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ASSESSING THE POTENTIAL OF AIR-SOURCE HEAT PUMPS IN THE CANADIAN RESIDENTIAL SECTOR

CanmetENERGY

In Varennes

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May 2023

RESIDENTIAL SECTOR: AN OVERVIEW



Building Sector: A Major Contributor to Global Emissions

Global: 27% of total GHG emissions

EU: 35% of total GHG emissions

Canada: 18% of national direct emissions



Space and Water Heating: Driver of Building Related Emissions

Global: 80% of direct building emissions (2.5 GT)

Canada: 99% of direct emissions in residential buildings (42.6 MT)

9M homes heated using fossil fuels (56% of Canadian homes)

Major opportunity for heat pumps to drive decarbonisation



HEAT PUMPS IN CANADA: SUPPORTING POLICY



Canada's 2050 Vision

2050: Net-zero emissions from buildings
Transitioning from fossil-fuel home heating



Canada's 2030 Emission Reduction Plan

“Regulatory standards, incentive framework to support **transition off fossil fuels for heating**”



Current National Policy & Programs

Canada Greener Homes Program: HP Incentives

Oil to HP Affordability Grant

Canada Green Buildings Strategy (in development)

- Standards, incentive framework for transition off fossil fuels for heating

CANADIAN CONTEXT – CLIMATE

Whitehorse, YK

- Climate: Subarctic
- HDD: 6580
- T_{design} : -41.1°C (-42°F)

Vancouver, BC

- Climate: Marine
- HDD: 2825
- T_{design} : -7.2°C (19°F)

Edmonton, AB

- Climate: Very Cold
- HDD: 5120
- T_{design} : -30.0°C (-22°F)

Winnipeg, MB

- Climate: Very Cold
- HDD: 5670
- T_{design} : -32.8°C (-27°F)

Montreal, QC

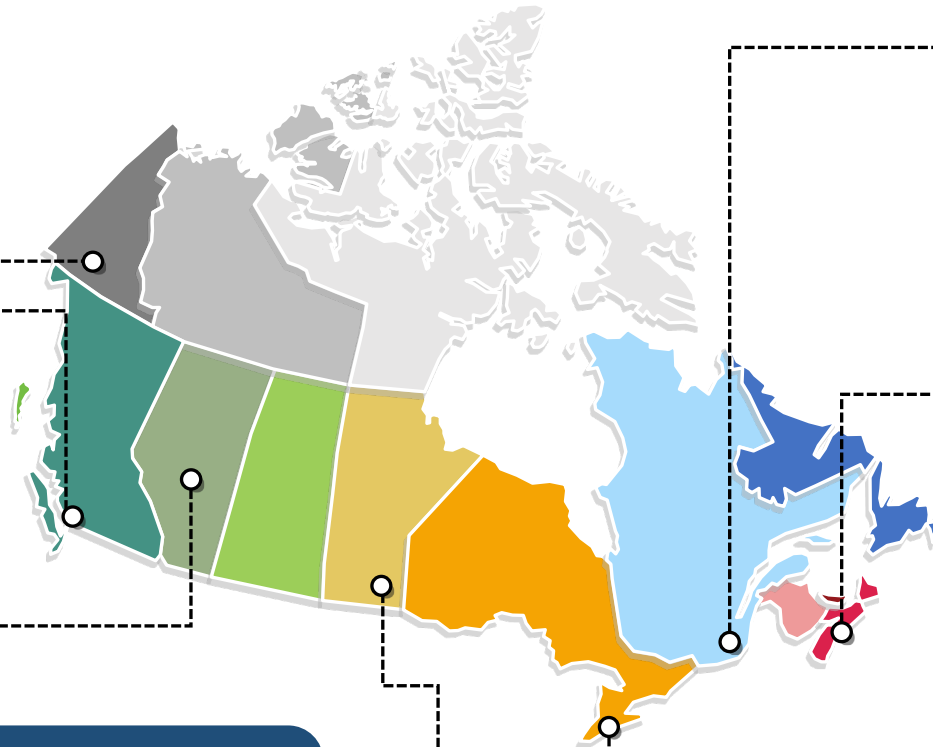
- Climate: Cold-Humid
- HDD: 4200
- T_{design} : -22.8°C (-9°F)

Halifax, NS

- Climate: Cold-Humid
- HDD: 4000
- T_{design} : -16.1°C (3°F)

Toronto, ON

- Climate: Cold-Humid
- HDD: 3520
- T_{design} : -17.8°C (0°F)



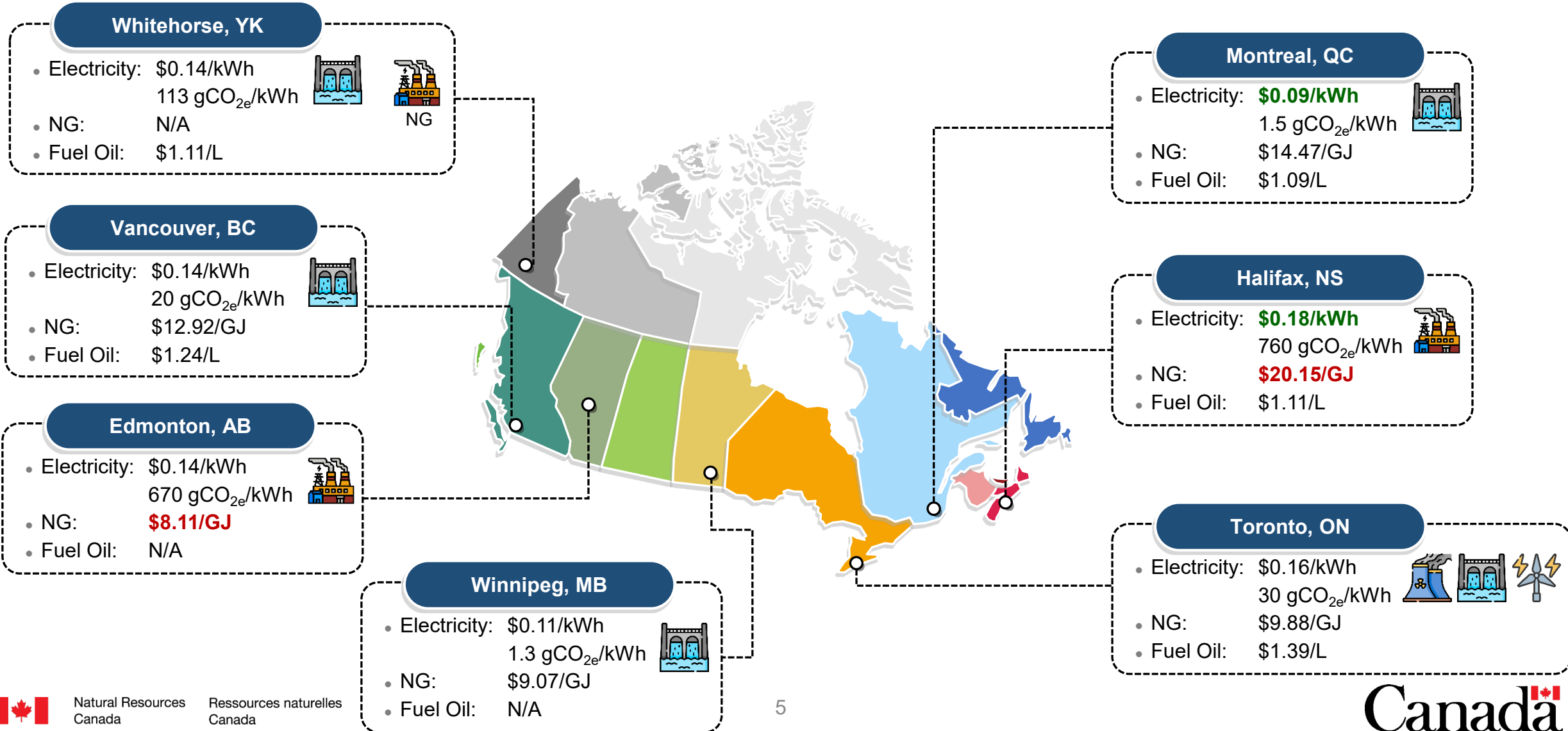
HDD = Heating Degree Days



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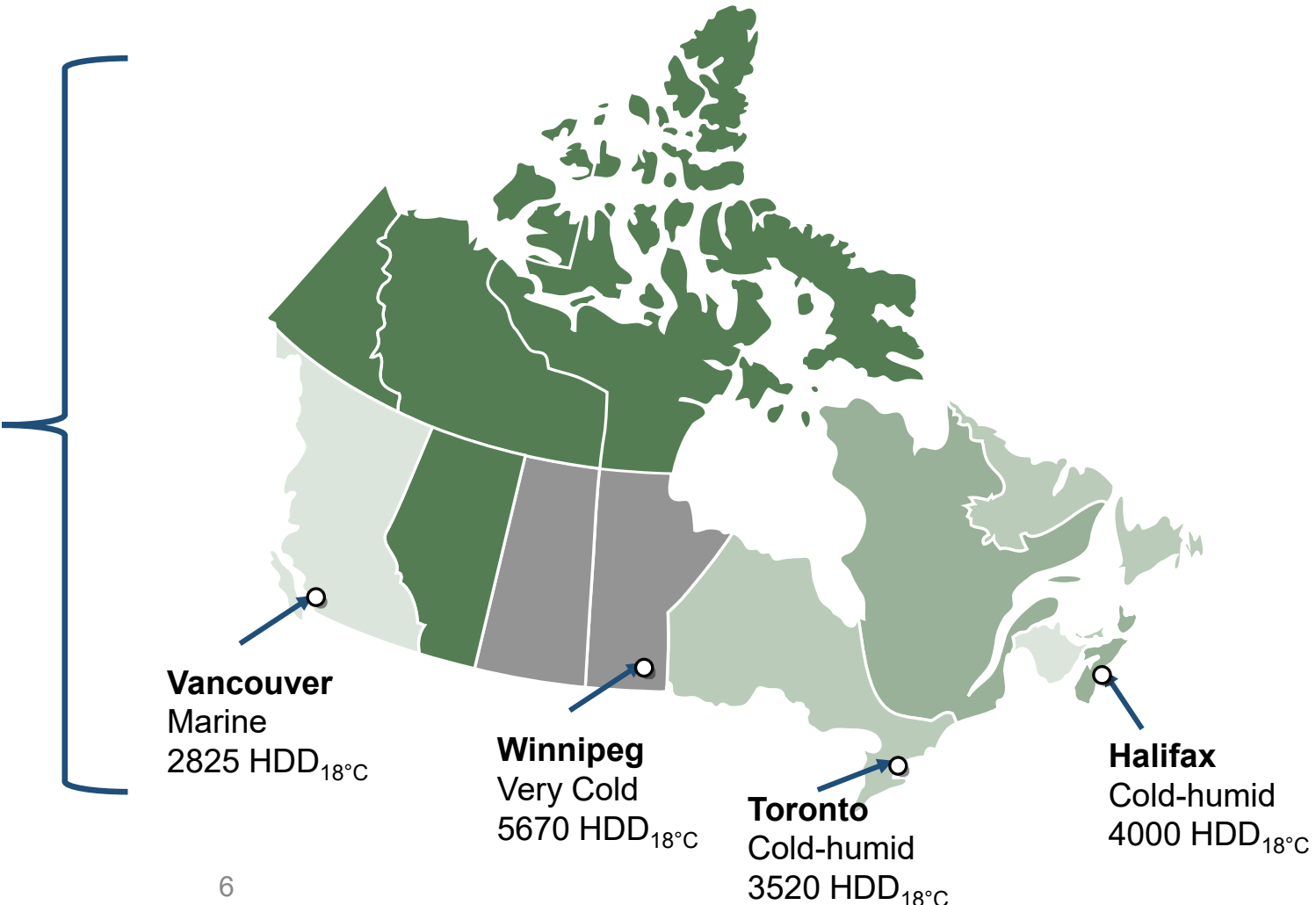
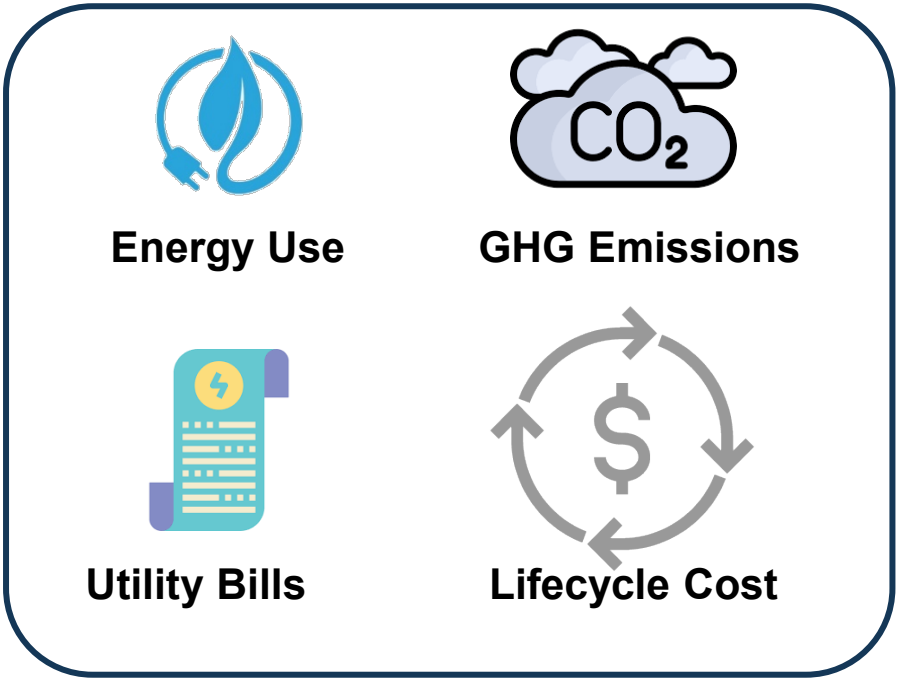
CANADIAN CONTEXT – ENERGY



OBJECTIVES

How do air-source heat pumps perform across Canada?

Typical HP Performance Metrics



METHODOLOGY: OVERVIEW

Simulation-based Approach: Simulation using TRNSYS v.18



Building Model

Three housing types
Three base case heating systems



Heat Pump Integrations

Two air-source HP types

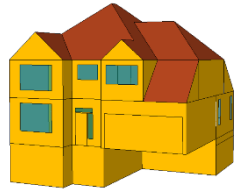


System Assessment

Energy, emissions
Lifecycle cost analysis

METHODOLOGY: BUILDING MODEL

Case 1 NG Heating to HP

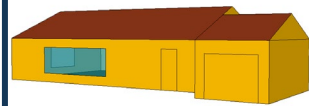


Large Two-Storey Home
284 m² heated floor area
New construction



Natural Gas Heating
95% efficient condensing furnace
Central AC unit

Case 2 Oil Furnace to HP



Small Bungalow Home
110 m² heated floor area
1960s construction



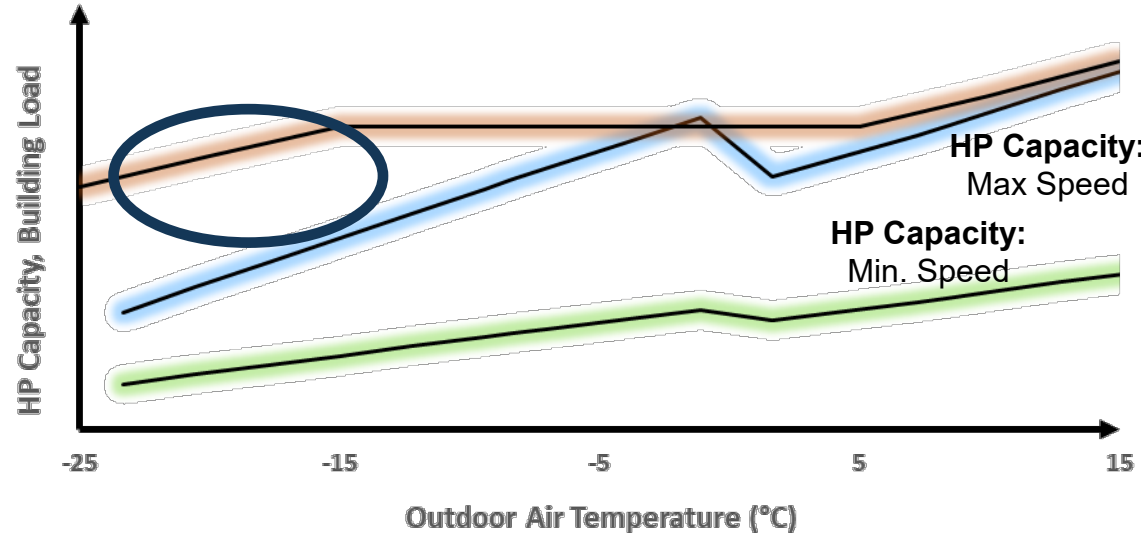
Oil Furnace Heating
71% nominal efficiency
Central AC unit

Paper also includes analysis of transition from elec. BB to HP



METHODOLOGY: HEAT PUMP MODELS

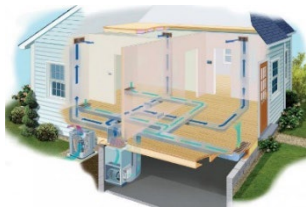
Technologies



Unit 1: Variable Capacity HP (**VCHP**)
Modulate between Max, Min speed
Less cycling, more efficient operations

Unit 2: Cold Climate HP (**CCHP**)
Improved cold climate performance
Var. capacity: Modulate at milder OATs

Integrations



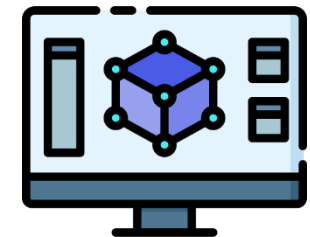
Central Systems

Thermal energy from HP to all occ. spaces
Sized to cover majority of heating loads



Auxiliary Heating

Elec. resistance to supplement HP



HP Performance Modelling

Custom, data driven TRNSYS model
Captures part load, defrost, startup

All HP integrations also include electrification of DHW (via resistance heating) for full decarbonisation

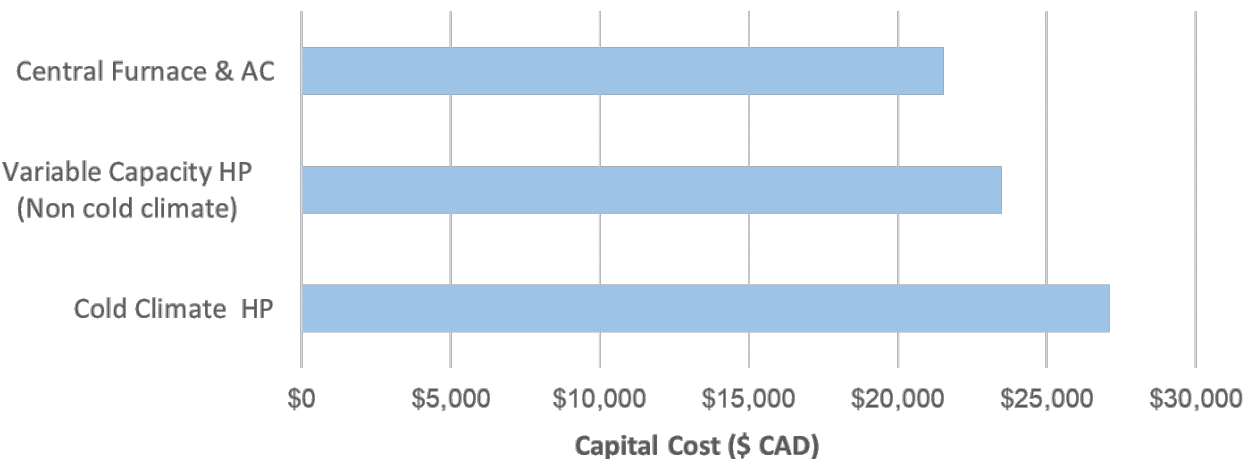
METHODOLOGY: TECHNO-ECONOMIC ANALYSIS

Analysis: Lifecycle costs over 20 year period

Includes capital, maintenance, operating costs

Heat Pump Capital Costs

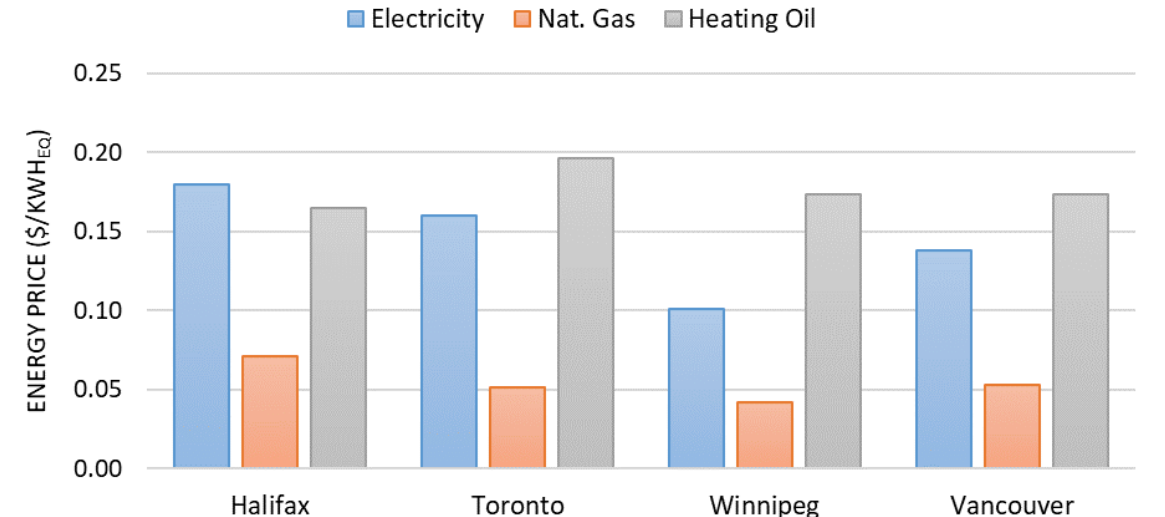
Includes equipment & labour costs



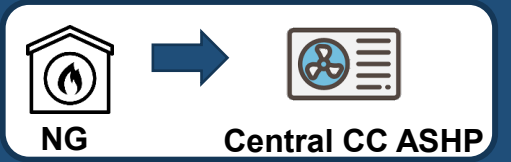
*Typical Costs in Toronto
Includes Capital, Installation, Controls

Utility Rates

Full implementation incl. all fixed costs, energy costs, rate riders



IMPACTS: REPLACING NAT. GAS FURNACES ENERGY, & GHG EMISSIONS



Winnipeg

NG: 74% of Homes

VCHP Savings:

- Energy ≈ -28%
- GHG Emissions ≈ -99%

CCHP Savings:

- Energy ≈ -30%
- GHG Emissions ≈ -99%

Halifax

NG: <1% of Homes

VCHP Savings :

- Energy ≈ -29%
- GHG Emissions ≈ +54%*

CCHP Savings :

- Energy ≈ -32%
- GHG Emissions ≈ +47%*

Vancouver

NG: 44 % of Homes

VCHP Savings :

- Energy ≈ -36%
- GHG Emissions ≈ -90 %

CCHP Savings :

- Energy ≈ -42%
- GHG Emissions ≈ -91%

Toronto

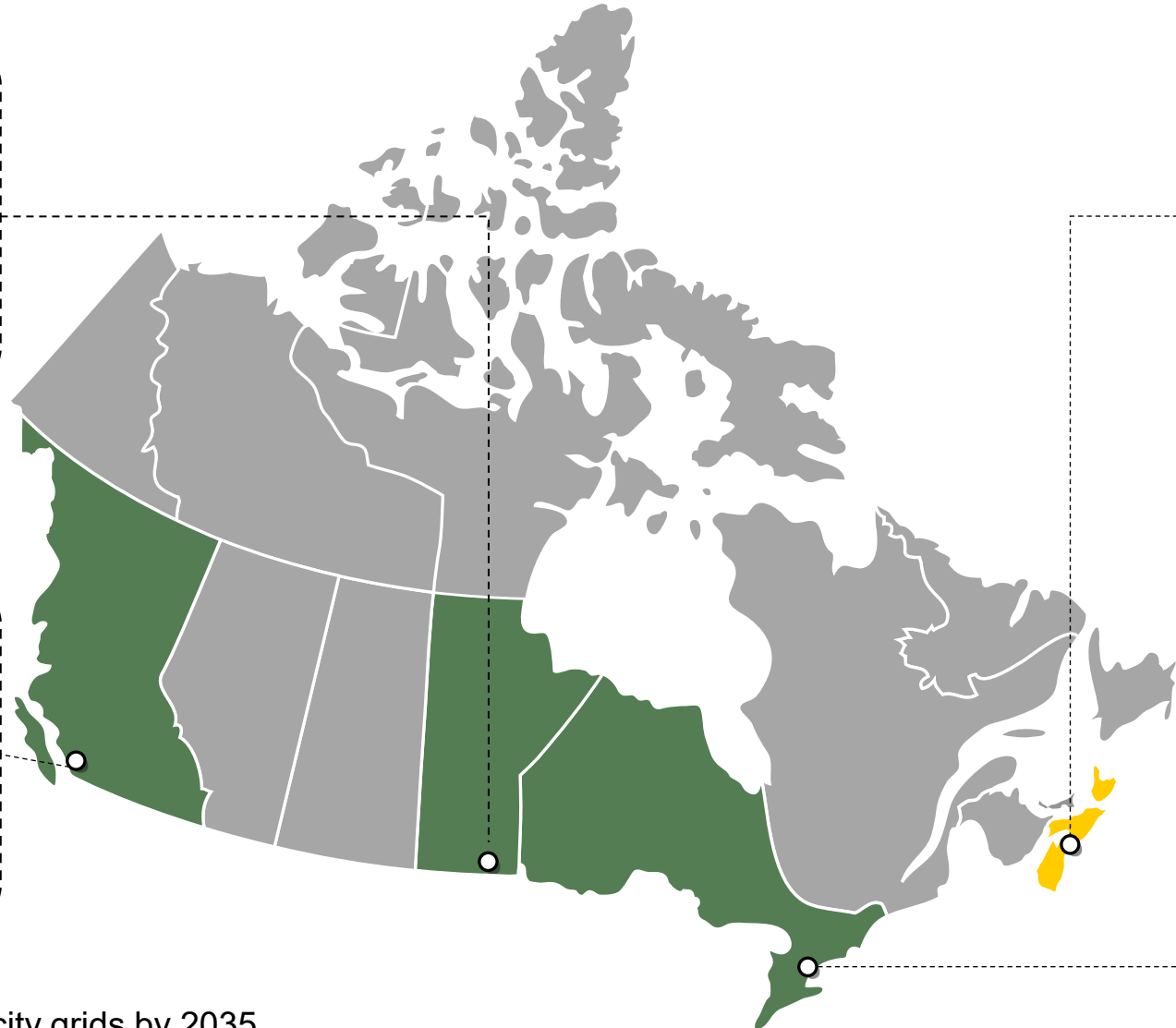
NG: 67% of Homes:

VCHP Savings :

- Energy ≈ -30%
- GHG Emissions ≈ -84%

CCHP Savings :

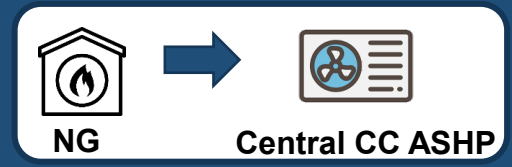
- Energy ≈ -32%
- GHG Emissions ≈ -85%



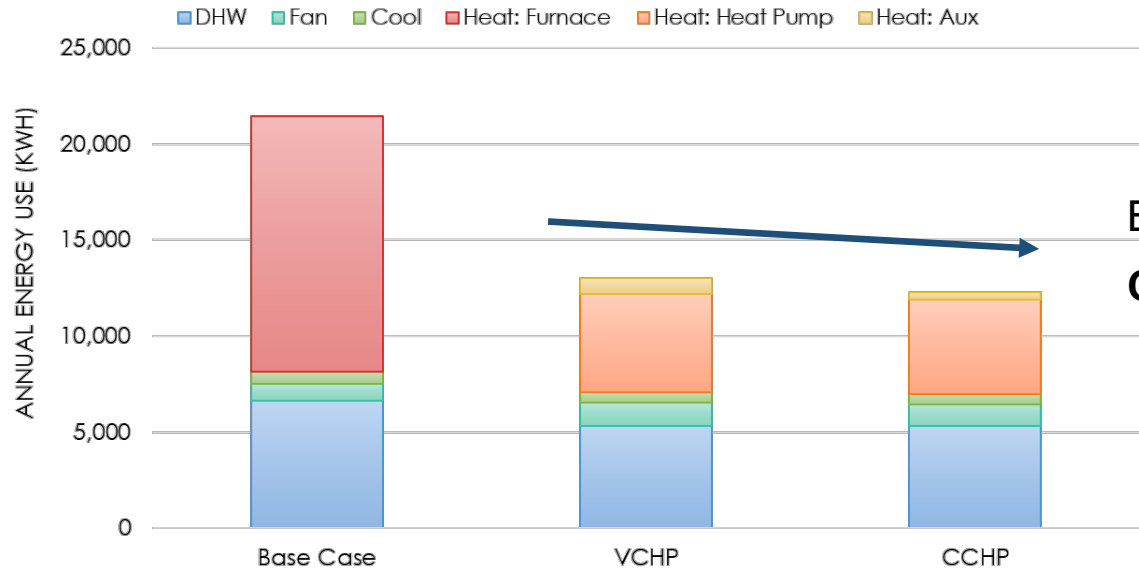
* Fed Govt.: Target Net-zero electricity grids by 2035

Note: Results dependant on utility rates & system costs used, and may change in future

IMPACTS: REPLACING NAT. GAS FURNACES ENERGY, & GHG EMISSIONS



Toronto Mech System Energy Use

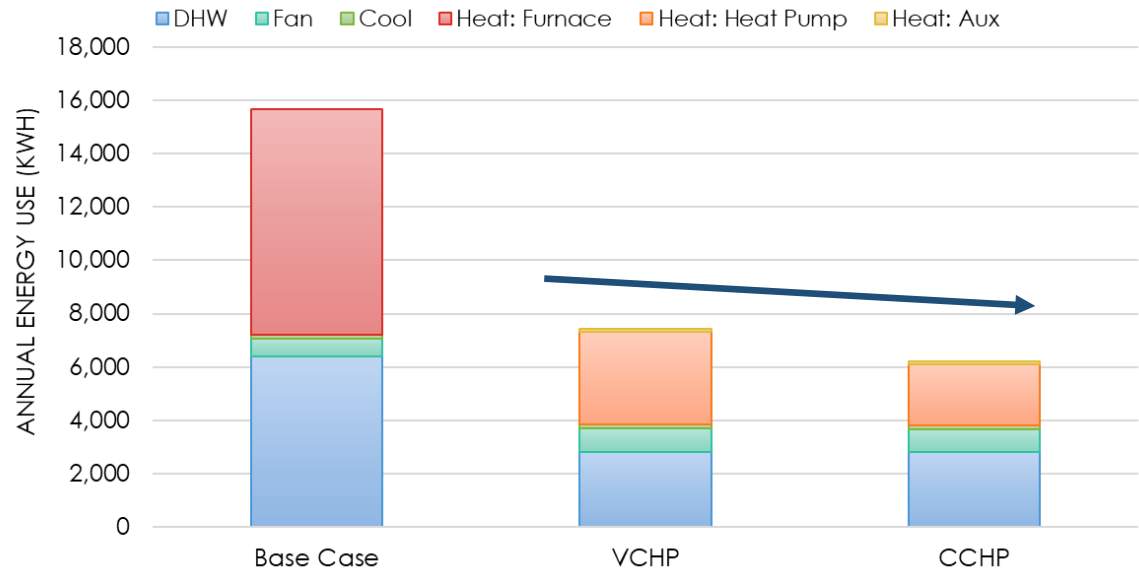


Both HPs offer strong reductions

CCHP: Maximum savings

Avoid HP low temperature limit

Vancouver Mech System Energy Use

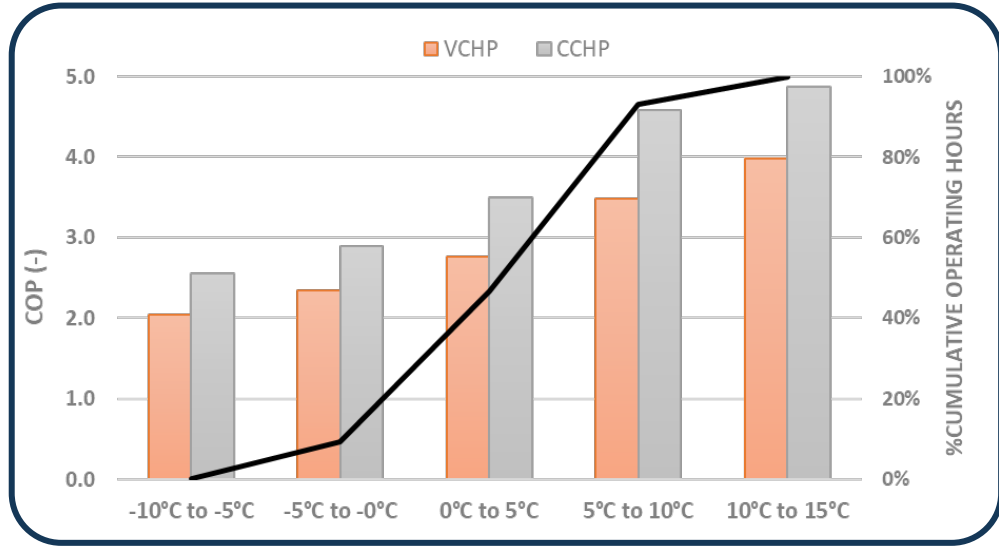
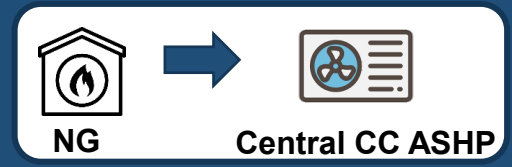


Milder climate: HPs nearly eliminate aux. heat

CCHP: Maximum savings

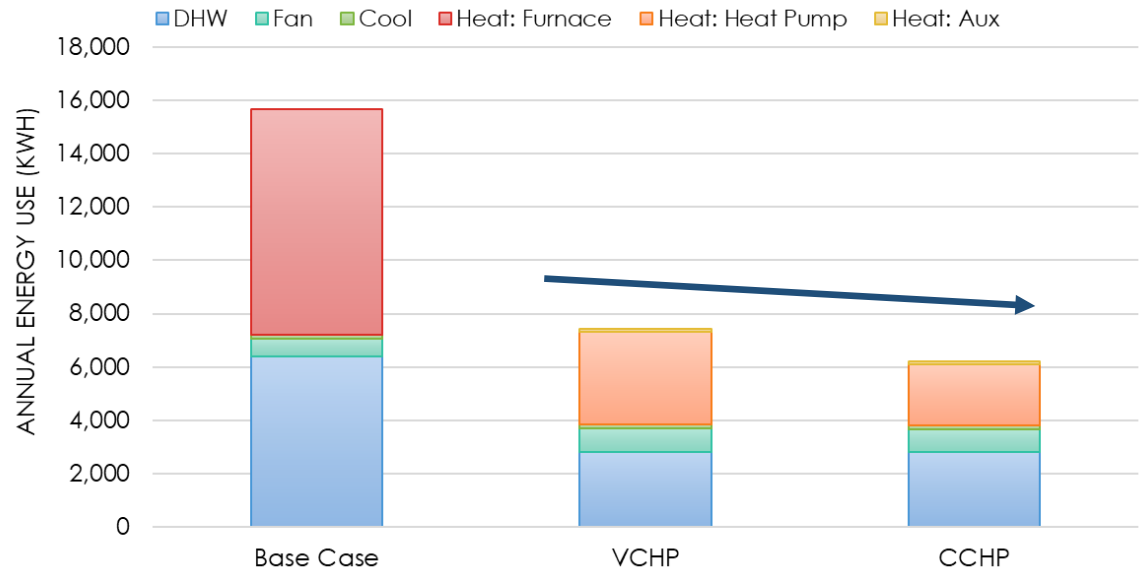
Driven by improved operating COPs

IMPACTS: REPLACING NAT. GAS FURNACES ENERGY, & GHG EMISSIONS



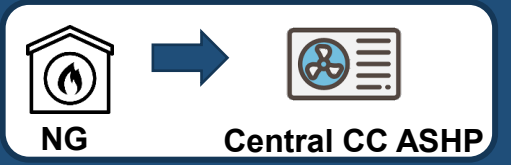
Modelled VCHP: Lower COP over most frequent operating temps.
NOT a statement on general VCHP performance

Vancouver
 Mech System
 Energy Use



Milder climate: All HPs nearly eliminate aux. heat
CCHP: Maximum savings
 Driven by improved operating COPs

IMPACTS: REPLACING NAT. GAS FURNACES LIFECYCLE COSTS OVER 20 YEARS



Winnipeg

NG: 74% of Homes

VCHP

- Lifecycle Utility \approx + 14%
- Lifecycle Total \approx + 14%

CCHP

- Lifecycle Utility \approx + 11%
- Lifecycle Total \approx + 15%

No current payback

Halifax

NG: <1% of Homes

VCHP

- Lifecycle Utility \approx - 16%
- Lifecycle Total \approx - 11%

CCHP

- Lifecycle Utility \approx - 19%
- Lifecycle Total \approx - 10%

Payback < 20 years

Vancouver

NG: 44 % of Homes

VCHP

- Lifecycle Utility \approx + 7%
- Lifecycle Total \approx + 3%

CCHP

- Lifecycle Utility \approx - 4%
- Lifecycle Total \approx + 5%

No current payback, but possible via incentives for high performing units

Toronto

NG: 67% of Homes:

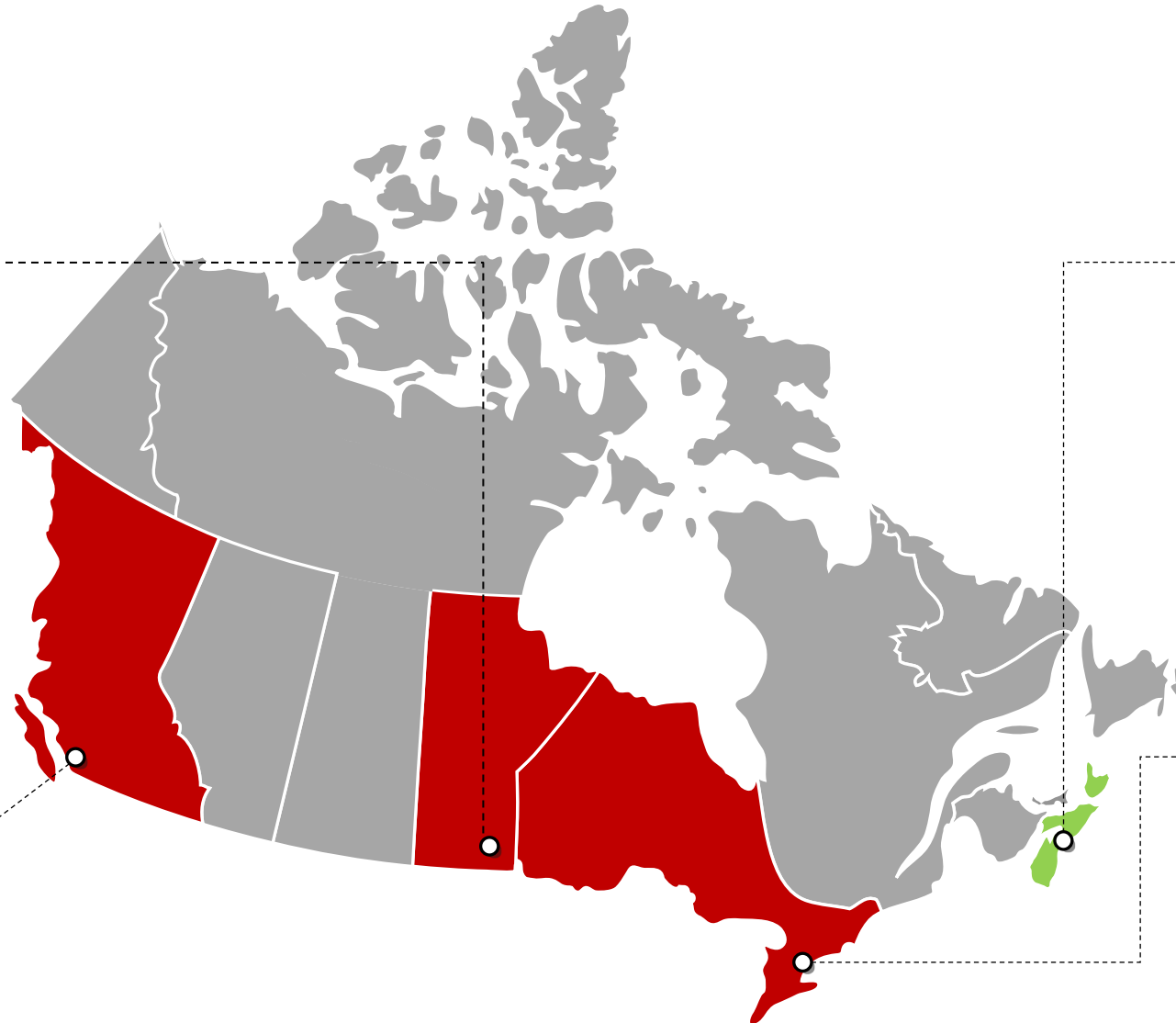
VCHP

- Lifecycle Utility \approx + 9%
- Lifecycle Total \approx + 6%

CCHP

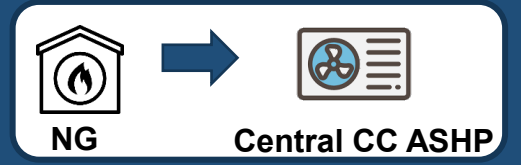
- Lifecycle Utility \approx + 5%
- Lifecycle Total \approx + 9%

No current payback

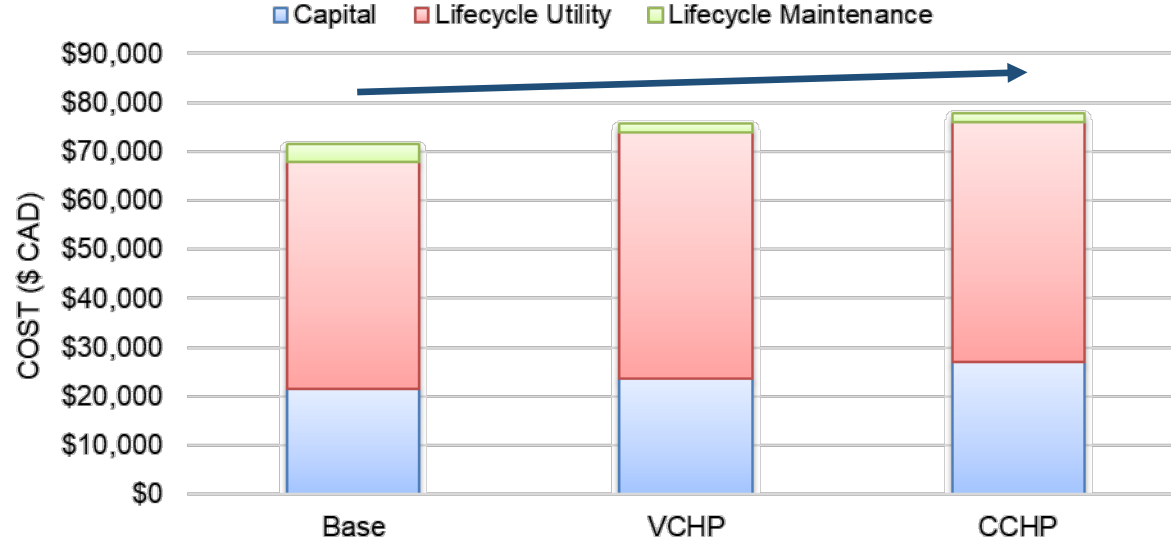


Note: Results dependant on utility rates & system costs used, and may change in future

IMPACTS: REPLACING NAT. GAS FURNACES LIFECYCLE COSTS OVER 20 YEARS



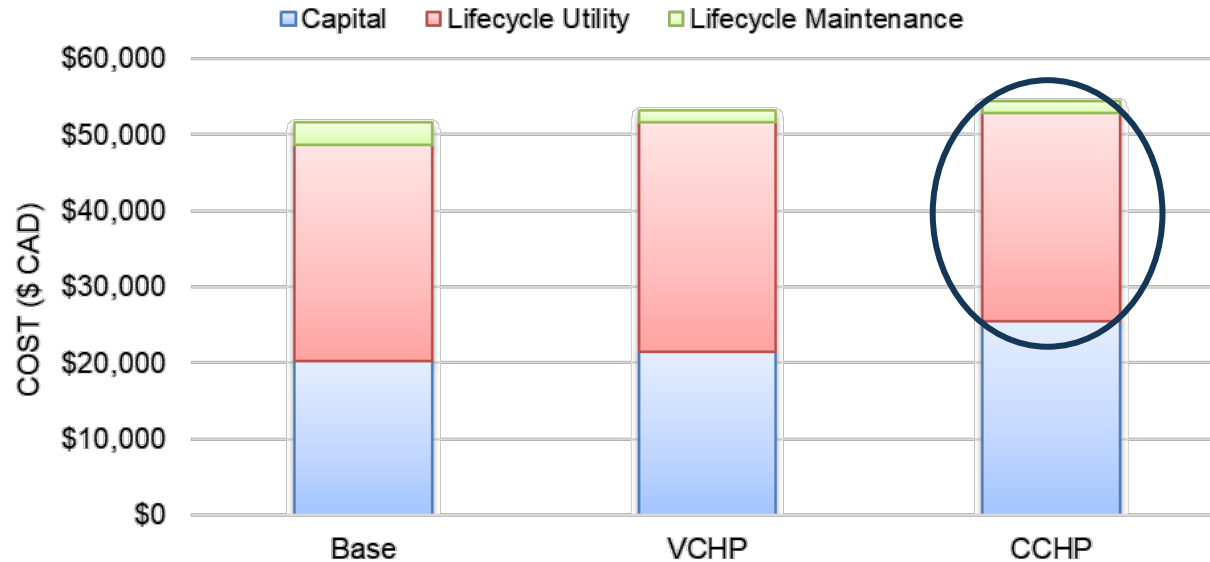
Toronto



All HPs yield higher lifecycle costs

High cost of Elec. Vs. NG: Operating cost increase

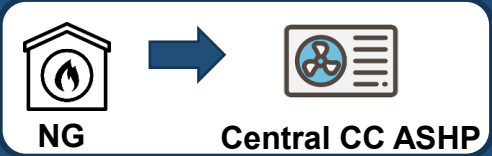
Vancouver



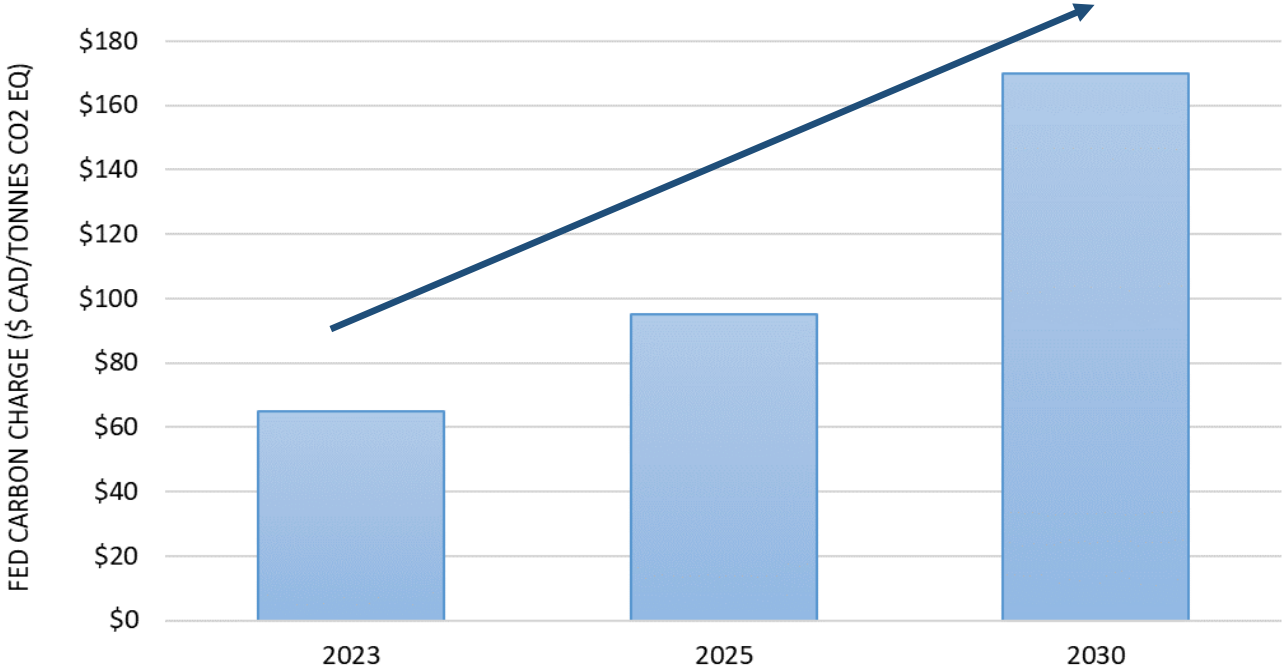
CCHP achieves utility cost savings

Incentives could help high perf. units break even vs. NG

IMPACTS: REPLACING NAT. GAS FURNACES SENSITIVITY ANALYSIS ON CARBON TAX



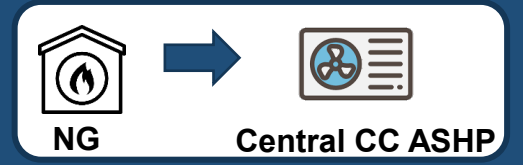
How do changes in carbon pricing impact results?



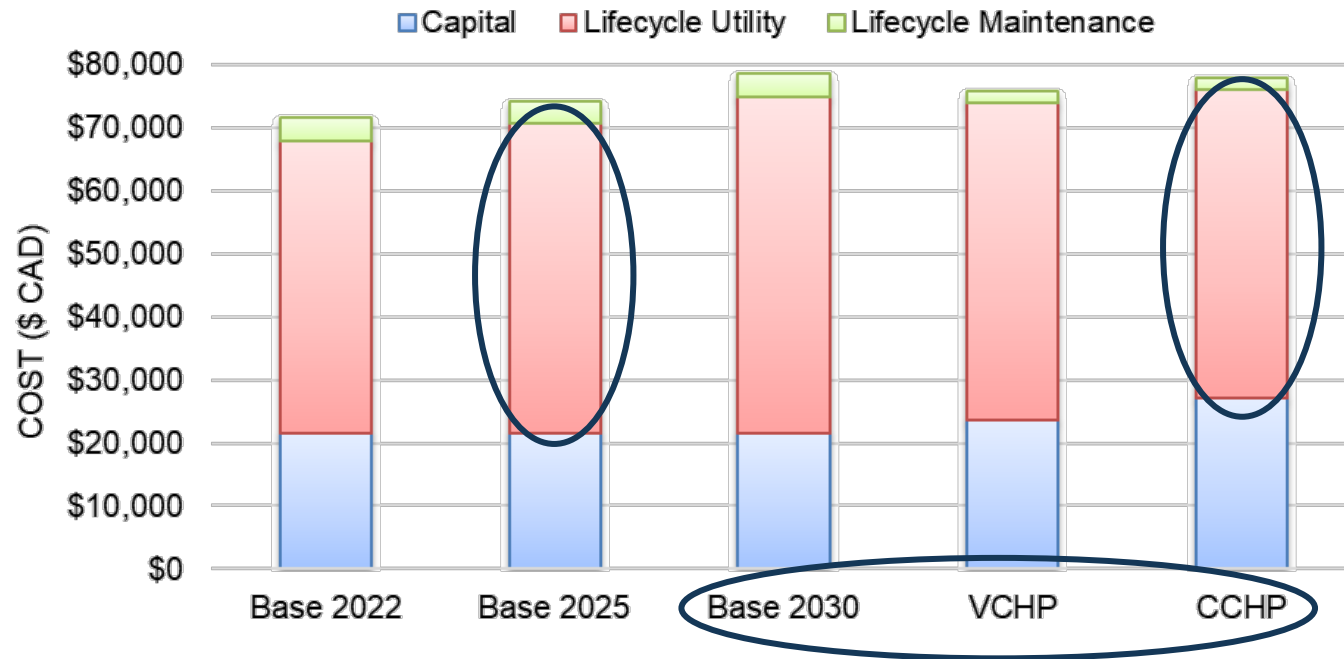
Federal Carbon Charge:
Progressive increases up to 2030

Reference: <https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/carbon-pollution-pricing-federal-benchmark-information/federal-benchmark-2023-2030.html>

IMPACTS: REPLACING NAT. GAS FURNACES SENSITIVITY ANALYSIS ON CARBON TAX



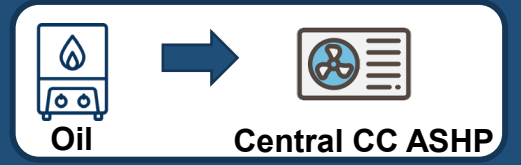
Impact of Federal Carbon Tax in Toronto



CCHP: Break even utility costs with 2025 carbon charge
Total cost parity possible w. capital cost incentive

VCHP, CCHP: Total lifecycle cost savings with 2030 charge

IMPACTS: REPLACING OIL FURNACES ENERGY, & GHG EMISSIONS



Winnipeg

Oil: <1% of Homes

VCHP Savings:

- Energy ≈ -41%
- GHG Emissions ≈ -99%

CCHP Savings:

- Energy ≈ -44%
- GHG Emissions ≈ -99%

Halifax

Oil: 24% of Homes

VCHP Savings:

- Energy ≈ -46%
- GHG Emissions ≈ +15%*

CCHP Savings:

- Energy ≈ -51%
- GHG Emissions ≈ +4%*

Vancouver

Oil: <1 % of Homes

VCHP Savings:

- Energy ≈ -49 %
- GHG Emissions ≈ -95 %

CCHP Savings:

- Energy ≈ -57 %
- GHG Emissions ≈ -96 %

Toronto

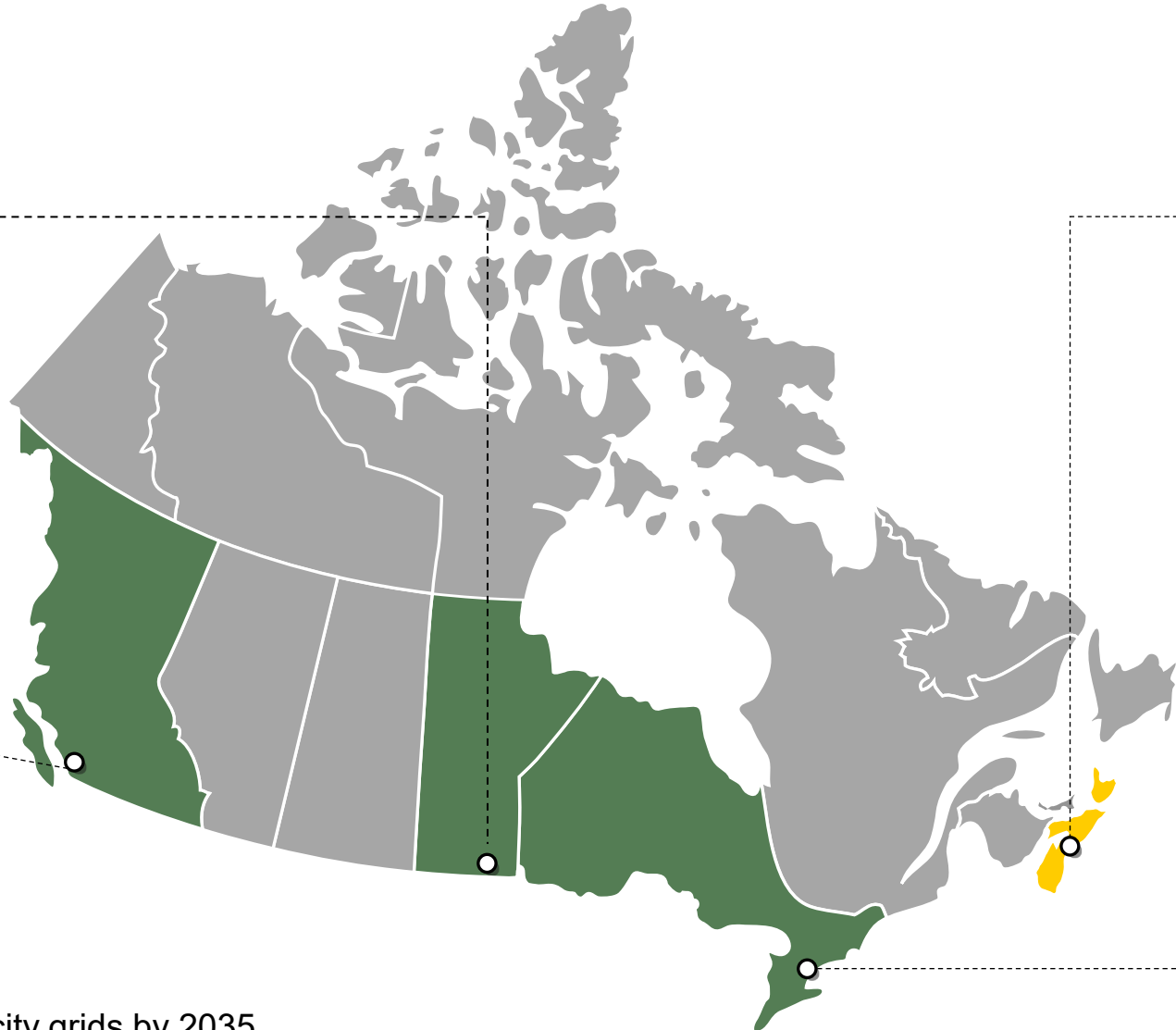
Oil: 2% of Homes:

VCHP Savings:

- Energy ≈ -43%
- GHG Emissions ≈ -92%

CCHP Savings:

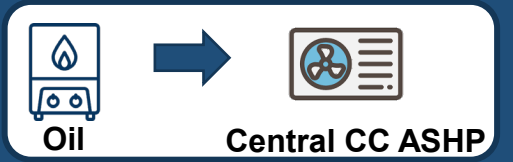
- Energy ≈ -48%
- GHG Emissions ≈ -93%



* Fed Govt.: Target Net-zero electricity grids by 2035

Note: Results dependant on utility rates & system costs used, and may change in future

IMPACTS: REPLACING OIL FURNACES LIFECYCLE COSTS OVER 20 YEARS



Winnipeg

Oil: <1% of Homes

VCHP

- Lifecycle Utility ≈ -70 %
- Lifecycle Total ≈ -54 %

CCHP

- Lifecycle Utility ≈ -71 %
- Lifecycle Total ≈ -54 %

Payback < 20 years

Vancouver

Oil: <1 % of Homes

VCHP

- Lifecycle Utility ≈ -65 %
- Lifecycle Total ≈ -54 %

CCHP

- Lifecycle Utility ≈ -72 %
- Lifecycle Total ≈ -56 %

Payback < 20 years

Halifax

Oil: 24% of Homes

VCHP

- Lifecycle Utility ≈ -52 %
- Lifecycle Total ≈ -43 %

CCHP

- Lifecycle Utility ≈ -57 %
- Lifecycle Total ≈ -44 %

Payback < 20 years

Toronto

Oil: 2% of Homes:

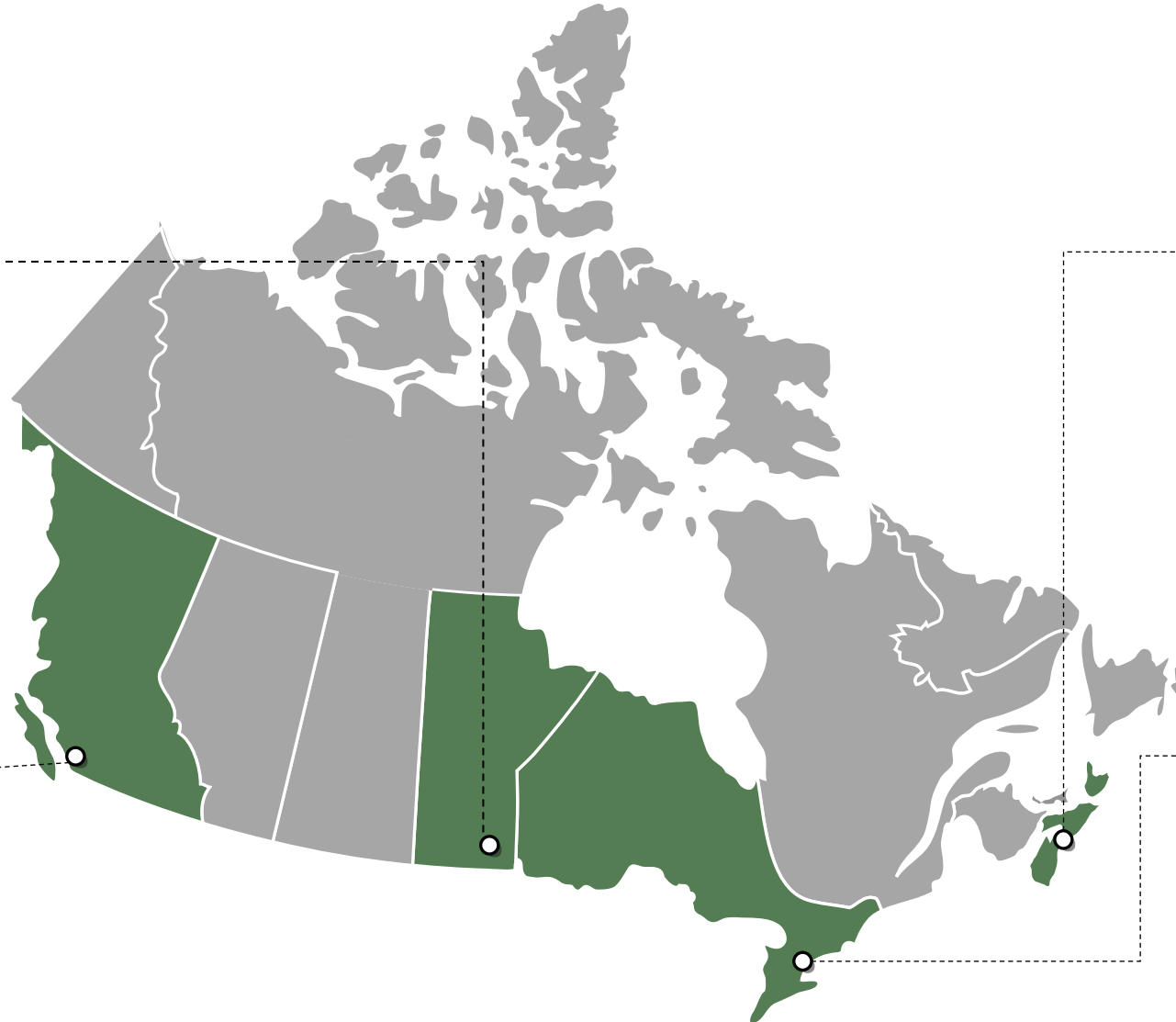
VCHP

- Lifecycle Utility ≈ -61 %
- Lifecycle Total ≈ -50 %

CCHP

- Lifecycle Utility ≈ -64 %
- Lifecycle Total ≈ -50 %

Payback < 20 years



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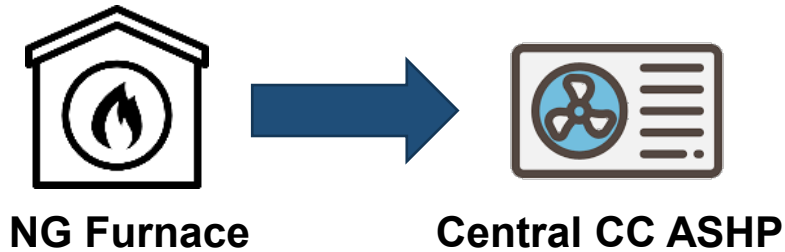
Note: Results dependant on utility rates & system costs used, and may change in future

Canada

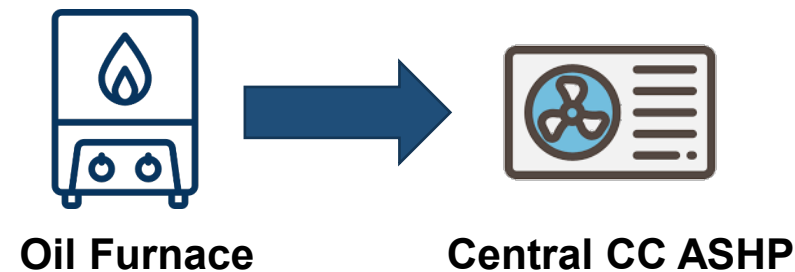
TAKEAWAYS

Air-source HPs in Canada: Key element of space heating decarbonisation

Energy, GHG, cost impacts depend on regional context, integration



Energy Use: Decrease in all cases ✓
GHG Emissions: Decrease in most regions* ✓
Utility Costs: Increase in all regions except Halifax
Savings under 2030 carbon charge rates ⚠



Energy Use: Decrease in all cases ✓
GHG Emissions: Decrease in most regions* ✓
Utility Costs: Decrease in all regions ✓

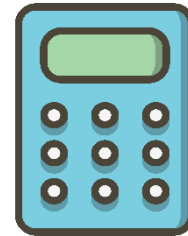
Transition from elec. BB to HP also yields energy, GHG, cost savings (outlined in paper) ✓

Note: Results dependant on utility rates & system costs used, and may change in future

* Fed Govt.: Target Net-zero electricity grids by 2035

WHAT OTHER BARRIERS EXIST?

Driving HP adoption also means considering other issues



How do systems actually perform?
Performance ratings for Canada

How can deployment be supported?
Training/guidance on HP integration
Support to codes, standards

Implications of large HP adoption
Grid impacts of HP adoption

CANADIAN R&D FOR NEXT GEN HP SYSTEMS



Peak Demand of HP Systems

HPs must be optimized to support peak management

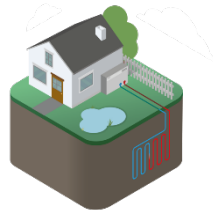
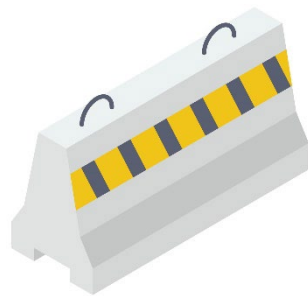
R&D Activity: HP + Thermal Storage systems (Grid Optimized HPs),
Advanced controls



Transition to Low-GWP Refrigerants

Transition to low-GWP refrigerants requires new solutions

R&D Activities: CO₂-based HP systems and thermal networks
Refrigerant mixtures for cold climates



First Cost of GSHPs

GSHPs are an efficient solution, but have high first cost

R&D Activity: Compact ground heat exchangers
CO₂ DX GSHPs

Canada 

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PRESENTATIONS IN THIS SESSION

Focus: **Better understanding of HP performance in residential buildings**

HpCosy - Heat Pump Comfort System

- *Christoph Messmer*, Robert Haberl, Kanchan Bohara, Michel Haller, Michele Zehnder, Ralph Eismann*

Performance evaluation of multi-functional cascade heat pump system for a residential building

- *Beom-Jun Kim, Hye-Jin Cho, Soo-Jin Lee, Taek-Don Kwon, Jae-Weon Jeong**

Heat pumps in existing heating and hot water systems: an evaluation of primary energy savings and reduction of CO2 produced

Alberta Carella, Luca Del Ferraro, Annunziata D'Orazio*

