In Hot Water! The Challenges and Barriers of Decarbonizing Water Heating in Multifamily Buildings

Preprint

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ABSTRACT

Domestic hot water heating is responsible for 32% of the total energy consumption in multifamily buildings and offers a significant decarbonization opportunity. An extensive market assessment was conducted to understand and document key technical and economic barriers to electrification of domestic water heating in multifamily buildings throughout the U.S. Through the program, 77 interviews were conducted to understand key market drivers and technical challenges associated with electrification of water heating systems in both retrofit and new construction scenarios. Interviewees encompassed a wide range of stakeholders in the ecosystem surrounding water heating systems, including suppliers, manufacturers, designers, owners, utilities, and developers. This paper documents key interview takeaways, including an extensive list of market barriers, technical challenges, and sought-after technology attributes that can inform pertinent design criteria for electric water heating research, development, and deployment efforts. Among economics and energy efficiency features, interviewees overwhelmingly alluded to space constraints, cold air exhaust, and lack of clear guidance regarding distributed versus centralized design selections as key challenges associated with mass adoption of electric water heating. Owners and developers seek systems with minimal footprint, which maximize rentable space and profits. Moreover, distributed heat pump solutions should balance ducting costs that mitigate cold exhaust entrainment into conditioned zones. Lastly, the market needs clear guidance regarding the selection of distributed versus central electric hot water systems.

Introduction

Electrification of water heating systems in multifamily buildings offers a significant opportunity for decarbonization. The U.S Energy Information Administrations (EIA) Residential Energy Consumption Survey (RECS) indicates that domestic hot water heating is responsible for 32% of the total energy consumption in multifamily buildings, with fossil fuel water heating accounting for the second largest (22%) end use consumption (EIA, 2015). A recent ACEEE report estimates that replacing gas water heater with electric heat pumps could save 175 trillion Btu/year and reduce GHG emissions by an amount that is equivalent to that produced from 1.4 million passenger vehicles (Perry et all, 2021). Numerous studies have outlined energy, carbon, economic, and grid benefits of heat pump water heaters; however, mass, scalable, and routine adoption remains hindered by technical challenges and market barriers.

U.S. state policies have historically prohibited incentivizing fuel switching (i.e., converting gas fueled appliances to electricity); however, numerous states have recently modified or implemented new policies that promote electrification of building end uses. For example, on August 1, 2019, the California Public Utilities Commission (CPUC) revised its policies to allow California utilities to incentivize electrification measures to its customers (GTM 2022). In addition, many cities and states are requiring residential new construction be all electric

(Sierra Club 2022, David 2021). Other states have adopted policies and regulations that set building performance standards that target minimum GHG emissions (i.e., New York Local Law 97 (NYC 2019)). This shift towards electrification may increase adoption of electric water heating systems in multifamily buildings. Nonetheless, technical, and economic barriers to widespread adoption of high efficiency electric water heating systems in multifamily buildings still exist.

Through the U.S. Department of Energy (DOE) I-Corps Program (US DOE 2022), an extensive market assessment was conducted to understand and document key technical and economic barriers to electrification of domestic water heating in multifamily buildings throughout the U.S. Interviews were conducted to understand key market drivers and technical challenges associated with electrification of water heating systems in both retrofit and new construction scenarios. Interviewees encompassed a wide range of stakeholders in the water heating ecosystem, including suppliers, manufacturers, designers, owners, utilities, and developers. In the following sections, we document key interview takeaways, including an extensive list of market barriers, technical challenges, and sought-after technology attributes that can inform pertinent design criteria for electric water heating research, development, and deployment efforts.

Interview Approach

In the following sections, we provide an overview of the DOE I-Corps program followed by an overview of the typical questions asked by the interviewers, and key statistics of the interview process.

DOE I-Corps Overview

I-Corps (US DOE 2022) seeks to expose researchers at national laboratories to the market, and to enable first-hand understanding of the market challenges and barriers for energy related technologies. The program offers researchers with an opportunity to engage with industry stakeholders and, ultimately, to guide and inform the alignment of laboratory directed research efforts with market needs. The I-Corps program spans two months of intensive training and industry engagement activities, primarily in the form of stakeholder and customer discovery interviews. Each research team is coupled with an industry mentor that 1) supports researchers in identifying interview candidates and 2) supports the team with obtaining real-world insights from interviews.

The Energy I-Corps program follows principles from Steve Blank's lean start-up approach (HBR 2013), in which customer discovery and feedback drives product and business model development. This approach moves away from the traditional start-up business models, where extensive upfront investments in time and funds are directed towards business model plans and product development with little to no market inquiry and feedback. Instead, the lean/agile approach promotes engagement of anticipated customers at conception and tailoring/pivoting the technology and associated business model to align with market needs. By starting with the customer and market needs, the premise of the lean start-up approach is to shorten the time between innovation and market adoption.

Interview Questions

The lean start-up principles were used to identify market barriers, technology challenges, desirable system attributes, customer segments, and the stakeholder ecosystem[1] associated with domestic hot water heating and storage technologies. One important premise of the interview process is to ensure confirmation bias is avoided, therefore personal ideas, opinions, and experiences were removed from the interviewers' queries. Each interview spanned a 30-minute duration, and a total of 77 interviews were conducted throughout the duration of the project. The interviews did not have fixed questions, but instead were based on a framework for the interview that is listed below:

1. When purchasing a new domestic water heater, what are the important water heating system characteristics/attributes that you consider?
    a. Can you rank the system attributes in the order of importance?
2. Explain the last time you specified, recommended, or bought a hot water system.
    a. What pain points did you encounter in this process?
3. Who is the decision maker for new technology adoption?
4. Can you explain the ecosystem of stakeholders in the water heating industry?
5. Based on our discussion, who else should we interview?

Interview Statistics

An initial set of candidate interviewees were identified through existing and subject-relevant personal contacts, however many of the interviewed candidates were subsequently identified through referrals (i.e., last question from the interview framework). Candidates across the entire multifamily building stakeholder space were interviewed, ranging from architects, engineers, and contractors to owners and developers. Our interview referral progression is visually summarized in Figure 1.

Green-shaded squares represent a successful interview with an individual or a group of individuals from one firm, yellow-shaded squares represent solicitations to individuals that rejected to participate, and brown boxes represent individuals that did not participate in an interview but referred a candidate for an interview. Interviewee names were redacted from Figure 1 for anonymity purposes. A total of 77 successful interviews were conducted. 35 candidate solicitation attempts declined to be interviewed and29 referrals were provided by the interviewees.69% of total solicitations resulted in a successful interview, 31% of total solicitations were rejected, and 38% of interviewed candidates provided referrals to additional interviewees.

[1] The "ecosystem" in this context refers to the network of stakeholders (i.e., manufacturers, suppliers, distributors, etc.) that are involved in the delivery of a heat pump water heating system through the industry to the customer.

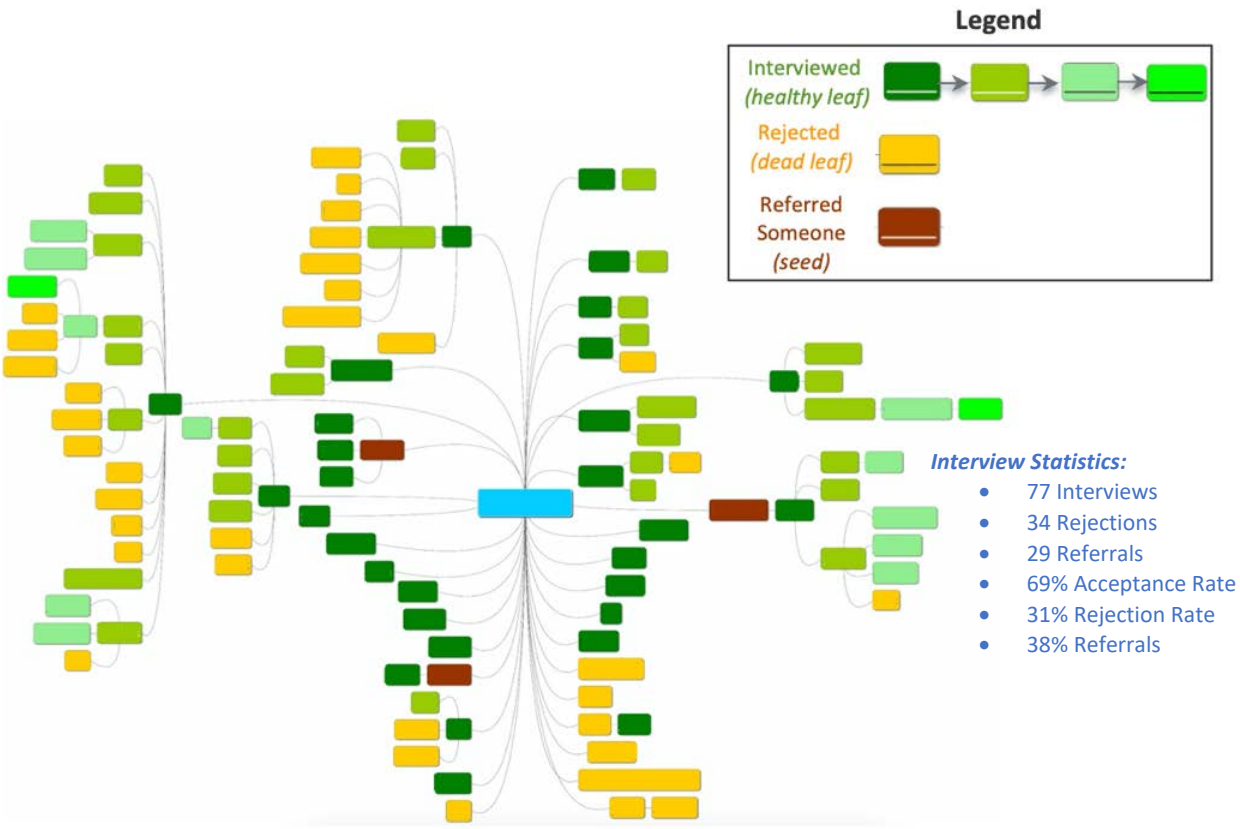

Figure 1: A visual diagram of the I-Corps program interview statistics and candidate referral progression throughout the duration of the project.

Interview Analysis and Discussion

In the following subsections we synthesize key technical heat pump water heater system challenges reported by the interviewees. We summarize notable challenges and associated opportunities for future research and outline the identified market stakeholders and associated market ecosystem in the water heating system industry.

Synthesized Interview Data

Through the course of interviews, 32 unique hot water heating system attributes were mentioned by the interviewees as being desirable and associated with the decision-making process when purchasing a new hot water heating system. The complete list of desirable hot water heating system attributes identified through the interviews is provided in Figure 2. In addition, Figure 2 illustrates the weighted average scores of each attribute based on the interviewee's responses. It is important to note that the average interviewee listed three to six system attributes, therefore the weighted average scores provided in Figure 2 reflect instances of the mentioned attributes by the interviewees in addition to their associated ranking. A rank of 0 (i.e., not important) was applied to datapoints of an attribute that were not mentioned by an interviewee. The formula used to calculate the weighted average score of each attribute is shown below

$$W_{attribute} = \frac{\sum_{i=1}^{n} \omega_i X(\omega_i)}{N} \quad (1)$$

Where n represents the total number of weights ($n = 7$), ω_i is weight i applied to the attribute, which corresponds to each interviewees rank of the attribute (ω_i ranges from 0-6, where 6 is very important and 0 is not important), $X(\omega_i)$ is the total number of instances of the attribute with a score of ω_i, and N is the total number of collected datapoints.

While the weighted average scores demonstrated in Figure 2 may reveal relative importance of the attributes to market stakeholders, all identified attributes are important. In some instances, if lower ranked attributes are unmet, it may partially or entirely hinder the adoption of the associated emerging hot water system technology. Many of the reported attributes may be intertwined. For example, operational cost and efficiency are highly dependent attributes, therefore the results are approached with caution and should be leveraged to better understand the considerations of a subset of the larger market.

As indicated in Figure 2, cost and energy efficiency ranked among the highest metrics used by the interviewees in the selection process for a new hot water heating system. Given the diverse array of interviewees and due to limited time during each interview, the distinction between operational, capital, and life-cycle costs was not emphasized. Nonetheless, for emerging heat pump water heater solutions to compete with existing gas heat systems their economics will need to compete with existing gas fired systems.

Compared with single family buildings, multifamily buildings present a unique set of challenges for heat pump water heater technology adoption, primarily due to limited space availability and space constraints. This issue is exhibited in Figure 2 by the "space" category, which was ranked as the third most important metric following cost and energy efficiency considerations. For proper and optimal performance, heat pump water heaters require sufficient inlet air volume from the surroundings (for example, 750 to 1000 ft^3 of air space for unitary systems), which is typically available in single-family residences in areas such as garages, basements, and laundry spaces. However, multifamily building water heaters are typically located in mechanical/utility rooms with, often, insufficient air volume requirements for heat pump water heaters to meet standard operating conditions. In addition, heat pump water heater compressors are designed with lower heating rates, and hence operate over longer durations (12 to 16 hr/day), compared with natural gas burners (Perry et all, 2021). Therefore, larger water storage volumes are needed to compensate for the lower heating rates of heat pump water heaters compared with natural gas systems. The lower capacity of heat pump water heaters compared with gas fueled units and the increase in associated storage size further exacerbates the space limitation and constraint challenge in multifamily building circumstances. The space limitation challenges are equally relevant in unitary and central heat pump water heater architectures.

Notable Challenges and Opportunities for Future Research

The following list elaborates on key challenges identified through the interviews, as outlined in Figure 2. In addition, the following items reflect notable future research opportunity topics surrounding heat pump water heating systems for multifamily building applications:

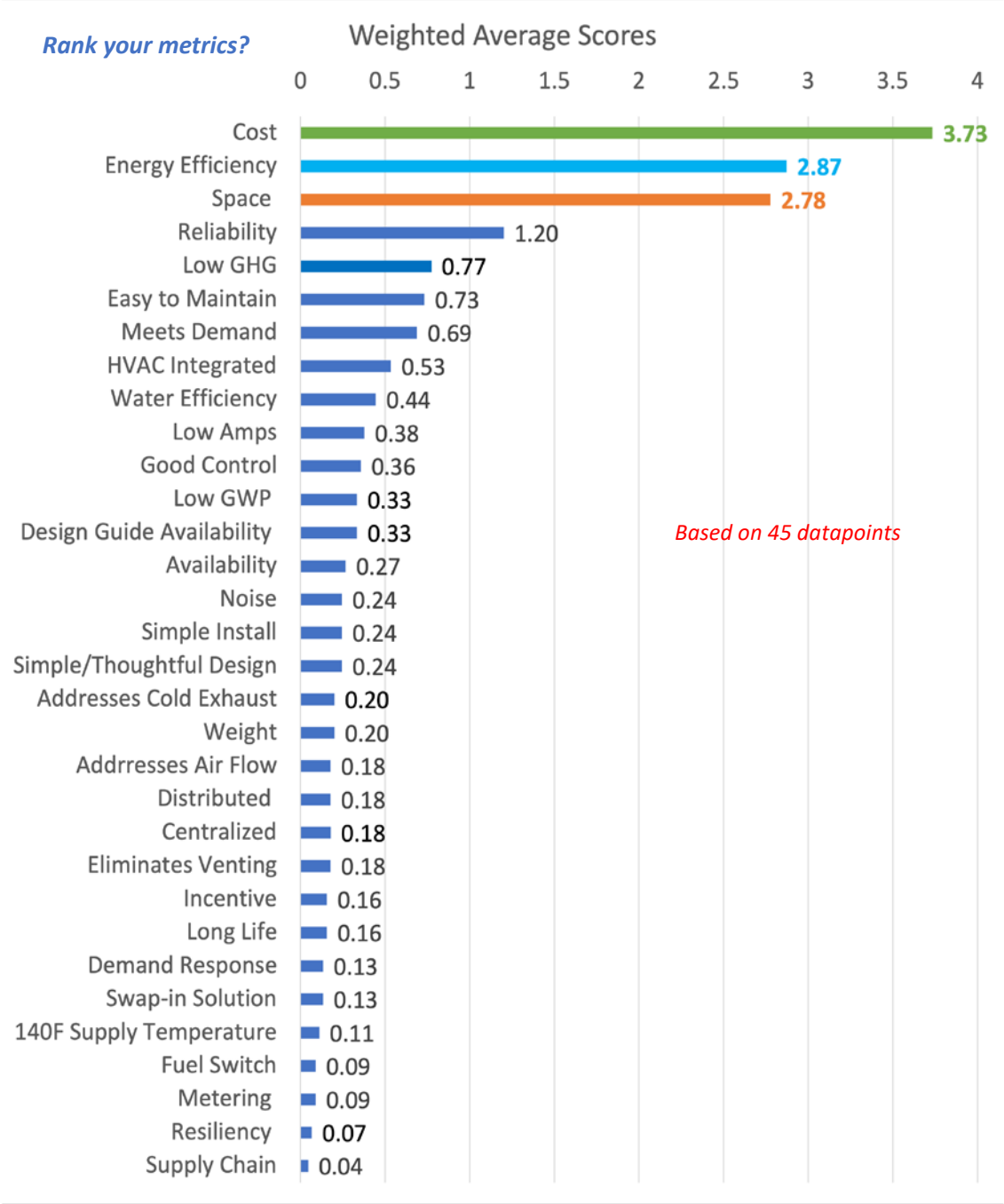

Figure 2: Weighted average scores of desirable hot water heater system attributes

a. Cold exhaust:

Heat pump water heaters use a reverse refrigeration cycle to increase water temperature using heat from the surrounding space or inlet air. As a result, a heat pump water heater produces cold exhaust air and cools the surrounding space. Ducting the cool air can cool other spaces, which can be problematic in some scenarios. In hot climates, cold exhaust air from heat pumps can be favorable given the associated reduction in space cooling loads. However, in cold climates, and during colder months, the cold exhaust from the heat pump cycle can add to space heating loads and could reduce the overall efficiency of the building's operation.

b. Electrical infrastructure:

Electrification of building systems may require additional electric infrastructure, adding costs, compared with mixed fuel system designs. Furthermore, added electric compressor loads from heat pump water heaters may require additional electric wiring and higher rated wire amperage capacities to additional areas of a multifamily building (i.e., rooftop, closets, basements, etc.) that can further increase costs. To meet hot water loads, in terms of amount and rate of hot water drawn, there is a tradeoff between tank size and compressor size. The larger tanks create space issues, especially in multifamily buildings while the larger compressors increase electrical infrastructure and negatively impact demand charges. From a multifamily building developers' perspective, lower space requirements for mechanical systems could translate to additional rentable space and higher profit margins. Larger compressors translate to more capital cost in electrical infrastructure and higher operational costs with demand charges.

c. Distributed vs. central systems:

Most interviewees expressed a lack of clear guidance regarding the tradeoffs and capacity sizing of distributed versus central heat pump water heating system options for multifamily buildings. While central systems can offer the convenience of a single point-source location for maintenance in a building, distributed unitary systems offer individual electric metering capabilities to tenants. Central system performance is hindered by recirculation losses, while unitary systems can introduce added heating or cooling loads to the occupiable space in some instances. A lack of common configuration scenarios causes each system to be custom designed including the sizing of tanks, compressors, and distribution systems creating a perceived higher cost, which can result in a barrier to adoption.

d. Noise levels:

Several interviewees alluded to compressor noise levels in unitary heat pump water heating systems as a potential concern. In unitary systems, the location of the heat pump water heater within the building can play a critical role in ensuring the compressor noise levels (~50db) do not disturb the occupants. This can be challenging to circumvent in retrofit scenarios given preexisting space assignments in existing buildings.

Key Stakeholder Segments in the Heat Pump Water Heating Market

Through the interviews, five key market stakeholder segments within the heat pump water heating industry were identified. These five key market stakeholder segments include the 1) developer 2) architect, 3) engineer, 4) heat pump water heater manufacturer, and 5) the manufacturer's representative. Each stakeholder plays a role in the decision-making process that ultimately leads to a hot water system selection and adoption. A summary of the interview takeaways from each of these five key market stakeholder segments is summarized in Table 1.[2]

[2] While additional market stakeholder segments exist, Table 1 focuses on five key stakeholder segments based on our interpretation of the collective feedback from the interviews.

Table 1: A summary of the interview takeaways from five of the key market stakeholder segments

Stakeholder Segment	Developer	Architect	Engineer	Heat Pump Water Heater Manufacturer	Manufacturer's Representative
Interview Takeaways	Challenged by limited indoor, basement, rooftop, and outdoor space, and added structural and excavation costs associated with mechanical systems. *(key influencer)*	Sustainability enthusiasts with focus on simple, thoughtful design. Typically geared towards maximizing occupiable space and cognizant of potential noise disturbances. Struggles with system centric feedback and suggestions.	Challenged by lack of clear industry sizing guidance of heat pump water heaters for multifamily buildings. " *Heat pumps are not designed for Multifamily*" *(key influencer)*	Focused on minimizing product costs – typically resulting in relatively smaller compressor for larger tank. Considerations to accommo-date building space limita-tions is not a priority.	Engineers rely on manufacturer's representatives for insights on available products in the market. *(key influencer)*

Table 2: Common hypotheses involving the heat pump water heating market and technical challenges

Hypothesis	Validated/ Invalidated	Interview Insights
Owners are the decision markers (customers)	Invalidated	Architects and Engineers (and contractors for smaller buildings) have a major influence. *Multi-sided market*. Owners have high-level goals, not system-level goals
Space is not an issue	Invalidated	*Space limitations pose a significant challenge for multifamily buildings. In addition, rooftop space and basements also come at a premium* (compete with PV/green roof/parking /leasing office/amenities) – for new build, basements are expensive. Developers often avoid placing mechanical system outside of the building due to vandalism concerns. Central systems also have a space issue. Manufacturers have a unitary solution, but limited *space availability hinder product sales in multifamily building applications*. Manufacturers want to minimize compressor size to minimize product cost, but struggle with larger tank size.
Cost is a driver	Validated	*Cost is not always the product costs*, it's the value of the product – externalities in value such as faster installations, easier installations, less infrastructure upgrades, etc.
Industry is prepared to efficiently electrify water heating in multifamily buildings	Invalidated	Heat pumps are perceived as a high-risk solution. "*Heat pumps are not designed for Multifamily"*. Need a small heat pump that can be placed outside but serviced inside.

As indicated in Table 1, developers, engineers, and manufacturers' representatives play a key influential role in the decision-making process for hot water system selections in multifamily building projects. The hot water system market is multi-sided; meaning the market has strong influencers that do not directly purchase market products. Developers, who ultimately pay for the products, typically set project-level performance goals (i.e., energy, carbon, economic or financial) and rely on the engineers to make mechanical system purchasing decisions that meet their specified targets. Subsequently, engineers often rely on manufacturers' representatives for insights on available products in the market that meet their specific performance objectives as well as application engineering guidance. This engagement creates a complex ecosystem of stakeholder engagements that ultimately leads to purchasing decisions.

Table 2 summarizes common hypotheses of the heat pump hot water heating technology market for multifamily buildings and takeaways based on the conducted interviews. As indicated in Table 2, owners typically require high-level project goals and architects/engineers ultimately decide on systems that meet those goals. In multifamily building applications, space constraints pose a notable challenge and includes internal, rooftop, and basement space. Cost remains a key driver, and includes wholistic considerations pertaining product value, such as ease of product installation and maintenance. Lastly, the interviewees seem to agree that the industry is not currently well positioned to electrify water heating in multifamily building given the form factor of currently available heat pump water heating systems in the market.

Water Heating Technology Market Ecosystem

Through the course of the program, interviewees were asked to describe the ecosystem of stakeholders within the heat pump water heating industry. This includes decision makers, recommenders, influencers, customers, early adopters, and others. Prior to concluding each interview, the interviewers asked the candidates for referrals to speak with the identified market stakeholder segments. This process was repeated over the course of the program, and Figure 3 was developed based on the findings from the collection of discussions. Figure 3 illustrates the heat pump water heating technology market ecosystem, and direction of money transfer through the market ecosystem that leads to the heat pump manufacturer.

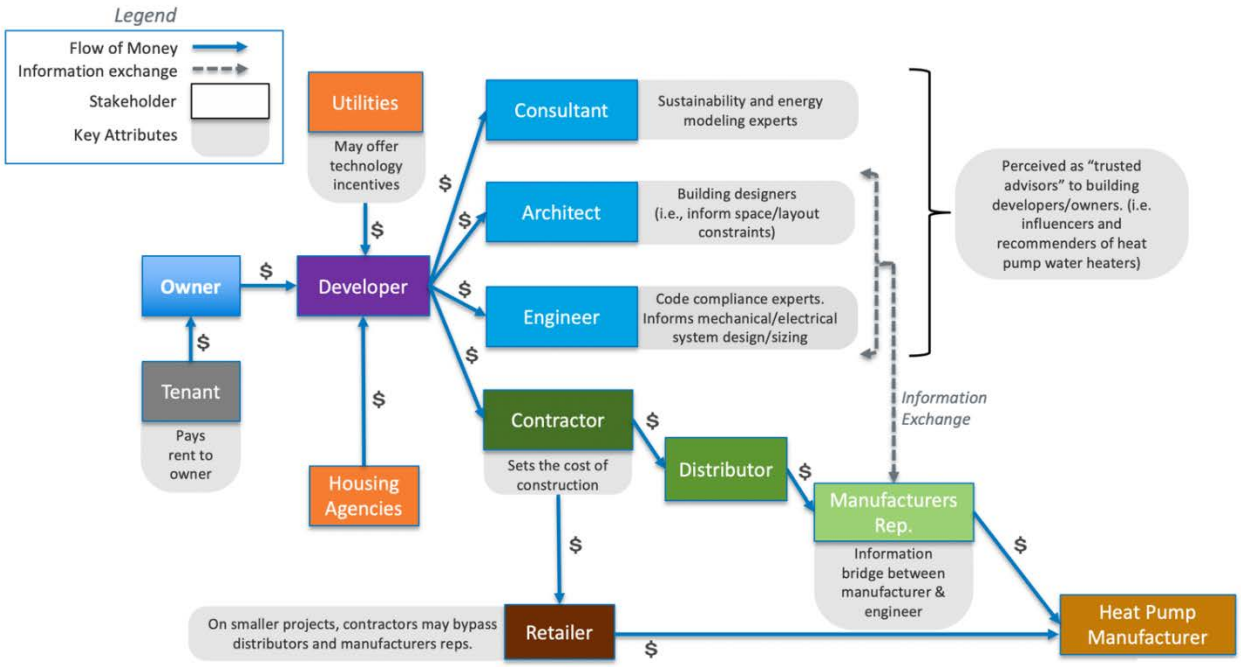

Figure 3: Heat pump water heating technology market ecosystem

As indicated in Figure 3, developers hire consultants, architects, and engineers as trusted advisors to achieve the assigned project goals. In new construction projects, architects dictate space assignments, while engineers and consultants identify system-level selections and designs that meet building constraints. Engineers typically rely on manufacturers' representatives to understand the selection of available products in the market that meet their project goals. Manufacturer's representatives act as a bridge between engineers and manufacturers, particularly on larger projects. Once the developer is satisfied with the plans presented by the architect, engineer, and consultant, the developer hires a contractor to implement the plans. The contractor then sets the cost of construction, and relies on the distributor, who intern relies on manufacturer's representative for products, and product information, that manufacturers of heat pump water heaters offer. On smaller projects, contractors typically bypass the distributor and manufacturer's representative by accessing a retailer that offers a variety of water heating technologies.

Available Market

This section outlines a brief assessment of the current available water heating system market. This section illustrates the substantial opportunity for future researchers and entrepreneurs to design systems that address the heat pump water heating challenges outlined throughout this paper. The estimated total available market (TAM), serviceable available market (SAM), and serviceable obtainable market (SOM) for domestic water heating technologies in multifamily building applications is shown in Figure 4.

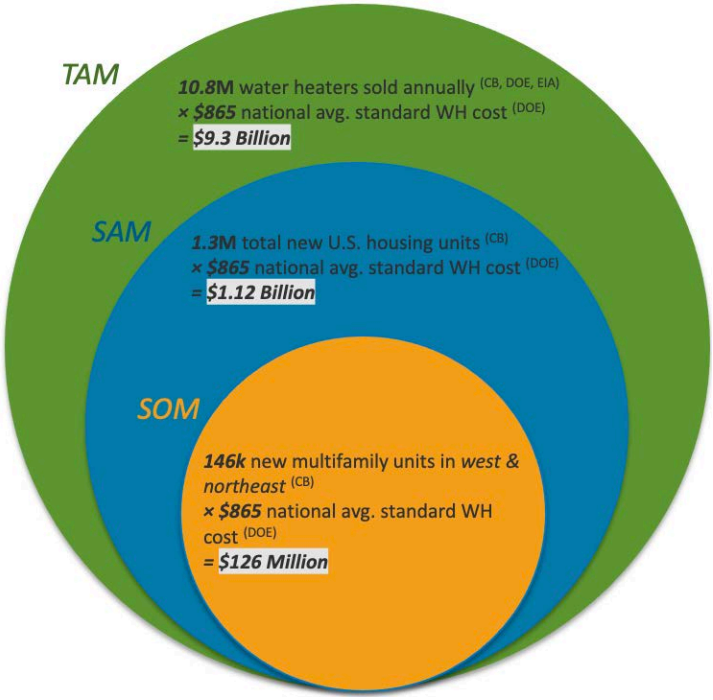

Figure 4: Estimated TAM, SAM, and SOM for domestic water heating technologies in residential building applications[3]

TAM represents the total U.S. market (retrofit + new construction) for domestic unitary hot water heating systems in residential (multifamily + single family) building applications. SAM represents the available new construction market for multifamily building applications only, while SOM represents the new construction multifamily building application in the west and northeast portions of the United States, which locationally aligns with current and most aggressive U.S. policies and incentives for electrification. As indicated by Figure 4, a substantial opportunity exists for efficient electrification of domestic water heating technologies in multifamily buildings. For emerging multifamily heat pump water technologies, a market on the order of one billion U.S. dollars is available, while for domestic water heating technologies that scale to all residential buildings and project types (retrofit + new construction) the market is increased to the order of ~10 billion dollars.

Conclusion

An extensive market survey was conducted to understand the following items in the context of heat pump water heating system adoption in multifamily building applications: 1) technical and market challenges 2) key stakeholder segments, including market influencers and recommenders of new technologies, and 3) the market ecosystem surrounding water heating technologies. Through the interviews, notable challenges that alluded to future research opportunities included 1) cold exhaust challenges from heat pumps in colder climates, 2) understanding the balance between compressor capacity and water storage size on total project costs, including electric infrastructure costs and impacts on total rentable space availability, 3)

[3] The values in Figure 4 were calculated based on nationally recognized market and census survey data (DOE, EIA, CB) and are not based on the interviews conducted through this study.

clear guidance regarding the tradeoffs and capacity sizing of distributed versus central heat pump water heating options for multifamily buildings, and 4) potential noise level concerns of unitary heat pump water heating systems, particularly in retrofit applications. Moreover, our interviews indicated that the hot water system market is multi-sided. Owners and/or developers, who ultimately pay for the products, typically set project-level performance goals, and rely on the engineers to make mechanical system purchasing decisions that meet their specified targets. Subsequently, engineers often rely on manufacturers' representatives for insights on available products in the market that meet their specific performance objectives. Understanding the multi-sided market and complex ecosystem of stakeholders in the heat pump water heating industry is key to ensuring proper messaging is conveyed to the influencers and recommenders of the billion-dollar market that is available for multifamily building applications.

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