Heat Pump Buyers Be Wary: Weighing the Effects of Refrigerants

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ABSTRACT

With climate change upon us like an ever-darkening cloud, governing stakeholders are making serious commitments to decarbonization. Heat pump technologies offer a viable path to decarbonize buildings, and policymakers advocate for aggressively installing heat pumps, heat pump water heaters (HPWHs), and heat pump clothes dryers (HPCDs). However, it is crucial to both understand and address the environmental risks posed by the hydrofluorocarbon (HFC) refrigerants typically used by these systems. This paper integrates refrigerant legislation and emissions calculations using a variety of sources used by California's DEER/eTRM databases to determine the net CO_{2e} effects of electrifying single-family homes. We determine the net per-home, state-specific global warming impacts of installing:

1. HPs (ducted and ductless) in existing homes that either have no air conditioning (AC), have only room/window ACs, or have central AC
2. HPWHs to replace existing fossil-fuel or electric storage water heaters
3. HPCDs to replace existing fossil-fuel or electric clothes dryers

Answers to these questions will be useful to policymakers and program implementers who are promoting and incentivizing heat pump technology as the centerpiece of electrification. Using these analyses, we also determine the maximum refrigerant global-warming potential that—alongside an electric generation mix that is gradually lessening emissions—would yield a net benefit for each state. Finally, we explore possible legislative advances and programmatic measures designed to minimize refrigerant leakage and its deleterious effects by improving contractor education and compliance.

Introduction

In the past five years, dozens of government agencies around the world have developed roadmaps to achieve zero net carbon emissions by 2050. Some have granted these plans the force of law. Most if not all call for the electrification of fossil-fueled space and water heating equipment and appliances in most buildings, using energy-efficient heat pump technology which is available today. Of the nearly 1 million single-family homes built in the United States in 2021, 39% had air-source heat pumps (US Census 2022). While heat pumps are installed in approximately 10% of housing units across the US, in regions with high heating loads, heat pumps are used in only approximately 2% (NREL 2022). This is likely due to older heat pump systems that were less able to meet high heating loads and may have caused persistent reluctance to adopt this technology in very cold regions.

Meeting ambitious carbon reduction goals will require stimulating growth in customer demand for heat pumps as well as strengthening the capacity of the supply chain to promote, manufacture, deliver, install, maintain, and decommission them. Utilities, energy efficiency program administrators, regulators, and other policymakers require key information, insights, and solutions to design and deploy effective initiatives to accelerate the installation of heat pumps by their customers and constituents, but with an eye to managing the unintended environmental consequences of such policies.

Technology and Benefits

Rather than burning fuel in the home to make heat—as in a traditional furnace or boiler—a heat pump moves heat from one environment to a refrigerant and then from that refrigerant to a second environment. A heat pump brings heat to conditioned spaces by reversing the vapor-compression cycle used in air conditioning and refrigeration processes—and does so very efficiently. Heat pumps can achieve efficiencies (defined as the ratio of heat output to electricity input) above 300%. Newer heat pump products are emerging using variable speed fans and variable speed compressors to achieve higher efficiencies in the 400% to 450% range. Given these developments, the lifetime cost of ownership for heat pumps has fallen below that of comparable fossil fuel systems in many, but not all, use cases and market situations.

Recent and ongoing technological advances have expanded the range of applications and conditions in which heat pumps can be used economically (Deetjen, Walsh, and Vaishnav 2021). Low-temperature systems enable heat pumps to operate in outside temperatures as low as 5 °F. The application of variable speed compressors and fans, as well as room-by-room temperature controls, deliver enhanced occupant comfort, reduced noise, and increased energy savings.

Heat pump technology has been further leveraged for electrification of domestic hot water and clothes drying by way of heat pump water heaters and heat pump clothes dryers for both residential and commercial applications. It is only in the last few years, however, that cost/benefit assessments also considered refrigerant leakage. The analysis results presented in this paper allow policymakers to understand the nuances of these effects on the net emissions avoided for residential equipment involving heat pump technology.

Background

The analyses presented herein rely upon many sources to determine the net emissions avoided that result from installing heat pump technologies. These are described in the subsections that follow and include the electric and natural gas emissions rates, refrigerant leakage emissions, and the prevalence of air conditioning in homes in California.

Emissions Rates in California

Every two years, the California Public Utilities Commission (CPUC 2022) updates the avoided costs estimates that result from installing energy efficiency measures that reduce the generation and distribution of electricity or natural gas. Included in the avoided costs are the monetary impacts of greenhouse gases and high global warming potential gases emission rates, or the mass of emissions per unit of energy, in metric tonne/MWh or metric tonne/Therm. In 2022, the considered emissions were expanded from CO_2 emissions to include CO_{2e} methane leakage emissions and CO_{2e} refrigerant leakage emissions. The methane leakage emissions considered include both those occurring upstream of natural gas power plants and those occurring behind-the-meter at residential buildings. For electricity, the total emissions rates are forecast to decline over the coming decades to account for the planned increase in renewable energy and energy storage. For natural gas, the emissions rates are held constant over the coming decades. All analyses presented in this paper use the electric emissions rates and natural gas emissions rates as updated in 2022.

Refrigerants

Refrigerant leakage from heat pump technologies occurs in two ways: annual operational leakage and end-of-life leakage events. The first is due to leakage through valves, seals, piping, and tubing that contain the refrigerant as it travels the refrigerant loop, carrying absorbed heat from one location and releasing it to another. The second occurs when equipment is decommissioned and the refrigerant is rarely—if ever—properly recovered by the contractor. The leakage rates used by the California Air Resources Board are provided in Table 1.

Table 1. Refrigerant leakage rates in residential equipment involving heat pump technologies

Equipment	Operational leakage rate	End-of-life leakage rate	Year(s) since last refrigerant added[1]
HVAC	5.3%	80.0%	3
Water heating	1.0%	100.0%	14
Clothes dryer	1.0%	100.0%	14

Source: California Air Resources Board

For residential heat pumps and air conditioning equipment, the leakage at each year of life, assuming it is installed in 2024 and has a 15-year effective useful life, is shown in Figure 1. The refrigerant leakage emissions rates of central air conditioning systems are indicated by the broken yellow line whereas the refrigerant leakage emissions rates of the heat pump are indicated by the solid green line. Although both systems use the same refrigerant (R-410a), their emissions rate (per ton of equipment cooling capacity) are offset because heat pumps require a slightly higher refrigerant charge (in pounds) than air conditioning systems.

[1] This value indicates the number of year(s) between when refrigerant is typically last added to equipment and the end of its effective useful life.

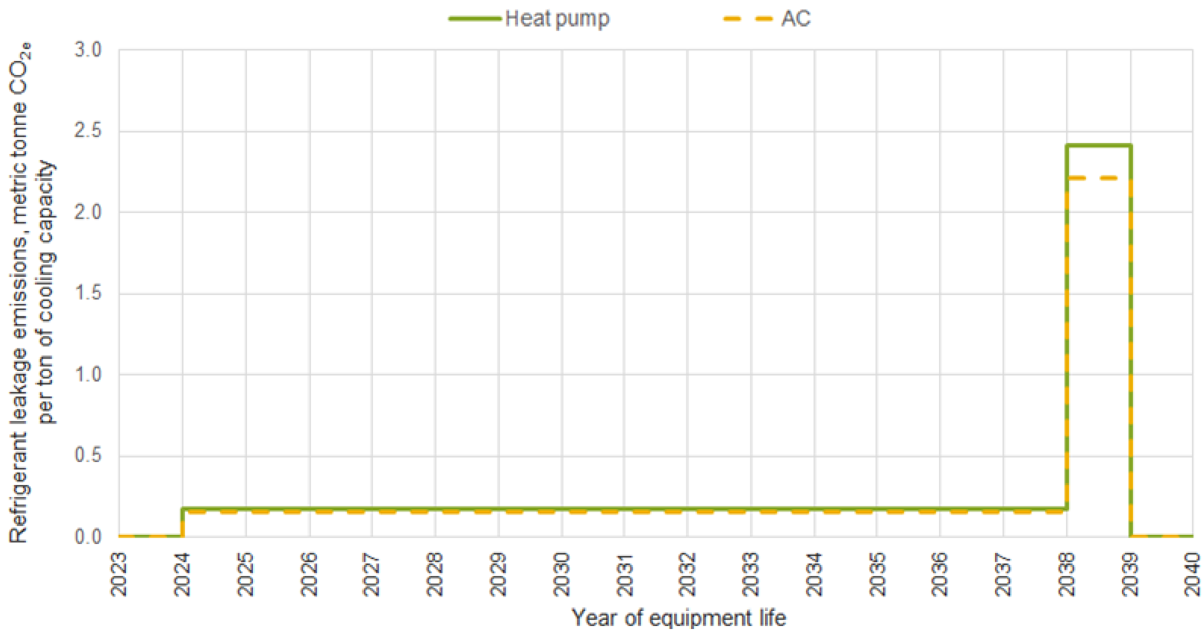

Figure 1. Emissions due to refrigerant leakage over the lifetime of a central heat pump and a central air conditioner, both containing R-410a refrigerant. *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).

Refrigerant Policies in California

For those interested in understanding the policies developed for deemed and custom fuel substitution measures in California, the progression of policies and the year they went into effect are summarized in Table 2. Key changes from one update cycle to the next are shown in blue text.

Table 2. Evolution of California policies pertaining to fuel substitution measures

2020	2022	2024
Source energy shall not increase	Source energy shall not increase	Source energy shall not increase
Net lifecycle electric + natural gas emissions shall not increase	Net lifecycle electric + natural gas emissions shall not increase	Net lifecycle electric + natural gas (incl. methane leakage) + refrigerant leakage emissions shall not increase[2]
Shall be cost-effective (TRC ≥ 1.0)	Costs of refrigerant leakage emissions shall be considered to determine cost effectiveness	Costs of refrigerant leakage emissions shall be considered to determine total system benefit

[2] The 2024 policy modifications were only applied to those measures added to the portfolio after April 1, 2024; previously approved measures were not directed to be modified until 2026.

Refrigerant Policies in the United States

In 2023, the US Environmental Protection Agency (EPA) finalized the AIM Act including the Technology Transitions and Refrigerant Management rules. The act requires that, beginning in 2025, HVAC equipment must be manufactured using refrigerant having a global warming potential (GWP) of no more than 700.[3,4] This requirement will have a dramatic effect on the net emissions of electrifying space conditioning in single-family homes. Table 3 presents the prevalent refrigerants currently in use in 2024 and two others that, according to industry stakeholders interviewed by DNV, are the only ones likely to be in use in HVAC systems manufactured in 2025.

Table 3. Prevalent refrigerants used in residential AC and heat pump systems/products

Equipment	Year	Refrigerant	GWP
Central HPs/ACs and Ductless HPs	2024	R-410a	2,088
	≥ 2025	R-454b (a.k.a. HFC-454b)	466
		R-32	675
Room/Window AC Products	≥ 2024	R-454b (a.k.a. HFC-454b)	466
		R-32	675
HPWH	≥ 2024	R-134a	1,430
		R-410a	2,088
		CO_2 (rare)	1
HPCD	≥ 2024	R-134a	1,430
		Propane (R-290)	3

Source: DNV research conducted for California Public Utilities Commission and using GWP values for 100-year horizon (IPCC 4th Assessment)

Prevalence of Air Conditioning in California Homes is Increasing

To explore the possibility that more residential air conditioning has been installed in recent years, two studies on residential appliance usage in California from 2009 (KEMA 2010) and 2019 (DNV GL 2020) were used as sources. The 2009 study reported that air conditioning—either central systems or room/window units—was present in a weighted average of 67.4% of California homes; in 2019, this number increased to 80.1%. This trendline was projected forward to estimate that, by 2024, the proportion could reasonably be expected to have risen to 86.6%. Thus, the standard practice baseline for heat pumps assumes that 86.6% of homes would have chosen some form of air conditioning if they had not decided to install a heat pump.

[3] This rule allows for inventory of higher-GWP HFC equipment manufactured or imported before January 1, 2025, to be installed until January 1, 2026.
[4] This same limit was placed on room/window AC products one year earlier.

Lifecycle Avoided Emissions Due to Heat Pump Technologies in California

Ducted Heat Pumps Replacing Ducted Natural Gas Furnaces with Central AC

The electrification of space conditioning equipment has been offered as a deemed measure in California since 2020 wherever the net avoided emissions—excluding refrigerant leakage—would not increase. Given that nearly all of the current refrigerants used in central heat pump and air conditioning systems have a high global warming potential (GWP), the net emissions avoided were not always beneficial to the climate because of the high CO_{2e} emissions due to refrigerant leakage. The analyses in this and subsequent sections use emissions rates and annual energy savings approved for use in energy efficiency programs by the California Public Utilities Commission (CPUC) in 2024 and 2025.

The net emissions avoided (the sum of the electric, natural gas, and refrigerant leakage emissions) when replacing central natural gas furnaces—with or without central air conditioning— with central heat pumps containing the predominant high-GWP refrigerant in use today, R-410a (GWP=2,088), are presented in Figure 2. The avoided natural gas source energy emissions, in gold, always appear above the x-axis (shown at the middle of the y-axis) whereas the added electric source energy emissions, in green, always appear below the x-axis due to the added load from using the condenser/compressor loop during the heating months. The avoided refrigerant leakage emissions, in blue, also typically appear below the x-axis because: 1) heat pumps, like ACs, always contain refrigerant; and 2) heat pumps typically contain approximately 9% more refrigerant charge than ACs. The findings drawn from Figure 2 include:

- For a SEER2 15.2/HSPF2 7.7, 1-ton heat pump replacing a natural gas furnace and a 1-ton AC unit in California, the average net avoided lifecycle CO_{2e} emissions is 2.55 metric tonnes. (This result—and those that follow—assumes that the refrigerant contained in the existing AC system was reclaimed 80% of the time.)
- For a SEER2 15.2/HSPF2 7.7, 1-ton heat pump replacing a natural gas furnace <u>without</u> AC, the net *added* lifecycle CO_{2e} emissions is 2.71 metric tonnes.[5] This is largely due to the heat pump containing a high-GWP refrigerant, R-410a (GWP=2,088) where there had been no refrigerant before.
- For each 1-point increase of the heat pump's SEER2 rating, the net avoided lifecycle CO_{2e} emissions increase by approximately 0.05 metric tonnes due to the reduction in added electric load.

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[5] Since AC is presumed to occur in 87.7% of homes in California, once the baseline for replacement of natural gas furnaces with heat pumps is adjusted to reflect that, the net avoided lifecycle CO_{2e} emissions increase to 1.8 metric tonnes.

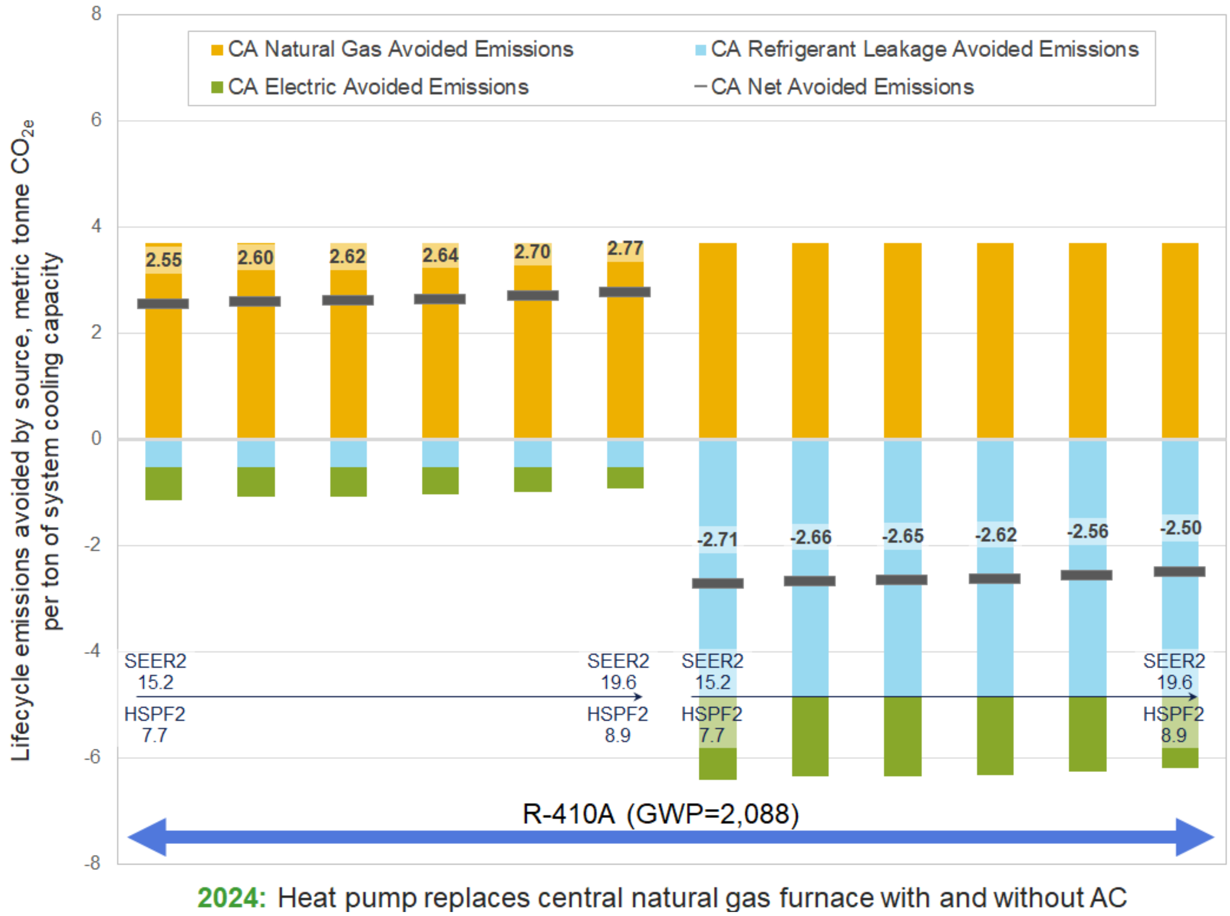

Figure 2. Statewide weighted-average net lifecycle emissions for a 1-ton heat pump using R-410a replacing a comparably-sized natural gas furnace with/without air conditioning in California (left/right). *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).[6]

As previously indicated, though, EPA's recent updates require that all heat pumps and ACs manufactured after January 1, 2025 contain a refrigerant having a GWP no higher than 700. Figure 3 presents the dramatic emissions improvement that results from this change at heat pumps containing R-454b (GWP=466). The outcomes of changing the refrigerant are presented in Figure 3:

- For a SEER2 15.2/HSPF2 7.7, 1-ton heat pump replacing a natural gas furnace and a 1-ton AC unit in California, the average net avoided lifecycle CO_{2e} emissions jumps from 2.55 to 2.99 metric tonnes.
- For a SEER2 15.2/HSPF2 7.7, 1-ton heat pump replacing a natural gas furnace <u>without</u> AC, the net avoided lifecycle CO_{2e} emissions jumps from -2.71 to 1.14 metric tonnes.
- The net avoided lifecycle CO_{2e} emissions decrease slightly (0.05 metric tonnes) when R-32 (GWP=675) is used in place of R-454b.

[6] Although California is divided into 16 climate zones (CZ01 to CZ16), CZ15 was often excluded from HVAC heat pump analyses because no permutations were available for them. These permutations were unavailable because they rarely resulted in net avoided lifecycle emissions ≥ zero. CZ15 is a sparsely populated, desert region of the state that has more cooling degree days (CDD) and fewer heating degree days (HDD) than any other climate zone in California. It also has an insignificant effect on the weighted-average statewide values presented herein.

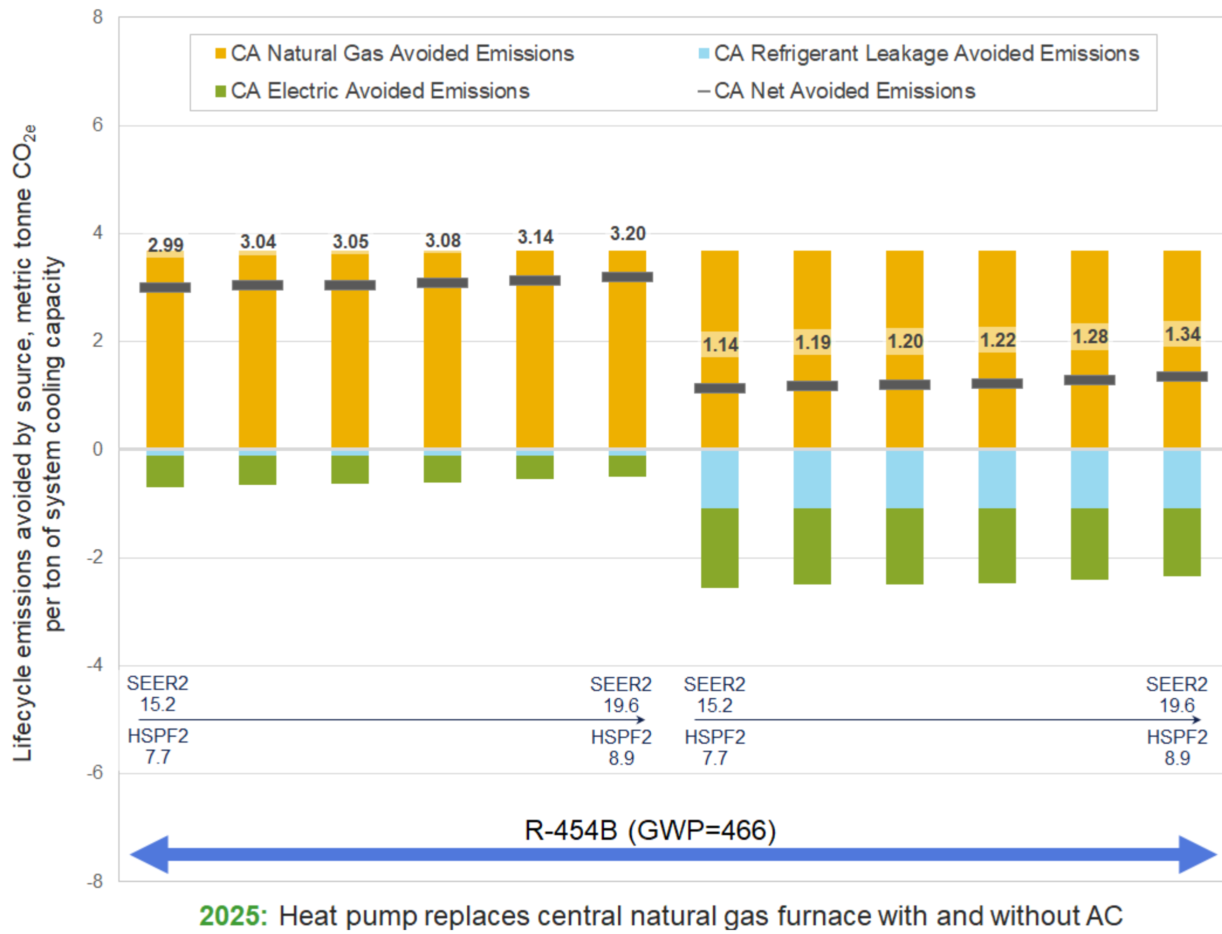

Figure 3. Statewide weighted-average net lifecycle emissions for a 1-ton heat pump using R-454b replacing a comparably-sized natural gas furnace with/without air conditioning in California (left/right). *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).

Previous research has shown that emissions either from intentional venting, improper disposal, or leaks during transport, are highest for residential and small commercial HVAC equipment (Hoover, Kanungo, and Johnson 2022). The end-of-life refrigerant leakage event that was shown in Figure 1 occurs in approximately 80% of residential air conditioning equipment removals in California, according to the California Air Resources Board. When the effect of the existing AC equipment's end-of-life emission event of R-410a is considered alongside the refrigerant emissions for the heat pump that contains R-454b, as shown in Figure 4—consisting of most of the red emissions spike—the overall benefit of the electrification measure is dwarfed. This event amounts to 2.06 metric tonnes (per ton of cooling capacity).

In California, the average air conditioning system at a single-family home has a cooling capacity of approximately 3.5 tons. Given California's non-compliance rate of 80%, preventing the end-of-life refrigerant leakage event at one single-family home would avoid just over 7 metric tonnes of CO_{2e}—or the equivalent of removing about 1½ automobiles from roadways for a year.

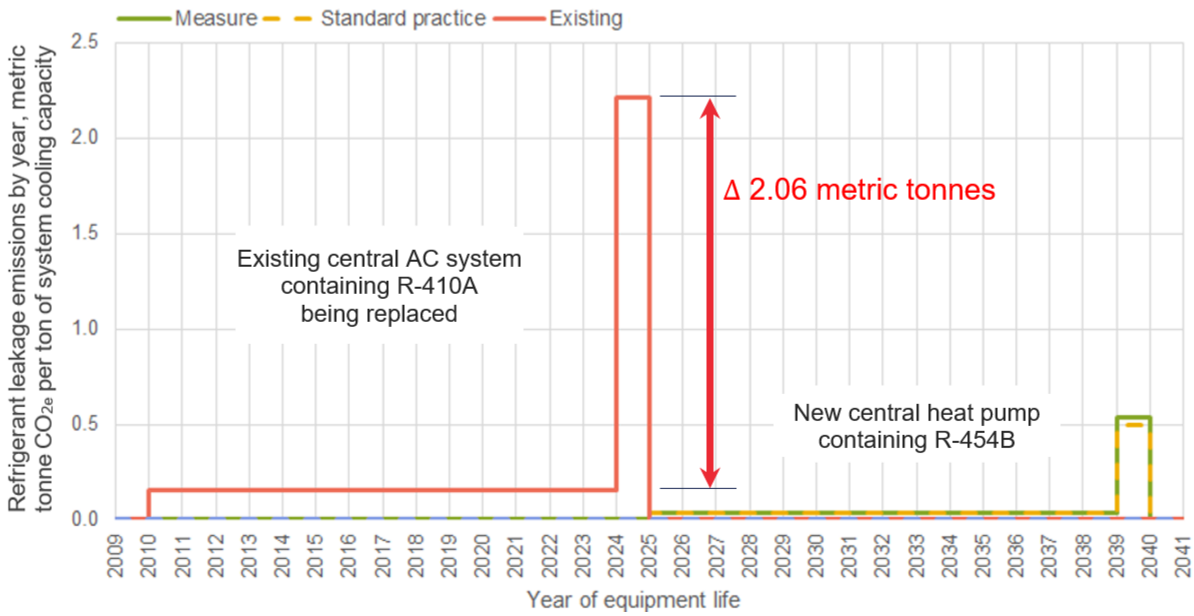

Figure 4. Refrigerant leakage emissions for a 1-ton AC that contains R-410a and being replaced by heat pump. *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).

While no known programs assure or incentivize the recovery of refrigerant from AC equipment being decommissioned whenever an energy efficiency or electrification measure is installed, this should be a requirement for programs everywhere.[7]

Ductless Heat Pumps Replacing Natural Gas Wall Furnaces and Room AC

Much like the central heat pumps, the net emissions avoided (the sum of the electric, natural gas, and refrigerant leakage emissions) when replacing a natural gas wall furnace—with or without room/window air conditioning— with a ductless mini-split heat pump containing the predominant high-GWP refrigerant in use today, R-410a (GWP=2,088), were analyzed (see Figure 5).

For a SEER2 15.2/HSPF2 7.7, 1-ton ductless heat pump replacing a natural gas wall furnace and a 1-ton room AC unit in California, the average net avoided lifecycle CO_{2e} emissions is 0.00 metric tonnes. This is significantly less net avoided emissions than for ducted heat pumps for two reasons: 1) ductless heat pumps tend to contain less refrigerant due to significantly shorter refrigerant lines; and 2) EPA limited the GWP of AC products (those factory sealed) to a maximum of 700 in 2024 (one year earlier than for ducted heat pumps).

[7] The California Public Utilities Commission is currently considering what documentation would be appropriate to collect to demonstrate appropriate refrigerant recovery from decommissioned equipment.

- For a SEER2 15.2/HSPF2 7.7, 1-ton ductless heat pump replacing a natural gas wall furnace without AC, the net *added* lifecycle CO_{2e} emissions is 1.45 metric tonnes.[8] Again, this is largely due to the heat pump containing a high-GWP refrigerant, R-410a (GWP=2,088) where there had been no refrigerant before.
- For each 1-point increase of the heat pump's SEER2 rating, the net avoided lifecycle CO_{2e} emissions increase by approximately 0.03 metric tonnes due to the reduction in added electric load.

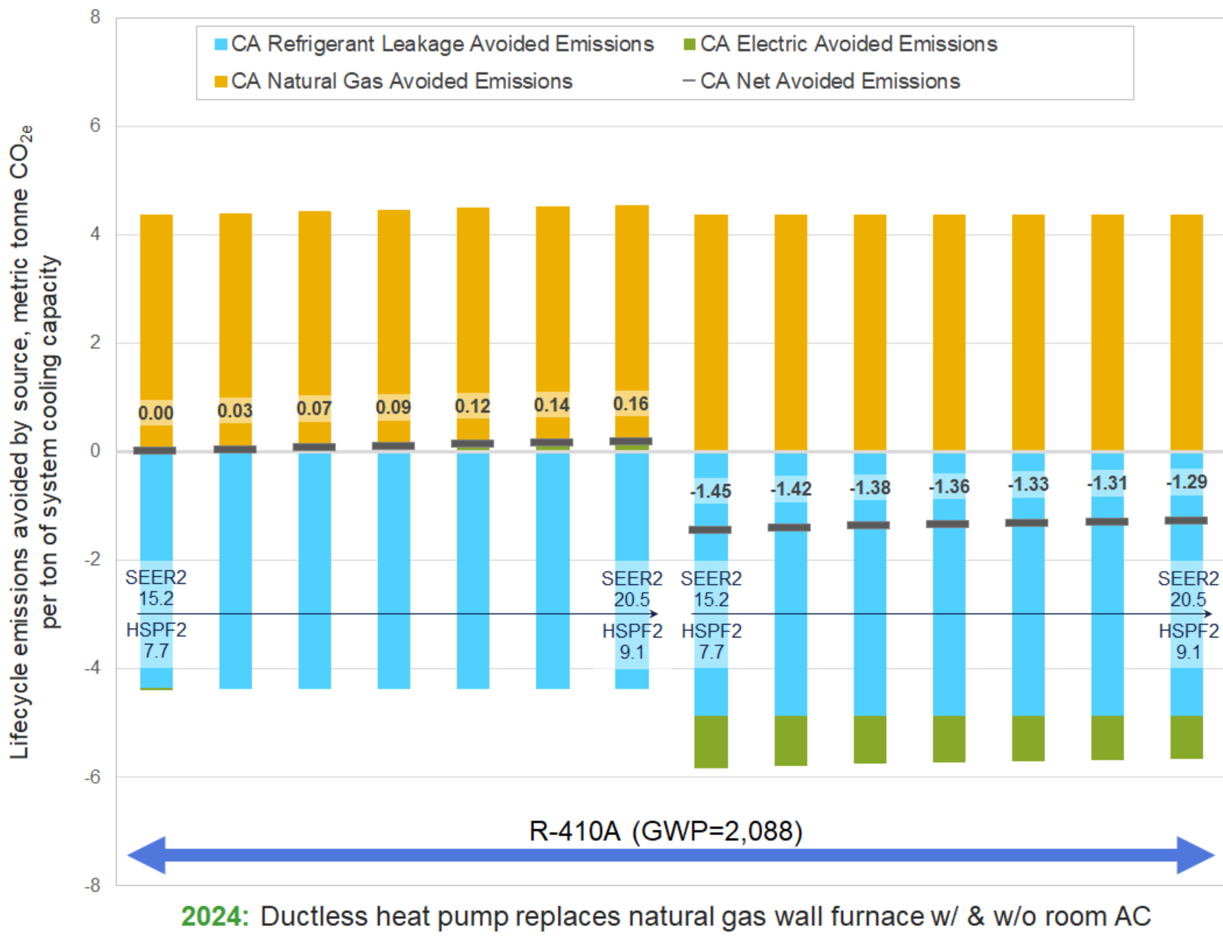

Figure 5. Statewide weighted-average net lifecycle emissions for a 1-ton heat pump using R-410a replacing a comparably-sized natural gas furnace with/without air conditioning in California (left/right). *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).

As previously indicated, EPA's recent updates require that all ductless heat pumps manufactured after January 1, 2025 contain a refrigerant having a GWP no greaterer than 700. Figure 6 presents the dramatic emissions improvement that results from this change at heat pumps containing R-454b (GWP=466). The outcomes of changing the refrigerant are presented in Figure 6:

[8] Since AC is presumed to occur in 87.7% of homes in California in 2024, once the baseline for replacement of natural gas furnaces with heat pumps is adjusted to reflect that, the net avoided lifecycle CO_{2e} emissions increase to 1.8 metric tonnes.

- For a SEER2 15.2/HSPF2 7.7, 1-ton ductless heat pump replacing a natural gas wall furnace and a 1-ton room AC unit in California, the average net avoided lifecycle CO_{2e} emissions jumps from 0.00 to 3.78 metric tonnes.
- For a SEER2 15.2/HSPF2 7.7, 1-ton ductless heat pump replacing a natural gas furnace without AC, the net avoided lifecycle CO_{2e} emissions jumps from -1.45 to 2.37 metric tonnes.
- The net avoided lifecycle CO_{2e} emissions decrease (0.22 metric tonnes) when R-32 (GWP=675) is used in place of R-454b.

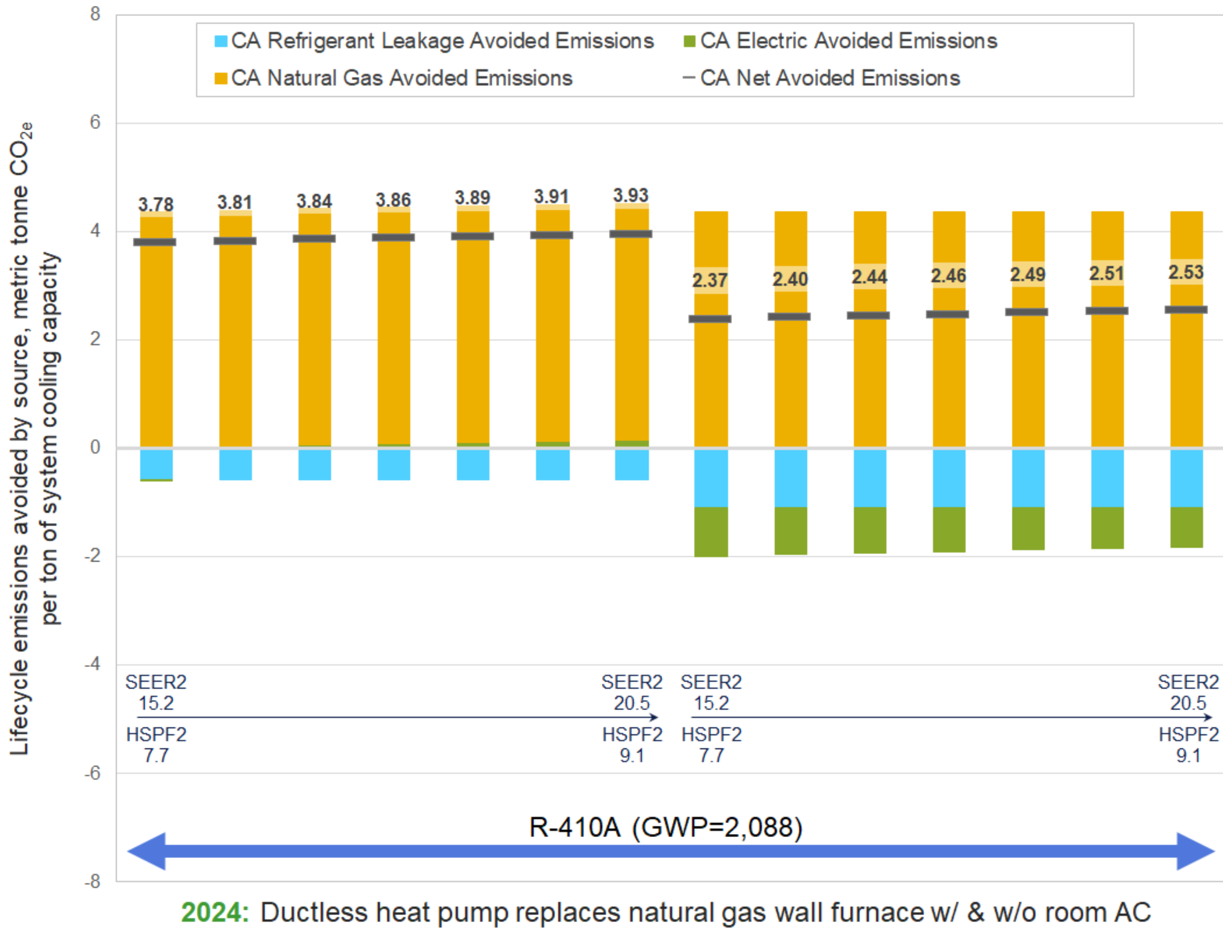

Figure 6. Statewide weighted-average net lifecycle emissions for a 1-ton heat pump using R-454b replacing a comparably-sized natural gas furnace with/without air conditioning in California (left/right). *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).

Much like was observed when the effect of the existing room AC equipment's end-of-life emission event of R-410a is considered alongside the refrigerant emissions for the ductless heat pump that contains R-454b, as shown in Figure 7—consisting of most of the red emissions spike—the overall benefit of the electrification measure is dwarfed. This event amounts to 2.06 metric tonnes (per ton of cooling capacity).

Again, requiring documentation showing that the existing room AC product's refrigerant was appropriately recovered would avoid 1.09 metric tonnes of CO_{2e}.

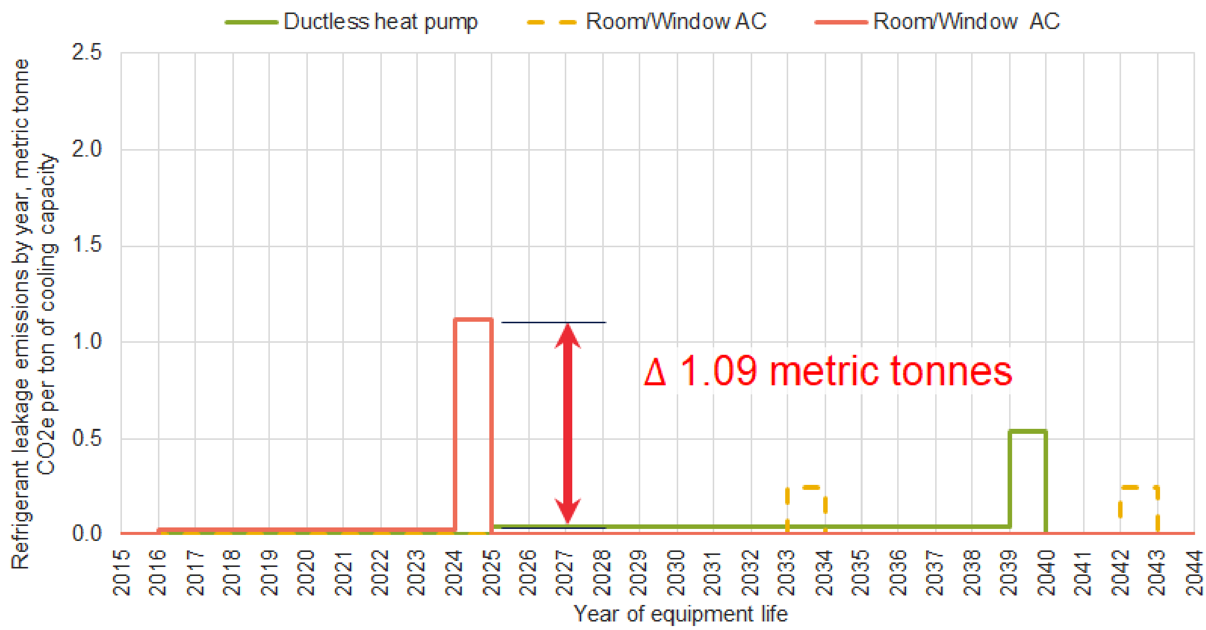

Figure 7. Refrigerant leakage emissions for a 1-ton room AC product that contains R-410a and being replaced by ductless heat pump. *Source:* DNV analysis using permutation data (CA eTRM 2024b) and the RACC-FSC_v3.0 tool (CEDARS 2024).

Heat Pump Water Heaters Replacing Natural Gas Water Heating

Efficient electrification of natural gas water heating equipment—in the form of heat pump water heaters (HPWHs)—has been offered as a deemed measure in California since 2020. The increased costs of HPWHs compared to natural gas storage tanks and the frequent additional costs to upgrade electrical service panels or wiring remain a barrier to transforming this market, however. Typically, HPWHs use those refrigerants listed in Table 3.

The net emissions avoided in California for residential, 240-volt[9] heat pump water heaters (HPWHs) replacing natural gas water heating equipment are presented in Figure 8 where the HPWHs contain R-134a (GWP=1,430). Heat pump water heaters are offered with three efficiency tiers where the most efficient tier has a uniform energy factor (UEF) of 3.75 or greater (shown at the left edge of each set of three stacked columns in Figure 8) and the least efficient tier has a UEF rating of 3.30 (shown at the right edge of each set). Each pair of three stacked columns represents a packaged HPWH with a hot water storage tank that replaces either a natural gas storage water heater or a natural gas instantaneous water heater. The avoided natural gas source energy emissions always appear above the x-axis (shown at the middle of the y-axis) whereas the added electric source energy emissions and added refrigerant leakage emissions always appear below the x-axis.

The sizes of the HPWHs vary as indicated by the ranges shown along the top of the chart whereas the natural gas equipment they will replace is shown beneath the stacked columns. Even

[9] 12-volt HPWHs are presently in the process of being added to the portfolio of deemed measures in California.

when refrigerant leakage emissions are considered, all HPWH electrification combinations yield net positive avoided emissions.

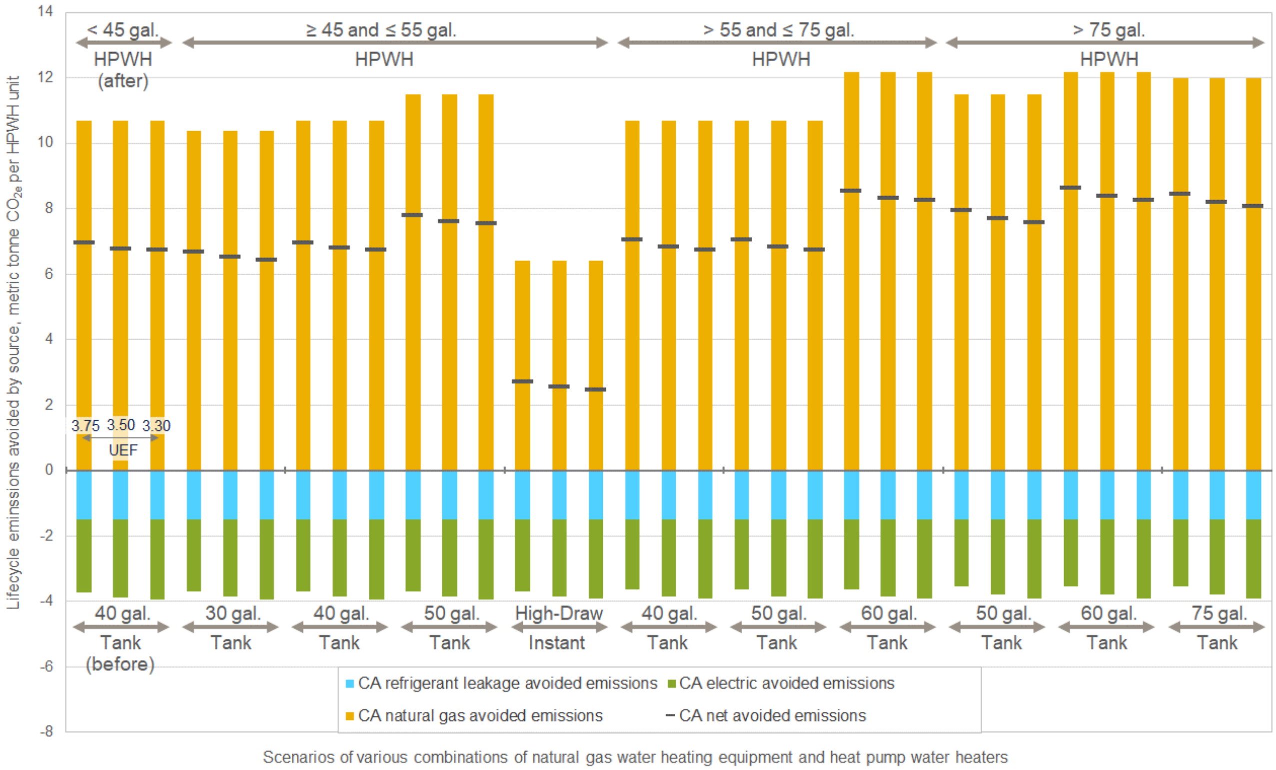

Figure 8. Statewide weighted-average lifecycle emissions (per HPWH) due to electric source energy, natural gas source energy, and refrigerant leakage—assuming R-134a refrigerant—for HPWHs replacing natural gas water heating equipment that include storage tanks and instantaneous (a.k.a. tankless) in California. *Source:* DNV analysis using permutation data (CA eTRM 2024c) and the RACC-FSC_v3.0 tool (CEDARS 2024).

Presently, HPWHs typically contain either R-134a (GWP=1,430) or R-410a (GWP=2,088). Figure 8 shows the refrigerant leakage emissions for HPWHs that contain R-134a; for those HPWHs that contain R-410a, the net emissions avoided decrease—for all combinations of water heating equipment shown—by 0.69 metric tonnes CO_{2e}. There are a few split-system HPWHs on the market that use CO_2 (GWP=1) as the refrigerant, but these remain expensive and are not cost-effective to provide as a deemed measure in California.

- Even though nearly all refrigerants presently used in heat pump water heaters have a high GWP, the net emissions avoided remain beneficial to the environment—even when the CO_{2e} emissions due to refrigerant leakage are considered.
- The resulting net lifecycle emissions avoided of replacing natural gas storage water heaters with HPWHs is comparable to eliminating one automobile from roadways for a year.

Heat Pump Clothes Dryers Replacing Natural Gas Clothes Dryers

Efficient electrification of clothes drying equipment has been offered as a deemed measure in California since 2020. The net emissions for 2024 and 2025 for residential HPCDs, like heat pumps, have slightly more complicated results, as shown in Figure 9.

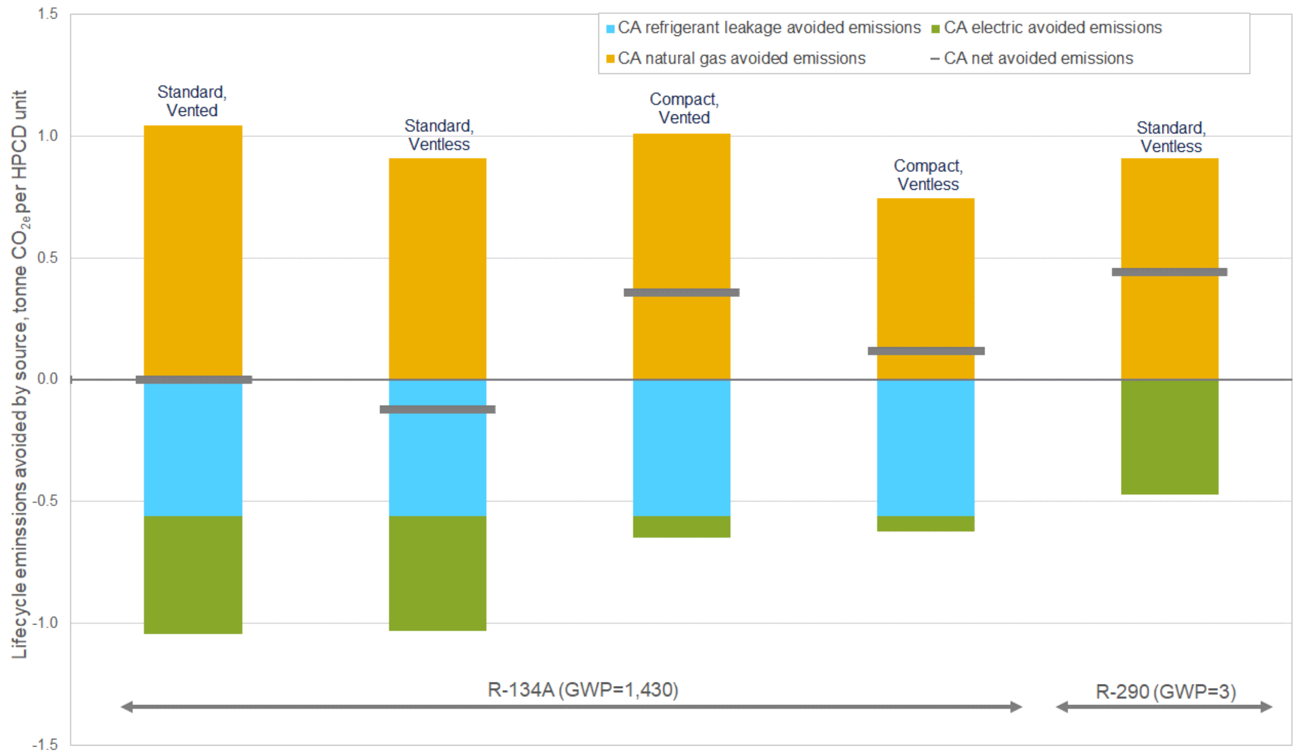

Figure 9. Statewide weighted-average lifecycle emissions (per HPCD) due to electric source energy, natural gas source energy, and refrigerant leakage—assuming R-134a or R-290 (butane) refrigerant—for HPCDs replacing natural gas clothes dryers in California. *Source:* DNV analysis using permutation data (CA eTRM 2024a) and the RACC-FSC_v3.0 tool (CEDARS 2024).

Presently, HPCDs typically contain either R-134a (GWP=1,430) or a very small fraction—in the high-end market—R-290 (a.k.a. propane, GWP=3). Figure 9 shows the refrigerant leakage emissions for HPCDs that largely contain R-134a; only the rightmost stacked column reflects the avoided emissions for the few available HPCDs on the market that contain R-290. While the net emissions avoided are generally higher for the compact[10] HPCDs than for the standard-size ones, it is expected that the standard dryer is more likely to be selected for single-family homes.

- Ventless dryers—both compact and standard sizes—yield lower net lifecycle avoided emissions than vented models.
- Among the standard size HPCDs, ventless models only yield positive net emissions avoided when R-290 is used as the product's refrigerant according to California data.

[10] Compact clothes dryers have a capacity less than 4.4 ft^3.

Space Conditioning Characteristics in the United States

Although the analyses presented in this paper pertain to California, many of the conclusions and recommendations can be applied in other states. The heating fuels and system types in single-family homes—detached and attached—have been summarized in Table 4 for the continental United States using NREL's Building Stock Analysis webtool (Murray, Minaei, and Gopalan 2022). With 67% of homes using fossil fuels to produce heat, there is a great deal of opportunity to electrify space heating. Central boiler and furnace systems typically connect to central ductwork systems and can readily be converted to heat pumps; wall and floor furnaces can more readily be replaced with ductless heat pumps without incurring the added first cost of duct fabrication and installation. Overall, 93% of U.S. homes have some degree of air conditioning and the need for more continues to grow.

Table 4. Proportions of fossil-fuel heated single family homes that have central ductwork and/or air conditioning

Ductwork	Cooling	ResStock Homes by Heating Fuel, percent		
		Natural Gas	Fuel Oil	Propane
Central	Central AC	52%	5%	6%
	Room AC	6%	1%	1%
	None	8%	1%	1%
None	Room AC	11%	2%	1%
	None	6%	1%	1%

Source: NREL, 2022. *NREL ResStock Data Viewer*

Conclusion

While the shift to electrify homes across the United States will take time, it is critical that the transformation avoids instances when the resulting net lifecycle emissions increase. As demonstrated in the analyses presented herein, this is highly dependent upon the type of refrigerant contained within the heat pump technology. Energy efficiency programs would be well advised to adopt policies that encourage energy efficiency improvements *and* discourage heat pump systems and products that contain high-GWP refrigerants. Awareness on the part of program administrators, utilities, and regulators is growing, but many are overwhelmed by the steep learning curve regarding refrigerant management. They should be heartened to know that a rigorous tool has been developed for use in California that can be used elsewhere with some adjustments.

Further, for each ton of cooling in existing air conditioning systems at single-family homes, there exists an opportunity to avoid 2.06 metric tonnes of CO_{2e} emissions and transform the HVAC contractor industry by always requiring appropriate recovery of the refrigerant contained within those systems being decommissioned. Given both the potential to avoid CO_{2e} emissions on a large scale whenever replacing existing AC systems with heat pumps and the extremely high rates of residential AC refrigerant recovery non-compliance, supporting contractor education about the deleterious effects of venting refrigerants to the atmosphere is desperately needed.

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