Pacific Gas and Electric Company

Zero Net Energy Program

Technology Assessment Report #xxxxx

Ground Coupled Heat Pump Technology Assessment

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Executive Summary

This study evaluates ground coupled heat pump (GCHPs) as a potential component of a Zero Net Energy (ZNE) strategy for new and existing homes in PG&E service territory. This technology is one of a total of twenty five measures which will be evaluated for PG&E to assess their viability as productive ZNE strategies for new and existing homes and commercial buildings. These reports fit under the Technology Advancement Subprogram of the PG&E ZNE Pilot Program which has the goal of "delivering information, insights, analytical tools, and resources to accelerate and expand the commercialization of innovative technologies as stated in the Strategic Plan", as defined by the California Public Utility Commission's Decision Approving 2010 to 2012 Energy Efficiency Portfolios and Budgets.

In certain climates, GCHPs represent a potentially attractive option to reduce space conditioning energy use and peak cooling demand. GCHPs demonstrate high efficiencies by taking advantage of relatively stable ground temperatures throughout the year for heat extraction and rejection. They use a refrigerant-to-water heat exchanger as opposed to refrigerant-to-air thus making use of improved heat transfer properties of water over air. The impact is most significant during peak summer and winter times when outdoor temperatures are extremely high or low and traditional air conditioners or heat pumps operate less efficiently.

To evaluate the GCHP technology, Davis Energy Group completed the following activities:

- Complete a literature review of recent monitoring and modeling studies.
- Collect equipment pricing data and marketing information from manufacturers.
- Select appropriate simulation tools that can model performance of GCHPs appropriately with a water loop and ground heat exchanger.
- Develop simulation model inputs that best describe "representative" residential household energy consumption for the various cases and climates.
- Utilize the Residential Appliance Saturation Survey (RASS) and Department of Energy's Building America Benchmark Definition as a guideline for defining typical energy end uses.
- Complete simulations for three representative PG&E climate zones and three home efficiency vintages (existing building stock, Title 24 compliant new home, and Tier 2[1] new home).

[1] This represents a home ~ 30% better than Title 24.

eQUEST (using DOE-2.2) energy simulation model was used to estimate energy use and project GCHP performance. Three climate zones within PG&E territory were evaluated: Climate Zone 3 (Oakland), Climate Zone 4 (San Jose), and Climate Zone 13 (Fresno). Model results were used to estimate typical source energy savings relative to two space conditioning options: 1) standard gas furnace with air conditioner and 2) heat pump. Defining the source energy[2] impacts of the potential ZNE technologies is the primary goal of this evaluation process. A secondary goal involves assessing customer economics under "typical" usage assumptions.

Key findings of the study include:

1. Total space conditioning energy is projected to represent an average of 27% of households annual source energy usage for the cases evaluated, with higher fractions in homes with substantial cooling and heating loads (~37%) and lower for homes in coastal climates where cooling loads are trivial (~19%).

2. <u>Relative to a conventional gas furnace space heating w/ compressor based cooling</u>, GCHPs are projected to reduce annual space conditioning source energy by about 45%, resulting in a whole house savings of about 13%.

3. <u>Relative to a high efficiency furnace and air conditioner package</u> that will be common in higher efficiency Tier 2 homes, GCHPs are projected to reduce annual space conditioning source energy by about 35%, resulting in a whole house savings of about 8%.

4. <u>Relative to a standard efficiency electric heat pump</u>, GCHPs are projected to reduce annual space conditioning source energy by about 36%, resulting in a whole house savings of about 10%.

5. <u>Relative to a high efficiency electric heat pump</u>, GCHPs are projected to reduce annual space conditioning source energy by about 30%, resulting in a whole house savings of about 7%.

6. GCHPs offer an important strategy for peak summer demand savings in ZNE homes. Demand savings are approximately 39% for existing building stock and Title 24 compliant new homes and 27% for Tier2 new homes.

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[2] For purposes of this study, the source energy conversion assumes that three units of energy are consumed to generate, transmit, and distribute one unit of electrical energy to the house.

7. Ground loop costs are a significant contribution to total system costs. Costs for loop installation vary significantly by loop type. While vertical loop installations can be 2-3 times more expensive that horizontal loops, they are most commonly installed due to footprint limitations. The largest opportunity for system cost reductions lie in reducing ground loop costs.

8. From a customer viewpoint, GCHP economics are challenging due to high incremental first costs the availability of inexpensive natural gas. Low current natural gas rates and PG&E's current steep tiered E-1 electric rate structure will result in increased household utility costs relative to a house with a gas water heater. Even with natural gas costs 50% higher than current rates, an attractive customer simple payback cannot be achieved. A potential niche market may exist for customers who currently do not have access to natural gas and are able to participate in all-electric E-1 rates.

9. Utility cash incentives or tax credits will continue to be necessary in the short term to improve GCHP economics.

Tables E-1 through E-6 summarize the expected annual energy and peak demand impacts for the various scenarios. The results shown are based on typical usage patterns and are presented compared to both a gas heating base case and a heat pump base case.

Table E-1: Projected Annual Whole Building Savings for Title 24 Home Over Gas Base Case

	Gas Furnace Base Case Whole Building Usage			% Savings with GCHP Technology		
Climate Zone	kW	kWh	therms	kW	kWh	therm
San Francisco (CZ3)	0.87	5,166	492	0%	-19%	39%
San Jose (CZ4)	2.38	5,591	536	37%	-19%	45%
Fresno (CZ13)	3.94	7,600	481	41%	0%	41%

Table E-2: Projected Annual Whole Building Savings for Title 24 Home Over Heat Pump Base Case

	HP Base Case Whole Building Usage			% Savings with GCHP Technology		
Climate Zone	kW	kWh	therms	kW	kWh	therm
San Francisco (CZ3)	0.87	6,633	298	0%	8%	0%
San Jose (CZ4)	2.34	7,547	294	35%	12%	0%
Fresno (CZ13)	3.98	9,304	286	41%	18%	0%

Table E-3: Projected Annual Whole Building Savings for Existing Home Over Gas Base Case

	Gas Furnace Base Case Whole Building Usage			% Savings with GCHP Technology		
Climate Zone	kW	kWh	therms	kW	kWh	therm
San Francisco (CZ3)	1.05	6,163	558	0%	-23%	54%
San Jose (CZ4)	3.09	6,770	506	36%	-15%	50%
Fresno (CZ13)	5.39	9,655	521	42%	1%	53%

Table E-4: Projected Annual Whole Building Savings for Existing Home Over Heat Pump Base Case

	HP Base Case Whole Building Usage			% Savings with GCHP Technology		
Climate Zone	kW	kWh	therms	kW	kWh	therm
San Francisco (CZ3)	1.05	8,384	259	0%	9%	0%
San Jose (CZ4)	3.07	8,841	255	35%	12%	0%
Fresno (CZ13)	5.42	12,030	246	43%	21%	0%

Table E-5: Projected Annual Whole Building Savings for Tier 2 Home Over Gas Base Case

	Gas Furnace Base Case Whole Building Usage			% Savings with GCHP Technology		
Climate Zone	kW	kWh	therms	kW	kWh	therm
San Francisco (CZ3)	0.67	4,058	360	0%	-17%	31%
San Jose (CZ4)	1.67	4,351	392	24%	-18%	37%
Fresno (CZ13)	2.49	5,370	420	29%	-12%	42%

Table E-6: Projected Annual Whole Building Savings for Tier 2 Home Over Heat Pump Base Case

	HP Base Case Whole Building Usage			% Savings with GCHP Technology		
Climate Zone	kW	kWh	therms	kW	kWh	therm
San Francisco (CZ3)	0.67	5,005	250	0%	5%	0%
San Jose (CZ4)	1.70	5,627	247	26%	9%	0%
Fresno (CZ13)	2.53	6,964	242	30%	14%	0%

In summary, for areas within PG&E service territory where natural gas is available, GCHPs appear to be of little value to PG&E as a ZNE strategy. In some situations, customers may find themselves paying more for energy when switching technologies. They can also serve as a potential component of a Zero Net Energy (ZNE) strategy for new and existing homes. However, the customer economics are unfavorable in most cases without the assistance of the 30% existing federal tax credit.

Background

Zero Net Energy Technology Evaluations

This study evaluates ground coupled heat pump (GCHPs) as a potential component of a Zero Net Energy (ZNE) strategy for new and existing homes in PG&E service territory. This technology is one of a total of twenty five measures which will be evaluated for PG&E to assess their viability as productive ZNE strategies for new and existing homes and commercial buildings. These reports fit under the Technology Advancement Subprogram of the PG&E ZNE Pilot Program which has the goal of "delivering information, insights, analytical tools, and resources to accelerate and expand the commercialization of innovative technologies as stated in the Strategic Plan", as defined by the California Public Utility Commission's Decision Approving 2010 to 2012 Energy Efficiency Portfolios and Budgets.

California Space Conditioning Overview

Residential space heating in California has for a long time been typically dominated by natural gas furnaces, due to the availability of inexpensive natural gas as a fuel, and the relatively low heating degree days experienced in California climates by comparison with Midwestern and Northern States. The 2009 Residential Appliance Saturation Survey (RASS) shows that of all California residential buildings surveyed that have space heating, 78% of homes are fueled by natural gas, and 5% are electric.[3] The proportion of electric space heating fell 6% compared with 2004 RASS, two thirds of which shifted to other sources of fuels. 85% of single family homes are currently fueled by natural gas.

Residential air conditioning has become increasingly common throughout much of the PG&E service territory over the past 30 years as the comfort demands have increased and market demands have pushed compressor based cooling into climates not previously seen. In all three climate zones reviewed, the 2009 RASS showed increases in saturation of central air conditioning systems. In the central valley (Forecast Zone 3), 80% of single family homes have central air conditioning, up from 72% in 2004 RASS study. Transitional climates (Forecast Zone 4) show 50% of single family homes have central air up from 43% in 2004.[4]

Air conditioning energy use is very dependent upon climate. The 2009 RASS indicates the average California single family residential customer uses 894 kWh of electricity for central air

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[3] 2009 RASS
[4] 2009 RASS

conditioning annually, while the average customer in the central valley consumes 1359 kWh/year. RASS data also shows that air conditioning energy use is higher in newer homes.

Ground Coupled Heat Pump Technology Overview

A ground coupled heat pump (GCHP) is comprised of a ground source heat exchanger, a heat pump, which controls the extraction of heat from the ground source via the vapor compression cycle during the winter, and discharges heat to the ground during the summer, and an air delivery system that provides the heating and cooling to the space. GCHPs operate like air-source heat pumps to provide space heating and cooling through control of a reversible metering valve. The terms geothermal, or GeoExchange™, systems are sometimes used to describe a ground coupled heat pump system. However, geothermal heating is more accurately reserved for geothermal energy systems that tap into hot rocks or water in the earth for heating or power production. The GeoExchange™ term was introduced about 15 years ago to avoid confusion with the "geothermal" term, but is still vague in its description of the technology. We are using ground coupled heat pumps (GCHP) in this study, as it most accurately describes the function of the technology.

Ground temperatures are relatively stable throughout the year, which provides an advantage to GCHPs over air source heat pumps which depend on variable outdoor ambient conditions for heat extraction and rejection. Ground source heat exchangers can be either buried shallow in a wide horizontal coverage, or deep and vertical, if the space isn't available horizontally. An alternative horizontal method called the Slinky, curls of loop piping laid over each other, traversing horizontally can help minimize the trench field required. Another alternative is to install shallow vertical helix loops, which in the reduction of bore depth can potentially reduce installation costs 50%.[5] In previous studies soil conductivity increases with moisture content, allowing higher efficiencies for horizontal loop configurations when coupled with irrigation.[6] In some variations, the heat exchanger can also be sourced under a body of water if available, or be designed open loop and extract and discharge water from an underground aquifer via wells. In this review, closed loop ground source heat pump systems are modeled and evaluated for performance.

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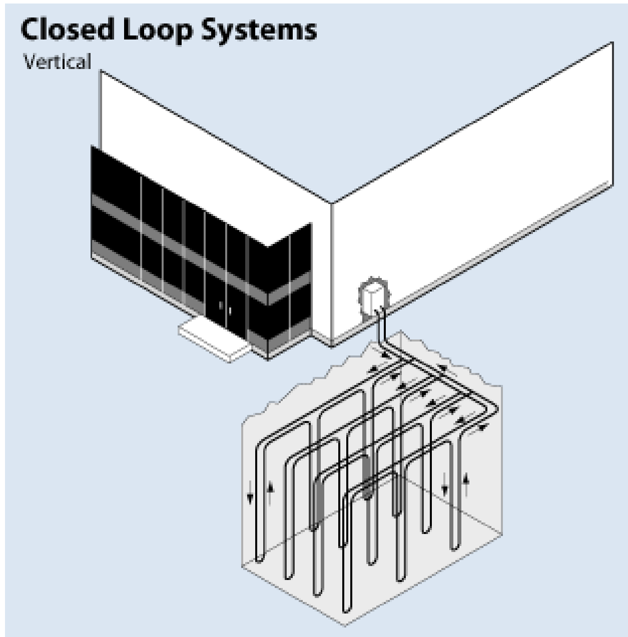
[5] DEG, 1999. "*California Ground Loop Development Project Report*" PG&E Report, May 1999
[6] DEG, 1999. "*Field Study, Assessment, and Recommendations for Irrigated Ground-Coupled Heat Pump Horizontal Heat Exchangers*" PG&E Report, May 1999

Figure 1 - Ground Coupled Heat Pump[7]



GCHPs typically use 20% - 50% less electricity than conventional heating or cooling systems.[8] They have the potential for savings in climates with more inclement weather, where demands for space conditioning are higher. A previous study conducted by Davis Energy Group in 1999 for PG&E showed that GCHPs have stronger opportunities in non-natural gas market areas.[9]

GCHP equipment is rated under different conditions than air-cooled equipment. Residential air conditioners and heat pumps (under 5 tons) are rated using a seasonal energy efficiency ratio (SEER) for cooling, and heating seasonal performance factor (HSPF) for heating. Most equipment manufacturers also provide equipment efficiencies in terms of EER (energy efficiency ratio) for cooling and COP (coefficient of performance) for heating. These values are most commonly used to compare the performance relative to GCHP equipment, which are also rated by EER and COP. The rating conditions for GCHP equipment are also different than the rating systems for air conditioners or air source heat pumps. Table 1 summarizes the heating and cooling rating standards for both. In GCHP systems, the energy of the ground source fluid

[7] Graphic source: http://www.eere.energy.gov/basics/renewable_energy/geothermal_heat_pumps.html
[8] http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12660
[9] DEG, 1999. "*PG&E Geothermal Heat Pump Commercialization/ Model Utility Program Demonstration Final Report*" PG&E Report, May 1999

and transport pump are assumed in the published COP, but actual energy use varies widely in the field based on loop size and site design.

Table 1: Equipment Performance Standards

	Standard	Cooling (EER)	Heating (COP)
Air-Source HP	ANSI/AHRI 210 / 240	95°F Outdoor Dry Bulb	47°F Outdoor Dry Bulb
GCHP	ANSI/ISO/AHSRAE 13256-1	77°F Entering Loop Temperature	32°F Entering Loop Temperature

Careful consideration to the design of the loop is critical to produce long lasting energy savings. Often loops are inadequately sized, leading to unsatisfactory comfort levels which require an auxiliary system to provide conditioning. Loops that are oversized experience stagnant locations, which can freeze and create blockage in loop piping. Imbalance between heating and cooling season loads have shown to cause the ground temperatures to drift over several seasons, which affects performance and efficiency over the life of the system.

Ground Loop Options

The two primary loop types found in California installations are horizontal loops with the tubes laid in horizontal trenches, and vertical bores where ground loops are installed in deep vertical bores 150 to 300 feet deep. Horizontal loops can be installed at lower cost than vertical bore loops and do not require specialized drilling equipment, but vertical bores can be installed in a much smaller footprint than horizontal loops making it more feasible in retrofit applications, and homes with small lots. Vertical bores are also less susceptible to seasonal temperature shifts and damage from future trenching. Vertical loops require significant bore depths which may be a problem if soil compositions are unknown. Geotechnical site evaluations before design will help with appropriate sizing, location and orientation of ground loops. Performing in-situ ground loop testing can provide better ground conductivity and transmissivity data, which can result in smaller ground loop sizing. Without this information, the designer will need to size the loop based on typical soil conditions in the region.

Vertical helix loops offer the potential for significant installation cost reductions, while still minimizing the amount of area needed for the ground loop. The helix loop design was developed as part of the PG&E GHP Model Utility Program Demonstration Project (DEG, 1999). They consist of 36" diameter bores at 20 to 25 feet deep, with tubes aligned in a helical coil along the outside of the bore. Specialized drilling rigs are not needed. The holes can be drilled using a 3 foot diameter auger attached to a backhoe. Performance tests in field applications showed promising performance with each vertical helix coil being equivalent to approximately

75 feet of vertical bore. Despite its potential, there was no industry interest and there has been no further development of the design or strategy.

In some unique situations, where an existing body of water is available on site, coils of tubing can be installed in the bottom of a pond, reducing loop costs significantly. If the body of water is sufficiently sized for the loads, pond loops can provide equivalent performance to vertical bores without the need for specialized drilling equipment or the labor required to drill.

Marketing Status

In 1999, as part of the GHP Model Utility Program Demonstration Project, DEG provided to PG&E a report that assessed GCHP market viability under a range of conditions in eight climate zones in the PG&E service territory (DEG, 1999). Traditionally, market penetration of GCHPs has been low in California where mild climates and the low cost of natural gas contribute to low space conditioning costs. The largest market potential for GCHP technology was deemed to be in regions of the state where natural gas is typically not available and both heating and cooling loads exist. However, significant market barriers still exist in California including lack of customer awareness & infrastructure. Many installers, builders, and designers are unfamiliar with the technology and may resist moving towards GHCP technology as it requires additional design and coordination. There can be unreasonably long payback periods, in certain instances with misaligned or split incentives. Lastly, this is still an emerging technology and there is uncertainty concerning long-term system performance.

For this study, we spoke with representatives from Hydronic Heat Pumps and Sigler, a Carrier distributor out of Sacramento, CA. There has been little market penetration change for GCHPs in California since the 1999 market study. They still represent a niche market, installed mostly in custom homes where early adopters are willing to pay a premium for a high efficiency alternative to heating and cooling homes, and in zero net energy projects, where there is budget for the additional costs.

Installation Requirements and Issues

By their nature, GCHPs require intensive trenching or drilling, which often make this technology more feasible in new construction as opposed to retrofit. Horizontal loops can be installed at lower cost than vertical bore loops and do not require specialized drilling equipment, but vertical bores can be installed in a much smaller footprint than horizontal loops making it more feasible in retrofit applications, and homes with small lots.

Proper sizing of the ground loop is critical in actual GCHP performance. Smaller loop sizes are less costly but can lead to poor heat pump performance and reduction of savings expectations.

Sizing the loop larger will usually provide improved performance and efficiencies but at a cost that can affect cost effectiveness.

The ground loop header and manifold design is also critical to minimize loop pressure drop and provide proper flushing of the loop. After the ground loop is filled and pressurized, air must be purged from the system to avoid problems with pump and air delivery equipment as well as to reduce noise.

Water Heating / Desuperheaters

GCHPs can be used for water heating either as dedicated heat pump water heaters or with the addition of a desuperheater. The desuperheater extracts heat from the discharge side of the compressor where the refrigerant gases are at their highest. In the winter, the desuperheater adds to the heating load, which affects sizing of the unit for heating, and aids the unit in absorbing heat from indoors during the summer. In systems with desuperheaters, it's important to note that desuperheaters are more effective as hot water pre-heaters than at maintaining water heater tank temperatures, and should not be directly plumbed to water heaters. A smart control or reversing valve is recommended, to mitigate the space heating capacity impacts.

Oak Ridge National Laboratory (ORNL) has done some research recently looking at using heat pumps for water heating only and using existing on-site excavations for running the ground loops, including foundation and utility trenches. This can reduce trenching costs significantly and was found to be successful in applications in the south where basements are built and soil moisture levels are higher than typically seen here.

Maintenance

Ground coupled heat pumps are often reported to be near maintenance-free, offering an attractive alternative to standard HVAC equipment. In closed loop systems, the ground loop is maintenance free, however in open loop configurations, water levels must be maintained and corrosive effects from lower water quality need to be mitigated. Because the compressor is usually located at the indoor unit and no field-installed refrigerant lines are required, there is less chance for performance degradation due to exposure to the elements and improper field charging of refrigerant. All GCHPs require regular filter changes similar to air-source heat pumps and furnaces.

System Costs

Current equipment cost and warranty information was obtained via communication with Hydronic Heat Pumps (HPP) and Sigler (Carrier Distributor) and is presented in Table 2 and

Table 3. HHP sells Econar and Geo Excel GCHP models and provides design and installation of complete GCHP systems. The ground loop material and installation cost varies significantly by ground loop type and equipment size. Vertical ground loops are noticeably more expensive than other types; however, these are the most likely to be installed due to footprint restrictions. Vertical bore costs are based on $14.92 per foot of bore. Pond loops are the least labor intensive and thus the least expensive since no trenching is necessary. Equipment and vertical ground loop prices from HHP were used in the cost effectiveness analysis presented later in this report. All prices are for new construction. Retrofit applications require an additional $8/sqft for ground restoration.

Table 2: Hydronic Heat Pump Product Cost Information

Equipment Size (Tons)	Equipment			Ground Loop		
	Equipment Price	Flow Center	HP & Flow Center Installation	Vertical Loop Material & Labor	Horizontal Loop Material & Labor	Pond Loop Material & Labor
2	$3,086	$415	$1,520	$7,915	$3,500	$1,775
3	$3,589	$773	$1,520	$13,503	$3,885	$2,378
4	$4,242	$773	$1,520	$18,503	$5,501	$2,571
5	$4,822	$773	$1,520	$24,091	$7,339	$2,764

Carrier manufactures two packaged GCHP lines. The pricing provided is for the lower efficiency series for which cooling and heating efficiencies were calculated and used in the modeling process. Sigler does not offer loop design and therefore was unable to provide any costs. The product costs presented are for equipment only and do not include installation labor. Carrier supplies a 10 year limited warranty on parts for all units.

Table 3: Carrier Product Cost Information

Model #	Equipment Size (Tons)	Equipment Price	Flow Controller, Pumps & Valves
50YED024	2	$3,988	$1,040
50YED036	3	$4,328	$1,040
50YED048	4	$5,129	$1,040
50YED060	5	$5,663	$1,040
50YES070	6	$5,908	$1,040

HHP also provided costs for the installation of a desuperheater that can be combined with the GCHP to provide water heating. While water heating savings are not evaluated within the report, the addition and installation of a desuperheater with appropriate storage tank and fittings is $1,987.

Prior Research

Geothermal Heat Pump Commercialization/Model Utility Program Demonstration

In May 1999 Davis Energy Group concluded a two year GCHP Model Utility Program Demonstration Project for PG&E, co-sponsored by the Geothermal Heat Pump Consortium and the California Energy Commission. The resulting eighteen reports addressed the design, installation, monitoring, and public awareness efforts related to several demonstration systems of varying types, market evaluation and feasibility studies, revising DOE-2 modeling assumptions, analysis of alternative technology options, optimization of hybrid systems, developing Title 24 options, analyze cost effectiveness and providing suggestions for a business plan and utility program possibilities.

Demonstration Sites

The first objective of the study was to add 100,000 square feet of commercial and 150 units of residential demonstration sites on which GCHP systems would be installed. Davis Energy Group consulted on the designs, analyzed performance projections, estimated savings and provided commissioning reviews. At the start of the study, there were only 2,648 tons of GCHPs in all of California, half of which existed in only two commercial installations. Part of the plan to recruit sites included recruitment of volume single family home builders, providing prototype installation training and design assistance and evaluating production installations. This objective was not met due to resistance from volume builders, supporting the viewpoint of GCHPs as a technology for individual custom site installations. At the conclusion of the study 771 tons were added to California inventory, comprised of 94,128 square feet of commercial, 267,508 square feet of multifamily (304 units) and 22 single family residential units. Of the sites not recruited, the reasons for failure to adopt were just as instructive as the lessons learned through the design, installation and commissioning process. For instance, GCHPs are an ideal option for schools due to the low maintenance costs and the availability of large ground area, but low savings potential in mild climates may not substantiate the large installation costs. As with other advanced or energy efficient technologies, especially in the residential sector, the issue of first cost often trumps the adoption of technologies that save over time. In installations where the design changes during construction, installation costs can increase, which in this study led to the rejection of GCHPs.

Market Analysis

The second objective was to evaluate the PG&E service territory for potential GCHP markets, validate performance modeling assumptions with monitored data from five of the demonstration sites and analyze technology options for improving cost effectiveness.

Using the DOE2.2 hourly energy simulation program, detailed simulations were performed for various residential and non-residential systems for eight climate zones within the PG&E market territory. Residential systems were simulated to have three different ground loop options (vertical, horizontal and vertical helix) and compared against four conventional fuel and system combinations. Non-residential systems were simulated under two ground loop options and compared against conventional fuel and system combinations. The resulting over 800 simulations yielded minimal benefit/cost ratios (BCRs) for residential systems where natural gas is available and maximum BCR for large office buildings with variable air volume gas hot water reheat.

For residential systems, savings when compared with natural gas were less than half of projected savings when the alternate fuel was either propane, wood or air-source heat pumps. Incremental costs when compared to gas/propane had a 34% variance for horizontal loops and 27% for vertical loops, however can be expected to be reduced by 35% for mature market and volume scenarios. The economics and projected growth considerations showed climate zones 12, 13 and 16 to have the best potential for residential GCHP systems, most significantly affected by the lack of natural gas service in the territories.

For non-residential systems, savings showed little trend between fuels, but between 8% and 9% incremental savings between load ranges. Under mature market conditions, savings for vertical and helix systems are projected to be between 30% and 28%. The economics and projected growth considerations showed climate zone 16 to have the best potential for non-residential GCHP systems.

Monitoring

Five existing residential systems and one large commercial system were identified for monitoring. Four additional residential demonstration sites and another commercial site were also monitored but for a shorter period due to construction delays. Of the monitored sites, seven of the residential sites were located in the central valley; the remaining two were in Napa Valley and Placerville foothills. The commercial sites were located in Sacramento and Quincy. The residential sites covered variations in ground loop design from vertical bores, pond loop, horizontal trenches, horizontal slinky design, and vertical spiral loops. The commercial site in Sacramento consisted of 450’ vertical bores and an additional cooling tower. The site in Quincy was originally slated for vertical bores but horizontal loops were added due to geological constraints discovered during drilling.

For nearly all the sites, the COP was measured to be approximately equal to the ARI-330 rating for the equipment. The cooling EER was on average 23% lower than the ARI-330 cooling rating. For all residential sites during the cooling season, the average return water temperatures exceeded the 77°F rating point defined by ARI-330, four reaching over 100°F. Peak demand averaged 1.22 kW per ton. Annual residential space conditioning energy use ranged between 0.90 to 4.91 kWh/ft2 conditioned floor area-year, averaging 2.56 kWh/ft2-year.

Model Calibration

At the end of monitoring, the data was used against the DOE-2 Model to provide calibration of the ground loop model. It was observed that the difference between return water temperatures measured and modeled were between 3.4% and 9.2%. With calibrated heat pump curves, the difference in annual energy use was between 5% and 7%. The DOE2 model proved very accurate to predicting annual energy usage and savings.

GCHP Sizing Recommendations

At the time of the study, loop sizing recommendations were not optimal for California where the climate often dictates higher loop temperatures and GCHP install costs are significant. At the time, little correlation between climate and loop sizing existed in commercial loop sizing software. Analysis was performed to exemplify these disparities, and suggestions for sizing resulted. Entering water temperatures for modeling should be 105^{o}F and 45^{o}F during cooling and heating seasons. Soil properties and weather data have significant impact on the loop size and performance. For large installations, test bores and in-situ conductivity tests are recommended along with hourly simulations for verifying proper sizing.

Flow Optimization Study

Flow properties were studied as a potential technology optimization pathway. Reverse return header designs were evaluated, header pipe designs for parallel loops were studied and optimization around flow-rate was analyzed. Reverse return headers were observed to have no impact and eliminating them from the design proved some installation savings. Designing headers to appropriately distribute flow proved some savings, along with specific design suggestions in the cases of vertical bore systems. From the perspective of economics, an optimal loop flow rate was not determined, within normal design ranges.

Ground Loop Field Study

Ground loop field installations were analyzed for install cost optimization, including a recommended shallow vertical helical loop brought to light in the study. Directional drilling with high conductivity ground and home run manifolds provided 37% savings for vertical bore systems, shallow helical loops increased to more than 50% savings. Slinky loops provided only 2% savings for horizontal loops, but trench irrigation with pre-fabricated serpentine arrays could provide between 12 and 15% savings.

Ground loop irrigation as an option for increased savings and efficiency in horizontal loop systems was analyzed and tested at a demonstration site. Drip irrigation lines were installed to increase the soil moisture content and therefore conductivity. One of two trenches was lined with plastic to observe the effect of conductivity by retaining moisture. Moisture levels were tested before installation, and increased by 9% to 32% during irrigation tests. The thermal conductivity was observed to double, increasing to 1.0 BTU/hr-°F-ft. The loop size in these conditions could be optimized to reduce between 26% and 54%, resulting in installation savings between $146 and $3,706, with the original soil conductivity dominating potential savings with this technology.

GCHP Business Plan and Design/Information Handbook

A GCHP business plan was developed to promote GCHPs in the markets identified in the previous task to be cost effective. As a result of the market analysis, it was determined that good markets for GCHP systems are custom single family homes where buyers are more involved in the decision process, multi-family housing and schools. Suggestions for potential promotional programs and the costs associated were identified.

The last deliverable of the study was a handbook on GCHP systems. The handbook covers background information on the technology, benefits, design guide, case studies and resources for additional information and assistance for installing GCHP systems.

<u>In-Field Monitoring Studies</u>

In the 2010 Geothermal Resources Council Transactions Journal (Volume 34) the result of monitoring three residential GCHP systems in Connecticut, Virginia and Wisconsin was published. The study was conducted by members of CARB, Consortium for Advanced Residential Buildings, one of the six Building America Research Teams, led by Steven Winter Associates, INC, and sponsored by the Department of Energy's (DOE) Building America Program.

The three locations monitored are heating dominant, having between 4,925 and 8,196 heating degree days and 234-538 cooling degree days. The three locations were monitored a minimum of one heating season, ranging from 2007 to 2010. The three systems have similar two-stage compressors, and horizontally opposed ground loops. The locations in Connecticut and Wisconsin employ a desuperheater to supply water heating as well, and the location in Virginia includes two heat pumps, one for each floor, the smallest of which was not monitored.

The Connecticut System included a WaterFurnace Envision GCHP with a two stage compressor and was rated at heating COP of 5.1 for low stage and 4.2 for high stage. The installed system performed at 3.6 for the low stage and 3.76 for the high stage, nearly 10-30% lower than the rated efficiency. The lower performance is likely due to the differences in the ground loop flow rates in comparison with rated efficiencies, as well as the conditions of the rated tests. Three years after installation, the system was verified to be extracting 17,460 BTU/hr, close to the 17,600 BTU/hr as was rated.

The Virginia System, also utilizing a WaterFurnace Envision GCHP, was rated for a heating COP of 4.6 for the low stage and 4.1 for the high stage. The installed system operated at 3.32 for the low stage and 3.48 for the high stage. The loop design was intended to be communal for both GSHPs, and therefore was designed with a significantly higher loop pump load. The calculated performance assumes the monitored GCHP consumes half the loop pump load, in spite of it being nearly twice the capacity of the second floor GCHP. The system also experienced air in the loop piping after installation, which caused the upper air handler to freeze up and fail when the second floor heat pump was not in service for more than two weeks.

The Wisconsin System used a 3-ton dual capacity Water Furnace Synergy 3-D GCHP, providing space conditioning and hot water, and also used a heat recovery ventilator connected to the ducts. The rated heating COP was 4.5 for the low stage and 4.0 for the high stage. The installed system operated on average 3.44 for both stages.

The study found measured COPs to be 13-27% lower than rated values. These results point to the fact that rated efficiencies do not account for installed conditions, including pumping energy in the loop piping and distribution fan energy. These energy uses are design and installation dependent and difficult to account for in the ratings.

<u>GHPs RUS Study</u>

Bob Lawrence and Associates, INC along with the California Geothermal Energy Collaborative (GEC) is currently leading a 3 year study collecting data on potential deployment of GCHP throughout 30 metropolitan areas across the United States (including both the San Francisco Bay Area and the Sacramento region). The data being collected include costs for drilling, installation and manufacturing, and geological and geographical data including soil types, thermal conductivity, heat flow, hydrological, and heating and cooling demand.[10] In the end, the study will aim to establish criteria to evaluate and quantify the benefits of GCHP deployment in the 30 areas.

Methodology

The goals of the study were to:

- Identify the current market status of GCHPs and their applicability to Zero Net Energy projects.
- Determine the best tool for evaluating GCHPs and develop a baseline single family model using 2009 RASS as a guideline.
- Evaluate performance and provide energy impacts of GCHPs. Evaluation should consider both new and existing single family homes.

DOE-2.2 software, using the eQUEST front-end was selected as the preferred model given its ability to model water source heat pumps and vertical well ground loops. Loop calibration completed in the PG&E GHP marketing study (DEG, 1999) was used to improve the DOE-2 ground loop model. More recently, additional enhancements to the DOE-2.2 ground loop model were made. The software now uses the G-function method, developed by researchers in Sweden, to more accurately model vertical wells. The new model allows specification of grout properties, heat exchanger fluid type, and 42 vertical well configurations. Recent versions of DOE-2 also expanded the number of systems that can allow assignment of a water loop to a heat pump system.

<u>Baseline Model Development</u>

The following reports and studies were used to determine baseline assumptions for the study:

- KEMA, 2009 - "Residential New Construction (Single Family Home) Market Effects Study, Phase I Final Report"
- KEMA, 2010 - "2009 Residential Appliance Saturation Study (RASS)"
- KEMA, 2004 - "California Statewide Residential Appliance Saturation Study (RASS), Final Report"
- RLW, 2005 - "2005 California Statewide Residential Lighting and Appliance Efficiency Saturation Study – Final Report"
- PG&E, 1997 - "Residential Energy Survey Report"

[10] http://ghpsrus.com/about.html

- NREL, 2010 - "2010 Building America Benchmark Definition"
- CEC, 2010 - "2008 Building Energy Efficiency Standards – Residential Compliance Manual"

Three climate zones were evaluated for this study: Coastal climate zone (Climate Zone 3), Transitional (Climate Zone 4), and Valley (Climate Zone 13). Cooling savings were not evaluated in Climate Zone 3. 2009 RASS indicates central cooling system saturations of less than 10% in the coastal regions. Cooling loads are not high in transitional climates but saturation of air conditioning is between 40 and 50%. Based on the initial research and review of the above studies, along with communications with PG&E staff, the baseline model includes the following:

- Single story 1,787 square foot home with three bedrooms, consistent with RASS averages
- 16% glass as a percentage of conditioned floor area, based on RASS averages
- Glass is equally distributed on all four sides to eliminate orientation effects
- Wall area and slab perimeter based on an aspect ratio of 2.0. This is consistent with a sampling of actual homes and will better reflect actual typical construction. To maintain equal wall and glazing areas distribution on all orientations, an L-shape building model was used.

A summary of the assumptions used in the six base models are summarized in Table 3 through Table 5. The six baseline cases used were three types of homes, existing, new construction (Title 24), and Tier 2 (30% below the Title 24 budget), employing either a combination of a gas furnace and standard AC systems, or a similarly sized air source heat pump. In addition to climate variations, ground temperature varies across all three sites; therefore the ground loops are sized differently and appropriately for each climate and equipment size.

The tables below show building assumptions for new construction and are based on 2008 Title 24 Prescriptive Package D measures. Appliance, lighting, and plug (MEL) energy end uses are based on the assumptions used for Department of Energy's Building America program (NREL, 2010). 25% fluorescent lighting is assumed based upon the current Title 24 prescriptive lighting requirements.

Table 4: New Construction Packages - 2008 T-24 Package D

Specification Package		Climate Zone 3 Oakland, CA	Climate Zone 4 San Jose, CA	Climate Zone 13 Fresno, CA
Envelope				
Exterior Wall Construction		2x4 16"o.c. R-13	2x4 16"o.c. R-13	2x4 16"o.c. R-13 w/ R-4 ext. foam
Foundation		Slab on Grade - Uninsulated	Slab on Grade - Uninsulated	Slab on Grade - Uninsulated
Floor Over Garage/Exterior		n/a	n/a	n/a
Ceiling Construction		Vented Attic, Trusses 24"o.c. - R-30	Vented Attic, Trusses 24"o.c. - R-30	Vented Attic, Trusses 24"o.c. - R-38
*Radiant Barrier		No	Yes	Yes
Roofing Material: (roof slope > 2:12)		Comp. Shingle Dark	Comp. Shingle Dark	Comp. Shingle Dark
House Leakage (SLA)		4.9	4.9	4.9
*House Infiltration/Blower Door Test	HERS	No	No	No
*Verified Insulation Installation	HERS	No	No	No
Glass Properties: U-Value / SHGC				
Description		Vinyl frame, 2-pane	Vinyl frame, 2-pane	Vinyl frame, 2-pane, Low-E
Max U-factor / SHGC		0.40 / 0.65	0.40 / 0.40	0.40 / 0.40
Glazing % of CFA		16.0%	16.0%	16.0%
Glazing Distribution		Uniformly distributed	Uniformly distributed	Uniformly distributed
Building Shading		1 ft. overhangs	1 ft. overhangs	1 ft. overhangs
HVAC				
Gas Furnace Base Case				
Heating		Gas Furnace 78% AFUE	Gas Furnace 78% AFUE	Gas Furnace 78% AFUE
AC		No Cooling	13 SEER Split System	13 SEER Split System
Heat Pump Base Case				
Heating		Heat Pump 7.7 HSPF	Heat Pump 7.7 HSPF	Heat Pump 7.7 HSPF
AC		No Cooling	13 SEER Heat Pump	13 SEER Heat Pump
Heating/Cooling Thermostat Set points		78 / 68 w/ 5 dF heat setback	78 / 68 w/ 5 dF heat setback	78 / 68 w/ 5 dF heat setback
*Verify EER	HERS	No	No	No
Duct Location / Insulation		Attic / R-6	Attic / R-6	Attic / R-6
*Verify Duct Leakage	HERS	<6% Leakage	<6% Leakage	<6% Leakage
Cooling Fan Watt Draw	HERS	< 0.58 Watts/cfm	< 0.58 Watts/cfm	< 0.58 Watts/cfm
DHW				
Water Heater Fuel / Type		Gas Storage 50 gallon	Gas Storage 50 gallon	Gas Storage 50 gallon
Water Heater Energy Factor		0.58	0.58	0.58
Daily Hot Water Use (gal/day)		42	42	42
Lighting & Appliances				
EnergyStar Appliances		Dishwasher	Dishwasher	Dishwasher
Dryer		Gas	Gas	Gas
Oven / Range		Gas Range	Gas Range	Gas Range
Fluorescent Lighting Package: Hardwired fixtures		Per Title-24 ~25%	Per Title-24 ~25%	Per Title-24 ~25%

Building assumptions for existing homes are based on the Title 24 vintage assumptions for homes built between 1984 and 1991. The assumptions include R-11 in walls, R-19 ceilings, and metal dual-pane windows without low-E coating. For HVAC, we assumed that the HVAC equipment is being replaced. Therefore, base case HVAC systems will be minimum efficiency equipment (13 SEER AC and 80 AFUE gas furnace or 7.7 HSPF heat pump) with tight ducts, since these are required elements for equipment replacement. Appliance, lighting, and plug energy end uses are also based on Building America assumptions. 10% fluorescent lighting is assumed for existing homes.

Table 5: Existing Home Packages - 1984 - 1991 Vintage Assumptions

Specification Package		Climate Zone 3 Oakland, CA	Climate Zone 4 San Jose, CA	Climate Zone 13 Fresno, CA
Envelope				
Exterior Wall Construction		2x4 16"o.c. R-11	2x4 16"o.c. R-11	2x4 16"o.c. R-11
Foundation		Slab on Grade - Uninsulated	Slab on Grade - Uninsulated	Slab on Grade - Uninsulated
Floor Over Garage/Exterior		n/a	n/a	n/a
Ceiling Construction		Vented Attic, Trusses 24"o.c. - R-19	Vented Attic, Trusses 24"o.c. - R-19	Vented Attic, Trusses 24"o.c. - R-19
*Radiant Barrier		No	No	No
Roofing Material: (roof slope > 2:12)		Comp. Shingle Dark	Comp. Shingle Dark	Comp. Shingle Dark
House Leakage (SLA)		4.9	4.9	4.9
*House Infiltration/Blower Door Test	HERS	No	No	No
*Verified Insulation Installation	HERS	No	No	No
Glass Properties: U-Value / SHGC				
Description		Metal frame, 2 pane	Metal frame, 2 pane	Metal frame, 2 pane
Max U-factor / SHGC		0.79 / 0.70	0.79 / 0.70	0.79 / 0.70
Glazing % of CFA		16.0%	16.0%	16.0%
Glazing Distribution		Uniformly distributed	Uniformly distributed	Uniformly distributed
Building Shading		2 ft. overhangs, mature tree shading	2 ft. overhangs, mature tree shading	2 ft. overhangs, mature tree shading
HVAC				
Gas Furnace Base Case				
Heating		Gas Furnace 78% AFUE	Gas Furnace 78% AFUE	Gas Furnace 78% AFUE
AC		No Cooling	13 SEER Split System	13 SEER Split System
Heat Pump Base Case				
Heating		Heat Pump 7.7 HSPF	Heat Pump 7.7 HSPF	Heat Pump 7.7 HSPF
AC		No Cooling	13 SEER Heat Pump	13 SEER Heat Pump
Heating/Cooling Thermostat Set points		78 / 68 w/ 5 dF heat setback	78 / 68 w/ 5 dF heat setback	78 / 68 w/ 5 dF heat setback
*Verify EER	HERS	No	No	No
Duct Location / Insulation		Attic / R-2.1	Attic / R-6	Attic / R-6
*Verify Duct Leakage	HERS	<6% Leakage	<6% Leakage	<6% Leakage
Cooling Fan Watt Draw	HERS	No	No	No
DHW				
Water Heater Fuel / Type		Gas Storage 40 gallon	Gas Storage 40 gallon	Gas Storage 40 gallon
Water Heater Energy Factor		0.525	0.525	0.525
Daily Hot Water Use (gal/day)		42	42	42
Lighting & Appliances				
EnergyStar Appliances		None	None	None
Dryer		Electric	Electric	Electric
Oven / Range		Gas Range	Gas Range	Gas Range
Fluorescent Lighting Package: Hardwired fixtures		10%	10%	10%

Tier 2 case was used to reflect efficient new homes and deep retrofits. The assumptions used for Tier 2 include a package of commonly accepted energy efficiency measures to meet the Tier 2 Advanced Home rebate requirements of 30% better than Title 24. In addition they also assume 100% fluorescent lighting, and EnergyStar appliances.

Thermostat assumptions used for all cases are 78°F cooling and 68°F with a 65° daytime setback for heating. Initially, the plan was to adjust thermostat settings on the existing homes baseline to reflect RASS but this adjustment resulted in unreasonable thermostat set points because of low heating and cooling energy use reported in RASS. This was especially evident in climate zone 13, where cooling energy use reported in RASS seemed unusually low. It was decided to keep uniform thermostat settings for all evaluations for reporting consistency.

Mechanical ventilation for indoor air quality, and its associated fan energy use and effect on heating and cooling, is assumed in both new construction and Tier 2 but not for existing homes.

Table 6: Tier 2 Packages - 30% + 2008 T-24

Specification Package		Climate Zone 3 Oakland, CA	Climate Zone 4 San Jose, CA	Climate Zone 13 Fresno, CA
Envelope				
Exterior Wall Construction		2x4 16"o.c. R-15 w/ R-4 ext. foam	2x4 16"o.c. R-15 w/ R-4 ext. foam	2x4 16"o.c. R-15 w/ R-4 ext. foam
Foundation		Slab on Grade - Uninsulated	Slab on Grade - Uninsulated	Slab on Grade - Uninsulated
Floor Over Garage/Exterior		n/a	n/a	n/a
Ceiling Construction		Vented Attic, Trusses 24"o.c. - R-49	Vented Attic, Trusses 24"o.c. - R-49	Vented Attic, Trusses 24"o.c. - R-49
*Radiant Barrier		No	Yes	Yes
Roofing Material: (roof slope > 2:12)		Comp. Shingle Dark	Comp. Shingle Dark	Comp. Shingle Dark
House Leakage (SLA)		2.2	3.0	3.0
*House Infiltration/Blower Door Test	HERS	Yes	Yes	Yes
*Verified Insulation Installation	HERS	Yes	Yes	Yes
Glass Properties: U-Value / SHGC				
Description		Vinyl frame, 2-pane	Vinyl frame, 2-pane	Vinyl frame, 2-pane, Low-E
Max U-factor / SHGC		0.30 / 0.50	0.30 / 0.40	0.30 / 0.22
Glazing % of CFA		16.0%	16.0%	16.0%
Glazing Distribution		Uniformly distributed	Uniformly distributed	Uniformly distributed
Building Shading		1 ft. overhangs	1 ft. overhangs	1 ft. overhangs
HVAC				
Gas Furnace Base Case				
Heating		Gas Furnace 95% AFUE	Gas Furnace 92% AFUE	Gas Furnace 90% AFUE
AC		No Cooling	14 SEER / 12 EER Split System	15 SEER/12.5 EER Split System
Heat Pump Base Case				
Heating		Heat Pump 8.5 HSPF	Heat Pump 8.5 HSPF	Heat Pump 8.5 HSPF
AC		No Cooling	14 SEER/12 EER Heat Pump	15 SEER/12.5 EER Heat Pump
Heating/Cooling Thermostat Set points		78 / 68 w/ 5 dF heat setback	78 / 68 w/ 5 dF heat setback	78 / 68 w/ 5 dF heat setback
*Verify EER	HERS	No	Yes / 12 EER	Yes / 12.5 EER
Duct Location / Insulation		Attic / R-8	Attic / R-6	Attic / R-6
*Verify Duct Leakage	HERS	<6% Leakage	<6% Leakage	<6% Leakage
Cooling Fan Watt Draw	HERS	< 0.58 Watts/cfm	< 0.58 Watts/cfm	< 0.58 Watts/cfm
DHW				
Water Heater Fuel / Type		Gas Tankless	Gas Tankless	Gas Tankless
Water Heater Energy Factor		0.82	0.82	0.82
Daily Hot Water Use (gal/day)		42	42	42
Lighting & Appliances				
EnergyStar Appliances		Dishwasher, Clothes Washer, Fridge	Dishwasher, Clothes Washer, Fridge	Dishwasher, Clothes Washer, Fridge
Dryer		Gas	Gas	Gas
Oven / Range		Gas Range	Gas Range	Gas Range
Fluorescent Lighting Package: Hardwired fixtures		100% Fluorescent	100% Fluorescent	100% Fluorescent

Ground Coupled Heat Pump Model Assumptions

Vertical bores were used in modeling GCHP performance since they comprise the majority of installations in California. While horizontal loops have significantly lower installation costs, in most cases there is not enough available land to accommodate the needed area for horizontal loops. Table 7 summarizes the ground loop assumptions and loop sizing used for the study. Design ground loop temperatures of 45°F and 95°F for heating and cooling, respectively, were used for sizing ground loops for each climate. Ground conditions vary widely throughout the state, depending on soil/rock type and moisture content. Because vertical bores are typically installed 150 to 300 feet deep it is more likely for the ground loops to operate in moist or saturated soil conditions. Soil conditions for heavy damp soil were assumed in the modeling.[11]

Table 7: Ground Loop Sizing and Assumptions

	Climate Zone 3	Climate Zone 4	Climate Zone 13
Ground Thermal Conductivity (Btu/hr-ft-°F)	0.75	0.75	0.75
Ground Thermal Diffusivity (ft^2/hr)	0.025	0.025	0.025
Mean Earth Temperature (°F)	61	61	64
Loop Configuration / Bore Depth			
Title 24	2 bores / 180 ft	2 bores / 180 ft	3 bores / 195 ft
Existing	3 bores / 160 ft.	3 bores / 145 ft.	4 bores / 200 ft.
Tier 2	2 bores / 135 ft.	2 bores / 175 ft.	3 bores / 160 ft.

Equipment Costs

Base gas and electric and GCHP system costs, along with incremental costs, are summarized in Table 8. Total GCHP costs are based on the values provided for HHP, and assume a trained contractor is hired to install the equipment and no additional charges are incurred for travel. Installation costs for existing homes assume $1,600 for ground restoration (based on $8/sqft cost and 200 sq. ft. of disturbed area). Base equipment costs were provided by Beutler Corporation. Installation labor costs were estimated to be 125% of the base case equipment costs for a 3 ton unit. For retrofit (existing home) cases, it was assumed that both the indoor and outdoor units were replaced in all cases. A small additional cost based on data from NREL's BEOpt model cost database was added to the base costs for the retrofit cases to account for removal and disposal of equipment. Unit costs reflect both heating and cooling equipment and installation costs; these prices do not include ductwork. Equipment size in Table 8 is listed by cooling capacity in tons for heating and cooling systems (climate zones 4 & 13) and by heating capacity in kBtu/h for systems with only heating (climate zone 3).

PV System Costs

For evaluation of technologies relative to ZNE, GCHP performance and costs are compared to the performance and cost of residential PV installations. For the purpose of this study installed PV system costs of $6.80 / Watt ($STC_{DC}$) were assumed. This is a typical cost for PV system installation in production home new construction.

[11] These values are consistent with in-situ testing results performed on demonstration sites during the PG&E GHP study (DEG, 1999).

Table 8: Installed Cost Comparison Summary

CZ 03

	Equip Size (kBtu/h)	Loop Size (ft)	Gas Furnace Base Cost	Heat Pump Base Cost	Ground Coupled Heat Pump Cost	Incremental Cost vs Gas	Incremental Cost vs HP
New	36	630	$820	$2,877	$15,281	$14,461	$12,404
Tier 2	36	600	$1,369	$3,737	$14,833	$13,464	$11,096
Existing	48	720	$892	$3,531	$18,876	$17,985	$15,346

CZ 04

	Equip Size (Tons)	Loop Size (ft)	Gas Furnace Base Cost	Heat Pump Base Cost	Ground Coupled Heat Pump Cost	Incremental Cost vs Gas	Incremental Cost vs HP
New	2	660	$2,345	$2,566	$14,867	$12,522	$12,301
Tier 2	2	510	$3,693	$3,280	$12,630	$8,937	$9,350
Existing	2	880	$2,993	$2,926	$19,749	$16,756	$16,823

CZ 13

	Equip Size (Tons)	Loop Size (ft)	Gas Furnace Base Cost	Heat Pump Base Cost	Ground Coupled Heat Pump Cost	Incremental Cost vs Gas	Incremental Cost vs HP
New	3	480	$2,454	$2,877	$13,043	$10,589	$10,166
Tier 2	2.5	510	$3,729	$3,497	$13,060	$9,331	$9,563
Existing	4	860	$3,295	$3,531	$20,965	$17,671	$17,434

Incentives and Rebates

Costs for GCHP equipment and PV do not include the current incentives available for both. GCHP installations may qualify for a 30% federal tax credit. The total installed cost of the system, both loop and equipment is eligible. This credit will remain in place until December 31, 2016.

PV systems can qualify for both California state incentives and the homeowner federal tax credit. The current state PV incentives are:

- New Construction – New Solar Homes Program (NSHP): $2.60/AC Watt incentive
- Existing Homes – California Solar Initiative (CSI): $0.35/AC Watt incentive

The federal homeowner tax credit is currently 30% of installed system cost of the PV system. Like GCHP equipment, the tax credit will remain in place until December 31, 2016.

Utility Rate Assumptions, Customer Economics, and Peak Demand

Current PG&E utility rates and baseline quantities were used to evaluate total household monthly energy costs. Table 9 presents baseline energy allowances by PG&E service territory. PG&E defines ten service territories (designated by letters) which are divided into climate zones that reflect energy consumption needs. While the climate zones analyzed may span multiple service territories we selected service territories based on the cities listed in Table 9. Table 10 shows current E-1 electric rates. The key point to highlight is the rapid increase in electric rates as one moves from Tier 2 to Tier 3 (per kWh rates more than double). This has significant implications for an appliance such as GCHPs which will add electrical usage during heating months compared to gas the furnace base case.

Table 9: Baseline Electric and Gas Allowances

	PG&E	Basic Quantities		All-Electric Quantities	
Location	Territory	Summer	Winter	Summer	Winter
Electric (kWh/day)					
San Jose	X	12.1	12.6	12.2	22.9
San Francisco	T	8.3	9.8	11.1	20.2
Fresno	R	18.1	12.3	23.2	32.6
Gas (therms/day)					
San Jose	X	0.62	2.05		
San Francisco	T	0.69	1.79		
Fresno	R	0.49	1.85		

Table 10: Current E-1 Electric Rates by Tier

Tier	Percent of Baseline	Rate ($/kWh)
Tier 1	100%	$ 0.11877
Tier 2	130%	$ 0.13502
Tier 3	200%	$ 0.29062
Tier 4	300%	$ 0.40029
Tier 5	above	$ 0.40029

Gas rates were based on G-1 rates over the past twelve months. The baseline gas rates varied from $0.92 to $1.09 per therm over this period, and Tier 2 gas rates varied from $1.16 to $1.37 per therm. Clearly both electric and gas rates are on an upward trend, with gas indicating significantly more volatility over the past decade.

In addition to the tiered PG&E rate structures, household energy usage patterns strongly influence monthly bills. Whole building analysis completed to assess monthly total bill impacts.

Summer peak demand was evaluated for the period of noon to 6 pm between the months of May through October. Demand figures are not reported for Climate Zone 3 since no cooling system was modeled that would result in any demand savings.

Source Energy Savings

Source energy use was used to evaluate whole building energy use and savings for this study. Site-to-source conversion factors of 3 for electricity, and 1 for natural gas were assumed. These values are based on California's Title 24 methodology prior to the implementation of Time Dependent Valuation (TDV). The factor of 3 for electricity means three units of energy are needed to generate and deliver one unit of energy. This accounts for generation, transmission and distribution losses from using the raw fuel at the power plant to usable electricity on site. Because natural gas is a raw fuel, the factor is one; all inefficiencies occur on site when the fuel is burned.

National averages for site-to-source conversion, based on the Department of Energy's Building America program assumptions (3.365 for electricity and 1.092 for natural gas), are higher than the values used here and reflect greater usage of fossil fuel. The Title 24 source for site-to-source electricity factor is likely high for PG&E territory, which gets much of its electricity from hydroelectricity, but serves as a reasonable benchmark for this study. As California utilities add more renewable generation to their portfolio, factor for electricity will also drop. Site energy use was also used in the savings evaluations to show the other end of the conversion efficiency boundary, where all electricity is generated on-site with renewables. The effects of site-to-source conversion factors are not seen when comparing electric technologies, but are significant when evaluating technologies when fuel switching from gas to electric for space or water heating.

Project Results

Significance of Space Conditioning as ZNE Targeted End Use

To fully understand the potential benefit of any one technology as part of a ZNE package, we have developed household source energy comparisons that indicate the significance of the targeted end use. By evaluating "whole building" energy use along with space conditioning projections and converting the end use totals to source energy[12], one can develop a good picture of the overall technical potential associated with employing ZNE energy efficiency strategies.

Based on the Residential Appliance Saturation Survey (KEMA, 2010), space cooling and heating represent approximately 7% and 22%, respectively, of average household source energy use

[12] Source energy use kBtu/year is based on site-to-source energy use conversion of 3.0 for electricity and 1.0 for gas. (10.239 kBtu/kWh and 100 kBtu/therm).

across PG&E territory. However, space conditioning energy use varies widely by climate. Cooling energy is much higher in the valley climates and nearly non-existent in the coastal climates. Heating energy increases to 32% of average source household energy in coastal climates.

Figure 1 through Figure 3 show source energy consumption breakdown by end use for the Title 24 gas heating base case, in Climate Zones 3, 4 and 13, respectively. Table 1, Table 2 and Table 3 summarize space conditioning energy use as a percentage of total household source energy for all the evaluated scenarios. Space conditioning energy use is 32-43% of total household source energy for both the gas and heat pump heating base cases in Climate Zone 13, but only 14-27% in Climate Zone 3 in which no cooling system is defined in our model. Because of low cooling energy use in climate zones 3 and 4, additional costs for efficient cooling technologies are difficult to justify under the current residential rate structure.

GCHPs provide source energy savings relative to both gas and heat pump base cases. Relative to gas heating, GCHPs reduce space conditioning end use energy between 8 and 13% for the Title 24 and existing home cases, and between 4 and 9% for Tier 2. Relative to heat pump heating, GCHPs reduce space conditioning end use energy between 5 and 12% for the Title 24 and existing home cases. The reductions relative to heat pumps are lower in climates with less cooling.

Figure 1: Source Energy Breakdown by End-Use for Title 24 Case

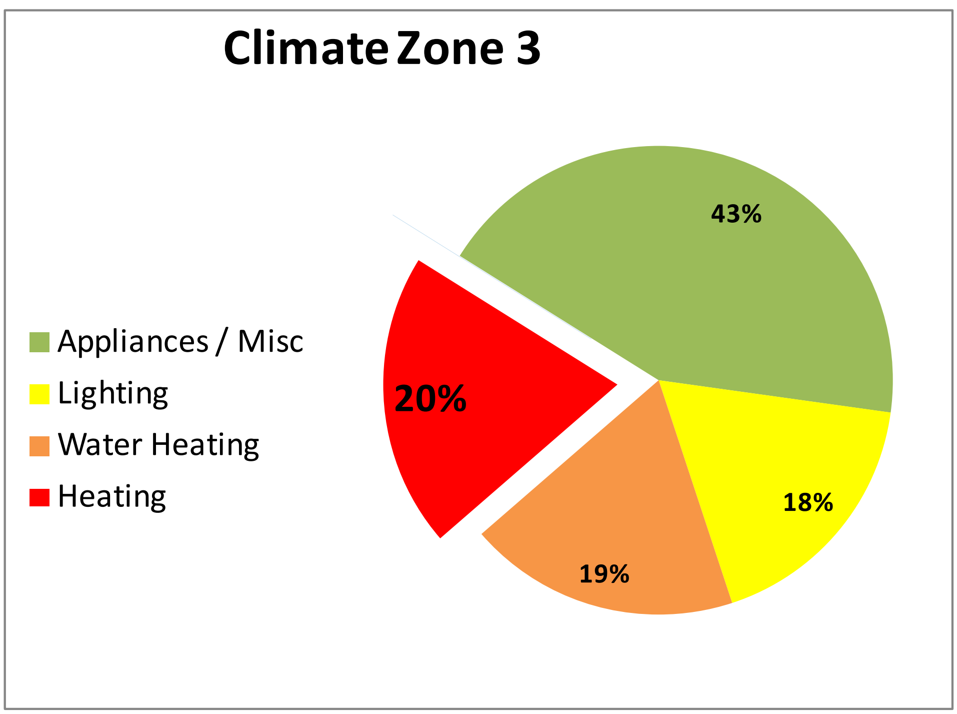


Figure 2: Source Energy Breakdown by End-Use for Title 24 Case

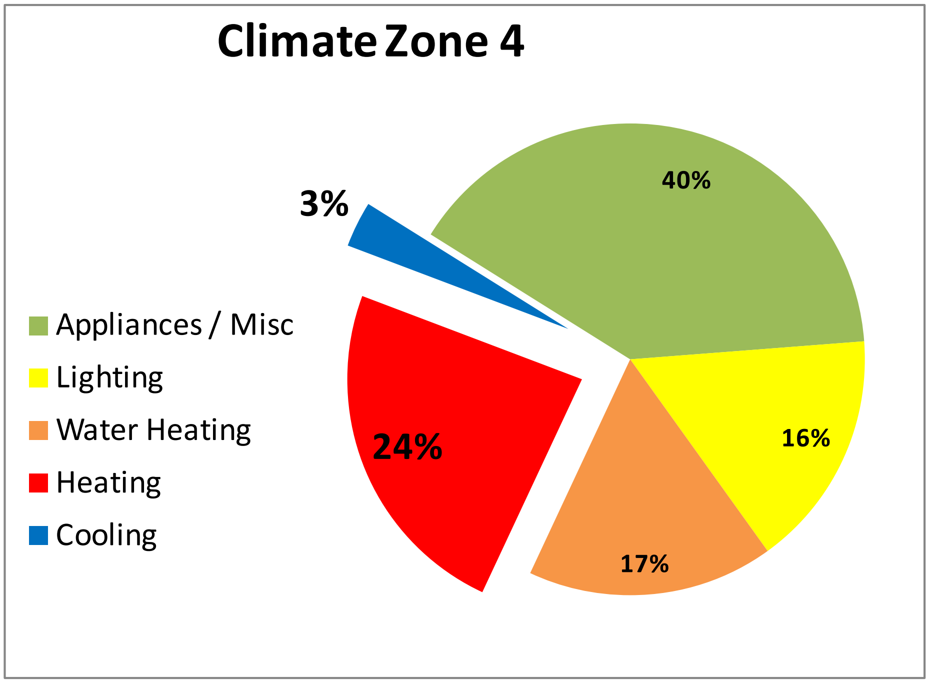


Figure 3: Source Energy Breakdown by End-Use for Title 24 Case

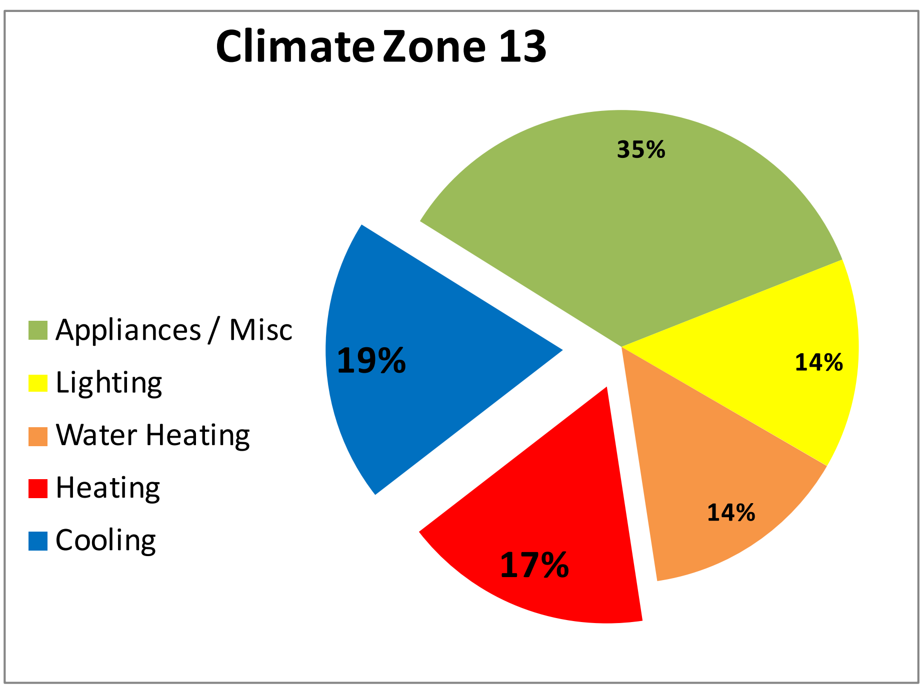


Table 1: Source Energy Breakdown for Space Conditioning End-Use for Climate Zone 3

Source Energy (kBtu/year)	Gas Furnace T24	Heat Pump T24	GCHP T24	Gas Furnace Tier 2	Heat Pump Tier 2	GCHP Tier 2	Gas Furnace Existing	Heat Pump Existing	GCHP Existing
Total House Energy	102,095	97,715	92,507	77,550	76,246	73,440	118,893	111,734	103,580
Space Conditioning Energy	20,690	16,311	11,102	11,840	10,536	7,730	31,866	24,707	16,553
% End Use	20%	17%	12%	15%	14%	11%	27%	22%	16%

Table 2: Source Energy Breakdown for Space Conditioning End-Use for Climate Zone 4

Source Energy (kBtu/year)	Gas Furnace T24	Heat Pump T24	GCHP T24	Gas Furnace Tier 2	Heat Pump Tier 2	GCHP Tier 2	Gas Furnace Existing	Heat Pump Existing	GCHP Existing
Total House Energy	110,846	106,674	97,761	83,750	82,315	77,240	119,879	115,984	105,454
Space Conditioning Energy	29,842	25,669	16,756	18,340	16,905	11,830	33,281	29,386	18,856
% End Use	27%	24%	17%	22%	21%	15%	28%	25%	18%

Table 3: Source Energy Breakdown for Space Conditioning End-Use for Climate Zone 13

Source Energy (kBtu/year)	Gas Furnace T24	Heat Pump T24	GCHP T24	Gas Furnace Tier 2	Heat Pump Tier 2	GCHP Tier 2	Gas Furnace Existing	Heat Pump Existing	GCHP Existing
Total House Energy	125,916	123,864	106,535	96,983	95,504	85,568	150,961	147,778	122,194
Space Conditioning Energy	45,712	43,659	26,331	32,073	30,594	20,658	65,220	62,038	36,454
% End Use	36%	35%	25%	33%	32%	24%	43%	42%	30%

Space Conditioning Energy Use and Savings

Table 4 through Table 6 show space conditioning source energy consumption and comparisons for the three scenarios and three climate zones. Both the gas furnace and air-source heat pump models are used as base cases for comparison. Site kBtu savings are also presented for the gas base case only. Since there are only kWh savings for the heat pump base case there is no difference in the percent savings between source and site. Because of the low saturation of cooling systems in Climate Zone 3, only heating savings were evaluated.

Annual source energy savings are greater when comparing GCHP end-use energy to the gas heating base case than to the electric heat pump case. Based on relative efficiencies of the base case gas and electric heating systems, and the source energy conversions for electricity, base case heat pump source energy use is less that the source energy use for a gas furnace. For the Title 24 and retrofit scenarios total savings are between 42% to 48% over the gas furnace base case and 32% to 41% over the heat pump base case. Compared to the heat pump base case GCHP technology presents the largest opportunity for savings in Climate Zone 13 due to significant cooling loads and nontrivial heating loads. This trend is not found with the gas furnace base case, because of higher relative source energy use with gas heating. The heating savings due to fuel switching can be isolated in Climate Zone 3 for which the end-use energy represents heating energy only and percent savings are between 35% and 48%.

Table 4: Space Conditioning End-Use Source & Site kBtu Energy Consumption Comparison – Title 24 House

	Gas Furnace Base Case		GCHP		% Saved	
Climate Zone	Source kBtu	Site kBtu	Source kBtu	Site kBtu	Source	Site
San Francisco (CZ3)	20,690	19,830	11,102	3,701	46%	81%
San Jose (CZ4)	29,842	26,081	16,756	5,585	44%	79%
Fresno (CZ13)	45,712	28,237	26,331	8,777	42%	69%

	HP Base Case	GCHP	% Saved
Climate Zone	Source kBtu	Source kBtu	Source
San Francisco (CZ3)	16,311	11,102	32%
San Jose (CZ4)	25,669	16,756	35%
Fresno (CZ13)	43,659	26,331	40%

Table 5: Space Conditioning End-Use Source & Site kBtu Energy Consumption Comparison – Existing House

	Gas Furnace Base Case		GCHP		% Saved	
Climate Zone	Source kBtu	Site kBtu	Source kBtu	Site kBtu	Source	Site
San Francisco (CZ3)	31,866	30,555	16,553	5,518	48%	82%
San Jose (CZ4)	33,281	27,827	18,856	6,285	43%	77%
Fresno (CZ13)	65,220	40,073	36,454	12,151	44%	70%

	HP Base Case	GCHP	% Saved
Climate Zone	Source kBtu	Source kBtu	Source
San Francisco (CZ3)	24,707	16,553	33%
San Jose (CZ4)	29,386	18,856	36%
Fresno (CZ13)	62,038	36,454	41%

Table 6: Space Conditioning End-Use Source & Site kBtu Energy Consumption Comparison - Tier 2 House

	Gas Furnace Base Case		GCHP		% Saved	
Climate Zone	Source kBtu	Site kBtu	Source kBtu	Site kBtu	Source	Site
San Francisco (CZ3)	11,840	11,280	7,730	2,577	35%	77%
San Jose (CZ4)	18,340	15,780	11,830	3,943	35%	75%
Fresno (CZ13)	32,073	22,558	20,658	6,886	36%	69%

	HP Base Case	GCHP	% Saved
Climate Zone	Source kBtu	Source kBtu	Source
San Francisco (CZ3)	10,536	7,730	27%
San Jose (CZ4)	16,905	11,830	30%
Fresno (CZ13)	30,594	20,658	32%

Savings for the Tier 2 case are slightly lower around 35% over the gas base case and 30% over the heat pump case. The efficiency of the Tier 2 equipment (15 SEER, 8.5HSFP) is higher than that for the Title 24 and existing home base cases which results in lower overall savings.

Percent savings of site kBtu are much higher than source since the penalty for generation, distribution, & transmission of electricity is not included.

<u>Energy Use, Savings and Economics</u>

Table 7 through Table 9 summarizes space conditioning gas and electric energy use and peak summer demand for both base cases and GCHP options. Table 10 summarizes incremental costs, customer cost savings and simple paybacks. More details on savings for the three climates can be found in Appendix A. Space heating fuel switching from gas furnace to electric GCHP results in the elimination of gas space conditioning energy use and an increase in electrical energy use.

As shown in the tables, peak demand savings are between 45% to 50% for both Title 24 and existing home scenarios and 34% to 38% for the Tier 2 scenario. Percentage savings are relative to space conditioning end use and not whole house building use. GCHP technology offers an important ZNE strategy to significantly reduce peak load in all climate zones.

Table 7: Space Conditioning End-Use Site Energy Consumption Comparison – Title 24 House

Climate Zone	HP Base Case End-Use Consumption			End-Use Consumption with GCHP			End-Use Consumption Reduction			% Saved		
	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm
San Francisco (CZ3)	0.87	1,593	0	0.87	1,084	0	0.00	509	0	0%	32%	0%
San Jose (CZ4)	1.81	2,507	0	0.97	1,637	0	0.83	870	0	46%	35%	0%
Fresno (CZ13)	3.50	4,264	0	1.81	2,572	0	1.69	1,692	0	48%	40%	0%

Climate Zone	Gas Furnace Base Case End-Use Consumption			End-Use Consumption with GCHP			End-Use Consumption Reduction			% Saved		
	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm
San Francisco (CZ3)	0.87	126	194	0.87	1,084	0	0.00	-958	194	0%	-761%	100%
San Jose (CZ4)	1.85	551	242	0.97	1,637	0	0.87	-1,086	242	47%	-197%	100%
Fresno (CZ13)	3.46	2,560	195	1.81	2,572	0	1.65	-12	195	48%	0%	100%

Table 8: Space Conditioning End-Use Site Energy Consumption Comparison – Existing House

Climate Zone	HP Base Case End-Use Consumption			End-Use Consumption with GCHP			End-Use Consumption Reduction			% Saved		
	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm
San Francisco (CZ3)	1.05	2,413	0	1.05	1,617	0	0.00	796	0	0%	33%	0%
San Jose (CZ4)	2.38	2,870	0	1.30	1,842	0	1.08	1,028	0	45%	36%	0%
Fresno (CZ13)	4.82	6,059	0	2.41	3,560	0	2.41	2,499	0	50%	41%	0%

Climate Zone	Gas Furnace Base Case End-Use Consumption			End-Use Consumption with GCHP			End-Use Consumption Reduction			% Saved		
	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm
San Francisco (CZ3)	1.05	192	299	1.05	1,617	0	0.00	-1,425	299	0%	-742%	100%
San Jose (CZ4)	2.41	799	251	1.30	1,842	0	1.10	-1,043	251	46%	-130%	100%
Fresno (CZ13)	4.79	3,684	275	2.41	3,560	0	2.38	124	275	50%	3%	100%

Table 9: Space Conditioning End-Use Site Energy Consumption Comparison - Tier 2 House

Climate Zone	HP Base Case End-Use Consumption			End-Use Consumption with GCHP			End-Use Consumption Reduction			% Saved		
	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm
San Francisco (CZ3)	0.67	1,029	0	0.67	755	0	0.00	274	0	0%	27%	0%
San Jose (CZ4)	1.26	1,651	0	0.81	1,155	0	0.44	496	0	35%	30%	0%
Fresno (CZ13)	2.12	2,988	0	1.32	2,018	0	0.80	970	0	38%	32%	0%

Climate Zone	Gas Furnace Base Case End-Use Consumption			End-Use Consumption with GCHP			End-Use Consumption Reduction			% Saved		
	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm	kW	kWh	therm
San Francisco (CZ3)	0.67	82	110	0.67	755	0	0.00	-673	110	0%	-821%	100%
San Jose (CZ4)	1.23	375	145	0.81	1,155	0	0.42	-780	145	34%	-208%	100%
Fresno (CZ13)	2.08	1,394	178	1.32	2,018	0	0.77	-624	178	37%	-45%	100%

The cost savings reported in Table 10 are based on total household energy use. PG&E residential tiered electric and gas rates (E-1 and G-1, respectively) were used to determine total building annual utility bill costs. Total annual household energy use was used to properly account for the tiered rate structures. Simple paybacks are based on an incremental installed cost presented in the table and annual energy cost savings.

Simple paybacks are long in all scenarios, primarily due to high incremental costs. While paybacks are lower against the heat pump base case than the gas base case, there are no scenarios under which the payback is less than 20 years. While total source energy savings are greater for the gas furnace base cases, based on current electricity and gas rate structures annual utility costs in heating dominated climates are significantly lower with gas heating. Savings and economics of GCHP compared to the gas heating base case are worse as a result. In the heating dominated and transitional climates negative savings are seen. It is cheaper to heat with gas than with efficient electric heating because of the tiered electric rate structures. GCHP heating energy use is in Tier 4 rates in most of the cases during the peak heating months.

Table 10: Projected Annual Energy Impacts, Costs, and Paybacks

	Gas Space Heating			Heat Pump Space Heating		
	Title 24	Existing	Tier 2	Title 24	Existing	Tier 2
San Francisco (CZ3)						
Incremental Cost	$14,461	$17,985	$13,464	$12,404	$15,346	$11,096
Annual Cost Savings	($101)	($207)	($50)	$191	$320	$85
Simple Payback (yrs)	-	-	-	65	48	130
San Jose (CZ4)						
Incremental Cost	$12,522	$16,756	$8,937	$12,301	$16,823	$9,350
Annual Cost Savings	($30)	($64)	$17	$297	$363	$122
Simple Payback (yrs)	-	-	540	41	46	77
Fresno (CZ13)						
Incremental Cost	$10,589	$17,671	$9,331	$10,166	$17,434	$9,563
Annual Cost Savings	$201	$345	$44	$517	$879	$243
Simple Payback (yrs)	53	51	210	20	20	39

Two alternative rate scenarios, shown in Table 11 and Table 12, were developed to see how GCHP economics could be improved. One case looks at allowing all PG&E GCHP customers to be billed as all-electric customers, and the second looks at a case where natural gas rates are 50% higher than current gas rates. Allowing GCHP households to utilize the higher all electric tier quantities provides a significant benefit, reducing the simple paybacks from 20 years, in Table 10 for Climate Zone 13 Title 24 and existing homes, to 13 – 15 years. The assumption of 50% higher natural gas costs improves the comparison to gas space heating, but still does not generate sufficient savings to create favorable paybacks. The shortest payback is still over 30 years.

Table 11: Projected Annual Cost Savings and Paybacks for GCHP over the Heat Pump Base Case Using All-Electric Rate Baselines for the GCHP

	Title 24	Existing	Tier 2
San Francisco (CZ3)			
All-Electric Annual Cost Savings/year	$535	$898	$177
Adjusted Simple Payback (yrs)	23	17	63
San Jose (CZ4)			
All-Electric Annual Cost Savings/year	$463	$632	$153
Adjusted Simple Payback (yrs)	27	27	61
Fresno (CZ13)			
All-Electric Annual Cost Savings/year	$686	$1,308	$308
Adjusted Simple Payback (yrs)	15	13	31

Table 12: Projected Annual Cost Savings and Paybacks for GCHP over the Gas Base Case w/ a 50% Increase in Gas Rates

	Title 24	Existing	Tier 2
San Francisco (CZ3)			
"High" Gas Rate Cost Savings/year	($1)	($48)	$4
Adjusted Simple Payback (yrs)	-	-	3,690
San Jose (CZ4)			
"High" Gas Rate Cost Savings/year	$94	$64	$87
Adjusted Simple Payback (yrs)	134	260	103
Fresno (CZ13)			
"High" Gas Rate Cost Savings/year	$303	$491	$134
Adjusted Simple Payback (yrs)	35	36	70

When the 30% federal tax credit for GCHPs is considered, simple paybacks improve significantly. The tax credit allows a homeowner to write off 30% of their entire mechanical system, including ductwork, and can provide substantial savings. Against the heat pump base case GCHPs in Climate Zone 13 Title 24 and existing home scenarios result in a 10 and 12 year simple payback, respectively. For the case in which the GCHP house is allowed to use the all-electric rate, simple paybacks drop to 8 years for these two scenarios.

Table 13 evaluates the potential benefits of photovoltaic (PV) array downsizing through the implementation of GCHPs and presents a cost comparison between GCHP technology and PV for the case of a ZNE home. "Cost per first year kWh saved" is compared to the price per kWh for PV, which varies by climate due to slight variations in PV generation per kW. The PV cost figure was calculated using an average price of $6.80 per Watt (STCDC) and climate specific performance data provided by a major PV installer. The cost per kWh for PV is $4.74/kWh in Climate Zone 3, $4.62/kWh in Climate Zone 4 and $4.56/kWh in Climate Zone 13. These PV costs do not include current state incentives through the NSHP or CSI programs or the 30% federal tax credit potentially available to homeowners. In all the scenarios, the price of installing PV is less expensive than for GCHP. There are opportunities to downsize the PV array necessary to achieve a ZNE home by 6% to 21% but at a higher incremental cost.

Table 13: Cost Comparison with PV for the Heat Pump Base Case

	Title 24	Existing	Tier 2
San Francisco (CZ3)			
Cost per first year kWh Saved	$24.31	$19.18	$40.22
Cost of PV per kWh	$4.74	$4.74	$4.74
% Array Size Reduction	8%	10%	6%
San Jose (CZ4)			
Cost per first year kWh Saved	$14.11	$16.35	$18.87
Cost of PV per kWh	$4.62	$4.62	$4.62
% Array Size Reduction	12%	12%	9%
Fresno (CZ13)			
Cost per first year kWh Saved	$6.01	$6.97	$9.86
Cost of PV per kWh	$4.56	$4.56	$4.56
% Array Size Reduction	18%	21%	14%

In evaluating technologies where fuel switching occurs, a different methodology must be developed for an accurate comparison against PV and characterization of total savings over the base case. Instead of relying on simple payback and cost per kWh saved, we have looked at life cycle costs of each scenario to better compare options.

Table 14 and Table 15 show the results from this analysis for GCHPs over both the gas furnace and heat pump base case for a 25 year life cycle. Two scenarios are introduced and results are presented in life cycle incremental costs over the base case. The first scenario is the base case also with a PV array that would supply annual kWh. It does not include additional PV to offset gas heating use. The second scenario is a house with a GCHP and onsite PV electricity generation that would supply the remainder of the annual kWh consumption (system is sized to net-zero electricity use). Results are presented per site kBtu saved to take into account both electricity and gas savings. No site-to-source conversions are used. For the PV case these savings are simply the utility kWh displaced by PV generation. For the GCHP case the savings represent both the heating therms and cooling kWh saved by installation of the GCHP along with the additional kWh displaced by the PV. Following are the assumptions used.

- 25 year useful life for PV
- 20 year useful life for GCHP
- Discount rate of 3%
- Electricity & gas escalation rate of 3%

The LCC analysis shows that with current equipment and utility costs, and in the absence of incentives, PV is always more cost effective from a LCC cost perspective and almost always is less expensive per site kBtu saved than GCHPs. The Tier 2 Climate Zone 13 gas base case scenario is the only scenario that results in lower incremental LCC per site kBtu saved, although these savings are very minimal. With all of the Tier 2 heat pump base case scenarios, GCHP with PV has lower life cycle incremental costs per site kBtu saved than PV alone. Since electricity use is in the lower tiers in a Tier 2 home, installing PV to offset utility costs is not as cost effective. However, none of these scenarios provide any payback over the lifetime analyzed.

Table 14: Life Cycle Cost Analysis of Incremental Cost per Site Energy Savings for GCHP with PV Compared to the Gas Base Case with PV

	Gas Base Case w/ PV			GCHP w/ PV		
Scenario	Title 24	Existing	Tier 2	Title 24	Existing	Tier 2
San Francisco (CZ3)						
Incremental LCC	$4,992	$2,478	$6,807	$19,956	$20,583	$21,847
Incremental LCC per Site kBtu Saved	$0.0113	$0.0047	$0.0197	$0.0215	$0.0162	$0.0351
San Jose (CZ4)						
Incremental LCC	$8,417	$6,689	$7,137	$20,304	$22,339	$16,471
Incremental LCC per Site kBtu Saved	$0.0176	$0.0116	$0.0192	$0.0188	$0.0185	$0.0225
Fresno (CZ13)						
Incremental LCC	$7,835	$2,405	$8,436	$14,053	$12,968	$16,541
Incremental LCC per Site kBtu Saved	$0.0121	$0.0029	$0.0184	$0.0124	$0.0086	$0.0183

Table 15: Life Cycle Cost Analysis of Incremental Cost per Site Energy Savings for GCHP with PV Compared to the Heat Pump Base Case with PV

	Heat Pump Base Case w/ PV			GCHP w/ PV		
Scenario	Title 24	Existing	Tier 2	Title 24	Existing	Tier 2
San Francisco (CZ3)						
Incremental LCC	($386)	($8,129)	$5,254	$10,186	$4,130	$15,546
Incremental LCC per Site kBtu Saved	($0.0033)	($0.0514)	$0.0681	$0.0180	$0.0058	$0.0364
San Jose (CZ4)						
Incremental LCC	$3,114	($796)	$6,885	$11,872	$11,770	$14,357
Incremental LCC per Site kBtu Saved	$0.0286	($0.0060)	$0.0906	$0.0184	$0.0156	$0.0299
Fresno (CZ13)						
Incremental LCC	$2,611	($7,426)	$6,260	$5,642	($692)	$11,857
Incremental LCC per Site kBtu Saved	$0.0033	($0.0466)	$0.0715	$0.0071	($0.0007)	$0.0200

This study was based on a 1,787 single story house. As a result, most cooling energy use remains within baseline limits. Large homes and big energy consumers, who are using electricity in the upper tiers, provide a potential niche market for GHCPs. The economics are much more favorable when the marginal cost for electricity is $0.30 per kWh and above.

Conclusions

In certain climates, GCHPs represent a potentially attractive option to reduce space conditioning energy use and peak cooling demand. The impact is most significant during peak summer and winter times when outdoor temperatures are extremely high or low and traditional air conditioners or heat pumps operate less efficiently. Electricity savings are greatest in climates with significant cooling and heating loads, such as the inland valley climates. GCHP market in California is challenged by relatively mild climates in much of the state, high incremental installed costs, and cheap natural gas prices relative to electricity throughout much of the state.

GCHPs have been on the market for several years but have suffered wide-spread dissemination mostly due to large incremental costs and unconfirmed long-term reliability and durability. They traditionally have served a niche market of large custom single family homes with large space conditioning loads and the ability to invest in technologies with high capital costs. California represents a unique situation since the market is dominated by natural gas space heating, and higher than national average electric rates, along with the electric tiered structure, reduce the cost effectiveness of any electric space heating strategy.

Specific project conclusions include the following:

1. Total space conditioning energy is projected to represent an average of 27% of households annual source energy usage for the cases evaluated, with higher fractions in homes with substantial cooling and heating loads (~37%) and lower for homes in coastal climates where cooling loads are trivial (~19%).

2. <u>Relative to a conventional gas furnace space heating w/ compressor based cooling</u>, GCHPs are projected to reduce annual space conditioning source energy by about 45%, resulting in a whole house savings of about 12%.

3. <u>Relative to a high efficiency furnace and air conditioner package</u> that will be common in higher efficiency Tier 2 homes, GCHPs are projected to reduce annual space conditioning source energy by about 35%, resulting in a whole house savings of about 8%.

4. <u>Relative to a standard efficiency electric heat pumps</u>, GCHPs are projected to reduce annual space conditioning source energy by about 36%, resulting in a whole house savings of about 10%.

5. <u>Relative to a high efficiency electric heat pump</u>, GCHPs are projected to reduce annual space conditioning source energy by about 30%, resulting in a whole house savings of about 7%.

6. GCHPs offer an important strategy for peak summer demand savings in ZNE homes. Whole house demand savings are approximately 39% for Title 24 compliant new homes and existing building stock and 27% for Tier2 new homes. If residential rate structures change to better reflect real-time pricing, the economics for GCHPs can be more favorable.

7. Ground coupled heat pumps provide greatest whole building source energy savings in hot-dry valley climates, Climate Zone 13, where both heating and cooling energy use is significant. Average savings are 15% of whole building source energy use and 38% for peak demand.

8. Ground loop costs are a significant contribution to total system costs. Costs for loop installation vary significantly by loop type. While vertical loop installations can be 2-3 times more expensive that horizontal loops, they are most commonly installed due to footprint limitations.

9. From a customer viewpoint, GCHP economics are challenging due to high incremental first costs and the availability of inexpensive natural gas. Low current natural gas rates and PG&E's current steep tiered E-1 electric rate structure will result in increased

household utility costs relative to a house with gas space heating. Even with natural gas costs 50% higher than current rates, an attractive customer simple payback cannot be achieved. A potential niche market may exist for customers who currently do not have access to natural gas and are able to participate in all-electric E-1 rates.

10. Utility cash incentives or tax credits will be necessary in the short term to improve GCHP economics. The 30% federal tax credit can push simple paybacks compared to air-source heat pumps in Climate Zone 13 into the 10 year range at current electricity rates. The payback improves further if GCHP customers are able to participate in all-electric E-1 rates.

11. Careful attention to loop design is critical to produce long lasting energy savings. Both undersized and oversized loops can result in systems that do not perform per design. Soil properties and weather data have significant impact on the loop size and performance. Proper sizing may require test bores and in-situ conductivity tests along with hourly simulations.

12. Predicted cost effectiveness may be more favorable in other parts of the country where electric rates are below the national average. Current California residential electric rates are approximately 30% higher than the national average[13] and natural gas is relatively inexpensive.

13. There is an opportunity, through intelligent and efficient design, to eliminate air conditioning in transitional and coastal climates. Money saved by not installing air conditioning can be directed to other technologies that can benefit the ZNE goals. Elimination of air conditioning also results in more significant and guaranteed peak demand reductions. In these situations lower cost ZNE technologies should be investigated for space heating alone.

14. There is a large potential for substantial ground loop cost reductions. These include:
    a. Development scale installations in new construction
    b. Utilization of vertical helix loop installations which have the ability to be installed at a much lower cost but lacks manufacturer and industry support.
    c. Increased GCHP market penetration which will result in more installation contractors and drillers, potentially bringing vertical drilling costs down. The current niche market that GCHPs exist includes higher profit margin than would

[13] http://www.eia.doe.gov/electricity/epm/table5_6_a.html

exist if in a mature market. Ground loop installation costs are significantly lower in parts of the country where an established industry exists.

15. There is the potential for cost effective use of GCHPs for water heating alone. These systems require smaller loops. If the ground loop can be installed in existing utility and foundation trenches, installed costs can be reduced. Water loop heat pump water heaters provide improved water heating performance and efficiency over the current heat pump water heater products available today. More research is needed to determine if enough loop can be installed with California conditions and construction practices.

16. Over the years, there have been continued improvements to heat pump efficiency, especially with water loop heat pumps. We can expect to see additional incremental efficiencies in heat pump performance but no large efficiency improvements are anticipated in the near future.

References

DEG, 1999. "*California Ground Loop Development Project Report*" PG&E Report, May 1999

DEG, 1999. "*Evaluation of California GeoExchange Market Potential*" PG&E Report, May 1999

DEG, 1999. "*Field Study, Assessment, and Recommendations for Irrigated Ground-Coupled Heat Pump Horizontal Heat Exchangers*" PG&E Report, May 1999

DEG, 1999. "*PG&E Geothermal Heat Pump Commercialization/ Model Utility Program Demonstration Final Report*" PG&E Report, May 1999

KEMA, Inc. 2010. *2009 California Residential Appliance Saturation Study.* California Energy Commission. Publication number: CEC- 200-2010-004-ES.

Puttagunta, Srikanth et Al. 2010. *"Residential Ground-Source Heat Pumps: In-Field Performance and Energy Modeling"*, GRC Transactions. Volume 34.

Straube, John 2010. "*Ground Source Heat Pumps for Residential Heating and Cooling: Carbon Emissions and Efficiency*", Building Science Digest 113. June 2010

Appendix A

Results Tables

Table A-1: Projected Annual Costs and Paybacks for GCHP over the Gas Base Case

Scenario	CZ3			CZ4			CZ13		
	T24	Tier 2	Existing	T24	Tier 2	Existing	T24	Tier 2	Existing
Base Case House w/ Gas Furnace									
Total Operating Cost ($/year)	$1,285	$854	$1,647	$1,245	$908	$1,496	$1,576	$1,070	$2,211
House w/ Ground Coupled Heat Pump									
Total Operating Cost ($/year)	$1,386	$904	$1,855	$1,274	$891	$1,560	$1,375	$1,026	$1,866
Incremental Cost over Gas ($)	$ 14,461	$13,464	$17,985	$12,522	$8,937	$16,756	$10,589	$9,331	$17,671
Savings Summary									
GCHP Annual Cost Savings over Gas ($)	($101)	($50)	($207)	($30)	$17	($64)	$201	$44	$345
Simple Payback over Gas (years)	-	-	-	-	540	-	53	210	51

Table A-2: Projected Annual Costs and Paybacks for GCHP over the Heat Pump Base Case

Scenario	CZ3			CZ4			CZ13		
	T24	Tier 2	Existing	T24	Tier 2	Existing	T24	Tier 2	Existing
Base Case House w/ Air Source Heat Pump									
Total Operating Cost ($/year)	$1,577	$989	$2,175	$1,571	$1,013	$1,922	$1,892	$1,269	$2,745
House w/ Ground Coupled Heat Pump									
Total Operating Cost ($/year)	$1,386	$904	$1,855	$1,274	$891	$1,560	$1,375	$1,026	$1,866
Incremental Cost over HP ($)	$12,404	$11,096	$15,346	$12,301	$9,350	$16,823	$10,166	$9,563	$17,434
Savings Summary									
GCHP Annual Cost Savings over HP ($)	$191	$85	$320	$297	$122	$363	$517	$243	$879
Simple Payback over HP (years)	65	130	48	41	77	46	20	39	20

Table A-3: Projected Annual Cost Savings and Paybacks for GCHP over the Heat Pump Base Case Using All-Electric Rate Baselines for the GCHP

Scenario	CZ3			CZ4			CZ13		
	T24	Tier 2	Existing	T24	Tier 2	Existing	T24	Tier 2	Existing
Base Case House w/ Air Source Heat Pump									
Total Operating Cost ($/year)	$1,577	$989	$2,175	$1,571	$1,013	$1,922	$1,892	$1,269	$2,745
House w/ Ground Coupled Heat Pump									
Total Operating Cost ($/year)	$1,042	$812	$1,277	$1,108	$859	$1,290	$1,206	$961	$1,437
Incremental Cost over HP ($)	$12,404	$11,096	$15,346	$12,301	$9,350	$16,823	$10,166	$9,563	$17,434
Savings Summary									
GCHP Annual Cost Savings over HP ($)	$535	$177	$898	$463	$153	$632	$686	$308	$1,308
Simple Payback over HP (years)	23	63	17	27	61	27	15	31	13

Table A-4: Projected Annual Cost Savings and Paybacks for GCHP over the Gas Base Case w/ a 50% Increase in Gas Rates

Scenario	CZ3			CZ4			CZ13		
	T24	Tier 2	Existing	T24	Tier 2	Existing	T24	Tier 2	Existing
Base Case House w/ Gas Furnace									
Total Operating Cost ($/year)	$1,537	$1,033	$1,936	$1,519	$1,102	$1,753	$1,827	$1,284	$2,483
House w/ Ground Coupled Heat Pump									
Total Operating Cost ($/year)	$1,538	$1,029	$1,984	$1,425	$1,015	$1,688	$1,524	$1,150	$1,993
Incremental Cost over Gas ($)	$ 14,461	$13,464	$17,985	$12,522	$8,937	$16,756	$10,589	$9,331	$17,671
Savings Summary									
GCHP Annual Cost Savings over Gas ($)	($1)	$4	($48)	$94	$87	$64	$303	$134	$491
Simple Payback over Gas (years)	-	3690	-	134	103	260	35	70	36