Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011

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Abstract

Water heating is typically the second largest energy end use in buildings in the U.S., exceeded only by space conditioning. Better buildings and technologies have reduced many energy loads such as lighting, refrigeration, and air conditioning, but hot water has received much less attention. Recently, however, market forces, accelerated by the ENERGY STAR® Program, have stimulated availability and marketing of advanced water heating products that use much less energy. New work has documented high waste in hot water distribution, and ways to dramatically reduce losses. ACEEE examined sixteen technologies and practices, and found that these technologies can save a cumulative 2.3 quadrillion Btu through 2025, or about 5% of projected demand in residential and commercial buildings in the year 2025 (43 quads). Collectively, they save an average of 37% of energy over federal minimum efficiency standards for water heaters and conventional water heating systems. In some cases, the technologies do not promise high returns on investment (fast payback), but the technologies offer new or improved amenity that consumers value (shorter waits for hot water, continuous hot water, etc.). These technologies are likely to be chosen for these tangible benefits, and will also save energy.

Technologies evaluated in this report include: Electric Tankless Water Heaters, ENERGY STAR Heat Pump Water Heaters, Northern Climate Heat Pump Water Heaters, Add-On Heat Pump Water Heaters, Condensing Tankless Gas Water Heaters, Solar-Assisted Water Heaters, Condensing Gas Hybrid Water Heaters, Non-Condensing Gas Hybrid Water Heaters, ENERGY STAR Non-Condensing Gas Water Heaters, Condensing Gas Storage Water Heaters, Advanced Ground Source Heat Pump Approaches, Drain Water Heat Recovery, Single Family On-Demand Recirculation Pumps, Commercial Point-Of-Use Applications, and Multifamily Building Best Practices.

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Author Nate Kaufman, formerly with ACEEE, is now with OPOWER.

RESULTS OF THE 2011 EMERGING WATER HEATING TECHNOLOGIES STUDY

Introduction

The 2011 ACEEE review of emerging building sector focuses on water heating technologies. ACEEE'S work on emerging technologies in the buildings sector began with a broad-based review in 1993, followed by publications in 1998 and 2004 that were similar in scope.[1] Since then, ACEEE has concentrated on more narrowly focused annual or biennial efforts. The present water heating review is the second of an anticipated five-part cycle of reports. It was preceded by heating, ventilation, and cooling (HVAC) technologies in 2008–2009. The next "volume" will address lighting, to be followed in later years by building-scale onsite power generation (CHP), appliances (including electronic equipment) and motors, and whole-building measures (shell and energy management).

The methods used in this study are adapted from Chapter 3 of Sachs and others.[2] In this study, we have expanded our treatment of technologies from one-page synopses to brief essays that introduce the technologies. Our reported metrics remain the same, but we place less emphasis on likelihood of success and priority than in earlier studies across broader ranges of technologies. Additionally, we have added both present and mature market product and installation costs, as well as present and mature market cost-of-saved-energy figures. This change should help program administrators and other interested parties estimate both current and projected costs, while assuming conservative estimates of market penetration and product and installation costs. Each measure analysis details our assumptions about mature costs.

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Energy Savings Potential and Economics

Table 1 summarizes the savings from the measures studied, all converted to source energy saved in 2025. The sixteen technologies evaluated in this report represent a selection of the emerging products and practices that have captured the attention of national and international markets. For the most part, these technologies offer either substantial savings, or have been adopted by mainstream market transformation programs, such as ENERGY STAR. Cumulatively, these sixteen technologies can save 2.29 quadrillion Btu through 2025, or about 5.3% of projected demand in residential and commercial buildings in the year 2025 (42.97 quads).[3] Collectively, they save an average of 37% of energy over federal minimum efficiency standards for water heaters and conventional water heating systems.

Energy savings vary greatly across the suite of measures, from >300 TBtu (ENERGY STAR Heat Pump Water Heaters) to under 20 TBtu (Condensing Tankless and Non-Condensing Hybrid Water Heaters). One reason for this variance is high incremental cost. Upfront costs inhibit market uptake, driving down potential savings. As markets mature and costs decline, we expect to see greater market adoption and greater energy savings potential.

Nearly every measure also offers valuable "non-energy" benefits such as increased first hour rating for water heaters (drain water heat recovery), "endless" hot water (tankless gas and electric water heaters), and delivery of hot water to fixtures that previously did not receive it (commercial point-of-use water heaters). We assume no credit for these amenities, although they tend to impact purchasing decisions of consumers. Similarly, our measure analyses assume no credit for smart grid controls available on some new water heaters. These technologies can allow consumers to take advantage of low off-peak electricity rates by heating water only during certain hours. By doing so, consumers can reduce their water heating bills and utilities can reduce peak loads, which in turn can delay or eliminate construction of new power plants.

[1] Respectively ACEEE Publications A931, A984, and A042. See http://aceee.org/emertech/buildings.htm.

[2] Sachs, H., S. Nadel, J. Amann, M. Tuazon, E. Mendelsohn, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar. 2004. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004.* http://aceee.org/pubs/a042.htm. Washington D.C.: American Council for an Energy-Efficient Economy.

[3] EIA. 2011. *Annual Energy Outlook,* Reference Case Table A2: Energy Consumption by Sector and Source. http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf. Washington D.C.: EIA.

Nearly half (7 out of 16) of the evaluated technologies are cost effective with today's product, installation, and energy prices. With mature market costs, 10 out of 16 become cost effective, including all but one electric technology. One electric technology, commercial point-of-use water heaters, has a *negative* cost of saved energy because installation in new construction will avoid the need to run a separate hot water line. With current natural gas prices, many natural gas technologies are not cost effective. However, natural gas prices are historically volatile, and it is conceivable that unanticipated market shifts may drive other technologies evaluated in this report toward cost effectiveness in the future.

Of mention, consumers often purchase advanced water heating technologies, such as electric and natural gas tankless water heaters, for the *amenity* that they provide (in these two cases, "endless" hot water), not just their energy savings. If consumer preferences continue to gravitate toward this feature, we may see market share grow at a faster rate than predicted. Regardless, this purchasing trend remains noteworthy because it suggests that amenity can have a greater impact on market potential than cost-of-saved-energy, for some technologies. Likewise, on-demand recirculation pumps offer faster delivery of hot water than a traditional hot water distribution system, and do so at a low cost of saved energy. With increased market awareness, we may see consumers gravitate toward this additional amenity.

Table 1. Per-Technology Energy Savings in 2025

Technology	Priority	Sector	Fuel	2010–2025 Cum. TBtu	Current CSE, $/kWh	Mature CSE, $/kWh	Current CSE, $/MMBtu	Mature CSE, $/ MMBtu
Electric Tankless Water Heaters	Medium	Residential	Elec.	124	$ 0.13	$ 0.11		
ENERGY STAR Heat Pump Water Heaters	High	Residential	Elec.	301	$ 0.04	$ 0.03		
Northern Climate Heat Pump Water Heaters	Medium	Residential	Elec.	95	$ 0.06	$ 0.05		
Add-On Heat Pump Water Heaters	High	Residential	Elec.	194	$ 0.03	$ 0.03		
Condensing Tankless Water Heaters	Medium	Residential	NG	18			$ 24.28	$ 17.26
Solar-Assisted Water Heaters (Electric Backup)	High	Residential	Elec.	195	$ 0.17	$ 0.14		
Solar-Assisted Water Heaters (Natural Gas Backup)	High	Residential	NG	243			$ 33.66	$ 27.72
Condensing Gas Hybrid Water Heaters	Medium	Residential and Commercial	NG	63			$ 16.09	$ 8.55
Non-Condensing Gas Hybrid Water Heaters	Medium	Residential	NG	14			$ 37.51	$ 33.08
ENERGY STAR Non-Condensing Gas Storage Water Heaters	Low	Residential	NG	51			$ 20.17	$ 15.75
Condensing Storage Water Heaters	High	Residential	NG	223			$ 17.96	$ 12.91
Ground Source Heat Pump Water Heaters	High	Residential	Elec.	271	$ 0.05	$ 0.03		
Drain Water Heat Recovery	Medium	Residential	NG	49			$ 7.74	$ 6.78
Single Family On-Demand Recirculation Pumps	High	Residential	Elec.	238	$ 0.12	$ 0.03		
Commercial Point-of-Use Water Heaters	High	Commercial	Elec.	33	$ (0.04)	$ (0.11)		
Multifamily Building Best Practices	High	Residential	Elec.	179	$ 0.003	$ 0.002		

Although breadth of technologies in ACEEE's Emerging Technologies studies has changed over time (Table 2), it is interesting to compare the average *per measure* savings from this water heating study with estimates from our 1998 and 2004 broad-span studies that looked at HVAC, shell, lighting, and many other measures (Table 3).

Table 2. Numbers of Measures Studied in 1998 and 2004, by Technology Group[4]

Measures Group	1998	2004	2008	2011
appliances	8	2		
motors and drives	6	4		
HVAC	19	23	15	
lighting	15	14		
power	5	4		
practices	2	7		
refrigeration	1	3		
shell	5	10		
water heating	**7**	**4**		**16**
laundry	3	0		
miscellaneous, other	1	2		

Savings in this study average about 143 TBtu/measure, a slight, but statistically insignificant increase from the 2004 study's average of 136 TBtu/measure. Although potential savings remained about equal, costs of saved energy increased since the 2004 study.[5] Costs of saved energy for electric measures remained essentially equal, while costs increased precipitously for natural gas measures. Table 3 provides these comparisons in detail.

Table 3. Average Cost of Saved Energy and Cumulative Savings from the 2004 Water Heating Measures and the Present Study[6]

	CSE, $/kWh	CSE, $/MMBtu	Savings, TBtu
2004 water heating avg.	$ 0.03	$ 5.18	136
2011 avg.	$ 0.03	$ 17.44	143

Note: the cumulative savings are based on 2005–2020 for the 2004 study, and on 2010–2025 for this study.

Lessons Learned and Implications of the Study

Perhaps the most striking element of this study is the variety of energy-efficient water heaters on the market today. Only ten years ago, consumers had little choice when their water heater failed beyond calling a local plumber or contractor and buying the latest incarnation of the defunct unit. Now, both gas and electric models come in tank and tankless configurations, and gas hybrid models blend some of the advantages of each. This shift has several ramifications. First, consumers can select a model that will offer much higher efficiency and *performance*. Indeed, matching a consumer's home and hot water usage patterns with the appropriate high efficiency water heating system can supply hot water faster and more reliably while using less energy than a typical federal minimum efficiency storage water heater. Users can also select an appropriate backup water heater to link with a solar water heating or combination (water and space heating) system in order to maximize overall performance. And, savvy plumbers and contractors can help their customers increase efficiency, save money, and minimize water waste by designing water heating systems effectively. All of this, however, requires forethought on behalf of the consumer, and emergency replacements (still the lion's share of water heater purchases) rarely lend themselves towards selecting high efficiency units that often require a more complex and expensive installation.

Resistance-electric and non-condensing gas storage water heaters have long dominated the residential water heating market, with each serving approximately half of the market. However, a number of

[4] See Footnote 2, Table 4-6.
[5] See Footnote 2.
[6] CSE figures in this table for the 2011 study are mature market costs, which were the basis for cost effectiveness in the 2004 study as well.

manufacturers have begun to introduce heat pump and condensing gas technologies in recent years. Fourteen brands currently offer heat pump water heaters, including a new water heater manufacturer, General Electric. These units typically save 50% or more above conventional electric resistance units, while offering the additional benefit of space cooling and dehumidification. Cold, arid climates will have some space conditioning penalty for these characteristics of the technology when the heat pump water heater is installed inside the thermal envelope. Still, due to interest in heat pumps in cold climates, the Northwest Energy Efficiency Alliance has developed a technical specification to augment ENERGY STAR criteria in the interest of ensuring heat pump water heaters meet consumer demands in northern climates. A number of utilities and energy efficiency groups across the Northwest and Midwest have supported development of this specification.[7] There are also several manufacturers of aftermarket heat pumps designed to interface with existing resistance-electric storage water heaters. These units boast comparable savings at a very low cost of saved energy ($0.03/kWh), while offering consumers a lower price premium for adopting the technology. One can envision plumbers and contractors opting to stock resistance electric units on their trucks for emergency replacements, while offering an upgrade to heat pumps with these aftermarket devices. This method could reduce a contractor's total investment in stock while offering substantial, cost-effective savings to the customer.

Condensing gas water heaters have also experienced market growth in the past few years. Currently, the only storage models available have gas inputs too large for them to qualify as residentially-rated units (above 75,000 Btu/hour), but the accompanying energy savings and tank sizes available make many units appropriate candidates for homes (as well as commercial applications). Such water heaters achieve savings of about 40% above federal minimum efficiency models, and in new construction, offer the additional benefits of reduced installation costs and at times even simplified chimney construction.[8] A number of manufacturers offer tankless and hybrid gas water heaters that condense, achieving savings of about 37% and 30% savings, respectively. Current costs can be prohibitive in retrofit applications, but in new construction, the reduced installation costs and small footprint of these products make them excellent candidates for apartments and other buildings with space constraints. However, most consumers will purchase these products for the advertised "endless" hot water.

Solar-assisted water heating systems, which have had some pitfalls in past decades due to unrealized savings expectations and disappointing longevity, have again started to receive a substantial push from manufacturers, local governments, and utility programs in the Sunbelt, particularly California, as well as federal tax credits. For example, as of mid-2011, the California Solar Initiative helped fund over 300 residential and commercial projects with expected savings of about 170,000 therms/year for gas customers and 312,000 kWh/year for electricity customers.[9] Hawaii also has experienced growing interest in solar-assisted water heating, as electricity rates on the islands are the highest in the country. Current product offerings are more sophisticated, durable, and suggest savings of 50% or more in sunny climates. ENERGY STAR program support may help hasten market acceptance of solar systems.

In the coming years, we are likely to see not only an uptake of the emerging technologies in this report, but also a general shift toward distributed water heating. Most consumers think of water heaters as tanks of 30 to 60 gallons (or more) that hold hot water in reserve, and are used as the central supply for an entire building. Consider, however, the water coolers found in office buildings across the country. These tanks do not supply entire buildings, but rather offer distributed service to individual suites and offices. The amount of energy lost through a centrally plumbed cold water distribution system would almost certainly dwarf that of the individual loads of each cooler. By analogy, we can envision the benefits of distributed water heating. By shifting hot water architecture toward heating water at the fixture rather than by a centrally located water heater, we may see vastly greater energy (not to mention water) savings in a number of applications.

[7] http://www.bpa.gov/energy/n/HPWH.cfm
[8] Simplified chimney construction accounts for use of direct power venting instead of atmospherically-vented models that use chimneys to exhaust combustion gases.
[9] California Solar Initiative project data sheet

This study included a broad range of measures, from water heaters to distribution system improvements and improved maintenance practices. It also included both brand new and existing technologies that ACEEE featured in previous iterations of our emerging technology reports. Table 4 details previously surveyed technologies and a comparison with our current findings. The reader will note that in some cases our findings remained largely similar while others varied. Revised assumptions about incremental costs, savings, and market adoption contributed to the degrees of similarity or change.

Table 4. Comparison of Measures and Savings in the 1998, 2004, 2006, and 2011 ACEEE Emerging Technologies in Buildings Studies

	1998 CSE	1998 cum. TBtu	2004 CSE	2004 Cum. TBtu	2006 CSE	2006 Cum. TBtu	2011 CSE	2011 Cum. TBtu
Solar Water Heating (Electric Base System)	—	—	—	—	$ 0.15/kWh	22	$0.14/ kWh	195
Solar Water Heating (Nat. Gas Base System)	—	—	—	—	$ 26.00/MM Btu	636	$27.72/M MBtu	243
Condensing Storage Water Heaters	—	—	$6.39/ MMBtu	217	—	—	$12.91/M MBtu	223
Heat Pump Water Heaters	$0.04/ kWh	320	$0.02/kWh	158	—	—	$0.03/ kWh	301
Drain Water Heat Recovery	$0.03/ kWh	90	—	—	—	—	$6.78/M MBtu	49

Note: the cumulative savings are based on 1999–2015 for the 1998 study, 2005–2020 for the 2004 study, 2008–2020 for the 2006 study, and on 2010–2025 for this study.

Technologies evaluated in this study vary not only by degree of market adoption, but also the amount of "push" given to them by leading market transformation actors. For example, solar, heat pump, "high efficiency" gas storage, and condensing tankless gas water heaters are included in the ENERGY STAR program for residential water heating. Many utilities and government entities offer incentives to purchasers of these products, and together these market actors will likely hasten market penetration of these products. On the other hand, ground source heat pumps and drain water heat recovery have existed for years with proven savings potential, but have not yet garnered much market share in the U.S. Incentives are few and far between and contractor and consumer awareness is low for these technologies.

EMERGING TECHNOLOGIES DESCRIPTIONS

Residential Point-of-Use (POU) Electric Water Heaters[10]

Definition	Electric resistance POU tankless water heater					
Base Case	50 gal. storage electric water heater with operating "efficiency" of 84%					
New Measure	POU electric water heater with operating "efficiency" of 95%	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		38%	124	$1,200	$0.13/kWh	4
Mature Market		38%	124	$1,000	$0.11/kWh	4

Summary

Central storage water heaters that serve distributed loads (such as a bathroom remote from the water heater) waste energy and water each time the remote location calls for hot water: the tap has to run until hot water arrives, and remaining hot water in the line after the draw is complete cools quickly, wasting more energy. New water distribution system models and better understanding of hot water draw patterns help quantify these losses. They suggest applications for which very small electric water heaters may be more efficient, because they nearly eliminate distribution and standby losses. They could also serve as efficient "trim" or "boost" devices where central solar tanks are installed. In typical applications such as a master bathroom remote from the central electric resistance tank water heater, savings of 35 to 40% have been estimated,[11] with a cost of saved energy about $0.13/kWh with current product and installation costs. The calculated savings reflect lower water heater temperature required, reduced hot water loss in pipes, and lower stand-by loss in the water heater. Where loop delays and water use are acceptable, a central heat pump water heater with EF > ~1.4 would be expected to use less site energy (current units are ≥ 2.0), and a point-of-use tankless electric is unlikely to use less source energy than a condensing gas water heater.

Background & Description

The North American residential water heating market is dominated by large storage or tank water heaters, with roughly equal market shares for electric resistance and atmospheric gas heat sources.[12] However, new technologies are entering the market. For example, the ENERGY STAR® Web site lists 26 electric heat pump water heater models with 14 brands, and 728 whole-house tankless gas water heaters from 28 different brands.[13]

Tankless and "mini-tank" electric water heaters could be the basis for an alternative supply and distribution architecture for hot water in buildings where the major hot water use centers are spatially separated enough to cause large distribution losses. A house with master bedroom and kitchen both remote from the water heater in basement or garage would be a common example. In such a case, a small POU water heater at each principal hot water use location would eliminate the distribution losses. As important, a well-designed unit could serve as a "finisher" for a central solar-assisted water heater that

[10] This report is limited to compact resistance units no larger than 25 kW designed for residential applications. Small tankless gas could serve well in some situations, but the gas lines and vents required present a large burden for retrofits, which dominate the market. Hence, this discussion focuses on electric units, implicitly for retrofits. In these cases the only new infrastructure needed is electric service for the unit, since the water lines will already be present, in general. We focus on tankless units, which are marketed in significant numbers now, but do not preclude "mini-tank" storage water heaters, for which POU specification development is beginning.

[11] Klein, G. 2010. *Energy Savings Potential of Electric Tankless Water Heaters.* Prepared for the Coalition of Energy Efficient Electric Tankless Water Heaters.

[12] http://ahrinet.org/ARI/util/showdoc.aspx?doc=1453; http://ahrinet.org/ARI/util/showdoc.aspx?doc=1454. March 9, 2011.

[13] http://www.ENERGYSTAR.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WHH, March 9, 2011.

cannot meet 100% of demands. It could boost the supplied water temperature to the desired temperature for the specific use, with no "down-mixing" with cold water.

ACEEE finds no estimate of the expected life of a tankless electric water heater. In the absence of such data, we assume a 13 year service life. This is consistent with expectations for tank resistance water heaters.[14] It may overestimate life, because the power density is much higher in ETWH than in tank units, or underestimate for various technology reasons.

ENERGY STAR has not included electric resistance water heaters in its program to date. Site energy use of resistance water heaters is very high, as measured by the federal rating method (EF).[15] As important, resistance water heaters are close to their maximum efficiency. Since ENERGY STAR typically does not recognize products unless there are numerous models expected to save at least 5% relative to the DOE standard, resistance water heaters were screened out. Even the efficiency standards that take effect in 2015 did not find savings potential of that magnitude.[16]

In addition, POU electric units face several other problems. The federal method limits residential tankless to 12 kW capacity, and 12 kW barely raises the temperature of 1 gallon per minute (gpm) by the 77°F assumption of the energy factor test. 1 gpm is much less than the 2.5 gpm maximum legal flow for a showerhead,[17] or even the WaterSense specification for efficient shower heads (2.0 gpm[18]). This shows two things: first, ETWH have relatively high power demand, and second, ETWH will be most successful where they are paired with very efficient, low-flow fixtures and with solar pre-heating that minimizes the temperature lift required. A POU electric unit may be able to satisfy the demand of a single shower in some low-flow applications even with the 12 kW capacity limit. To wit, research has shown that most showers are taken at 100-105° F.[19] Given that some cold water is mixed with hot during a shower, a POU could theoretically supply enough hot water for a 2.0 GPM fixture if the incoming cold water were around 65ºF or warmer. Still, this will only apply to the nation's warmer climates, as cooler water temperatures in the winter would prevent the POU unit from satisfying demand. In theory, ENERGY STAR could rate larger ETWH as commercial products, but ENERGY STAR does not yet include any commercial-rated water heaters.[20] Similarly, "mini-tanks" with capacity < 20 gallons are not NAECA-covered (federal covered products); the EF rating method requires more capacity than they can deliver.

Almost by definition, a POU water heater should be installable below sinks and in other inconspicuous locations. ACEEE infers that their highest value will be as point-of-use temperature boosters, avoiding all distribution losses of water and energy. This is consistent with a careful field study showing only 6% energy savings for a whole-house electric tankless water heater compared with a conventional tank water heater—but equivalent or higher peak demand.[21] Instead of commodity products, ENERGY STAR or similar premium products could be differentiated on characteristics that offer real amenity, and save both water and energy. Such features should include:[22]

- External adjustment of desired hot water temperature,[23] so cold water tempering at the fixture is not required.
- Ability to operate as supplemental heater. This requires the ability to boost pre-warmed water from any ambient temperature in the pipe, to the temperature desired by the user.

[14] Technical Support Document, Table 8.7.1. U.S. Department of Energy, January 2009.
[15] DOE test procedures for residential water heaters are set forth at 10 CFR part 430, subpart B, appendix E.
[16] "Energy Conservation Program: Energy Conservation Standards for Residential Water Heaters, Direct Heating Equipment, and Pool Heaters." 10 CFR Part 430. *Federal Register* 75 (73): Friday, April 16, 2010 / Rules and Regulations, 20111–20236.
[17] Energy Policy Act (EPAct), 1992
[18] WaterSense® Specification for Showerheads, http://www.epa.gov/WaterSense/docs/showerheads_finalspec508.pdf
[19] Selover, C. 2011. Personal communication.
[20] ENERGY STAR excludes all water heaters except solar and those rated with the EF test.
[21] Colon, C. and D. Parker. 2010. *Side-by-Side Testing of Water Heating Systems: Results from the 2009-2010 Evaluation.* FSEC CR-1856-10. Florida Solar Energy Center, University of Central Florida, Cocoa, FL.
[22] Adapted from presentation by Coalition for Energy Efficient Electric Tankless Water Heaters, to ACEEE, July 8, 2010.
[23] We think of this as an inconspicuous control panel at the fixture, allowing the user to set temperature (within safety limits).

- Low minimum flow requirement for stable operation. In commercial lavatories, some efficient faucets with aerators deliver only 0.5 gpm total flow, wide open. Thus, minimum flow to actuate (and operate stably) should be much lower.
- Short-draw sensing. If plumbed into a single-lever faucet, should be able to delay current flow and heating to minimize energy use when activation was inadvertent.
- High temperature stability: outlet temperature constant (+/- 3F?) regardless of inlet temperature variations.

A collaborative effort let by manufacturers working with advocates, is attempting two policy efforts now: raising the statutory capacity limit for residential electric tankless water heaters from 12 kW to 25 kW, and developing a set of requirements (such as those above) that would define products worthy of inclusion in an expanded ENERGY STAR water heater program. This could be expanded to include “mini-tank” water heaters.

Data Summary Table

Market Sector	Market Application	End Use	Fuel Type
Residential	New/Replace on Burnout	Water Heating	Electricity
Current Status	**Date of Com.**	**Product Life (years)**	**Source**
Commercialized	2010	13	TSD, Table 8.7.1

Base Case Energy Use		Units	Notes, Explanation	Source
Efficiency	0.84	"efficiency"	Generalized alternative to EF	G. Klein
Electricity Use	2,520	kWh/year	HS worksheet, Klein method	
Summer Demand	1.1	kW	Resistance WH, from New England Power, 1987, Table A-2	
Winter Peak Demand	1.7	kW	Resistance WH, from New England Power, 1987, Table A-2	
Fuel Use	—	MMBtu/year		
New Measure Energy Use				
Efficiency	0.95	"efficiency"	Generalized alternative to EF	G. Klein
Electricity Use	1,550	kWh/year	HS worksheet, Klein method	
Summer Demand	0.9	kW	127 Apt, Cane Creek, FPL	D. Seitz
Winter Peak Demand	0.7	kW	Assume 70°F lift; 50°F in summer	Sachs
Fuel Use	—	MMBtu/year		
Savings				
Electricity Savings	970	kWh/year		
Summer Demand Savings	0.2	kW		
Winter Peak Demand Savings	1.0	kW		
Fuel Savings	—	MMBtu/year		
Percent Savings	38%		See table in ‘Savings Potential and Cost Effectiveness’ section	
Percent Feasible	25%		Estimate for Comm. + Residential	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 1,200	2010 $	Estimated POU install cost, with wiring, as addition to central tank system. Single unit for remote but extensively used bathroom.	
Mature Market Incremental Cost	$ 1,000	2010 $		
Other Costs/ (Savings)	—	$/ year	Estimated annual non-energy benefit	

Ranking Metrics				
2025 Savings Potential (Site)	11800	GWh		
2025 Savings Potential (Source)	124	TBtu		
Cost of Saved Energy	$ 0.13	$/kWh	for commercial and residential uses combined	
Cost of Saved Energy	—	$/MMBtu		
Mature Market Cost of Saved Energy	$ 0.11	$/kWh		
Mature Market Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Lack of confidence Need for building operation changes 12 kW capacity limit for DOE-regulated products	Much quicker hot water delivery Reduced water waste		Private sales through various channels	Demonstrations Field Testing Incentives
Likelihood of Success	4	(1–5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
Harvey Sachs, ACEEE; Gary Klein, Gary@aim4sustainability.com				

This analysis assumes a point of use water heater serving a single bathroom that is far from the central water heater, but used a reasonable amount. An example would be a master bedroom suite in a wing at the opposite end of the house from the water heater, kitchen, and other bathrooms. We do not calculate the value as a solar post-heater. This will be much more site-specific (both geography and size of tank and solar collector), and not as many tankless models seem to be available with the ability to respond to small as well as large calls for temperature boosting.

Current Status of Measure

In 2010, industry estimates that roughly 200,000 tankless units were sold in the USA in sizes < 24 kW.[24]

Savings Potential and Cost-Effectiveness

ACEEE estimates of savings are rough but conservative, *if* an electric tankless WH is installed as a point-of-use device instead of a central water heater. We also assume that the application is one in which the hot water distribution line substantially cools between many of the daily draws. There are few available studies of energy savings potential, but we have summarized them below. In each case, we assume an electric resistance tank water heater as the baseline, and electric resistance tankless water heater as the new measure.

Study Name	Savings Estimate	Basis
Klein	38%	Simple spreadsheet model[25]
Lutz 2010	30%	Waste Estimate, 5 showers, 3 houses, 1 second monitoring[26]
NAHB-RC	24%	ETWH vs. Electric Tank, one house, compact layout[27]

[24] K. Ruppelt, personal communication, March 11, 2011. Data from ~6 of 12 U.S. firms.
[25] ACEEE estimate using methods employed in materials developed by Klein for Electric Tankless Water Heater Coalition.
[26] Lutz, J.D. 2010. Water and Energy Efficiency of Shower Events. Session 4c at ACEEE Hot Water Forum, May 2011.

FPL		Diversified demand <1 kW in 127 unit apartment complex with individual tankless electric water heaters[28]

Klein is an ACEEE spreadsheet model of the gains to be made by point-of-use relative to central electric resistance tank water heaters with typical losses. Efficiency gains come from allowed by proximity to point of use (reduced temperature losses warming pipes), reduced distribution losses from heated water that cools in the pipes after the draw is completed, and higher "efficiency" value used by Klein accounting for reduced standby losses of low-mass, low-surface area tankless units. It is reasonable and plausible, but the only data involved are the imputed efficiency differences.

Lutz summarizes a study of detailed water and energy use for a total of five showers in three California houses. These showers averaged 6:10 minutes actual hot water delivered at desired temperature, with another 1.5 minutes of waste when the water was running but the shower was not in use. Energy wasted (30%) was separately measured and calculated from water flow and temperature. We infer that this is a decent estimate of energy savings potential of point-of-use water heating.

NAHB-RC, a field study, compared alternating periods of use of tank and tankless electric water heaters installed side-by-side to serve a very compact single-family house. So, the distribution runs are roughly a "worst case" for point-of-use tankless.

Given the large number of distribution variables that are involved and the paucity of relevant field data, ACEEE infers that 30% savings of energy are reasonable for typical installations of point-of-use electric tankless, when compared to standard central tank electric water heaters. This savings potential is a calculated estimate based on the limited number of field studies available.

ACEEE estimates that product and installation costs will decline by a combined $200 per unit as POU water heaters gain market share. Mature market cost estimates are detailed in the following table:

	Current Market	**Mature Market**	**Notes, Explanation**
Purchase Price	$ 650	$ 500	Case assumes POU as *addition* to central system rather than new construction
Installation Cost	$ 550	$ 500	New circuit + unit installation
Total Cost	$ 1,200	$ 1,000	
Incremental Cost	$ 1,000	$ 1,000	

Market Barriers

1) The regulatory status of some desirable product sizes is unclear. USDOE does not regulate tankless electric water heaters larger than 12 kW, and they are not listed as certified products in the AHRI directory, as either residential or commercial products.[29] This limits the information available to purchasers. Similarly, "mini-tank" storage units < 20 gallons are not NAECA products. Progress will require federal legislative action.

2) Understanding the application. Hot water fixtures are limited by law to much lower flow rates than before the energy crises of the 1970s, but the plumbing codes still require large diameter (and thus large volume) hot water pipes. This results in large energy losses when pipes cool down between uses, and very long waits for hot water to arrive from a remote tank water heater. This wastes both water and energy. Point-of-use tankless electric water heaters eliminate these negatives, providing relatively efficient "instant" hot water. The barrier is that plumbers and code officials may be tempted to install these units centrally, with great waste from warming pipes and flushing the ambient temperature water in the pipes.

[27] NAHB-RC. 2003. *Field Evaluation of PATH Technologies, Carl Franklin Houses,* Dallas, TX, p. 11
[28] Cited by D. Seitz, Seisco, in presentation at ACEEE Hot Water Forum, May 2011, Session 7b.
[29] http://cafs.ahrinet.org/gama_cafs/sdpsearch/search.jsp?table=CWH. March 9, 2011.

3) Lack of robust, trusted, field studies limits the ability of endorsement programs like ENERGY STAR and public benefit incentives for these products. Resistance water heating inherently has very low source energy efficiency. This leads to reflexive opposition to all resistance-based technologies, even when their use would lead to more cost-effective and energy saving solutions.

4) When all is said and done, point-of-use electric water heaters remain products that will be chosen only where their amenities (control of temperature and immediate hot water) are highly valued, and where alternative installations are awkward. For example, a point-of-use gas tankless water heater is likely to be a much more expensive installation than point of use electric.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[30]
Average Price of Natural Gas	$11.52/MMBtu[31]
Projected 2025 End Use Electricity Consumption[32]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[33]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Validated field study data are essential for establishing the actual operating cost savings of point-of-use electric tankless water heaters. Such data and case studies are required so manufacturers can justify marketing statements.[34] Field data are also essential as a basis for utility incentive programs to promote the products and as a basis for which to promote inclusion in the ENERGY STAR program.

NAECA (appliance standards law) currently limits rated residential electric resistance water heaters to capacities < 12 kW. The law will require change to a limit of 25 kW for products to be rated. In turn, this is one key for utility programs and product credibility. Manufacturers and advocates are addressing this issue.

[30] EIA. *Electric Power Monthly—Feb 2011*. Residential Price.
[31] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[32] EIA. 2009. *Annual Energy Outlook 2010.* Residential and Commercial Sector Key Indicators and Consumption Tables.
[33] Ibid.
[34] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.

ENERGY STAR® [Moderate Climate] Heat Pump Water Heaters

Definition	Heat Pump tank water heaters for moderate climate installation					
Base Case	50 gal. Storage electric water heater, EF = 0.92					
New Measure	ENERGY STAR-rated integrated heat pump water heaters, with tank size at least 50 gal, EF at least 2.0, and first hour rating at least 50 gal.	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		55%	301	$1,574	$0.04/kWh	5
Mature Market		55%	301	$1,470	$0.03/kWh	5

Summary

Heat pump water heaters use a vapor compression refrigeration cycle to “concentrate” ambient heat, cooling and dehumidifying the room in which they are installed to heat water. This section treats ENERGY STAR water heaters,[35] which are integrated or “drop-in” devices designed to replace existing resistance water heaters. Other approaches are treated separately.[36] Basement installations in moderate climates can save over half of the energy used by a resistance water heater. We estimate the cost of saved energy for these heat pump water heaters as ~$0.04/kWh based on current market costs (including modest benefit from dehumidification), and consider them to have very high potential.

Background & Description

The North American residential water heating market is dominated by storage or tank water heaters, with roughly equal market shares for electric resistance and atmospheric gas heat sources.[37] However, new technologies, including heat pump water heaters, are entering the market. In general, a good heat pump water heater will use less than half as much electricity for the same amount of hot water provided as a comparable resistance water heater. Because HPWHs dehumidify and cool the air in spaces where they are installed, they will be particularly attractive in humid climates and spaces like cellars. There, they can offset the operational cost of a stand-alone dehumidifier.

A heat pump water heater (HPWH) comprises a relatively large tank/reservoir, and a refrigeration engine that moves heat from the ambient environment to heat service water for residential or other use. For economic (and sound level) reasons, most designs use a relatively large tank and a very small compressor designed to run most the time. Almost all include supplemental resistance elements for intervals when the heat pump engine is inadequate. We expect the market to continue to offer tank units exclusively: there are few hot water users who have level loads that would be well matched to a tankless heat pump water heater.

It is useful to differentiate several classes by technology and applications (these classes are not exclusive):

- **Self-contained, or “drop-in,” integrated heat pump water heaters, vs. “add-on” refrigeration engines designed for retrofit into existing resistance tank water heaters.**[38] As discussed below, the Department of Energy efficiency standards program excludes the add-on class, so it is also excluded from the ENERGY STAR program.

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[35] http://www.ENERGY STAR.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WHH
[36] 2b treats designs for cold climates and 2c considers “Add-on” units sold as retrofits for existing resistance water heaters.
[37] http://ahrinet.org/ARI/util/showdoc.aspx?doc=1453; http://ahrinet.org/ARI/util/showdoc.aspx?doc=1454. July 19, 2010.
[38] Tomlinson, JJ, and R. W. Murphy 1974. Measured Performance and Impacts of “Drop-In” Residential Heat Pump Water Heaters. ASHRAE Transactions v. 110, Par 2. ASHRAE NA-04-5-2. http://www.ornl.gov/sci/engineering_science_technology/eere_research_reports/appliances/water_heaters/heat_pump_water_heaters/ashrae_na_04_5_2/ashrae_na_04_5_2.pdf

- **Hydrofluorocarbon (HFC) vs. carbon dioxide (CO_2) refrigerant.** At present, all HPWH on the US market use HFC refrigerants similar to those used in air conditioners. In general, the HFC cycle is optimized by repeatedly lifting the water temperature a few degrees at a time. In contrast, the Japanese "EcoCute" HPWH use a CO_2 refrigerant with one-pass lift.
- **Pumped vs. immersed or wrapped condenser.** The Rheem HPWH circulates water from the reservoir through a refrigerant-to-water condenser above the tank. Some other HPWH designs wrap the refrigerant condenser around the tank, beneath its insulation, or immerse the condenser in the tank itself. AO Smith[39] and GE[40] use wrapped condensers, while AirTap[41] uses an immersed condenser.
- **Remote evaporator vs. self-contained.** Some remote evaporator HPWH have been marketed in commercial sizes, in relatively small numbers. "Drop-in" residential units have the evaporator integrated into the refrigeration engine, and extract energy from the air where the unit is located

Rather than a pure technology classification, for this set of emerging technology evaluations, ACEEE recognizes four alternative approaches, differentiated mostly by intended application:

1. ENERGY STAR "drop-in" tank water heaters for typical residential applications, the focus of this description
2. Northern or cold climate "drop-in" heat pump water heaters
3. "Add-on" heat pump water heaters, which are refrigeration engines designed to work with existing resistance tank water heaters
4. "EcoCute" (Japanese) heat pump water heaters that use carbon dioxide as refrigerant instead of halocarbons

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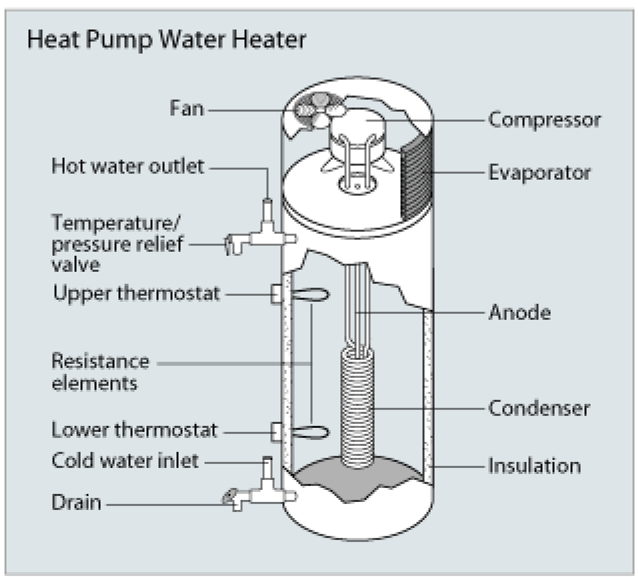
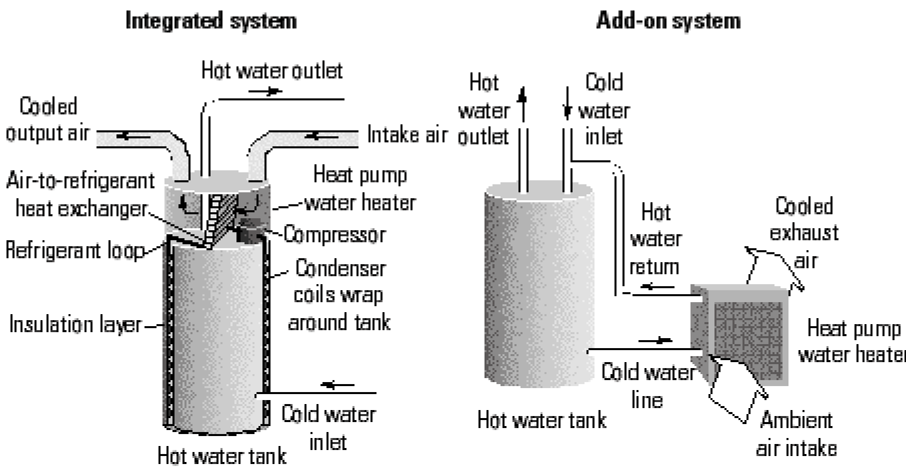


Source: U.S. Department of Energy

[39] http://www.hotwater.com/Water-Heaters/Residential/Hybrid/Voltex/
[40] http://www.geappliances.com/heat-pump-hot-water-heater/
[41] http://www.airgenerate.com/integrated.php



Source: Reliant Energy

Together, these alternatives lead to great product variability in a relatively small marketplace.

As noted, this ET note focuses on the ENERGY STAR tank heat pump water heater. The ENERGY STAR® web site lists 26 electric heat pump water heater models from 14 brands (but a smaller number of manufacturers that offer several brands each).[42]

The ENERGY STAR specification requires EF ≥ 2.0 (more than twice the typical electric resistance water heater, which is 0.90 for comparable 50 gallon unit), first hour rating ≥ 67 gallons, and warranty ≥ 6 years on the sealed refrigeration system. That is, an ENERGY STAR heat pump water heater should perform very much like a resistance water heater—except that it will use less than half as much energy in appropriate installations.

Data Summary Table

Market Sector		**Market Application**	**End Use**	**Fuel Type**
Residential		New/Replace on Burnout	Water Heating	Electricity
Current Status		**Date of Com**	**Product Life (years)**	**Source**
Commercialized		2010	13	Consumer Guide
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.90	EF	Conventional Resistance Electric	text table
Electricity Use	4,878	kWh/year	Calculated based on HPWH energy consumption	
Summer Peak Demand	1.1	kW	3 hottest month avg., coincident	New England PowerService 87, A-2
Winter Peak Demand	1.7	kW	3 coldest month avg., coincident	New England PowerService 87, A-2
Fuel Use	—	MMBtu/year		
New Measure Energy Use				
Efficiency	2.0	EF	Minimum Heat Pump EF	
Electricity Use	2195	kWh/year	As per ENERGY STAR	
Summer Peak Demand	0.6	kW	Justified as ½ of tank resistance WH	See "Water heater demand notes"

[42] Product listings by product class available from http://www.ENERGY STAR.gov/index.cfm?c=products.pr_find_es_products, as of July 19, 2010.

Winter Peak Demand	0.8	kW	Justified as ½ of tank resistance WH	See "Water heater demand notes"
Fuel Use	—	MMBtu/year		
Savings				
Electricity Savings	2,683	kWh/year		
Summer Peak Demand Savings	0.5	kW		
Winter Peak Demand Savings	0.9	kW		
Fuel Savings	—	MMBtu/year		
Percent Savings	55%			
Percent Feasible	25%		Half of electric water heater installations. ACEEE estimate assumes that half of electric water heating market features difficult installations for HPWHs (slab on grade, inside envelope, attic, etc.)	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$1,005	2010 $		DOE TSD
Mature Market Incremental Cost	901	2010 $		
Other Costs/ (Savings)	($20)	$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	28,600	GWh		
2025 Savings Potential (Source)	301	TBtu		
Cost of Saved Energy	$ 0.04	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
Mature Market Cost of Saved Energy	$ 0.03	$/kWh		
Mature Market Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Noise and air space, and space heating considerations can make installations tricky.	Dehumidification Reduced space cooling load in warm climates		ENERGY STAR program Manufacturer Marketing	Incentives Education Training
Likelihood of Success	5	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Manufacturers: See ENERGY STAR product list online.				
Principal Contacts				
Harvey Sachs, ACEEE				

Current Status of Measure

The ENERGY STAR® web site lists 26 electric heat pump water heater models from 14 brands (but a smaller number of manufacturers that offer several brands each). Purchase prices are in the range of $1500 to $2000.

Savings Potential and Cost-Effectiveness

ACEEE estimates of savings are rough but conservative, and based on data from the Department of Energy *Technical Support Document.*[43] The cost of saved energy is ~$0.04/kWh, which is extremely attractive. This is particularly true since ACEEE estimates do not include the value of dehumidification in many installations.

ACEEE estimates that product costs will experience a marginal decrease as production scales up over the next decade or so. Mature market cost estimates are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 1,039	$ 935	Modest decline w. volume (ignored by TSD)
Installation Cost	$ 535	$ 535	
Total Cost	$ 1,574	$ 1,470	
Incremental Cost	$ 1,005	$ 901	

Market Barriers

1) First hour rating may be lower than comparably-sized resistance electric unit, requiring upsizing the storage capacity, which may limit installation options in rooms with low ceilings.
2) HPWH will require some understanding by owners and contractors to avoid poor installation choices, such as noisy HPWH near sleeping areas. There will be mistakes, and callbacks poison the well for contractors.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[44]
Average Price of Natural Gas	$11.52/MMBtu[45]
Projected 2025 End Use Electricity Consumption[46]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[47]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

The ENERGY STAR listing is a key early step that has been accomplished. Field study data are essential for establishing the actual operating cost differences between HPWH and conventional units. Such data and case studies are required so manufacturers can justify marketing statements.[48] Field data are also essential as a basis for utility incentive programs to promote the products. In parallel, good, easy-to-use,

[43] http://www1.eere.energy.gov/buildings/appliance_standards/residential/waterheat_0300_r.html
[44] EIA. *Electric Power Monthly—Feb 2011*. Residential Price.
[45] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[46] EIA. 2009. Annual Energy Outlook 2010. Residential and Commercial Sector Key Indicators and Consumption Tables
[47] Ibid.
[48] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.

well-calibrated, simulation programs that help professionals choose the most appropriate applications for HPWH are critical.

The 2015 US DOE standards for electric water heaters will require HPWH for all units > 55 gallons. Using this experience basis as it happens, the next step will be to incrementally move the market toward somewhat smaller units.

Sample Price Data

Brand	Model	Price Found	Web Page
Rheem	HP40RH	$1,240	http://www.wamhomecenter.com/productcart/pc/viewPrd.asp?idcategory=6536&idproduct=210057
Rheem	HP50RH	$1,250	http://www.buyplumbing.net/index.html?pg=pd&_i=HP50RH
Rheem EcoSense	HP40ES	$1,400	http://www.homedepot.com/Rheem-EcoSense/h_d1/N-5yc1vZ467/R-202552735/h_d2/ProductDisplay?langId=-1&storeId=10051&catalogId=10053
Rheem EcoSense	HP50ES	$1,500	http://www.homedepot.com/buy/plumbing/water-heaters/rheem-ecosense/50-gal-hybrid-electric-water-heater-with-heat-pump-technology-42207.html
G.E.	GEH50DNSRSA	$1,600	http://www.sears.com/shc/s/p_10153_12605_04232100000P?sid=IDx20070921x00003a&ci_src=14110944&ci_sku=04232100000P
G.E.	GEH50DXSR		Could not find price online at time of publishing
A. O. Smith	PHPT-60	$2,300	http://www.pexsupply.com/AO-Smith-PHPT-60-60-Gallon-Voltex-Residential-Hybrid-Electric-Heat-Pump-Water-Heater
A. O. Smith	PHPT-80	$2,200	http://www.pexsupply.com/AO-Smith-PHPT-80-80-Gallon-Voltex-Residential-Hybrid-Electric-Heat-Pump-Water-Heater

Northern Climate Heat Pump Water Heaters[49]

Definition	Air source heat pump water heater for cold climates (drop-in or add-on)					
Base Case	50 gallon electric resistance tank water heater					
New Measure	ENERGY STAR HPWH with additional features to manage cold exhaust air and perform well in expected cold-climate conditions.[50]	Percent Savings	2025 Savings TBtu (Source)	Installed Cost	Cost of Saved Energy	Success Rating (1–5)
Current Market		40%	95	$1,700	$0.06/kWh	4
Mature Market		40%	95	$1,590	$0.05/kWh	4

Summary

Heat pump water heaters can save 30% or more over conventional units by using electricity to move heat from ambient air to water in the storage tank, rather than generating heat directly. This section treats Northern heat pump water heaters for which we estimate savings of 40% over conventional units. These are a proposed variant of the ENERGY STAR heat pump water heater.[51] They are integrated or "drop-in" devices designed to replace existing resistance water heaters. Other approaches are treated separately.[52] We estimate the cost of saved energy for these heat pump water heaters as $0.06/kWh with current market prices, and consider them to have very high potential.

Although heat pump water heaters can reduce cooling loads if installed within the conditioned space in warm climates, and provide beneficial dehumidification in basements, they face energy and acceptance challenges in cold climates. In response, the Northwest Energy Efficiency Alliance and others have prepared a specification for acceptable units in cold climates, and circulated it to manufacturers.

Background & Description

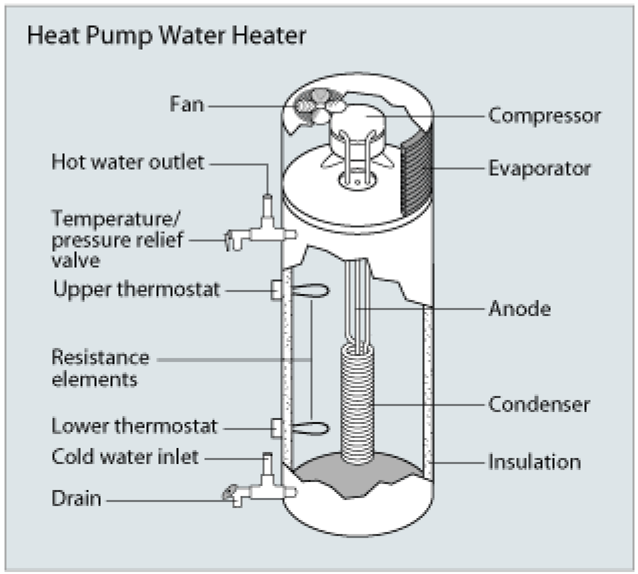
A heat pump water heater (HPWH) comprises a relatively large tank/reservoir, and a refrigeration engine that moves heat from the ambient environment to heat service water for residential or other use. For economic (and sound level) reasons, most designs use a relatively large tank and a very small compressor designed to run almost all the time. Almost all include supplemental resistance elements for intervals when the heat pump engine is inadequate. We expect the market to continue to offer tank units exclusively: there are few hot water users who have level loads that would be well matched to a tankless heat pump water heater. Still it is useful to differentiate several classes by technology and applications (these classes are not exclusive):

- **Self-contained, or "drop-in," integrated heat pump water heaters, vs. "add-on" refrigeration engines designed for retrofit into existing resistance tank water heaters.**[53] As discussed below, the Department of Energy efficiency standards program excludes the add-on class, so it is also excluded from the ENERGY STAR program.
- **Hydrofluorocarbon (HFC) vs. carbon dioxide (CO_2) refrigerant.** At present, all HPWH on the market in the US use HFC refrigerants similar to those used in air conditioners. In general, the

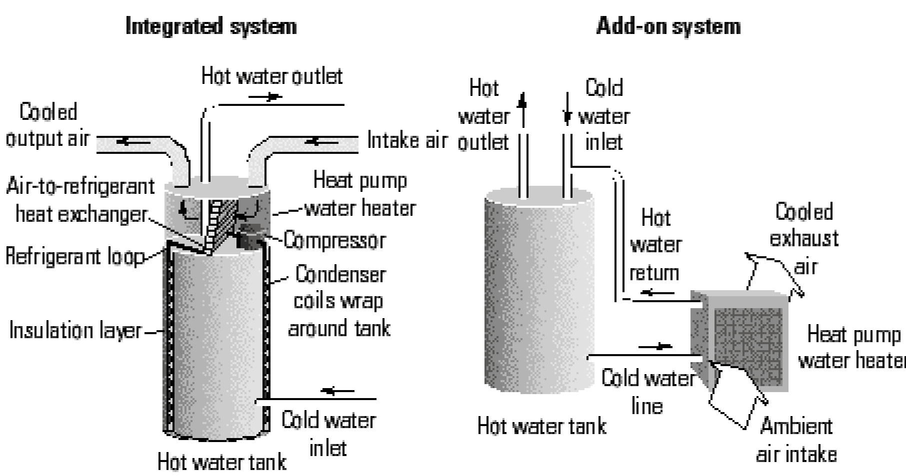
[49] This discussion is limited to *air-source* heat pumps. Water-to-water and other ground source heat pumps are excluded.
[50] Northwest Energy Efficiency Alliance and others, 2009. *A Specification for Residential Heat Pump Water Heaters Installed in Northern Climates Version 3.0.*
[51] http://www.ENERGY STAR.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WHH
[52] 2a treats designs for cold climates; 2c considers "add-on" units sold as retrofits for existing resistance water heaters, and 2d discusses HPWH that use CO_2 as refrigerant instead of halocarbons used in the other classes.
[53] Tomlinson, JJ, and R. W. Murphy. 1974. "Measured Performance and Impacts of "Drop-In" Residential Heat Pump Water Heaters." *ASHRAE Transactions* v. 110, Par 2. ASHRAE NA-04-5-2. http://www.ornl.gov/sci/ees/etsd/btric/eere_research_reports/appliances/water_heaters/heat_pump_water_heaters/ashrae_na_04_5_2/ashrae_na_04_5_2.pdf.

HFC cycle is optimized by repeatedly lifting the water temperature a few degrees at a time. In contrast, the Japanese "EcoCute" HPWH use a CO_2 with one-pass lift.

- **Pumped vs. immersed or wrapped condenser.** The Rheem HPWH circulates water from the reservoir through a refrigerant-to-water condenser above the tank. Other HPWH designs wrap the refrigerant condenser around the tank, beneath its insulation, or immerse the condenser in the tank itself. AO Smith[54] and GE[55] use wrapped condensers, while AirTap[56] uses an immersed condenser.
- **Remote evaporator vs. self-contained.** Some remote evaporator HPWH have been marketed in commercial sizes, in relatively small numbers. All "drop-in" residential units have the evaporator integrated into the refrigeration engine, and extract energy from the air where the unit is located.



Source: U.S. Department of Energy



Source: Reliant Energy

Together, these alternatives lead to great product variability in a relatively small marketplace.

This discussion focuses on Northern Heat Pump Water Heaters, products that meet the Specification developed by the Northwest Energy Efficiency Alliance (NEEA). We find no products yet that specifically

54 http://www.hotwater.com/Water-Heaters/Residential/Hybrid/Voltex/
55 http://www.geappliances.com/heat-pump-hot-water-heater/
56 http://www.airgenerate.com/integrated.php

claim to meet this specification. As noted by NEEA, "Beginning in the early 1980's, electric utilities in colder, northern portions of North America implemented programs to introduce heat pump technology into the residential water heating market. These program efforts spanned three generations of technology over the course of two decades. They included detailed measurement of both technical performance and consumer acceptance.[57] The *Northern Climate Specification…* identified seven issues that its authors felt were inadequately addressed by the national ENERGY STAR specification: comfort (cold evaporator exhaust air in the living space), capacity, efficiency, condensate management, freeze protection, noise, and reliability and service. Many of these elements are climate-independent enhancements to heat pump water heater acceptability, so we focus here on the climate-specific performance aspects.

The most critical issue is the actual (ambient) heat source for the HPWH. To illustrate, consider an older southern house, with a basement and relatively warm ground temperature year-around. A HPWH installed in that basement would draw most or all of its heat from the ground, through the slab and foundation. Conversely, consider a Northern (insulated) slab-on-grade house with a HPWH located inside the thermal envelope. The heat source for this unit, the indoor air, must itself be heated in winter, so the HPWH will add to the space heating load during a long cold winter.[58] Thus, regardless of the COP or EF of the HPWH, its system efficiency is less than that of the heat source of the house, whether fossil or electric. Beyond that, there can be a large comfort issue: the air exhausted from the evaporator will be cold. NEEA's specification proposes that the evaporator exhaust be carried out of the house, but does not include a seasonal control to get the benefits of cooling and dehumidification in the warm months. The specification does include requirements for enough fan power to allow the necessary ductwork.

Temperature is also a significant issue.[59] In the North, winter incoming water temperatures are likely to be less than 40F, which means an 80°F lift to acceptable tank temperature. By itself, this requires more energy than with warmer incoming water. The second temperature complication is that the ambient air is cold, so even an outdoor evaporator would have a low-grade heat source.

The electricity impact on the serving utility is a substantial reduction of early morning and early evening demand peaks, from > 2 kW (15 min) with resistance to < 1 kW with the heat pump cycle. In most cases, it should be possible to use a time control to lock out the resistance elements during peak times without loss of amenity.

The NEEA Northern HPWH specification was developed as a discussion paper for conversations with manufacturers. The principal concerns of the authors are reflected in the core requirements:

- ENERGY STAR qualified (see ENERGY STAR HPWH discussion).
- Additional First Hour Rating requirement of comparability to equivalent resistance water heater. Depending on interpretation, this may move the FHR requirement from the 50 gallon of ENERGY STAR to about 60 gallon, approximately the median for 50 gallon tank water heaters.[60]
- The Northern specification proposes additional safety and service parameters for condensate management, air filters, diagnostics, and freeze protection.
- The Northern specification requires additional exhaust ducting and noise control features for units to be installed in living spaces.

To date, no manufacturer has introduced a product that claims to qualify. Discussions continue with potential manufacturers and limited field studies are underway using modified ENERGY STAR residential HPWH units.

Data Summary Table

[57] neea.org/ourwork/documents/HPWHNorthernTierSpecFinal.pdf
[58] Consider the alternative, installing the HPWH outside the thermal envelope, in the attic. First, this would require rigorous measures to prevent freezing any water pipe. Second, the ambient would be too cold for too long a winter period for the heat pump to function, or to function efficiently. So, the HPWH must be in a conditioned or semi-conditioned space like a basement.
[59] Tomlinson & Murphy. ASHRAE. 2004.
[60] AHRI certified products directory, March 11, 2011. Roughly equal numbers with 50 to 60 gallon and 60 to 70 gallon FHR.

Market Sector	Market Application		End Use	Fuel Type
Residential	New or Retrofit		Water Heating	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Concept Stage	2013		13	DOE TSD
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.90	EF	Conventional Resistance Electric, DOE minimum EF	
Electricity Use	4,878	kWh/year	= moderate climate HPWH analysis	
Summer Peak Demand	1.1	kW	3 hottest month avg., coincident	New England PowerService 87, A-2
Winter Peak Demand	1.7	kW	3 coldest month avg., coincident	New England PowerService 87, A-2
Fuel Use	—	MMBtu/year		
New Measure Energy Use				
Efficiency	2.00	EF	Federal min. for electric >55 gal, effective 2015	
Electricity Use	2,927	kWh/year	Assumes 25% of energy use is parasitic from house	
Summer Peak Demand	0.6	kW	Justified as ½ of tank resistance WH	See “Water heater demand notes”
Winter Peak Demand	0.8	kW	Justified as ½ of tank resistance WH	See “Water heater demand notes”
Fuel Use	—	MMBtu/year		
Savings				
Electricity Savings	1,951	kWh/year		
Summer Demand Savings	0.5	kW		
Winter Demand Savings	0.9	kW		
Fuel Savings	0	MMBtu/year		
Percent Savings	40%			
Percent of USA Feasible	14%		ACEEE estimate. See table in 'Savings Potential and Cost Effectiveness' section.	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 1,131	2010 $	Assumes 20% increase for ducting, etc.	
Mature Market Incremental Cost	$ 1,021	2010 $		
Other Costs/ (Savings)	0	$/ year	No dehumidification savings claimed	
Ranking Metrics				
2025 Savings Potential (Site)	9000	GWh		
2025 Savings Potential (Source)	95	TBtu		
Cost of Saved Energy	$ 0.06	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
Mature Market Cost of Saved Energy	$ 0.05	$/kWh		
Mature Market Cost of Saved Energy	—	$/MMBtu		

Unusual Market Barriers	Non-Energy Benefits		Current Activity	Next Steps
Public awareness and manufacturer integration with specification Concerns about ability of plumbers to properly vent cold air outside	Improved confidence in system performance for residents in cold climates		NEEA has published draft specification	Market Aggregation
Likelihood of Success	4	(1–5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	D	(A–D)		
Principal Contacts				
Jeff Harris, NEEA				
By: Harvey Sachs, with Nate Kaufman				

Current Status of Measure

ENERGY STAR currently lists 30 heat pump models, representing 14 brands but a smaller number of manufacturers. Some, typically called "hybrid" models, include user-selected settings that will minimize discomfort by shifting to resistance mode, for example when ambient temperatures are too cold for efficient heat pump cycle operation. Of course, this sacrifices the efficiency of the heat pump components. Several of the ENERGY STAR brands advertise that their products may be used in any region of the U.S., with a few—such as the Rheem EcoSense—explicitly acknowledging that in colder climates, electric heating elements will need to be used for a longer period of time. None of these companies' consumer-oriented Web pages refer to the NEEA specification or claim to satisfy it.

Savings Potential and Cost-Effectiveness

Federal Energy Factor ratings for the ENERGY STAR listed heat pump water heaters range from 2.0 to 2.5. ACEEE believes that a dedicated, fluorocarbon cycle northern HPWH will have an annual EF in the range of 2.0. In the long run, a CO_2 cycle may yield a somewhat higher EF, but at a much higher purchase price. We expect no maintenance beyond user cleaning or replacement of the air filter for the evaporator.

Note that the US Energy Factor test requires that the water heater tank temperature of 135°F.[61] However, R-410A, R134a, and other refrigerants used in HPWH have poor performance at temperatures above 120°F to 125°F, so the test requires some resistance "boost" to the required test condition. This is noteworthy because manufacturers ship residential products with thermostats set in the range of 120°F to 125°F, so the test handicaps heat pump water heaters. Care is required for this and other test procedure reasons in estimating savings potential. In this context, it is noteworthy that the ENERGY STAR program does not include a savings calculator.

The following table details U.S. population statistics by climate and fuel use. We estimate that 14% of the U.S. water heating market is in cold climates with electricity as the fuel for water heating.

[61] 10 CRF Ch. II (1-1-02 Edition), Pt. 430, Subpt. B, App. E, Item 2.4, p. 150, [46 FR 27326, May 19, 1981].

	Population	Percent of Total U.S. Population
Total U.S.	308,700,000	100%
Cold Climate	143,700,000	47%
Cold with Electric Water Heating	44,600,000	14%

ACEEE estimates a modest product cost decline of about $100 as production scales up. Mature market cost estimates are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 1,100	$ 990	Slight up-price for shroud & fan/controls changes, but some economies of production
Installation Cost	$ 600	$ 600	Up-price for duct installation
Total Cost	$ 1,700	$ 1,590	
Incremental Cost	$ 1,131	$ 1,021	

Market Barriers

1) First cost for the Northern climate heat pump water heaters will remain higher than resistance water heaters, but competitive with or lower than condensing gas units.

2) Major manufacturers may require strong indications that there will be a receptive market before they invest in development, certification, and marketing a product. A market aggregation program analogous to the "Golden Carrot" refrigerator program may be required to demonstrate an early market. In that program, a large group of utilities guaranteed incentives for sales in their service territories of an advanced refrigerator better than any then on the market. Details would vary in a program this decade.

3) Low consumer awareness, and poor guidance to contractors on how to install HPWH for cold climates.

4) A significant fraction of electric water heaters are sold directly to consumers, and installed by homeowners themselves. Northern climate HPWH are likely to require some (air) ductwork for winter evaporator exhaust. The skills required are comparable to those for installing venting for a clothes dryer, but may discourage some homeowners.

5) We expect manufacturers to focus first on the Southern market, for several reasons. First, the value of dehumidification and cooling is greatest there, and the heating penalty is smallest because winters are shorter and milder than in other regions. Second, and as important, the South is the only one of four major census regions where a majority of housing units use electricity as their primary water heating energy source: 59%. In the other regions, electric water heating has 10% to 17% share.[62] HPWH are generally designed to be installed as direct substitutes for resistance tank water heaters, so the barrier to conversion is much lower than for a conversion from natural gas. The potential need for evaporator venting for a tough-to-serve market is unlikely to quickly stimulate manufacturers to modify equipment and its documentation for northern needs.

6) Incomplete awareness of potential benefits and ways to structure incentive programs by utilities and public benefit programs. Regional organizations (NEAA, NEEP) are attempting to provide information,[63] and ET programs are evaluating heat pump water heaters in general.[64]

[62] RECS 2005, Table HC10.8. http://www.eia.doe.gov/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html.
[63] http://neep.org/news/webinars, as of January 17, 2011

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[65]
Average Price of Natural Gas	$11.52/MMBtu[66]
Projected 2025 End Use Electricity Consumption[67]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[68]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Field study data are essential for establishing the seasonal and annual operating cost differences between Northern heat pumps and conventional alternatives, particularly electric resistance tank water heaters. Such data and case studies are required so manufacturers can justify marketing statements.[69] Field data are also essential as a basis for utility incentive programs to promote the products. For these programs, winter demand savings are likely to be as important as energy savings, in some cases. Because Northern heat pump water heaters will remain more expensive than the conventional fossil or resistance alternatives, it is essential to develop the value proposition by showing economic and "non-energy" benefits.

Rating method changes that will allow better comparisons across water heater types are in process. One possible outcome of this work might be product ratings that reflect alternative use intensity and climate; ACEEE advocates such an approach.

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[64] For example, PG&E 2010, Laboratory evaluation and field testing of residential heat pump water heaters. Application Assessment Report # ETP10PGE1001; PG&E 2009, Energy Performance Analysis for Heat Pump Water Heaters - ETCC # 0916; http://neea.org/participate/docs/NEEA_BusinessPlan_Board-Approved.pdf.
[65] EIA. *Electric Power Monthly—Feb 2011.* Residential Price.
[66] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[67] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[68] Ibid.
[69] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.

Add-On Heat Pump Water Heaters

Definition	Heat pump module used in conjunction with tank resistance water heater.					
Base Case	50 gal. Storage electric water heater, EF = 0.92					
New Measure	Add-On Heat Pump Water Heater Module with 2.00 EF	Percent Savings	2025 Savings TBtu (Source)	Installed Cost	Cost of Saved Energy	Success Rating (1–5)
Current Market		55%	194	$800	$ 0.03	4
Mature Market		55%	194	$720	$ 0.03	4

Summary

Heat pump water heaters use a vapor compression refrigeration cycle to "concentrate" ambient heat, cooling and dehumidifying the room in which they are installed to heat water. Basement installations in moderate climates can save over half of the energy used by a resistance water heater. Heat pumps are available as both stand-alone units and as add-on retrofits for existing electric water heaters. This section treats "add-on" water heaters. Other write-ups discuss integrated or "drop-in" approaches.[70] In warm climates, heat pump water heaters can reduce cooling loads if installed within the conditioned space. Similarly, heat pumps offer the benefit of dehumidification for residents in humid climates and spaces like cellars, which can offset the operational cost of a stand-alone dehumidifier.

We assume that the federal EF rating is an appropriate measure for comparison with tank resistance baseline units. Under these conditions and current market prices, we estimate the cost of saved energy for these heat pump water heaters as ~$0.03/kWh (including modest benefit from dehumidification), and consider them to have very high potential *if* controls work correctly, the products prove reliable, and market barriers can be overcome. Heat flow through imperfectly-insulated basement walls and floor is likely to be sufficient to supply low-grade heat for the water heater.[71]

Background & Description

The North American residential water heating market is dominated by storage or tank water heaters, with roughly equal market shares for electric resistance and atmospheric gas heat sources.[72] However, new technologies, including heat pump water heaters (including solar, and tankless gas water heaters), are entering the market. In general, a good heat pump water heater will use less than half as much electricity for the same amount of hot water provided as a comparable resistance water heater. Because HPWH dehumidify and cool the air in spaces where they are installed, they will be particularly attractive in humid climates and humid spaces like cellars. There, they can offset the operational cost of a stand-alone dehumidifier.

A heat pump water heater (HPWH) comprises a relatively large tank/reservoir, and a refrigeration engine that moves heat from the ambient environment to heat service water for residential or other use. For economic (and sound level) reasons, most designs use a relatively large tank and a very small compressor designed to run most the time. Almost all include supplemental resistance elements for intervals when the heat pump engine is inadequate. We expect the market to continue to offer tank units exclusively: there are few hot water users who have level loads that would be well matched to a tankless heat pump water heater.

It is useful to differentiate several classes by technology and applications (these classes are not exclusive):

[70] 2b treats designs for cold climates; 2a considers ENERGY STAR heat pump water heaters.
[71] http://www.buildinggreen.com/auth/article.cfm/2008/6/27/An-Affordable-Heat-Pump-Water-Heater-Retrofit/
[72] http://ahrinet.org/ARI/util/showdoc.aspx?doc=1453; http://ahrinet.org/ARI/util/showdoc.aspx?doc=1454. July 19, 2010.

- **Self-contained, or "drop-in," integrated heat pump water heaters, vs. "add-on" refrigeration engines designed for retrofit into existing resistance tank water heaters.**[73] As discussed below, the Department of Energy efficiency standards program excludes the add-on class, and it is also currently excluded from the ENERGY STAR program.
- **Hydrofluorocarbon (HFC) vs. carbon dioxide (CO_2) refrigerant.** At present, all HPWH on the North American market use HFC refrigerants similar to those used in air conditioners. In general, the HFC cycle is optimized by repeatedly lifting the water temperature a few degrees at a time. In contrast, the Japanese "EcoCute" HPWH use a CO_2 with one-pass lift.
- **Pumped vs. immersed or wrapped condenser.** The Rheem HPWH circulates water from the reservoir through a refrigerant-to-water condenser above the tank. Some other HPWH designs wrap the refrigerant condenser around the tank, beneath its insulation, or immerse the condenser in the tank itself. AO Smith[74] and GE[75] use wrapped condensers, while AirTap[76] uses an immersed condenser.
- **Remote evaporator vs. self-contained.** Some remote evaporator HPWHs have been marketed in commercial sizes, in relatively small numbers. "Drop-in" residential units have the evaporator integrated into the refrigeration engine, and extract energy from the air where the unit is located.

Rather than a pure technology classification, for this set of emerging technology evaluations ACEEE recognizes four alternative approaches, differentiated mostly by intended application:

1. ENERGY STAR "drop-in" tank water heaters for typical residential applications, the focus of this description
2. Northern or cold climate "drop-in" heat pump water heaters
3. "Add-on" heat pump water heaters, which are refrigeration engines designed to work with existing resistance tank water heaters
4. "EcoCute" (Japanese) heat pump water heaters that use carbon dioxide as refrigerant instead of halocarbons. These are not included in this series, since no UL-certified products have been released to the US market

Add-on heat pump water heaters from specialty firms have been marketed for decades. One product was developed with substantial financial and technical assistance from EPRI.[77] Northeast Utilities offered two different add-on brands to customers for a number of years, continually refining the program to use the best possible contractors in the most appropriate applications. The program ended in 2002, with less than satisfactory results after several thousand units had been installed.[78] The verdict was that these products from small manufacturers had been inadequately tested before release, and proved too unreliable for service in customer residences. These early products also required more maintenance than mainstream technologies.[79]

Add-on heat pump water heaters are *not* federally regulated products: DOE does not consider them to be complete water heaters, because they rely on a third party tank (with unknown thermal properties) to operate.[80] This means that there is not a recognized rating method for these products.

[73] Tomlinson, JJ, and R. W. Murphy 1974. Measured Performance and Impacts of "Drop-In" Residential Heat Pump Water Heaters. ASHRAE Transactions v. 110, Par 2. ASHRAE NA-04-5-2. http://www.ornl.gov/sci/engineering_science_technology/eere_research_reports/appliances/water_heaters/heat_pump_water_heaters/ashrae_na_04_5_2/ashrae_na_04_5_2.pdf

[74] http://www.hotwater.com/Water-Heaters/Residential/Hybrid/Voltex/

[75] http://www.geappliances.com/heat-pump-hot-water-heater/

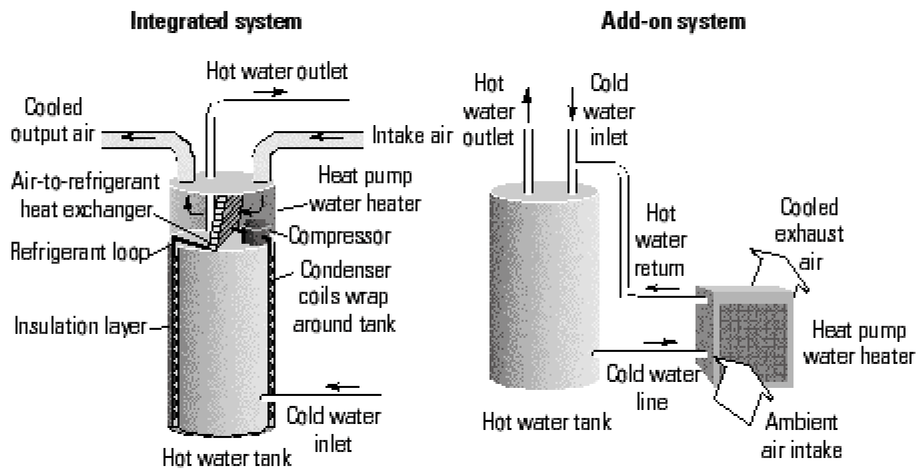
[76] http://www.airgenerate.com/integrated.php

[77] Electric Power Research Institute largely funded by electric utilities. http://my.epri.com/portal/server.pt

[78] Russ Johnson, former Conn. Light & Power official responsible. Personal communication, April 2011.

[79] "Maintenance costs for residential HPWHs are significantly higher than for other water heating technologies. Experience at bases that use HPWHs suggests that two hours per year should be expected for preventative maintenance activities. In addition, typical in-service life spans have in the past been lower than manufacturers' expectations, often because of faulty installation or component failure. Maintenance costs beyond preventative maintenance are largely unknown for the newest generation of HPWHs."
" – FEMP

[80] This DOE position appears inconsistent with its regulation of central air conditioners. These rely on the air handler of another product (the furnace) to perform, just as an add-on heat pump water heater relies on another product, the tank. Indeed, for central



Source: Reliant Energy

Data Summary Table

Market Sector	**Market Application**		**End Use**	**Fuel Type**	
Residential	New/Replace on Burnout		Water Heating	Electricity	
Current Status	**Date of Com**		**Product Life (years)**		**Source**
Commercialized	1990		10.5		DOE TSD for RAC
Base Case Energy Use		**Units**	**Notes, Explanation**		**Source**
Efficiency	0.90	EF	Conventional Resistance Electric		text table
Electricity Use	4,878	kWh/year	Calculated based on HPWH energy consumption		
Summer Peak Demand	1.1	kW	3 hottest month avg., coincident		New England PowerService 87, A-2
Winter Peak Demand	1.7	kW	3 coldest month avg., coincident		New England PowerService 87, A-2
Fuel Use	—	MMBtu/year			
New Measure Energy Use					
Efficiency	2.0	EF	Minimum Heat Pump EF, 2015 rule		
Electricity Use	2195	kWh/year	As per ENERGY STAR		
Summer Peak Demand	0.6	kW	Justified as ½ of tank resistance WH		See “Water heater demand notes”
Winter Peak Demand	0.8	kW	Justified as ½ of tank resistance WH		See “Water heater demand notes”
Fuel Use	—	MMBtu/year			
Savings					
Electricity Savings	2,683	kWh/year			
Summer Demand Savings	0.5	kW			
Winter Demand Savings	0.9	kW			
Fuel Savings	—	MMBtu/year			

air conditioners, the rating method recognizes that furnace, air conditioner condensing unit, and air conditioner evaporator may be provided by three different firms.

Percent Savings	55%			
Percent Feasible	25%		Half of electric water heater installations. ACEEE estimate assumes that half of electric water heating market features difficult installations for HPWHs (slab on grade, inside envelope, attic, etc.)	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 800	2010 $	Web search, w. installation. See text	DOE TSD
Mature Market Incremental Cost	$ 720	2010 $		
Other Costs/ (Savings)	($ 20)	$/ year	80% of ENERGY STAR dehumidifier estimated savings	
Ranking Metrics				
2025 Savings Potential (Site)	18,400	GWh		
2025 Savings Potential (Source)	194	TBtu		
Cost of Saved Energy	$ 0.03	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
Mature Market Cost of Saved Energy	$ 0.03	$/kWh		
Mature Market Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Replacement market dominates, but plumbers don't consider HPWH for emergency replacements	Dehumidification Reduced space cooling load in warm climates		Manufacturer Marketing	Standards & Codes ENERGY STAR action Incentives
Likelihood of Success	4	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	B	(A–D)		
Principal Contacts				
Manufacturers: AirTap, E-Tech, others. Price from http://www.rexresearch.com/airtap/airtap.htm				
By: Harvey Sachs, Jacob Talbot				

Current Status of Measure

In Spring, 2011, there are several brands and models of add-on heat pump water heaters in the North American market.[81] Sales numbers are not known. One manufacturer lists one product[82] in the AHRI directory of certified products. It is assigned an EF of 2.2, presumably from testing with a tank sold by others. That product is recommended by the manufacturer for retrofit of existing electric resistance water heaters in good condition. For our analyses, we assume a post-2004 tank resistance with a 50 gal. tank

[81] Including AirTap, Geyser (North Road Technologies), E-Tech (A.O. Smith-owned)
[82] Airtap A7. http://www.airgenerate.com/retrofit.php.

and EF=0.90, the DOE minimum for 50 gallon resistance tank water heaters.[83] We also assume that the federal EF rating is an appropriate measure for comparison with tank resistance baseline units. We believe that installing an add-on HPWH requires no significant skills lacked by a plumber or other person capable of installing a “drop-in” or integral HPWH. It will require some additional time (0.5 to 1 hr?) to properly mount the HPWH unit, if wall-hung.

Savings Potential and Cost-Effectiveness

ACEEE estimates of savings are conservative, and based on data from the Department of Energy *Technical Support Document*[84] for integrated units with comparable EF values. We assume that an add-on HPWH will have about the same delivered efficiency as a drop-in with pump instead of condenser wrapped around the tank (see the write-up on drop-in heat pump water heaters). For an EF ≥ 2.0, the cost of saved energy is ~$0.03 /kWh, which is extremely attractive. This is particularly true since ACEEE estimates do not include the value of dehumidification in many installations.

ACEEE estimates that product costs will see a nominal decrease as sales increase and installation costs will also fall about 10%. Mature market cost estimates are detailed in the following table:

	Current Market	**Mature Market**	**Notes, Explanation**
Purchase Price	$ 550	$ 495	Economies of scale
Installation Cost	$ 250	$ 225	Estimate for plumber at $90/hr. including windshield time
Total Cost	$ 800	$ 720	
Incremental Cost	$ 800	$ 720	Requires existing storage tank

Market Barriers

1) Add-on HPWH are likely to remain relatively invisible in the market for efficient water heating technologies until their capabilities are recognized by ENERGY STAR, and until the Department of Energy includes them in its water heater efficiency standards. Thus, we consider addressing these issues as the highest priority.
2) Most purchases are influenced by plumbers and other installers. In emergency situations, even where speed is more important than cost, the plumber is most likely to carry the unit on the truck that is least likely to cause any complications for the installation—that would be the current model as similar to the one that failed as possible. Making mental space for the proposition that the energy-saving but more complicated option can be more profitable and no more risky for the plumber will require some hard work.
3) The next challenge is figuring out a market strategy that will make upstream market participants (plumbers and distributors) want to profit by moving this merchandise. Several strategies suggest themselves:

    a. Marketing to recent purchasers of electric water heaters, as a way to cut water heating bills in half and eliminating the need for a dehumidifier there. Smart plumbers (and big box firms) with sales records are well-positioned for these augmenting sales.
    b. Marketing as an option for early replacements. Perhaps 1/3 of water heater sales are done before unit failure in the house.[85] Add-on HPWH are an option that may be competitive with integrated units. They also provide flexibility where ceiling height or other issues prevent installation of drop-in HPWH.
    c. Marketing as option in emergency replacement situations. Carrying an add-on HPWH in the truck takes much less space than carrying a second full tank on the truck. Indeed, many

[83] Federal Register /Vol. 66, No. 11 /Wednesday January 17, 2001 /Rules and Regulations, 4473–4497. EF= 0.97¥(0.00132 × Rated Storage Volume in gallons).
[84] http://www1.eere.energy.gov/buildings/appliance_standards/residential/waterheat_0300_r.html
[85] Mike Parker, A.O. Smith Co, personal communication based on firm’s market research.

variants are feasible, built around the proposition that buying it now saves the cost of a separate installation charge.

4) Historically, the field reliability of add-on heat pump water heaters has not met expectations. Many of these sales were supported (with rebates, contractor selection and training, and credibility) by utilities. They are unlikely to start a new generation of programs, even with ENERGY STAR certification, until they are convinced that the units will give the same trouble-free service as conventional resistance water heaters.
5) HPWH will require some understanding by owners and contractors to avoid poor installation choices, such as noisy HPWH near sleeping areas. There will be mistakes, and callbacks poison the well for contractors.
6) First cost premiums are always a barrier.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[86]
Average Price of Natural Gas	$11.52/MMBtu[87]
Projected 2025 End Use Electricity Consumption[88]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[89]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

1. ACEEE believes that the Energy Factor rating method can be adapted to use for add-on heat pump water heaters, in a way that is consistent with federal law and practice for other products. DOE should move to adopt regulations for the product class.
2. ENERGY STAR could include add-on heat pump waters in its program by the expedient of requiring certification of products, as is now done for one listed in the AHRI product directory. With the current ENERGY STAR specification

The ENERGY STAR listing is a key early step that has been accomplished for drop-in but not for add-on HPWH. In turn, ENERGY STAR listing may (but may not) hinge on acceptance of add-on HPWH as regulated products. Field study data are essential for establishing the actual operating cost differences between HPWH and conventional resistance units. Such data and case studies are required so manufacturers can justify marketing statements.[90] Field data are also essential as a basis for utility incentive programs to promote the products. In parallel, good, easy-to-use, well-calibrated, simulation programs that help professionals choose the most appropriate applications for HPWH are critical.

The 2015 US DOE standards for electric water heaters will require HPWH for all units > 55 gallons. Using this experience basis as it happens, the next step will be to incrementally move the market toward somewhat smaller units. Add-on products ought to benefit from increased visibility of HPWH in the marketplace as well.

Sample Price Data

Estimated price given as $570 at Amazon, but not in stock.[91]
Price given as $675 at Compact Appliance, but not in stock.[92]
ACEEE infers a market price of $600 in a more mature and competitive market.

[86] EIA. E*lectric Power Monthly—Feb 2011.* Residential Price.
[87] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[88] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[89] Ibid.
[90] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.
[91] http://www.consumersearch.com/water-heaters/airgenerate-airtap-a7, May 26, 2011
[92] http://www.compactappliance.com/AIRTAP-Air-Generate-Attachable-Water-Heater/AIRTAP,default,pd.html

Residential Condensing Gas Tankless Water

Definition	Residential gas tankless water heater with Energy Factor of 0.92 or greater					
Base Case	Gas storage water heater with Energy Factor of 0.59					
New Measure	High efficiency gas tankless water heater that condenses	Percent Savings	2025 Savings TBtu (Source)	Installed Cost	Cost of Saved Energy	Success Rating (1–5)
Current Market		36%	18	$2,896	$24.28/MMbtu	3
Mature Market		36%	18	$2,164	$17.26/MMbtu	3

Summary

Tankless water heaters promise greater efficiency and an endless supply of hot water—up to the limits of their firing rate. Market share of units at 0.82 EF is high enough that they are no longer considered an emerging technology. Condensing units are more sophisticated versions that use two separate heat exchangers (usually one copper and one stainless steel) to extract more usable heat from flue gases, increasing rated efficiencies to about 0.92 EF, and achieving efficiency gains of about 36% over conventional gas storage water heaters. As additional heat is removed from the combustion gases the water vapor cools and condenses. Our estimate of the likelihood of success is muted because of the high cost of saved energy relative to present natural gas prices, but these are historically volatile.

Market

Tankless water heater sales are growing quickly and annual shipments are forecast to top 1.6 million by 2025, or about 14% of the total water heating marker (DOE data). Even as overall water heater sales have slowed since 2004, sales of tankless units have increased at an average annual rate of 38%, reaching 380,000 in 2009, or 5% of the market (DOE Data). Currently, most tankless water heater manufacturers are based in Japan and Europe, and import their products to the U.S. (Oregon TWH study). Many leading American manufacturers now offer diverse tankless product lines including both condensing and noncondensing models, but these products are produced overseas and imported to the U.S. for sale.

Background & Description

The Department of Energy defines residential tankless water heaters as units with input of 50,000 to 200,000 Btu per hour and a rated storage volume of 2 gallons or less. In these units, a large gas burner heats water only when there is demand. As water is drawn through the unit, sensors determine the temperature of the incoming water and adjust the modulating burner to heat the water to the desired temperature accordingly. By substituting a large burner for a storage tank, tankless water heaters virtually eliminate standby losses.

All gas tankless units require a specified minimum water flow to avoid overheating even at minimum firing rate (typically around 0.5 to 0.75 GPM). When there is no or very low hot water demand, the unit shuts down immediately to avoid overheating, and always takes a few seconds with water flowing to restart. Combined, these characteristics result in a “cold water sandwich” when the water heater is used intermittently, as for rinsing dishes. However, the small size of tankless heaters allows them to be installed in compact spaces near primary water fixtures, provided there is adequate room for ventilation pipes, which can decrease water and energy waste.

Tankless water heaters perform very well in the federal test procedure, readily reaching efficiencies of 0.82 and higher for even non-condensing units[93]. The test procedure is based on 6 long draws and a long period in standby. Tankless units excel because they have virtually no standby losses (except for units with a standing pilot light) and perform well on long water draws. However, their performance decreases during short, intermittent draws that are common in the average home. There is little field data regarding field performance of both condensing and non-condensing tankless water heaters. Studies to date have suggested savings up to, and exceeding 36% for non-condensing tankless water heaters.[94] Savings can vary significantly depending on the assumed patterns of use.

Data Summary Table

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Residential	New or Retrofit		Water Heating	Natural Gas
Current Status	**Date of Commercialization**		**Product Life (years)**	**Source**
Commercialized	2008		20	DOE TSD
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.59	Energy Factor	Gas storage baseline	DOE TSD
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	24.8	MMBtu/year	0.59 EF Unit uses 254 therms	ENERGY STAR
New Measure Energy Use				
Efficiency	0.92	Energy Factor	Condensing baseline	DOE TSD
Electricity Use	80	kWh/year	Inducer fan and standby controls	
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	15.9	MMBtu/year	Calculated from baseline use	
Savings				
Electricity Savings	(80)	kWh/yr	Inducer, igniter, and controls in condensing unit	
Summer Peak Demand Savings	—			
Winter Peak Demand Savings	—			
Fuel Savings	8.9	MMBtu/year	Calculated from baseline and new measure use	
Net Fuel Savings	8.0	MMBtu/year	Difference of fuel savings and additional electric load (source)	
Percent Savings	36%			
Percent Feasible	6%		40% of the 14% projected market share for tankless water heaters in 2025	ACEEE estimate, DOE TSD
Costs				
Incremental Cost	$ 1816	2010 $	Difference between product and installation costs of baseline and new measure units	DOE TSD
Mature Market Incremental Cost	$1084	2010 $		

[93] Currently, the federal minimum efficiency standard for gas tankless water heaters is set at 0.62 EF. Effective April 15, 2015, the standard will increase to 0.82 EF. At present there are only a handful of units available in the U.S. that are below 0.82.

[94] http://www.state.mn.us/mn/externalDocs/Commerce/CARD_Natural_Gas_Tankless_Water_Heater_Study_100510053932_DomesticWaterHeatingReport.pdf, http://www.energy.ca.gov/title24/2008standards/prerulemaking/documents/2006-05-18_workshop/2006-05-11_GAS_WATER.PDF

Other Costs/ (Savings)	$ 85	$/year	DOE tankless maintenance average, TSD 8.6.1.4	
Ranking Metrics				
2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	18	TBtu		
Cost of Saved Energy	—	$/kWh		
Cost of Saved Energy	$ 24.28	$/MMBtu		
Mature Market Cost of Saved Energy	—	$/kWh		
Mature Market Cost of Saved Energy	$ 17.26	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Upfront cost of product and installation Installation restrictions	Reduced risk of running out of hot water Longer mechanical life		Commercialized	Field Testing Demonstrations Incentives
Likelihood of Success	3	(1–5)		
Priority	Med	Low, Med, High		
Data Quality Assessment	B	(A–D)		
Principal Contacts				
By Harvey Sachs, Jacob Talbot, ACEEE				

Current Status of Measure

In 2011, 71 models of condensing tankless water heaters from 17 different brands are available in the US marketplace. Many of these models are available for both natural gas and propane fuel. Total installed prices are in the range of $1,700 to $3,100.[95]

Savings Potential and Cost-Effectiveness

Tankless water heaters, both condensing and non-condensing, are significantly more expensive than traditional storage units. The average tankless unit costs around $1,100 for a 0.82 EF unit, not including installation, while condensing units can range from about $1,200 to $2,500, with an average price of around $1,900 (DOE TSD, Internet search).

Retrofit Installations of gas tankless water heaters can be very expensive because most units require a ¾" inlet gas line, while typical homes in the U.S. are plumbed with a ½" line. Basic installation for a power vented non-condensing tankless water heater is estimated at around $1,270, which includes an upgraded vent, additional water piping, installing an electrical outlet, as well as the physical installation of the new unit and removal of the old one. Installation costs for a natural draft unit with a standing pilot light are lower, but few units of this type are sold, and they will be too inefficient to sell when the 2015 efficiency standard[96] goes into effect. Condensing tankless installation also includes installation of a condensate drain or pump, but this additional expense is more than offset by constructing the ventilation system out of PVC pipe instead of the stainless steel required for non-condensing tankless water heaters. DOE estimates condensing tankless installation at around $960 (DOE TSD). Field studies have shown that contractor bids for retrofit installations of condensing tankless water heaters can reach $3,500 or more including the cost of the unit. In one study, installation bids alone ranged from $700 to $2,300, with an

[95] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_ch8.pdf
[96] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_correction.pdf

average of around $1,400.[97] We predict that installation costs will decline to around the level projected in the DOE TSD as contractors attain greater experience with tankless water heaters.

Incremental costs for tankless water heater installation in new construction are significantly lower than retrofit because homes can be plumbed with a ¾" gas line and the applicable vent system from the start. Adding a condensate drain and power outlet is also significantly less expensive when the work is incorporated into the original construction plan rather than added as a retrofit project.

ACEEE estimates that product and installation costs will decline by about a third as tankless heater market share increases. Mature market cost estimates are detailed in the following table:

	Current Market	**Mature Market**	**Notes, Explanation**
Purchase Price	$ 1,936	$ 1,300	All attributed to G&A and distribution with market growth
Installation Cost	$ 960	$ 864	Modest decline with contractor experience, competition
Total Cost	$ 2,896	$ 2,164	
Incremental Cost	$ 1,816	$ 1,084	

Market Barriers

Condensing tankless water heaters carry a substantial price premium. Combined with installation costs, a condensing tankless system can easily reach $3,000 or more. Because of the different amenity they provide, energy savings are uncertain. Installation requirements can serve as both a boon and a barrier: tankless units require less physical space, but require immediate access to the outdoors for proper venting.

Two national programs are currently in place to encourage adoption of tankless water heaters: ENERGY STAR and the Consortium for Energy Efficiency (CEE) tiers. ENERGY STAR certifies products that achieve at least a 0.82 rating from the federal test procedure. Virtually all tankless models on in the U.S. market meet this qualification due to incentives to manufacturers to bring qualifying products to market. The following table shows additional criteria for ENERGY STAR certification:

Whole-Home Gas Tankless	EF >= 0.82	GPM >= 2.5 over a 77°F rise	>= 10 years on heat exchanger and 5 years on parts

In 2008, CEE launched its water heating program in an effort to increase market share for high efficiency units and encouraging innovation by manufacturers. The CEE tiers are designed for use by energy efficiency program administrators as guidelines for incentives to consumers to purchase high efficiency equipment. The initiative features a three-tier rating method for storage water heaters and one tier for tankless water heaters, in addition to voluntary NOx emissions specifications. The current specification for tankless water heaters is in keeping with the ENERGY STAR criteria, at 0.82 EF.

CEE Criteria for Residential Gas Tankless Water Heaters

Tier	Tankless Water Heater >50,000 and <200,000 Btu/hr
0	EF >= 0.82 w/ (electric ignition)

[97] http://www.state.mn.us/mn/externalDocs/Commerce/CARD_Natural_Gas_Tankless_Water_Heater_Study_100510053932_DomesticWaterHeatingReport.pdf

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[98]
Average Price of Natural Gas	$11.52/MMBtu[99]
Projected 2025 End Use Electricity Consumption[100]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[101]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Field studies are needed to quantify energy savings and patterns of use. At present, it is unknown if, and how much switching from a storage to tankless water heater will alter water consumption. Manufacturers frequently highlight the “endlessness” of hot water provided by tankless water heaters, which may encourage additional consumption by homeowners. The effects of intermittent draws on energy consumption are also not fully understood.

[98] EIA. El*ectric Power Monthly—Feb 2011.* Residential Price.
[99] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[100] EIA 2009. “Annual Energy Outlook 2010,” Residential and Commercial Sector Key Indicators and Consumption Tables
[101] Ibid.

Solar Water Heater aka Solar Assisted Water Heater

Definition	Solar-assisted water heating system that uses solar energy to provide at least half of the water heating load with conventional electric or natural gas storage backup					
Base Case	Electric: conventional 50 gallon storage unit with EF of 0.90 Natural gas: conventional 40 gallon storage unit with EF of 0.59					
New Measure	Complete solar-assisted water heating system (freeze protected or not) with SF of at least 0.5. Includes collectors, pumps, and controllers.	Percent Savings	2025 Savings	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market (Electric Base System)		50%	195 GWh	$ 4,250	$0.17/kWh	3
Current Market (Natural Gas Base System)		50%	243 TBtu	$ 4,250	$33.66/ MMbtu	2
Mature Market (Electric Base System)		50%	195 GWh	$ 3,500	$0.14/kWh	3
Mature Market (Natural Gas Base System)		50%	243 TBtu	$ 3,500	$27.72/ MMbtu	2

Summary

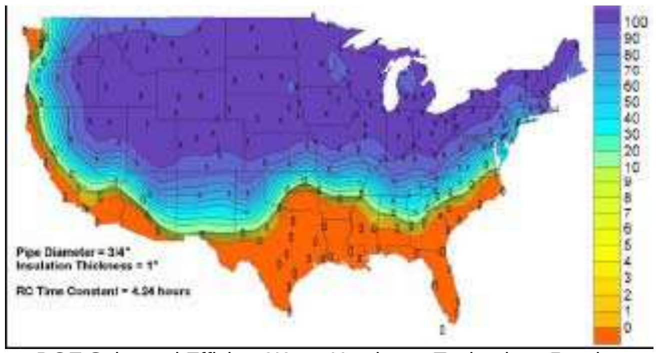
This analysis is an update of the 2006 Solar Water Heater study found on the ACEEE Web site at: http://aceee.org/files/pdf/2006_SolarWH.pdf

Solar assisted heaters (SWHs) have been on the market for decades but have never achieved significant market share. High equipment and installation costs, reliability concerns, and lack of consumer awareness have prohibited most homeowners from investing in the systems, while low energy prices prevent investments from being cost effective. Yet properly sized solar-assisted water heaters can provide at least 50% of the annual water heating load in most climates across the country, saving significant amounts of energy nationwide. SWHs can integrate with both electric and natural gas water heaters, in storage, tankless, and hybrid configurations.

Background & Description

In general, SWH systems are mounted on a south-facing roof, or adjacent to the house at ground level. In either case, it is generally remote from the back-up and supplementary storage water heater and its tank. This distance, or the amount of finished space the loop must traverse in a retrofit installation, impacts the method and cost of installation, and operating efficiency. The most fundamental distinction is between systems that must resist freezing (closed-loop systems), and those located in “sun belt” (see the figure on next page) climates with very rare freezing severe enough to threaten the system (open-loop systems). Because closed-loop systems require either drain-back provisions or a separate freeze-protected loop to indirectly heat water in the storage tank, they generally have active components (pumps) and are more complex. In addition to system configuration, a number of collector technologies are used in existing systems, including flat plate collectors, several types of evacuated-tube collectors, integral, and batch collectors (FSEC undated).

Probability of at Least One Pipe Freeze in 20 Years
(assuming house is always occupied)



Source: DOE Solar and Efficient Water Heating, a Technology Roadmap, 2005

There are times when prolonged periods of cloudiness will prevent the solar collectors from receiving adequate sunlight to provide hot water. For this reason, SWH systems nearly always include a backup water heater. Our analysis assumes that the consumer will keep their minimum efficiency water heater in use, although they may opt to upgrade the water heater when installing a solar water heating system. Replacing a conventional storage water heater with an electric point-of-use backup water heater, for example, might realize greater savings.

SWH efficiency is generally described by solar energy factor (SEF) or solar fraction (SF). SEF, a rating method devised by the Solar Rating and Certification Corporation (SRCC), uses a modified version of the federal test procedure and is designed to compare the efficiency of a conventional water heater to a complete solar water heating system. SEF is the ratio of energy delivered by the solar system to the electricity or natural gas input from the backup heater plus “parasitic” losses such as those devoted to running the circulation pump. SEFs generally range from about 1–20.

$$SEF = \frac{Q_{DEL}}{Q_{AUX} + Q_{PAR}}$$

Where:

QDEL = Energy delivered to the hot water load: Using the SRCC rating conditions, this value is 43,302 kJ/day (41,045 Btu/day).

QAUX = Daily amount of energy used by the auxiliary water heater or backup element with a solar system operating, kJ/day (Btu/day).

QPAR = Parasitic energy: Daily amounts of AC electrical energy used to power pumps, controllers, shutters, trackers, or any other item needed to operate the SDHW system, kJ/day (Btu/day).

In contrast, SF describes the portion of the total water heating load provided by the SWH system and is calculated by subtracting from one the ratio of the rated EF of the backup water heating system to the SEF of the solar system. SFs generally range from 0.5–0.75[102]

$$SF = 1 - \frac{EF}{SEF}$$

The ENERGY STAR criteria for solar water heaters require a minimum SF of 0.5 for inclusion in the program. ENERGY STAR normalizes SF in its listings by using the federal minimum efficiency for both

[102] http://solar-rating.org/facts/system_ratings.html

gas and electric water heaters: 0.59 EF for natural gas backup and 0.90 for electric. Our analysis also uses these efficiencies as a baseline, thus for our purposes, solar fraction is a reasonable approximation of percent savings from a SWH system. ENERGY STAR also mandates a minimum factory warranty of 10 years on the solar collector, 6 years on the storage tank, 2 years on the controls, and 1 year on piping and parts.[103]

Data Summary Tables

Market Sector	Market Application		End Use	Fuel Type
Residential	New or Retrofit		Water Heating	***ELECTRICITY***
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized	1975		14	DOE (2001)
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.90	EF	Federal minimum	
Electricity Use	4,878	kWh/year		
Summer Peak Demand	1.1	kW	3 hottest month avg., coincident	New England PowerService 87, A-2
Winter Peak Demand	1.7	kW	3 coldest month avg., coincident	New England PowerService 87, A-2
Fuel Use	—	MMBtu/year		
New Measure Energy Use				
Efficiency	0.5	SF	ENERGY STAR minimum	
Electricity Use	2,439	kWh/year		
Summer Peak Demand	0.1	kW	80 W for pump	
Winter Peak Demand	1.7	kW	Assume backup water heater needed	
Fuel Use	—	MMBtu/year		
Savings				
Electricity Savings	2,439	kWh/year		
Summer Peak Demand Savings	1.0	kW	Solar meeting nearly 100% of demand, 80W deduction for pump	
Winter Peak Demand Savings	0	kW		
Fuel Savings	—	MMBtu/year		
Percent Savings	50%			
Percent Feasible	24%		ACEEE estimates technology applies to 80% of single-family and 2–4-unit multifamily households in all U.S. climate zones (78% of residential construction)	EIA 2003
Industrial Savings > 25%?	No			
Costs				
Current Incremental Cost	$ 4,250	2010 $	Average of 2006 survey of SWH cost and CSI installed costs, minus baseline	
Mature Incremental Cost	$ 3,500	2010 $		
Other Costs/ (Savings)	—	$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	18,493	GWh		
2025 Savings Potential (Source)	—	TBtu		
Current Cost of Saved Energy	$ 0.17	$/kWh		

[103] http://www.ENERGY STAR.gov/index.cfm?c=water_heat.pr_crit_water_heaters

Current Cost of Saved Energy	—	$/MMBtu		
Mature Cost of Saved Energy	$ 0.14	$/kWh		
Mature Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Permitting & Inspections Consumer awareness and confidence	In favorable weather, hot water without use of fossil fuels		Commercialized Limited incentive programs ENERGY STAR	Field Testing Standards and Codes Incentives
Likelihood of Success	3	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
By: Harvey Sachs and Jacob Talbot, ACEEE				

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Residential	New or Retrofit		Water Heating	***NATURAL GAS***
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized	1975		14	DOE (2001)
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.59	EF	Federal minimum	
Electricity Use	—	kWh/year		
Summer Peak Demand	—	kW		
Winter Peak Demand	—	kW		
Fuel Use	24.8	MMBtu/year		
New Measure Energy Use				
Efficiency	0.50	SF	ENERGY STAR minimum	
Electricity Use	—	kWh/year		
Summer Peak Demand	—			
Winter Peak Demand	—	kW		
Fuel Use	12.4	MMBtu/year		
Savings				
Electricity Savings	—	kWh/year		
Summer Peak Demand Savings	—	kW		
Winter Peak Demand Savings	—	kW		
Fuel Savings	12.4	MMBtu/year		
Percent Savings	50%			
Percent Feasible	24%		ACEEE estimates technology applies to 80% of single-family and 2–4-unit multifamily households in all U.S. climate zones (78% of residential construction)	EIA 2003
Industrial Savings > 25%?	No			

Costs				
Current Incremental Cost	$ 4,250	2010 $	Average of 2006 survey of SWH cost and CSI installed costs, minus baseline	
Mature Incremental Cost	$ 3,500	2010 $		
Other Costs/ (Savings)		$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	243	TBtu		
Current Cost of Saved Energy	—	$/kWh		
Current Cost of Saved Energy	$ 33.66	$/MMBtu		
Mature Cost of Saved Energy	—	$/kWh		
Mature Cost of Saved Energy	$ 27.72	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Permitting & Inspections	In favorable weather, hot water without use of fossil fuels		Commercialized	Field Testing
Consumer awareness and confidence			Limited incentive programs	Standards and Codes
			ENERGY STAR	Incentives
Likelihood of Success	2	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
By: Harvey Sachs and Jacob Talbot, ACEEE				

Current Status of Measure

The most recent data available (from 2005) suggests that the market for SWH systems, excluding pool heating, is in the range of 6,000 units/year, with more than half of these sales in Hawaii.[104] Actual sales, thanks predominantly to increased market share in California, may be higher today. This number compares with sales of about 380,000 for tankless water heaters, and about 7,500,000 conventional gas and electric storage water heaters in 2009.[105]

DOE does not currently regulate the efficiency of solar water heaters. In its 2010 Final Rule on energy conservation standards for water heaters and pool heaters, DOE explains the rationale as "because EPCA currently covers only water heaters and pool heaters that use electricity or fossil fuels, and because any energy conservation standard currently adopted under EPCA for these two products must address or be based on the quantity of these fuels, but not solar power, that the product consumes."[106]

In general, SHW systems have not been a priority for many organizations seeking to promote energy conservation. Groups that have been more active in promoting, testing, and/or certifying solar water heating technologies include the Florida Solar Energy Center (FSEC) and the SRCC. ASHRAE also provides a Method of Test.[107]

[104] U.S. Department of Energy, *Solar and Efficient Water Heating, a Technology Roadmap.* Developed by representatives of the water heating industry
[105] TSD spreadsheet
[106] http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/htgp_finalrule_fedreg.pdf
[107] ASHRAE, *Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems*

SWH technology is relatively simple and the materials and manufacturing involved are well-understood. Historically, market penetration and promotional activity have depended primarily on financial incentives that lower the upfront cost to consumers. The federal Energy Policy Act of 2005 established a substantial federal tax credit of 30% of the cost of a new system up to $2,000. This credit has been extended through 2016 and no longer features an upper limit on the incentive. Additionally, a number of utilities and municipalities offer incentives for solar water heating systems, and the California Tax Code provides an exemption of "solar property" installation from property tax increases. Without this exclusion, capital-intensive solar systems would suffer an additional property tax burden.

Savings Potential and Cost-Effectiveness

Fairey[108] noted that a well-designed solar water heating system is likely to save about 2,000 kwh/yr almost anywhere in the United States. This is somewhat counterintuitive. Although there is more solar radiation in the South, it has more value in the North, where the temperature of the incoming water is much lower, so the required temperature "lift" is much higher.

System cost varies more widely. Main cost drivers for whole-system installations include open vs. closed loop (explained above) and new construction vs. retrofit, equipment costs, and economies of scale, explained below. When varying our analysis by installed cost based on California Solar Initiative data and conservative assumptions for price reductions with increased market share, we find costs of saved energy in the range of 14–17¢/kWh for an electric base system and $27.72 to $33.66/MMBtu for a natural gas base system. Stated cost reduction goals for 2020 from the DOE Water Heating Roadmap[109] fall on the low end of this range based on ACEEE analysis (see following table).

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 1,750	$ 1,500	Economies of scale
Installation Cost	$ 2,500	$ 2,000	
Total Cost	$ 4,250	$ 3,500	Based on CSI installation and contractor survey, with $1,000 buffer for installation variations
Incremental Cost	$ 4,250	$ 3,500	

New construction vs. retrofit. In theory, installing a solar water heater at time of construction can be much less expensive than retrofitting because wall finishes don't have to be disturbed to run piping and wiring. Nonetheless, in practice the costs are often comparable. In certain parts of the country, manufacturers quoted similar pricing for new construction due to multiple visits during the construction phase. According to FSEC,[110] common trade practices raise the cost of new installations.

Equipment costs. System costs today are high and vary depending primarily on size. (Our analysis averages cost estimates for 4-person and 6-person household installations, as well as average costs for CSI projects.) Compared to size increases, freeze-protection does not incur significant incremental costs.

Economies of scale. DOE suggested that designs for larger-scale manufacturing can help reduce prices by 25–50%, with cost of saved energy targets of 4–6¢/kWh for open or passive systems (25–50% cost reduction), and 6¢/kWh for active or closed systems.[111] Certainly, for collector technologies such as vacuum panel and polymer collectors, very large cost reductions should be anticipated with large-scale production, which will reduce average installed system prices. Muller and Sachs[112] argued by analogy that a solar water heating system, without the back-up water heater, should cost no more than a

[108] Fairey, Philip (Florida Solar Energy Center), personal communication with Harvey Sachs, 2007

[109] U.S. Department of Energy, *Solar and Efficient Water Heating, a Technology Roadmap.* Developed by representatives of the water heating industry

[110] Kettles, C. (Florida Solar Energy Research and Education Foundation), Personal communication with Harvey Sachs, 2007

[111] U.S. Department of Energy, *Solar and Efficient Water Heating, a Technology Roadmap.* Developed by representatives of the water heating industry

[112] Muller, F. and H. Sachs, *Renewable Energy and Pollution Prevention in Southern California: A Report for the South Coast Air Quality Management District.*

refrigerator in mass production: The product mass is similar, and if anything the product complexity is greater for the refrigerator. The biggest difference (in a mass production environment) is that the labor component for installation is much higher for the solar water heating system.

Market Barriers

SWH systems by nature are generally visible to the community, whether ground- or roof-mounted. In some cases, community associations or jurisdictions have attempted to limit or prohibit both solar thermal and photovoltaic systems mounted where they may be visible. To balance aesthetic and energy concerns, California Civil Code 714 prescribes and limits allowable prescriptions. It includes the concept and definition of a “solar easement” (Section 801.5): that is, the conditions under which a property owner can have access to sunlight without blockage by neighbors. Regulations regarding permitting and inspections in some states add an additional barrier and cost to installations. These regulations can apply to both SWH and solar photovoltaic systems.[113] Additionally, home builders rarely consider optimal home orientation for SWH and PV systems during construction.

Other barriers to solar water systems are common to other emerging technologies: awareness; high purchase prices; historical reliability problems (real and perceived); and very rare support from incentive programs.[114] In addition, solar water heaters bring the unique limitation that it is hard to actually measure the avoided purchased energy, that is, the contribution of the solar heater itself.

Key Assumptions Used in Analysis

Our cost estimates are based on total system installation costs reported through the California Solar Initiative (with a $2,000 buffer for system variance), and inferences drawn from the *DOE Technology Roadmap*. We assume 17% system price reductions for 2020 due to increased contractor experience and economies of scale.

Average Price of Electricity	$0.1158/kWh[115]
Average Price of Natural Gas	$11.52/MMBtu[116]
Projected 2025 End Use Electricity Consumption[117]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[118]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

ACEEE recommends that utilities and public benefit programs immediately start activities to increase the understanding of the potential of these technologies. In particular, we recommend undertaking well-structured field demonstrations to develop case studies for climate-appropriate systems. This is probably the best way to generate actual data and provide structured feedback to manufacturers on installation and performance questions.

We strongly recommend that the ENERGY STAR New Homes program, and all other utility and public benefit programs, require rough-in piping (and wiring) for participation. This will move the task from the solar contractor to the construction plumber, greatly reducing costs. It will also establish a class of identifiable houses for early marketing of solar water heaters. We encourage states and municipalities to look toward including these measures in their building codes as well.

[113] Itron, *California Center for Sustainable Energy Solar Water Heating Pilot Program: Final Evaluation Report*
[114] Id.
[115] EIA. El*ectric Power Monthly—Feb 2011.* Residential Price.
[116] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[117] EIA 2009. “Annual Energy Outlook 2010,” Residential and Commercial Sector Key Indicators and Consumption Tables
[118] Id.

Serious market transformation, whether led by tax credits or other incentives, will require sustained programs, perhaps for as long as a decade. In addition to current types of incentives and credits, it may be worth considering mass procurement—for example, for government housing and housing subsidized or guaranteed by federal funds (such as FHA loans). The goal would be to combine several elements: multi-year bids, for a minimum of 5–7 years; substantial annual increases in number procured (perhaps 20%); annual *decreases* in cost per unit, at a smaller rate; and performance guarantees. This can lead to cost-effectiveness for sponsors, and enables industry to finance expansion to mass production on the strength of the procurement contracts.

Solar water heaters can be rated three ways: by the performance of the collector (SRCC OG-100; RM-1) and by performance of the complete water heating system (SRCC OG-300), and solar fraction. ACEEE recommends that incentive programs focus on system standards, requiring OG-300, and also require certified collectors.

Condensing Gas "Hybrid:" Smaller Tank, Large Burner

Definition	Hybrid Condensing Gas Water Heater, characterized by large burner & small tank					
Base Case	40 gal. Gas Tank WH, EF= 0.595 (NAECA minimum)					
New Measure	Advanced condensing, tank-tankless hybrid, with similar installation to tank water heater, except uses PVC (plastic) vent instead of stainless steel. Large models will require ¾" gas service	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		30%	63	$2,257	$16.09 /MMBtu	4
Mature Market		30%	63	$1,706	$8.55 /MMBtu	4

Summary

0.70 is about the maximum Energy Factor (EF) expected for atmospheric- and power-vented center-flue gas water heaters, which are ubiquitous and the least expensive gas water heaters available. Hybrid condensing gas water heaters attempt to capture the advantages of both advanced tankless and tank-type water heaters. Condensing improves thermal efficiency, and modest tank size minimizes standby losses. The tank also eliminates two leading disadvantages of conventional tankless designs: the infamous "cold water sandwich" when using hot water intermittently, and delays in hot water delivery time due to time required to activate and warm the heat exchanger. Finally, a relatively large burner promises "endless hot water" as long as the demand is moderate. This write-up focuses on premium units with condensing gas "engines;" we treat non-condensing designs separately. Units rated residential would be expected to have EF ~0.80 or higher; units rated with thermal efficiency as commercial products would have efficiency ≥ 0.90.

Background & Description

Tank water heaters have dominated North American residential practice for at least half a century, and the federal rating method was developed primarily to compare these units with each other.[119] Gas water heaters comprise about half of all units shipped.[120] Almost all gas water heaters are atmospheric-vented tank-type units with EF ≤ 0.67.[121] During the past decade, tankless water heaters have gradually penetrated the market, reaching 5% of the market in 2009.[122]

Typical Values:	tank	tankless	hybrid
Energy Factor, EF	≤ 0.67	0.82	No rating method
Storage Volume	40 gal	< 2 gal	2–30 gal
Fuel Input Rate	40,000 Btu/h	150,000–199,000 Btu/h	100,000 Btu/h

Tank water heaters are less efficient than tankless, but test method limitations suggest that the discrepancy is much less than indicated by the difference between ratings. Because the gas input rate

[119] Title 10 of the Code of Federal Regulations (CFR) part 430, subpart B, appendices E. Cited in *Federal Register* / Vol. 75, No. 73 / Friday, April 16, 2010, pp. 20112 - 20236

[120] For example, http://www.ahrinet.org/App_Content/files/Statistics/Monthly%20Shipments/Dec%2010%20Stat%20Release%20-%20FINAL.pdf

[121] "Power-vent" tank water heaters are basically center-flue atmospheric units, an inducer fan added. The blower assembly also introduces large amounts of room air to cool the flue gases and allow sidewall venting through PVC pipe. Tank power vents solve difficult venting situations rather improving efficiency.

[122] DOE TSD, "Water Heater National Impacts Analysis Spreadsheet" http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_spreadsheets.html

and first hour rating are relatively low, users fear that tank units will exhaust their capacity, perhaps in the middle of the second or third near simultaneous shower. Tankless units have their own challenges in large US houses: retrofitting the special vents and large capacity gas lines can be very expensive. In addition, whenever the hot water draw rate drops below a threshold, typically 0.5 to 0.75 gpm, the unit turns off, so only cold water flows. Similarly, start-up requires a "reboot" after water flow starts, inserting a "slug" of cold water into the line.

This discussion focuses on condensing gas units, for two reasons. First, they are truly emerging, with relatively few products on the market today. Second, they are significantly more efficient than non-condensing products. Finally, because they are more efficient, the flue gases are cool enough to exhaust through rated plastic pipe, generally to a sidewall. This is typically the least expensive venting option feasible, for both retrofit and new construction. Like all condensing (and almost all tankless) water heaters, hybrids require a 120v electrical connection.

Hybrid gas water heaters use various approaches to combine the best features of both design classes:[123]

- The *Eternal Hybrid Condensing water heater* is essentially a tankless water heater with a small buffer tank, but many options including recirculation[124].[125] Two *Eternal* condensing models are ENERGY STAR rated, both with 31,000 Btu/hr low-fire rate. One has 145,000 Btu/h maximum (about 4 gpm rated maximum at 77°F lift), and the other is rated at 199,000 Btu/r (about 5 gpm). The units look much like a conventional tankless unit and can be wall-hung.
- The A.O. Smith *Next Gas Hybrid* combines a 100,000 Btu/h tankless water heater "engine" and a secondary (condensing) heat exchanger with a 25 gallon storage tank.[126] This gives a very high first hour capacity, and conventional installation. The AO Smith product has roughly the size of a residential washing machine or clothes dryer.[127] Because its storage volume and burner capacity are greater than 2 gallons and 75,000 Btu/hr, it does not get a residential "EF" rating, but is rated as a commercial water heater, at 90% thermal efficiency. However, the 100,000 Btu/h gas input can usually be served by ½" natural gas pipe, rather than requiring a ¾" service for most tankless water heaters.

Data Summary Table

Market Sector		Market Application	End Use	Fuel Type
Residential and Commercial		New or Retrofit	Water Heating	Natural Gas
Current Status		**Date of Com**	**Product Life (years)**	**Source**
Commercialized		2009	16.5	DOE TSD (Avg. of tank and tankless)
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.59	EF	Federal minimum for 40 gallon tank	
Electricity Use	—	kWh/year		
Summer Peak Demand	—	kW		
Winter Peak Demand	—	kW		
Fuel Use	24.8	MMBtu/year	Calculated from DOE TSD Table 7.2.13	
New Measure Energy Use				
Efficiency	0.85	EF	Estimated, as midpoint between condensing tank and tankless	
Electricity Use	102	kWh/year	Estimated 150 W x 400 hr/yr+ 5W standby	

[123] Web search February 21, 2011, found no other comparable condensing hybrid products.
[124] http://eternalwaterheater.com/products.html.
[125] http://www.ENERGY STAR.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WH
[126] Installation and Operating Manual, HYBRID GAS WATER HEATERS. 0610 316888-000 Rev. 00. Downloaded from http://www.hotwater.com/Water-Heaters/Residential/Hybrid/NEXT-Hybrid-Gas/, February 21, 2011.
[127] Also available in the State, Reliance, and American brands. And perhaps others, as well.

Summer Peak Demand	30	W	Estimated from 150 W fan & igniter, 5% duty cycle, peak hr. 4x average	
Winter Peak Demand	30	W	Estimated from 150 W fan & igniter, 5% duty cycle, peak hr. 4x average	
Fuel Use	17.3	MMBtu/year	Estimate based on EF ratio, top quartile of users	
Savings				
Electricity Savings	(102)	kWh/year		
Summer Peak Demand Savings	—	kW		
Winter Peak Demand Savings	—	kW		
Fuel Savings	7.5	MMBtu/year		
Net Savings	6.4			
Percent Savings	30%			
Percent Feasible	25%		Gas is half of WH market, assume ½ of that.	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 1,178	2010 $	Cost differential between baseline equipment and installation costs and condensing tankless costs	
Mature Market Incremental Cost	$ 626	2010 $		
Other Costs/ (Savings)	—	$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	63	TBtu		
Cost of Saved Energy	—	$/kWh		
Cost of Saved Energy	$ 16.09	$/MMBtu		
Mature Market Cost of Saved Energy	N/A	$/kWh		
Mature Market Cost of Saved Energy	$ 8.55	$/MMBtu		

Unusual Market Barriers	**Non-Energy Benefits**	**Current Activity**	**Next Steps**
Novelty: neither consumers nor contractors know the product	No delay in startup or cold water sandwich" associated with tankless	Commercialized	Research and Development Incentives Standards and Codes

Likelihood of Success	4	(1–5)
Priority	Med	Low, Med, High
Data Quality Assessment	C	(A–D)
Principal Contacts		
By Harvey Sachs		

Current Status of Measure

Few non-condensing hybrid products are marketed today. *Eternal* offers four two capacities of high-end indoor condensing *Eternal Hybrid* models, with modulating burner peak capacities of 145,000 and

199,000 Btu/h.[128] These are rated EF 0.96. The Eternal models use an integrated burner and tank design. All have a two-pass fire-tube construction, and are rated for sealed combustion direct vent with suitable plastic pipe. Since they use outdoor air for combustion (and are wall-mounted), there should be no flammable vapor concerns. Prices for the Eternal units range from around $1,600 for the 145,000 Btu/hr model to $1,800 for the 199,000 Btu/hr model.[129] We find no other non-condensing hybrid gas water heaters on the US market today.

AO Smith offers the “Next” hybrid, with a retail price of around $2,000.[130] The status of other products under development is not known.

Savings Potential and Cost-Effectiveness

ACEEE assumes that the condensing hybrid can cost no more than the condensing tankless with which it will compete in the marketplace. This implies an installed price of about $2260, corresponding to future competitive product pricing.[131] Relative to the estimated cost of a tank water heater plus a condensing tankless water heater, there are some cost savings: The hybrid unit can use a smaller, simpler, non-condensing tankless burner (such as a non-modulating 100,000 Btu/hr) than a condensing 199,000 Btu/hr modulating tankless product), which partly offsets the cost of the tank and relatively simple secondary heat exchanger.

Our comparison case is a consumer in the upper quartile of all households, one using 60 gallons per day (gpd) instead of the median 40 gpd.[132] For such a consumer, the baseline model would use 250 5 MMBtu/yr, and the condensing hybrid only 17.3 MMBtu/yr—a 30% savings. On the other hand, the condensing hybrid would use an estimated 102 kWh/yr in power for the igniter, inducer, and standby power.

ACEEE estimates the cost of saved energy for the condensing hybrid water heater as 16.09 $/MMBtu, including the penalty for electricity use. Under present natural gas prices, this product category is not yet cost effective, although the improved amenities that the buffer tank offers over conventional tankless units will attract some consumers. In a mature market, ACEEE estimates that both product and installation costs will decline from current levels. Complete mature market cost estimates are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 1,361	$ 900	Reasonable for non-modulating tankless+tank combo
Installation Cost	$ 896	$ 806	No gas line change, just ventilation. Reduction from experience.
Total Cost	$ 2,257	$ 1,706	
Incremental Cost	$ 1,178	$ 626	

Market Barriers

The tank/tankless condensing hybrid is one of several alternative, high-performance combustion-based water heating technologies competing for consumer dollars in the marketplace. Others include non-condensing hybrids, and both non-condensing and condensing tankless approaches. ACEEE projects that this competition will play out as a more differentiated marketplace, with more consumer options.

The premium water heater market seems to have two key characteristics:

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128 http://eternalwaterheater.com/index.html.
129 http://shop.buyplumbingnow.com/searchquick-submit.sc?keywords=eternal
130 http://www.pexsupply.com/AO-Smith-HYB-90N-100000-BTU-NEXT-Hybrid-Residential-Gas-Water-Heater
131 DOE Water Heater, Direct Heating Products and Pool Heaters TSD, 2009 Table 8.2.15
132 The rating method assumes about 66 gpd, which is well understood to be considerably more than actual average usage. See TSD chapter 7, Energy Use.

- It is certainly less than about 30% of the market, since the fraction of emergency replacements on burn-out is roughly 2/3.[133]
- This implies that the actual decision is made, or strongly influenced, by the plumber or other contractor, in response to a failed water heater incident.

Thus, the major task for product marketers is to convince plumbers that advanced products are low risk and more profitable than installing commodity products. In turn, "risk" is associated with two factors: losing sales to lower price quotes, and call-backs if the new, less familiar product, fails or simply does not meet expectations. ENERGY STAR and utility/public benefits incentives can reduce risk and raise awareness, but it is likely that initial penetration levels will be modest. And, this would be true even without the substantial first cost premium (estimated at $1300 over a baseline 0.59 EF non-condensing, atmospheric, tank or storage water heater). Indeed, with savings <$100/yr, the payback period is about equal to the expected product life, so these water heaters will principally be purchased for non-energy benefits or amenity value.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[134]
Average Price of Natural Gas	$11.52/MMBtu[135]
Projected 2025 End Use Electricity Consumption[136]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[137]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Field study data are essential for establishing the actual operating cost differences of advanced water heaters. Such data and case studies are required so manufacturers can justify marketing statements.[138] Field data are also essential as a basis for utility incentive programs to promote the products

Rating method changes based on these findings are desirable, but likely to take many years to work their way through ASHRAE, AHRI, and DOE processes.

These steps may pave the way for increased sales that will help the products move down the cost curve, to become more cost-effective than traditional products.

[133] Even during times when the new construction market is booming, the ratio of replacement to new construction water heater sales is about 4:1, and the replacement market is dominated by emergency installations.
[134] EIA. El*ectric Power Monthly—Feb 2011.* Residential Price.
[135] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[136] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[137] Ibid.
[138] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.

Non-Condensing Gas "Hybrid:" Small Tank, Large Burner

Definition	Hybrid **non**-condensing Gas Water Heater, characterized by large burner, small tank, and installation similar to atmospheric gas tank water heater. Analysis for top 25% users (60 gpd hot water)					
Base Case	40 gal. Gas Tank WH, EF= 0.595 (until 2015)					
New Measure	Moderate to small tank-tankless hybrid, **non**-condensing, fits in footprint of 40 gal. tank WH, with same installation as smaller tankless (<100,000 Btu/h)	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		20%	14	$1,981	$37.51 /MMBtu	2
Mature Market		20%	14	$1,795	$33.08 /MMBtu	2

Summary

0.70 is about the maximum Energy Factor (EF) expected for atmospheric- and power-vented center-flue gas water heaters, which are ubiquitous and the least expensive gas water heaters available. Most tankless and condensing tank water heaters would be expected to be in the range of 0.82, but cost about twice as much, installed. Hybrid non-condensing hybrid gas water heaters could offer a significant increase in efficiency. Although this emerging product class is still being defined, two approaches are visible. One uses an integrated fire-tube mini-tank with multiple flues, and is on the market today. The other, in development, combines a smaller, single stage tankless burner integrated via a heat exchange loop with a downsized, storage only tank without center flue. Both approaches promise "endless hot water" as long as demand is moderate. Both also eliminate two disadvantages of conventional tankless designs: the infamous "cold water sandwich" when using hot water intermittently and water wastage, due to minimum draws and transient startup effects of burner operation. This write-up focuses on units with non-condensing tankless gas "engines;" we treat condensing designs separately. Based on current product and installation prices, the cost of saved energy (>$37/MMBtu) is about three times the average residential gas price in 2011, suggesting that lower incremental costs and/or higher gas prices are required for acceptable economics.[139] Instead, this unit is likely to be marketed as a great compromise that offers almost the entire amenity of the tankless water heater without its exorbitant retrofit installation price.

Background & Description

Tank water heaters dominated North American residential practice for at least half a century, and the federal rating method was developed primarily to compare these units with each other.[140] Gas water heaters comprise about half of all units shipped.[141] Almost all gas water heaters are atmospheric-vented, center-flue, tank-type units with EF $\leq$ 0.67. During the past decade, tankless water heaters have gradually penetrated the market, reaching 7% of the market in 2007.[142]

[139] The estimated annual gas savings are ~$50/yr, but this is offset by ~$10/yr in electricity use and DOE's estimate of $85 in annual maintenance costs for tankless units in general.
[140] Title 10 of the Code of Federal Regulations (CFR) part 430, subpart B, appendices E. Cited in *Federal Register* / Vol. 75, No. 73 / Friday, April 16, 2010, pp. 20112 - 20236
[141] For example, http://www.ahrinet.org/App_Content/files/Statistics/Monthly%20Shipments/Dec%2010%20Stat%20Release%20-%20FINAL.pdf
[142] DOE TSD, Chapter 3, Table 3.2.17

Typical Values:	tank	tankless	hybrid
Energy Factor, EF	≤ 0.67	0.82	No current rating method, but expected 0.70 to 0.75 for lower cost units, if EF test applied.
Storage Volume	40 gal	< 2 gal	2–30 gal
Fuel Input Rate	~40,000 Btu/h	150,000–199,000 Btu/h	<100,000 Btu/h

Tank water heaters are less efficient than tankless, but the limitations of the test method suggest that the discrepancy is less than indicated by relative value of their ratings. Because the gas input rate and first hour rating are relatively low, users fear that tank units will exhaust their capacity, perhaps in the middle of the second or third nearly simultaneous shower. Tankless units have their own challenges in large US houses: retrofitting the special vents and large capacity gas lines can be very expensive. In addition, any time the hot water draw rate drops below a threshold, typically 0.5 to 0.75 gpm, the unit turns off, so only cold water flows. Start-up requires a “reboot” after water flow starts, inserting a “slug” of cold water into the line.

We confine this discussion to non-condensing gas units. Condensing hybrids are treated separately. Clearly, such a non-condensing product would eliminate the perceived disadvantages of both tank and tankless units, by providing somewhat greater efficiency, some continuous operation capability, and relatively low cost to buy and install. The analysis in our *Data Summary Table* is based on a relatively low price unit designed to have installed price and efficiency both roughly half-way between ENERGY STAR tank (0.67) and tankless (0.82) water heaters.

Data Summary Table

Market Sector	**Market Application**	**End Use**	**Fuel Type**
Residential	New or Retrofit	Water Heating	Natural Gas
Current Status	**Date of Com**	**Product Life (years)**	**Source**
Prototype	2011	16.5	DOE TSD

Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.6	EF	40 gal. NAECA minimum	
Electricity Use	—	kWh/year	No electricity supply, standing pilot	
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	24.8	MMBtu/year	DOE TSD	
New Measure Energy Use				
Efficiency	0.75	EF	Assumed intermediate between top Atmospheric (~0.7) and condensing (~0.8)	
Electricity Use	102	kWh/year	est. 150 W x 400 hr/yr+ 5W standby	
Summer Peak Demand	30	W	Estimated from 150 W fan & igniter, 5% duty cycle, peak hr. 4x average	
Winter Peak Demand	30	W	Estimated from 150 W fan & igniter, 5% duty cycle, peak hr. 4x average	
Fuel Use	20.0	MMBtu/year		
Savings				
Electricity Savings	(102)	kWh/year		
Summer Peak Demand Savings	(30)	W		
Winter Peak Demand Savings	(30)	W		

Fuel Savings	4.7	MMBtu/year		
Net Energy Savings	3.7	MMBtu/year		
Percent Savings	20%			
Percent Feasible	10%		Top quartile of half the market (gas water heaters are about 50% of sales)	Cost not justified for low use applications
Industrial Savings > 25%?	No			
Costs				
Current Incremental Cost	$ 901	2010 $	Interpolation from data in TSD Table 8.2.12	
Mature Incremental Cost	$ 715	2010 $		
Other Costs/ (Savings)	$ 85	$/ year	DOE tankless maintenance average, TSD 8.6.1.4	
Ranking Metrics				
2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	14	TBtu		
Cost of Saved Energy	—	$/kWh		
Cost of Saved Energy	$ 37.51	$/MMBtu		
2025 Mature Cost of Saved Energy	—	$/kWh		
2025 Mature Cost of Saved Energy	$ 33.08	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Limited market, will be hard to keep price down to level commensurate with efficiency gains	Reduced risk of running out of hot water No cold water "slug"		Prototype only	Field Testing Demonstrations Incentives
Likelihood of Success	2	(1–5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
Doug Kosar, Paul Glanville; both at GTI				
Prepared by Harvey Sachs, with Nate Kaufman				

Current Status of Measure

Only one product line marketed today approaches the hybrid defined earlier. *Grand Hall USA* offers four high-end indoor non-condensing *Eternal Hybrid* models, with modulating burner peak capacities ranging from 145,000 to 236,000 Btu/h, and tank capacities of 3.8 or 6.4 gallons.[143] These are rated by thermal efficiency, at 86%, because the product parameters fall outside the DOE boundaries for residential equipment rated under EF. The Eternal models use an integrated burner and tank design, unlike the hybrid tankless and tank configuration defined above. All have a two-pass fire-tube construction, and are rated for sealed combustion direct vent with suitable plastic pipe. Since they use outdoor air for combustion (and are wall-mounted), there should be no flammable vapor concerns. We find no other non-condensing hybrid gas water heaters on the U.S. market today.

The Gas Technology Institute (GTI) and participating manufacturers are working toward a much lower cost alternative, based on integration of widely available, mass-produced subassemblies. In essence, they would integrate a small to moderate passive, insulated, tank with a moderate-sized, non-modulating tankless water heater "engine." This is likely to require active controls and a small pump. ACEEE infers that the unit is likely to have the following characteristics:

[143] http://eternalwaterheater.com/index.html. There are also four variants designed for outside installation with freeze-protection kits.

- Fuel input 75,000 to 95,000 Btu/h, so it can use ½" nominal gas lines in almost all installations. This avoids expensive upsizing.
- Footprint of conventional 40 gal gas storage water heater. Tank size probably 30 gal, +/- 10.
- One of two likely venting options:
    - Compatible with Category 1 venting
    - Power or direct venting Power-venting would probably requiring mixing in room air to cool the flue gasses.
- Will require 120 v. AC connection.

The table below shows some of the design trade-offs:

Continuous Flow vs. Temperature Rise and Burner Capacity

	Maximum Flow Rate (gpm)		
Btu/h*	50°F Rise	65°F Rise	77°F Rise
40,000	1.4	1.0	0.9
75,000	2.6	2.0	1.7
95,000	3.2	2.5	2.1
*0.85=recovery efficiency used			

In this table, gray cells are flows too low to support a relatively high efficiency (WaterSense) showerhead, at 2.2 gpm, assuming some mixing at the shower with cold water. Temperature rise is from the water main to the tank exit. 77°F is the federal EF test rating condition. For 120°F exiting, this corresponds to 43°F entering water temperature, roughly characteristic of the expected winter water temperature in northern states.

What this table suggests is that 40,000 Btu/h, which is characteristic of standard tank water heaters, is not enough for "endless hot water" for conventional showers, under any conditions. Indeed, families occasionally run out of hot water with conventional tank water heaters. Correspondingly, a 95,000 Btu/h burner will support an efficient shower all evening—but not an illegal "waterfall" at 6 gpm or more. 95,000 Btu/r will generally conform to Code with ½" pipe in almost all installations, but much higher capacity is likely to require ¾" pipe.[144] Finally, 75,000 Btu/h is the upper limit for residential-rated water heaters in the US. Thus, Table 1 reflects the boundary conditions (transition from gray to white cells) for product development teams.

These attributes will greatly reduce installation cost relative to tankless water heaters that require stainless steel venting, gas line upsizing, and often must be moved (in retrofit or replacement) from the former location to mount on an exterior wall. Based on current EF rating criteria, if the unit is sized at <75,000 Btu/h and if the tank size is at least 20 gallons, it could be classified as a residential product and rated in EF units. If the burner is larger, it will be a commercial-rated (thermal efficiency metric) product.

Savings Potential and Cost-Effectiveness

Our savings and cost estimates are based on our judgment of installed prices and energy use for the GTI prototype unit. It is speculative, because no manufacturer has announced that they will produce such a product, although several are working with GTI. We assume that the product will have a 0.75 EF, and that this translates linearly into 80% of the energy use of a 0.595 EF baseline gas water heater. We also run our numbers on the basis that the product is designed for above-average hot water users, specifically the top quartile. DOE analyses suggest that the 25th percentile user consumes 60 gpd of hot water, compared with the median of 40 gpd.[145]

[144] Pipe size is almost irrelevant for new installations, but matters a great deal for retrofits, where the larger pipe would have to run all the way from the gas meter.
[145] DOE Technical Support Document, Figure 7.2.3

If the price increment is required to be proportional to the energy savings for these users, cost-effectiveness is extremely sensitive to whether or not this unit will require maintenance like most tankless products, or not (as for atmospheric tank water heaters). The DOE average value of $85/yr in service to clean the heat exchanger, etc.,[146] brings the cost of saved energy (CSE) in a mature market to $33.08/MMBtu, more than double the expected average retail price. If maintenance-free, this drops to about $17.02. This is not too far outside the expected and observed gas prices. Under these circumstances, the non-energy benefits of the product will strongly appeal to many purchasers. These include moderate flow "endless hot water," and easy "no surprises" installation.

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 709	$ 650	Economies of scale
Installation Cost	$ 1,272	$ 1,145	No gas line change, just ventilation. Reduction from experience.
Total Cost	$ 1,981	$ 1,795	
Incremental Cost	$ 901	$ 715	

Market Barriers

1) It is relatively straight-forward to build a premium product such as the Eternal, and it is often feasible to profitably market such a niche product. It is much harder to create a value proposition that includes a price differential low enough to make the product cost-effective for relatively large consumer groups. So, the first challenge is developing a product inexpensive enough to even be considered, so consumers can evaluate the importance to them of features like moderate "endless hot water" capability.
2) Although gas water heaters are half the market, we expect that more electric than gas water heaters are replaced by owners themselves (DIY), because of the life-safety issues associated with gas piping and venting. To the extent that this is true, plumbers will be the key to penetrating the replacement market, which is usually an emergency replacement of a leaking or otherwise failed unit. What program tools will stimulate plumbers to carry these units on their trucks and take the effort required to sell the consumer on its virtues?
3) For some fraction of potential installations in the retrofit market, there will be a substantial additional expense to bring a 120V AC outlet within range of the water heater.
4) It is likely that sales will have to be based on benefits (like "endless hot water") since the federal ratings may not make a strong case for cost-effectiveness when gas prices are so volatile. This issue is likely to persist even if the rating method changes.
5) On the other hand, ACEEE does not expect building codes or gas distribution companies to impose challenges to the technology, since it is very close to conventional tanks in its installation and operations needs.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[147]
Average Price of Natural Gas	$11.52/MMBtu[148]
Projected 2025 End Use Electricity Consumption[149]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[150]	1.42 quads
Heat Rate	10.54 kBtu/kWh

[146] DOE tankless maintenance average, TSD 8.6.1.4
[147] EIA. E*lectric Power Monthly—Feb 2011.* Residential Price.
[148] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[149] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[150] Ibid.

Recommended Next Steps

For the intermediate-performance tank-tankless hybrid being developed by GTI, the following steps seem to be required:

1. Prototype development must lead to a robust design that will not require annual maintenance, or product sales should be restricted to soft-water regions where scaling is not a threat.
2. Design for manufacture and the business case must be very disciplined to meet the required installed retail price (~$1700) and incremental installed cost over a baseline product (~$900).
3. Field studies before or simultaneous with roll-out are highly recommended, to demonstrate product reliability and get performance feedback from users.
4. We recommend that sales roll-out focus on areas with above-average gas prices and low probability of hard water in the region. New England could be a primary target area.

ENERGY STAR High Efficiency Gas Storage

Definition	Non-condensing gas-fired storage water heater with EF of at least 0.67					
Base Case	Gas storage water heater with Energy Factor of 0.59					
New Measure	EF of at least 0.67, but less than 0.80	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		12%	51	$1,314	$20.17/MMBtu	2
Mature Market		12%	51	$1,238	$15.75/MMBtu	2

Summary

"High efficiency" (HE) gas storage units are non-condensing gas-fired water heaters with EF ratings of 0.67 or greater. They offer energy savings of about 12–16% over minimum efficiency units at a relatively low incremental cost. These units increase efficiency through use of features such as electronic ignition, improved flue baffling, flue dampers, additional insulation, heat traps, forced air intake systems, and power venting. Some available models meet SCAQMD Rule 1121 for NOx emissions.[151]

Background & Description

In 2009, ENERGY STAR launched its residential water heater program, including a specification for HE gas storage water heaters at 0.62 EF. From the outset, ENERGY STAR planned to sunset this specification, a marginal increase in efficiency above the federal minimum (0.59 for the most common 40 gallon size) within a year. In August 2010, the criteria for non-condensing gas storage water heaters increased to 0.67 EF. The short-term 0.62 was intended to help important market participants learn about ENERGY STAR. Manufacturers responded to both of these criteria by offering models that qualify for ENERGY STAR certification.

Manufacturers mix conventional and propriety technologies to raise the efficiency of non-condensing water heaters. These technologies generally reduce heat losses or improve heat exchange, rather than addressing combustion efficiency. Electric ignition devices save about 3 MMBtu/year by eliminating losses associated with a standing pilot light. Flue dampers reduce heat escaping through the flue when the burner isn't firing: during the off-mode, the open flue of a conventional atmospheric water heater continually heats a column of air in the flue, and this air buoyantly rises through the chimney. Heat traps prevent convective heat flow in the inlet and outlet water pipes going to the water heater.[152] Several manufacturers offer their own methods of forced air intake systems that are designed to increase heat transfer from the flue gases to the water in the storage tank. These intake systems require electricity to run, but gas savings should more than offset this additional load.

Although savings potential is significantly smaller than condensing gas storage units, HE non-condensing are simpler and cost less. For homeowners with limited capital or space constraints that prohibit installation of a condensing water heater, these models offer savings with an average incremental cost of less than $600. Installation may be less expensive if the water heater location already has access to an electrical outlet, and more expensive if the unit is power vented. But because of the relatively small savings, these units are not recommended for new construction, where installations can be designed to accommodate condensing models. For the same reason, we do not view non-condensing units as a long-term strategy to reduce energy waste, but rather as a transitional technology toward condensing gas water heaters.

[151] For example, http://www.rheem.com/product.aspx?id=1894FB6E-3BFB-488A-B8DA-8A6669AC6B57
[152] http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13100

HE gas storage water heaters are the only gas storage models currently certified by ENERGY STAR because, while there are “residential” condensing models on the market that would qualify, their high output classifies them as commercially rated products. Thus, the 0.67 EF HE units benefit from the brand recognition of the ENERGY STAR label in retail outlets and contractor sales. This should help encourage homeowners to choose these models over minimum efficiency units.

Tank sizes for HE storage models range from 29 to 65 gallons, with the vast majority in the 40–50 gallon range. Burner input capacities range from 36,000 to 65,000 Btu/hour, and are heavily weighted toward 40,000 Btu/hour. Estimated natural gas consumption is 21.8 MMBtu/year, compared to approximately 24.8 MMBtu/year for a minimum efficiency model.

Data Summary Table

Market Sector		**Market Application**	**End Use**	**Fuel Type**
Residential		Retrofit	Water Heating	Natural Gas
Current Status		**Date of Com**	**Product Life (years)**	**Source**
Commercialized		2010	13	DOE TSD
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.59	EF	Gas storage baseline in DOE TSD	DOE TSD
Electricity Use	—			
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	24.8	MMBtu		Calculation based on ENERGY STAR Data
New Measure Energy Use				
Efficiency	0.67	EF	ENERGY STAR minimum	ENERGY STAR
Electricity Use	—			
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	21.8	MMBtu		ENERGY STAR
Savings				
Electricity Savings	—			
Summer Peak Demand Savings	—			
Winter Peak Demand Savings	—			
Fuel Savings	3.0			
Percent Savings	12%			
Percent Feasible	45%		100% of gas retrofit installations	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 576	2010 $		DOE TSD
Mature Market Incremental Cost	$ 450	2010 $		
Other Costs/ (Savings)	—	$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	51	TBtu		
Cost of Saved Energy	—	$/kWh		
Cost of Saved Energy	$ 20.17	$/MMBtu		

Mature Market Cost of Saved Energy	—	$/kWh		
Mature Market Cost of Saved Energy	$ 15.75	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Limited savings considering incremental cost	Some models meet SCAQMD Rule 1121 for NOx emissions		ENERGY STAR certification	Strategic Marketing Field studies
Likelihood of Success	2	(1–5)		
Priority	Low	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
By: Jacob Talbot and Harvey Sachs				

Current Status of Measure

In 2011, there are currently 204 qualifying models on the market from 17 brands, ranging in efficiency from 0.67 to 0.70 EF. The majority are atmospherically vented, but about 60 are power vent models. The power vent models are all rated at 0.67 EF.

Savings Potential and Cost-Effectiveness

High Efficiency non-condensing gas water heaters offer savings of 10–17% depending on efficiency.[153] Our analysis is based on a 0.67 EF unit, which can save a cumulative 51 TBtu through 2025 with a cost of saved energy of $20.17/MMBtu. The cost of saved energy declines with higher efficiency models such as the 0.70 EF units, as their retail prices may not increase significantly.[154]

Because these products are very new to the market, field performance is not well documented. For this reason, our savings estimates are based on EF ratings. Thus, estimated energy consumption may vary from real world energy use.

ACEEE estimates that product costs will see about a 10% decline with increased mark share. Mature market cost estimates are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 771	$ 695	Decline with increased production
Installation Cost	$ 543	$ 543	
Total Cost	$ 1,314	$ 1,238	
Incremental Cost	$ 576	$ 450	

Market Barriers

Upfront cost is always a barrier to market penetration for water heaters. Replacements are usually made on an emergency basis when the old unit fails, and consumers are sold whatever units the contractor keeps on the truck, typically minimum efficiency units. Even a moderate incremental cost can prevent market acceptance, particularly if that cost is not recouped quickly, as is currently the case for HE gas units with present natural gas prices.

[153] Based on the ratio of the respective EF ratings.
[154] http://www.vidavici.com/Scripts/prodView.asp?idproduct=28740

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[155]
Average Price of Natural Gas	$11.52/MMBtu[156]
Projected 2025 End Use Electricity Consumption[157]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[158]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Field studies of HE gas water heaters are critical to help quantify real world energy savings. If savings exceed those estimated in our analysis, these models may warrant consideration by utilities for incentive programs, particularly in programs aimed at targeting customers who cannot install condensing units in the homes due to space restrictions.

[155] EIA. El*ectric Power Monthly—Feb 2011.* Residential Price.
[156] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[157] EIA. 2009. *Annual Energy Outlook 2010.* Residential and Commercial Sector Key Indicators and Consumption Tables
[158] Ibid.

Condensing Residential Tank Gas Water Heaters

Definition	Condensing gas storage water heater for residential & light commercial applications					
Base Case	Atmospheric-vented legal minimum 50 gal. storage EF= 0.58					
New Measure	Condensing 50 gal. gas storage water heater, EF >= 0.80. Application for relatively high-use installations.	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		39%	223	$2,533	$17.96/MMBtu	4
Mature Market		39%	223	$2,114	$12.91/MMBtu	4

Summary

Condensing gas appliances are both more efficient and more costly than non-condensing ones. Some of the major cost adders include a corrosion-resistant heat exchanger, power vent, intermittent ignition, and advanced safety controls. These have fairly high costs that do not increase quickly with increasing capacity. Thus, the cost of smaller condensing units will be relatively high, compared with larger ones. In addition, the higher cost of the condensing product is likely to be more acceptable to customers who expect to use larger amounts of hot water. For both these sets of reasons, condensing hot water heaters tend to be built in large sizes. Indeed, a true "residential" market is only emerging slowly, and there are not yet any North American models that qualify for ENERGY STAR listing. However, various models of smaller condensing commercial-rated water heaters are being installed in residences with larger hot water demands.

Background & Description

In theory, a condensing natural gas appliance offers about 10% better efficiency than its non-condensing counterpart. They capture the latent heat released when steam, a product of combustion of natural gas, condenses into liquid water.[159] In practice, gains can be much larger: condensing units don't have standing pilots, and the inducer fan acts as a flue damper to reduce off-cycle losses. In addition, because the combustion gases are so cool, dilution air is not required to protect the PVC flue, unlike the situation with power-vented non-condensing units. The trade-off is higher costs, because the units are more complex and the heat exchanger must be corrosion-resistant on the fire side. Thus, condensing has largely been restricted to high-use light commercial installations such as restaurants and laundries, and is only now penetrating the residential market. Questions have also been raised for residential installations, since commercial units lack the "FVIR" (flammable vapor ignition retarder) screen of residential atmospheric units.[160]

North American law and practice differentiate between residential products, whose efficiency is measured by the *Energy Factor* (EF), and commercial products, which are rated on *Thermal Efficiency*[161]*.* For tank water heaters, the line between them is 75,000 Btu/h input capacity. Gas tankless water heaters are residential products if the storage volume is no more than 2 gallons, and the input capacity <200,000 Btu/h. As of early 2011, legislation has been introduced to require that the Department of Energy develop a consolidated system for all capacities. Groups at AHRI, the relevant trade association, and at ASHRAE, a technical society, are working on alternatives. It is not clear what changes will occur, or whether they will affect 2015 federal minimum energy regulations. The 2015 rules will require EF values that can only

[159] Propane combustion yields slightly less latent heat, since the carbon:hydrogen ratio is higher.
[160] Of course, tankless water heaters do not have FVIR, either, but they are typically wall hung. Thus, they are thought to be less susceptible to (heavier) flammable vapors.
[161] And idle (standby) loss.

by met by condensing gas or heat pump water heaters for units larger than 55 gallons, about 5 to10% of the market.

Data Summary Table

Market Sector		Market Application	End Use	Fuel Type
Residential		New or Retrofit	Water Heating	Natural Gas
Current Status		**Date of Com**	**Product Life (years)**	**Source**
Commercialized		2009	13	DOE TSD (Avg. of tank and tankless)
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.59	EF	40 gal. atmospheric storage water heater	Federal minimum until 2015
Electricity Use	—	kWh/year	self-powered milliamp controls, no flue damper or intermittent ignition	
Summer Peak Demand	—	W	0	
Winter Peak Demand	—	W		
Fuel Use	24.8	MMBtu/year	Uppermost quartile of households	TSD, 7.2.3&7.2.13
New Measure Energy Use				
Efficiency	0.8	EF	estimated from SEGWHAI for condensing	
Electricity Use	80	kWh/year	H: 10 W, standby, 1 hr/day fan@ 100 W	
Summer Peak Demand	30	W	Estimated from 150 W fan & igniter, 5% duty cycle, peak hr. 4x average	
Winter Peak Demand	30	W	Estimated from 150 W fan & igniter, 5% duty cycle, peak hr. 4x average	
Fuel Use	15.2	MMBtu/year	Based on EF ratio of new v. baseline	
Savings				
Electricity Savings, Annual	(80)	kWh/year	Inducer, igniter, controls	Estimated, subsheet
Summer Peak Demand Savings	(30)	W		
Winter Peak Demand Savings	(30)	W		
Fuel Savings	9.6	MMBtu/year		
Percent Savings	39%		Based on EF ratio of new v. baseline, + pilot elimination	
Percent Feasible	25%		Top quartile (heaviest use) of gas WH users for whom most cost-effective, half of WH are gas	RECS, TSD
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 1,460	2010 $	ACEEE analysis of current market prices and installation costs from DOE	DOE TSD
Mature Market Incremental Cost	$ 1,034	2010 $		
Other Costs/ (Savings)	$8.21	$/yr	National average cost of electricity for inducer, ignition, etc.	
Ranking Metrics				

2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	223	TBtu		
Cost of Saved Energy	—	$/kWh		
Cost of Saved Energy	$ 17.96	$/MMBtu		
Mature Market Cost of Saved Energy	—	$/kWh		
Mature Market Cost of Saved Energy	$ 12.91	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
No marketing strategy Lack of education	Continuous hot water at several GPM if incoming water temperature moderate Large reservoir		OEM marketing	Standards & Codes ENERGY STAR action
Likelihood of Success	4	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
Harvey Sachs, ACEEE				

Current Status of Measure

No condensing tank water heaters meet the current ENERGY STAR specification,[162] because it requires (residential) EF-rated products. Several qualifying units are expected to be introduced soon. On the other hand, relatively small "commercial" condensing water heaters are available from several firms, under more brand names. In ≤50 gallon capacity, 84 named models are listed, and an additional 34 models between 50 and 75 gallons.[163] Some of these are factory-equipped with additional threaded ports to allow simultaneous use for water- and space-heating. They are not true "combo" appliances, since they are not shipped with the necessary fan-coil and air handler, but they can be the "engines" for field applications serving both functions.

Savings Potential and Cost-Effectiveness

ACEEE estimates that average users in the top quartile of households will save about 40% of hot water energy required, relative to a current (2011) base efficiency model. Part of the savings are from the EF ratio (23% savings), and the remainder from elimination of the standing pilot. We have not assumed additional savings from the effect of the inducer as a flue damper replacing the draft diverter.

The weighted average (20% new construction, 80% retrofit/replacement) incremental cost of a 50 gallon condensing tank water heater is about $1300, largely attributable to DOE's high estimate for the average cost of installing plastic vent cost in existing houses:[164]

	new	retrofit	wt. av.
non-condensing	$1,785	$1,089	$1,228
condensing	$2,399	$2,567	$2,533
	$614	$1,478	$1,305

The equivalent cost of saved energy for the top quartile is $17.96/MMBtu, which compares with current national average retail price of about $11.52/MMBtu. This suggests that the condensing tank water heater

[162] http://www.ENERGY STAR.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=WHC
[163] AHRInet.org directory search, 21 February 2011.
[164] ACEEE analysis of current condensing and conventional water heater costs and installation costs per DOE TSD

is not yet cost-effective for households that use large amounts of hot water. Of course, if the condensing water heater is used as the "engine" for a "combo" appliance that provides both service hot water and space heating, the economics can be more favorable.

ACEEE estimates that product costs will decline by about 20% with increased production. Installation costs will decrease nominally with increased contractor experience. Mature market cost estimates are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 1,662	$ 1,330	Estimate 20% reduction from production volume
Installation Cost	$ 871	$ 784	
Total Cost	$ 2,533	$ 2,114	
Incremental Cost	$ 1,460	$ 1,034	

Market Barriers

6) Lack of ENERGY STAR recognition is a barrier for utility program incentives, and for credibility in the market.
7) Published ratings impede meaningful comparisons, because of the historical distinction between "residential" and "commercial" water heaters. It is difficult for trade allies, including salesmen, to credibly establish the savings potential when comparing products that are rated differently.
8) First costs will be high in the emerging market, until manufacturing scale economies are reached and the sales-installation industry is experienced and comfortable with the products.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[165]
Average Price of Natural Gas	$11.52/MMBtu[166]
Projected 2025 End Use Electricity Consumption[167]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[168]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

The most important step is to rationalize the water heater rating methods so consumers can compare "residential" and "commercial" products to find optimum solutions for their needs. This work is underway at AHRI and ASHRAE, and legislation has been introduced to accelerate the process.

Field study data are essential for establishing the actual operating cost differences between advanced and conventional water heaters. Such data and case studies are required so manufacturers can justify marketing statements.[169] Field data are also essential as a basis for utility incentive programs to promote the products.

[165] EIA. El*ectric Power Monthly—Feb 2011.* Residential Price.
[166] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[167] EIA. 2009. *Annual Energy Outlook 2010.* Residential and Commercial Sector Key Indicators and Consumption Tables
[168] Ibid.
[169] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.

Advanced Ground Source Heat Pump Approaches[170]

Definition	Residential desuperheater or "priority" water heating with ground source heat pumps					
Base Case	Normal air-source heat pump, SEER 13, EER 10, HSPF 7.7					
New Measure	HP, SEER 16, EER 12, HSPF 9.6, multi-stage compressor, large HX, and optimized controls	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		40%	271	$ 900	$0.05/kWh	3
Mature Market		40%	271	$ 675	$0.03/kWh	3

Summary

Ground-source heat pumps[171] today account for a few percent of new residential HVAC systems. Most are sold with “desuperheaters,” to augment resistance tank water heaters. The desuperheater is a small auxiliary refrigerant-to-water heat exchanger, installed in series between the compressor and the main (ground loop) heat exchanger. A pump circulates water between the water heater and the desuperheater in the heat pump cabinet when the compressor is running—typically about 40% of annual hours. In cooling mode, the contribution of the desuperheater is “free,” since it captures heat that would otherwise be rejected to the ground. In heating mode, it is still very efficient. These units are very common, because contractors and consumers believe they are cost-effective. There are options from virtually all manufacturers, and thought to be pervasive, or at least installed in most residential geothermal systems. Based on very limited field performance data, ACEEE estimates the water heating energy savings of 30 to 50%, with the cost of saved energy about $0.05 to $0.06 /kWh, for the top quartile of hot water users, based on current market conditions.[172] For median electric hot water users (39 gpd), the cost of saved energy rises to $0.05 to $0.09/kWh, respectively.

A higher performance alternative is offered by a small number of specialty manufacturers.[173] These units are called priority, full-condensing, demand, or triple-function geothermal heat pumps. Using more complex refrigerant valving and controls, priority systems can direct the full heating capacity of the compressor to a condenser that is installed in parallel with the refrigerant to loop heat exchanger. A typical three ton system that produces 36,000 Btu/h of cooling will have even more heating capacity—since the unit must reject the heat of compression, etc. Thus, a priority water heater system can have recovery efficiency as large as that of a conventional tank natural gas water heater, much greater than a conventional tank resistance water heater (ca. 15,000 Btu/h with a 4500 watt element). Because these units are generally installed in relatively well-built houses whose temperature changes gradually with the HVAC system off, and since they link to a relatively large tank water heater, users are unlikely to ever notice that the heat pump capacity has prioritized the water heating load, and they are less likely to run out of hot water than with a same-size resistance water heater.

Background & Description

Residential ground source heat pumps (GSHP) have been available from multiple manufacturers for several decades. Major firms in this niche include ClimateMaster, WaterFurnace, Florida Heat Pump (now Bosch), and Trane. At any given time, there may be an additional score or so of specialty firms in the market with products catalogued by AHRI, the trade association. Most residential GSHP are sold with a “desuperheater,” an auxiliary water heating device that works only when the compressor is running to provide space conditioning. The desuperheater may heat water with very high efficiency in the cooling

[170] This discussion is limited to *air-source* heat pumps. Ground-source units optimized for cold climates are also available, such as the Econar line, http://www.econar.com/index.htm. Ground-source systems are typically substantially more expensive than air-source systems, due to the smaller market, the premium nature of the product, and the cost of installing a ground loop.
[171] Also known as “GeoExchange” or “Geothermal”, among other terms.
[172] Phetteplace, personal comm., June 9, 2011, report on Ft. Polk study prior to base retrofit, using 2-tank approach. This may be an upper limit.
[173] A Web search found five or six firms offering these products. Two of them are manufacturers of “GDX”

season, and slightly lower efficiency in the heating season, but it does little or no work during shoulder seasons when the heat pump does not run much. Thus, its contribution to total service hot water demand depends upon climate, house heating and cooling load, and hot water use patterns. Our savings estimates for desuperheaters are based on a relatively average climate with 2000 full-load heating hours and 1500 full load cooling hours, or the compressor operating 40% of the annual hours of the year. A 10% change in the inferred EF of the system yields a smaller change, ~6–7% in energy savings computed, which are about 1/3 of annual electricity that would be used with a purely resistance tank system.

Priority, full-condensing, or triple-function systems have also been listed in catalogues for at least two decades, but few models are offered, the price premium is high, and they tend to be offered by smaller manufacturers to differentiate their capabilities. Costs are very uncertain, and we do not explicitly evaluate them; they are simply not yet widely available enough to be considered “emerging technologies” in our sense.

Data Summary Table

Market Sector	Market Application	End Use	Fuel Type
Residential	New or Retrofit	Water Heating	Electricity
Current Status	**Date of Com.**	**Product Life (years)**	**Source**
Commercialized	1980	18.4	DOE TSD, Res AC

Base Case Energy Use		Units	Notes, Explanation	Source
Efficiency	0.90	EF	Conventional Resistance Electric	
Electricity Use	3,915	kWh/year	Uppermost quartile, TSD extrapolation	TSD chapter 7
Summer Peak Demand	—	kW		
Winter Peak Demand	—	kW		
Fuel Use	—	MMBtu/year		
New Measure Energy Use				
Efficiency	1.80	inferred EF	Phetteplace, Ft. Polk Demo, measured energy use	
Electricity Use	2,370			
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	—			
Savings				
Electricity Savings	1,580	kWh/year		
Summer Peak Demand Savings	—	kW		
Winter Peak Demand Savings	—	kW		
Fuel Savings	—	MMBtu/year		
Percent Savings	40%		Assigned, based on evaluation of available studies. Inc. parasitics.	
Percent Feasible	15%		half of electrically heated houses could use GSHP, if economic	ACEEE Research Report A042, technology H10b
Industrial Savings > 25%?	no			
Costs				
Incremental Cost	$ 900	2010 $	“Full condensing” increment over desuperheater. No change in WH connections, substantial change in GSHP for second condenser (double wall), controls, etc.	
Mature Market Incremental Cost	$ 675	2010 $		

Other Costs/ (Savings)	—	$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	25706	GWh		
2025 Savings Potential (Source)	271	TBtu		
Cost of Saved Energy	$ 0.05	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
Mature Market Cost of Saved Energy	$ 0.03	$/kWh		
Mature Market Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
More precise specs for installation required AC Rating methods do not reflect efficiency gains	Improved recovery efficiency relative to non-condensing systems		Limited market penetration	Research & Development Incentives Standards & Codes
Likelihood of Success	3	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
Harvey Sachs, ACEEE				

Current Status of Measure

ACEEE understands that residential GSHPs with desuperheaters are more commonly sold than those without; so they are “normative” in this specialty market. “Priority” or “full-condensing” systems are not yet sold in large numbers.

Savings Potential and Cost-Effectiveness

At an assumed current incremental cost of a desuperheater at time of purchase of a GSHP system of $900,[174] the cost of saved energy is $0.05 to $0.06/kWh.

National savings are highly dependent on the “mother technology,” the GSHP system itself: if the cost of ground-source systems declines substantially with improved loop installation methods, desuperheater-equipped systems will become more common. On the other hand, past efforts to commercialize air-source heat pumps with water heating capability have proved unsuccessful. The difference is largely that the typical GSHP condensing unit is indoors, integral with the air handler, so connections to the (indoor) water heater are relatively easy. In contrast, the compressor and condensing unit for an ASHP are outdoors, so the water heating option requires running refrigerant lines to an indoor heat exchanger at the water heater, or running water lines to the outdoors—with all the concomitant issues of freeze protection. A new generation of water heating options for “mini-split” systems, such as the Daikin “Altherma,” may breech this barrier.

ACEEE estimates that costs will decline by about 25% with increased experience. Mature market cost estimates are detailed in the following table:

[174] We assume $500 as the retail price of the desuperheater option, and the remainder as labor charge for installing the connections and pump.

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 900	$ 675	Increment for full condensing over desuperheater, 25% decline with experience
Installation Cost	$ —	$ —	No change with regard to desuperheater installation, may decrease since should not need second tank (not done often enough)
Total Cost	$ 900	$ 675	
Incremental Cost	$ 900	$ 675	

Market Barriers

9) First cost premiums are a huge barrier to GSHP system in general,[175] and thus for water heating technologies that are components of these systems.

10) Published ratings impede meaningful comparisons, because they do not account for the benefits of the water heating option. This is a subset of the more general problem of rating “combo” equipment that serves multiple functions. ENERGY STAR specifications do not require desuperheater installation.[176]

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[177]
Average Price of Natural Gas	$11.52/MMBtu[178]
Projected 2025 End Use Electricity Consumption[179]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[180]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Because the industry already expects to install desuperheaters on most residential ground source heat pump systems, market penetration will exactly follow that of the underlying ground source technology. No additional steps are needed. However, it would be worthwhile to generate actual field data on savings with these systems.

[175] Until 2016, a 30% federal tax credit is available for these systems.
[176] http://www.ENERGY STAR.gov/index.cfm?c=geo_heat.pr_crit_geo_heat_pumps
[177] EIA. El*ectric Power Monthly—Feb 2011.* Residential Price.
[178] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[179] EIA.2009. *Annual Energy Outlook 2010,* Residential and Commercial Sector Key Indicators and Consumption Tables
[180] Ibid.

Drain Water Heat Recovery

Definition	Drain water heat recovery device installed on shower drain					
Base Case	Gas storage water heater with Energy Factor of 0.59					
New Measure	Copper drain water heat recovery device with thermal transfer effectiveness of 50%	Percent Savings	2025 Savings TBtu (Source)	Installed Price (Retrofit)	Cost of Saved Energy, $/MMBtu	Success Rating (1–5)
Current Market		30%	49	$ 933	$ 7.74	2
Mature Market		30%	49	$ 817	$ 6.78	2

Summary

Around 80–90% of a shower's delivered energy in hot water is lost down the drain immediately after use.[181] Drain water heat recovery (DWHR) devices are copper heat exchangers designed to transfer as much of the waste heat into incoming cold water as economically feasible. Lab testing has suggested that DWHR devices can recover 46–67% of the heat in drain water from showers.[182] Cold climates offer particularly attractive opportunities for savings as the cooler incoming water requires more energy to heat through electric and gas-fired water heaters. DWHR can reduce this load significantly, saving about 30%[183,184] of total water heating energy use. With current product and installation costs, ACEEE estimates that DWHR can be installed in new construction and retrofit applications at a cost of saved energy of $7.74/MMBtu, and with market maturation the cost can drop to approximately $6.78/MMBtu.

Background & Description

Modern DWHR devices have been on the market since around 2004, and have steadily grown in popularity in Canada, where incoming water temperatures are low, making the economics of DWHR favorable. Market share in the U.S. remains very low. DWHR devices consist of a 3–4" diameter copper pipe 3–5' long, wrapped tightly by one or more smaller copper pipes. As hot water runs down the drain, surface tension draws it onto the sides of the large pipe. Cold water running up through the supply pipe(s) is warmed as it flows around the large pipe. Through this method of heat transfer, 46–67% of the waste heat can be captured and used again. Efficiencies increase if the DWHR device is insulated, which increases heat transfer and decreases heat loss.

Warmed potable water exiting the DWHR device is generally used one of three ways. First, and most common, is to install a DWHR device beneath a shower and send the warmed water to the inlet cold water fixture for the shower, reducing the amount of hot water needed to bring the water up to a usable temperature. Because less hot water is used, this method also extends a water heater's first hour rating. However, through this method savings are only achieved during long water draws where hot water is both drained and drawn at the same time. Second, water can be plumbed to the main cold water line where it can be used by any fixture in the home. This option offers increased versatility in use, but can lead to unwanted warm water draws at sinks when cold wanted is desired. Finally, warm water can be sent to the water heater, reducing the amount of energy required to heat it for use. Due to popularity, relative ease of installation, and high savings potential, we have assumed the first of these methods in our analysis.

Because almost all DWHR devices require 3–5' or more of clearance or more beneath the drain, applicability is limited to homes and apartments with basements and/or bathrooms on the second story with sufficient clearance beneath the drain. Apartment buildings offer an excellent opportunity for savings with DWHR where construction has included suitable maintenance spaces with access. At least one

[181] http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13040
[182] Zaloum et al., Drainwater Heat Recovery Performance Testing at CCHT, 2006
[183] *Drain-Water Heat Recovery Credits For Ontario ENERGY STAR Qualified Homes*, Energy Building Group Ltd. 21 March, 2006
[184] Zaloum et al., *Drain Water Heat Recovery Characterization and Modeling,* Sustainable Buildings and Communities, Natural Resources Canada, Ottawa, June 29, 2007

company is currently developing a DWHR device that can be mounted horizontally, but it has not yet been brought to market.

The heat exchanger reduces the water pressure of the supply line: it is much longer than the original supply, and typically has a smaller cross section area. DWHR devices with only one supply line can exacerbate this pressure loss, which may be more noticeable when the water source is at low pressure, such as with a single-family private supply well. Units with multiple copper pipes and a municipal water tank as the water source experience less pressure drop. Testing conducted by NRCAN[185] did not result in insufficient water pressure for any of the units tested, but product selection and installation decisions should keep water pressure in mind. Additionally, lab testing has suggested that the shape of the cold water wrapping pipes can impact energy savings. DWHR devices with square-shaped cold water pipes consistently performed better than round pipes, presumably due to increased surface contact between the warm and cold water pipes.[186]

The following image depicts three styles of DWHR devices. The unit on the top features two inlet cold water pipes that wrap around the DWHR device independently. This method is intended to reduce flow restriction. The second device features one cold water coil, which can maximize heat transfer due to increase contact area, but can also reduce flow. The last device features three square-shaped cold water pipes that wrap about the inner pipe in tandem. This method increases flow but loses some of the contact area with the inner pipe. Still, testing has shown that this last method performs at a higher efficiency level than the other methods of DWHR.

Image source: Natural Resources Canada "Performance Evaluation of Drain Water Heat Recovery Technology at the Canadian Centre for Housing Technology"

Data Summary Table[187]

Market Sector	Market Application	End Use	Fuel Type
Residential	New and Retrofit	Water Heating	Natural Gas
Current Status	**Date of Com**	**Product Life (years)**	**Source**
Commercialized	2005	30	ACEEE Estimate

[185] Zaloum et al., *Drain Water Heat Recovery Characterization and Modeling,* Sustainable Buildings and Communities, Natural Resources Canada, Ottawa, June 29, 2007.

[186] Id.

[187] DWHR is applicable for water heating systems fueled by both gas and electricity. Because the majority of homes in the northern U.S. use gas water heating, we have assumed natural gas as the fuel. Cost of saved energy would likely decrease with homes that use electricity as electricity rates are typically higher than natural gas.

Base Case Energy Use		Units	Notes, Explanation	Source
Efficiency	0.59	EF	Federal minimum efficiency	DOE
Electricity Use	—	kWh/year		
Summer Peak Demand	—	kW		
Winter Peak Demand	—	kW		
Fuel Use	24.8	MMBtu/year		
New Measure Energy Use				
Efficiency	50%	Thermal effectiveness	Testing has shown 46-67% effectiveness	
Electricity Use	—			
Summer Peak Demand	—			
Winter Peak Demand	—			
Fuel Use	—			
Savings				
Electricity Savings	—			
Summer Peak Demand Savings	—			
Winter Peak Demand Savings	—			
Fuel Savings	7.4	MMBtu/year		
Percent Savings	30.0%		Tests have shown 9–40.5% total water heating savings	Energy Building Group Ltd., NRCAN
Percent Feasible	15%		Half of new construction and 10% of retrofit market, concentrated in the northern U.S.	ACEEE Estimate
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 933	2010 $	Retrofit installation costs from phone survey of contractors in Minnesota and online survey of equipment costs. New construction installation ACEEE estimate ($100)	
Mature Incremental Cost	$ 817	2010 $	Economies of scale and contractor experience	
Ranking Metrics				
2025 Savings Potential (Site)	—	GWh		
2025 Savings Potential (Source)	49	TBtu		
Cost of Saved Energy	—	$/kWh		
Cost of Saved Energy	$ 7.74	$/MMBtu		
Mature Cost of Saved Energy	—	$/kWh		
Mature Cost of Saved Energy	$ 6.78	$/MMBtu		

Unusual Market Barriers	Non-Energy Benefits	Current Activity	Next Steps
Price premium Consumer and contractor Awareness and confidence	Improved first hour rating on water heater	Commercialized A few incentive programs	Field Studies Incentives

Likelihood of Success	2	(1–5)
Priority	Med	Low, Med, High
Data Quality Assessment	B	(A–D)

Principal Contacts

By: Jacob Talbot and Harvey Sachs, ACEEE

Current Status of Measure

There are currently four leading brands of DWHR devices (Eco Innovation Technologies Inc., Renewability Energy Inc., Watercycles Energy Recovery Inc., and Retherm), each with multiple models in varying lengths. Equipment costs range from around $300–700 depending on manufacturer and the length of pipe selected. Although many utilities in Canada offer incentives for DWHR, there are only a few active programs in the U.S., including Austin Energy (Minnesota), Vermont Gas, and an incentive program through Oregon Department of Energy. The utility rebates are presently set at $200 and Oregon offers tax rebates from $80–120, depending on the efficiency of the system.[188]

Savings Potential and Cost-Effectiveness

Savings can vary based on climate, installation method, size and length of DWHR device, and patterns of use. Studies have shown 46–67% of waste heat can readily be recaptured from shower drains, which can result in savings of 9–40% of total hot water energy use in one-bathroom homes. A typical retrofit installation costs around $1000 including equipment costs, which can be recouped in 2.5–7 years[189] or so with typical use patterns. Installation costs can increase dramatically if pipes are located behind a wall or if new pipes need to be installed to route the incoming cold water or exiting warmed water. Installation costs are lower in new construction where plumbers can build the DWHR device into the plumbing system from the outset.

Because DWHR devices are made of copper and have no moving or electrical parts, ACEEE does not anticipate a significant decrease in price with increased market adoption. Costs will see some decline with improved manufacturing efficiencies and plumber experience. Complete mature market cost projections are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$ 700	$ 650	Improved efficiencies at factory
Installation Cost	$ 300 (retrofit) $ 100 (NC)	$ 200 (retrofit) $ 100 (NC)	Contractor experience
Total Cost	$ 933	$ 817	Assumed 2/3 retrofit and 1/3 new construction
Incremental Cost	$ 933	$ 817	

Market Barriers

1) First costs are high. However, in cold climates, payback periods are swift and utility incentives can help close this financial gap.

2) In many cases, installation can be very expensive, and few contractors have experience installing DWHR devices. Units can only be installed vertically and typically require three feet of clearance or more beneath the drain. As such, installations are generally limited to basements and two-story buildings with bathrooms on the second floor. Multifamily buildings represent an excellent opportunity for large savings.

3) Consumer awareness is currently very low and there are no national programs aimed at DWHR.

4) Despite their success in Canada, there is still some skepticism about the potential for DWHR devices in the U.S., particularly in warmer climates.

[188] http://www.retherm.com/IncentivesUSA.htm, http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN46F&re=1&ee=1

[189] http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13040

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[190]
Average Price of Natural Gas	$11.52/MMBtu[191]
Projected 2025 End Use Electricity Consumption[192]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[193]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

Field testing in a variety of installation configurations, water heaters, and climates will help to validate savings opportunities and offer utilities the assurance needed to justify investments in incentives. Contractor training and education, as well as marketing aimed at the general public will also help increase awareness of the potential for DWHR devices. Once savings claims are validated in the U.S., ENERGY STAR may be able to justify initiating a program for DWHR, which will help utilities develop programs and increase visibility to the public.

[190] EIA. *Electric Power Monthly—Feb 2011*. Residential Price.
[191] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[192] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[193] Ibid.

Single-Family Demand-Activated Recirculation Systems

Definition	User-activated recirculation pump that turns off when hot water arrives at fixture					
Base Case	Central tank water heater system in typical house					
New Measure	User-activated recirculation pump that draws hot water to the fixture quickly while recycling cold water	Percent Savings	2025 Savings TBtu (Source)	Installed Cost	Cost of Saved Energy	Success Rating (1–5)
Current Market		25%	238	$1,000	$0.12/kWh	4
Mature Market		25%	238	$400	$0.03/kWh	4

Summary

Large, spread-out houses with central water heaters that are far from major water use areas lead to large wastes of water and energy, and great resident frustration from long waits for hot water—up to several minutes in some houses. Hot water recirculation loops reduce water waste greatly, but poor pipe insulation guarantees energy waste that costs much more than the value of the saved water. One technical solution is the user-activated recirculation pump. It is activated when hot water is desired, but turns off as soon as hot water reaches the fixture that needs it. These are marginally cost effective with current market costs as retrofits ($0.12/kWh), and should be highly cost-effective for new construction, for electric water heaters. Mid- to long-term, they should be very attractive for gas, also. Consumer uptake will be amenity-driven, because consumers want hot water quickly, which makes the economics less important.

Background & Description

Conventional North American single-family housing generates hot water with a central tank water heater, and distributes it through "trunk and branch" piping. When houses are small, and have compact water services (all fixtures close horizontally and/or vertically), this architecture works well. However, several factors combine to make this less satisfactory today:

- Median house size has more than doubled since 1950, and bathrooms have followed bedrooms to the far corners of the houses, to make "suites."
- Water heaters are located to meet builders' needs, rather than for proximity to major water uses.
- Legislation has restricted flow rates through common hot water fixtures (showerheads, faucets), while plumbing codes still require large pipe diameters.

Together, these factors mean that the time for hot water to be delivered to a fixture has increased remarkably. This unsatisfactory situation leads to enormous waste of cold water (down the drain while waiting for hot water to arrive) and hot water (cooling in the pipes after a successful draw). Indeed, most measured hot water draws *never deliver hot water to the user*[194] The systems evaluated here, demand-actuated recirculation systems, offer a huge consumer amenity: they deliver hot water in one-fifth the time, while saving energy and water. The high flow rate increases savings beyond the simple arithmetic of pipe volume: higher flow rates are associated with flow that approaches plug flow, with near perpendicular interface between hot and cold water. Hiller[195] established that as flow rates decline, the interface length becomes much longer, with the result that up to 50% more water must move through the fixture before it is hot enough for use.

There are several approaches to reducing this frustration and waste:

[194] This is anecdotal, but based on examination of draw records analyzed from multiple field studies. Most individual draws are so short (a few seconds) that hot water could not have traveled from water heater to fixture by the time the fixture was shut off. See Lutz and others (2011)

[195] Hiller, Carl. Hot-Water Distribution System Piping Time,Water, and Energy Waste - Phase III: Test Results. ASHRAE Transactions, 2011.

- Some experts advocate "home run" pipe architecture, in which each hot water fixture gets a dedicated, very small diameter, line back to a manifold at the hot water heater. This greatly reduces water waste. It is rarely possible, except in new construction. For a variety of reasons, savings have often been less than predicted. For example, for convenience of the plumber, the manifold may be too far from the water heater, and connected by too large a pipe. This creates a large dead volume of cold water.
- In some applications, distributed POU water heaters are worth considering. One example, the electric tankless water heater, is treated separately in this series. It will make sense in homes where hot water fixtures are far from each other and the central water heater, particularly when water draws are not tightly clustered (so that water in the pipes cools between uses).
- Several varieties of recirculation loops are available. Most systems use a pump installed on a continuous hot water loop between the water heater hot water outlet and the cold water inlet. One variety is the topic of this report. The return leg of the loop can be a dedicated line, or the cold water line serving the fixture can be employed when "priming" the fixture supply line with hot water.

Residential recirculation systems vary principally in system architecture and pump control strategy. For new construction, a complete hot water loop is generally specified, with the circulating pump near the water heater. Particularly with poorly insulated and slab-in-grade hot water piping, the radiative and/or conductive energy losses to the environment from the hot water are enormous with continuous pumping. One way to reduce this heat loss is to install a timer that turns off the pump when no use is expected, such as overnight. In general, this can reduce water waste, by having hot water instantly available at the fixture almost all the time it is wanted. Ironically, it will *increase* energy use, relative to the case with no pump at all. One model suggests that timer-controlled loops can waste more than twice as much energy as a demand-controlled loop, or none at all.[196] This is because the loop continues to radiate heat when it is running, typically 16 hr/day. With a timer, the loop can lose twice as much energy as a simple non-recirculating system with no pump.[197] However, the simple system will take much longer to deliver hot water, and will waste much more cold water down the drain. So, timer-based and uncontrolled recirculation systems are very energy-inefficient.

In retrofits, installing a return line is rarely feasible.[198] Instead, retrofit applications move the pump to a fixture as far as possible from the water heater. When there is a call for hot water, the pump is activated to draw hot water, and push the pipe burden of cold water back to the water heater through the cold water pipe, as noted above. These systems are *demand-controlled.* A person who wants to use hot water activates the pump (with a switch or motion detector). When hot water reaches the fixture, the pump turns off automatically, eliminating or minimizing warm water entry into the cold water line.

The pump itself is typically a small unit drawing only 20–30 W.[199] Running it continuously would use about 175 to 250 kWh/yr in most houses. However, since the demand system only turns on when actuated by the user, and then only if the water in the line is cold it winds up being used only about 30 minutes/day.[200] So, its electricity use is in the range of $1/yr. This is trivial compared to energy use and distribution-related losses in the hot water system.

The pioneer *demand-activated recirculating pump controller* was ACT, with its "D'mand" controller,[201] available since 1992. Systems are offered by others, too.[202] The demand-activated system is "semi-

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[196] Grieshop, D., 2011. On Demand Pumps: (Residential hot water recirculation) Do they make sense for consumers & communities? ACEEE Hot Water Forum. http://aceee.org/files/pdf/conferences/hwf/2011/6C%20-%20Dave%20Grieshop.pdf.
[197] Grieshop, D. 2011 and 2010. ACEEE Hot Water Forum.
[198] It may be feasible, if not cost-effective with professional installation, where the living area is above an unfinished basement. It is less likely to be feasible with slab-on-grade houses, where pipes are buried or in finished walls.
[199] The Metlund unit is specified for 12 to 16 feet of head, and produces up to 5 gpm (Acker and Klein. "Benefits of Demand-Controlled Plumbing." *Home Energy Magazine*. September/October 2006), yet more efficient pumps may be available, but savings will be very small since the pump runs so little.
[200] Acker and Klein. 2006.
[201] http://www.gothotwater.com/, ACT "D'Mand" technology.

automatic:" the pump is activated by a user (pushing a button, or equivalent), when hot water is desired. It turns off when hot water is sensed at the pump, which is installed at a distant fixture. In new construction, the demand pump is connected to a loop line that carries water back to the heater inlet.[203] In retrofits, the demand pump straddles the hot and cold lines at the fixture. When it runs, it pumps water from the hot line into the cold line, and stops pumping when it senses the arrival of hot water.

Data Summary Table

Market Sector	Market Application		End Use	Fuel Type
Residential	New or Retrofit		Water Heating	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized	1992		15	http://www.gothotwater.com/
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.84	"efficiency"	Generalized alternative to EF, inc. dist.	G. Klein
Electricity Use	2,703	kWh/year	DOE 2009, TSD. Table 7.2.14	
Summer Peak Demand	1.13	kW	New England Power Service Co. 1987, Table A.2	
Winter Peak Demand	1.7	kW	New England Power Service Co. 1987, Table A.2	
Fuel Use	—	MMBtu/year		
New Measure Energy Use				
Efficiency	1.12	"efficiency"	Reflects 25% less waste	Grieshop
Electricity Use	2,027	kWh/year	Derived from base case and "efficiency" correction	
Summer Peak Demand	0.8	kW		
Winter Peak Demand	1.3	kW		
Fuel Use	—	MMBtu/year		
Savings				
Electricity Savings	676	kWh/year		
Summer Peak Demand Savings	0.3	kW		
Winter Peak Demand Savings	0.4	kW		
Fuel Savings	—	MMBtu/year		
Percent Savings	25%			
Percent Feasible	60%		Estimated fraction with plumbing spread out enough to benefit (gas and electric)	
Industrial Savings > 25%?	no			
Costs				
Incremental Cost	$ 1,000	2009 $	Relative to no recirculation, no pump, retrofit, inc. wiring.	Grieshop
2025 Mature Incremental Cost	$ 400	2010 $	New construction, w. recirc. loop	ACEEE
Other Costs/ (Savings)	$ (19.43)	$/ year	Wholesale value of water not wasted	ACEEE, from Grieshop
Ranking Metrics				

[202] Uponor http://www.uponorpro.com/en/Products-and-Applications/Products/Plumbing.aspx and Taco http://www.taco-hvac.com/en/products.html?current_category=59 use the "D'Mand" technology, which uses Taco pumps. "Chilipepper," http://www.chilipepperapp.com/ also offers a product.

[203] In new construction, the pump is located at the water heater's cold water inlet.

2025 Savings Potential (Site)	22607	GWh		
2025 Savings Potential (Source)	238	TBtu		
Cost of Saved Energy	0.12	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
2025 Mature Cost of Saved Energy	0.03	$/kWh		
2025 Mature Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
More precise specs for installation required AC Rating methods do not reflect efficiency gains	Reduced water waste Shortened waiting period for hot water to arrive		Some utility incentive programs	Research & Development Incentives Standards & Codes
Likelihood of Success	4	(1–5)		
Priority	High	Low, Med, High		
Data Quality Assessment	C	(A–D)		
Principal Contacts				
By: Harvey Sachs, Jacob Talbot				

Current Status of Measure

As noted above, several firms offer demand-activated recirculation system pumps and controllers. Most seem to use the Metlund D'mand components, but they are available through mainstream suppliers to the plumbing industry and internet sources, if not yet at major "big box" retailers. Market share is thought to be < 1%. Although some entities may offer rebates or other incentives, they are not prevalent enough to be catalogued at DSIRE.[204]

Because major international firms such as Taco and Upanor have begun to offer the products, and because an increasing number of jurisdictions face both water and energy problems, ACEEE expects uptake to increase greatly over the next decade.

At this time, neither ENERGY STAR nor the WaterSense programs recognize efficient service hot water systems or components.

Savings Potential and Cost-Effectiveness

The median hot water use in a recent meta-study was 50.6 gallons/day, with a median of 61 separate hot water draws/day. Both variables show very large variability within and between houses.[205] Still, some inferences can be drawn:

- These numbers set an upper bound to the median number of times the pump would turn on. In practice, some draws are clustered tightly enough that the supply line to the fixture would still have hot water, and the pump would not start.

[204] http://dsireusa.org/

[205] J.D. Lutz, Renaldi, A. Lekov, Y. Qin, and M. Melody, 2011. *Hot Water Draw Patterns in Single-Family Houses: Findings from Field Studies*. LBNL-4830E. Lawrence Berkeley Laboratory.

- If we divide the median number of gallons used by the median number of draws, we get about a gallon/draw as typical. This makes sense as a weighted average of frequent uses for basins and kitchens with low flow rates, plus infrequent shower and tub events, but it is only qualitative.
- From these approximations, we can infer that the pump runs no more than half an hour/day, and possibly significantly less.

ACEEE estimates that the cost of saved energy today is about $0.12/kWh at present market costs, with moderate cost reduction potential for retrofit applications. This includes an estimate of the value of saved water. Our $1000 installed price for this as retrofit assumes that a new outlet will be required at the fixture served, and that this must be done by a licensed electrician. The product cost alone is in the range of $400 to $500, and has cost reduction potential.

ACEEE projects that product costs will decline with economies of scale, and mature market costs assume new construction installation costs. Mature market cost estimates are detailed in the following table:

	Current Market	Mature Market	Notes, Explanation
Purchase Price	$500	$350	Economies of scale with increased market penetration
Installation Cost	$500	$50	New construction cost of installation
Total Cost	$1000	$400	
Incremental Cost	$1000	$400	

Market Barriers

1) Awareness seems to be universally low, among consumers, plumbers, builders, and code officials, even in rapidly growing areas with major water supply issues such as Arizona.
2) Education is needed. Builders need to learn that water delivery time matters to their customers. If they can't cluster hot water uses, they need to think in terms of distributed water heaters or outstanding recirculation systems to avoid dissatisfaction, even ignoring the energy penalty. We believe that few in the industry or among policymakers understand that timer-controlled recirculation pumps can increase energy use far more than the value of saved water (at regulated prices), while demand control can save both water and energy.
3) First cost premiums are always a barrier, particularly for auxiliary products. Ironically, the demand recirculation system is likely to be the least expensive way to adequately serve houses with widely separated water use centers, costing little more than timer-controlled systems in new construction, and much less expensive than adding a dedicated return line to an existing system.
4) Demand-actuated recirculation systems are distribution system components, not "widgets." This seems to be a barrier for programs like ENERGY STAR and WaterSense that are focused on energy-saving water heaters and water-saving fixtures, respectively. In turn, this helps keep the products invisible to consumers and the trades.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[206]
Average Price of Natural Gas	$11.52/MMBtu[207]
Projected 2025 End Use Electricity Consumption[208]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[209]	1.42 quads
Heat Rate	10.54 kBtu/kWh

[206] EIA. *Electric Power Monthly—Feb 2011*. Residential Price.
[207] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[208] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[209] Ibid.

Recommended Next Steps

Actual field data on the performance of the demand-based recirculating systems are rare; more are needed. In addition, much more effort is required to bring solid results to policymakers and the plumbing and construction industries. These efforts may be beyond the budgets of the manufacturers. ACEEE recommends seeking public entities (water utilities) that are capacity-constrained, to find larger-scale demonstration sites for the technology. This is needed to “bootstrap” the systems into acceptance for utility programs and recognition by groups like ENERGY STAR and WaterSense.

Although not urgent, it is time for manufacturers to consider developing performance standards. As popularity grows, there is some risk that low-quality, unsatisfactory “mimics” will come to market, and poison the well for good equipment. Standards might include capacity class, minimum efficiency (gpm/watt) at standard conditions, speed of shutoff when hot water reaches the fixture, or other parameters.

Commercial Point-of-Use Applications

Definition	Small point-of-use water heaters for office, school, and similar lavatory and eating area applications.					
Base Case	Residential-type electric tank water heaters, with distribution losses.					
New Measure	0.97 EF or equivalent with minimal distribution losses—located close to fixtures served. At least 50% *system* energy savings.	Percent Savings	2025 Savings TBtu (Source)	Installed Price	Cost of Saved Energy	Success Rating (1–5)
Current Market		51%	33	$(100)	$(0.04)/kWh	5
Mature Market		51%	33	$(300)	$(0.11)/kWh	5

Summary

In schools and commercial buildings that do not have large "process" hot water loads (laundries, health clubs, food service/commercial kitchens, etc.), central hot water systems typically waste more energy than they deliver to fixtures where hot water is used. These *system* losses are associated with long pipe runs between the water heater and the point of use, whether or not there is a recirculating loop between them.

Although data are limited, actual hot water use in lavatories can often be less than five gallons per day. If draws are sporadic, much more heat may be lost in pipes as they cool between uses. Available data suggest 51% savings are quite feasible by simply turning off central systems in many buildings and replacing them with very small point of use water heaters. Ironically, central hot water generation contrasts vividly with ubiquitous distributed chilled water service using the proverbial office water coolers for each floor or area. Why should small hot water uses be done differently?

Distributed POU water heaters also offer an important amenity: providing hot water to locations that previously did not receive it. The long pipe runs, short draws, and aerator-equipped fixtures that are prevalent in lavatories in commercial buildings result in sinks that rarely, if ever, receive hot water. Delivering hot water to these deficient fixtures can provide a number of benefits. With the water heater located in close proximity to the fixture, the temperature of the water heater can be lowered because transmission losses drop precipitously. In turn, standby losses approach zero because electric POU units typically house under a gallon of water within the heat exchanger. And with hot water readily accessible, fixtures provide greater comfort, which can lead to improved hand washing habits and better hygiene.

Background & Description

Across the sector, about 8%, or 0.5 Quad/yr. of North American commercial building energy use is for hot water service.[210] However, this varies enormously by building type: for education, it is about 7%, while it is only about 2% or less for non-mall retail, offices, and religious worship buildings.[211] Energy sources are about evenly divided between electricity and fossil fuels, with natural gas dominating the latter.[212] The median commercial building with a hot water system is ~10,000 sf. About ¾ are served by central hot water systems. The remainder is dominated by distributed systems, but about 5% have a combination of central and distributed systems.

Smaller buildings often use residential equipment[213] and residential-type distribution architectures, with trunks, branches, and twigs serving individual fixtures distributed around the building or in a central core. Larger buildings typically use recirculation loops, which may or may not have controls to limit pump hours.

[210] CBECS 2003, Tables E01 (non-mall) and E1a (all buildings)
[211] CBECS 2003, Table EO1 (non-mall)
[212] CBECS 2003, Table B31, Water-Heating Energy Sources
[213] C. Adams, personal communication, June 2, 2011 (e-mail).

This reflects the diversity of commercial buildings and applications. At one extreme are office, assembly, and many retail establishments. Their only loads may be lavatory and convenience cooking areas for lunch rooms. Few draws will be >1 gallon of hot water, drawn through a 0.5 or 1.0 gpm aerator. Total lavatory hot water use is frequently <5 gpd.[214] At the other extreme are facilities with significant process loads, such as food service, laundry, and some health care facilities. For these, typical service hot water needs are hundreds to thousands of gallons per day.

Over the past two decades, field and laboratory measurements, coupled with modeling, have shown the potential of alternative service hot water architectures that can save large amounts of energy while providing better user amenity. The keys are reducing the time wasted waiting for hot water, the energy wasted when hot water cools in the pipes between uses, and the electricity required for poorly controlled recirculation pumps. One substantial non-energy benefit is that having hot water available *at the tap* within 5 to 10 seconds encourages hand washing,[215] which may contribute substantially to reduced transmission of pathogens.

In a classic study of hot water use in Tennessee schools, Hiller determined that very large savings are possible where there is only incidental hot water use for hand washing and similar needs.[216] 24x7 demand loops are inappropriate for schools, which are typically unoccupied, with no hot water demand, more than ¾ of annual hours. Similarly, an office building used 10 hours/day, 5 day/wk., may only require service hot water 30% of annual hours. In one school, turning the recirculation loop off six hours/night saved 14% of the energy. Substituting conventional resistive tank water heaters at fixture clusters reduced site energy use 90%. Indeed, site energy use with these clustered water heaters was 2788 kWh, about the same as the 2614 kWh used by the pump for the prior recirculating loop. This suggests the magnitude of pumping energy required for the loop and the huge heat losses from long runs, even with insulated piping.

Gary Klein[217] has proposed building code provisions for service water heating architecture that can help determine when a point-of-use alternative may be appropriate. Effectively, if the piping connecting a fixture to the water heater holds more than 80 fluid ounces, a POU unit will be preferred. Similarly, if the pipe volume between a fixture and a recirculation loop has more than 24 oz. nominal volume, then POU is preferred.[218]

Of course, substantially changing distribution architectures in existing buildings is generally very difficult, with costs well above the benefits of quicker hot water availability and less energy and water waste. However, it may be cost-effective to install small point-of-use water heaters at each location where hot water is used, or all such locations that are far from the central water heater.

Such POU water heaters are most likely to be electric. Small gas water heaters are less likely to be considered, because running gas lines is generally more expensive than a new electric circuit, and gas appliances require venting that is not needed by electric ones. Since lavatories, convenience kitchens, and similar facilities are likely to be in building cores, venting can be very expensive.

Several electric approaches are possible, including:

- Small tank electric water heaters, generally smaller than 20 gallons. At present, tank water heaters smaller than 20 gallons are not NAECA products subject to efficiency regulation.
- Tankless electric water heaters small enough to be mounted under sinks.

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214 Hiller, Carl 2005. "Rethinking School Potable Water Heating Systems." *ASHRAE Journal*, 48 - 56

215 Klein, Gary, personal communication, HWF, May 2011.

216 Hiller, Carl 2005. "ethinking School Potable Water Heating Systems." *ASHRAE Journal*, 48 - 56

217 Mr. Klein (gary@aim4sustainability.com) supervised research in this area as a staff member at the California Energy Commission, and developed language under consideration by Code bodies.

218 Measuring the pipe volume can be done with a watch and a container of known volume, any time that the pipe leg is cool: Just measure the cold water volume delivered before the water reaches usable hot temperature, at maximum flow rate. 80 oz is about 50' of ½" nominal pipe, or 20' of ¾" nominal, not very long pipe runs in commercial buildings.

- Small heat pump water heaters, not currently on the market, that probably would use lavatory exhaust air as the principal heat source.[219]

For this write-up, we focus on well-controlled electric resistance POU water heaters. The technology is similar or identical to residential electric tankless water heaters. However, they may use different supply voltages (may be 277 v for larger commercial buildings instead of 230 v of single-phase systems). In general, units much smaller than 25 kW will suffice for lavatory or lunchroom applications.[220]

Data Summary Table

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Commercial	New		Water Heating	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized	1990		13	TSD, Table 8.7.1
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	0.96	EF	Formula for 5 gal storage as proxy	final rule
Electricity Use	555	kWh/yr	Assume 50% loss in distribution, 5 gpd, 55°F lift	
Summer Peak Demand	1.1	kW	Resistance WH, from New England Power, 1987, Table A-2	
Winter Peak Demand	1.7	kW	Resistance WH, from New England Power, 1987, Table A-2	
Fuel Use	—	MMBtu/ year		
New Measure Energy Use				
Efficiency	0.97			
Electricity Use	274	kWh/yr	EF adjusted, 50% distribution saved	ACEEE calcs.
Summer Peak Demand	0.9	kW	127 Apt, Cane Creek, FPL	D. Seitz
Winter Peak Demand	0.7	kW	Assume 70°F lift; 50°F in summer	Sachs
Fuel Use	—	MMBtu/ year		
Savings				
Electricity Savings	281	kWh/yr		
Summer Peak Demand Savings	0.2	kW		
Winter Peak Demand Savings	1.0	kW		
Fuel Savings	—	MMBtu/ year		
Percent Savings	51%			
Percent Feasible	50%		Estimate, from thinking about sinks/1000 sf	
Industrial Savings > 25%?	no			
Costs				
Incremental Cost	$ (100)	2010 $	unit, new circuit, installation (new construction)	
Mature Market Incremental Cost	$ (300)	2010 $		
Other Costs/ (Savings)	—	$/ year		
Ranking Metrics				
2025 Savings Potential (Site)	3,109	GWh		

[219] As a rough guide, 100 cfm of toilet room exhaust to meet indoor air quality requirements, with reasonable equipment efficiency, would heat tens of gallons/hr of water by 50°F—more than adequate for lavatory use and clean-up.
[220] Typical office suite kitchen area units can support 1 gpm aerator faucets with <10 kW.

2025 Savings Potential (Source)	33	TBtu		
Cost of Saved Energy	$ (0.04)	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
Mature Market Cost of Saved Energy	$ (0.11)	$/kWh		
Mature Market Cost of Saved Energy	—	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
More precise specifications for installation required	Hot water within a few seconds promotes personal hygiene by encouraging handwashing after lavatory use.		Manufacturer Promotion	Demonstrations Training ENERGY STAR Action
Likelihood of Success	5	(1–5)	Expect to become common for new commercial construction for spaces that need very little hot water; harder for retrofits (est. cost > $1000 for unit, circuit, installation.	
Priority	High	Low, Med, High		
Data Quality Assessment	D	(A–D)		
Principal Contacts				
Harvey Sachs, ACEEE				
Gary Klein, Gary@aim4sustainability.com				
Carl Hiller, chiller@cal.net				

Current Status of Measure

As noted in the note on point of use for residential applications in this series, there are hundreds of tankless models available currently, and annual sales are in the hundreds of thousands. However, those with inputs >12 kW are not rated under NAECA.[221] In addition, 10 gallon storage water heaters are commonly available.

Savings Potential and Cost-Effectiveness

The economic case for point of use water heaters for light-duty applications like lavatories and office suite convenience kitchens or lunch rooms is challenging because these applications use so little hot water. Nonetheless, with reasonable estimates of use and the waste associated with alternative central systems, we estimate that each unit will save on the order of 300 kWh/yr. In commercial installations in many regions, the value of saved electricity and reduced water consumption may approach $50/yr. If the installed cost of single point of use water heater in an existing building is only $1000 (including adding a circuit breaker and running a new electric supply line), then the cost of saved energy will be about $0.37/kWh, which is higher than the average cost of electricity almost everywhere in the US.

On the other hand, consider new construction. In the commercial sector, the definition generally includes new buildings, substantial additions (such as a new classroom wing), and extensive renovation (such as "fit-out" of a suite for a new tenant in a commercial office building). In any situation in which providing service hot water would involve pipe runs of more than 80 fluid ounces to a central water heater or 24 oz. to a recirculation loop, the point of use application will provide better service. In almost every case, it will cost less to install than the alternative central system (extension), because of the avoided hot water line. This and the energy savings lead to a small but significant *negative* cost of saved energy. That is, POU

[221] However, a large tankless point of use water heater cannot be very inefficient. For example, a 95% efficient 50 kW water heater would dissipate 2500 W through its case instead of into the water, which would get quite warm.

water heaters cost less than the mainstream alternative today. This is the argument for the Code provisions discussed above.

This measure is unusual in that the advantages of the emerging technology for the preferred applications are *not* driven principally by energy savings, but instead by reduced capital costs. Conversely, the very low energy use for these applications means that any installed cost above about $300 will have a cost of saved energy higher than average commercial energy costs.[222] Thus, because relatively little hot water is used in these applications (although there are millions of them), the national energy savings are relatively modest.

ACEEE estimates that product and installation costs will decline by a combined $200 per unit as POU water heaters gain market share. Mature market cost estimates are detailed in the following table:

	Current Market	**Mature Market**	**Notes, Explanation**
Purchase Price	$ 650	$ 500	No bulk purchase discount assumed
Installation Cost	$ (200)	$ (300)	Substitute electric line for hot water plumbing and insulation
Total Cost	$ 450	$ 200	
Incremental Cost	$ (100)	$ (300)	

Market Barriers

1) In the overall context of commercial construction, service hot water supply is a minor concern: the first cost impact is small, and the service hot water energy use is "trivial" as a fraction of total energy in sectors like offices. Further, client expectations are generally low, if expressed at all. So, the first barrier is just that the opportunity is invisible to decision-makers in the construction industry. This is why the buildings codes work is critical: it forces adoption of methods that can save money and energy.

2) Published ratings impede meaningful comparisons. Service water heating energy can be dominated by distribution losses, which are completely (and appropriately) ignored in water heater ratings. To do it right, designers need to think about the complete system, and how to serve needs better (such as hot water delivery delay time).

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[223]
Average Price of Natural Gas	$11.52/MMBtu[224]
Projected 2025 End Use Electricity Consumption[225]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[226]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

ACEEE believes that early adoption of building energy code language that limits the water volume in pipes between the hot water system and the use point is the greatest opportunity: it raises visibility of water heating system design options, gives easy ways to lay out very good systems, and is very likely to *reduce* first costs in almost every situation where POU is considered. Please note that our definition of

[222] Commercial electricity rates vary greatly with region and season, with the most recent monthly national average being in the range of $0.102/kWh. http://www.eia.gov/cneaf/electricity/epa/epates.html
[223] EIA. *Electric Power Monthly—Feb 2011*. Residential Price.
[224] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[225] EIA 2009. "Annual Energy Outlook 2010," Residential and Commercial Sector Key Indicators and Consumption Tables
[226] Ibid.

"POU" is not limited to small, hand-washing size tankless water heaters, but includes larger units appropriate for clusters of hot water uses distant from a central boiler. Fortunately, multiple code-writing bodies are exploring such requirements now, including ICC (IGCC, IECC) and ASHRAE (90.1,189).[227]

Additional field study data are important for establishing the actual operating cost differences between POU and central systems in commercial applications. Such data and case studies are required so manufacturers can justify marketing statements.[228] Field data are also essential as a basis for utility incentive programs to promote the products. For these programs, winter demand savings are likely to be as important as energy savings, in some cases.

[227] Gary Klein has been a foremost advocate of these provisions, as well as the analyst and author.
[228] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.

Multifamily Best Practices

Definition	Optimized service hot water systems for multifamily buildings that use central hot water systems with recirculation loops					
Base Case	"As found" system with gas boilers and 'smart' loop control in large (300 unit) apartment building, with controls in place					
New Measure	Optimized system in same building; no capital investment	Percent Savings	2025 Savings TBtu (Source)	Installed Cost	Cost of Saved Energy	Success Rating (1–5)
Current Market		25%	179	$43.75/yr	$0.003/kWh	5
Mature Market		25%	179	$30.00/yr	$0.002/kWh	5

Summary

Multifamily buildings are generally characterized by central tank water heaters (or boilers) with recirculation loops. Each branch from the loop serves one or several apartments. In many cases, less than one third of the site energy is actually delivered to the fixtures.[229] The rest is lost at the water heater (combustion and standby) and in the recirculation loop. Proper operation and maintenance, and improved controls, can improve performance by 15% to 30%. For new installations, choosing high efficiency equipment, placing the water heater(s) as near as possible to demand locations, and properly insulating the recirculation loop can dramatically reduce losses.

Background & Description

In this report, the term “multifamily” (MF) means buildings with five or more apartments.[230] In the US, there are more than five single-family attached and detached households for every household in a multi-family apartment building with five or more units: Approximately 16.7 million multifamily, vs. 87.5 million single-family detached and attached (plus 6.9 million mobile homes).[231] It is thus expected that the multifamily housing stock (including its hot water systems) has received less attention from building scientists than most other housing types.

Work during the past decade suggests that multifamily dwellings and their service hot water systems (SHW) warrant attention for both technical and socio-economic reasons. An overwhelming fraction of these buildings (over 90%) use central hot water systems, generally employing a single boiler or water heater[232] and a pumped circulation loop to serve the apartments.[233] A “bad” MF SHW delivers about 1/3 of the site energy to the hot water serving fixtures, while a “good” one will deliver over 1/2.[234] In other terms, the “delivered efficiency” of four systems studied varied by a factor of two, from 23% to 49%.[235] At the low end, the source energy use of individual apartment electric resistance water heaters would be

229 Bonneville, Charlotte 2010. Central Domestic Hot Water Systems in Multi-Family Buildings. ACEEE Hot Water Forum presentation. Session 3C. http://aceee.org/files/pdf/conferences/hwf/2010/3C_Charlotte_Bonneville.pdf

230 Buildings with fewer apartments are typically built like single-family houses, and use residential equipment for space conditioning and water heating.

231 RECS 2005, Table HC2.1 Housing Unit Characteristics by Type of Housing Unit. We exclude mobile homes from these data. http://205.254.135.24/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html

232 RECS 2005, Table HC2.8 Water Heating Characteristics by Type of Housing Unit. http://205.254.135.24/emeu/recs/recs2005/hc2005_tables/detailed_tables2005.html

233 This is typically a dedicated service hot water boiler or water heater. In the East, service hot water needs may be supported by an indirect storage tank, with water heated by the main boiler, or other arrangements using the heating boiler. Brooks, Andy. 2011. Domestic Hot Water Assessments in Multifamily Buildings. ACEEE Hot Water Forum, Session 3C, http://aceee.org/files/pdf/conferences/hwf/2011/3C%20-%20Andrew%20Brooks.pdf

234 Zhang 2009. Multifamily Recirculating System Study, Controls. ACEEE Hot Water Forum, Session 2B. http://aceee.org/files/pdf/conferences/hwf/2009/2B-Multifamily2-Zhang.pdf

235 Bonneville, Charlotte 2010. Central Domestic Hot Water Systems in Multi-Family Buildings. ACEEE Hot Water Forum presentation. Session 3C. http://aceee.org/files/pdf/conferences/hwf/2010/3C_Charlotte_Bonneville.pdf

less than the present gas systems, despite the ~3:1 source to site energy conversion factor for electricity.[236]

Statistically, apartment units use about 57% as much energy for water heating as single-family housing.[237] However, this has wide variability: one study reports average hot water energy use of 210 therm/unit-yr, with a range from 99 to 515 therms/yr.[238]

Ironically, the distribution losses in central systems in MF housing are roughly comparable to those in SF housing with conventional non-recirculating "trunk and branch" distribution systems.[239] That is, a good (well designed and well-insulated) MF recirculation system can have system standby losses comparable to distributed systems characteristic of single-family housing.[240] With a single-family system, there are few control options other than changing the hot water supply temperature, increasing it when there are complaints of inadequate hot water supply. MF buildings are more complicated: occupants can't control the supply temperature; an operating engineer or maintenance employee or contractor responds to complaints, usually by increasing the supply temperature. Of course, this increases energy waste, because the higher temperature in the storage tank means higher standby losses—and much higher radiative/convective losses from the continuous circulation loop.

In addition, field monitoring has discovered other significant energy losses related to recirculation. For example, the design of many single-level faucets allows "crossover,"[241] the movement of hot water into the cold side. Crossover may account for 5% to 10% of hot water energy use.[242] This can be large enough to repay batch faucet cartridge replacement costs in as little as five months.[243]

SHW in multifamily buildings have been considered excellent candidates for utility programs addressing energy waste. Unfortunately, early efforts focused on retrofit with improved controls achieved much smaller savings (on average) than forecast.[244] And field studies consistently find systems plagued by design and installation errors, such as missing insulation, water leaks, and piping errors.[245] In one study, all of the 139 MF sites studied had at least one system fault, and generally speaking, fixing these was outside the scope of controls installations for utility programs.[246] Building operators rarely have the skills to "tune" the circulation controls to minimize energy loss, instead of just increasing the supply temperature, and few MF buildings (5% in one study) have maintenance contracts that would assure proper monitoring and upkeep.

Stone (2008) concludes that MF hot water systems require both care in design and continuing monitoring, because components fail, often in ways that are not obvious but can cause enormous energy waste. Specialist contractors may be warranted, just because the controls are too complex to just be treated as thermostats or "widgets."

[236] One such approach, Electric Tankless Water Heaters (ETWH) is written up in this series.
[237] RECS 2001, Table CE4-4c; 12.4 MMBtu/yr (gas) vs. 21.8 MMBtu for SF houses.
[238] Offerman, Dawn 2010 Session 4c, slide 5. A Multifamily Energy Efficiency Solution. http://aceee.org/files/pdf/conferences/hwf/2010/4C_Dawn_Offerman.pdf
[239] Sachs and Talbot 2011, this report, Residential Point-of-Use (POU) Electric Water Heaters, pg.7, gives derivation of an estimate.
[240] Zhang, Yanda, ACEEE Hot Water Forum 2009 Session 1B. Multifamily Central Domestic Hot Water Systems: Central v. Distributed Architectures, http://aceee.org/files/pdf/conferences/hwf/2009/1B-Multifamily1-Zhang.pdf
[241] Howlett 2008. Getting Hot Water—Multifamily Technologies Sacramento. ACEEE Hot Water Forum, Session 4B. http://aceee.org/files/pdf/conferences/hwf/2008/4b_howlett.pdf
[242] Stone 2008 Central Domestic Hot Water System Study Within SoCal Gas' and SDG&E's Multifamily Energy Efficiency Rebate Program. ACEEE Hot Water Forum, Session 4b. Gutierez, G. and Woo, K. 2008. Hot Water Recirculating System Study. ACEEE Hot Water Forum, Session 4B. http://aceee.org/files/pdf/conferences/hwf/2008/4b_woo-gutierrez.pdf
[243] Pfaff, Terry 2009. Cross Over Historical Analysis The effect on energy efficiency and hot water system operation. ACEEE Hot Water Forum presentation. Session 1B. http://aceee.org/files/pdf/conferences/hwf/2009/1B-Multifamily1-Pfaff.pdf. Typically 5 month payback for batch replacement of all cartridges.
[244] Stone 2008 *op. cit.* Session 4B.
[245] Stone 2008 *op. cit.* Session 4B.
[246] Stone 2009, ACEEE Hot Water Forum Session 1b Multifamily CDHW Control: QC Manual and Training. http://aceee.org/files/pdf/conferences/hwf/2009/1B-Multifamily1-Stone.pdf

If operators don't understand advanced controls, they will defeat them and manually raise the tank temperature and/or set the recirculation pump to run full-time to respond to tenant complaints. We draw two inferences from this observation: First, designers must keep the ultimate client, a building operator, in mind when designing MF hot water systems. As important, it again suggests that a third party contractor who can "tune" and remotely monitor system energy use and performance may be very cost-effective.

Thus, although multifamily hot water systems are largely ignored if tenants are not complaining too much, they may have significant opportunities at many levels:

- Better water heaters for new construction and replacements. Depending on local situations, these could range from commercial heat pump water heaters to condensing gas units. It remains to be seen whether distributed water heaters would provide better service at lower life cycle cost, but this argument has been advanced for electric tankless water heaters.[247]
- Where recirculating loops are used, large savings are achievable. Brooks notes NYSERDA findings of 6% to 11% just from controlling the pump. It does require proper controls of flow rates and timing, and well-timed responses to changes in usage through the day. Zhang[248] has shown loop losses that vary 10-fold between systems, between 4 and 43 kWh/day. However, where hot water is provided as an auxiliary service by the heating boiler, some mixing valves for temperature control may require constant pumping.[249]
- System architecture matters, to minimize loop lengths, and to control pressure differences and problems such as cross-flow.

An important message from this is that continuing monitoring and maintenance—human factors—are keys to reduced waste and improved performance.[250]

Multifamily hot water opportunities also have a social context that may be important to public benefits programs, too. Although multifamily dwellings serve a very broad range of constituencies, on average their occupants pay a high fraction of their income for housing. Stone (2008) reports that the average multifamily household pays 30% of its income for housing, while the burden is only 22% for single-family households.

Data Summary Table

Market Sector	Market Application		End Use	Fuel Type
Residential	New or Retrofit		Water Heating	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized	2008		15	Hot Water Forum Pres.'s
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	—	Therms/apt-yr	Sidebar: derived from savings	Seidel, HWF 2009
Electricity Use	43	kWh/yr-apt.	Assume 2 hp pump, constant	ACEEE
Summer Peak Demand	5.0	watts		
Winter Peak Demand	5.0	watts		
Fuel Use	—			

[247] This is mentioned in Sachs and Talbot 2011, this report, Electric Tankless Water Heaters.
[248] Zhang, Yanda, ACEEE Hot Water Forum 2009 Session 1B. Multifamily Central Domestic Hot Water Systems: Central v. Distributed Architectures, http://aceee.org/files/pdf/conferences/hwf/2009/1B-Multifamily1-Zhang.pdf
[249] Brooks, Andy. 2011. Domestic Hot Water Assessments in Multifamily Buildings. ACEEE Hot Water Forum, Session 3C, http://aceee.org/files/pdf/conferences/hwf/2011/3C%20-%20Andrew%20Brooks.pdf
[250] Stone 2008 (session 4B)

New Measure Energy Use				
Efficiency	—	therms/apt	savings-based	Seidel, HWF 2009
Electricity Use	4.3	kWh/yr-apt.	assume 10% pumping time	Seidel, HWF 2009
Summer Peak Demand	0.5	watts	assume 2x coincidence over av.	
Winter Peak Demand	0.5	watts	assume 2x coincidence over av.	
Fuel Use	—	MMBtu/year		
Savings				
Electricity Savings	39.1	kWh/yr-apt.		
Summer Peak Demand Savings	4.5	watts		
Winter Peak Demand Savings	4.5	watts		
Fuel Savings	—	MMBtu/year		
Percent Savings (gas)	25%			
Percent Feasible	15%		Percentage of housing units located in multifamily buildings of 5 units or more	RECS 2005, Table HC 2.1
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	—	2010 $		
2025 Mature Incremental Cost	—	2010 $		
Other Costs/ (Savings)	$ 43.75	$/ year	Service contract for 25% savings	
Mature Other Costs/ (Savings)	$ 30.00	$/year	Service contract for 25% savings	
Ranking Metrics				
2025 Savings Potential (Site)	16,962	GWh		
2025 Savings Potential (Source)	179	TBtu		
Cost of Saved Energy	$ 0.003	$/kWh		
Cost of Saved Energy	—	$/MMBtu		
2025 Mature Cost of Saved Energy	$ 0.002	$/kWh		
2025 Mature Cost of Saved Energy	—	$/MMBtu		

Unusual Market Barriers	Non-Energy Benefits	Current Activity	Next Steps
More precise specs for installation required AC Rating methods do not reflect efficiency gains			Research & Development Incentives Standards & Codes

Likelihood of Success	5	(1–5)
Priority	High	Low, Med, High
Data Quality Assessment	C	(A–D)

Principal Contacts
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Current Status of Measure

Several firms offer commercial services now to diagnose, optimize, and remotely monitor hot water systems for multi-family buildings. The state of the art seems to build on the following sequence:

1. Bring the system to its "as designed" condition, undoing installation variances and operational changes made to keep the system running, albeit poorly.[251]
2. Diagnose the system, determining energy input, hot water supply and return temperature and volume. For example, if the return flow to the water heater is comparable to the SHW supply flow, this indicates substantial cross-flow between the hot water and cold water lines.
3. Where there are single-lever faucets, the diagnostics may reveal substantial cross-flow between the hot and cold service lines, because of failed cartridges. Replacing all fixture cartridges as a batch process may have 5 month payback when done, although there is some uncertainty about how long replacement cartridges will last.[252] Replacing the cartridges is one part of restoring the system to the designed configuration.
4. Implement improved control strategies that include using the smallest feasible water heater, circulating hot water at the lowest temperature that supports the instantaneous load, and using temperature-based demand control for the circulation pump(s). In some cases, flow rate changes may be warranted.

Savings Potential and Cost-Effectiveness

The major strategies for improving efficiency in existing buildings:

Demand control of the recirculation loop can reduce gas consumption by 15%, compared with savings in one studied building of 9% for a simple pump timer and 10% for loop temperature modulation.[253] A demand-controlled pump will only run 1 to 2 hr/day while supporting 24 hour hot water service, and can save 17% of hot water energy.[254] The pump control should sallow the pump to run only when there is demand for hot water, or the hot water temperature is too cool.

Monitoring and Commissioning. In one case study of a 300 unit apartment tower, a contractor approached the problem as "commissioning with data."[255] The program starts with instrumented monitoring of the system as operated by the owner. In the case study, this identified large problems with cold water intrusion, that the second boiler was malfunctioning, and that the existing "smart" control was erratic. Phase two disabled the smart controller, to determine baseline performance with the aquastat (water loop thermometer) only. This helped isolate problems (such as the malfunctioning boiler), and establish baseline system efficiency. Only after all of this work did the contractor begin to tune the system. For example, running one pump continuously uses additional electricity, but in this case reduces much more wasteful cold water intrusion. Monitoring continued, to spot problems as they occurred. Savings of 37%, or 17,500 therms/yr, were claimed.

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[251] Stone 2008 Central Domestic Hot Water System Study Within SoCal Gas' and SDG&E's Multifamily Energy Efficiency Rebate Program. ACEEE Hot Water Forum, Session 4b. Gutierez, G. and Woo, K. 2008. Hot Water Recirculating System Study. ACEEE Hot Water Forum, Session 4B. http://aceee.org/files/pdf/conferences/hwf/2008/4b_woo-gutierrez.pdf

[252] Pfaff, Terry 2009. Cross Over Historical Analysis The effect on energy efficiency and hot water system operation. ACEEE Hot Water Forum presentation. Session 1B. http://aceee.org/files/pdf/conferences/hwf/2009/1B-Multifamily1-Pfaff.pdf

[253] Bonneville 2010 Session 3C, slide 12. Central Domestic Hot Water Systems in Multi-Family Buildings. ACEEE Hot Water Forum presentation. http://aceee.org/files/pdf/conferences/hwf/2010/3C_Charlotte_Bonneville.pdf

[254] Offerman 2010, Session 4C, slide 9. A Multifamily Energy Efficiency Solution. http://aceee.org/files/pdf/conferences/hwf/2010/4C_Dawn_Offerman.pdf

[255] Seidel, Jim 2009. Commissioning With Data: A case-Study Demonstration of the Value of Data, Feedback, and Analysis in Optimizing Boiler Operations. ACEEE Hot Water Forum, Session 2B. http://aceee.org/files/pdf/conferences/hwf/2009/2B-Multifamily2-Seidel.pdf

	Current Market	Mature Market	Notes, Explanation
Purchase Price	N/A	N/A	
Maintenance Cost	$ 43.75/year	$ 30.00/year	Contractor experience
Total Cost	$ 43.75/year	$ 30.00/year	
Incremental Cost	$ 43.75/year	$ 30.00/year	

Market Barriers

1) Multifamily owners and facility managers are far more concerned with tenant satisfaction than hot water system design and optimization. Relative to risks (tenant retention) the benefits are small: Although ACEEE estimates of the energy savings in aggregate are substantial—in the range of $50,000/yr for a 300 unit complex, that's only $3 to $5 per apartment per month, in the range of 1% or much less of apartment revenue. Do the potential benefits justify a substantial investment of management time, and what are the potential returns on investment (beyond the small value of the energy savings)?
2) Similarly, given the small stakes, owners are wary of "snake-oil" salesmen who promise infinite savings for zero investment (shared savings)—they are highly skeptical about the proverbial $20 bills lying on the sidewalk. How could their facilities people—the best they could find with their budgets—possibly be doing such a poor job? This is particularly true because of the large perceived negative consequences of less satisfied tenants (or condominium owners as an association).
3) Lack of awareness has slowed the development and implementation of utility and other public benefit programs that could address these barriers, both through funding and through the investment of their own credibility.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1158/kWh[256]
Average Price of Natural Gas	$11.52/MMBtu[257]
Projected 2025 End Use Electricity Consumption[258]	0.53 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[259]	1.42 quads
Heat Rate	10.54 kBtu/kWh

Recommended Next Steps

ACEEE finds that enough field research and early commercialization has taken place to warrant widespread propagation of techniques to optimize service hot water systems in multi-family projects. The first element, one requiring modest funding, is just increasing awareness by publication of case studies in the trade press that owners and facility managers read and trust. These include the National Multi-housing Council[260] and corresponding state and local associations of apartment owners. The technical "aura" of ASHRAE publications may be useful. Presentations at apartment and condominium conferences are essential, and should build on documented case studies.[261]

These publications are also the basis for moving public benefit programs from the research phase to operating programs in the field. They should become a commonly used arrow in the quiver for utility and public benefits account representatives. And, program experience should be evaluated for improvement and sharing the lessons learned.

[256] EIA. *Electric Power Monthly—Feb 2011*. Residential Price.
[257] EIA. *Natural Gas Monthly—March 2011.* Residential Price.
[258] EIA. 2009. *Annual Energy Outlook 2010,* Residential and Commercial Sector Key Indicators and Consumption Tables
[259] Id.
[260] National Multi Housing Council, http://www.nmhc.org/
[261] It is left to the reader to judge whether aggregating studies like this one are useful in advancing the cause.