Exhibit L.ED.1

Analysis of Enbridge Gas' proposed low carbon transition program for cost effectiveness and climate alignment.

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Contents

Glossary of terms

AC = Air Conditioner

ASHP = Air Source Heat Pump

ccASHP = cold climate Air Source Heat Pump, heat pump that is designed and sized for heating in cold climates.

EF = Energy Factor, a measure of the overall energy efficiency of a water heater

HPWH = Heat Pump Water Heater

HSPF = Heating Seasonal Performance Factor. It is the average efficiency of moving heat into a home over the entire heating season. The HSPF changes based on the climate region. All figures in this report are for HSPF region V, which applies to most of Ontario. An HSPF of 10 region V equates to heating season average co-efficient of performance ("sCOP") of 2.93.

GHP = Gas Heat Pump, any heat pump that uses gas instead of electricity to power the heat pump or drive the refrigeration cycle.

GSHP = Ground Source Heat Pump.

NPV = Net Present Value, a measure of the current value of future payments

SEER = Seasonal Energy Efficiency Ratio for cooling, a measure of the average efficiency of moving heat out of a home over the entire cooling season

VRF = Variable Refrigerant Flow, a heat pump design that allows for zone heating and cooling by controlling the flow of refrigerant

Executive Summary

Enbridge Gas has proposed a Low Carbon Transition market transformation program to support the adoption of hybrid heating systems and gas heat pumps in residential buildings; and gas heat pumps in commercial buildings (EB-2021-0002 Exhibit E). To be most effective, this program should support technologies that are likely to be widely adopted in the future and be cost effective in a low carbon society: they should be cost effective and climate aligned.

Our research shows that the prevailing recommendation for achieving a low carbon society involves large scale electrification of building systems that rely on heat pumps for space and water heating. We therefore examined the cost effectiveness and climate alignment of these fully electrified heat pump systems relative to conventional gas heating systems, hybrid heating systems and gas heat pumps for low rise residential buildings and commercial buildings in Ontario.

Fully electric heat pumps are the option most aligned with a net-zero future. They are also the most cost effective for new construction in some residential developments and for existing communities that are not already connected to the gas supply. This is because they avoid the cost of adding gas infrastructure. These electrified systems use cold climate air source heat pumps (ccASHPs) and heat pump water heaters (HPWHs). Furthermore, this electrified option reduces the potential for stranded gas infrastructure investments arising from the shrinking dependence on fossil fuels in a low carbon society.

Electric heat pumps (ccASHPs) are also operationally more cost effective than conventional gas systems in homes with an existing gas connection and will likely be fully cost-effective on a lifetime net present value basis if improvements in heat pump price and efficiency continue to rise and as carbon costs rise.

Hybrid heating systems with smart controls are currently the most cost effective heat pump system for homes that are already connected to the gas supply. They could play a role during the net zero transition period because they reduce the energy requirements and emissions from heating. They could also help develop the market for fully electrified heating if programs are designed with that goal in mind. In the long term, however, this hybrid heating technology is unlikely to be consistent with plans for a net zero emission society because low carbon alternatives to fossil gas are expensive and have limited availability.

Gas heat pumps are the least cost effective option for residential buildings. Gas heat pumps are also not climate aligned for residential and commercial buildings as they are unlikely to support the carbon free operation of buildings required of a net zero emissions future.

Enbridge's decision to exclude fully electrified heat pumps from its proposed program and to subsidize gas heat pump systems does not appear to be justified by the relative cost effectiveness of the systems or a forward-looking need to develop a market. Electric ccASHPs would benefit from a market transformation program aimed at overcoming low consumer and installer awareness of the technology, and misconceptions about their performance and overall cost.

CONCLUSIONS

Electric heat pumps are the best option for a net zero transition for buildings.

Electric heat pumps are the most cost effective option for homes where major investments are required to add gas infrastructure.

For other homes, electric heat pumps will likely become more cost effective than conventional gas systems if improvements in price and efficiency continue and as carbon costs rise.

For existing homes with gas service, hybrid heating systems are currently the most cost effective.

In the short term, hybrid heating systems can help in the low carbon transition, but these are unlikely to play a major role in a net zero emissions future.

Gas heat pumps are the least cost effective and climate aligned option for homes and the least climate aligned option for commercial buildings.

Background on Heating Systems

Heat pumps are systems that move heat from one place to another and can often be reversible, moving heat into a building in winter and out of a building in summer, for example. A fridge is a single direction heat pump, as is an air conditioner. Moving heat is more efficiency than generating heat and heat pumps can have efficiencies far greater than the 100% theoretical limit of a furnace[1]. There are many different types of heat pumps.

Air source heat pumps (ASHPs) extract from or deposit heat into the air. The ASHPs discussed in this report provide both heating and cooling without the need for a separate air conditioner. The efficiency of an ASHP for space heating drops as outside temperatures fall and many ASHPs require a backup heating system at low outdoor temperatures, either an integrated electric resistance coil, or a fuel-based furnace[2]. Newer cold climate heat pumps (ccASHPs) can extract heat efficiently at temperatures as low as -30°C[3]. ccASHP systems replace a single stage compressor with a variable stage compressor, and also have improved heat exchanger designs and improved controls[4]. The fully electrified heat pumps analyzed in this report are cold climate versions (ccASHPs).

Heat pump water heaters (HPWH) are a type of air source heat pump that draws heat from the air to heat water for domestic use[5]. In Canada, HPWHs are generally installed in a home and generally draw heat from the surrounding air in the utility room. An assumed heating penalty and cooling benefit of drawing indoor heat for the HPWH are factored into our analysis.

The hybrid heating systems analyzed in this report are electric heat pumps with a gas system for backup heat and a smart controller that switches between the two systems to optimize savings and performance. These hybrid heating systems can work with cold climate heat pumps, but they can also work with single stage heat pumps that are designed and sized only for heating in the shoulder seasons.

Ground source heat pumps exchange heat with the ground. These do not require backup systems as the ground temperatures below the frost line stay relatively constant throughout the seasons[6].

Gas heat pumps have started to enter the market[7]. These systems use gas to either power the heat pump or drive the refrigeration cycle that the heat pump depends on. Although many are still in development, these systems tend to have lower efficiencies than electric heat pumps. Some gas heat pumps are not designed to provide summer cooling and some gas heat pumps can provide both space and water heating.

The conventional gas system analyzed in this report consists of a gas furnace paired with a central air conditioning system and in some analyses also paired with a high efficiency gas tank water heater.

When it comes to efficiency, not all heat pumps are the same. Air source heat pumps can be 210% to 390% efficient over the winter season in Ontario's climate, while ground source heat pumps can be 320% to 500% efficient in the heating season[8]. Gas heat pumps are expected to have efficiencies overall efficiencies in the range of 120% to 140% (Exhibit I.10h.EGI.STAFF.77). Gas furnaces and water heaters have a theoretical upper limit of 100% efficiency as the energy generated cannot exceed the energy contained in the fuel.

Residential heat pumps for a low carbon transition

A review of publicly available literature on the role of residential heat pumps in a low carbon transition was conducted for consideration in relation to Enbridge Gas's Low Carbon Transition program in Ontario. The analysis considers cold climate air source heat pumps (ASHPs), gas heat pumps (GHPs), hybrid heating systems (air source heat pumps with gas furnace backup), and heat pump water heaters (HPWHs). The key findings are outlined below.

Future-looking heating technologies should be net zero. According to the NRCan Comprehensive Energy Use Database, natural gas for residential heating systems accounted for 19.8 (megatonnes) Mt of CO2e in 2018[9], which represented 12.1% of the province's total emissions in 2019[10].

In response to the climate crisis, governments, institutions, businesses and households around the world are making plans to cut greenhouse gas (GHG) emissions and transition to a low carbon economy. The federal government aims to reduce greenhouse gas (GHG) emissions by 40-45% below 2005 levels by 2030 and achieve net zero emissions by 2050[11]. Ontario has a goal of reducing emissions by 30% below 2005 greenhouse gas (GHG) emission levels by 2030[12]. And many Ontario municipalities, businesses, institutions and industries have similar goals. For example, Toronto aims to achieve net zero by 2050 and has proposed moving that target date to 2040[13]. Heating technologies will need to be net zero emissions to meet these goals. Forward-looking market development should therefore focus on net zero technologies.

Electrification is the key recommended strategy for a low carbon transition for buildings by leading institutions. For buildings, a low carbon transition involves shifting away from the use of fossil fuels for space and water heating toward renewable energy sources. In the majority of cases, the recommended pathway involves electrification of space and water heating alongside decarbonization of the electricity supply. For example, the 2018 IPCC's (Intergovernmental Panel on Climate Change) analysis of mitigation pathways for global warming of 1.5°C requires a "rapid decline in the carbon intensity of electricity and an increase in electrification of energy end use"[14]. The International Energy Agency recommends the complete phase out of fuel-based heating systems by 2025 to achieve net zero emissions by mid-century[15]. The City of Toronto's TransformTO climate action plan calls for fuel switching all buildings to "electric heat pumps or alternative sources of low emissions heating" (p56)[16].

Renewable natural gas and hydrogen have limited potential as a low carbon fuel for residential applications. Hydrogen blends and renewable natural gas, which can include biomethane and synthetic natural gas, have been proposed as an alternative low carbon fuel[17]. However, research suggest that these alternatives have limited availability and/or are projected to be very expensive. A 2020 Torchlight Bioresources study of feasible biomethane feedstocks in Canada showed that only 3.3% of current natural gas use could be replaced with biomethane[18]. Biogas and synthetic gas are also expected to be many times more expensive than fossil gas[19]. Low carbon hydrogen can be blended with natural gas to reduce the carbon emissions of the fuel. Yet low carbon hydrogen is expensive and would have limited impact: residential distribution systems can support up to 20% hydrogen by volume, or 7% by energy and some end use equipment would need to be adapted or replaced to accommodate this mixture[20]. Many believe the supply of zero-carbon fuels should be kept for applications that are harder to decarbonize (aviation, long distance trucking, some industrial processes, etc.)[21].

Electric heat pumps are the preferred choice for electrified residential heating. Electric heat pumps have very high energy efficiencies because they move heat rather than generating heat. Electric heat pumps are a mature technology that continues to improve. New cold climate heat pump models with electric backup heating can provide all of the space and water heating needs of most Ontario homes at very high efficiencies. Furthermore, as the technology improves and gains wider market share, their efficiencies and costs are expected to improve[22],[23].

Electric heat pumps are explicitly recommended as the main mechanism for reducing emissions from residential heating systems by a growing number of influential groups both internationally and locally. A sampling of these groups or consultant reports include:

- International Energy Agency[24]
- California Energy Commission report on retail gas in California's low carbon future[25]
- BC Building Electrification Roadmap[26]
- Rocky Mountain Institute[27]
- Northeast Energy Efficiency Partnerships[28]
- National Renewable Energy Laboratory[29]
- Dunsky analysis for the HRAI on the economic value of ground source heat pumps[30]
- City of Toronto TransformTO[31] and other Ontario municipality climate action plans

Cold climate heat pumps are ideal for a market transformation program. As noted above, cold climate heat pumps are the prevailing recommendation for a net zero transition. Common barriers to their greater adoption are low consumer and installer awareness of the technology, misconceptions about their performance, and their higher overall cost[32]. A market transformation program could help to overcome these barriers.

Hybrid heating systems could support a low carbon transition in the short term. Hybrid heating are more efficient than conventional gas systems and could help to address some of the barriers to greater adoption of cold climate heat pumps. These impacts would be maximized when the hybrid heating systems use heat pumps with variable stage compressors that are sized to provide most of the heating needs of the home. Hybrid heating systems with single stage heat pumps, however, have been the dominant heat pump in the marketplace for many decades[33] and do not require market development. In the long term, hybrid heating systems that rely on gas are likely to be incompatible with many net zero plans.

Gas heat pumps are a high risk solution for a low carbon transition. Residential gas heat pumps are not expected to be commercially available in Canada until 2024[34]. In 2018, NRCan rated the technology as not yet accessible, affordable or acceptable for Canadian applications[35]. The reliability and performance of these systems in Ontario have therefore yet to be proven. With an average heat pump life-expectancy of 15 years, there is a high risk that this technology will see only a tiny market share, that fossil gas will be phased out to meet our climate targets, and that the equipment could even be forced into an expensive early retirement.

Summary

More and more governments, institutions, businesses and other groups are committing to climate targets that include steep reductions in greenhouse gas emissions. For residential buildings, this transition to net zero emissions will require changes to how indoor spaces and water are heated. If ratepayer-funded market transformation programs are not aligned with this low carbon transition, there is a high risk that those dollars will be wasted on technologies that are ultimately inconsistent with a net zero future. Shifting homes that use natural gas for space and water heating to electrified alternatives is the recommended approach by the International Energy Agency and the Intergovernmental Panel on Climate Change. Also, low carbon renewable gas alternatives are limited in supply and expensive and so cannot support the continuation of gas-based equipment as we approach net zero. Cold climate electric heat pumps are a highly energy efficient mature technology that continues to improve. Hybrid heating systems could have a role in the net zero transition, but likely only for the short term. Gas heat pumps are still in development and risk being phased out as we move toward tighter climate targets.

Residential cost effectiveness analysis

The cost-effectiveness of various low rise residential heat pump systems were compared. The data sources and methodology used in this analysis can be seen in Appendix A, while Appendix B contains the spreadsheets used for this analysis. The modelling is based on Enbridge's avoided cost estimates and gas consumption for a typical home.[a]

Electric ccASHP vs conventional gas with AC

Existing homes with gas

At the current time, an electric cold-climate air-source heat pump (ccASHP) is operationally more cost effective than a gas furnace with a SEER 13 air conditioner (see Table 1). The higher upfront cost of ccASHPs, however, means that a gas furnace and air conditioner system has a lower lifetime overall cost and a lower net present value (NPV) in homes with an existing gas supply.

Table 1: Cost-effectiveness of a ccASHP compared to a gas furnace and air conditioner.

	Gas furnace (95%) with SEER[b] 13 AC	ccASHP (HSPF[c] 10)
Upfront cost	$8,000	$11,100
15-yr operational cost	$20,297	$18,944
15-yr operational cost savings	NA	$1,353
Lifetime savings	NA	-$1,747
NPV (compared to gas/AC)	NA	-$2,757

[a] Note that the cost-effectiveness conclusions remain the same even if the assumed gas consumption doubles.
[b] SEER is the Seasonal Energy Efficiency Ratio. It measures the average efficiency of moving heat out of a home over the entire cooling season.
[c] HSPF is the Heating Seasonal Performance Factor. It is the average efficiency of moving heat into a home over the entire heating season. The HSPF changes based on the climate region. All figures in this report are for HSPF region V, which applies to most of Ontario. An HSPF of 10 region V equates to heating season average co-efficient of performance ("sCOP") of 2.93.

Existing homes and new homes without a gas connection

In many cases it is more cost effective to go all electric in lieu of installing new gas infrastructure for an existing community without gas service or to a new residential development. An all-electric home can use cold climate heat pumps for space heating and heat pump water heaters for domestic hot water use. Furthermore, investing in new natural gas infrastructure in these communities with a 40+ year lifespan also risks generating costly assets that may be underutilized or stranded as our society shifts toward greater electrification.

If the cost for gas connection is more than $4,100 per customer, the all-electric option is more cost effective than a conventional gas system. In other words, the current break-even point for the all-electric heat pump scenario modeled here is $4,100 (see Table 2). This is far greater than the average $26,700 per customer that will be spent in phase 2 of the Government of Ontario Natural Gas Expansion Program. This phase of the program will invest $234 million in connecting 8750 customers in 43 communities to the natural gas system[36].

Table 2: Cost-effectiveness of a ccASHP and HPWH compared to a gas furnace, air conditioner and gas water heater in gas expansion area homes.

	Gas furnace (95%) with SEER 13 AC and EF 0.81 gas water heater	ccASHP (HSPF 10) and HPWH (EF 3.75)
Upfront cost, including NG infrastructure investments	$37,200	$15,357
15-yr operational cost	$23,646	$21,484
15-yr operational cost savings	NA	$2,162
Lifetime savings	NA	$24,005
NPV (compared to gas/AC)	NA	$22,625

For new residential developments, the average capital cost to connect a new home to the natural gas system is roughly $3,300 per home (Exhibit I.10.EGI.ED.26, average of Union Gas and Enbridge Gas values for 2022-2024), and trending upward. For a portion of these developments, the all-electric option will be more cost effective than installing new gas infrastructure and conventional gas heating systems. With time, that portion will likely grow as heat pump advancements, economies of scale from a growing electric heat pump marketplace, climate policies, and other factors come into play.

In the long term, investments in building gas infrastructure and gas heating systems may be made redundant as our society transitions to net zero emissions.

Table 3: Cost-effectiveness of a ccASHP compared to a gas furnace, air conditioner, and gas water heater in new housing developments.

	Gas furnace (95%) with SEER 13 AC and EF 0.81 gas water heater	ccASHP (HSPF 10) and HPWH (EF 3.75)
Upfront cost, including NG connection	\$13,800	\$15,357
15-yr operational cost	\$23,646	\$21,484
15-yr operational cost savings	NA	\$2,162
Lifetime savings	NA	\$605
NPV (compared to gas/AC or gas/AC/DHW)	NA	-\$775

Heat pump advancements

While gas furnaces are already close to their theoretical upper limit on efficiency (100%), heat pumps have room to improve, especially in cold climates[37]. The costs of ccASHPs are also expected to come down as their market share increases and economies of scale take effect[38]. Heat pumps with an HSPF of 13.2 in zone V are already available[39]. These are cost effective relative to a gas furnace with air conditioning, if available at our modeled upfront cost. Similarly, a 16% drop in the cost of an HSPF 11 system would also be comparable in cost to a gas furnace with air conditioning. Finally, heat pump water heaters are also seeing improvements in efficiency and cost. An 18% drop in the installed cost of a HPWH would make a fully electrified system cost comparable to gas systems in a new home on a NPV basis. These scenarios are shown in Appendix B.

ccASHPs vs hybrid heating systems with Smart controls

The hybrid heating system proposed by Enbridge Gas is an electric heat pump with a natural gas furnace backup and a smart controller that switches between the two systems to optimize savings and performance. These hybrid heating systems can work with cold climate heat pumps, but they can also work with single stage heat pumps that are designed and sized only for heating in the shoulder seasons.

It is not clear what type of heat pump Enbridge Gas proposes to use in their Low Carbon Transition program and how it will be sized. Their models in Exhibit I.10h.EGI.STAFF.77 use an HSPF 10 system[d] which is designed for cold climate use but models the same 3 ton unit in two homes with very different heating loads. As a consequence, the balance point (where a heat pump is no longer able to meet the full heating load) is -14.3°C in the newer post '80s home and -1.6°C in the older pre '80s home with higher heat loss. Furthermore, in Exhibit I.10.EGI.ED.36, Enbridge Gas estimates that the incremental cost of a hybrid heating system would be $1,500-$2,000 over a code-minimum air conditioner. This cost difference is consistent with a single stage heat pump, not a variable stage heat pump that is designed for cold climate use. This cost difference is also not consistent with the upfront cost estimates in Exhibit I.10h.EGI.STAFF.77 where heat pumps designed for cold climate use were used. The cost and climate alignment of the heat pump design and sizing requirements are expected to be significant.

We did not model the cost effectiveness of hybrid heating systems with smart controls as the modeling is complex and we did not have access to the NRCan modeling tool that Enbridge Gas used.

Nevertheless, it is clear from the Enbridge Gas analysis that the fully electrified heat pump system (ccASHP with a HPWH) is more cost effective than a hybrid heating system in gas expansion areas (their NPV difference values are far less than the $26,700 cost of gas expansion). ccASHPs are also currently very similar in cost effectiveness to hybrid heating systems in homes where they are sized and designed for heating (Exhibit I.10h.EGI.STAFF.77 Table 1) and the cost difference could be overcome if electricity or natural gas avoided costs were to change.

Hybrid heat pumps are more energy efficient than conventional gas systems and can therefore support a low carbon transition in the short term. In the long term, it is likely that fully electric heat pumps will be the preferred technology for achieving our net zero emissions climate goals (see page 6). Market development programs may therefore be more impactful if they focus on fully electric heat pump.

[d] It is unclear whether this is HSPF for region IV or V.

ccASHP + HPWH vs GHP

Electric cold climate air source heat pumps are more cost-effective than gas heat pumps.

The gas heat pump (GHP) proposed by Enbridge Gas is capable of providing both space and water heating but does not provide air conditioning. This technology is not expected to be commercially available in Canada until 2024 and therefore the cost, reliability and performance of the gas heat pump systems are based on a US DOE study and NRCan's 2030 performance goal (I.10h.EGI.STAFF.77). The electrified alternative to this system is a ccASHP paired with a HPWH and is compared to a gas heat pump with an additional air conditioning system.

As Table 4 shows, ccASHPs with HPWHs are more cost effective than gas heat pumps in terms of lifetime savings and NPV. Furthermore, as discussed in the previous section (page 6), gas heat pumps are unlikely to see widespread adoption in a low carbon world and investments in building a market for this technology risk being undone by climate policies or market forces that are directed toward electrification.

Table 4: Cost effectiveness of a ccASHP paired with a HPWH compared to a gas heat pump with an air conditioning system.

	Gas heat pump (120%) with SEER 13 AC	**ccASHP (HSPF 10) with HPWH (EF 3.75)**
Upfront cost	$18,250	$15,357
15-yr operational cost	$18,754	$21,484
15-yr operational cost savings	NA	-$2,730
Lifetime savings	NA	$163
NPV (compared to gas/AC)	NA	$554

Our all-electric scenario differs in a few important ways from that shown in Exhibit I.10h.EGI.STAFF.77 Table 3. The modeling tool used by Enbridge Gas was unable to calculate the savings from a HPWH and assumed a 50% savings in electricity compared to a conventional electric water heater (energy factor ~0.93). HPWHs currently on the market have reported efficiency values of 3.75 energy factor (EF) and higher[40], which results in far greater savings. These HPWHs are also commercially available at a much lower installed cost than the $6,150 assumed by Enbridge Gas[41],[42].

Ground Source Heat Pumps (GSHPs)

Ground source heat pumps were not included in Enbridge Gas's analysis and are not modeled here. Yet GSHPs deserve some attention. These systems have greater overall efficiencies as the temperature of the ground where the heat pump draws and deposits heat energy changes very little over the seasons. This results in lower peak electricity loads and lower overall electricity use compared to a ccASHP, but at a higher upfront cost[43]. A 2020 study by Dunsky Energy Consulting showed that under scenarios of policy-driven widespread adoption across Canada, GSHPs have the potential to save billions in total costs relative to ccASHPs, primarily by reducing overall and peak electricity demand[44].

Summary

In many cases, electric heat pumps for space conditioning and water heating are more cost effective systems than gas systems in areas that require new gas infrastructure. In areas with gas service, electric heat pumps are operationally less expensive than conventional gas systems and will be fully cost-effective on a lifetime net present value basis if improvements in heat pump efficiency and price continue. Hybrid heating systems with smart controls are more cost effective in the remaining homes and may be consistent with a low carbon transition in the short term, but as the next section shows, the technology risks being made redundant by our climate goals in the long term. Gas heat pumps are the least cost effective system and are not recommended as they have high upfront costs, uncertain performance, and risk generating stranded assets in an electrifying world.

Commercial heat pumps for a low carbon transition

A review of publicly available literature on heat pumps for commercial buildings was performed to assess their climate and economic impacts for consideration in Enbridge Gas's Low Carbon Transition program in Ontario. There are four options for commercial buildings considered in this review: a) Air source heat pumps (ASHPs) with electric backup heating, b) hybrid heating systems that use an ASHP with a natural gas furnace as backup, c) ground source heat pumps (GSHP) that are also fully electrified, and d) gas heat pumps of various configurations (GHP: e.g. absorption, engine driven and thermal compression technologies). All of these technologies can use variable refrigerant flow (VRF) systems to provide zoned heating/cooling.

Future-looking heating technologies should be net zero. Enbridge and Union Gas operate in areas with ambitious climate targets. In Ontario, we have a climate target of a 30% reduction below 2005 greenhouse gas (GHG) emission levels by 2030[45], while our federal targets are for a 40-45% reduction below 2005 levels by 2030 and net zero emissions by 2050[46]. Furthermore, many municipalities and businesses are setting ambitious climate targets and financial institutions are looking at the climate impacts of their investment portfolios[47].

According to the NRCan Comprehensive Energy Use Database, natural gas for commercial heating systems accounted for 10.3 (megatonnes) Mt of CO_2e in 2018[48], which represented 6.3% of the province's total emissions in 2019[49].

Achieving the climate goals above will require all sectors, including commercial buildings, to significantly reduce emissions. Forward-looking market development should therefore focus on commercial building heating technologies that are consistent with a net zero future: they should be climate aligned.

Time is running out to meet our climate goals. The average lifespan of many commercial gas heating systems (rooftop gas systems, boilers, furnaces) is 15-25 years[50], while larger systems and district heating systems may have longer lifespans. Therefore, in the coming decade nearly half of commercial systems will be replaced, and some of these replacement systems could still be operational by 2050 when net emissions must be zero. Commercial building equipment must therefore maximize emissions reduction potential and avoid locking buildings into heating systems that may be forced into early retirement to achieve our 2050 climate goals.

Electric and hybrid heating systems have greater potential to reduce energy use than gas heat pumps. According to Dunsky Energy Consulting, air source heat pumps in commercial buildings can achieve an average heating season efficiency of 210%-250% in Toronto, while ground source heat pumps can achieve 270-370% efficiency[51]. These values may be conservative as Dunsky's reported residential efficiencies are lower than those reported for many EnergyStar-rated systems[52],[53] and efficiencies are expected to increase[54]. Gas heat pumps are expected to achieve efficiencies of 140% or greater, although lab and field testing in Canada have yet to be completed[55]. Two manufacturers of commercial GHPs report efficiencies of 130-140%, although details were not available on the climate zones to which these apply[56]. Conventional, non-heat pump systems have a maximum theoretical efficiency of just under 100%.

Gas heat pumps are not ready for widespread deployment. While ccASHPs and GSHPs are mature technologies that continue to improve, only a small number of commercial gas heat pumps are available in Canada at this time[57]. In 2018, the technology was rated as not accessible, not affordable and not yet acceptable for Canadian applications[58]. An industry-sponsored report also highlighted how even the commercialized gas heat pump products were considered to be in the testing and validation phase[59]. The reliability and performance of these systems have therefore yet to be proven in Ontario.

Electric heat pumps have greater potential to reduce GHGs. Ontario's current low carbon electricity supply mix[60] means that an electric heating system will generate fewer emissions than a gas or hybrid heating system with the same efficiency. As noted above, electric heat pumps have greater energy efficiencies than gas heat pumps thereby amplifying this difference. In the long term, the federal government has committed to achieving a net zero electricity system in Canada by 2035[61]. Net zero emissions by 2050 targets will likely require nearly all Canadian buildings to operate heating systems fueled by decarbonized electricity or renewable natural gas.

Renewable natural gas has limited potential for powering GHPs. It may be possible to replace some fossil gas with renewable biogas, however this option faces multiple limitations such that it is not an alternative to electrification, as discussed above on page 6.

The upfront costs of commercial heat pump systems are difficult to compare. A 2020 ACEEE report noted that the economics of paybacks for commercial heat pump systems varies significantly based on a variety of factors including building type, energy use, energy costs, and others[62]. Gas heat pumps were included in ACEEE's report but there was insufficient data for an economic analysis: the technology was deemed "mostly still in development" but was expected to be more expensive than electric heat pumps[63].

Summary

The growing concern about climate change will create greater pressure to reduce emissions from commercial building heating systems in line with our targets. Utilities should ensure that their future-looking market transformation programs are aligned with provincial and federal targets because they otherwise risk investing ratepayer funds in technologies without a future. In addition, commercial systems have long lives and therefore should be compatible with future needs to avoid the risk of expensive early retirement.

Heat pumps are one of the best strategies for reducing emissions from the commercial sector due to their very high energy efficiencies. Gas heat pumps, however, have lower energy efficiencies, lower current and long term emissions reduction potential, and are still in development. Furthermore, there is limited potential for renewable natural gas and hydrogen to supply the demand from widespread use of gas-dependent heating systems including gas heat pumps. The upfront cost of commercial heat pump systems depends on many variables and are difficult to generalize, especially for gas heat pumps which are largely still in development.

Conclusions

Enbridge Gas has proposed a Low Carbon Transition market transformation program to support the adoption of hybrid heating systems and gas heat pumps in residential buildings; and gas heat pumps in commercial buildings (EB-2021-0002 Exhibit E). To be most effective, this program should support technologies that are likely to be widely adopted in the future and be cost effective in a low carbon society: they should be cost effective and climate aligned.

Our research shows that the prevailing recommendation for achieving a low carbon society involves large scale electrification of building systems that rely on heat pumps for space and water heating. We therefore examined the cost effectiveness and climate alignment of these fully electrified heat pump systems relative to conventional gas heating systems, hybrid heating systems and gas heat pumps for low rise residential buildings and commercial buildings in Ontario.

Fully electric heat pumps are the option most aligned with a net-zero future. They are also the most cost effective for new construction in some residential developments and for existing communities that are not already connected to the gas supply. This is because they avoid the cost of adding gas infrastructure. These electrified systems use cold climate air source heat pumps (ccASHPs) and heat pump water heaters (HPWHs). Furthermore, this electrified option reduces the potential for stranded gas infrastructure investments arising from the shrinking dependence on fossil fuels in a low carbon society.

Electric heat pumps (ccASHPs) are also operationally more cost effective than conventional gas systems in homes with an existing gas connection and will likely be fully cost-effective on a lifetime net present value basis if improvements in heat pump price and efficiency continue to rise and as carbon costs rise.

Hybrid heating systems with smart controls are currently the most cost effective heat pump system for homes that are already connected to the gas supply. They could play a role during the net zero transition period because they reduce the energy requirements and emissions from heating. They could also help develop the market for fully electrified heating if programs are designed with that goal in mind. In the long term, however, this hybrid heating technology is unlikely to be consistent with plans for a net zero emission society because low carbon alternatives to fossil gas are expensive and have limited availability.

Gas heat pumps are the least cost effective option for residential buildings. Gas heat pumps are also not climate aligned for residential and commercial buildings as they are unlikely to support the carbon free operation of buildings required of a net zero emissions future.

Enbridge's decision to exclude fully electrified heat pumps from its proposed program and to subsidize gas heat pump systems does not appear to be justified by the relative cost effectiveness of the systems or a forward-looking need to develop a market. Electric ccASHPs would benefit from a market transformation program aimed at overcoming low consumer and installer awareness of the technology, and misconceptions about their performance and overall cost.

Appendix A: Methodology and data sources

Data values and sources

Enbridge Gas values for a post-80's archetype home were used in most cases (Exhibit I.10h.EGI.STAFF.77 Page 5 of 14). This included values for gas use, electricity use (assumed the electricity in a gas heated home was all used for air conditioning), furnace efficiency, AC efficiency, heat pump efficiency, all upfront costs, lifespans, and net present value discount rate (6.08%). These values can be seen in Tables 5 and 6.

Table 5: Equipment characteristics.

	Gas furnace	AC	Gas water heater	GHP with AC	ccASHP	HPWH
Upfront cost incl. installation	$8,000		$2,500	$18,250	$11,100	$4,257
Efficiency	95%	SEER 13	81%	120% SEER 13	HSPF 10[e] SEER 20	375%
lifespan	15 years	15 years	15 years	15 years	15 years	15 years

Table 6: post 80's archetype home characteristics

	gas	Electricity
Total heating load	1,707 m3	22,420 kWh
Total cooling load	NA	2,368 kWh
Total water heating load	267 m3	2,822 kWh

Heat pump SEER values were not included in Enbridge Gas's report. We used NRCan's database of heat pump systems[64], which showed an average SEER value of 20 for HSPF 10 (zone V) heat pumps.

Heat pump water heaters (HPWH) efficiency values and prices were taken from the Home Depot Canada website and were as follows: $2,457 plus $1,800 for installation ($4,257 total) and EF of 3.75[65]. Since HPWHs draw heat from the surrounding indoor air, we included the additional heating costs to supply that heat in the home and subtracted the avoided cooling costs from the ccASHP. The formula can be seen in the calculations section.

[e] It is unclear if Enbridge used HSPF values for region V or IV. We used values for region V as that covers most of Ontario and NRCan lists over 1,500 ccASHP's with efficiencies above HSPF 10 for region V.

Unless otherwise noted, it was assumed that the systems were installed in 2025, the midpoint in the proposed DSM program.

Enbridge Gas and Union Gas avoided cost values (from 1.5.EGI.ED.16) for gas and electricity were averaged. The carbon price schedule outlined by the federal government was used until 2030, after which it was assumed that the price would continue to rise at the same rate ($15 per tonne per year).

The natural gas expansion surcharge ($0.23/m3) was taken from Enbridge Gas's website[66].

Calculations

Heat pump heating HSPF values were converted to a % efficiency value using:

$$\%\ efficiency = HSPF * 0.293$$

AC and heat pump SEER values were converted to a % efficiency value using:

$$\%\ efficiency = \left((1.12 * SEER) - 0.02 * SEER^2\right) * 0.293$$

The operational costs for space heating were calculated for every year using:

$$annual\ operational\ heating\ or\ cooling\ cost = \frac{heating\ or\ cooling\ load}{efficiency} * (total\ avoided\ cost\ per\ kWh\ or\ m3)$$

The total operational cost of the HPWH system is includes the cost of generating the heat absorbed from the air by the water heater in winter and the air conditioning energy avoided due to this heat absorption in summer. Since the HPWH also loses heat while in standby, these values are reduced by 5%. The formula used was:

$$HPWH\ operational\ cost = (avoided\ cost\ of\ electricity) * ((water\ heat\ load)/(HPWH\ efficiency) + (\frac{0.5 * (water\ heat\ load)}{ccASHP\ efficiency} - \frac{0.5 * (water\ heat\ load)}{ccASHP\ cooling\ efficiency})$$

The lifetime operational cost for heating and cooling systems were the 15-year total of each annual operational cost.

Lifetime costs are the lifetime operational costs plus the upfront cost of the installed equipment.

The net present value was calculated using:

$$NPV = upfront\ cost + \sum_{t=0}^{14} (operational\ cost\ in\ year\ t)/(1.0608)^t$$

The savings value for the lifetime operational cost, lifetime cost and NPV are the difference of these values between the two systems under consideration.

The attached spreadsheet can be used to alter any of these values to test their effects on the lifetime operational savings for an ccASHP, the lifetime savings for an ccASHP and the NPV of the savings for an ccASHP.

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ONTARIO ENERGY BOARD

EB-2021-0002

IN THE MATTER OF the *Ontario Energy Board Act*, 1998, S. O. 1998, c. 15, Schedule B;

AND IN THE MATTER OF an application for a Multi-Year Natural Gas Demand Side Management Plan (2022 to 2027).

Acknowledgment of Expert's Duty

1. My name is Heather McDiarmid. I live in Kitchener, in the Province of Ontario.
2. I have been engaged by or on behalf of Environmental Defence to provide evidence in relation to the above-noted proceeding before the Ontario Energy Board.
3. I acknowledge that it is my duty to provide evidence in relation to this proceeding as follows:
   (a) to provide opinion evidence that is fair, objective and non-partisan;
   (b) to provide opinion evidence that is related only to matters that are within my area of expertise; and
   (c) to provide such additional assistance as the Board may reasonably require, to determine a matter in issue.
4. I acknowledge that the duty referred to above prevails over any obligation which I may owe to any party by whom or on whose behalf I am engaged.

Date: December 1, 2021

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Heather McDiarmid

Heather McDiarmid, MCC, PhD

heatheratp2@gmail.com

Experience

Independent Consultant *Dec 2017 to present*

- Clients have included the University of Waterloo, Ontario Clean Air Alliance, ClimateActionWR, Reep Green Solutions, GreenUP Peterborough, Waterloo Region Community Energy.
- Analyzed the cost effectiveness and climate mitigation impacts of electrifying homes in the Waterloo region using heat pumps for space and water heating.
- Explored a housing archetype-based approach to decarbonizing residential homes in Waterloo Region.
- Conducted a residential retrofit financing program feasibility study to meet FCM requirements.
- Prepared a research-based study of the potential for active transportation hubs and programs to encourage transportation mode shifts in the tri-cities.
- Unearthed and detailed residential carbon mitigation programs and strategies from across North America to inform Toronto's climate action plan.
- Prepared a climate impact analysis and developed an evaluation framework for a non-profit.
- Performed primary and secondary market research on the feasibility of retrofit management.

Sustainability Living Lab Coordinator, *University of Waterloo* *Oct 2021 to present*

- Facilitated opportunities for students to apply their skills and knowledge to campus sustainability challenges
- Documented campus work related to the UN Sustainable Development Goals
- Developed resources to support integration of sustainability content in courses and programs

Research Associate and Lecturer*, University of Waterloo* *Jun 2020 to present*

- Analyzed a database of over 44,000 home energy audit results to explore the emissions impacts of different retrofit and electrification approaches for the residential sector.
- Engaged to teach a graduate course in Climate Change Mitigation in Fall 2021.
- Presented research findings at the International Green Energy Conference, Jul 15-18, 2021.
- Invited as a guest lecturer on Climate Change Communications and on Climate Change and Housing.

Research Assistant and Writer, *University of Waterloo and David Miller* *Mar 2019-Apr 2020*

- Investigated municipal programs from around the world that have been successful in cutting carbon emissions, highlighting the most relevant and universally applicable details for a book.
- Advised on structuring the book and collaborated in choosing programs to profile.
- Wrote early drafts of many chapters.
- David Miller, Director of International Diplomacy at C40 Cities, is the author of the book titled Solved: how the world's great cities are fixing the climate crisis.

Heather McDiarmid, MCC, PhD

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Researcher, *Clean Air Partnership* — *Apr- Aug 2019*

- Prepared a toolkit on municipal financing options for residential retrofit programs.
- Completed a 16-week research project in 10 weeks.
- Prepared and presented webinars to municipal representatives.

Academic Instructor, *Wilfrid Laurier University and University of Guelph* — *2002 - 2011*

- Shared a passion for biochemistry with 6-200 students at the 2^{nd}, 3^{rd} and 4^{th} year levels.
- Researched and developed new course content.
- Explored innovative ways of engaging students.

Leadership in Sustainability

- **Blog Writer,** McDiarmid Climate Consulting
- **Project Lead,** Homeowner's guide to heat pumps for WR — *Jan. 2021-present*
- **Guest Lecturer,** Climate Change Communication, Climate Change and Housing Affordability
- **Committee Member and Chair**, ClimateAction WR Residential Sector — *Dec. 2018 - present*
- **Committee Member**, UW CAP Climate and Energy Working Group — *2019*

Writing and Publications

- Should electrification, not retrofits, be the focus for decarbonisation of most residential buildings? Submitted to Climate Policy May 2021.
- Deep energy efficiency retrofits vs direct electrification for urgent emissions reduction: a case study using 33,780 residential energy profiles in Waterloo, Canada. Presented to the 13^{th} International Green Energy Conference Jul 2021.
- Active Transportation Hubs in Waterloo Region: a research pilot project
- Aerial thermal imaging and building energy efficiency updates in WR: a sustainable buildings pilot
- Analysis of the Residential Electrification Potential for the Waterloo Region
- Residential heat pump water heaters as a climate action for the Waterloo Region
- Deep Energy Residential Retrofit: financing feasibility study for Waterloo Region
- How to cut emissions from the residential sector in Waterloo Region
- Accelerating Home Energy Efficiency Retrofits through LIC Programs: a toolkit for municipalities
- Climate Change and the Tree Canopy of Waterloo Region
- Climate Change and Housing Affordability in Canada