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Energy Consumption and Emissions of Residential Heat Pump Water Heaters

Additional submitted attachment is included below.

Berkeley, CA
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Energy Consumption and Emissions of Residential Heat Pump Water Heaters

High efficiency electric heat pumps are available today to heat water as well as to provide space heating and cooling for residential and commercial buildings. However, the subject of this comment letter is on residential heat pump water heaters (HPWH).

Widespread adoption of highly efficient HPWH in California can leverage the steadily decarbonizing electricity and thus help the state meet its climate and air quality goals. However, the refrigerants used in HPWH result in direct emissions due to leakage while operating as well as losses at the end of life of the appliance. The most common refrigerants today are hydro-fluorocarbons (HFC or "F-gas") that have high global warming potential (GWP), but do not have any ozone depleting potential.

In 2016, California set a 40% reduction target for HFC based refrigerants in 2030 below 2012 levels (CA SB 1383)[1]. This policy combined with developments in the refrigerant market will lead to use of refrigerants with much lower global warming potential. R-134a is a conventional refrigerant used in HPWHs today. It has a GWP of 1430.[2] Use of this refrigerant is being phased out of production by 2020. With the promise of an eventual phase-down of HFC refrigerants, one potential refrigerant, R-1234yf with a GWP of 4 has emerged. Results from initial tests of R-1234yf in lieu of R-134a in General Electric's HPWH indicate that a more optimized R-1234yf design may closely match the performance of R-134a (Nawaz et al, 2016).[3] Moreover, advanced HPWH which use CO_2 refrigerant (called "Eco- Cute"), is commonly used in residential and commercial buildings in Japan for years (E3T, 2016). Sanden markets the SANCO2, a heat pump with CO_2 as refrigerant (GWP = 1) in North America.[4] The Association for Energy Affordability currently installs Sanden CO2 HPWHs in multi-family retrofit projects across California as part of California's Low Income Weatherization Program.

Energy and Emission Comparison of Water Heating Technologies

Below we compare five kinds of water heaters - natural gas storage water heater (NGWH), instantaneous or tank-less natural gas WH (INGWH), electric resistant WH (ERWH), air source heat pump WH (HPWH) with different refrigerants (differing GWP), and advanced heat pumps (AdvHP) with CO2 as refrigerant.

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[1] CA State Bill No. 1383: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB1383
[2] https://www.arb.ca.gov/cc/rmp/rmprefrigerants.htm
[3] Nawaz, Shen, Elatar, "Max Tech Efficiency Electric HPWH with Low-GWP Halogenated Refrigerant", Oak Ridge National Laboratory Report, November 2016 https://info.ornl.gov/sites/publications/Files/Pub72209.pdf

[4] https://www.sandenwaterheater.com/products/

The annual energy consumption by a water heater is assumed to be fixed for a given appliance over its lifetime assuming a daily average hot water demand of 50 gallons. The average annual energy consumption of WH technologies are compared in Figure 1. Two different natural gas based water heaters: NGWH – with storage and INGWH – instantaneous natural gas water heaters are compared. Along with this, three different HPWH technologies (HP1, HP2, AdvHP) with three different energy factors and three different refrigerant types are compared.

The annual emissions of a WH can vary. Beyond the hot water demand and efficiency of the appliance will depend on other factors: carbon intensity of the fuel for the specific year of operation, and the GWP of the refrigerant and the leakage assumptions. We continue to assume daily average hot water demand is 50 gallons. We assume, the efficiency and refrigerant GWP of water heaters improve every decade as given in table 1 below. The carbon intensity of the grid gradually reduces and the 2050 emissions are 80% below 1990 levels[5]. For natural gas, a fixed carbon intensity of 6.1 kg/therm[6] is assumed throughout the years. In Figure 2, solid colors in the bottom of the bars reflect the emissions from fuel sources, the top hatched in HPWH (**) represent the emissions due to refrigerant leakage. The assumptions on annual leakage and end of life leakage are given in Table 2.

While the emissions from NGWH and INGWH based water heaters decrease with efficiency improvement, emission from ERWH and HPWH decrease with both efficiency improvements and the lowering carbon intensity of the grid. The most conservative assumption is that a refrigerant with a GWP of 1430 is used in a HPWH in 2020, and hence the indirect emissions (**) remain fixed for the installations in these years. In 2030, we assume the refrigerant used in HPWH will be R-1234yf with a GWP of 4. Beyond 2030, we assume CO2 as the refrigerant for HPWHs, as is commonly used in Japan today.

The average CO2e emissions due to refrigerant leakage from a single HPWH even with the high GWP of refrigerants today is on the order 0.1 ton/year relative to 0.8 tons/year from natural gas based water heaters.

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[5] Carbon intensity of grid assumed in the model: 0.277 kg/kWh, 0203 kg/kWh and 0.063 kg/kWh for years 2020, 2030 and 2050.

[6] https://www.pge.com/includes/docs/pdfs/about/environment/calculator/assumptions.pdf

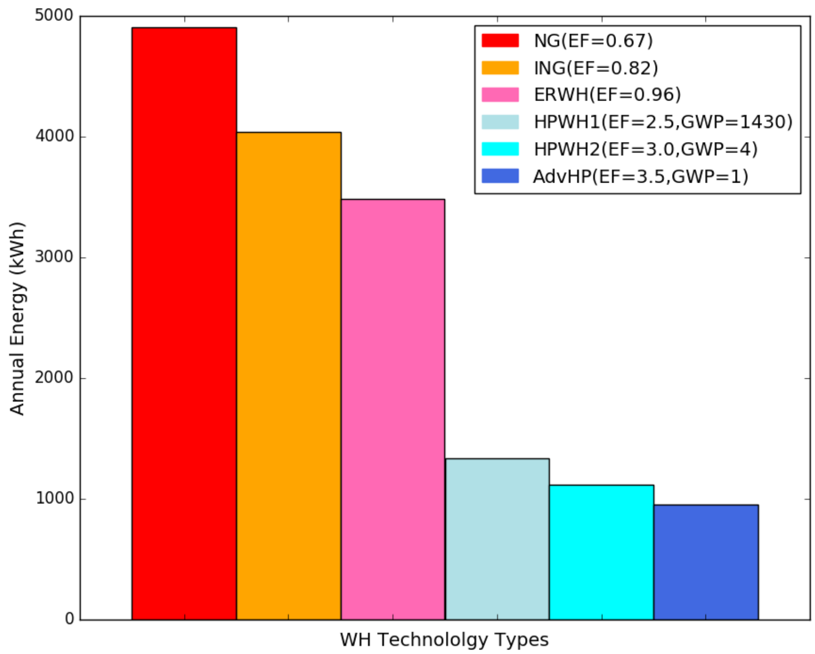

Figure 1: Annual Energy Consumption of Water Heater Technologies

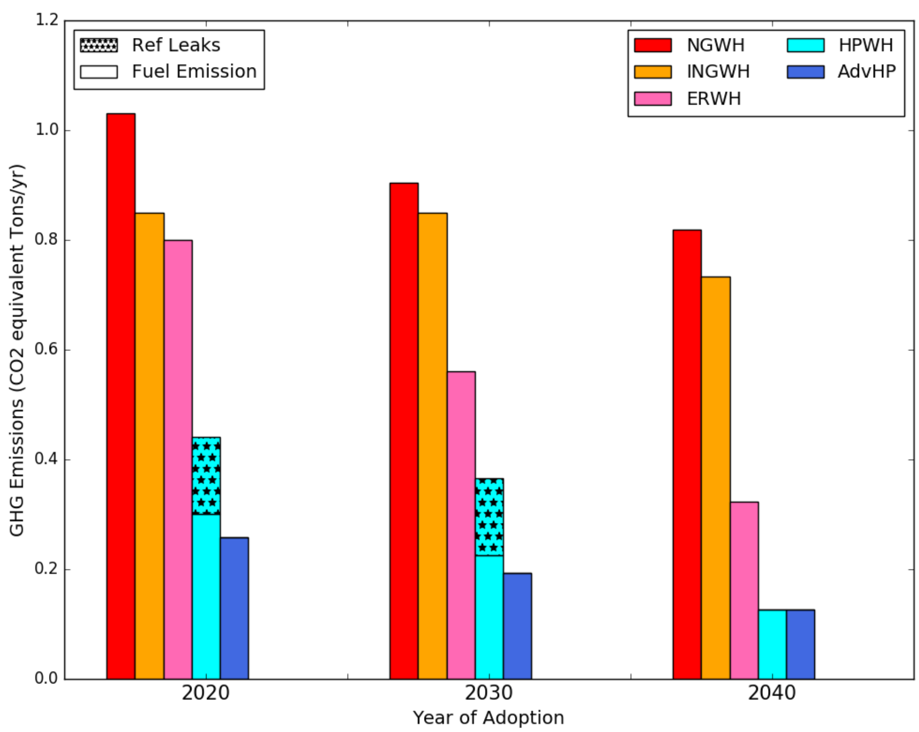

Figure 2: Average Annual Emissions from source fuel and refrigerant leakage.

As suggested in Raghavan et al. *Scenarios to decarbonize residential water heating in California* (2017),[7] in order to achieve air quality and climate goals in a cost-effective and timely maker, California must phase in HPWHs no later than 2020.

I will be glad to clarify or provide further data, analysis or references regarding the above discussion. Thank you for considering my comments.

Sincerely,

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[7] Raghavan, Wei, Kammen, Scenarios to decarbonize residential water heating in California, Energy Policy 109 (2017) 441-451

Appendix

Table 1: Energy Factors and Refrigerant GWPs

WH Technology	Time Horizon	Energy Factor Assumption *
Natural Gas	2016	0.62 (weighted avg. EF of existing stock)
	2016-2020	0.675
	2020 -2030	0.77
	2030-2050	0.85
Instantaneous Natural Gas	2016-2030	0.82
	2030 -2050	0.95
Electric Resistance	<2020	0.96
	>2020	0.96
Heat Pumps	<= 2020	2.5 with Refrigerant GWP =1430
	2020-2030	3.0 with Refrigerant GWP = 1430
	2030-2050	3.5 with Refrigerant GWP = 4
Advanced HP	2016	3.5 with Refrigerant GWP = 1

Table 2: Refrigerant Leakage

Average amount of Refrigerant in a heat pump*	0.75 kg
Average leakage in installation	0.05%
Average annual leakage**	2%
End of life loss rate**	100%

* Baxter, et al., 2016, US EPA GHG, 2015, ** Gallagher et al., 2013