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Hannah Cassard, Paul Denholm, and Sean Ong

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.

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Executive Summary

This paper examines the break-even cost for residential rooftop solar water heating (SWH) technology, defined as the point where the cost of the energy saved with a SWH system equals the cost of a conventional heating fuel purchased from the grid (either electricity or natural gas). We examine the break-even cost for the largest 1,000 electric and natural gas utilities serving residential customers in the United States as of 2008. Currently, the break-even cost of SWH in the United States varies by more than a factor of five for both electricity and natural gas (from less than $2,250/system to over $10,000/system for electric and from less than $1,000/system to approximately $5,000/system for natural gas, excluding Hawaii and Alaska), despite a much smaller variation in the amount of energy saved by the systems (a factor of approximately one and a half). The break-even price for natural gas is lower than that for electricity due to a lower fuel cost. It was found that for a $7,000 SWH system capital cost (electric auxiliary heater), break-even conditions currently exist in 73 electric utility service territories (serving 16% of all residential customers). To see similar economics for SWH systems with natural gas backup, the SWH system capital cost would have to drop to $2,500. We also consider the relationship between SWH price and solar fraction (percent of daily energy requirements supplied by the SWH system) and examine the key drivers behind break-even costs. Overall, the key drivers of the break-even cost of SWH are a combination of fuel price, local incentives, and technical factors including the solar resource location, system size, and hot water draw.

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1 Introduction

Water heating accounts for approximately 20% of all household energy use in the United States and 16% of all household energy expenditures (EIA 2005). This corresponds to a national annual consumption of 2.11 quadrillion BTU, or $32 billion, spent each year for water heating (assuming 2005 fuel prices).

Solar water heating (SWH) technology has the potential to reduce household energy consumption by 50% or more. Solar water heaters make use of freely available solar energy to preheat water before it enters a conventional water heater, thereby substantially reducing energy usage, expenditures, and carbon dioxide emissions. Additionally, SWH helps reduce our dependence on uncertain foreign energy supplies.

Market adoption of SWH in the United States remains minimal, with only 100 MWth added in 2007, as compared to 16,000 MWth added in China and 2,000 MWth added in Europe (REN21 2009). A number of reasons for this low penetration include limited retailer presence and associated lack of product offerings and support. In addition, perceived or real issues with aesthetics and reliability and a lack of familiarity and knowledge about the technology have combined to limit consumer adoption, and many people are not aware that SWH is a viable option to reduce energy expenditures. However, a primary driver remains the high initial cost—the life-cycle benefits often do not greatly exceed the capital cost of the system, and benefits such as reduced reliance on fossil fuels and reduced carbon dioxide emissions are external to the consumer and difficult to quantify. This paper attempts to evaluate the economic potential of SWH in the United States in terms of a break-even cost.

The break-even cost for SWH technology is defined as the point where the value of the energy saved with a SWH system equals the cost of the electricity or natural gas required to run an equivalent conventional water heating system. This is essentially the point at which the net present cost (NPC) of the system—installation plus maintenance—is equal to its net present benefits (NPB)—the value of reduced fuel expenditures plus any incentives.[1] This target may be expressed in $/system or $/square foot of collector area.[2] The break-even cost is a function of many variables, including the solar resource, local electricity or gas prices, hot water usage, and available incentives. As a result, for a country like the United States where these factors vary regionally, there can be considerable variation in break-even cost.

In this report, we provide an analysis of SWH break-even costs for residential customers in the United States, and we evaluate some of the key drivers of SWH break-even costs on a regional basis. This study begins by considering a base case scenario evaluating the break-even cost for residential SWH for both an electric and natural gas auxiliary water heater. We consider break-even for the largest 1,000 electric and natural gas utilities in the United States (serving 97% of the total residential demand for electricity and 99% of

[1] This is also equivalent to the point at which the net present value (NPV) of the system is zero.
[2] $/system refers to the initial installed cost of all SWH system components; $/square foot of collector area refers to the initial installed system cost divided by the area of the collecting surface.

the total residential demand for natural gas as of 2008). The base case includes a single set of assumptions for financing, system performance, hot water usage, and several other factors. While we evaluate a base case for both gas and electric backup heaters, the primary focus of this paper is on households with electric water heating (as of 2005, 39% of residential water heaters in the United States were electric with an average water heating demand of 2,814 kWh per house per year, and 54% were natural gas with an average water heating demand of 236 therms per house per year) (EIA 2005). We examine SWH with electric backup in more detail primarily because the economics of these systems are significantly better than those for households using natural gas due to the difference in fuel prices. Currently, the break-even cost of SWH for electric systems in the United States is typically more than double the break-even cost of SWH for natural gas systems. Follow-on studies will examine the potential of SWH for supplementing natural gas in more detail.

We also examine the individual components of break-even cost, including various incentive structures, and analyze the relationship between SWH price and solar fraction (percent of daily energy requirement supplied by the SWH system). Finally, we examine the sensitivity of the break-even cost to five major drivers: system performance, hot water usage, financing parameters, fuel prices, and policies. Currently, federal, state, and local incentives are an important driver of break-even cost, as are technical factors such as system size, hot water usage, and solar resource. It should also be noted that prices charged by different contractors for essentially the same product can vary significantly in a given marketplace. This analysis of the break-even cost of SWH represents neither an estimate of market size nor an estimate of the rate of consumer adoption, but it does provide insight about the potential viability of SWH markets.

2 Base Case Residential SWH Break-even Costs

The break-even cost of a SWH system is influenced by a number of factors, including auxiliary fuel type, available solar irradiation, system performance, hot water usage, fuel price, and local incentives. For the base case scenario, break-even SWH system costs were determined for the solar resource and fuel price location corresponding to the largest electric utility and the largest natural gas utility in each state, using a single set of assumptions for financing, system orientation, hot water usage, and incentives. The following sections describe the base case assumptions and discuss the technical and economic performance of the SWH system. Section 2.1 describes the regional variation in water heating fuel, Section 2.2 the variation in energy demand for water heating, Section 2.3 the technical performance of the system, Section 2.4 the variation in fuel cost and energy value by utility, Section 2.5 the break-even costs and required fuel price increases, and Section 2.6 the breakdown in break-even cost. Sensitivities to these assumptions are evaluated in Section 3.

2.1 Regional Variation in Water Heating Fuel

Of the 110 million households in the United States that require fuel for water heating, 39% use electricity and 54% use natural gas (EIA 2005). Figure 1 illustrates the regional distribution of residential water heating fuel type for each of the nine census regions, as derived from the Energy Information Administration's (EIA's) Residential Energy Consumption Survey (RECS) (DOE 2005). Additionally, specific values are listed for the four most populous states (California, Texas, Florida, and New York).[3] The pie charts indicate the percentage of households in each region that use a given fuel type. A list of region-specific values is provided in Appendix A.

[3] Where a census region includes one of these large states, two pie charts are shown: one for the specific state, and another for the rest of the states in that region.

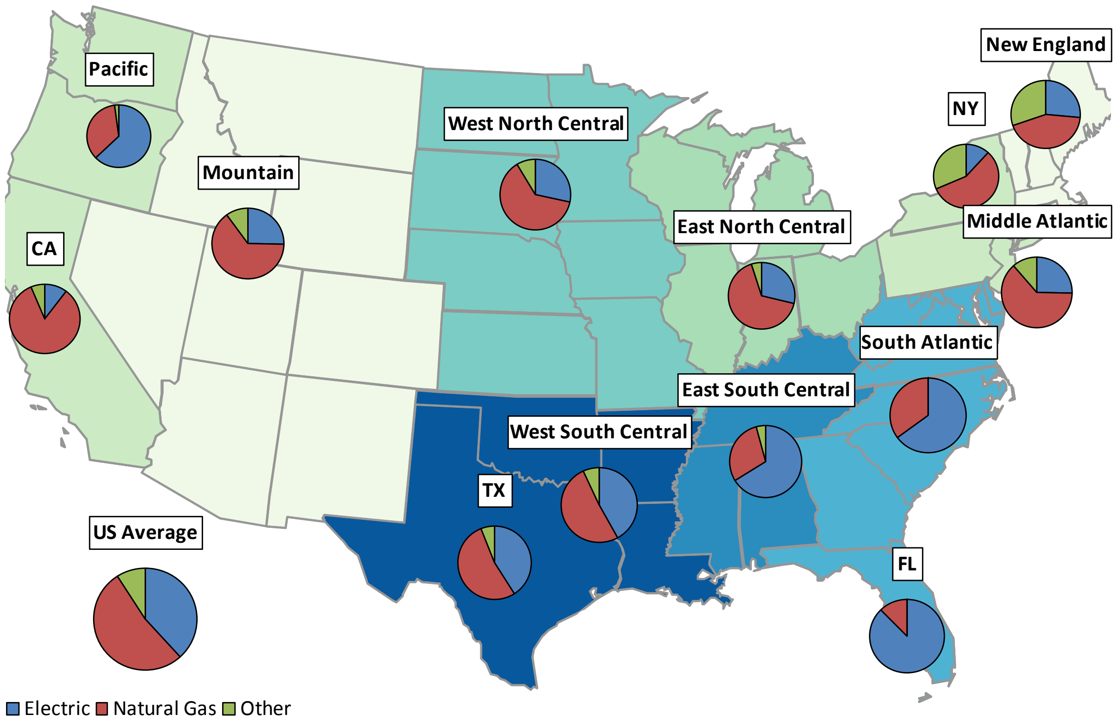

Figure 1. Regional distribution (by U.S. census region) of the number of houses using a particular water heating fuel type

Source: EIA 2005

As shown in Figure 1, a majority of all households utilize either electricity or natural gas for water heating. With the exception of the Northeast, where a quarter to a third of the residences use fuel oil (primarily in older residences), electricity and natural gas account for 90% of all water heating fuel consumption in the United States. Natural gas is the most common fuel type for most of the country, most notably in the Mountain region and California, where natural gas accounts for 68% and 85% of all water heating fuel consumption, respectively. It should be noted that the only regions where electricity is the most common fuel type is in the Pacific Northwest (California excluded) and the South. In Florida, for example, 90% of water heating is electric, primarily due to limited space heating requirements, and therefore, a lack of residential natural gas infrastructure. The low cost of electricity in the Pacific Northwest is one reason why 64% of houses use electric water heating. This paper does not represent a depth of market analysis, but rather, a regional assessment of the viability of SWH systems with either an electric or natural gas auxiliary system.[4]

2.2 Regional Variation in Water Heating Energy Demand

Energy demand for hot water heating is a function of climate, inlet water temperature, house size, and usage patterns of the residents. To determine energy requirements, climate data from the 1991–2005 National Solar Radiation Database (NSRDB) was used (NREL 2007). Referred to as typical meteorological year (TMY3) data, climate info is

[4] It is assumed that the SWH system will use the same auxiliary fuel as the current water heating system.

complied for 1,020 stations throughout the United States (Wilcox 2008). Given these climate parameters and assuming a constant load profile for a single-family house, Figure 2 shows the variation in hot water energy demand for the United States.

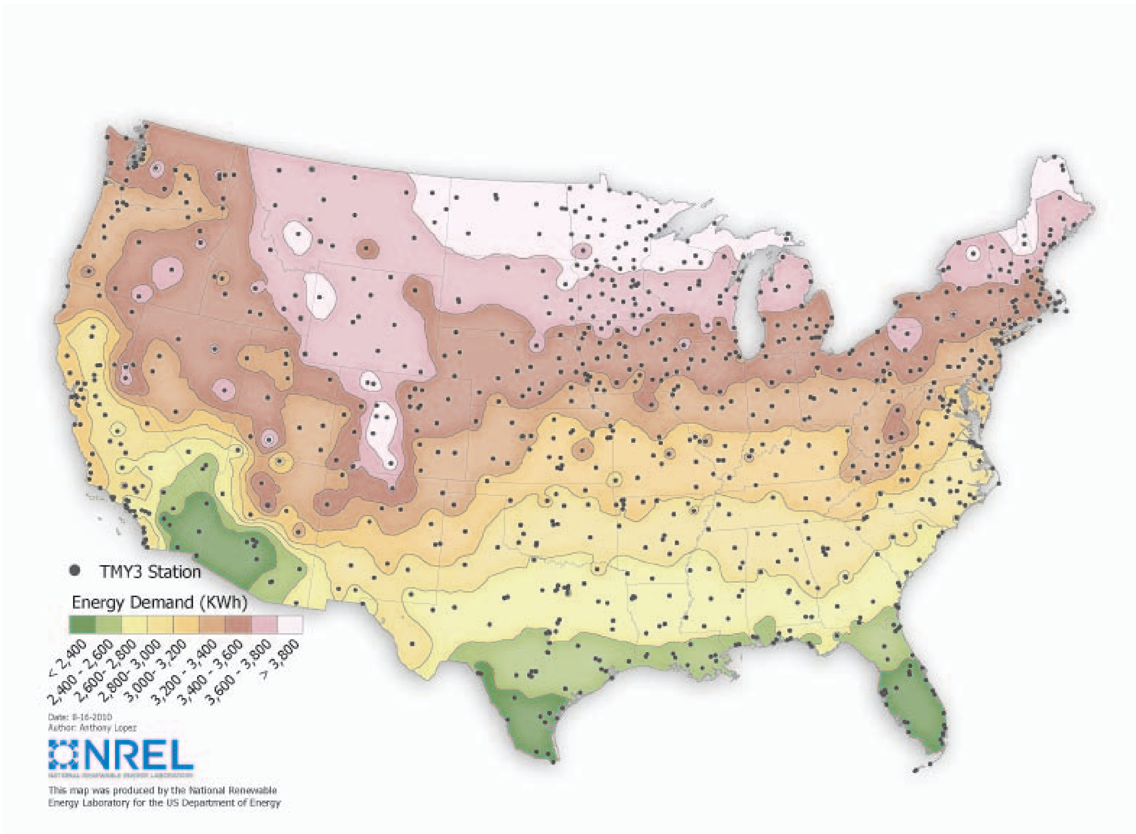

Figure 2. Regional variation in hot water heating energy demand (kWh) for a single-family residence with a constant load profile

As illustrated in Figure 2, the energy required to heat water in warmer climates is significantly less than in colder climates. For the United States, this energy demand ranges from less than 2,400 kWh (in southern California, Texas, and Florida) to over 3,800 kWh (in North Dakota, northern Minnesota, and northern Maine). The Rocky Mountain region generally has a higher water heating energy demand due to cooler inlet water temperatures. The solar fraction and energy savings of a SWH system is influenced by the energy demand. A complete list of the energy demand for the largest utility in each state is included in Appendix B.

2.3 System Performance and Energy Generation

To determine the annual amount of energy saved by the SWH system, we used the Solar Advisor Model (SAM), an analysis tool for solar energy systems developed by the National Renewable Energy Laboratory (NREL). SAM converts solar insolation values to solar energy savings by simulating a two-tank glycol active SWH system with an auxiliary electric heater and storage tank, a typical hot water load profile, 40 ft^2 of collector area,[5] 60 gal of storage volume, a water heater set temperature of 120°F, a water heater energy factor of 90% for electric and 60% for gas, and a burn efficiency of 80% for natural gas (NREL 2010). The base case assumptions include a south-facing system with panels tilted at 26.5°,[6] an annual degradation of 0.5% per year,[7] and all collector and tank loss parameters given in SAM. For consistency, the same system type was simulated for all locations. Active indirect systems are common throughout most of the United States; however, in warmer climates (notably Hawaii and southern Florida) this system is not representative of what might actually be installed. Direct systems are much more common in areas where only occasional freeze protection is required; however, it should be noted that some state incentive programs restrict the use of direct systems (California and Oregon, for example).

For the specified system, SAM calculates the thermal energy savings. In order to convert this value to a fossil fuel input (for natural gas backup), external calculations and the burn efficiency are required. For systems with electric backup, parasitic pumping energy is automatically deducted from the useful output of the system,[8] while for systems with natural gas, backup pumping energy is assumed to be electric and is deducted from the annual value of the energy savings.[9]

For each of the top 1,000 electric and natural gas utilities, a solar resource location (TMY3 station) was selected by choosing the location closest to the population-weighted center of the service territory in each state. A complete list and map of the largest utilities in each state and the corresponding TMY3 site is provided in Appendix B.

The electric energy savings of the base case SWH system across the United States is presented in Figure 3.

[5] Although 40 ft^2 is a common collector size, actual system sizes will vary regionally based on available solar resource, hot water usage, and required solar fraction. It is possible that the selected collection area will be oversized in states with a high solar resource (primarily in the southwestern United States) and undersized in regions with a low solar resource (such as the Pacific Northwest). Sensitivities to collector area will be analyzed in Section 3.
[6] 26.5° corresponds to a roof pitch angle of about 6/12 or roughly midway between the most common roof ranges of 4/12 to 8/12.
[7] This is likely an overly conservative assumption.
[8] This lowers the actual amount of energy produced by approximately 10 kWh per month for an electric system.
[9] The amount of energy required for pumping was computed with SAM, and then the electric price for the largest utility in each state was used to determine how much pumping energy would cost for each natural gas utility.

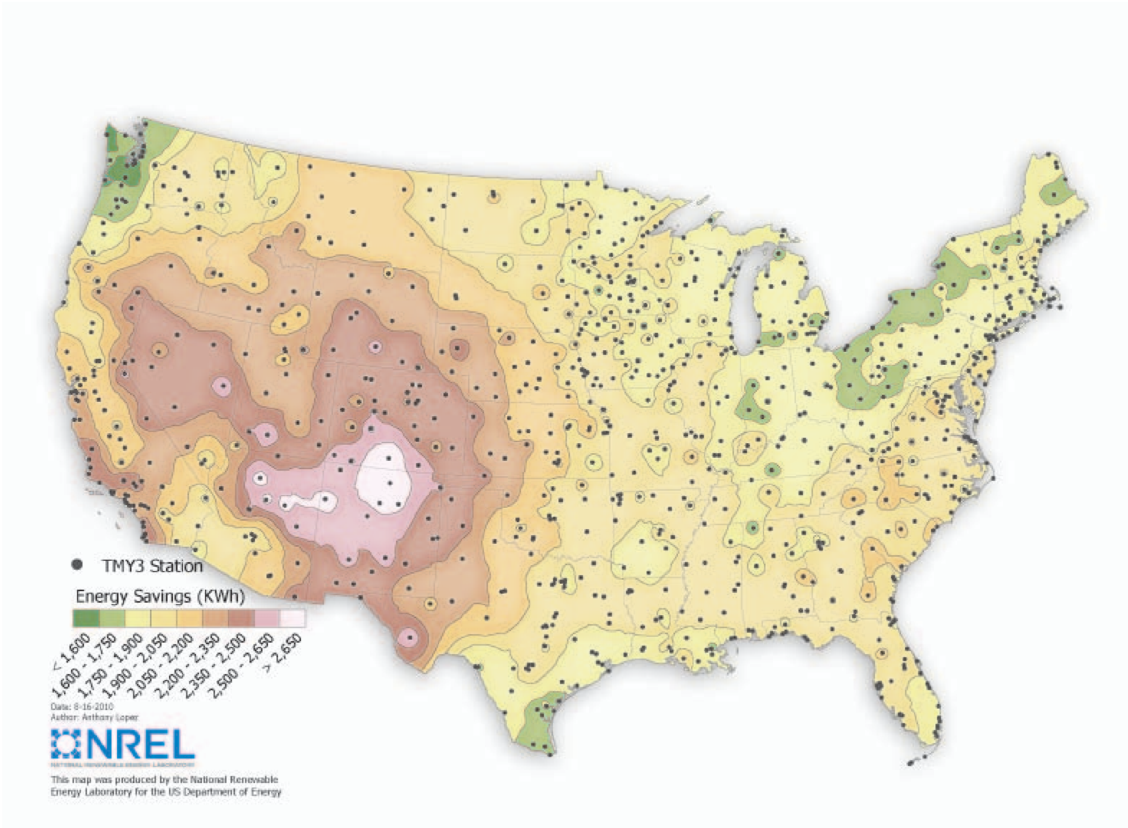

Figure 3. Variation in annual energy savings (kWh/year) for the base case SWH system with an electric auxiliary water heater

As shown in Figure 3, New Mexico and Colorado have the highest energy savings, exceeding 2,400 kWh per year. Except for southwestern Arizona and northern Montana, all states in the Mountain region save over 2,000 kWh annually, as do many in the Midwest. States in the Middle Atlantic and Pacific Northwest generally have lower energy savings, dropping below 1,800 kWh annually. The amount of energy saved is primarily driven by climate factors such as solar resource, cloud cover, precipitation, and inlet water temperature. The higher the inlet water temperature (as in Arizona), the less energy required for water heating, and the lower the quantity of energy saved. Areas with high amounts of annual precipitation and cloud cover (such as Oregon, Washington, and Ohio) have less solar energy available for water heating. States with year-round good solar resource and cooler inlet water temperatures (such as Colorado) will have high energy savings.

The solar fraction is a performance metric that indicates how much of the energy demand is supplied by the SWH system. It is typically expressed in terms of percent of total load met and varies between 0% (no SWH system) and 100% (all energy supplied by the SWH system). On winter days or days with inclement weather, the SWH system may meet none of the daily hot water demands, whereas on sunny, summer days, the system may save more energy than is required to satisfy 100% of the hot water needs. This parameter will vary geographically and with time based on hot water usage and solar resource. Assuming a constant load profile for a single-family home, Figure 4 illustrates the solar fraction of the base case SWH system over the contiguous United States.

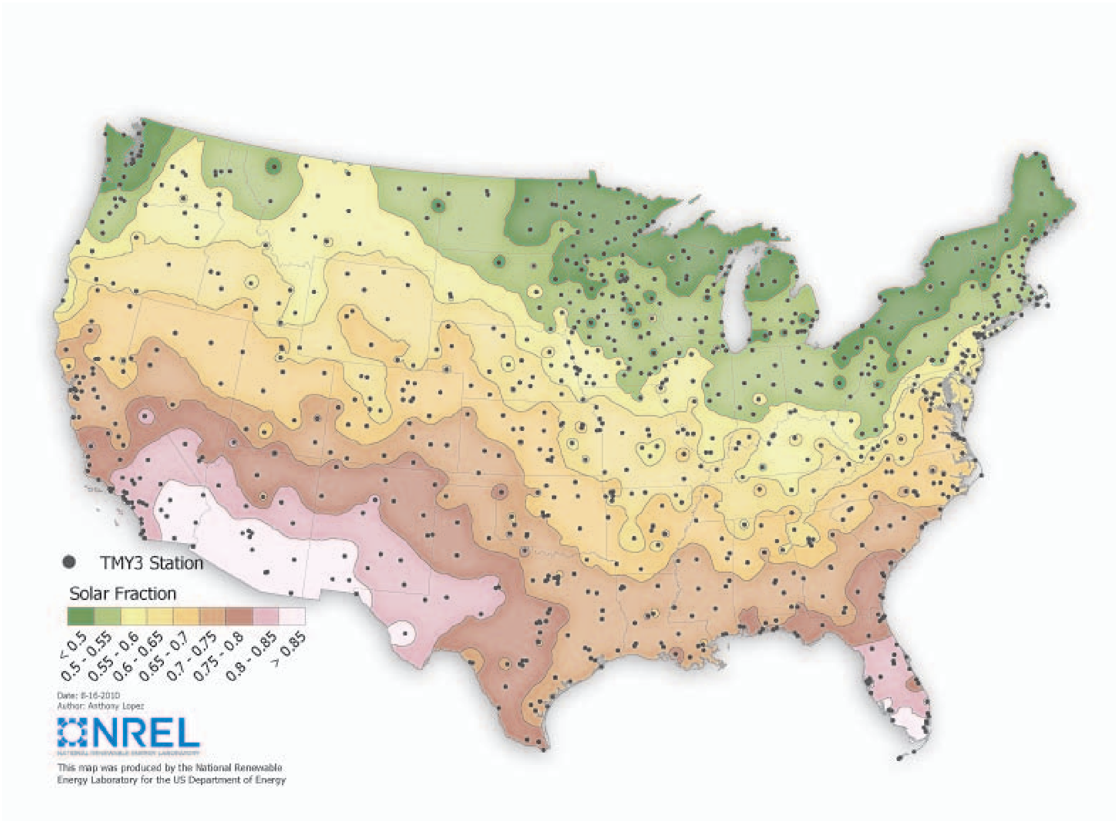

Figure 4. Variation in annual solar fraction (percent of daily load met by the SWH system) for the base case SWH with an electric auxiliary water heater

As shown in Figure 4, the solar fraction is highest in the Southwest and southern Florida and decreases toward the north and east of the country. Arizona and Florida have the highest solar fractions, exceeding 85%, while in northern Washington, Minnesota, and Michigan, the solar fraction drops below 45%. A complete list of state-specific energy savings and solar fraction values is provided in Appendix B.

Seasonal variations in the solar fraction are also significant. Depending on the amount and consistency of the solar resource over the course of a year, there may be considerable variation in the solar fraction for a given location from month to month. For example, Arizona and Florida have a relatively constant solar fraction (corresponding to little seasonal variation in annual solar resource), while in Oregon and Washington, the solar fraction varies from less than 40% between October and February to more than 70% between May and September. A complete list of winter/summer solar fractions for the largest electric utility in each state is included in Appendix C. Factors that contribute to this seasonal variation in solar fraction include cloud cover, precipitation, and ambient temperature. Oregon and Washington have a relatively cloudy winter, which significantly decreases the solar fraction during these months. Additionally, cooler ambient temperatures yield lower inlet water temperatures and require more energy for heating. A system that has a solar fraction of 100% during any time of the year is oversized and curtailment occurs, indicating that more solar energy is available than can be utilized by the system. A smaller system size reduces the amount of energy curtailed. The relationship between break-even SWH system cost and solar fraction is discussed in Section 3.

2.4 Fuel Prices and Value of Energy Saved

The net present benefit (NPB) realized to the consumer is based on the discounted cumulative benefits of reduced electricity or natural gas bills over the evaluated period, driven by the local SWH system performance, hot water usage, and electricity or gas rate. The NPB is highly sensitive to the price of the fuel used and the daily hot water draw. In this analysis, we considered only flat rates for both electricity and natural gas—due to the high level of variability in hot water usage, it is difficult to estimate the impact of time-of-use rates.

The break-even cost for SWH was calculated for the top 1,000 electric and natural gas utilities in the United States, which represent about 97% of the total residential load for electricity (based on annual revenue) and 99% of the total residential load for natural gas. For both electricity and gas rates, the EIA utility data for 2008 were used (EIA 2010a; 2010b; 2010c). Form EIA-861 data provides the average monthly and annual retail electric price for the residential sector by state in addition to the average annual residential electric price by utility. Form EIA-176 data provides the average retail natural gas price by utility, while form EIA-857 data provides the average monthly and annual retail natural gas prices for the residential sector by state. Using the state average monthly and annual data, a scaling parameter was generated by dividing the monthly fuel price by the annual fuel price to determine what percentage of the annual average fuel price occurs in each month. This parameter was then used to generate monthly utility price data from the annual average prices for each utility. These values provide no insight into the actual rate structure because they average over a month and include fixed billing charges and other components that would not be offset by customer-sited SWH. Since the EIA fuel price data includes components such as fixed charges that would not be offset by the addition of a SWH system, an adjustment factor was generated to establish the relative difference between the reported monthly fuel prices and the actual value of SWH. Information from the current tariff sheet for the largest electric or gas utility in each state was used to generate this adjustment factor.[10]

Using monthly simulation data from SAM, we multiplied the output of the SWH system by the monthly electric or gas price and summed over a year to determine the weighted annual average value of the energy saved ($). The first year values for the largest utility in each state are presented in Figure 5 and Figure 6 for electricity and natural gas.

[10] There is no known single database for all utility tariff sheets. Tariff sheets were gathered from each utility's website. Because the base tariff sheets often do not include additional costs such as fuel adjustment clauses, the tariff sheets should be read with care. Also, rates from utilities in states that offer customer choice programs may only provide delivery charges with energy costs added separately.

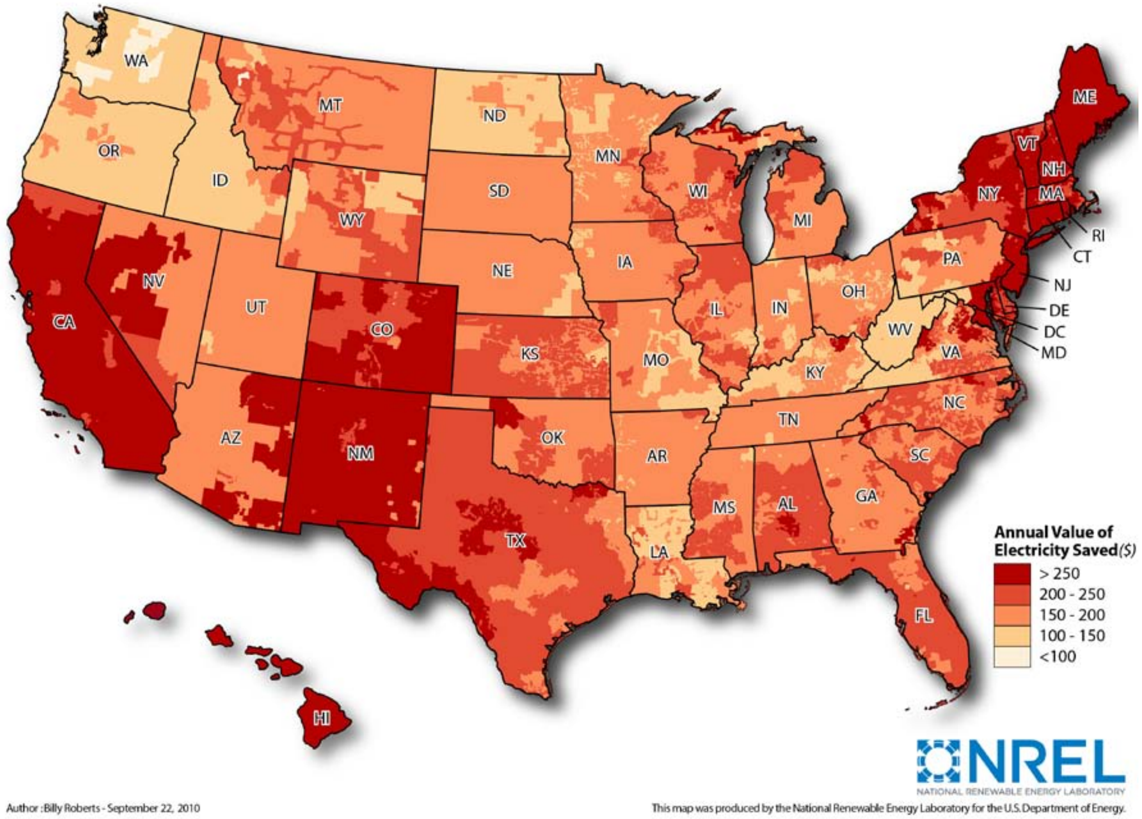

Figure 5. Annual value of energy saved ($) for the base case SWH system with an electric auxiliary water heater for the top 1,000 residential electric utilities

As illustrated in Figure 5, locations with a combination of high energy production and high electric prices have a high value of the NPB. Currently 10% of residential electricity sales are in utilities that have energy savings greater than $300/year, while all but 3% of residential electricity sales are in utilities that have energy savings greater than $100/year. A complete list of energy savings for the largest electric utility in each state is presented in Appendix B.

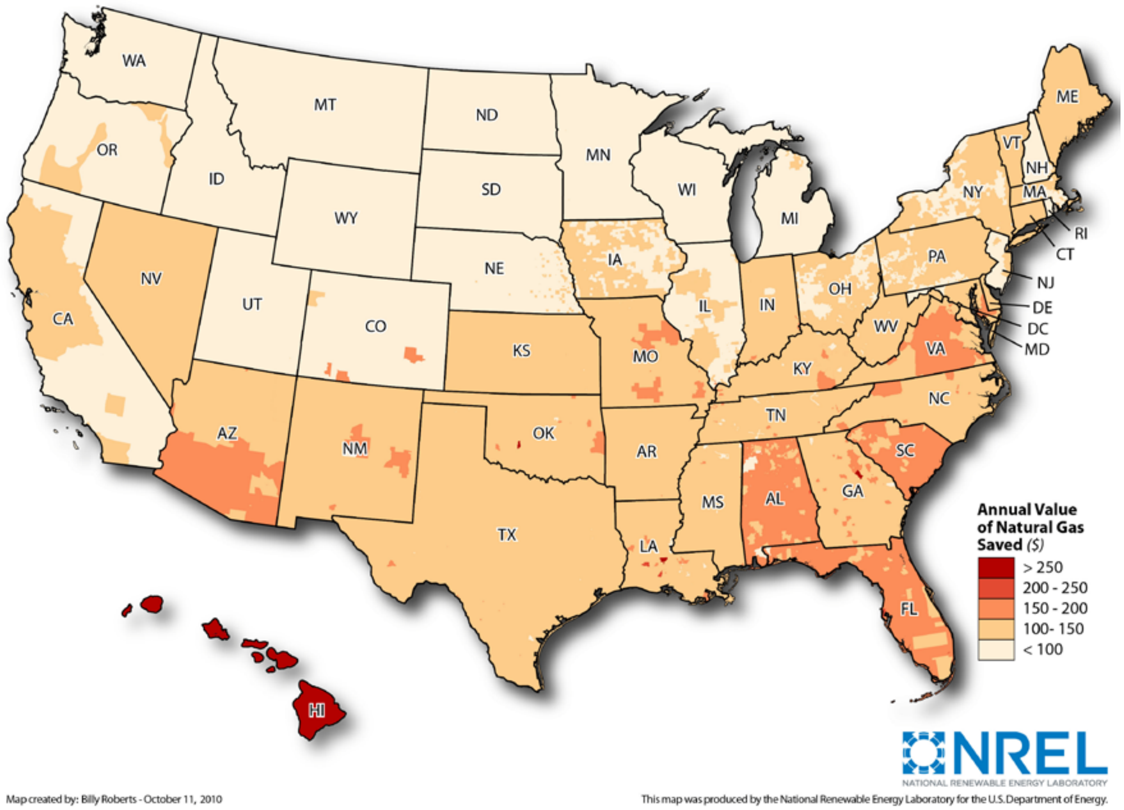

Figure 6. Annual value of energy saved ($) for the base case SWH system with a natural gas auxiliary water heater for the top 1,000 natural gas utilities serving residential customers

The value of the energy savings from SWH systems with natural gas auxiliary is significantly less than for those with electric auxiliary. As the energy production of the systems is approximately the same, this difference in value is primarily driven by low gas prices. As shown in Figure 6, 41% of residential natural gas sales are in utilities that have energy savings of less than $100/year. Almost all (99.9%) residential sales occur in utilities that save less than $200/year. Again, a complete list of energy savings for the largest natural gas utility in each state is presented in Appendix B.

2.5 Break-even Costs

We define the break-even cost of SWH as the point at which the net present cost (NPC) of the SWH system equals the NPB realized to its owner—the difference between the NPB and NPC yields the net present value (NPV) of the system. This can be used to find the installed system cost ($/system) required for a given fuel price *or* the price of fuel (cents/kWh or $/therm) required for a given installed system cost. By definition, a SWH system is at break-even or better when its installed cost falls below the break-even value or when no increase in fuel price is required. For example, in an area with a break-even cost of $7,000, all SWH systems that have an installed cost of less than $7,000 are at break-even (and the fuel price increase would be zero or negative). The break-even system cost was calculated by iteratively varying the price of SWH until the NPC equaled the NPB. Alternately, the break-even fuel price was calculated by iteratively varying the cost of electricity or natural gas until the NPB equaled the NPC. A review of the methods used to calculate NPC and NPBs is provided in Appendix D.

The NPC of the system includes all financing and incentives, while the NPB is the cumulative discounted benefits of reduced electric or gas bills (as described in Section 2.3).[11] The NPC in our base case scenario assumes a system financed with a home-equity-type loan (with tax-deductible interest and a 28% marginal federal tax rate), a 20% down payment, a real interest rate and discount rate of 5%, and a loan term of 30 years.[12] The evaluation period for the analysis was 30 years.[13] Future price escalation is also considered in the cash-flow calculation. In the base case, we assume that both electricity and gas have a real price escalation of 0.5%/year.[14]

The analysis considered several incentive programs, including the 30% federal investment tax credit (ITC), as well as known state, local, and utility incentives derived from the DSIRE database.[15] Where multiple incentive programs are available, they are assumed to be additive (this is the case for most but not all incentive programs). Tax credits were applied at the end of year one in the NPC calculation.[16] When considering rebates, their taxability and effect on the federal ITC must be considered. In our base case assumption, we assume that the rebate is paid to the installer rather than the homeowner. This effectively reduces the installation price to the homeowner by the amount of the rebate and also reduces the basis for the federal ITC.[17] A list of the state and local incentives used in this analysis is provided in Appendix E.

[11] Again, it is assumed that the auxiliary fuel type is the same as that which would be in use if no SWH system were installed.

[12] Here and elsewhere, we use real interest rates as opposed to nominal interest rates. The relationship is real interest rate = nominal interest rate – inflation rate. To calculate the nominal interest rate, an average inflation rate must be assumed. Our assumption of a 5% real interest rate is based on the 2008–2009 average home equity loan rate of about 8% and the average inflation rate of about 3% during this period.

[13] This implies an expected 30-year life of the system.

[14] This is a real price escalation (before the effects of inflation). Estimates of future electricity prices are highly uncertain, and sensitivities to this assumption are provided in the next section. For reference, the EIA's Annual Energy Outlook 2009 (EIA 2009) projects an annual real increase from 2008 to 2030 of 0.4%.

[15] Database of State Incentives for Renewables and Efficiency (DSIRE), http://www.dsireusa.org/. All incentives are as of June 14, 2010.

[16] This analysis makes several assumptions that are generally favorable to SWH. First, it assumes that SWH systems are exempt from sales tax, which is true in some but not all states. In states where SWH systems are taxed, the break-even cost would be reduced by a percentage roughly equal to the sales tax rate. Second, the analysis assumes that SWH systems are exempt from property tax, which is also true for many but not all regions and states. For a list of states and localities that exempt SWH systems from sales and property tax, see DSIRE (http://www.dsireusa.org/).

[17] The actual treatment of incentives varies depending on their type and source. The primary alternative treatment of incentive taxability occurs when the incentive acts as taxable income but does not decrease the basis for the federal ITC. In reality, with our assumption of a marginal tax rate of 28%, the difference in break-even price is quite small.

When calculating the near-term break-even electricity or gas price (where the SWH system cost is fixed), we assumed a 2008 installed cost of $7,000/system and a tank and heat exchanger fluid replacement at 10 and 20 years.[18]

Overall, the combination of factors described above represents a customer with excellent home orientation and access to attractive financing but who places no additional value on locally produced renewable energy. Sensitivities to these assumptions will be evaluated in Section 3.

As discussed previously, the break-even point is found by iteratively increasing the cost of the SWH system or the fuel cost until the NPC equals the NPB over the evaluation period. A spreadsheet/Visual Basic for Applications tool (Denholm et al. 2009) was utilized to perform the financial calculations.

Figure 7 provides the break-even cost of SWH ($/system) needed in the base case electric rate scenario for the largest utility in each state. All assumptions are identical to those of the base case. A complete list of state-specific break-even values is given in Appendix F.

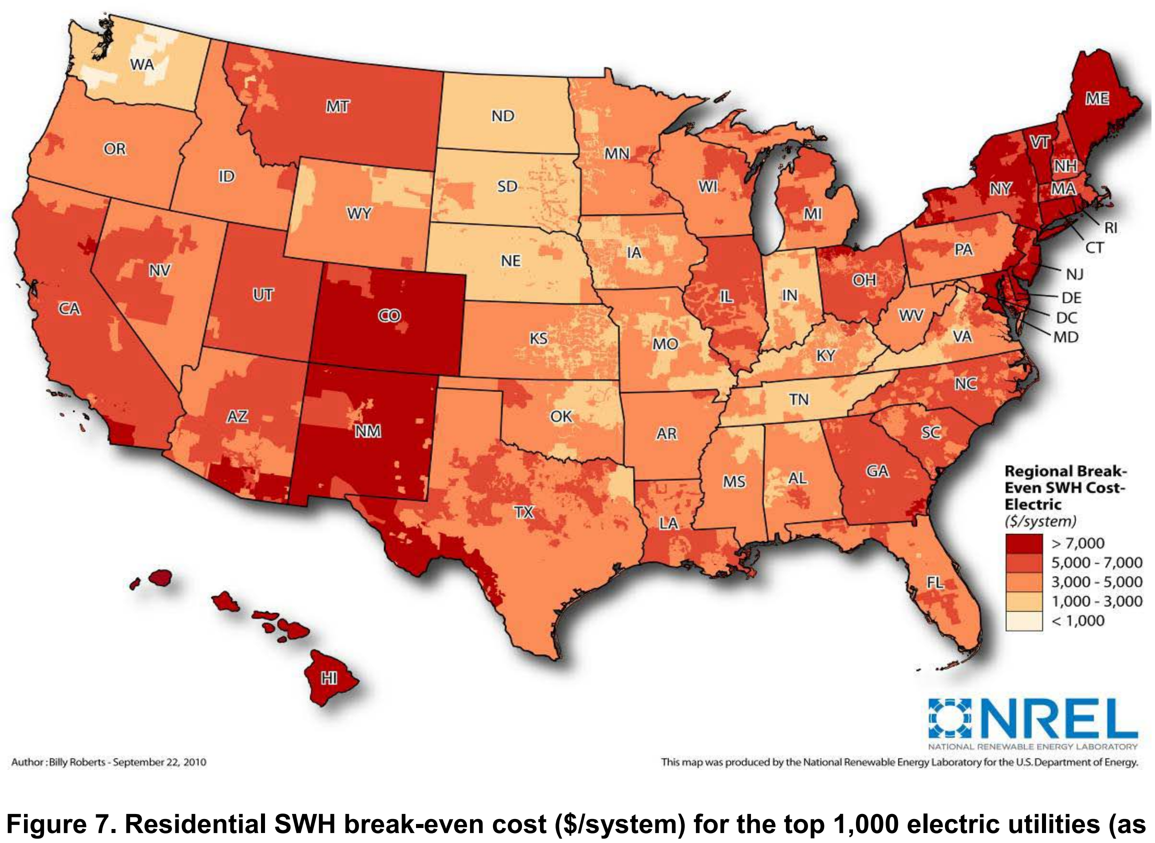

Figure 7. Residential SWH break-even cost ($/system) for the top 1,000 electric utilities (as of 2008) for a SWH with an electric auxiliary water heater and using all incentives

[18] It is assumed that operation and maintenance costs are $1,000 every 10 years to cover tank and heat exchanger fluid replacement.

When considering the results presented in Figure 7 and elsewhere, readers should note that this analysis represents a single point in time. Because incentives and fuel prices are constantly changing, results for any single area may be substantially different when evaluated later.

Figure 7 indicates that the only areas where a SWH system is at break-even or better is where there is a combination of high electricity prices (as in Hawaii and much of the east coast), good solar resource (as in Hawaii, Colorado, and New Mexico), and local incentives. At the base case assumption of $7,000/system, break-even conditions currently exist in 73 utility service territories (serving 16% of the total residential electricity demand). This means that in these service territories, the break-even cost is above the assumed SWH system cost of $7,000. If the cost of a SWH system were to drop to $5,000/system, break-even conditions would exist for 366 electric utilities (51% of the total residential demand). It is important to note that in practice, only a fraction of customers in these utility service territories are likely to meet all the criteria (good solar exposure, good incentives, and financing) to be at break-even, and the presence of break-even conditions does not necessarily equate to large consumer adoption. Furthermore, there are budget caps for most current incentive programs.[19]

This basic methodology used to generate Figure 7 was repeated for the gas rate scenario. All assumptions are identical to the base case. The results of this analysis are shown in Figure 8.

[19] See DSIRE, http://www.dsireusa.org/.

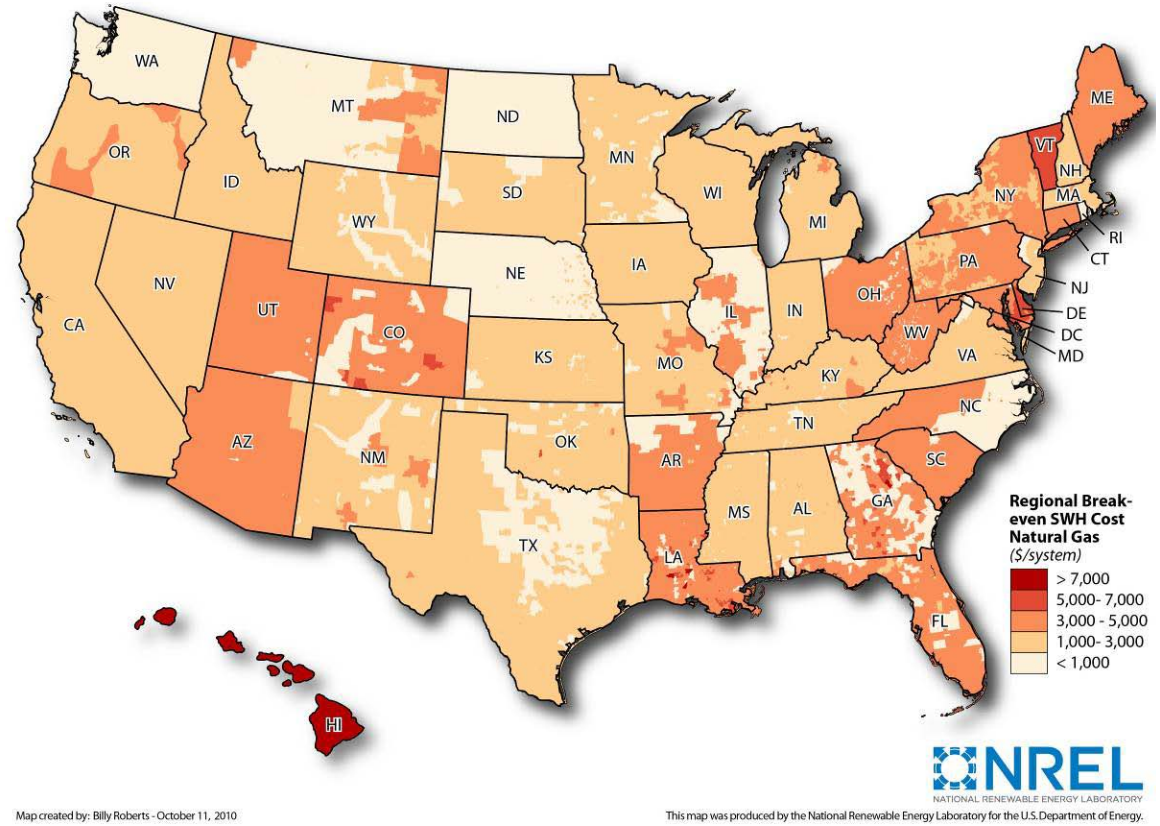

Figure 8. Residential SWH break-even cost ($/system) for the top 1,000 natural gas utilities (as of 2008) for a SWH with a natural gas auxiliary water heater and using all incentives

There are significantly fewer states currently at break-even for a $7,000 system cost when deployed with natural gas. In general, gas prices tend to be lower than electricity, and annual savings are therefore less. A state-by-state comparison of annual energy savings is provided in Appendix B. At the base case assumption of $7,000/system, break-even conditions exist in less than eight utilities (0.04% of the total residential energy demand), whereas at a SWH system cost of $4,000/system, break-even conditions exist in just over 200 utilities (serving 11% of the total residential energy demand). In order for break-even conditions to exist in half of the United States, the SWH system price would need to drop to $2,500/system. As noted before, actual adoption will be restricted by consumer adoption behavior and limits on incentives.

Figure 9 repeats the analysis in Figure 7 but illustrates the break-even electricity price increase (in cents/kWh) rather than the break-even SWH system price. In this case, the price of SWH is assumed to be $7,000/system, and the values on the chart represent the *increase* in retail electricity price relative to the assumed system price needed to break-even. Values less than zero represent utilities for which break-even cost was achieved (or very nearly achieved) at $7,000/system with the base case assumptions. All other assumptions are identical to the base case.

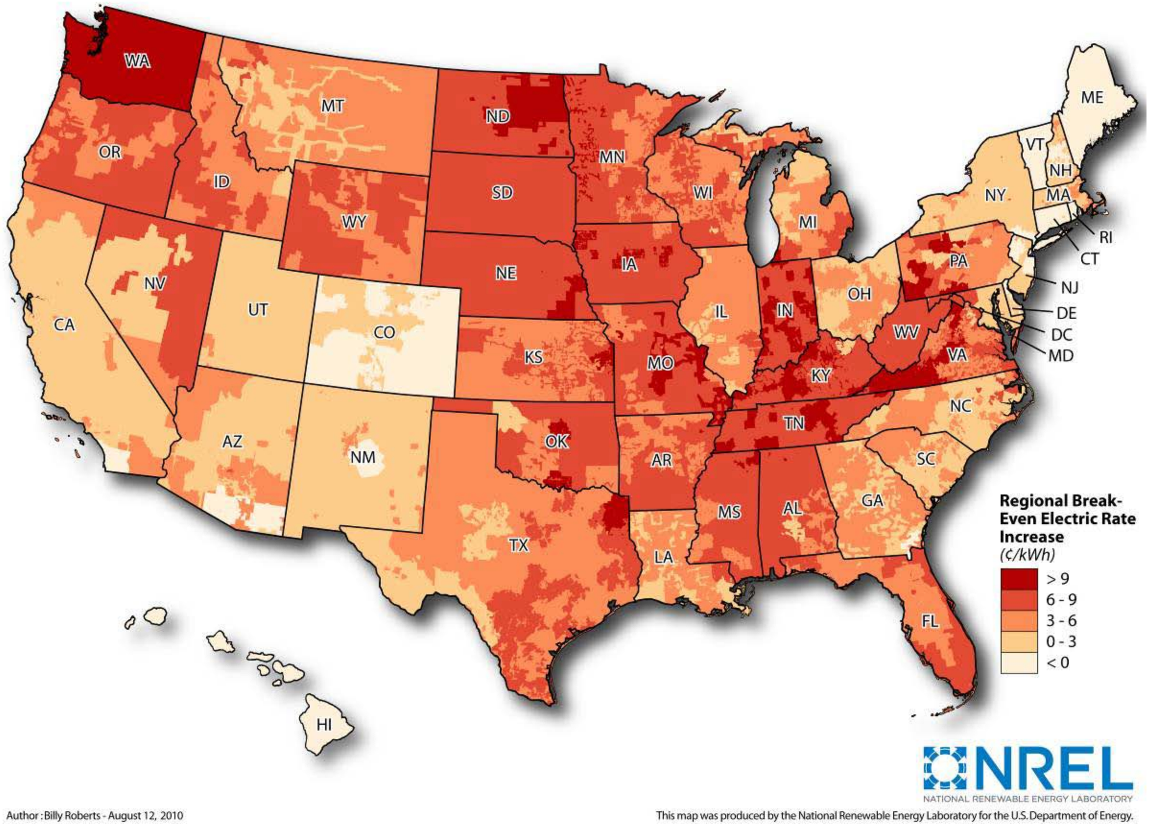

Figure 9. Increase in electricity price required for the base case residential SWH break-even at $7,000/system

Figure 9 shows the same trends as Figure 7. The areas indicated by a rate difference of less than zero cents/kWh are by definition at break-even and match the areas in Figure 7 where the break-even price is greater than $7,000/system. The break-even electric price is largely affected by solar resource and incentives. Figure 9 shows that some areas of the country are already at break-even, although a minor increase in the price of electricity is needed in about half the country to achieve break-even conditions, assuming no further decrease in the price of SWH. For example, if the price of electricity were to increase five cents/kWh (from the baseline 2008 values) across the United States, break-even conditions would exist in over half of the country. Again, note that this is not a depth of market analysis and only a fraction of customers are likely to meet all the criteria for break-even.

A substantial increase in natural gas prices would need to occur in most of the United States to achieve break-even conditions. As an example, if natural gas prices doubled (from the 2008 baseline), only 25% of the residential energy demand would be in utilities where break-even conditions exist for a $7,000 system.[20] Since SWH has been shown to

[20] Over the past 10 years there has been considerable fluctuation in average residential natural gas prices, ranging from $0.78/therm in 2000 to $1.39/therm in 2008 (EIA 2010c).

be more competitive with electricity than natural gas, this analysis will primarily focus on systems that replace electricity.

2.6 Components of Break-even Costs

The total break-even cost in each location is the sum of the value of SWH from the fuel savings and the additional value derived from incentives. This is illustrated for electricity in Figure 10, which shows the break-even cost for the largest utility in each state along with a distribution of the break-even cost components, including the net value derived from the electricity savings [includes both operation and maintenance (O&M) expenses of the solar system and annual revenues in electricity savings], the effect of the home-equity-type loan, and federal and local incentives. The black line indicates the break-even cost without any federal or state incentives. Also included are error bars indicating the range in break-even values for the largest 1,000 utilities. California was divided into two sub-regions, northern and southern, due to its large size. New York was also divided into two regions due to the large differences between the New York City/Long Island region (together labeled "NYC") and the remainder of the state (labeled "NY"). The scale is cut off at $13,000/system, which is estimated to be the maximum 2010 market price of residential SWH.

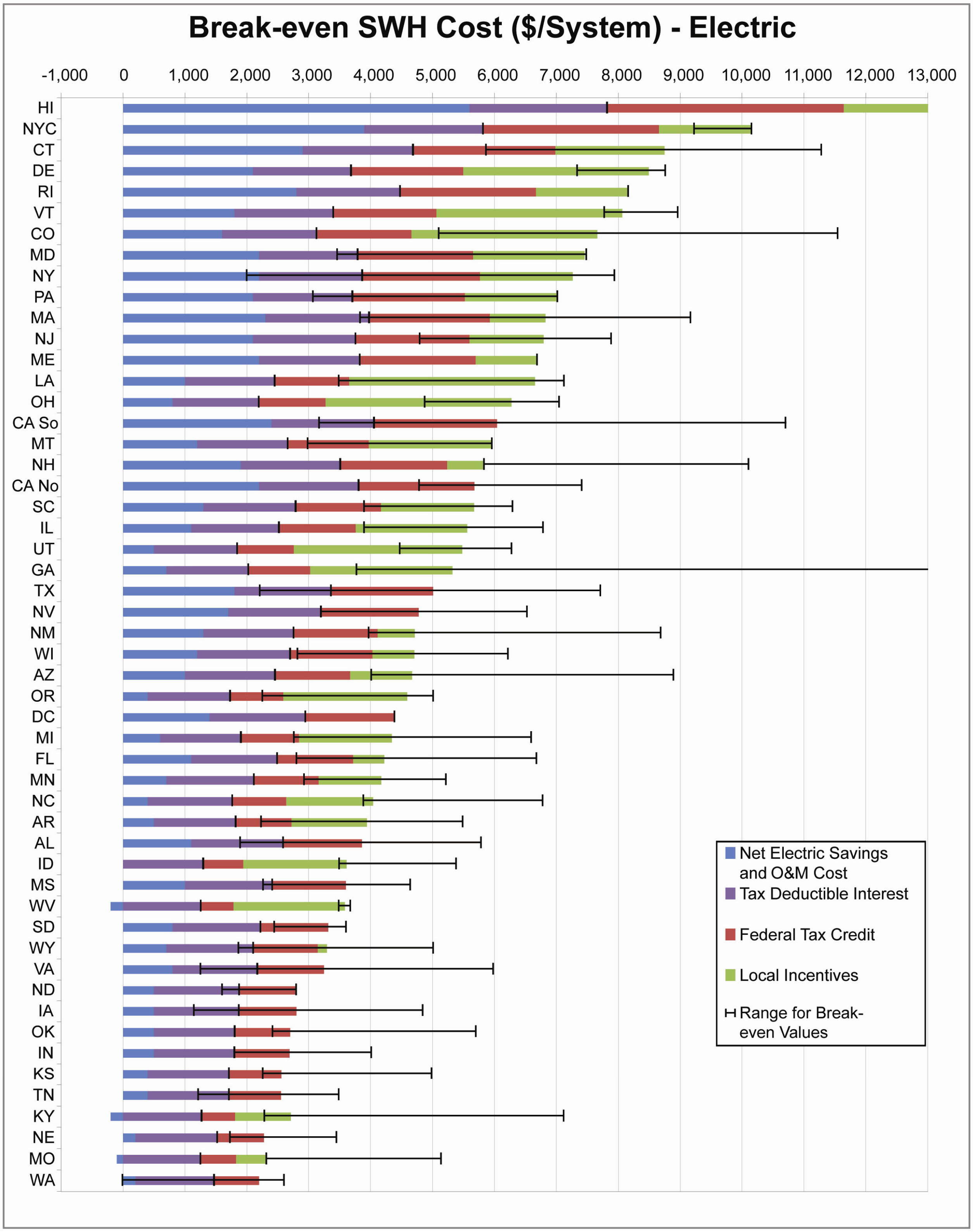

Figure 10. Components of the electric break-even value and range in break-even value for each region (as of June 14, 2010)

As shown in Figure 10, the break-even SWH price shows significant variability. In some cases, the break-even value for the most attractive utility is several thousand dollars more than the largest utility. However, these more attractive utilities tend to be significantly smaller than the largest utility, often providing less than a few percent of the state's sales. For electricity, we see break-even prices above $7,000/system in only a few places without local incentives. In addition, without local incentives or the federal ITC, two-thirds of the largest electric utilities in each state have a break-even cost of under $3,000/system. Three states, Kentucky, West Virginia, and Missouri, have a negative value for the net electricity savings. This indicates that the savings in electricity were not sufficient to cover the O&M expenses of the system. The factors affecting break-even cost are discussed in more detail in Section 3.

3 Market Sensitivities of Break-even Costs

The high break-even costs in many states that were noted in the previous section are driven primarily by state, utility, and federal incentive programs. Incentive programs are designed primarily to encourage the development of SWH markets; however, over time they are expected to be phased down as the cost of SWH systems decrease and SWH markets become self-sustaining. In this section, we consider the sensitivity of SWH break-even costs to a number of factors.

In order to determine how much more (or less) a SWH system could potentially cost based on its solar fraction, relationships between SWH cost and solar fraction were developed for each state and are presented in Figure 11 (electric). For a given location, systems with large collector areas or improved performance (due to higher quality materials, glazings, and insulation, for example) will have higher solar fractions than systems with small collector areas or lower quality materials. To determine the relationship between SWH cost and solar fraction, the base case break-even SWH price was plotted against solar fraction for three typical system sizes: 20, 40, and 60 ft^2. The base case scenario utilizes a 40 ft^2 collector area. The low value could represent either a system with a smaller collector area or decreased performance (unglazed, no cover), while the high value could represent a system with a larger collector area or improved performance (dual covers, improved glazing). It is important to note that an increased solar fraction may not necessarily correspond to an economic advantage. Oversized systems will be curtailed, and excess energy will not be utilized. For states with a high solar resource, Figure 11 may be utilized to determine how much *less* the SWH system could cost in order to maximize use of the energy collected.

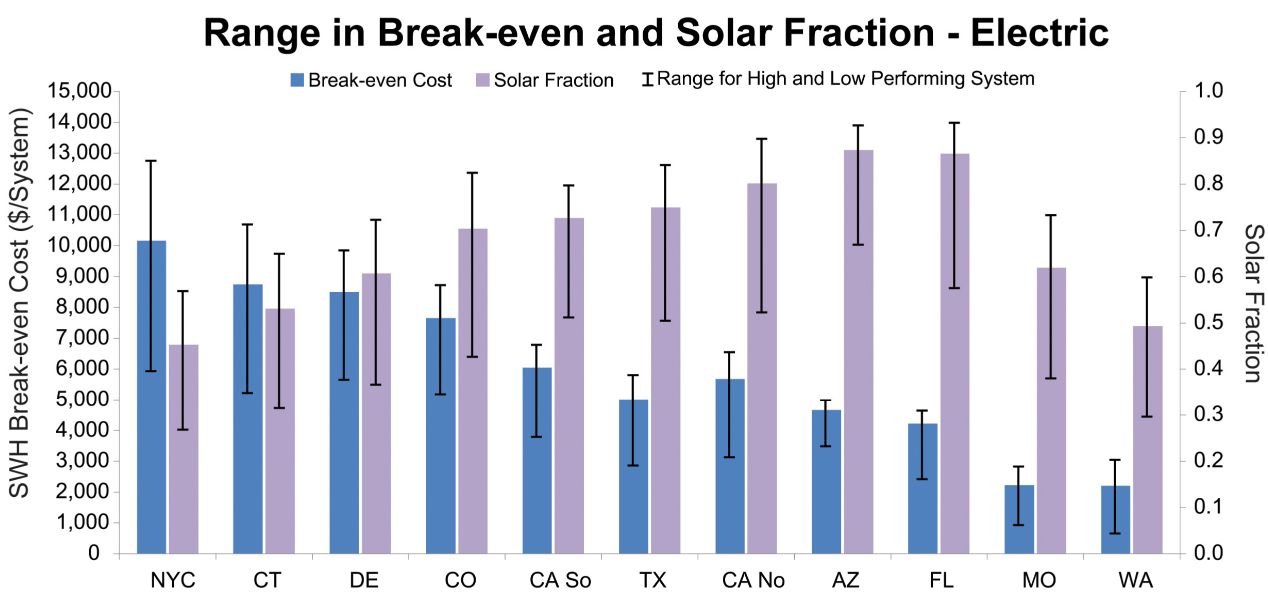

Figure 11. Range in SWH break-even cost and solar fraction for select states for a SWH with an electric auxiliary water heater

Figure 11 shows the base case SWH break-even cost and solar fraction (represented by the blue and purple bars in Figure 11) for select states for a 40 ft^2 collector area, in addition to error bars representing the break-even cost and solar fraction for both a 20 ft^2 collector area (low end of error bars) and 60 ft^2 collector area (high end of error bars). The SWH break-even cost varies linearly with solar fraction, indicating that for a given state, direct interpolation is possible between the two error bars to determine the SWH break-even cost corresponding to a system with a given solar fraction and vice versa. A sample interpolation calculation is provided in Appendix G. For a number of states, the base case system size already has a high solar fraction, which means that many of the error bars are skewed towards the lower value. This indicates that increasing the system size or performance does not yield a significant increase in the amount of energy produced. A complete list of state-specific break-even values and solar fractions for each of the three collector area sizes is provided in Appendix F.

The results presented above may be utilized to determine if a more expensive system with a higher solar fraction is economical. For example, for a SWH system in Colorado, the base case break-even cost is $7,660 with a solar fraction of 70%. To determine what the SWH break-even cost should be for a system with a solar fraction of 80%, it is necessary to find the point along the error bar for solar fraction that corresponds to 80%. Since this point appears to lie nearly at the high end of the error bar, the break-even SWH system cost should also lie near the high end of the error bar, or at approximately $8,500. If a SWH system with an 80% solar fraction in Colorado is available for less than $8,500, then it would be at break-even. Solar fractions for all rated systems and a variety of locations may be found on the SRCC website (http://www.solar-rating.org/).

Finally, we examined the sensitivity of the break-even cost for each state to a set of five classes of impacts: financing, system performance, hot water usage,[21] fuel cost, and policies. Table 1 lists the base case and the five sensitivity cases evaluated.

[21] Information on hot water usage in the United States was taken from the Energy Efficiency and Renewable Energy website (http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12850).

Table 1. SWH Sensitivity Cases [a]

<table>
<tr><th colspan="2" rowspan="2">Base Case</th><th colspan="2">Financial</th><th colspan="2">System Performance</th><th colspan="2">Hot Water Usage</th><th colspan="2">Fuel Price</th><th colspan="2">Policy</th></tr>
<tr><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th></tr>
<tr><td>Down Payment</td><td>20%</td><td>20%</td><td>0%</td><td colspan="2" rowspan="6">Base</td><td colspan="2" rowspan="14">Base</td><td colspan="2" rowspan="16">Base</td><td colspan="2" rowspan="18">Base</td></tr>
<tr><td>Federal Tax Bracket</td><td>28%</td><td>20%</td><td>35%</td></tr>
<tr><td>Discount Rate</td><td>5%</td><td>7%</td><td>4%</td></tr>
<tr><td>Interest Rate</td><td>5%</td><td>7%</td><td>4%</td></tr>
<tr><td>Loan Type</td><td>30-y home equity</td><td>15-y home equity</td><td>30-y home equity</td></tr>
<tr><td>Evaluation Period</td><td>30 y</td><td>20 y</td><td>30 y</td></tr>
<tr><td>Tilt</td><td>26.5°</td><td colspan="2" rowspan="14">Base</td><td>15°</td><td>26.5°</td></tr>
<tr><td>Azimuth</td><td>360° (S)</td><td>45° (SW)</td><td>360° (S)</td></tr>
<tr><td>System Size (Collector Area, Volume)</td><td>40 ft², 60 gal</td><td>32 ft², 48 gal</td><td>64 ft², 96 gal</td></tr>
<tr><td>Water Heater Energy Factor (Gas)</td><td>0.6</td><td>0.5</td><td>0.7</td></tr>
<tr><td>Water Heater Energy Factor (Elec)</td><td>0.9</td><td>0.8</td><td>0.98</td></tr>
<tr><td>Solar Resource Location</td><td>Largest Utility</td><td>Lowest</td><td>Highest</td></tr>
<tr><td>System Degradation</td><td>0.5% per year</td><td>0.5%</td><td>0%</td></tr>
<tr><td>O&M</td><td>$1,000 per 10 years</td><td>$1,500</td><td>$500</td></tr>
<tr><td>Hot Water Draw</td><td>60 gal/d</td><td colspan="2" rowspan="6">Base</td><td>30 gal/d</td><td>100 gal/d</td></tr>
<tr><td>Water Heater Set Temp</td><td>120°F</td><td>120°F</td><td>140°F</td></tr>
<tr><td>Real Fuel Price Escalation</td><td>0.5% per year</td><td colspan="2" rowspan="4">Base</td><td>0%</td><td>1.5%</td></tr>
<tr><td>Fuel Cost Location</td><td>Largest Utility</td><td>Lowest</td><td>Highest</td></tr>
<tr><td>CO² Cost</td><td>$0</td><td colspan="2" rowspan="2">Base</td><td>$0</td><td>$25/ton</td></tr>
<tr><td>Incentives</td><td>DSIRE (6/14/10)</td><td>None</td><td>DSIRE (6/14/10)</td></tr>
</table>

[a] The values used in Table 1 are not intended to represent all possible scenarios but were chosen to provide a reasonable range of values for each parameter.

Figure 12 and Figure 13 provide the results of the sensitivity analyses. In each state, a base case break-even cost based on the largest utility in the region is provided; five error bars show the range of break-even costs for the sensitivity cases. Each of the five drivers has a low case and a high case. The low case, which decreases the economic performance of SWH and moves the error bar left, represents a lower break-even cost. Examples include lower SWH output from non-optimal orientation or a premature elimination of the federal ITC. The high case represents improved economic performance, increasing the break-even price. Examples include a higher solar fraction (perhaps corresponding to a larger system) or a larger effective cost of carbon.

The scenarios and error bars in the figures are partially additive. For example, both a more aggressive carbon policy and a high solar fraction could occur, increasing the break-even cost more than these factors individually. However, these factors are not completely additive; for example, the highest solar resource location in each state may not correspond to the highest price region.

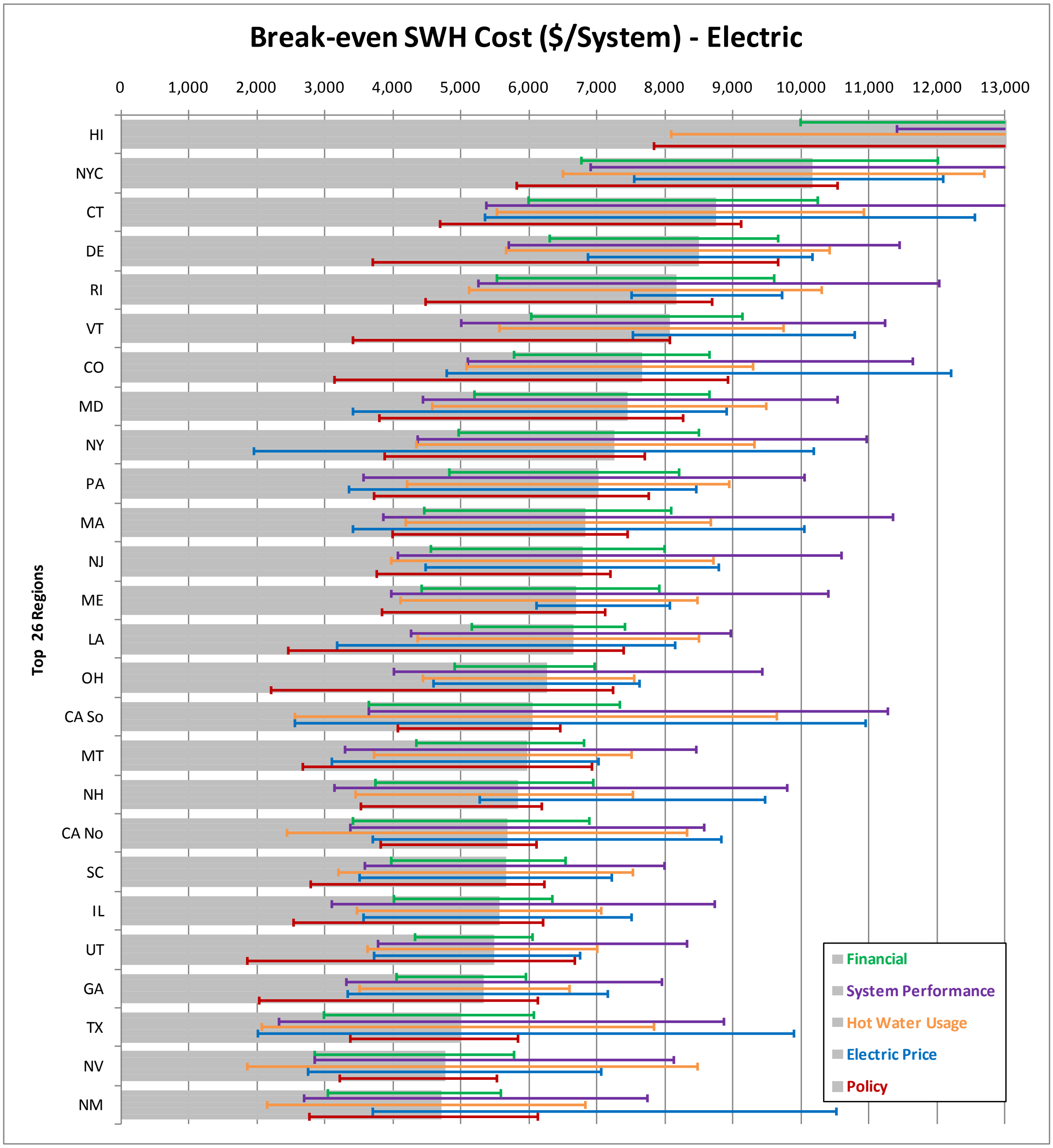

Figure 12. Range of SWH break-even costs: Top 26 regions—electric

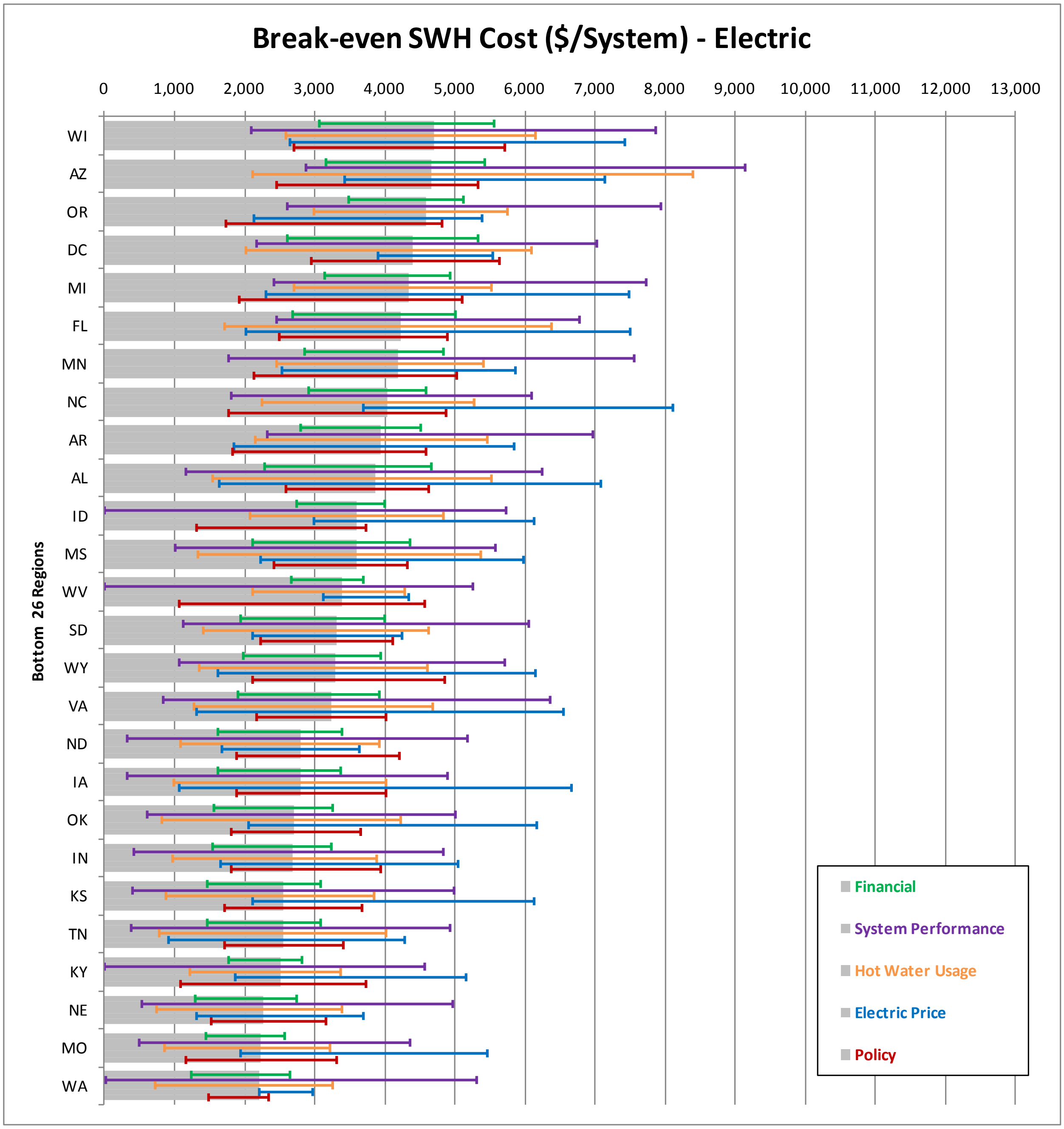

Figure 13. Range of SWH break-even costs: Bottom 26 regions—electric

As shown in Figure 12 and Figure 13, the base case break-even price is between $2,200/system and $10,160/system (excluding Hawaii and Alaska). Figure 12 and Figure 13 show that system performance (including solar resource location, system orientation, and size) is the biggest driver of break-even price variation, followed generally by hot water usage, electricity price, policy issues, and finance factors. The variation in the solar system parameters is primarily due to the solar resource location and system size. The impact on break-even costs is large for all states; however, there is also a high level of variability from state to state, from about a ±40% to ±90% impact. The variation in the electricity prices is due more to the spread between utilities within a state than the variation in the price escalation assumed. Hot water usage assumptions result in a roughly symmetrical impact on break-even costs, also with a large range—from ±30% to ±60% by state. The ITC is the single largest policy driver evaluated. Availability of system financing was the least important sensitivity case, generally only affecting the break-even SWH cost by ±20%.

Each of the five impact categories reported in Table 1 combines several drivers, obscuring the contribution from each. For example, the break-even cost is highly sensitive to the daily hot water draw and system size, both of which can have relatively large ranges, which increases the range of break-even costs due to these factors. While the water heater energy factor or system degradation may also have an impact on break-even costs, these factors can only vary by a small amount and are difficult to separate out from the other highly variable factors in each category. Individual sensitivity charts for key factors are provided in Appendix H. It appears that the primary drivers of the system performance category are the system size and O&M. Solar resource location has a variable impact—for certain states the difference between solar resource locations is large (Arizona, Illinois, Wyoming, and Texas), whereas for other states (Delaware and Vermont) the difference is quite small.

4 Conclusions

We evaluated the break-even price for residential SWH customers in the United States and found that the current break-even price varies by more than a factor of five even though the amount of energy produced varies by less than a factor of two. This difference is largely driven by incentives, which can exceed $3,000/system, and the difference in electricity or natural gas prices, which can vary by a factor of four. Even without incentives, large variations in break-even cost will remain given the range of hot water usage and solar energy available.

The general trend observed in this analysis is that SWH systems that replace conventional electric systems are more likely to achieve break-even costs than SWH systems replacing conventional natural gas systems. Break-even conditions appear first in the Southwest where they are driven by resource and in the Northeast where they are driven by high electricity prices. As SWH system prices continue to decline, break-even conditions begin to occur in the Southeast and Midwest. Very low electricity and natural gas prices will preclude break-even conditions in certain areas in the Northwest and Midwest even with SWH prices at $3,000/system and a continuation of the federal ITC.

Overall, the scenarios evaluated represent a market entry point for SWH. However, the scenarios do not consider the potential for a deep, sustained market. Therefore, caution must be used when considering this analysis. SWH break-even does not imply that customers will necessarily adopt SWH, and only a fraction of customers in each utility will have the necessary combination of good solar access and attractive financing options. A true depth or market analysis is required to determine a “demand curve” for SWH at various price points. This must be combined with analysis of commercial buildings to provide an estimate for the market potential of rooftop SWH.

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Appendix A: Regional Variation in Water Heating Fuel by U.S. Census Region

Table A-1 shows the regional distribution (by U.S. census region) of the number of houses using a particular water heating fuel.[22] "Other" includes fuel oil, liquefied petroleum gas (LPG), and other fuels. Where data for a specific state is available (New York, Florida, Texas, and California), this data is excluded from the rest of the region (i.e., the Pacific region includes only Oregon and Washington). Data was taken from the RECS (DOE 2005b).

Table A-1. Regional Variation in the Number of Houses Using a Particular Fuel Type by U.S. Census Region

Region	Electric	Natural Gas	Other
U.S. Average	39.4%	54.4%	9.5%
New England	26.4%	43.4%	30.2%
Middle Atlantic	25.6%	64.1%	11.5%
New York	11.9%	56.7%	31.3%
East North Central	29.5%	68.2%	5.1%
West North Central	29.5%	65.4%	9.0%
South Atlantic	63.3%	34.0%	0.0%
Florida	90.0%	12.9%	0.0%
East South Central	68.1%	30.4%	4.3%
West South Central	43.9%	53.7%	7.3%
Texas	43.0%	55.7%	6.3%
Mountain	26.7%	68.0%	10.7%
Pacific	64.4%	35.6%	2.2%
California	10.7%	85.1%	6.6%

Source: EIA 2005

[22] Since it is possible that some houses use multiple fuel types for water heating, the values in Table A-1 may not necessarily sum to 100%.

Appendix B: Base Energy Savings, Fuel Price, Energy Value, and Solar Fraction for the Largest Utility in Each Region

Figure B-1 shows the largest utility service territory in each state and the corresponding TMY site. California and New York were split into two regions due to large populations and discrepancy between electric utilities. Table B-1 and Table B-2 list the largest electric and natural gas utility in each state or region, along with the corresponding TMY site, annual energy saved, fuel price, annual value of saved energy, and annual solar fraction. All assumptions are for the base case scenario.

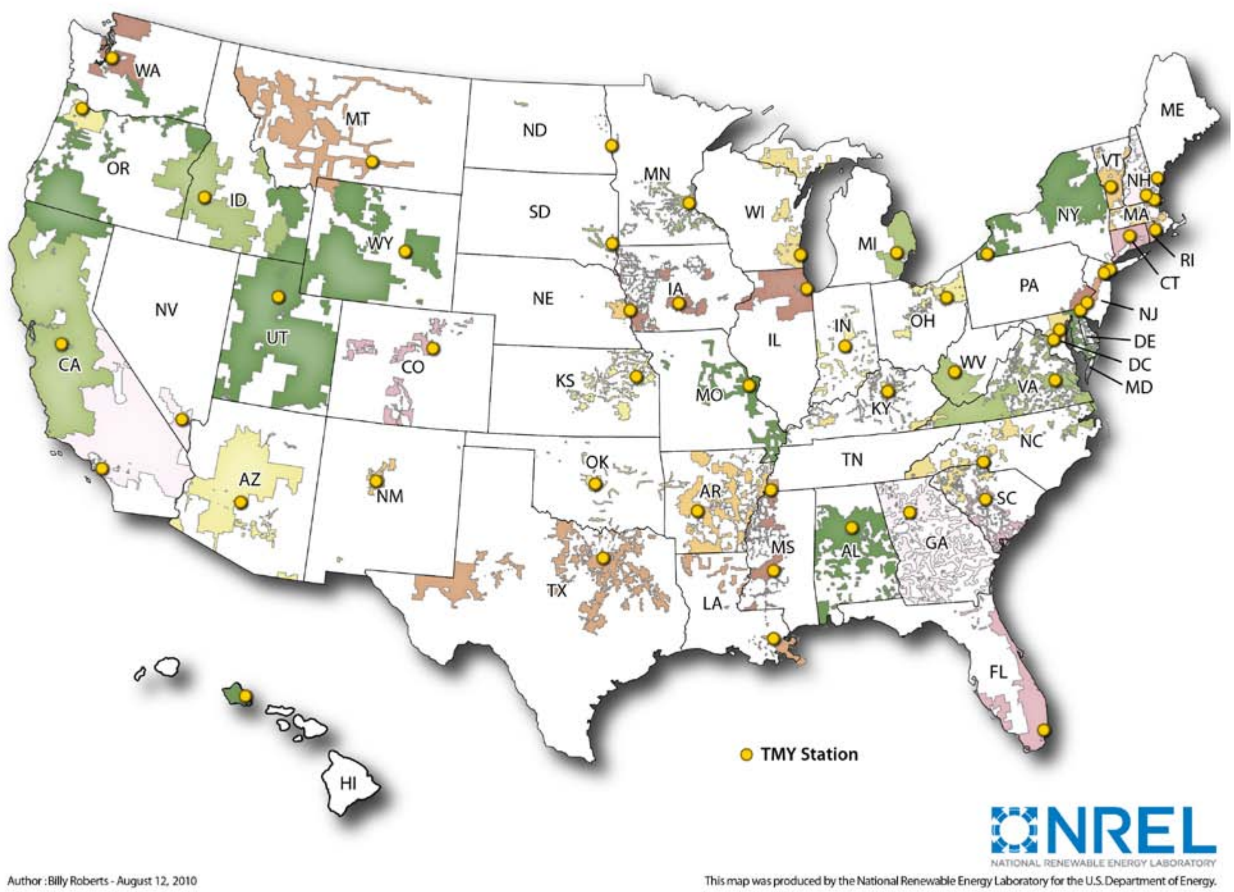

Figure B-1. Largest utility service territory by state with corresponding TMY3 site

Table B-1. Results of the Base Case Scenario for a SWH System with an Electric Auxiliary Water Heater

State	Largest Electric Utility Name	TMY3 Site Number	Annual Energy Demand (kWh)	Annual Energy Saved (kWh)	Electric Price (cents/kWh)	Annual Value of Electricity Saved ($)	Annual Solar Fraction
AL	Alabama Power Co	722280	2,818	2,019	10.2	$206	0.72
AR	Entergy Arkansas Inc	723415	2,862	1,752	9.4	$164	0.61
AZ	Arizona Public Service Co	722784	2,285	1,995	10.0	$199	0.87
CA No	Pacific Gas & Electric Co	722976	2,752	2,206	12.4	$274	0.80
CA So	Southern California Edison Co	724926	2,822	2,050	14.0	$287	0.73
CO	Public Service Co of Colorado	724695	3,458	2,431	9.7	$236	0.70
CT	Connecticut Light & Power Co	725087	3,374	1,790	18.0	$322	0.53
DC	Potomac Electric Power Co	724050	3,080	1,894	11.9	$226	0.62
DE	Delmarva Power	724089	3,251	1,972	13.5	$267	0.61
FL	Florida Power & Light Co	722020	2,120	1,835	10.9	$201	0.87
GA	Georgia Power Co	722196	2,936	1,826	9.6	$175	0.62
HI	Hawaiian Electric Co Inc	911760	2,076	1,819	27.2	$495	0.88
IA	MidAmerican Energy Co	725460	3,437	2,083	8.0	$167	0.61
ID	Idaho Power Co	726810	3,349	2,102	6.4	$135	0.63
IL	Commonwealth Edison Co	725340	3,333	1,829	11.1	$202	0.55
IN	Duke Energy Indiana Inc	724380	3,364	1,928	8.4	$163	0.57
KS	Westar Energy Inc	724560	3,205	2,073	7.6	$158	0.65
KY	Kentucky Utilities Co	724220	3,217	1,892	6.5	$123	0.59
LA	Entergy Louisiana Inc	722310	2,498	1,866	10.6	$199	0.75
MA	Massachusetts Electric Co	744904	3,444	1,767	16.0	$283	0.51
MD	Baltimore Gas & Electric Co	724060	3,165	1,954	14.0	$273	0.62
ME	Kennebunk Light & Power Dist	726064	3,711	1,954	14.0	$274	0.53
MI	Detroit Edison Co	726375	3,439	1,660	10.1	$168	0.48
MN	Northern States Power Co	726584	3,725	1,842	9.8	$180	0.49
MO	Union Electric Co	724345	3,109	1,926	6.6	$127	0.62

MS	Entergy Mississippi Inc	722350	2,748	2,019	9.7	$197	0.73
MT	NorthWestern Corporation	726770	3,563	2,106	10.0	$210	0.59
NC	Duke Energy Carolinas, LLC	723140	2,909	2,068	7.8	$161	0.71
ND	Northern States Power Co	727530	3,897	2,066	8.1	$167	0.53
NE	Omaha Public Power District	725500	3,357	1,935	7.6	$147	0.58
NH	Public Service Co of NH	743945	3,479	1,796	14.3	$257	0.52
NJ	Public Service Elec & Gas Co	725020	3,229	1,895	14.3	$271	0.59
NM	Public Service Co of NM	723650	3,122	2,521	8.6	$216	0.81
NV	Nevada Power Co	723860	2,557	2,135	11.2	$240	0.84
NY	Niagara Mohawk Power Corp.	725030	3,129	1,892	14.6	$277	0.60
NYC	Consolidated Edison Co-NY Inc	725235	3,661	1,658	23.2	$384	0.45
OH	Ohio Edison Co	725210	3,478	1,717	10.7	$184	0.49
OK	Oklahoma Gas & Electric Co	723540	2,970	2,038	8.0	$163	0.69
OR	Portland General Electric Co	726986	3,329	1,745	9.1	$159	0.52
PA	PECO Energy Co	724080	3,207	1,953	13.7	$268	0.61
RI	The Narragansett Electric Co	725070	3,412	1,889	16.4	$311	0.55
SC	South Carolina Electric&Gas Co	723100	2,789	2,003	10.9	$218	0.72
SD	Northern States Power Co	726510	3,657	2,100	8.8	$186	0.57
TN	Memphis City of	723340	2,812	1,940	8.1	$158	0.69
TX	TXU Energy Retail Co LP	722590	2,657	1,992	12.5	$249	0.75
UT	PacifiCorp	725720	3,289	2,111	7.8	$165	0.64
VA	Virginia Electric & Power Co	724010	3,029	2,008	9.1	$183	0.66
VT	Central Vermont Pub Serv Corp	725165	3,671	1,888	13.3	$251	0.51
WA	Puget Sound Energy Inc	727934	3,288	1,621	8.9	$145	0.49
WI	Wisconsin Electric Power Co	726400	3,635	1,919	11.1	$212	0.53
WV	Appalachian Power Co	724140	3,210	1,882	6.5	$122	0.59
WY	PacifiCorp	725690	3,668	2,309	7.8	$180	0.63

Source: Fuel prices are from the EIA 2010b

Table B-2. Results of the Base Case Scenario for a SWH System with a Natural Gas Auxiliary Water Heater

State	Largest Natural Gas Utility Name	TMY3 Site Number	Annual Energy Demand (therm)	Annual Energy Saved (therm)	Gas Price ($/therm)	Annual Value of Gas Saved ($)	Annual Solar Fraction
AL	Alabama Gas Co	722280	107.2	80.5	2.07	$154	0.75
AR	Centerpoint Energy Arkansas	723403	108.3	80.3	1.82	$135	0.74
AZ	Southwest Gas Corporation	722780	89.4	92.3	1.97	$170	1.03
CA No	Pacific Gas	724945	112.6	91.4	1.36	$109	0.81
CA So	Southern California Gas Co	747188	88.2	92.6	1.24	$97	1.05
CO	Pub Service Co of Colorado	724695	125.2	92.6	1.10	$91	0.74
CT	Yankee Gas Svc Co	725029	126.6	70.8	2.19	$134	0.56
DC	Washington Gas Light Company	724050	114.6	74.1	1.83	$122	0.65
DE	Delmarva Power	724089	119.4	76.3	1.76	$118	0.64
FL	Peoples Gas Sys	722110	93.3	86.3	2.10	$168	0.92
GA	Austell Nat Gas Sys	722270	113.3	75.9	1.87	$130	0.67
HI	The Gas Company Llc	911760	86.1	78.6	4.32	$305	0.91
IA	Midamerican Energy Co	722190	108.0	83.2	1.41	$108	0.77
ID	Intermountain Gas Company	722250	109.5	80.7	1.04	$76	0.74
IL	Nicor Gas	725300	125.3	72.0	1.36	$85	0.57
IN	Northern Indiana Public Service Co	725470	131.0	72.5	1.62	$108	0.55
KS	Kansas Gas Service Company	724463	113.1	73.1	1.72	$117	0.65
KY	Louisville Gas And Electric Co	722180	106.3	84.8	1.62	$129	0.80
LA	Atmos Energy Co	722250	109.5	80.7	1.78	$130	0.74
MA	Boston Gas Co D B A Key Span Energy	725054	127.0	71.9	1.85	$115	0.57
MD	Baltimore Gas & Electric Co	724060	117.0	76.3	1.85	$124	0.65
ME	Northern Utilities Inc	725470	131.0	72.5	1.86	$119	0.55
MI	Consumers Energy Company	724238	119.3	78.7	1.35	$94	0.66
MN	Centerpoint Energy	723403	108.3	80.3	1.26	$90	0.74
MO	Laclede Gas Company	725314	116.4	75.8	1.85	$133	0.65

MS	Atmos Energy Corporation	722250	109.5	80.7	1.53	$112	0.74
MT	Northwestern Corporation	725484	123.9	76.3	1.37	$93	0.62
NC	Piedmont Natural Gas	722285	110.8	78.0	1.90	$138	0.70
ND	Montana Dakota Utilities Co	727478	138.2	69.3	1.30	$81	0.50
NE	Metropolitan Utilities Dist Of Omaha	725500	122.4	75.2	1.27	$87	0.61
NH	Energynorth Nat Gas Inc	743945	125.8	68.3	1.68	$98	0.54
NJ	Public Service Elec & Gas Co	724236	115.2	73.8	1.45	$90	0.64
NM	Pnm Gas Services	723650	115.8	103.1	1.43	$137	0.89
NV	Southwest Gas Corporation	722780	89.4	92.3	1.38	$113	1.03
NY	Keyspan Energy Dba Natioal Grid Ny	744864	119.0	76.4	1.87	$126	0.64
NYC	The Brooklyn Union Gas Co	744860	118.6	72.8	1.93	$113	0.61
OH	Columbia Gas Dist Co	724220	118.4	73.1	1.70	$111	0.62
OK	Oklahoma Natural Gas Co	723535	113.7	88.2	1.58	$130	0.78
OR	Northwest Natural Gas Co	723235	108.3	66.5	1.36	$79	0.61
PA	Philadelphia Gas Works	722250	109.5	80.7	2.02	$146	0.74
RI	National Grid	725280	127.7	67.7	1.75	$99	0.53
SC	South Carolina Electric & Gas Co	722230	101.3	78.9	2.16	$157	0.78
SD	Midamerican Energy Company	725460	124.6	80.5	1.33	$96	0.65
TN	Memphis Light Gas And Water	723340	107.0	80.1	1.69	$125	0.75
TX	Atmos Energy Corporation	722250	109.5	80.7	1.56	$111	0.74
UT	Questar Gas Company	724754	103.2	97.6	0.91	$80	0.95
VA	Washington Gas Light Company	724050	114.6	74.1	1.82	$124	0.65
VT	Vermont Gas Systems Inc	726170	130.7	68.5	2.02	$122	0.52
WA	Puget Sound Energy Inc	727935	120.4	60.8	1.32	$70	0.50
WI	Wisconsin Gas Company	725470	131.0	72.5	1.51	$97	0.55
WV	Mountaineer Gas Co	724250	117.7	71.1	1.62	$108	0.60
WY	Source Gas Distribution Llc	725690	131.0	88.5	1.23	$100	0.68

Source: Fuel prices are from the EIA 2010c

Appendix C: Seasonal Variation in Solar Fraction

The solar fraction of a SWH system varies from month to month for a given location. Table C-1 shows the solar fraction in January and July for the largest electric utility in each state.

Table C-1. Solar Fractions in January and July for the Largest Electric Utility in Each State

State	Solar Fraction (%)	
	January	July
AL	40%	92%
AR	41%	94%
AZ	78%	93%
CA No	67%	95%
CA So	25%	95%
CO	54%	89%
CT	37%	76%
DC	32%	87%
DE	32%	90%
FL	76%	93%
GA	36%	77%
HI	67%	93%
IA	32%	92%
ID	25%	96%
IL	23%	91%
IN	27%	87%
KS	40%	89%
KY	27%	86%
LA	49%	91%
MA	32%	75%
MD	34%	86%
ME	21%	82%
MI	20%	79%
MN	20%	74%
MO	24%	92%

MS	44%	93%
MT	27%	93%
NC	44%	92%
ND	21%	85%
NE	26%	95%
NH	39%	75%
NJ	28%	82%
NM	58%	95%
NV	60%	93%
NY	33%	88%
NYC	23%	83%
OH	17%	82%
OK	54%	95%
OR	17%	91%
PA	33%	85%
RI	29%	81%
SC	42%	91%
SD	29%	90%
TN	41%	93%
TX	50%	94%
UT	30%	95%
VA	38%	87%
VT	27%	80%
WA	20%	86%
WI	26%	83%
WV	26%	86%
WY	34%	92%

Appendix D: Calculation of Break-even Cost

The break-even cost of a SWH system is defined as the point where the NPC of the system equals the NPB to its owner.

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.

$$\text{The discount factor in year } y = \frac{1}{(1+d)^y}$$

where d is the discount rate.

The cost in each year is based on the system financing. At the beginning of the financing period, a down payment and then a loan amount are established by:

Loan Amount = SWH System Cost - Down Payment - Initial Rebates

The annual loan payment is then calculated by:

$$\text{Loan Payment} = \text{Loan Amount} * \frac{i(1+i)^n}{(1+i)^n - 1}$$

where i is the interest rate and n is the loan term in years. The tax savings on the loan interest in each year is given by:

$$\text{Interest Deduction}_y = \text{Marginal Federal Tax Rate} * i * \text{Current System Balance}_y$$

where Current System Balance$_y$ is the loan amount that has not yet been paid off.

Some incentives (such as tax incentives) may not occur until a year or so after installation. These incentives are discounted by one year.

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.

Appendix E: Incentives Used in this Study

Table E-1 and Table E-2 show the state- and utility-based incentives used in the base case break-even analysis. All values are current as of June 14, 2010 (DSIRE 2010).

Table E-1. Statewide Incentives in the Form of Tax Credits or Rebates

State	Incentive
AR	$1,221
AZ	$1,000
CO	$3,000
CT	$1,765
DE	$3,000
FL	$500
GA	$2,299
HI	$2,850
ID	$1,662
IL	$1,800
KY	$900
LA	$3,000
MA	$900
MD	$1,800
ME	$1,000
MI	$1,500
MN	$1,017
MO	$500
MT	$2,000
NC	$1,400
NH	$600
NJ	$1,200
NM	$600
NY	$1,500
OH	$3,000
OR	$2,000
PA	$1,500
RI	$1,500
SC	$1,500
UT	$2,721
VT	$3,000
WI	$683
WV	$1,800
WY	$150

Source: DSIRE 6/14/2010

Table E-2. Utility-based Incentives

State	Utility Name	Incentive
AZ	Arizona Public Service Co	$1,000
AZ	Salt River Project	$1,000
AZ	Sulphur Springs Valley E C Inc	$1,500
AZ	Trico Electric Cooperative Inc	$1,500
AZ	Tucson Electric Power Co	$1,250
AZ	UNS Electric, Inc	$1,250
CA	San Diego Gas & Electric Co	$1,000
CA	Sacramento Municipal Util Dist	$1,500
CA	City of Redding	$1,750
FL	Beaches Energy Services	$500
FL	City of Tallahassee	$450
FL	Clay Electric Cooperative, Inc	$600
FL	Gainesville Regional Utilities	$500
FL	Gulf Power Co	$1,000
FL	JEA	$400
FL	Orlando Utilities Comm	$60
FL	Progress Energy Florida Inc	$450
GA	Cobb Electric Membership Corp	$450
GA	GreyStone Power Corporation	$500
GA	Jackson Electric Member Corp	$450
GA	Walton Electric Member Corp	$400
HI	Kauai Island Utility Cooperative	$800
IA	Maquoketa City of	$1,221
IA	City of Independence	$1,221
IA	City of Preston	$1,221
MI	Alger-Delta Coop Electric Assn	$1,221
MI	City of Crystal Falls	$1,221
MI	City of Gladstone	$1,221
MI	City of Negaunee	$1,221
MI	City of Norway	$1,221
MO	City of Columbia	$400
NC	Piedmont Electric Member Corp	$500
NC	Progress Energy Carolinas Inc	$1,000
NC	South River Elec Member Corp	$1,000
NH	New Hampshire Elec Coop Inc	$1,500
OR	Central Electric Coop Inc	$500
OR	Consumers Power, Inc	$500
OR	Douglas Electric Coop, Inc	$500
OR	Emerald People's Utility Dist	$600
OR	Eugene City of	$600
OR	Salem Electric	$600
SC	Progress Energy Carolinas Inc	$1,000
TX	Austin Energy	$1,500
TX	City of Bryan	$1,000
TX	City of Denton	$300
TX	Guadalupe Valley Elec Coop Inc	$1,000
TX	San Antonio City of	$1,200
WA	PUD No 1 of Clallam County	$500
WA	PUD No 1 of Clark County	$1,000
WA	PUD No 1 of Franklin County	$500
WA	PUD No 1 of Grays Harbor Cnty	$600
WA	Snohomish County PUD No 1	$500

Source: DSIRE 6/14/2010

Appendix F: Break-even Results by System Size

Table F-1 shows the SWH break-even cost and solar fraction for the base SWH system (40 ft^2 collection area) as well as for a low performance system (20 ft^2) and high performance system (60 ft^2). These values may be used to determine the break-even value for a system with a different solar fraction than the base case (sample calculation provided in Appendix G).

Table F-1. Break-even SWH Cost and Solar Fraction for the Base Case (40 ft^2), Low Performing (20 ft^2), and High Performing (60 ft^2) Solar Collector

State	Break-even Cost ($/System)			Solar Fraction (%)		
	Low Performance (20 ft^2)	Base Performance (40 ft^2)	High Performance (60 ft^2)	Low Performance (20 ft^2)	Base Performance (40 ft^2)	High Performance (60 ft^2)
AL	1,735	3,860	4,695	44%	72%	83%
AR	2,330	3,940	4,655	39%	61%	71%
AZ	3,465	4,670	4,965	67%	87%	93%
CA No	3,110	5,675	6,535	52%	80%	90%
CA So	3,765	6,045	6,775	51%	73%	80%
CO	5,160	7,660	8,705	43%	70%	82%
CT	5,210	8,750	10,665	31%	53%	65%
DC	2,000	4,395	5,515	37%	62%	73%
DE	5,635	8,495	9,830	37%	61%	72%
FL	2,395	4,220	4,625	57%	87%	93%
GA	3,420	5,325	6,285	37%	62%	75%
HI	9,870	14,495	15,100	57%	88%	92%
IA	1,045	2,800	3,580	37%	61%	71%
ID	2,315	3,605	4,115	40%	63%	72%
IL	3,405	5,560	6,630	33%	55%	66%
IN	965	2,690	3,535	35%	57%	68%
KS	955	2,560	3,305	40%	65%	76%
KY	1,185	2,510	3,150	35%	59%	70%
LA	4,705	6,655	7,340	47%	75%	85%
MA	3,685	6,825	8,755	30%	51%	64%
MD	4,565	7,455	8,840	37%	62%	74%
ME	3,695	6,700	8,510	31%	53%	66%
MI	2,505	4,345	5,390	29%	48%	60%
MN	2,230	4,180	5,330	30%	49%	61%
MO	910	2,225	2,805	38%	62%	73%

MS	1,675	3,600	4,295	46%	73%	83%
MT	3,765	5,970	6,975	36%	59%	70%
NC	2,355	4,040	4,690	43%	71%	82%
ND	1,010	2,805	3,730	32%	53%	64%
NE	730	2,275	3,020	35%	58%	69%
NH	2,995	5,840	7,600	30%	52%	65%
NJ	3,880	6,795	8,220	35%	59%	70%
NM	2,745	4,715	5,370	53%	81%	90%
NV	3,075	4,775	5,385	62%	84%	91%
NY	4,320	7,265	8,670	36%	60%	72%
NYC	5,915	10,160	12,735	27%	45%	57%
OH	4,260	6,275	7,400	29%	49%	61%
OK	1,140	2,700	3,275	44%	69%	78%
OR	2,875	4,590	5,490	31%	52%	63%
PA	4,145	7,025	8,390	37%	61%	73%
RI	4,795	8,170	10,095	33%	55%	68%
SC	3,475	5,670	6,490	45%	72%	82%
SD	1,345	3,315	4,330	35%	57%	69%
TN	1,030	2,555	3,175	44%	69%	79%
TX	2,840	5,010	5,785	50%	75%	84%
UT	3,905	5,480	6,135	41%	64%	74%
VA	1,335	3,245	4,130	41%	66%	78%
VT	5,340	8,065	9,535	31%	51%	63%
WA	640	2,200	3,020	30%	49%	60%
WI	2,405	4,710	5,975	32%	53%	65%
WV	2,085	3,385	4,040	35%	59%	70%
WY	1,425	3,295	4,130	39%	63%	74%

Appendix G: Sample Break-even Interpolation Calculation

In order to calculate the new break-even cost for a SWH system with a different solar fraction, it is necessary to know the initial break-even cost and solar fraction for the base case (given in Appendix F). For southern California:

Base SWH Cost = $6,675

Base Solar Fraction = 0.80

A quote for a SWH cost may be obtained from an installer, and solar fractions are listed for a number of systems on the SRCC website (http://www.solar-rating.org/). To determine if a $7,500 system with a solar fraction of 0.85 is at break-even, it is necessary to interpolate between the high (60 ft^2 collector area) and base case (40 ft^2 collector area) solar fraction values:

Interpolation: (0.85–0.80)/(0.90–0.80) = 0.5 or 50%

The total possible increase in SWH break-even cost is established by multiplying the range in SWH break-even values (listed in Appendix F) by the percentage calculated above:

Range in SWH Break-even: ($7,640–$6,675) = $965

Total possible Increase: 50% x $965 = $483 increase

Adding this increase onto the old SWH break-even value yields the new cost:

New SWH Cost = $6,675 + $483 = $7,158

Therefore, a $7,500 system would not be at break-even costs, while a $7,150 system would.

Appendix H: Drivers of the System Performance Sensitivity Category

In order to determine the primary drivers of the system performance sensitivity bar, the category was broken down into five sub-categories, each assessing the impact of one or, at most, two individual factors. The system orientation (collector tilt and azimuth) used in the base case was optimal, while the system degradation used was the least optimal. As shown in Figure H-1, size and O&M costs have the largest impact on the break-even cost. The impact of solar resource location varies by region. For states with a high level of variation in solar resource, the impact is large, while for states with a low level of variation, the impact is relatively small.

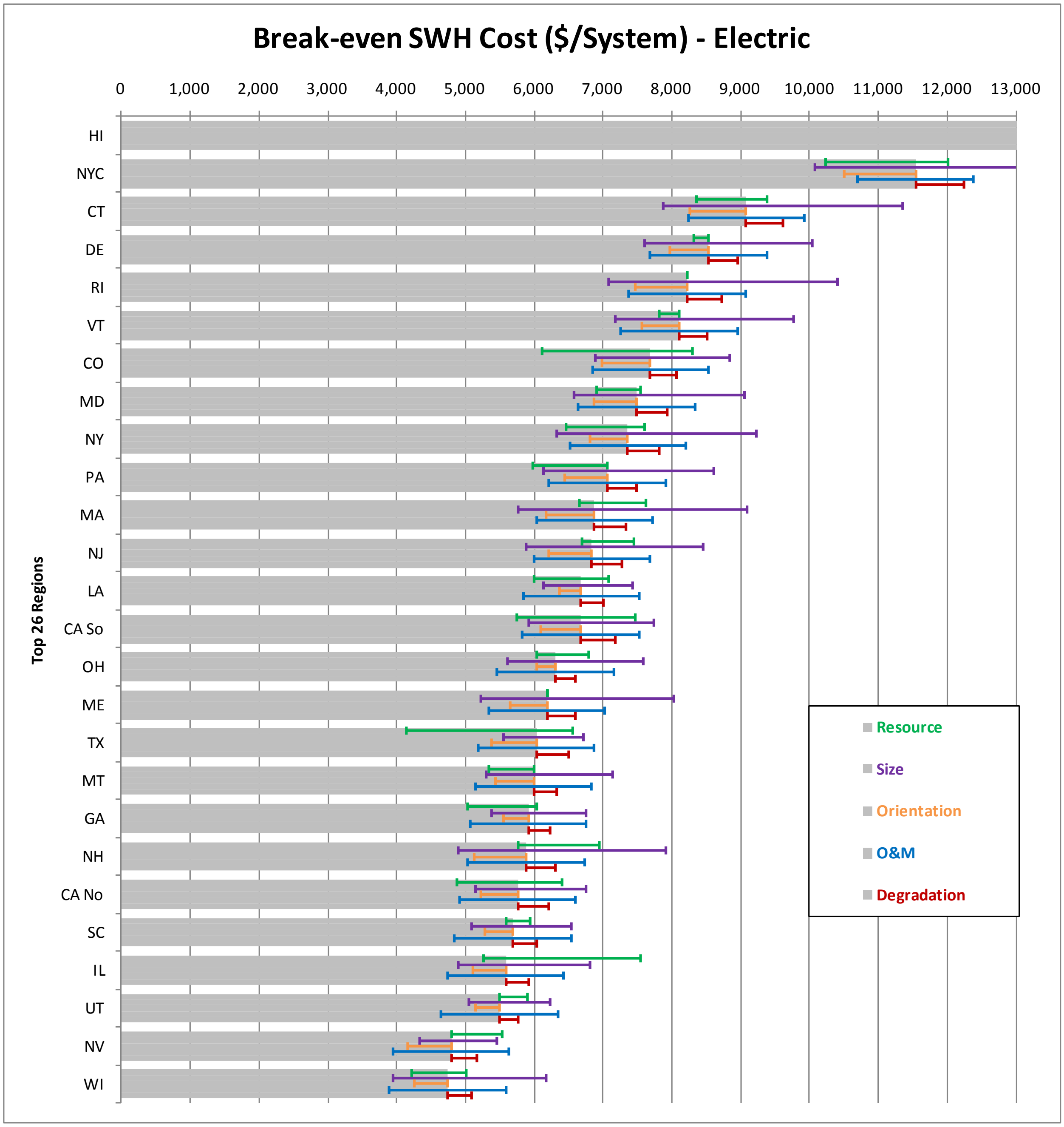

Figure H-1. Drivers of the system performance sensitivity category

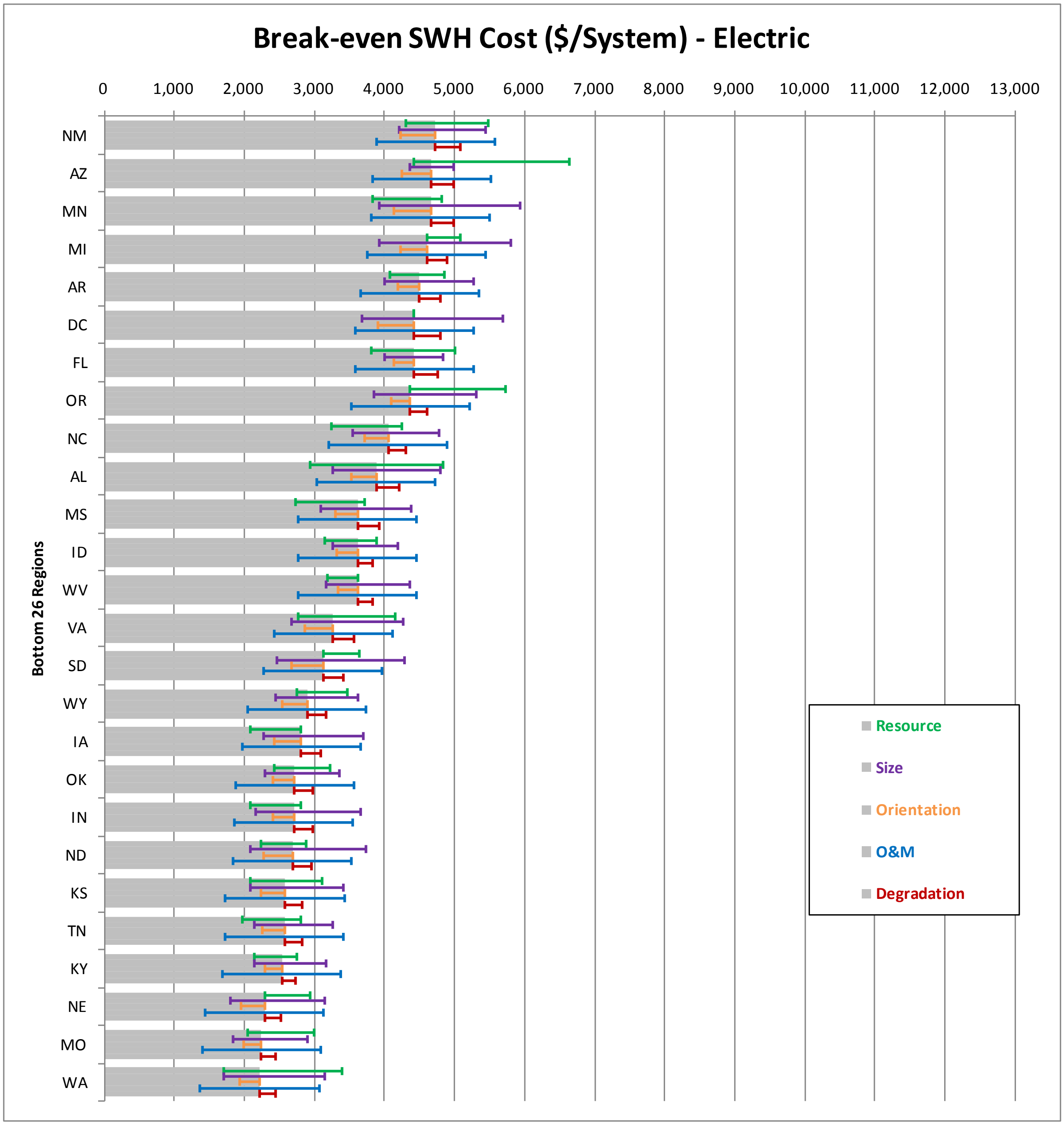

Figure H-2. Drivers of the system performance sensitivity category

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This paper examines the break-even cost for residential rooftop solar water heating (SWH) technology, defined as the point where the cost of the energy saved with a SWH system equals the cost of a conventional heating fuel purchased from the grid (either electricity or natural gas). We examine the break-even cost for the largest 1,000 electric and natural gas utilities serving residential customers in the United States as of 2008. Currently, the break-even cost of SWH in the United States varies by more than a factor of five for both electricity and natural gas, despite a much smaller variation in the amount of energy saved by the systems (a factor of approximately one and a half). The break-even price for natural gas is lower than that for electricity due to a lower fuel cost. We also consider the relationship between SWH price and solar fraction and examine the key drivers behind break-even costs. Overall, the key drivers of the break-even cost of SWH are a combination of fuel price, local incentives, and technical factors including the solar resource location, system size, and hot water draw.

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