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Permit Prescriptive Use of Instantaneous Electric Water Heating in Distributed, Point-of-Use and Ultra-Low-Flow Applications

Additional submitted attachment is included below.

Permit Prescriptive Use of Instantaneous Electric ("IE") Water Heating in Distributed, Point-of-Use and Ultra-Low-Flow Application under California Building Energy Code

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Executive Summary

California's Building Energy Code should allow in a prescriptive use, in distributed, point-of-use and ultra-low-flow applications, of instantaneous electric ("IE") water heaters as an alternative to heat pump ("HP") water heaters.

Reasons for this are as follows:

1. IE has similar overall system efficiency to that of HP in many applications, greater in some applications.
2. IE has low impact on peak electric grid load as does HP.
3. IE offers advantages to homeowners in terms of saving space and providing more prompt water temperature changes and lower water use.
4. For those homeowners switching from instantaneous gas, there are disadvantages, financial cost and loss of space if HP is used instead of IE.
5. IE eliminates noisy and unattractive exterior HP condensers used with many HP units.
6. HP units are not ideal for separate Accessory Dwelling Units (ADUs), as the commonly available HP units are oversized and less efficient for an ADU, with the space limits much greater for an ADU, and noise and appearance concerns greater as separate ADUs reduce home separation. An IE avoids these problems.
7. Disfavoring IE would limit technological and product innovation.
8. Installed costs of IE versus HP are similar.

The reasons above are supported below by research studies, manufacturers' data, system design constraints and field measurements detailed in the body of this paper.

As California continues and furthers its leadership in energy efficiency, reduction of greenhouse gas production, solar and wind production, and building electrification, it should encourage all technologies that contribute and not favor one over others. As such, it is crucial that California encourage use of IE in the applications where IE is roughly as efficient, on a systems and in-field basis, as HP. Failing to do so will lessen innovation and hamper efforts to reduce energy and greenhouse gas emissions.

California could essentially guarantee that IE has similar energy use to that of HP systems by several requirements for IE installation, such as all of these (although the most significant of such measures are often nearly necessitated by the low-flow and high instantaneous maximum current draw of IE, as described in detail in Section 2.2.2 below):

1. Installation of ultra-low flow faucet aerators (for example, perhaps maximums of 1 gpm for kitchen, laundry and utility room sinks, and 0.75 gpm for bathroom and other sinks) and shower heads (maximum of 1.25 gpm) with IE;
2. IE systems must be distributed and point-of-use, with all hot water pipe runs limited to 10 feet from each IE unit to the farthest hot water usage fed by that IE unit;
3. A limitation on the maximum kW of power drawn for IE within a home based on the number of bedrooms as a proxy for a reasonable number of showers. The limit could be, for example, 12kW plus an additional 12 kW for each additional bedroom;
4. The home must have sufficient annual photovoltaic solar electricity energy production in excess of the annual electrical energy use by the home, including the IE system to be installed;
5. The efficiency of all IE units must be 99% or more;
6. All IE units must be installed within the heated and insulated portion of the home (ie, within the conditioned building envelope);
7. All IE hot water pipes must be insulated to at least the R-2 level (or higher levels, as otherwise required by code).

While current California building code permits the use of IE, this is done via the performance-based approach, which is often quite onerous for the home or property owner (or contractor or architect) in requirement extensive energy usage analysis (even whole-house analysis) for building permit applications. HP, on the other hand, qualifies for the very easy prescriptive building permit application approach. To level the playing field and encourage multiple meritorious technologies, IE should also get prescriptive-based treatment, subject to reasonable limitations such as those outlined above.

Finally, it is a commonly held view that heat pump (HP) water heaters are far more efficient than instantaneous electric (IE) water heaters. To avoid the need for the reader to plow through the long analysis in the following body of this paper to understand why HP units actually use similar amounts of energy as do IE units, here is a quick summary of the reasons:

1. The manufacturer stated COPs (coefficient of performance) for HPs are overstated, with the federal mandated and more accurate UEFs (uniform efficiency factors) significantly lower.
2. Field conditions, tank heat losses, pipe heat losses and stranded hot water losses add to efficiency reductions for HP.
3. The very large HP tanks have the highest UEFs, with lower UEFs and efficiencies for the more typical residential tank sizes in California.
4. When adjusted for California climate conditions, the efficiency of HPs drop.
5. Efficiency of HPs drop further when the HP condenser is installed in a confined space and when household hot water use is low.
6. IE systems have no tanks to lose heat and tend to be distributed, point-of-use systems with short pipe runs, much reducing pipe heat losses and stranded water heat losses.
7. IE systems do not lose efficiency as a result of climate conditions, level of household water use or confinement into small spaces.
8. IE systems make necessary ultra-low flow devices, much reducing hot water use.

0. Review of this White Paper and Comments on Use of IE.

This paper was reviewed, in part or in full, by several, including Amory Lovins (cofounder and Chairman Emeritus of Rocky Mountain Institute), Glenn Friedman (Principal of Taylor Engineering, which has done analysis for the State of California to assist it in developing building code changes), Imran Sheikh (Professor at Western Washington University focused on water and space heating electrification in California), Garrett Keating (Piedmont Connect board member and Environmental Scientist at Lawrence Livermore National Laboratory), and Tom Webster (Piedmont Connect board member, and retired Project Scientist at University of California at Berkeley focused on building technology, design and operation). Of these reviewers, three, Amory, Glenn and Imran seemed to read and comment on the entire paper, with others just focusing on the early part, perhaps just the summary. Also, I discussed use of IE with a leading expert and proponent of heat pump hot water heating, Carl Hiller (President of Applied Energy Technology Inc.).

For most comments, I merely incorporated them into the body of this paper. But I will provide a summary of some overall aspects of the comments here, as well as comments that have substantial bearing on the central conclusions of this paper. Below is this feedback and my thoughts on this feedback:

Many agreed that there are circumstances where IE makes more sense than HP, especially where there is not adequate space for a water tank, and in low usage (low hot water volume, or infrequent hot water use) applications far from any high and frequent use application. As such, in the view of many of these reviewers, IE might be the best option for separate accessory dwelling units (ADUs) and for a sink or shower in a larger home separated by some distance from the location of a central HP water heating unit.

Nearly all of those consulted with indicated that they thought that the reliance of this paper primarily on using ultra-low flow faucets and showers to bring IE close to parity with HP in energy use is inappropriate given that such ultra-low flow devices could also be used with HP systems. My response to this is several-fold. First, virtually no one uses or even knows of ultra-low flow devices and none would have motivation to seek these devices out without IE. IE's hot water output is so low as to effectively require the use of ultra-low flow devices. Second, many folks already feel that they are being very water efficient by using the relatively recently mandated (here in California) low flow water devices. In fact, many complain about these low flow devices, sometimes effectively going around these restrictions by changing plumbing after inspection or by installing two shower heads in one shower. As such, it would unlikely that many would go beyond what is mandated (low-flow), when many or most view that as already too restrictive, unless driven my necessity, such as in an IE system. Third, use of ultra-low flow devices with a centralized HP system is generally not practical, as the long pipe runs in a central system mean that the wait time for hot water would be 2 to 4 times longer with ultra-low flow devices. With a distributed, point of use IE system, this delay is short even with ultra-low flow devices as the pipe runs are very short. Fourth, while there are a number of ultra-flow faucet aerators available for standard sink threads, many have sinks lacking such standard threads. Thus, ultra-low flow faucets are not available for many sinks, including many high-end modern sinks increasingly common in California. Fifth, there are few ultra-low flow shower heads available and only from small, niche manufacturers. I could find only two small suppliers (Bricor, with shower heads with flow rates as low as 0.625 gpm, and Niagara/AM Conservation Group with flows down to 0.5 gpm) after much searching. There is another company, Nebia, a venture capital backed startup making a system. But the system has several drawbacks, such as its high cost (up to $499) and insufficient water flow except for the head area. If you add in the second shower head to make up for the inadequate flow for below the head area, the flow rate rises to 1.54 gpm (from 1.26 gpm) for the low-cost version and 1.3 gpm (from 0.9 gpm) for the most expensive version.

Amory Lovins indicated that heat pumps with a COP of 12 may be available from a US startup company within five years, and that such an HP system is already available in Switzerland from BS2 (bs2.ch). He also indicated that currently some HP units are available in the US from major manufacturers with

COP/UEF higher than those on the California prescriptively approved list, but I have not been able to find these units. In any case, the prescriptively approved list of HP water heaters are the ones assumed below, and most homeowners are likely to choose one of these rather than pay to have an expensive and extensive whole-house performance-based energy analysis done to use a unit. Moreover, with respect to higher COP/UEF units in the future, it is not clear if they will be cost efficient to purchase or will become widely available in the US.

Amory also indicated that there are some HP units with UEF higher than those on the HP units prescriptively approved under the California building code. Homeowners in California are less likely to use HP units not on the prescriptive list, however, as the other approval method, via a performance calculation, is more complex and expensive. Nonetheless, there do appear to be some widely available HP units with UEFs above the range of 2.8 to 3.4 for those prescriptively approved in California, specifically, some 40 to 65 gallon tank units with UEF up to 3.7, and some larger tank size with UEFs up to 4.0.

Despite most reviewers differing with certain assumption as described above, none of the reviewers disputed the approximate overall conclusions of this paper if such assumptions were accepted.

Here is one notable quotation from a notable heat pump water heating advocate (he was not able to review the paper), regarding only permitting only heat pumps for hot water heating:
"I am aware of the push toward eliminating all other water heating options except heat pumps. I am a strong proponent of heat pumps. In fact I did my PhD work on heat pumps. However, we have an array of different water heating options for a reason - each one is the best option for some types of applications. Trying to make heat pump water heaters the only option is like trying to put square pegs in round holes - they are simply not always the best option, from a variety of viewpoints, including environmental. In the long run it would be good to see more heat pump water heaters used, but they cannot and must not be made to be the only option. That would be foolish at many levels." – Carl Hiller, President of Applied Energy Technology Inc.

1. Regulatory framework

1.1. Federal Regulations

It appears that instantaneous electric water heaters in residences cannot be barred by state or local law if they meet the federal "residential-duty commercial water heater" standards, which merely require that the unit have between 12 kW and 58.6 kW of power usage and no more than 2 gallons of water storage and with efficiency of at least 80%. [FN 1.1.1]. Under federal law, states and local governments are generally preempted from having energy efficient standards different from federal unless an exemption is granted. [FN 1.1.2]. Even the California residential guide to Title 24 appears to confirm this, stating that "residential-duty commercial water heaters" effectively meet the prescriptive approach to qualification, exempting them from the much more onerous performance approach to qualification under the California Title 24, Part 6 energy efficiency code. Also, this California residential Title 24 guide indicates the 12 kW minimum does not apply. [FN 1.1.3] It is possible that a separate set of federal regulations require higher efficiency of 91% to 92% for residential IE water heaters. [FN 1.1.4] Nonetheless, for IE units that I have seen meet this requirement with substantial margin.   I am not aware of any residential IE with power higher than 36 kW or efficiency lower than 80% (or even 97%).

My units are all 99% efficient and have not more than 24 kW of power each (and less than 58.6 kW for all IE units combined).

FN 1.1.1. https://www.ecfr.gov/cgi-bin/text-idx?SID=a69096e892b13c204bbe6da3a92f8111&mc=true&node=se10.3.431_1110&rgn=div8

FN 1.1.2. https://www.nrdc.org/experts/lauren-urbanek/states-step-progress-efficiency-standards ; https://www.energy.gov/eere/state-petitions-exemption-federal-preemption ; and https://www.bayrencodes.org/reachcodes/legal-requirements-for-reach-codes/

FN 1.1.3. See Section 5.2.2.3 of https://ww2.energy.ca.gov/2018publications/CEC-400-2018-017/chapters/05-WaterHeating_Requirements.pdf

FN 1.1.4. https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8 .

1.2.California Regulations

Title 24, Part 6 of the 2019 California Code provides for two methods of qualification for a home system. The first is prescriptive, where certain systems are approved by their own nature. The second is a performance standard, whereby a whole house energy analysis must be done and the proposed new home system (such as water heating) must be shown not to upset the home energy budget. This second option is far more difficult and costly, and would appear to be the only option for instantaneous electric water heating (ignoring the apparent federal preemption discussed above). [FN 1.2.1]

FN 1.2.1. Section 150.1 of https://ww2.energy.ca.gov/2018publications/CEC-400-2018-020/CEC-400-2018-020-CMF.pdf ; See Section 5.2.1, 5.2.2.3, 5.5, and 5.6.2; Tables 5.1, 5.4 and 5.5 of https://ww2.energy.ca.gov/2018publications/CEC-400-2018-017/chapters/05-WaterHeating_Requirements.pdf)

2. Detailed Analysis of Heat Pump versus Instantaneous Electric Water Heater Efficiency

2.1. Heat Pump Water Heater Efficiency

In summary, the manufacturer stated coefficients of performance (COPs) for heat pumps far overstate actual heat pump (HP) efficiency, generally by factor greater than 2. COPs are used in marketing, so consumers and others tend to focus on them, but they are not regulated or calculated under standard conditions from manufacturers and are measured in laboratory, not in the field. The Uniform Efficient Factors (UEFs), mandated by Federal law, measured consistently under standards and account for tank heat losses, are significantly lower than COPs. Further, Field Efficiency Factors (FEFs), which are taken in the field and include pipe heat losses, are lower yet. Finally, actual California in-home efficiency is reduced even further by numerous other factors, including temperature and humidity conditions in California, stranded hot water losses, smaller tanks sizes typically used in California, lower efficiencies of heat pump in low water use households, and confined spaces for single unit heat pump systems (single unit systems can avoid the confined space inefficiency by using ductwork to access outside air, but this adds installation expense and may not be practical depending on the situation). As a result, while COPs are often stated to be 3 or 4 or higher, the actual in-home efficiency of a heat pump water heater varies from between a bit over 1 to a bit under 2, compared to the efficiency of about 1 (typically .98 or .99) of instantaneous electric water heaters, even before applying other factors that significantly reduce the relative effective energy use of instantaneous units.

2.1.1. Actual COP is lower that manufacturer stated COP

Heat pump water heaters (HP) often have a manufacturer stated coefficient of performance (COP) over 3, implying that they are over 3 times as efficient in converting electricity to hot water than a 100% efficient electric resistance water heater. But in practice, the measured COP in the field is lower for HP is lower, typically about 2, but often lower in climates similar to that of much of California.[FN 2.1.1.1, 2.1.1.2, 2.1.1.3] But COP measurements between manufacturers are not comparable because there is no mandated standard for measurement of COP, resulting in manufacturers using different measurement techniques. [FN 2.1.1.4]. Indeed, manufacturers may tend to measure COP in a manner most favorable to their heat pump units to assist with marketing and sales, which would result in COPs being overstated.

FN 2.1.1.1. Electric Power Research Institute field measurements at 4 locations, mostly in the southeast US, showing COP in the range of 0.7 and 2.7, with an average and median below 2, even when monthly average temperatures exceeded 70 degrees F for each of the 3 heat pump models tested. Amarnath, A., and J. Bush. 2012. "Heat Pumps Water Heaters: Field Evaluation of New Residential Products" Presented at ACEEE Hot Water Forum. May 21–23, 2012. https://www.aceee.org/files/proceedings/2012/data/papers/0193-000013.pdf

FN 2.1.1.2. PG&E field measurements in Sonora, CA showing COP of 1.29 for heat pump water heaters at average air intake temperatures of 68.6 degrees F. Hu, S., and R. Davis. 2011. "PG&E Field Study on Heat Pump Water Heaters." Presented at ACEEE Hot Water Forum. May 10, 2011. Cited in https://www.nrel.gov/docs/fy16osti/64904.pdf .

FN 2.1.1.3. Most current heat pumps for water heating have actual COP between 1.8 and 2.5. H Willem, Y Lin, A Lekov (Lawrence Berkeley National Laboratory; Review of energy efficiency and system performance of residential heat pump water heaters; Energy and Buildings, volume 143, 15 May 2017, Elsevier. https://www.sciencedirect.com/science/article/abs/pii/S0378778817304760 ; https://doi.org/10.1016/j.enbuild.2017.02.023 .

FN 2.1.1.4. https://www.energyguide.com/library/EnergyLibraryTopic.asp?bid=austin&prd=10&TID=17239&SubjectID=8374

2.1.2. UEF is significantly lower than COP

There is a US Department of Energy does mandate standards for measure of the unified energy factor (UEF) for HPs via a 24-hour test methodology including tank losses. This standard requires these conditions: an intake temperature (outside temperate for split system where the condenser is placed outside of the home) of 65 to 70 degrees F, water input temperature of 56 to 60 degrees F, humidity of 48% to 52%, and water discharge temperature of 120 to 130 degrees F. [FN 2.1.2.1]

Let us consider one example, the highly efficient Stiebel-Eltron Accelera 220E and 300E HP units. At air temperature of 68 degrees F, incoming water temperature of 59 degrees F, and humidity of 70%, the manufacturer reported COPs are 4.21 for the 220E model and 4.39 for the 300E model. But the manufacturer measured UEFs are much lower, 2.83 and 3.18, down by 28% and 33%. [FN 2.1.2.2]

Federal DOE regulations for UEF require that HP units with tanks between 20 and 55 gallons to have a UEF of about 0.9 or higher and with tanks between 55 and 120 gallons have UEFs between about 1.9 and 2.2, with the variation resulting dependence on exact volume. [FN 2.1.1.3] To qualify for the Federal Energy Star qualification, the UEF must be at least 2 for tanks up to 55 gallons and 2.2 for larger tanks. [FN 2.1.2.4]

Under California Title 24 residential energy efficiency regulations, one option for qualifying use of an HP under the prescriptive approach requires listing under NEEA tier 3 or higher. [FN 2.1.2.5] The qualifying HP units have UEFs between 2.8 and 3.4. [FN 2.1.2.6]. However, as described above, Title 24 also allows qualification under the performance approach, meaning the heat pumps with lower UEFs could qualify in California for use in residences. Further, as federal pre-emption would seem to apply to heat pump water heaters, it would seem that UEFs could be permitted to be much lower, 0.9 for tanks up to 55 gallons and as low as 1.9 for larger tanks.

Instantaneous electric water heating units do not have tanks, and thus do not have heat loss from a tank.

FN 2.1.2.1.
https://www.govinfo.gov/content/pkg/CFR-2016-title10-vol3/pdf/CFR-2016-title10-vol3-part430-subpartB-appE.pdf

FN 2.1.2.2. Materials provided by Ernie Wilson, Applications Engineer, Renewable Sales, Stiebel-Eltron USA on February 28, 2020 and March 6, 2020.

FN 2.1.2.3.
https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8
https://www.aceee.org/sites/default/files/pdf/conferences/hwf/2017/Stanonik_Plenary_HWF17_2.27.17.pdf

FN 2.1.2.4.
https://www.energystar.gov/products/water_heaters/residential_water_heaters_key_product_criteria

FN 2.1.2.5. https://ww2.energy.ca.gov/2018publications/CEC-400-2018-017/chapters/05-WaterHeating_Requirements.pdf

FN 2.1.2.6. https://neea.org/img/documents/qualified-products-list.pdf

2.1.3. Adjustment for average California Temperature and Humidity

Heat pumps are more efficient at higher air intake temperatures, as a heat pumps have less work to do to pull heat out of warmer air. The relationship is roughly linear over average temperature levels common in the most populated portions of California, with an increase of about 0.1 of COP for each 1degree F of temperature increase in that range. Further, heat pumps are more efficient at higher humidity, again via a roughly linear relationship, by about 0.1 of COP value for each 10% increase in relative humidity [FN 2.1.3.2]. The UEF standard is 67.5 degrees F and 50% humidity, so UEFs must be adjusted for local temperature and humidity conditions. As 75% of the California population is within three major metropolitan areas, here are the average temperatures and humidity (over 24 hours, 365 days) for those areas and as well the corresponding change to the UEF from the standard:

Area	Population	Ave Temperature	Ave Humidity	UEF adj
Los Angeles	18.8 million	66.5 degrees F	52.5%	+0.15
San Diego	3.3 million	65 degrees F	70%	-0.05
San Francisco	7.8 million	60 degrees F	75%	-0.5
Population weighted average:				-0.05

The average UEF over a full year is lower than the numbers above, as, during the cold weather, when the lower efficiency of a HP lowers UEF, hot water usage is 45% higher on average in the US [FN 2.1.3.3], in part, no doubt, because showers are likely hotter and longer in the winter. With the temperatures in the coldest half of the year in California roughly 10+ degrees F colder than the rest of the year, and the higher use of water in California during the colder weather results in a further (in addition to the change for average annual temperature and humidity) results in a 0.1 reduction to UEF.

The combination reduction to UEF for California is 0.15. This provides an adjusted UEF range of 2.65 to 3.25 for the NEEA tier 3 or higher HPs, and values for the Stiebel-Eltron Accelera HP units of 2.68 and 3.03.

Instantaneous electric units do not have an outside air intake, and thus do not vary in efficiency with outside air temperature and humidity.

FN 2.1.3.1. Materials and information provided by Ernie Wilson, Applications Engineer, Renewable Sales, Stiebel-Eltron USA on February 28, 2020 and March 6, 2020, including those attached at the end of this paper.

FN 2.1.3.2. https://www.fsec.ucf.edu/en/publications/pdf/FSEC-PF-464-15.pdf .

2.1.4. Adjustment for Typical Tank Size (in the US and California)

The most common water tank sizes are those between 40 and 60 gallons [FN 2.1.4.1]. Household size typically the major factor in sizing a tank on installation, with recommended tank sizes of 36 to 46 gallons for households with 2 to 3 people, 46 to 56 gallons for households with 3 to 4 people and only over 56 gallons for 5 or more people. [FN 2.1.4.2] With an average household size of 2.95 in California (2.6 is the US average) [FN 2.1.4.3] and with the average California home being about the same as the average in the US [FN 2.1.4.4], it would seem very likely that the majority of water heating tanks in California would be 65 gallons or smaller. Thus, we can focus on such smaller tanks, which are less efficient, as volume of a tank (representative of heat reserve) rises with the square of tank radius and has a greater multiple of the radius (volume = 2 x pi x height x radius^2) and thus rises faster with radius than tank surface area (representative of the area through which heat can be lost) which rises in part linearly with tank radius and in part with the square of radius with a lower multiple of radius squared (surface area = 2 x pi x radius^2 + height x pi x radius) than volume does. For smaller tanks, the larger fixed tank heat loss, relative to tank volume, causes the smaller tanks' percentage of energy usage to become more dominant relative to heating energy for actual water use.

The Steibel-Eltron 220 E model mentioned above has a tank capacity of 58 gallons versus 80 gallons for the 300 E model. This 220 E model, as described above, has a stated UEF of 2.83 and an UEF (adjusted for California climate) of 2.68. For the models with 65 gallons or less on the NEEA list as tier 3 or higher, one-half of the units have a stated UEF of 2.8, nearly all of the units have stated UEFs between 2.9 and 3.2, and the average stated UEF for all such units is 3.08. This average adjusts to 2.93 after accounting for California's climate, as described in Section 2.1.3 above.

Thus, 2.93 seems the appropriate HP UEF to assume for California.

Instantaneous electric units lack a tank and do not vary in efficiency with size (ie, power level and water flow), so the adjustments discussed here do not apply to them.

FN 2.1.4.1. https://www.waterheaterhub.com/what-size-water-heater-do-i-need/

FN 2.1.4.2. https://www.remodelingcalculator.org/how-to-size-a-hot-water-heater/

FN 2.1.4.3. For the US, a population of 328.24 million (https://www.census.gov/quickfacts/fact/table/US/HSD410218) divided by 128.57 million households (https://www.census.gov/quickfacts/fact/table/US/HSD410218). For California, see https://www.census.gov/quickfacts/CA .

FN 2.1.4.4. California average room count of 4.8: https://www.infoplease.com/us/census/california/housing-statistics . US average bedroom count is 3.4: https://www.creditdonkey.com/average-bedroom-size.html /

2.1.5. FEF is lower than EF

The field energy factor (FEF) is an even better measurement than UEF, as it takes into account both tank and water pipe heat losses. Heat losses in uninsulated, long pipe runs common in centralized HP systems [FN 2.1.5.1], result in the water temperature drop of about 12 degrees F. [FN 2.1.5.2]. The percentage drop from 120 degree F to 108, assuming a water intake temperature of 60 degrees F, is 20%. This 20% reduction would result in a California FEF of 2.34, from an adjusted (for California weather and tank size) UEF of 2.93.

The heat loss in a distributed, point-of-use water heating system, such as typical instantaneous electric, is much less. For example, I measure this loss at a 120 degree F water temperature to be 1 degree F in my home from the point-of-use unit to the faucet output, or a mere 1.7%. Even with insulation held constant, the loss from a centralized water heating unit is 3.3 times that of a point-of-use system, under the application loss amounts specific in the Title 24 California code. [FN 2.1.5.3]

FN 2.1.5.1. In California, hot water pipe insulation requirements did not become effective until January 1, 2017. https://www.ricks-energy-solutions.com/new-pipe-insulation-requirements-take-effect-in-january/ Thus, with its many older homes, California homes often tend to have un-insulated hot water pipes. And adding pipe insulation comes at a tremendous expense if walls must be ripped apart to do so.

FN 2.1.5.2. NAHB Research Center, Inc. *Domestic Hot Water System Modeling for the Design of Energy Efficient Systems*. Prepared for NREL. April 2, 2002. https://www.homeinnovation.com/~/media/Files/Reports/domestichotwater.pdf .

FN 2.1.5.4. Section 5.6.2.4 of of https://ww2.energy.ca.gov/2018publications/CEC-400-2018-017/chapters/05-WaterHeating_Requirements.pdf .

2.1.6. Stranded hot water reduces system efficiency of HP

These numbers above are prior to consideration of the significant stranded hot water (resulting from hot water left in pipes after hot water use or run off after hot water use to get to desired cold water), which is higher in centralized tanked water heating systems (such as HP) than in distributed, point of use systems (common for IE systems).

The amount water contained in 25 feet of ½ inch pipe is 0.26 gallons, reasonable assumption for the average extra length of pipe for a centralized water system versus a point-of-use system. [FN 2.1.6.1]. Assuming an average use of 10 gallons per use of hot water (it might be 20 gallons for a 12 minute shower, but only a gallon or two for a sink usage), the loss of heat from stranded hot water is 2.6%. This reduces the California FEF, relative to a point-of-use system, from 2.34 to 2.28.

FN 2.1.6.1. https://www.inchcalculator.com/pipe-volume-calculator/ ; Section 5.6.2 of https://ww2.energy.ca.gov/2018publications/CEC-400-2018-017/chapters/05-WaterHeating_Requirements.pdf .

2.1.7. Low usage homes have lower HP efficiency

HP systems are less efficient for water conserving households using with ultra-low flow devices or just lower usage, as tank heat losses (fixed regardless of hot water usage) start to dominate. This separate to and in addition to the lower UEFs for small tank sizes, as those UEFs are based on normal usage levels for that tank size. Based on 30 gallons of usage per day (20 minutes at 1.5 gallons per minute of 120 degree F hot water), versus 15 gallons per day in low use hot water (15 minutes a 1.0 gallons per minute), UEF would drop by 25% for the low usage household. [FN 2.1.7.1] Moreover, while HP units with tanks as small as 20 gallons the lowest capacity, the California prescriptively approved HP units include no HP units with tank capacity less than 40 gallons. [FN 2.1.7.2]. The performance-based approach is more complex [FN 2.1.7.3] and thus more expensive than the prescriptive approach, providing substantial incentive to go with the prescriptive approach. This would also be a problem for separate ADUs, with low water use even with regular low-flow devices mandated in California. Thus, the California FEF for low use households would drop to 1.71.

This reduction does not apply to instantaneous electric water heating units, as they only use energy when delivering water, with no fixed tank temperature maintenance use without any water use.

FN 2.1.7.1. Materials and information provided by Ernie Wilson, Applications Engineer, Renewable Sales, Stiebel-Eltron USA on February 28, 2020 and March 6, 2020.

FN 2.1.7.2. Section 5.4 of https://ww2.energy.ca.gov/2018publications/CEC-400-2018-017/chapters/05-WaterHeating_Requirements.pdf and https://neea.org/img/documents/qualified-products-list.pdf .

FN 2.1.7.3. https://www.balancedcomfort.com/title-24-performance-or-prescriptive/ , https://www.ekotrope.com/blog/prescriptive-vs-performance-building-energy-codes and https://vca-green.com/performance-vs-prescriptive-modeling/ .

2.1.8. Confined Condenser Spaces decrease HP efficiency

A number of HP units have a condenser integrated with the tank, and thus inside the home. Many consumers may prefer these units to split units that have the condenser outside because of: lower installation costs (no need to install the condenser outside the house, or a fluid line to the inside tank, or electricity to the separate condenser), outdoor noise from the condenser (inside, it can be placed in a utility closet, crawlspace or basement to block off the noise) and unattractiveness of the outside condenser. If an integrated HP is installed inside in a confined space, such as a small utility closet, the air around it is cooled, which makes the HP less efficient, generally by between 10% and 16%. [FN 2.1.8.1]. Manufacturers do recommend against using a small space and ducting can be installed to partially mitigate this reduction in inefficiency, but limited spaces in homes and for ducting, which may tend motivate use of small utility closets or other spaces, may cause homeowners to avoid heeding this advice. For homes with confined condenser spaces (often true for use of single unit HP systems), this would, using the average of the range above, reduce the California FEF to 1.98 for average hot water use households, and to 1.49 for low hot water use households.

You might think that the higher inside temperature of the home could offset this, but the inside temperature in a confined inside space could drop very low, perhaps to 56 degrees F, low enough to cause the drop-in efficiency shown above. I visited a home here in Piedmont, California with a recently installed one-piece HP located entirely indoors in a confined space. The temperature was very cool in the confined indoor space occupied by the single unit HP system, and may have had a lower humidity level as might result for the equivalent of air conditioning, which lower humidity would also reduce heat pump efficiency.

Single unit HP systems can avoid the confined space inefficiency by using ductwork to access outside air, but this adds installation expense and may not be practical because of distance from outside walls, difficult to penetrate walls (such as cement foundation wall or intervening wood structural elements) or other factors.

Even a split HP unit with an outside condenser can have some efficiency loss if placed in a somewhat confined space outdoors, as cold air could still pool a bit around the condenser.

Confined spaces do not affect the efficiency of instantaneous electric systems, as they do not depend on air temperature for heating water or give off any heat or cooling to the air of any significance.

FN 2.1.8.1. https://www.nrel.gov/docs/fy16osti/64904.pdf

2.1.9. Summary: In field system efficiency of HP systems in the field is far lower than manufacturer COP

As such, the in-home efficiency of the average HP system is far lower than advertised COP values, with actual efficiency (relative to a point-of-use 100% efficient instantaneous electric system) varying between 1.49 and 2.28, depending on water use level and whether the unit is within a confined space. Instantaneous units are not 100% efficient, of course, but most are 98% to 99% efficient.

2.2. Efficiency of Instantaneous Electric Water Heating

2.2.1. Baseline efficiency of IE systems

The efficiency of the two major IE brands (Stiebel-Eltron and Ecosmart) sold in the US are 98% to 99%. Because COP is substantially over-stated for HP systems, one might wonder if this is also true for IEs. But the measurements are far more simple for IEs: no complex condenser system and fluid line (for split units), no variable air intake temperature, and no temperature variable of outside compressor in most HP systems. For IEs, it is simple electrical resistance that heats the water, inside with constant air and input water temperature.

2.2.2. Ultra-low flow required for IE systems reduces water use

The hot water flow of the maximum capacity IE system is quite low, given the manufacturer specifications for maximum size system because of high instantaneous current flow. This essentially requires the use of ultra-low flow water devices with IE, much reducing energy use. For a home with 300 amp or greater service, the maximum size for an IE system is 36kW with a maximum instantaneous current draw of 150 to 160 amps and providing just 4.0 gpm of water flow at 110 to 120 degrees F based on 60 degrees F cold water intake temperatures. For a home with only 200 amps of service, quite common in California, the IE limits are 24kW, 100 amps and 3.0 gpm. Note that the very high instantaneous current draw is not reflective of the relative energy use of IE compared to HP (typically 7.2 kW, with a 30 amp, 240 volt input), as an HP unit runs for quite a long time after use to reheat its tank, while the IE system just runs during use and tends to run at well under its maximum power rating.

These hot water flow rates compare to near limitless supply from tanked water heaters (such as HP) with respect to the demands of virtually any reasonably sized home (extremely large homes might require multiple tanked units), although the water from a tank can run out prior to being reheated. Gas instantaneous water heaters also provide high flow, typically 7 gpm.

The low-flow of IE units essentially require ultra-low flow faucet aerators (0.3 to 0.75 gpm versus 1.8 for kitchens and 1.2 for bathrooms) and shower heads (1.125 gpm or less, down to 0.5 gpm, versus low-flow of 1.8). For a home with 300 amp service (rare in many older cities in California), a total of 4 gpm of hot water at a modest temperature of 110 to 120 degrees limits usage to about 2 showers at once with ordinary low-flow shower heads, with insufficient additional hot water available for even one sink. For a home with just 200 amps (common in California), 3 gpm with regular low-flow aerators does not provide enough hot water for even one sink and one shower at once. The ultra-low devices are now very sophisticated, with aerators that give the impression of much greater water flow, and thus do not result in significantly longer hot water use. Based on a home with 3 ½ bathrooms, the average in US ane California, use of ultra-low flow devices versus low-flow devices results in about a 32% hot water usage reduction, or use of low-flow devices versus ultra-low boosting hot water use by about 46%. [FN 2.2.2.1]

Ultra-low flow devices for IE are made even more essential in an all-electric home, given an already very high electrical load. For example, in my home, we have an inductive cooktop wired with 50 amps at 240 volts, two electric ovens wired with a total of 100 amps at 240 volts, two Level 2 EV chargers (each 30 amps at 240 volts), and a 30 amp dryer at 240 volts. And our home only gets 230 amps of our 320 amp service, the remainder stopping at the garage, where the two Level 2 EV changers reside.

One can also deal with the limited output of IE units by adjusting the hot water temperature downward to allow the IT unit to provide higher volume (IE units provide less hot water at higher temperatures, and more at lower temperatures, as it takes more energy to boost the water temperature higher). We have used this tactic to a small extent, setting our water temperatures to 110 degrees F where possible.

The low flow of IE units may be less desirable for certain uses, such as filling a bathtub. A bathtub, with a typical total capacity of 80 gallons, often filled with 36 gallons of water, with a 4 gpm flow. Thus, those taking frequent baths, IE may not be a good choice.

FN 2.2.2.1. Assumes for the low flow option, 3 showers at 1.8 gpm, 1 kitchen sink at 1.8 gpm, 4 bathroom sinks at 1.2 gpm and one clothes washer at 0.67 gpm, with the daily length of flow twice as long for the showers and kitchen sink. For the ultra-low flow option, assumes 3 showers at 1.125 gpm, 5 sinks at 0.67 gpm, and one clothes washer at 0.67 gpm, with the same flow length differential as for low-flow. These assumptions also result in shower use consuming about half of hot water, consistent with https://www.homeinnovation.com/~/media/Files/Reports/domestichotwater.pdf . With the very lowest flow options commercially available (as described and specified in Section 2.2.2), the reduction would be greater, in excess of 50%, using the other assumptions above.

FN 2.2.2.2. https://stanfordmag.org/contents/shower-or-bath-essential-answer

2.2.3. Other factors increasing efficiencies of any IE system over HP

These efficiency differences are already discussed and accounted for above in the HP discussion, but, in summary, they include: no tank heat loss for IE, no low water use efficiency reduction for IE, no reduction for use of tanks under 65 gallons, no adjustment to efficiency for local outdoor climate conditions, and no reduction in efficiency for IE from having a condenser in a confined space.

2.2.4. Other factors increasing efficiency of distributed, point-of-use IE over HP

These efficiency differences are also already discussed and accounted for above in the HP discussion, but, in summary, they include: less heat loss in longer pipe runs, and less stranded hot water left in longer pipe runs. As mentioned above, distributed, point-of-use IE systems are very common.

2.2.5. Summary, bottom line efficiency comparison between HP and IE – no substantial difference

Accounting for the essentially required ultra-low hot water use of a IE system, their effective efficiency factor (compared to a mere low flow HP system) is 1.5 (included the impact of ultra-low flow devices for IE versus low-flow devices for HP). Of course, even if an HP system were to use ultra-low flow devices, the efficiency factor of the HP system would drop about 13%, as the tank losses will dominate more, as discussed in Section 2.1 above. Further, households are not likely to seek ultra-low flow devices for use with an HP system, as described in Section 0 above.

Based on a range of 1.49 to 2.28 for HP systems, and an effective efficiency factor for a IE system of 1.5 (accounting for a virtual requirement of ultra-low flow devices, using perceived gallons of hot water for IE), the IE energy usage is within the range of that for an HP system. For a low hot water usage household with a confined space for the condenser, which may be true of an ADU or conserving household, the effective efficiency of an IE system would be nearly identical to that of an HP system. With typical water usage levels and an unconfined space for the HP condenser, HP has a 50% energy usage advantage over IE, with respective factors of 2.28 versus 1.5, a far cry from a 200% to 300% advantage implied by COPs for HP. Even in this last case, use of the very lowest ultra-low flow faucets and shower head would provide rough parity between IE and HP. [FN 2.2.2.1]

2.3. Field Measurement of HP system versus distributed, point-of-use IE system here in Piedmont, California

2.3.1. Annual Energy Use of IE System

My house has a 99% efficient, distributed, point-of-use, three IE unit, 52.8 kW IE system with ultra-low flow devices (all faucets at 0.5 to 0.66 gpm, all showers at 1.125 gpm). Review of my PG&E bills before and after installation seems to show annual energy usage of 1,000 kWh, similar to HP at 30 gallons of hot water per day (about 50% of annual average in the US). [FN 2.3.1.1]

FN 2.3.1.1. https://www.energy.gov/energysaver/estimating-costs-and-efficiency-storage-demand-and-heat-pump-water-heaters ; Materials and information provided by Ernie Wilson, Applications Engineer, Renewable Sales, Stiebel-Eltron USA on February 28, 2020 and March 6, 2020.

2.3.2. Comparisons of actual IE and HP systems in Piedmont, California

2.3.2.1. Comparisons of actual system measurements

I have measured the power consumption per gallon of two hot water systems: my instantaneous electric point-of-use Stiebel-Eltron system described above in Section 2.3.1, and, along with another Piedmont home's recent vintage HP system (AO Smith HPTU-50N, with a 50 gallon tank and a UEF of 2.9). This measurement included measuring actual current, actual water output and actual time elapsed (to determine a flow rate, and to determine the time for a heat pump tank to reheat).

The summary is that the instantaneous unit used 74.7 Wh to heat up one gallon of water, and the heat pump system used 56.9 Wh per gallon. The instantaneous unit used 31% more, or, to put it another way, the heat pump used 24% less, prior to application of the hot water savings from using ultra-low flow devices with IE but low-flow with HP.

The major factor not accounted for in Section 2.1 is the ultra-low flow nature of my water system (essentially required for an IE system), as described above in Section 2.3.1. This ultra-low flow factor alone brings the effective relative efficiencies of these two HP and IE systems to approximate parity, based on these field measurements.

Here are the calculations to arrive at the numbers above:

My house with IE: Ran one shower (1.125 gpm) on full hot: 10.5 amps on each of two 240 volts lines into hot water heater (or 21 amps total at 240 volts). Power = I x V (current x voltage) = 240 x 21 = 5,040 watts = 5.04 kW. Energy per gallon of water heated = 5.04 kW x (1 hour / 60 minutes) x (1 minute / 1.125 gallon) = 0.07467 kWh / gallon = 74.67 Wh / gallon. My hot water temperature level was set at 110 degrees F.

House with HP: Ran shower on hot until hot water heater turned on to reheat the tank. Used 30 liters of water, or 7.925 gallons, as measured with a bucket. Hot water heater then ran for 80.5 minutes (1.342 hours) to reheat the tank. Current draw of 1.4 amps at 240 volts. Power = I x V = 1.4 x 240 = 336 watts = 0.336 kW. Energy per gallon of water heated = 0.336 kW x (1.342 hours/gallon) / 7.925 gallons = 0.05690 kWh = 56.90 Wh. Let us assume that output hot water temperature was set at 120 degrees F, the legal high limit.

Since the ultra-low flow devices in my home reduce hot water usage by about 32% (see Section 2.2.2), this brings energy use between these two houses to about parity.

Note that the different water heater output temperatures (120 degrees F for HP and 110 degrees F for IE) shown above are actually comparable, given that my IE system is point-of-use with very short pipe runs (and thus low heat loss through the pipes – I have measured the heat loss at 1 degree F to 109 degrees F) and that heat loss in uninsulated (often the case in the mostly old California homes) long pipe runs can be as much as 12 degrees F. See Section 2.1.5 above.

2.3.2.2 Modification of measurements based on energy equations

One can also use heat transfer rate and power use equations to calculate power use. This is particular simple for IE systems, with their similar electrical resistance and lack of dependence on outside climate conditions. For IE, energy use in kWh = (0.00224) x (increase in water temperature in degrees F) x (gallons of water heated) x (efficiency) . Based on our high-volume IE units for our showers set at 110 degrees F and considering use of 1 gallon, energy use per gallon heated = (0.00244 kWh) x (50) x 1 x .99 = 0.121 kWh. This is a bit more than my measured number above, so let's take it as correct.

To calculate the something close to the COP of the HP system, we can divide the energy use per gallon of water heated by a 100% efficient system (0.00244 x 60 = 0.1464 kWh) by the observed energy usage of 0.05690 kWh for the HP unit, giving amount of 2.57. To get from this number to an FEF, we would need to account for stranded water losses and tank heat losses (when water is not being used). Based on Sections 2.1.2 and 2.1.6 above, the FEF is about 1.72. Applying this FEF, the effective energy for the HP system to deliver to an end use device a gallon of 108 degrees F water would increase from the measured amount of 0.0569 kWh by the fraction 2.57/1.72, or to about 0.0850 kWh.

But to account for the ultra-low flow devices in my home, versus low-flow devices home with HP water heating, one must decrease to energy use from our system by the 32% reduction in hot water use (to give energy per perceived gallon of water use – really energy use per time passage of hot water flow, rather than water volume – see Section 2.2.2 above). This lowers the relative energy use of our system to 0.0823 kWh per perceived gallon.

These modified numbers are approximately equal, showing that actual field usage of these two different systems results in similar energy usage, and that the commonly stated COP numbers of 3 or 4 or more for HP units does not reflect relative system energy efficiency.

2.3.2.3. Consistency between multiple ways to compare HP and IE

This paper has gone through four methods (shown in Section 2.2, 2.3.1, 2.3.2.1, and 2.3.2.2) to compare HP and IE energy usage and all have provided similar results, giving some confidence in the conclusion that use of IE provides energy usage similar to that of HP.

3. Peak Electrical Grid Load – HP versus IE

With respect to peak load on the electric grid, this also varies little between instantaneous electric and heat pump, for three reasons. First, as set forth above, the instantaneous units use a very similar amount of energy per gallon of hot water, and have less flow per unit time with ultra-low flow devices and less flow before (wait time for hot water) and after use (stranded hot water), as a result of the shorter, point-of-use pipes. Second, a heat pump also runs at the time of usage, just after the time of usage to heat the tank up again. Third, hot water usage in residences varies over a great many hours of the day. To this last point, some people are up at 4 am and shower early, and some are not to bed until midnight, showering late. Exercise, often preceding showers, can happen throughout this range of hours, even during work and school hours, often at lunch time. A large and increasing share of the population can shower at any time as they are at home during the day as a result of retirement or working from home.

A study shows that electric instantaneous water heating results in no more problems for peak grid load than tanked, electric resistance water heating. [FN 3.1]. While this study does not compare IE to HP, that is not much of an issue, given the rough parity of energy usage by IE and HP, as described above.

While it is true that use of timers with HP units may reduce peak grid load by heating water only or primarily during the night and/or during the middle of the day, this is not a requirement for homeowners or automatic. Very few homeowners would even know that they could install a timer for their HP unit or know of the possible benefits of doing so, let alone being willing to undertake to work and expense of buying, installing and setting a timer. The economic benefits to a home owner of using a timer are not very significant, and it is very complex to calculate these benefits, as doing so requires comparing hot water time of use (which varies and is difficult to measure with any precision) to utility rate schedules. Further, a homeowner may risk running out of sufficiently hot water during peak times if heating of the HP tank is only scheduled during off-peak hours. And for the most heat pump hot waters with an electric resistance backup mechanism [FN 3.3], energy use may actually increase by using a timer and some manufacturers thus recommend against using a timer. [FN 3.2] Thus, it is very likely that the vast majority or nearly all homeowners will not opt to have heating of an HP unit off during peak hours.

FN 3.1
https://www.thefreelibrary.com/Tankless+Electric+Water+Heater+Diversified+Electrical+Demand+in+...-a0509016656

FN 3.2
https://products.geappliances.com/appliance/gea-support-search-content?contentId=17716

FN 3.3 See page 28 of https://www.redwoodenergy.tech/wp-content/uploads/2020/04/SF-Guide-4-10-2020.pdf .

4. Advantages of IE to homeowners

The burden to homeowners of barring them from using instantaneous water heaters on replacement of gas water heaters can be very substantial. First, for homeowners with a distributed, point-of-use, multiple unit gas instantaneous water heating system, replacement with a heat pumps will result in great cost and inconvenience. The cost of re-working plumbing is substantial, wait times for hot water will be longer and living space may be lost to accommodate a water tank. Second, for those with a centralized gas instantaneous system now may lose living space by converting to a HP with a tank rather than to a tankless IE system, although the will be cost associated with running higher capacity electrical lines to each IE unit. Third, those with a gas tank system wishing to convert instantaneous electric for its advantages (less space, and, for point-of-use systems, shorter wait times and less water and energy use) will be barred from doing so if IE were not permitted as an option.

In addition, point-of-use IE virtually dramatically reduces hot water wait times (saving water in the process), eliminates the need for wasteful recirculation systems, and greatly reduces heat loss from uninsulated pipes and stranded hot water. The very small IE size and lack of vents and air inputs allows IE placement nearly anywhere (under sinks, etc.). IE is extremely efficient for low water usage when using point-of-use IE placement.

Further, homeowners may prefer IE systems as a result of the significant noise from an HP unit and the ugly outdoor condenser portion of a split unit HP, as described below in Section 5.

For a separate ADU, barring the use of IE is especially onerous. As separate ADUs generally lack a basement for a hot water tank, an HP system with a tank would eat in to very limited ADU living space. Further, because of likely low water use in an ADU (with fewer occupants than a house), the energy of an HP system in an ADU will be higher than that of IE by 10% to 20% as described in Section 2.2.5. Finally, the small size of ADU and the reduced building separation caused by adding a separate ADU will make HP condenser noise and ugliness issues worse (see Section 5 below). The small size of an ADU may limit the ability to place an HP condenser is a way to avoid annoying condenser noise within the ADU. Thus, even energy efficiency experts recommend use of electric resistance water heating for small homes. [FN 4.1]

FN 4.1. See pages 29 and 25 of https://www.redwoodenergy.tech/wp-content/uploads/2020/04/SF-Guide-4-10-2020.pdf .

5. HPs: Noisy and Ugly

Instantaneous electric water heating systems have several quite significant advantages over HP in terms exterior appearance and noise level. Many heat pumps having an exterior condenser which is both noisy (from 40 to 65 dB [FN 5.1]) and unattractive to the homeowner and neighbors and as well as those on the street. These problems are not an issue for one-piece HP units installed inside, although the noise may be an issue if the location of the HP units in near living space. This is a worse problem in areas of California where homes are very close together, and worse for separate ADUs, as they reduce the space between homes (on lot and off). Instantaneous electric water systems, on the other hand, make no noise and are placed in the building interior.

FN 5.1. https://www.buildinggreen.com/news-article/look-heat-pump-water-heaters and https://www.nordicghp.com/2016/06/air-to-water-heat-pump-noise/ .

6. Negative Impact of barring IE on Innovation

Focusing solely on heat pumps for hot water will do far more than bar valid current clean and efficient technologies such as solar hot water (with resistive or heat pump supplementation for long cloudy periods) and instantaneous electric hot water. A focus on heat pumps for hot water would stifle development of new hot water technology, including those technologies that can be imagined today, and that that cannot be imagined.

Here are a number of examples of foreseeable and quite efficient and reasonable alternative technologies that a sole focus on heat pumps would bar:
1) A hot water system that gets heat from an HVAC heat pump refrigerant lines. This could done in a distributed way or not. Using the distributed technique, cold water and hot water are not wasted filling long pipe runs, and leading to shorter waits for hot and cold water for homeowners. And the refrigerant pipes for HVAC would already go all over the house in a more efficient distributed HVAC system. Such a system would require a temperature boast (likely instantaneous electric) at the end point of usage, as heat pump HVAC tends to have refrigerant temperatures of about 95 degrees F.
2) A hybrid tank/instantaneous system, such as exists for gas, whereby a small tank, perhaps 5 gallons, is powered by a small heat pump, which tank gives a supply adequate for many usages (in our house, it is enough for a full, single shower, because of our ultra-low flow shower heads and short showers), and instantaneous electric backup that covers heavy usage (in our house, just for simultaneous shower use, which is not so common).
3) A mix of the two above, whereby the small tank in 2 above is heated by the HVAC heat pump (as in 1 above) to, say, 90-95 degrees F, and the instantaneous device boasts it further (as in 1 above) and provides backup after the tank runs out (as in 2 above).
4) A large tank heated by the heat pump also used by HVAC to 90-95 degrees, with instantaneous providing a temperature boast, either just after the tank, or in a distributed manner just before the usage points.
5) Further development of even more distributed hot water heating, now at an early stage, whereby instantaneous heat (or mere temperature boosting) occurs within the shower head. Once perfected, this is fabulous technology, saving much water during the wait for hot water and wasting of hot water (ie, energy) because of pipes filled with hot water after usage of hot water stops (ie, after the end of a shower).

This does not even consider technologies that I cannot imagine, and technologies that others cannot now imagine.

7. Comparison of purchase and installation costs to consumers for IE versus HP

The costs of purchase of, and installation of, IE and HP systems are similar.

First, the costs of the individual units are similar. The AO Smith HPTU-50N HP unit that used in the Piedmont, California where measurement were taken sells for $1370 on SupplyHouse.com, versus the combined Amazon.com selling price of my three Steibel Eltron units (two Tempra 24 Plus units at $590 each, and one DHC 5-2 unit at $175) is $1355. If a homeowner were to opt for a single, whole house (rather than distributed) IE system, the cost drops, with Stiebel-Eltron Tempra 36 Plus (36 kW) costing $810 on Amazon.com. EcoSmart units are even less, with the 36 kW unit (model ECO 36) costing just $562 on Amazon.com, with the cost for a Ecosmart system equivalent to mine costing $1120. But HP units can also be purchased for as low as $1,215.

Second, installation costs are similar. IE requires a greater current draw and would have higher installation cost. But somewhat high capacity (30 amps and 240 volts generally) wiring is also needed for HP, meaning that the only difference would be higher wire and breaker costs and well as increased cost from making slightly larger corridors for the wires. Since tank gas units (typical in California) generally have no electric power supply, this wiring would need to be added for both IE and HP, with similar costs. A point-of-use IE system, would require more wiring (but smaller current requirements at each location), increasing cost. But the larger footprint of a HP system would increase costs, and having a split unit HP system would increase costs, with the need to install two units (each larger than an IE units) and the need to add a fluid line between the two HP units (as well as electrical wiring to the second unit). Third party estimates confirm rough parity of installation costs of HP versus IE. [FN 8.1]

The high current draw of an IE unit (or units, for point-of-use) could motivate a homeowner to add increase an electrical panel size or increase service amperage from the electric utility at some cost. However, this nearly always be avoided by use ultra-low flow faucets aerators and shower heads. in the case of my home, we have 230 amps, but we supply 3 showers, laundry and 5 sinks with our three IE units, and we could have done so with 200 amps, which is common in California.

FN 7.1. Installation costs of $150 to $700 for IE as per https://www.pickhvac.com/tankless-water-heater/cost-with-installation/ ; installation costs of $350 to $585 for HP as per https://www.remodelingexpense.com/costs/cost-of-heat-pump-water-heaters/