysis to better compare between technologies.

Absorption Gas Heat Pump Water Heater

Below is a diagram of a typical absorption gas heat pump water heater system set up from "Robur Heat Pump Field Trial" (Northwest Energy Efficiency Alliance, 2020).

Figure 6 Absorption Gas Heat Pump Water Heater System © (Northwest Energy Efficiency Alliance, 2020)



The manufacturer indicated that their system is best installed in applications where it meets 60-80% of the total hot water load. This is due to the overall cost and efficiency of the system. For example, a building owner might be able to meet their load with ten (10) absorption gas heat pump water heater units and get an overall COP of 1.25, but the cost would be more economical if the building met their load with five (5) absorption gas heat pump water heater units and one (1) hot water boiler with an overall COP of 1.21. Therefore, building types where (1) absorption gas heat pump water heater unit could meet between 60-80% of the total DHW load were selected. The DWHC provides the "Required Capacity for Peak Volume" for each building type. This value is independent of climate zone. The required capacity for peak volume for all commercial building types available in the DWHC were pulled out. The building types where the absorption gas heat pump water heater serves 60%-80% of the load are shown in Table 13.

Table 13: Required Capacity and % Capacity met by Absorption Gas Heat Pump Water heater based on DEER Water Heater Calculator

Building type	Required Capacity [btu/h]	% Capacity met by (1) Absorption Gas Heat Pump Water Heater
Assembly	207,544	60%
Hotel	187,476	66%

To select which building type/climate zone combination to run from the list in Table 13, the DEER Building weights were used. Building weights by climate zone irrespective of PA and vintage are summarized in Table 14.

Table 14: DEER Weights by Climate Zone: Assembly and Hotel

Climate Zone	DEER Weight – Assembly	DEER Weight – Hotel
1	1.09	0.98
2	10.41	4.52
3	51.72	27.11
4	28.22	9.55
5	4.34	4.32
6	86.22	41.31
7	20.24	20.68
8	126.98	28.59
9	84.78	32.47
10	81.74	9.21
11	7.91	2.57
12	30.28	8.88
13	27.74	6.84
14	15.84	3.56
15	26.17	17.82
16	10.93	5.51

Assembly in Climate Zone 8 has the highest DEER weight, so that combination was selected for savings analysis.

Adsorption Gas Heat Pump Water Heater

This water heater is most applicable to a single-family home as a drop-in replacement for a standard gas storage water heater. Therefore, a single-family home was selected as the building type. The climate zone for single-family home with the highest DEER weight (irrespective of IOU and vintage) is in climate zone 10. Savings were calculated for a Single-Family Home in Climate Zone 10.

Gas Engine, Absorption, and Thermal Compression Gas Heat Pump Combi Building Type Selection

All the gas heat pump water heaters that were selected for combination space/water heating are most efficient when their operating hours are maximized and the excess capacity they can't meet is minimized. Therefore, in order to select the appropriate building type for each of these technologies, DEER eQuest models were used to determine the total heating load for each building type, and that load was added to the load from the DWHC to determine the total DHW and space heating load. Note, DEER calculates water heating exclusively using the DWHC, and DEER template eQuest models do not have water heating.

Since there is a separate eQuest DEER prototype permutation for each climate zone, vintage and available HVAC system for each commercial building type, it was not feasible to determine the total heating load for every permutation of every commercial building type. Instead, the DEER Weights for each building were compared for each climate zone and vintage. The climate zone with the highest weight for each building type was selected. The DEER weight for a 1975 building is always the highest weight for all building type/climate zone selections, so this vintage was chosen. All building types had a model with a direct expansion with gas furnace system (DXGF) so this HVAC system was chosen for this building type selection step even though these emerging technologies would use a hydronic system for heating (Not all building types had a model with a hydronic heating system). Table 15 below summarizes the DEER models that were used for building type selection.

Table 15: DEER Commercial Building/Climate Zone/Vintage Combinations Selected for Heating Load eQuest runs

Building Type	Climate Zone	Vintage	HVAC
Asm	8	1975	DXGF
ECC	8	1975	DXGF
Epr	8	1975	DXGF
ERC	8	1975	DXGF
Ese	8	1975	DXGF
EUD	8	1975	DXGF
Eun	8	1975	DXGF
HGR	6	1975	DXGF
Hsp	8	1975	DXGF
Htl	6	1975	DXGF
Nrs	8	1975	DXGF
OFL	8	1975	DXGF
Ofs	8	1975	DXGF
RFF	8	1975	DXGF
RSD	8	1975	DXGF

MAS Control 3 was used to generate .inp files for each of these combinations for the measure "PkgFurn-0.98AFUE." Once .inp files were generated, hourly heating end-use energy was exported from the eQuest models. This energy was divided by the Furnace Heat Input Ratio from the eQuest model to determine the total heating load. The total yearly heating load and maximum hourly heating load were then determined for each building type.

Next, the total required water heating capacity (from the DWHC) was added to the total heating load to determine the total required hot water load for each building type. Then, the total required hot water load was divided by the capacity of each emerging technology to determine how many of each would be needed to satisfy the max capacity. The summary of these results is shown below in Table 16.

Table 16: Total Heating Loads of Commercial Buildings

Building Type	Heating		DHW		DHW and Heating	Gas Heat Pump Water Heaters (# Required)		
	Max Hourly Btu/hr	Total Yearly Btu	Required Capacity [Btu/hr]	Total hot water volume [Gallons]	Total Required Capacity [btu/hr]	# Absorption	# Gas Engine	# Thermal Compression
Assembly	2,162,299	816,508,776	207,544	870,357	2,369,843	19.27	4.74	36.46
Education Community College	4,204,292	557,531,626	924,370	2,608,391	5,128,662	41.70	10.26	78.90
Education Primary School	924,775	160,734,053	136,874	276,687	1,061,649	8.63	2.12	16.33
Education Relocatable Classroom	51,562	15,717,327	12,300	24,864	63,862	0.52	0.13	0.98
Education Secondary School	2,625,666	453,609,621	632,122	1,277,811	3,257,788	26.49	6.52	50.12
Education University	14,034,104	2,932,725,280	1,778,924	6,105,518	15,813,029	128.56	31.63	243.28
Hospital	1,968,248	654,702,890	2,279,928	13,496,438	4,248,176	34.54	8.50	65.36
Hotel	563,311	325,727,469	187,477	1,444,597	750,788	6.10	1.50	11.55
Nursing Home	374,973	284,890,000	334,767	2,207,326	709,739	5.77	1.42	10.92
Office Large	1,073,628	67,644,956	129,150	378,162	1,202,778	9.78	2.41	18.50
Office Small	129,527	22,255,375	7,380	19,813	136,907	1.11	0.27	2.11
Restaurant Fast Food	48,715	18,168,681	45,166	128,303	93,880	0.76	0.19	1.44
Restaurant Sit Down	57,681	8,400,920	77,729	235,498	135,409	1.10	0.27	2.08
Retail MultiStory Large	754,050	25,951,031	27,700	93,281	781,750	6.36	1.56	12.03
Retail Large	806,811	147,422,780	15,424	58,248	822,235	6.68	1.64	12.65
Retail Small	104,219	18,271,597	6,731	20,243	110,949	0.90	0.22	1.71

DEER weights were compared for each technology where the number required was between 1-2. This indicates that the technology could be base loaded but would need another water heater/boiler or another one of itself to satisfy the peak load. The building type with the largest DEER weight was selected. Table 17 below summarizes the selected building type for each emerging technology.

Table 17: Building Type Selections for Each

Emerging Technology	Building Type Selected	Comments
Absorption Gas Heat Pump Combi	Office Small, Nursing Home	The absorption gas heat pump combi is commercially available and may be piloted. Therefore, one of the extra calculations was done on this system in a Nursing Home.
Gas Engine Heat Pump Combi	Nursing Home	Both retail building types have much higher DEER weights, but due to the smaller overall yearly total space/water heating load, the savings for those is very low per Cap-btuh. Nursing home was chosen to maximize the savings per Cap- kBtuh
Thermal Compression Gas Heat Pump Combi	Restaurant Fast Food, Single Family	Retail Small had a higher building weight. However, the manufacturer indicated the thermal compression gas heat pump water heater is best utilized where there is concurrent heating and cooling need. A restaurant most likely has a walk-in cooler/freezer that could benefit from cooling offset from this technology. Although that is not considered in these calculations. This technology is small enough to apply to single-family homes, so a second energy savings calculation was done in single-family homes for this technology

Total Resource Costs and Total System Benefits

The total energy savings for a technology only gives part of the story. The cost of the technology and its cost-benefit to California EE programs are also important factors when technologies are transferred to EE programs. The next task done in this study was to use the high-level energy savings calculations, estimate measure costs and calculate the Total Resource Cost (TRC) and Total System Benefit (TSB). Measure costs were estimated based upon available information from measure packages and manufacturers. The energy savings values come from Table 10. TRC and TSB values were calculated with no incentive and with the incentive equal to the measure cost to give the full range of TRC/TSB values. Table 18 below summarizes the TSB and TRC values of the technologies.

Table 18: TSB and TRC values for High Priority Technologies

	TSB/TRC Without Incentives		TSB/TRC With Incentives	
Technologies	**Total System Benefit (TSB)**	**Total Resource Cost (TRC)**	**Total System Benefit (TSB)**	**Total Resource Cost (TRC)**
Gas Engine Heat Pump Water Heater– Hotel Guest Room (HGR), CZ08	$95,375	1.03	$95,375	0.88
Absorption Gas Heat Pump Water Heater– Assembly (ASM), CZ08	$17,756	1.20	$17,756	1.02
Adsorption Gas Heat Pump Water Heater – Single Family Home (SFM). CZ10	$436	0.53	$436	0.45
Gas Engine Heat Pump Combi– Nursing Home (NRS). CZ08	$100,309	1.06	$100,309	0.91
Adsorption Gas Heat Pump Combi– Office-Small (OFS). CZ08	$3,442	0.25	$3,442	0.21
Adsorption Gas Heat Pump Combi– Nursing Home (NRS), CZ08	$64,425	0.72	$64,425	0.62
Thermal Compression Gas Heat Pump Combi– Restaurant Fast Food (RFF), CZ08	$5,332	3.74	$5,332	3.17
Thermal Compression Gas Heat Pump Combi– Single Family Home (SFM). CZ10	$1,369	0.36	$1,369	0.31

CET Calculations – Assumptions

The Cost Effectiveness Tool (CET) was used to determine the TSB and TRC for each measure. Inputs to the CET were determined using engineering judgement. Some CET input values were the same across all technologies and some varied. Table 19 presents CET inputs that are the same across all technologies. Table 20 presents inputs that varied for each technology. A discussion of input values chosen for the CET runs can be found in **Error! Reference source not found.**.

Table 19: Constant CET Inputs Across All Technologies

CET Input	Value
DeliveryType	DnDeem DI
MeasAppType	NR
E3GasSavProfile	Annual
TechGroup	WaterHtg_eq
UseCategory	SHW
UseSubCategory	Heating
NTG_ID	ET-Default
NTGRkW	0.85
NTGRkWh	0.85
NTGRTherm	0.85
NTGRCost	0.85
PA	SCG
EUL_ID	WtrHt-TankIns-Gas
MeasImpactType	DEER
UnitRefrigBens	0

Table 20: Varying CET Inputs Across All Technologies

CET Input	Gas Engine Heat Pump Water Heater	Absorption Gas Heat Pump Water Heater	Adsorption Gas Heat Pump Water Heater	Absorption Gas Heat Pump Combi-OFS	Absorption Gas Heat Pump Combi -Nrs	Gas Engine Heat Pump Combi	Thermal Compression Gas Heat Pump Combi-RFF	Thermal Compression Gas Heat Pump Combi- SFm
Sector	Com	Com	Res	Com	Com	Com	Com	Res
BldgType	HGR	Asm	SFm	OfS	Nrs	Nrs	RFF	SFm
E3ClimateZone	8	8	10	8	8	8	8	10
E3GasSector	Commercial	Commercial	Residential	Commercial	Commercial	Commercial	Commercial	Residential
E3MeaElecEndUseShape	DHW HtPmp	DHW HtPmp	DEER:Res_ClothesDishWasher	DHW HtPmp	DHW HtPmp	DHW HtPmp	DHW HtPmp	DEER:Res_ClothesDishWasher
E3TargetSector	Misc._Commercial	Misc._Commercial	Res	Misc._Commercial	Misc._Commercial	Misc._Commercial	Misc._Commercial	Res
TechType	Boiler_Et	Boiler_Et	Stor_UEF	Boiler_Et	Boiler_Et	Boiler_Et	Boiler_Et	Boiler_Et
NormUnit	Cap-kBTUh	Cap-kBTUh	Each	Cap-kBTUh	Cap-kBTUh	Cap-kBTUh	Cap-kBTUh	Cap-kBTUh
NumUnits	530	193.5	1	167.5	1029	1076	130	65
UnitTherm1stBaseline	21.006	10.54	64	2.36	7.19	11.1	4.71	2.37
UnitMeaCost1stBaseline	205.53	90.1	978	97.91	102.28	103.04	12.92	68.04
UnitEndUserRebate	0 or 205.53	0 or 90.1	0 or 978	0 or 97.91	0 or 63.4	0 or 103.04	0 or 12.92	0 or 68.04
EUL_Yrs	15	15	11	15	15	15	15	15
UnitRefrigCosts	4.04	0	0	0	0	4.04	0	0

Comparable TRC Data

Overall portfolio TRC requirements are 1.25, so measures that meet or exceed a TRC of 1.25 are most desirable in a program. It is understood that often emerging technologies do not meet this TRC when they are first released into programs since they do not have the benefit of economies of scale. The TRCs for the emerging technologies in a commercial application range from 0.21 – 3.17. These are discussed for each technology in the Results & Discussion section. However, the TRCs for the emerging technologies in the single-family home with incentives are 0.45 for absorption gas heat pump water heater and 0.31 for the thermal compression gas heat pump water heater and combi. Since these are low, an additional analysis of comparable residential measure TRCs was completed using California Energy Data and Reporting System (CEDARS) data. This data was used extensively in the parallel project ET22SWG0001 and more information about it can be found in that project report. The comparable measures to these two technologies are:

- Residential Gas Storage Water Heater, Condensing
- Residential Gas Storage Water Heater, Non-Condensing
- Residential Gas Tankless Water Heater, Condensing
- Residential Gas Tankless Water heater, Non-Condensing
- Residential Solar Thermal /Gas Water Heating System

There were no claims of solar thermal or residential condensing storage water heaters from 2017-2021 so those are not shown. Table 21 shows the average TRC for each measure from 2017-2021. The TRC depends upon each climate zone, building type, actual efficiency level, and incentive.

Table 21: Comparable Residential Measure TRCs

Year	Average TRC				
Measure	**2017**	**2018**	**2019**	**2020**	**2021**
Storage Water Heater, Residential, Non-condensing	0.79	0.76	0.44	0.42	0.48
Tankless Water Heater, Residential, Condensing	0.75	0.65	0.31	0.20	0.42
Tankless Water Heater, Residential, Non-condensing	0.65	0.98	0.26	0.34	0.39

The range of TRCs for comparable residential measures is from 0.20 – 0.79 from 2017 to 2021. This shows that the gas heat pump water heater TRCs in a residential setting fall in this range of existing technologies.

Subject Matter Expert Interviews

During initial scanning and screening, no recent water heating market studies specific to California could be found. Market information is important because it affects participation of technologies in EE programs. Therefore, subject matter experts (SMEs) in water heating were contacted to understand:

- Market availability of emerging technologies
- Ease of adoption/use of identified emerging technologies
- Drivers and market barriers
- Installation and commissioning costs

This SME interview effort was done in conjunction with a parallel project (ET22SWG001) and included SMEs that were not specific to emerging technologies.

Target Audience

SMEs were interviewed across multiple categories, including various high-priority water heating manufacturers (MFG), technical experts (TE), installers (INSTR), and distributors (DIST) to characterize the emerging gas water heating market. Experts were recruited from the following sources:

- Hot Water Forum presenters
- Statewide Midstream Water Heating participation distributor list (Statewide Midstream Water Heating Program, 2022)
- South Coast Air Quality Management District List of Certified Units Pursuant to Rule 1146.2 & South Coast Air Quality Management District List of Certified Units Pursuant to Rule 1121 (which both contained contact information for certified units) (South Coast Air Quality Management District, 2022), (South Coast Air Quality Management District, 2022)
- Previous professional relationships with the GET team

Survey Questionnaire

The survey questionnaire was divided into two categories: technology adoption drivers and technology adoption barriers. The questions included the perspective of the SME, i.e., manufacturer, contractor, distributor, and the end-user. The questions used for the survey can be found in **Error! Reference source not found.**.

SME Responses

The survey responses were recorded using a 5-Point Likert Scaling system to maintain consistency and provide quantifiable answers for statistical analysis. The scaling system is based on the importance of the specific driver or barrier being questioned. Some questions do not apply to all respondents, such as manufacturing-related questions for contractors, distributors, or technical experts, which are voided. The average, standard deviation (SD), and coefficient of variations are included at the bottom for later analysis. SME interviews for this study were conducted at the same time as the parallel project ET22SWG001. However, this study focuses on the emerging technologies represented through the responses of the six (6) high-priority manufacturers and an additional anonymous manufacturer with an emerging technology that was not high priority. Table 22 and Table 23 summarize the responses from all SMEs interviewed because those results still inform the conclusions for the emerging technologies. Table 24 and Table 25 only consider the responses from manufacturers for technology adoption drivers and barriers.

Market availability of emerging technologies

There were seven (7) manufacturers of emerging technologies included in this survey. Two manufacturers produce gas-fired vapor absorption heat pump water heaters and combination systems. Of those two, (2) one manufacturer has commercially available units and one is on track to start production in 2023. There was one (1) manufacturer which produces a gas-fired thermal compression heat pump water heater and combination system. This system is not yet commercially available and there is no date for availability listed on the manufacturer website. There was one (1) manufacturer who produces an absorption heat pump water heater. This unit is not commercially available. There was one (1) manufacturer who produces a gas-engine heat pump water heater and combination system which is commercially available. Lastly, there was one manufacturer who produces a high-efficiency water heater which has a damper that does not require an electrical connection which can reduce the cost of installation since it does not require relocation of an existing electrical outlet. This unit is commercially available.

Ease of adoption/use of identified emerging technologies

Several technologies are not yet market ready, so ease of adoption does not apply until the products enter the market. In most cases for commercially available technologies, the high cost hindered the initial adoption by customers or end-users. However, many of these technologies use refrigerants that have no global warming potential or are non-toxic which helps ease adoption.

The survey results indicated that lower production costs are essential for market adoption, which could subsequently lower the initial cost of these products to customers. Most respondents indicated that customers, or end-users, opt for the lowest first-cost water heater. Several respondents expressly indicated that cost-effectiveness and historically low natural gas prices are barriers to adopting emerging, energy-efficient water heating technologies. Respondent #1 indicated there is currently no cost-effective, contractor-friendly gas-fired heat pump in the market, and there is no clear path to getting incentives in place for emerging water heating technologies, which increases the risk to the manufacturers and stakeholders when introducing emerging technologies into the market. Respondent #6 claimed that getting the customers to pay the extra premium for higher efficiency water heaters is especially challenging without incentives. Thus, providing a more straightforward means to obtain incentives for emerging technologies is critical for ease of market adoption. However, Respondent #1 has not entered the market yet but also proposed that current market research indicated a small segment of customers are willing to pay the premium. This response is consistent with Respondent #3 that stated the bulk of the market sales is minimum efficiency water heaters with only a small customer base for the high-efficiency units, which indicates that large-scale manufacturers typically focus on the minimum efficiency bulk sales acting as a barrier to market adoption for high-efficiency water heaters in the general market. This could further indicate a need for more stringent codes/standards for material movement in average efficiency of new water heater units sold.

In addition, the emerging technologies evaluated in this study generally offer better performance, more advanced features, and are better for the environment due to lower emissions. From the survey questions, it appears that better performance is essential. However, it also appears that some manufacturing SMEs view performance uncertainty, from a customer perspective, as an issue only in some cases while not an issue in others. This could mean that customers generally trust the product to perform at levels indicated by the manufacturer. Similarly, the customer's need for advanced features was considered necessary in some cases, but some customers are concerned with reliability issues that may come with additional advanced features. Thus, basic controls are preferred to maintain a reliable and straightforward operation.

Most manufacturers reported that incompatibility with existing systems is of a lower concern to adoption. This could be because some manufacturers design their products to cause minimal disruption during installations and ongoing operations. Most respondents also reported that customers are not looking at lifecycle costs during their decision process, which could mean that some customer education is necessary to increase technology uptake.

Drivers and market barriers

The refined survey results for the emerging technology SMEs show that the most significant adoption drivers are lower production costs, followed by government support for technology uptake. The most significant barriers are cost and lack of awareness by the customer or end-user, followed by adverse regulatory environments. Also, it is worth noting that one respondent indicated that the lack of installer and maintenance personnel training for new water heating technologies are considerable adoption barriers.

Lower production cost remains the most critical driver for market adoption from a manufacturer perspective. The second most important driver is government support for technology uptake (Q14). Thus, the emerging technology manufacturers are slightly more concerned about government support for emerging water heating technologies, specifically incentives and rebates that help drive the customers to pay the premium, as mentioned by several manufacturers. Almost equally important is the independent verification of performance (Q15).

As for barriers, there is an equal top scoring for technology cost (Q17) and lack of awareness among the customers (Q23). It seems that manufacturers find a lack of awareness more concerning as a barrier, followed by adverse environmental regulations (Q20). Several manufacturers mentioned designing products specific to the local regulations, but this is a barrier for many technologies.

Installation and commissioning costs

For each of the identified high-priority emerging technologies that are market ready, the commissioning costs are relatively high and act as a barrier. However, most respondents indicated incompatibilities with existing systems were not a barrier.

Survey Response Variation

The variation in responses is characterized by the coefficient of variation (CV). The top three responses with the lowest variation are (Q12), (Q17), and (Q23), showing the most agreement regarding lowering production costs as a driver, cost as a barrier, and lack of awareness by the customers as a barrier. Also, these questions scored nearly at the top, which means that these are essential considerations for the respondents, and they agree on their importance.

There is a considerable variation in (Q5) and (Q16) for drivers, which shows disagreement on the reduction of non-GHG pollutants and a shorter-to-market cycle. Some manufacturing respondents indicated that emerging water heating technologies are generally slow integrating into the market, but other respondents indicated that a shorter-to-market cycle would be very beneficial.

As for barriers, there is larger variation (Q18), (Q21), and (Q25). Thus, there was disagreement with uncertainty with future codes, uncertainty of technology performance, and higher lifecycle costs to the end-user among the high priority manufacturers.

In summary, it seems the most noticeable change, when only considering the high-priority technology manufacturers, is the uncertainty in technology performance. The respondents have widespread agreement on whether the customer considers certain performance as an important driver specifically for the high-priority technologies. Still, the largest market drivers are lower production costs and independent verification of performance. And the largest market barriers are cost, adverse regulatory environments, and lack of awareness from the customers.

In addition, (Q1), (Q4), (Q10), (Q11), (Q14), (Q15), (Q20),and (Q29) also scored high in the survey responses, indicating that positive public image, compliance with regulations, improved performance for the end user, the potential to increase customer base by utilizing emerging technology, any government support, independent verification of performance, adverse regulatory environments and lack of installer and/or contractor training are all important considerations for manufacturers as they evaluate their emerging technology product line up.

Table 22: Technology and Adoption Driver Responses All SMEs

No.	TYPE	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
1	MFG	4	3	2	3	2	1	4	2	3	4	5	5	4	4	3	3
2	MFG	5	5	5	2	2	2	2	2	2	5	5	4	4	5	4	2
3	MFG	5	1	2	5	1	4	2	3	3	2	2	4	3	5	5	3
4	MFG	3	3	3	5	–	4	4	3	4	4	4	5	4	4	5	4
5	MFG	5	3	3	5	5	5	4	4	2	4	5	5	3	3	5	5
6	MFG	4	4	3	5	5	4	3	2	4	5	–	5	4	5	5	5
7	MFG	4	2	2	5	5	3	4	1	2	5	4	5	5	4	3	3
8	TE	5	2	2	5	5	–	5	3	5	5	5	5	5	5	5	5
9	TE	4	2	2	5	–	–	2	–	–	5	–	–	3	5	3	3
10	INSTR	3	2	3	4	3	–	4	4	3	5	4	–	5	5	5	3
11	INSTR	5	2	3	5	4	–	4	1	4	5	5	5	4	4	4	3
12	INSTR	5	2	2	5	5	–	4	5	2	5	5	–	3	4	5	5
13	INSTR	3	2	2	4	4	–	2	2	3	3	5	–	3	2	5	–
14	INSTR	4	2	2	4	2	–	4	4	2	4	4	–	3	3	4	–
15	INSTR	5	4	4	3	4	–	5	3	3	4	1	–	4	4	5	–
16	DIST	5	5	2	5	5	–	2	5	4	5	3	4	4	3	5	3
Average:		4.3	2.7	2.5	4.5	3.7	3.3	3.3	2.9	3.1	4.4	4.3	4.7	3.8	4.1	4.4	3.6
STD DEV:		0.8	1.2	0.8	0.9	1.5	1.4	1.0	1.3	1.0	0.9	0.9	0.5	0.8	1.0	0.8	1.0
COV:		0.2	0.39	0.25	0.22	0.35	0.26	0.32	0.43	0.31	0.2	0.31	0.1	0.2	0.23	0.18	0.32

Table 23: Technology and Adoption Barrier Responses All SMEs

No.	TYPE	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
1	MFG	5	5	3	5	4	4	4	3	4	5	2	2	–	–	–	5
2	MFG	4	4	4	5	1	2	5	3	1	4	2	1	–	–	–	4
3	MFG	5	2	4	4	3	4	4	2	4	4	2	1	–	–	–	5
4	MFG	4	3	3	3	3	4	4	4	3	2	2	2	4	3	3	4
5	MFG	4	2	3	4	3	4	4	2	3	3	2	2	3	3	3	4
6	MFG	5	4	4	4	5	4	5	3	5	4	3	5	5	4	3	5
7	MFG	4	1	1	5	4	5	5	3	5	5	1	1	4	4	5	4
8	TE	5	5	5	2	4	1	5	2	1	5	1	1	–	–	–	5
9	TE	2	2	3	5	3	3	4	4	3	–	–	–	2	–	–	2
10	INSTR	5	5	5	5	5	5	5	3	2	2	–	2	3	3	3	5
11	INSTR	5	3	4	4	4	5	4	2	4	4	1	4	3	3	4	5
12	INSTR	4	4	2	2	4	3	3	3	4	5	2	2	3	2	3	4
13	INSTR	5	3	5	1	4	3	2	5	5	2	–	2	4	2	4	5
14	INSTR	5	3	5	4	4	4	3	4	3	1	4	4	4	4	4	5
15	INSTR	4	5	3	5	4	5	5	–	4	3	–	3	5	5	5	4
16	DIST	5	5	5	5	5	5	5	5	3	5	3	3	2	2	2	5
Average:		4.5	3.4	3.7	3.9	3.7	3.7	4.1	3.2	3.3	3.6	2.1	2.3	3.4	3.0	3.4	4.5
STD DEV:		0.8	1.3	1.2	1.3	1.0	1.2	0.9	1.0	1.3	1.4	0.9	1.3	0.9	0.8	0.8	0.8
COV:		0.18	0.38	0.32	0.38	0.27	0.31	0.21	0.31	0.37	0.38	0.43	0.53	0.29	0.31	0.26	0.18

Table 24: Technology and Adoption Driver Responses – High Priority Technology SMEs

No.	TYPE	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
1	MFG	4	3	2	3	2	1	4	2	3	4	5	5	4	4	3	3
2	MFG	5	5	5	2	2	2	2	2	2	5	5	4	4	5	4	2
3	MFG	5	1	2	5	1	4	2	3	3	2	2	4	3	5	5	3
4	MFG	3	3	3	5	–	4	4	3	4	4	4	5	4	4	5	4
5	MFG	5	3	3	5	5	5	4	4	2	4	5	5	3	3	5	5
6	MFG	4	4	3	5	5	4	3	2	4	5	–	5	4	5	5	5
7	MFG	4	2	2	5	5	3	4	1	2	5	4	5	5	4	3	3
Average:		4.1	2.7	2.6	4.3	3.7	3.7	3.3	2.4	2.9	4.1	4.2	4.7	3.9	4.3	4.3	3.4
STD DEV:		0.9	1.0	0.5	1.3	1.8	1.0	1.0	1.0	0.9	1.1	1.2	0.5	0.7	0.8	1.0	1.3
COV:		0.21	0.35	0.21	0.29	0.48	0.26	0.29	0.40	0.31	0.26	0.28	0.1	0.18	0.18	0.22	0.37

Table 25: Technology and Adoption Barrier Responses – High Priority Technology SMEs

No.	TYPE	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16
1	MFG	5	5	3	5	4	4	4	3	4	5	2	2	–	–	–	5
2	MFG	4	4	4	5	1	2	5	3	1	4	2	1	–	–	–	4
3	MFG	5	2	4	4	3	4	4	2	4	4	2	1	–	–	–	5
4	MFG	4	3	3	3	3	4	4	4	3	2	2	2	4	3	3	4
5	MFG	4	2	3	4	3	4	4	2	3	3	2	2	3	3	3	4
6	MFG	5	4	4	4	5	4	5	3	5	4	3	5	5	4	3	5
7	MFG	4	1	1	5	4	5	5	3	5	5	1	1	4	4	5	4
Average:		4.4	3.0	3.1	4.3	3.3	3.9	4.4	2.9	3.6	3.9	2.0	2.0	4.0	3.5	3.5	4.4
STD DEV:		0.5	1.4	1.1	0.8	1.3	0.9	0.5	0.7	1.4	1.1	0.6	1.4	0.8	0.6	1.0	0.5
COV:		0.12	0.47	0.34	0.18	0.38	0.23	0.12	0.24	0.39	0.28	0.29	0.71	0.2	0.17	0.29	0.12

Results & Discussion

The key findings are summarized in Table 26 below. Each separate technology is discussed after that. The two technologies which are applicable to single family residential (adsorption gas heat pump water heater and thermal compression gas heat pump combi) have low TSB and TRC values. However, that is not uncommon for residential measures. The TRC for the thermal compression gas heat pump combi in Restaurant Fast Food is very high (3.17). However, the performance data for this technology was the least robust so this should be approached cautiously. Even so, this indicates that this could be a good fit for fast food restaurants and could result in additional savings when the cooling is considered.

Table 26: High Priority Technology Overall Results

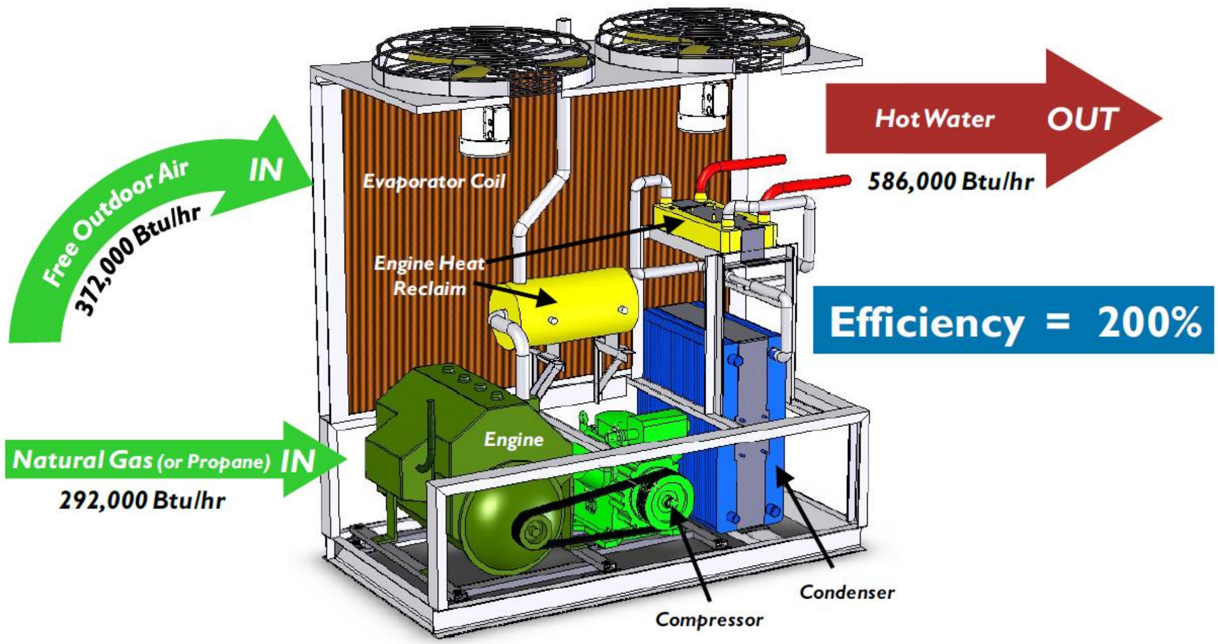
Technology/Building Type/Climate Zone	Key Barriers	% Savings	Savings/ Normalizing Unit	TSB	TRC Without Incentives	TRC with Incentives
Gas Engine Heat Pump Water Heater (Commercial Application)– Hotel Guest Room (HGR), CZ08	1. High Cost 2. Customers not aware of technology and its decarbonization benefits 3. Adverse regulatory environment 4. High ICE maintenance requirements and costs that decrease overall cost savings 5. More complex than a simple boiler 6. Performance degrades as Hot water supply temperature increases and ambient temperature decreases 7. Limited to facilities with large DHW use like very large nursing homes, hospitals, or hotels with on-site laundry[8] 8. Products not regulated now, but with some market momentum, AQMD may regulate it	44%	21.01/Cap-kBtuh	$95,375	1.03	0.88
Absorption Gas Heat Pump Water Heater (Commercial Application)– Assembly (ASM), CZ08	1. High Cost 2. Customers not aware of technology and its decarbonization benefits 3. Adverse regulatory environment 4. Lack of installer and maintenance personnel training 5. Limits on supply water temperature and return water temperature 6. Potential for complex site integration	31%	10.54/Cap-kBtuh	$17,760	1.20	1.02

Technology/Building Type/Climate Zone	Key Barriers	% Savings	Savings/ Normalizing Unit	TSB	TRC Without Incentives	TRC with Incentives
	7. When system providing space cooling, small net electricity increase coming from the electricity for the circulation pumps and HVAC fans that is not completely offset by A/C savings.					
Adsorption Gas Heat Pump Water Heater (Residential Application) – Single Family Home (SFM). CZ10	1. High Cost 2. Customers not aware of technology and its decarbonization benefits 3. Adverse regulatory environment	32%	63.6/Household	$436	0.53	0.45
Gas Engine Heat Pump Combi (Commercial Application)– Nursing Home (NRS). CZ08	1. Customers not aware of technology 2. Customers not aware that they can decarbonize with these gas-fired units 3. High ICE maintenance requirements and costs that decrease overall cost savings 4. High purchase and installation price 5. More complex than a simple boiler 6. Performance degrades as Hot water supply temperature increases and ambient temperature decreases 7. Limited to facilities with large DHW use like very large nursing homes, hospitals, or hotels with on-site laundry[8] 8. Products not regulated now, but with some market momentum, AQMD may regulate it	41%	11.10/Cap- kBtuh	$100,308	1.06	0.91

Technology/Building Type/Climate Zone	Key Barriers	% Savings	Savings/ Normalizing Unit	TSB	TRC Without Incentives	TRC with Incentives
Absorption Gas Heat Pump Combi (Commercial Application)– Office-Small (OFS). CZ08	1. Customers not aware of technology 2. Customers not aware that they can decarbonize with these gas-fired units 3. High cost of systems relative to existing tankless or gas storage 4. Limits on supply water temperature and return water temperature 5. Potential for complex site integration 6. Need for training of the workforce to install and maintain 7. When system providing space cooling, small net electricity increase coming from the electricity for the circulation pumps and HVAC fans that is not completely offset by A/C savings.	31%	2.36/Cap- kBtuh	$3,442	0.25	0.21
Absorption Gas Combi (Commercial Application)–Nursing Home (NRS), CZ08	1. Customers not aware of technology 2. Customers not aware that they can decarbonize with these gas-fired units 3. High cost of systems relative to existing tankless or gas storage 4. Limits on supply water temperature and return water temperature 5. Potential for complex site integration 6. Need for training of the workforce to install and maintain 7. When system providing space cooling, small net electricity increase coming from the electricity for the Circulation pumps and HVAC fans that is not completely offset by A/C savings.	26%	7.19/Cap- kBtuh	$64,425	0.72	0.61

Technology/Building Type/Climate Zone	Key Barriers	% Savings	Savings/ Normalizing Unit	TSB	TRC Without Incentives	TRC with Incentives
Thermal Compression Gas Heat Pump Combi (Commercial Application) – Restaurant Fast Food (RFF), CZ08	1. Customers not aware of technology 2. Customers not aware that they can decarbonize with these gas-fired units 3. High cost of systems relative to existing tankless or gas storage	46%	4.71/Cap- kBtuh	$5,332	3.74	3.17
Thermal Compression Gas Heat Pump Combi– Single Family Home (SFM). CZ10	1. Customers not aware of technology 2. Customers not aware that they can decarbonize with these gas-fired units 3. High cost of systems relative to existing tankless or gas storage	49%	2.37/Cap- kBtuh	$1,368.89	0.36	0.31

Figure 7: Air-Source Gas Engine Heat Pump Water Heater and Combi (Tecogen, 2022)



Gas Engine Heat Pump Water Heater and Combi

There is a commercially available air source unit as well as a water source unit from one manufacturer. Both can be operated in a DHW-only system, DHW & space heating (combi) system, or a space heating-only system. These units do not currently have to meet AQMD requirements because they are under 50 hp. However, they may have to meet these requirements in the future. They have an existing emissions control system that that manufacturer claims meets AQMD requirements that apply to other units. These systems are regulated by Title 24, but the Title 24 minimum COP is based upon ANSI Z21.40.4A. The manufacturer's unit was certified by ANSI Z21.40.2. More research is necessary to understand how these standards differ.

These units fall in the middle of the pack regarding the amount of solar offset they require for a building to achieve Zero Net Energy.

There is third-party information available for the performance of these units. These systems can modulate to meet the water heating demand (DHW and/or HHW) which is an advantage. The TRCs for these systems are close to 1.0 which is also an advantage for an emerging technology.

However, the biggest drawback of these systems is their high upfront cost and the additional maintenance cost required for the internal combustion engine. Of all the technologies examined in this study, these have the highest up-front cost. The additional maintenance cost for these systems was not considered in the TRC analysis but will affect a customer's decision whether to install them or not. Additionally, over the course of this study, it was found that these are installed most commonly in areas where electrical service is hard to get which does not characterize most of California.

Absorption Gas Heat Pump Water Heater & Combi

Figure 8: Robur Absorption Gas Heat Pump Water Heater & Combi Air Source Unit

Figure 9: Robur Absorption Gas Heat Pump Water Heater & Combi Water Source Unit

There is one (1) manufacturer who has a commercially available air source and water source units which can be used in a DHW-only system, a DHW and space heating (combi) system, and a space heating-only system. There is one (1) manufacturer with a unit that is available outside the U.S. There are two (2) manufacturers with units that are not yet commercially available and are planned to launch in 2023. One of these units that is not yet commercially available is launching in a residential application first, and it is unknown when they will launch their unit for a commercial application. The GET team was unable to contact the other two manufacturers over the course of this study.

Figure 10: ANESI Absorption Water Heater and Combi (Stone Mountain Technologies, Inc, 2022)

These units do have to meet AQMD Ultra-Low NOx requirements. The manufacturer's provided emissions data for the commercially available unit in the U.S. meets those requirements. Title 24 and Title 20 have gaps in their standards regarding these systems. Title 24 does not have an applicable table for gas-fired absorption heat pumps. In Title 20, none of the definitions of boilers or heat pump water heaters completely describe these systems. These systems require the most amount of solar offset for a building to achieve Zero Net Energy.

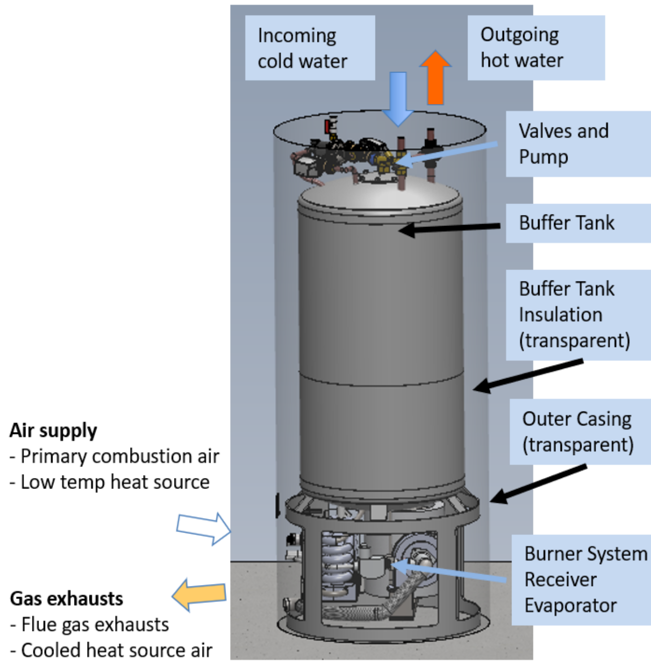
There is publicly available third-party performance data via field studies for the commercially available air source unit in the U.S. There is some publicly available third-party performance data available for one of the units expected in 2023. However, data that is useful to create a performance curve with COP and ambient air temperature was done at a residential site. At the time of this writing, data for a commercial site does not appear to be publicly available. Summaries of testing at commercial sites are available, but these could not be used in the energy savings analyses done in this study. No performance data for the commercially available water source unit could be found and no performance data for the other two (2) manufacturers could be found.

Data for the commercially available air source unit in the U.S. has been used to create a measure package for multifamily systems. However, more data is required to reinforce the measure package based upon feedback shared with the GET team from the CPUC. These systems do not modulate to the load of a building. Rather, they cycle ON and OFF based upon the water temperature returning to the equipment.

The TRCs for the absorption gas heat pump water heater & combi range from 0.21 to 1.02. This indicates that the unit needs to be properly sized for the DHW/HHW demand in the building this system is installed in to maximize the cost-effectiveness. Conversations with contractors over the course of this study indicate that there is a need to understand characteristics of buildings which are good candidates for this technology. Additionally, the lack of installer and maintenance professional training is a barrier for this technology which needs to be addressed to see adoption of this technology.

Adsorption Gas Heat Pump Water Heater

Figure 11: Adsorption Gas Heat Pump Water Heater



There is one (1) unit from one (1) manufacturer that is currently in research and development. It is assumed that AQMD standards will apply to this unit and no information is available on its NOx emissions. It is also assumed that the Title 20 standards for the minimum UEF of gas-fired storage water heaters will also apply to this unit. The manufacturer provided estimates of UEF meet & exceed the minimum UEF. This technology falls towards the lower end of the required amount of solar offset for zero net energy.

This technology does not require performance curves since it is rated based on a single UEF value. However, it does need third-party testing to validate the UEF. Further, this technology is not yet commercially available, and a commercial launch date has not yet been set.

The TRC of this technology is less than 1.25 but that is not uncommon for residential measures. Further since the cost of this unit is projected to be similar to the cost of tankless condensing efficiency water heaters, the cost is probably not a huge barrier. The participation of tankless condensing efficiency water heaters in the residential sector has increased significantly over the last 3 years.

Thermal Compression Gas Heat Pump Combi

There is one (1) manufacturer with one (1) unit in field testing studies across North America. There was another manufacturer that had commercially available units outside of the U.S., but the units had some reliability issues, so the company is addressing those before continuing production. The data in this study is from the manufacturer with the unit in field testing.

AQMD standards do apply to these units. However, the emissions of these units are unknown. Title 24 and Title 20 have gaps in their standards regarding these systems. Title 24 does not have an applicable table for gas-fired thermal compression heat pumps. In Title

20, none of the definitions of boilers or heat pump water heaters completely describe these systems.

This system requires the least amount of solar offset for a zero net energy building. It is also being designed to be hydrogen-ready according to the manufacturer, and it can accept heat from electric heating sources to run the thermodynamic cycle that creates the hot and cold reservoir. Additionally, the costs to replace a space heater and offset space cooling need to be considered to understand the cost comparison of this technology to typical baseline systems.

This system lacks performance data. Over the course of this study, no third-party data was found that gives COP as a function of outside air temperature. Assumptions were made in the energy savings calculations about COP as a function of outside air temperature.

The TRC for this measure in fast food restaurant is attractive at 3.17. This number should be taken with caution due to the lack of third-party performance data, but that TRC is an indication that this technology is a good candidate for future study. The TRC for this measure in single family homes is less than 1, but that is not uncommon in residential measures. However, the cost of the technology is very high for a residential measure. If this technology can replace the space heating system and off-set the cooling in addition to replacing the water heater, it may be attractive to single family home customers. However, much more research is needed to understand how much cooling could be offset by this technology and what kind of modifications would need to be made to existing homes for that to happen.

Gaps

Calculation gaps were discussed at length in the "High-Level Energy Savings and Gaps" section. A summary of those gaps and other gaps is presented here.

Codes & Standards

There were several gaps identified in codes & standards. Title 24 has minimum space heating COP requirements for gas engine heat pumps in Table 110.2C. However, the COP in Table 110.2C is based upon test procedure ANSI Z21.40.4A while the commercially available unit is certified using ANSI Z21.40.2. More research would need to be done to determine the differences in these two test procedures. Title 24 does not have space heating COP requirements for gas-fired absorption heat pumps, gas-fired adsorption heat pumps, or gas-fired thermal compression heat pumps. Title 24 refers to Title 20 for water heating minimum efficiencies. Title 20 section 1602 has definitions for "package boiler," "hot water supply boiler," and "commercial heat pump water heater," but none of these definitions fully describes any of the gas-fired heat pump technologies. It appears that energy efficiency codes & standards have been written with electric-driven heat pumps in mind. This is a gap which will require coordination between the GET program and codes & standards groups.

Calculation Tools

The DWHC and DEER models will both require modifications to correctly represent energy consumption of these gas heat pump water heaters. The DWHC will require less effort to modify than the DEER template models. It is unknown if the planned update to the DEER prototype models using Energy Plus (rather than eQuest) will include DHW in the models. If DHW is not included in the models, a workaround will still be required to model combination systems.

Performance Data

More third-party part-load performance data is needed on all of these technologies to properly model the savings. Available part-load performance data is from a mixture of field and lab studies and does not include all available units in all sectors. For example, performance data for the commercially available air source absorption gas heat pump water heater & combi is from field studies that gives COP as a function of ambient air temperature, but it does not give COP at varying supply or return water temperatures. On the other hand, part-load performance data for the other absorption system that is launching in North America in 2023 does include data on COP at varying outside air temperatures, return water temperatures, and supply water temperatures, but it is from a residential setting. The performance data on this same system in a commercial setting is not yet publicly available. There is no third-party performance data available for the adsorption gas heat pump water heater, thermal compression gas heat pump water heater & combi, or the water source gas engine and absorption gas heat pump water heaters & combis.

Glycol is often added to the water loops for these systems to prevent freezing which impacts performance curves. Additionally, the addition of glycol will likely require the addition of a double walled heat exchanger, which will further impact performance. Performance data to correct for the glycol and heat exchanger are also needed.

Lastly, there are no testing standards for gas-fired heat pump water heaters at part-load conditions. This has resulted in part-load performance information that is presented differently in each study with differing data points.

Measure Case Installations

Measure case installations vary and need more investigation. In conversations with one manufacturer, it was found that there are three main system configurations that incorporate the emerging water heating technologies:

1. The new system is comprised solely of one or more gas heat pump water heaters which are sized for the peak hot water load of the building. The system may cycle one or more units off when the difference in supply and return temperature is too low. If the system can modulate, it may modulate down to match the load of the buildings.
2. The new system is comprised of one or more gas heat pump water heaters and integrates with the existing water heaters and/or boilers. If the existing boilers/water heaters are not condensing efficiency boilers the gas heat pump water heaters do not run at the same time as the boilers. This is because the output water temperature of the gas heat pump water heaters is too low to run at the same time as a non-condensing boiler/water heater. Therefore, when the load of the building is higher than the gas heat pump water heater(s) or the required supply water temperature exceeds what the gas heat pump water heater can provide, the controls system shuts down the emerging technology water heater(s) and turns ON the existing boilers.
3. The new system is comprised of one or more gas heat pump water heaters and integrates with new condensing efficiency water heaters and/or boilers. Condensing efficiency water heaters/boilers can run at lower supply water temperatures, so they can run at the same time as the emerging technology water heaters. In this case, when the hot water load exceeds the capacity of the emerging technology water heaters, the controls system turns on the water heater/boiler(s) and both run at the same time.

Each measure-case system has different implications for energy usage inputs and EE reporting metrics (Measure Cost, EUL, etc). Additionally, measure costs are a gap that has implications for customer return on investment and EE reporting metrics.

Market Barriers

The most substantial market barriers found were:

1. High cost of the emerging technologies: respondents indicated that cost is the number one concern for a customer
2. Lack of awareness about these technologies: Customers do not know that these technologies exist and that they can decarbonize with these technologies.

3. Lack of installer and maintenance personnel training: Contractors/installers/DHW&HVAC maintenance personnel do not know how to install or maintain these technologies which limits adoption.
4. Adverse regulatory environment: Many requirements banning the use of natural gas altogether have created a barrier for more efficient gas technologies to compete in the market.

Conclusions & Recommendations

A list of seventeen (17) emerging water heating technologies from a Water Heating Technology Table (WHTT) generated in project ET22SWG001 were prioritized. Out of seventeen (17) technologies, six (6) were selected as high-priority for further analysis. These six (6) technologies were:

- Gas Engine Heat Pump Water Heater (Commercial Application)
- Absorption Gas Heat Pump Water Heater (Commercial Application)
- Adsorption Gas Heat Pump Water Heater (Residential Application)
- Gas Engine Heat Pump Combi (Commercial Application)
- Absorption Gas Heat Pump Combi (Commercial Application)
- Thermal Compression Gas Heat Pump Combi (Residential and Commercial Application)

For all six (6) technologies, further research was completed on applicable codes & standards, applicability to zero net energy (ZNE) and applicability to disadvantaged communities and hard to reach customers (DAC/HTR). Energy savings and cost-effectiveness were also calculated for each of these six (6) technologies. Lastly, subject matter expert (SME) interviews were conducted in conjunction with project ET22SWG001 and results were presented in this study with a focus on the six (6) high-priority technologies.

A summary of the findings for each technology was presented which includes:

- Key barriers
- Percent energy savings over baseline equipment
- Energy savings per normalizing unit
- Total system benefit (TSB)
- Total resource cost (TRC) with and without incentives

Market barriers were discussed further after the summary of key findings. In addition, gaps in codes and standards, calculation tools, performance data, and measure case installation configuration options were identified.

After review of the overall findings, the following technologies are recommended for further study:

- Absorption Gas Heat Pump Water Heaters (Commercial Application)
- Adsorption Gas Heat Pump Water Heaters (Residential Application)
- Absorption Gas Heat Pump Combi (Commercial Application)
- Thermal Compression Gas Heat Pump Water Heaters and Combis (Residential and Commercial Application)

These are promising emerging water heating technologies based upon their energy savings, cost-effectiveness and applicability to the California market. No further testing is recommended on the Gas Engine Heat Pump Water Heater (commercial application) and Gas Engine Heat Pump Combi (commercial application) at this time due to the high-up front cost, additional maintenance costs for the combustion engine, and typical sites where the commercially available unit has been installed. It is also recommend that the GET Program perform work to close identified gaps and address the market barriers for these technologies. The specific recommendations for each technology are discussed below.

Currently, an absorption gas heat pump water heater is in development for use as a drop-in replacement for existing residential water heaters. This unit was on the initial list of seventeen (17) emerging technologies, and it is different than the high-priority absorption heat pump water heaters discussed in this project (the absorption heat pump water heaters in this project are applicable to commercial buildings rather than residential). It has shown positive performance and has a large potential market size because it is a drop-in replacement. Due to the manufacturer focusing on the launch of other products at this time, it was not selected as a high-priority technology so no further analysis was completed. When the time comes for its commercial launch, it is also recommended that lab and field studies be initiated for further evaluation.

Absorption Gas Heat Pump Water Heaters & Combis

Field and/or lab testing should be conducted on commercially available units (air-source and water-source) to obtain performance curve data, installation cost data, and installation configurations. Lab and/or field testing should be performed on pre-commercialized units when available. It is also recommended that any cooling offsets of these technologies be further evaluated in a lab or in the field. Field and/or lab testing should be performed on all manufacturer units that could not be reached during this study. Emissions testing should be completed on these units when emissions data is not available. CO_2 load shapes should be investigated for these units and compared to their electric competitors.

Adsorption Gas Heat Pump Water Heater

Lab testing should be conducted on these units, including its UEF and NOx emissions. CO_2 load shapes should also be investigated for this unit for comparison to its electric competitors.

Thermal Compression Gas Heat Pump Water Heater and Combi

Lab testing should be conducted on these units to obtain performance curve data and NOx emission data. Additionally, more recent cost data is needed along with investigation of the implications that can occur when these systems are installed to provide DHW heating, HHW heating and space cooling. CO_2 load shapes should be investigated for these units for comparison to their electric competitors.

Closing Gaps & Addressing Market Barriers

The GET Program will work with other organizations to support the development of tools and models that can accurately replicate Gas-Fired Heat Pump Water Heating systems in general, and in the context of California EE programs.

The GET Program should investigate the different measure case system configurations for all of the emerging technologies recommended herein for further study. Costs and whole-system performance should also be investigated for each system configurations.

The GET Program should also provide the gaps found in Title 24 and Title 20 to the Codes & Standards teams so they can be addressed.

The GET Program should work with Workforce Education & Training to address the lack of awareness for these technologies and the need for professional installer and maintenance training. The program should work with Marketing to address the lack of customer awareness of these technologies that offer better performance and decarbonization.

Appendices

Appendix I. Technology Scoring Details

Below are the specific scoring guidelines used for the emerging water heating technologies

Table 27: Technology Scoring Details

Consideration	Description
Program	TRC/Simple Payback TRC: 5: 1.25+ 4: 1.0-1.25 3: 0.9-1.0 2: 0.8-0.9 1: <0.8 Simple Payback 5: 5-7 years 4: 7-10 years 3: 10-15 years 2: 15-20 years 1: 20+ years
Program	Market Size- Residential 5: >150k 4: 100-150k 3: 75k – 100k 2: 25k-75k 1: <25k Commercial 5: 5 - >10k 4: 4 – 7k-10k 3 : 5k-7k 2: 3k-5k 1: 1- <3k
Program	Potential to complete a field/lab study within 3 years? 5: Yes 3: Maybe 1: No
Program	Potential for a joint project with cooperation from other internal IOU programs 5: Yes 3: Maybe 1: No

Consideration	Description
Program	Product performance 5: COP>1.9 4: COP 1.5-1.8 3: COP 1.1-1.4 2: COP 0.8-1.0 1: COP <.7
Program	Time to commercialization 5: 0 yrs 4: 1 yr 3: 2 yrs 2: 3 yrs 1: 4+ yrs
Customer	Added functionality 5: 3 addl functions (space heating, space cooling, remotely controlled) 4: 2 functions (heating, cooling) 3: 1 function (heating) 2: 1 function (remote control) 1: no added functions
Customer	Material Cost 5: Equal to or less than condensing efficiency material cost 4: 1-1.5x condensing efficiency material cost 3:1.5- 2x condensing efficiency material cost 2: 2-3x condensing efficiency material cost 1: 3X or greater than condensing efficiency material cost
Customer	Installation Cost/Complexity *If install costs available* 5: Equal to or less than condensing efficiency installation cost 4: 1- 1.5x condensing efficiency installation cost 3: 1.5-2x condensing efficiency installation cost 2: 2-3x condensing efficiency installation cost 1: 3X or greater than condensing efficiency installation cost *If costs not available use engineering judgement of complexity of installation* 5: Low Complexity (Nothing new required) 4: Medium-Low Complexity (New venting, new gas lines) 3: Medium complexity (Residential – new electrical) 2: Medium-High Complexity (Residential – new electrical and new venting or gas lines, new hydronic loops) 1: High complexity (Residential – new electrical and new water lines)
Market	Market Readiness 5: Mature 4: Growing 3: Niche 2: Limited Availability 1: Pre-Commercialization

Consideration	Description
Market	Technology brand awareness/brand equity among customers, distributors, and installers 5: Brand already established in the market 4: Brand not already established in the market
Market	Confidence in technology – distributor and installers confident in the technology 5: A distributor already carrying technology 4: No distributor carrying technology
Regulatory	Testing standards 5: Testing standards exist 3: No testing standards but they are being developed 1: No testing standards and none being developed
Regulatory	Software Tools 5: Compliance software exists 4: No compliance software, but software to calculate energy usage/savings exists 3: No compliance or energy usage software exists but at least one is being developed 1: No compliance or energy savings software and none being developed
Regulatory	Risk that technology will be prohibited/made obsolete by state or local codes 5 – Low risk 3 – Medium risk 1 – High risk

Table 28: Emerging Water Heating Technology Prioritization

Technology Name & Sector	Description	Priority
Machine Learning Water Heating Controls-Res	Machine learning controls that save water heating energy by reducing temperature setpoint of hot water during low-demand times. Single Family	Medium
Commercial Gas Engine Heat Pump Water Heater-Com	Heat pump water heater utilizing **mechanical** output of a gas-driven internal combustion engine to drive a vapor compression cycle (Multifamily & Commercial)	High
Residential Vapor Absorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Single-Family)	Medium
Commercial Vapor Absorption Gas Heat Pump Water Heater-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Multifamily & Commercial)	High
Residential Adsorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. (Single-Family)	High
Ejector Sorption Assisted Gas Heat Pump Water Heater-Res	Thermal energy provided by the combustion of natural gas drives an ejector heat pump system assisted by sorption to increase COP. Ejector replaces the compressor in a vapor-compression cycle[18].	Low
Self-Powered High Two-Phase Thermo-Syphoning Residential Gas Storage Water Heaters-Res	Competitive cost higher efficiency (non-condensing) tank water heater utilizing Two-Phase Thermo-Syphoning Technology	Medium
Non-Powered Damper Commercial Gas Storage Water Heaters-Com	Competitive cost higher efficiency tank water heater with non-powered damper	Low
Residential Waste-Water Heat Recovery HX (Water Pre Heat)-Res	Utilizing a heat exchanger to use waste hot drain water to pre heat water going into a water heater (Single-family)	Low
Commercial or Multifamily Wastewater Heat Recovery HX (Water Pre Heat)-Com	Utilizing a heat exchanger to use waste heat to pre heat water going into a water heater (Multifamily & Commercial)	Low
Equipment Specific Greywater Recycling with Heat Recovery-Res	Means to collect grey water and recover heat from it for pre-heating hot water for an individual piece of equipment or sink/shower	Medium

Technology Name & Sector	Description	Priority
Commercial Gas Engine Heat Pump Combi System-Com	Heat pump utilizing **mechanical output** of a gas-driven internal combustion engine to drive a vapor compression cycle to provide 2+ of the following 1. Space heating 2. Space cooling 3. DHW heating	High
Residential Vapor Absorption Gas Heat Pump Combi System-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	Medium
Commercial Vapor Absorption Gas Heat Pump Combi System-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	High
Residential Vapor Adsorption Gas Heat Pump Combi System-Res	Heat pump utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	Low
Thermal Compression Gas Heat Pump Combi System-Res & Com	Thermal energy provided by the combustion of natural gas powers a thermodynamic compression cycle. Helium is the working fluid. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	High
Combination Space and Gas Heat Pump Water Heating System Controls -Res & Com	Controls for equipment that provides heating and hot water using gas-burner.	Medium

Appendix II. Codes & Standards Information

Gas Engine Heat Pump Water Heater and Combination

AQMD

1. SCAQMD standards regulating emissions from stationary Internal Combustion Engines (rule 1470, rule 1110.2) regulate IC engines with >50 hp. Manufacturer spec sheet states it is <50hp so these standards do not apply

Title 24/Title20/DOE

1. Space Heating
    a. Section 110.2 regulates space conditioning systems. Table 110.2C Air Cooled Gas-Engine Heat Pumps regulates COP for heating and cooling mode.
    b. GAP: Title 24 COP based upon ANSI Z21.40.4A. The manufacturer's unit was certified by ANSI Z21.40.2. The standards are similar in name.
1. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 © includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
        i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
        ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
        iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
        iv. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Absorption Gas Heat Pump Water Heater and Combination

AQMD

1. Boiler
    a. SCAQMD definition of Boiler or Steam Generator from Rule 1146.2 is as follows:
        i. "BOILER OR STEAM GENERATOR means any equipment that is fired with or is designed to be fired with natural gas, used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale."
    b. These units are designed to be fired by natural gas and they heat water (though indirectly), so this SCAQMD rule applies to this unit when it is heating HHW or both HHW and DHW.
    c. Rule 1146.2 defines a Type I unit as "TYPE 1 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY less than or equal to 400,000 BTU per hour excluding TANK TYPE WATER HEATERS subject to the limits of District Rule 1121"
    d. These units are less than 400,000 btu/h so they are "Type 1" units
    e. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).
    f. Manufacturer's provided emissions are 0.021-0.026 lb/MMbtu which converts to 21-26 lb/billion BTU
2. Water Heater
    a. SCAQMD definition of water heater from Rule 1146.2 is as follows "WATER HEATER means any equipment that is fired with or designed to be fired with natural gas and that is used solely to heat water for use external to the equipment"
    b. These units are designed to be fired by natural gas and when installed in a DHW only configuration, it solely heats water for use external to the equipment (though indirectly), so this SCAQMD rule applies to this unit. These units are less than 400,000 btu/h so they are "Type 1" units
    c. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).

Title 24/Title20/DOE

1. Space Heating
    a. Title 24 Section 110.2 regulates space conditioning systems. However, there is no table for gas-fired absorption heat pumps.
    b. Therefore, Title 24 does not apply and there is a gap in the standards

2. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
        i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
        ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
        iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
        iv. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Adsorption Gas Heat Pump Water Heater

AQMD

1. No info available on the size of this unit, but since it is designed to be a residential unit assume that SCAQMD rule 1121 applies.
2. Definition of a water heater from Rule 1121 is as follows "WATER HEATER means a closed vessel other than a mobile home water heater in which water is heated by combustion of gaseous fuel and is withdrawn for use external to the vessel at pressures not exceeding 160 psig, including the apparatus by which heat is generated and all controls and devices necessary to prevent water temperatures from exceeding 210°F (99°C)."
3. This technology meets this definition, because it is a closed vessel in which water is heated by combustion of gaseous fuel and water is withdrawn for use external to the vessel at pressures not exceeding 160 psig. The technology has integral potable water storage. Therefore, NOx limits ©(c)(3) apply: limit of 10 nanograms per Joule or 15 ppm

Title 24/Title20/DOE

1. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. No Spec sheet with input rating of this water heater is available so assume it meets the definition of a "Gas-fired storage water heater" that is a federally regulated consumer product from definitions in 1602(f)
    e. Standards for minimum UEF for gas-fired storage water heater from section 1605.1(f) apply to this unit
    f. On 1/11/22 DOE published a supplemental notice of proposed rulemaking to amend the test procedure for consumer water heaters and residential duty-commercial water heaters. The updated test procedure proposes to allow for voluntary representations at certain additionally specified test conditions for heat pump water heaters (Department of Energy, 2022).

Thermal Gas Compression Combi – Residential & Commercial

AQMD

1. Boiler
    a. SCAQMD definition of Boiler or Steam Generator from Rule 1146.2 is as follows:
        i. "BOILER OR STEAM GENERATOR means any equipment that is fired with or is designed to be fired with natural gas, used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale."
    b. These units are designed to be fired by natural gas and they heat water (though indirectly), so this AQMD rule applies to this unit when it is heating HHW or both HHW and DHW.
    c. These units are less than 400,000 btu/h so they are "Type 1" units
    d. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).
2. Water Heater
    a. Documentation on technology is not clear if it has an internal potable water tank, but conversations with manufacturer indicate the equipment does not have internal potable water storage so it is not a "water heater" as defined by rule 1121.
    b. SCAQMD definition of water heater from Rule 1146.2 is as follows "WATER HEATER means any equipment that is fired with or designed to be fired with natural gas and that is used solely to heat water for use external to the equipment"
    c. These units are designed to be fired by natural gas and, when installed in a DHW only configuration, it solely heats water for use external to the equipment (though indirectly), so this SCAQMD rule applies to this unit.
    d. These units are less than 400,000 btu/h so they are "Type 1" units
    e. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).

Title 24/Title20/DOE

1. Space Heating
    a. Title 24 section 110.2 regulates space conditioning systems.
    b. Therefore, Title 24 does not apply and there is a gap in the standards
2. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)

b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
    i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
    ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
    iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
    iv. It is not a gas-fired storage water heater because it does not contain potable water
    v. It is not a gas-fired instantaneous water heater because it does not contain potable water
    vi. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Additional AQMD Information

SCAQMD Rule Names and Applicability

Rules 1121: CONTROL OF NITROGEN OXIDES FROM RESIDENTIAL TYPE, NATURAL GAS-FIRED WATER HEATERS- Applicable to: This rule applies to manufacturers, distributors, retailers, and installers of natural gas-fired water heaters, with heat input rates less than 75,000 Btu per hour.

Rule 1146.2: EMISSIONS OF OXIDES OF NITROGEN FROM LARGE WATER HEATERS AND SMALL BOILERS AND PROCESS HEATERS- Applicable to: This rule applies to units that have a rated heat input capacity less than or equal to 2,000,000 BTU per hour. Type 1 Units as defined in this rule are typically, but not exclusively, large water heaters or smaller-sized process heaters in the above range. Type 2 Units as defined in this rule are typically, but not exclusively, small boilers or larger-sized process heaters in this range but Excludes Tank Type Water Heaters that are subject to limits in rule 1121.

Rule 1146: EMISSIONS OF OXIDES OF NITROGEN FROM INDUSTRIAL, INSTITUTIONAL, AND COMMERCIAL BOILERS, STEAM GENERATORS, AND PROCESS HEATERS- Applicable to: This rule applies to boilers, steam generators, and process heaters of equal to or greater than 5 million Btu per hour rated heat input capacity used in all industrial, institutional, and commercial operations.

Definitions

Rule 1146 & 1146.2: "BOILER or STEAM GENERATOR means any combustion equipment fired with liquid and/or gaseous (including landfill and digester gas) and/or solid fossil fuel and used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale. Boiler or Steam Generator does not include any open heated tank, adsorption chiller unit, or waste heat recovery boiler that is used to recover sensible heat from the exhaust of a combustion turbine or any unfired waste heat recovery boiler that is used to recover sensible heat from the exhaust of any combustion equipment."

Rule 1146 & 1146.2 "PROCESS HEATER means any equipment that is fired with or is designed to be fired with natural gas and which transfers heat from combustion gases to water or process streams. Process Heater does not include any kiln or oven used for annealing, drying, curing, baking, cooking, calcining, or vitrifying; or any unfired waste heat recovery heater that is used to recover sensible heat from the exhaust of any combustion equipment."

Rule 1146.2 “TANK TYPE WATER HEATER means a WATER HEATER with a RATED HEAT INPUT CAPACITY from 75,000 BTU per hour to 2,000,000 BTU per hour and with an integral closed vessel in which water is heated and stored for use external to the vessel.”

Rule 1146.2 “TYPE 1 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY less than or equal to 400,000 BTU per hour excluding TANK TYPE WATER HEATERS subject to the limits of District Rule 1121.”

Rule 1146.2 “TYPE 2 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY greater than 400,000 BTU per hour up to and including 2,000,000 BTU per hour.”

Rule 1121 “WATER HEATER means a closed vessel other than a mobile home water heater in which water is heated by combustion of gaseous fuel and is withdrawn for use external to the vessel at pressures not exceeding 160 psig, including the apparatus by which heat is generated and all controls and devices necessary to prevent water temperatures from exceeding 210°F (99°C).”

Additional Title 20 Information

Definitions from Section 1602

"Boiler" means a space heater that is a self-contained appliance for supplying steam or hot water primarily intended for space-heating. "Boiler" does not include hot water supply boilers."

"Commercial packaged boiler" means a type of packaged low-pressure boiler that is industrial equipment with a capacity (rated maximum input) of 300,000 Btu per hour (Btu/hr) or more which, to any significant extent, is distributed in commerce:

1. For heating or space conditioning applications in buildings; or
2. For service water heating in buildings but does not meet the definition of "hot water supply boiler" in this part."

"Packaged boiler" means a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls, usually shipped in one or more sections and does not include a boiler that is custom designed, and field constructed. If the boiler is shipped in more than one section, the sections may be produced by more than one manufacturer and may be originated or shipped at different times and from more than one location."

"Space heater" means an appliance that supplies heat to a space for the purpose of providing warmth to objects within the space. "Space heater" includes but is not limited to boilers (except hot water supply boilers), furnaces, room heaters, floor furnaces, wall furnaces, infrared heaters, unit heaters, duct furnaces, and combination space-heating and water-heating appliances."

"Hot water supply boiler" means a packaged boiler that is industrial equipment and that:

1. has an input rating from 300,000 Btu/hour to 12,500,000 Btu/hour and of at least 4,000 Btu/hour per gallon of stored water.
2. is suitable for heating potable water; and
3. meets either or both of the following conditions:
   a. it has the temperature and pressure controls necessary for heating potable water for purposes other than space heating; or
   b. the manufacturer's product literature, product markings, product marketing, or product installation and operation instructions indicate that the boilers intended uses include heating potable water for purposes other than space heating.

"Air-source commercial heat pump water heater" means a commercial heat pump water heater that utilizes indoor or outdoor air as the heat source."

"Commercial heat pump water heater (CHPWH)" means a water heater (including all ancillary equipment such as fans, blowers, pumps, storage tanks, piping, and controls, as applicable) that uses a refrigeration cycle, such as vapor compression, to transfer heat from a low-temperature source to a higher-temperature sink for the purpose of heating potable water, and has a rated electric power input greater than 12 kW. Such equipment includes, but is not limited to, air-source heat pump water heaters, water-source heat pump water heaters, and direct geo-exchange heat pump water heaters.

"Gas-fired storage water heater" that is a federally regulated consumer product means a water heater that uses gas as the main energy source, has a nameplate input rating of 75,000 Btu/h or less, and contains more than one gallon of water per 4,000 Btu per hour of input.

"Gas-fired storage water heater" that is federally regulated commercial and industrial equipment means a water heater that uses gas to heat and store water within the appliance at a thermostatically controlled temperature for delivery on demand and has a rated input both greater than 75,000 Btu/hour and less than 4,000 Btu/hour per gallon of stored water.

"Gas-fired instantaneous water heater" that is a federally regulated consumer product means a water heater that uses gas as the main energy source, has a nameplate input rating less than 200,000 Btu/h, and contains no more than one gallon of water per 4,000 Btu per hour of input.

"Gas-fired instantaneous water heater" that is federally regulated commercial and industrial equipment means a water heater that uses gas as the main energy source and has a rated input both greater than 200,000 Btu/h and not less than 4,000 Btu/h per gallon of stored water.

Title 20 Section 1605.1(f) Standards for Water Heaters

Product Class	*Rated Storage Volume and Input Rating (if applicable)*	*Draw Pattern*	*Minimum Uniform Energy Factor**
Gas-fired Storage Water Heater	≥ 20 gallons and ≤ 55 gallons	Very small	0.3456 – (0.0020 × V_r)
		Low	0.5982 – (0.0019 × V_r)
		Medium	0.6483 – (0.0017 × V_r)
		High	0.6920 – (0.0013 × V_r)
	> 55 gallons and ≤ 100 gallons	Very small	0.6470 – (0.0006 × V_r)
		Low	0.7689 – (0.0005 × V_r)
		Medium	0.7897 – (0.0004 × V_r)
		High	0.8072 – (0.0003 × V_r)
Oil-fired Storage Water Heater	≤ 50 gallons	Very small	0.2509 – (0.0012 × V_r)
		Low	0.5330 – (0.0016 × V_r)
		Medium	0.6078 – (0.0016 × V_r)
		High	0.6815 – (0.0014 × V_r)
Electric Storage Water Heaters	≥ 20 gallons and ≤ 55 gallons	Very small	0.8808 – (0.0008 × V_r)
		Low	0.9254 – (0.0003 × V_r)
		Medium	0.9307 – (0.0002 × V_r)
		High	0.9349 – (0.0001 × V_r)
	> 55 gallons and ≤ 120 gallons	Very small	1.9236 – (0.0011 × V_r)
		Low	2.0440 – (0.0011 × V_r)
		Medium	2.1171 – (0.0011 × V_r)
		High	2.2418 – (0.0011 × V_r)
Tabletop Water Heater	≥ 20 gallons and ≤ 120 gallons	Very small	0.6323 – (0.0058 × V_r)
		Low	0.9188 – (0.0031 × V_r)
		Medium	0.9577 – (0.0023 × V_r)
		High	0.9884 – (0.0016 × V_r)
Instantaneous Gas-fired Water Heater	< 2 gallons and >50,000 Btu/h	Very small	0.80
		Low	0.81
		Medium	0.81
		High	0.81
Instantaneous Electric Water Heater	< 2 gallons	Very small	0.91
		Low	0.91
		Medium	0.91
		High	0.92
Grid-Enabled Water Heater	> 75 gallons	Very small	1.0136 – (0.0028 × V_r)
		Low	0.9984 – (0.0014 × V_r)
		Medium	0.9853 – (0.0010 × V_r)
		High	0.9720 – (0.0007 × V_r)
* V_r = Rated Storage Volume in gallons.			

Appendix III. Gas Engine and Absorption Gas Heat Pump Water Heater Energy Savings Calculations

This section gives details on the energy savings calculations for gas engine and absorption gas heat pump water heaters. These systems can also be installed as combination systems, but this appendix only shows the energy savings in a water heating-only application.

Gas Engine Heat Pump Water Heater

Baseline Energy Usage

The baseline for measure SWWH007-04 I was used as the baseline for this calculation. The measure offering description for this measure is "Commercial Stor. heater, > 75 kBtu/hr, 0.96 TE." The gas engine heat pump water heater is not a storage water heater, but it does have a storage tank and it is >75kkBtu/hr.

The appropriate baseline water heater was selected in the DWHC ("Stor_TE-Gas-100gal-gte75 kBtuh-0.80Et') in Hotel Guest Room/Climate Zone 8. See Appendix IV for more details on the DWHC Baseline.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix IV. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the gas engine heat pump water heater operating alongside a new condensing efficiency storage water heater. Therefore, the total measure case energy usage is the sum of the total gas engine heat pump water heater energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the gas engine heat pump water heater capacity.

The measure case system is one (1) 500 kbuth gas engine heat pump water heater and one (1) 30gallon, 30 kBtuh, 0.83 UEF water heater.

Heating Load

The total heating load in the measure case is the same as the baseline case. Tank temperature, hourly water volume, and water main temperature remain the same.

Tank Loss – Gas Engine Heat Pump Water Heater

The baseline water heater in the DWHC was 100 gallons, so the storage tank in the measure case was assumed to be 100 gallons which equates to 31.3 sqft of tank surface area. This equates to a UA_{Tank} of 2.034 btu/hr-°F

Auxiliary Load – Gas Engine Heat Pump Water Heater

The gas engine heat pump water heater does not have a pilot light nor does the storage tank, so there is no auxiliary load for it.

Heat Exchanger Loss

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the measure-case system.

Total load

The total load is the sum of the heating load, tank loss load, and heat exchanger load

Gas Engine Heat Pump Water Heater Energy Use

The study "Natural Gas Internal Combustion Engine Heat Pump Field Trial Final Report" (Northwest Energy Efficiency Alliance, 2019) gives two equations for the COP as a function of outside air temperature (see Figure 12).

Equation 1: Gas engine heat pump water heater COP between 30°F and 40°F

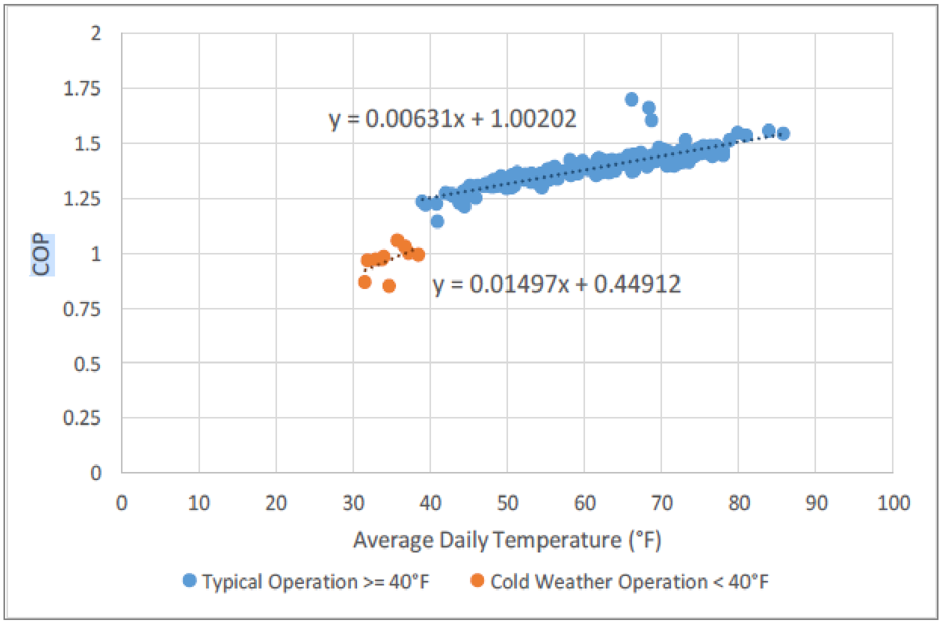
$$COP_{Gas-Engine} = 0.01497 * T_{amb} + 0.44912 \; (30°F \le T_{amb} < 40°F)$$

Equation 2: Gas engine heat pump water heater COP above 40°F

$$COP_{Gas-Engine} = 0.00631 * T_{amb} + 1.00202 \; (40°F \le T_{amb})$$

Figure 12: Gas engine heat pump water heater COP as a function of Ambient Air Temperature © (Northwest Energy Efficiency Alliance, 2019)

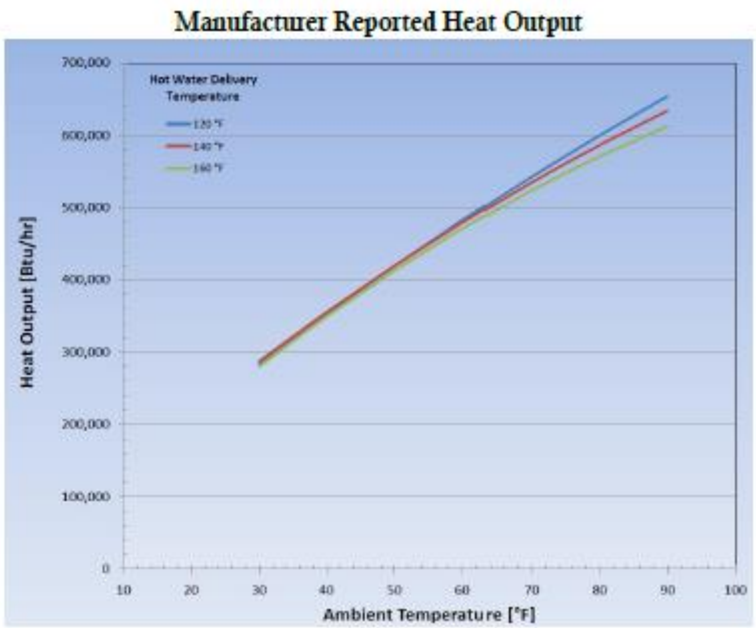
FIGURE 33 - DAILY AVERAGE HEAT PUMP PERFORMANCE



Storage Water Heater Energy Use

The gas engine heat pump water heater can only satisfy loads up to 600,000 btu/h and its hourly capacity is determined by the glycol/water output temperature and the ambient air temperature. The NEEA study provides this chart from the manufacturer for capacity as a function of ambient air temperature and water/glycol output temperature.

Figure 13: Gas engine heat pump water heater Capacity as a Function of Ambient Air Temperature © (Northwest Energy Efficiency Alliance, 2019)



The capacity for a 140°F outlet was used to determine the hourly capacity of the gas engine heat pump water heater. The storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The storage water heater uses extra fuel in hours where the gas engine heat pump water heater cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Total Energy Usage – Measure Case

The total measure case energy usage is the sum of the gas engine heat pump water heater energy use and the storage water heater energy use.

Absorption Gas Heat Pump Water Heater

The calculations here are for the absorption gas heat pump water heater in a water heating only mode in a commercial building. There is one manufacturer with commercially available absorption gas heat pump water heater units. There are other manufacturers which produce these units, but they do not currently have commercially available units in the United States. Since these calculations were meant to be high-level, a decision was made to use only the available third-party performance data for the commercially available unit in the calculation methodology. When units become available from additional manufacturers, performance curve data must be gathered for those units and decisions made about how to incorporate them into any existing calculation methodologies

Baseline Energy Usage

The baseline for measure SWWH007-04 I: Commercial Stor. heater, > 75 kBtu/hr, 0.96 TE was used as the baseline for this calculation. The absorption gas heat pump water heater is not a storage water heater, but it does have a storage tank and it is >75kBtu/hr.

The appropriate baseline water heater was selected in the DWHC ("Stor_TE-Gas-100gal-gte75 kBtuh-0.80et') in Assembly/Climate Zone 8. See Appendix IV for more details on the DWHC Baseline.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix IV. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the absorption gas heat pump water heater operating alongside a new condensing efficiency storage water heater. The manufacturer indicated that the absorption gas heat pump water heater is best utilized when it serves the base load of the system, and the existing equipment serves the peaking loads. Therefore, the total measure case energy usage is the sum of the total absorption gas heat pump water heater energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the absorption gas heat pump water heater capacity.

The measure-case system is one (1) absorption gas heat pump water heater and one (1) 75 gallon, 70 kBtuh, 0.94 UEF gas water heater.

Heating Load

The total heating load in the measure case is the same as the baseline case. Tank temperature, hourly water volume, and water main temperature remain the same.

Tank Loss – Absorption Gas Heat Pump Water Heater

The baseline water heater in the DWHC was 100 gallons, so the storage tank in the measure case was assumed to be 100 gallons which equates to 31.3sqft of tank surface area. This equates to a UA_{Tank} of 2.034 btu/hr-°F

Auxiliary Load – Absorption Gas Heat Pump Water Heater

The absorption gas heat pump water heater does not have a pilot light nor does the storage tank, so there is no auxiliary load for it.

Heat Exchange Loss – Absorption Gas Heat Pump Water Heater

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the measure-case system.

Total Load

The total load is the sum of the heating load, tank loss load, and heat exchanger load

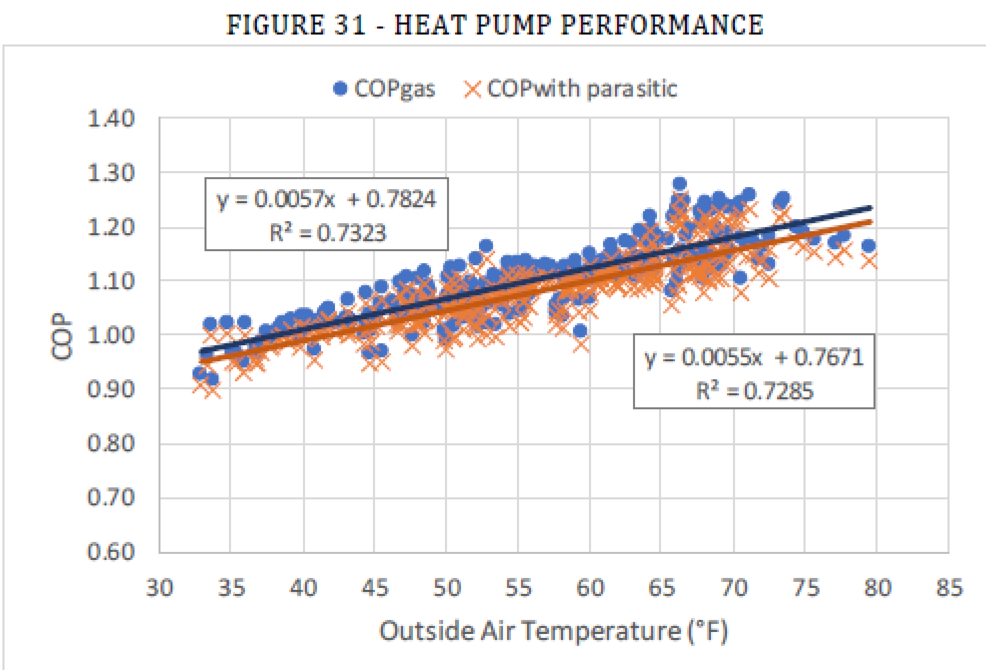
Energy Use – Absorption Gas Heat Pump Water Heater

The study "Robur Heat Pump Field Trial" gives the following equation for the COP as a function of outside air temperature in Figure 31 of the report (Northwest Energy Efficiency Alliance, 2020).

Equation 3: Absorption gas heat pump water heater coefficient of performance

$$COP_{Absorption} = 0.0055 * T_{amb} + 0.7671$$

Figure 14: Absorption gas heat pump water heater COP as a Function of Outside Air Temperature © (Northwest Energy Efficiency Alliance, 2020)

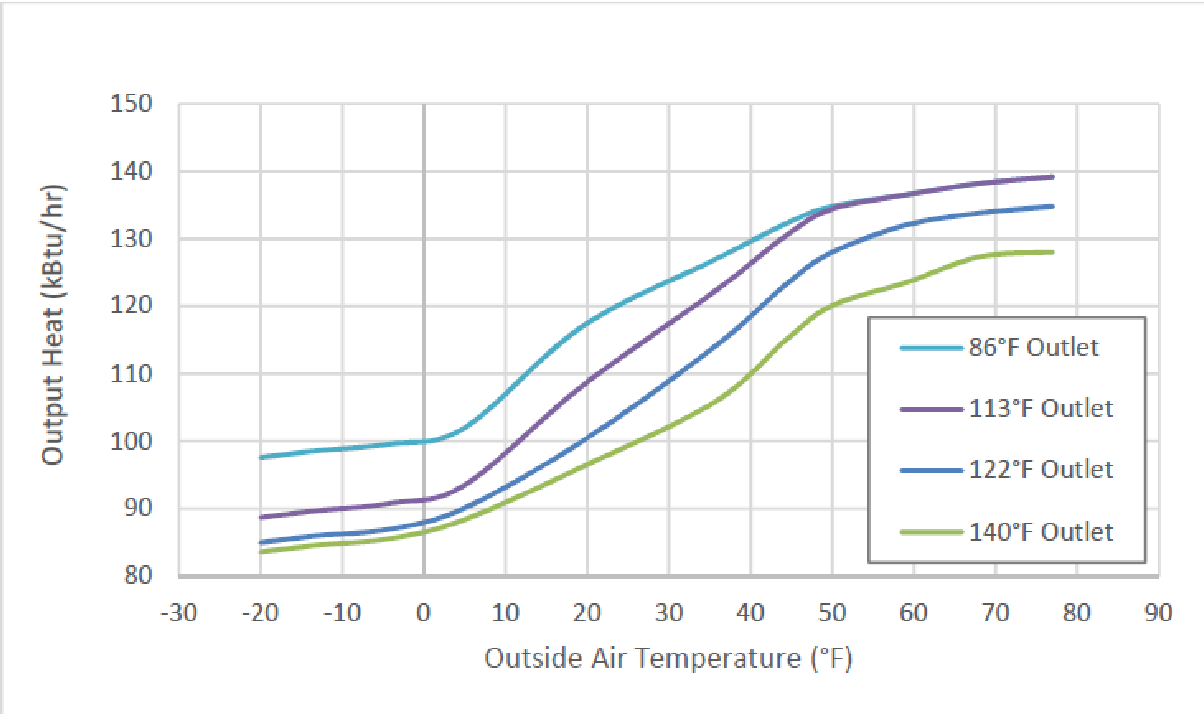


Energy Use – Water Heater

The absorption gas heat pump water heater can only satisfy loads up to 123,000 btu/h and its hourly capacity is determined by the glycol/water output temperature and the ambient air temperature. The NEEA study provides this chart from the manufacturer for capacity as a function of ambient air temperature and water/glycol output temperature (Northwest Energy Efficiency Alliance, 2020).

Figure 15: Absorption Gas Heat Pump Water Heater Capacity as a Function of Outside Air Temperature © (Northwest Energy Efficiency Alliance, 2020)

FIGURE 42 - GAHP-A OUTPUT CAPACITY CURVES



The capacity for a 140°F outlet was used to determine the hourly capacity of absorption gas heat pump water heater. The storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The water heater uses extra fuel in hours where the absorption gas heat pump water heater cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Total Energy Usage – Measure Case

The total measure case energy usage is the sum of the absorption gas heat pump water heater energy use and the storage water heater energy use.

Appendix IV. Gas Engine & Absorption Gas Heat Pump Water Heater Calculation Methodology

This appendix outlines the calculation methodology for the absorption and gas engine heat pump water heaters in a water heating only application. This methodology is also used for the combination systems but there are some extra steps and calculations that have to be done for the space heating portion of the combination systems. Those additional steps and calculations are in Appendix VII.

Baseline – Water Heating

The baseline energy usage for all water heating measures was determined using the DWHC. Each specific section discusses which inputs were used in the DWHC to get the appropriate baseline information.

The DWHC automatically calculates the hot water load, heat loss through the storage tank, and auxiliary load and applies the efficiency of the water heater to determine the total annual therm consumption. This therm consumption is per water heater and the DWHC automatically calculates the number of water heaters to satisfy the load. So, the yearly therm value output by the DWHC must be multiplied by the number of water heaters in order to get the total baseline therm consumption.

Measure – Water Heating

The measure case calculations follow the methodology of the DWHC with a few revisions.

Water Heating Load

The hourly ambient air temperature, water main temperature, and water profile for the selected building type/climate zone combination was copied from the DEER Calculator. The water heating load was calculated using Equation 1-1 from the DEER Water Heater Documentation

$$HW_{load} = HW_{gal} \times (T_{tank} - T_{mains}) \times 8.2$$

Equation 4: Heating Hot Water Load

Where,

HW_{load} = hourly hot water load in Btu/hr
HW_{gal}= hourly hot water volume, in gallons
T_{tank}= water heater temperature, 135 °F
T_{mains} = water mains (ground water) temperature
8.2 = specific heat and density conversion factor for water

The baseline calculation assumes a water heater tank temperature (either 110°F or 135°F) and this was used as the measure case water supply temperature (equal to the storage tank temperature).

Tank Loss – Emerging Technology

The Tank loss for the emerging technology is calculated using the DWHC methodology using the following equation (which is not directly stated in the DWHC documentation):

$Load_{UA} = (T_{tank} - T_{amb}) * UA_{tank}$

Equation 5: Load from Storage Tank Losses

Where:

$Load_{UA}$ = hourly load from storage tank losses

T_{amb} = ambient air temperature

T_{tank}= water heater temperature, 135 °F

UA_{tank} = tank heat losses to ambient air

UA_{tank} is automatically populated by the DWHC for the specific selected baseline water heater. In order to estimate the UAtank for the storage tank in the measure case systems an average surface area/gallon of storage tank was calculated using spec sheet information for Lochnivar water storage tanks. A 120-gallon Lochnivar storage tank was used in the "Robur Heat Pump Field Trial" study. The average Surface area/gallon was found to be 0.313 sqft/gallon. Section 110.3(3)(c)3C Title 24 states

"The heat loss of the tank surface based on an 80°F water-air temperature difference shall be less than 6.5 Btu per hour per square foot."

This works out to 0.08125 Btu/hr-sqft-F when 6.4 btu/h-sqft is divided by the water-air temperature difference of 80°F. UA_{tank} for the storage tank is therefore equal to:

$UAt_{ank} = SA_{Tank}$ sqft * 0.08125btu/hr-sqft-F = 2.0398 btu/hr-F

Equation 6: Tank Heat Losses to Ambient Air

Where:

SA_{Tank} = surface area of the tank

Auxiliary Load – Gas Heat Pump Water Heater

The DWHC includes an auxiliary load for the water heater pilot light. This load is described by the following equation.

$Load_{Aux} = -Btu_{Aux} * Eff_{Aux}$

Equation 7: Auxiliary Load

Where

$Load_{Aux}$ = Auxiliary load offset

Btu_{Aux} = energy input of the auxiliary load [btu]

Eff_{Aux} = auxiliary efficiency

Heat Exchanger Losses

It was assumed that the heat exchangers between the Robur water/glycol loop and the DHW loop has an efficiency of 95%. Therefore, the additional load due to the heat exchanger is calculated as

$Load_{HX} = (HW_{load} + Load_{UA}) \times 0.05$

Equation 8: Heat Exchanger Load

Where:

$Load_{HX}$ = the hourly load due to heat exchanger efficiency

$Load_{UA}$ = hourly load from storage tank losses

HW_{load} = hourly hot water load in Btu/hr

Total load

The total load is calculated as

$Load_{total,DHW} = HW_{load} + Load_{UA} + Load_{HX}$

Equation 9: Total DWH Load

Where:

$Load_{total,DHW}$ = total hourly DHW load [btu]

Total Energy Use – Gas Heat Pump Water Heater

The gas heat pump water heater energy use was determined by dividing the total load by the technology's COP at each hourly ambient air temperature using the following equation:

$EnergyUse_{ET} = Load_{total}/COP_{ET}$

Equation 10: Energy Use of Gas Heat Pump Water Heater

Where:

$EnergyUse_{ET}$ = The hourly energy use by emerging technology [btu]

COP_{ET} = Hourly average COP based upon outside air temperature

When the total load exceeds the hourly capacity of the emerging technology, $Load_{Total}$ is equal to the hourly capacity of the emerging technology, and it is assumed that the water heater makes up the difference.

Water Heater Energy Use

All of the absorption and internal combustion engine technologies have a maximum capacity based upon the constant tank temperature and the ambient air temperature. Therefore, this capacity varies hourly. For all these technologies, the capacity was calculated as a function of the outside air temperature from field study data or engineering judgement.

In conversations with manufacturers, it was found that there are three main system configurations that incorporate the emerging water heating technologies:

1. The new system is comprised solely of one or more gas heat pump water heaters which are sized for the peak hot water load of the building. The system may cycle one or more units off when the difference in supply and return temperature is too low. If the system can modulate, it may modulate down to match the load of the buildings.
2. The new system is comprised of one or more gas heat pump water heaters and integrates with the existing water heaters and/or boilers. If the existing boilers/water heaters are not condensing efficiency boilers the gas heat pump water heaters do not run at the same time as the boilers. This is because the output water temperature of the gas heat pump water heaters is too low to run at the same time as a non-condensing boiler/water heater. Therefore, when the load of the building is higher than the emerging technology water heater(s) or the required supply water temperature exceeds what the emerging technology water heater can provide, the controls system shuts down the emerging technology water heater(s) and turns ON the existing boilers.
3. The new system is comprised of one or more gas heat pump water heaters and integrates with new condensing efficiency water heaters and/or boilers. Condensing efficiency water heaters/boilers can run at lower supply water temperatures, so they can run at the same time as the gas heat pump water heaters. In this case, when the hot water load exceeds the capacity of the gas heat pump water heaters, the controls system turns on the water heater/boiler(s) and both run at the same time.

In these calculations, the third system was assumed to be the measure case to maximize the effective useful life of the new system and minimize the cost of the new system. Therefore, for all calculations, a new condensing efficiency water heater or boiler was selected from the DWHC that had enough capacity to satisfy the maximum hourly load that could not be satisfied by the emerging technology water heater.

When the hourly heating load exceeds the hourly capacity of the emerging technology, it is assumed that the new condensing water heater/boiler kicks on to satisfy the excess load.

The same methodology for the baseline water heater energy usage was used to determine the water heater energy usage in the measure case. The only difference is the load on the water heater was defined as

$Load_{WaterHeater}$ = the greater of: (0, $Load_{total} - ET_{Capacity}$)

Equation 11: Load on Additional Water Heater

Where:

$Load_{WaterHeater}$ = The hourly load the water heater must handle in excess of the emerging technology's capacity

$ET_{Capacity}$ is the capacity of the emerging technology based upon the ambient air temperature

The total load on the water heater also includes the tank losses through the water heater tank and the auxiliary load on the water heater. The tank load and auxiliary load for the water heater use the same values that were used in the baseline DWHC. The total energy use of the water heater is defined by the following equation

$EnergyUse_{WaterHeater} = (Load_{WaterHeater} + Load_{Aux} + Load_{UA})\ EFF_{WaterHeater}$

Equation 12: Additional Water Heater Energy Use

Where:

$EnergyUse_{WaterHeater}$ = the energy use of the water heater to satisfy the excess load

$EFF_{WaterHeater}$ = the recovery efficiency of the existing water heater from the baseline calculation

Total Energy Usage

The total energy usage is equal to

$EnergyUse_{Total} = EnergyUse_{ET} + EnergyUse_{WaterHeater}$

Equation 13: Total Measure Case Energy Use

Where:

$EnergyUse_{Total}$ = the total energy use of the measure case system (gas heat pump water heater + existing water heater)

The total measure case energy usage is then converted into annual therms.

Appendix V. Adsorption Gas Heat Pump Water Heater Calculations

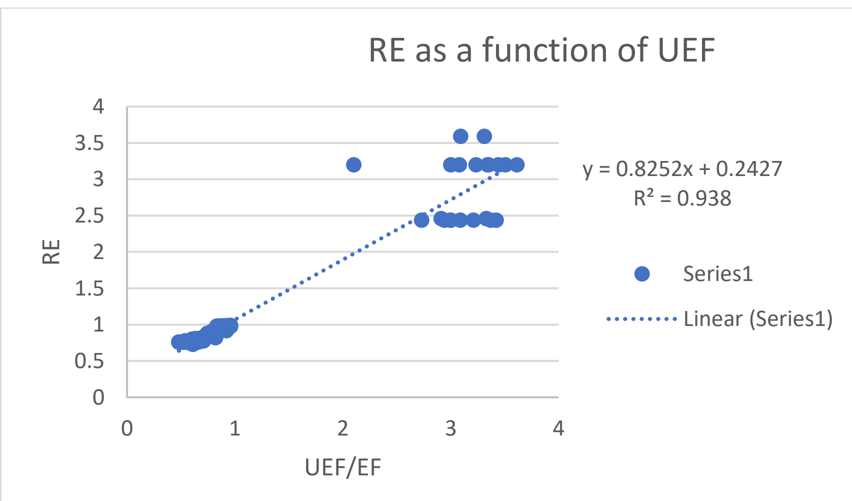
Baseline Energy Usage

Measure SWWH012-02 G: Condensing storage water heater: 40 gal (UEF = 0.83), high draw is the most applicable measure for this technology. The baseline for that measure is "Storage water heater, 40 gal, <= 75 kB–u/hr - high draw, EF = 0.58." The baseline water heater used in the DWHC was "Stor_EF-Gas-040gal-0.58EF" in Single-Family Home in Climate Zone 10. The DWHC automatically calculates the annual energy usage.

Measure Energy Usage

The DWHC uses recovery efficiency of the water heater as the key efficiency parameter for a gas storage water heater. COP is used for an electric heat pump water heater, but COP will vary based upon outside air temperature. The manufacturer for the residential absorption gas heat pump water heater only provided a single uniform energy factor (UEF) value. The DWHC "Technologies" tab has many technologies with their UEF/EF values and recovery efficiency. This data was used in a scatter plot to create an equation for Recovery Efficiency as a function of the UEF/EF. The scatterplot and curve fit are shown below in Figure 16.

Figure 16: Recovery Efficiency as a Function of UEF/EF



The equation below was used to convert the adsorption gas heat pump water heater stated UEF into a recovery efficiency:

Equation 14: Adsorption Gas Heat Pump Water Heater Recovery Efficiency as a Function of UEF

$$RE = 0.8252 * UEF + 0.2427$$

Where:

RE = Recovery Efficiency

UEF = Uniform Energy Factor

The adsorption gas heat pump water heater UEF was taken from slides presented by the manufacturer from the Hot Water Forum in 2022. The UEF was 1.2, which equates to a recovery efficiency of 1.23.

For the measure case, the recovery efficiency was changed to 1.23 in the DWHC, and all other variables were the same as the baseline.

Appendix VI. Gas Engine, Absorption, and Thermal Compression Gas Heat Pump Combi Calculations

This appendix outlines the calculations for the gas engine, absorption and thermal compression gas heat pump water heaters in a combination DHW and space heating application. This methodology is also used for the combination systems but there are some extra steps and calculations that have to be done for the space heating portion of the combination systems. Those additional steps and calculations are in Appendix VII.

Internal Combustion Engine Heat Pump Combi

Baseline Energy Usage

Baseline Energy Usage – Space Heating

SWHC004-03 "Space Heating Boiler" has two measures for a boiler in commercial building that is between 400,000 – 600,000 btuh. Those measures are

- SWHC004-03D: Hot water boiler– (300 - 2500 kBtu/hr, 94.0% TE, condensing, N–nRes - OA reset from 115 to 140 deg F)"
    - SWHC004-03C: Hot water boiler– (300 - 2500 kBtu/hr, 94.0% TE, condensing, N–nRes - OA reset from 140 to 165 deg F– Res - no OA reset)

Since this combination system serves DHW which has a maximum temperature of 140F, SWHC004-03D was selected as the appropriate measure to match with. This measure uses DEER Measure ID "NG-HVAC-Blr-HW-300to2500kBtuh-94p0Et-CndLow" for its savings calculations. The baseline for this measure is "Nrs-CZ08-1975-cAVVG-WBlr-300to2500-80p0Et." That DEER model is used as the baseline for the savings calculation.

Baseline Energy Usage – Water Heating

The total energy use for "Store-TE-Gas-100gal-gte75 kBtuh-0.80Et" in Nursing Home in Climate zone 8 is the baseline water heating energy.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix VII. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the gas engine heat pump combi operating alongside a new condensing efficiency storage water heater. Therefore, the total measure case energy usage is the sum of the total gas engine heat pump combi energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the gas engine heat pump combi capacity.

The measure case system is one (1) 500 kbuth gas engine heat pump combi and two (2) 120 gallon, 288 kBtuh, 94% Thermal Efficiency boiler.

The input values used for measure energy usage for the gas engine heat pump combi system are the same that were used for the gas engine heat pump combi.

Absorption Gas Heat Pump Combi

Baseline Energy Usage – Office Small

Space Heating

Workpaper SWHC004-03 "Space Heating Boiler" has only one measure for boilers that are <300kbtu capacity, but it is for residential. Since this is for a commercial building, the DEER measure for an 84% efficient <300 kbuth boiler is used as the baseline. The DEER Measure ID used is "NG-HVAC-Blr-HW-lt300kBtuh-84p0AFUE-Drft." The total heating end-use energy from the DEER model "OfS-CZ08-1975-cPVVG-WBlr-lt300-82p0AF" is the baseline space heating energy.

Water Heating

The total energy use for "Stor-TE-Gas-100gal-gte75 kBtuh-0.80Et" in Small Office in Climate zone 8 is the baseline water heating energy.

Baseline Energy Usage – Nursing Home

Space Heating

Workpaper SWHC004-03 "Space Heating Boiler" has only one measure for boilers that are <300kbtu capacity, but it is for residential. Since this is for a commercial building installation the DEER measure for an 84% efficient <300 kbuth boiler will be used as the baseline. The DEER Measure ID used is "NG-HVAC-Blr-HW-lt300kBtuh-84p0AFUE-Drft." The total heating end-use energy from the DEER model "Nrs-CZ08-1975-cAVVG-WBlr-lt300-80p0AF" is the baseline space heating energy.

Water Heating

The total energy use for "Store-TE-Gas-100gal-gte75 kBtuh-0.80Et" in Nursing Home in Climate zone 8 is the baseline water heating energy.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix VII. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the absorption gas heat pump combi operating alongside a new condensing efficiency storage water heater or boiler. The manufacturer indicated that the absorption gas heat pump combi is best utilized when it serves the base load of the system, and the existing equipment serves the peaking loads. Therefore, the total measure case energy usage is the sum of the total absorption gas heat pump combi energy usage and the total storage water heater/boiler energy usage. It is assumed that the water heater/boiler must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the absorption gas heat pump combi capacity.

The measure-case system for Small Office is one (1) absorption gas heat pump combi and one (1) 50 gallon, 44 kBtuh, 0.79 UEF water heater.

The measure-case system for Nursing Home is six (6) absorption gas heat pump combis and one (1) 120 gallon, 288 kBtuh, 96% Thermal Efficiency boiler.

The input values used for measure energy usage for the absorption gas heat pump combi system are the same that were used for the absorption gas heat pump water heater system.

Thermal Compression Gas Heat Pump Combi

This unit can be used in a residential or a commercial setting. Therefore, one analysis was done in a commercial setting, and one analysis was done in a residential setting.

Baseline Energy Usage – Restaurant Fast Food

Space Heating

Restaurant Fast Food was selected as the building type because it could have one (1) thermal compression gas heat pump combi and has both heating and cooling needs. In meeting with the manufacturer representatives, they specifically stated that the best scenario for their unit is where it can provide both heating and cooling simultaneously. However, the cooling offset provided by this system was not considered in this calculation. DEER models do not have a hydronic heating and cooling system for restaurants. So, the baseline for Workpaper SWHC011 Furnace, Commercial is used. The DEER measure for that workpaper is "Furnace-Pkg-AFUE95-ECM-lt65kBtuh" and the baseline for that measure is "PkgFurn-0.80AFUE." The DEER model "RFF-CZ08-1975-cDXGF-PkgFurn-0.80AFUE-ForMsr" was used for the baseline space heating.

Water Heating

The thermal compression gas heat pump combi is 55,000 – 75,000 btu/hr and does not give a suggested water storage tank capacity (It does require an external storage tank). Measure SWWH007-004 C: Commercial stor. heater, <= 75 kBtu/hr, 40-gal, high draw (HI), 0.68 UEF is the most similar measure. The baseline for measure is "Storage water heater 40 gal, <= 75 kBtu/hr - high draw, EF = 0.58." The baseline energy usage for "Stor-EF-Gas-

040gal-0.58EF" in Fast-Food Restaurant and climate zone 8 was used for the baseline water heating energy usage.

Baseline Energy Usage – Single Family Home

The highest DEER weight for a single-family home irrespective of the vintage is in climate zone 10. Therefore, Single-Family Home in Climate Zone 10 was selected as the building type/climate zone combination.

Space Heating

Single-Family Homes do not have a DEER model with a hydronic heating system. Therefore, a gas-furnace was selected as the closest measure to get the total baseline energy usage and space heating load. Measure SWHC031-002 C: Residential furnace, AFUE 80% is the closest measure to this emerging technology. The DEER measure for this is "Res-GasFurnace-AFUE97-ECM." The base case for this DEER measure is "Res-GasFurnace-AFUE81-ECM." DEER model "SFm-CZ10-1975-rNCGF-T3-Furnace-0.81-Sizing" was used for the baseline.

In single family DEER models, the model is two (2) one-story homes and two (2) two-story homes. The file "DEER_Res_Tables.xlsm" provides the conditioned floor area and average number of stories for Single Family Homes in each climate zone and vintage. The total conditioned floor area for Single Family Home-Climate Zone 10-1975 is 1,636 ft^2. The total conditioned floor area for the DEER eQuest model is 7,380 ft^2 so an adjustment factor of 1,636/7,380 = 0.22 was applied to the total heating end use energy so that the energy only accounts for the average conditioned area of one (1) single-family home.

In single-family DEER models, the energy use is reported separately for the first and second floors so, total energy use and total load are the sum of the first floor and second floor values.

Water Heating

Measure SWWH012-02 G "Condensing storage water heater: 40 gal (UEF = 0.83), high draw" is the most applicable measure for this technology. The baseline for that measure is "Storage water heater, 40 gal, <= 75 kBtu/hr - high draw, EF = 0.58." The baseline water heater used in the DWHC was "Stor_EF-Gas-040gal-0.58EF" in Single Family Home in Climate Zone 10.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix VII. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the thermal compression gas heat pump combi operating alongside a new condensing efficiency storage water heater or boiler. Therefore, the total measure case energy usage is the sum of the total thermal compression gas heat pump combi energy usage and the total storage water heater/boiler energy usage. It is assumed that the storage water heater/boiler must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the thermal compression gas heat pump combi capacity.

The measure-case system for restaurant fast food is one (1) thermal compression gas heat pump combi and one (1) 30 gallon, 65 kBtuh, 0.84 UEF water heater.

The thermal compression gas heat pump combi can handle the full single-family load, so no additional water heater was needed.

Heating Load

The total heating load in the measure case is the sum of the total water heating load from the baseline and the space heating load from the model.

Tank Loss – Thermal Compression Gas Heat Pump Combi

The baseline water heater in the DWHC was 40 gallons, so the storage tank in the measure case was assumed to be 40 gallons which equates to 12.55 sqft of tank surface area. This equates to a UA_{Tank} of 0.815 btu/hr-°F

Auxiliary Load – Thermal Compression Gas Heat Pump Combi

It is assumed that the thermal compression gas heat pump combi does not have a pilot light nor does the storage tank, so there is no auxiliary load for the thermal compression gas heat pump combi.

Heat Exchanger Loss

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the thermal compression gas heat pump combi system.

Total load

The total load is the sum of the heating load, tank loss load, and heat exchanger losses.

Thermal Compression Gas Heat Pump Combi Energy Use

The only available COP information comes from the study "DOE Energy Savings Potential and RD&D Opportunities for Com Building HVAC Systems" (Department of Energy, 2017) It lists a COP of 1.6. It was assumed that this COP is for an outside air temperature of 90°F. It was assumed that the COP drops to 1.0 at an outside air temperature of 30°F based upon engineering judgement. The COP for outside air temperatures between those two values is a linear interpolation.

Water Heater Energy Use

The thermal compression gas heat pump combi can only satisfy loads up to 75,000 btu/h and it was assumed its hourly capacity is determined by the water output temperature and the ambient air temperature. No capacity data as a function of outside air temperature was available, so it was assumed that the capacity is 75,000 btuh at 90°F and 55,000 btuh at 30°F. The capacity for temperature between these two values was a linear interpolation between the two.

The calculations showed that the thermal compression gas heat pump combi could handle the capacity of both Restaurant – Fast Food and Single-Family Home for all hours of the day. The maximum excess capacity of the thermal compression gas heat pump combi in Restaurant Fast Food was 6,005 btuh so it was assumed that an additional 30-gallon water heater would be required for unexpected load spikes. The maximum excess capacity of the thermal compression gas heat pump combi in a single-family home is 29,172 btuh so it was assumed that there is no need for an additional water heater in this case.

For restaurant fast food, the storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The storage water heater uses extra fuel in hours where the thermal compression gas heat pump combi cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Appendix VII. Calculation Methodology Combi

This appendix outlines the additional calculation steps that have to be taken for combination heat pump systems. These steps are used in conjunction with the steps outlined in Appendix IV.

Baseline - Combi

Baseline – Water Heating

The baseline energy usage for water heating was determined using the DWHC Each technology specific section discusses which water heating/building type/climate zone were used to get the baseline water heating energy use.

The DWHC automatically calculates the hot water load, heat loss through the storage tank, and auxiliary load and applies the efficiency of the water heater to determine the total annual therm consumption. This therm consumption is per water heater and the DWHC automatically calculates the number of water heaters to satisfy the load. So, the yearly therm value output by the DWHC must be multiplied by the number of water heaters in order to get the total baseline therm consumption.

Baseline – Space Heating

Baseline space heating was determined using the appropriate DEER eQuest model selected for each technology. Each technology specific section discusses which DEER eQuest model was used to get baseline space heating information. Once the model was generated using MAS Control 3, the eQuest model was opened at an hourly report block was created for space heating end-use energy. The hourly results were exported from eQuest, and the total yearly heating end-use energy was considered to be the baseline heating energy.

Baseline – Total

The total baseline energy is the sum of the baseline water heating energy and the baseline space heating energy. See the equation below:

Equation 15: Combi Baseline Energy Usage

$Baseline_{Combi,Total} = Baseline_{WH} + Baseline_{SH}$

Where:

$Baseline_{Combi,Total}$ = Total baseline energy consumption for the combination system

$Baseline_{WH}$ = baseline energy consumption from the DWHC

$Baseline_{SH}$ = baseline end-use heating energy consumption from the appropriate DEER eQuest model

Measure – Combi

Appendix VIII. It is assumed that all of these technologies are installed alongside the existing hot water heaters/boilers. Therefore, there is a technology energy use component and a water heater/boiler energy use component. The technology energy use and water heater/boiler energy use are calculated the same as shown in Technology Scoring Details

Below are the specific scoring guidelines used for the emerging water heating technologies

Table 27: Technology Scoring Details

Consideration	Description
Program	TRC/Simple Payback TRC: 5: 1.25+ 4: 1.0-1.25 3: 0.9-1.0 2: 0.8-0.9 1: <0.8 Simple Payback 5: 5-7 years 4: 7-10 years 3: 10-15 years 2: 15-20 years 1: 20+ years
Program	Market Size- Residential 5: >150k 4: 100-150k 3: 75k – 100k 2: 25k-75k 1: <25k Commercial 5: 5 - >10k 4: 4 – 7k-10k 3 : 5k-7k 2: 3k-5k 1: 1- <3k
Program	Potential to complete a field/lab study within 3 years? 5: Yes 3: Maybe 1: No

Consideration	Description
Program	Potential for a joint project with cooperation from other internal IOU programs 5: Yes 3: Maybe 1: No
Program	<u>Product performance</u> 5: COP>1.9 4: COP 1.5-1.8 3: COP 1.1-1.4 2: COP 0.8-1.0 1: COP <.7
Program	<u>Time to commercialization</u> 5: 0 yrs 4: 1 yr 3: 2 yrs 2: 3 yrs 1: 4+ yrs
Customer	<u>Added functionality</u> 5: 3 addl functions (space heating, space cooling, remotely controlled) 4: 2 functions (heating, cooling) 3: 1 function (heating) 2: 1 function (remote control) 1: no added functions
Customer	<u>Material Cost</u> 5: Equal to or less than condensing efficiency material cost 4: 1-1.5x condensing efficiency material cost 3:1.5- 2x condensing efficiency material cost 2: 2-3x condensing efficiency material cost 1: 3X or greater than condensing efficiency material cost
Customer	<u>Installation Cost/Complexity</u> *If install costs available* 5: Equal to or less than condensing efficiency installation cost 4: 1- 1.5x condensing efficiency installation cost 3: 1.5-2x condensing efficiency installation cost 2: 2-3x condensing efficiency installation cost 1: 3X or greater than condensing efficiency installation cost *If costs not available use engineering judgement of complexity of installation* 5: Low Complexity (Nothing new required) 4: Medium-Low Complexity (New venting, new gas lines) 3: Medium complexity (Residential – new electrical) 2: Medium-High Complexity (Residential – new electrical and new venting or gas lines, new hydronic loops) 1: High complexity (Residential – new electrical and new water lines)

Consideration	Description
Market	Market Readiness 5: Mature 4: Growing 3: Niche 2: Limited Availability 1: Pre-Commercialization
Market	Technology brand awareness/brand equity among customers, distributors, and installers 5: Brand already established in the market 4: Brand not already established in the market
Market	Confidence in technology – distributor and installers confident in the technology 5: A distributor already carrying technology 4: No distributor carrying technology
Regulatory	Testing standards 5: Testing standards exist 3: No testing standards but they are being developed 1: No testing standards and none being developed
Regulatory	Software Tools 5: Compliance software exists 4: No compliance software, but software to calculate energy usage/savings exists 3: No compliance or energy usage software exists but at least one is being developed 1: No compliance or energy savings software and none being developed
Regulatory	Risk that technology will be prohibited/made obsolete by state or local codes 5 – Low risk 3 – Medium risk 1 – High risk

Table 28: Emerging Water Heating Technology Prioritization

Technology Name & Sector	Description	Priority
Machine Learning Water Heating Controls-Res	Machine learning controls that save water heating energy by reducing temperature setpoint of hot water during low-demand times. Single Family	Medium
Commercial Gas Engine Heat Pump Water Heater-Com	Heat pump water heater utilizing **mechanical** output of a gas-driven internal combustion engine to drive a vapor compression cycle (Multifamily & Commercial)	High
Residential Vapor Absorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Single-Family)	Medium
Commercial Vapor Absorption Gas Heat Pump Water Heater-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Multifamily & Commercial)	High
Residential Adsorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. (Single-Family)	High
Ejector Sorption Assisted Gas Heat Pump Water Heater-Res	Thermal energy provided by the combustion of natural gas drives an ejector heat pump system assisted by sorption to increase COP. Ejector replaces the compressor in a vapor-compression cycle[18].	Low
Self-Powered High Two-Phase Thermo-Syphoning Residential Gas Storage Water Heaters-Res	Competitive cost higher efficiency (non-condensing) tank water heater utilizing Two-Phase Thermo-Syphoning Technology	Medium
Non-Powered Damper Commercial Gas Storage Water Heaters-Com	Competitive cost higher efficiency tank water heater with non-powered damper	Low
Residential Waste-Water Heat Recovery HX (Water Pre Heat)-Res	Utilizing a heat exchanger to use waste hot drain water to pre heat water going into a water heater (Single-family)	Low
Commercial or Multifamily Wastewater Heat Recovery HX (Water Pre Heat)-Com	Utilizing a heat exchanger to use waste heat to pre heat water going into a water heater (Multifamily & Commercial)	Low
Equipment Specific Greywater Recycling with Heat Recovery-Res	Means to collect grey water and recover heat from it for pre-heating hot water for an individual piece of equipment or sink/shower	Medium

Technology Name & Sector	Description	Priority
Commercial Gas Engine Heat Pump Combi System-Com	Heat pump utilizing **mechanical output** of a gas-driven internal combustion engine to drive a vapor compression cycle to provide 2+ of the following 1. Space heating 2. Space cooling 3. DHW heating	High
Residential Vapor Absorption Gas Heat Pump Combi System-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	Medium
Commercial Vapor Absorption Gas Heat Pump Combi System-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	High
Residential Vapor Adsorption Gas Heat Pump Combi System-Res	Heat pump utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	Low
Thermal Compression Gas Heat Pump Combi System-Res & Com	Thermal energy provided by the combustion of natural gas powers a thermodynamic compression cycle. Helium is the working fluid. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	High
Combination Space and Gas Heat Pump Water Heating System Controls -Res & Com	Controls for equipment that provides heating and hot water using gas-burner.	Medium

Appendix IX. Codes & Standards Information

Gas Engine Heat Pump Water Heater and Combination

AQMD

2. SCAQMD standards regulating emissions from stationary Internal Combustion Engines (rule 1470, rule 1110.2) regulate IC engines with >50 hp. Manufacturer spec sheet states it is <50hp so these standards do not apply

Title 24/Title20/DOE

2. Space Heating
    a. Section 110.2 regulates space conditioning systems. Table 110.2C Air Cooled Gas-Engine Heat Pumps regulates COP for heating and cooling mode.
    b. GAP: Title 24 COP based upon ANSI Z21.40.4A. The manufacturer's unit was certified by ANSI Z21.40.2. The standards are similar in name.
2. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 © includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
        i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
        ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
        iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
        iv. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Absorption Gas Heat Pump Water Heater and Combination

AQMD

3. Boiler
    a. SCAQMD definition of Boiler or Steam Generator from Rule 1146.2 is as follows:
        i. "BOILER OR STEAM GENERATOR means any equipment that is fired with or is designed to be fired with natural gas, used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale."
    b. These units are designed to be fired by natural gas and they heat water (though indirectly), so this SCAQMD rule applies to this unit when it is heating HHW or both HHW and DHW.
    c. Rule 1146.2 defines a Type I unit as "TYPE 1 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY less than or equal to 400,000 BTU per hour excluding TANK TYPE WATER HEATERS subject to the limits of District Rule 1121"
    d. These units are less than 400,000 btu/h so they are "Type 1" units
    e. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).
    f. Manufacturer's provided emissions are 0.021-0.026 lb/MMbtu which converts to 21-26 lb/billion BTU
4. Water Heater
    a. SCAQMD definition of water heater from Rule 1146.2 is as follows "WATER HEATER means any equipment that is fired with or designed to be fired with natural gas and that is used solely to heat water for use external to the equipment"
    b. These units are designed to be fired by natural gas and when installed in a DHW only configuration, it solely heats water for use external to the equipment (though indirectly), so this SCAQMD rule applies to this unit. These units are less than 400,000 btu/h so they are "Type 1" units
    c. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).

Title 24/Title20/DOE

3. Space Heating
    a. Title 24 Section 110.2 regulates space conditioning systems. However, there is no table for gas-fired absorption heat pumps.
    b. Therefore, Title 24 does not apply and there is a gap in the standards

4. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
        i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
        ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
        iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
        iv. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Adsorption Gas Heat Pump Water Heater

AQMD

4. No info available on the size of this unit, but since it is designed to be a residential unit assume that SCAQMD rule 1121 applies.
5. Definition of a water heater from Rule 1121 is as follows "WATER HEATER means a closed vessel other than a mobile home water heater in which water is heated by combustion of gaseous fuel and is withdrawn for use external to the vessel at pressures not exceeding 160 psig, including the apparatus by which heat is generated and all controls and devices necessary to prevent water temperatures from exceeding 210°F (99°C)."
6. This technology meets this definition, because it is a closed vessel in which water is heated by combustion of gaseous fuel and water is withdrawn for use external to the vessel at pressures not exceeding 160 psig. The technology has integral potable water storage. Therefore, NOx limits ©(c)(3) apply: limit of 10 nanograms per Joule or 15 ppm

Title 24/Title20/DOE

2. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. No Spec sheet with input rating of this water heater is available so assume it meets the definition of a "Gas-fired storage water heater" that is a federally regulated consumer product from definitions in 1602(f)
    e. Standards for minimum UEF for gas-fired storage water heater from section 1605.1(f) apply to this unit
    f. On 1/11/22 DOE published a supplemental notice of proposed rulemaking to amend the test procedure for consumer water heaters and residential duty-commercial water heaters. The updated test procedure proposes to allow for voluntary representations at certain additionally specified test conditions for heat pump water heaters.

Thermal Gas Compression Combi – Residential & Commercial

AQMD

3. Boiler
    a. SCAQMD definition of Boiler or Steam Generator from Rule 1146.2 is as follows:
        i. "BOILER OR STEAM GENERATOR means any equipment that is fired with or is designed to be fired with natural gas, used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale."
    b. These units are designed to be fired by natural gas and they heat water (though indirectly), so this AQMD rule applies to this unit when it is heating HHW or both HHW and DHW.
    c. These units are less than 400,000 btu/h so they are "Type 1" units
    d. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).
4. Water Heater
    a. Documentation on technology is not clear if it has an internal potable water tank, but conversations with manufacturer indicate the equipment does <u>not</u> have internal potable water storage so it is not a "water heater" as defined by rule 1121.
    b. SCAQMD definition of water heater from Rule 1146.2 is as follows "WATER HEATER means any equipment that is fired with or designed to be fired with natural gas and that is used solely to heat water for use external to the equipment"
    c. These units are designed to be fired by natural gas and, when installed in a DHW only configuration, it solely heats water for use external to the equipment (though indirectly), so this SCAQMD rule applies to this unit.
    d. These units are less than 400,000 btu/h so they are "Type 1" units
    e. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).

Title 24/Title20/DOE

3. Space Heating
    a. Title 24 section 110.2 regulates space conditioning systems.
    b. Therefore, Title 24 does not apply and there is a gap in the standards
4. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)

b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
    i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
    ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
    iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
    iv. It is not a gas-fired storage water heater because it does not contain potable water
    v. It is not a gas-fired instantaneous water heater because it does not contain potable water
    vi. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Additional AQMD Information

SCAQMD Rule Names and Applicability

Rules 1121: CONTROL OF NITROGEN OXIDES FROM RESIDENTIAL TYPE, NATURAL GAS-FIRED WATER HEATERS- Applicable to: This rule applies to manufacturers, distributors, retailers, and installers of natural gas-fired water heaters, with heat input rates less than 75,000 Btu per hour.

Rule 1146.2: EMISSIONS OF OXIDES OF NITROGEN FROM LARGE WATER HEATERS AND SMALL BOILERS AND PROCESS HEATERS- Applicable to: This rule applies to units that have a rated heat input capacity less than or equal to 2,000,000 BTU per hour. Type 1 Units as defined in this rule are typically, but not exclusively, large water heaters or smaller-sized process heaters in the above range. Type 2 Units as defined in this rule are typically, but not exclusively, small boilers or larger-sized process heaters in this range but Excludes Tank Type Water Heaters that are subject to limits in rule 1121.

Rule 1146: EMISSIONS OF OXIDES OF NITROGEN FROM INDUSTRIAL, INSTITUTIONAL, AND COMMERCIAL BOILERS, STEAM GENERATORS, AND PROCESS HEATERS- Applicable to: This rule applies to boilers, steam generators, and process heaters of equal to or greater than 5 million Btu per hour rated heat input capacity used in all industrial, institutional, and commercial operations.

Definitions

Rule 1146 & 1146.2: "BOILER or STEAM GENERATOR means any combustion equipment fired with liquid and/or gaseous (including landfill and digester gas) and/or solid fossil fuel and used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale. Boiler or Steam Generator does not include any open heated tank, adsorption chiller unit, or waste heat recovery boiler that is used to recover sensible heat from the exhaust of a combustion turbine or any unfired waste heat recovery boiler that is used to recover sensible heat from the exhaust of any combustion equipment."

Rule 1146 & 1146.2 "PROCESS HEATER means any equipment that is fired with or is designed to be fired with natural gas and which transfers heat from combustion gases to water or process streams. Process Heater does not include any kiln or oven used for annealing, drying, curing, baking, cooking, calcining, or vitrifying; or any unfired waste heat recovery heater that is used to recover sensible heat from the exhaust of any combustion equipment."

Rule 1146.2 “TANK TYPE WATER HEATER means a WATER HEATER with a RATED HEAT INPUT CAPACITY from 75,000 BTU per hour to 2,000,000 BTU per hour and with an integral closed vessel in which water is heated and stored for use external to the vessel.”

Rule 1146.2 “TYPE 1 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY less than or equal to 400,000 BTU per hour excluding TANK TYPE WATER HEATERS subject to the limits of District Rule 1121.”

Rule 1146.2 “TYPE 2 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY greater than 400,000 BTU per hour up to and including 2,000,000 BTU per hour.”

Rule 1121 “WATER HEATER means a closed vessel other than a mobile home water heater in which water is heated by combustion of gaseous fuel and is withdrawn for use external to the vessel at pressures not exceeding 160 psig, including the apparatus by which heat is generated and all controls and devices necessary to prevent water temperatures from exceeding 210°F (99°C).”

Additional Title 20 Information

Definitions from Section 1602

"Boiler" means a space heater that is a self-contained appliance for supplying steam or hot water primarily intended for space-heating. "Boiler" does not include hot water supply boilers."

"Commercial packaged boiler" means a type of packaged low-pressure boiler that is industrial equipment with a capacity (rated maximum input) of 300,000 Btu per hour (Btu/hr) or more which, to any significant extent, is distributed in commerce:

3. For heating or space conditioning applications in buildings; or
4. For service water heating in buildings but does not meet the definition of "hot water supply boiler" in this part."

"Packaged boiler" means a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls, usually shipped in one or more sections and does not include a boiler that is custom designed, and field constructed. If the boiler is shipped in more than one section, the sections may be produced by more than one manufacturer and may be originated or shipped at different times and from more than one location."

"Space heater" means an appliance that supplies heat to a space for the purpose of providing warmth to objects within the space. "Space heater" includes but is not limited to boilers (except hot water supply boilers), furnaces, room heaters, floor furnaces, wall furnaces, infrared heaters, unit heaters, duct furnaces, and combination space-heating and water-heating appliances."

"Hot water supply boiler" means a packaged boiler that is industrial equipment and that:

4. has an input rating from 300,000 Btu/hour to 12,500,000 Btu/hour and of at least 4,000 Btu/hour per gallon of stored water.
5. is suitable for heating potable water; and
6. meets either or both of the following conditions:
    a. it has the temperature and pressure controls necessary for heating potable water for purposes other than space heating; or
    b. the manufacturer's product literature, product markings, product marketing, or product installation and operation instructions indicate that the boilers intended uses include heating potable water for purposes other than space heating.

"Air-source commercial heat pump water heater" means a commercial heat pump water heater that utilizes indoor or outdoor air as the heat source."

"Commercial heat pump water heater (CHPWH)" means a water heater (including all ancillary equipment such as fans, blowers, pumps, storage tanks, piping, and controls, as applicable) that uses a refrigeration cycle, such as vapor compression, to transfer heat from a low-temperature source to a higher-temperature sink for the purpose of heating potable water, and has a rated electric power input greater than 12 kW. Such equipment includes, but is not limited to, air-source heat pump water heaters, water-source heat pump water heaters, and direct geo-exchange heat pump water heaters.

"Gas-fired storage water heater" that is a federally regulated consumer product means a water heater that uses gas as the main energy source, has a nameplate input rating of 75,000 Btu/h or less, and contains more than one gallon of water per 4,000 Btu per hour of input.

"Gas-fired storage water heater" that is federally regulated commercial and industrial equipment means a water heater that uses gas to heat and store water within the appliance at a thermostatically controlled temperature for delivery on demand and has a rated input both greater than 75,000 Btu/hour and less than 4,000 Btu/hour per gallon of stored water.

"Gas-fired instantaneous water heater" that is a federally regulated consumer product means a water heater that uses gas as the main energy source, has a nameplate input rating less than 200,000 Btu/h, and contains no more than one gallon of water per 4,000 Btu per hour of input.

"Gas-fired instantaneous water heater" that is federally regulated commercial and industrial equipment means a water heater that uses gas as the main energy source and has a rated input both greater than 200,000 Btu/h and not less than 4,000 Btu/h per gallon of stored water.

Title 20 Section 1605.1(f) Standards for Water Heaters

Product Class	Rated Storage Volume and Input Rating (if applicable)	Draw Pattern	Minimum Uniform Energy Factor*
Gas-fired Storage Water Heater	≥ 20 gallons and ≤ 55 gallons	Very small	0.3456 – (0.0020 × V_r)
		Low	0.5982 – (0.0019 × V_r)
		Medium	0.6483 – (0.0017 × V_r)
		High	0.6920 – (0.0013 × V_r)
	> 55 gallons and ≤ 100 gallons	Very small	0.6470 – (0.0006 × V_r)
		Low	0.7689 – (0.0005 × V_r)
		Medium	0.7897 – (0.0004 × V_r)
		High	0.8072 – (0.0003 × V_r)
Oil-fired Storage Water Heater	≤ 50 gallons	Very small	0.2509 – (0.0012 × V_r)
		Low	0.5330 – (0.0016 × V_r)
		Medium	0.6078 – (0.0016 × V_r)
		High	0.6815 – (0.0014 × V_r)
Electric Storage Water Heaters	≥ 20 gallons and ≤ 55 gallons	Very small	0.8808 – (0.0008 × V_r)
		Low	0.9254 – (0.0003 × V_r)
		Medium	0.9307 – (0.0002 × V_r)
		High	0.9349 – (0.0001 × V_r)
	> 55 gallons and ≤ 120 gallons	Very small	1.9236 – (0.0011 × V_r)
		Low	2.0440 – (0.0011 × V_r)
		Medium	2.1171 – (0.0011 × V_r)
		High	2.2418 – (0.0011 × V_r)
Tabletop Water Heater	≥ 20 gallons and ≤ 120 gallons	Very small	0.6323 – (0.0058 × V_r)
		Low	0.9188 – (0.0031 × V_r)
		Medium	0.9577 – (0.0023 × V_r)
		High	0.9884 – (0.0016 × V_r)
Instantaneous Gas-fired Water Heater	< 2 gallons and >50,000 Btu/h	Very small	0.80
		Low	0.81
		Medium	0.81
		High	0.81
Instantaneous Electric Water Heater	< 2 gallons	Very small	0.91
		Low	0.91
		Medium	0.91
		High	0.92
Grid-Enabled Water Heater	> 75 gallons	Very small	1.0136 – (0.0028 × V_r)
		Low	0.9984 – (0.0014 × V_r)
		Medium	0.9853 – (0.0010 × V_r)
		High	0.9720 – (0.0007 × V_r)

* V_r = Rated Storage Volume in gallons.

Appendix X. Gas Engine and Absorption Gas Heat Pump Water Heater Energy Savings Calculations

This section gives details on the energy savings calculations for gas engine and absorption gas heat pump water heaters. These systems can also be installed as combination systems, but this appendix only shows the energy savings in a water heating-only application.

Gas Engine Heat Pump Water Heater

Baseline Energy Usage

The baseline for measure SWWH007-04 I was used as the baseline for this calculation. The measure offering description for this measure is "Commercial Stor. heater, > 75 kBtu/hr, 0.96 TE." The gas engine heat pump water heater is not a storage water heater, but it does have a storage tank and it is >75kkBtu/hr.

The appropriate baseline water heater was selected in the DWHC ("Stor_TE-Gas-100gal-gte75 kBtuh-0.80Et') in Hotel Guest Room/Climate Zone 8. See Appendix IV for more details on the DWHC Baseline.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix IV. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the gas engine heat pump water heater operating alongside a new condensing efficiency storage water heater. Therefore, the total measure case energy usage is the sum of the total gas engine heat pump water heater energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the gas engine heat pump water heater capacity.

The measure case system is one (1) 500 kbuth gas engine heat pump water heater and one (1) 30gallon, 30 kBtuh, 0.83 UEF water heater.

Heating Load

The total heating load in the measure case is the same as the baseline case. Tank temperature, hourly water volume, and water main temperature remain the same.

Tank Loss – Gas Engine Heat Pump Water Heater

The baseline water heater in the DWHC was 100 gallons, so the storage tank in the measure case was assumed to be 100 gallons which equates to 31.3 sqft of tank surface area. This equates to a UA_{Tank} of 2.034 btu/hr-°F

Auxiliary Load – Gas Engine Heat Pump Water Heater

The gas engine heat pump water heater does not have a pilot light nor does the storage tank, so there is no auxiliary load for it.

Heat Exchanger Loss

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the measure-case system.

Total load

The total load is the sum of the heating load, tank loss load, and heat exchanger load

Gas Engine Heat Pump Water Heater Energy Use

The study "Natural Gas Internal Combustion Engine Heat Pump Field Trial Final Report" gives two equations for the COP as a function of outside air temperature (see Figure 12).

Equation 1: Gas engine heat pump water heater COP between 30°F and 40°F

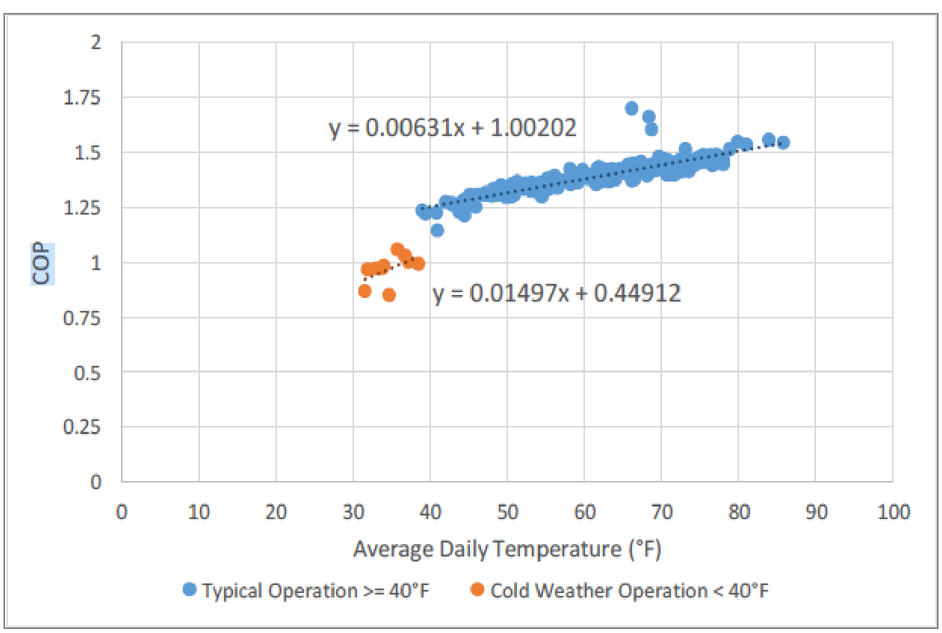
$$COP_{Gas-Engine} = 0.01497 * T_{amb} + 0.44912 \; (30°F \leq T_{amb} < 40°F)$$

Equation 2: Gas engine heat pump water heater COP above 40°F

$$COP_{Gas-Engine} = 0.00631 * T_{amb} + 1.00202 \; (40°F \leq T_{amb})$$

Figure 12: Gas engine heat pump water heater COP as a function of Ambient Air Temperature ©

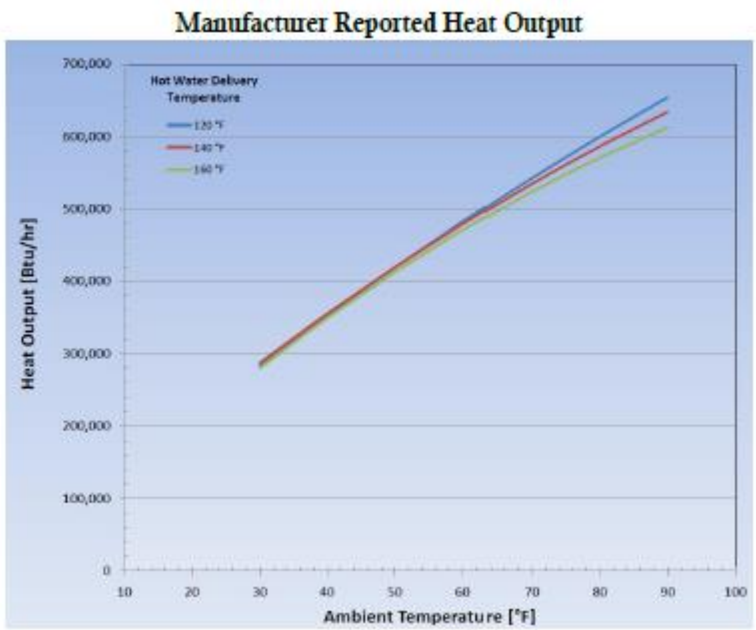
FIGURE 33 - DAILY AVERAGE HEAT PUMP PERFORMANCE



Storage Water Heater Energy Use

The gas engine heat pump water heater can only satisfy loads up to 600,000 btu/h and its hourly capacity is determined by the glycol/water output temperature and the ambient air temperature. The NEEA study provides this chart from the manufacturer for capacity as a function of ambient air temperature and water/glycol output temperature.

Figure 13: Gas engine heat pump water heater Capacity as a Function of Ambient Air Temperature ©



The capacity for a 140°F outlet was used to determine the hourly capacity of the gas engine heat pump water heater. The storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The storage water heater uses extra fuel in hours where the gas engine heat pump water heater cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Total Energy Usage – Measure Case

The total measure case energy usage is the sum of the gas engine heat pump water heater energy use and the storage water heater energy use.

Absorption Gas Heat Pump Water Heater

The calculations here are for the absorption gas heat pump water heater in a water heating only mode in a commercial building. There is one manufacturer with commercially available absorption gas heat pump water heater units. There are other manufacturers which produce these units, but they do not currently have commercially available units in the

United States. Since these calculations were meant to be high-level, a decision was made to use only the available third-party performance data for the commercially available unit in the calculation methodology. When units become available from additional manufacturers, performance curve data must be gathered for those units and decisions made about how to incorporate them into any existing calculation methodologies

Baseline Energy Usage

The baseline for measure SWWH007-04 I: Commercial Stor. heater, > 75 kBtu/hr, 0.96 TE was used as the baseline for this calculation. The absorption gas heat pump water heater is not a storage water heater, but it does have a storage tank and it is >75kBtu/hr.

The appropriate baseline water heater was selected in the DWHC ("Stor_TE-Gas-100gal-gte75 kBtuh-0.80et') in Assembly/Climate Zone 8. See Appendix IV for more details on the DWHC Baseline.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix IV. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the absorption gas heat pump water heater operating alongside a new condensing efficiency storage water heater. The manufacturer indicated that the absorption gas heat pump water heater is best utilized when it serves the base load of the system, and the existing equipment serves the peaking loads. Therefore, the total measure case energy usage is the sum of the total absorption gas heat pump water heater energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the absorption gas heat pump water heater capacity.

The measure-case system is one (1) absorption gas heat pump water heater and one (1) 75 gallon, 70 kBtuh, 0.94 UEF gas water heater.

Heating Load

The total heating load in the measure case is the same as the baseline case. Tank temperature, hourly water volume, and water main temperature remain the same.

Tank Loss – Absorption Gas Heat Pump Water Heater

The baseline water heater in the DWHC was 100 gallons, so the storage tank in the measure case was assumed to be 100 gallons which equates to 31.3sqft of tank surface area. This equates to a UA_{Tank} of 2.034 btu/hr-°F

Auxiliary Load – Absorption Gas Heat Pump Water Heater

The absorption gas heat pump water heater does not have a pilot light nor does the storage tank, so there is no auxiliary load for it.

Heat Exchange Loss – Absorption Gas Heat Pump Water Heater

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the measure-case system.

Total Load

The total load is the sum of the heating load, tank loss load, and heat exchanger load

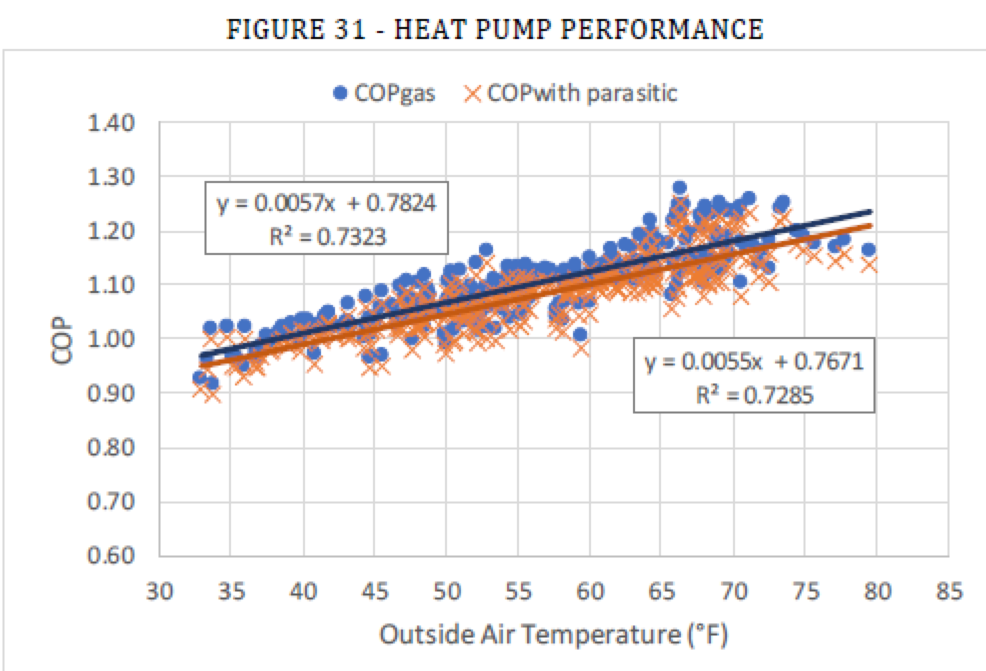
Energy Use – Absorption Gas Heat Pump Water Heater

The study "Robur Heat Pump Field Trial" gives the following equation for the COP as a function of outside air temperature in Figure 31 of the report .

Equation 3: Absorption gas heat pump water heater coefficient of performance

$$COP_{Absorption} = 0.0055 * T_{amb} + 0.7671$$

Figure 14: Absorption gas heat pump water heater COP as a Function of Outside Air Temperature ©

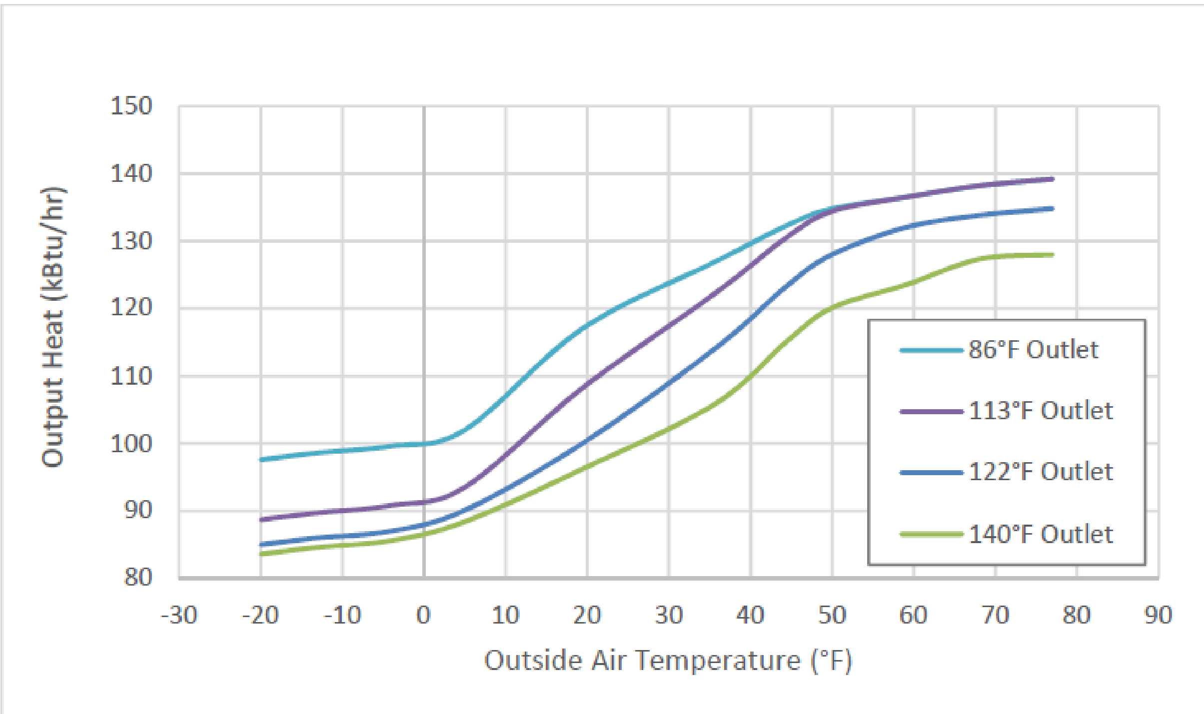


Energy Use – Water Heater

The absorption gas heat pump water heater can only satisfy loads up to 123,000 btu/h and its hourly capacity is determined by the glycol/water output temperature and the ambient air temperature. The NEEA study provides this chart from the manufacturer for capacity as a function of ambient air temperature and water/glycol output temperature .

Figure 15: Absorption Gas Heat Pump Water Heater Capacity as a Function of Outside Air Temperature ©

FIGURE 42 - GAHP-A OUTPUT CAPACITY CURVES



The capacity for a 140°F outlet was used to determine the hourly capacity of absorption gas heat pump water heater. The storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The water heater uses extra fuel in hours where the absorption gas heat pump water heater cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Total Energy Usage – Measure Case

The total measure case energy usage is the sum of the absorption gas heat pump water heater energy use and the storage water heater energy use.

Gas Engine Sections 2.2 – 2.6. The difference between the water heating only calculation and combi calculation is the total load. The total load calculations are shown below.

Measure Load – Water Heating

Appendix XI. The calculation for the hourly water heating load in the measure case is the same as described in the “Measure Energy Usage Section” in Technology Scoring Details

Below are the specific scoring guidelines used for the emerging water heating technologies

Table 27: Technology Scoring Details

Consideration	Description
Program	TRC/Simple Payback TRC: 5: 1.25+ 4: 1.0-1.25 3: 0.9-1.0 2: 0.8-0.9 1: <0.8 Simple Payback 5: 5-7 years 4: 7-10 years 3: 10-15 years 2: 15-20 years 1: 20+ years
Program	Market Size- Residential 5: >150k 4: 100-150k 3: 75k – 100k 2: 25k-75k 1: <25k Commercial 5: 5 - >10k 4: 4 – 7k-10k 3 : 5k-7k 2: 3k-5k 1: 1- <3k
Program	Potential to complete a field/lab study within 3 years? 5: Yes 3: Maybe 1: No

Consideration	Description
Program	Potential for a joint project with cooperation from other internal IOU programs 5: Yes 3: Maybe 1: No
Program	Product performance 5: COP>1.9 4: COP 1.5-1.8 3: COP 1.1-1.4 2: COP 0.8-1.0 1: COP <.7
Program	Time to commercialization 5: 0 yrs 4: 1 yr 3: 2 yrs 2: 3 yrs 1: 4+ yrs
Customer	Added functionality 5: 3 addl functions (space heating, space cooling, remotely controlled) 4: 2 functions (heating, cooling) 3: 1 function (heating) 2: 1 function (remote control) 1: no added functions
Customer	Material Cost 5: Equal to or less than condensing efficiency material cost 4: 1-1.5x condensing efficiency material cost 3:1.5- 2x condensing efficiency material cost 2: 2-3x condensing efficiency material cost 1: 3X or greater than condensing efficiency material cost
Customer	Installation Cost/Complexity *If install costs available* 5: Equal to or less than condensing efficiency installation cost 4: 1- 1.5x condensing efficiency installation cost 3: 1.5-2x condensing efficiency installation cost 2: 2-3x condensing efficiency installation cost 1: 3X or greater than condensing efficiency installation cost *If costs not available use engineering judgement of complexity of installation* 5: Low Complexity (Nothing new required) 4: Medium-Low Complexity (New venting, new gas lines) 3: Medium complexity (Residential – new electrical) 2: Medium-High Complexity (Residential – new electrical and new venting or gas lines, new hydronic loops) 1: High complexity (Residential – new electrical and new water lines)

Consideration	Description
Market	Market Readiness 5: Mature 4: Growing 3: Niche 2: Limited Availability 1: Pre-Commercialization
Market	Technology brand awareness/brand equity among customers, distributors, and installers 5: Brand already established in the market 4: Brand not already established in the market
Market	Confidence in technology – distributor and installers confident in the technology 5: A distributor already carrying technology 4: No distributor carrying technology
Regulatory	Testing standards 5: Testing standards exist 3: No testing standards but they are being developed 1: No testing standards and none being developed
Regulatory	Software Tools 5: Compliance software exists 4: No compliance software, but software to calculate energy usage/savings exists 3: No compliance or energy usage software exists but at least one is being developed 1: No compliance or energy savings software and none being developed
Regulatory	Risk that technology will be prohibited/made obsolete by state or local codes 5 – Low risk 3 – Medium risk 1 – High risk

Table 28: Emerging Water Heating Technology Prioritization

Technology Name & Sector	Description	Priority
Machine Learning Water Heating Controls-Res	Machine learning controls that save water heating energy by reducing temperature setpoint of hot water during low-demand times. Single Family	Medium
Commercial Gas Engine Heat Pump Water Heater-Com	Heat pump water heater utilizing **mechanical** output of a gas-driven internal combustion engine to drive a vapor compression cycle (Multifamily & Commercial)	High
Residential Vapor Absorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Single-Family)	Medium
Commercial Vapor Absorption Gas Heat Pump Water Heater-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle with Ammonia/water solution or Lithium-Bromide/water solution (Multifamily & Commercial)	High
Residential Adsorption Gas Heat Pump Water Heater-Res	Heat pump water heater utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. (Single-Family)	High
Ejector Sorption Assisted Gas Heat Pump Water Heater-Res	Thermal energy provided by the combustion of natural gas drives an ejector heat pump system assisted by sorption to increase COP. Ejector replaces the compressor in a vapor-compression cycle[18].	Low
Self-Powered High Two-Phase Thermo-Syphoning Residential Gas Storage Water Heaters-Res	Competitive cost higher efficiency (non-condensing) tank water heater utilizing Two-Phase Thermo-Syphoning Technology	Medium
Non-Powered Damper Commercial Gas Storage Water Heaters-Com	Competitive cost higher efficiency tank water heater with non-powered damper	Low
Residential Waste-Water Heat Recovery HX (Water Pre Heat)-Res	Utilizing a heat exchanger to use waste hot drain water to pre heat water going into a water heater (Single-family)	Low
Commercial or Multifamily Wastewater Heat Recovery HX (Water Pre Heat)-Com	Utilizing a heat exchanger to use waste heat to pre heat water going into a water heater (Multifamily & Commercial)	Low
Equipment Specific Greywater Recycling with Heat Recovery-Res	Means to collect grey water and recover heat from it for pre-heating hot water for an individual piece of equipment or sink/shower	Medium

Technology Name & Sector	Description	Priority
Commercial Gas Engine Heat Pump Combi System-Com	Heat pump utilizing **mechanical output** of a gas-driven internal combustion engine to drive a vapor compression cycle to provide 2+ of the following 1. Space heating 2. Space cooling 3. DHW heating	High
Residential Vapor Absorption Gas Heat Pump Combi System-Res	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	Medium
Commercial Vapor Absorption Gas Heat Pump Combi System-Com	Heat pump water heater utilizing **thermal output** by combustion of natural gas to drive a thermodynamic absorption cycle. Uses Ammonia/water solution or Lithium-Bromide/water solution. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	High
Residential Vapor Adsorption Gas Heat Pump Combi System-Res	Heat pump utilizing **thermal output** from exothermic and endothermic reactions with a sorbent and solution. Sorbents can be zeolite or silica gel. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	Low
Thermal Compression Gas Heat Pump Combi System-Res & Com	Thermal energy provided by the combustion of natural gas powers a thermodynamic compression cycle. Helium is the working fluid. Provides 2+ of the following: 1. Space heating 2. Space cooling 3. DHW heating	High
Combination Space and Gas Heat Pump Water Heating System Controls -Res & Com	Controls for equipment that provides heating and hot water using gas-burner.	Medium

Appendix XII. Codes & Standards Information

Gas Engine Heat Pump Water Heater and Combination

AQMD

3. SCAQMD standards regulating emissions from stationary Internal Combustion Engines (rule 1470, rule 1110.2) regulate IC engines with >50 hp. Manufacturer spec sheet states it is <50hp so these standards do not apply

Title 24/Title20/DOE

3. Space Heating
    a. Section 110.2 regulates space conditioning systems. Table 110.2C Air Cooled Gas-Engine Heat Pumps regulates COP for heating and cooling mode.
    b. GAP: Title 24 COP based upon ANSI Z21.40.4A. The manufacturer's unit was certified by ANSI Z21.40.2. The standards are similar in name.
3. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 © includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
        i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
        ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
        iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
        iv. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Absorption Gas Heat Pump Water Heater and Combination

AQMD

5. Boiler
    a. SCAQMD definition of Boiler or Steam Generator from Rule 1146.2 is as follows:
        i. "BOILER OR STEAM GENERATOR means any equipment that is fired with or is designed to be fired with natural gas, used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale."
    b. These units are designed to be fired by natural gas and they heat water (though indirectly), so this SCAQMD rule applies to this unit when it is heating HHW or both HHW and DHW.
    c. Rule 1146.2 defines a Type I unit as "TYPE 1 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY less than or equal to 400,000 BTU per hour excluding TANK TYPE WATER HEATERS subject to the limits of District Rule 1121"
    d. These units are less than 400,000 btu/h so they are "Type 1" units
    e. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).
    f. Manufacturer's provided emissions are 0.021-0.026 lb/MMbtu which converts to 21-26 lb/billion BTU
6. Water Heater
    a. SCAQMD definition of water heater from Rule 1146.2 is as follows "WATER HEATER means any equipment that is fired with or designed to be fired with natural gas and that is used solely to heat water for use external to the equipment"
    b. These units are designed to be fired by natural gas and when installed in a DHW only configuration, it solely heats water for use external to the equipment (though indirectly), so this SCAQMD rule applies to this unit. These units are less than 400,000 btu/h so they are "Type 1" units
    c. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).

Title 24/Title20/DOE

5. Space Heating
    a. Title 24 Section 110.2 regulates space conditioning systems. However, there is no table for gas-fired absorption heat pumps.
    b. Therefore, Title 24 does not apply and there is a gap in the standards

6. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
        i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
        ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
        iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
        iv. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Adsorption Gas Heat Pump Water Heater

AQMD

7. No info available on the size of this unit, but since it is designed to be a residential unit assume that SCAQMD rule 1121 applies.
8. Definition of a water heater from Rule 1121 is as follows "WATER HEATER means a closed vessel other than a mobile home water heater in which water is heated by combustion of gaseous fuel and is withdrawn for use external to the vessel at pressures not exceeding 160 psig, including the apparatus by which heat is generated and all controls and devices necessary to prevent water temperatures from exceeding 210°F (99°C)."
9. This technology meets this definition, because it is a closed vessel in which water is heated by combustion of gaseous fuel and water is withdrawn for use external to the vessel at pressures not exceeding 160 psig. The technology has integral potable water storage. Therefore, NOx limits ©(c)(3) apply: limit of 10 nanograms per Joule or 15 ppm

Title 24/Title20/DOE

3. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)
    b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
    c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
    d. No Spec sheet with input rating of this water heater is available so assume it meets the definition of a "Gas-fired storage water heater" that is a federally regulated consumer product from definitions in 1602(f)
    e. Standards for minimum UEF for gas-fired storage water heater from section 1605.1(f) apply to this unit
    f. On 1/11/22 DOE published a supplemental notice of proposed rulemaking to amend the test procedure for consumer water heaters and residential duty-commercial water heaters. The updated test procedure proposes to allow for voluntary representations at certain additionally specified test conditions for heat pump water heaters.

Thermal Gas Compression Combi – Residential & Commercial

AQMD

5. Boiler
    a. SCAQMD definition of Boiler or Steam Generator from Rule 1146.2 is as follows:
        i. "BOILER OR STEAM GENERATOR means any equipment that is fired with or is designed to be fired with natural gas, used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale."
    b. These units are designed to be fired by natural gas and they heat water (though indirectly), so this AQMD rule applies to this unit when it is heating HHW or both HHW and DHW.
    c. These units are less than 400,000 btu/h so they are "Type 1" units
    d. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).
6. Water Heater
    a. Documentation on technology is not clear if it has an internal potable water tank, but conversations with manufacturer indicate the equipment does <u>not</u> have internal potable water storage so it is not a "water heater" as defined by rule 1121.
    b. SCAQMD definition of water heater from Rule 1146.2 is as follows "WATER HEATER means any equipment that is fired with or designed to be fired with natural gas and that is used solely to heat water for use external to the equipment"
    c. These units are designed to be fired by natural gas and, when installed in a DHW only configuration, it solely heats water for use external to the equipment (though indirectly), so this SCAQMD rule applies to this unit.
    d. These units are less than 400,000 btu/h so they are "Type 1" units
    e. The Type 1 unit emissions limits are ≤40 nanograms NOx per joule of heat output or 55ppm NOx emissions (93 lb NOx per billion BTU).

Title 24/Title20/DOE

5. Space Heating
    a. Title 24 section 110.2 regulates space conditioning systems.
    b. Therefore, Title 24 does not apply and there is a gap in the standards
6. Water Heating
    a. Title 24 Section 110.1 includes mandatory requirements for appliances that points to Title 20 section 1601 and 1608(a)

b. Title 20 Section 1601 (e) includes gas-fired combination space-heating and water-heating appliances
c. Title 20 section 1608 (a) requires appliances to be tested in accordance with relevant standards (section 1603 & 1604) and that appliance complies with efficiency standards in 1605.2 and 1605.3
d. None of the definitions from Title 20 Section 1602 apply completely to this technology.
    i. It is not a packaged boiler because it doesn't have all the things listed in the packaged boiler definition
    ii. It is not a Hot Water Supply Boiler because it does not store water so it cannot meet the requirement of at least 4,000 kbtuh gallon of stored water
    iii. It is not a commercial heat pump water heater because it doesn't have a kw rating; rather it has a kbtuh rating.
    iv. It is not a gas-fired storage water heater because it does not contain potable water
    v. It is not a gas-fired instantaneous water heater because it does not contain potable water
    vi. Therefore, Title 20 has a gap and does not regulate these kinds of water heaters

Additional AQMD Information

SCAQMD Rule Names and Applicability

Rules 1121: CONTROL OF NITROGEN OXIDES FROM RESIDENTIAL TYPE, NATURAL GAS-FIRED WATER HEATERS- Applicable to: This rule applies to manufacturers, distributors, retailers, and installers of natural gas-fired water heaters, with heat input rates less than 75,000 Btu per hour.

Rule 1146.2: EMISSIONS OF OXIDES OF NITROGEN FROM LARGE WATER HEATERS AND SMALL BOILERS AND PROCESS HEATERS- Applicable to: This rule applies to units that have a rated heat input capacity less than or equal to 2,000,000 BTU per hour. Type 1 Units as defined in this rule are typically, but not exclusively, large water heaters or smaller-sized process heaters in the above range. Type 2 Units as defined in this rule are typically, but not exclusively, small boilers or larger-sized process heaters in this range but Excludes Tank Type Water Heaters that are subject to limits in rule 1121.

Rule 1146: EMISSIONS OF OXIDES OF NITROGEN FROM INDUSTRIAL, INSTITUTIONAL, AND COMMERCIAL BOILERS, STEAM GENERATORS, AND PROCESS HEATERS- Applicable to: This rule applies to boilers, steam generators, and process heaters of equal to or greater than 5 million Btu per hour rated heat input capacity used in all industrial, institutional, and commercial operations.

Definitions

Rule 1146 & 1146.2: "BOILER or STEAM GENERATOR means any combustion equipment fired with liquid and/or gaseous (including landfill and digester gas) and/or solid fossil fuel and used to produce steam or to heat water, and that is not used exclusively to produce electricity for sale. Boiler or Steam Generator does not include any open heated tank, adsorption chiller unit, or waste heat recovery boiler that is used to recover sensible heat from the exhaust of a combustion turbine or any unfired waste heat recovery boiler that is used to recover sensible heat from the exhaust of any combustion equipment."

Rule 1146 & 1146.2 "PROCESS HEATER means any equipment that is fired with or is designed to be fired with natural gas and which transfers heat from combustion gases to water or process streams. Process Heater does not include any kiln or oven used for annealing, drying, curing, baking, cooking, calcining, or vitrifying; or any unfired waste heat recovery heater that is used to recover sensible heat from the exhaust of any combustion equipment."

Rule 1146.2 “TANK TYPE WATER HEATER means a WATER HEATER with a RATED HEAT INPUT CAPACITY from 75,000 BTU per hour to 2,000,000 BTU per hour and with an integral closed vessel in which water is heated and stored for use external to the vessel.”

Rule 1146.2 “TYPE 1 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY less than or equal to 400,000 BTU per hour excluding TANK TYPE WATER HEATERS subject to the limits of District Rule 1121.”

Rule 1146.2 “TYPE 2 UNIT means any WATER HEATER, BOILER or PROCESS HEATER with a RATED HEAT INPUT CAPACITY greater than 400,000 BTU per hour up to and including 2,000,000 BTU per hour.”

Rule 1121 “WATER HEATER means a closed vessel other than a mobile home water heater in which water is heated by combustion of gaseous fuel and is withdrawn for use external to the vessel at pressures not exceeding 160 psig, including the apparatus by which heat is generated and all controls and devices necessary to prevent water temperatures from exceeding 210°F (99°C).”

Additional Title 20 Information

Definitions from Section 1602

"Boiler" means a space heater that is a self-contained appliance for supplying steam or hot water primarily intended for space-heating. "Boiler" does not include hot water supply boilers."

"Commercial packaged boiler" means a type of packaged low-pressure boiler that is industrial equipment with a capacity (rated maximum input) of 300,000 Btu per hour (Btu/hr) or more which, to any significant extent, is distributed in commerce:

5. For heating or space conditioning applications in buildings; or
6. For service water heating in buildings but does not meet the definition of "hot water supply boiler" in this part."

"Packaged boiler" means a boiler that is shipped complete with heating equipment, mechanical draft equipment, and automatic controls, usually shipped in one or more sections and does not include a boiler that is custom designed, and field constructed. If the boiler is shipped in more than one section, the sections may be produced by more than one manufacturer and may be originated or shipped at different times and from more than one location."

"Space heater" means an appliance that supplies heat to a space for the purpose of providing warmth to objects within the space. "Space heater" includes but is not limited to boilers (except hot water supply boilers), furnaces, room heaters, floor furnaces, wall furnaces, infrared heaters, unit heaters, duct furnaces, and combination space-heating and water-heating appliances."

"Hot water supply boiler" means a packaged boiler that is industrial equipment and that:

7. has an input rating from 300,000 Btu/hour to 12,500,000 Btu/hour and of at least 4,000 Btu/hour per gallon of stored water.
8. is suitable for heating potable water; and
9. meets either or both of the following conditions:
    a. it has the temperature and pressure controls necessary for heating potable water for purposes other than space heating; or
    b. the manufacturer's product literature, product markings, product marketing, or product installation and operation instructions indicate that the boilers intended uses include heating potable water for purposes other than space heating.

"Air-source commercial heat pump water heater" means a commercial heat pump water heater that utilizes indoor or outdoor air as the heat source."

"Commercial heat pump water heater (CHPWH)" means a water heater (including all ancillary equipment such as fans, blowers, pumps, storage tanks, piping, and controls, as applicable) that uses a refrigeration cycle, such as vapor compression, to transfer heat from a low-temperature source to a higher-temperature sink for the purpose of heating potable water, and has a rated electric power input greater than 12 kW. Such equipment includes, but is not limited to, air-source heat pump water heaters, water-source heat pump water heaters, and direct geo-exchange heat pump water heaters.

"Gas-fired storage water heater" that is a federally regulated consumer product means a water heater that uses gas as the main energy source, has a nameplate input rating of 75,000 Btu/h or less, and contains more than one gallon of water per 4,000 Btu per hour of input.

"Gas-fired storage water heater" that is federally regulated commercial and industrial equipment means a water heater that uses gas to heat and store water within the appliance at a thermostatically controlled temperature for delivery on demand and has a rated input both greater than 75,000 Btu/hour and less than 4,000 Btu/hour per gallon of stored water.

"Gas-fired instantaneous water heater" that is a federally regulated consumer product means a water heater that uses gas as the main energy source, has a nameplate input rating less than 200,000 Btu/h, and contains no more than one gallon of water per 4,000 Btu per hour of input.

"Gas-fired instantaneous water heater" that is federally regulated commercial and industrial equipment means a water heater that uses gas as the main energy source and has a rated input both greater than 200,000 Btu/h and not less than 4,000 Btu/h per gallon of stored water.

Title 20 Section 1605.1(f) Standards for Water Heaters

Product Class	Rated Storage Volume and Input Rating (if applicable)	Draw Pattern	Minimum Uniform Energy Factor*
Gas-fired Storage Water Heater	≥ 20 gallons and ≤ 55 gallons	Very small	0.3456 – (0.0020 × V_r)
		Low	0.5982 – (0.0019 × V_r)
		Medium	0.6483 – (0.0017 × V_r)
		High	0.6920 – (0.0013 × V_r)
	> 55 gallons and ≤ 100 gallons	Very small	0.6470 – (0.0006 × V_r)
		Low	0.7689 – (0.0005 × V_r)
		Medium	0.7897 – (0.0004 × V_r)
		High	0.8072 – (0.0003 × V_r)
Oil-fired Storage Water Heater	≤ 50 gallons	Very small	0.2509 – (0.0012 × V_r)
		Low	0.5330 – (0.0016 × V_r)
		Medium	0.6078 – (0.0016 × V_r)
		High	0.6815 – (0.0014 × V_r)
Electric Storage Water Heaters	≥ 20 gallons and ≤ 55 gallons	Very small	0.8808 – (0.0008 × V_r)
		Low	0.9254 – (0.0003 × V_r)
		Medium	0.9307 – (0.0002 × V_r)
		High	0.9349 – (0.0001 × V_r)
	> 55 gallons and ≤ 120 gallons	Very small	1.9236 – (0.0011 × V_r)
		Low	2.0440 – (0.0011 × V_r)
		Medium	2.1171 – (0.0011 × V_r)
		High	2.2418 – (0.0011 × V_r)
Tabletop Water Heater	≥ 20 gallons and ≤ 120 gallons	Very small	0.6323 – (0.0058 × V_r)
		Low	0.9188 – (0.0031 × V_r)
		Medium	0.9577 – (0.0023 × V_r)
		High	0.9884 – (0.0016 × V_r)
Instantaneous Gas-fired Water Heater	< 2 gallons and >50,000 Btu/h	Very small	0.80
		Low	0.81
		Medium	0.81
		High	0.81
Instantaneous Electric Water Heater	< 2 gallons	Very small	0.91
		Low	0.91
		Medium	0.91
		High	0.92
Grid-Enabled Water Heater	> 75 gallons	Very small	1.0136 – (0.0028 × V_r)
		Low	0.9984 – (0.0014 × V_r)
		Medium	0.9853 – (0.0010 × V_r)
		High	0.9720 – (0.0007 × V_r)

* V_r = Rated Storage Volume in gallons.

Appendix XIII. Gas Engine and Absorption Gas Heat Pump Water Heater Energy Savings Calculations

This section gives details on the energy savings calculations for gas engine and absorption gas heat pump water heaters. These systems can also be installed as combination systems, but this appendix only shows the energy savings in a water heating-only application.

Gas Engine Heat Pump Water Heater

Baseline Energy Usage

The baseline for measure SWWH007-04 I was used as the baseline for this calculation. The measure offering description for this measure is "Commercial Stor. heater, > 75 kBtu/hr, 0.96 TE." The gas engine heat pump water heater is not a storage water heater, but it does have a storage tank and it is >75kkBtu/hr.

The appropriate baseline water heater was selected in the DWHC ("Stor_TE-Gas-100gal-gte75 kBtuh-0.80Et') in Hotel Guest Room/Climate Zone 8. See Appendix IV for more details on the DWHC Baseline.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix IV. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the gas engine heat pump water heater operating alongside a new condensing efficiency storage water heater. Therefore, the total measure case energy usage is the sum of the total gas engine heat pump water heater energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the gas engine heat pump water heater capacity.

The measure case system is one (1) 500 kbuth gas engine heat pump water heater and one (1) 30gallon, 30 kBtuh, 0.83 UEF water heater.

Heating Load

The total heating load in the measure case is the same as the baseline case. Tank temperature, hourly water volume, and water main temperature remain the same.

Tank Loss – Gas Engine Heat Pump Water Heater

The baseline water heater in the DWHC was 100 gallons, so the storage tank in the measure case was assumed to be 100 gallons which equates to 31.3 sqft of tank surface area. This equates to a UA_{Tank} of 2.034 btu/hr-°F

Auxiliary Load – Gas Engine Heat Pump Water Heater

The gas engine heat pump water heater does not have a pilot light nor does the storage tank, so there is no auxiliary load for it.

Heat Exchanger Loss

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the measure-case system.

Total load

The total load is the sum of the heating load, tank loss load, and heat exchanger load

Gas Engine Heat Pump Water Heater Energy Use

The study "Natural Gas Internal Combustion Engine Heat Pump Field Trial Final Report" gives two equations for the COP as a function of outside air temperature (see Figure 12).

Equation 1: Gas engine heat pump water heater COP between 30°F and 40°F

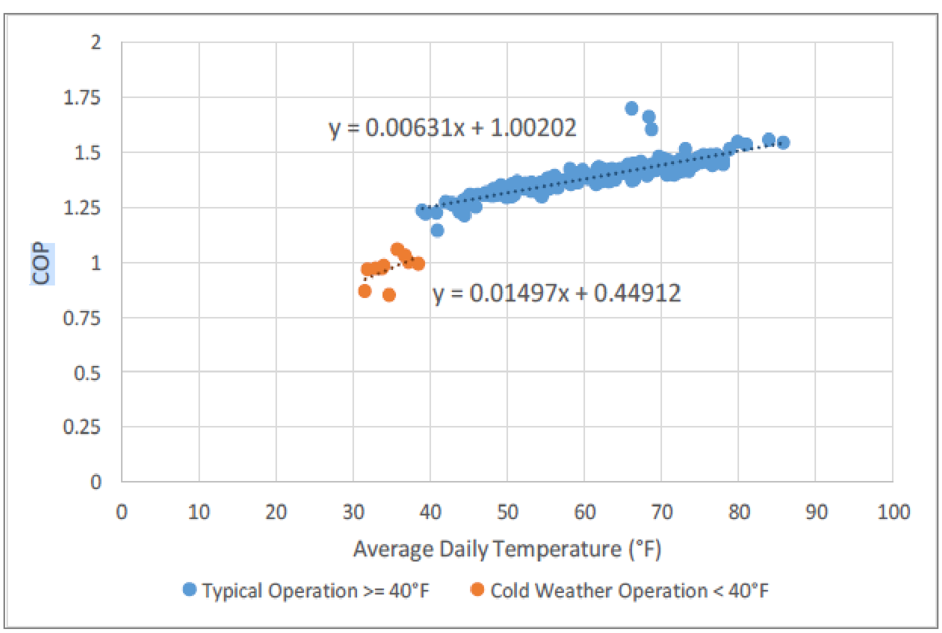
$$COP_{Gas-Engine} = 0.01497 * T_{amb} + 0.44912 \ (30°F \leq T_{amb} < 40°F)$$

Equation 2: Gas engine heat pump water heater COP above 40°F

$$COP_{Gas-Engine} = 0.00631 * T_{amb} + 1.00202 \ (40°F \leq T_{amb})$$

Figure 12: Gas engine heat pump water heater COP as a function of Ambient Air Temperature ©

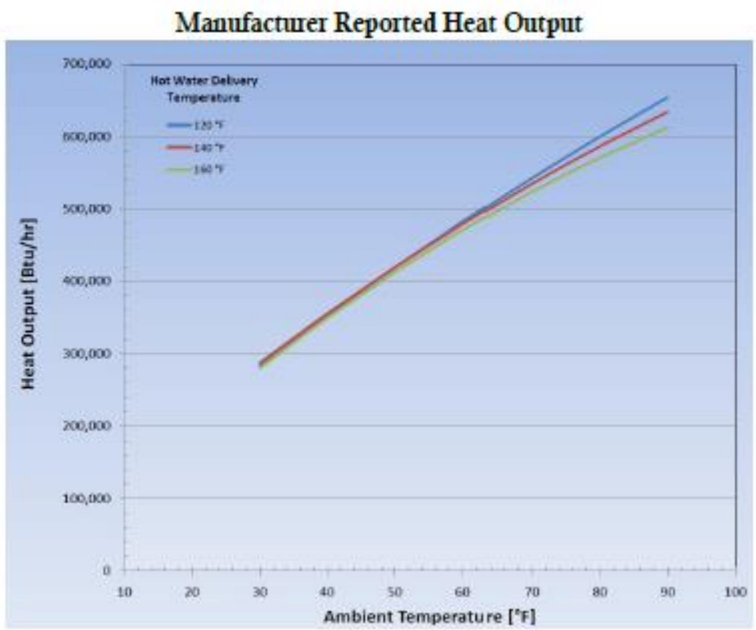
FIGURE 33 - DAILY AVERAGE HEAT PUMP PERFORMANCE



Storage Water Heater Energy Use

The gas engine heat pump water heater can only satisfy loads up to 600,000 btu/h and its hourly capacity is determined by the glycol/water output temperature and the ambient air temperature. The NEEA study provides this chart from the manufacturer for capacity as a function of ambient air temperature and water/glycol output temperature.

Figure 13: Gas engine heat pump water heater Capacity as a Function of Ambient Air Temperature ©



The capacity for a 140°F outlet was used to determine the hourly capacity of the gas engine heat pump water heater. The storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The storage water heater uses extra fuel in hours where the gas engine heat pump water heater cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Total Energy Usage – Measure Case

The total measure case energy usage is the sum of the gas engine heat pump water heater energy use and the storage water heater energy use.

Absorption Gas Heat Pump Water Heater

The calculations here are for the absorption gas heat pump water heater in a water heating only mode in a commercial building. There is one manufacturer with commercially available absorption gas heat pump water heater units. There are other manufacturers which produce these units, but they do not currently have commercially available units in the

United States. Since these calculations were meant to be high-level, a decision was made to use only the available third-party performance data for the commercially available unit in the calculation methodology. When units become available from additional manufacturers, performance curve data must be gathered for those units and decisions made about how to incorporate them into any existing calculation methodologies

Baseline Energy Usage

The baseline for measure SWWH007-04 I: Commercial Stor. heater, > 75 kBtu/hr, 0.96 TE was used as the baseline for this calculation. The absorption gas heat pump water heater is not a storage water heater, but it does have a storage tank and it is >75kBtu/hr.

The appropriate baseline water heater was selected in the DWHC ("Stor_TE-Gas-100gal-gte75 kBtuh-0.80et') in Assembly/Climate Zone 8. See Appendix IV for more details on the DWHC Baseline.

Measure Energy Usage

The methodology for the measure energy usage is documented thoroughly in Appendix IV. This section lists the required inputs to that methodology and the rationale behind them. The chosen measure-case system was the absorption gas heat pump water heater operating alongside a new condensing efficiency storage water heater. The manufacturer indicated that the absorption gas heat pump water heater is best utilized when it serves the base load of the system, and the existing equipment serves the peaking loads. Therefore, the total measure case energy usage is the sum of the total absorption gas heat pump water heater energy usage and the total storage water heater energy usage. It is assumed that the water heater must remain on at all times, so it constantly uses energy for the pilot light and to keep its tank at temperature, but it only uses additional energy when the water heating load exceeds the absorption gas heat pump water heater capacity.

The measure-case system is one (1) absorption gas heat pump water heater and one (1) 75 gallon, 70 kBtuh, 0.94 UEF gas water heater.

Heating Load

The total heating load in the measure case is the same as the baseline case. Tank temperature, hourly water volume, and water main temperature remain the same.

Tank Loss – Absorption Gas Heat Pump Water Heater

The baseline water heater in the DWHC was 100 gallons, so the storage tank in the measure case was assumed to be 100 gallons which equates to 31.3sqft of tank surface area. This equates to a UA_{Tank} of 2.034 btu/hr-°F

Auxiliary Load – Absorption Gas Heat Pump Water Heater

The absorption gas heat pump water heater does not have a pilot light nor does the storage tank, so there is no auxiliary load for it.

Heat Exchange Loss – Absorption Gas Heat Pump Water Heater

It is assumed that there is a 5% loss in the water-to-water heat exchanger in the measure-case system.

Total Load

The total load is the sum of the heating load, tank loss load, and heat exchanger load

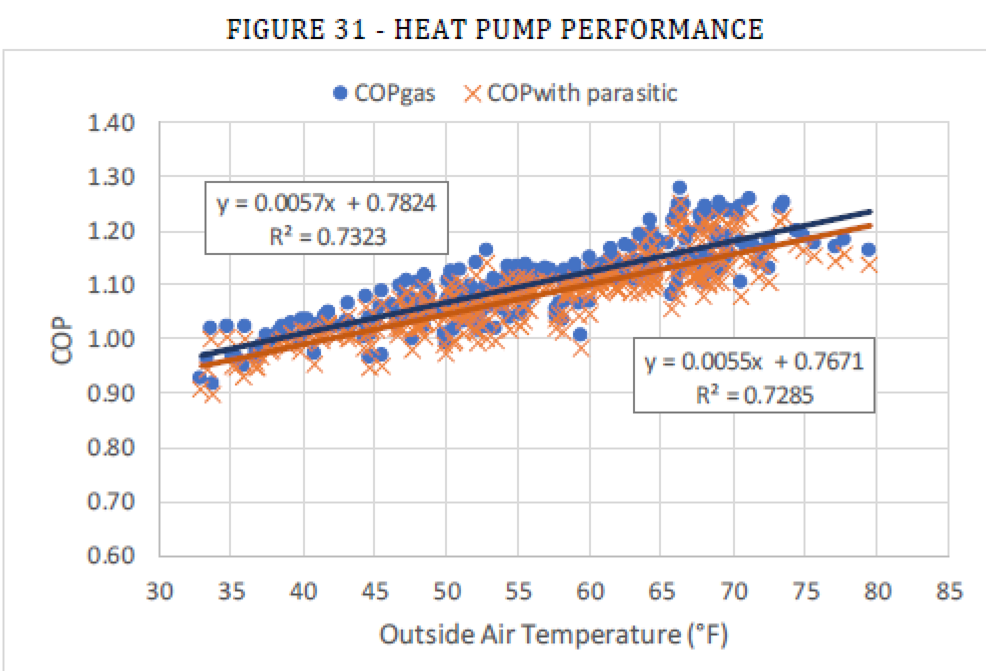
Energy Use – Absorption Gas Heat Pump Water Heater

The study "Robur Heat Pump Field Trial" gives the following equation for the COP as a function of outside air temperature in Figure 31 of the report .

Equation 3: Absorption gas heat pump water heater coefficient of performance

$$COP_{Absorption} = 0.0055 * T_{amb} + 0.7671$$

Figure 14: Absorption gas heat pump water heater COP as a Function of Outside Air Temperature ©

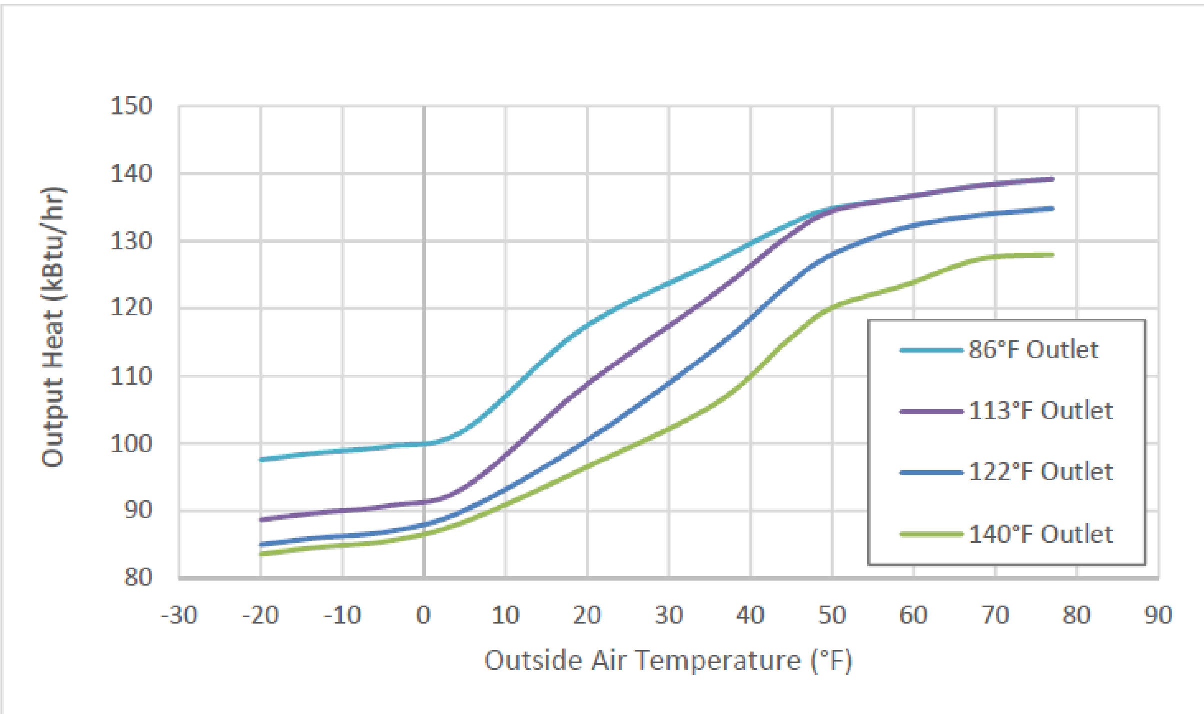


Energy Use – Water Heater

The absorption gas heat pump water heater can only satisfy loads up to 123,000 btu/h and its hourly capacity is determined by the glycol/water output temperature and the ambient air temperature. The NEEA study provides this chart from the manufacturer for capacity as a function of ambient air temperature and water/glycol output temperature .

Figure 15: Absorption Gas Heat Pump Water Heater Capacity as a Function of Outside Air Temperature ©

FIGURE 42 - GAHP-A OUTPUT CAPACITY CURVES



The capacity for a 140°F outlet was used to determine the hourly capacity of absorption gas heat pump water heater. The storage water heater uses energy every hour for the auxiliary load (pilot light) and maintaining the tank at a set temperature. The water heater uses extra fuel in hours where the absorption gas heat pump water heater cannot satisfy the total load. The auxiliary load and tank losses are the same as the baseline calculations.

Total Energy Usage – Measure Case

The total measure case energy usage is the sum of the absorption gas heat pump water heater energy use and the storage water heater energy use.

Gas Engine Equation 9 From that section is restated here:

The total load is calculated as

Equation 9: Total Water Heating Load

$Load_{total,DHW} = HW_{load} + Load_{UA} + Load_{HX}$

Where:

$Load_{total,DHW}$ = total hourly DHW load [btu]

Measure Load – Space Heating

The hourly measure space heating load was determined by dividing the hourly heating end-use energy by the energy input ratio from eQuest (Furnace Heat Input Ratio or Boiler Heat Input Ratio).

Measure Load – Total

The total measure case heating load is given by the equation below

Equation 16: Total Measure Case Load Combi

$Load_{Total} = Load_{Total,DHW} + Load_{SH}$

Where:

$Load_{Total}$ = Total DWH and Space Heating load

$Load_{SH}$ = Total space heating load from eQuest hourly results

Appendix XIV. CET Inputs

This section gives more detail about the CET inputs for the TRC/TSB calculations

Sector: The CET designates the appropriate sector by measure. The selected technologies were either Commercial (Com) or Residential (Res).

Building Type: The building types were chosen by comparing the required capacity for the building type with the rated capacity of the technology. See the energy savings analysis for the methodology for choosing each measure's building type. The building type used in CET was the same one used in energy savings calculations.

Climate Zone: See the energy savings analysis for the methodology for choosing each technology's climate zone. The climate zone in CET was the same one used in energy savings calculations.

E3GasSavProfile: Measure savings occur throughout the year and therefore all technologies have 'Annual' as their entries.

E3GasSector: There are 3 codes under E3GasSector: Commercial, Core, and Residential. These technologies were either "Commercial" or "Residential."

Load Shape and Target Sector: The 'E3MeaElecEndUseShape' and 'E3TargetSector' are interdependent, and they also depend on the Program Administrator (PA), and Climate Zone. The selected PA for all measures is SCG. The 3MeaElecEndUseShape/E3TargetSector combination is DHW_HtPmp/Misc_Commercial for the commercial measures and it is DEER:Res ClothesDishWasher/Res for residential measures. These were the most fitting available combinations for each measure.

NormUnit, Therms, and Measure Costs: Normalizing Unit and Unit Therms come from the energy savings analysis. Measure Costs were determined using the best available data from manufacturers and existing measure packages. Measure costs used in the CET are incremental measure costs since these were assumed to be normal replacement measures. Baseline measure costs were calculated using available measure package costs. The Normalizing Unit is Cap-kBtuh for all measures except adsorption gas heat pump water heater. This measure uses "Each" as the normalizing unit because is meant to be a drop-in replacement for residential water heaters and the existing Measure Package (SWWH012) uses "Each" as the normalizing unit. The measure packages for commercial water heaters and boilers use "Cap- kBtuh" as the normalizing unit.

Unit Rebate: Two sets of CET runs were performed for each technology, with and without incentives. The incentive values were taken to be equal to the unit measure cost.

EUL and RUL: The Effective Useful Life (EUL) was selected to be 15 years for all technologies except the adsorption gas heat pump water heater system. An EUL of 11 years was used for this measure to be consistent with the residential storage water heater measure package (SWWH012-03). The Remaining Useful Life (RUL) is assumed to be 0 years as these technologies are normal replacement.

NTG, Installation Rates, and Realization Rates: A NTG value of 0.85 was the input for all the emerging technologies. Installation Rates and Realization rates were set to 1.0 for all measures.

Measure Code and Measure ID – left blank

PA: SCG was the chosen PA for all the emerging technologies.

Refrigerant Costs and Benefits: The internal combustion engine heat pump water heater and internal combustion engine heat pump combi technologies use a refrigeration cycle that uses refrigerant with a global warming potential (GWP) where the baseline equipment does not. Therefore, these measures have UnitRefrigCosts in the CET. The value for this input was found using the "Refrigerant Avoided Cost Calculator" (RACC). The UnitRefrigBens was 0 for all measures.

Appendix XV. Subject Matter Interview Questions

Technology Adoption Drivers

1. How much of a driver is a positive public image for your emerging or existing technologies?
2. How much of a driver is it for end-users to reduce dependence on fossil fuels?
3. How much of a driver is it for end-users to reduce GHG emissions?
4. How much of a driver is the compliance with environmental regulations?
5. How much of a driver is the reduction of pollutants other than CO2, such as SOx and NOx?
6. How much of a driver is the reduction in manufacturing waste?
7. How much of a driver are new or added advanced (smart) features for the end-user?
8. How much of a driver is the recyclability of your units?
9. How much of a driver is local manufacturing to the end-user? i.e., Made in the USA.
10. How much of a driver is improved performance for the end-user?
11. How much of a driver is the potential to increase your customer base?
12. How much of a driver is lowering production costs?
13. How much of a driver is the customer's willingness to pay a premium for a better product?
14. How much of a driver is government support for technology uptake for you?
15. How much of a driver is independent verification of performance?
16. How much of a driver is a shorter-to-market cycle when it was entering the market?

Technology Adoption Barriers

1. How much of a barrier is the cost of your technologies?
2. How much of a barrier is the uncertainty of future codes/standards?
3. How much of a barrier are the market fluctuations in price and cost?
4. How much of a barrier is adverse regulatory environments?
5. How much of a barrier is the uncertainty of technology performance by the end-user?
6. How much of a barrier is uncertain reliability in your product by the end-user?
7. How much of a market barrier is the lack of awareness from the customers?

8. How much of a market barrier is incompatibility with existing systems for your technology?
9. How much of a market barrier is higher lifecycle costs to the end user?
10. How much of a barrier is the lack of awareness of GHG savings by the end-user?
11. How much of a barrier is any possible environmental impact of manufacturing?
12. How much of a barrier is any adverse disposal effects? i.e., refrigerant.
13. How much of a barrier is the lack of installer and/or contractor training?
14. How much of a barrier is the lack of maintenance personnel training?
15. How much of a barrier is the lack of awareness among designers and engineers?

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