Comparing Residential Water Heaters for Energy Use, Economics, and Emissions

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by Newport Partners LLC

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About the Authors

This research project was conducted by Newport Partners LLC of Davidsonville, MD. Newport Partners performs technical, regulatory, and market research and analysis related to the built environment, with a specific focus on the energy performance of buildings and building systems.

Executive Summary

Residential water heating is often the second largest energy use in the home and can account for nearly a quarter of overall household energy consumption. Home residents depend on a reliable and sufficient supply of hot water for multiple uses in the home, and they are increasingly aware of the energy and carbon implications of different hot water systems. Rising energy prices and other economic pressures have created more interest in energy efficient hot water systems which reduce monthly utility bills while still providing reliability and comfort.

At the same time, more stringent federal equipment standards for residential water heaters were announced in 2010, ENERGY STAR has developed minimum requirements for residential water heaters and now labels this product category, builders are labeling and marketing their homes with Home Energy Ratings, and a surge of innovative technologies are creating more water heating options for builders, contractors and homeowners than ever before. In both new and existing homes, water heating options include traditional storage tank units, condensing storage tank systems, tankless systems (condensing and non-condensing) systems, solar hot water systems, heat pump water heaters, and systems which combine space heating with water heating. These systems can vary dramatically in terms of first cost, annual energy cost, space requirements, carbon footprint, and their ability to provide an adequate supply of hot water.

To address the need for credible analysis of water heating options, this study provides an energy, environmental, and economic analysis of 10 residential water heating systems in 10 geographic locations throughout the United States, with emphasis on the performance of propane-based systems relative to alternatives. The objective of the study is to compare the different performance and economic characteristics of water heating systems to inform builder, contractor, and homeowner decisions on water heater selection. The analysis and the resulting findings on performance are based on energy modeling coupled with cost estimating, economic analysis, and the determination of CO_2 emissions. The research followed a detailed methodology in order to provide balanced, reasonable treatment of the many factors which can influence the performance and costs of water heating systems such as first hour rating and energy factor. One key decision variable beyond the scope of this analysis was installation feasibility, with systems like the heat pump water heater (HPWH) having unique space and location requirements which in some cases could eliminate it as a viable option.

Modeling of annual water heating energy costs for the different systems in a typical home revealed that the standard efficiency electric storage tank was the highest energy cost system, at $449/year averaged across all 10 locations. This is important to note, as this type of system is common for installations in both new construction and also as a replacement. The solar hot water system with propane tankless back-up had the lowest annual energy costs, averaging just $166 annually. The HPWH and the propane condensing tankless system were the 2nd and 3rd lowest energy cost systems across all of the climate regions, and varied positions with each other depending on the climate region.

A key point evident in the annual energy cost analysis is that the Energy Factor (EF) rating for a water heater is not useful on its own for comparing the annual energy costs across water heating systems with different fuel sources. While this point may be obvious to some within the housing industry, it is often not as clear to other groups like consumers and warrants emphasis. For example, within this study the standard efficiency propane storage system with an Energy Factor of 0.59 had lower annual energy costs than the standard efficiency electric storage tank with an Energy Factor of 0.90. PERC offers an online Energy Cost and Carbon Calculator where Users can run their own pricing analysis of different hot water systems with varying Energy Factors and energy prices.

Annual energy costs were also analyzed at the regional level, and generally showed the same trends seen in the overall averages across all locations, with the solar DHW, HPWH, and propane tankless condensing units representing the lowest energy cost systems. The Northeast was notable, with higher electric rates driving the standard efficiency electric storage system annual energy costs above $600/year. Annual energy costs for the heating oil-fired water heater in this region were $435, while the propane condensing tankless was $340.

In terms of Home Energy Ratings, high performance water heaters can indeed have a significant impact on a home's HERS Index. For example, for a new home modeled in the Northeast U.S. with a standard efficiency electric storage unit, the HERS Index was 75. This same home with a propane condensing tankless water heater had a HERS Index of 69, meaning that the home is approximately 6% more efficient.

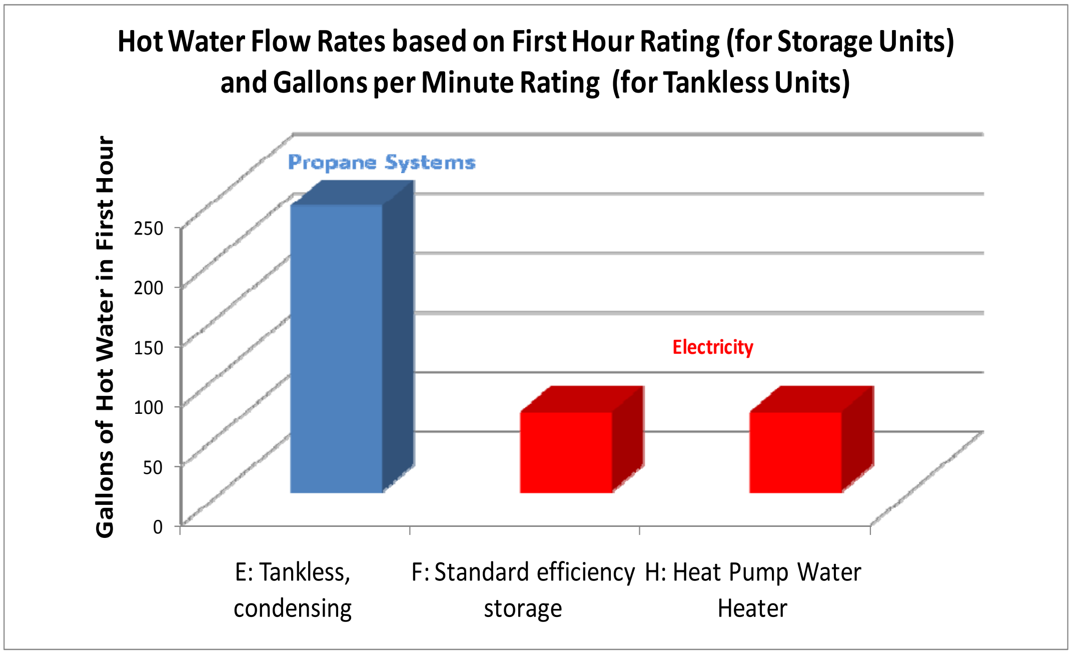
Despite the straightforward appearance of the annual energy cost or even the Energy Factor rating, it is critical for industry professionals to also consider several other water heater characteristics, including the hot water flow rate, the ability to easily install a unit, unit service life, and system first cost. The economic metric used in this analysis, the Annual Cost of Ownership, characterizes systems based on the last two of these factors as well as annual energy cost. The "ACO" essentially estimates the cost for buying a water heater and paying for its annual energy bills, spread out over the system's rated service life. The ACO includes the sum of the annual energy cost incurred in the first year of system operation and the annual principal and interest payment on the system's first cost amortized over the equipment's rated service life. It is particularly effective to use in this study, to compare systems with significantly different service life ratings.

The importance of considering the ACO in purchasing decisions is seen in the figure below, which illustrates the lowest ACO water heater for each climate region, for both new construction and system replacements. In all but one climate region, the lowest ACO system is a propane tankless water heater. This reflects the propane tankless system's long service life (20 years) and low annual energy costs, despite the fact that other "on the truck" units might be cheaper initially to install.

Water Heaters with the Lowest Annual Cost of Ownership by Climate Region and Type of Installation

Climate Region	System with Lowest Annual Cost of Ownership – New Construction	System with Lowest Annual Cost of Ownership - Replacements
Mixed/Humid	Propane condensing tankless	Propane condensing tankless
Hot/Humid	Standard efficiency electric storage	Standard efficiency electric storage
Cold: Northeast	Propane condensing tankless	Propane condensing tankless
Cold/Very Cold: Midwest	Propane condensing tankless	Propane condensing tankless & propane non-condensing tankless (tie)
Hot-Dry/Mixed-Dry	Propane condensing tankless	Propane non-condensing tankless

When considering hot water output capacity as well, tankless systems can deliver their rated GPM *continuously* – even over the course of an entire hour. As a result, propane tankless systems achieve more than triple the hot water flow rate of the electric storage tanks or HPWHs in the study during the first hour of operation (see graph). Thus, hot water output – in addition to the ACO economic metric – is a significant factor for contractors and homeowners to consider in selecting a system.



The analysis of CO_2 emissions associated with water heater operation showed that the standard efficiency electric tank storage system typically had CO_2 emissions which were at least double the rates for propane fired systems like the high efficiency non-condensing storage unit. Compared to the propane condensing tankless system (System E), the electric storage unit had roughly triple the CO_2 emissions in three of the climate regions.

HPWHs were found to have CO_2 emissions roughly 33% greater than the propane condensing tankless system, averaged across all analysis locations. This underscores the reality that even highly efficient electric water heaters still use significant quantities of electricity, which mostly comes from fossil-based power generation plants (with a few exceptions for states with heavy nuclear or gas-fired generation). These power plants will typically consume roughly 3 units of energy to produce 1 output unit of electricity, so the resulting emissions from the production of electricity are often significant. This then results in significant CO_2 emissions for downstream electric-based water heating systems.

The heating oil water heater assessed in the Northeast also had CO_2 emissions which were at least 35% higher than comparable propane systems, and as much as twice the emissions rate of the high efficiency propane tankless systems.

Considering this study's findings on annual energy costs, the Annual Cost of Ownership, hot water output rates, and CO_2 emissions, it is strikingly clear that deciding on the "best" water heater for either new construction or a replacement should factor in much more than selecting the cheapest system, the easiest system to install, or a system with a high Energy Factor. The results of this study offer a better characterization of system performance to inform better decisions, and underscore the need to examine the longer-term energy and environmental performance of water heaters.

Table of Contents

I. Introduction

Water heating is a major component of residential energy use, often ranking as the second largest energy use in the home and accounting for 14-25%[1] of overall household energy consumption. Further, hot water energy use is common to all housing types and all climates, making it a relevant issue for the entire residential sector.

Home residents depend on a reliable and sufficient supply of hot water for multiple uses in the home. They are also increasingly aware of the energy and carbon emission implications of different hot water systems. Rising energy prices and other economic pressures have created more interest in energy efficient hot water systems which reduce monthly utility bills while still providing reliability and comfort.

At the same time, more stringent federal equipment standards for residential water heaters and a surge of innovative technologies are creating more water heating options for builders, contractors and homeowners than ever before. In both new and existing homes, water heating options include traditional storage tank units, condensing storage tank systems, tankless systems (condensing and non-condensing), solar hot water systems, heat pump water heaters, and even systems which combine space heating with water heating. These systems can vary dramatically in terms of their first cost, their annual energy cost, their carbon footprint, and their ability to provide an adequate supply of hot water. Making informed choices also offers a tremendous opportunity to positively impact energy use and carbon emissions on a wide scale, because the replacement cycle of water heaters is roughly 12-15 years. With this replacement frequency, every year there is a window of opportunity in millions of American homes to impact the energy and carbon performance of one of the largest energy consumers in the home. Clearly there is much at stake.

Given the importance of water heating energy use, carbon emissions, and the changing landscape of technologies and regulations, a credible analytical study comparing systems is essential. This study provides an energy, environmental, and economic analysis of 10 residential water heating systems in 10 geographic locations throughout the United States, with emphasis on the performance of propane-based systems relative to alternatives. The objective of the study is to compare the different performance and economic characteristics of water heating systems to inform builder, contractor, and homeowner decisions on water heater selection. The analysis and the resulting findings on performance are based on energy modeling coupled with cost estimating, economic analysis, and the determination of CO_2 emissions.

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[1] U.S. Department of Energy, Energy Savers Program: www.energysavers.gov. Accessed July 2011.

II. Residential Water Heater Background

Technology Categories

Residential water heaters are available in a variety of technology categories, and may use different energy sources to heat water, including electricity, propane/natural gas, heating oil, and solar energy. For gas-fired units, this study concentrates only on propane systems, which are very similar to natural gas systems in both their design and performance. Different product categories are discussed below, with much of the background in this section based on information from the U.S. Department of Energy's (DOE) Energy Savers program (www.energysavers.gov).

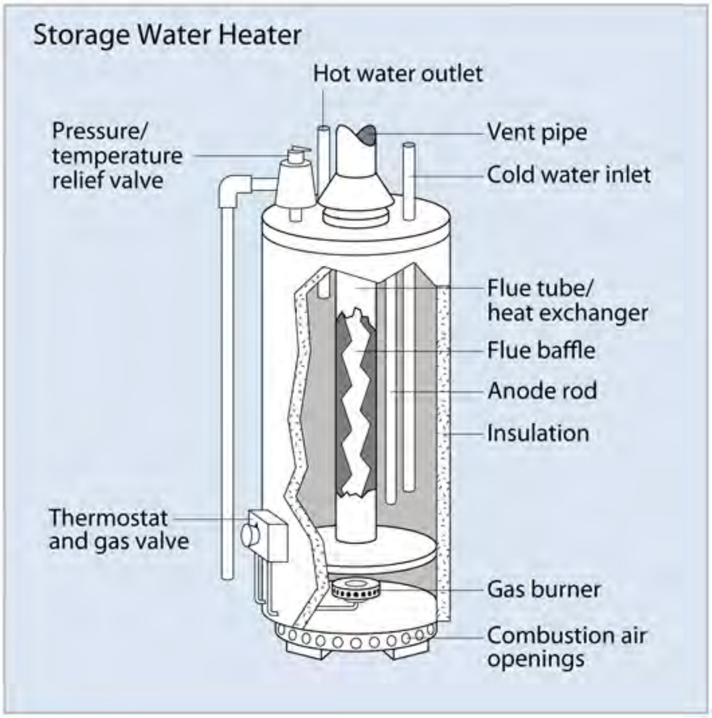

Figure 1: Storage Water Heater
(Propane/Natural Gas Model)
Source: US DOE Energy Savers Program

Storage tank water heaters are the most common type of system in U.S. homes. A storage water heater offers a reservoir of hot water typically between 20-80 gallons. The storage tank releases hot water from the top of the tank when there is a hot water demand in the home (see Figure 1). Incoming cold enters at the bottom of the tank and replaces the outgoing hot water.

Storage water heater fuel sources include natural gas, propane, heating oil, and electricity. Propane/natural gas units utilize a gas valve, burner, and thermostat to heat water. Heating oil-fired water heaters have similar components, and also use a power burner to mix oil and air in a vaporized mist which is then ignited with an electric spark. Electric water heaters differ in that no combustion actually takes place in the unit. However it is important to note that the electricity used in electric storage tank units is most commonly generated from fossil fuel combustion in generation plants which are "upstream" from the home (e.g. coal-fired power plants). In electric storage units, water is heated by an electric element(s) in the tank.

For all storage water heaters, “standby losses” occur as the hot water stored in the tank loses thermal energy to the area around the tank. Higher tank insulation levels can cut down the heat loss from the tank, with insulation levels of R-12 to R-25 used in some models to reduce standby losses.

Additionally, propane- and heating oil-fired water heaters have losses related to the escape of thermal energy in hot combustion gasses which are exhausted to outdoors. Some of these units employ different venting strategies (e.g. power venting, sealed combustion) to help to control the combustion process more precisely and minimize thermal losses. Similarly, propane- and oil-fired storage water heaters can utilize electric ignition systems for combustion instead of standing pilot lights. This measure reduces fuel consumption and increases efficiency.

A separate class of storage tank water heaters uses condensing technology to extract as much heat as possible from the combustion process and transfer it to the water. These units are referred to as **Condensing Storage Water Heaters**. Propane-fired condensing storage water heaters differ from non-condensing units in that the hot combustion gasses are utilized to a much greater extent through the flue design to transfer more heat to the stored water (see Figure 2). As a result, they can achieve significantly higher efficiency levels than are possible with non-condensing storage tank units. They can also produce hot water at a faster rate because of their ability to extract more heat from the combustion process. Condensing storage water heaters are emerging in the residential marketplace and are recognized as a separate product class within the ENERGY STAR water heater labeling program.

Figure 2: Propane Condensing Storage Water Heater. *Source:* [ENERGY STAR/Condensing Water Heaters]

Tankless, or on-demand, water heaters provide hot water only when it is needed within a building and generally do not store water[2]. Since tankless units (Figure 3) do not store large volumes of water like traditional storage units, they also avoid standby losses.

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[2] “Hybrid” water heaters are also emerging in the marketplace and consist of a tankless unit coupled with a very small storage tank. They are designed to realize the best characteristics of both systems, by virtually eliminating standby losses which larger storage units experience and avoiding “cold water sandwich” issues which tankless systems can encounter. This term refers to a small plug of cold water which can result if a hot water demand is momentarily interrupted, causing the tankless unit to cease heating operation for a moment. ENERGY STAR qualifying tankless units have a rated storage volume of 2 gallons or less.

When hot water is called for in the home, the tankless unit will respond by allowing cold water to enter the unit, where it is then heated up by a burner or an electric heating element. In this manner, tankless units provide a readily available and steady flow of hot water. However, because they do not have any hot water stored in reserve, the flow of hot water which a tankless system is capable of providing at any given time is limited to its output rate. Tankless units generally provide flow rates between 2 and 5 gallons/minute, with propane- and natural gas-fired units delivering higher flow rates than electric systems. The flow rate capacity of a tankless unit is an important factor in selecting a system, and in extreme cases tankless units with lower output rates cannot meet the peak hot water demands in a house. In such cases, two or more tankless units are required. Tankless units may also be used in applications other than whole-house hot water systems, such as providing the hot water to a single remote bathroom or providing back-up heating for a solar hot water system (discussed below).

Figure 3: Propane Tankless Water Heater.
Source:
[ENERGY STAR/Whole-Home Gas Tankless]

Some tankless units boost their efficiency though a condensing design, similar to how condensing storage tank water heaters boost their efficiency beyond traditional storage tanks. In condensing tankless systems, heat in the flue gases is transferred to pre-heat incoming water, which boosts the system's efficiency significantly.

Heat pump water heaters look somewhat like traditional storage tank water heaters, and also use electricity as their energy source – as many storage tank units do. However, heat pump water heaters "pump" heat, or transfer it, to the water instead of *generating* heat from an electric resistance element. In fact, they act much like an air-source heat pump used to heat the air in a home, by taking heat from the air surrounding the unit and "pumping" it into the water to heat it up. This is a fundamental difference between heat pump water heaters (HPWHs) and electric storage units, which simply use electric resistance elements in the storage tank. By heating the water through heat transfer from the surrounding environment, HPWHs have efficiency levels which are over twice as high as the efficiencies of conventional electric resistance storage water heaters. The main components of a heat pump water heater, including the compressor, condenser coil, and back-up resistance elements, are shown in Figure 4.

Heat pump water heaters acquire the thermal energy that they use to heat up water from the environment where the unit is situated, like a basement. Because their source for thermal energy is the surrounding air, HPWHs need to be installed in areas which remain at moderate temperatures (40º–90ºF) in a space of at least 1,000 cubic feet, such as an 11' x 12' room with 8' ceilings. Like an air-source heat pump used to heat a home, HPWHs will perform less efficiently when the surrounding air is colder.

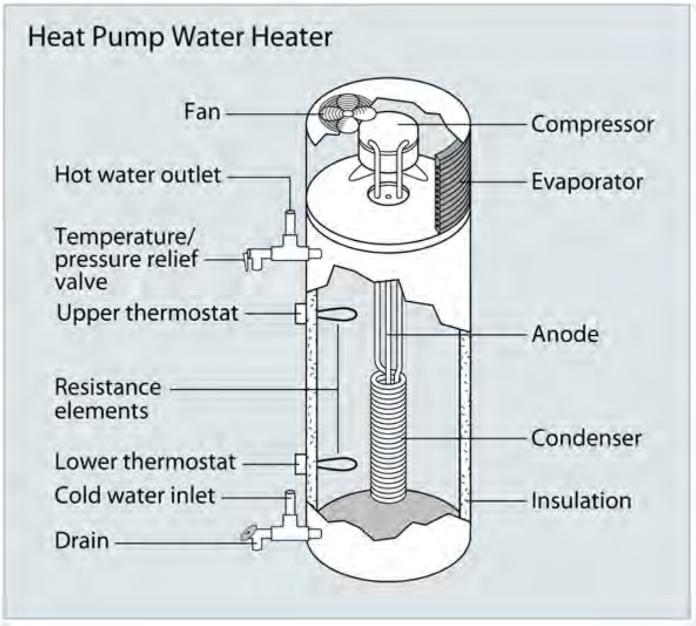


Figure 4: Heat Pump Water Heater Example

Source: US DOE Energy Savers Program

The heat pump portion of the unit outputs cool exhaust air, which can be exhausted to the surrounding room or ducted to outdoors. This cool airstream tends to cool the surrounding area like a basement. This cooling effect can assist in cooling a home during the summer, but adds to the heating load in the winter. Due to this cooling effect, it is not recommended to place HPWH units in tight spaces like closets. In a tight environment like this, HPWHs will cool the closet space, which in turn makes the unit operate less efficiently as it attempts to extract heat from a cooler environment.

Another feature of HPWHs is their different operating modes. The heat pump mode of the unit is very efficient but can sometimes not satisfy high hot water demands. For this reason, some models offer hybrid operating modes in which electric resistance heating elements also serve to heat water in tandem with the heat pump. This reduces efficiency but increases hot water output. HPWHs may also operate in a resistance-only mode, where they behave essentially like traditional electric storage tanks and have a lower efficiency in return for more hot water output.

A few more key differences between heat pump water heaters and traditional electric storage units include:

- HPWHs are typically taller than conventional storage units and should not be placed in tight spaces like closets
- HPWHs generate some noise from the operation of the heat pump

"Add-on" heat pump units can be retrofitted onto existing storage water heaters in homes. However, this study concentrates only on integrated heat pump water heater units which are constructed as a single system, like the system shown above in Figure 5. Likewise, this study does not include systems which utilize hot water produced by ground source heat pump systems. These systems, and any other combined space and water heating system, are beyond the scope of this research.

Solar domestic hot water systems utilize solar energy to heat a portion of the hot water used in a household. These systems typically include a solar collector which harnesses solar energy, along with at least one storage tank to hold the heated water. Solar domestic hot water systems fall into the categories of “active” systems which use circulating pumps to move water within the system, and “passive” systems which do not mechanically move water with pumps. Pump systems require more energy but can also simplify the design of a system.

Solar domestic hot water (DHW) systems are also categorized as either direct or indirect circulation systems. In direct circulation, pumps will circulate the home’s water directly through the solar collectors on the roof and back into the house. This type of arrangement operates effectively in warm climates where outdoor temperatures rarely fall below the freezing point. Conversely, with *indirect* circulation a non-freezing heat transfer fluid is pumped through the solar collectors. This fluid then travels through a heat exchanger where it transfers heat to the domestic hot water. This type of system allows solar energy to be a source for domestic hot water, but without exposing the system to water freezing hazards which could damage the system. Figure 5 shows an active system (characterized by use of a pump) with indirect circulation (antifreeze circulates through the flat plate collector).

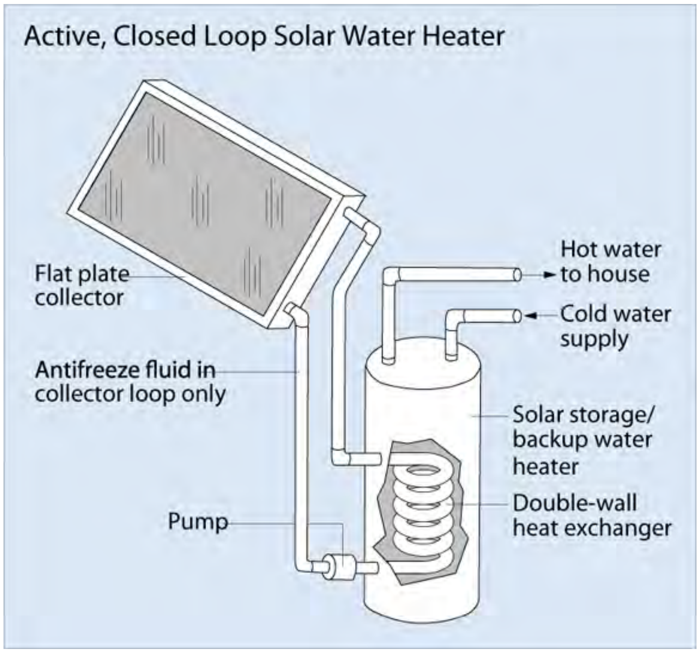


Figure 5: Example of active solar domestic hot water system with indirect circulation.
Source: US DOE Energy Savers Program

Solar collectors for residential hot water systems generally fall into these three types:

- Flat-plate collectors which are insulated, weatherproofed boxes that contain a dark absorber plate under one or more glass or plastic covers.
- Integral collector-storage systems or “batch” systems, which have one or more dark tanks or tubes in an insulated, glazed box.

- Evacuated-tube solar collectors, which have parallel rows of transparent glass tubes.

Flat plate collectors are common for residential applications and are the collector type used in the solar system for this study.

Solar domestic hot water systems also typically include a back-up water heating source. Back-up heating for domestic water is needed during periods of high demand and/or limited solar resources. Back-up heating may take the form of a traditional storage tank, or tankless water heater. In this study, a propane-fired tankless unit provides the back-up to the solar collector system.

This brief introduction to solar domestic hot water systems illustrates that many different system types are possible. For this study, a commercialized system was selected for the analysis which features flat plate collectors, a large and well insulated storage tank, and a tankless back-up system. The system is analyzed as an indirect circulation system in all but the two warmest analysis locations in the study, where it is modeled as a *direct* system.

Factors Affecting Water Heater Efficiency Levels

Installation Scenarios Impact Water Heater Efficiency

The U.S. residential water heater market has sales of 8-10 million units per year, split roughly evenly between propane/natural gas and electric units (with a small number of heating oil units too). The majority of these units are for replacement applications. Unfortunately, most replacements are driven by a failure of the existing water heater in a home. This results in an emergency type of scenario in which the homeowner's top priority is restoring hot water service to their residence. In this crisis mode, the important considerations of higher efficiency, payback periods and life cycle costs, and fuel switching opportunities are often lost and an opportunity which arises once every 12-15 years passes by.

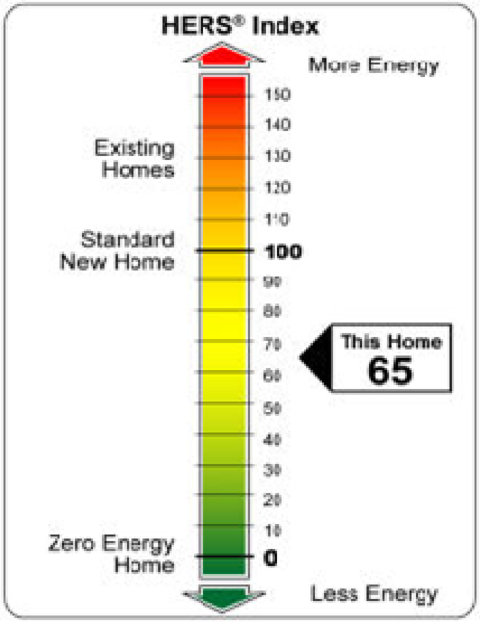
In this emergency replacement scenario, plumbing contractors often install the water heaters that they have on their truck or which are easily accessible. These units are typically on the lower end of the efficiency spectrum, near the federal minimum standard. Thus, emergency replacements of water heaters result in a large number of near-minimum efficiency units being installed in U.S. homes each year.

Other installation scenarios afford greater opportunities for homeowners, builders, and contractors to make more informed decisions on hot water system selection. For example, proactive water heater replacements in existing homes (e.g. before the existing system actually fails) allow a homeowner to research performance, costs, available incentives, and paybacks of different systems and energy sources.

New construction programs like ENERGY STAR Homes recognize high performance homes in the marketplace. Homes which qualify for these voluntary programs must meet strict energy performance requirements, and builders often use higher performance water heaters, such as Energy Star-labeled units, to help qualify a home.

Similarly, builders are increasing using the "HERS Index" to rate, label, and differentiate energy-efficient new homes. "HERS" stands for the Home Energy Rating System. This system of scoring and labeling home energy performance has been established over the last 15 years by the Residential Energy Services Network (RESNET). The product of a home energy rating using the HERS system is a "HERS Index," which is intended to be like car's MPG sticker – but for homes (Figure 6).

In the first half of 2011, several national and regional builders have committed to having their new homes rated and labeled with the HERS Index. Groups like RESNET and the Earth Advantage Institute are tracking this market trend, which is seen as a method for builders to clearly communicate the energy performance of their homes and differentiate them from competing new and existing homes.



Source: RESNET

Figure 6: Home Energy Rating System (HERS) Label for Rating Home Energy Performance

High performance water heaters can indeed have a significant impact on a home's HERS Index. For example, for a new home modeled in the Northeast U.S. with a standard efficiency electric storage unit, the HERS Index was 75. This same home with a propane condensing tankless water heater had a HERS Index of 69, meaning that the home is approximately 6% more efficient.

Federal Standards for Residential Water Heater Efficiency are Increasing

The minimum allowable efficiency for residential water heaters is regulated by federal standards. In April 2010, U.S. DOE amended the existing federal standards for residential water heaters[3]. These new standards will introduce significant changes for several product classes. The updated standards will take effect starting April 16, 2015 for residential water heaters which are either manufactured or imported into the United States.

The current standards have been in place since 2004. The minimum required "Energy Factor" - or "EF" – for storage systems depends on the storage tank volume. The Energy Factor is the ratio of useful energy output from the water heater to the total amount of energy delivered to the water heater, and is determined from a specific test procedure. The amended standards which will take effect in 2015 are shown in Figure 7 below.

Figure 7: Amended Energy Conservation Standards for Residential Water Heaters

Source: Federal Register

Product Class	Standard Level	
Gas-Fired Storage Water Heater	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.675 – (0.0015 x Rated Storage Volume in gallons)	For tanks with a Rated Storage Volume above 55 gallons: EF = 0.8012 – (0.00078 x Rated Storage Volume in gallons)
Electric Storage Water Heater	For tanks with a Rated Storage Volume at or below 55 gallons: EF = 0.960 – (0.0003 x Rated Storage Volume in gallons)	For tanks with a Rated Storage Volume above 55 gallons: EF = 2.057 – (0.00113 x Rated Storage Volume in gallons)
Oil-Fired Storage Water Heater	EF = 0.68 – (0.0019 x Rated Storage Volume in gallons)	
Gas-Fired Tankless Water Heater	EF = 0.82 – (0.0019 x Rated Storage Volume in gallons)	

The general implications of these changes to the residential water heater standards include:

- Storage tank water heaters for all energy sources will become more efficient.
- Larger electric storage tank water heaters (≥56 gallons) will be required to make a major jump in efficiency. In fact, the new efficiency level for such units essentially means that they will have to be heat pump water heaters, as traditional electric resistance storage tanks will not be able to meet the efficiency requirements. Heat pump water heaters (HPWHs) exist in the U.S. market to a limited extent currently and the supporting infrastructure is still developing, so this will be a major change with first cost implications.

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[3] Federal Register / Vol. 75, No. 73 / Friday, April 16, 2010 / Rules and Regulations. Available online: http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_fedreg.pdf

- Larger propane/gas storage tank water heaters (≥56 gallons) will also be required to make a major jump in efficiency. Units in this size range will have required Energy Factors around 0.75, which will necessitate the use of condensing storage tank units. Propane/natural gas tank water heaters of this size are used much less frequently than smaller units like 40- and 50-gallon tanks, because these smaller units can typically serve the hot water needs in most homes.
- Propane/natural gas tankless water heaters will also experience a big jump in efficiency requirements, from an EF of 0.62 up to 0.82. However, about 97% of the propane/natural gas-fired tankless units listed in the AHRI products database already meet or exceed this efficiency level, with some propane tankless units as high as EF 0.94.[4] So while the minimum bar is being raised for this product type, nearly all tankless units would already comply.

ENERGY STAR Now Labels Residential Water Heaters

Until recently, water heating was the only major residential energy end use that the ENERGY STAR program did not address. U.S. DOE bridged this gap by issuing Energy Star requirements for residential water heaters in early 2009. The Energy Star program covers the following product classes of water heaters:

- Storage units: propane- and natural gas-fired (including condensing tanks), heat pump units, and tabletop units
- Tankless units: propane- and natural gas-fired
- Solar with propane/natural gas or electric back-up

DOE also considered the inclusion of traditional electric resistance storage tank units in the program as well, but concluded that "while there may be slight initial savings to be attained, there are few, if any, technology improvements possible with this form of water heating to warrant the long-term qualification of electric resistance water heaters in the program."[5]

The minimum ENERGY STAR requirements for the covered product classes are shown below in Figure 8:

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[4] Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Certified Products Directory, www.ahridirectory.org/ahriDirectory/pages/home.aspx. Accessed July 2011.

[5] Final Criteria Announcement from Richard Karney, ENERGY STAR Program Manager. U.S. DOE, April 2008. www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/WaterHeater_CriteriaLetter_Final.pdf; Accessed July 2011.

Figure 8: Energy Star Criteria for Residential Water Heaters

Product Class	Energy Factor (EF)	First Hour Rating or Gallons per Minute (for tankless systems)	Warranty	Safety
Propane/natural gas-fired storage	≥ 0.62 (ending 8/31/2010)	≥ 67 gallons/hour	Warranty > 6 years on sealed system	ANSI Z21.10.1/CSA 4.1
	≥ 0.67 (starting 9/1/2010)	≥ 67 gallons/hour	Warranty > 6 years on sealed system	ANSI Z21.10.1/CSA 4.1
Propane/natural gas-fired tankless	≥ 0.82	GPM > 2.5 over a 77°F rise	Warranty > 10 years on heat exchanger and 5 years on parts	ANSI Z21.10.1/CSA 4.1 or ANSI Z21.10.3/CSA 4.3, depending on burner size
Propane/natural gas-fired condensing	≥ 0.80	≥ 67 gallons/hour	Warranty > 8 years on sealed system	ANSI Z21.10.1/CSA 4.1
Heat Pump Water Heater	≥ 2.0	FHR > 50 gallons per hour	Warranty > 6 years on sealed system	UL 174 and UL 1995
Solar Water Heater	Solar Fraction ≥ 0.5		Warranty > 10 years on solar collector, 6 years on storage tank, 2 years on controls and 1 year for piping and parts.	OG-300 Certification from the SRCC.

The key implications of the ENERGY STAR requirements include:

- Some of today's ENERGY STAR minimum EF requirements are essentially on par with the federal standards which will go into effect in 2015. This is the case for propane/natural gas-fired tankless units and heat pump water heaters (which will replace large electric resistance storage tanks).

- Electric resistance storage units – no matter what their Energy Factor – were not deemed suitable for inclusion in the program.
- Nearly all (97%) propane/natural gas-fired tankless units listed in the AHRI database meet ENERGY STAR's EF requirement of 0.82.
- Condensing tank propane/natural gas water heaters are also recognized by ENERGY STAR as a highly efficient form of storage tank water heating. This technology is emerging in the residential marketplace and is also used in commercial applications.
- The ENERGY STAR requirements for propane/natural gas storage water heaters had an initial tier of 0.62 EF. This expired August 31, 2010, when the requirement shifted upward to 0.67 for this product class.

III. Research Methodology

Given the number of variables involved in this study, such as water heater system types, efficiency levels, and analysis locations, it was crucial to adopt a consistent methodology to generate meaningful, balanced results. Key elements of this methodology are discussed below.

Prototype Homes

In modeling the energy performance of the different hot water systems, prototype homes were developed for each of the analysis locations. The key building characteristics which affect hot water energy use in building simulation models include the number of occupants (which is based on the number of bedrooms) and the location of the water heater itself. Based on building characteristics data from the U.S. Energy Information Administration (EIA) and the U.S. Census Bureau, the prototype home for the analyses was a 3 bedroom home with 2 ½ bathrooms. For homes with a basement foundation, which was determined based on the analysis location, it was assumed that the water heater was located in the basement. For homes on a slab foundation or crawlspace (also based on analysis location), it was assumed that the water heater was located in the garage.

Water Heating System Types and Specifications

Selection of Water Heating Systems

A primary goal of this study is to provide objective energy, economic, and emissions data on a range of water heating technologies found in today's marketplace, including several high performance systems. The determination of which water heating systems to include was based on:

- **The most relevant water heating technologies** in the industry, including traditional systems like the electric resistance storage tank and “emerging” systems like heat pump water heaters (HPWHs) and solar hot water systems. Only commercially available systems were assessed.
- **Diversity of energy source**, with electric, propane-fired, and heating-oil fired systems included. Natural gas systems were not included, as they generally share the same technology types and characteristics as propane-fired systems.
- **Diversity of efficiency levels**, with multiple efficiency levels analyzed for some product classes. The efficiency levels used in the research represent minimum federal standards; ENERGY STAR efficiency levels for eligible product types; and typical efficiency levels for two other systems of interest (electric tankless; solar DHW).

Add-on heat pump units were not included in the study, nor were systems integrating space heating with water heating.

The resulting list of 10 water heating systems which were analyzed in this study is shown several pages below in Figure 11.

System Sizing – Storage Tank Units

As discussed above, both the new and existing prototype homes are 3 bedroom homes with 2.5 bathrooms. This design is based on building characteristics data from U.S. Energy Information Administration’s (EIA) Residential Energy Consumption Survey (RECS) and the U.S. Census Bureau.

The size of the storage tank systems analyzed in this study is important because it impacts both the first cost estimation of systems and also the efficiency levels used in the modeling (since minimum EF values are a function of storage tank volume). To select an appropriately sized storage water heater for analysis in these homes, the First Hour Rating (FHR) needed for the prototype homes was evaluated. The FHR is the amount of hot water that the storage heater can supply per hour, when starting with a tank full of hot water. FHR is measured in gallons, and will depend on the system’s tank capacity, its heating source (a burner or an element), the size of this heating source, and the design of the heat transfer process (e.g., condensing or non-condensing).

The sizing process for a storage-type water heater involves estimating a home’s First Hour Rating. This is based upon the home’s daily peak 1-hour hot water demand, which can be approximated using worksheets describing hot water end-uses and their associated flow rates to estimate gallons used during the peak hour. Alternatively, less detailed sizing guidelines can be used – often based on the number of bedrooms or bathrooms – to estimate the required FHR. These more generic sizing guidelines are useful when residents' specific hot water usage habits are not known, which is often the case. For the purpose of this analysis, sizing guidelines based on number of bedrooms and bathrooms were used to arrive at a minimum First Hour Rating of 67 gallons for both the new and existing prototype homes.

With this First Hour Rating determined, the next step for storage water heaters was to then determine what capacity units could meet this FHR value. The Air-Conditioning, Heating, and Refrigeration Institute's (AHRI) Director of Certified Product Performance was referenced to determine the tank capacities which generally correspond to the required FHR value. Based on the water heater product listings in this product directory, the following results were found:

- For propane-fired storage tank units, an FHR of 67 generally correlated to a 40 gallon storage volume, with 71% of the listed units with FHR=67 being 40 gallon tanks.
- For electric storage tank units, this FHR range corresponded most closely to a tank size of 50 gallons. For listed electric tank units with FHR = 67, over 83% were 50 gallon tanks.
- For heating oil-fired storage tank units, a very low number of units are found in the marketplace compared to propane-fired and electric storage tanks. Further, the heating oil-fired storage tank units which *are* found have FHRs ≥ 100, and at tank sizes as low as 30 gallons. The most commonly listed tank size (about one-half) of units listed in the AHRI product directory is 32 gallons. Therefore that size was selected for this product class, since it is a representative tank size and smaller units with a FHR value closer to 67 were not listed in the AHRI database.
- For the heat pump water heater units, a limited number of these units are currently manufactured and available. These units most commonly have 50-gallon capacity tanks (within a range of 40-80 gallons). HPWHs with a 50-gallon capacity most commonly have an FHR value of 67.
- For propane-fired condensing storage water heaters, these units have very high FHRs, greater than 120 gallons for 50 gallons tanks. Thus, a 50-gallon unit was selected as appropriate for the study since this is the typical capacity in the market and it more than satisfies the minimum FHR requirement.

System Sizing – Tankless Units

For tankless units, gallons per minute (GPM) at a certain temperature rise was used to size systems. Since these systems do not store hot water like storage tank units, their ability to meet the hot water demand in a home is a matter of providing enough hot water flow at the exact time when it is needed. The ENERGY STAR program requirement for gas/propane-fired tankless systems is flow ≥ 2.5 GPM with 77 F temp rise. For the purpose of this analysis, a more stringent flow requirement of ≥ 4 GPM with a 75 F temp rise was adopted. This level represents the flow which could be required to supply two simultaneous hot showers in a home, especially in colder climates during the winter when incoming water temperatures to the home will be lower.

It should be noted that tankless systems can deliver their rated GPM *continuously* - even over the course of an entire hour - even though it would be extremely rare for this to be necessary. For the sake of comparison however, a tankless system which delivers 4 GPM at a 75 F rise is like a storage tank system with a First Hour Rating of 240 gallons. So as long as tankless systems are sized appropriately to accommodate the peak hot water demand in real time, they act like very large storage units in terms of their ability to meet hot water loads over time.

It should also be noted that most electric tankless systems cannot achieve flows of 4 GPM with a 75 F temp rise. Instead, large capacity electric tankless units are more likely to be in the range of 2.0 – 2.6 GPM. Thus, they are not truly sized to the same specification as the other tankless units in this study. However, because it was important to include this class of technology in the analysis, they are still included despite not meeting the sizing specification.

Specification of System Efficiency Levels

The efficiency levels for the hot water systems, which are Energy Factors (EF) in most cases, were determined in a consistent manner which allows meaningful comparisons across different product classes. For example, electric, propane, and heating oil storage water heaters are each evaluated at the base level efficiency (the federal minimum) for that product class in a unit size which is appropriate to the prototype home. In this way, a consistent comparison of a “standard efficiency” electric storage heater for a 3 bedroom home to a “standard efficiency” propane-fired storage heater for the same size house – in terms of energy consumption, first cost, and CO_2 emissions - is possible.

The basis for selecting system efficiency levels for each hot water system is included in the far right column of the specifications Figure 11 below. The EF for “standard efficiency” storage tank units (propane, electric, heating oil) are based on the current federal minimum standards for a tank of an appropriate capacity to meet the FHR. Energy Factor values for high efficiency equipment are developed from ENERGY STAR minimum criteria for propane high efficiency storage tanks (condensing and non-condensing), propane tankless units (non-condensing), and heat pump water heaters. Market data is used to characterize typical EF values for the electric and propane tankless (condensing) units. Finally, the solar DHW system efficiency specifications are based on typical efficiency metrics for the solar collectors, with the tankless back-up system meeting the relevant ENERGY STAR criteria.

It should be noted that hot water system efficiency and energy savings can be gained in several other ways besides the heater itself. For example, low-flow fixtures will reduce hot water demand, thus saving energy. Pipe insulation and centrally located plumbing areas with short hot water supply lines are additional examples of efficiency measures which can be used. While this study focuses on a comparison of water heating systems, these other measures are effective for both new and existing homes.

Analysis Locations

The analysis locations selected for this study are based on geographic diversity, climate diversity, and the inclusion of markets where heating oil is commonly used as a residential energy source. The 10 analysis locations, shown in Figure 10, address these criteria by providing a range of locations in terms of geography and climate, and covering two markets where heating oil is commonly used. Further, the analysis locations also capture some areas where basements are commonly used and others where they are not the norm. This in turn results in a set of prototype homes where in some cases the water heater is in the basement, and in other cases it is located in a garage.

Cost Estimating

The economic analysis evaluated systems based on both their annual energy cost, as well as the initial installation cost (equipment and labor). Installation labor costs and requirements (e.g. venting HPWH exhaust to outdoors in cold climates) were based primarily on the U.S Department of Energy's (DOE) recent rulemaking analysis on residential water heaters[6]. In conducting this analysis, DOE created robust cost estimating models to estimate labor hours, materials, and installation steps required to install different water heaters. Under the current research project, the DOE analysis was reviewed and used with minor adjustments to fit the objectives of this analysis. In a few instances, R.S. Means was used to develop a cost for a particular installation item not covered in the DOE analysis, such as the cost to install a dedicated electric circuit. It should also be noted that the DOE analysis relied extensively on RS Means.

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[6] "Residential Heating Products Final Rule Technical Support Document," US Department of Energy, 2010. http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr.html. Accessed July 2011.

For equipment costs, such as the retail price for a tankless propane water heater, price surveys of suppliers conducted were used to develop cost estimates. This method was found to be more representative of current equipment pricing, as the equipment prices developed in the DOE analysis built in assumptions about future economies of scale for producing some units. Both equipment and labor costs were adjusted with location factors from RS Means.

Installation requirements for different systems which were captured in the cost analysis, specifically venting issues, are discussed more in the Economic and Environmental section below. Further, Appendix A summarizes installation requirements assumed for each system in new construction or replacements, and also includes First Cost summary charts for both new construction and replacements.

Numerous potential cost issues were also reviewed as part of the cost estimating. Several of them were not included in the final cost estimate, often because they would only apply in limited circumstances and this analysis was not set up to accommodate installation cost ranges for a single system. Installation issues which are not quantified in the cost analysis include:

- Costs to conceal vents in water heater replacement scenarios, because these would only apply in limited cases.
- Costs for drain pans, given the basement or garage location of water heater units in this study
- Costs for a condensate filter for condensing systems, as this is not a universal code requirement at this time and may/may not be required.
- Costs to deal with space constraints for larger tanks with thicker insulation levels; although this could likely be an issue in some circumstances, it will not apply universally to all replacements of higher efficiency systems.
- Costs to provide a drain, as it was assumed that water heater units would be located in close proximity to a drain within a basement or garage location
- Costs to address constraints on HPWH system location. No economic cost was assigned to HPWH units to account for the fact that they will not be able to be located in some homes due to their need to operate in a temperate environment and in an open space[7]. Although these are relevant issues, they will occur in a limited number of homes (e.g. they would not affect placement of a HPWH in a conditioned, unfinished basement), and therefore were not assigned a cost in the study.

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[7] DOE's Energy Savers website states that "heat pump water heaters require installation in locations that remain in the 40º–90ºF (4.4º–32.2ºC) range year-round and provide at least 1,000 cubic feet (28.3 cubic meters) of air space around the water heater."

- Costs for maintenance; in the case of propane tankless no cost was assigning for cleaning of the units heat exchanger which can be necessary if the unit is exposed to hard water. This issue will only occur in the presence of a hard water supply and when no water softener system is being used.
- Costs for electric outlets for propane systems which require electricity. For new construction, this methodology followed DOE's model where they included the cost of hooking into existing power in the vicinity of the water heater in the general setup costs for new construction. Thus, this cost was already captured in the installation cost build-up, so no separate electrical supply cost was applied. This approach was used for both propane storage and propane tankless in new construction. For replacements (both propane storage and tankless systems), it was assumed that systems had access to existing 110V power supplies and could make use of that power.
  - For electrical storage systems, these units were assigned a cost to install a dedicated circuit, unless there was a pre-existing electric tank in a replacement scenario.
  - For electric tankless systems, a cost was assigned to install two 60A circuits. It was assumed that the overall electrical service to the house was adequately sized (at least 200 Amps), so no cost for upgrading electrical service was applied. And while codes may require a sub-panel for installations where the tankless unit is not within line-of-sight to the main electrical panel, the application of this requirement will not occur in all cases so no cost was assigned.
- Costs associated with adding larger diameter piping for a propane tankless system. In some cases, the piping in a house might not be large enough to accommodate the propane input rate of a propane tankless unit. In some cases however, a home will already have adequately sized piping from the propane tank. Due to this uncertainty no cost was assigned to these systems for this variable.

Energy Prices

While the energy simulations were used to develop projections of the energy consumption of each system in each location (e.g., gallons of propane per year), actual energy rates (e.g., dollars per gallon of propane) were needed to develop annual energy cost data. Energy rates used in the study were derived from market data which is regularly collected and made available by the U.S. Energy Information Administration (EIA). At the time of this analysis, data from the U.S. Energy Information Administration for the 2010 calendar year was obtained for deriving estimates of residential rates for heating oil, propane, and electricity. EIA's energy rate data is arranged by geographic regions such as states, regions, and other geographic groupings, which allowed this study to develop rates for each location in the study (as a function of the state).

The results of this effort – which are the energy rates used in the analysis – are shown in Figure 9 below. Heating oil prices are only provided for those locations (Manchester, NH and Buffalo, NY) where these systems were analyzed.

Figure 9: Energy Rates used for Different Analysis Locations, based on U.S. Energy Information Administration 2009 Data

Analysis Location		Propane Cost ($/gallon)	Heating Oil ($/gallon)	Electricity ($/kWh)
Sacramento	CA	2.44	n/a	0.15
Orlando	FL	2.60	n/a	0.12
Baltimore	MD	2.57	n/a	0.14
Grand Rapids	MI	1.99	n/a	0.12
Duluth	MN	1.73	n/a	0.10
Columbia	MO	1.74	n/a	0.09
Manchester	NH	2.67	2.63	0.16
Las Vegas	NV	2.44	n/a	0.12
Buffalo	NY	2.49	2.82	0.19
Dallas	TX	2.28	n/a	0.12
AVERAGE		**2.30**	**2.75**	**0.13**

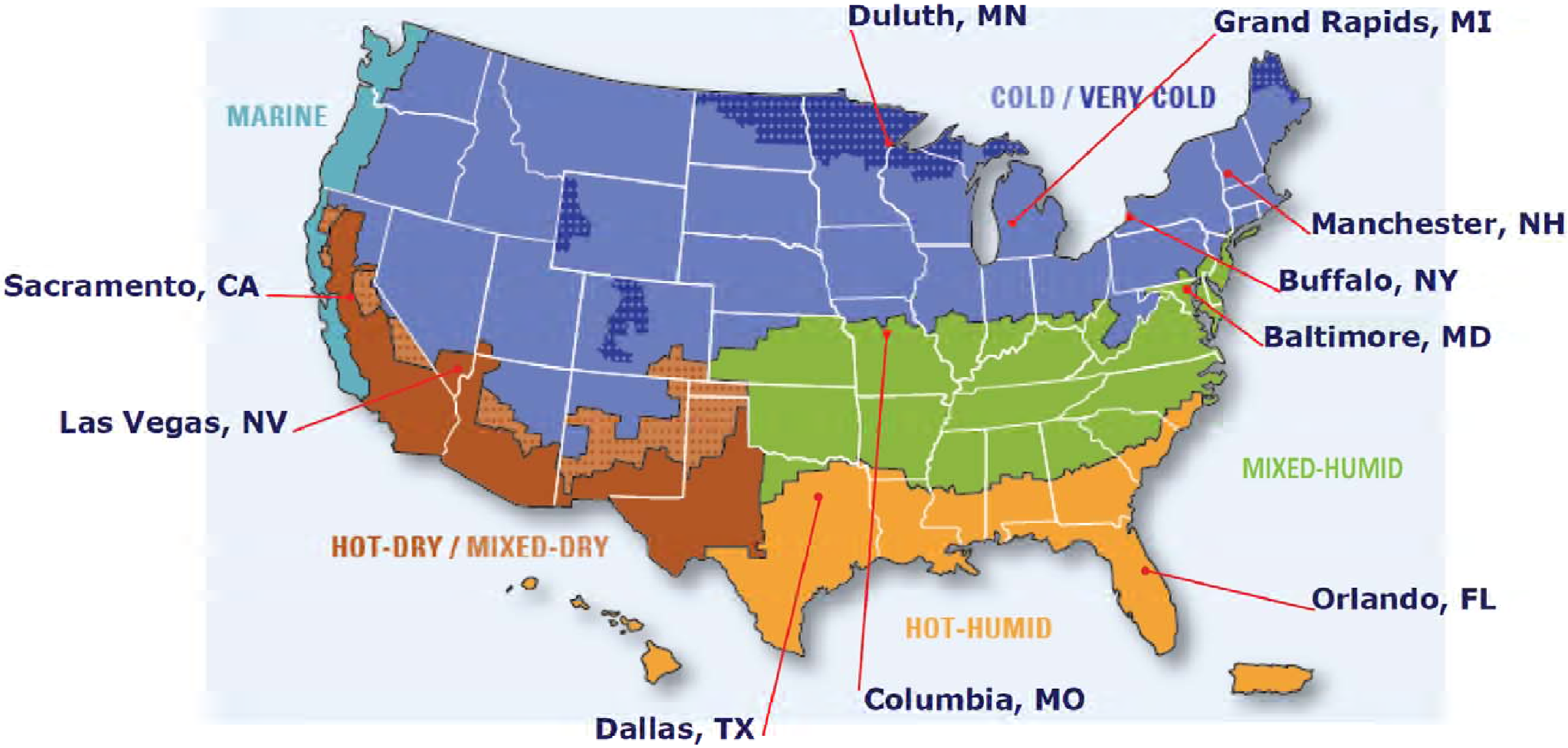

Figure 10: Analysis Locations

Figure 11: Water Heating System Specifications

System	System Type	Energy Factor (EF)	Minimum Efficiency per Current (as of 2010) Federal Standards	Storage Capacity (gallons)	First Hour Rating or Gallons per Minute (for tankless systems)	Basis for Efficiency Level
A	Propane standard efficiency storage	0.59	0.59	40	67	0.59 is the current federal minimum standard for this product.
B	Propane high efficiency storage, non-condensing	0.67	0.59	40	67	ENERGY STAR Water Heater requirements calls for EF ≥ 0.67 for residential gas storage water heaters, effective September 1, 2010. There was a lower specification prior to this date.
C	Propane high efficiency storage, condensing	0.80	0.59	50 (based on the market)	120+ (based on the market)	0.80 is the ENERGY STAR minimum for residential gas condensing WH units; ENERGY STAR FHR minimum ≥ 67
D	Propane tankless, non-condensing	0.82	0.62	0	4 GPM with a 75 F temp rise	0.82 is the ENERGY STAR minimum for residential gas tankless WH units. This value is also very common within the market of gas/propane tankless units, with > 97% of units listed in AHRI's product directory having an EF = 0.82.
E	Propane	0.94	0.62	0	4 GPM with a	The average EF of several leading

System	System Type	Energy Factor (EF)	Minimum Efficiency per Current (as of 2010) Federal Standards	Storage Capacity (gallons)	First Hour Rating or Gallons per Minute (for tankless systems)	Basis for Efficiency Level
	tankless, condensing				75 ˚F temp rise	manufacturers of gas/propane condensing tankless units was 0.94.
F	Electric standard efficiency storage	0.90	0.90	50	67	0.90 is the current federal minimum standard for this product.
G	Electric tankless	0.99	0.93		2-2.6 GPM with a 75 ˚F temp rise	Current federal minimum EF for this product class would be lower, but nearly all units on the market are 0.99 EF. This basis for determining the EF is consistent with the approach used for System C: propane tankless, non-condensing.
H	Heat Pump Water Heater (HPWH)	2.0	0.90	50	67	Current ENERGY STAR requirement for this product class is EF > 2.0

System	System Type	Energy Factor (EF)	Minimum Efficiency per Current (as of 2010) Federal Standards	Storage Capacity (gallons)	First Hour Rating or Gallons per Minute (for tankless systems)	Basis for Efficiency Level
I	Heating oil standard efficiency storage	0.53	0.53	32	130 (this higher FHR value reflects products in the market)	0.53 is the current federal minimum standard for this product.
J	Active solar DHW with a storage tank and propane tankless (non-condensing) back-up	2 flat plate collectors with a propane tankless back-up heater @ EF 0.82		80	4 GPM with a 75 F temp rise	

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IV. Annual Energy Costs

Annual energy costs for the 10 water heating systems were estimated using Energy Gauge modeling software for the 10 analysis locations in the study. The annual energy cost for a given water heating system reflects the system's efficiency in producing and storing (for tank systems) hot water, as well as the energy prices for the analysis location. The basis for determining energy prices for the analysis locations is discussed in the Methodology section above. The modeling software also assumes a certain amount of hot water consumption for a given house. The daily hot water demand of 60 gallons was the same for all systems in the analysis.

Figure 12 illustrates the annual energy costs for the water heating systems, averaged across all 10 locations in the study. These energy cost estimates apply to both new construction water heater installations as well as replacement systems.

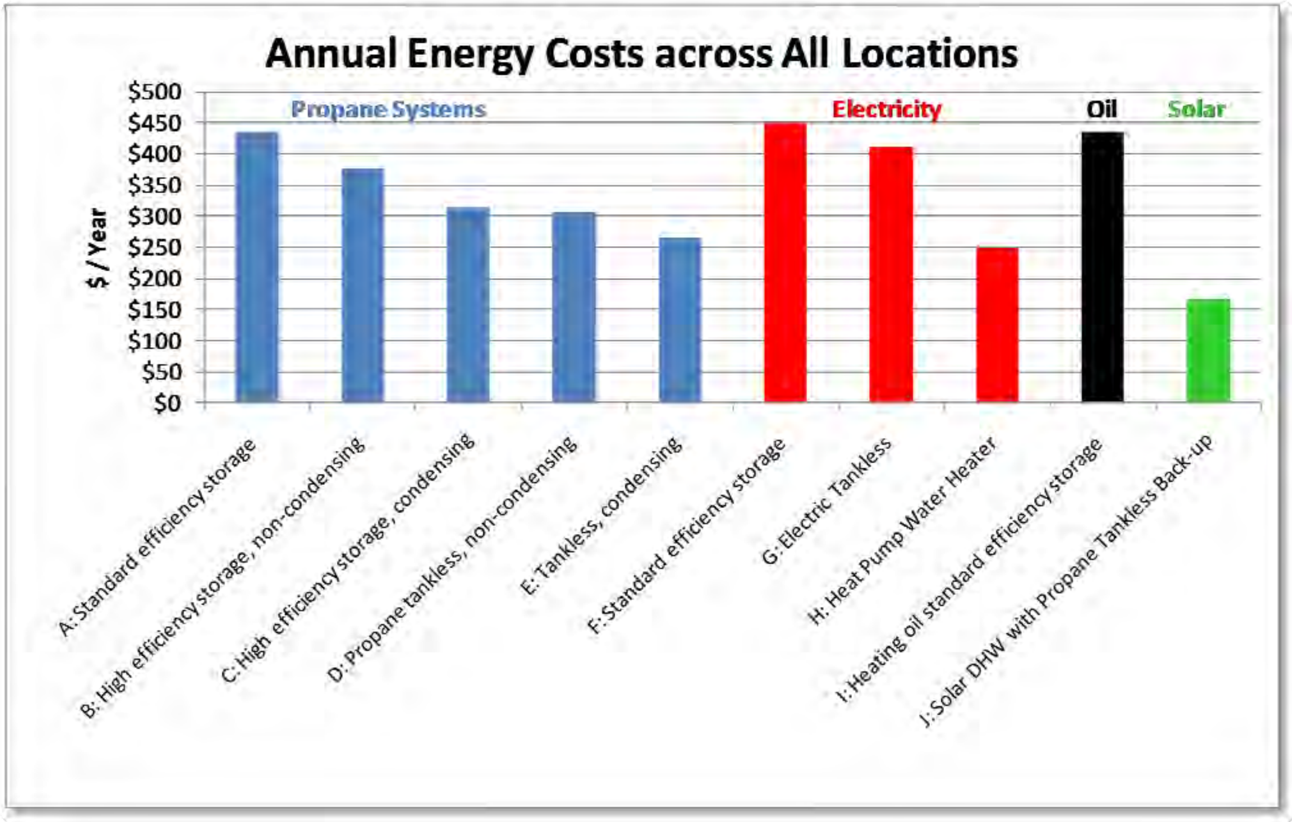

Figure 12: Annual Water Heating Energy Costs, Average of All Analysis Locations

As expected, annual energy costs decrease within a particular product category as the efficiency ratings increase. For example, System A – Standard Efficiency Propane Storage (0.59 EF) is the most costly propane system to operate while System E – Propane Condensing Tankless (0.94 EF) is the least expensive propane water heating system in terms of annual energy costs. This same type of relationship is also seen for the electric water heating systems.

In terms of “standard” systems, or those at the federal minimum efficiency levels, the standard efficiency propane storage system (A) has energy costs 3% lower than the standard efficiency electric storage system (F). System F is also the highest energy cost system among all 10 systems, based on averages across all locations. This is very important to note, as the standard efficiency electric storage tank is extremely common for installations in both new construction and as a replacement.

The fact that System F – with an Energy Factor of 0.90 – has the highest annual energy cost of all 10 systems, underscores a critical point. The Energy Factor rating is not useful on its own for comparing the annual energy costs across water heating systems with different fuel sources. For example, the standard efficiency propane storage system with an Energy Factor of 0.59 has lower annual energy costs than the electric storage tank (EF 0.90) and is even within 6% of the electric tankless system with an Energy Factor of 0.99. See the adjacent text box for more discussion on the appropriate use of the Energy Factor rating.

Energy Factor is a standardized measurement of a water heater’s ability to convert incoming energy – in the form of propane, natural gas, oil, or electricity – into hot water. The “EF” of a water heater takes into account a unit’s:

1. Standby Losses – which are thermal losses from storage (tank) water heaters to the surrounding environment. Tankless units do not have standby losses – one of their advantages.
2. Recovery Efficiency – which is how efficiently a unit can heat up water.
3. Cycling Losses – which are thermal losses experienced as water circulates through a water heater tank.

Energy Factor is very useful for comparing the efficiency of water heaters **with the same energy source**, and predicting which one will have lower annual energy costs. For example, it can be used to compare a high efficiency storage (condensing) propane water heater (EF = 0.80) to a propane tankless condensing water heater (EF = 0.94). Within the same energy source (propane in this example), the system with the higher Energy Factor will have lower annual energy costs. In this example, the condensing storage system would have annual energy costs of about $314 compared to $267 for the tankless system (based on Figure 11 above).

But using Energy Factor comparisons to predict annual energy costs across water heaters of different fuel types is not reliable. For example, an electric storage water heater with EF = 0.90 (System F) might appear to be a better option than a propane storage water heater with a much lower Energy Factor of 0.67 (System B). But if one also considers the **price of the energy source**, the propane water heater in this example would cost roughly **$72/year LESS** to operate than the electric water heater – even though the electric unit has a higher Energy Factor.

The heating oil-fired water heater (System I), shown in black in the chart above, is a standard efficiency unit which has energy costs equal to those of the standard efficiency propane storage tank system (A). System I is only evaluated in 2 Northeast markets because heating oil is much less common in other regions of the country. Therefore the discussions of heating oil system performance are isolated to the Northeast regional analysis below.

Figure 12 above also shows the systems with the lowest annual energy costs:

1. System J: Solar DHW with propane tankless back-up ($166/year)
2. System H: Heat Pump Water Heater ($248/year)
3. System E: Propane Tankless, Condensing ($267/year)

These systems offer significant annual savings compared to other, lower efficiency hot water options. The low annual costs for these systems should be balanced against system first costs, a topic which is discussed in the next section.

Among these three systems, it is noteworthy that the propane tankless (EF 0.94), condensing system has an annual energy cost within $19 of the heat pump water heater unit (EF 2.0). This again illustrates that efficient propane systems' energy costs compete well with electric systems with higher Energy Factor values, and that the EF value alone should not be used to evaluate systems.

The solar hot water system, coupled with a propane tankless back-up, is clearly the lowest energy cost system across the 10 locations. This reflects the fact that the system utilizes solar energy to heat water to meet a significant portion of the home's hot water demand. The solar resources which make this possible vary significantly by location, as seen in Figure 13 below. The results of this figure indicate both the variation in the amount of solar energy (sunlight) by location, as well as variation in propane prices (since a propane tankless system provides the balance of the hot water demand not supplied by the solar collectors).

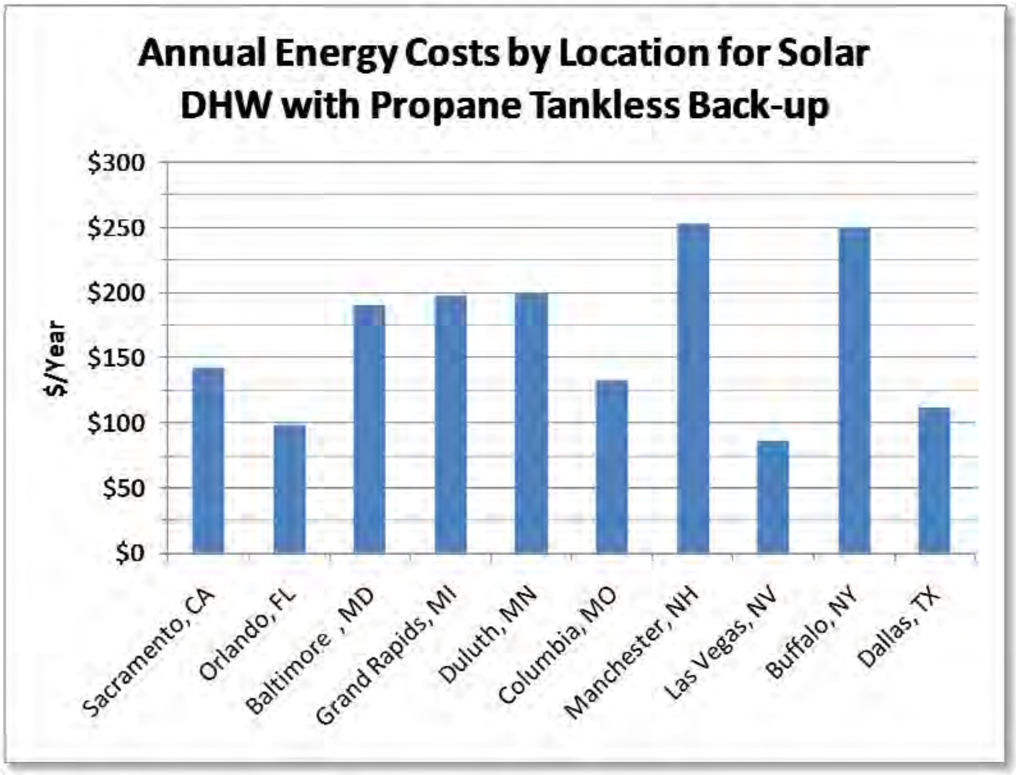

Figure 13: Solar DHW System Annual Energy Costs by Location

Figures 14 - 18 which follow present the annual energy costs by climate, based on the climate regions shown above in the map (Figure 10). Each chart is followed by a short summary of key findings from the climate-based breakdown of energy costs.

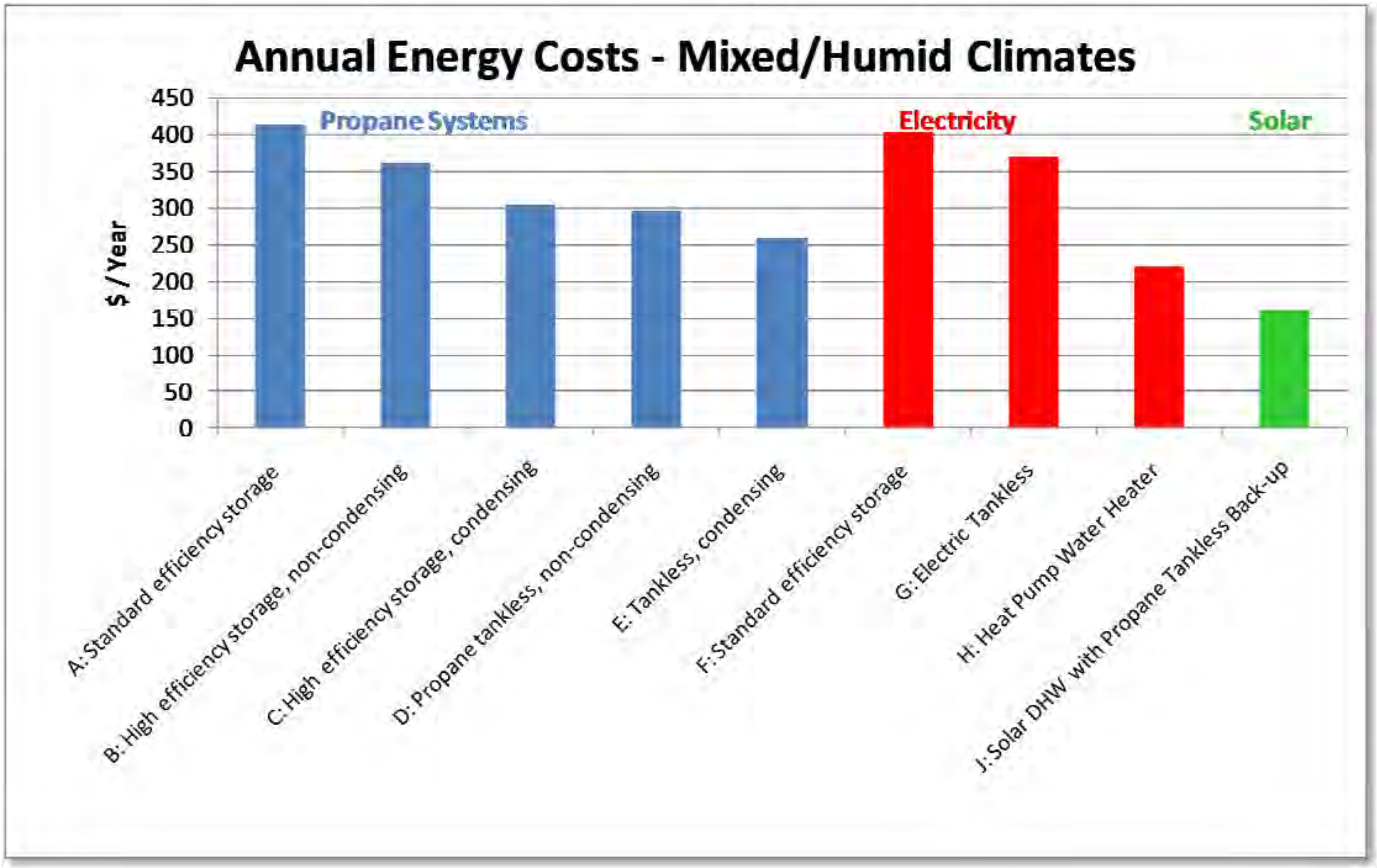

Figure 14: Annual Energy Costs for Mixed/Humid Climate Analysis Locations

Key findings for the mixed/humid climate zone include:

- The lowest energy cost system is System J once again, followed by the HPWH system (System H) and the propane tankless condensing system (System E), which are within $38 of each other.
- Propane systems exhibit a pattern of lower annual energy costs with increasing system efficiency, with Systems B, C, D, and E all less than $365/year. Each of these systems has lower energy costs than the traditional electric storage unit (System F) as well as the electric tankless system (System G). These 2 systems ranged from $370 to $403.
- The high efficiency condensing propane storage tank (System C) has the lowest energy costs of any non-heat pump storage unit (either propane or electric resistance). In fact, System C is about 33% less expensive to operate than the electric storage tank (System F). It is also within $8 annually of System D, the tankless non-condensing propane unit.

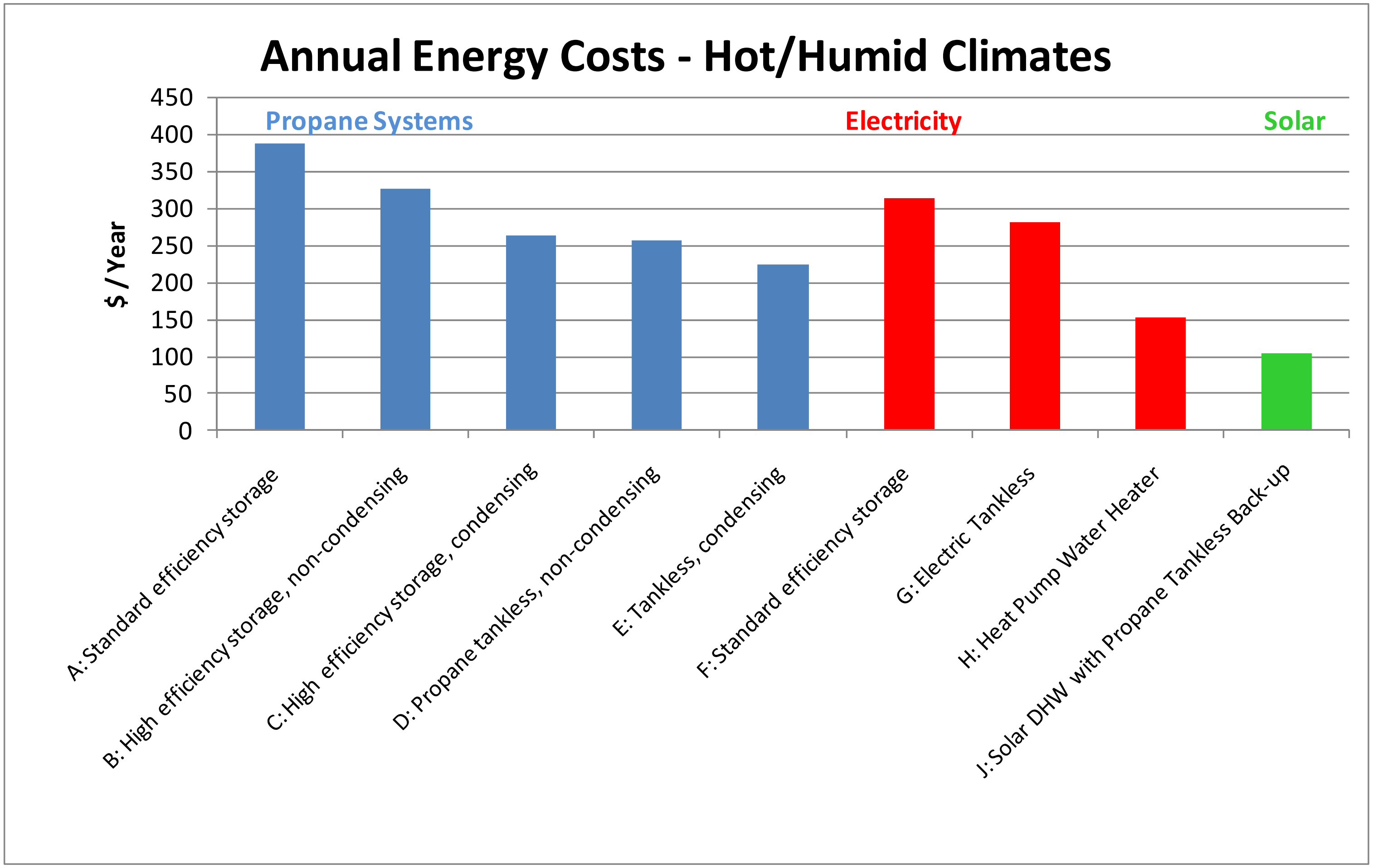

Figure 15: Annual Energy Costs for Hot/Humid Climate Analysis Locations

Key findings for the hot/humid climate zone, which are based on analysis for Dallas and Orlando, include:

- The lowest energy cost system is System J: Solar DHW with propane tankless back-up, with an annual energy cost of just over $100. This reflects good availability of solar resources in the 2 hot/humid locations upon which these findings are based: Dallas and Orlando. It also reflects efficient operation of the propane tankless back-up system. The low carbon emissions of this type of system are discussed later in this report.
- The two next least-cost systems are System H (HPWH) and System E (propane tankless condensing). This “top 3” is the same set of systems which was seen for the national average data.
- Propane systems exhibit a pattern of lower annual energy costs with increasing system efficiency, with Systems C, D, and E all less than $265/year. Each of these systems has lower energy costs than the traditional electric storage unit (System F) as well as the electric tankless system (System G).

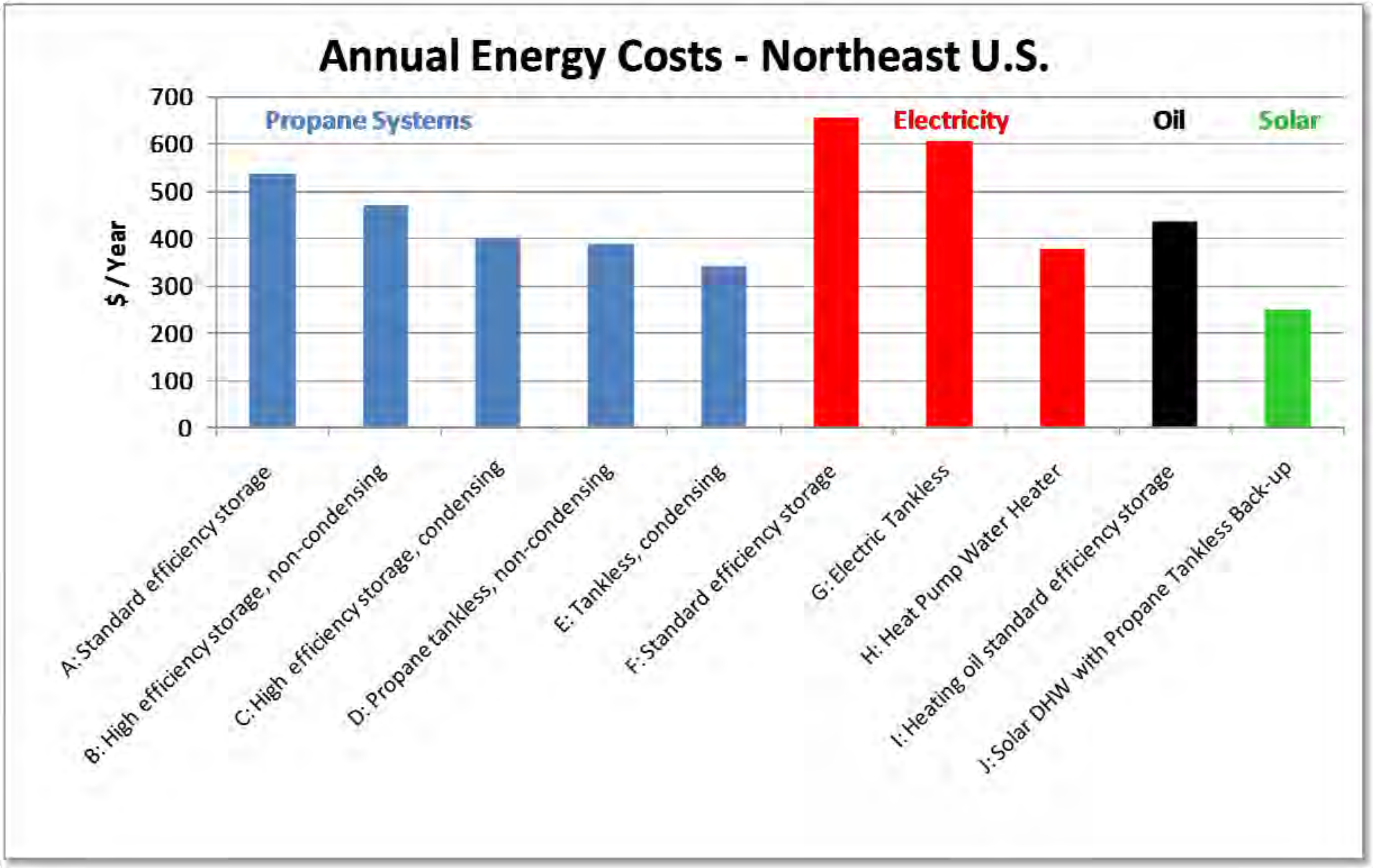

Figure 16: Annual Energy Costs for Cold Climate Zone: Northeast

The locations in the Cold/Very Cold climate zone are grouped separately into Northeast results and Midwest findings. This was done to create a separate set of results for the two locations in the Northeast which include heating oil systems. In this manner, the results involving heating oil systems compare performance and energy prices (across all systems) specifically for the two locations where this fuel source was analyzed.

For the Northeast locations (Buffalo, NY and Manchester, NH) analysis above in Figure 16, key findings include:

- The lowest energy cost system is System J at $251/year. The next two least-cost systems are the two propane tankless condensing system (E, $340/year) and the HPWH (H, $378/year).
- The heating oil storage tank system (System I) ranks in the middle of the systems (6th lowest cost out of 10). It has significantly lower energy costs (~51% lower) than the electric storage tank systems (F). System I (heating oil standard efficiency) is also about 9% less expensive than propane System B, while it is 9% more expensive than condensing propane storage unit (System C) and an average of 19% more expensive than the propane tankless systems (D, E).
- The HPWH unit (System H) has the highest annual energy cost in the Northeast compared to all other regions. Its annual energy cost in the Northeast is about 52% higher than its average across all analysis locations, driven by the relatively higher electricity costs in this region (17.4 cents/kWh).
- The high efficiency, condensing propane storage tank (System C) has the lowest energy costs of any non-heat pump storage unit (either propane, heating oil, or electric resistance). The high efficiency, condensing propane storage tank is also within $23 of the HPWH system.
- The lowest efficiency propane storage unit (System A) is still $120 less expensive per year than the standard efficiency electric storage unit (System F). System B – a propane storage tank unit which qualifies for ENERGY STAR labeling – is $184 less costly than the standard electric storage unit (System F).

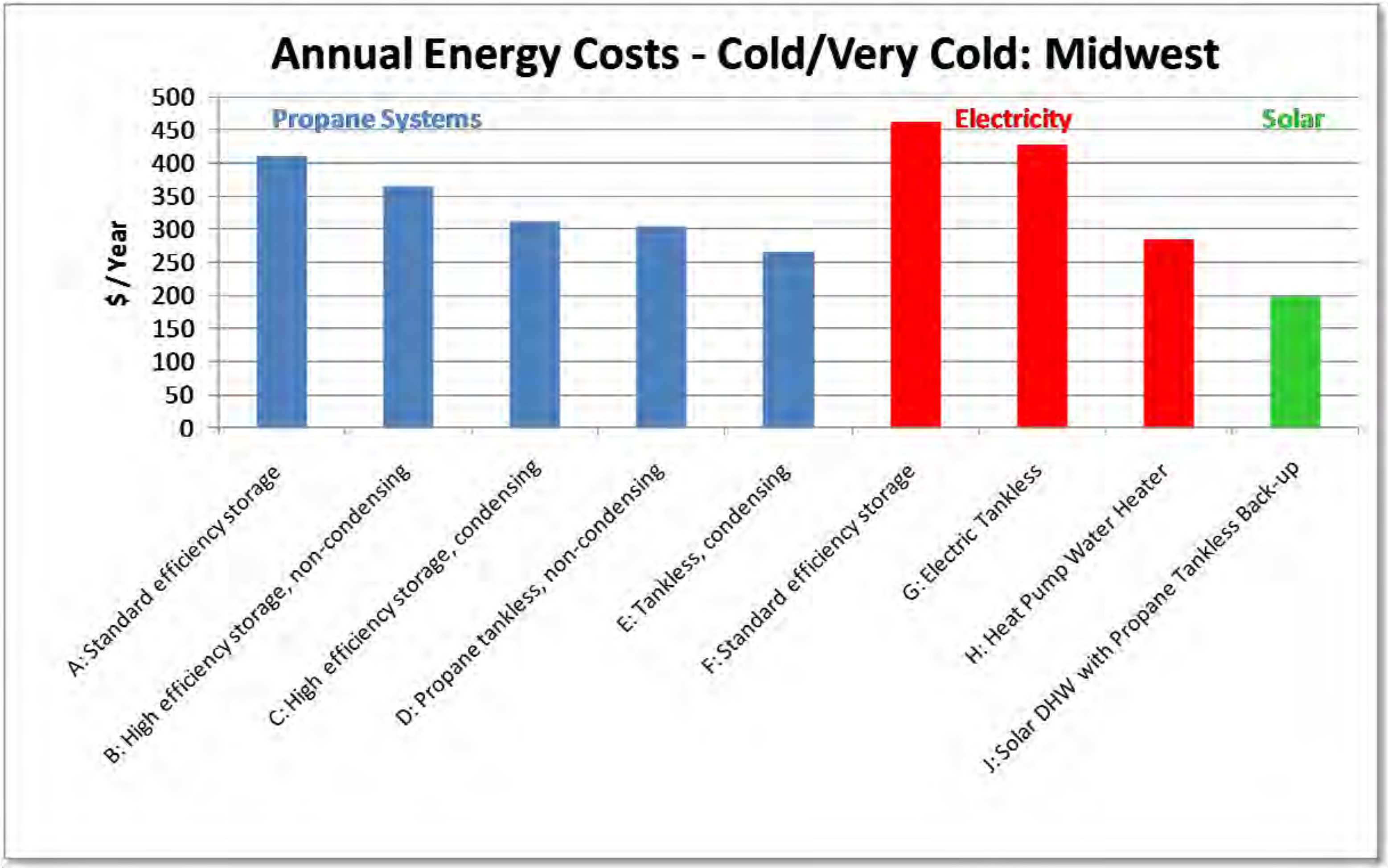

Figure 17: Annual Energy Costs for Cold/Very Cold: Midwest

For the Midwest locations (Grand Rapids, MI and Duluth, MN) analysis shown above in Figure 17, key findings include:

- The lowest energy cost system is System J once again ($199 annual energy cost), followed by the propane tankless condensing system (System E) at $265 and the HPWH system (System H) at $284. The propane non-condensing tankless unit (System D) is slightly more costly ($20) than the heat pump water heater.
- The electric storage tank system (F) has annual energy costs of $461. By contrast, the standard and high efficiency propane storage tank systems (A and B) have annual energy costs which are $412 and $364, respectively. The average savings of these two propane systems over the electric storage system is about $73/year.
- The electric tankless unit (System G) has an annual energy cost of $429, placing it as the second most expensive system, behind the electric storage tank (System F).
- System B - the high efficiency propane storage tank (non-condensing) – is about $97 less annually compared to the standard efficiency electric storage tank (System F). System B is essentially an Energy Star-qualified propane water heater, which is a viable replacement alternative to a standard electric storage unit. Replacement scenarios and costs are discussed in subsequent sections of the report.

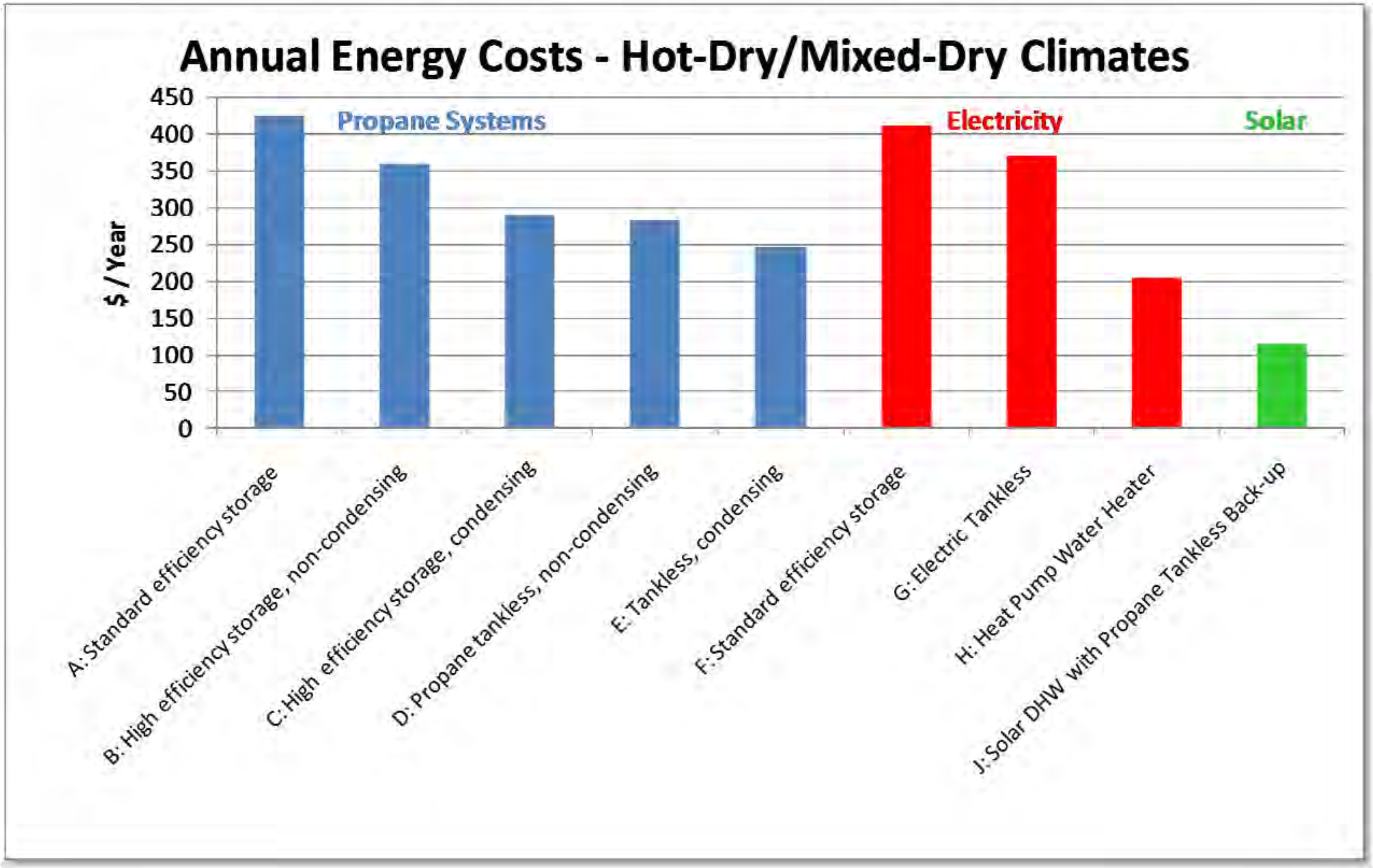

Figure 18: Annual Energy Costs for Hot-Dry/Mixed-Dry

For the Hot-Dry/Mixed-Dry locations shown above in Figure 18, key findings include:

- The lowest energy cost system is System J once again ($115 annual energy cost), followed by the HPWH system (System H) at $205 and the propane tankless condensing system (System E) at $246.
- The two standard efficiency storage tank systems (A – propane; F-electric) have the highest annual energy costs at $424 and $412, respectively. By contrast, the high efficiency (condensing) propane storage tank systems (C) is about $130 less per year compared to these standard efficiency options.
- The electric tankless unit (System G) has annual costs of $369, placing it among the three most expensive systems.
- System B - the high efficiency propane storage tank (non-condensing) – is about $53 less annually compared to the electric storage tank (System F). System B (EF = 0.67) is essentially an Energy Star-qualified propane water heater, which shows significant annual savings compared to an electric storage water heater with a higher Energy Factor (0.90).

V. Economic & Environmental Analysis

Along with annual energy analysis, this research investigated the economic and environmental aspects of water heater performance.

Economic Analysis Background

The economic analysis evaluated systems based on both their annual energy cost, as well as the initial installation cost (equipment and labor). Installation costs were estimated based on a combination of data from U.S. DOE's recent rulemaking analysis on residential water heaters (which included detailed cost estimating methods and data)[8], surveys of retail equipment prices, and cost estimates drawn from RS Means.

Installation costs were developed separately for new construction installations and replacements. In some cases, the installation cost for a given system was significantly different between these two scenarios, due in part to assumed requirements for combustion venting and system electrical supply. Venting requirements for replacements depended on the system which was being replaced, which was assumed to be an electric storage tank unit in all locations except the two Northeast locations. In the Northeast, the existing system was assumed to be a heating oil water heater with vertical steel venting. Thus, in 8 of the 10 analysis locations, propane water heaters installed as a replacement were assigned a cost for either plastic horizontal venting (Systems B, C, E) or stainless steel horizontal venting (System D). In the 2 Northeast locations, only System A was assumed to be able to make use of the pre-existing vertical venting when installed as a replacement unit. This was a somewhat conservative assumption, which increased installation costs for propane systems. In actual replacement situations where existing venting may be re-used, installation costs will be lower.

For electric water heaters, installation costs included provisions for a dedicated electrical supply, unless an electric tank was replacing an existing electric tank (in which case it could likely make use of the existing circuit). The heat pump water heater system was assigned an added man-hour of labor due to a more complex installation, which was consistent with the approach used by DOE in the standard rulemaking. Unlike the DOE rulemaking analysis, however, the cost estimating for HPWH installation did not include added costs for framing modifications to

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[8] "Residential Heating Products Final Rule Technical Support Document," US Department of Energy, 2010. http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr.html. Accessed July 2011.

accommodate a larger unit or the need to add a louvered door for sufficient ventilation for the HPWH. Because these installation requirements would only apply in limited circumstances, their associated costs were not included. HPWHs installations in basement locations in cold climates (Climate Zone 5 and higher) followed a similar approach to that used in the DOE rulemaking analysis, by assigning a cost for ducting the cool exhaust air from the HPWH to outdoors, which avoids increasing the home's heating load during much of the year.

In replacement system analyses, the cost estimating did not include potential costs associated with switching fuels for the new water heater. In some cases, a house may already have access to the energy source for the new type of water heater (e.g., there is already propane on site to supply a new propane tankless unit). Access to electricity on site can certainly be assumed, although in some circumstances the capacity of a home's electrical service may need to be upgraded to accommodate an electric tankless system. However, because this type of installation requirement would only apply in limited circumstances, the associated cost was not included.

In the case of adding propane service to a house, the costs for this transition can often be minor due to flexible tank placement, little/no trenching, and leasing arrangements with propane suppliers which avoid the need to purchase the propane tank. It should also be noted that the cost to run a gas line within the home to a new propane water heater was included in the installation cost. Finally, there can sometimes be costs associated with ceasing to use heating oil in a home, such as removal and disposal of an underground tank. Such issues are difficult to predict in a study of this type, and therefore no costs for this type of activity were applied in the cost analysis.

Installation requirements for different systems which were captured in the cost analysis are summarized in Appendix A, along with First Cost summary charts for both new construction and replacements. Also, the Methodology section above provides additional details on the overall cost estimating analysis as well as explanations of costs which were considered but not included.

The economic metric which was used to relate first cost, annual energy cost, and the expected service life for a given system is the "Annual Cost of Ownership", or ACO. The ACO approximates the annual costs which the homeowner expects to pay for that system, including energy, equipment, and installation costs.

The ACO includes the sum of the annual energy cost incurred in the first year of system operation and the annual principal and interest payment on the system's first cost amortized over the equipment's rated service life. The interest rate used in the analysis, 6%, was selected to estimate a rate which could reasonably represent the loan rate to finance a water heater purchase (either in new construction or a replacement). The loan term is the expected service life of the water heater: 13 years for storage tank systems and 20 years for tankless systems. These service life estimates are based on multiple sources, which all estimate 20 years for tankless systems and a range of 10 to 15 years for storage systems. [9] [10] [11]

Environmental Analysis Background

Beyond costs, another very important performance metric for residential water heating systems is their environmental footprint in terms of carbon emissions. The CO_2 emissions which are associated with the operation of each water heating system in each location were analyzed as part of this project. This analysis was conducted through the use of "emissions factors" from the U.S. EPA's Emissions & Generation Resource Integrated Database (eGRID). These emission factors provide a multiplier to estimate the emissions which result from the production of a unit of electricity. The emissions factors in eGRID are given down to the state level. So for a given state, the emissions factor takes into account the mix of fuel sources used to generate electricity in that state (e.g. coal, nuclear, hydro) and develops the state's emission factor based on this blend of sources. For this reason, a unit of electricity in a state with a high proportion of hydropower-generated electricity will result in lower emissions than a unit of electricity in a state heavily reliant on coal-generated electricity. Emissions factors which relate CO_2 emissions from combusting propane or heating oil are also incorporated into this analysis. These emission factors were sourced from U.S. Energy Information Administration's "Carbon Dioxide Emission Factors for Stationary Combustion"[12].

It should be noted that System J, the solar hot water system with propane tankless back-up, is discussed separately from the regional results below. The primary reason for this is that the study's scope does not include the potential economic benefits of tax credits or incentives for certain hot water systems. While the rationale for this approach makes sense for the purpose of this study, one implication is that System J appears extremely costly compared to all other systems. In most real-world cases, solar systems will benefit from one or more credits which can reduce the system cost substantially. Thus, these systems are covered in a separate section.

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[9] California Energy Commission, Consumer Energy Center. http://www.consumerenergycenter.org/home/appliances/waterheaters.html. Accessed July 2011.

[10] Energy Star Products Website. http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WH. Last accessed July 2011

[11] "Study of Life Expectancy of Home Components," National Association of Home Builders and Bank of America, February 2007.

[12] www.eia.doe.gov/oiaf/1605/coefficients.html. Last accessed July 2011.

Economic & Environmental – Mixed/Humid

The Mixed/Humid region results (Figure 19), which are based on analysis findings for Baltimore and Columbia, Missouri, reflect that propane tankless systems (D, E) are very competitive new construction options compared to all other systems based on their Annual Cost of Ownership (ACO). In other words, the combined effect of propane tankless' low annual energy costs (Figure 14 from the previous section) and longer service life (20 years) make the true cost of owning and operating these systems less than traditional storage tank units (propane or electric) and less than HPWHs. For example, System E has an ACO which is 17% lower than System B (propane high efficiency storage); and 10% lower than both System F (standard efficiency electric storage) and System H (HPWH).

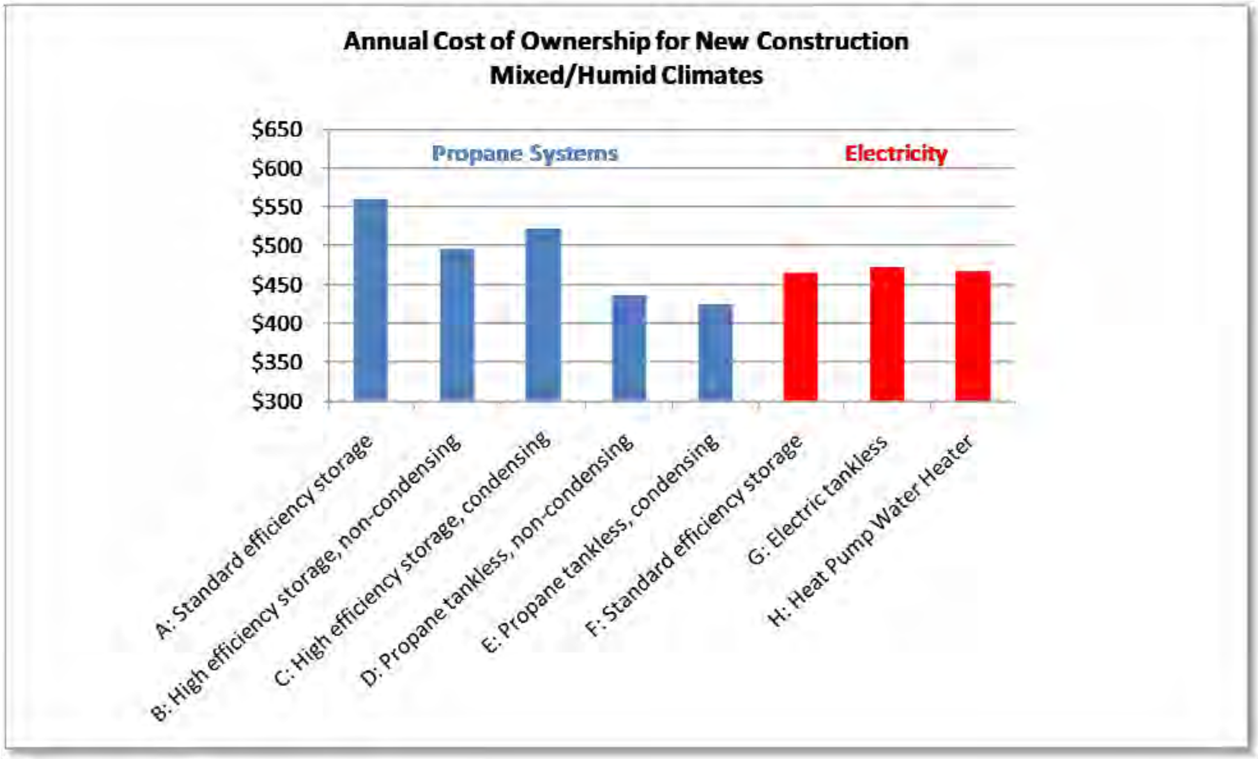

Figure 19: Annual Cost of Ownership for Water Heaters in New Construction, Mixed/Humid Climate

For replacement applications, Figure 20 below shows similar results. The propane tankless systems (D, E) have the lowest Annual Cost of Ownership again. In terms of direct comparisons, System E (propane tankless, condensing) has an ACO which is 21% lower than System B (propane high efficiency storage); 3% lower than System F (standard efficiency electric storage), and 4% lower than System H (HPWH). Note that System A is not shown as a replacement option in any region except the Northeast, due to the assumption that the pre-existing system is an electric storage tank unit.

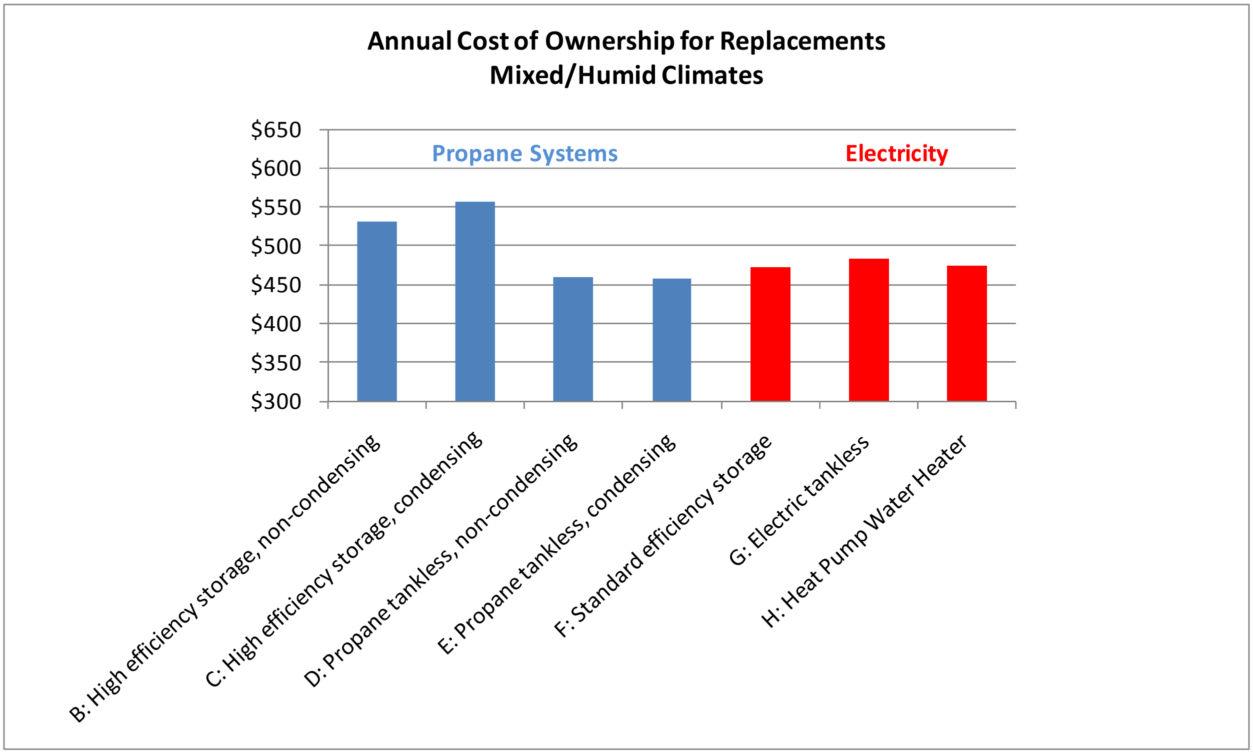

Figure 20: Annual Cost of Ownership for Water Heater Replacements, Mixed/Humid Climate

A comparison of these same four systems in terms of CO_2 emissions is shown below in Figure 21. The figure illustrates that the standard efficiency electric storage unit (F) emits 2.5 times more CO_2 than the high efficiency propane tank (B) and more than triple the CO_2 emissions of the propane tankless condensing system (E). Taken over the 13 year estimated life for System F, the emissions benefits of using the propane tankless condensing system (E) is like removing 4 passenger cars from the road for a year.

Further, the heat pump water heater (H) has emissions which are 39% higher than System B and nearly <u>double</u> the emissions from System E. This underscores the reality that even highly efficient electric water heaters still use significant quantities of electricity, which generally comes from fossil-based power generation plants. These power plants will typically consume roughly 3 units of energy to produce 1 output unit of electricity, so the resulting emissions from the production of electricity are often significant. This then results in significant CO_2 emissions for downstream electric-based water heating systems, like the heat pump water heater.

It should be noted that the CO_2 emission results characterize water heater performance in both new and existing homes, so these results are not broken out separately.

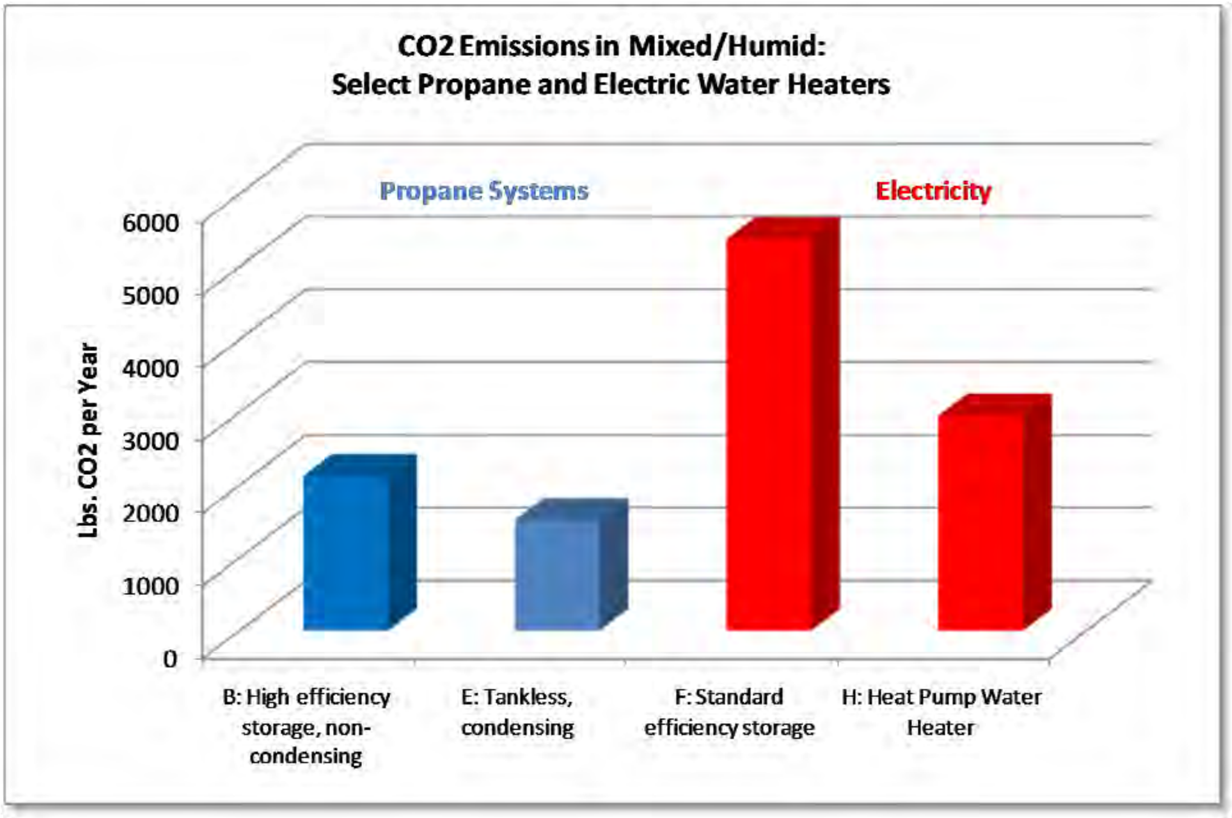

Figure 21: Annual CO_2 Emissions for Selected Water Heaters, Mixed/Humid

Economic & Environmental – Hot/Humid

The Hot/Humid region results, which are based on analysis findings for Orlando and Dallas, are shown for New Construction systems in Figure 22 below. System F (standard efficiency electric storage) has the lowest ACO; with 3 other systems within 5%: Systems G (2%), E (3%), H (5%), and D (5%). The tight grouping of these systems is driven in-part due to lower electric rates in this region of the country.

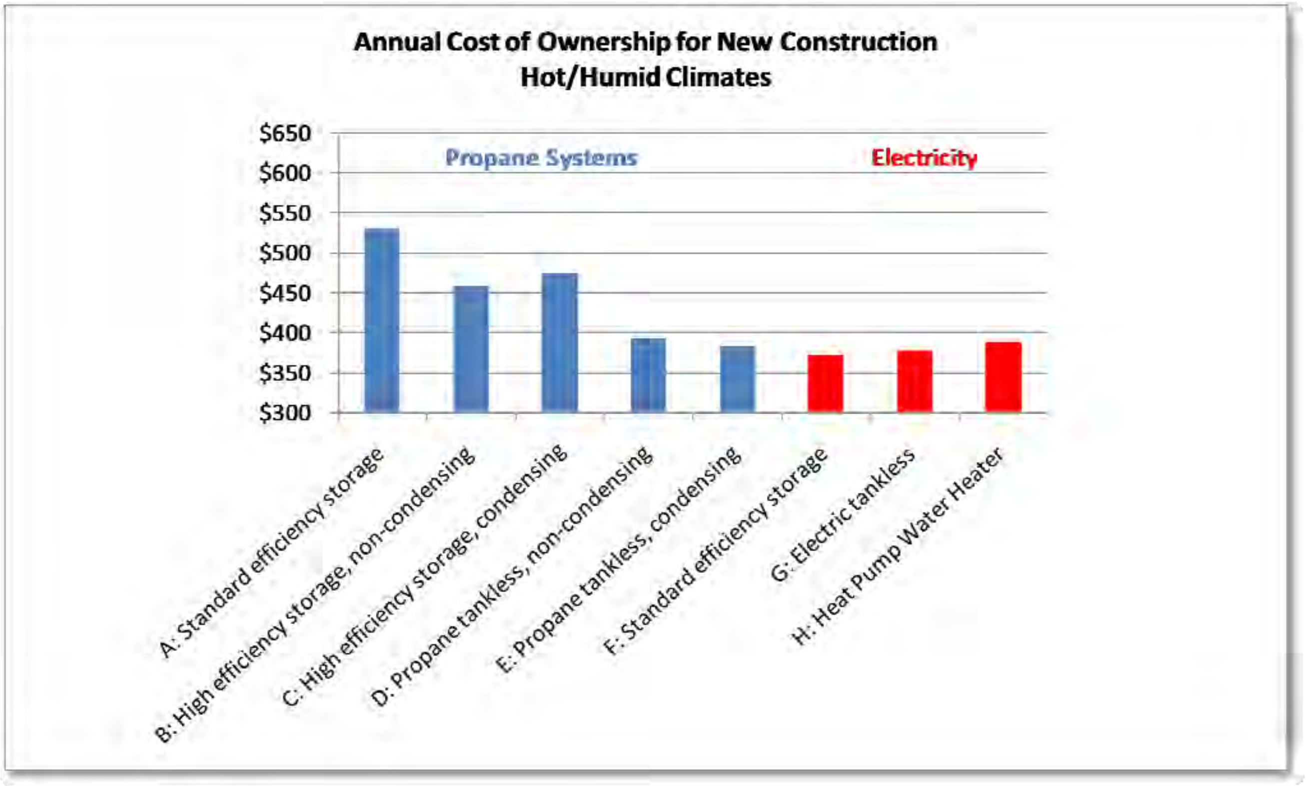

Figure 22: Annual Cost of Ownership for New Construction, Hot/Humid Climate

For replacement applications, Figure 23 below shows similar results although the standard efficiency electric storage is lower than the competing systems to a greater extent: 1% for the electric tankless (G), 5% for the HPWH (H), and 9% for both propane tankless systems (D, E).

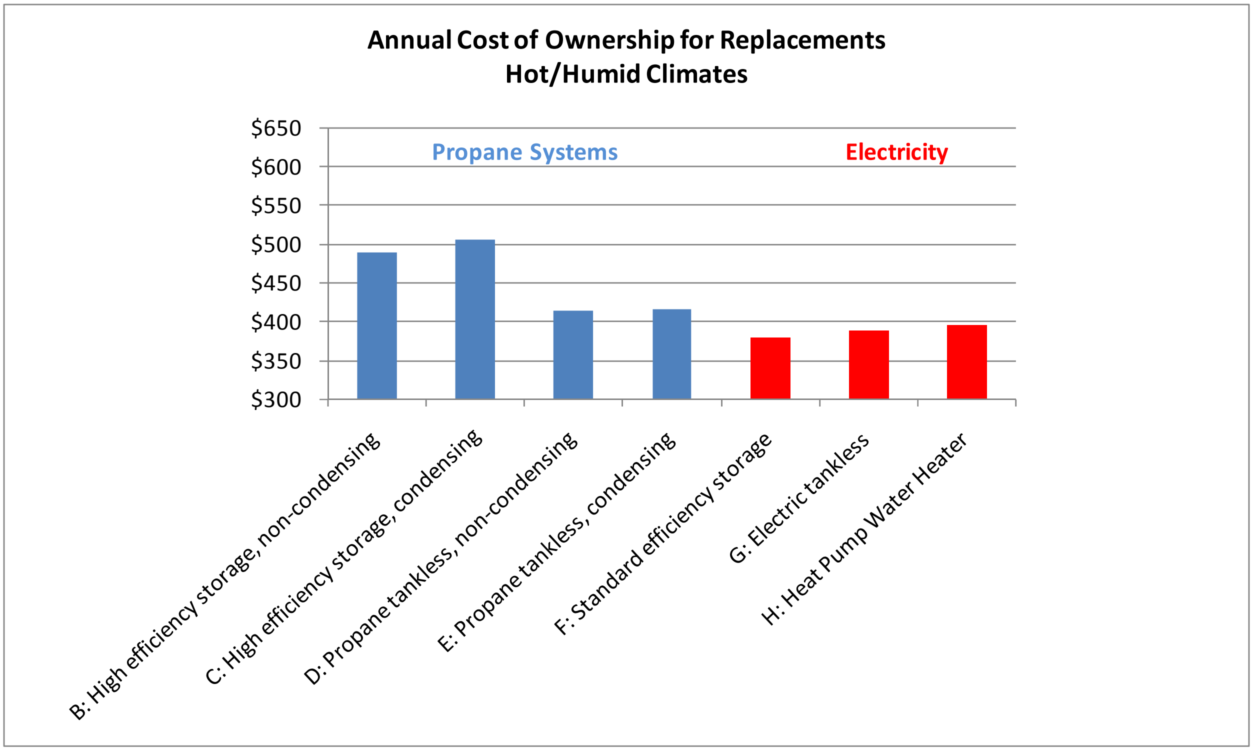

Figure 23: Annual Cost of Ownership for Water Heater Replacements, Hot/Humid Climate

Focusing on Systems D, E, F, G, and H in terms of CO_2 emissions, Figure 24 illustrates that the propane tankless systems (D, E) have emissions which are 64% lower than the standard efficiency electric storage tank (F). For the propane condensing tankless system, it has emissions which are 67% lower than the standard efficiency electric storage (F); 63% lower than the electric tankless (G); and 31% lower than the heat pump water heater (H). The most extreme difference in CO_2 emissions – the propane condensing tankless

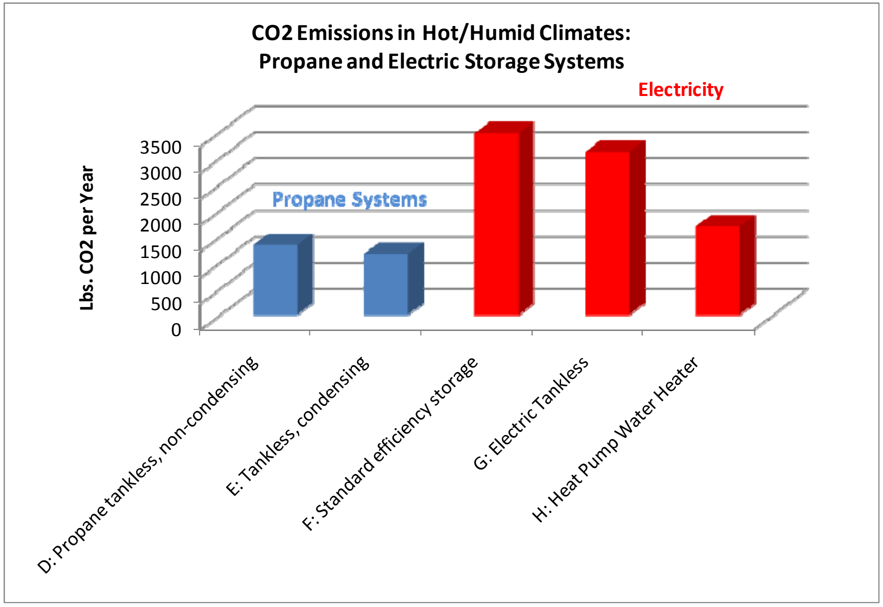

Figure 24: CO_2 Emissions for Select Propane and Electric Water Heaters, Hot/Humid

compared to the standard efficiency electric storage – results in over 1 ton of CO_2 savings every year.

Economic & Environmental – Cold: Northeast

The Cold/Northeast region results are based on analyses for Buffalo and Manchester, NH, and include the heating oil water heating system (I). The Annual Cost of Ownership for New Construction systems is shown below in Figure 25. All five propane systems (both storage units and tankless) have lower ACOs than competing electric or heating oil systems. The two propane tankless units (D, E) have the lowest ACOs and are 26% and 24% lower than the electric storage tank (F) and the HPWH (H), respectively.

Compared to the standard efficiency heating oil storage unit (I), the standard propane storage unit (A) is 11% lower while the propane condensing tankless system (E) is 33% lower. This means that if a homeowner in the Northeast were to finance the purchase of a new propane tankless water heater over the life of the system, the annual cost of paying for the unit plus the annual energy costs would be 33% (or $260) lower compared to a heating oil storage unit.

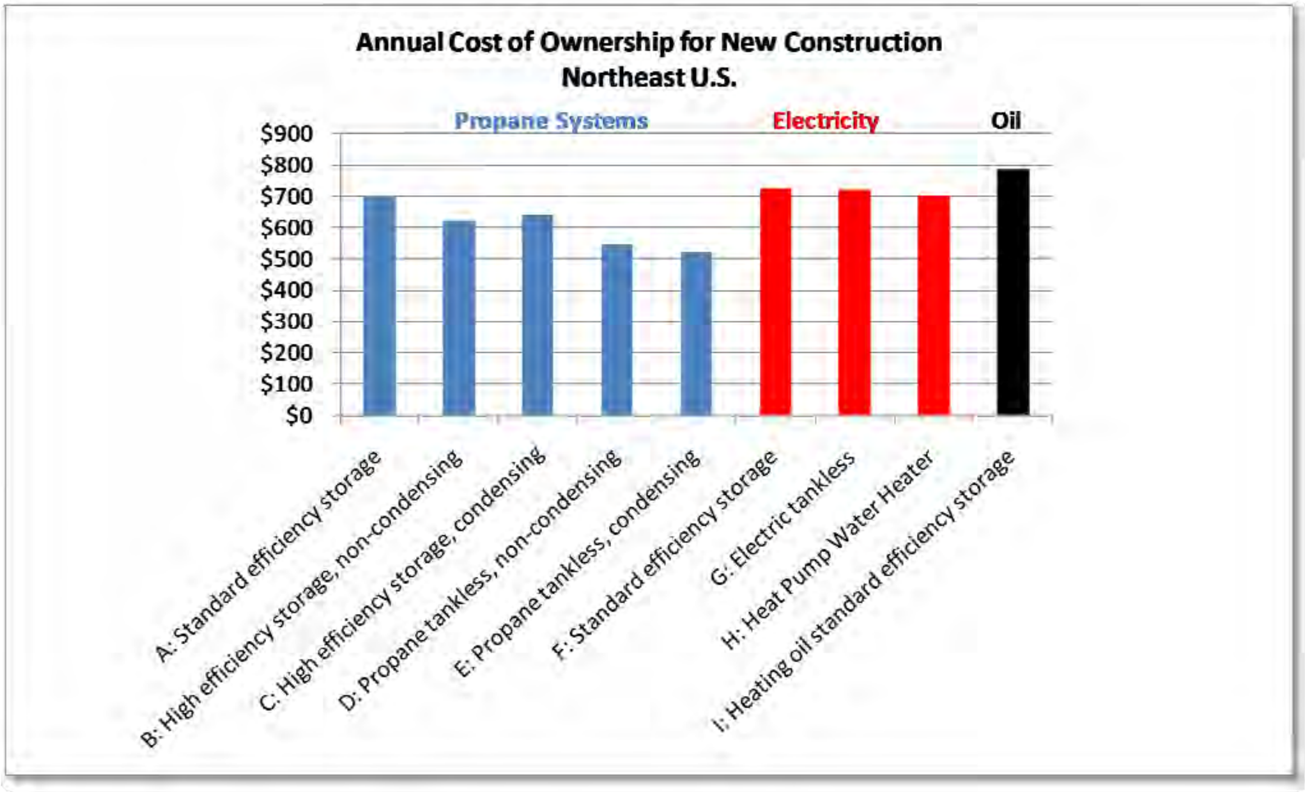

Figure 25: Annual Cost of Ownership for New Construction, Cold Climate/Northeast U.S.

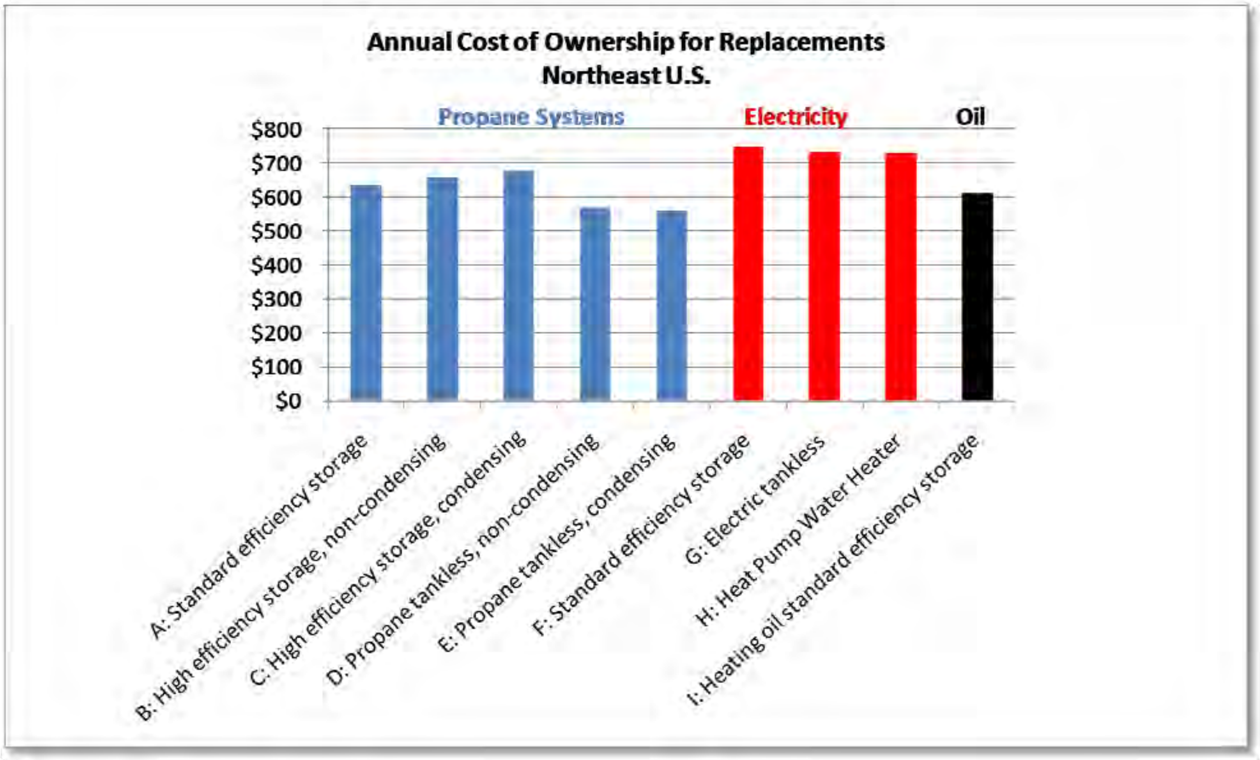

Figure 26: Annual Cost of Ownership for Water Heater Replacements, Cold Climate/Northeast U.S.

For replacement applications, Figure 26 shows the same trends for propane systems compared to electric water heaters. Propane tankless systems (D, E) have ACOs which average 25% and 23% lower than the ACOs for the standard efficiency electric storage (F) and the HPWH (H). Part of propane's competitive advantage in the Northeast is a relatively high cost for electricity at 17 cents/kWh. However, as issues like national or regional carbon emissions regulations become increasingly relevant, electricity prices in various regions around the country could also experience price increases.

The Annual Cost of Ownership for the heating oil storage unit (I) is more competitive for replacements than for new construction, due in-part to the assumption that the replacement unit can make use of the existing venting. However, the ACO for System I is still 8% higher than for the propane condensing tankless (E).

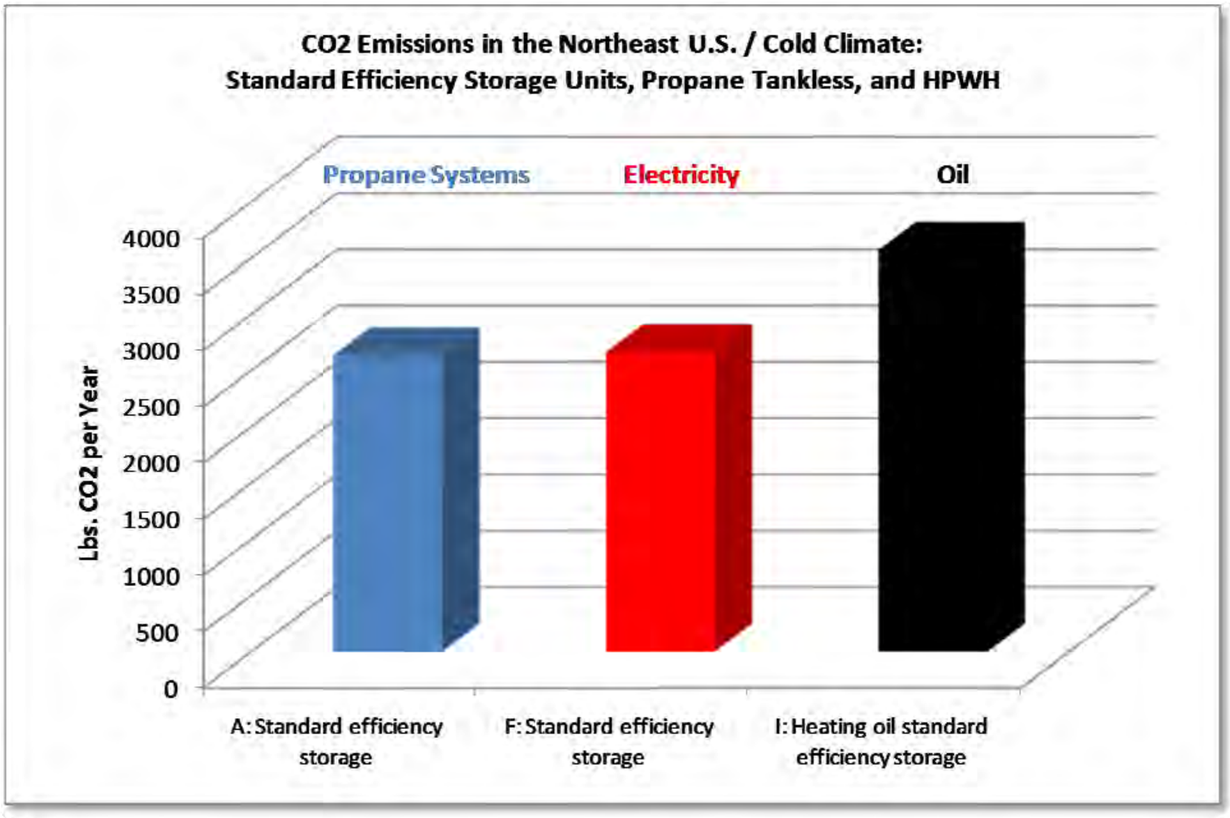

Figure 27: CO_2 Emissions for Standard Propane, Electric, and Heating Oil Storage Water Heaters, Northeast U.S./Cold Climate

In terms of "standard" efficiency storage tank systems, Figure 27 illustrates CO_2 emissions for propane, electric, and heating oil. CO_2 emissions from the heating oil storage unit (I) are 36% higher than for the standard propane storage system (A). The electric storage system (F) does not have the extremely high CO_2 emissions seen for System F in other regions, due primarily to a mix of electric generation fuels in the Northeast (nuclear, gas) which are less carbon intensive compared to generation fuels used in most of the U.S. (coal).

Economic & Environmental – Cold/Very Cold: Midwest

The Cold/Very Cold – Midwest results are based on the analyses for Grand Rapids, MI and Duluth, MN. The Annual Cost of Ownership for New Construction systems is shown below in Figure 28.

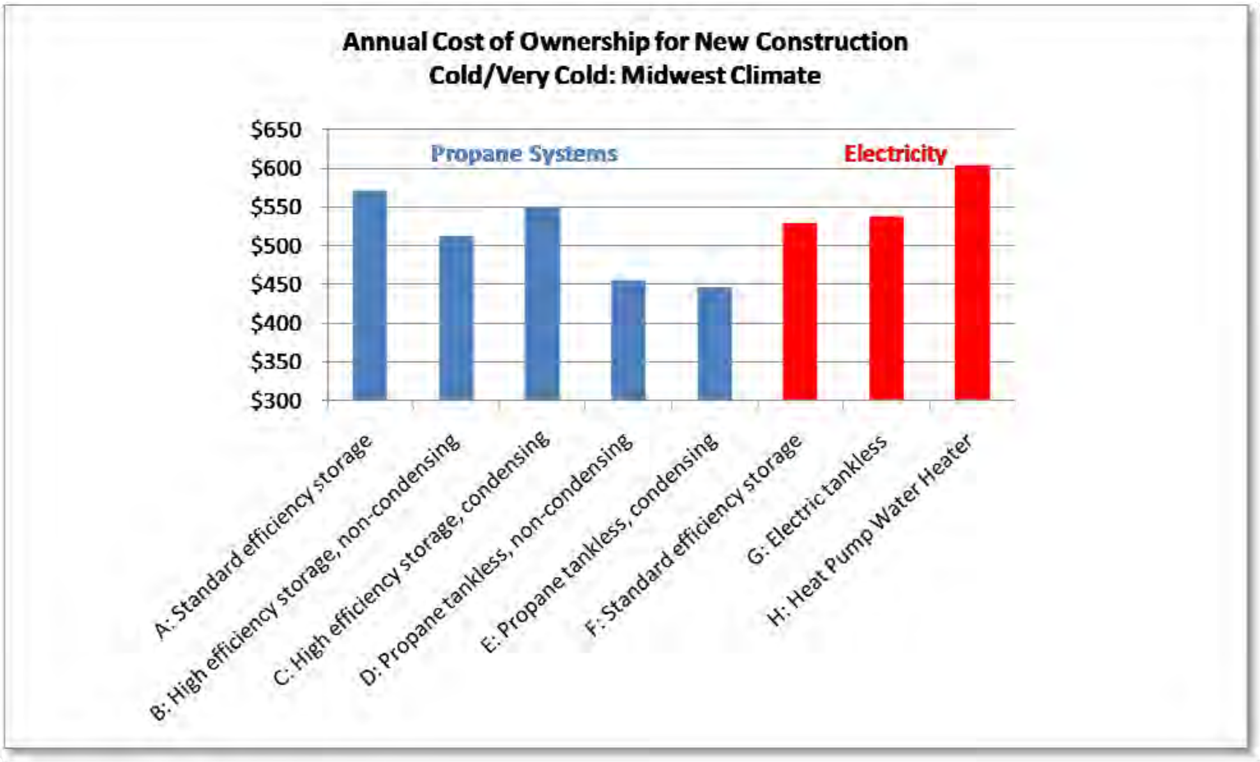

Figure 28: Annual Cost of Ownership for New Construction, Cold/Very Cold: Midwest.

While the traditional storage tank systems (A,B,C, and F) are within about 10% of each other in terms of the Annual Cost of Ownership, the propane tankless systems and the heat pump water heater are at the opposite extremes of the ACO scale. Comparing the HPWH (H) to the propane tankless condensing (E), the HPWH has an ACO which is 35% higher. Comparing a “typical” new system to a high performance option, the standard efficiency electric storage (F) is 18% higher than the propane condensing tankless (E) based on ACO.

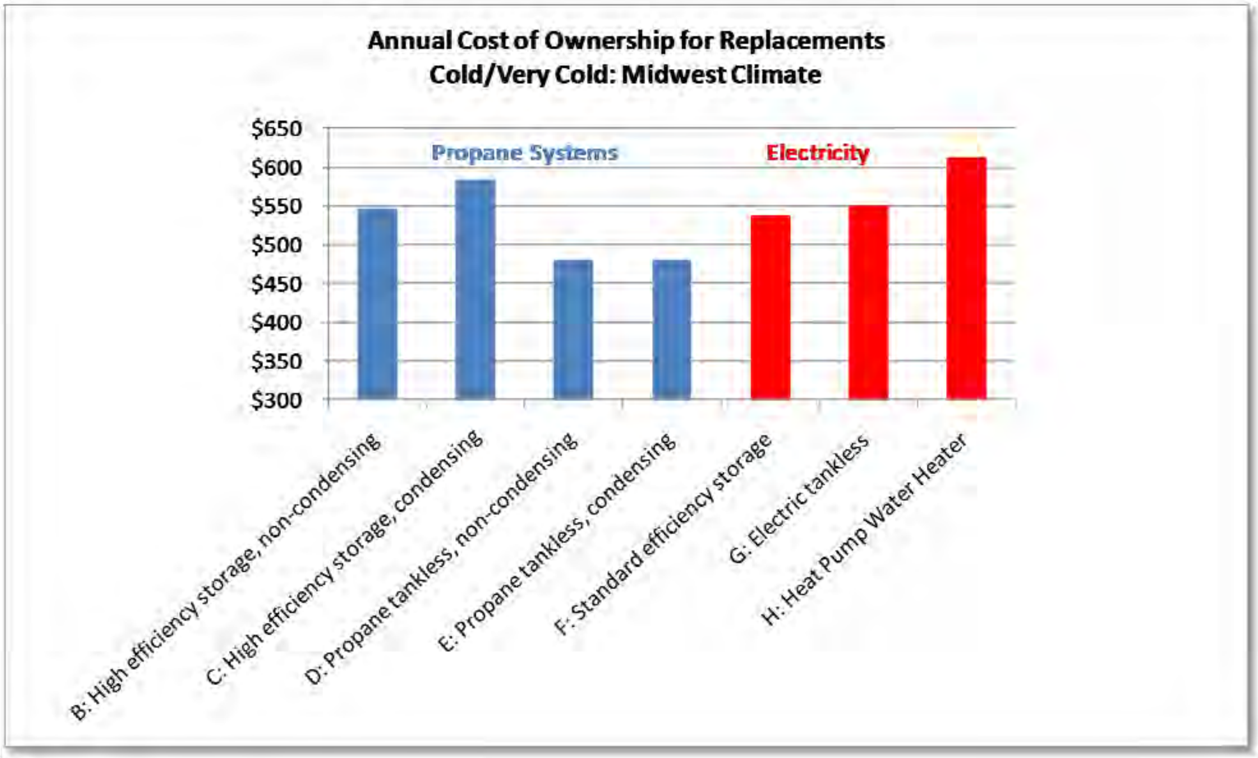

Figure 29: Annual Cost of Ownership for Water Heater Replacements, Cold/Very Cold: Midwest.

For water heater replacement applications, Figure 29 shows similar trends to the new construction data in the Midwest climate region. The traditional storage tank systems (B,D, and F) have comparable ACO values – within 8% of each other. Comparing the HPWH (H) to the propane tankless condensing (E), the HPWH has an ACO which is 27% higher. And the standard efficiency electric storage unit (F) is 12% higher than the propane condensing tankless (E) based on ACO.

Figure 30 compares the propane tankless condensing (E), standard efficiency electric storage (F), and the HPWH (H) based on CO_2 emissions associated with their operation. The propane tankless system (E) has emissions levels which are 70% and 51% lower than the standard electric tank (F) and the HPWH (H), respectively. In more understandable terms, over the 13-year service life expected for systems F and H, their higher emissions (relative to the propane condensing tankless) are roughly equivalent to the annual CO_2 emissions from 5 cars and 2 cars, respectively.

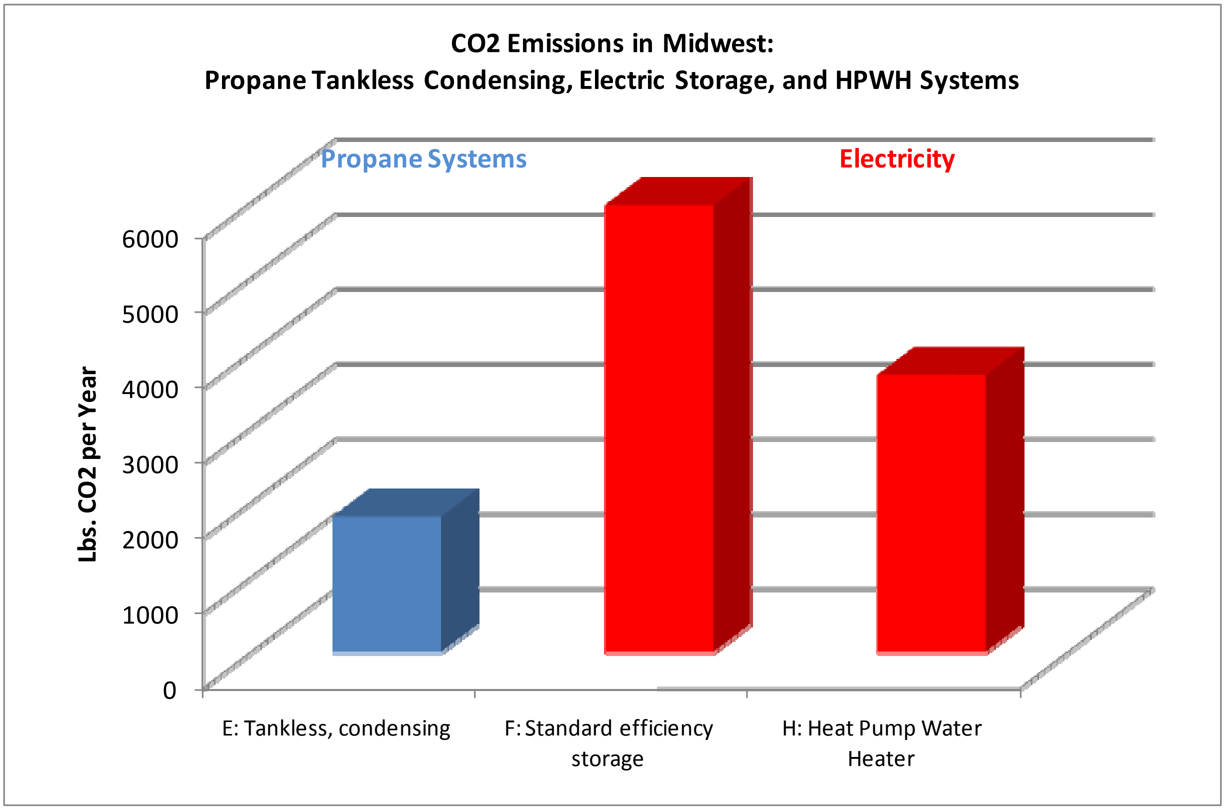

Figure 30: CO_2 Emissions for Propane Condensing Tankless, Standard Electric Storage, and HPWH Cold/Very Cold: Midwest

Economic & Environmental – Hot-Dry/Mixed-Dry

The Hot-Dry/Mixed-Dry results are based on the analyses for Las Vegas and Sacramento. The Annual Cost of Ownership for New Construction systems is shown below in Figure 31.

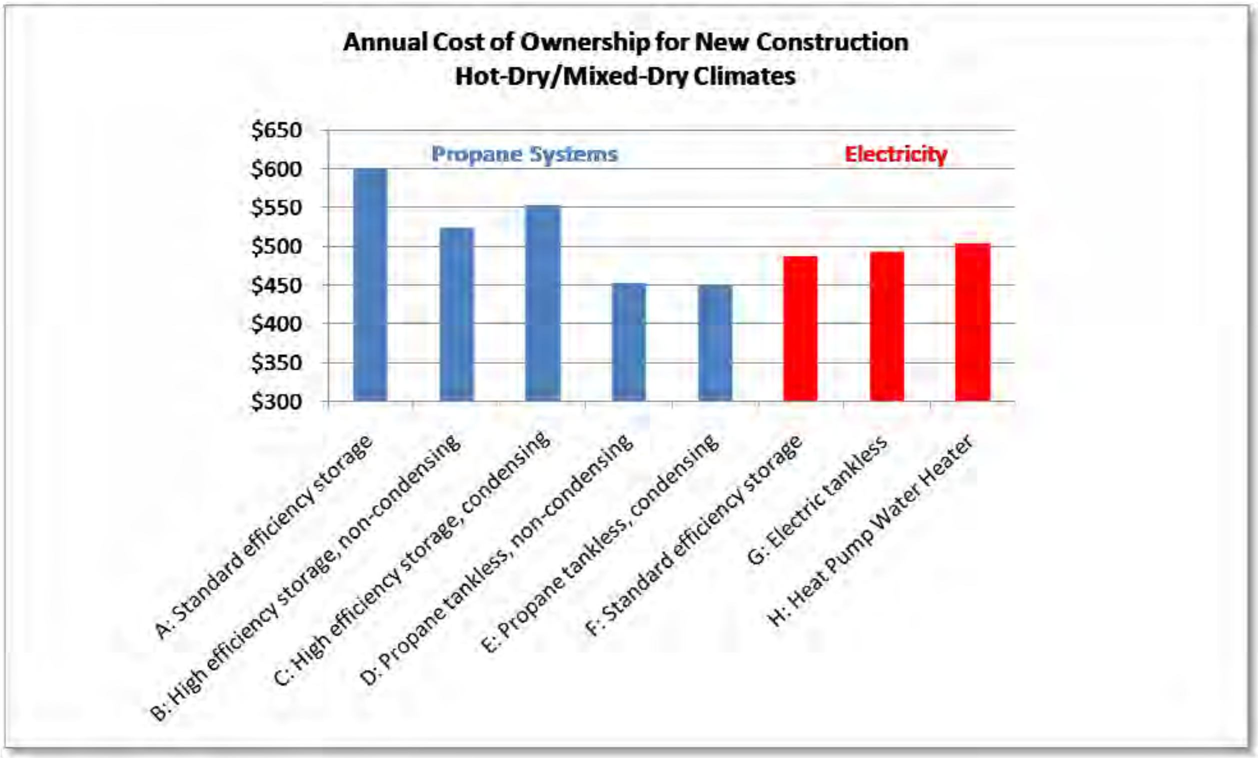

Figure 31: Annual Cost of Ownership for New Construction, Hot-Dry/Mixed-Dry Region

As the graph indicates, Systems D and E (propane tankless non-condensing and condensing) have the lowest Annual Cost of Ownership values. This means that for water heaters that are financed (via mortgage or some other type of loan) and operated, on an annual basis the propane tankless systems cost less than competing systems. The propane tankless condensing system, for example, is 8% lower than System F (standard efficiency electric storage); 11% lower than System H (HPWH); and 26% lower than System A (standard efficiency propane storage).

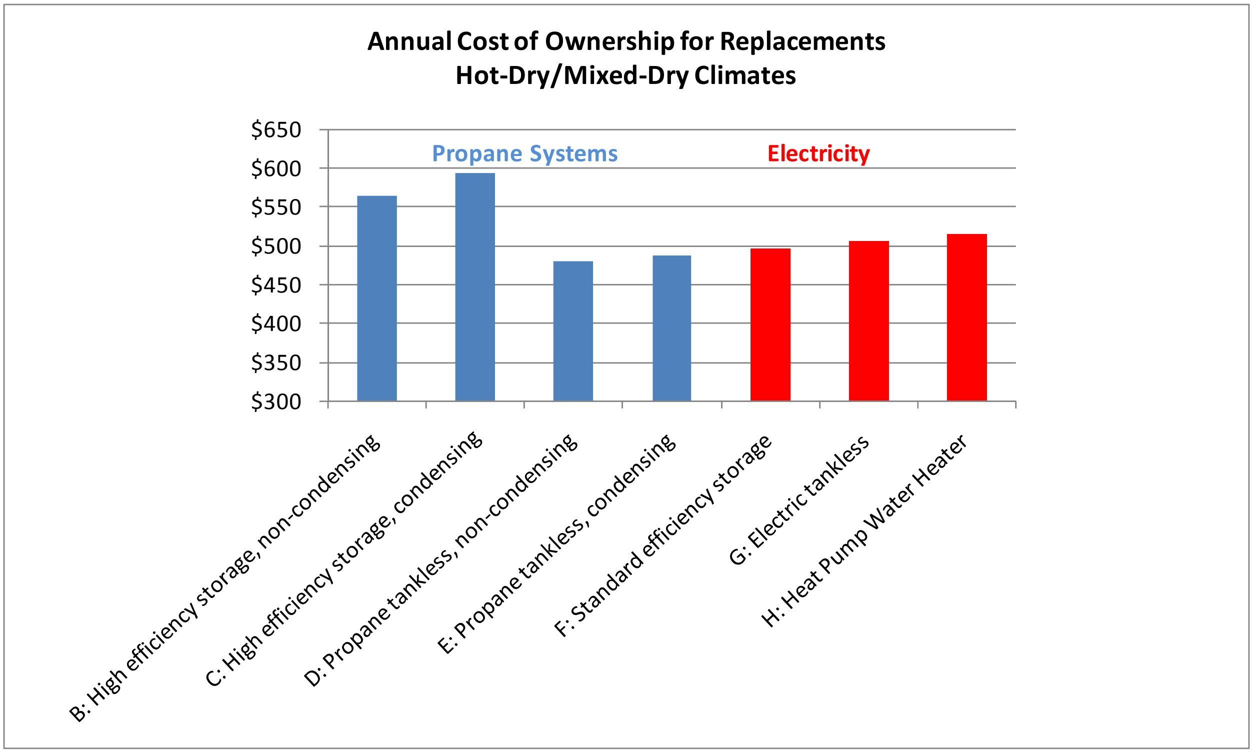

Figure 32: Annual Cost of Ownership for Water Heater Replacements, Hot-Dry/Mixed-Dry Region

Figure 32 illustrates that for replacement systems, propane tankless systems again have lower ACO values than competing electric or propane systems. In the common scenario where an electric storage tank unit needs to be replaced, Figure 32 demonstrates that installing another standard efficiency electric unit (System F) results in a higher (3%) annual cost to the homeowner over the life of the system. The same is true when comparing a HPWH (H) replacement, which has a 7% higher ACO than for a propane tankless non-condensing system (D).

A comparison of Systems E, F, and H based on CO_2 emissions is shown in Figure 33. Whereas in other regions, System F typically has emission levels which are triple the levels of the propane tankless condensing system, in the Hot-Dry/Mixed-Dry region the emissions of the electric storage tank are about double those of System E. Likewise, the CO_2 emissions from the HPWH (H) are lower in this region and actually 4% lower than System E. These shifts are due to a very low electricity emissions factor for Sacramento which is 43% lower than the national average, reflecting California's relatively higher use of gas-fired, nuclear, and hydropower for electric generation.

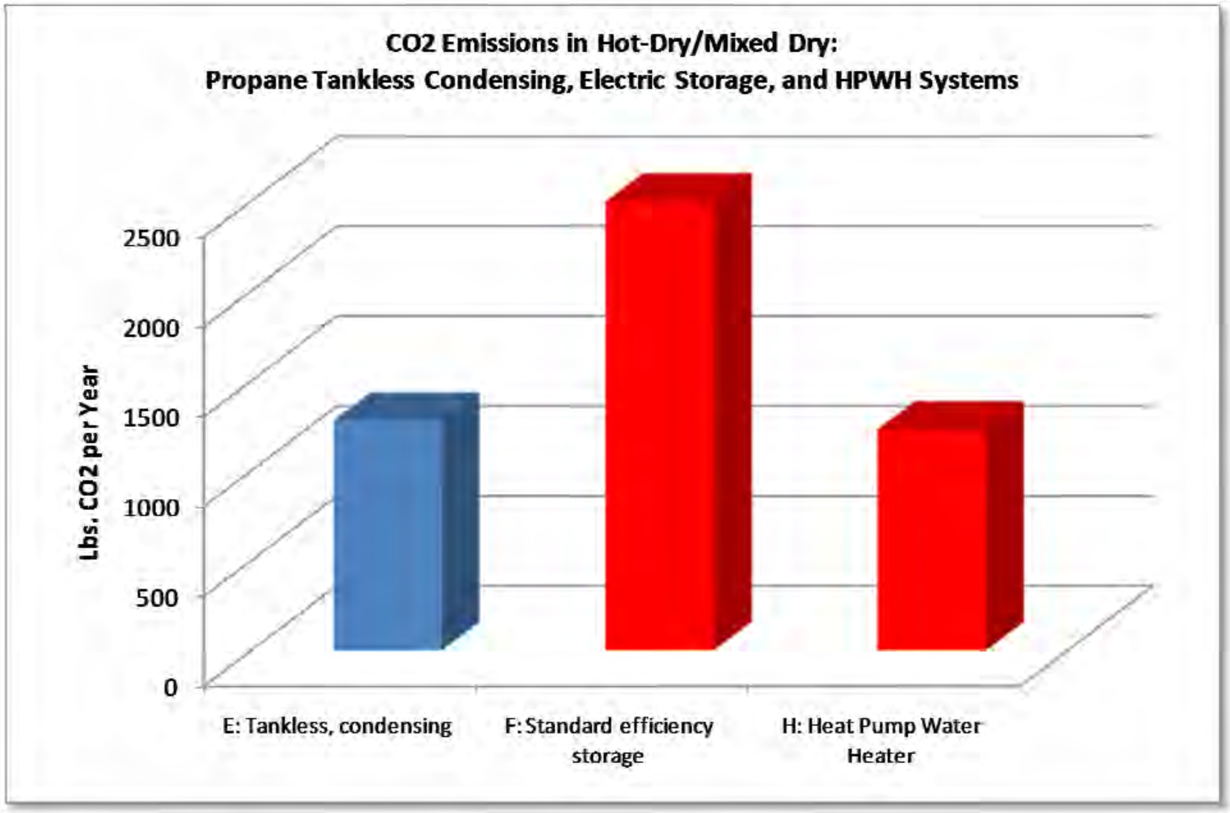

Figure 33: CO_2 Emissions for Propane Condensing Tankless, Standard Electric Storage, and HPWH Hot-Dry/Mixed-Dry Region

Analysis of Solar Hot Water with Tankless Back-Up System

System J, the solar hot water system with propane tankless back-up, is discussed separately in terms of economic and environmental results. The primary reason for this is that the study's scope does not include the potential economic benefits of tax credits or incentives, and this has significant implications for the cost-effectiveness of System J.

The federal "Residential Renewable Energy Tax Credit" offers a personal tax credit of 30% of the cost of a solar water heating system through 2016. Additionally, several states or utilities offer additional rebates or incentives. As a result, the first cost of these systems – which is quite high compared to the other 9 systems in this study without the benefit of incentives – is typically reduced by 30% or more in real-world installations. Credits and incentives could also apply to some of the other water heaters in the study; however such incentives are transient and may not apply in all circumstances (e.g., income limits, rental property, maximum benefit limits, etc.).

Thus, it is reasonable to exclude credits and incentives from the economic analysis, but this approach also creates misleading results for System J more so than for any other system.

Therefore, economic and environmental results for System J are confined to this section of the report. Within this section, limited results are provided which do allow System J the benefit of a 30% first cost reduction, based on the estimated impact of the Residential Renewable Energy Tax Credit. Note that other systems which could potentially earn credits or incentives are not assigned any discounts here, despite this possibility. The primary reason for this approach is that a major federal personal tax credit which would benefit Systems D, E, and I – the Residential Energy Efficiency Tax Credit – is scheduled to expire at the end of 2011.

Against this backdrop, Figure 34 below shows that System J has a significantly higher ACO, even when accounting for a 30% first cost reduction based on the federal tax credit and 13 years of operating costs which are less just over $100/year. It is worth noting, however, that other state- or utility-level credits will often apply and lower the effective cost of a solar DHW system further, beyond the 30% reduction from the federal credit. Also, the installation price for solar systems, which was estimated at $7,160 in the hot/humid region including the tankless back-up and the 30% tax credit, can vary quite significantly depending on the maturity of the local solar industry, the complexity and size of the system, and the layout of the home.

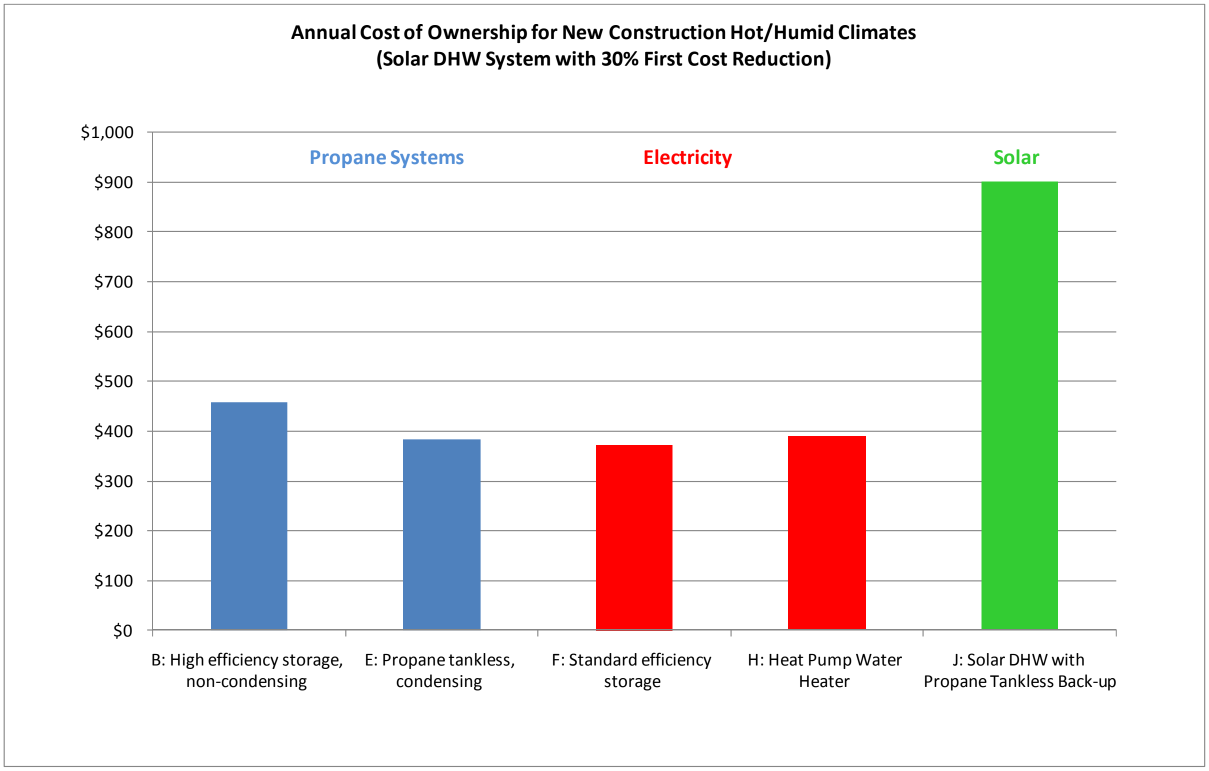

Figure 34: Annual Cost of Ownership for New Construction, Hot/Humid Region, including the Solar DHW System with Propane Tankless Back-up with 30% Tax Credit

In terms of CO_2 emissions in this same region, the solar hot water system outperforms all other systems by a wide margin because it uses solar energy instead of electricity or propane to meet a substantial portion of the hot water load (Figure 35). This figure illustrates the same systems as seen in Figure 34 for the sake of consistency. System J's emissions are about one-half those of the propane tankless system (E), and about one-sixth the emissions from the standard efficiency electric storage tank (F).

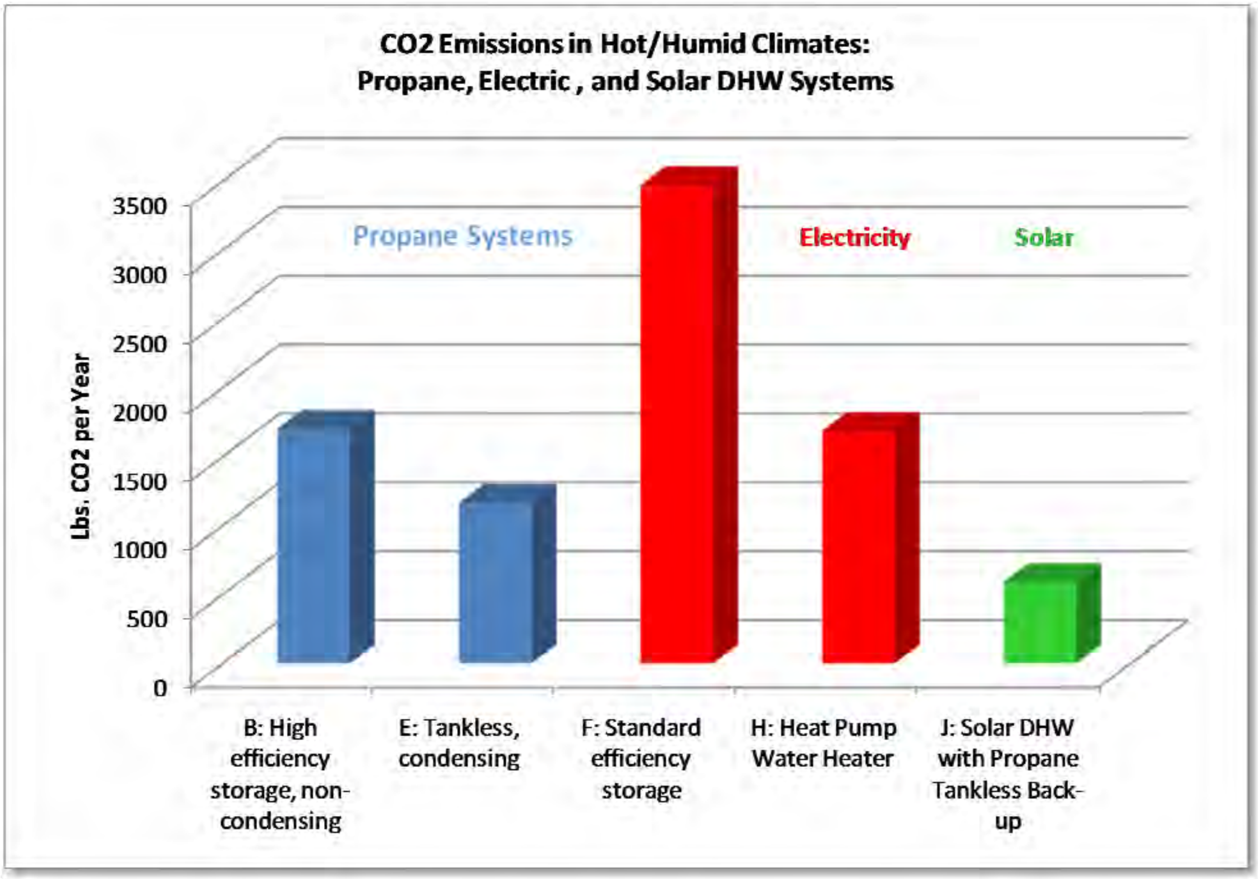

Figure 35: CO_2 Emissions for Hot Water Systems in the Hot/Humid Region, including the Solar DHW System with Propane Tankless Back-up

VI. Conclusions

This project provides a detailed analysis of 10 water heating systems across 10 locations throughout the United States. At a time when the landscape of residential water heating is undergoing major changes, this research will help to facilitate and inform decision making which accounts for the energy, economic, and environmental performance of water heating systems.

The conclusions drawn from this research are grouped according to the main areas of analysis.

Annual Energy Costs for Hot Water Systems

Modeling of annual water heating energy costs for the different systems in a typical home revealed that the standard efficiency electric storage tank was the highest energy cost system, at $449/year averaged across all 10 locations. This is important to note, as this type of system is common for installations in both new construction and as quick "on the truck" replacement.

The solar hot water system with propane tankless back-up had the lowest annual energy costs, averaging $166 annually averaged across all 10 locations. The next lowest system was the heat pump water heater (HPWH) at $248, which was slightly less costly than the propane condensing tankless unit ($267). The propane high efficiency storage (non-condensing) system was about $72/year lower than the electric storage tank model.

Predictably, annual energy costs decreased within a particular product category as the efficiency ratings increased. However, the Energy Factor (EF) rating for a water heater is not useful on its own for comparing the annual energy costs across water heating systems with different fuel sources. For example, within this study the standard efficiency propane storage system with an Energy Factor of 0.59 had lower annual energy costs than the standard efficiency electric storage tank with an Energy Factor of 0.90.

Annual energy costs were also analyzed at the regional level, and generally showed the same trends seen in the overall averages across all locations, with the solar DHW, HPWH, and propane tankless condensing units representing the lowest energy cost systems. The Northeast was notable, with higher electric rates driving the standard efficiency electric storage systems above $600/year. The heating oil-fired water heater in this region was $435, while the propane condensing tankless was $340 and the propane high efficiency storage (non-condensing) system was $472.

Annual Cost of Ownership (ACO)

Despite the straightforward appearance of the annual energy cost or even the Energy Factor rating, it is critical for industry professionals to also consider several other water heater characteristics, including the hot water flow rate, the ability to easily install a unit, unit service life, and system first cost. The economic metric used in this analysis, the Annual Cost of Ownership, characterizes systems based on the last two of these factors as well as annual energy cost. The "ACO" essentially estimates the cost for buying a water heater and paying for its annual energy bills, spread out over the system's rated service life. It is particularly effective to use in this study, to compare systems with significantly different service life ratings. The service life estimates used in the ACO calculations were 20 years for tankless systems and 13 years for storage systems, based on multiple references.

The impact of considering the ACO in purchasing decisions is seen in Figure 36 below, which illustrates the lowest ACO water heater for each climate region, for both new construction and system replacements. In all but one climate region, the lowest ACO system is a propane tankless water heater. This reflects propane tankless system's long service life and low annual energy costs, despite the fact that other "on the truck" units might be cheaper initially to install.

Figure 36: Water Heaters with the Lowest Annual Cost of Ownership by Climate Region and Type of Installation

Climate Region	System with Lowest Annual Cost of Ownership – New Construction	System with Lowest Annual Cost of Ownership - Replacements
Mixed/Humid	Propane condensing tankless	Propane condensing tankless
Hot/Humid	Standard efficiency electric storage	Standard efficiency electric storage
Cold: Northeast	Propane condensing tankless	Propane condensing tankless
Cold/Very Cold: Midwest	Propane condensing tankless	Propane condensing tankless & propane non-condensing tankless (tie)
Hot-Dry/Mixed-Dry	Propane condensing tankless	Propane non-condensing tankless

The other two variables mentioned above - hot water flow rate and the ability to easily install a water heater – are every bit as critical as the ACO and need to be considered by contractors and homeowners. Figure 37 below illustrates the difference in hot water flow rate for propane condensing tankless, HPWHs, and standard efficiency electric storage units. As discussed in the Research Methodology section above, tankless systems can deliver their rated GPM *continuously* - even over the course of an entire hour. When comparing these systems based on the first full hour of operation, the hot water output of a propane tankless system is more than triple the capacity of the electric storage tank or heat pump water heater evaluated in the study.

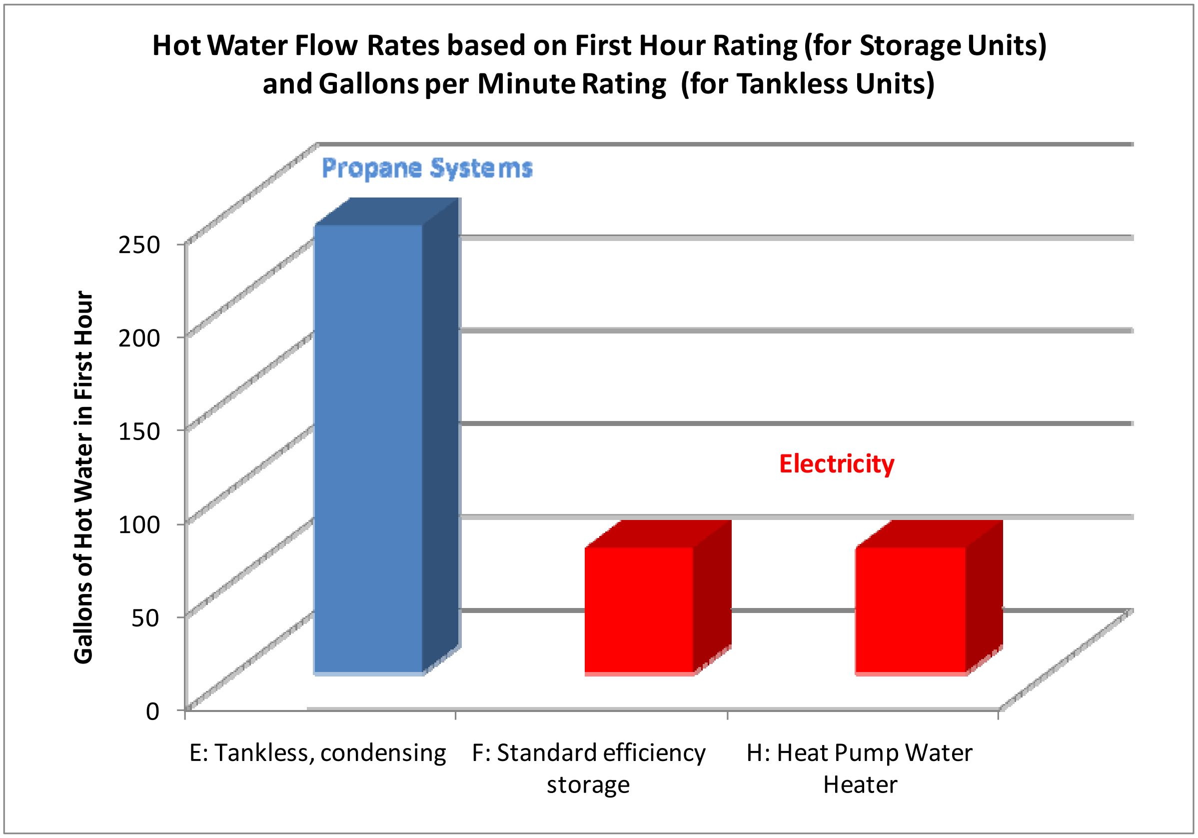

Figure 37: First Hour Hot Water Output Rates for Propane Tankless, Electric Storage, and HPWH

Carbon Dioxide Emissions

CO_2 emissions associated with the operation of the water heating systems were analyzed and compared within the research. Numerous dramatic differences in CO_2 emissions were found between propane, electric, and heating oil systems.

The standard efficiency electric tank storage system typically had CO_2 emissions which were at least double the rates for propane fired systems like the high efficiency non-condensing storage unit (System B). Compared to the propane condensing tankless system (E), the electric storage unit had roughly triple the CO_2 emissions in three of the climate regions.

HPWHs were found to have CO_2 emissions roughly 33% greater than the propane condensing tankless system, averaged across all analysis locations. This underscores the reality that even highly efficient electric water heaters still use significant quantities of electricity, which mostly comes from fossil-based power generation plants (with a few exceptions for states with heavy nuclear or gas-fired generation). These power plants will typically consume roughly 3 units of energy to produce 1 output unit of electricity, so the resulting emissions from the production of electricity are often significant. This then results in significant CO_2 emissions for downstream electric-based water heating systems.

In the Northeast, the heating oil-fired water heater also had CO_2 emissions which were at least 35% higher than comparable propane systems, and as much as twice the emissions rate of the high efficiency propane tankless systems.

To give a sense of typical CO_2 emissions across the different climate regions, Figure 38 below illustrates emissions data for select system averaged across all 10 analysis locations.

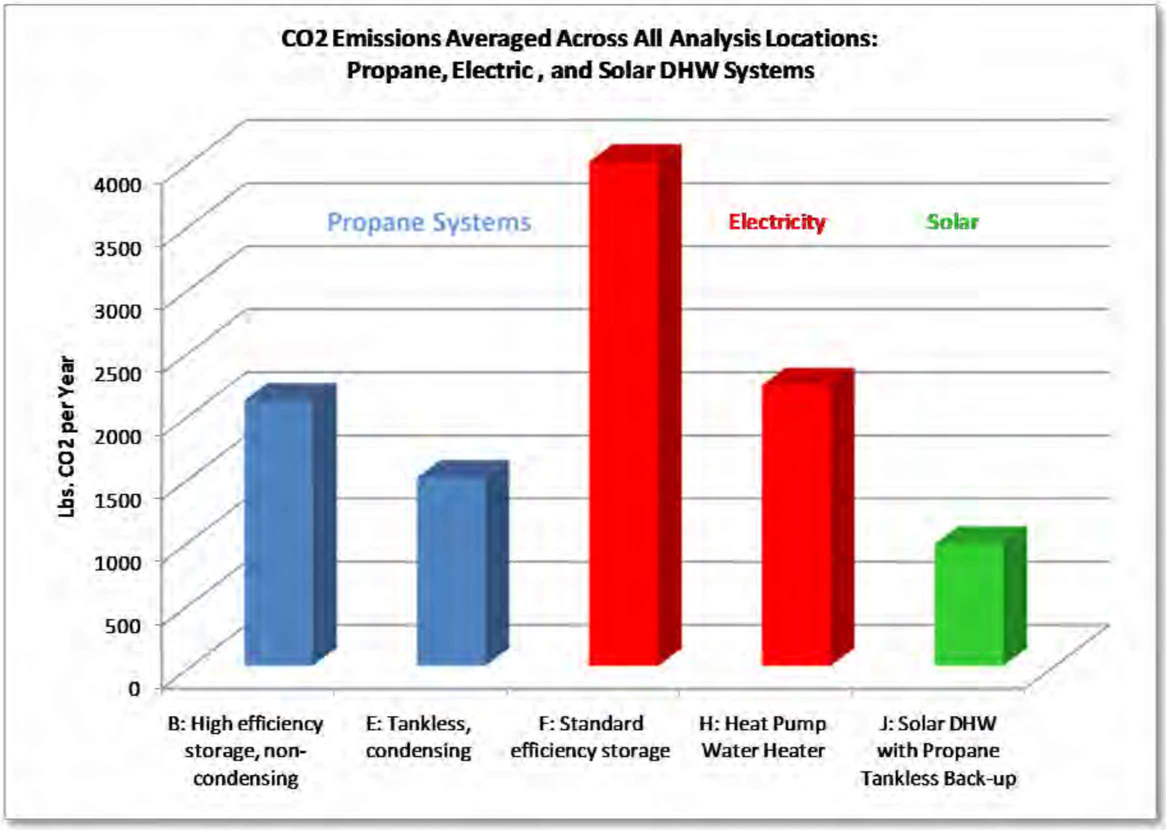

Figure 38: CO_2 Emissions, Averaged Across All Analysis Locations, for Select Systems

Appendix A – Installation Requirements and First Costs Summary

The 3 figures which follow provide a summary of:

1. The different installation requirements which were "assigned" to hot water systems as part of the cost estimating analysis
2. Total Installed Costs (equipment + installation) for New Construction
3. Total Installed Costs (equipment + installation) for Replacements

Installation Requirement	A: Standard efficiency storage	B: High efficiency storage, non-condensing	C: High efficiency storage, condensing	D: Propane tankless, non-condensing	E: Tankless, condensing	F: Standard efficiency storage	G: High efficiency storage	H: Tankless	I: Heat Pump Water Heater	J: Heating oil standard efficiency storage	K: Solar DHW with Propane Tankless Back-up
Natural Draft Exhaust Venting	Y - for new; only considered for retrofits where existing vertical vent was									Y - for new construction & replacements; System J only considered in 2 Northeast	
Plastic Exhaust Venting		Y	Y		Y						
Stainless Steel Horizontal Venting				Y							Y
Add Electric Supply Costs						Y - for new construction a dedicated 30A circuit; Y - for existing, only in the 2 Northeast locations	Y - for new construction a dedicated 30A circuit; Y - for existing, only in the 2 Northeast locations	Y - two 60A circuits ar assumed to be required	Y - for new construction a dedicated 30A circuit; Y - for existing, only in the 2 Northeast locations		
Additional Labor Hour Cost for More Complex Installation									Y - based on DOE rulemaking assumptions for dealing with system installation requirements		
Evaporator Coil Vented to Outdoors									Y - only for scenarios where unit HPWH is located in basement in Climate Zone 5 or higher		

Figure 39: Summary of Installation Requirements included in Cost Estimating

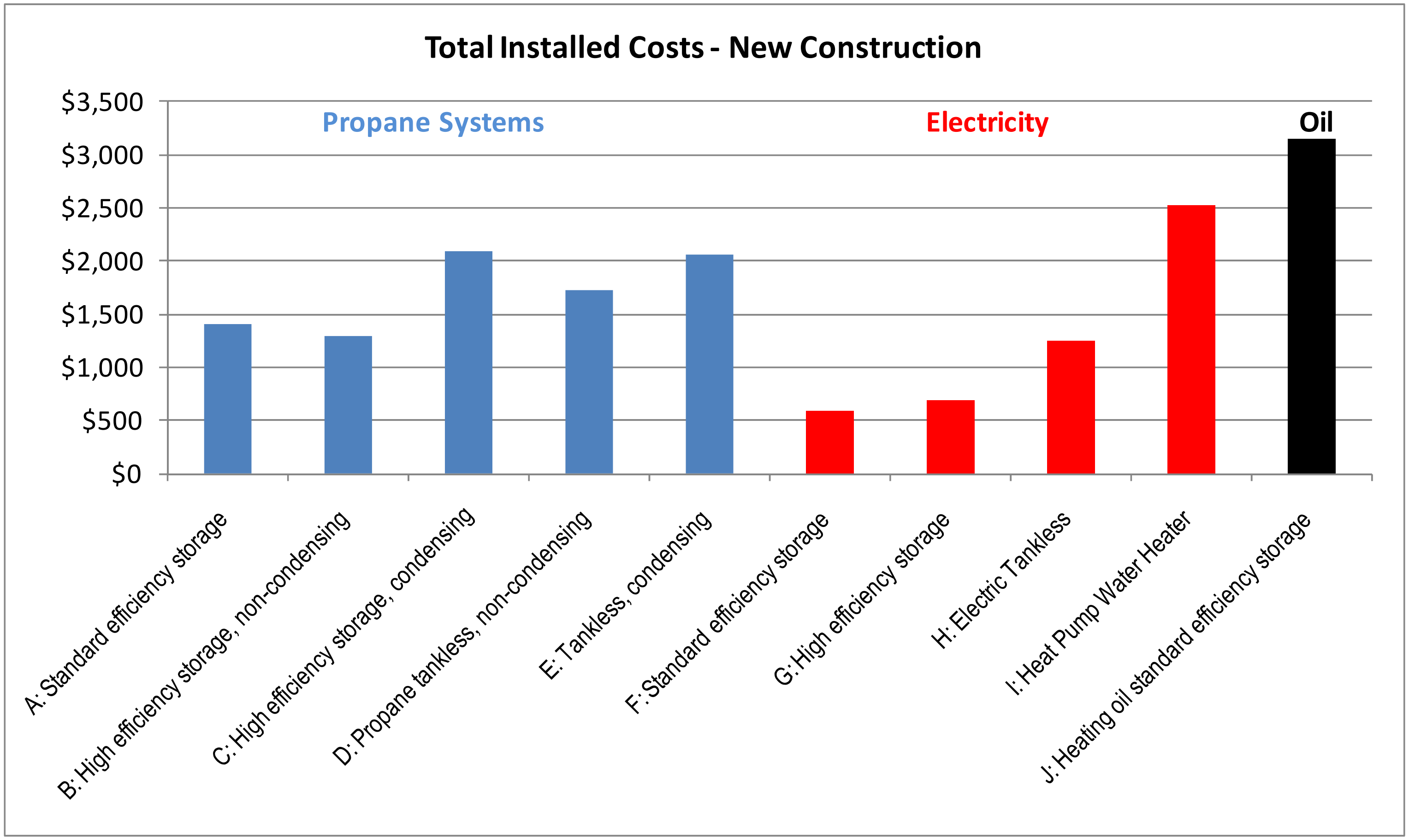

Figure 40: Total Installed Costs (equipment + installation) for New Construction

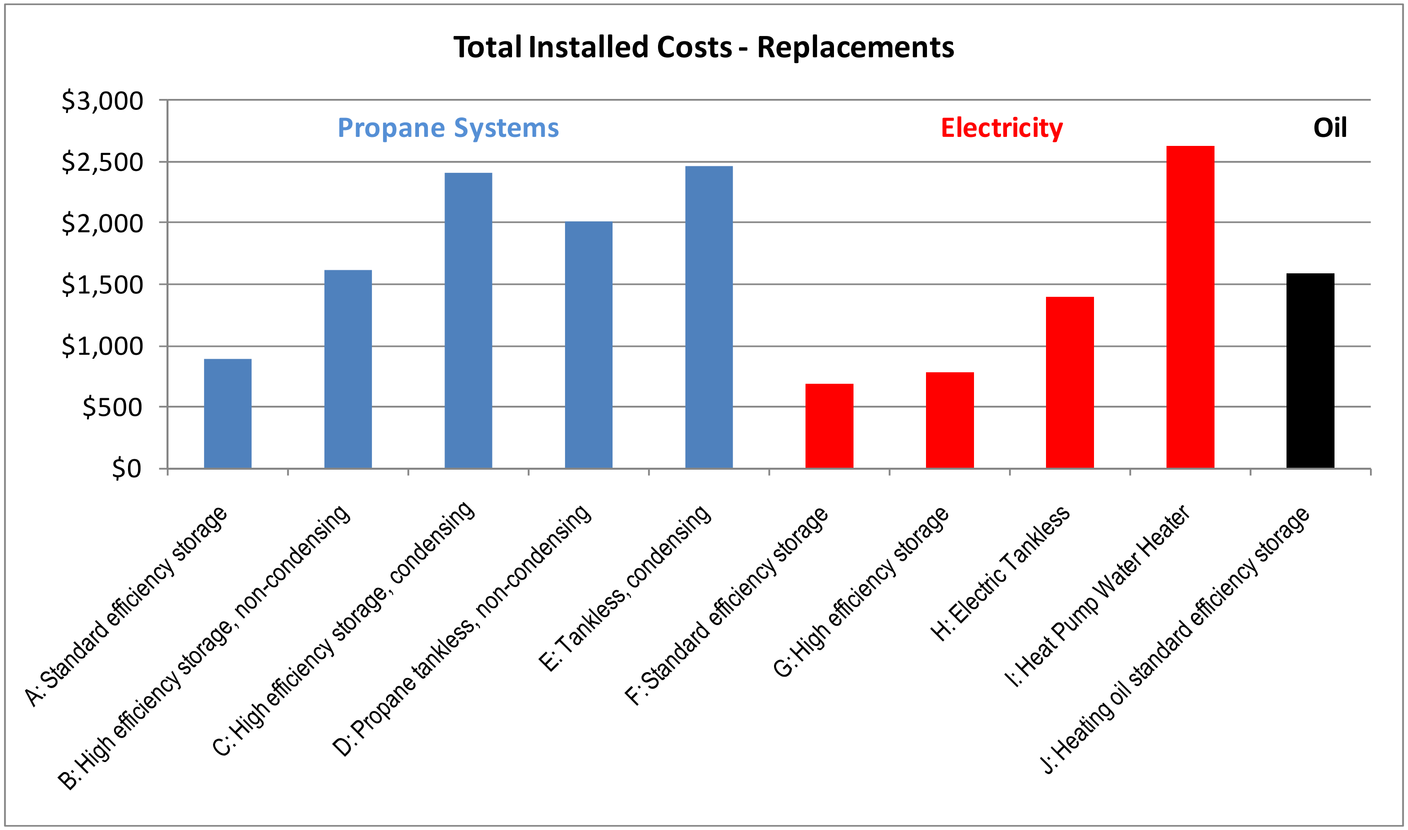

Figure 41: Total Installed Costs (equipment + installation) for New Construction