# Residential heat pump water heaters as a climate action measure for Waterloo region

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## Executive Summary

The Waterloo region and all associated municipalities have committed to reducing the community's greenhouse gas emissions (GHGe) by 80% below 2010 levels by 2050[1]. For residential buildings (18% of emissions), most emissions come from the fossil fuels used for space and water heating.

Heat pump water heaters (HPWHs) are a proven technology that, when replacing conventional systems for domestic hot water use, can cut a home's emissions by 6-11%[2]. They are also an ideal retrofit for a turnkey delivery model. Furthermore, HPWHs have the potential to help utilities in their demand management strategies in at least three ways: by shifting demand through the day, by allowing load up and load shed, and by hourly optimization of demand.

HPWH systems operate somewhat differently than conventional water heaters and there are some additional factors to consider when installing HPWHs. It is important that installers and homeowners be aware of these factors but not turned away by them: good communication is key.

Under current conditions, incentives of approximately $1000 would be required to make HPWHs economically appealing for most homeowners. There are many examples of rebate programs from across North America that offer rebates in this price range. Other communities have incentivized the adoptions of heat pump systems through bulk purchase or carbon offset programs.

An estimated 16,500 households replace their hot water heating system every year in the Waterloo region, and every household will replace their system about twice between now and 2050. This means that we need to develop programs <u>now</u> to help built trust in the technology, build the installation capacity, and grow the market share for HPWHs if our targets are to be met. Stabilizing our climate for future generations depends on it.

## Introduction

The Waterloo region has committed to reducing greenhouse gas emissions (GHGe) by 80% below 2010 levels by 2050[3]. With 18% of our community's GHGe coming from our homes, programs are needed to help eliminate their use of fossil fuels. This report focusses on cutting emissions from residential water heating systems through the adoption of heat pump water heaters (HPWHs) and outlines programs that have been used elsewhere to drive this adoption.

Heat pumps are inherently very efficient systems because they move heat rather than generating heat. Just like a fridge, these systems use refrigerants that absorb heat in one location and deliver it in another location through the use of condensers. Modern HPWHs are capable of generating all of the hot water needs of a residential home many times more efficiently than conventional water heaters.

In the average Canadian home, the hot water heater uses nearly a fifth of a home's total energy from all fuel sources[4].

In the Waterloo region, analysis of NRCan data from home energy audits show that the predominant fuel for heating water is natural gas, with most of the remaining homes using conventional electric water heaters[5]. In both cases, switching to HPWHs can improve the energy efficiency of the home and significantly reduce household GHGe.

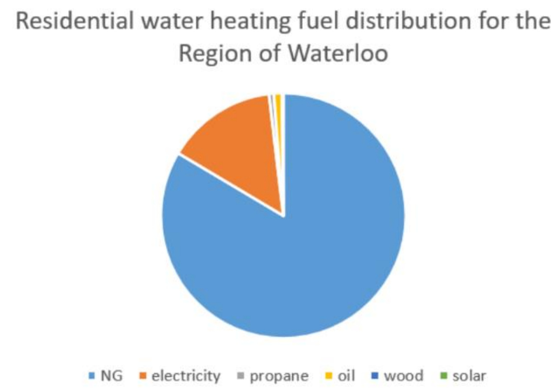


*Figure 1 Residential water heating fuel distribution for the Waterloo region.*

## Benefits of HPWH

### Energy efficiency and GHGe reductions

Heat pump water heaters have great potential for reducing a home's total energy and GHGe. The higher energy efficiency of HPWHs over other systems means that their installation can achieve a total 15-16% whole home energy efficiency improvement[6]. Since electricity in Ontario is largely decarbonized, the whole home emissions reduction potential for replacing an existing system with a HPWH is approximately 6-11%.

> *The single measure of replacing the water heating system with an HPWH can achieve nearly half of the GHGe reductions achieved with an average home energy retrofit.*

Analysis of historical retrofit activity gleaned from NRCan home energy audits conducted in the Waterloo region show that the average energy efficiency improvement from a single measure was 6% and the GHGe reduction was 8%[7]. Whole home retrofits in this dataset yielded an average 21% energy efficiency improvement and 24% GHGe reduction. Our analysis shows that up to half of this result could be achieved from the single measure of replacing the water heating system with a HPWH: an impressive outcome and a tremendous opportunity.

***Table 1 Energy efficiency gain and GHGe reduction for a home that switches to a HPWH***

| | oil | propane | Natural gas | Electric heat | HPWH |
|---|---|---|---|---|---|
| **% efficiency gain** | 85% | 82% | 84% | 77% | na |
| **% whole home efficiency gain[a]** | 16% | 16% | 16% | 15% | na |
| **kg CO2/yr** | 1,140 | 764 | 721 | 273 | 64 |
| **% GHGe reduction** | 94% | 92% | 91% | 77% | na |
| **% whole home GHGe reduction[b]** | 11% | 9.8% | 10% | 5.7% | na |

[a] assumes water heating accounts for 19% of the home's energy use [8]

[b] assumes the same fuel is used for space and water heating

## Opportunity for turnkey delivery

The installation of HPWHs are an excellent opportunity for a turnkey delivery model. In this way, bulk purchases plus efficient tradesperson scheduling can reduce the total cost for the homeowner. The HeatSmart Mass program is a good example wherein select communities were targeted for installation of heat pump home heating systems using aggregated buying power. In 2019, 282 heat pump space heating systems were installed across Massachusetts as a result of this program[9].

## Opportunity for demand management

Water heaters can be viewed as energy storage systems. Once a tank is filled with hot water, the heat energy contained in the water is stored until it is needed. In a typical house, hot water usage takes place predominantly in the morning and in the evening when bathing, dishwashing and laundry tend to occur. Consequently, electric water heaters can be programmed to draw energy when electricity is available in excess (eg when renewables are at their peak production) to be stored for use during peak demand times. There are three ways that this can be done with both HPWH and conventional electric water heaters[10].

1. **Water heater on a timer for demand shifting.** The water heater is set to heat water during the off-peak hours and stores the hot water for use during peak times while also ensuring that hot water is always available when needed.
2. **Load-up and load shed.** The water heater is set to heat the water above the normal temperatures when electricity generation is in excess (e.g. 57-63$^{o}$C rather than 52$^{o}$C). During peak demand times, the water heater is allowed to fall below to a lower set temperature (e.g. 43$^{o}$C). A mixing valve is used to ensure water leaving the system does not exceed recommended temperatures. The heater may be controlled based on homeowner settings, or it may be grid connected to allow the utility to shift demand.
3. **Grid connected hourly optimization.** A fully grid integrated system optimizes heat pump operation based on normal use patterns and short term price or demand signals. The utility uses the water heater as a battery to shift demand from periods when supply is strained to periods when supply is in excess.

**A note about Legionnaire's disease.**

Legionnaire's disease is caused by a strain of bacteria that has been associated with hot water tanks set to lower temperatures. The associated illness has a high death rate (up to 12%), particularly in vulnerable populations. To prevent Legionnaire's disease, the WHO recommends that hot water tanks be heated to 60°C throughout the tank at least once a day, a regime that will kill the bacteria that cause this Legionnaire's disease. All demand management approaches described here can conform to WHO recommendations.

Sourced from:

Levesque, B. Lavoie, M. Joly, J. (2004). Residential water heater temperature: 49 or 60 degrees Celsius? *Can J Infect Dis* 15(1):11-12 https://doi.org/10.1155/2004/109051

Grid integrated systems require additional technology to control the water heater and communicate with the user and the utility. Ideally the technology would be built into the water heaters but to date, few manufacturers have invested in adding this feature to their assembly lines. This is likely to change, however: recently the states of Oregon and Washington have required new tank water heaters to contain demand response technology starting in 2021 or 2022[11],[12]. Alternatively, controllers can be added to existing water heaters. While regular timers for option 1 are available, more complex systems for grid integration of HPWH are not readily available at this time. The manufacturers that I have approached have indicated that they are working on such a product. For conventional electric water heaters, these controllers run at approximately $150 US[13].

Several utilities in Canada and the US have experimented with demand management using conventional water heaters and HPWHs plus grid integrated technology[14],[15]. The figure below shows how the electrical load for water heating in Hawaii was shifted from the peak demand time in the late afternoon and evening hours to midday when solar generated power is in excess. Surveys have shown that in the vast majority of cases, the customer did not notice any impact of the demand management measures on hot water availability.

FIGURE 23

WATER HEATER LOAD SHIFTING FOR HAWAII TIME-OF-USE RATE

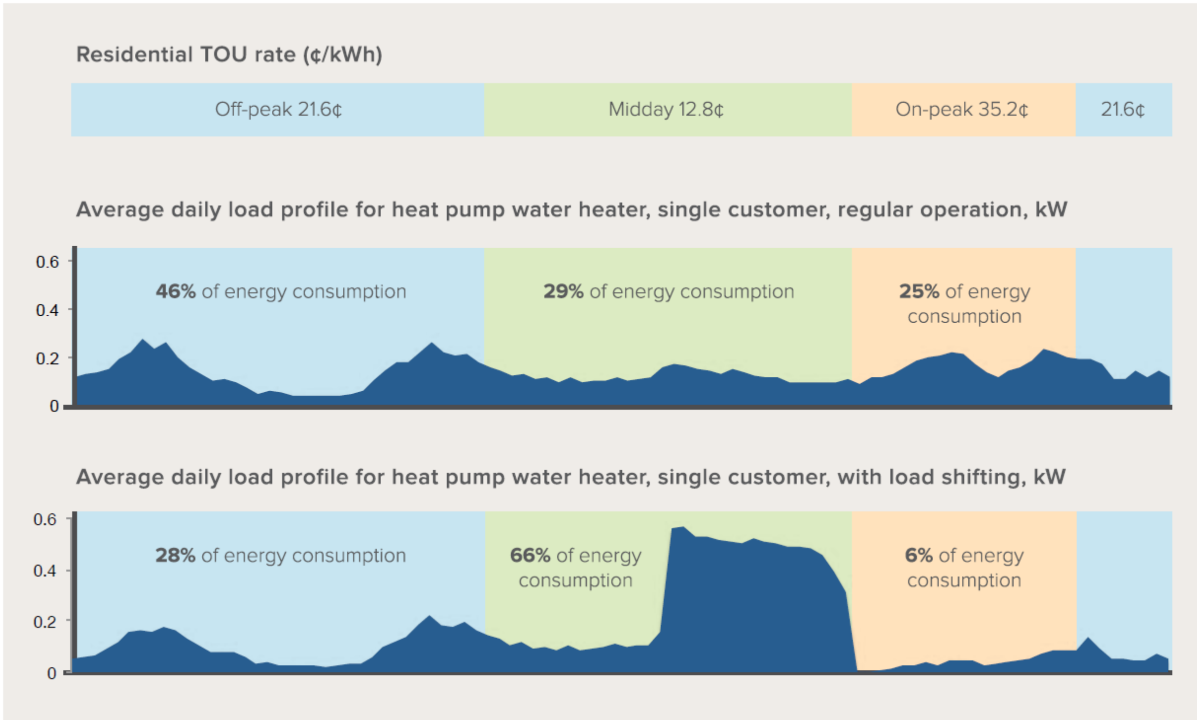


*Figure 2 Water heater load shifting for Hawaii, (sourced from Rocky Mountain Institute[16])*

Communications with local professionals working in the field of utility-scale energy storage solutions suggest that a program would need at least 500 homes participating in a water heater demand management program to make it viable for a utility[17].

In Ontario, the greatest potential for demand management using water heaters is with demand shifting. Currently, Ontario frequently produces more electricity than it uses and exports the excess at a financial loss[18],[19]. This excess supply often occurs during off-peak hours when demand falls below baseload generation. Indeed, the Ontario Energy Association recently proposed incentives to promote load growth as a means of reducing electricity costs for all consumers[20]. Although not mentioned in the report, switching homes from natural gas powered water heaters to HPWHs that draw electricity primarily during off peak hours could provide some of this load growth.

The use of HPWHs for demand management can also save Ontario Power Generation significant investments in new infrastructure. As our society electrifies its transportation and buildings, demand for electricity will increase. Any measure that optimizes or shifts electricity demand will reduce the total required capacity of the electricity grid. This can mean huge savings in new generation, transmission lines, and other infrastructure investments: savings that can help keep our electricity prices low.

## Opportunities for grid stabilization

A utility may also use grid integrated water heaters for grid stabilization.  When unexpected events, such as transformer tripping occur, the utility can stabilize the grid by increasing or shedding load very rapidly with grid integrated systems[21].

Furthermore, grid integrated conventional electric water heaters have been used by utilities for frequency regulation, but HPWH are unsuited for this application as they cannot be controlled on a second by second basis.

## Considerations when installing a HPWH

HPWHs are a different form of water heating technology with different requirements, and it is important that a homeowner be aware of these when considering an HPWH. When installed in a large utility room or basement, and with regular maintenance, most of these HPWH considerations are not a concern. The real challenge will be in communicating these new considerations in a way that does not intimidate or turn away installers and homeowners.

### Economic considerations

On a per unit energy basis, electricity is currently one of the most expensive fuel sources in the Waterloo region. However, conventional water heaters can waste a lot of energy when heating water, and generally perform at 55-80% efficiency[22]. Meanwhile, heat pump water heaters can perform at 350% efficiency[23] because moving heat takes less energy than generating heat.

To calculate the annual local operating costs for water heaters, I used the average modeled water heater energy usage from NRCan's local home energy audit data: 13.6 GJ/yr. This value is comparable to the 15.8 GJ/yr value used on US government websites[24].

Table 2 shows the annual and purchase costs of heating water using different fuel sources and July 2020 utility prices[25]. Also included is the cost of heating water if the electric water heaters are timed to only use off-peak electricity. Heat pump water heaters cost more upfront but generally last longer than conventional water heaters. Prices and lifespans can vary significantly so these estimates should be taken as guidelines only. However, heat pumps clearly outperform all but the natural gas heated systems for operational and annualized costs.

***Table 2 Operational, purchase and annualized costs of different hot water systems.***

| | oil | propane | NG | electric | electric (off-peak) | HPWH | HPWH (off-peak) |
|---|---|---|---|---|---|---|---|
| **Operational cost ($/yr)** | 307 | 453 | 98 | 377 | 304 | 89 | 71 |
| **Purchase cost ($)** | 1,150 | 1,150 | 1,150 | 1,150 | 1,150 | 2,250 | 2,250 |
| **Avg lifespan (yrs)** | 11 | 11 | 11 | 11 | 11 | 14 | 14 |
| **Annualized cost ($/yr)** | 411 | 558 | 202 | 481 | 408 | 249 | 232 |

To compete with natural gas water heating systems on cost, incentives of approximately $1000 for HPWHs would be needed. This value is in line with existing incentive programs from across North America (see the existing incentive programs section).

## System considerations

Heating a full tank of water using heat pump technology can take longer than with a conventional water heater[26]. It is therefore important to consider the system, size and first hour rating when choosing a HPWH. If the demand for hot water is concentrated at certain times of the day, a water heater may not have the time to replenish the supply to meet all needs. One solution is to use a larger tank system that contains more hot water. Alternatively, a hybrid HPWH can be used: one that uses a conventional, and less efficient, heating element to supplement hot water generation during times of peak demand. The first hour rating indicates the volume of hot water the system can generate in an hour (usually in gallons per hour)[27].

## Installation considerations

Because a HPWH extracts heat from the surrounding air, it must be located in a warm area with adequate airflow. EnergyStar recommends siting it in a room with 1000 cu ft of space (roughly 12 ft x 12 ft or 3.5 m x 3.5 m)[28]. A basement or large utility room may be ideal. Alternatively, a heat pump can be ducted to draw air and/or vent to a larger space. In warmer climates, where temperatures remain above freezing, HPWHs are often placed or vented outside or in garages.

HPWHs will also cool and dehumidify the surrounding air. This can be an advantage in the hot and humid summer months but may cause an increase in the heating needs of the home. This effect is small, however, since the cooling effect is localized[29], and HPWHs are generally not located in living spaces where warmer temperatures are maintained. The dehumidifying effect means that a condensate drain or pump is required with HPWHs to remove the water that accumulates on condensing coils. These systems also contain an air filter that must be replaced or cleaned periodically.

Just like a conventional electric water heater, HPWHs generally require 240V 30amp service and a dedicated circuit. Homes that are switching from natural gas water heaters may require the installation of this dedicated circuit. The cost of this upgrade depends on many factors, including access to wall space and the distance to the electrical panel. This work can generally be performed by the installer at an estimated average cost of $300-$700[30].

In addition, HPWHs make more noise than conventional heaters: about as much as refrigerator.

## Tradesperson considerations

The HVAC (Heating Ventilation and Air Conditioning) industry may also prove to be a barrier to the installation of HPWHs. Many installers are unaware of the existence of HPWHs, misinformed about their potential, or wary of trying something new. The industry is accustomed to replacing like with like and representatives are unlikely to risk their reputation by recommending or even suggesting alternatives such as HPWHs. Education campaigns are definitely needed for the HVAC industry, but it is only when their customers ask for and even demand HPWHs that they are likely to take the technology seriously.

## Considerations for utilities

A common concern about the electrification of home heating systems is the increased demand that they will place on the electrical grid. Yet it is important to remember that heat pumps use a fraction of the energy that a conventional resistance heating system do and that demand can be shifted to off-peak hours. The increased electricity use can also mean greater revenues for electric utilities, revenues that may not require extra generating capacity if these energy storage and demand management opportunities are maximized. The benefits of electrification of water heating could be far greater than the challenges for customers and electric utilities alike.

## Environmental impacts of refrigerants

Most current HPWHs appear to use R-410a, a refrigerant with a low ozone depleting potential but high global warming potential (global warming potential of 2088[31]). Although reportedly rare[32], any suspected refrigerant leakage should be investigated promptly. Refrigerants with low ozone depleting potential and low global warming potential are coming on the market, including systems that use $CO_2$ as a refrigerant[33] (global warming potential of 1).

## Existing incentive programs

### Rebates

Several utilities and municipalities across North America offer rebates for the purchase of HPWHs. Some target homes replacing conventional electric water heaters, some target homes replacing water heaters powered by fossil fuels, and others are available to all homeowners. Rebates generally fall between $500 and $1000. It should be noted that purchase prices for HPWHs appear to be lower in the US and the potential for utility bill savings with these systems appears to be greater in many locations. Table 3 shows some examples.

***Table 3 Example HPWH rebate programs from across North America***

| Program name | Rebate | Additional notes |
|---|---|---|
| Clean BC[34] | $1000 | Some municipalities offer further incentives ($350-$1000)<br>Has eligible model list |
| Efficiency Maine[35] | $750-$850 | Replacing electric water heaters only<br>Survey showed >80% satisfied with the program |
| Idaho Rocky Mountain Power Incentives[36] | $400-$550 | |
| Eugene (OR) Water and Electric Board[37] | $800 | Seems to apply to Rheem products only<br>Greater rebates for income-eligible households |
| Central Electric Cooperative[38] | $500 | Replacing electric water heaters only |
| Silicon Valley Energy Rebate Program[39] | $1000-$2000 | $1000 for replacing electric<br>$2000 fro replacing NG water heater<br>Additional $1500 for service panel upgrades<br>Additional rebates for low income |
| Efficiency Connecticut[40] | $750 | Minimum efficiency standards |
| Wasco Electric Cooperative[41] | $600 | Rheem models only |

## Bulk purchase programs

One way to reduce costs is to negotiate better pricing from bulk purchases of HPWHs and to take advantage of the associated economies of scale through the use of a limited number of installers.

In Australia, several communities offer HPWH bulk purchase programs. In the state of Victoria, the Community Heat Pump Hot Water Programme[42] supports communities in making bulk purchases of HPWHs. The goal is to increase energy efficiency, reduce GHGe, and help homeowners save on energy costs. The HPWH model being promoted in Victoria is designed for installation outside the home and can use excess onsite photovoltaic electricity generation. It uses CO2 as a refrigerant and claims to be five times more efficient than a conventional electric tank system. The program also offers one-stop shop services for enquiries, quotes, installation, and rebate applications. National and state rebates of up to $2750AU are available for replacing an existing electric or gas system with an HPWH. Bulk purchases of 10 or more units are required to negotiate pricing support and the offer is good for only a short time per community[43].

In Massachusetts, the Muni Heat Pump program has partnered with Mitsubishi to offer $300-$600 discounts on qualified heat pumps for space heating in select municipalities[44]. Additional rebates are also available from municipal utilities. As noted in the turnkey model section, the larger program of which this is a part, installed 282 heat pump space heating systems in 2019[45].

## Carbon offset programs

Another interesting approach to encouraging the adoption of heat pumps in low income households is through the use of carbon offsets. In Juneau Alaska, where expensive heating oil is in common use, the community has raised funds through a carbon offset program to replace home space heating systems with air-source heat pumps in low income homes[46]. Each heat pump system costs US$4,800 to install (Juneau has a milder climate than Waterloo region), is expected to last 15 years, and avoids an estimated 5.5t GHGe per year. Carbon offsets are sold for US$33/t (CN$44/t: a fairly typical carbon offset price) and the program has targeted the tourists that visit the community, offering to offset their travel emissions. The math would suggest that this program covers US$2,700 toward each heat pump. Just over one year into the program, ten heat pump systems have already been installed.

We applied Juneau's math to HPWHs in the Waterloo region. Each HPWH would, on average, reduce annual emissions by 650-1000kg/yr[47]. With a 14-year lifespan and $44/t, each unit could earn roughly $400-$600 from a carbon offset program: insufficient to overcome the upfront cost barrier to adoption of HPWHs.

## Next Steps

Replacing conventional water heaters with HPWHs is a tremendous energy efficiency and GHGe reduction strategy.  Achieving our regional 2050 climate goals will require the majority of homes to switch to electrified water heating and this will not and can not take place overnight. The average water heater has a lifespan of 10-12 years, so most homeowners will only consider what system to install two to three times before our target deadline.  It takes time for a relatively new technology to gain consumer confidence, it takes time for tradespeople to learn to install and promote alternatives, it takes time for utility demand management programs to develop.  We need to start now.  The Urban Green Council has laid out a strategy for how to do this in New York City (see Figure 2).

There are 181,655 single family and other low-rise dwellings in the Waterloo region[48], each of which is likely to have its own water heater.  With an average lifespan of 11 years, we can expect 16,514 of these to replace their water heater every year.  Convincing just 1% of these to slash their carbon footprint by switching to a HPWH would help to build trust in the technology, build tradesperson capacity, and build demand for the incentive programs that can make HPWHs the affordable choice for all.

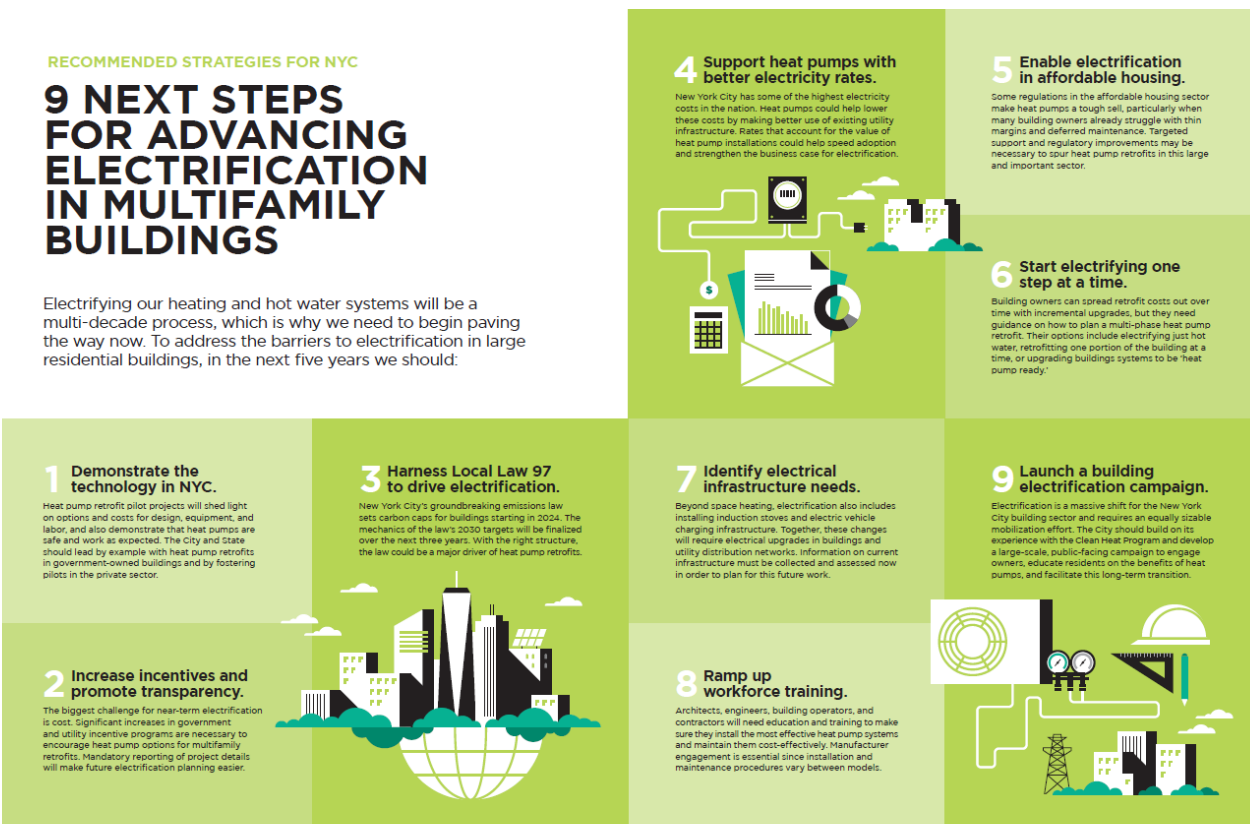


***Figure 3 Urban Green strategy for electrifying NYCs multifamily buildings[49].***

## Conclusions

Ultimately all homes will have to decarbonize their water heating if our community's climate targets are to be met. HPWHs appear to be the best available technology to perform this task efficiently and effectively for both the homeowner and the utilities that supply the electricity. Yet most homeowners, and even many tradespersons, are unaware of the heat pump options for heating water and they may be intimidated by the additional considerations that go in to choosing a HPWH. Incentives of approximately $1000 would address the economic barrier to HPWH adoption. Alternatively, HPWHs may be promoted through utility programs that make use of the demand management opportunities for HPWHs, or uptake may be encouraged through bulk purchase or carbon offset program. These programs must be developed to attract early adopters now. Time is running out to build the confidence in HPWH technology needed if we are to see market penetration at a pace that is essential to stabilizing our climate.

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