FUTURE OF HOME HEATING

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A COLLABORATION

ADVANCED ENERGY CENTRE
MaRS Cleantech | Ontario, Canada

ENBRIDGE
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- Natural Resources Canada
- Independent Electricity System Operator (IESO)
- Alectra Utilities
- The Atmospheric Fund

EXECUTIVE SUMMARY

In Ontario, buildings account for approximately one quarter of total greenhouse gas (GHG) emissions.[1] Given the province's relatively clean electricity supply, any efforts to decarbonize must address building heating. The most common proposed solution is electrification. However, an effective electrification strategy needs to account for affordability to ratepayers, ability to reduce GHG emissions, and impacts and potential strains on the distribution grid.

This report compares the economic, electrical demand and GHG-reducing performance of different electrification options, all using air source heat pumps (ASHP) in both retrofit and new homes. These scenarios include: 1) Full-Electric, using electric resistance heaters as a supplemental heat source, 2) ASHP/Gas Hybrid, which uses a high efficiency gas appliance as backup, and 3) CC-ASHP/Gas Hybrid, which uses a cold-climate ASHP (CC-ASHP) with a high efficiency gas appliance as backup. The high-level results are presented in this paper and summarized in the executive summary.

The results demonstrate the following:

- Lifetime energy costs are significantly lower in a hybrid scenario compared to the full-electric scenario. At the same time, capital costs of a hybrid system are higher than a full-electric scenario (Exhibit 1). Total lifetime-spend (equipment and energy costs), however, is lower for both hybrid scenarios compared to the full-electric scenario.
- All three scenarios, however, result in higher operating costs compared to using high efficiency gas appliances. Furthermore, current electricity rates in the province would not financially incentivize a homeowner to run a heat pump during lower temperatures, which is required to achieve the full emission reduction benefit. The analysis shows that electricity would need to be priced at 6c/kWh in order to run a heat pump during these times.
- A full-electric scenario would have a high impact to the grid, raising a household peak by as much as 13kW[2] on the coldest days of the year, compared to 0kW peak increase for ASHP/Gas Hybrid at the same temperatures. This increase for full electrification would result in a requirement for substantial grid infrastructure upgrades (Exhibit 2).
- Although the hybrid scenarios utilize natural gas, with smart controls and operating strategies, deep GHG emission reductions are achievable (Exhibit 2).

BOX 1. KEY ASSUMPTIONS

The hybrid scenarios' results are highly dependent on how the ASHP units are operated. The results presented here assume the user maximizes use of the heat pump, using the gas appliance as supplementary heat only when necessary to meet the home's heat load. Usage patterns of hybrid units are one of the major challenges to achieving effective GHG emissions reductions, given the low cost of gas. Under current rates, most users would simply run the gas appliance the majority of the time, regardless of outside temperatures.

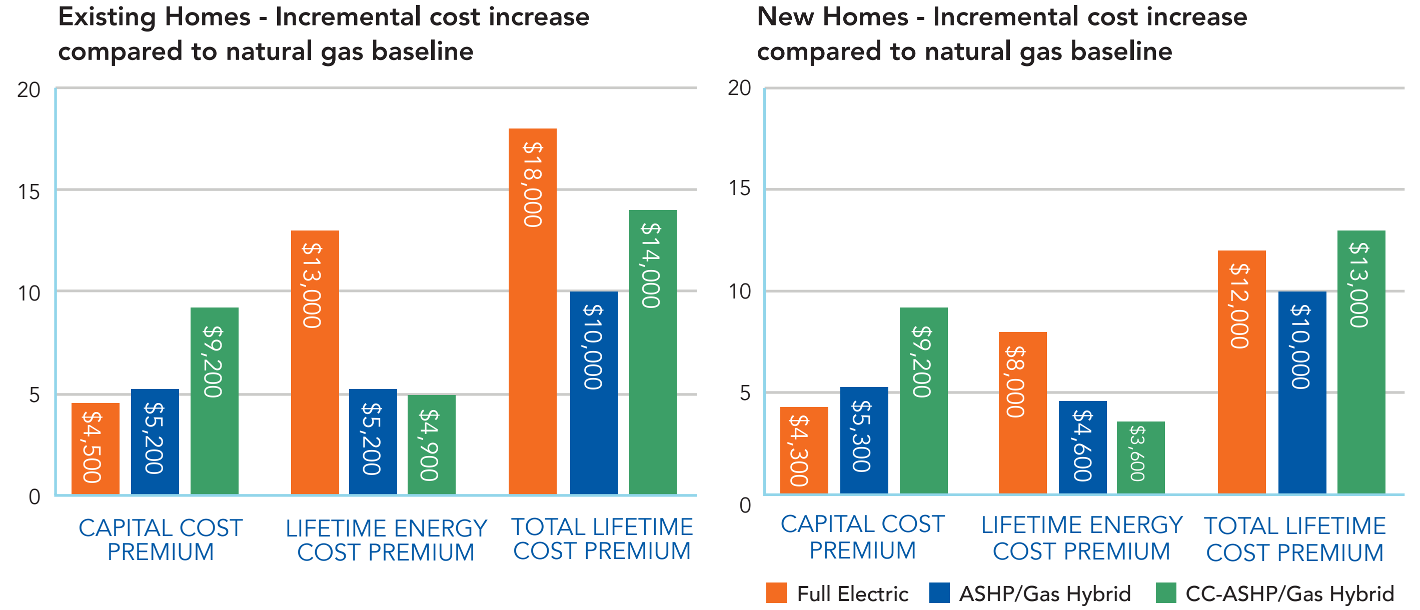
This report is intended to inform discussion on how to decarbonize residential gas heating across the province, and is based on Ontario averages and archetype homes. Each individual home and HVAC system is different, so individual results would vary. Please see the Supplemental Information Report for detailed results and assumptions.

[1] Government of Ontario. 2016. *Ontario's Five Year Climate Change Action Plan 2016-2020*. Queen's Printer for Ontario: Toronto. Available at: http://www.applications.ene.gov.on.ca/ccap/products/CCAP_ENGLISH.pdf

[2] For comparison, a typical home peaks at between 7 and 8 kW in the summer.

Ultimately, when balancing costs to ratepayers, demands on the grid, and the need for deep GHG reductions, beneficial electrification (Box 2) of Ontario's space heating demands will more likely occur through adoption of hybrid heating, ventilation, and air conditioning (HVAC) systems rather than through full electrification of HVAC equipment.

EXHIBIT 1. INCREMENTAL COST INCREASE COMPARED TO NATURAL GAS BASELINE PER HOME[3]
COST $ CDN



Flexibility is an added benefit to the hybrid approach when ASHPs are aggregated. As electricity demand increases, signals and controls can switch HVAC operating modes to gas, relieving stress on the grid. In times of surplus electricity, the unit can operate in heat pump mode. Real-time fuel switching capabilities enable the system to leverage infrastructure that already exists.

Hybrid systems can optimize beneficial electrification of heating in Ontario in the near- to mid-term. However, because electrification, even using hybrid equipment, results in higher operating costs compared to high efficiency gas appliances, smart controls and innovative rate designs are required in order for mass-market adoption to occur. Additionally, while beyond the scope of this report, ongoing research in gas innovation (including renewable natural gas and hydrogen) offers the potential for additional GHG reduction benefits to the hybrid systems. These innovations should be further explored to understand the full benefits for emission reductions and cost.

BOX 2. BENEFICIAL ELECTRIFICATION

Beneficial electrification refers to the conversion of fuel-consuming equipment and systems to use electricity, in a manner which is both affordable and reduces net GHG emissions.

EXAMPLE: Charging electric vehicles (EVs) overnight using available, non-emitting, surplus electricity.

[3] Totals may not match due to rounding

EXHIBIT 2. ASHP SCENARIOS AND THEIR PERFORMANCE – ALL NUMBERS ARE INCREMENTAL TO A NATURAL HIGH EFFICIENCY GAS APPLIANCE BASELINE

		FULL-ELECTRIC	ASHP-GAS HYBRID	CC-ASHP-GAS HYBRID
Air Source Heat Pump Type		Traditional	Traditional	Cold-Climate
Back-up Heat Source		Electric Resistance	Gas Appliance	Gas Appliance
EXISTING HOMES	Peak electricity demand at -25°C (kW)	13	0	2.7
	Annual net emissions impact (tCO_2e/ yr)[4]	-2.6	-2.1	-2.6
NEW HOMES	Peak electricity demand at -25°C (kW)	8.9	0	2.8
	Annual net emissions impact (tCO_2e/ yr)	-1.9	-1.7	-2.0

1. INTRODUCTION

Ontario is a global leader in climate change commitments, demonstrated through the elimination of coal-fired generation, substantial investments in both wind and solar generation and support for the usage of storage in the grid. The decarbonization of the electricity grid sets the stage for the electrification of heating loads, leveraging the very low GHG emissions profile of the province's electricity system. While electrification can be promising from a GHG emissions perspective, electrifying space heating in Ontario represents a significant new load, putting severe strain on grid infrastructure and the potential for unintended GHG increases if poorly implemented. This report explores new pathways for an energy system that balances cost and GHG emission reductions, while also utilizing existing infrastructure more fully.

Natural gas is relatively inexpensive and abundant. It is inherently storable, which means it is very good at meeting seasonal peaks (winter heating load). To the end-user, electrifying this load is significantly more expensive than using high efficiency gas appliances from both a capital cost and operating cost perspective. This can be contrasted to switching from a gasoline-powered car to an EV. The capital cost of an EV is higher, but the operating costs are lower, meaning that, long-term, there is likely to be a return on investment, even if it is quite modest. At current power prices and carbon costs, a homeowner has no investment return on deep electrification of heating loads. Therefore, a new strategy is needed.

BOX 3. WHAT IS AN ASHP?

ASHPs draw heat from outside air during the heating season and remove interior heat during the summer cooling season. This report focuses on the two most common types of ASHPs: full-electric and hybrid. Full-electric pumps come equipped with their own supplementary heating system in the form of electric-resistance heaters; hybrid pumps are used with another source of supplementary heat such as natural gas, propane, etc.

Efficiencies of heat pumps vary depending on outdoor temperatures. For example, at +5°C, the coefficient of performance (COP) of an ASHP is roughly 3.5, whereas at -8°C, the COP drops to 2.3. The COP decreases with temperature because it is more difficult to extract heat from cooler air.

(Source: Modified from NRCAN 2017)

[4] Annual net emission impacts listed in this table are based on an illustrative scenario where natural gas fired electricity generation is 20% of the total electricity generation mix. This number was chosen under the assumption that there will be greater peak electricity demand in Ontario in the future, requiring more natural gas in the electricity system.

2. ASHP TECHNOLOGY

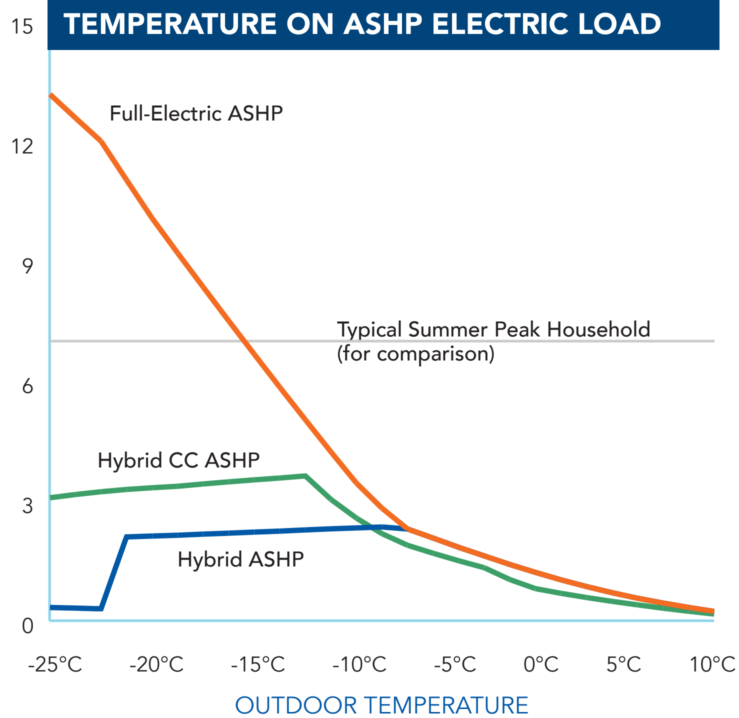
ASHPs are more efficient than conventional electric resistance heating in moderately cold climates. However, both the efficiency and capacity of the heat pump decline as the outdoor temperature declines, which means a secondary supply of input energy to heat the home in the coldest temperatures is required (See Box 3 above for more on ASHPs). ASHPs achieve a typical efficiency of around 2.3 when outdoor temperatures are around -8°C[5]. This means 2.3 units of heat are delivered to the home for every unit of electricity consumed. This leads to highly efficient operation during the shoulder seasons and moderate winter conditions.

3. CONTEXTUALIZING HYBRID SOLUTIONS IN ONTARIO

Over 58%[6] (or 3 million) of homes in Ontario rely on natural gas as their primary supply of heating fuel, representing the most common heating system in Ontario. While electrification of heating offers a substantial GHG-mitigation opportunity for Ontario, it comes with significant challenges. First, the capital cost of an ASHP is higher than that for a highly efficient natural gas appliance. Operating costs are also much higher. For example, electricity prices in Ontario remain three to eight times more expensive (depending on time of use) than natural gas on an energy basis. This is expected to remain the case for the foreseeable future. Therefore, even though ASHPs are highly efficient throughout most seasons, the price of electricity does not enable those efficiency gains to offset the cost of electricity over natural gas. This is particularly the case during colder periods when electric heat is not as efficient. A hybrid solution, while more expensive up-front, can greatly reduce operating costs. Although operating costs are more than conventional high efficiency gas appliances, different hybrid operating strategies can be implemented to support GHG reductions while lessening the cost impact to homeowners.

The second challenge relates to the stress a full-electric solution places on the grid on the coldest days of the year. For a typical existing home in Southern Ontario, an outdoor temperature around -5°C to -8°C represents the point where the secondary resistive heating source begins to support heat pump operations. Exhibit 3 shows how the electricity requirements of the all-electric scenario climbs rapidly as temperatures fall below -5°C, rising to a per-home electricity draw of 13kW just for space heating. For comparison, a typical peak load for homes currently heated by natural gas is 7 - 8kW, and the peak is usually in the summer. Urban and dense suburban distribution grids were not engineered to supply 13kW distributed loads. This means that local distribution companies (LDC) would require significant upgrades to many areas of their grid to enable widespread deployment of full-electric ASHP units.[7]

EXHIBIT 3. EFFECT OF OUTDOOR TEMPERATURE ON ASHP ELECTRIC LOAD



[5] Natural Resources Canada. 2017. *Heating and Cooling with a Heat Pump: Air Source Heat Pumps.* Accessed online: http://www.nrcan.gc.ca/energy/publications/efficiency/heating-heat-pump/6831

[6] Number based on total private dwellings in Ontario, as per 2016 Statistics Canada data. Statistics Canada. 2016. Census Profile: 2016 Census. Online at: http://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=PR&Code1=35&Geo2=PR&Code2=01&Data=Count&SearchText=ontario&SearchType=Begins&SearchPR=01&B1=All&TABID=1

[7] The costs of these grid upgrades – which would be substantial - have not been factored into this study's model.

In an all-electric scenario, incremental demands on the electricity grid would occur during short spurts throughout the winter. This means that most grid upgrades required as a result of peaks from electrified heating would go underutilized most of the year. But, as Exhibit 3 shows, a hybrid HVAC unit has no incremental electricity draw during peak times, as the ASHP switches off and the high efficiency gas appliance comes on. As the system peaks, electricity loads shift to direct gas, mitigating the need for massive distribution grid upgrades and new low-carbon generation that would be underutilized the remainder of the year.

The aggregate impact of 300,000 homes with the full-electric ASHP unit on the electric grid was also modeled. The incremental peak demand would represent 17% of Ontario's current winter grid peak and an increase of 2.8 TWh of energy annually (roughly 2% of Ontario's total energy consumption in 2017). Worse, the times of the day that the energy would be required could overlap with existing peak times, so there is potential that some of this load would have to be satisfied by natural-gas fired electricity (Ontario's current source for peak electricity). The need to increase the operation of large-scale natural gas fired generation as the marginal power supply would have a net-negative effect on emissions, therefore increasing the need for smart controls.

4. HYBRID ASHP OPERATION

While the hybrid scenario involves gas consumption, it still offers substantive emission reduction potential. However, the deepest GHG reductions are only possible if end-users operate the ASHP rather than the gas appliance for much of the heating season. In other words, the switchover temperature[8] would be set to several degrees below 0°C. Extensive usage of the ASHP throughout the heating season has been assumed throughout this report. But, given current energy prices, it does not represent the way most end-users would use the equipment today.

With the current technology, it is most logical to start with a hybrid heating system that utilizes the ASHP during more moderate winter temperatures. Exhibit 4 compares annual energy consumption and costs for a hybrid system under different control strategies: the right-hand side indicates scenarios where the ASHP only operates in mild weather (with high switchover temperatures[8]); the left-hand side indicates scenarios where the ASHP operates as much as possible (including in very low temperatures).

The Exhibit[9] illustrates that at high switchover temperatures, annual electricity and gas consumption remain similar to using a conventional all-gas heating solution. As well, energy consumption is much higher in the high switchover mode compared to the low, which demonstrates the overall energy efficiencies gained by using ASHPs more often. At a low switchover temperature, the electricity usage of the heat pump is maximized, with natural gas used only in the coldest temperatures. For an existing home in Southern Ontario, a hybrid ASHP with a switchover temperature of -10°C can reduce annual natural gas consumption from approximately 1,800 m^3 to under 800 m^3. On the other hand, energy costs follow an opposite trend; they are much higher when the ASHP use is maximized (at low temperatures) versus when it is only used in mild weather.

Ultimately, both full-electric and hybrid scenarios are more expensive to operate than the current market preference: high efficiency gas appliances. Even if ASHP capital costs drop, either through subsidies or economies of scale, heating with electricity remains more expensive than with natural gas, even when taking the ASHPs efficiency into account. For a typical existing Ontario home, an all-electric ASHP would increase annual heating costs by approximately $990 compared to an all-gas heating solution, an increase of over 100%, whereas the hybrid ASHP control strategy would reduce the price premium to approximately $420 while still delivering deep GHG reductions as illustrated in Exhibit 4. Once the hybrid control platform exists, creative control strategies and rate structures can evolve in the market place to further reduce the annual price premium to homeowners while still providing benefits to the bulk electricity system.

[8] The switchover temperature refers to the outdoor temperature below which the heat pump ceases to operate and the system uses the gas heating system to meet the home's full load.

[9] Note: The input assumption for carbon price included in the annual energy costs in Exhibit 4 are based on the current (2017-2018) carbon price rate.

5. ACHIEVING BENEFICIAL ELECTRIFICATION OF ONTARIO'S SPACE HEATING DEMANDS: TACKLING THE CHALLENGES

Given the system benefits of hybrid ASHPs, Ontario needs to investigate strategies to tackle the pricing barriers to mass market adoption. Smart controls and operational strategies for hybrid heating, as well as development of new price structures, can help overcome the challenges identified in this report.

Smart controls and operational strategies

Hybrid ASHP systems are typically programmed to use electricity in mild conditions and switch to gas when the outdoor temperature drops below a certain level. Controls that can fully optimize the system, balancing cost, GHG emissions and peak savings, are not yet available. Smart system controls are necessary to deliver the full benefits to the homeowner and the bulk energy system while maximizing cost-effectiveness and providing meaningful GHG emissions reductions.

For example, a control strategy could be programmed to operate the ASHP during mild to moderate winter conditions that also align with off-peak electricity.

Hybrid controls can also assist in managing grid demands for electrification of transportation – which represents a new, large and unpredictable electrical load - and what could be competing electrical heating demands. These trends will present challenges and considerations that hybrid heating systems can help address when smart controls are integrated.

Additionally, the beneficiaries of the control systems need to be investigated. For example, it is worthwhile considering the benefits that the hybrid system could offer to LDCs, if LDCs had some control over how they operate. As localized areas of distribution grids reach capacity at cold temperatures, they could automatically switch some homeowners over to the high efficiency gas appliance, enabling grid data-driven demand response.

Development of new price structures

In order for Hybrid ASHPs to achieve meaningful levels of adoption, while still maintaining affordability, new energy pricing structures will be necessary. These could include new rate structure designs, as well as targeted time-of use (TOU) pricing.

Exhibit 4. Effects of Hybrid ASHP Control Strategy

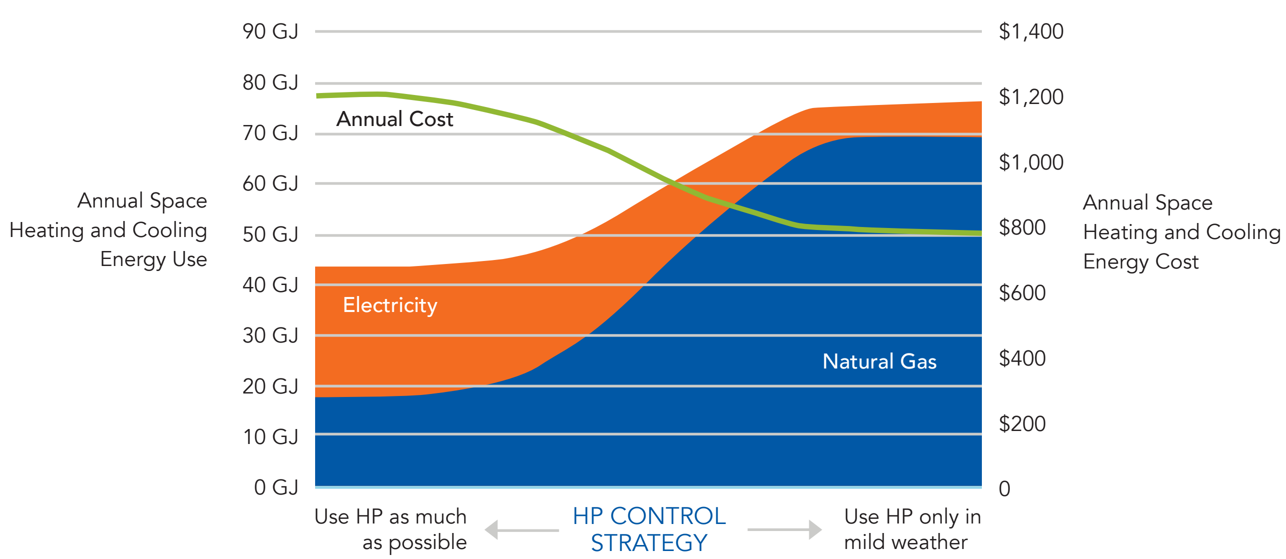
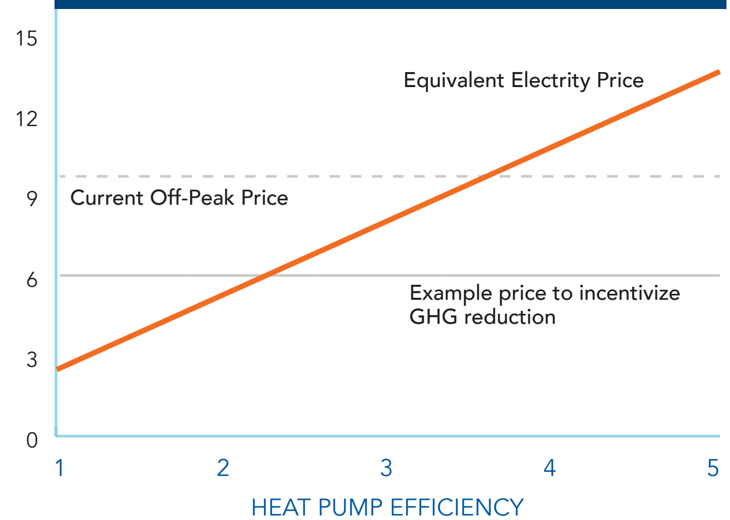


Exhibit 5 demonstrates the price of electricity that would be required to make ASHP operating costs competitive with gas at different ASHP efficiencies, which are in turn dependent on outside air temperatures. In Ontario, based on the current off-peak electricity rate of around 9.7c/kWh, electricity-gas price equivalency occurs at an efficiency of 3.5. This is the efficiency of a typical ASHP at around +5°C. A heat pump that only operates in +5°C or warmer temperatures would meet less than 1% of a typical home's annual heat load. An electricity price of 6c/kWh would be needed during relatively cold periods (efficiency of ~2.2) in order to incentivize a homeowner to run a heat pump.[10]

In addition to innovative rate structures, other options to incent ASHP utilization include targeted TOU pricing, or rewarding the energy dispatch flexibility offered by hybrid systems. Regardless of the options, there is a need to rethink economic signals to incentivize homeowners to operate ASHPs to minimize emissions. Additionally, we need to ensure unintended GHG increases do not occur by running ASHPs in extreme cold periods. If the heating demand is supported by less-efficient thermal power plants, GHG emissions will increase.

Exhibit 5. Equivalent Electricity Price, C/kWh (full commodity cost, delivery costs etc.)



6. CONCLUSION

This paper takes a first step at understanding a feasible pathway to significantly lowering the GHG emissions of space heating in Ontario's building stock. It identifies that a hybrid ASHP solution offers flexibility to homeowners, utilities and the province to grow and adapt to evolving low-carbon technologies while preserving energy affordability. It finds that hybrid heating delivers benefits that include:

- Deep emission reductions, using technology that is readily available today. With the development of new smart control strategies that are integrated with new economic and rate signals, these heating systems offer meaningful GHG reductions at the start, and can enable deep GHG reductions in the building sector.
- Improved energy affordability, including total lifecycle cost of equipment and operations, compared to alternatives that target 100% electrification of building heating demand.
- Improved optimization of Ontario's bulk electricity infrastructure to lessen ratepayer impacts and to achieve GHG reductions at a lower cost per tonne compared to all-electric spacing heating.

To access these benefits and support the market adoption of hybrid heating solutions, while preserving home energy affordability, further research needs to be done:

1. Investigate incentive program designs for heat pumps that encourage deployment of hybrid heating.
2. Evaluate rate designs tailored to encourage ASHP operation during periods of low-carbon electricity supply.
3. Identify and assess pilot projects that further the understanding of hybrid performance with a particular focus on smart control strategies and development of controls capabilities/infrastructure.
4. Develop a roadmap that identifies how other forms of non-emitting energy (renewable natural gas, etc.) and next-generation appliances (natural gas heat pumps, etc.) can complement emission reductions of hybrid heating.

[10] Compared against a gas price of 27c/m^3, and a 95% gas heat efficiency; Off-peak price based on off-peak TOU rate plus consumption-based delivery and regulatory charges (based on rates effective Nov 2017)