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Addressing the barriers to heating electrification in the US

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Abstract

One of the greatest challenges in US electrification efforts to reduce carbon emissions is to utilize electric heat pumps for space and water heating rather than fossil fuels. Although the number of *heat pumps* for space conditioning is growing, they still represent only 35% of sales and only 12% of installed base. While it has been over forty years since one of the first *heat pump water heaters* was introduced, they only account for 2% of sales and less than 1% of the installed base.

Several barriers exist that impede the widespread adoption of heat pump technology for space and water heating in the US, especially for retrofit applications. This paper will examine the various barriers and identify potential solutions and strategies to address those barriers, including various research activities related to equipment, and potential cost reduction strategies, both for the product and installation. Also included will be a discussion of programs and incentives by utilities and efficiency organizations.

Keywords: Electrification;heat pump;barriers;heat pump water heater;incentives;cost reduction

1. Introduction

The United States (US) has set an ambitious goal to reduce greenhouse gas (GHG) emissions by at least 50% by 2030. Achieving this goal would put the United States on a path to limit global warming to 1.5 degrees Celsius, the target scientists say is required to avoid the worst consequences of the climate crisis.

A recent study by a team of scientists and policy analysts from across the nation indicates there are multiple pathways to achieve this goal. However, commitments to the actions need to be made as soon as possible. The study consolidates findings from six recently published techno-economic models that simulate U.S. energy system operations. According to the authors, the separate models all agree on four major points:

- The majority of the country's greenhouse gas emissions come from power generation and transportation, so to reduce overall emissions by 50%, the electricity grid needs to run on 80% clean energy (up from today's 40%), and the majority of vehicles sold by 2030 need to be electric. Other important sources of GHG emissions reduction include *electrification of buildings* and industries.
- The primary barrier to increased alternative energy use will not be cost, it will be enacting new policies. A coordinated policy response between states and the federal government will be necessary to succeed.

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- Thanks to advances in wind, solar, and energy storage technologies, powering the electric grid with renewables will not be more expensive; and electric vehicles could save every household up to $1,000 per year in net benefits.
- A clean-energy transition would reduce air pollution, prevent up to 200,000 premature deaths, and avoid up to $800 billion in environmental and health costs through 2050. Many of the health benefits will occur in communities of color and frontline communities that are disproportionately exposed to vehicle, power plant, and industrial pollution. [1]

The US Department of Energy (DOE) is one of the primary US government agencies involved with ensuring America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

DOE's analysis of greenhouse gas pollution reductions from the clean energy provisions of the Inflation Reduction Act and Bipartisan Infrastructure Law finds that the combined impact of both laws could reduce emissions by approximately 1,000 million metric tons (MMT) in 2030, with a total of nearly 1,150 MMT when considering other provisions of each law. The expected emissions reduction from these measures is equivalent to the approximate combined annual emissions released from every home in the U.S. [2]

"The Inflation Reduction Act (IRA) is a triumph of historic scope and ambition that will enable a whopping 40% reduction in greenhouse gas emissions below 2005 levels. Combined with President Biden's Bipartisan Infrastructure Law and the CHIPS and Science Act, these investments will transform our economy and bring us closer to achieving our nation's climate goal," said U.S. Secretary of Energy Jennifer M. Granholm. "These historic legislative accomplishments are delivering on the President's promise to build a new American clean energy economy that creates millions of good jobs while lowering energy bills for families and combating the climate crisis." [2]

In support of the IRA, the Building Technologies Office in DOE's Office of Energy Efficiency and Renewable Energy develops, demonstrates, and accelerates the adoption of cost-effective technologies, techniques, tools and services that enable high-performing, energy-efficient and demand-flexible residential and commercial buildings in both the new & existing buildings markets, in support of an equitable transition to a decarbonized energy system by 2050, starting with a decarbonized power sector by 2035.

2. Carbon Dioxide Emissions

As shown in Figure 1, the transportation sector has the highest percentage CO_2 emissions (37%), followed closely by the combined emissions (35%) from the buildings sector [3]. Electricity used to power equipment in the residential and commercial sector comprises the largest source of CO_2 emissions (67%), followed by natural gas (26%).

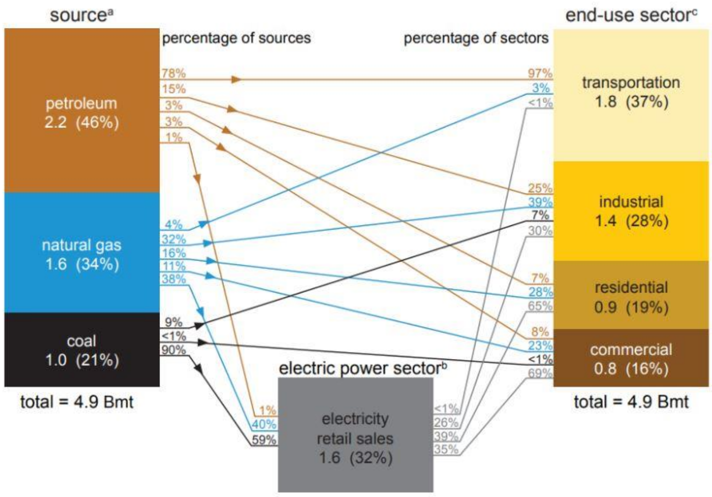

Fig. 1. U.S. CO_2 Emissions from Energy Consumption by Source and Sector.

One of the strategies to address decarbonization in the buildings sector is to increase the use of renewables to replace existing fossil-fueled power plants and address future growth. An additional strategy is to replace natural gas equipment, such as furnaces and water heaters, with heat pumps. As shown in Figure 2, space heating with natural gas is the largest contributor to direct emissions in both residential and commercial buildings [4]. Natural gas water heating is the next largest contributor in residential buildings. Together, space and water heating with natural gas account for over 90% of the *direct* emissions in the residential buildings and approximately 60% in commercial buildings.

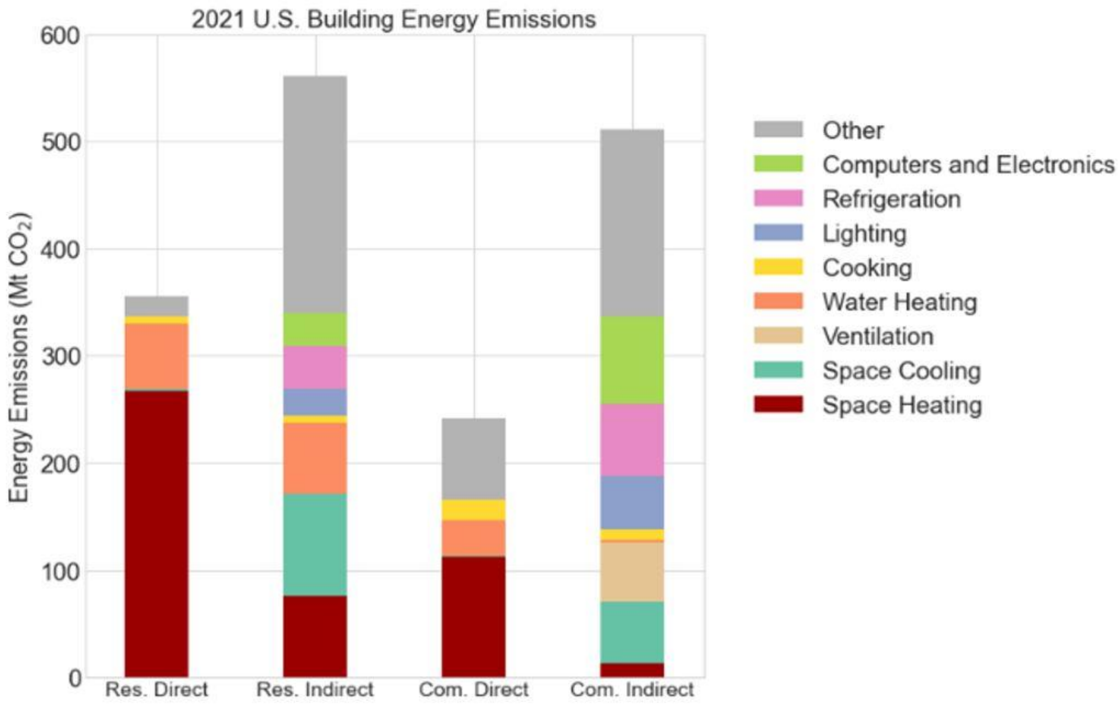

Fig. 2. U.S. CO_2 Emissions from Energy Consumption by End Use.

3. Heat Pump/Heat Pump Water Heater Market

The number of heat pumps in the US for space conditioning is growing (Figure 3) [5]. Since 2000, sales have increased 20%. However, they still represent only 35% of sales and 12% of the installed base. The highest saturation is in the south, accounting for 24% of the installed base (Figure 4) [6].

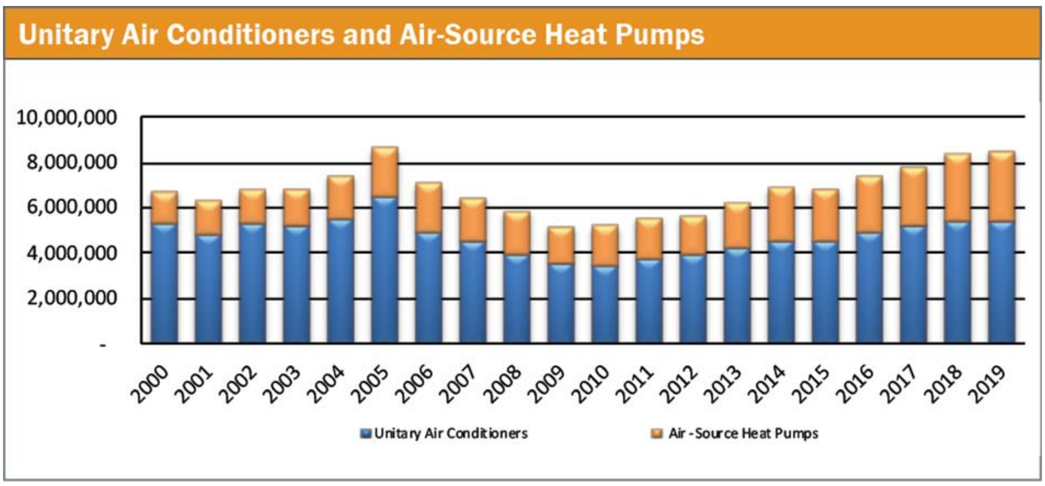

Fig. 3. US Heat Pump Annual Sales.

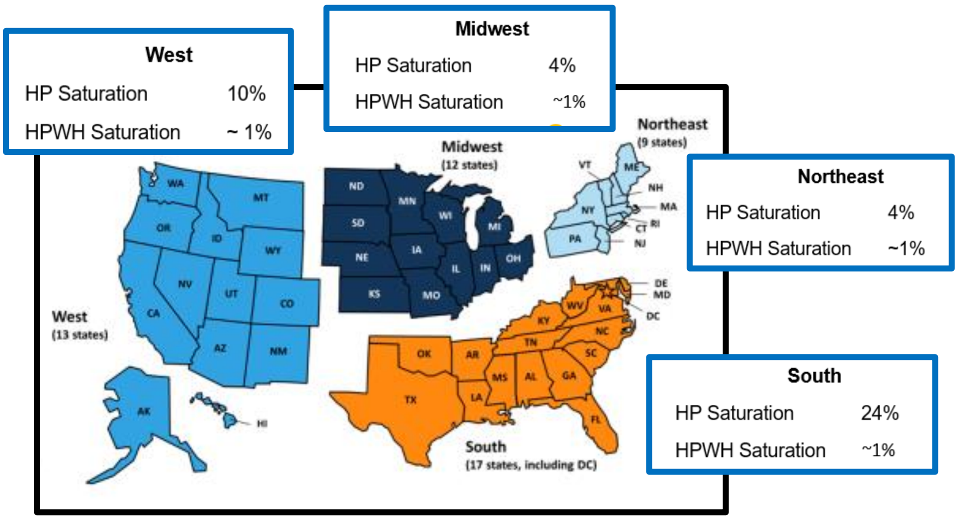

Fig. 4. US Heat Pump Installations by Region.

Heat pump water heaters are the future of water heating, with local jurisdictions promoting all-electric buildings and a new national effort to accelerate market transformation. Numerous reputable water heating manufacturers have released their own models, and by 2017-2018, HPWH shipments totalled about 70,000 on average (Figure 5) with an estimated market penetration of almost 2% [7]. Factors driving the future growth of the heat pump water heater market include their efficiency relative to electric resistance coupled with the ability to use renewable sources of energy to power the unit, which requires three to four times less energy. In addition, supportive regulations and incentives are also expected to play a key role in the growth of this market [8].

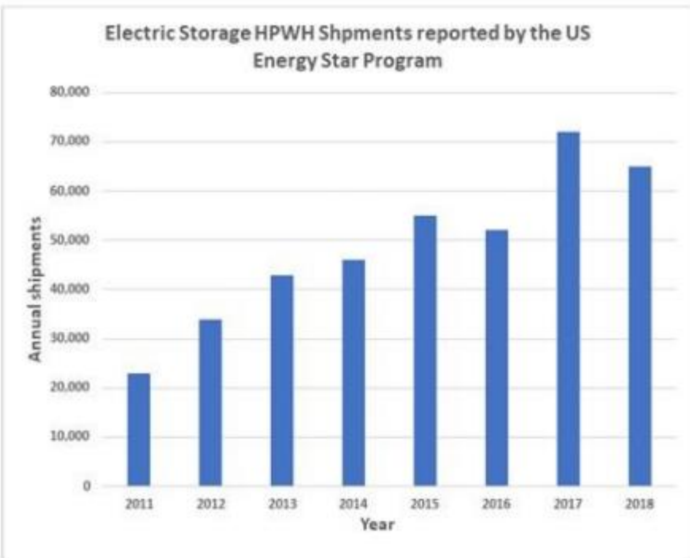

Fig. 5. US Heat Pump Water Heater Annual Sales.

4. Barriers to Heating Electrification

As shown in Figure 6, all states are not equal in the amount of carbon emissions [9]. The main contributors, highlighted in green, are some of the most populous states, such as California, Texas, and Florida. However, population alone doesn't impact carbon emissions. Other factors, such as the fuel used for building equipment (natural gas, electricity, fuel oil), the energy source for power generation (natural gas, nuclear, hydropower, coal), and the climate all influence the amount of carbon released from buildings to the atmosphere.

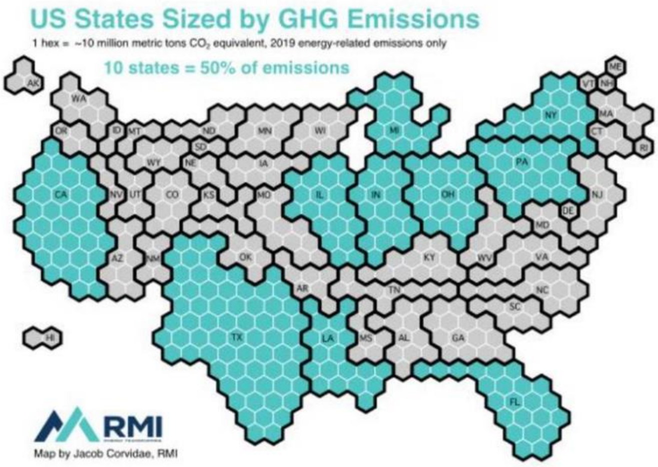

Fig. 6. U.S. States Sized by CO_2 Emissions.

To significantly reduce carbon emissions in the buildings sector, the US must concentrate on addressing some of the main barriers to electrification of building equipment in the ten states, many of which are also problematic in the other states. Following are the major barriers encountered when consumers consider replacing their fossil-fired equipment with an electric heat pump.

4.1 Heat pump barriers

Several barriers exist that inhibit greater numbers of heat pumps being installed in the US. Among these are installed cost, operational cost, space constraints, panel upgrades required when replacing natural gas equipment, installer familiarity, shortage of trained installers, product availability, and consumer acceptance. These barriers can be generally grouped by 1) cost; 2) installation challenges; 3) consumer issues; 4) work force issues, and 5) capacity. Most of these barriers apply to both retrofit and new installations in residential and commercial markets. However, there are some differences which are unique to the building type, especially for multifamily housing, which will be highlighted in section *4.1.6*.

4.1.1 Cost

Installation costs are one of the main barriers to increasing the number of heat pumps, especially in northeastern regions where the present equipment is a natural gas or oil-fired furnace. In the Northeast, natural gas fuels 55% of homes; this is broken down by 75% of New Jersey homes, 61% of New York's, and 51% of Pennsylvania's [10]. In Figure 7, installation costs were estimated in New York for an air-source heat pump compared to a gas furnace with an air-conditioning (3-ton unit) [11]. Estimated costs were based on an average from Long Island, New York City, and the Hudson Valley/Upstate/Western New York region databases and vetted through stakeholder conversations. The average shows the cost difference between an air-source heat pump versus a furnace/electric air-conditioner is $4584, an increase of 55% over the cost for the furnace/electric air-conditioner.

HVAC System Type	Installed Cost
Air-Source Heat Pump	$12,964
Gas Furnace w/ AC	$8,380
Incremental Cost	$4,584
Incremental Cost %	55%

Fig. 7. Installation Cost Estimates for New York.

One of the main drivers for the higher installed cost is that heat pumps in colder climates require larger units to provide sufficient heating at lower temperatures (capacity drops at lower temperatures) and variable-speed compressors and fans to reduce capacity in the summer to prevent frequent cycling that would otherwise result from oversizing the units for winter operation.

Another factor is that in some areas where contractors are unfamiliar with heat pumps, they charge a premium to install a heat pump system versus a natural gas or oil furnace since they will need to spend more time properly designing the system. In addition, they may be concerned about call backs if the customer is unhappy with their new system due to cooler temperatures leaving the register. This would result in less profit for the installer due to the increased cost for labor and vehicle charges (gas and maintenance) to address the issue with the consumer.

In addition to installation costs, operating costs must also be considered to evaluate the overall life-cycle cost for an electric heat pump versus a natural gas/electric air-conditioner. The American Council for an Energy Efficient Economy investigated the life-cycle costs in all regions of the US [12]. The results, shown in Figure 8, indicate that, in general, heat pumps have lower life-cycle costs in states with lower rates for electricity versus natural gas (Southern, Pacific Northwest) and higher life-cycle costs in states with higher rates for electricity versus natural gas (Northeast and Midwest). The higher installed costs in those regions are also a large factor in the differences.

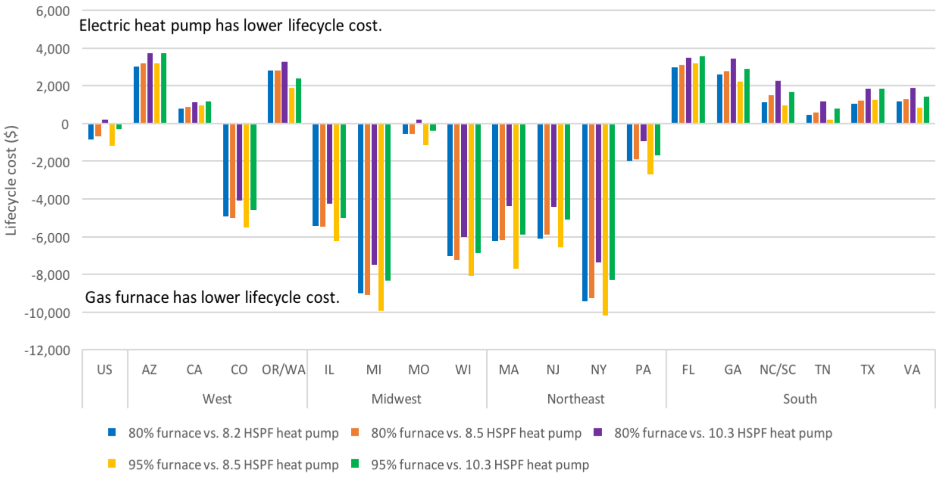

Fig. 8. Life-Cycle Cost Estimates for Various Equipment Types.

4.1.2 Installation challenges

According to new research from residential electricity research group Pecan Street, electric panels in up to 48 million U.S. single-family homes will need to be upgraded to fully transition away from fossil fuels and use electricity for space and water heating, and other applications. Most older homes have a 100-amp breaker panel and heat pumps require a circuit breaker up to 60 amps. With an average cost of $2,000 for an upgraded panel, that represents a nearly $100 billion impediment to residential electrification [13]. This can be problematic when replacing a natural gas furnace to a heat pump in some states, especially California, where natural gas is the most popular residential heating fuel type. Some 64 percent of occupied housing units in the state rely on natural gas for heating in 2020 [14].

4.1.3 Consumer issues

The majority of consumers don't evaluate the total cost of ownership when purchasing a heat pump. They gravitate towards the lowest cost product which is usually minimum standard efficiency. However, it was shown in section *4.1.1* that a higher cost product, such as the cold climate heat pump, can save enough money in energy costs over its lifetime such that the life-cycle costs that are lower than a 97% AFUE furnace in St. Louis.

Consumers are also reactive, meaning they don't plan replacements of heating and cooling equipment ahead of time, but only replace in emergency situations (failure). In addition, they typically replace like for like, e.g., a natural gas furnace is replaced with another natural gas furnace.

4.1.4 Work force issues

Contractors are a key stakeholder in electrification retrofits because they are the main point of contact for home and building owners. In many parts of the US, there are simply not enough contractors trained to properly install heat pumps, particularly in retrofit situations. At the same time, many trained contractors are retiring and not enough people are entering the contractor workforce to replace them. This gap can severely limit the number of electrification retrofits in each area [15].

Contractors may also be hesitant to learn about new equipment because they have limited resources for training and they may worry that there is not enough market demand to justify retraining and changing their business model.

4.1.5 Capacity

Heat pump capacity drops as the outdoor temperature gets colder. The capacity for single-speed heat pumps at low outdoor temperatures can be roughly half of what it is at the rated condition. One remedy for this is to equip heat pumps with electric resistance heaters to maintain the set-point temperature in the house. However, this increases the operating cost since electric resistance heaters only have an efficiency of 1 versus heat pump efficiencies as high as 4. Another remedy is to use variable-speed motors to increase the capacity at low temperatures by increasing the speed (moving more refrigerant through the system) to better match the house load. Unfortunately, variable-speed designs tend to be more expensive than single-speed. Thus, trade-offs must be made when deciding on which heat pump design is most cost-effective.

4.1.6 Multifamily applications

Multi-family housing is a large portion of the U.S. housing stock, with 26% of total housing units located in multifamily buildings [15]. Space constraints are one of the major barriers to heating electrification in multifamily housing since many apartments and condo buildings do not have sufficient space for heat pumps, especially the associated ductwork necessary to distribute conditioned air evenly throughout the space. The locations where electric heat pumps are installed may result in noise complaints, particularly if located in common spaces, balconies or other locations that could disrupt tenants.

Multifamily buildings can also face market barriers with respect to renter occupied units, which comprise the majority (86%) of multifamily units. The large number of renters in multifamily buildings leads to the issue of *split incentives* which refers to building owners being unwilling to invest energy upgrades for tenants who pay for their own utility costs. Because the value of energy efficiency upgrades benefits the tenant, property owners see little to no return which creates a motivational barrier to the installation of heat pumps [15].

4.2 Heat pump water heater barriers

Barriers for heat pump water heaters are similar to those for heat pumps, such as cost, installation challenges, consumer issues, and capacity. For heat pump water heaters, there are a few barriers that are unique or more pronounced, such as space constraints, location of the unit, and availability of units. As in the case with heat pumps, most of these barriers apply to both retrofit and new installations in residential and commercial markets. However, there are some differences, which will be highlighted in section *4.2.6*.

4.2.1 Cost

Installation costs for heat pump water heaters can be approximately $1000 higher when replacing an existing natural gas water heater with a heat pump water heater. This is a 65% increase and for homeowners that base their decisions on first cost, it is difficult hurdle to overcome [16]. Replacing an existing electric resistance water heater with a heat pump water heater may seem to be an easier upsell, especially with paybacks of around 3 years for a family of four [17]. However, the first cost difference is even higher than that for a gas water heater scenario (approximately $1300) [16].

4.2.2 Installation challenges

Heat pump water heaters face the same electrical panel upgrade challenge as heat pumps when replacing an existing gas unit. Although the breaker required is only 30 amps versus 60 amps for a heat pump, this still can be a difficult hurdle to overcome, especially if there is no wiring in the vicinity of the gas water heater to provide power to the unit. The additional labor and materials for wiring and condensate piping further increase the cost by approximately $500 [16]. This issue can be extremely problematic for states like California where 90% of water heating is supplied by natural gas [18].

4.2.2.1 Space constraints

In residential applications where the water heater is located in a closet, the installation space requirements for heat pump water heaters are much different than for the existing water heater (electric resistance or natural gas) they will replace. The National Building Code requirements for a gas water heater are: 1) it should have a minimal 1-inch clearance between it and any combustible material, such as wall framing or wall finish; 2) it must have a self-closing gasketed door that prevents carbon monoxide or other products of combustion from entering the home; and 3) fresh air needed for combustion must be drawn from *outside* the home using double wall metal pipe [19]. On the other hand, electric water heaters don't require even a minimal clearance space. This is because, unlike their gas-powered counterparts, they don't release exhaust. The main difference when locating a heat pump water heater in a closet is that it has to have adequate ventilation from the *indoor* space. In order to run efficiently, heat pump water heaters need 700 to 800 cubic feet of available space (air in the room) to operate properly, which requires louvered doors when this space is not available [20].

4.2.2.2 Location

Another issue regarding the installation space concerns the ambient temperature at which the heat pump water heater must operate. Since it is a heat pump, the efficiency and capacity get worse as the surrounding air temperature gets colder. Therefore, for a northern climate, locating the heat pump water heater in a garage or attic will severely degrade its performance during the winter.

4.2.3 Consumer issues

Heat pump water heaters are an unfamiliar technology to most consumers. When it comes to replacing their water heater, consumers typically replace in kind because of their familiarity with what has been working for them. One complaint from consumers is that heat pump water heaters are perceived as being noisy. Although they make about as much noise as a refrigerator, consumers are not used to hearing a noise from their electric resistance water heater [18]. Also, for consumers replacing a fossil-fired water heater, they may expect a heat pump water heater to be less noisy than their existing unit.

Because heat pump water heaters transfer heat from ambient air, they do not work well, or sometimes at all, in colder temperatures. For this reason, it may be difficult to utilize a heat pump water heater in certain regions due to a loss in capacity [21]. If hot water recovery is limited to the heat pump alone, it will take a lot longer to reheat the tank after a long draw. Electric resistance heat can hasten the recovery, but at the price of eliminating much of the savings [22].

4.2.4 Capacity

Heat pump water heaters take a relatively long time to heat a volume of water to the pre-set temperature, approximately 3 to 4 hours when running in compressor-only mode for a 40-gallon tank. For comparison, an electric resistance water heater takes 40 to 60 minutes and a natural gas water heater takes 30 to 45 minutes. In order to keep up with the hot water demand, particularly at peak times, most heat pump water heaters are equipped with electric heating elements which would enable them to match the recovery performance of an electric resistance water heater. When properly installed, a heat pump water heater rarely needs to revert to its less efficient backup mode where the heating elements are energized [23]. One strategy for reducing the amount of time a heat pump water heater avoids turning on the back-up electric resistance heaters is to install a larger tank, 50- to 80-gallon versus a traditional 40 gallon.

4.2.5 Product availability

Another main drawback to heat pump water heaters is the availability of residential products both in big box stores and stocked by plumbers. Plumbers install 43% of all residential water heaters. Homeowners (26%) and retailers (17%) account for another 43% of installations (Figure 9) [24]. Typically, water heaters are an emergency installation following a catastrophic tank failure. Thus, product availability is critical. The majority of plumbers and retailers don't routinely stock heat pump water heaters, thus the only type of water heater available is a standard natural gas or electric resistance version. The reason availability is limited is due to the market demand. Since heat pump water heaters represent 2% of all water heaters sold, there is no incentive for retailers and plumbers to stock them.

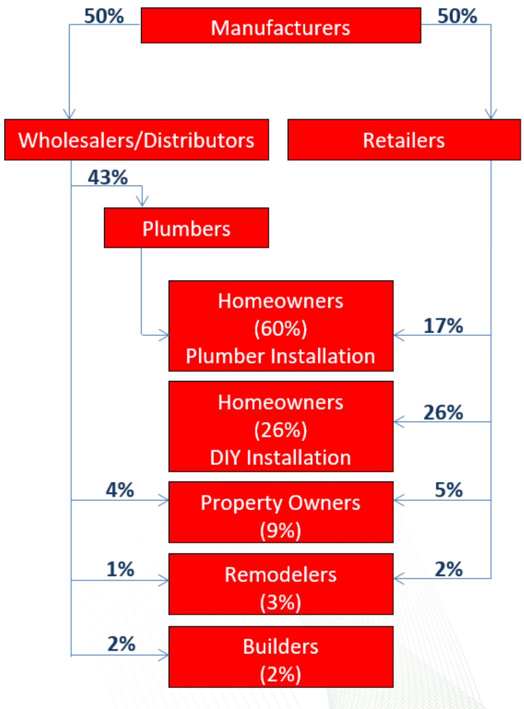

Figure 9. Heat Pump Water Heater Installations.

4.2.6 Multifamily and large commercial applications

For multifamily housing, two options are commonly used: 1) a central domestic hot water system with one or more commercial storage water heaters or one or more boilers coupled with a storage tank to serve the entire building, or 2) alternatively, water heaters are installed in each dwelling unit (similar to single-family). The availability of large heat pump water heater models for central systems is limited compared to residential products. This is especially true for applications that require higher temperatures, such as boiler applications and in large buildings where recirculation losses would require electric resistance boosters. For applications where a single heater services each unit, tankless and low boy water heaters are more popular due to their ability to be located in small spaces, However, this becomes an impediment for replacing with a heat pump water heater since they necessitate more space due to their size and ventilation requirements.

5. Solutions: Heat Pumps/Heat Pump Water Heaters

5.1 Incentives

Financial incentives, whether provided through utility programs or by state agencies, can spur market development. Incentives directly to consumers for heat pumps for space and water heating can aid in mitigating barriers associated with upfront cost. Incentives to distributors and retailers (rather than through customer rebates) can also be tied to the sale of high-efficiency electric equipment. Incentives can also encourage distributors and plumbers to keep heat pump water heaters in stock for use in emergency replacement situations.

Beginning in 2023 and through the end of 2032, all homeowners will be eligible for a 30% federal tax credit on the total cost of buying and installing their new heat pump, with a maximum credit of $2,000. For heat pumps installed in 2022, there is currently a smaller tax credit of 10% of the cost up to $500 or a specific amount from $50-$300 [25].

The High-Efficiency Electric Home Rebate Act, part of the Inflation Reduction Act, can also help offset the cost of purchasing a heat pump, depending on your income. Homeowners could be eligible for up to $1,750 for a heat-pump water heater and $8,000 for a heat pump if household income is less than 150% of their state's median income. If household income is less than 80% of their state's median household income, then homeowners qualify for the full rebate; meaning if both the heat pump and heat pump water heater are purchased, the homeowner could get $9,750 back. If income is between 80 to 150% of their state's median income, the homeowner would be eligible for 50% of the rebate, and they could receive up to $4,875 back [25].

One potential drawback to incentives is that once they are removed, the market may return to pre-incentive levels. The aftereffects could be that manufacturers would have to absorb the excess inventory as a result of scale-up during periods of higher demand and contractors may have to lay off workers. A better approach would be to create demand for high efficiency space and water heating equipment that is sustainable without the need for incentives.

5.2 Installation challenges

In an older home or a home with a natural gas for heating and water heating, installing a heat pump or heat pump water heater might require a panel upgrade. Several water heater manufacturers are responding to this issue by introducing 120v heat pump water heaters in the market. Presently, at least four manufacturers have brought products to the market that operate on 120v electrical power and others will soon follow. The 120v heat pump water heaters are available in both shared circuit and dedicated circuit models [26]. Field tests are ongoing in California that will provide useful information on the performance of 120v water heaters.

Tall, slim, natural gas water heaters typically found in manufactured homes where space is limited. The market for these units is limited. However, there is a project underway by a national laboratory to develop a 120v heat pump water heater with equivalent first hour rating that can be replace water heaters of this type.

More demonstrations of multi-split heat pump water heaters (i.e., one outdoor unit tied to multiple indoor storage tanks) are needed to prove the technology and facilitate their use to displace electric resistance and fossil-fired water heaters for medium-sized commercial and multi-family buildings. Replacing low-boy water heaters in multi-family buildings is a prime candidate for a demonstration of this type.

5.3 Consumer education

Lack of awareness is one of the key barriers to adoption of this clean energy technology. Programs to raise awareness and educate on a heat pump technology's availability, financial, health, safety, and comfort benefits would help consumers to make informed decisions when it comes time to replace their existing space conditioning or water heating equipment.

The National Resources Defense Council details three successful program designs used by Efficiency Vermont, Association for Energy Affordability in California, and Efficiency Maine [27]. To summarize, the features of currently-successful programs are:

- A midstream/upstream design with incentives that bring costs into parity or better
- Customer education through mass market and targeted outreach
- Strong engagement of supply chain participants
- Trade ally networks that provide a range of benefits to contractor and distributors

• Positive referrals by word of mouth
• Planned and emergency replacements can be installed within one day if panel upgrade isn't required

5.4 Reduce costs

Beyond incentives, several ways to reduce installation/product/operating costs for heat pumps and heat pump water heaters have been proposed. Among these are modular designs that enable homeowners to install the units, reducing installation costs with better tools for right-sizing and smart diagnostic tools to reduce installation time, increasing the efficiency of to reduce operating costs, and reducing the manufacturing cost.

Developing modular designs that enable homeowners to install the units themselves is a novel idea that has merit. Recently, two companies were awarded contracts to develop a window unit heat pump for multifamily housing that operates in cold climates, only requires 120v electrical power, and can be installed by the consumer [28]. One of the main benefits of modular designs is that they are portable and can be taken with the consumer when moving to another location. This is especially beneficial for tenants that live in apartments. It also helps to solve the split incentive issue by shifting the responsibility for the cost of the unit to the tenant rather that the building owner.

Improved tools for sizing heat pumps help to avoid over-sizing which could result in a smaller, lower cost unit being specified. Smart diagnostic tools, comprised of wirelessly connected digital measuring probes, enable real-time fault detection and diagnostics during installation and can reduce costs by reducing the time it takes to verify units are correctly installed.

Increasing the efficiency of the units to reduce operating costs seems to be a reasonable idea. However, this usually comes at a higher unit cost which is then passed down through the value chain, resulting in multiplying the difference in the manufacturer's cost of the unit by three times. The higher unit cost needs to be evaluated to determine if the reduction in operating cost over the life of the product justifies the higher cost.

Reducing manufacturing cost is challenging. However, research is presently being funded by the DOE to reduce costs through lower cost, more compact heat exchangers and compressors. More compact heat exchangers also have the added benefit of reducing the refrigerant charge to enable the possible use of lower GWP refrigerants that are flammable.

5.5 Work force development

Work force training on how to build and maintain equipment for low-carbon buildings is a promising candidate for public-private partnerships. Such training aligns the interests of the public (emissions reduction and safe and comfortable buildings), the building trades (quality installations with high customer satisfaction), and equipment suppliers (having their products installed correctly in homes and businesses).

While consumer awareness is important to drive demand, it is equally necessary to train installers to be able to support and fulfil the demand. There is a focus within the Advanced Water Heating Initiative to develop training and tools to support both contractors and designers. Several hours of training material and videos have been developed and more are planned to support the central systems [29].

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