NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Energy Savings and Breakeven Cost for Residential Heat Pump Water Heaters in the United States

Jeff Maguire, Jay Burch, Tim Merrigan, and Sean Ong
National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5500-58594
July 2013

Contract No. DE-AC36-08GO28308

Energy Savings and Breakeven Cost for Residential Heat Pump Water Heaters in the United States

Jeff Maguire, Jay Burch, Tim Merrigan, and Sean Ong
National Renewable Energy Laboratory

Prepared under Task No. SH12.1000

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-5500-58594
July 2013

Contract No. DE-AC36-08GO28308

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/help/ordermethods.aspx

Cover Photos: (left to right) photo by Pat Corkery, NREL 16416, photo from SunEdison, NREL 17423, photo by Pat Corkery, NREL 16560, photo by Dennis Schroeder, NREL 17613, photo by Dean Armstrong, NREL 17436, photo by Pat Corkery, NREL 17721.

Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

Acknowledgments

The authors thank Craig Christensen, Bethany Sparn, Kate Hudon, Eric Wilson, Jenny Melius, Billy Roberts, and Nathan Clark of NREL, Moncef Krarti of the University of Colorado Boulder, and Hannah Cassard of Abengoa (formerly of NREL) for their reviews and other contributions.

Nomenclature

AC	Air conditioner
ASHP	Air source heat pump
BA	Building America
COP	Coefficient of performance
COP_{sys}	System coefficient of performance
c_p	Specific heat
d	Discount rate
DF	Discount factor
DHWESG	Domestic hot water event schedule generator
e	Fuel escalation rate
E_{cons}	Consumed site energy
E_{cool}	Space cooling energy
E_{del}	Delivered site energy
E_{elem}	Heat added by electrical element
E_{heat}	Space heating energy
$E_{hp,tank}$	Heat added by a heat pump
E_{nrmlz}	Normalization energy
E_{WH}	Water heater energy consumption
EF	Energy factor
FEF	Fuel escalation factor
ER	Electric resistance
HPF	Heat pump fraction
HPWH	Heat pump water heater
HVAC	Heating, ventilation, and air conditioning
IC_{base}	Base case water heater net installed cost
IC_{HPWH}	Heat pump water heater net installed cost
m	Mass
MC	Heat pump water heater maintenance cost
n	Study length
NPB	Net present benefit
NPC	Net present cost

NPV	Net present value
PTC	Personal tax credit
SRP	State rebate program
URP	Utility rebate program
WH	Water heater
$\$_{saved}$	Annual utility bill savings
T_{out}	Water heater outlet temperature
T_{req}	Required outlet temperature
η	Efficiency

Executive Summary

Heat pump water heaters (HPWHs) have recently reappeared in the U.S. residential market and have the potential to provide homeowners with significant energy savings over traditional electric resistance (ER) water heaters (WHs). HPWHs typically have a rated efficiency at least twice as high as typical electric WHs. However, questions remain about their actual performance and energy savings potential, especially in unconditioned space, and their impact on space heating and cooling loads when they are located in conditioned space. To help answer these questions, a 50-gal HPWH was simulated in both conditioned and unconditioned space at more than 900 locations across the continental United States and in Hawaii. Base cases of typical residential gas and electric WHs were also simulated so the energy savings of an HPWH relative to both technologies could be calculated.

Simulations included a Building America benchmark home and several combinations of space heating and cooling equipment to quantify the HPWH's impact on a home's annual energy consumption. A mixed draw profile, consistent with the hot water use level of a three-bedroom home in the Building America House Simulation Protocol, was used. The tempered draws allowed for variations in the hot water usage level, with a low draw volume of about 45 gal in locations with warm mains water and 60 gal for locations with cold mains water. All energy savings calculations were done on a source energy basis to account for the net savings in any mixed fuel cases. The breakeven cost (the required net installed cost of an HPWH to make it cost neutral with a traditional WH) was calculated for all cases to show their cost savings potential.

The HPWH can save some source energy savings relative to a typical electric WH in all cases considered here, although the source energy savings are often lower than expected based on the rated efficiency of the HPWH. The largest source energy savings are seen in the southern regions of the United States, especially in the hot-humid climate. For all-electric homes with high efficiency space heating equipment (an air source heat pump [ASHP]), higher source energy savings are seen when the HPWH is installed in conditioned space in heating-dominated climates; for cases with low efficiency space heating (ER heat) installations in unconditioned space have higher source energy savings. The source energy savings for a case with an ASHP when the HPWH is installed in unconditioned space is shown in Figure ES–1. When comparing to gas WHs, positive source energy savings are only realized in the Southeast, parts of southern California and Arizona, and Hawaii. This is true for installations in conditioned and unconditioned space, although higher source energy savings are seen in conditioned space.

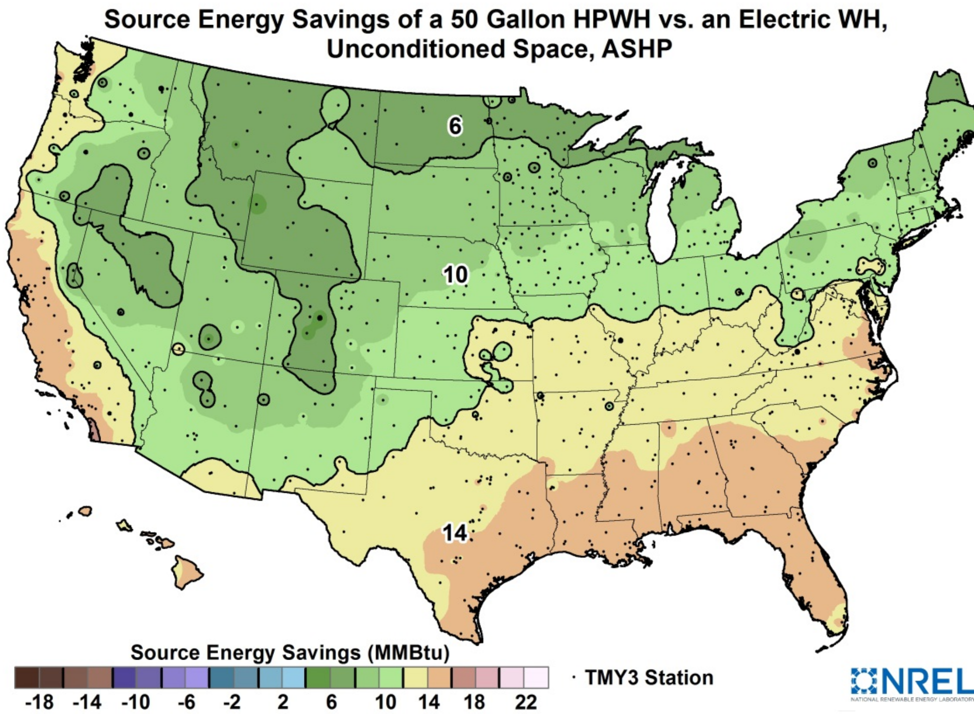


Figure ES–1. Source energy savings of an HPWH versus an electric WH in unconditioned space for a home with an ASHP

The 50-gal HPWH has a favorably high breakeven cost compared to an electric WH in most of the country, except the Pacific Northwest and parts of the northern Mountain region when located in conditioned space for homes with highly efficient space conditioning equipment. The highest breakeven costs occur in California, the South, and the Northeast. For homes with less efficient space heating equipment, the breakeven costs are significantly reduced across the country and high breakeven costs are most common in locations with the smallest heating loads. When installing in unconditioned space (see Figure ES–2), the HPWH may break even in most locations except the Pacific Northwest, most of the Mountain census region, and the northern Midwest, depending on its actual net installed cost. When comparing to gas WHs, breakeven is only likely in parts of the Southeast, central Washington, and Hawaii. However, when federal and local incentives are factored in, HPWHs become cost effective in several more locations.

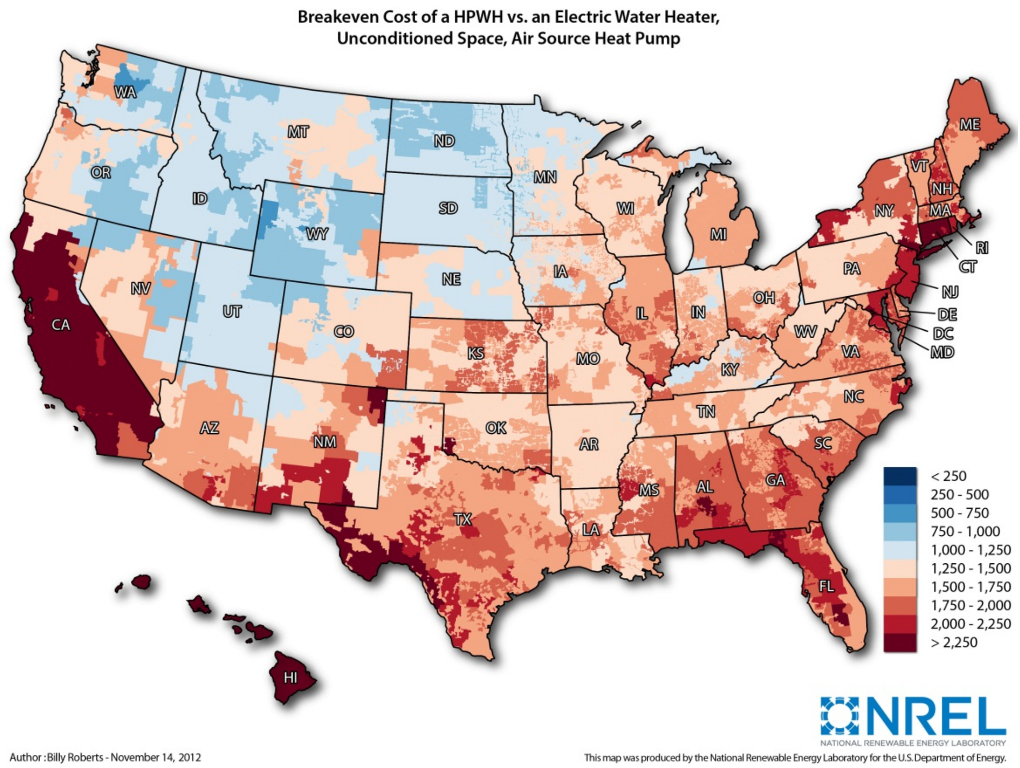


Figure ES–2. Breakeven cost of an HPWH versus an electric WH in unconditioned space for a home with an ASHP

To account for differences in potential energy savings and breakeven costs for different sized HPWHs, an 80-gal HPWH was also modeled and presented in Appendix B. In the 80-gal case, higher source energy savings and breakeven costs are possible, particularly in colder regions. Although this study does examine regional variations in HPWH performance and savings, it looks at only one hot water usage level and one home. The parameters chosen for this study were assumed to be roughly representative, but actual savings will vary significantly with hot water use, the overall efficiency of a home, and the actual HPWH installed.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Heat Pump Water Heaters Versus Traditional Water Heaters

Water heating is a significant energy use in U.S. homes (EIA, 2009). It accounts for 17.7% of the total energy consumed, or 1.8 quads annually. The U.S. residential water heater (WH) market is dominated by storage type WHs. Gas and electric resistance storage WHs comprised about 94% of residential WH shipments in 2009 (U.S. Department of Energy, 2010). Although conventional gas and electric storage WHs are the cheapest and most common options, many higher efficiency water heating options are available. One such option that has recently reappeared on the U.S. market is the integrated heat pump water heater (HPWH) (see Figure 1), which takes heat from the ambient air and adds it to a hot water storage tank via a vapor compression refrigeration cycle. These units are much more efficient than conventional electric WHs, with a rated efficiency (energy factor [EF], defined as the average efficiency over a standard 24-h test) of 2–2.5; typical electric WHs have an EF of ~0.9.

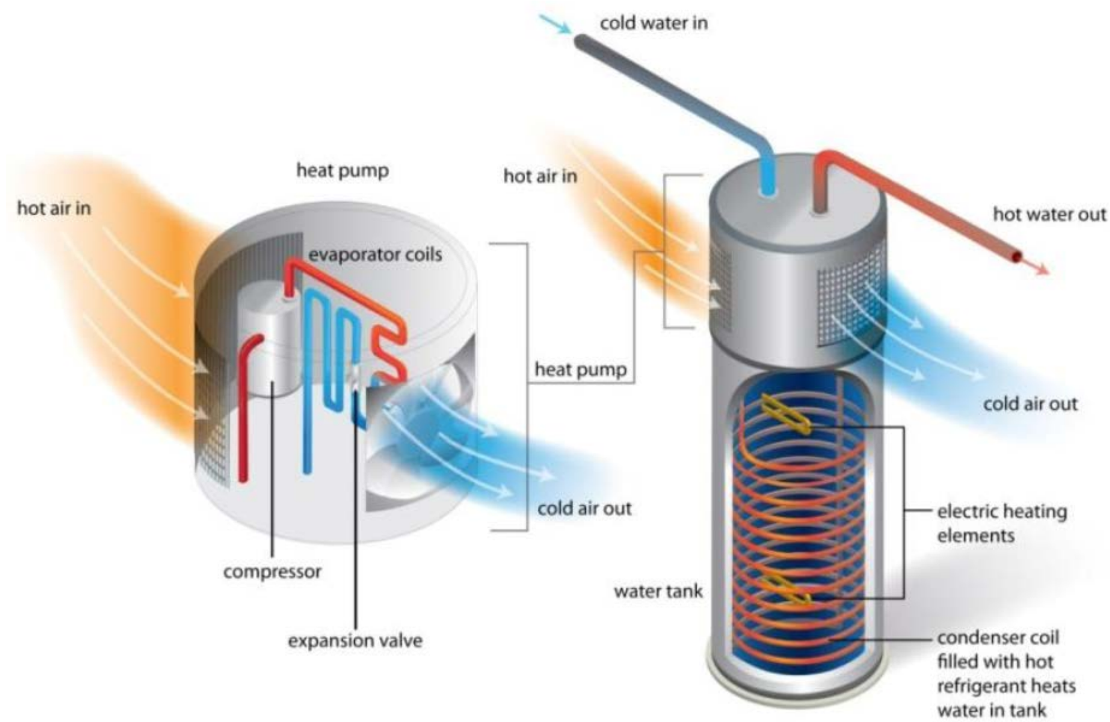


Figure 1. Schematic of an HPWH

(Illustration by Marjorie Schott/NREL)

HPWHs in the United States typically feature both a heat pump and at least one electric resistance element for heating. The electric resistance element(s) are activated if the heat pump cannot keep up with the load, or if the ambient air conditions prevent the heat pump from running. Each manufacturer has its own control logic (designed to work with its particular HPWH) for determining when to switch to the backup electric resistance element(s). How often these element(s) have to be used is heavily dependent on climate and hot water use and has a large impact on overall efficiency.

1.2 Heat Pump Water Heater Efficiency, Reliability, and Cost

The heat pump efficiency (coefficient of performance [COP], defined as the amount of energy delivered divided by the amount of energy consumed) depends heavily on the temperature of water adjacent to the condenser, ambient air temperature and humidity, set point temperature, hot water draw profile, and operating mode. All these factors can cause efficiency to vary widely, particularly if the unit is in unconditioned space where the ambient air temperature can vary significantly over the course of a year. This unit will cool and dehumidify the space it is in while the heat pump is running, which may be either a net benefit or a detriment, depending on the climate and the efficiency of the space conditioning equipment. An HPWH could be ducted to the outdoors or to an unconditioned space to offset the heating penalty associated with running the heat pump; however, many HPWHs are not configured for ducting. Ducting was not simulated in this study, but may provide some benefits to HPWH performance in some locations.

HPWHs have historically seen poor market penetration, although they have been sporadically available for many years. The main reason for this is the high first cost, which can be several times as high as a comparable electric storage WH. This presents a significant barrier to market entry. HPWHs are also perceived by some to have reliability issues (Dubay, Ayee, & Gereffi, 2009), based on experience with earlier generations of HPWHs. Although the current generation has not yet shown any of the problems previous generations had, people who were aware of previous HPWH pilot programs may still be skeptical. Several large manufacturers have recently entered the market and currently have ENERGY STAR®-qualified HPWHs available, which may bode well for improved reliability. Also, new residential WH efficiency standards, which go into effect in 2015, will effectively require all new electric WHs larger than 55 gal to be HPWHs (U.S. Department of Energy, 2010), which should increase market penetration.

Fifty-two percent of U.S. homes use natural gas as the primary water heating fuel and 41% use electricity (EIA, 2009). The rest use other fuel sources such as fuel oil, propane, wood, and solar. Figure 2 shows the distribution of WH fuels by census region. A more detailed breakdown, including a state-by-state breakdown of water heating fuel for the 16 most populous states, is provided in Appendix A.

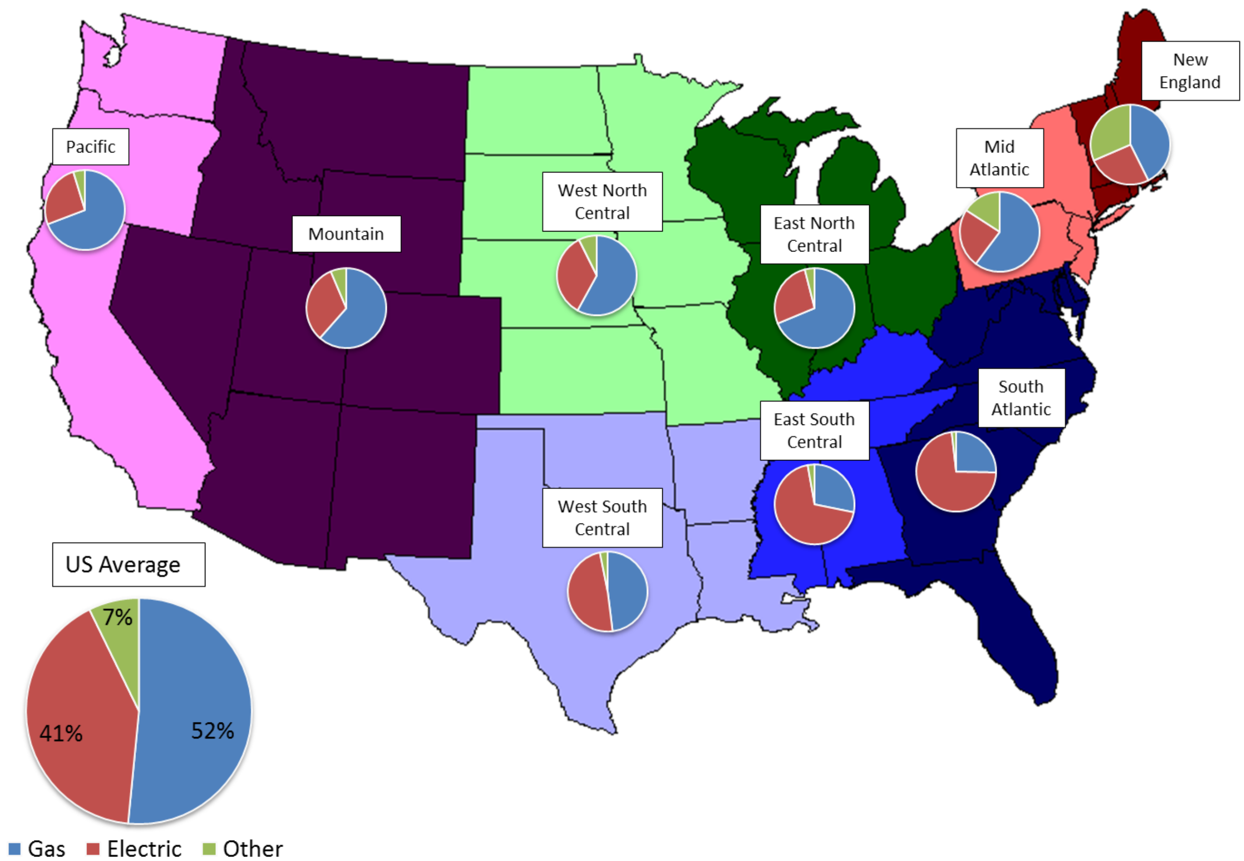


Figure 2. Distribution of fuel types for installed residential WHs by census region (EIA, 2009)

To determine the in-use efficiency of an HPWH in the United States, annual simulations were performed of an HPWH at Typical Meteorological Year 3 sites (Wlicox & and Marion, 2008) across the continental United States and in Hawaii. A sub-hourly hot water draw profile, described in further detail in Section 2.2, was used for this study. This draw profile is intended to represent typical hot water use and has an average daily draw volume of 45–60 gal/day, depending on mains water temperature. For every simulation, a home was also modeled to quantify the interaction between the HPWH and the space heating and cooling equipment. Simulations were performed with the WH located in both conditioned and unconditioned space for two sets of space conditioning equipment (a furnace/air conditioner [AC] combination and an air source heat pump [ASHP]); postprocessing calculations were done to create a case with electric resistance (ER) space heating and an AC. Simulations of standard gas and electric storage WHs were also performed to determine savings.

1.2.1 Source Energy Efficiency

An HPWH could be installed as a replacement for either electric or gas storage WHs. However, several factors come into play when considering a switch from natural gas to electricity for water heating. One key factor is the difference between site and source energy. Source energy takes into account all the primary energy that must be consumed to provide energy to a home; site energy takes into account only the energy consumed at the home. To calculate how much source energy is consumed by a WH in this study, national average source to site ratios of 3.365 for electricity and 1.092 for gas are used throughout (Hendron & Engelbrecht, Building America House Simulation Protocol, 2010). Although the EF of an HPWH is much higher than that of a gas storage WH (EF ≈ 0.6 for typical natural draft units), EF is defined in terms of site energy. Source efficiency, calculated as EF divided by the source to site ratio, provides a more general metric for determining how efficient switching fuel would be. Table 1 shows the EF and source efficiency of each WH considered here.

Table 1. EF and Source Efficiency of Each WH Considered Here

Water Heating Technology	EF	Source Efficiency
Natural draft gas storage	0.60	0.55
Electric storage	0.91	0.27
HPWH	2–2.5	0.59–0.74

1.2.2 Cost

It is also important to consider the relative cost of natural gas and electricity when looking at fuel switching scenarios. In 2010, national average residential electricity rates were $33.81/MMBtu ($0.1153/kWh); average residential gas rates were $11.13/MMBtu ($1.11/therm) (EIA, 2012). Gas costs about one third of what electricity costs per unit of site energy, so an HPWH needs to provide significant energy savings to be cost effective. In retrofit scenarios, it is generally easier to not switch fuels, as additional costs may be incurred.

The HPWH's breakeven was also calculated to determine its economic viability as a replacement for a typical gas or electric WH. Breakeven cost is the net system cost that achieves cost neutrality with the current water heating technology. Breakeven cost is used as the primary metric for economic analysis in this study because HPWHs are relatively new to the U.S. market and their installation costs and economic value are not fully understood. Capital costs may change quickly if their adoption was to rapidly increase and site-specific considerations may cause installation costs to vary significantly from household to household. Identifying the HPWH breakeven costs provides a benchmark that may be used as a point of comparison for fluctuating HPWH system prices. The breakeven costs here were calculated using the same methodology that has previously been applied to residential photovoltaic systems (Denholm, Margolis, Ong, & Roberts, 2009) and residential solar WHs (Cassard, Denholm, & and Ong, 2011).

2 Technical Approach

All modeling was done using TRNSYS (Klein, 2010), a modular energy simulation environment that provides a large library of models and allows new models to be easily created. The HPWH model used here is based on one 50-gal unit with an EF = 2.35 that recently appeared on the U.S. market. An 80-gal HPWH with an EF = 2.3 was also modeled to determine if greater savings could be achieved by installing a larger HPWH. Results are presented in Appendix B. The HPWH models used here are based on extensive laboratory testing of several HPWHs (Sparn, Hudon, & Christensen, 2011); each model is based on one specific HPWH. Both units were modeled as operating in the factory default mode, which attempts to balance efficiency with providing adequate hot water at the default set point temperature of 120°F. Performance curves for power and capacity were taken directly from laboratory testing results. The 50-gal HPWH was chosen and presented here because of its performance during laboratory testing and its size, which is comparable to a typical electric WH and would allow this unit to be easily installed in retrofit scenarios. Because the available HPWHs show considerable variations, a "typical" HPWH is difficult to define. However, this unit had roughly average performance during the laboratory testing compared to the other tested HPWHs.

Base cases of electric and gas storage WH were also simulated to determine the potential source energy savings from replacing one of these units with an HPWH. Both were 50-gal units with typical rated efficiencies for the technology (EF = 0.60 for gas, EF = 0.91 for electric). The model parameters for each were derived from its rated efficiency (Burch & Erikson, 2004). These units had the same set point temperature (120°F) as the HPWH. For an electric WH, all tank losses were assumed to go to the ambient air. For a gas WH, one third of the losses were assumed to go out the flue and two thirds to the ambient air. This split was determined based on the estimated impact of a flue damper on the overall tank loss coefficient of a gas WH (U.S. Department of Energy, 2001).

The TRNSYS house model used here is based on the Building America (BA) program Benchmark home (Hendron & Engebrecht, 2010), which is consistent with current building practices. The model is generally consistent with the BA specifications; however, some simplifications were made for this study. In general, these simplifications lead to the space heating and cooling loads (and corresponding energy consumption) being approximately 5%–30% larger than what is seen in a Benchmark home simulated in BEopt. A detailed description of the building model along with a list of differences between a Benchmark home and the building used here is provided in (Maguire, 2012). The home is a 2500-ft^2, two-story, single-family residence with three bedrooms, two bathrooms, and a 420-ft^2 attached garage. The envelope and all walls, floors, and ceilings separating conditioned and unconditioned spaces have insulation consistent with 2009 International Energy Conservation Code requirements (ICC, 2009)and the amount of insulation changes depending on which climate zone the home is modeled in. The foundation type (slab on grade, basement, or crawlspace) for each house was assumed to be consistent with regional building practices and was modeled as whatever is most common in each state (Labs, et al., 1988) (see Figure 3). When the WH is located in unconditioned space, that space is defined as a basement if a home has one or the garage if it has a slab or crawlspace. Basements were assumed to have insulation on the ceilings, and a small amount of infiltration was modeled to avoid scenarios where the heat pump could reduce the humidity to zero (because the basement model had no other moisture source). If the basement insulation had been applied only to the walls and there was no infiltration, the basement temperature would have approached the conditioned space temperature (which would benefit the HPWH in colder climates, where most basements are located.) However, an HPWH located in such a basement would have a greater impact on the home's space heating and cooling loads (which would be a net detriment in colder climates).

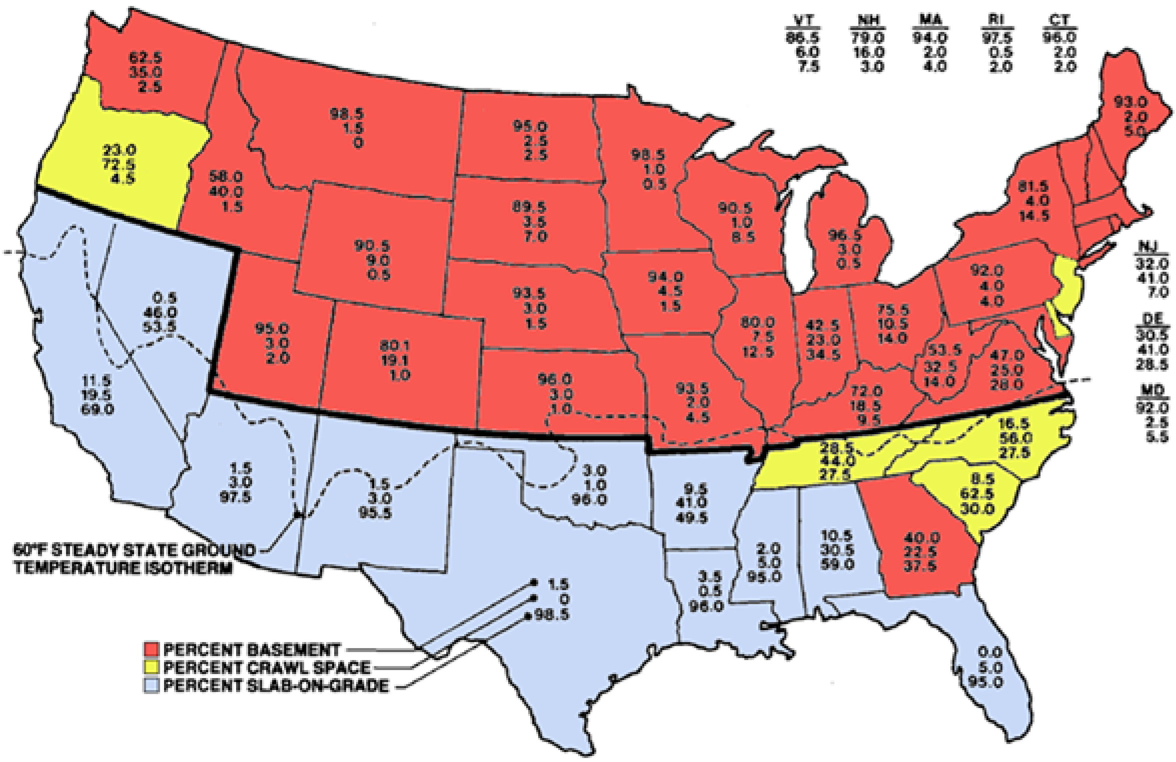


Figure 3. Share of residential foundations by state (Labs, et al., 1988)[1]

From *Building Foundation Design Handbook*,
ORNL/Sub-86-72143/1, Oak Ridge National Laboratory/US Dept. of Energy.

2.1 Space Conditioning Equipment

Two sets of space conditioning equipment were explicitly simulated here: a gas furnace and AC and a reversible ASHP. This home was modeled without ducts for simplicity. The furnace has an annual fuel utilization efficiency of 0.78 and the AC has a seasonal energy efficiency ratio of 13. The ASHP has a heating season performance factor of 7.7 and a seasonal energy efficiency ratio of 13. In addition to these two sets of equipment, a case of ER (baseboard) space heating with an efficiency of 1.00 and an AC was analyzed based on postprocessing of the results from the furnace/AC case. TRNSYS has no autosizing method for space heating and cooling equipment,

[1] For this study, whichever foundation had the largest share in a state was assumed for all homes in that state. Homes in Hawaii were assumed to have a slab-on-grade foundation.

so all equipment was oversized to ensure the space conditioning equipment would be able to meet the load in any climate. The furnace had a capacity of 100 kBtu/h and both the AC and the ASHP had a capacity of 5 tons. The capacity of the ER space heating was the same as the furnace.

2.2 Domestic Hot Water

An event-based domestic hot water draw profile was used for this study. The HPWH model needs a subhourly draw profile to accurately capture how the control logic for this WH responds to large draws. A 1-min time step was used for the draw profile to ensure this was captured. The BA Domestic Hot Water Event Schedule Generator (DHWESG) was used to provide the necessary discrete draw profile (Hendron & Burch, 2007). The DHWESG is a statistical tool that generates discrete events based on a probability distribution of draw events corresponding to the average distribution of hourly hot water use included in the Building America House Simulation Protocols (Hendron & Engebrecht, 2010). The DHWESG is based on studies of residential hot water use and uses separate probability distributions for each end use (showers, baths, clothes washing, dishwashing, and sinks) (Mayer, 1999). For each day, a number of discrete events for each end use are assigned based on distribution functions for each fixture. The DHWESG assigns these events to different times of day to account for the study results, including clustering for events of the same end use, differences in weekday and weekend hot water use, and several vacation periods per year. Vacations occur for three days in May, one week during August, and four days in December. A sample day of draws with all end uses aggregated is compared to the House Simulation Protocols draw event probability in Figure 4.

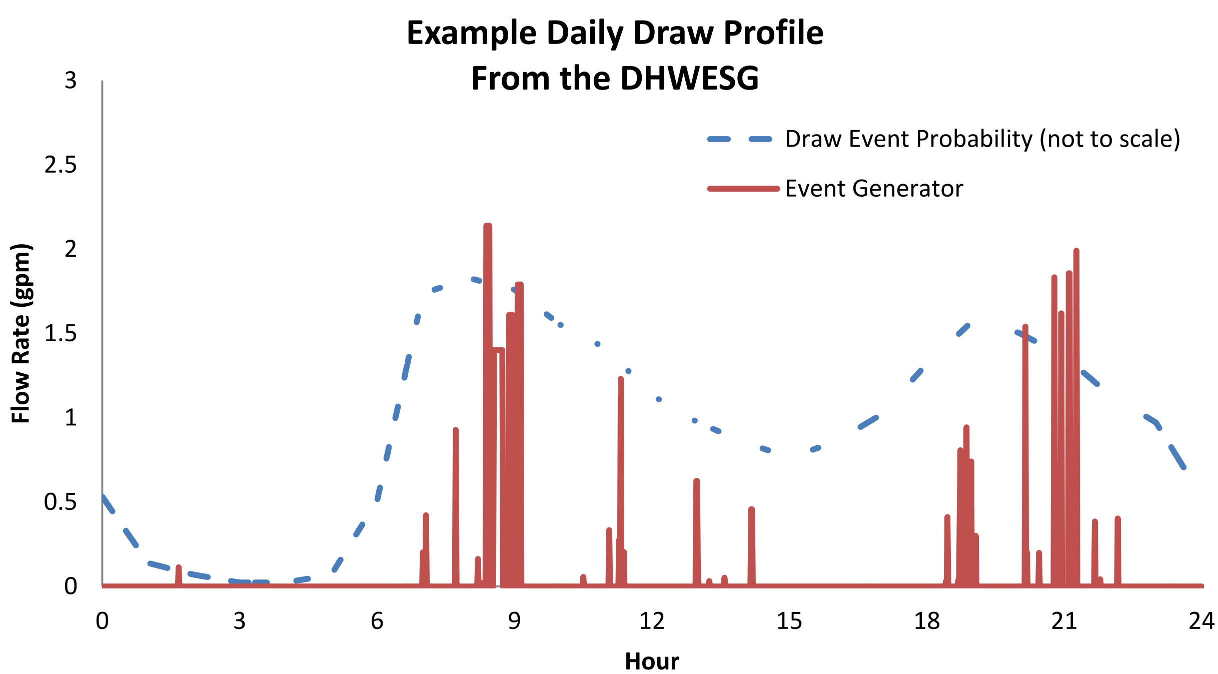


Figure 4. Sample daily draw profile

For sink, shower, and bath draws, events have a specified mixed flow rate, which is what an occupant would actually use. Appliances that use hot water (clothes washers and dishwashers) have a specified hot flow rate because these devices generally do not temper the incoming hot water to any specific temperature. For mixed events, a homeowner will temper the hot water with cold mains water to a useful mixed draw temperature. The mains water temperature used here is calculated based on an algorithm developed at the National Renewable Energy Laboratory (Burch & Christensen, 2007). The mixed draw temperature is defined as 105°F. Tempered draws comprise about 80% of the volume of hot water drawn annually (Hendron & Burch, 2007). Specifying a mixed flow rate as opposed to a hot flow rate allows the amount of hot water drawn to vary with mains water temperature, which leads to different volumes of water being drawn at different locations. The annual mains water temperature also influences the load that the WH needs to meet, as more energy is required to bring colder water up to the set point temperature. Figure 5 shows the simulated water heating load at various locations.

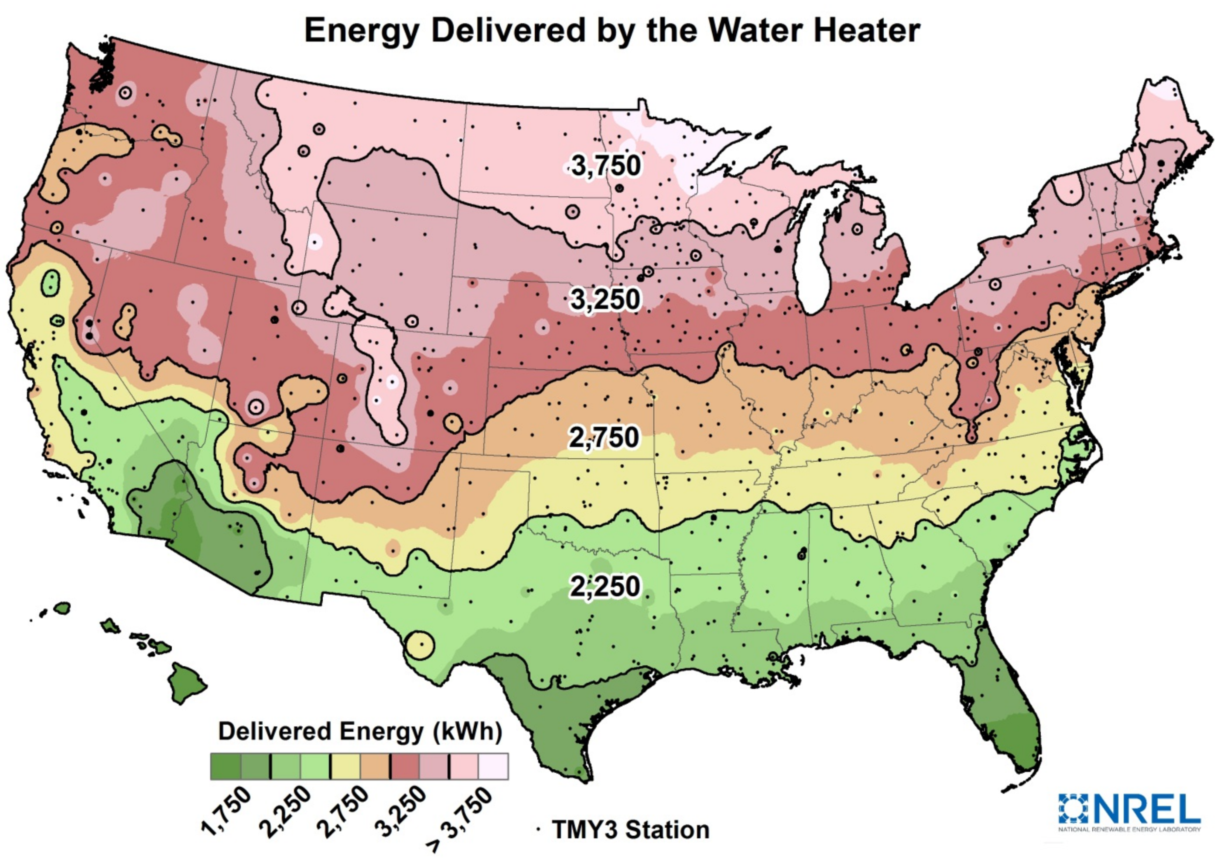


Figure 5. Simulated annual water heating load for the assumed draw profile and mains water temperatures

3 Heat Pump Water Heater Performance

Two metrics were used to evaluate the performance of an HPWH: heat pump fraction (HPF) and system COP (COP_{sys}). HPF is defined as the amount of heat added to the tank by the heat pump divided by the total amount of heat added by the heat pump and the backup electric elements. It is expressed as:

$$HPF = \frac{E_{hp,tank}}{E_{hp,tank}+E_{elem}} \quad (1)$$

where,

$E_{hp,tank}$	=	the heat added to the storage tank by the heat pump and
E_{elem}	=	the heat added to the storage tank by the electric elements

This gives a metric for how often the heat pump can be used to meet the water heating load. The COP_{sys} metric is defined as the amount of energy delivered by the HPWH divided by the net energy consumed (from the heat pump, electric elements, fan, and standby controls) by the HPWH and is expressed as:

$$COP_{sys} = \frac{E_{del}}{E_{cons}} \quad (2)$$

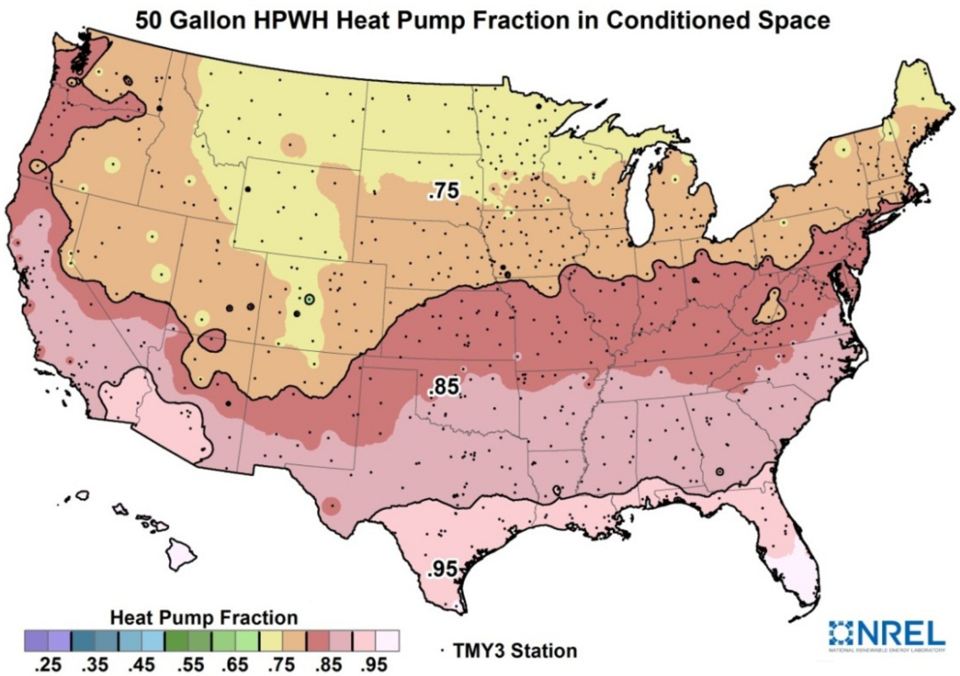
where,

E_{del}	=	the delivered site energy and
E_{cons}	=	the consumed site energy

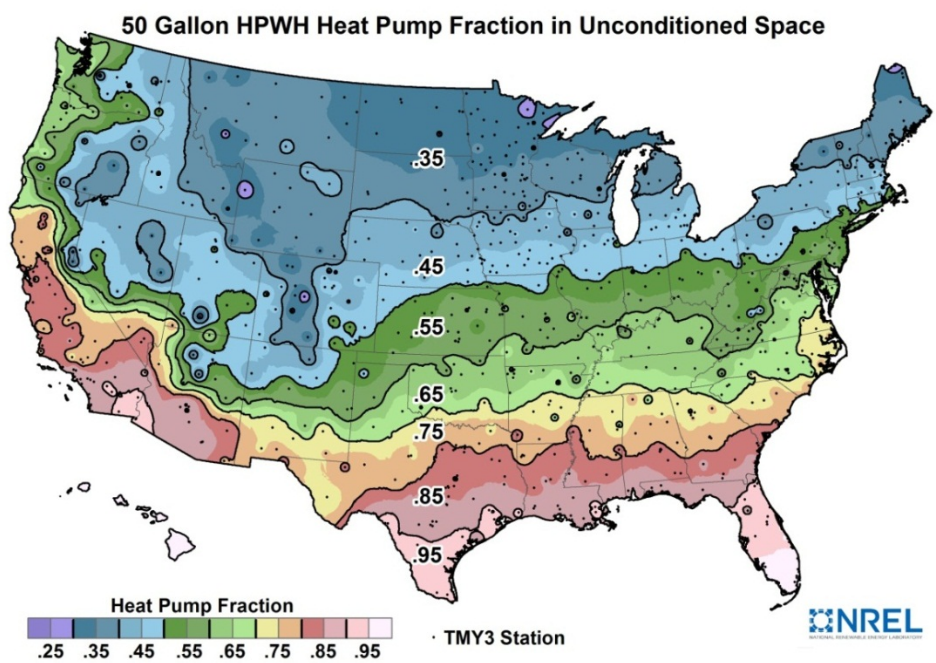
The COP_{sys} metric is calculated similarly to the efficiency (including the rated efficiency, EF) of traditional gas and electric WHs. Although COP_{sys} and HPF are related, the HPF metric provides information about how often the heat pump can run and COP_{sys} gives the overall efficiency of the HPWH. Neither accounts for any impacts on a home's heating, ventilation, and air conditioning (HVAC) energy use.

The performance of this HPWH is not necessarily representative of all available HPWHs, which vary in storage tank volume, heat pump design, control logics, and other factors. Thus, the HPF and COP_{sys} can vary significantly between units. However, the unit modeled here performed reasonably well during laboratory testing (Sparn, Hudon, & Christensen, 2011) and provides approximately typical performance for a 50-gal HPWH. The 50-gal unit is first analyzed here as units of this size are easier to install in retrofit scenarios (where they would often replace a 50-gal WH) and have been more widely available. Appendix B provides simulation results for an 80-gal HPWH.

Figure 6 shows the HPFs for this HPWH in both conditioned and unconditioned space. The HPF is generally much higher in conditioned space than in unconditioned space. If the ambient air temperature in unconditioned space is outside the range where the heat pump can run (45°–120°F for this particular HPWH), the HPWH uses the electric resistance elements to meet the water heating load. This happens in unconditioned space for part of the year in very cold locations, leading to low HPFs in these regions. The heat pump capacity (which is a function of wet bulb temperature and mains temperature) and tank control logic determines whether the heat pump can heat the tank quickly enough after a draw event or whether the electric elements need to turn on to provide faster recovery. In colder locations, the colder mains water temperature creates a larger load and the lower ambient air temperatures cause the heat pump's capacity to decrease. These factors lead to higher electric element use and a reduced HPF.



(a)

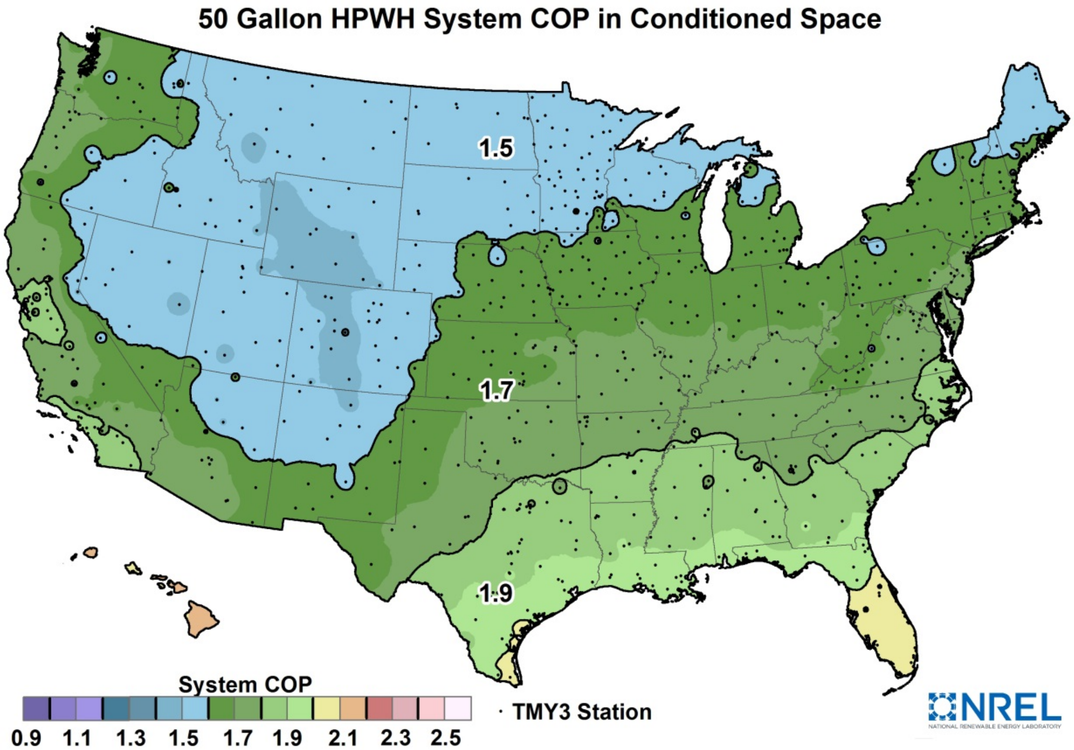


(b)

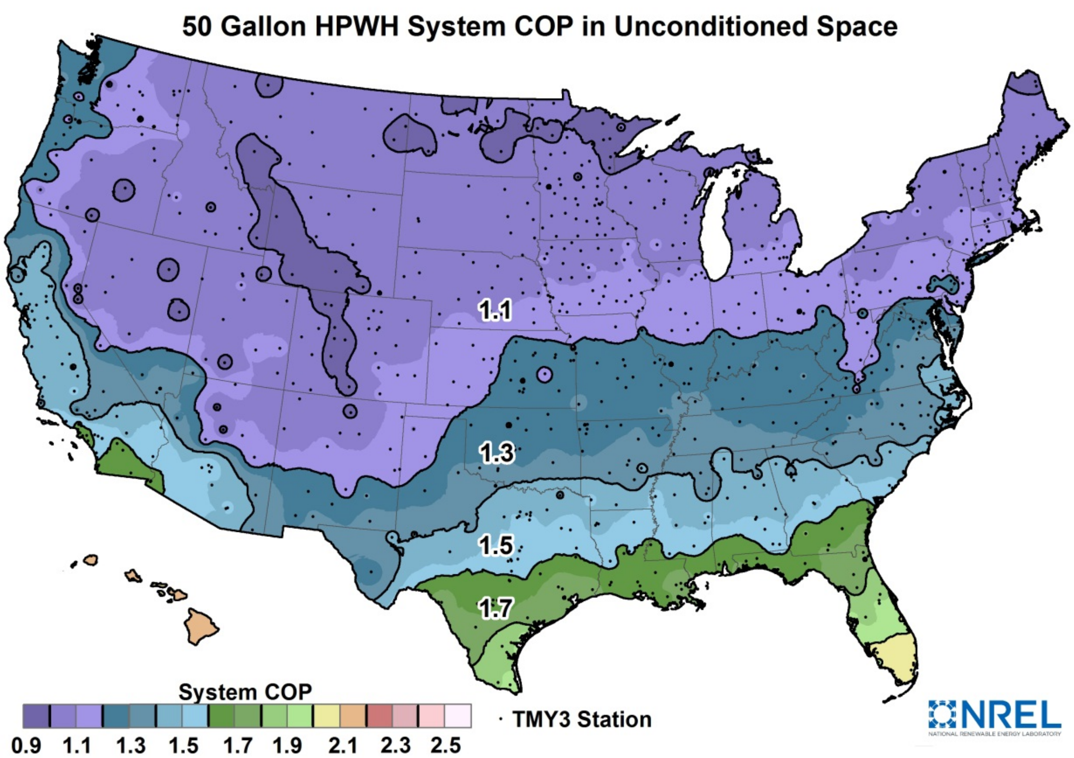
Figure 6. HPF of the 50-gal HPWH in (a) conditioned and (b) unconditioned space

Figure 7 shows the COP_{sys} in conditioned and unconditioned space. HPF and COP_{sys} are closely related metrics, so the same trends of higher performance in conditioned space and more variability in unconditioned space case are seen. COP_{sys} is an efficiency metric that can be compared with the rated efficiency, because it is similarly calculated. This particular HPWH has a rated EF of 2.35, which is higher than even the highest COP_{sys} seen in this study. The discrepancy between rated and simulated performance has also been seen in field studies (Amarnath & Bush, 2012) and is due to differences in the operating conditions used in the EF test procedure (which has an unrealistic draw profile) and what was simulated. There are also large variations in the COP_{sys}, especially when the WH is installed in unconditioned space, which indicates the difficulty in trying to use a single number (EF) to represent an HPWH's efficiency in all U.S. locations.

These metrics help to evaluate the performance of the HPWH; however, neither accounts for the change in a building's space conditioning energy consumption that comes from installing an HPWH. These factors are taken into account in Section 4.



(a)



(b)

Figure 7. COP_{sys} of the HPWH in (a) conditioned and (b) unconditioned space

4 Energy Savings Potential

When comparing WHs in the same location, several factors besides the WH energy consumption need to be considered. To keep the comparison as even as possible, all WHs should meet the same load. Because the heat pump has a lower heating capacity relative to a typical gas burner or electric resistance element, the HPWH outlet temperature sags more in high demand situations. To ensure all WHs met the same load, their energy use was normalized to account for unmet load. In actual use there would be no normalization energy, although homeowners may change their hot water use, the set point temperature of their WHs, or the operating mode if they frequently experience unacceptable sag in the outlet temperature. However, including normalization energy ensures WHs that frequently have sag in the outlet temperature do not receive an efficiency benefit from this sag without assuming exactly how occupants will deal with sag. The normalization energy is defined as the additional thermal energy required to meet the load divided by the efficiency of the WH during the time step (see Equation 3):

$$E_{nrmlz} = \frac{mc_p(T_{out} - T_{req})}{\eta} \tag{3}$$

where,

E_{nrmlz}	=	the normalization energy consumption,
m	=	the mass of water drawn during the time step,
c_p	=	the specific heat of water,
T_{out}	=	the water heater outlet temperature,
T_{req}	=	the required outlet temperature to meet the load, and
η	=	water heater efficiency

The efficiency is defined (Equation 4) as:

$$\eta = \frac{E_{del}}{E_{cons}} \tag{4}$$

where,

E_{del}	=	the delivered site energy and
E_{cons}	=	the consumed site energy

The normalization energy was calculated for any time step when the outlet temperature was lower than that required to meet the load (105°F for mixed draws and 120°F for hot draws). All the WHs required some normalization energy for very high demand situations, but the HPWH required significantly more than either of the conventional WHs considered here. Although the normalization energy is quantified here to ensure a fair comparison, the outlet temperature sag is a thermal comfort issue for homeowners. It may be dealt with in several ways, some of which will have impacts on the HPWH's annual energy consumption. For example, a homeowner could raise the HWPH set point to compensate for the sag, but this would increase standby losses and reduce the heat pump's efficiency, leading to higher energy consumption than what is predicted here.

The energy savings of an HPWH over either a gas or electric conventional WH is calculated as:

$$E_{saved,HPWH} = \Delta E_{WH} + \Delta E_{nrmlz} + \Delta E_{heat} + \Delta E_{cool} \tag{5}$$

where,

ΔE_{WH}	=	the change in water heater energy consumption,
ΔE_{nrmlz}	=	the change in normalization energy consumption,
ΔE_{heat}	=	the change in space heating energy consumption, and
ΔE_{cool}	=	the change in space cooling energy consumption.

In all cases, the change in energy consumptions was calculated as the energy consumed by a conventional WH minus the energy consumed by the HPWH. To ensure a fair comparison in cases where both gas and electricity were used all energy savings were calculated on a source energy basis. To demonstrate the impact of each factor considered in Equation 5 on the net source energy savings, the value of each term is given by climate zone for all cases in Appendix C.

Figure 8 shows the source energy savings of an HPWH relative to an electric WH for an all-electric home with an ASHP. In this case, there are source energy savings at all U.S. locations, even the worst-case scenario (installed in unconditioned space in a very cold climate). The HPWH saves significantly more energy in conditioned space than unconditioned space, especially in colder regions. This is due to the much higher HPF in conditioned space and the relatively high efficiency of the ASHP for heating. Installing in conditioned space allows the HPWH to operate using the heat pump for the entire year (except during high demand situations, when the electric elements will come on to provide faster recovery) and the high COP of the ASHP significantly reduces the HPWH's impact on increasing the space heating energy consumption. The lessened impact on the space heating equipment also leads to less variation in source energy savings across the United States. In cooling-dominated climates, the HPWH provides a net cooling benefit. Its impact is greater than the boost in performance the HPWH receives from being located in unconditioned space in hot locations, leading to higher energy savings in hot climates when the WH is located in conditioned space.

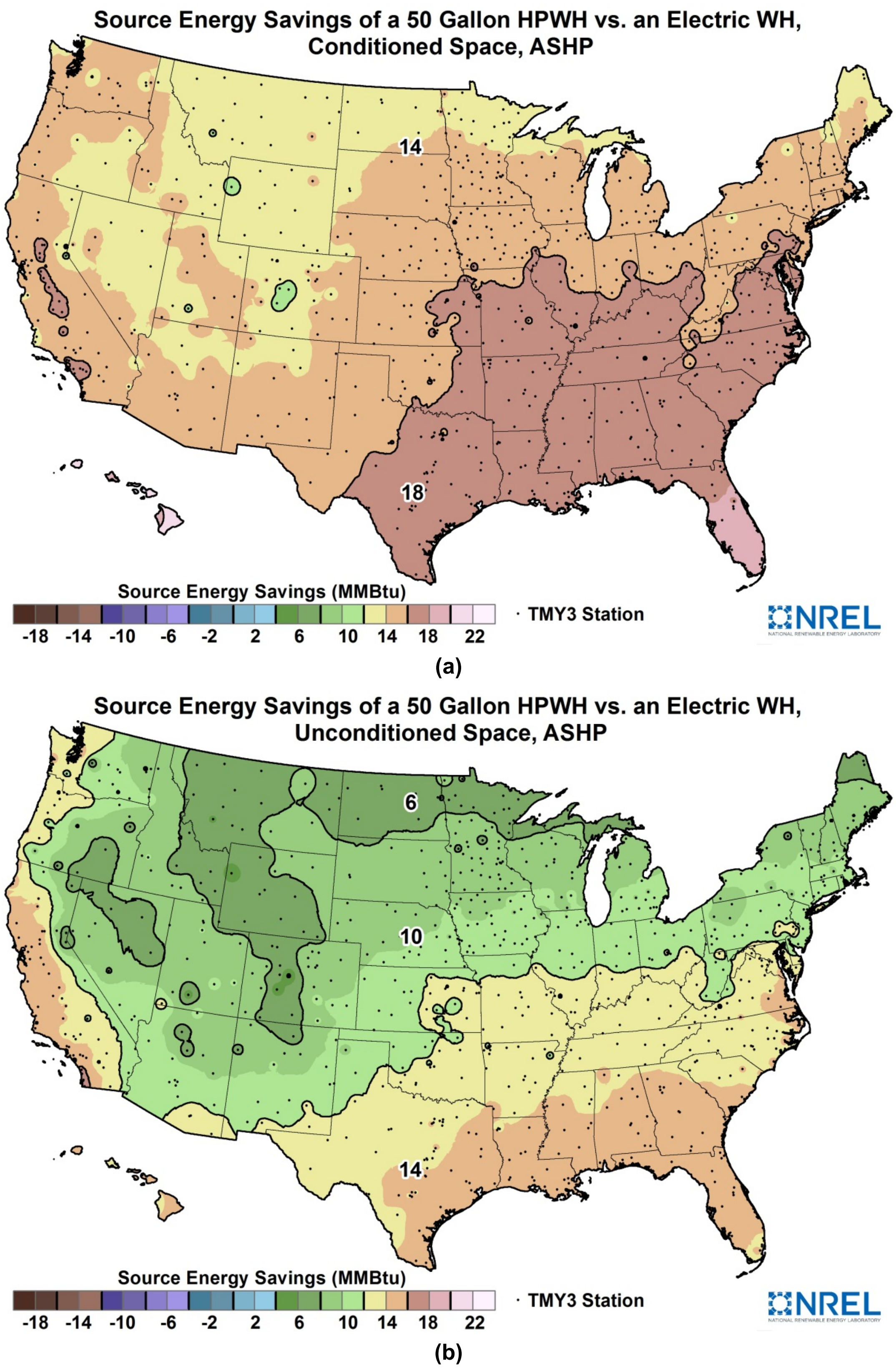
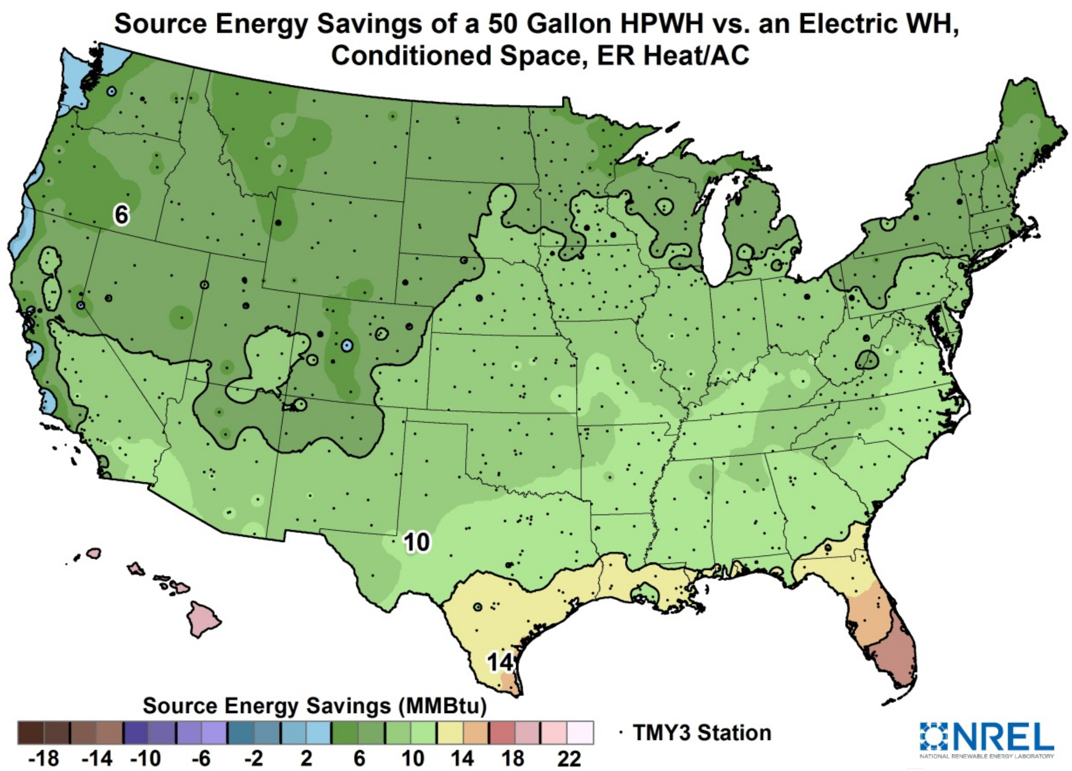


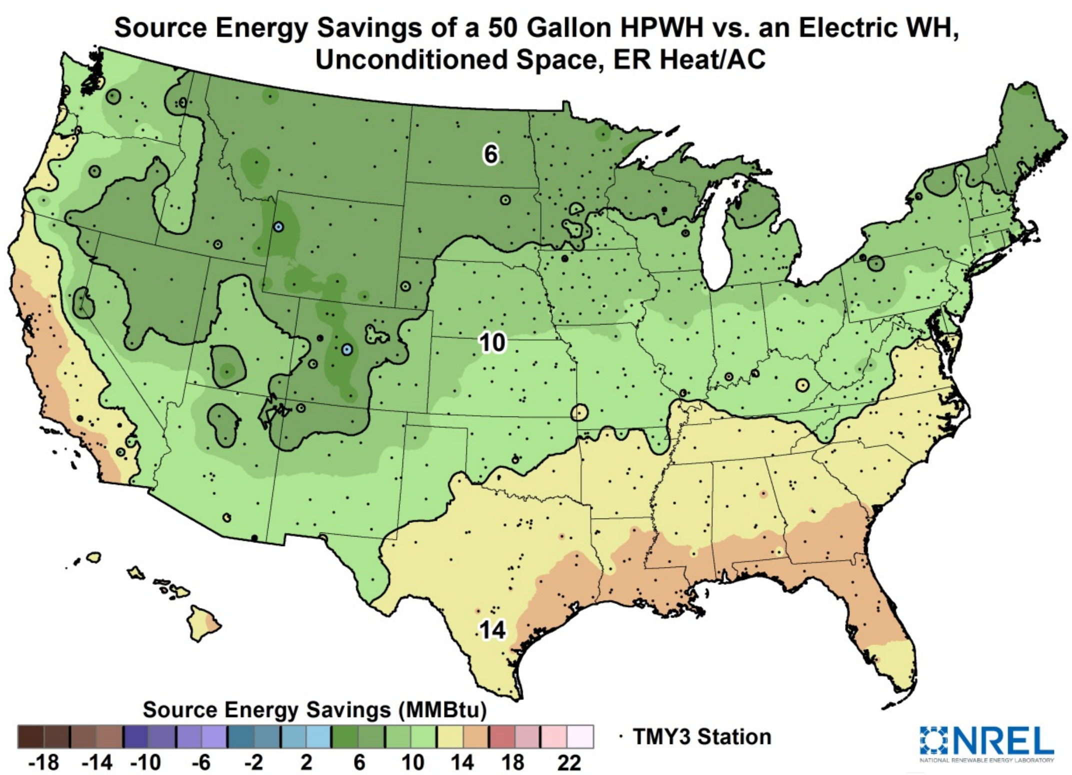
Figure 8. Source energy savings of an HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

If the ASHP is replaced by ER heating and an AC, HPWHs compare less favorably to electric WHs (see Figure 9). Although the source energy savings potential is lower in this case, especially when the WH is installed in conditioned space in heating-dominated climates, there are always some positive source energy savings. If the WH is located in unconditioned space, the change in HVAC energy consumption is slight. Interactions between unconditioned and conditioned space are relatively small for these homes because the walls and floors separating conditioned and unconditioned space are relatively well insulated. However, if these boundaries were not insulated, the interactions could be larger, although the space temperatures would also have fewer variations. The interactions are especially small when the WH is located in a garage, which is the predominant unconditioned space location in warmer climates. In colder climates where basements are more common, the impact of changing HVAC equipment is greater because of the higher levels of interaction between the basement and conditioned space.

For WHs located in conditioned space, cases with ER heat and an AC have significantly lower source energy savings than those with an ASHP. This is due to the lower efficiency of the ER heat (η=1) compared to an ASHP. The ASHP heating efficiency varies from 1 to 3 (the average efficiency across all climates is about 2) depending on climate. The lower efficiency of the ER heating means that it can take up to three times as much energy for ER heating equipment to meet the space heating load imposed by the HPWH on the conditioned space. Although the source savings decrease across the country (except for Hawaii and southern Florida, which has a negligible space heating load), the greatest change is along the west coast, particularly in the Pacific Northwest. This region has a marine climate, which is relatively mild but has a small heating load for much of the year. This means that the HPWH will have a greater detrimental effect as it imposes a net heating load all year long when it is located in conditioned space.



(a)

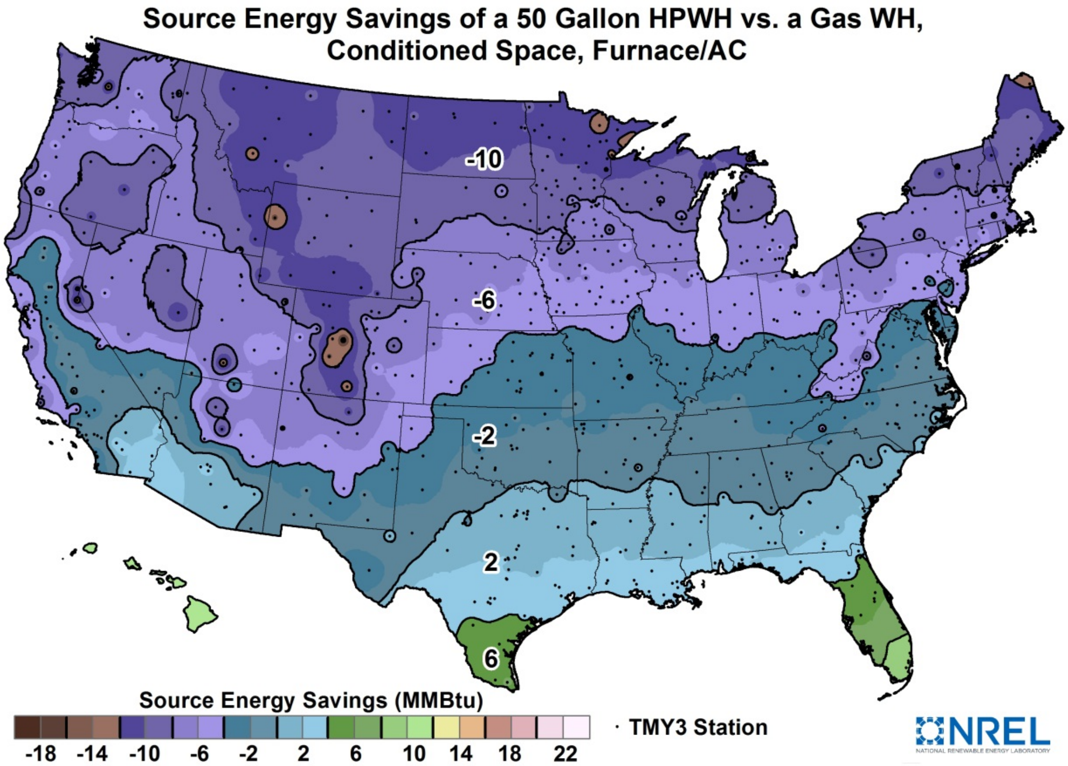


(b)

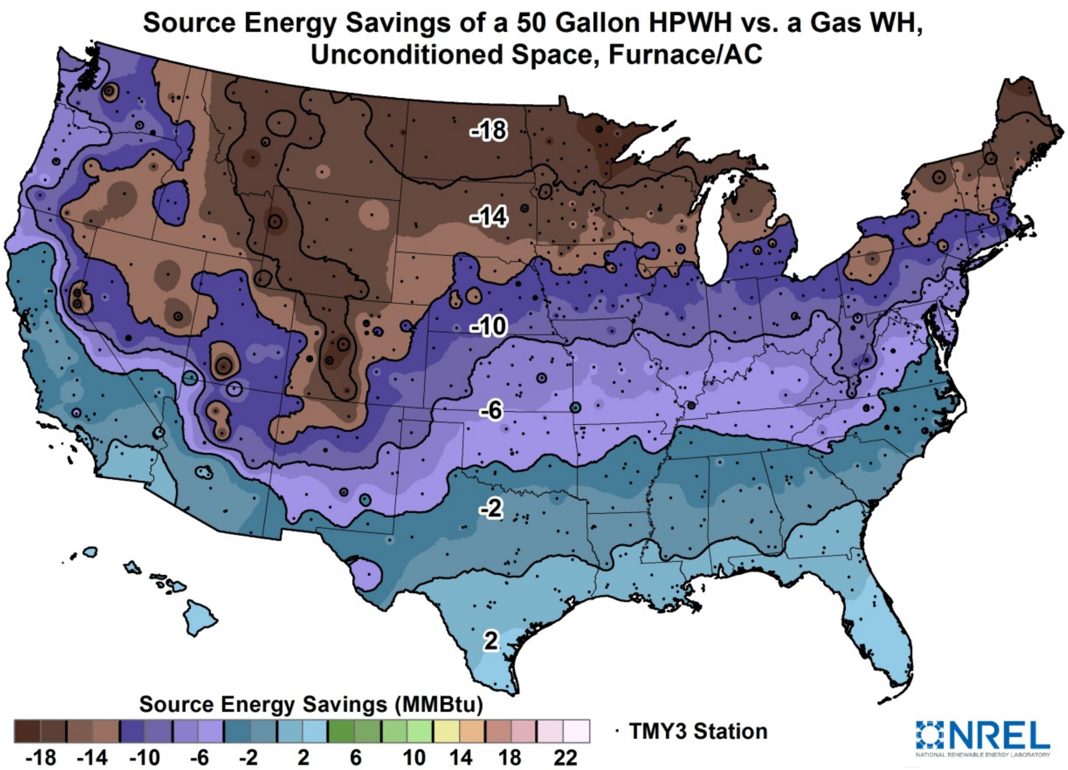
Figure 9. Source energy savings of an HPWH relative to an electric WH for a home with ER heat/AC when the WH is in (a) conditioned and (b) unconditioned space

When comparing an HPWH to a gas WH, the HPWH provides positive source energy savings only in the southernmost parts of the United States (see Figure 10). The source to site ratio for natural gas (1.092) is much smaller than that of electricity (3.365), so the site energy savings from the HPWH must be significant to reduce source energy consumption. There are thus net source energy savings only in Hawaii, the southeastern United States, and parts of Arizona and southern California, where the HPWH is most efficient and has the largest space conditioning benefit.

Although the HPWH does save a modest amount of source energy compared to a gas WH in some southern regions, these regions predominantly use electricity for water heating. Gas water heating is much more common in California and the northern and Mountain regions. The overall national source energy savings potential of replacing gas WHs with HPWHs is thus even lower than suggested in Figure 10.



(a)



(b)

Figure 10. Source energy savings of an HPWH relative to a gas WH for a home with a furnace/AC when the WH is in (a) conditioned and (b) unconditioned space

5 Heat Pump Water Heater Breakeven Cost

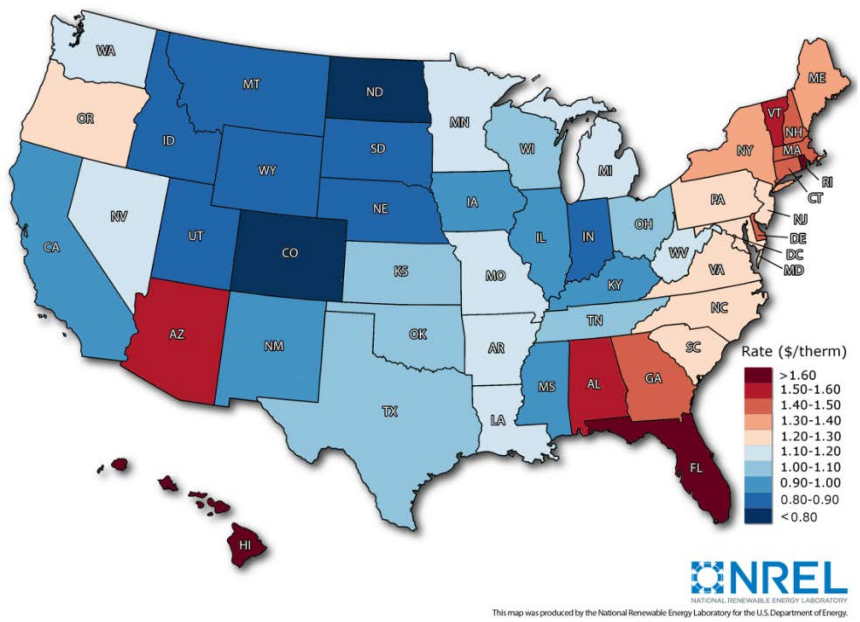
The HPWH breakeven cost is the net installed cost that achieves cost neutrality with a current water heating technology. It depends on climate, incentives, local utility rates, and other factors. In the United States, where these factors vary substantially across regions, breakeven costs vary significantly. Breakeven cost was used as the primary metric for economic analysis in this study, because these units are relatively new to the market. Their installation costs are thus not well known and the capital costs could change relatively quickly if their adoption were to rapidly increase. Installation costs may also vary significantly from household to household as some installations may incur additional costs associated with condensate drains, louvered doors, venting, or other site-specific considerations. Additional costs associated with fuel switching (for example, capping a gas line or adding a new circuit for the HPWH) may also be incurred if a gas WH is replaced by an HPWH. Recent estimates for the net installed cost (the cost of the WH plus all installation costs) of HPWHs with this efficiency range from $1300 to $2200; the estimated average net installed cost is about $1500 (U.S. Department of Energy, 2010).

The HPWH breakeven cost is defined as the point at which the net present cost (NPC) of the HPWH equals the net present benefit (NPB) realized to its owner—the difference between the NPB and NPC yields the net present value (NPV) of the system. By definition, an HPWH system is at (or better than) breakeven when its net installed cost falls below the breakeven value. For example, in an area with a breakeven cost of $2000, all HPWH systems that have an installed cost of less than $2000 are at—or better than—breakeven. Equations for the NPC, NPB, and breakeven cost are presented in Appendix D.

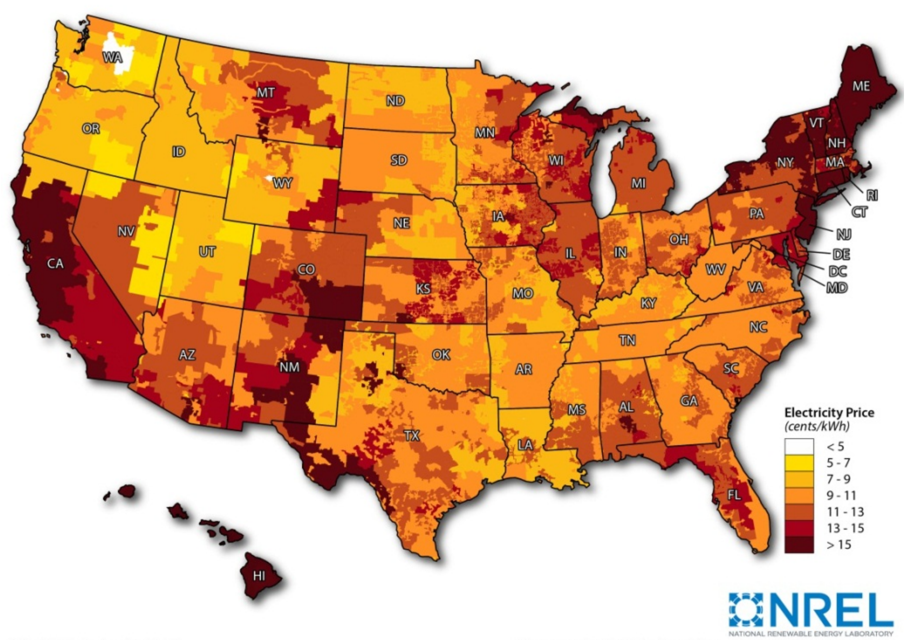
The NPC includes all capital costs, installation costs, maintenance costs, and incentives; the NPB is the cumulative discounted benefit of reduced electricity or gas bills. The NPC assumes a system purchased with cash (no financing) and a discount rate of 5% per year. Future fuel price escalation was also considered in the cash flow calculation. Both electricity and gas had a real price escalation of 0.5% per year. The HPWH was assumed to have a maintenance cost of $100 every 5 years for the heat pump; the typical gas and electric WHs were assumed to have no maintenance. Because the HPWH was assumed to be installed in either new construction or replacing a recently failed WH, the cost of a typical gas or electric WH factored into the breakeven cost. Typical gas and electric storage WHs were assumed to have net installed costs of $1,080 and $590, respectively (U.S. Department of Energy, 2010). These costs are the average of new construction and retrofit scenarios weighted by the annual number of new construction and retrofit installations. Breakeven costs for a case where the HPWH is replacing a functioning WH with remaining useful life are provided in Appendix E.

The evaluation period for this analysis was 15 years, which was assumed to correspond to the full lifetime of an HPWH or a typical gas or electric WH. Although this lifetime is slightly longer than the typical life of a gas or electric WH (13 years (U.S. Department of Energy, 2010)), a 15-year life makes any future comparisons to solar WHs (which have a lifetime of 30 years) (Cassard, Denholm, & and Ong, 2011) easier. The HPWH is assumed to have the same life as a typical gas or electric WH; however, the current generation of HPWHs has been on the market for only a few years and their actual lifetime is still unknown.

The breakeven costs were calculated using state average annual gas rates for 2010 (EIA, 2012) and utility-specific annual average electricity rates from the same year (EIA, 2012). These rates will fluctuate, so the breakeven costs here are only a snapshot of the recent market. Significant changes to utility rates (for example, the sharp decline in natural gas rates over the past few years) will change the breakeven results presented here. Figure 11 shows the gas and electricity rates used in this study.



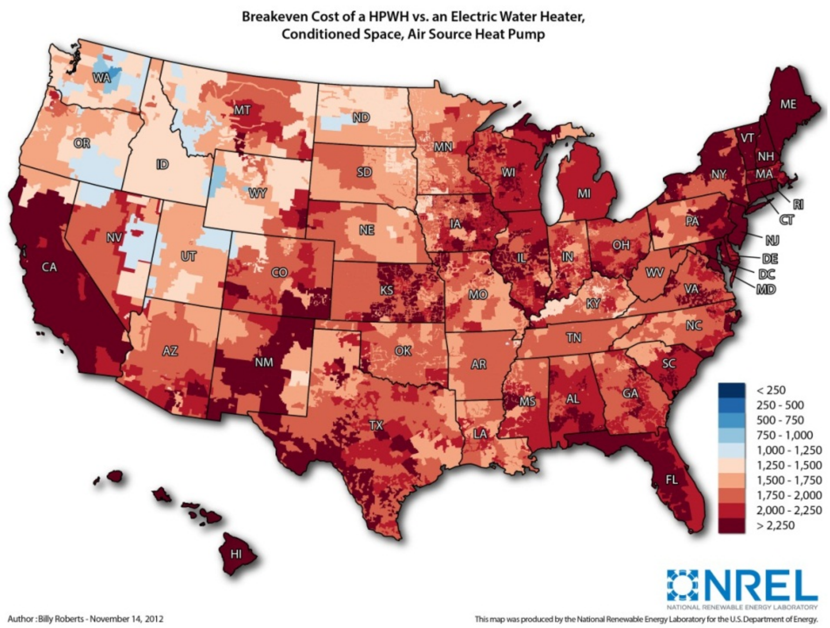
(a)



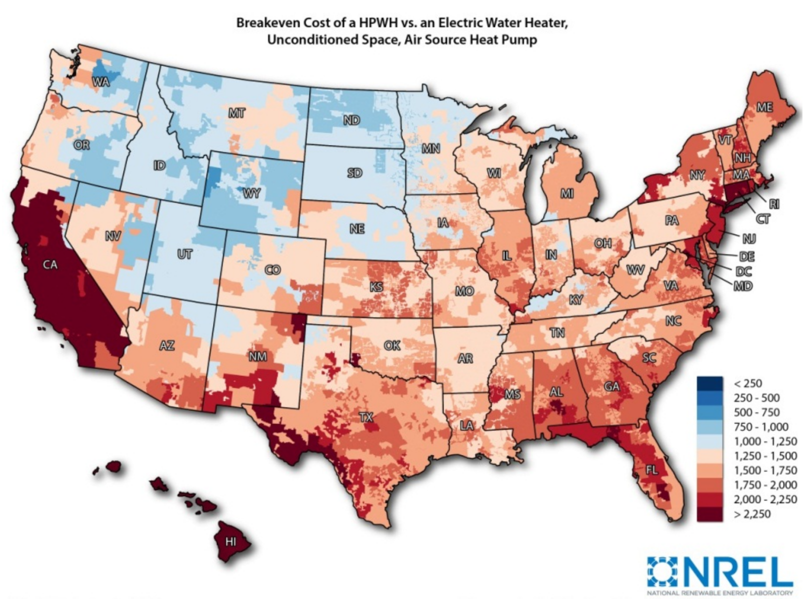
(b)

Figure 11. (a) Natural gas and (b) electricity rates used in this study

Figure 12 shows the breakeven cost for an HPWH relative to an electric WH for a home with an ASHP and no incentives. The breakeven cost depends on the net energy savings and local utility rates and varies significantly across the country. However, it is higher in conditioned space than in unconditioned space, because the energy savings for this case are always greater in conditioned space. In the conditioned space case, the highest breakeven cost is seen in Hawaii, California, Florida (because of high energy savings and high electricity rates for Hawaii and California) and New England (because of high electricity rates). When the WH is installed in unconditioned space the breakeven cost drops throughout most of the country.



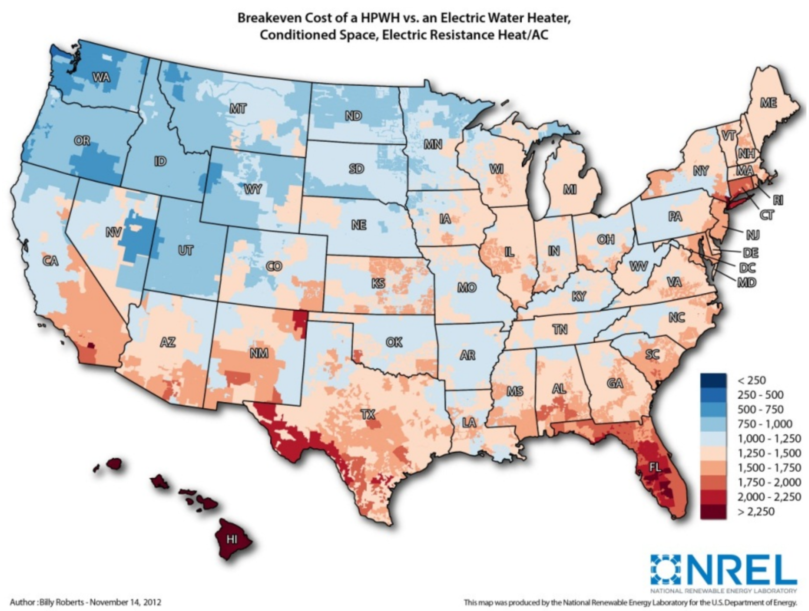
(a)



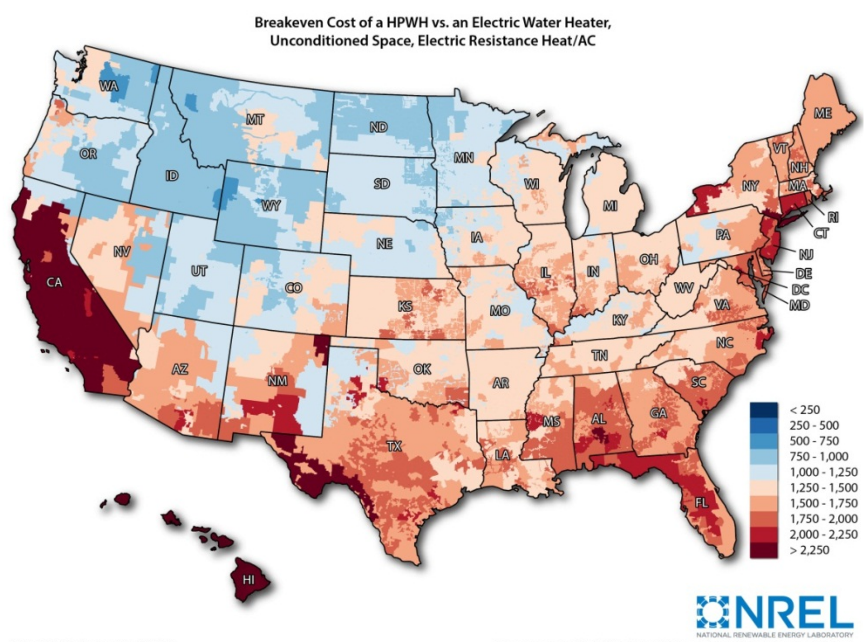
(b)

Figure 12. Breakeven cost of a 50-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

Figure 13 shows the breakeven costs for the case where an HPWH is replacing an electric WH in a home with ER heating and an AC. Because the space heating equipment is less efficient, the space heating penalty is significantly larger and the breakeven costs in the conditioned space case drop across the country. In many cases the space conditioning penalty was large enough to make installing in unconditioned space more cost effective. The breakeven costs in unconditioned space are largely unchanged from the case with an ASHP, because the space heating and cooling interactions are relatively small.



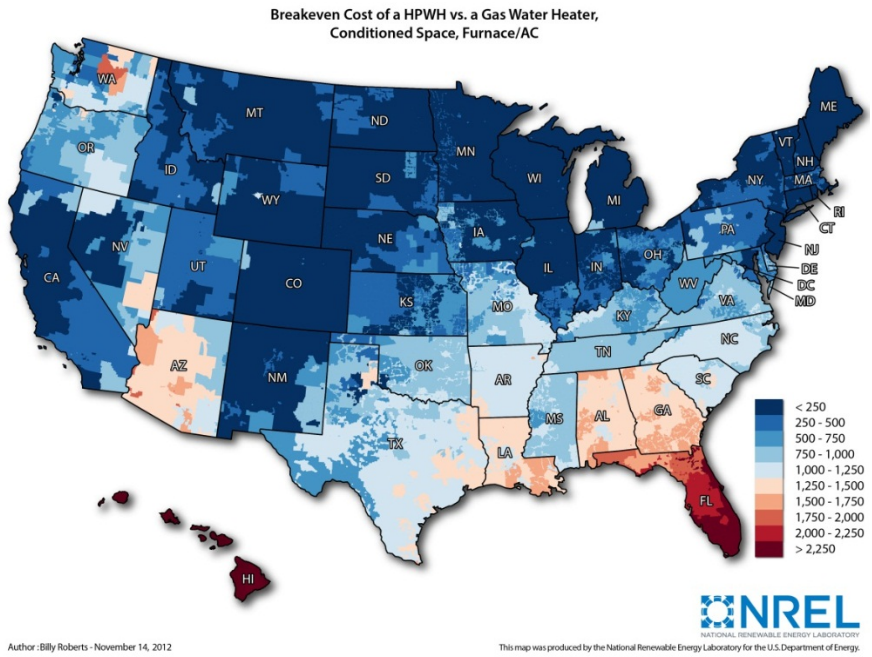
(a)



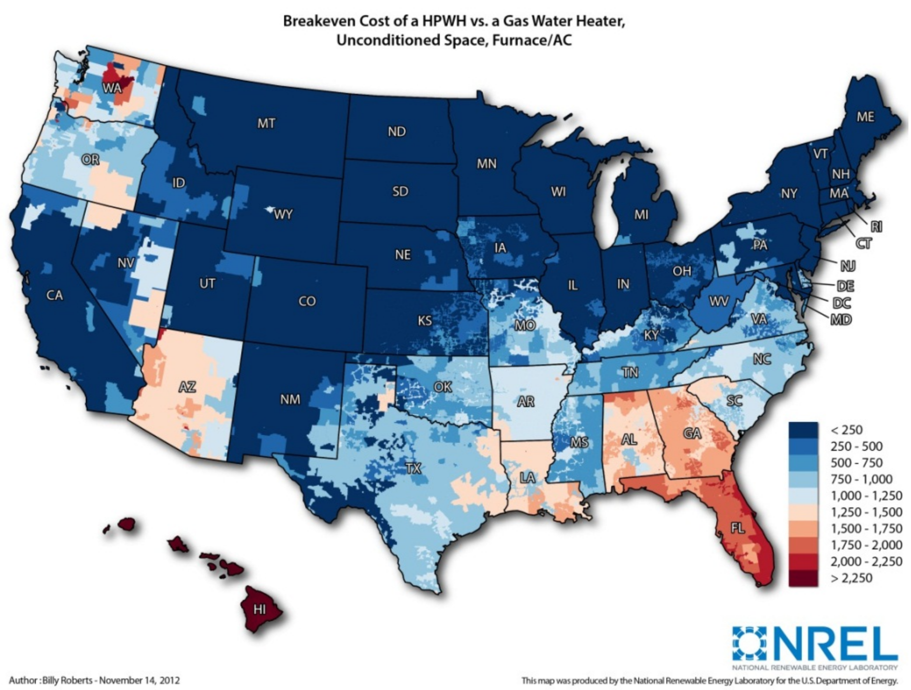
(b)

Figure 13. Breakeven cost of a 50-gal HPWH relative to an electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space

When looking at the breakeven costs of an HPWH relative to a gas WH, very few regions are likely to break even (Figure 14). For both the conditioned and unconditioned cases, the HPWH is likely to be economically viable only in parts of the Pacific Northwest, the Southeast, Arizona, and Hawaii. Both the Pacific Northwest and the Southeast are dominated by electric water heating, so the market for replacing gas WHs with HPWHs in these regions is relatively small.



(a)

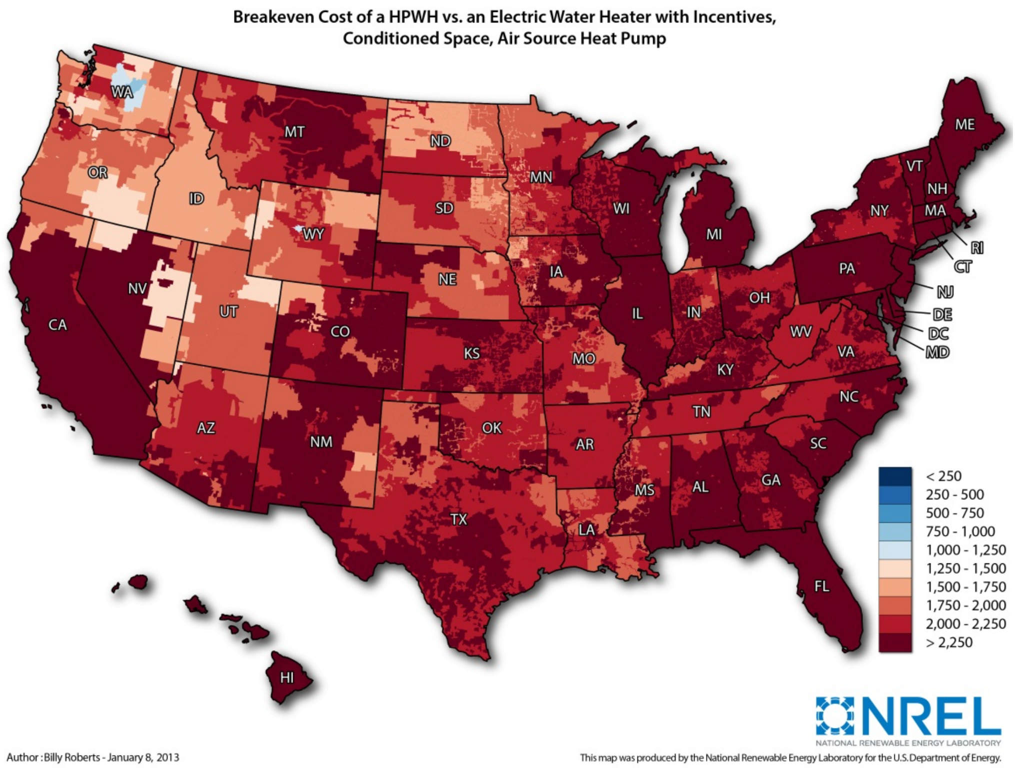


(b)

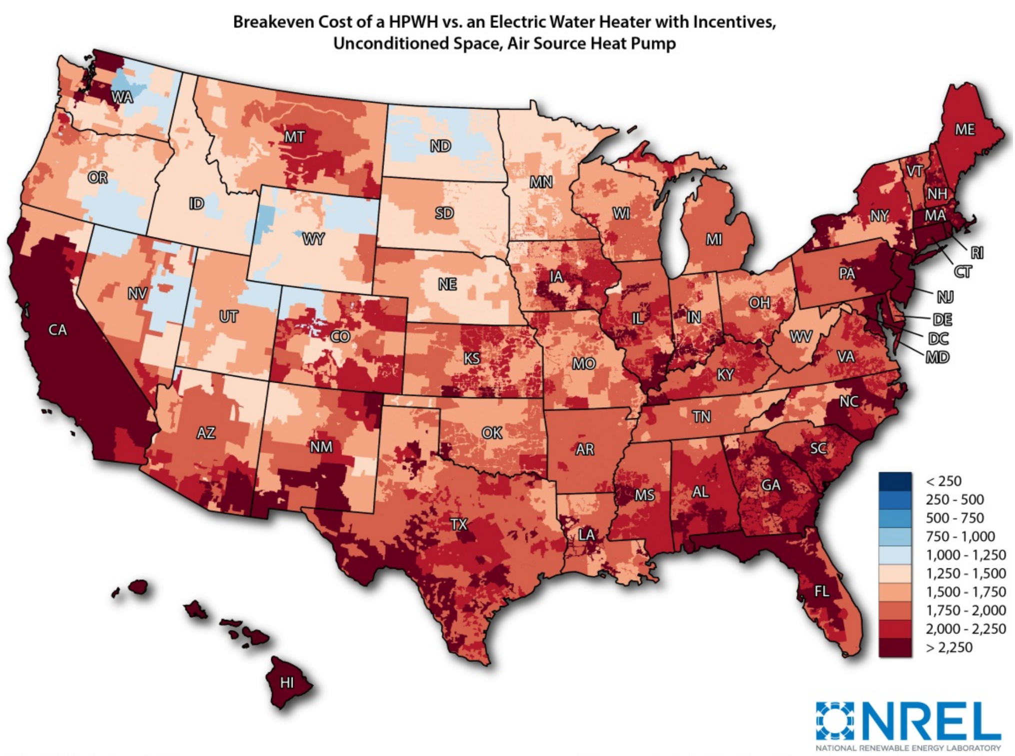
Figure 14. Breakeven cost of a 50-gal HPWH relative to a gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Cases with incentives were also considered to show the impact of current incentives on the breakeven cost of an HPWH. There are currently a $300 federal tax incentive and numerous local incentives for all HPWHs with an EF $\geq$ 2.0. All local incentives were taken from the Database of State Incentives for Renewable Energy (Interstate Renewable Energy Council, 2012) and a complete list of incentives is provided in Appendix F. Some are case specific and may apply only to situations where either a gas or electric WH is replaced or if the HPWH is installed in unconditioned space. Because the residential water heating market is dominated by retrofit situations, incentives that applied only to new construction scenarios were not considered here. Most incentives that applied to HPWHs were rebates, although a few states offered personal tax credits. To account for the delay in receiving a rebate or tax credit, all incentives were assumed to apply one year after the HPWH was installed and were discounted appropriately.

Figure 15 through Figure 17 show cases with incentives. Local incentives are distributed across the country; utilities in 35 states offer some incentives for HPWHs. Four states also offer some incentive for purchasing an HPWH. Although the federal incentive causes breakeven costs to rise everywhere, noticeable increases from large local incentives combined with the federal incentives are seen in several locations, including most of Massachusetts, Montana, Arkansas, Pennsylvania, and Kentucky.

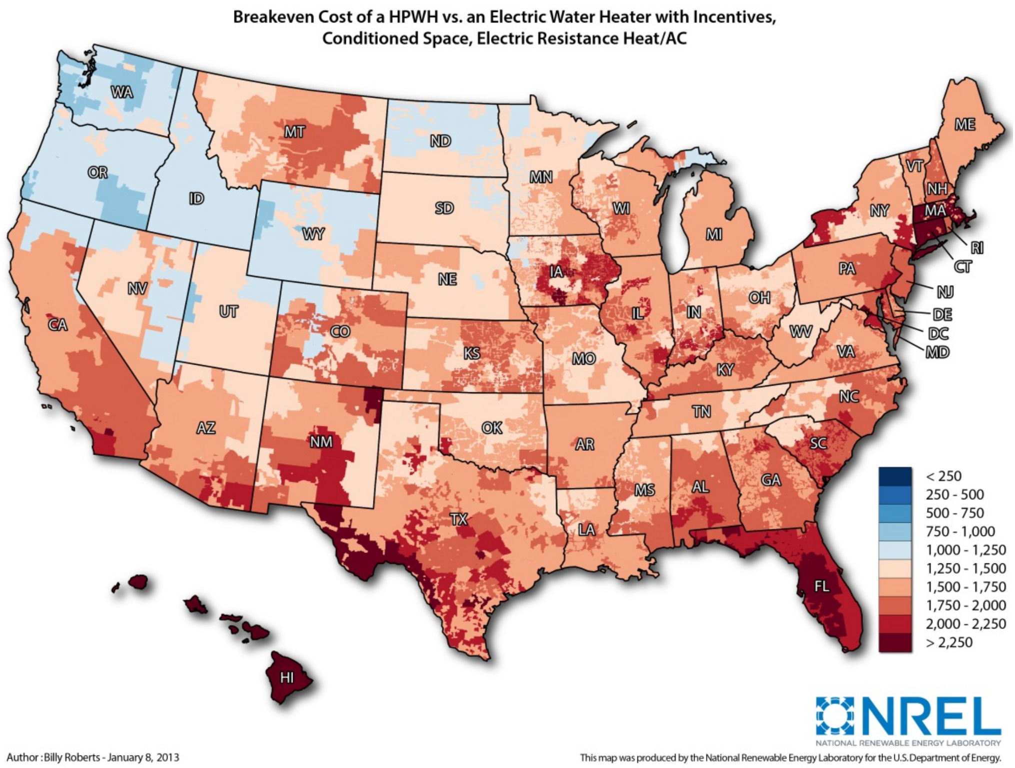


(a)

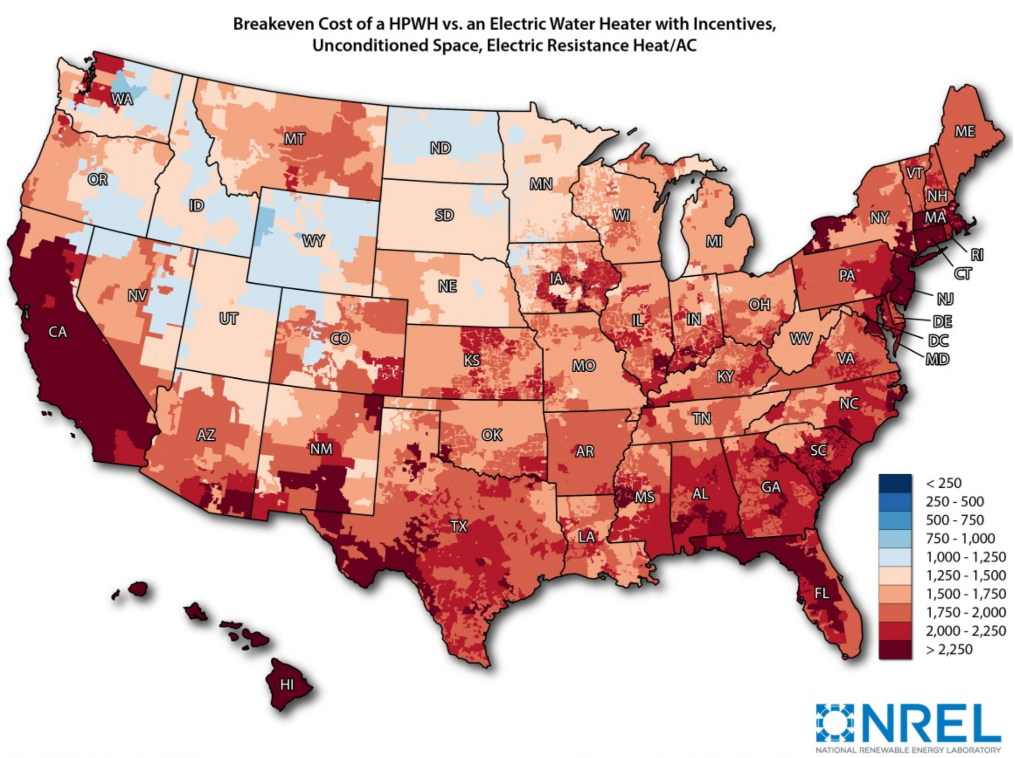


(b)

Figure 15. Breakeven cost with incentives of a 50-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

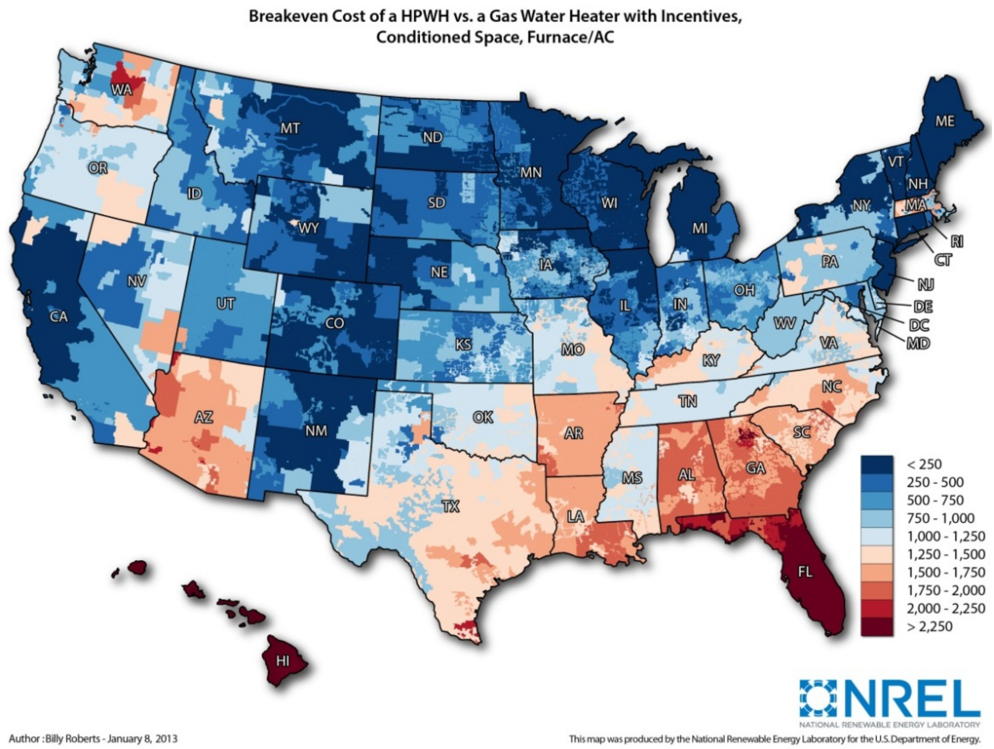


(a)

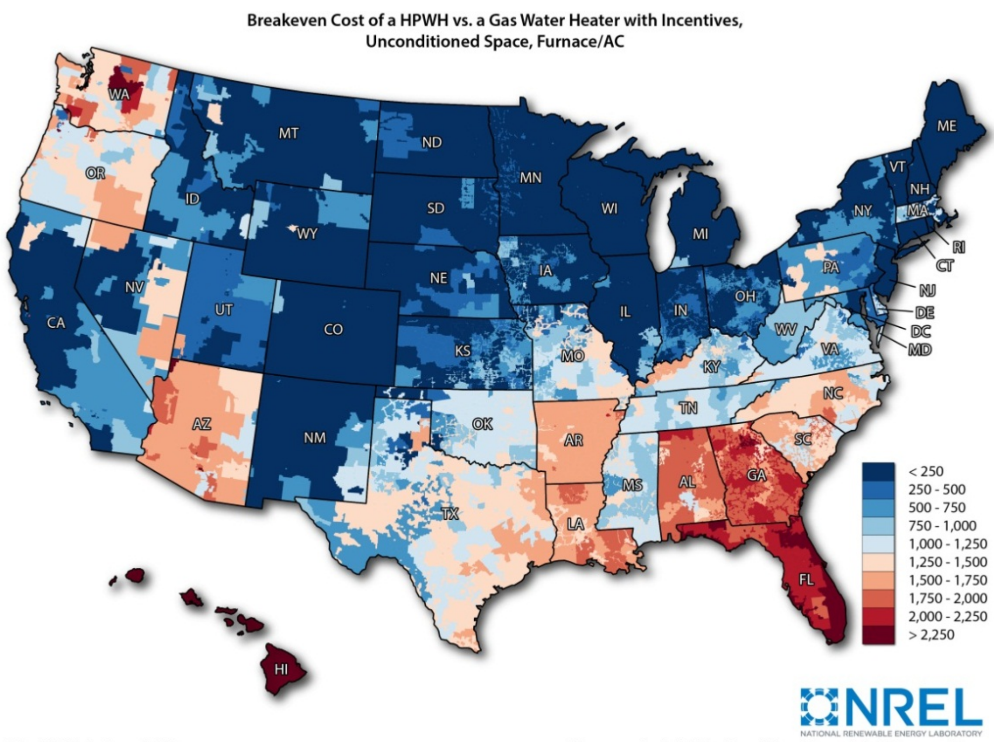


(b)

Figure 16. Breakeven cost with incentives of a 50-gal HPWH relative to an electric WH for a home with ER heat/AC when the WH is in (a) conditioned and (b) unconditioned space



(a)



(b)

Figure 17. Breakeven cost with incentives of a 50-gal HPWH relative to a gas WH for a home with a furnace/AC when the WH is in (a) conditioned and (b) unconditioned space

6 Conclusions

The energy and cost savings potential of HPWHs as replacements for gas and electric WHs is examined in this paper. HPWHs have a significant potential to save energy as replacements for standard electric WHs; annual source energy savings of 18 MMBtu are possible in the most favorable situations. Savings are highest in hot and humid locations and gradually decrease with colder locations, although positive source energy savings relative to an electric WH are possible in every situation considered here. If a home has high efficiency electric space heating equipment, installations in conditioned space can save more than those in unconditioned space because the HPWH performance increases from conditioned space in colder locations outweighing the HVAC penalty. In the case of lower efficiency electric space heating equipment, the HVAC penalty imposed by the HPWH is large enough that installing equipment in unconditioned space can save more energy.

To determine the economic viability of HPWHs, breakeven costs are also calculated. Local variations in utility rates cause the breakeven costs to vary significantly, even in regions with similar climates. In general, the highest (and most favorable) breakeven costs are seen for installations in conditioned space replacing an electric WH in homes with high efficiency electric space heating equipment. For cases with lower efficiency electric space heating equipment and installation in unconditioned space, the breakeven costs drop because of a larger space heating penalty from the lower equipment efficiency. An HPWH can likely be a cost-effective and energy-efficient replacement to an electric WH in many situations. However, local utility rates and the actual net installed cost of an HPWH vary significantly and the economic viability of an HPWH as a replacement for an electric WH will vary significantly on a case by case basis.

When comparing HPWHs to gas WHs, positive source energy savings are possible only in some locations in the South, and the HPWH is likely to break even in only a few southern states. Given that most WHs in these locations are electric, the potential national source energy and economic savings associated with replacing a gas WH with an HPWH are low.

This study demonstrates the regional variations in the efficiency and economic viability of an HPWH across the continental United States for several installation locations. However, this study considered only one HPWH (although an additional 80-gal unit is considered in Appendix B), subjected to a “typical” hot water draw profile, in one particular home. The efficiency, energy savings potential, and economic viability of an HPWH as a replacement for a typical gas or electric WH may vary significantly depending on the installation location, HPWH, and draw profile.

References

Amarnath, A., & Bush, J. (2012). Heat Pump Water Heaters: Field Evaluation of New Residential Products. Pacific Grove, CA: ACEEE Summer Study on Energy Efficiency of Buildings. Retrieved May 7, 2013, from http://www.aceee.org/files/proceedings/2012/data/papers/0193-000013.pdf

Burch, J., & Christensen, C. (2007). Towards Development of an Algorithm for Mains Water Temperature. *ASES Annual Conference.* NREL/CP-550-41614. Cleveland, OH: American Solar Energy Society. Retrieved May 7, 2013, from http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/AlgorithmForMainsWaterTemperature.pdf

Burch, J., & Erikson, P. (2004). Using Ratings Data to Derive Simulation-Model Inputs for Storage-Tank Water Heaters. *Poceedings of the 29th Passive Solar Conference.* NREL/CP-550-36035 Portland, Oregon. Retrieved May 7, 2013, from http://www.nrel.gov/buildings/pdfs/36035.pdf

Cassard, H., Denholm, P., & and Ong, S. (2011). *Break-even Cost for Residential Solar Water Heating in the United States: Key Drivers and Sensitivities.* NREL/TP-6A20-48986 Golden, CO: National Renewable Energy Laboratory. Retrieved May 7, 2013, from http://www.nrel.gov/docs/fy11osti/48986.pdf

Denholm, P., Margolis, R., Ong, S., & Roberts, B. (2009). *Breakeven Cost for Residential Photovoltaics in the United States: Key Drivers and Sensitivities.* NREL/TP-6A20-46909 Golden, CO: National Renewable Energy Laboratory. Retrieved May 7, 2013, from http://www.nrel.gov/docs/fy10osti/46909.pdf

Dubay, K., Ayee, G., & Gereffi, G. (2009). *Manufacturing Climate Solutions: Carbon-Reducing Technologies and U.S. Jobs-Chapter 6: Electric Heat Pump Water Heaters.* Duke University. Durham: Center on Globalization, Governance & Competitiveness. Retrieved May 7, 2013, from http://www.cggc.duke.edu/environment/climatesolutions/greeneconomy_Ch6_HeatPumpWaterHeaters.pdf

EIA. (2009). *Residential Energy Consumption Survey (RECS).* Washington, DC: U.S. Department of Energy. Retrieved May 7, 2013

EIA. (2012). *Annual Electric Power Industry Report 2010.* Washington, DC: U.S. Department of Energy. Retrieved August 1, 2012

EIA. (2012). *Annual Energy Report.* Washington, DC: U.S. Department of Energy. Retrieved August 1, 2012

EIA. (2012). *Natural Gas Monthly.* Washington, DC: U.S. Department of Energy. Retrieved August 1, 2012

Hendron, R., & Burch, J. (2007). Development of Standardized Domestic Hot Water Event Schedules for Residential Buildings. *Energy Sustainability*. NREL/CP-550-40874 Long Beach: National Renewable Energy Lab. Retrieved May 7, 2013, from http://www.nrel.gov/docs/fy08osti/40874.pdf

Hendron, R., & Engelbrecht, C. (2010). *Building America House Simulation Protocol.* NREL/TP-550-49426 Golden, CO: National Renewable Energy Laboratory. Retrieved May 7, 2013, from http://www.nrel.gov/docs/fy11osti/49246.pdf

ICC. (2009). *International Energy Conservation Code.* Falls Church, VA: International Code Council.

Interstate Renewable Energy Council. (2012, March 2). *U.S. National Database of State Incentives for Renewables and Efficiency (DSIRE)*. (Intersate Rnewable Energy Council) Retrieved May 7, 2013, from DSIRE: http://www.dsireusa.org/

Klein, S. e. (2010). TRNSYS 17: A TRaNsient System Simulation Program, User Manual.

Labs, K., Carmody, J., Sterling, R., Shen, L., Huang, Y., & Parker, D. (1988). *Building Foundation Design Handbook.* ORNL-Sub-86-72143/1 Oak Ridge, Tennessee: Oak Ridge National Laboratory/US Dept. of Energy.

Lowes.com. (2013). *Lowes water heaters*. Retrieved March 25, 2013, from Heat Pump Water Heaters: http://www.lowes.com/Plumbing/Water-Heaters/Hybrid-Heat-Pump-Water-Heaters/_/N-1z0zp1j/pl?Ns=p_product_qty_sales_dollar|1&cm_sp=RoughPlumbing-_-Plumbing|PopularCat-_-Merch|PopCat_WaterHeaters_Hybrid&cm_cr=Water+Heaters-_-Web+Activity-_-Water+Heaters+TF+Po

Maguire, J. (2012). A Parametric Analysis of Residential Water Heaters. *Master's Thesis*. Boulder, CO: University of Colorado Boulder. Retrieved from http://disexpress.umi.com/dxweb#download?&type=pdf&dpubno=1511987

Mayer, P. a. (1999). *Residential End Uses of Water.* Boulder CO: Aquacraft, Inc. Retrieved May 7, 2013, from http://www.waterrf.org/PublicReportLibrary/RFR90781_1999_241A.pdf

Pacific Northwest National Laboratory and Oak Ridge National Laboratory. (2010). *Building America Best Practice Series-Guide to Determining Climate Regions by County.* PNNL-17211 Richland, WA: PNNL. Retrieved May 7, 2013, from http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_climateguide_7_1.pdf

Sparn, B., Hudon, K., & Christensen, D. (2011). *Laboratory Performance Evaluation of Residential Integrated Heat Pump Water Heaters.* NREL/TP-5500-52635 Golden, CO: National Renewable Energy Laboratory. Retrieved May 7, 2013, from http://www.nrel.gov/docs/fy11osti/52635.pdf

U.S. Department of Energy. (2001). *Residential Water Heater Final Rule Making Technical Support Document.* Washington, DC: U.S. Department of Energy. Retrieved December 10, 2011

U.S. Department of Energy. (2010). *Energy Star Water Heater Market Profile.* Washington, DC: U.S. Department of Energy. Retrieved May 7, 2013, from http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/Water_Heater_Market_Profile_2010.pdf

U.S. Department of Energy. (2010). *Residential Heating Products Final Rule Technical Support Document.* Washington, DC: U.S. Department of Energy. Retrieved May 7, 2013, from https://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html

Wlicox, S., & and Marion, W. (2008). *Users Manual for TMY3 Data Sets.* NREL/TP-581-43156 Golden, CO: National Renewable Energy Laboratory. Retrieved May 7, 2013, from http://www.nrel.gov/docs/fy08osti/43156.pdf

Appendix A: Regional Variations in Water Heating Fuel by Census Region

Figure 18 shows the number of households using gas, electricity, or other fuels for water heating. The "other" category includes propane, fuel oil, solar, wood, and any other fuels that may be used for water heating. For each census region, any available state-specific data are also provided to show the breakdown of water heating fuels in a region. This can be especially useful for census regions such as the Pacific, which are dominated by one populous state.

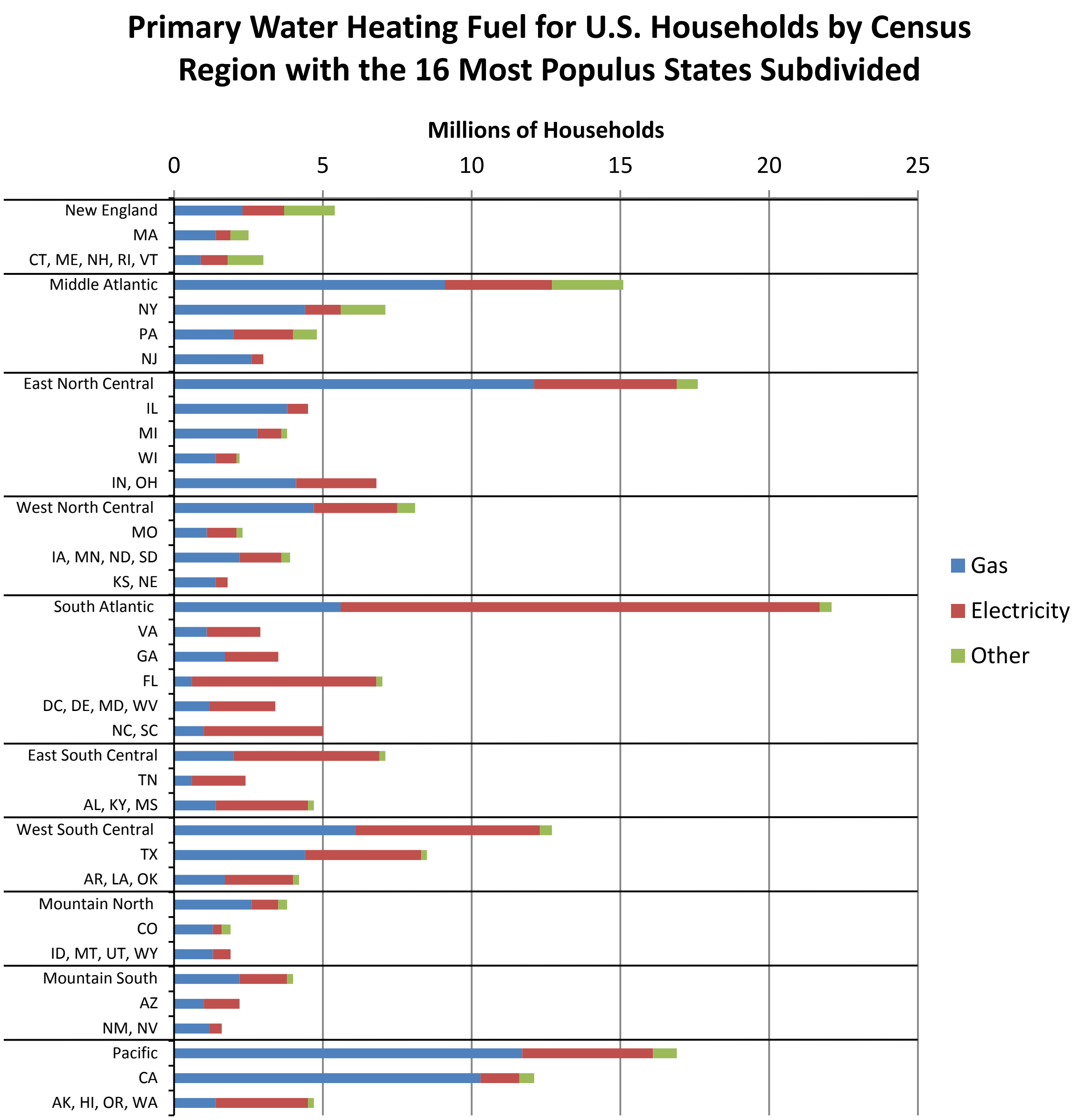


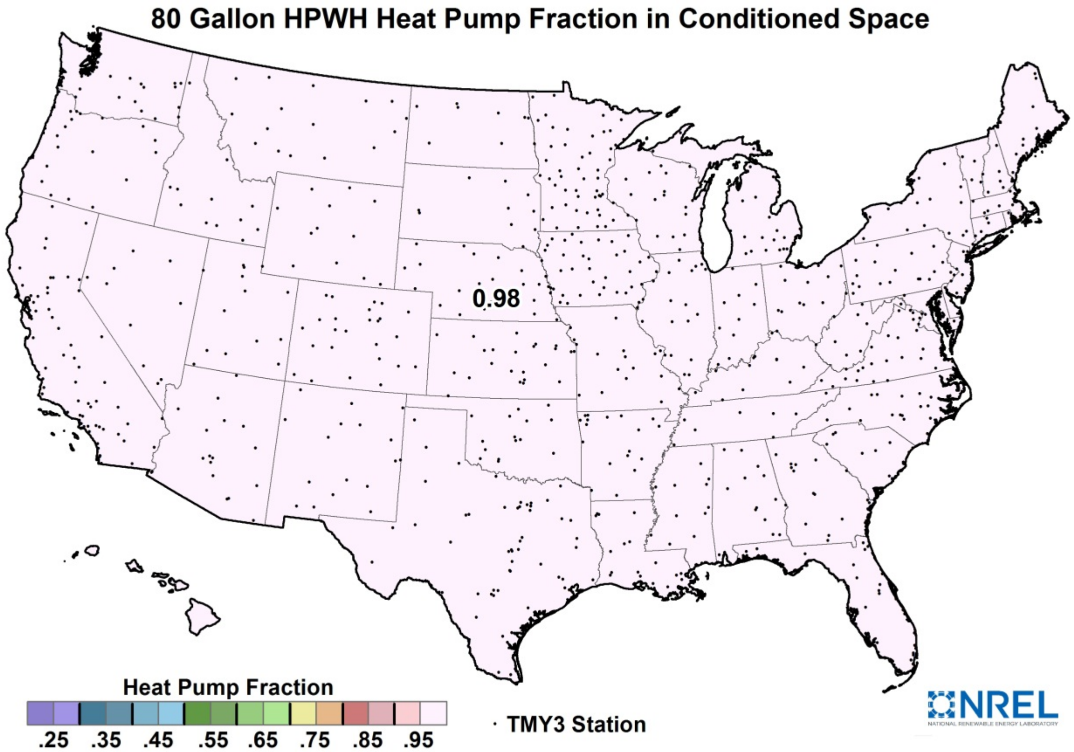
Figure 18. Water heating fuel use by census region, further subdivided for the 16 most populous states (EIA, 2009)

Appendix B: 80-Gallon Heat Pump Water Heater Modeling Results

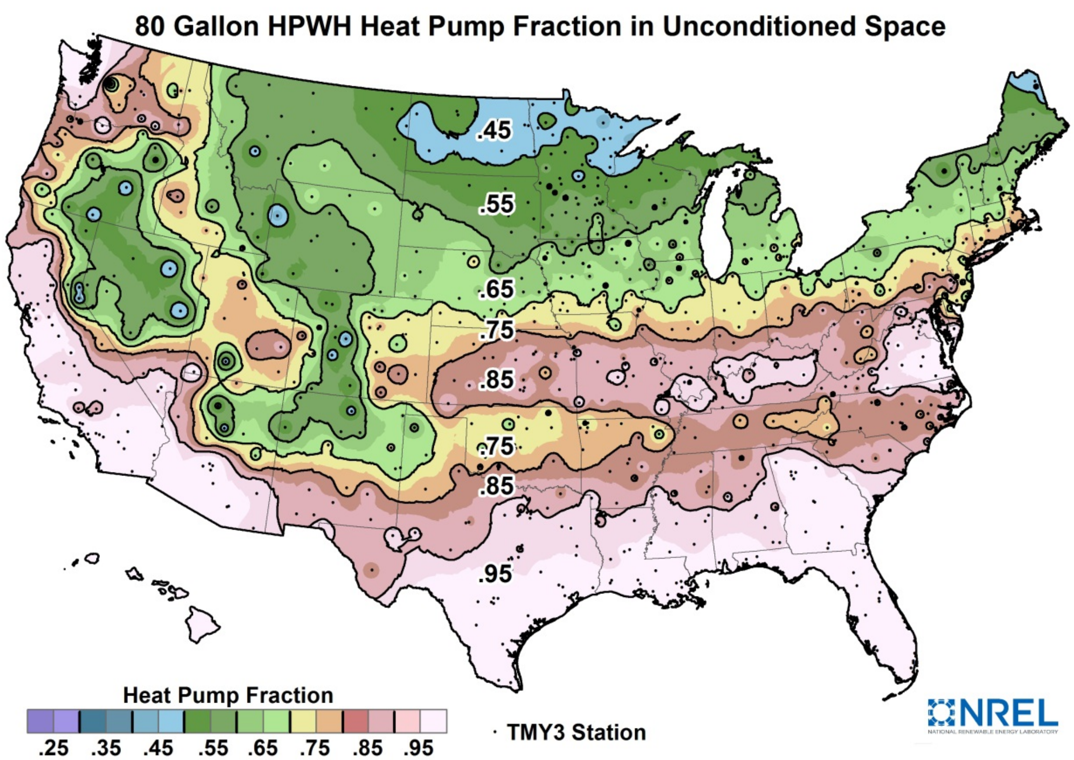
An 80-gal HPWH was also simulated; the model used here was also based on laboratory testing (Sparn, Hudon, & Christensen, 2011) and captures the actual performance of one tested unit. There are differences in the control logic, heat pump specifications, tank insulation, and element sizes and location between the two units. In particular, the control logic for this unit does not use the electric elements to fully recover any time an element turns on. Instead, if demand is large enough to trigger an electric element, the element will stay on until the tank has recovered to the set point that triggered it, then the heat pump will complete the remainder of the recovery. This control logic is much more efficient than the elements for full recovery, which further boosts the efficiency of this unit compared to the 50-gal HPWH.

Figure 19 shows the HPF of an 80-gal HPWH installed in conditioned and unconditioned space. For the conditioned space case, there is only slight variation in the HPF and it is above 0.95 for every location. In this case, the electric elements are rarely needed because the increased storage volume can provide enough hot water to meet the load. During high demand scenarios when the elements are triggered, the control logic of the 80-gal unit uses the elements for partial recovery only, which further increases the HPF.

In unconditioned space, regional variations in the HPF are considerable. Climate and installation location are particularly important. The heat pump could be used to meet almost the entire load in conditioned space; however, in unconditioned space the ambient air temperature can go outside its operating range (45°–120°F). The frequency of this occurrence has a strong impact on HPF, as the heat pump could otherwise meet most of the load. As ambient air temperature decreases, the heat pump capacity decreases, so the electric elements are required more often. For garage installation, the ambient air temperature is much more likely to go outside the heat pump's operating range for some part of the year. Basements have much less variation in space temperature, which is mostly dependent on ground and conditioned space temperatures. This results in a higher HPF for homes where the HPWHs are installed in basements instead of garages, even if the homes are in similar climates.



(a)

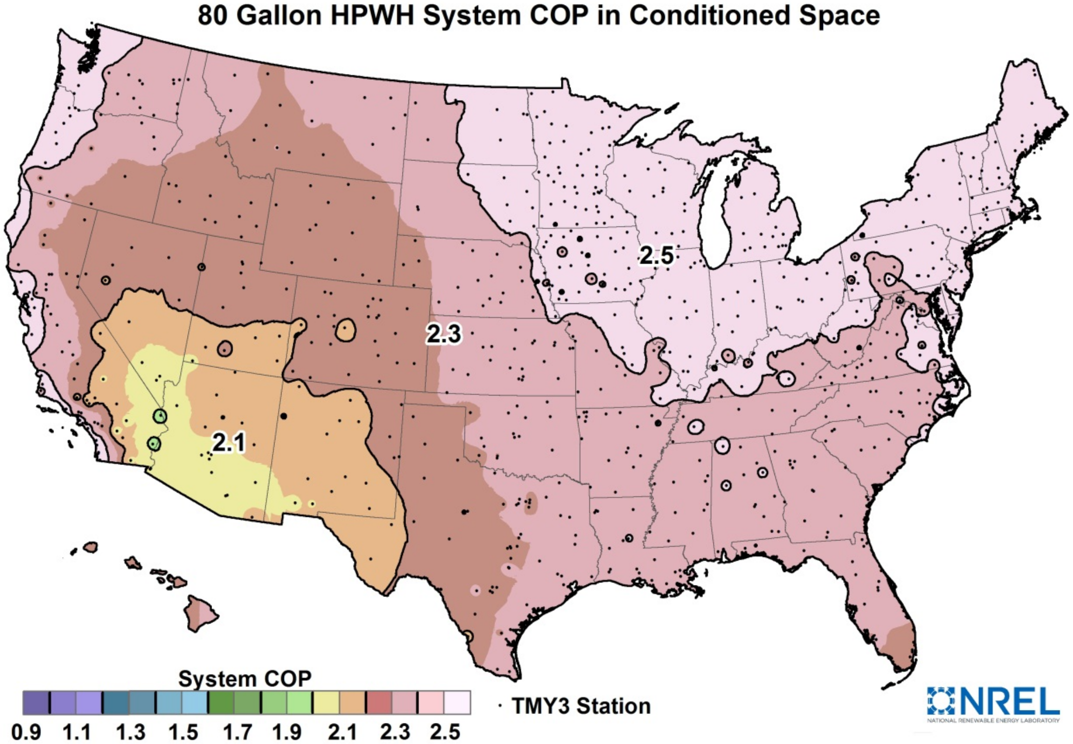


(b)

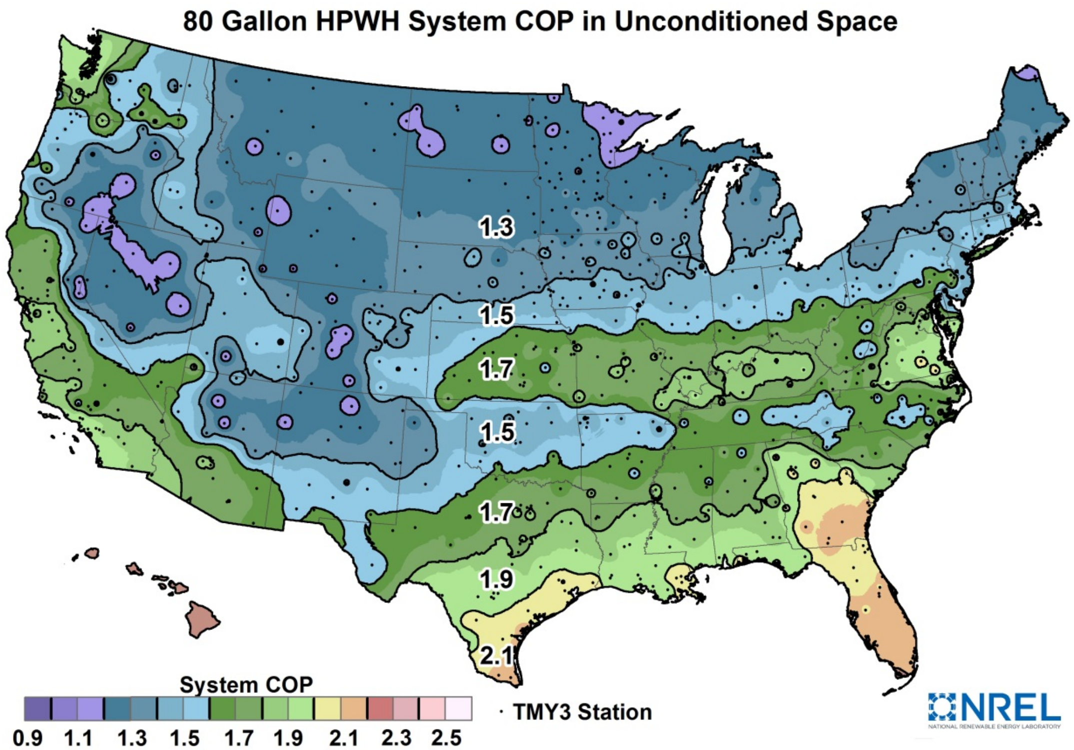
Figure 19. HPF of the 80-gal HPWH in (a) conditioned and (b) unconditioned space

Figure 20 shows the COP_{sys} for an 80-gal HPWH in conditioned and unconditioned space. In conditioned space, the COP_{sys} tends to increase as the mains temperature decreases because the lower mains water temperature leads to higher energy demand. In a lower energy demand situation, a larger portion of the heat from the heat pump goes to making up standby losses instead of meeting the load, which decreases overall efficiency. This same trend of higher efficiency at higher load is seen in gas and electric storage WHs. However, it is not seen in the case of a 50-gal HPWH because the HPF is lower in regions with high load: the heat pump cannot fully meet the load with only 50 gal of storage and the control logic between the two units varies significantly. The ambient humidity also has an impact on the COP_{sys}. The heat pump performance is affected by the storage tank temperature and the ambient wet bulb temperature. Although the conditioned space temperature is controlled, the humidity is not, which lowers wet bulb temperatures and reduces heat pump COP in drier locations such as the western United States. The lower wet bulb temperature and slight HPF variations with location lead to COP_{sys} in the locations with the highest loads being lower than locations such as the Pacific Northwest and New England, which have slightly lower loads but higher humidities. In unconditioned space, the COP_{sys} follows similar trends to the highly variable HPF, which is the primary driver of COP_{sys}.

The EF of this 80-gal HPWH is 2.3. The COP_{sys} is not always this high, but the unit can achieve a $COP_{sys} \geq 2.3$ for most of the country when it is installed in conditioned space. However, the COP_{sys} does not account for normalization or any changes in HVAC energy consumption, which may significantly impact the overall energy savings associated with installing an HPWH.



(a)

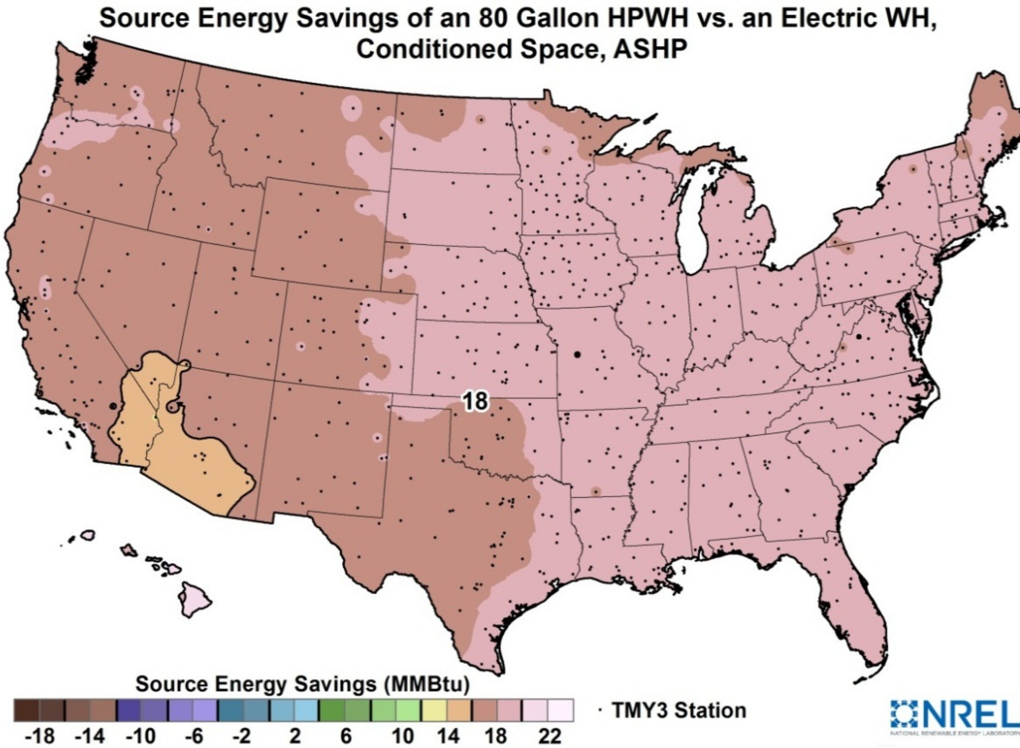


(b)

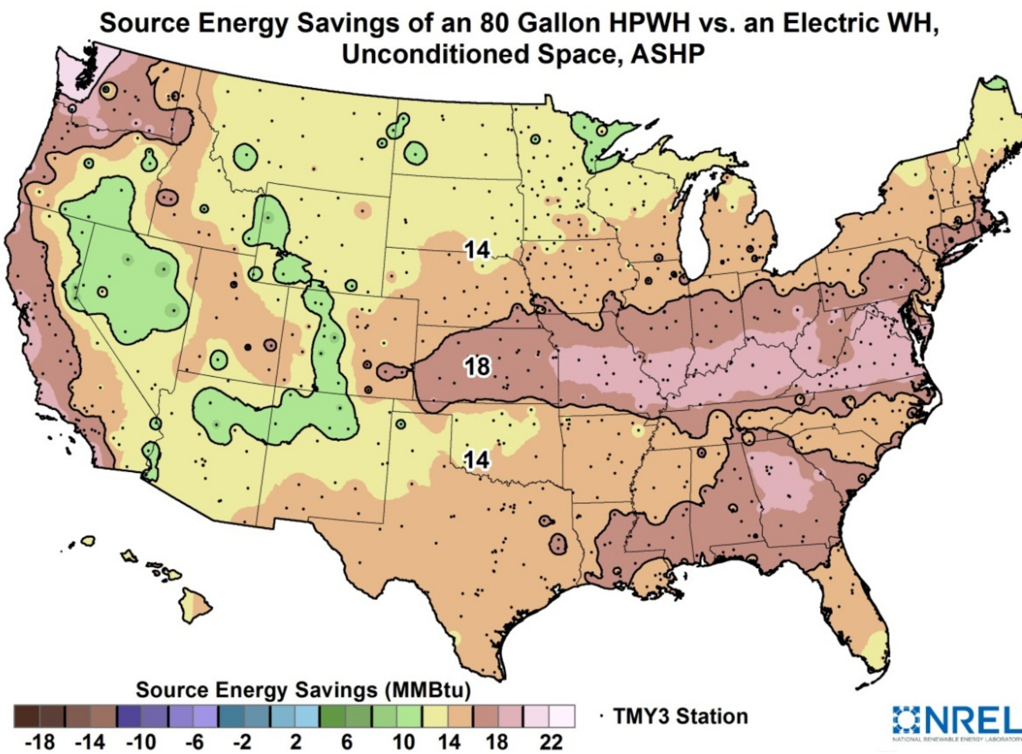
Figure 20. COP_{sys} of the 80-gal HPWH in (a) conditioned and (b) unconditioned space

Figure 21 shows the source energy savings for a home with an electric WH and an ASHP in conditioned and unconditioned space. In the conditioned space case, the potential source energy savings are relatively constant across the United States; savings are slightly higher in the East. Northern climates show high savings for the energy required to heat water because of the high heat pump COP and the larger load, but there is a correspondingly higher space conditioning penalty. Warmer locations receive a net space conditioning benefit from running the HPWH, but the smaller load leads to lower savings in the energy required to heat water. The net result of the space conditioning impact and variations in the load leads to the roughly constant savings across the country.

In unconditioned space, the source energy savings follow many of the same trends seen in the COP_{sys} plot. Although the space conditioning impact in this case is relatively small (especially in garage installations), the water heating load has a significant impact. The locations with the highest COP_{sys} (Hawaii and southern Florida) do not have the highest savings because the load is relatively low. Interestingly, the highest savings are seen in coastal Washington. This location has both a high COP_{sys} (because the unit is installed in a basement in a relatively mild climate with high ambient humidity) and a high load. Even though this is a heating-dominated climate, the relatively mild winters allow the ASHP to use the heat pump for most of the year, which lessens the HPWH's impact on the space conditioning load.



(a)



(b)

Figure 21. Source energy savings of an 80-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

Figure 22 shows the source energy savings for a home with an electric WH and ER heat/AC in conditioned and unconditioned space. For these homes the efficiency in conditioned space is significantly lower than the ASHP case in all locations that have some heating load. ER heat is significantly less efficient than an ASHP, so this drop is expected. The largest drops in savings are seen along the west coast, which has a mild climate but a small heating load for much of the year, especially in northern locations. The heat pump provides a small amount of cooling year round, so the space conditioning penalty is largest in these locations. However, positive source energy savings are possible in all locations. In unconditioned space, the efficiency is slightly lower for cases with ER heat than with an ASHP. The effect is more pronounced in locations with basement installations, which also tend to have a higher heating requirement.

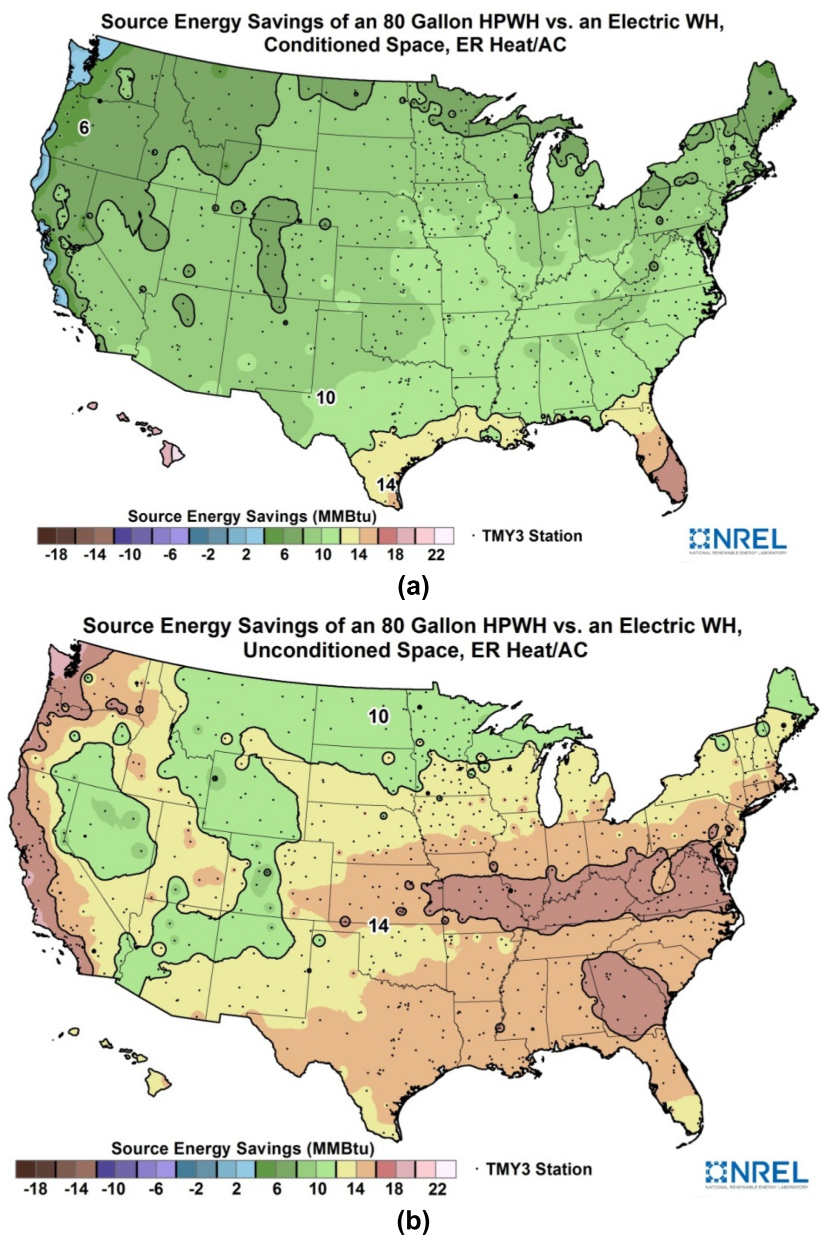
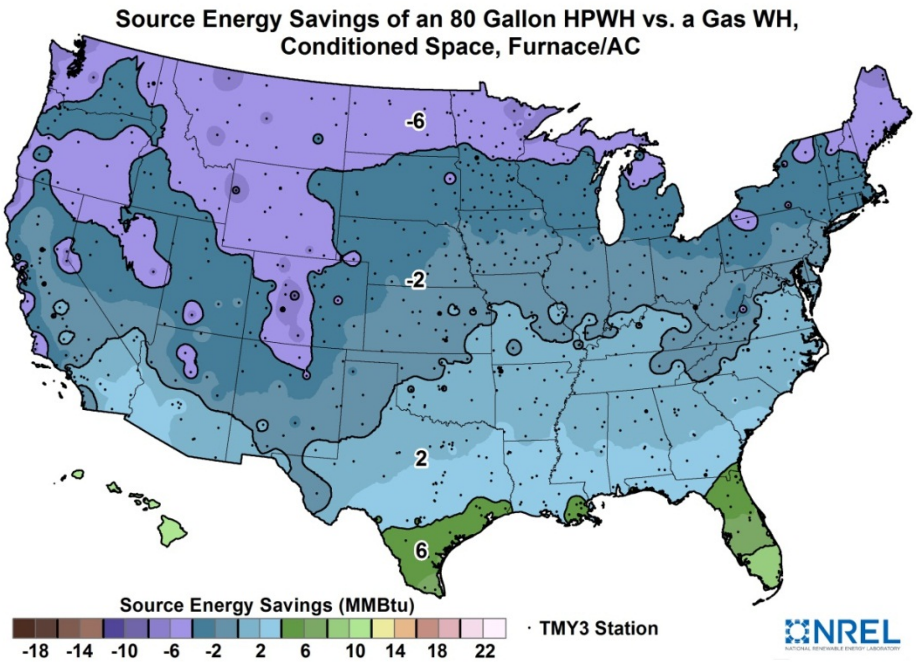
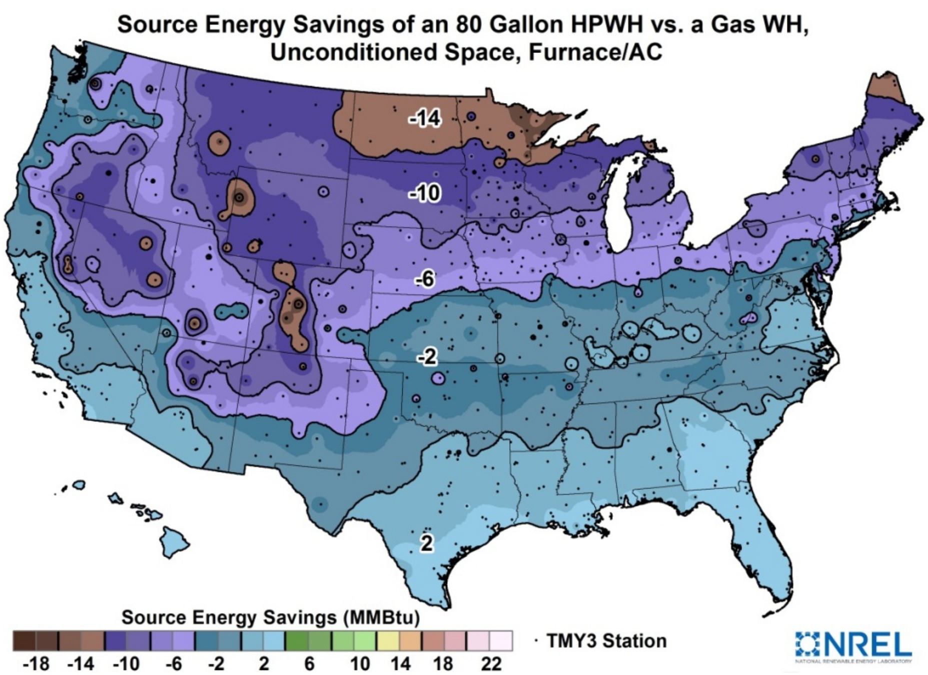


Figure 22. Source energy savings of an 80-gal HPWH relative to an electric WH for a home with ER heat/AC when the WH is in (a) conditioned and (b) unconditioned space

Figure 23 shows the source energy savings for a home with a gas WH and a furnace/AC in conditioned and unconditioned space. Even in the case of an 80-gal HPWH, positive source energy savings are limited to the South in conditioned and unconditioned space. The region where positive source energy savings are possible is larger in the 80-gal HPWH case than in the 50-gal case. However, this region still predominantly uses electric WHs.



(a)

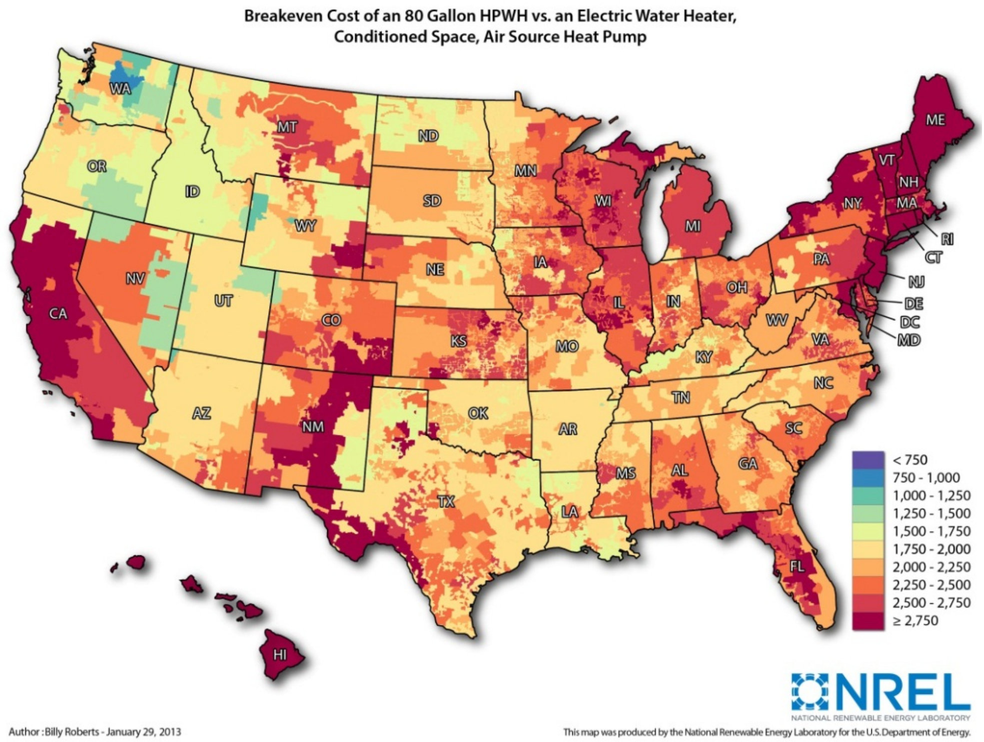


(b)

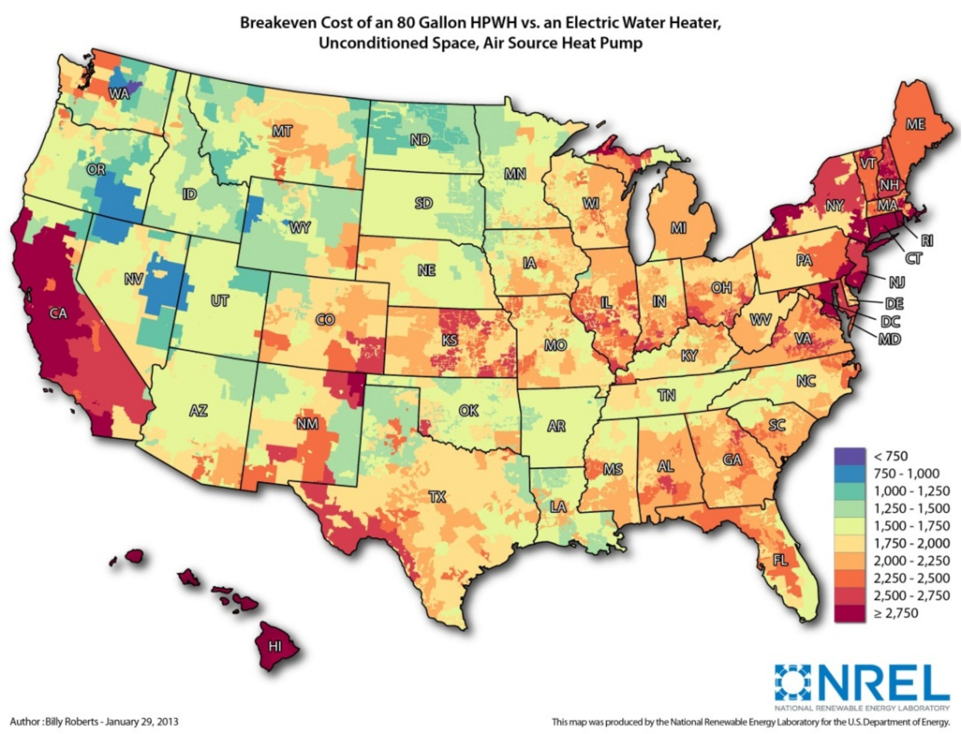
Figure 23. Source energy savings of an 80-gal HPWH relative to a gas WH for a home with a furnace/AC when the WH is in (a) conditioned and (b) unconditioned space

The breakeven costs for the case of an 80-gal HPWH were also calculated. The net installed cost of an 80-gal HPWH will be higher than that of a 50-gal HPWH. The 80-gal HPWHs are significantly more expensive than the 50-gal units (more than $1800 retail) (Lowes.com, 2013). This is higher than some estimates of the average net installed cost of the 50-gal unit and a significant premium, although it would be reasonable to expect that this cost will decrease as more manufacturers start offering multiple sizes of HPWHs. There may also be additional installation costs for the 80-gal HPWH, especially in retrofit scenarios where size is a factor. The current net installed cost of an 80-gal HPWH is thus higher than the 50-gal case and likely exceeds $2000 in many cases with current prices.

To emphasize the differences in net installed cost between the 50- and 80-gal cases and to better capture the range of likely net installed costs for an 80-gal HPWH, a new scale was used for these breakeven maps. However, all the details of how the breakeven cost was calculated are identical to the case of the 50-gal HPWH. Figure 24 shows the breakeven costs for an 80-gal HPWH in conditioned and unconditioned space when replacing an electric WH in a home with an ASHP. Many of the same trends that were seen in the 50-gal case are apparent here since the utility rates in both cases are the same. However, the breakeven cost is generally higher because the 80-gal case shows greater savings. In particular, there are greater savings in the northern Mountain region, which leads to significantly higher breakeven costs than the 50-gal case.



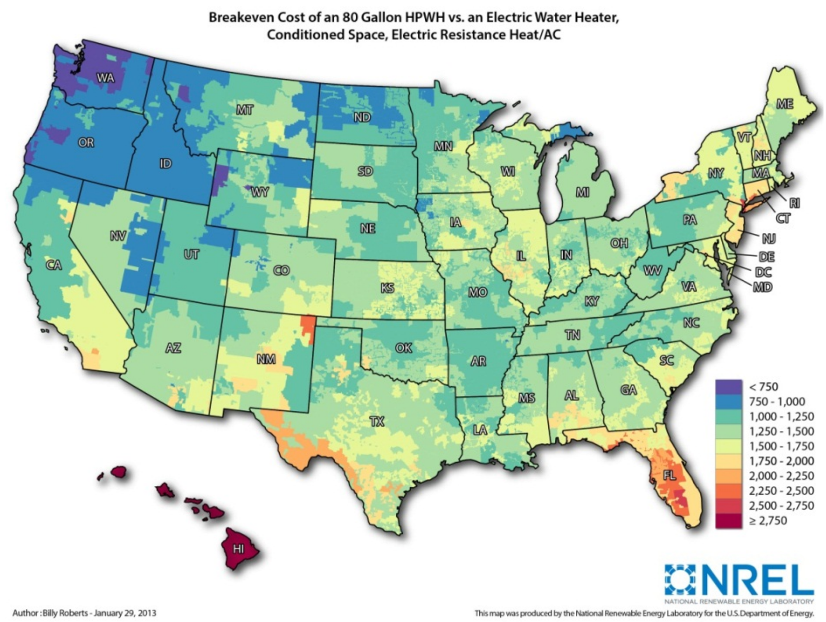
(a)



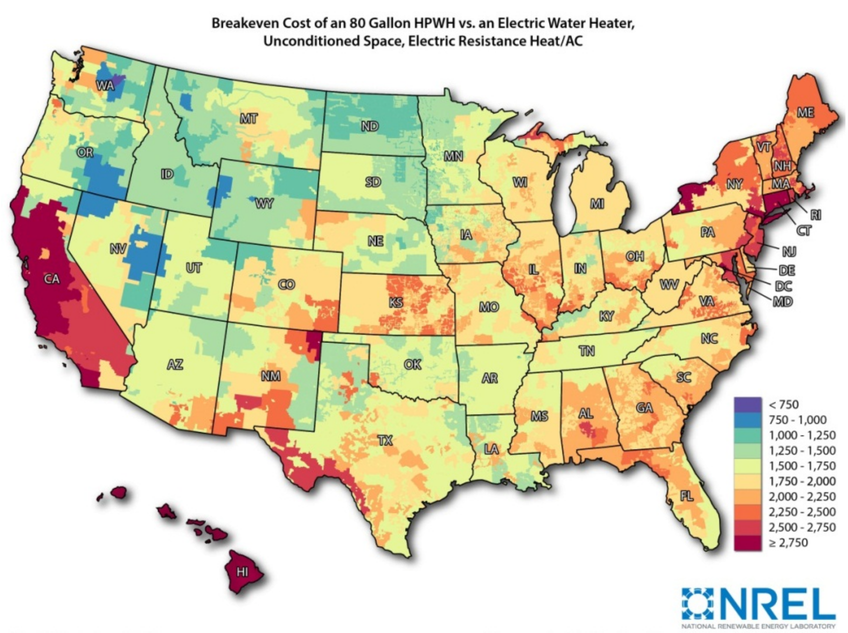
(b)

Figure 24. Breakeven cost of an 80-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

Figure 25 shows the breakeven costs for replacing an electric WH in a home with ER heat and an AC. The difference between this case and that of an ASHP is much more drastic for conditioned space. Nevertheless, in unconditioned space many regions had their breakeven costs drop by at least one scale level, particularly in locations with basements. In the conditioned space case, there is a significant drop in breakeven costs and only a few locations have breakeven costs that exceed $2000.



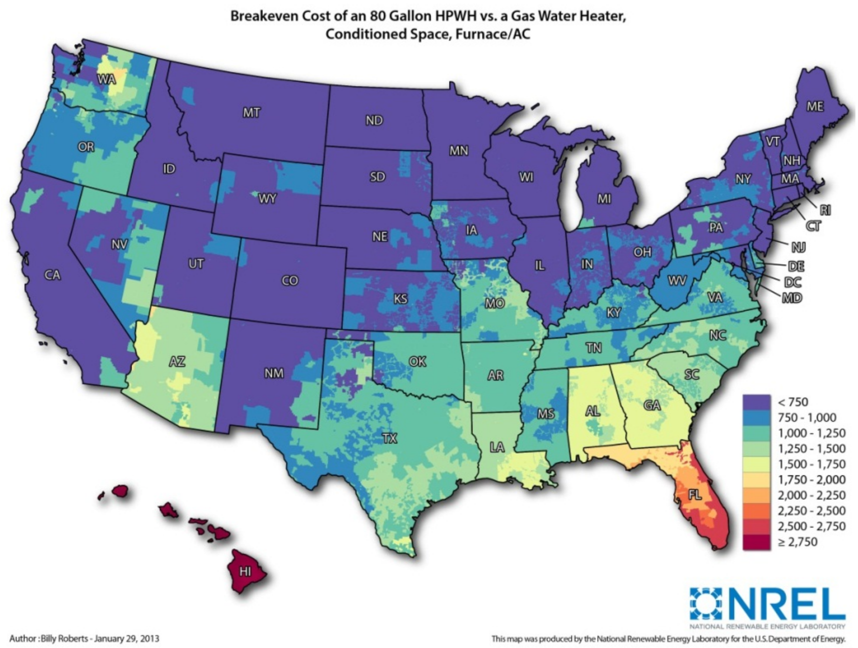
(a)



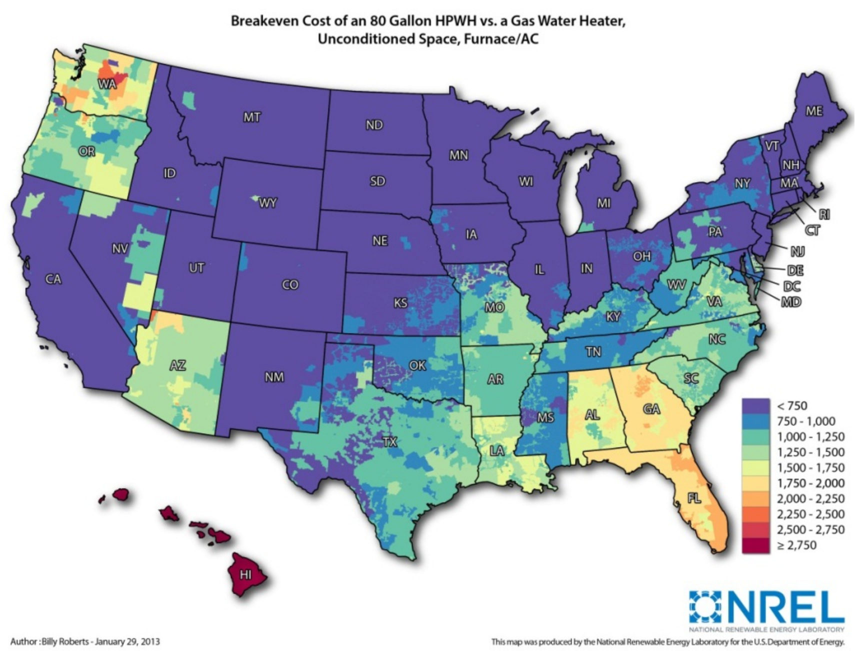
(b)

Figure 25. Breakeven cost of an 80-gal HPWH relative to an electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space

Figure 26 shows the breakeven costs for the case where the HPWH is replacing a gas WH in a home using a furnace/AC. In this case the breakeven costs are generally very low, although there are high breakeven costs in a few locations such as southern Florida. However, because gas WHs are uncommon in locations with high breakeven costs, the number of installations where it may be economically viable to replace a gas WH with an HPWH is low, even with the larger and generally more efficient 80-gal HPWH.



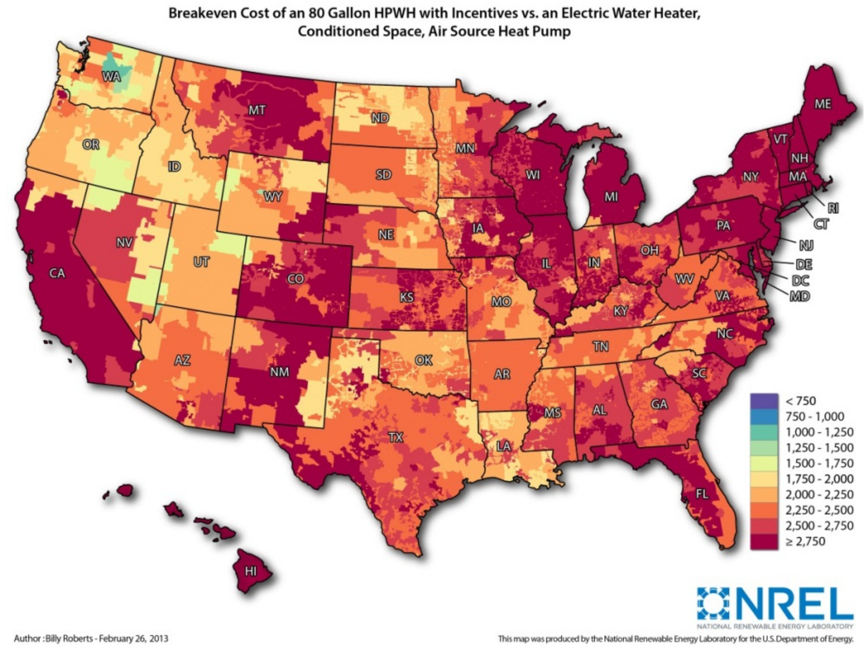
(a)



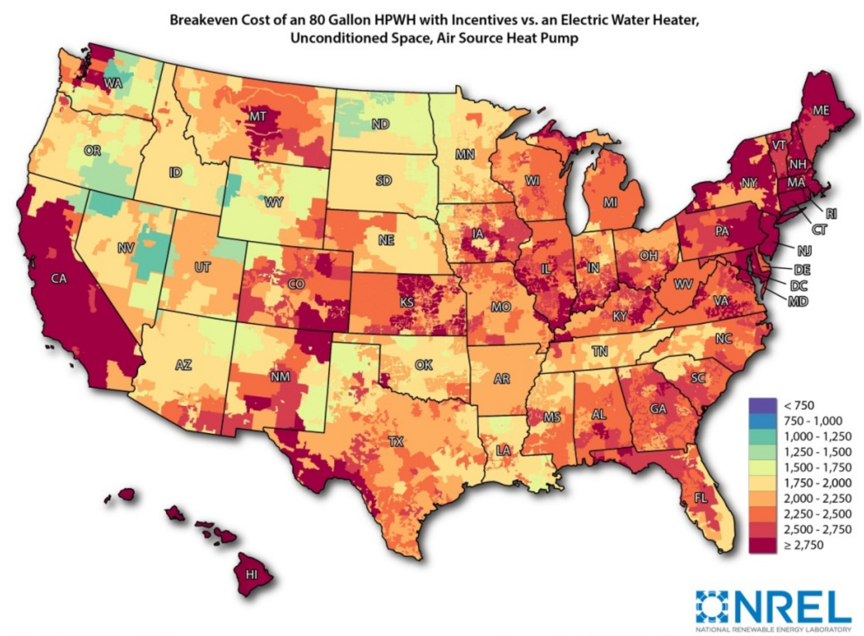
(b)

Figure 26. Breakeven cost of an 80-gal HPWH relative to a gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Figure 27 through Figure 29 show cases where incentives are considered. The same incentives that were used in the 50-gal case (including the $300 federal incentive) are applied here. Current incentives can frequently make the 80-gal HPWH significantly more attractive, although even with incentives installing an 80-gal HPWH is often still unattractive. For example, when replacing a gas WH, favorably high breakeven costs are still seen only in the South and a few parts of Washington.

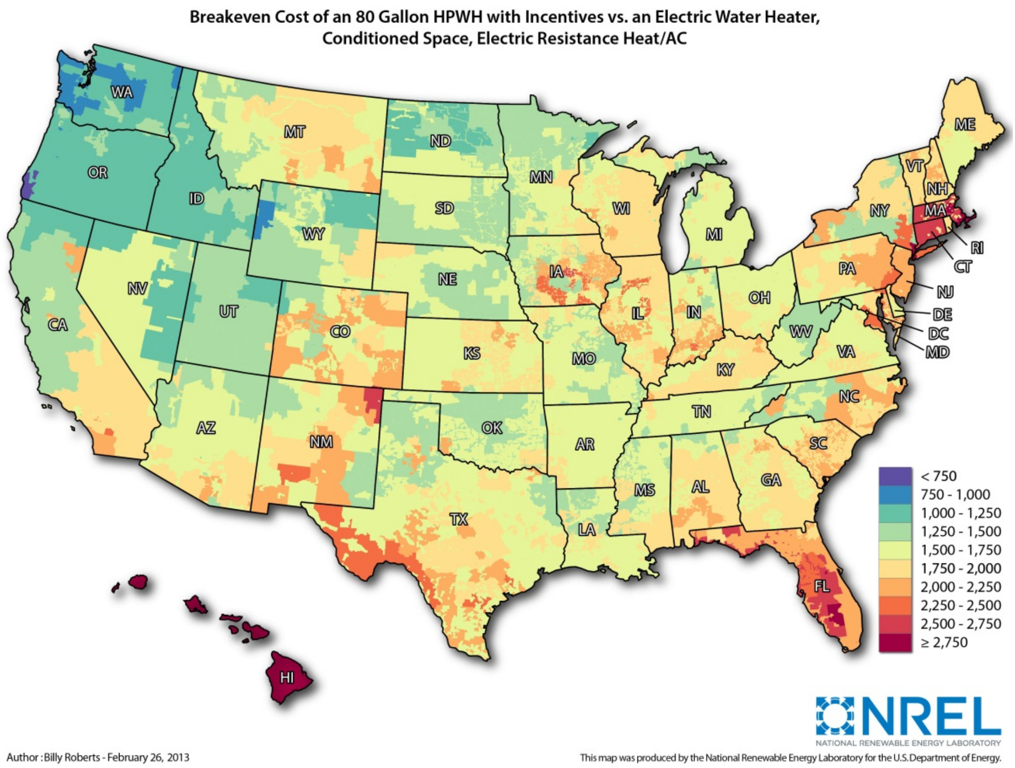


(a)

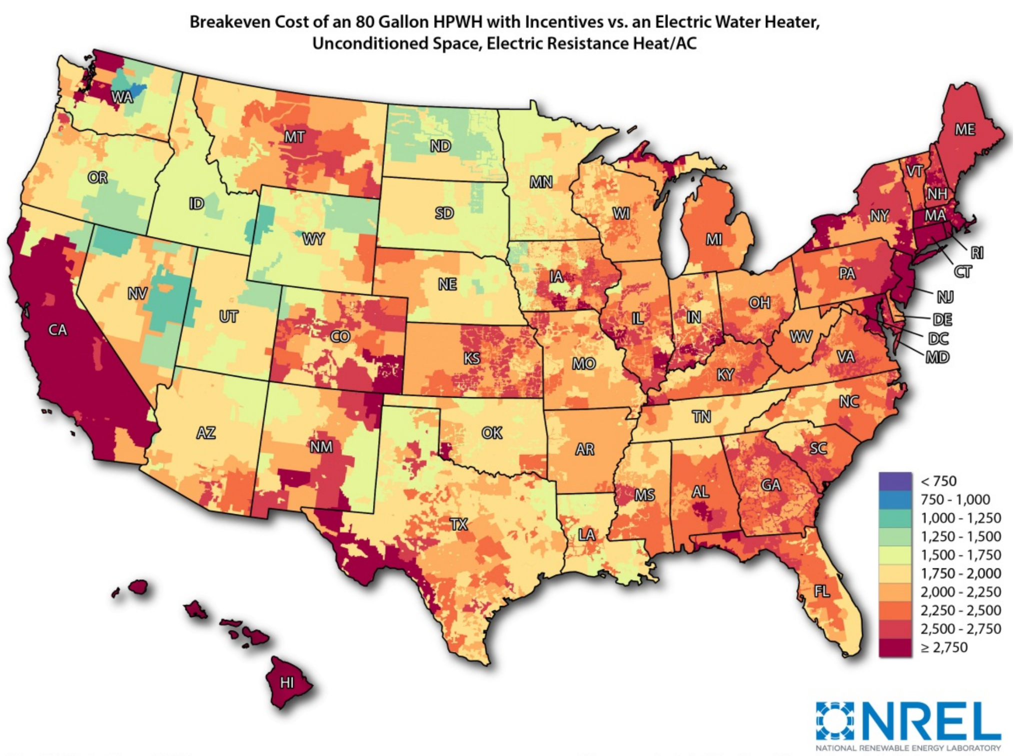


(b)

Figure 27. Breakeven cost with incentives of an 80-gal HPWH relative to an electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

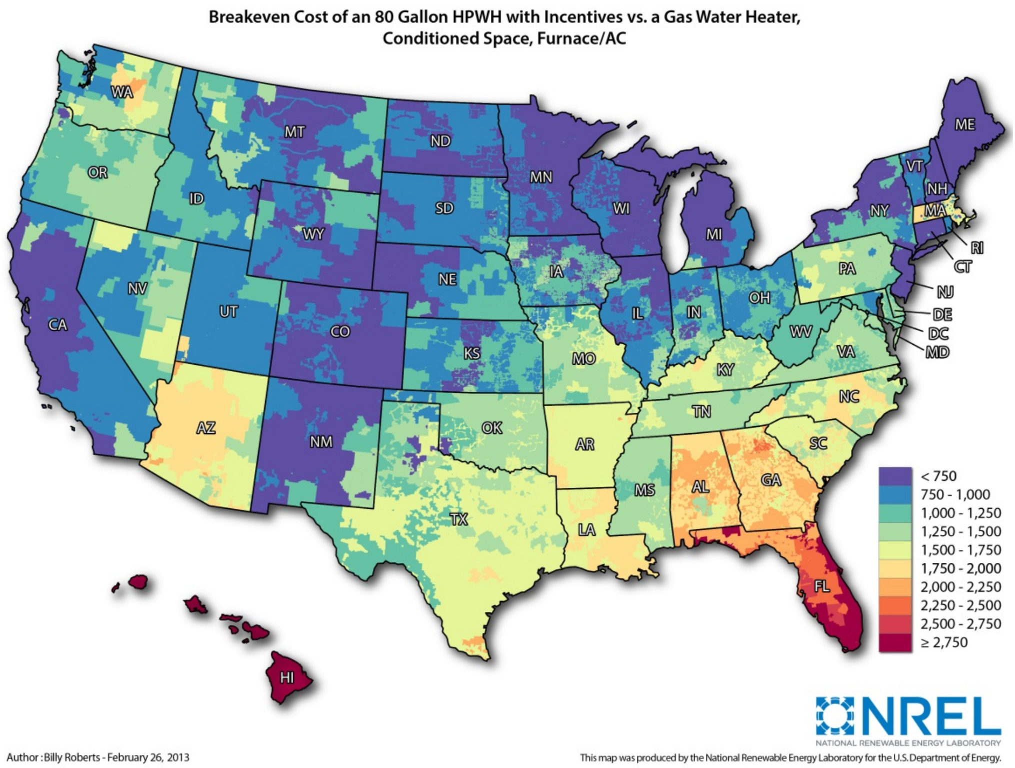


(a)

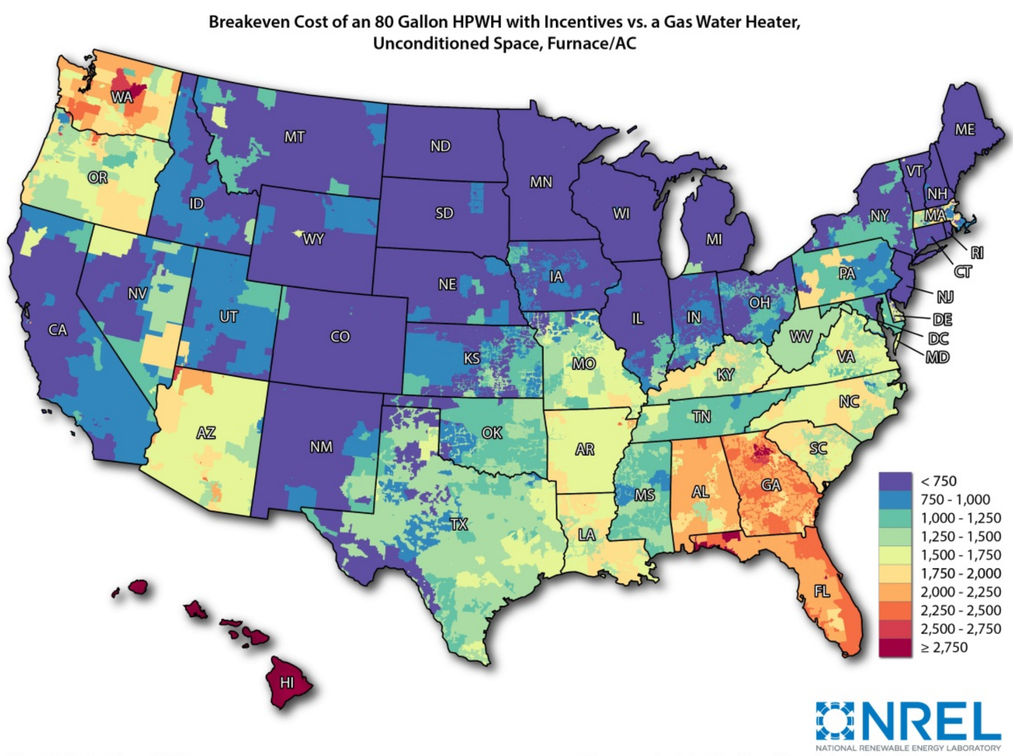


(b)

Figure 28. Breakeven cost with incentives of an 80-gal HPWH relative to an electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space



(a)



(b)

Figure 29. Breakeven cost of an 80-gal HPWH relative to a gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Appendix C: Components of Net Source Energy Savings

Table 2 through Table 13 show the source energy savings that comes from normalization energy, space heating and cooling interactions, and actual WH savings. To show the impact of climate on each factor, the results are split up by BA climate zone (Pacific Northwest National Laboratory and Oak Ridge National Laboratory, 2010) (see Figure 30). Tables were created for the 50-gal HPWH presented in the main body of this paper and the 80-gal HPWH presented in Appendix B to demonstrate the differences. All the tables provide the net annual source energy savings (in MMBtu); negative savings indicate an increase in source energy consumption when switching to an HPWH. Although the data are divided by climate region, there may be significant variations from site to site in a particular climate region.

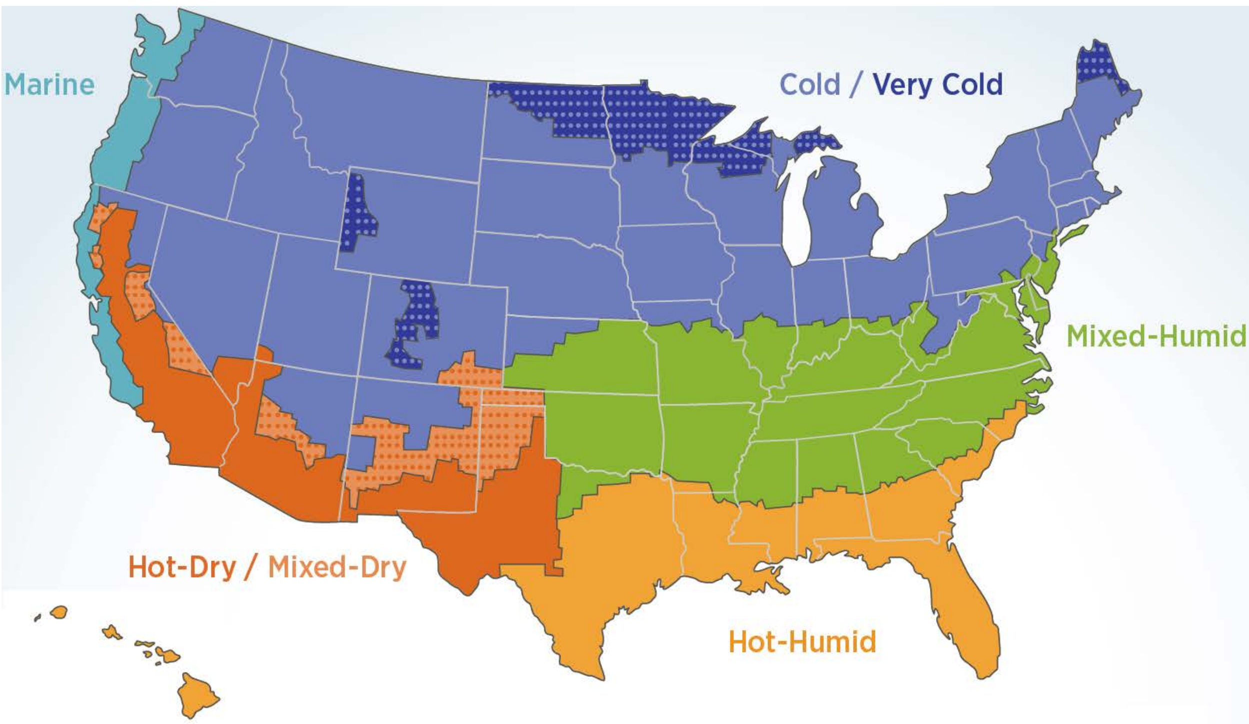


Figure 30. BA climate zones (Pacific Northwest National Laboratory and Oak Ridge National Laboratory, 2010)

Table 2. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ASHP/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	16.98	–1.90	3.65	–1.19	17.54
Mixed-Humid	19.78	–4.17	2.54	–1.77	16.38
Hot-Dry	17.50	–2.79	2.15	–1.49	15.37
Mixed-Dry	19.19	–4.28	1.79	–2.05	14.64
Marine	21.13	–5.28	0.59	–1.90	14.53
Cold	21.41	–6.16	1.68	–2.24	14.69
Very Cold	22.84	–8.09	1.03	–2.59	13.20

Table 3. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ASHP/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	15.64	–0.05	0.18	–1.33	14.44
Mixed-Humid	14.63	–0.28	0.36	–1.75	12.95
Hot-Dry	15.22	–0.05	0.08	–1.76	13.49
Mixed-Dry	12.24	–0.08	0.11	–2.08	10.18
Marine	16.46	–0.31	0.06	–2.14	14.06
Cold	11.67	–0.32	0.35	–2.06	9.63
Very Cold	9.76	–0.29	0.23	–2.28	7.41

Table 4. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ER Heat and AC/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	16.59	–5.44	3.14	–1.18	13.10
Mixed-Humid	19.38	–10.08	2.22	–1.73	9.79
Hot-Dry	17.08	–8.32	1.90	–1.47	9.19
Mixed-Dry	18.79	–9.97	1.62	–2.00	8.44
Marine	20.72	–15.44	0.52	–1.86	3.94
Cold	21.01	–12.66	1.49	–2.17	7.67
Very Cold	22.47	–14.95	0.91	–2.51	5.92

Table 5. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ER Heat and AC/Replacing an Electric WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	15.26	–0.16	0.10	–1.31	13.89
Mixed-Humid	14.25	–0.82	0.29	–1.72	12.00
Hot-Dry	14.84	–0.19	0.06	–1.73	12.98
Mixed-Dry	11.85	–0.24	0.08	–2.02	9.66
Marine	16.07	–0.97	0.04	–2.08	13.06
Cold	11.28	–0.99	0.30	–2.00	8.58
Very Cold	9.36	–1.01	0.20	–2.22	6.33

Table 6. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/Furnace and AC/Replacing a Gas WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	3.64	–2.81	4.07	–1.23	3.67
Mixed-Humid	2.09	–5.21	2.80	–1.90	–2.22
Hot-Dry	2.53	–4.31	2.48	–1.55	–0.85
Mixed-Dry	0.41	–5.28	2.08	–2.21	–5.01
Marine	1.97	–7.88	0.67	–2.04	–7.28
Cold	–0.02	–6.59	1.87	–2.48	–7.23
Very Cold	–1.64	–7.75	1.13	–2.96	–11.22

Table 7. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/Furnace and AC/Replacing a Gas WH with a 50-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	2.31	–0.10	0.14	–1.35	1.00
Mixed-Humid	–2.91	–0.55	0.39	–1.89	–4.96
Hot-Dry	0.33	–0.12	0.08	–1.81	–1.52
Mixed-Dry	–6.38	–0.18	0.12	–2.24	–8.68
Marine	–2.53	–0.57	0.06	–2.25	–5.30
Cold	–9.56	–0.82	0.41	–2.31	–12.28
Very Cold	–14.47	–0.98	0.26	–2.65	–17.83

Table 8. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ASHP/Replacing an Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	17.63	–2.45	3.95	–0.52	17.63
Mixed-Humid	22.07	–5.66	2.77	–0.38	18.80
Hot-Dry	18.71	–3.62	2.23	–0.52	16.81
Mixed-Dry	22.06	–5.86	1.97	–0.44	17.73
Marine	23.97	–6.97	0.60	–0.34	17.27
Cold	25.64	–8.85	1.91	–0.30	18.40
Very Cold	28.90	–12.13	1.19	–0.23	17.74

Table 9. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ASHP/Replacing An Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	16.01	–0.04	0.12	–0.70	15.38
Mixed-Humid	17.88	–0.53	0.35	–0.81	16.88
Hot-Dry	16.13	–0.03	0.01	–0.85	15.27
Mixed-Dry	14.39	–0.12	0.07	–1.12	13.22
Marine	19.95	–0.45	0.04	–0.84	18.69
Cold	15.99	–0.65	0.37	–1.04	14.67
Very Cold	13.51	–0.59	0.25	–1.10	12.07

Table 10. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/ER Heat and AC/Replacing an Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	17.24	–7.06	3.40	–0.51	13.08
Mixed-Humid	21.69	–13.59	2.43	–0.35	10.18
Hot-Dry	18.31	–10.77	1.97	–0.50	9.01
Mixed-Dry	21.68	–13.73	1.79	–0.41	9.34
Marine	23.59	–20.27	0.53	–0.31	3.54
Cold	25.27	–18.01	1.70	–0.26	8.70
Very Cold	28.54	–22.18	1.05	–0.18	7.23

Table 11. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/ER Heat and AC/Replacing an Electric WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	15.63	–0.14	0.03	–0.69	14.84
Mixed-Humid	17.49	–1.32	0.28	–0.79	15.67
Hot-Dry	15.75	–0.10	0.00	–0.83	14.82
Mixed-Dry	14.00	–0.29	0.04	–1.09	12.67
Marine	19.56	–1.25	0.03	–0.82	17.53
Cold	15.60	–1.66	0.32	–1.00	13.26
Very Cold	13.12	–1.64	0.23	–1.05	10.66

Table 12. Components of Source Energy Savings by BA Climate Zone, Conditioned Space/Furnace and AC/Replacing a Gas WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	3.75	–3.48	4.33	–0.55	4.05
Mixed-Humid	3.88	–6.68	3.01	–0.52	–0.31
Hot-Dry	3.18	–5.33	2.55	–0.58	–0.18
Mixed-Dry	2.68	–6.84	2.25	–0.62	–2.54
Marine	4.35	–9.89	0.68	–0.48	–5.34
Cold	3.66	–8.82	2.08	–0.58	–3.65
Very Cold	3.81	–10.76	1.26	–0.62	–6.30

Table 13. Components of Source Energy Savings by BA Climate Zone, Unconditioned Space/Furnace and AC/Replacing a Gas WH with an 80-Gal HPWH

BA Climate Zone	ΔE_{WH}	ΔE_{heat}	ΔE_{cool}	ΔE_{nrmlz}	Net Source Savings (MMBtu)
Hot-Humid	1.96	–0.09	0.07	–0.73	1.22
Mixed-Humid	–0.63	–0.76	0.39	–0.96	–1.96
Hot-Dry	0.33	–0.08	0.02	–0.91	–0.65
Mixed-Dry	–5.52	–0.20	0.08	–1.30	–6.94
Marine	–0.02	–0.69	0.05	–0.99	–1.65
Cold	–6.54	–1.10	0.43	–1.31	–8.51
Very Cold	–12.20	–1.24	0.30	–1.48	–14.62

Appendix D: Breakeven Cost Calculation Methodology

The breakeven cost of an HPWH is defined as the point where the NPC of the system equals the NPB to its owner:

$$NPC = NPB \tag{6}$$

The NPC is the cumulative discounted cost of the system, including initial cost, financing, tax impacts, incentives, and O&M, equal to the sum of the cost in each year multiplied by the discount factor in that year. The NPC is:

$$NPC = IC_{HPWH} - IC_{base} + \sum_{i=0}^{n} (MC_i - I_i) DF_i \tag{7}$$

where:

IC_{HPWH}	=	the net installed cost of the HPWH,
IC_{base}	=	the net installed cost of the base case water heater,
n	=	the study length (15 years),
MC_i	=	the maintenance costs in year i ($100 every 5 years),
I_i	=	the incentives in year i, and
DF_i	=	the discount factor in year i.

The discount factor can for any given year is:

$$DF_i = \frac{1}{(1+d)^i} \tag{8}$$

where d is the discount rate (5%).

The NPB is the discounted cumulative benefits of reduced electricity bills over the evaluated period or the sum of the benefits in each year multiplied by the discount factor. The NPB is:

$$NPB = \sum_{i=0}^{n} \$_{saved,i} \cdot DF_i \cdot FEF_i \tag{9}$$

where:

n	=	the study length (15 years),
$\$_{saved,i}$	=	the annual bill savings in year i, and
FEF_i	=	the fuel escalation factor in year i.

The fuel escalation factor for any given year is:

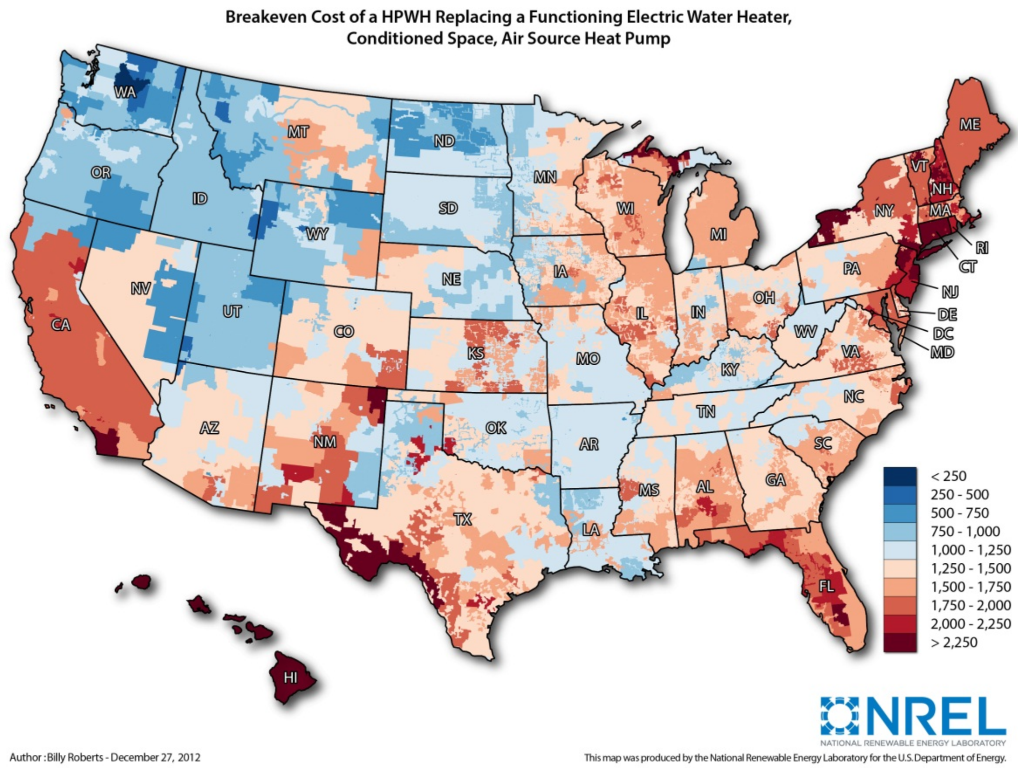
$$FEF_i = (1 + e)^i \tag{10}$$

Where e is the fuel escalation rate (0.5%).

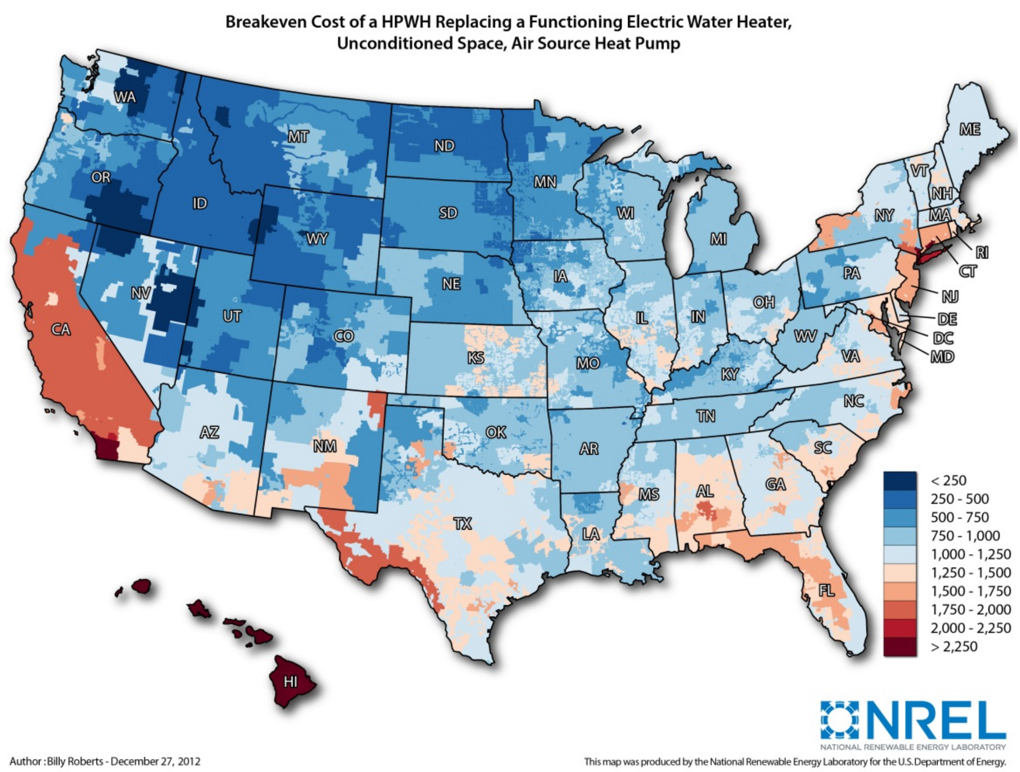
To calculate the breakeven cost of the HPWH, Equations 6–9 are combined and solved for IC_{HPWH}, the breakeven cost.

Appendix E: Breakeven Costs for Cases Replacing a Functioning Water Heater

The maps presented here show cases where a functioning WH is replaced by a 50-gal HPWH when no incentives are considered. In this case, the existing WH is assumed to have no value, even though it may have several years of useful life remaining; it is unlikely (although not impossible) that the used water heater will be sold. Thus, the breakeven costs in this case are all lower than when a failed WH is replaced or an HPWH is installed in new construction. Despite this, in a few locations (notably Hawaii, in New England, Florida, and California), it may make sense to replace a functioning electric WH with an HPWH when a home has an ASHP and the WH is installed in conditioned space. This also applies to California for all-electric homes when the WHs are in unconditioned space. Figure 31 through Figure 33 show the breakeven costs for all cases where functioning WHs are replaced with HPWHs.

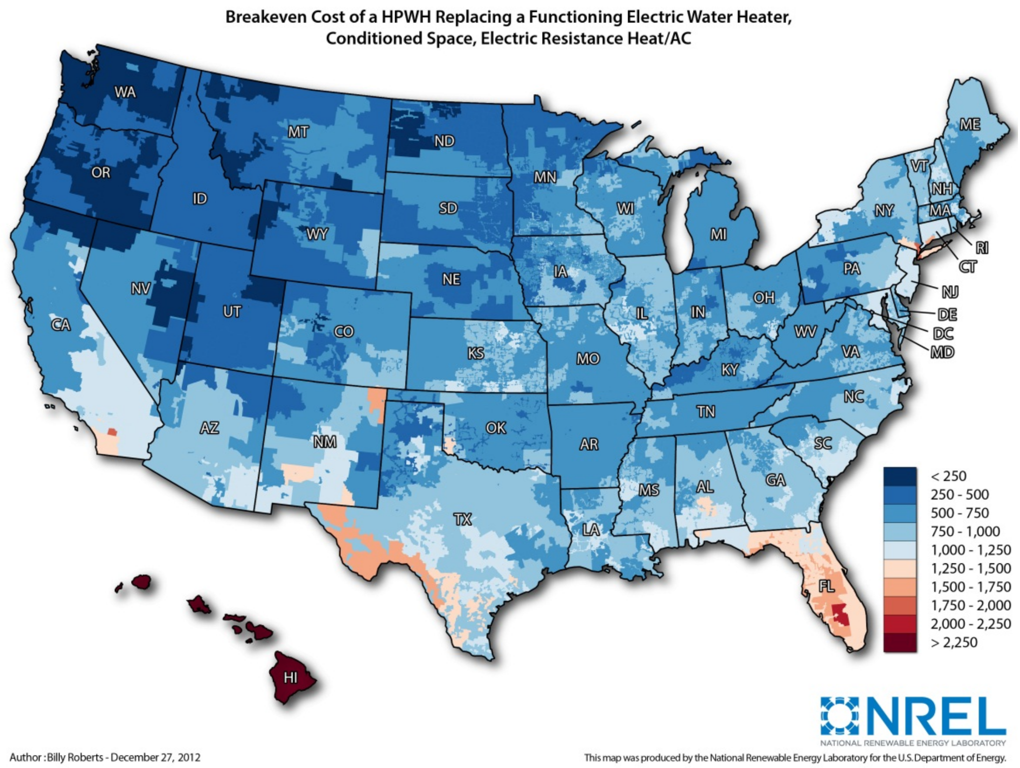


(a)

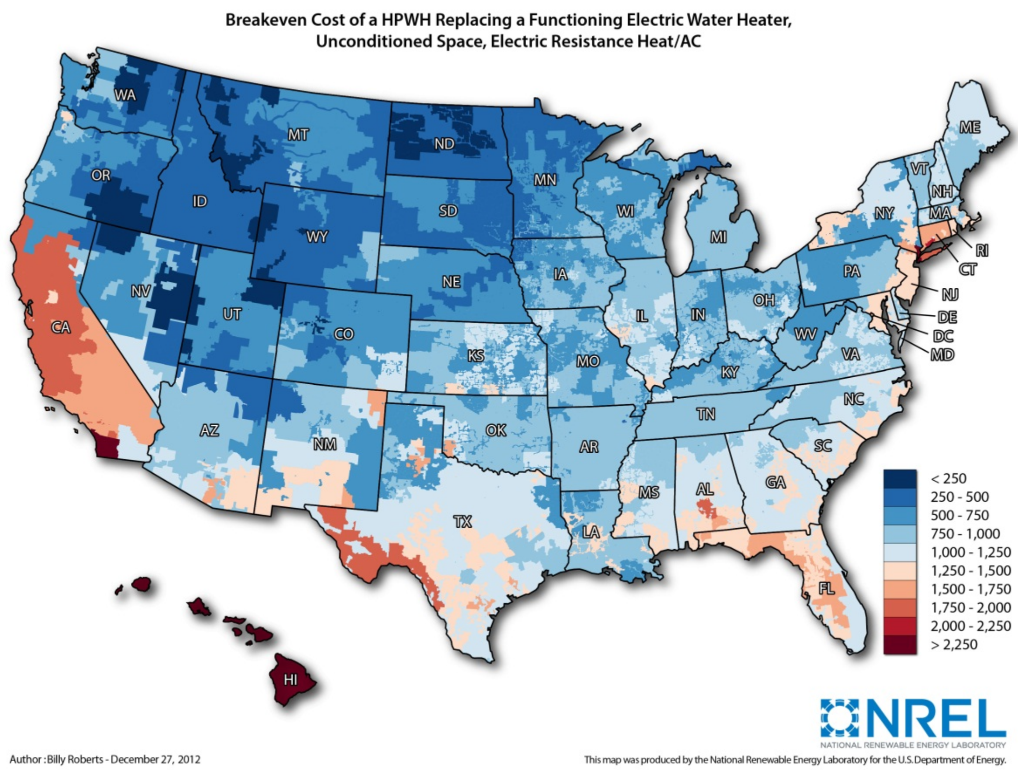


(b)

Figure 31. Breakeven cost of an HPWH replacing a functioning electric WH for a home with an ASHP when the WH is in (a) conditioned and (b) unconditioned space

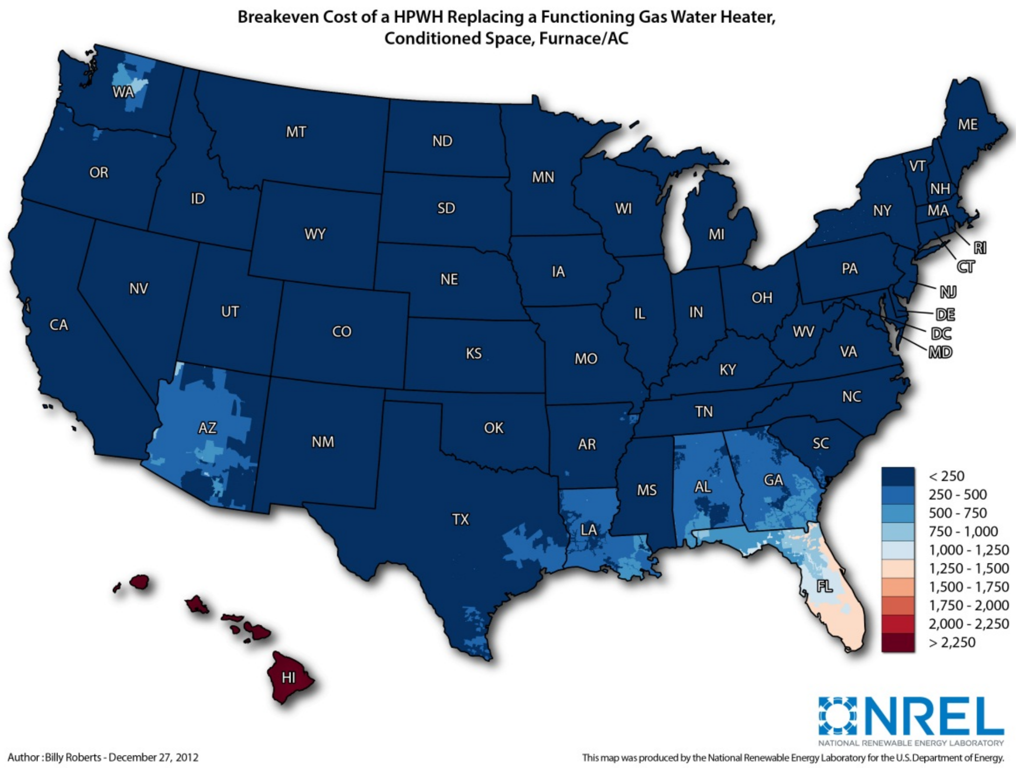


(a)

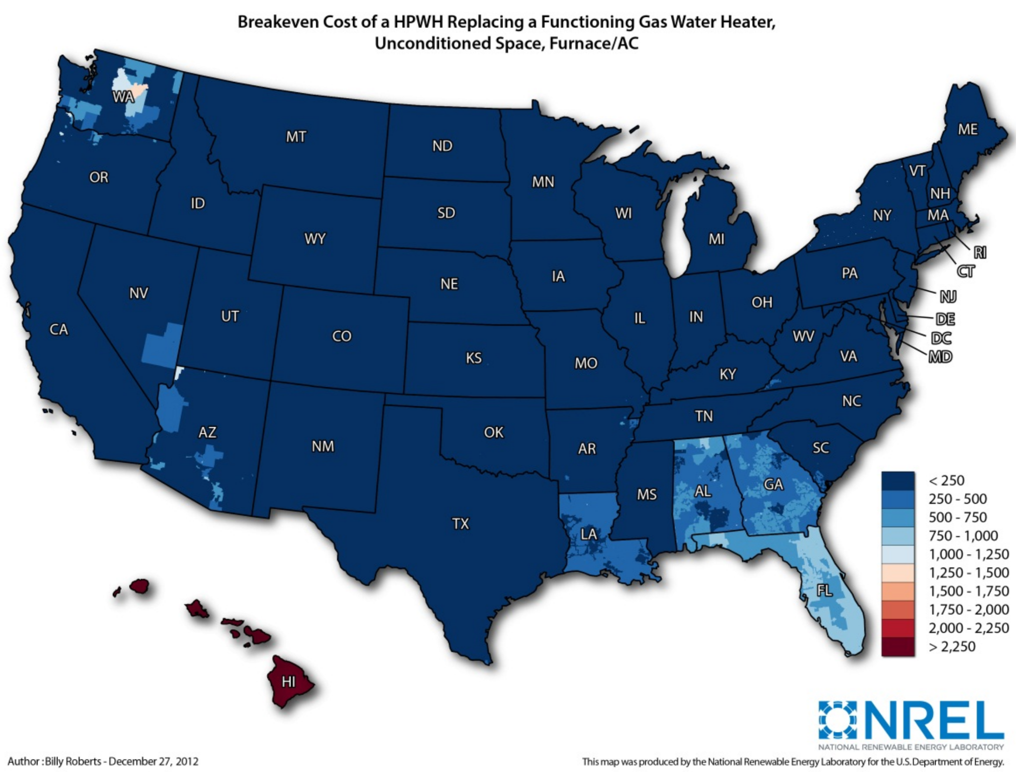


(b)

Figure 32. Breakeven cost of an HPWH replacing a functioning electric WH for a home with ER heat and an AC when the WH is in (a) conditioned and (b) unconditioned space



(a)



(b)

Figure 33. Breakeven cost of an HPWH replacing a functioning gas WH for a home with a furnace and an AC when the WH is in (a) conditioned and (b) unconditioned space

Appendix F: Incentives Used in This Study

Table 14 provides the full list of incentives used in this study. This list was created on March 2, 2012 and includes all incentives that were available at that time (Interstate Renewable Energy Council, 2012). The incentive type category indicates whether the incentive is a utility rebate program (URP), a state rebate program (SRP), or a personal tax credit (PTC). SRP and PTC incentives are statewide programs; URPs apply to the specific utility service territory. The notes indicate if the incentive applies to specific cases (for example, if it is available only for homes replacing a gas WH with an HPWH). The current $300 federal incentive was also applied to all locations for any case that includes incentives.

Table 14. Complete List of Local Incentives Used in This Study

State	Incentive Provider	Incentive Type	Value ($)	Notes
AL	Alabama Power	URP	200	Replacing gas WH
AL	Gulf Power	URP	700	
AZ	Sulphur Springs Valley Electric Co–Op	URP	100	
AR	Southwestern Electric Power Company	URP	40	
AR	State	SRP	200	
CA	City of Palo Alto	URP	200	
CA	Lassen MUD	URP	200	
CA	Modesto Irrigation District	URP	25	
CA	California Pacific Power	URP	40	
CA	Pacific Gas & Electric	URP	30	
CA	Southern California Edison	URP	30	
CA	San Diego Gas & Electric	URP	30	
CA	Silicon Valley Power	URP	1000	
CA	Truckee Donner Public Utility District	URP	100	
CO	Empire Energy Association	URP	250	
CO	Gunnison County Electric Association	URP	70	
CO	Highline Electric Association	URP	375	
CO	KC Electric Association	URP	75	
CO	KC Electric Association	URP	150	
CO	Morgan County Rural Electric Association	URP	370	
CO	Mountain Parks Electric Association	URP	20	
CO	Mountain View Electric Association	URP	70	
CO	Poudre Valley Rural Electric Association	URP	270	
CO	Sangre De Cristo Electric Association	URP	100	
CO	San Miguel Power Association	URP	100	
CO	San Isabel Electric Association	URP	100	

State	Incentive Provider	Incentive Type	Value ($)	Notes
CO	Southeast Colorado Power Association	URP	100	Replacing electric WH
CO	Southeast Colorado Power Association	URP	200	Replacing gas WH
CO	Xcel Energy	URP	450	
CO	Y–W Electric Association	URP	350	Replacing electric WH
CO	Y–W Electric Association	URP	400	Replacing gas WH
CT	Connecticut Light & Power	URP	400	Replacing electric WH
CT	Groton Utilities, Borzah L&P	URP	500	
FL	Clay Electric Co–Op	URP	175	
FL	Gainsville Regional Utility	URP	200	Replacing electric WH
FL	Gulf Power	URP	700	
FL	City of Tallahassee Electric	URP	600	Replacing gas WH
FL	Orlando Utility Commission	URP	650	
GA	Diverse Power	URP	150	Replacing electric WH
GA	Diverse Power	URP	500	Replacing gas WH
GA	Electric Power Board	URP	50	Replacing electric WH
GA	Georgia Power	URP	250	
GA	Jackson EMC	URP	525	
GA	Marietta Power & Water	URP	250	Replacing gas WH
GA	Walton EMC	URP	200	Replacing gas WH
GA	Sawnee Electric	URP	100	Replacing electric WH
HI	Hawaiian Energy	URP	200	
HI	Kauai Island Utility Cooperative	URP	300	
ID	Avista	URP	50	
ID	Idaho Northern Lights Corp.	URP	25	
ID	Rocky Mountain Power	URP	50	
IL	Adams Electric Cooperative	URP	75	Replacing gas WH
IL	City Water, Light, and Power	URP	200	Replacing gas WH
IL	Corn Belt Energy	URP	400	
IL	Rural Electric Convenience Cooperative	URP	200	
IL	Southeaster Illinois Electric Cooperative	URP	250	
IL	Wayne–White Electric Cooperative	URP	400	
IL	Western Illinois Electric Cooperative	URP	75	
IN	Bartholomew County REMC	URP	400	
IN	Clark County REMC	URP	400	
IN	Daviess–Martin County REMC	URP	400	
IN	Harrison REMC	URP	400	
IN	Henry County REMC	URP	400	
IN	Jackson REMC	URP	375	
IN	Johnson County REMC	URP	50	

State	Incentive Provider	Incentive Type	Value ($)	Notes
IN	Lagrange County REMC	URP	400	Replacing electric WH
IN	Marshall County REMC	URP	200	
IN	Orange County REMC	URP	400	
IN	Parke County REMC	URP	50	
IN	RushShelby Energy	URP	400	
IN	Southeastern Indiana REMC	URP	375	
IN	Southern Indiana Power	URP	400	
IN	Tipmont REMC	URP	400	
IN	United REMC	URP	100	Replacing gas WH
IN	Wabash Valley Power Association	URP	400	Replacing electric WH
IN	Whitewater Valley REMC	URP	50	
IN	Win Energy REMC	URP	400	
IA	Alliant Energy Interstate Light & Power	URP	100	
IA	Butler County REC	URP	300	
IA	Calhoun County REC	URP	300	
IA	Consumer Energy REC	URP	500	
IA	Clarke Electric Cooperative	URP	500	
IA	Coon Rapids Municipal Utilities	URP	100	
IA	East Central Iowa REC	URP	500	
IA	Easter Iowa REC	URP	500	
IA	Farmers Electric Cooperative	URP	400	
IA	Franklin REC	URP	300	
IA	Guthrie County REC	URP	500	
IA	Linn County REC	URP	500	
IA	Marquoketa Valley REC	URP	500	
IA	MidAmerican Energy	URP	50	
IA	Midland Power Cooperative	URP	500	
IA	Pella Electric Cooperative	URP	500	
IA	Raccoon Valley Electric Cooperative	URP	300	
IA	Southwest Iowa REC	URP	500	
IA	Spencer Municipal Utilities	URP	500	
IA	TIP REC	URP	600	
KY	State	PTC	250	
MD	Delmarva Power	URP	350	
MD	PEPCO	URP	350	
MD	Southern Maryland Electric Cooperative	URP	350	
MA	Cape Light Compact	URP	1000	
MA	Nstar	URP	1000	
MA	National Grid	URP	1000	

State	Incentive Provider	Incentive Type	Value ($)	Notes
MA	Unitil	URP	1000	
MA	Western Massachusetts Electric	URP	1000	
MI	Alger Delta Electric Cooperative	URP	100	Replacing electric WH
MI	Coverland Electric Cooperative	URP	100	Replacing electric WH
MI	City of Escanaba	URP	100	Replacing electric WH
MI	Great Lakes Energy	URP	100	Replacing electric WH
MI	Homeworks Tri–County Electric	URP	100	Replacing electric WH
MI	Marquette Board of Light & Power	URP	100	Replacing electric WH
MI	Midwest Energy	URP	100	Replacing electric WH
MI	Presque Isle Electric & Gas	URP	100	Replacing electric WH
MI	Thumb Electric	URP	100	Replacing electric WH
MN	Dakota Electric Association	URP	100	
MN	Marshall Municipal Utilities	URP	500	
MS	Mississippi Power	URP	300	Replacing gas WH
MS	Pearl River Valley Electric Power Association	URP	150	Replacing gas WH
MO	Co–Mo Electric Cooperative	URP	50	Replacing electric WH
MO	Missouri Cuivre River Electric	URP	50	Replacing electric WH
MO	Independence Power & Light	URP	300	
MO	Intercounty Electricity Cooperative	URP	50	Replacing electric WH
MO	Kirkwood Electric	URP	100	Replacing gas WH
MO	Missouri Rural Electric Cooperative	URP	50	Replacing electric WH
MO	Ozark Border Electric Cooperative	URP	75	Replacing gas WH
MO	Ozark Border Electric Cooperative	URP	50	Replacing electric WH
MO	White River Valley Electric Cooperative	URP	50	Replacing electric WH
MT	Montana	PTC	350	
MT	Flathead Electric Cooperative	URP	60	
MT	Yellowstone Valley Electric Cooperative	URP	150	
NM	Central New Mexico Electric Cooperative	URP	70	
NY	Central Hudson Gas & Electric	URP	400	
NY	Consolidated Edison	URP	400	
NC	Carteret–Craven Electric Cooperative	URP	200	
NC	City of High Point Electric	URP	150	
NC	City of Statesville	URP	150	
NC	Lumbee River EMC	URP	450	
NC	Progress Energy Carolinas	URP	350	
NC	South River Electric Membership Corporation	URP	200	
OR	Ashland Electric Utility	URP	65	

State	Incentive Provider	Incentive Type	Value ($)	Notes
OR	Central Electric Cooperative	URP	25	
OR	Central Lincoln People's Utility District	URP	25	
OR	EPUD	URP	30	
OR	EWEB	URP	25	
OR	Forest Grove Light & Power	URP	25	
OR	Mcminnville Water & Light	URP	25	
OR	Monmouth Power & Light	URP	25	
OR	Oregon Trail Electric Co–op	URP	100	
OR	Salem Electric	URP	60	
OR	Tillamook County PUD	URP	50	
PA	PenElec	URP	300	
PA	Penn Power	URP	300	
PA	Met–Ed	URP	300	
PA	West Penn Power	URP	300	
PA	PECO	URP	300	
PA	PPL Electric Utilities	URP	300	
SC	Progress Energy Carolinas	URP	350	
SC	Santee Cooper	URP	35	
SC	South Carolina Gas & Electric	URP	250	
SD	MidAmerican Energy	URP	50	
TN	Cookeville Electric Department	URP	100	
TN	Fort Loudoun Electric Cooperative	URP	50	
TN	Middle Tennessee Electric Membership Corporation	URP	200	Replacing gas WH
TN	Middle Tennessee Electric Membership Corporation	URP	50	Replacing electric WH
TN	Mursfreesbro	URP	100	Replacing gas WH
TN	Mursfreesbro	URP	25	Replacing electric WH
TN	Southwest Tennessee EMC	URP	200	Replacing gas WH
TN	Southwest Tennessee EMC	URP	50	Replacing electric WH
TN	Tennessee Valley Authority	URP	50	
TN	Upper Cumberland EMC	URP	100	
TN	Winchester Utilities	URP	100	
TX	Austin Energy	URP	500	Replacing electric WH
TX	CoServ Electric Co–op	URP	25	
TX	Farmers Electric Cooperative	URP	100	
TX	GVEC, Gonzales	URP	300	
TX	Magic Valley Electric Cooperative	URP	250	
TX	Tri–County Electric Cooperative	URP	75	
UT	Dixie Escalante Power Company	URP	500	Replacing gas WH

State	Incentive Provider	Incentive Type	Value ($)	Notes
UT	Dixie Escalante Power Company	URP	150	Replacing electric WH
UT	Rocky Mountain Power	URP	50	
VA	City of Danville Utilities	URP	100	
WA	Avista	URP	50	
WA	Benton PUD	URP	25	
WA	Clallam County PUD	URP	25	
WA	Columbia REA	URP	25	
WA	Cowlitz PUD	URP	25	
WA	Grays Harbor PUD	URP	25	
WA	Inland Power & Light Company	URP	25	Replacing electric WH
WA	Mason PUD	URP	250	
WA	Modern Electric Water Company	URP	25	
WA	Orcas Light & Power	URP	25	
WA	Pacific Power	URP	50	
WA	Peninsula Light Co	URP	50	
WA	Port Angeles Public Works & Utilities	URP	25	
WA	Puget Sound Electric	URP	500	Unconditioned space
WA	Richland Energy Services	URP	25	
WA	Seattle Light & Power	URP	250	Unconditioned space
WI	Focus on Energy	SRP	25	
WI	Riverland Energy Cooperative	URP	300	
WI	Vernon Electric Cooperative	URP	300	
WY	Cheyenne Light, Fuel & Power	URP	75	
WY	Rocky Mountain Power	URP	75	