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Enbridge Gas Inc.
500 Consumers Road
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VIA EMAIL and RESS

May 31, 2023

Nancy Marconi
Registrar
Ontario Energy Board
2300 Yonge Street, Suite 2700
Toronto, Ontario, M4P 1E4

Dear Nancy Marconi:

Re: Enbridge Gas Inc. ("Enbridge Gas" or the "Company")
Ontario Energy Board ("OEB") File No. EB-2022-0249
Hidden Valley Pipeline Project
Updated Interrogatory Response to Exhibit I.ED.16 part e)

Consistent with Enbridge Gas's initial May 2, 2023 response to Exhibit I.ED.16 part e) and the OEB's Procedural Order No. 2 dated May 23, 2023 in the above noted proceeding, enclosed please find the Company's updated response to Exhibit I.ED.16 part e) including attachments.

The updated interrogatory response is also relevant to the following proceedings, as the Company's previously filed interrogatory responses within these proceedings reference the response at EB-2022-0249 Exhibit I.ED.16 part e):

- EB-2022-0156 – Selwyn Pipeline Project[1]
- EB-2022-0248 – Mohawks of the Bay of Quinte First Nation Pipeline Project[2]

Enbridge Gas has reviewed the Company's previously filed interrogatory responses within all three proceedings and confirms that no additional updates are required to other interrogatory responses based on the update to the response at EB-2022-0249 Exhibit I.ED.16 part e).

If you have any questions, please contact the undersigned.

Sincerely,

Haris Ginis
Digitally signed by Haris Ginis
Date: 2023.05.31 11:19:29
-04'00'

Haris Ginis
Technical Manager, Leave to Construct Applications

[1] EB-2022-0156, Exhibit I.ED.16 part e) and Exhibit I.PP.10 part b).
[2] EB-2022-0248, Exhibit I.ED.16 part e).

c.c. Charles Keizer (Torys)
Henry Ren (Enbridge Gas Counsel)
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Catherine Nguyen (OEB Staff)
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Intervenors (EB-2022-0156/EB-2022-0248/EB-2022-0249)

ENBRIDGE GAS INC.

Answer to Interrogatory from
Environmental Defence ("ED")

INTERROGATORY

Reference:

Exhibit E, Tab 1, Schedule 1, Attachment 2

Question(s):

(a) Please provide a table showing the full calculations and assumptions used to generate the revenue forecast from the customer attachment forecast. Please include, among other things, the annual customer attachments, annual customer totals, the use per customer, and the revenue generated per customer.

(b) If the customer attachment forecast underlying the DCF table differs from the one set out in Exhibit B, Tab 1, Schedule 1, Page 6, please explain and provide a reconciliation table.

(c) Does Enbridge agree that the number of customer attachments could be impacted by the relative cost-effectiveness of converting to gas versus converting to high-efficiency cold climate air source heat pumps? If not, please explain.

(d) Does Enbridge agree that the number of customer attachments could be impacted by customer perceptions of the relative cost-effectiveness of converting to gas versus converting to high-efficiency cold climate air source heat pumps? If not, please explain.

(e) Please provide Enbridge's best estimate of the relative cost-effectiveness of an average customer in the project area converting to an air-source cold climate heat pump versus gas. Please generate (i) the lifetime difference in total capital costs and operational costs (NPV) based on customer prices over the equipment lifetime and (ii) the difference in average annual operational costs over the equipment lifetime. Please include all material customer-facing costs and benefits, including energy costs, carbon costs, the Greener Homes Grant incentives for heat pumps, and the gains from more efficient summer cooling of an air source heat pump versus a traditional air conditioner. Please provide all calculations and assumptions. Please make assumptions and state caveats as necessary.

Response

a) Please see Attachment 1 to this response.

b) As noted in the Cover Letter to Enbridge Gas's responses to interrogatories filed May 2, 2023, through refinement of Project design and investigation of the underlying attachment forecast, Enbridge Gas identified an error whereby it counted a multi-condo property containing 64 units as a single customer. As a result of adding 63 customers to the potential customer count, the Company's attachment forecast has been updated to 130 total attachments. Please see the corrected Attachment Forecast in Table 1 below. Please also see the responses to Exhibit I.ED.4, part a), and Exhibit I.STAFF.4 for additional details.

Table 1

Customer Attachments	Forecast									
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Residential Single-Family Attachment	13	18	18	9	9	4	4	4	4	4
Residential Multi-Family Attachment	7	9	9	4	4	2	2	2	2	2
Total Customer Attachment	20	27	27	13	13	6	6	6	6	6

c) and d)
No. The attachment forecast is based on the energy interests expressed by actual residents and business-owners within the Project area, which intrinsically incorporate all factors including financial and non-financial considerations. The Company has no reason to believe that the attachment forecast is inaccurate.

e) The Company does not have information regarding annual fuel costs and/or customer lifetime cost-effectiveness for electric heat pumps, specific to the Project area climates. However, in Q1 2023 the Company engaged Guidehouse Inc. ("Guidehouse") to provide an assessment of the annual operating costs of high-efficiency electric cold climate air source heat pumps within four Ontario climates (Windsor, Toronto, Ottawa, and Thunder Bay) at three peak winter design loads (2.5 tons, 4 tons, and 5 tons). The Guidehouse report can be found at Attachment 2 to this response. The spreadsheet model referenced on page 1 of the Guidehouse report is provided as a live Excel document at Attachment 3 to this response. /U

It is important to note that the scope of the Guidehouse report consisted of an assessment of operating costs and did not include an assessment of upfront capital costs which are required to conduct a customer lifetime cost-effectiveness analysis of converting a home to a high-efficiency electric cold climate air source heat pump configuration.

Assessing the upfront costs required to convert a home to a high-efficiency electric cold climate air source heat pump configuration requires consideration of several factors, which results in a more complex analysis than assessing the upfront costs required to convert a home to a natural gas furnace configuration. For example, in addition to the cost of the heat pump itself, a home could also require electrical panel upgrades, exterior service upgrades from the electric utility, internal wiring upgrades, duct work improvements, etc. Enbridge Gas understands that there is a wide range of potential upfront costs depending on the existing configuration of the home itself. For this reason, the Company is not able to provide an average upfront cost, which would be required to develop an average customer lifetime cost-effectiveness analysis for conversions to high-efficiency electric cold climate air source heat pump configurations. Any attempt to do so would result in an oversimplification of the conversion costs and would not necessarily be representative of the actual conversion costs for specific homes in the Project areas.

To be responsive to the interrogatory however, in May 2023 following receipt of ED’s interrogatory Enbridge Gas requested low-end and high-end upfront cost estimates from HVAC contractors for conversions to both high-efficiency electric cold climate air source heat pump configurations and natural gas furnace configurations. The request for information from Enbridge Gas to HVAC contractors can be found at Attachment 4 to this response. Five HVAC contractors responded to Enbridge Gas’s request, each providing low-end and high-end upfront cost estimates. A summary of the responses from HVAC contractors can be found at Attachment 5 to this response. The overall low-end and high-end results based on the information from HVAC contractors are provided in Table 1 below. Enbridge Gas cautions that the results are meant to be illustrative and that more refined research would be required to establish robust estimates/assumptions.

Table 1: Upfront Cost Comparison

	Low-end Upfront Cost	**High-end Upfront Cost**
Conversion to Natural Gas Furnace Configuration *(A)*	$3,890	$11,500
Conversion to High-Efficiency Electric Cold Climate Air Source Heat Pump Configuration *(B)*	$11,400	$50,500
Cost Comparison between High-Efficiency Electric Cold Climate Air Source Heat Pump Configuration and Natural Gas Furnace Configuration *(C = B – A)*	$7,510	$39,000

As per the response to Exhibit I.ED.17 part a), subject to meeting program eligibility requirements certain homeowners could be eligible for up to $5,000 in grants from the federal government for qualifying electric air source heat pumps. See Table 2 below for the inclusion of the grant to the low-end upfront cost scenario for the conversion to high-efficiency electric cold climate air source heat pumps. Since not all applications are necessarily eligible for the grant, the high-end upfront cost scenario does not include the grant amount.

Table 2: Upfront Costs Comparison, including $5,000 Federal Grant

	Low-end Upfront Cost	**High-end Upfront Cost**
Conversion to Natural Gas Furnace Configuration *(A)*	$3,890	$11,500
Conversion to High-Efficiency Electric Cold Climate Air Source Heat Pump Configuration *(B)*	$6,400	$50,500
Cost Comparison between High-Efficiency Electric Cold Climate Air Source Heat Pump Configuration and Natural Gas Furnace Configuration *(C = B – A)*	$2,510	$39,000

To provide ranges for the customer lifetime cost-effectiveness of converting a home to a high-efficiency electric cold climate air source heat pump configuration compared to a natural gas furnace configuration, Enbridge Gas combined the upfront cost information in Table 2 with the operational cost information from the Guidehouse study. The following 12 scenarios were assessed. Toronto and Ottawa were used in the assessment as they are the most relevant climates to the three Project areas.

- Toronto, low-end upfront cost, 2.5 ton
- Toronto, low-end upfront cost, 4 ton
- Toronto, low-end upfront cost, 5 ton

- Toronto, high-end upfront cost, 2.5 ton
- Toronto, high-end upfront cost, 4 ton
- Toronto, high-end upfront cost, 5 ton

- Ottawa, low-end upfront cost, 2.5 ton
- Ottawa, low-end upfront cost, 4 ton
- Ottawa, low-end upfront cost, 5 ton

- Ottawa, high-end upfront cost, 2.5 ton
- Ottawa, high-end upfront cost, 4 ton
- Ottawa, high-end upfront cost, 5 ton

Please see Attachment 6 to this response for details regarding the natural gas costs (including carbon costs) used in the assessment, provided as an Excel document with formulae intact. The natural gas costs used in the assessment are consistent with the approach described in the response to Exhibit I.ED.1 parts b) – c) (i.e., Rate 01 Northeast including SES) updated to reflect natural gas prices in effect as of April 1, 2023. The carbon costs reflect the Federal carbon charge escalating to \$170/tCO_2e by 2030.[1] The electricity costs used in the assessment are also consistent with the approach described in response to Exhibit I.ED.1 parts b) – c) (i.e., 0.1133 \$/kWh).

It is important to note that the energy costs used in the analysis are a snapshot in time and thus may not be reflective of consumer expectations for long-term energy prices. For example, natural gas commodity prices experienced a significant short-term increase in 2022 due to various factors including geo-political conflicts and COVID-19 pandemic-related economic impacts. Such factors impacting the volatility and increase in natural gas prices observed in 2022 are considered to be unique and commodity prices are already stabilizing and declining relative to 2022.

[1] https://www.enbridgegas.com/en/residential/my-account/rates/federal-carbon-charge

See Table 3 below for customer lifetime cost-effectiveness of high-efficiency electric cold climate air source heat pump configurations when compared to natural gas furnace configurations, based on the information described above. Please see Attachment 7 to this response for the calculations underlying the figures in Table 3, provided as an Excel document with formulae intact.[2]

Table 3: Customer Lifetime Cost-Effectiveness of High-efficiency Electric Cold Climate Air Source Heat Pump Configurations when compared to Natural Gas Furnace Configurations[3]

Scenario	**Customer Lifetime Cost-Effectiveness (using Low-End Upfront Cost Assumption)**	**Customer Lifetime Cost-Effectiveness (using High-End Upfront Cost Assumption)**
Toronto, 2.5 ton	+$6,043	-$30,447
Toronto, 4 ton	+$11,166	-$25,324
Toronto, 5 ton	+$14,582	-$21,908
Ottawa, 2.5 ton	+$6,890	-$29,600
Ottawa, 4 ton	+$12,515	-$23,975
Ottawa, 5 ton	+$16,261	-$20,229

Based on the information in Table 3 above, conversion to a high-efficiency electric cold climate air source heat pump configuration could be more cost-effective for space heating for some homeowners when compared to a conversion to a natural gas furnace configuration, whereas for other homeowners the natural gas solution would be more cost-effective.

Please note that the analysis does not consider water heating components which, if customers chose all-electric configurations, would require additional considerations (i.e., a comparison of upfront and operational costs for electric water heating solutions compared to natural gas water heating solutions). Additionally, Enbridge Gas does not have information regarding high-efficiency electric cold climate air source heat pumps with respect to summer space cooling.

Notwithstanding cost-effectiveness analysis related to any potential energy solution (natural gas, electric heat pumps, or otherwise) Enbridge Gas submits that it is critical to assess the interests of actual residents and business-owners within the Project areas. The Company cautions against relying on theoretical cost-effectiveness analysis as a solitary basis for determining consumer energy interests.

[2] Annual operational cost savings figures are not formulaic as they are outputs from the spreadsheet model.
[3] A 4% discount rate was used for the lifetime analysis.

Rather, the interests expressed by actual consumers within a particular Project area/community are directly reflective of those consumers' preferences and energy decisions as they inherently encompass all relevant factors, including financial and non-financial considerations.

Guidehouse

To: **Enbridge Gas Inc.**
From: **Guidehouse**
Date: **May 19th, 2023**

Re: **Comparison of heat pump configurations - All-electric (including air source heat pump/electric resistance supplemental) and Hybrid (ASHP/gas furnace backup) performance for space heating in Ontario homes**

Introduction

This memo has been prepared by Guidehouse to examine the performance and operational costs of all-electric and hybrid air source pump systems for typical Ontario homes. The presented costs reflect anticipated annual heating utility costs for an average homeowner, which represent the cost of operating the heating equipment only (note actual utility bills may range due to a variety of site-specific factors). Capital costs including equipment first costs, infrastructure upgrade costs within the home, and installation costs are out of scope and not considered in this analysis. The analysis does not represent an all-in lifecycle cost analysis. Given that installation costs are highly dependent on initial conditions and highly variable, the average installation cost is not useful from a policy perspective, as it is not indicative of any actual consumer experience. Four different heat pump configurations have been assessed with three different system sizes across four locations in Ontario. The analysis will assist Enbridge in evaluating the performance trade-offs between all-electric heat pump systems and hybrid heat pump systems backed up with natural gas.

Approach

Heat pump heating performance was calculated using a custom-built spreadsheet tool developed for this analysis. The spreadsheet tool, titled “Enbridge Heat Pump Model” herein referred to as “the spreadsheet model”, has been delivered with this memo and contains additional details regarding the specific calculation methodologies used for this analysis.

Four different heat pump configurations were considered for this analysis:

- Hybrid Heating Heat Pump Coil with Existing Furnace
- Hybrid Heating Heat Pump with New Furnace
- Cold Climate Heat Pump
- Non-Cold Climate Heat Pump

System performance criteria was developed to fully characterize each of the systems including the development of capacity and efficiency performance curves, heat pump efficiencies, and supplemental heating efficiencies. Whole building energy modeling with EnergyPlus was used to model single family residential prototype models and generate hourly heating profiles for four locations across Ontario: Ottawa, Toronto, Windsor, and Thunder Bay. The system performance criteria in conjunction with the heating profiles from the energy model are used within the spreadsheet model to calculate hourly consumption of natural gas and electricity for each of the system configurations. Performance is calculated for each system type and location at three peak winter design loads: 30,000 Btu/hr (2.5 tons), 48,000 Btu/hr (4 tons), and 60,000 Btu/hr.

A baseline scenario with new 95% annual fuel utilization (AFUE) furnace serves as the comparator the heat pump systems are measured against. The following performance metrics are reported:

- Electricity/natural gas consumption
- Peak hourly consumption
- Energy cost/savings
- Greenhouse gas emissions

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System Characterization

Heat pump heating performance curves were developed for four heat pump configurations: hybrid heating heat pump coil with existing furnace, hybrid heating heat pump with new furnace, cold climate heat pump with electric resistance backup heating, and a traditional non-cold climate heat pump with electric resistance supplemental heating[1]. To define these system configurations and develop the performance curves needed to assess heating system performance, a large database of heat pump equipment and performance values (Northeast Energy Efficiency Partnerships - NEEP 2019 database, which contains more than 5,000 heat pump systems) was used to calculate the average market performance for each of the system configurations. The heat pump criteria used to define each scenario and stratify the NEEP database entries are as follows:

Hybrid Heating Heat Pump Coil with Existing Furnace: AHRI Type HRCU-A-C with centrally ducted configuration. Heat pump maintenance capacity (max 5°F/-15°C capacity divided by rated 47°F/8°C capacity) less than 80% - non cold climate heat pump.

Hybrid Heating Heat Pump with New Furnace: AHRI Type HRCU-A-CB with integrated furnace and centrally ducted configuration. Heat pump maintenance capacity (max 5°F/-15°C capacity divided by rated 47°F/8°C capacity) less than 80% - non cold climate heat pump.

Cold Climate Heat Pump: AHRI Type HRCU-A-CB and HMSV-A-CB AHRI type with centrally ducted configuration and maintenance capacity (max 5°F/-15°C capacity divided by rated 47°F/8°C capacity) greater than 80% - cold climate heat pump.

Non-Cold Climate Heat Pump: AHRI Type HRCU-A-CB and HMSV-A-CB AHRI type with centrally ducted configuration and maintenance capacity (max 5°F/-15°C capacity divided by rated 47°F/8°C capacity) less than 80%.

The supplemental heating system types considered are as follows:

Hybrid Heating Heat Pump Coil with Existing Furnace: Natural gas 90% AFUE.
Hybrid Heating Heat Pump with New Furnace: Natural gas 95% AFUE
Cold Climate Heat Pump: Electrical resistance
Non-Cold Climate Heat Pump: Electrical resistance

Note the hybrid heat pump performance is not the same between the two configurations. Table 1 includes the different performance metrics used for each system configuration, which are based on the market performance from the NEEP database. The coil only heat pumps that are installed with existing furnaces and new hybrid systems where the heat pump is sold integrated with the furnace have different average performances, which are reflected in this analysis.

Performance curves were generated for capacities and efficiencies at maximum and rated conditions (performance reported at 8°C, -8°C, and -15°C) for each of the four heat pump configurations, see the “Curve Data” tab in the spreadsheet model for details. Capacity and efficiency curves in combination with additional input criteria are used to extrapolate system performance metrics at ambient temperatures ranging from 16°C to -34°C (the lowest temperature experienced across the four climate locations). Additional input criteria include sizing ratios, heating load profile, heat pump efficiency, furnace efficiency, capacity, airflow rates, and fan power. In addition to capacity and efficiency curves, a defrost performance curve is also used to account for negative performance impacts attributed to defrost mode during operation below 4°C[2]. The heat pump efficiencies and sizing ratios defined in Table 1 were derived from the NEEP database with the remaining fields reflecting standard performance values.

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[1] Supplemental heating refers to heating that occurs in tandem with heat pump heating whereas backup heating refers to a heating source that meets 100% of the heating load without the heat pump running.
[2] Winkler, Jon. Laboratory Test Report for Fujitsu 12RLS and Mitsubishi FE12NA Mini-Split Heat Pumps.

Table 1: Heat Pump Input Criteria

System Configuration	Heat Pump COP at Rated Capacity at 47°F/8°$^{(2)}$C	Heat Pump COP at Max Capacity at 47°F/8°C$^{(2)}$	Heat Pump Max Capacity Sizing Ratio[1]	Supplemental Efficiency	Fan Power (W/Ton)	Lockout Temp (C°)$^{(3)}$
Hybrid Heating Heat Pump Coil with Existing Furnace	3.4	3.1	1.08	90% AFUE	90	-18
Hybrid Heating Heat Pump Coil with New Furnace	4.0	3.8	1.08	95% AFUE	90	-18
Cold Climate Heat Pump	4.3	4.0	1.17	1 COP	90	-26
Non-Cold Climate Heat Pump	4.0	3.7	1.11	1 COP	90	-18

(1) Modern heat pumps are often variable capacity equipped with variable speed compressors. The rating performance values reflect the performance at rated conditions, but variable speed equipment is capable of modulating capacity beyond the rated values. The "Max" values in Table 1 are performance values achieved when the variable speed compressor is running at maximum speed.
(2) The efficiency values shown in Table 1 are consistent for all load sizes for each of the configurations
(3) The minimum temperature the heat pump can operate before the compressor shuts off

Heat pump controls were modeled based on smart controllers that automatically enable supplemental heating based on available capacity. A dynamic crossover strategy optimized for lowest operational cost is used to produce the results in this analysis where the supplemental heating is engaged when the heat pump heating cannot satisfy the heating load. If smart controllers were not used the temperature at which the hybrid heating systems switch from heat pump heating to furnace heating would be set to a fixed temperature by the HVAC contractor during installation. The most cost-effective switchover temperature will vary depending on utility rates, equipment performance, and load conditions and can vary home by home. HVAC contractors typically don't have access to the information required to determine the optimal switchover temperature and often use the same conservative (higher) switchover temperature for all homes. This results in longer furnace runtimes and minimizes the potential benefit of the heat pumps.

System Sizing

The results of this analysis include the performance of each heat pump configuration run at three different heating loads, 30,000 Btu/hr (2.5 tons), 48,000 Btu/hr (4 tons), and 60,000 Btu/hr (5 tons). These load sizes reflect low, medium, and large load conditions characterizing the full residential housing stock from small townhouses to large single family detached homes. The Canmet Air-Source Heat Pump Sizing and Selection Guide was used to determine the heating capacity for each heat pump configuration at the different load sizes – 2.5, 4, and 5 tons[3]. Different sizing guideline options were used for the different system configurations based on the supplemental/backup heating sources and heat pump prioritization.

Canmet guidelines option 4B, which utilizes a balanced heating and cooling approach, was used for the hybrid heating configurations resulting in a nominal heat pump heating capacity estimated at half a ton less than the design load. This analysis uses a simplified approach of a consistent half ton capacity reduction for all the system load sizes rather than changing the capacity reduction relative to load. Heat pump operation is prioritized during mild to moderate heating conditions while natural gas is used as the primary heating source during the coldest periods.

The non-cold climate heat pump configuration utilized sizing option 4C, which has an emphasis on heating. This sizing strategy resulted in a nominal heat pump capacity equal to the heating load. Electric resistance heating will supplement the heat pump with additional heating capacity during periods where the heating load cannot be met with heat pump heating alone.

For the cold climate heat pump configuration option 4D was used which sizes heating capacity based on the heating load at design conditions. This resulted in a nominal heat pump capacity half a ton larger than the heating load to account for the reduced capacity at colder temperatures ensuring nearly the entire heating load is met with heat pump and minimal electric resistance supplemental heating is used.

[3] https://natural-resources.canada.ca/maps-tools-and-publications/tools/modelling-tools/toolkit-for-air-source-heat-pump-sizing-and-selection/23558

Load Profiles

Whole building energy modeling was performed using the EnergyPlus simulation engine with US Department of Energy single family residential prototype energy models to generate hourly heating load profiles for each of the following weather locations: Toronto, Ottawa, Windsor, and Thunder Bay. These locations capture the range of heating load profiles found throughout Ontario. In order of lowest heating load to highest heating load the four weather locations are organized as follows: Windsor, Toronto, Ottawa, and Thunder Bay. See the “Weather Profiles” tab in the spreadsheet model for heating load profile details. TMYx weather files were used to simulate the energy models for each of the locations. TMYx weather files include hourly data and are based on recent 15-year weather data, which more accurately reflects current and changing weather profiles than traditional TMY weather files made up of 30 plus years of historic weather data.

The heating load profiles are used with the heat pump performance curves to calculate the hourly heating load, available heat pump heating capacity, heat pump heating efficiency, and heat pump supplemental heating coil run times. The peak demand is calculated as the maximum single hour consumption and the annual consumption is the combined total of all the hours of operation.

Utility Costs

Utility costs are based on Enbridge natural gas rates (EGD Rate 1) and Toronto time of use (TOU) electricity rates (as of May 2023), which were used to calculate the operational costs for each system configuration.[4,5] No assumptions have been made about forward price curves and utility rates for either natural gas or electricity, including increases in carbon costs. Note, utility costs can readily be updated in the “Utility Data” tab in the spreadsheet model to assess the impact of rate changes. While utility costs vary by region, the relative cost difference between electricity and natural gas is similar and regional differences in utility costs have a minimal impact on overall results.

Table 2: Utility Pricing

Electricity			
Electricity TOU Price Periods	Winter (Nov 1- Apr 30)	Summer (May 1 - Oct 31)	Prices (c/kWh)
Off-Peak	Weekdays 7pm-7am, Weekends All Day	Weekdays 7pm-7am, Weekends All Day	10.0
Mid-Peak	Weekdays 11am-5pm	Weekdays 7am-11am and 5pm - 7am	12.8
On-Peak	Weekdays 7am - 11am and 5pm-7pm	Weekdays 11am-5pm	17.8
Natural Gas Rate ($/m3)			
0.42			

Carbon Emissions

Marginal carbon emission rates for electricity generation are based on the Power Advisory Report “Marginal Greenhouse Gas Emission Factors for Ontario Electricity Generation and Consumption”[6] and natural gas carbon emission rates are based on the carbon content of the fuel, which is equivalent to 1.93 kg of CO_2e per cubic meter of natural gas.[7]

4 https://www.enbridgegas.com/residential/my-account/rates?gad=1&gclid=CjwKCAjwge2iBhBBEiwAfXDBR8ZtTx-o5AMck7eqhNsGF09TgHkGhWpLhwqPabwVtySQ8WVM95_NHhoCvdsQAvD_BwE
5 https://www.torontohydro.com/for-home/rates
6 http://consortia.myescenter.com/CHP/Power_Advisory_Report_on_Marginal_Emission_Factors_for_Ontario_Electricity_Generation_Oct2020.pdf
7 Environment and Climate Change Canada. (2022, April 14). 2022 National Inventory Report 1990-2020: Greenhouse Gas Sources and Sinks in Canada. Part 2. Table A6.1-1 and Table A6.1-3. https://unfccc.int/documents/461919

Results

Table 3 through Table 18 show performance summary results including total energy consumption, peak demand, energy cost, and carbon emissions for all four scenarios at each location and for each heating load.[8]

Key Findings

- The cold climate heat pump configuration emits the least CO_2 emissions of all system configurations regardless of location or load size.
- The cold climate heat pump has the best cost performance in Windsor (most mild climate) while the hybrid heating heat pump with new furnace is the cheapest to operate in Toronto, Ottawa, and Thunder Bay.
- Increase in electric peak demand is lower for hybrid heating systems with furnace backup than all electric system configurations with electric resistance supplemental heating.

Natural gas is approximately three times cheaper than electricity on a cost per unit energy basis, however the high efficiency of heat pump systems overcome the fuel pricing disparity resulting in net operational cost saving when using a heat pump in a moderate climate (COP> 3) compared to a furnace. While heat pump heating outperforms a furnace when operating at nameplate efficiencies the physical limitations of heat pump heating yields reduced efficiency and capacity at lower ambient temperatures ultimately requiring a supplemental heating source to satisfy the heating load. Note in Tables 7-18 the cold climate annual COP is often lower than the non-cold climate heat pump option because it spends more time running at lower temperatures with a lower efficiency. In contrast furnace efficiency is not impacted by ambient air temperature and operates at a consistent efficiency.

Between electric resistance (COP of 1) and natural gas furnace backup heating options, the furnace is more cost effective than electric resistance heating. Regions that are subject to extreme cold will experience lower average heat pump efficiencies and rely increasingly on supplemental heating sources compared to systems operating in more moderate climates. This means the system configurations that maximize heat pump operation and minimize electric resistance supplemental heating will have the best cost performance, which is supported in the modeling outputs shown below. The cold climate heat pump is the most cost-effective all electric option and the most cost effective overall for Windsor, the mildest simulated location, where no supplemental electric resistance heating is used. In Windsor both all-electric heat pump configurations can maintain an annual COP greater than 3 and operate at a lower cost than the hybrid configurations. The hybrid heat pump with a high efficiency furnace is the most cost-effective option for all other simulated weather locations - Toronto, Ottawa, and Thunder Bay, which experience colder temperatures and have a higher heating load requiring more supplemental heating resulting in lower average heat pump performance.

Additional Considerations

In addition to thermal performance and operational cost there are several practical issues that must be considered when electrifying existing fossil fuel HVAC systems. Additional infrastructure updates may also be required within the home, and the costs associated with addressing any of these issues can vary widely based on existing conditions and should be considered for all electrification endeavors.

[8] Costs shown in results tables reflect consumption-based costs and do not include monthly fixed costs. It is assumed that gas and electric service will remain in use at all sites for all system configurations.

Homeowner Considerations

- **Cost & Equipment Life:** First costs for a whole home heat pump system can range from CAD $10,000-$20,000[9]. and are typically two to four times as expensive as a conventional furnace. The expected equipment lifetime for heat pumps (15 years) is also shorter than traditional furnaces (20 years).[10]

- **Electric service**: The electric service to the home must be able to accommodate the additional load of an all-electric heating system. Many existing homes have 60–100 amp service, which will not be able to support electric heating, especially if other end-uses such as domestic hot water or cooking ranges are also being converted to electric. Upgrading service capacity to 200 amps will typically cost CAD $3,000-$5,000 and depending on the home vintage and existing conditions additional wiring upgrades beyond the electric panel may also be necessary. [9]

- **Existing HVAC infrastructure**: It is important to consider the distribution system effects when installing a heat pump with existing ductwork. The duct size, static pressure, duct leakage, duct location (conditioned vs unconditioned) should all be considered during system selection. For example, fossil fuel furnaces traditionally have a higher temperature rise than heat pumps, thus requiring smaller ductwork with less airflow than needed to run a heat pump. If the duct conditions are not properly accounted for the heat pump could have inadequate airflow resulting in thermal comfort and/or maintenance issues.

Utility Considerations

- **Peak demand period:** Typically, electric utilities experience peak demand during summer months driven by HVAC cooling operation. Electric heat pumps in cold climates often have a higher heating capacity than cooling capacity and subsequently have a higher peak demand when operating in heating mode compared to cooling. This can shift the peak demand period from the summer to the winter when fossil fuel heating equipment is replaced with electric heat pumps. Conversely, the installation of new high performance heat pump equipment will likely reduce summer peak demand due to increased equipment efficiency compared to existing cooling equipment.

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[9] https://www.electricity.ca/knowledge-centre/journal/we-are-so-close-to-affording-zero-carbon-electric-home-heating/
[10] https://remdb.nrel.gov/about.php

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Table 3 shows the annual peak hourly electric demand (kW) for each system configuration.

Table 3: Max Annual Electric Peak kW (Compressor and Supplemental Heating)

	Max Operational kW (Compressor and Auxiliary)				
	Scenario	**Toronto**	**Ottawa**	**Windsor**	**Thunder Bay**
New Furnace (Fan Only)	Small 30,000 Btuh (2.5 Tons)	0.2	0.2	0.2	0.2
	Medium 48,000 Btuh (4 Tons)	0.4	0.4	0.4	0.4
	Large 60,000 Btuh (5 Tons)	0.4	0.4	0.4	0.4
Hybrid Heating Heat Pump Coil with Existing Furnace	Small 30,000 Btuh (2.5 Tons)	2.2	2.2	2.2	2.1
	Medium 48,000 Btuh (4 Tons)	3.8	3.6	4.0	3.8
	Large 60,000 Btuh (5 Tons)	4.7	4.6	5.0	4.1
Hybrid Heating Heat Pump Coil with New Furnace	Small 30,000 Btuh (2.5 Tons)	2.4	2.4	2.4	1.6
	Medium 48,000 Btuh (4 Tons)	4.0	3.2	4.2	4.0
	Large 60,000 Btuh (5 Tons)	4.1	4.0	5.2	3.3
Cold Climate Heat Pump	Small 30,000 Btuh (2.5 Tons)	4.4	8.6	3.7	8.6
	Medium 48,000 Btuh (4 Tons)	7.2	13.7	6.0	7.2
	Large 60,000 Btuh (5 Tons)	9.1	17.1	7.5	17.1
Non-Cold Climate Heat Pump	Small 30,000 Btuh (2.5 Tons)	8.0	8.6	5.1	8.6
	Medium 48,000 Btuh (4 Tons)	12.9	13.7	8.2	12.9
	Large 60,000 Btuh (5 Tons)	16.1	17.1	10.2	17.1

Table 4 shows the peak hourly electric demand during the utility peak period defined as 7am – 9am Monday through Friday. Note the values in Table 4 are slightly smaller than Table 3 as the annual system peak demand does not always fall within the utility peak demand period.

Table 4: Max Peak Period kW (Compressor and Supplemental Heating)

	Max Peak Period kW (Compressor and Auxiliary)				
	Scenario	**Toronto**	**Ottawa**	**Windsor**	**Thunder Bay**
New Furnace (Fan Only)	Small 30,000 Btuh (2.5 Tons)	0.2	0.2	0.2	0.2
	Medium 48,000 Btuh (4 Tons)	0.4	0.4	0.4	0.4
	Large 60,000 Btuh (5 Tons)	0.4	0.4	0.4	0.4
Hybrid Heating Heat Pump Coil with Existing Furnace	Small 30,000 Btuh (2.5 Tons)	2.1	2.1	2.2	1.8
	Medium 48,000 Btuh (4 Tons)	3.8	3.6	3.9	3.8
	Large 60,000 Btuh (5 Tons)	4.7	4.5	4.9	3.7
Hybrid Heating Heat Pump Coil with New Furnace	Small 30,000 Btuh (2.5 Tons)	2.3	1.8	2.3	1.5
	Medium 48,000 Btuh (4 Tons)	3.0	2.9	3.1	3.0
	Large 60,000 Btuh (5 Tons)	3.7	3.6	5.2	2.9
Cold Climate Heat Pump	Small 30,000 Btuh (2.5 Tons)	3.9	8.5	2.5	7.6
	Medium 48,000 Btuh (4 Tons)	6.2	13.5	4.0	6.2
	Large 60,000 Btuh (5 Tons)	7.7	16.9	5.0	15.3
Non-Cold Climate Heat Pump	Small 30,000 Btuh (2.5 Tons)	6.2	8.5	3.1	7.6
	Medium 48,000 Btuh (4 Tons)	9.9	13.5	4.9	9.9
	Large 60,000 Btuh (5 Tons)	12.4	16.9	6.1	15.3

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Table 5 and Table 6 include performance summaries for annual cost and carbon emissions. Tables 7 through 18 include the summary outputs for each system configuration and load size at each weather location.

Table 5: Total Cost Savings by System Configuration and Location

Scenario		Annual Heating Operational Cost ($) Toronto	Ottawa	Windsor	Thunder Bay	Annual Heating Cost Savings ($) Toronto	Ottawa	Windsor	Thunder Bay
Baseline: Code 95% Furnace	Small (2.5 Tons)	$484	$565	$483	$623				
	Medium (4 Tons)	$775	$904	$772	$997				
	Large (5 Tons)	$969	$1,130	$965	$1,246				
Hybrid Heating Heat Pump Coil with Existing Furnace	Small (2.5 Tons)	$396	$484	$379	$549	$88	$81	$104	$74
	Medium (4 Tons)	$632	$774	$602	$878	$143	$130	$170	$118
	Large (5 Tons)	$790	$967	$751	$1,098	$179	$163	$214	$148
Hybrid Heating Heat Pump Coil with New Furnace	Small (2.5 Tons)	$361	$445	$343	$511	**$124**	**$120**	$140	**$112**
	Medium (4 Tons)	$577	$712	$548	$818	**$198**	**$192**	$225	**$178**
	Large (5 Tons)	$721	$890	$685	$1,022	**$248**	**$240**	$281	**$224**
Cold Climate Heat Pump	Small (2.5 Tons)	$371	$486	$335	$607	$114	$79	**$148**	$16
	Medium (4 Tons)	$594	$779	$535	$973	$181	$125	**$237**	$24
	Large (5 Tons)	$743	$974	$669	$1,217	$226	$156	**$296**	$29
Non-Cold Climate Heat Pump	Small (2.5 Tons)	$386	$562	$339	$745	$98	$3	$143	-$122
	Medium (4 Tons)	$618	$900	$543	$1,192	$157	$4	$229	-$195
	Large (5 Tons)	$773	$1,125	$679	$1,490	$196	$5	$287	-$244

Greatest Savings for 2.5 Ton Load
Greatest Savings for 4 Ton Load
Greatest Savings for 5 Ton Load

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Table 6: Total Emissions and Total Emissions Savings by System Configuration and Location

		Annual Heating Emissions (kgCO2e)					Annual Heating Emissions Savings (kgCO2e)			
	Scenario	Toronto	Ottawa	Windsor	Thunder Bay		Toronto	Ottawa	Windsor	Thunder Bay
Baseline: Code 95% Furnace	Small (2.5 Tons)	2,033	2,370	2,026	2,613					
	Medium (4 Tons)	3,253	3,792	3,242	4,181					
	Large (5 Tons)	4,066	4,739	4,052	5,226					
Hybrid Heating Heat Pump Coil with Existing Furnace	Small (2.5 Tons)	1,253	1,646	1,138	2,022		780	724	888	590
	Medium (4 Tons)	1,990	2,628	1,768	3,235		1263	1164	1474	945
	Large (5 Tons)	2,486	3,284	2,197	4,044		1580	1456	1856	1182
Hybrid Heating Heat Pump Coil with New Furnace	Small (2.5 Tons)	1,140	1,519	999	1,889		893	851	1028	723
	Medium (4 Tons)	1,823	2,429	1,591	3,023		1430	1362	1651	1158
	Large (5 Tons)	2,279	3,037	1,987	3,779		1788	1703	2065	1447
Cold Climate Heat Pump	Small (2.5 Tons)	1,018	1,321	918	1,652		**1016**	**1049**	**1108**	**961**
	Medium (4 Tons)	1,630	2,117	1,469	2,649		**1623**	**1674**	**1772**	**1531**
	Large (5 Tons)	2,038	2,649	1,837	3,314		**2028**	**2090**	**2216**	**1912**
Non-Cold Climate Heat Pump	Small (2.5 Tons)	1,060	1,528	932	2,029		973	842	1095	584
	Medium (4 Tons)	1,697	2,444	1,491	3,246		1557	1347	1751	935
	Large (5 Tons)	2,121	3,055	1,863	4,057		1946	1684	2189	1168

Greatest Savings for 2.5 Ton Load (green)
Greatest Savings for 4 Ton Load (blue)
Greatest Savings for 5 Ton Load (orange)

Table 7: Results Table for Toronto with a 2.5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions (kgCO$_2$e)
Baseline: Code 95% Furnace	**Furnace Fan**				30	263		0.2	82
	New 95% AFUE Furnace	4,798	33,658,351	100%	454	1,010	0.95	0.9	1,951
	Total				484				2,033
Hybrid Heating Heat Pump Coil with Existing Furnace	**Heat Pump**	4,370	26,917,219	80%	300	2,624	3.0	2.2	839
	Backup Furnace	429	6,741,133	20%	96	214	0.9	0.9	414
	Total	4,799	33,658,351	100%	396				1,253
Hybrid Heating Heat Pump Coil with New Furnace	**Heat Pump**	4,390	27,273,455	81%	274	2,405	3.3	2.4	769
	Backup Furnace	409	6,384,897	19%	87	192	0.95	0.9	371
	Total	4,799	33,658,351	100%	361				1,140
Cold Climate Heat Pump	**Heat Pump**	4,799	33,658,351	100%	371	3,243	3.0	4.4	
	Supplemental Electric Resistance	0	0	0%	0	0	1.0	0.0	1,018
	Total	4,799	33,658,351	100%	371	3,243	3.0	4.4	
Non-Cold Climate Heat Pump	**Heat Pump**	4,732	33,139,994	98%	369	3,226	3.0	2.9	
	Supplemental Electric Resistance	67	518,357	2%	17	152	1.0	7.8	1,060
	Total	4,799	33,658,351	100%	386	3,378	2.9	8.0	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature potentially resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 8: Results Table for Toronto with a 4 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	**Furnace Fan**				48	421		0.4	132
	New 95% AFUE Furnace	4,798	53,853,362	100%	727	1,616	0.95	1.4	3,121
	Total				775				3,253
Hybrid Heating Heat Pump Coil with Existing Furnace	**Heat Pump**	4,387	43,543,204	81%	485	4,250	3.0	3.8	1,357
	Backup Furnace	412	10,310,158	19%	147	328	0.9	1.4	633
	Total	4,799	53,853,362	100%	632				1,990
Hybrid Heating Heat Pump Coil with New Furnace	**Heat Pump**	4,391	43,668,680	81%	439	3,850	3.3	4.0	1,231
	Backup Furnace	408	10,184,682	19%	138	307	0.95	1.4	592
	Total	4,799	53,853,362	100%	577				1,823
Cold Climate Heat Pump	**Heat Pump**	4,798	53,852,168	100%	594	5,194	3.0	6.8	
	Supplemental Electric Resistance	1	1,194	0%	0	0	1.0	0.3	1,630
	Total	4,799	53,853,362	100%	594	5,195	3.0	7.2	
Non-Cold Climate Heat Pump	**Heat Pump**	4,732	53,023,991	98%	591	5,162	3.0	4.6	
	Supplemental Electric Resistance	67	829,372	2%	28	243	1.0	12.5	1,697
	Total	4,799	53,853,362	100%	618	5,405	2.9	12.9	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 9: Results Table for Toronto with a 5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	**Furnace Fan**				60	526		0.4	165
	New 95% AFUE Furnace	4,798	67,316,703	100%	909	2,020	0.95	1.7	3,902
	Total				969				4,066
Hybrid Heating Heat Pump Coil with Existing Furnace	**Heat Pump**	4,387	54,429,005	81%	607	5,310	3.0	4.7	1,695
	Backup Furnace	412	12,887,698	19%	184	409	0.9	1.8	791
	Total	4,799	67,316,703	100%	790				2,486
Hybrid Heating Heat Pump Coil with New Furnace	**Heat Pump**	4,391	54,585,850	81%	549	4,811	3.3	4.1	1,538
	Backup Furnace	408	12,730,853	19%	173	383	0.95	1.7	740
	Total	4,799	67,316,703	100%	721				2,279
Cold Climate Heat Pump	**Heat Pump**	4,798	67,314,055	100%	743	6,495	3.0	8.4	
	Supplemental Electric Resistance	1	2,648	0%	0	1	1.0	0.8	2,038
	Total	4,799	67,316,703	100%	743	6,496	3.0	9.1	
Non-Cold Climate Heat Pump	**Heat Pump**	4,732	66,279,988	98%	738	6,452	3.0	5.7	
	Supplemental Electric Resistance	67	1,036,715	2%	35	304	1.0	15.7	2,121
	Total	4,799	67,316,703	100%	773	6,756	2.9	16.1	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 10: Results Table for Ottawa with a 2.5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions (kgCO_2e)
Baseline: Code 95% Furnace	**Furnace Fan**				35	306		0.2	96
	New 95% AFUE Furnace	5,089	39,230,702	100%	530	1,177	0.95	0.9	2,274
	Total				565				2,370
Hybrid Heating Heat Pump Coil with Existing Furnace	**Heat Pump**	4,229	26,119,299	67%	298	2,598	2.9	2.2	842
	Backup Furnace	861	13,111,402	33%	186	416	0.9	0.9	803
	Total	5,090	39,230,702	100%	484				1,646
Hybrid Heating Heat Pump Coil with New Furnace	**Heat Pump**	4,233	26,190,562	67%	268	2,341	3.3	2.4	762
	Backup Furnace	857	13,040,140	33%	176	392	0.95	0.9	757
	Total	5,090	39,230,702	100%	445				1,519
Cold Climate Heat Pump	**Heat Pump**	5,064	38,991,748	99%	477	4,142	2.8	4.3	
	Supplemental Electric Resistance	26	238,953	1%	9	70	1.0	8.3	1,321
	Total	5,090	39,230,702	100%	486	4,212	2.7	8.6	
Non-Cold Climate Heat Pump	**Heat Pump**	4,825	34,804,326	89%	406	3,537	2.9	2.9	
	Supplemental Electric Resistance	265	4,426,376	11%	157	1,297	1.0	8.3	1,528
	Total	5,090	39,230,702	100%	562	4,834	2.4	8.6	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 11: Results Table for Ottawa with a 4 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	Furnace Fan	5,089	62,769,123	100%	56	490	0.95	0.4	153
	New 95% AFUE Furnace				848	1,883		1.4	3,638
	Total				904				3,792
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,232	41,873,877	67%	477	4,157	3.0	3.6	1,347
	Backup Furnace	858	20,895,245	33%	297	663	0.9	1.4	1,280
	Total	5,090	62,769,123	100%	774				2,628
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,233	41,904,899	67%	430	3,744	3.3	3.2	1,218
	Backup Furnace	857	20,864,223	33%	282	627	0.95	1.4	1,211
	Total	5,090	62,769,123	100%	712				2,429
Cold Climate Heat Pump	Heat Pump	5,061	62,343,809	99%	762	6,625	2.8	6.6	2,117
	Supplemental Electric Resistance	29	425,314	1%	16	125	1.0	13.4	
	Total	5,090	62,769,123	100%	779	6,750	2.7	13.7	
Non-Cold Climate Heat Pump	Heat Pump	4,825	55,686,921	89%	649	5,660	2.9	4.6	2,444
	Supplemental Electric Resistance	265	7,082,202	11%	251	2,074	1.0	13.4	
	Total	5,090	62,769,123	100%	900	7,734	2.4	13.7	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 12: Results Table for Ottawa with a 5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	Furnace Fan	5,089	78,461,403	100%	70	613	0.95	0.4	192
	New 95% AFUE Furnace				1,059	2,354		1.7	4,548
	Total				1,130				4,739
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,232	52,342,346	67%	595	5,192	3.0	4.6	1,683
	Backup Furnace	858	26,119,057	33%	371	828	0.9	1.8	1,600
	Total	5,090	78,461,403	100%	967				3,284
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,233	52,381,124	67%	537	4,680	3.3	4.0	1,523
	Backup Furnace	857	26,080,279	33%	353	784	0.95	1.7	1,514
	Total	5,090	78,461,403	100%	890				3,037
Cold Climate Heat Pump	Heat Pump	5,057	77,908,019	99%	953	8,283	2.8	8.2	2,649
	Supplemental Electric Resistance	33	553,384	1%	21	162	1.0	16.7	
	Total	5,090	78,461,403	100%	974	8,445	2.7	17.1	
Non-Cold Climate Heat Pump	Heat Pump	4,825	69,608,651	89%	811	7,074	2.9	5.7	3,055
	Supplemental Electric Resistance	265	8,852,752	11%	314	2,593	1.0	16.7	
	Total	5,090	78,461,403	100%	1,125	9,668	2.4	17.1	

***The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 13: Results Table for Windsor with a 2.5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions (kgCO₂e)
Baseline: Code 95% Furnace	Furnace Fan	4,797	33,541,597	100%	30	262	0.95	0.2	82
	New 95% AFUE Furnace				453	1,006		0.9	1,944
	Total				483				2,026
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,578	30,413,997	91%	324	2,830	3.1	2.2	899
	Backup Furnace	220	3,127,601	9%	55	123	0.9	0.9	238
	Total	4,798	33,541,597	100%	379				1,138
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,649	31,773,851	95%	309	2,693	3.5	2.4	852
	Backup Furnace	149	1,767,746	5%	34	76	0.95	0.9	147
	Total	4,798	33,541,597	100%	343				999
Cold Climate Heat Pump	Heat Pump	4,798	33,541,597	100%	335	2,925	3.4	3.7	918
	Supplemental Electric Resistance	0	0	0%	0	0	1.0	0.0	
	Total	4,798	33,541,597	100%	335	2,925	3.4	3.7	
Non-Cold Climate Heat Pump	Heat Pump	4,786	33,492,949	100%	338	2,954	3.3	2.9	932
	Supplemental Electric Resistance	12	48,648	0%	1	14	1.0	2.2	
	Total	4,798	33,541,597	100%	339	2,968	3.3	5.1	

***The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 14: Results Table for Windsor with a 4 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	Furnace Fan	4,797	53,666,556	100%	48	419	0.95	0.4	131
	New 95% AFUE Furnace				724	1,610		1.4	3,111
	Total				772				3,242
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,634	50,349,445	94%	538	4,712	3.1	4.0	1,490
	Backup Furnace	164	3,317,111	6%	65	144	0.9	1.4	278
	Total	4,798	53,666,556	100%	602				1,768
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,653	50,982,158	95%	495	4,315	3.5	4.2	1,364
	Backup Furnace	145	2,684,397	5%	53	117	0.95	1.4	227
	Total	4,798	53,666,556	100%	548				1,591
Cold Climate Heat Pump	Heat Pump	4,798	53,666,556	100%	535	4,680	3.4	6.0	1,469
	Supplemental Electric Resistance	0	0	0%	0	0	1.0	0.0	
	Total	4,798	53,666,556	100%	535	4,680	3.4	6.0	
Non-Cold Climate Heat Pump	Heat Pump	4,786	53,588,719	100%	541	4,727	3.3	4.6	1,491
	Supplemental Electric Resistance	12	77,837	0%	2	23	1.0	3.6	
	Total	4,798	53,666,556	100%	543	4,749	3.3	8.2	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 15: Results Table for Windsor with a 5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions (kgCO₂e)
Baseline: Code 95% Furnace	Furnace Fan	4,797	67,083,195	100%	60	524	0.95	0.4	164
	New 95% AFUE Furnace				906	2,012		1.7	3,888
	Total				965				4,052
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,643	63,311,433	94%	676	5,922	3.1	5.0	1,872
	Backup Furnace	155	3,771,762	6%	75	168	0.9	1.8	325
	Total	4,798	67,083,195	100%	751				2,197
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,654	63,780,830	95%	620	5,398	3.5	5.2	1,707
	Backup Furnace	144	3,302,365	5%	65	145	0.95	1.7	280
	Total	4,798	67,083,195	100%	685				1,987
Cold Climate Heat Pump	Heat Pump	4,798	67,083,195	100%	669	5,850	3.4	7.5	1,837
	Supplemental Electric Resistance	0	0	0%	0	0	1.0	0.0	
	Total	4,798	67,083,195	100%	669	5,850	3.4	7.5	
Non-Cold Climate Heat Pump	Heat Pump	4,786	66,985,899	100%	676	5,908	3.3	5.7	1,863
	Supplemental Electric Resistance	12	97,296	0%	3	28	1.0	4.4	
	Total	4,798	67,083,195	100%	679	5,937	3.3	10.2	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 16: Results Table for Thunder Bay with a 2.5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	Furnace Fan	5,720	43,257,475	100%	39	338	0.95	0.2	106
	New 95% AFUE Furnace				584	1,298		0.9	2,507
	Total				623				2,613
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,283	22,079,462	51%	249	2,176	3.0	2.1	727
	Backup Furnace	1,437	21,178,013	49%	301	671	0.9	0.9	1,296
	Total	5,720	43,257,475	100%	549				2,022
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,283	22,079,462	51%	225	1,967	3.3	1.6	662
	Backup Furnace	1,437	21,178,013	49%	286	635	0.95	0.9	1,228
	Total	5,720	43,257,475	100%	511				1,889
Cold Climate Heat Pump	Heat Pump	5,624	41,583,103	96%	551	4,774	2.6	4.3	1,652
	Supplemental Electric Resistance	97	1,674,372	4%	56	490	1.0	8.3	
	Total	5,721	43,257,475	100%	607	5,265	2.4	8.6	
Non-Cold Climate Heat Pump	Heat Pump	5,164	33,597,886	78%	412	3,572	2.8	2.8	2,029
	Supplemental Electric Resistance	556	9,659,590	22%	333	2,829	1.0	8.3	
	Total	5,720	43,257,475	100%	745	6,402	2.0	8.6	

*The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 17: Results Table for Thunder Bay with a 4 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	Furnace Fan	5,720	69,211,961	100%	62	541	0.95	0.4	169
	New 95% AFUE Furnace				935	2,076		1.4	4,012
	Total				997				4,181
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,283	35,327,139	51%	397	3,478	3.0	3.3	1,162
	Backup Furnace	1,437	33,884,821	49%	481	1,073	0.9	1.4	2,073
	Total	5,720	69,211,961	100%	878				3,235
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,283	35,327,139	51%	360	3,147	3.3	2.6	1,059
	Backup Furnace	1,437	33,884,821	49%	458	1,017	0.95	1.4	1,964
	Total	5,720	69,211,961	100%	818				3,023
Cold Climate Heat Pump	Heat Pump	5,613	66,464,849	96%	881	7,636	2.6	6.9	2,649
	Supplemental Electric Resistance	108	2,747,112	4%	92	805	1.0	13.4	
	Total	5,721	69,211,961	100%	973	8,441	2.4	13.7	
Non-Cold Climate Heat Pump	Heat Pump	5,164	53,756,617	78%	660	5,716	2.8	4.5	3,246
	Supplemental Electric Resistance	556	15,455,343	22%	532	4,527	1.0	13.4	
	Total	5,720	69,211,961	100%	1,192	10,243	2.0	13.7	

*The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

Table 18: Results Table for Thunder Bay with a 5 Ton Heating Load

Scenario	System	Heating Hours	Annual Heating Load (Btu)	Percent of Total Load	Total Annual Cost $	Annual Consumption (kWh or m3)	Annual Efficiency (COP or AFUE)	Operational Peak Demand (kW or m3/hr)*	Total Emissions ($kgCO_2e$)
Baseline: Code 95% Furnace	Furnace Fan	5,720	86,514,951	100%	78	676	0.95	0.4	211
	New 95% AFUE Furnace				1,168	2,595		1.7	5,014
	Total				1,246				5,226
Hybrid Heating Heat Pump Coil with Existing Furnace	Heat Pump	4,283	44,158,924	51%	497	4,347	3.0	4.1	1,452
	Backup Furnace	1,437	42,356,027	49%	601	1,341	0.9	1.8	2,591
	Total	5,720	86,514,951	100%	1,098				4,044
Hybrid Heating Heat Pump Coil with New Furnace	Heat Pump	4,283	44,158,924	51%	450	3,934	3.3	3.3	1,324
	Backup Furnace	1,437	42,356,027	49%	572	1,271	0.95	1.7	2,455
	Total	5,720	86,514,951	100%	1,022				3,779
Cold Climate Heat Pump	Heat Pump	5,608	83,045,026	96%	1,101	9,542	2.6	8.6	3,314
	Supplemental Electric Resistance	113	3,469,925	4%	116	1,016	1.0	16.7	
	Total	5,721	86,514,951	100%	1,217	10,559	2.4	17.1	
Non-Cold Climate Heat Pump	Heat Pump	5,164	67,195,772	78%	824	7,145	2.8	5.6	4,057
	Supplemental Electric Resistance	556	19,319,179	22%	666	5,659	1.0	16.7	
	Total	5,720	86,514,951	100%	1,490	12,804	2.0	17.1	

*****The operational peak demand values for the heat pump and supplemental heating are non-coincident and do not occur at the same time. Instead, they reflect their respective maximum peak hourly demand values throughout the year. The heat pump cannot operate below its lockout temperature resulting in periods of operation where supplemental heating satisfies the entire load. Supplemental heating peak demand does not include fan power while the total peak demand does.

PLACEHOLDER

This page is intentionally left blank. This Attachment has been provided in Excel format only. Please see Exhibit I.ED.16, Attachment 3.xlsx on the OEB's RDS.

From: Gerry Dennis <Gerry.Dennis@enbridge.com>
Sent: Tuesday, May 9, 2023 4:09:29 PM
Cc: Octavian Ghiricociu <Octavian.Ghiricociu@enbridge.com>
Subject: HVAC Contractor Survey

Good afternoon,
Enbridge Gas is seeking information to support the Company's understanding of the all-in upfront costs required for homes to convert to natural gas heating or electric cold climate air source heat pumps (ccASHPs). The purpose for the analysis is to determine conversion costs to ccASHPs (for the purpose of converting the homes to all-electric configurations) or to natural gas heating.

Please see the questions below and let us know if you have any questions. Some assumptions to help guide your responses are as follows:

- Assume the home has existing forced air heating (either oil, propane or electric furnace)
- For question #1 & #2, assume the home is converting to a natural gas furnace.
- For question #3 & #4 assume the home is converting to an all-electric heating system with a centrally ducted heat pump and air handler. The air handler should to be properly sized with the required electricity resistance backup.

Questions: Please provide typical all-in retail costs (installation and equipment) for products your company sells.

1. Natural gas furnace (95% AFUE)
    a. Installed cost for a natural gas furnace: Low end $____________ / High end $___________

2. Please identify and list any additional costs that may be required to convert homes to a gas furnace (95% AFUE) from oil, propane or electric furnace:________
    a. Additional costs: Low end $____________ / High end $___________

3. ccASHP with air handler and electric resistance backup
    a. Installed cost for the heat pump (equipment including A-coil and installation): Low end $_________ / High End $_________
    b. Installed cost for the air handler, including electric resistance heating required to meet design conditions (installation and equipment): Low end $_________ / High End $_________

4. Please identify any additional costs that may be required to convert homes to an all-electric heating system from oil, propane or electric furnace.
    a. Panel upgrade: Low end $_________ / High End $_________
    b. Utility service upgrades (i.e. 200A service): Low end $_________ / High End $_________
    c. Wiring or other costs inside the home: Low End $________ / High End $__________
    d. Any additional costs required for the conversion – please identify what these items are:_______________
        i. Additional costs: Low end $____________ / High end $___________

Trusting you are able to provide feedback to the above, and if so kindly respond by May 15th or sooner.

Best regards,

Gerry Dennis
647-515-7803

	Overall Results		HVAC Contractor 1			HVAC Contractor 2			HVAC Contractor 3			HVAC Contractor 4			HVAC Contractor 5		
	Low End	High End	Low End	High End	Comments	Low End	High End	Comments	Low End	High End	Comments	Low End	High End	Comments	Low End	High End	Comments
Natural gas furnace (95% AFUE)																	
a. Installed cost for a natural gas furnace: Low end $/ High end $	$ 3,390	$ 8,000	$ 3,390	$ 6,990		$ 4,200	$ 5,000		$ 4,500	$ 8,000		$ 3,600	$ 7,625		$ 4,200	$ 6,800	
Please identify and list any additional costs that may be required to convert homes to a gas furnace (95% AFUE) from oil, propane or electric furnace:																	
a. Additional costs: Low end $ / High end $	$ 500	$ 3,500	$ 500	$ 1,500	gas piping, electrical upgrades	$ 1,500	$ 3,500		$ 1,750	$ 3,000		$ 750	$ 2,000	Oil Pump Out, Oil Recycling, Duct Modifications, Gas Line up sizing	$ 700	$ 1,500	Gas line from new service and 120 volt circuit with breaker for furnace if switching from electric
ccASHP with air handler and electric resistance backup																	
a. Installed cost for the heat pump (equipment including A-coil and installation): Low end $/ High End $	$ 6,000	$ 20,000	$ 6,690	$ 20,000		$ 6,500	$ 9,500		$ 6,000	$ 12,000		$ 7,500	$ 12,500		$ 10,800	$ 11,600	
b. Installed cost for the air handler, including electric resistance heating required to meet design conditions (installation and equipment): Low end $ / High End $	$ 3,000	$ 12,500	$ 3,390	$ 7,990		$ 3,800	$ 5,200		$ 6,000	$ 12,000		$ 6,000	$ 12,500		$ 3,000	$ 5,000	
Please identify any additional costs that may be required to convert homes to an all-electric heating system from oil, propane or electric furnace.																	
a. Panel upgrade: Low end $ / High End $	$ 500	$ 4,000	$ 500	$ 2,500		$ 1,800	$ 4,000					$ 500	$ 2,500		$ 1,200	$ 1,800	
b. Utility service upgrades (i.e. 200A service): Low end $ / High End $	$ 1,000	$ 10,000				$ 6,500	$ 10,000					$ 1,000	$ 8,000	Dig Lines underground from pole, etc...)	$ 4,000	$ 6,000	
c. Wiring or other costs inside the home: Low End $ / High End $	$ 250	$ 1,500				$ 250	$ 1,500					$ 300	$ 1,000		$ 500	$ 1,000	
d. Any additional costs required for the conversion – please identify what these items are:																	
i. Additional costs: Low end $ / High end $	$ 650	$ 2,500							$ 750	$ 2,500	duck work and tank removal	$ 650	$ 2,000	Heat Loss/Gain, LP, Gas, or oil Removal			Oil tank removal, underground electrical service or recessed meter requiring upgrading, distance between the panel and the air handler

<u>OVERALL</u>		
Gas Furnace	**$ 3,890**	**$ 11,500**
Heat Pump	**$ 11,400**	**$ 50,500**
Incremental	**$ 7,510**	**$ 39,000**
Incentive	**$ 5,000**	**$ -**
	$ 2,510	**$ 39,000**

Rates effective 4/1/2023

		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Annual Volume (m^3)	
Monthly Customer Charge	$/year	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	$287.76	1007	11071.28
Delivery Charge per m3																	973	10434.07
First 100	cents/m^3	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	10.9965	220	2259.43
Next 200	cents/m^3	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	10.7192	2,200	10.8022
Next 200	cents/m^3	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795	10.2795		
Next 500	cents/m^3	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762	9.8762		
Over 1000	cents/m^3	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426	9.5426		
Delivery - Price Adjustment	cents/m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Commodity and Fuel	cents/m^3	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078	15.9078		
Commodity and Fuel - Price Adjustment	cents/m^3	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249	6.8249		
Transportation	cents/m^3	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945	2.0945		
Transportation - Price Adjustment	cents/m^3	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276	-0.1276		
Storage Service	cents/m^3	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158	6.1158		
Storage - Price Adjustment	cents/m^3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Federal Carbon Charge	cents/m^3	12.39	15.25	18.11	20.97	23.83	26.69	29.54	32.4	32.4	32.4	32.4	32.4	32.4	32.4	32.4		
Facility Carbon Charge	cents/m^3	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162	0.0162		
SES	cents/m^3	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23		
Typical Residential Customer	cents/m^3	67.10	69.96	72.82	75.68	78.54	81.40	84.25	87.11	87.11	87.11	87.11	87.11	87.11	87.11	87.11		
Typical Residential Customer incl. SES	cents/m^3	90.10	92.96	95.82	98.68	101.54	104.40	107.25	110.11	110.11	110.11	110.11	110.11	110.11	110.11	110.11		

Common inputs	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Carbon Tax ($/ton)	$65	$80	$95	$110	$125	$140	$155	$170	$170	$170	$170	$170	$170	$170	$170
$/m3	$0.901	$0.930	$0.958	$0.987	$1.015	$1.044	$1.073	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101
Prices ($/kWh)	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113
Discount Rate:	4%														

Assume that year 1 is 2023 and that full year savings accrue for installed year

Scenario 1 — **Toronto** — **Cold Climate Heat Pump** — **2.5 Tons**

Discount Rate 4%

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
Cost	$ (2,510)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost savings	$ 602	$ 631	$ 660	$ 689	$ 718	$ 747	$ 776	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804
Total	$ (1,908)	$ 631	$ 660	$ 689	$ 718	$ 747	$ 776	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804
PV	$ (1,908)	$ 607	$ 610	$ 613	$ 614	$ 614	$ 613	$ 611	$ 588	$ 565	$ 543	$ 523	$ 502	$ 483	$ 465
NPV	$ 6,043														

Scenario 2 — **Toronto** — **Cold Climate Heat Pump** — **4 Tons**

Discount Rate 4%

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
Cost	$ (2,510)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost savings	$ 963	$ 1,009	$ 1,055	$ 1,102	$ 1,148	$ 1,194	$ 1,240	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286
Total	$ (1,547)	$ 1,009	$ 1,055	$ 1,102	$ 1,148	$ 1,194	$ 1,240	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286
PV	$ (1,547)	$ 970	$ 976	$ 979	$ 981	$ 981	$ 980	$ 978	$ 940	$ 904	$ 869	$ 836	$ 803	$ 773	$ 743
NPV	$ 11,166														

Scenario 3 — **Toronto** — **Cold Climate Heat Pump** — **5 Tons**

Discount Rate 4%

Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
Cost	$ (2,510)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost savings	$ 1,203	$ 1,261	$ 1,319	$ 1,377	$ 1,435	$ 1,492	$ 1,550	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608
Total	$ (1,307)	$ 1,261	$ 1,319	$ 1,377	$ 1,435	$ 1,492	$ 1,550	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608
PV	$ (1,307)	$ 1,213	$ 1,220	$ 1,224	$ 1,226	$ 1,227	$ 1,225	$ 1,222	$ 1,175	$ 1,130	$ 1,086	$ 1,044	$ 1,004	$ 966	$ 928
NPV	$ 14,582														

Common inputs		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
	Carbon Tax ($/ton)	$65	$80	$95	$110	$125	$140	$155	$170	$170	$170	$170	$170	$170	$170	$170
	$/m3	$0.901	$0.930	$0.958	$0.987	$1.015	$1.044	$1.073	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101
	Prices ($/kWh)	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113
	Discount Rate:	4%														

Assume that year 1 is 2023 and that full year savings accrue for installed year

	Toronto	**Cold Climate Heat Pump**	**2.5 Tons**													
	Discount Rate	4%														
	Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario 1	**Discount factor**		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
	Cost	$ (39,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Cost savings	$ 602	$ 631	$ 660	$ 689	$ 718	$ 747	$ 776	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804
	Total	$ (38,398)	$ 631	$ 660	$ 689	$ 718	$ 747	$ 776	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804	$ 804
	PV	$ (38,398)	$ 607	$ 610	$ 613	$ 614	$ 614	$ 613	$ 611	$ 588	$ 565	$ 543	$ 523	$ 502	$ 483	$ 465
	NPV	$ (30,447)														

	Toronto	**Cold Climate Heat Pump**	**4 Tons**													
	Discount Rate		4%													
	Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario 2	**Discount factor**		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
	Cost	$ (39,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Cost savings	$ 963	$ 1,009	$ 1,055	$ 1,102	$ 1,148	$ 1,194	$ 1,240	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286
	Total	$ (38,037)	$ 1,009	$ 1,055	$ 1,102	$ 1,148	$ 1,194	$ 1,240	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286	$ 1,286
	PV	$ (38,037)	$ 970	$ 976	$ 979	$ 981	$ 981	$ 980	$ 978	$ 940	$ 904	$ 869	$ 836	$ 803	$ 773	$ 743
	NPV	$ (25,324)														

	Toronto	**Cold Climate Heat Pump**	**5 Tons**													
	Discount Rate		4%													
	Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario 3	**Discount factor**		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
	Cost	$ (39,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Cost savings	$ 1,203	$ 1,261	$ 1,319	$ 1,377	$ 1,435	$ 1,492	$ 1,550	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608
	Total	$ (37,797)	$ 1,261	$ 1,319	$ 1,377	$ 1,435	$ 1,492	$ 1,550	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608	$ 1,608
	PV	$ (37,797)	$ 1,213	$ 1,220	$ 1,224	$ 1,226	$ 1,227	$ 1,225	$ 1,222	$ 1,175	$ 1,130	$ 1,086	$ 1,044	$ 1,004	$ 966	$ 928
	NPV	$ (21,908)														

Common inputs	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Carbon Tax ($/ton)	$65	$80	$95	$110	$125	$140	$155	$170	$170	$170	$170	$170	$170	$170	$170
$/m3	$0.901	$0.930	$0.958	$0.987	$1.015	$1.044	$1.073	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101
Prices ($/kWh)	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113
Discount Rate:	4%														

Assume that year 1 is 2023 and that full year savings accrue for installed year

Scenario 1

Ottawa	**Cold Climate Heat Pump**		**2.5 Tons**												
Discount Rate	4%														
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
Cost	$ (2,510)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost savings	$ 653	$ 687	$ 720	$ 754	$ 788	$ 821	$ 855	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888
Total	$ (1,857)	$ 687	$ 720	$ 754	$ 788	$ 821	$ 855	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888
PV	$ (1,857)	$ 660	$ 666	$ 670	$ 673	$ 675	$ 676	$ 675	$ 649	$ 624	$ 600	$ 577	$ 555	$ 534	$ 513
NPV	$ 6,890														

Scenario 2

Ottawa	**Cold Climate Heat Pump**		**4 Tons**												
Discount Rate		4%													
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
Cost	$ (2,510)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost savings	$ 1,043	$ 1,097	$ 1,151	$ 1,205	$ 1,259	$ 1,313	$ 1,366	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420
Total	$ (1,467)	$ 1,097	$ 1,151	$ 1,205	$ 1,259	$ 1,313	$ 1,366	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420
PV	$ (1,467)	$ 1,055	$ 1,064	$ 1,071	$ 1,076	$ 1,079	$ 1,080	$ 1,079	$ 1,038	$ 998	$ 959	$ 923	$ 887	$ 853	$ 820
NPV	$ 12,515														

Scenario 3

Ottawa	**Cold Climate Heat Pump**		**5 Tons**												
Discount Rate		4%													
Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
Cost	$ (2,510)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cost savings	$ 1,303	$ 1,371	$ 1,438	$ 1,505	$ 1,573	$ 1,640	$ 1,707	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774
Total	$ (1,207)	$ 1,371	$ 1,438	$ 1,505	$ 1,573	$ 1,640	$ 1,707	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774
PV	$ (1,207)	$ 1,318	$ 1,329	$ 1,338	$ 1,344	$ 1,348	$ 1,349	$ 1,348	$ 1,297	$ 1,247	$ 1,199	$ 1,153	$ 1,108	$ 1,066	$ 1,025
NPV	$ 16,261														

Common inputs		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
	Carbon Tax ($/ton)	$65	$80	$95	$110	$125	$140	$155	$170	$170	$170	$170	$170	$170	$170	$170
	$/m3	$0.901	$0.930	$0.958	$0.987	$1.015	$1.044	$1.073	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101	$1.101
	Prices ($/kWh)	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113	$0.113
	Discount Rate:	4%														

Assume that year 1 is 2023 and that full year savings accrue for installed year

	Ottawa	**Cold Climate Heat Pump**		**2.5 Tons**												
	Discount Rate	4%														
	Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
Scenario 1		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
	Cost	$ (39,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Cost savings	$ 653	$ 687	$ 720	$ 754	$ 788	$ 821	$ 855	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888
	Total	$ (38,347)	$ 687	$ 720	$ 754	$ 788	$ 821	$ 855	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888	$ 888
	PV	$ (38,347)	$ 660	$ 666	$ 670	$ 673	$ 675	$ 676	$ 675	$ 649	$ 624	$ 600	$ 577	$ 555	$ 534	$ 513
	NPV	$ (29,600)														

	Ottawa	**Cold Climate Heat Pump**		**4 Tons**												
	Discount Rate		4%													
	Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
Scenario 2		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
	Cost	$ (39,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Cost savings	$ 1,043	$ 1,097	$ 1,151	$ 1,205	$ 1,259	$ 1,313	$ 1,366	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420
	Total	$ (37,957)	$ 1,097	$ 1,151	$ 1,205	$ 1,259	$ 1,313	$ 1,366	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420	$ 1,420
	PV	$ (37,957)	$ 1,055	$ 1,064	$ 1,071	$ 1,076	$ 1,079	$ 1,080	$ 1,079	$ 1,038	$ 998	$ 959	$ 923	$ 887	$ 853	$ 820
	NPV	$ (23,975)														

	Ottawa	**Cold Climate Heat Pump**		**5 Tons**												
	Discount Rate		4%													
	Year	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**
Scenario 3		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Discount factor		0.96154	0.92456	0.889	0.8548	0.82193	0.79031	0.75992	0.73069	0.70259	0.67556	0.64958	0.6246	0.60057	0.57748
	Cost	$ (39,000)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Cost savings	$ 1,303	$ 1,371	$ 1,438	$ 1,505	$ 1,573	$ 1,640	$ 1,707	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774
	Total	$ (37,697)	$ 1,371	$ 1,438	$ 1,505	$ 1,573	$ 1,640	$ 1,707	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774	$ 1,774
	PV	$ (37,697)	$ 1,318	$ 1,329	$ 1,338	$ 1,344	$ 1,348	$ 1,349	$ 1,348	$ 1,297	$ 1,247	$ 1,199	$ 1,153	$ 1,108	$ 1,066	$ 1,025
	NPV	$ (20,229)														