Future of Home Heating
Supplemental Materials

A Collaboration Between:

ADVANCED ENERGY CENTRE
MaRS Cleantech | Ontario, Canada

ENBRIDGE®
Enbridge Gas Distribution Inc.

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

Overview

- This technical supplement is provided to accompany the AEC’s Future of Home Heating report
- This analysis is based on numerous assumptions, with varying levels of uncertainty.
- These results are best used to compare the evaluated technology options.
- Each individual home is different. The analysis is intended to inform discussion on how to decarbonize residential gas heating across the province, and is based on Ontario averages and archetype homes.
- Many more options exist beyond those presented here, including other heat pump variants and equipment combinations – this analysis focuses on three specific technology scenarios, selected as illustrative examples to enable comparison between three high-level categories.
    - Detailed assumptions for each scenario are documented herein for the purposes of transparency. However, these represent just one way each system could be implemented.

Technology Scenarios

- Base Case:
  - Natural gas furnace and electric air conditioning using current standard new equipment
- Scenario A: Full Electric
  - Electric using conventional ASHP, with integrated electric resistance back-up heat
- Scenario B: Hybrid 1 (ASHP/Gas Hybrid)
  - Natural gas and electric using conventional Air Source Heat Pump (ASHP)
- Scenario C: Hybrid 2 (CC-ASHP/Gas hybrid)
  - Natural gas and electric using cold climate Air Source Heat Pump (CC-ASHP)

Scenarios Summary

Electrification Scenario:		Base Case	Scenario A: Full Electric Heat	Scenario B: Hybrid ASHP + gas	Scenario C: Hybrid CC ASHP + gas
Source of household heat		Natural Gas Furnace	ASHP with Electric Resistance Back-Up	ASHP with NG Back-Up	CC ASHP with NG Back-Up
Source of household cooling		Electric A/C	ASHP	ASHP	CC ASHP
Heating/Cooling System Capital Costs†	Existing Homes	$9,300	$13,750	$14,500	$18,500
	New Homes	$8,800	$13,100	$14,200	$18,000
Efficiency of Electric Heat*	Existing Homes	N/A	1.8	3.2	2.9
	New Homes	N/A	2	2.7	2.8
Efficiency of Gas Heat		0.95	N/A	0.95	0.95
SEER Rating for Cooling		15	15	15	20

†Costs are approximate and indicative of a range

*Effective COP during periods of electric heat operation only, based on modeled building heat load minus any load met by Nat Gas heat (this is *not* a standardized COP rating)

Results – Existing Homes, Per Home

Assumptions/Configuration	
Location	Toronto
Hybrid Switchover Control Mode	Unrestricted

Base Case Annual NG Emissions
3.4 tCO2e/yr

Type of home:		Existing Homes		
Electrification scenario:		Scenario A: Full Electric Heat	Scenario B: Hybrid ASHP + gas	Scenario C: Hybrid CC-ASHP + gas
Capital Costs (delta vs NG Base Case)		$4,500	$5,200	$9,200
Annual Energy Costs (delta vs NG Base Case)		$890/yr	$350/yr	$330/yr
Total Measure Spend (= Capital Cost + Lifetime Energy Costs)		$18,000	$10,000	$14,000
Annual Emissions from NG		0 tCO2e/yr	0.87 tCO2e/yr	0.35 tCO2e/yr
Annual Net Emissions Impact*	Gas-Fired Elec.	0.72 tCO2e/yr	-0.36 tCO2e/yr	-0.67 tCO2e/yr
	Zero-Carbon Elec.	-3.4 tCO2e/yr	-2.5 tCO2e/yr	-3.1 tCO2e/yr
	Illustrative Scenario Elec. (20% NG)	-2.6 tCO2e/yr	-2.1 tCO2e/yr	-2.6 tCO2e/yr
Increase in Annual Grid Electricity Consumption		9,900 kWh/yr	5,200 kWh/yr	5,700 kWh/yr
Change in Annual Household NG Consumption		-1,800 m3/yr	-1,400 m3/yr	-1,600 m3/yr
Additional Winter Peak Grid Demand	At Scenario Peak Electric Load	13 kW @ -25°C	2.2 kW @ -6.8°C	3.4 kW @ -11°C
	At Coldest Temperature in a Typical Year (@ -25°C)	13 kW	0 kW	2.7 kW
Lifetime Cost of Emission Reduction	Gas-Fired Elec.	Emissions Increase	$1,900 / tCO2e	$1,400 / tCO2e
	Zero-Carbon Elec.	$350 / tCO2e	$270 / tCO2e	$310 / tCO2e
	Illustrative Scenario Elec. (20% NG)	$460 / tCO2e	$330 / tCO2e	$370 / tCO2e

*The actual net emissions impact will fall between the book-ends of gas-fired & zero-carbon electricity, depending on the grid marginal emission factor

RED = measure increases emissions

Results – New Homes, Per Home

Assumptions/Configuration	
Location	Toronto
Hybrid Switchover Control Mode	Unrestricted

Base Case Annual NG Emissions
2.5 tCO2e/yr

Type of home:		New Homes		
Electrification scenario:		Scenario A: Full Electric Heat	Scenario B: Hybrid ASHP + gas	Scenario C: Hybrid CC-ASHP + gas
Capital Costs (delta vs NG Base Case)		$4,300	$5,300	$9,200
Annual Energy Costs (delta vs NG Base Case)		$530/yr	$310/yr	$240/yr
Total Measure Spend (= Capital Cost + Lifetime Energy Costs)		$12,000	$10,000	$13,000
Annual Emissions from NG		0 tCO2e/yr	0.35 tCO2e/yr	0.10 tCO2e/yr
Annual Net Emissions Impact*	Gas-Fired Elec.	0.20 tCO2e/yr	-0.24 tCO2e/yr	-0.57 tCO2e/yr
	Zero-Carbon Elec.	-2.5 tCO2e/yr	-2.1 tCO2e/yr	-2.4 tCO2e/yr
	Illustrative Scenario Elec. (20% NG)	-1.9 tCO2e/yr	-1.7 tCO2e/yr	-2.0 tCO2e/yr
Increase in Annual Grid Electricity Consumption		6,400 kWh/yr	4,500 kWh/yr	4,300 kWh/yr
Change in Annual Household NG Consumption		-1,320 m3/yr	-1,130 m3/yr	-1,270 m3/yr
Additional Winter Peak Grid Demand	At Scenario Peak Electric Load	8.9 kW @ -25°C	2.1 kW @ -11°C	3.3 kW @ -15°C
	At Coldest Temperature in a Typical Year (@ -25°C)	8.9 kW	0 kW	2.8 kW
Lifetime Cost of Emission Reduction	Gas-Fired Elec.	Emissions Increase	$2,800 / tCO2e	$1,500 / tCO2e
	Zero-Carbon Elec.	$330 / tCO2e	$310 / tCO2e	$360 / tCO2e
	Illustrative Scenario Elec. (20% NG)	$420 / tCO2e	$380 / tCO2e	$420 / tCO2e

*The actual net emissions impact will fall between the book-ends of gas-fired & zero-carbon electricity, depending on the grid marginal emission factor

RED = measure increases emissions

Results – Economy Level

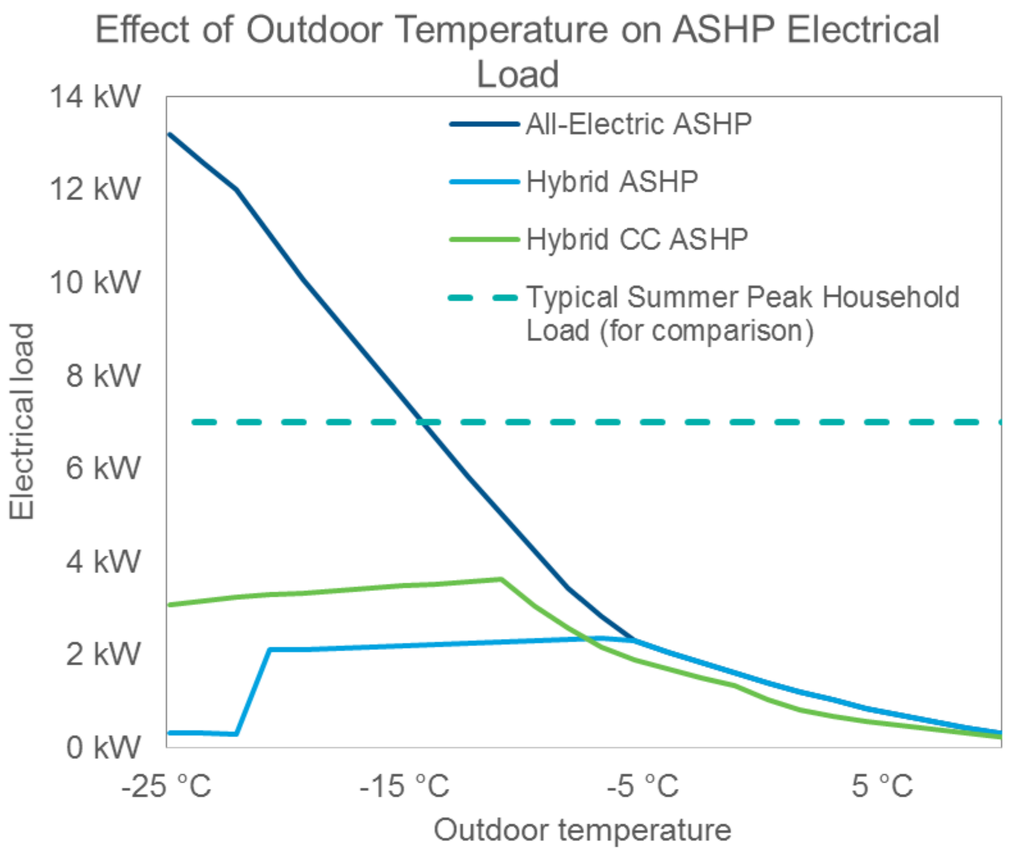
Assumptions/Configuration	
Location	Toronto
Hybrid Switchover Control Mode	Unrestricted

By Year:		2020			2030		
Electrification scenario:		Scenario A: Full Electric Heat	Scenario B: Hybrid ASHP + gas	Scenario C: Hybrid CC ASHP + gas	Scenario A: Full Electric Heat	Scenario B: Hybrid ASHP + gas	Scenario C: Hybrid CC ASHP + gas
# of Homes Converted to Electricity by 2020	Existing Homes	26,000			250,000		
	New Homes	6,700			47,000		
	Total	33,000			300,000		
Total Measure Spend (= Capital Cost + Lifetime Energy Costs)		$0.55B	$0.34B	$0.46B	$5.1B	$3.1B	$4.2B
Annual Net Emissions Impact	Gas-Fired Elec.	0.020 MtCO2e/yr	-0.011 MtCO2e/yr	-0.021 MtCO2e/yr	0.19 MtCO2e/yr	-0.10 MtCO2e/yr	-0.20 MtCO2e/yr
	Zero-Carbon Elec.	-0.11 MtCO2e/yr	-0.081 MtCO2e/yr	-0.096 MtCO2e/yr	-0.99 MtCO2e/yr	-0.75 MtCO2e/yr	-0.89 MtCO2e/yr
	Illustrative Scenario Elec. (20% NG)	-0.081 MtCO2e/yr	-0.067 MtCO2e/yr	-0.081 MtCO2e/yr	-0.75 MtCO2e/yr	-0.62 MtCO2e/yr	-0.75 MtCO2e/yr
Increase in Annual Grid Electricity Consumption		300 GWh	170 GWh	180 GWh	2,800 GWh	1,500 GWh	1,700 GWh
Additional Winter Peak Demand	At Scenario Peak Electric Load	410 MW @ -25°C	75 MW @ -6.8°C	120 MW @ -11°C	3,900 MW @ -25°C	690 MW @ -11°C	1,100 MW @ -15°C
	At Coldest Temperature in a Typical Year (@ -25°C)	410 MW	0.00 MW	95 MW	3,900 MW	0.00 MW	880 MW

RED = measure increases emissions

Illustrative Energy Performance Results

Effect of hybrid switch-over temperature on peak electrical load- Per home



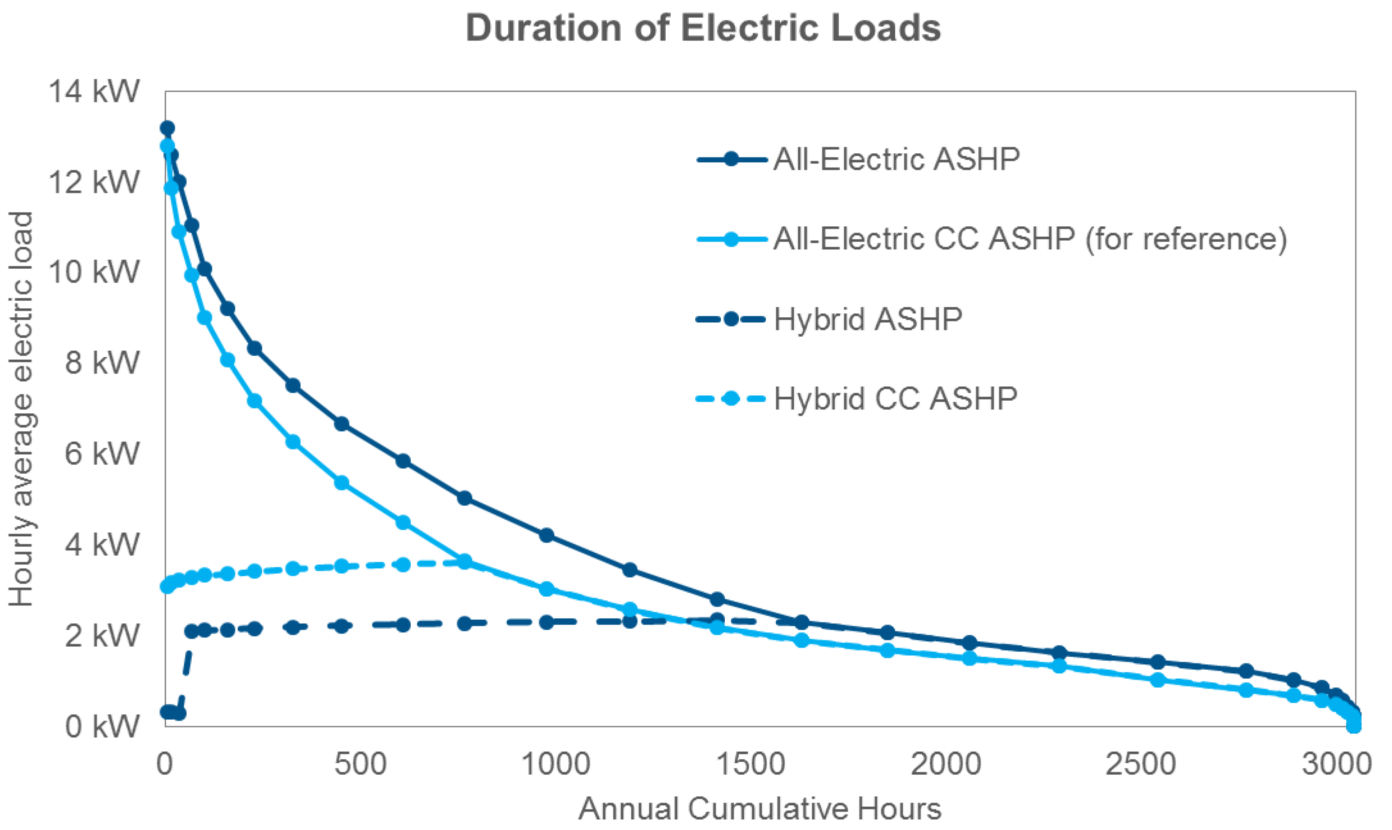
Source: NRCan calculator, with ICF adaptations

- Note: Peak for hybrid systems does not necessarily occur at the coldest operating temperature, because of 3 competing effects
- As temperature decreases:
  - Building Heat Load increases, ↗ HP Load
  - COP drops, ↗ HP Load
  - HP capacity drops, ↘ HP Load
- Despite higher efficiency, the unrestricted hybrid CC-ASHP peak is higher than ASHP because it operates to a lower temperature before needing gas back-up

Assumptions/Configuration	
Location	Toronto Existing Home
Hybrid Switchover Control Mode	Unrestricted

Illustrative Energy Performance Results

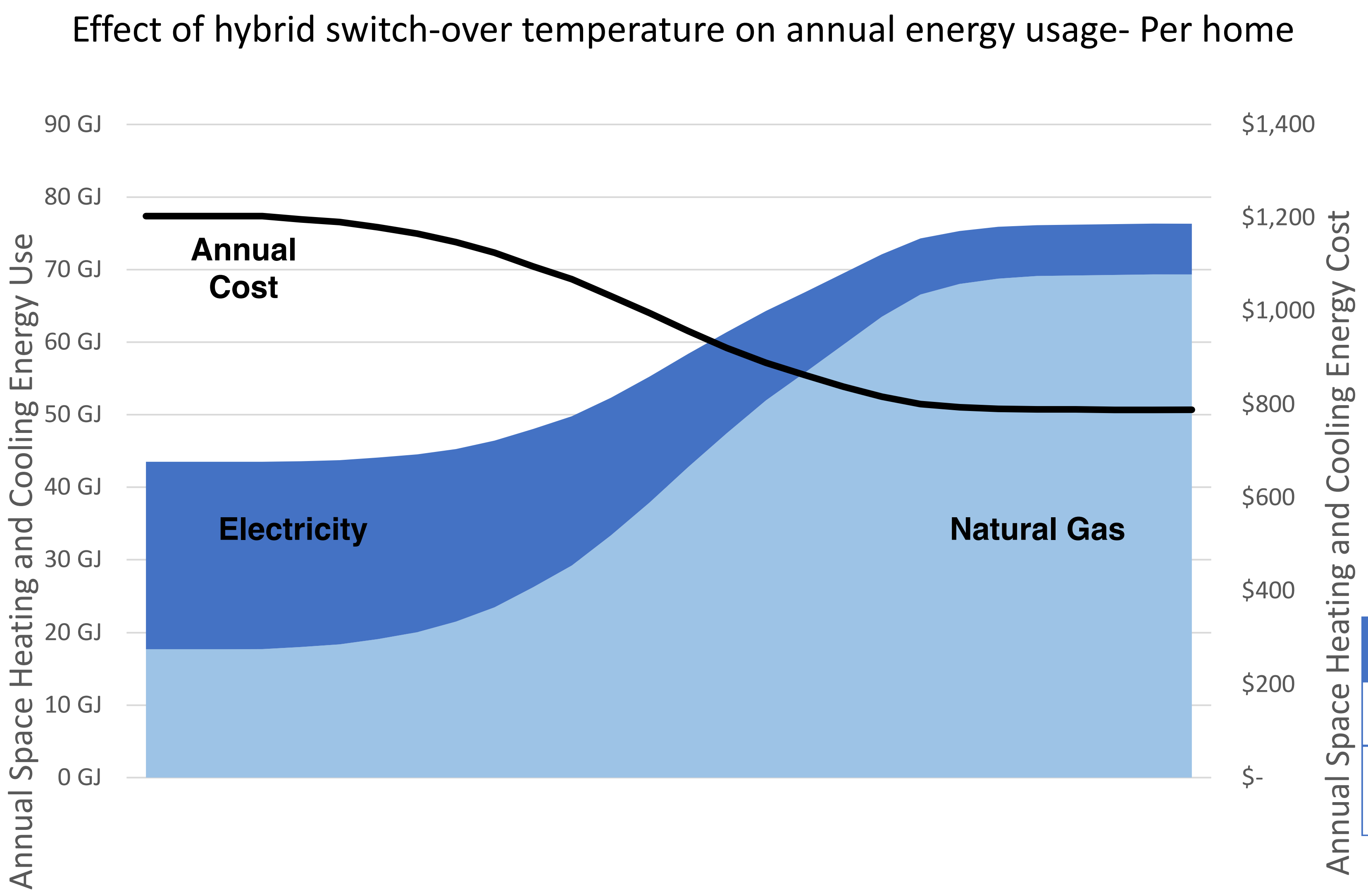
Load Duration Curves- Per home



- This graph plots the hourly average electric load, according to the number of hours that each load occurs in a typical year

Assumptions/Configuration	
Location	Toronto Existing Home
Hybrid Switchover Control Mode	Unrestricted

Illustrative Energy Performance Results

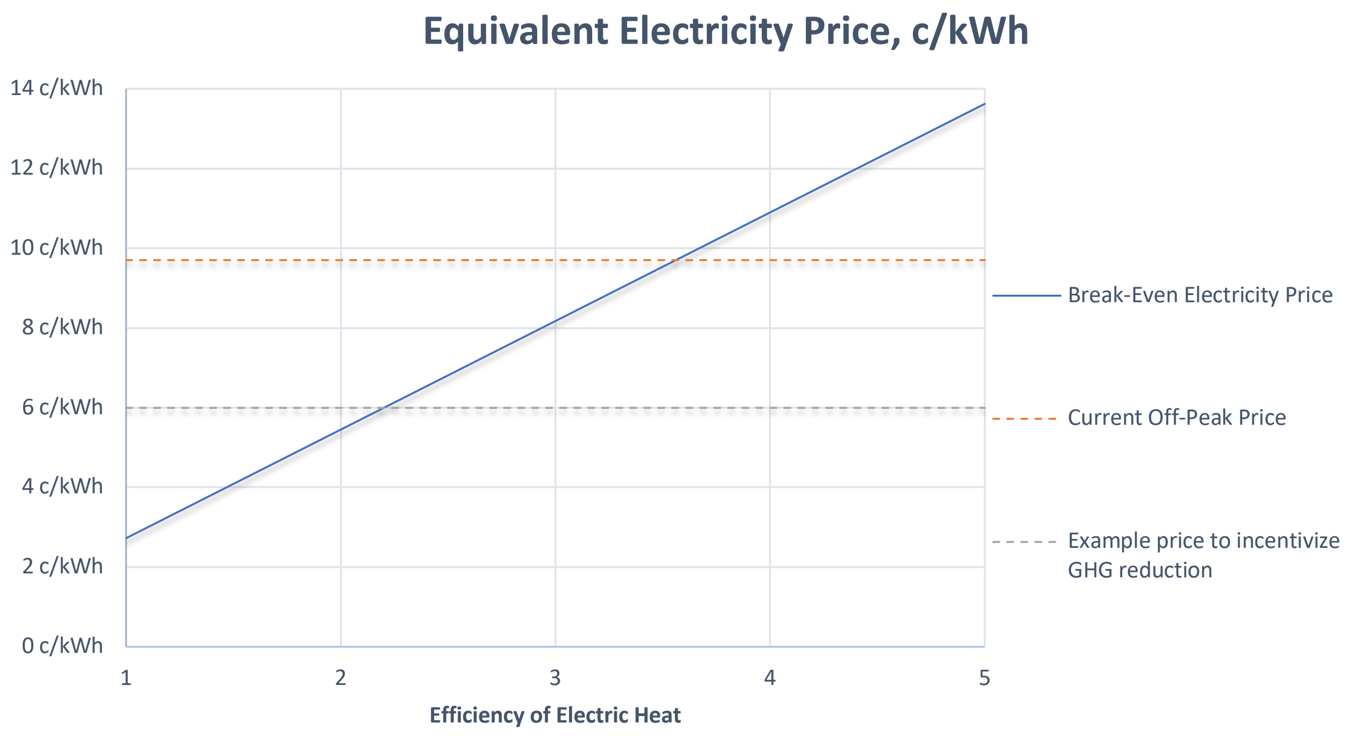


- Hybrid system control strategies may include a switch-over temperature - that is, an outdoor temperature threshold at which the heat pump ceases to operate and the system uses the gas heating system to meet the house load.
- This plot explores how varying the switch-over temperature would effect a gas-hybrid system, when installed in Existing housing.

Assumptions/Configuration	
Location	Toronto Existing Home
Hybrid Switchover Control Mode	[Multiple]

Equivalent Price Concept

Energy-Equivalent Rates	c/kWh	$/GJ	c/m3
Electricity	15	42	158
Natural Gas	2.3	6.3	24
Ratio of Electricity vs NG Energy Cost	6.6		
Spark Spread	13	35	134



- Operating costs are driven by the difference between natural gas and electricity costs
  - Electricity is much more expensive than natural gas on an energy basis, as shown in this table
  - Heat pumps can operate at much greater efficiencies than a natural gas furnace under some conditions
  - The balance between the two drives whether it is more cost effective to run a heat pump or to heat with NG

Heat pump efficiencies are temperature dependent

- The equivalent electricity price in this graph indicates the electricity price at which heat pump operating costs would be equivalent to natural gas operating costs
- Assuming 27 c/m^3 gas rate (including 3c/m^3 carbon cost), and 95% efficiency gas heat

Hybrid Switchover Control Modes

- Results tables are presented for “Unrestricted” mode
  - Heat pump is run to its full capacity and lowest temperature, gas is only used as back-up when required to meet building load

- GHG Minimized
  - Versus NG-fired Grid Electricity, the break-even point is achieved at COP ~2.2
  - Versus Zero Carbon Grid Electricity, equivalent to Unrestricted operation (minimize gas usage)

- Economic Operation
  - Switch between HP and gas to minimize operating costs
  - This is the most logical operation point from a homeowner’s perspective, regardless of the original capital costs
  - However, despite the efficiency gain with heat pumps, the economic switchover point under current rates is to use gas to meet all or almost all heating loads scenarios, resulting in operation equivalent to the base case

Key Methodology Assumptions

- High-level Approach:
  - Energy – NRCan custom calculator tool to quantify energy performance
    - Heat pump performance is highly climate-sensitive and sensitive to ‘right-sizing’
    - New homes assumed to have lower heat/cooling load than existing homes, but equal equipment size
  - Capital costs based on Enbridge Survey of GTA Wholesaler and Contractor Pricing and an NRCan - Enbridge Outlook on estimated cost reductions
    - Also validated against data from NRCan's Local Energy Efficiency Partnerships (LEEP)

- All technology scenarios are compared to the Natural Gas (NG) base case
  - This is because NG furnace/electric A/C represents a large proportion of homes and the largest source of GHG emissions from buildings in the province.
  - This study does NOT apply to conversion from oil nor from electric baseboard heat (for which the economics and GHG savings are very different)
    - Note that the Base Case for existing gas heated homes is very different than for existing electrically heated homes – for example, electric heated homes are built to different building codes recognizing that electricity is an expensive energy source, so they require less energy to heat than a house which is built to be gas-heated

Key Cost Assumptions

- Simple constant energy rates applied to all years (and no discount rate applied)
  - NG rate: 24 c/m3 (Validated by Enbridge)
  - Electricity Rate: 15 c/kWh (Based on Ontario's 2017 Long-Term Energy Plan)
  - Carbon costs were added to the natural gas rate (Based on the OEB Long Term Carbon Price Forecast)
    - Since carbon costs escalate over time, results tables represent annual average cost for a system installed in 2018 (end of life 2032).
- Notes:
  - Analysis considers end user/homeowner costs, not system costs
  - Analysis does not incorporate any capital cost incentives
  - Simple constant energy rates applied to all years (and no discount rate applied)
    - While future energy rates are uncertain, electricity is fundamentally more expensive than gas in Ontario and is expected to remain so for the foreseeable future.

Capital Cost Assumptions

- Technical Notes:
  - Capital costs include equipment purchase, installation, and cost to upgrade amperage service where applicable. All accessories included in costs including: TX valves, Controls, A coils, Electric & Gas connections, etc.
  - Costs which are equal between all scenarios are not included (e.g. disposal of previous equipment).
  - To create parity for all scenarios, Domestic Hot Water (DHW) equipment costs were included in all scenarios:
    - Base Case: High Efficiency Furnace, Std. A/C + tankless DHW
    - Full Electric: Std. ASHP with Electric Resistance Heat and Air Handler + tankless DHW
    - Hybrid 1: Std. ASHP with Hydronic Air Handler + Gas Combo Appliance
    - Hybrid 2: Cold Climate ASHP with Hydronic Air Handler + Gas Combo Appliance
  - CC-ASHP installation/accessories costs assumed to be similar to ASHP
  - Costs based on the Enbridge Survey of GTA Wholesaler and Contractor pricing and the NRCan - Enbridge Outlook on Cost Reductions
  - Capital costs are currently very variable, and installation is costly; prices expected to fall if market volume increases
    - Costs should be viewed as approximate and indicative of a range. While all-electric standard ASHP costs are relatively well understood in the electric-heated home market, adoption of heat pumps in gas-heated homes is in its very early days. Pilot studies are currently underway which may help provide data to improve estimates of equipment cost, and to explore how costs vary with different set-ups and equipment combinations.

Performance Calculations Methodology

- NRCan developed a custom calculator for hybrid heat pump analysis, which ICF used as a base for this analysis.
  - NRCan used HOT2000 to generate thermal load data for new and existing housing in Windsor, Toronto, Ottawa, North Bay and Timmins. NRCan then examined how different heat pumps models would perform relative to traditional gas furnaces. For each heat pump, two scenarios were examined:

a) All electric - where electric resistance is used to meet loads exceeding heat pump capacity, and

b) Hybrid - where a 95% efficient gas boiler is used.

- The calculator was populated with two home archetypes, based on average heat load per existing home and per new home from Ontario utility consumption data:
  - Typical Ontario existing home
  - Typical Ontario new-build home
- Results are presented for Toronto, a representative climate for Southern Ontario where the majority of Ontario households are concentrated
  - Illustrative graphics are presented for the Toronto existing home as an example (the profile for new homes is similar)

Performance Calculations Methodology

- Technical notes:
  - Unrestricted vs balance point control – gas & HP cannot run simultaneously (whereas electric resistance & HP can). However, we modeled it as such (“unrestricted”) because it trends towards that over an hour based on preliminary NRCan testing data (more during warm than cold hours) – in reality, it runs somewhere in between the two.
  - Performance is based on manufacturer data – NRCan testing indicates 10-15% difference versus manufacturer data under realistic test conditions (units generally perform less well under real conditions)
    - Our analysis does not account for performance degradation when unit is operating below minimum capacity and is cycling
    - Our analysis does not account for defrost – NRCan is finding this can be a material energy draw, and is highly sensitive to defrost settings and control
  - Fan power is accounted for in all scenarios
  - Appropriate sizing of hybrid HPs is an open question, and depends on the objective of the system – current HRAI guidelines may not be appropriate
  - Analysis assumes breakdown of hours between TOU price brackets remains the same in all scenarios (previous ICF analysis found this has negligible impact on average cost, absent intentional TOU shifting) – however, it is relevant to note that with a hybrid system, with the right controls, a homeowner could intentionally change their use profile to take advantage of a TOU rate structure
  - This study focused on residential space heating and cooling only. The equipment deployed for the hybrid ASHP scenarios may result in additional energy savings for domestic hot water heating – however, these were not modelled.