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A techno-economic analysis of compact thermal energy storage technology: energy & cost savings, load-shifting potential, and 2030 cost targets

Enerstock 2021 – June 10, 2021 (A5 Climate)

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Canada

Outline

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  - Energy & Cost Savings
  - Load Shifting Abilities
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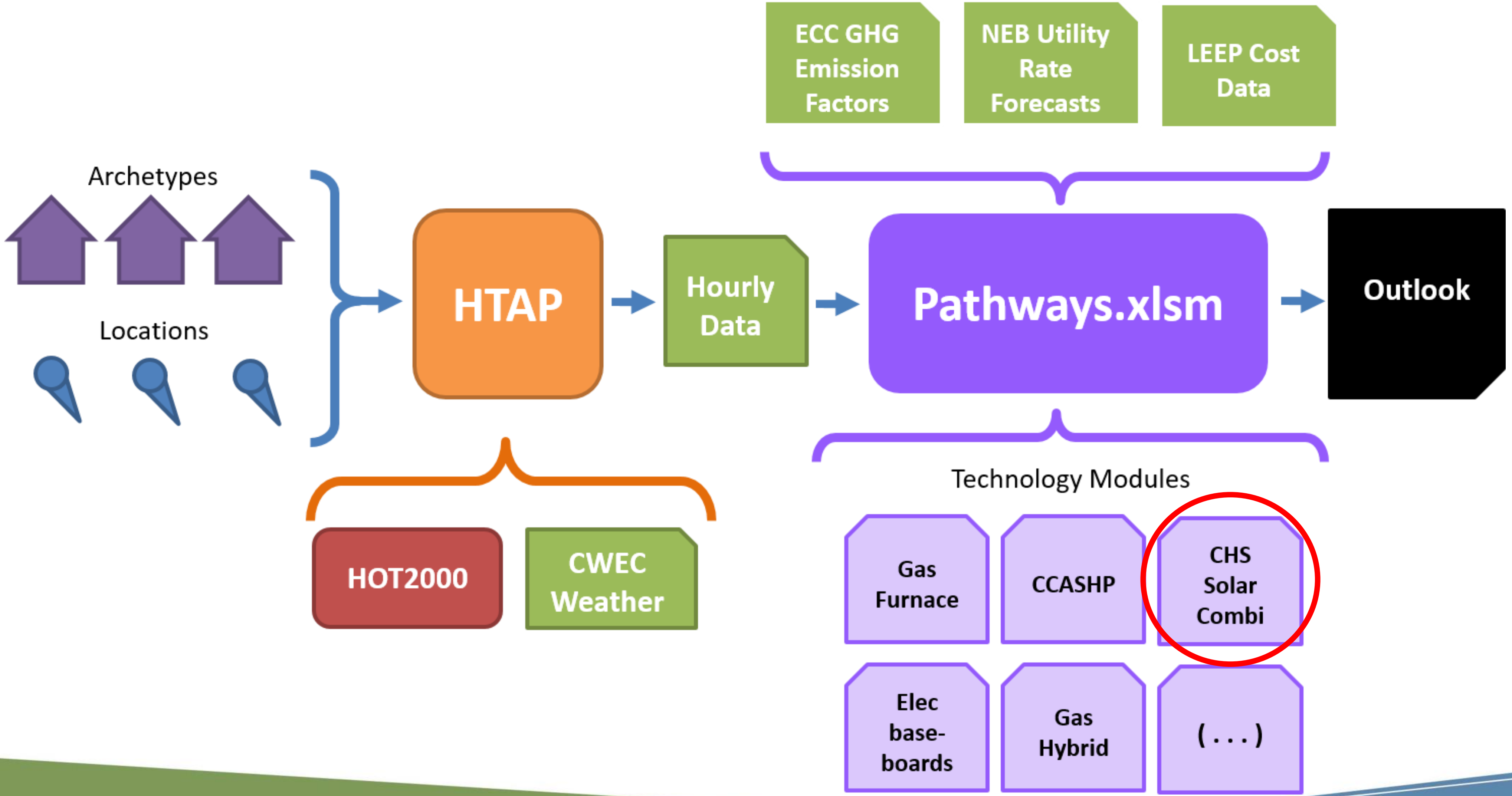
Research Questions

1. Could compact heat storage (**CHS**) technology **save energy & money** for Canadian households?
2. Could CHS technology support electrification by **shifting an electrified heating load** to off-peak times?
3. Which CHS system configurations appear promising?
4. **How much should a CHS system cost** to be viable relative to other heating technologies?

Modeling Approach



Economic Analysis – Net Present Cost (NPC)

- Net Present Cost (NPC) is the **target capital cost of the CHS in 2030** to break even and compete with reference technologies over a **20 year** lifespan.

Net Present Cost (NPC)

$$NPC = C_{\text{installation}} + \sum_{i=0}^{L} \frac{B_{\text{util},i}}{(1+r)^i}$$

Where:

- NPC is the net present cost (that is, the present value of all costs to the homeowner over the life of the equipment)
- $C_{\text{installation}}$ is the installation cost,
- $B_{\text{util},i}$ is the annual cost of all utilities in year i,
- r is the discount rate (3%), and
- L is the lifespan of the measure (20 years)

Economic Analysis – Capital Costs

Capital Costs

$$
\begin{aligned}
C_{\text{installation}} &= C_{\text{CHS}} + C_{\text{BOP}} \\
&= C_{\text{CHS}} + (C_{\text{air handler}} + C_{\text{aux. heater}} + \dots)_{\text{BOP}}
\end{aligned}
$$

Where:

$C_{\text{installation}}$ is the total installation cost,

C_{CHS} is the installation cost of the compact heat storage module,

C_{BOP} is the total installation of the balance of plant,

$C_{\text{air handler}}$, $C_{\text{aux.heater}}$, ... are the installation costs of conventional residential heating and cooling equipment that make up the balance of plant (BOP)

- We don't know how much a CHS module will cost, but we have good data from LEEP for **costing the balance of plant components**.
- Cost of individual **CHS components** (**thermochemical materials**, heat exchangers, vessel, valves and fittings, controls, etc.) were estimated.

Economic Analysis – Utility Costs

- HTAP used to **predict annual energy consumption** for reference and CHS techology scenarios.
- The NEB's residential energy price forecasts help us **predict the cost** of this energy in each year till 2040.

Utility Costs

$$B_{\text{util},i} = E_{\text{elec}} R_{\text{elec},i} + E_{\text{gas}} R_{\text{gas},i} + E_{\text{oil}} R_{\text{oil},i}$$

Where:

- $B_{\text{util},i}$ is the annual cost all utilities in year i,
- E_{elec}, E_{gas}, and E_{oil} are the annual consumption of electricity, gas and oil as computed by HTAP,
- $R_{\text{elec},i}$, $R_{\text{gas},i}$, and $R_{\text{oil},i}$ are the provincial rates for of electricity, gas and oil, as forecasted by Canada's National Energy Board, for year i.

Economic Analysis – Target Cost of CHS

- NPC of CHS must be ≤ NPC of reference technology.
- Substitute cost of installation and solve for cost of CHS.

Cost Targets for CHS Technology

1. Assume that the net present cost of the CHS system must be less than or equal to the NPC for a reference scenario:

$$NPC_{\text{CHS case}} \leq NPC_{\text{reference}}$$

2. Substituting:

$$\left(C_{\text{CHS}} + C_{\text{BOP}} + \sum_{i=0}^{L} \frac{B_{\text{util,i}}}{(1+r)^i}\right)_{\text{CHS case}} \leq \left(C_{\text{reference}} + \sum_{i=0}^{L} \frac{B_{\text{util,i}}}{(1+r)^i}\right)_{\text{reference}}$$

3. And solving for C_{CHS}:

$$C_{\text{CHS}} \leq \left(C_{\text{reference}} + \sum_{i=0}^{L} \frac{B_{\text{util,i}}}{(1+r)^i}\right)_{\text{reference}} - \left(C_{\text{BOP}} + \sum_{i=0}^{L} \frac{B_{\text{util,i}}}{(1+r)^i}\right)_{\text{CHS case}}$$

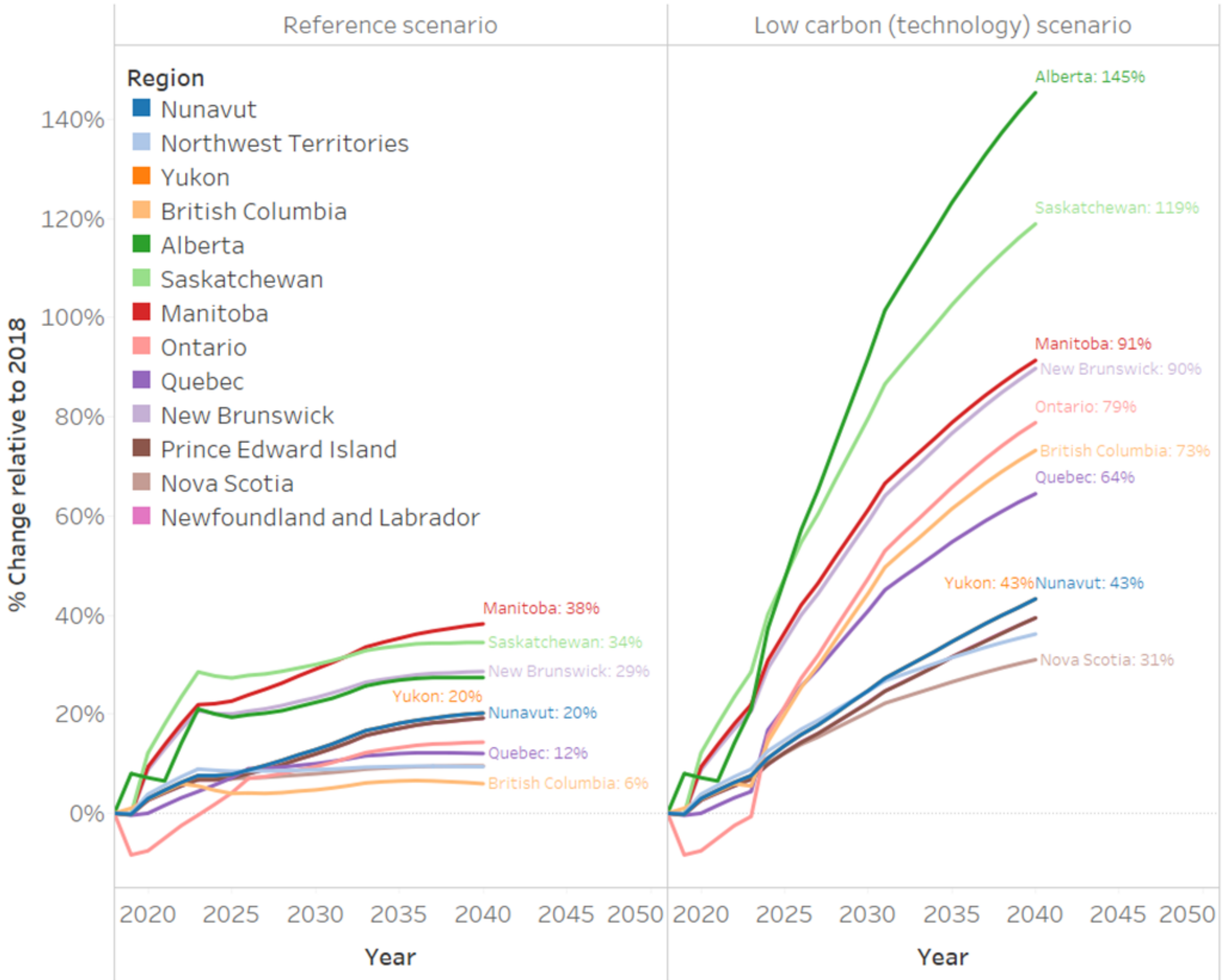
Energy Price: Time-Of-Use for Electricity

	IESO Regime		Proposed		
Hour of the day	Summer	Winter	Summer	Winter	Heating (W)
0	off-peak	off-peak	off-peak	mid-peak	7817 |====]
1	off-peak	off-peak	off-peak	mid-peak	8006 |=====]
2	off-peak	off-peak	off-peak	mid-peak	8315 |======]
3	off-peak	off-peak	off-peak	mid-peak	8481 |=======]
4	off-peak	off-peak	off-peak	mid-peak	8650 |=======]
5	off-peak	off-peak	off-peak	on-peak	8730 |=======]
6	off-peak	off-peak	off-peak	on-peak	8809 |========]
7	mid-peak	on-peak	mid-peak	on-peak	8889 |========]
8	mid-peak	on-peak	mid-peak	on-peak	8811 |========]
9	mid-peak	on-peak	mid-peak	on-peak	8455 |=======]
10	mid-peak	on-peak	mid-peak	on-peak	7971 |=====]
11	on-peak	mid-peak	on-peak	mid-peak	7406 |===]
12	on-peak	mid-peak	on-peak	off-peak	6877 |=]
13	on-peak	mid-peak	on-peak	off-peak	6649 |=]
14	on-peak	mid-peak	on-peak	off-peak	6558 |]
15	on-peak	mid-peak	on-peak	off-peak	6491 |]
16	on-peak	mid-peak	on-peak	off-peak	6661 |=]
17	mid-peak	on-peak	mid-peak	off-peak	6928 |=]
18	mid-peak	on-peak	mid-peak	off-peak	6933 |=]
19	off-peak	off-peak	off-peak	off-peak	7001 |==]
20	off-peak	off-peak	off-peak	off-peak	7121 |==]
21	off-peak	off-peak	off-peak	off-peak	7269 |===]
22	off-peak	off-peak	off-peak	off-peak	7454 |===]
23	off-peak	off-peak	off-peak	off-peak	7516 |===]

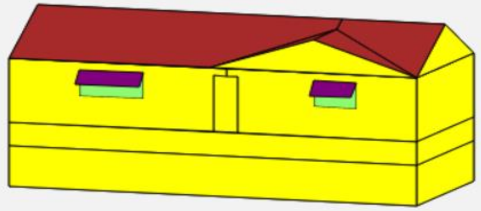
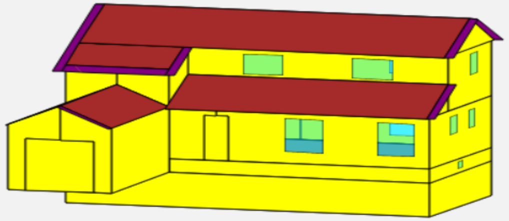
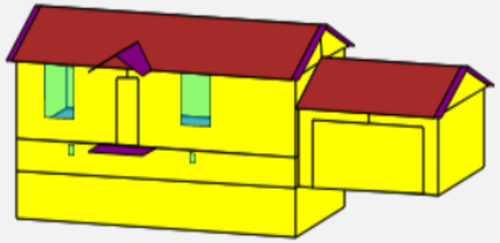
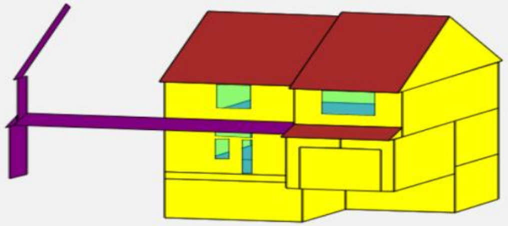
- Evaluated **current IESO** time-of-use (TOU) regimes , and **proposed** an alternate hypothetical TOU regime that would increase electricity prices **when heating demands are highest**.
- **Proposed regime** reflects guidance from electrification experts on **how utilities might respond** to uptake in heat pumps and electric vehicles.
- **Heating rate (W)** is the 95th percentile load for space and DHW heating of a select home archetype and location.

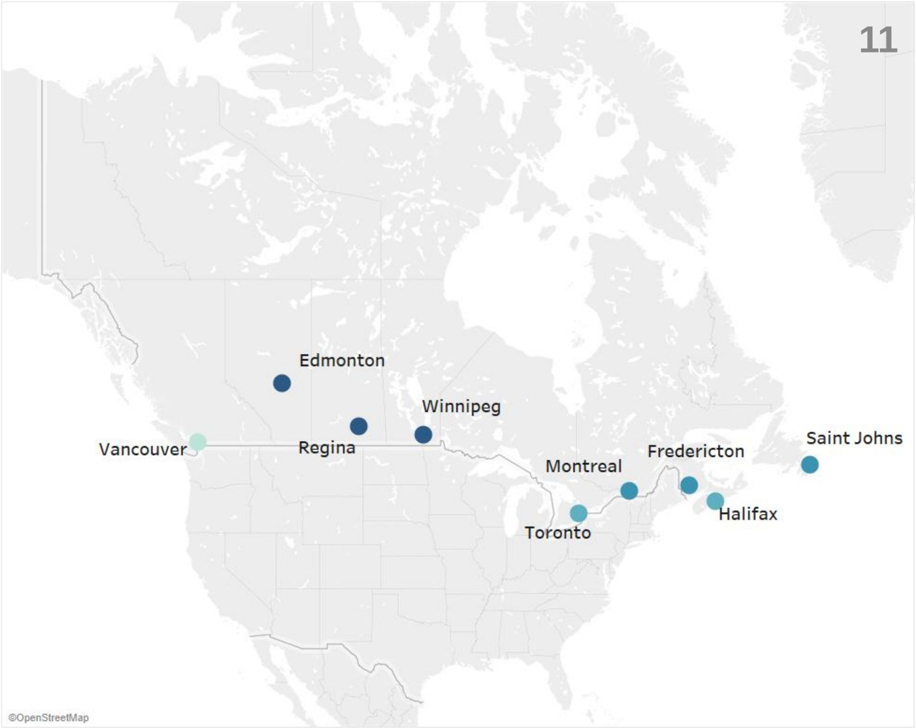
NEB 2040 Natural Gas Price Forecasts

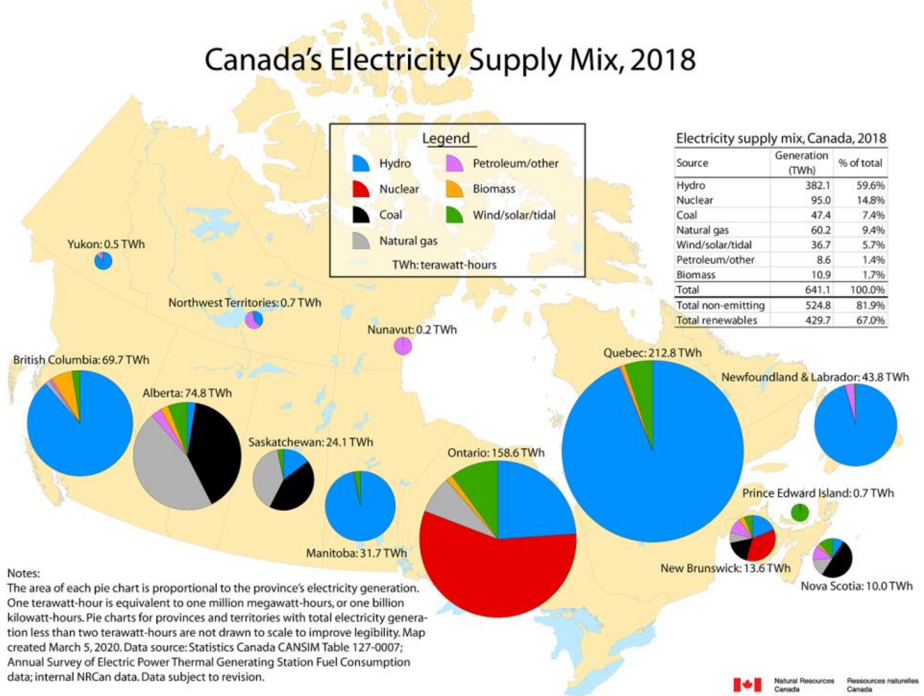
- **Reference Case:** NEB's best guess, based on published provincial policies (including carbon pricing), and macro-economic modeling.
- **High-Escalation:** NEB adjusts reference case assumptions to reflect reduced energy supply.
- **Low-Carbon (Technology):** Reflects global shift towards low-carbon economy via international carbon pricing, renewable energy uptake, electrification initiatives.



Locations & Home Archetypes

Home Archetype	
Pre 1980's (Oil) Single detached, single storey home (bungalow) with basement	
Post 1980's (Gas) Single detached, two storey home with basement and attached garage	
Post 1980's (Electric) Single detached, single storey home (bungalow) with basement and attached garage	
Net-Zero Energy Ready (NZE-R) Middle unit townhome, two storeys with basement and attached garage	



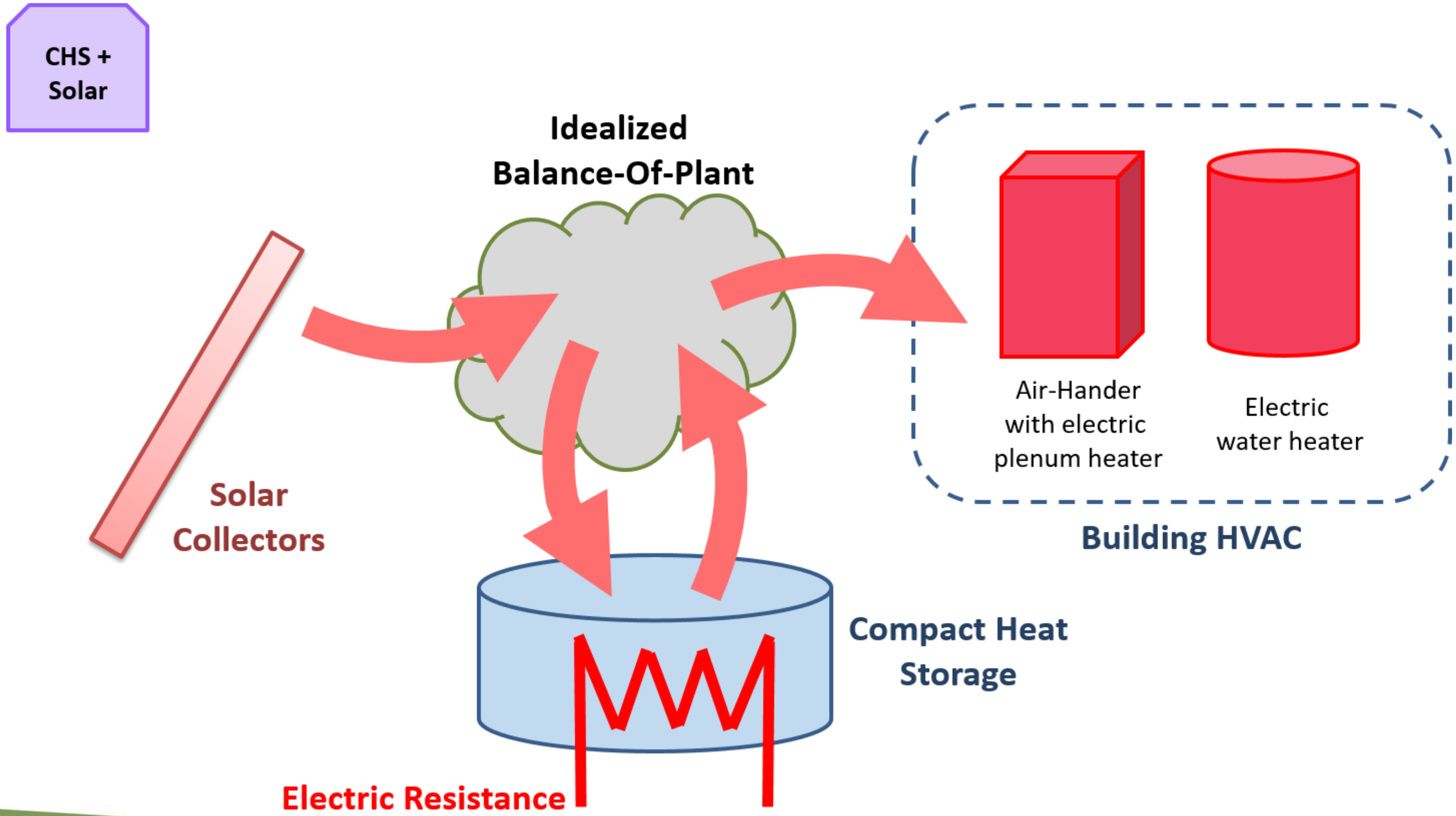


Electricity supply mix, Canada, 2018

Source	Generation (TWh)	% of total
Hydro	382.1	59.6%
Nuclear	95.0	14.8%
Coal	47.4	7.4%
Natural gas	60.2	9.4%
Wind/solar/tidal	36.7	5.7%
Petroleum/other	8.6	1.4%
Biomass	10.9	1.7%
Total	641.1	100.0%
Total non-emitting	524.8	81.9%
Total renewables	429.7	67.0%

Notes:
The area of each pie chart is proportional to the province's electricity generation. One terawatt-hour is equivalent to one million megawatt-hours, or one billion kilowatt-hours. Pie charts for provinces and territories with total electricity generation less than two terawatt-hours are not drawn to scale to improve legibility. Map created March 5, 2020. Data source: Statistics Canada CANSIM Table 127-0007; Annual Survey of Electric Power Thermal Generating Station Fuel Consumption data; internal NRCan data. Data subject to revision.

Example Schematic of Technology Module



CHS + Solar

Key Assumptions

1. Balance of plant supplies space heat (air-handler) and domestic hot water (water tank) .
2. Combi-systems: Collectors can supply CHS and Load simultaneously.
3. Heat Pump (HP) and CHS cannot both heat at same time.
4. Electrical resistance charges CHS at 100% efficiency.
5. CHS can switch from charging to discharging (and vice-versa) on demand.
6. Maximum discharge rate: 10 kW; minimum discharge rate: 0 W.
7. CHS can't charge & discharge at the same time.

VARIANT: SOLAR COMBI		
Solar Collector		
Generation per m2	2.70	GJ/m2
Area	10.0	m2
Efficiency - eta 0	0.73	
a1	0.5561	
a2	0.0061	
Inlet temp	40	°C
Outlet temp	70	°C
Compact heat storage (CHS)		
Energy Density	1.25	GJ/m^3
Size	1.0	m^3
Charge		
Max rate	10,000.00	W
Efficiency	70%	
Element power	8,894	w
Discharge		
Max Rate	17,000.00	W
Efficiency	100%	
Storage state on Jan 1	98%	Dec 31: 67%

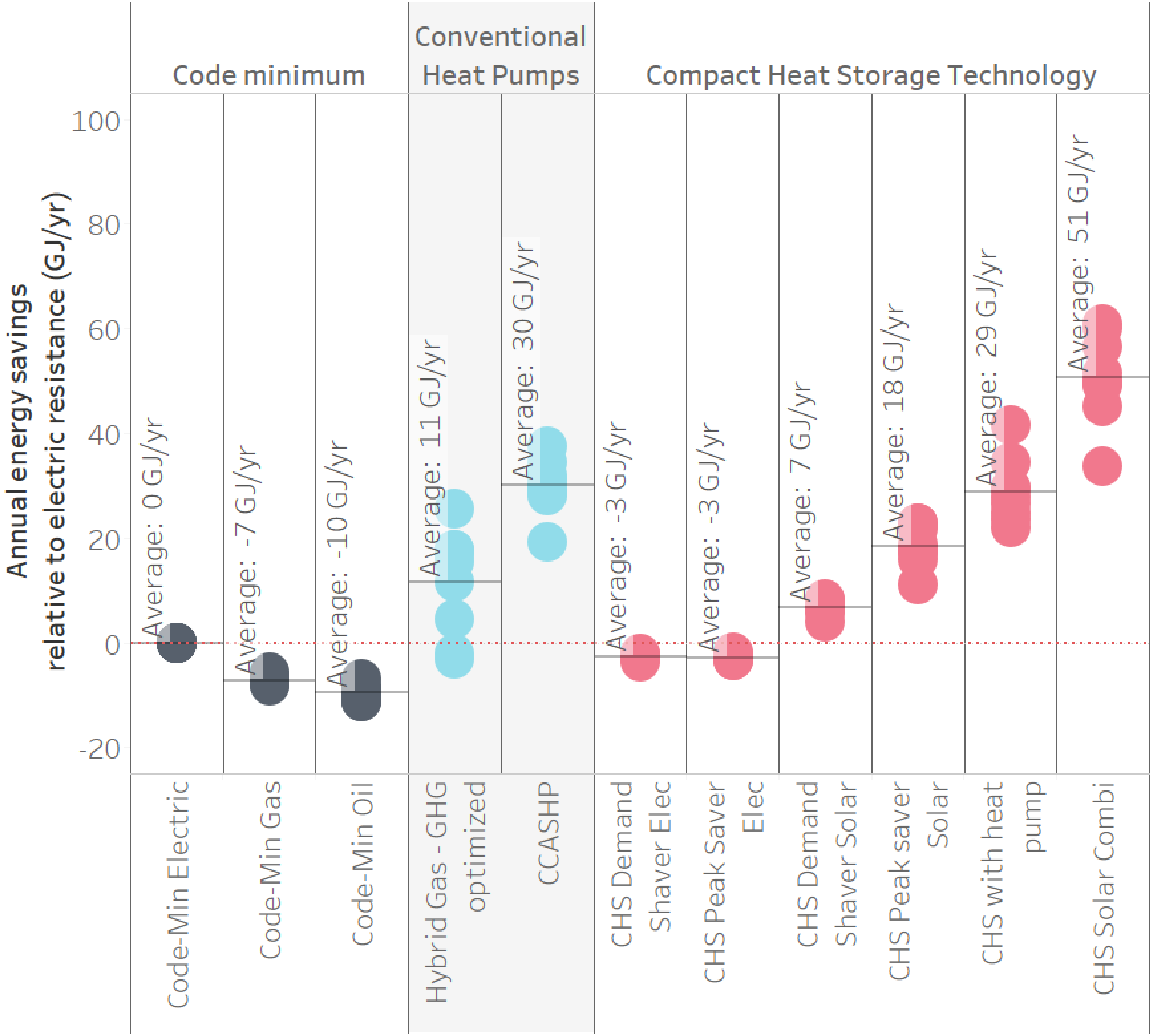
Key Assumptions (continued)

- Specifications of solar thermal collector(s)
- Size and energy density of CHS systems
- CHS charge and discharge rate & efficiency
- Performance map used for regular air-source heat pump (HP) and cold climate air-source HP (CCASHP).

CHS + Solar

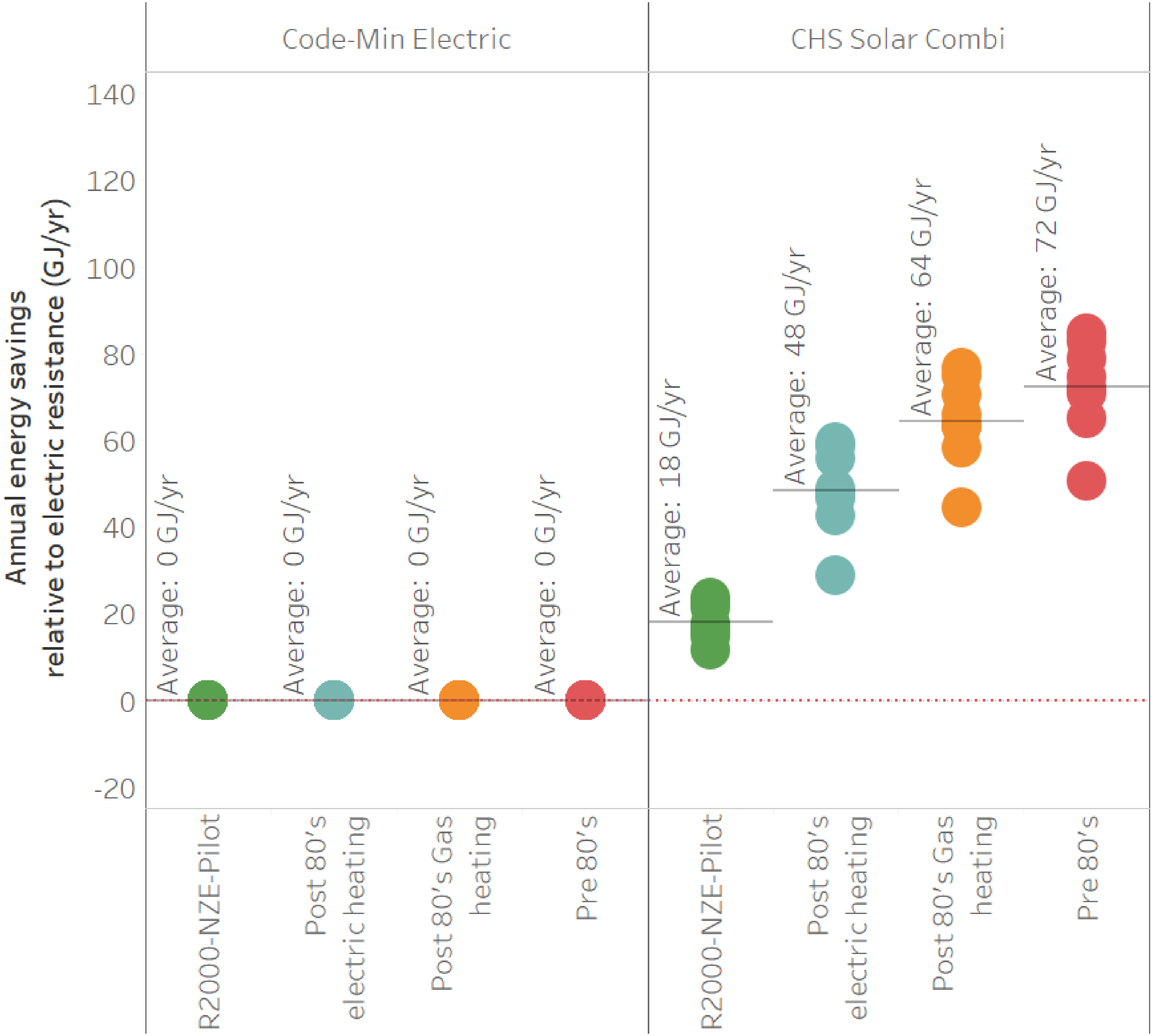
CHS Scenarios

Strategy	Electric Resistance	Solar	Heat Pump
Energy Saver	—	✓ Solar & CHS sized to maximize solar fraction	✓ CHS operated to minimize back-up energy
Peak saver	✓ 1 m³ CHS charges in off-peak, discharges on-peak	✓ Solar & CHS sized to on-peak load	—
Demand Saver	✓ 1 m³ CHS charges in off-peak, discharges when heating demand exceeds 7 kW	✓ Solar & CHS sized to 50 % of on-peak load	—



Energy Savings

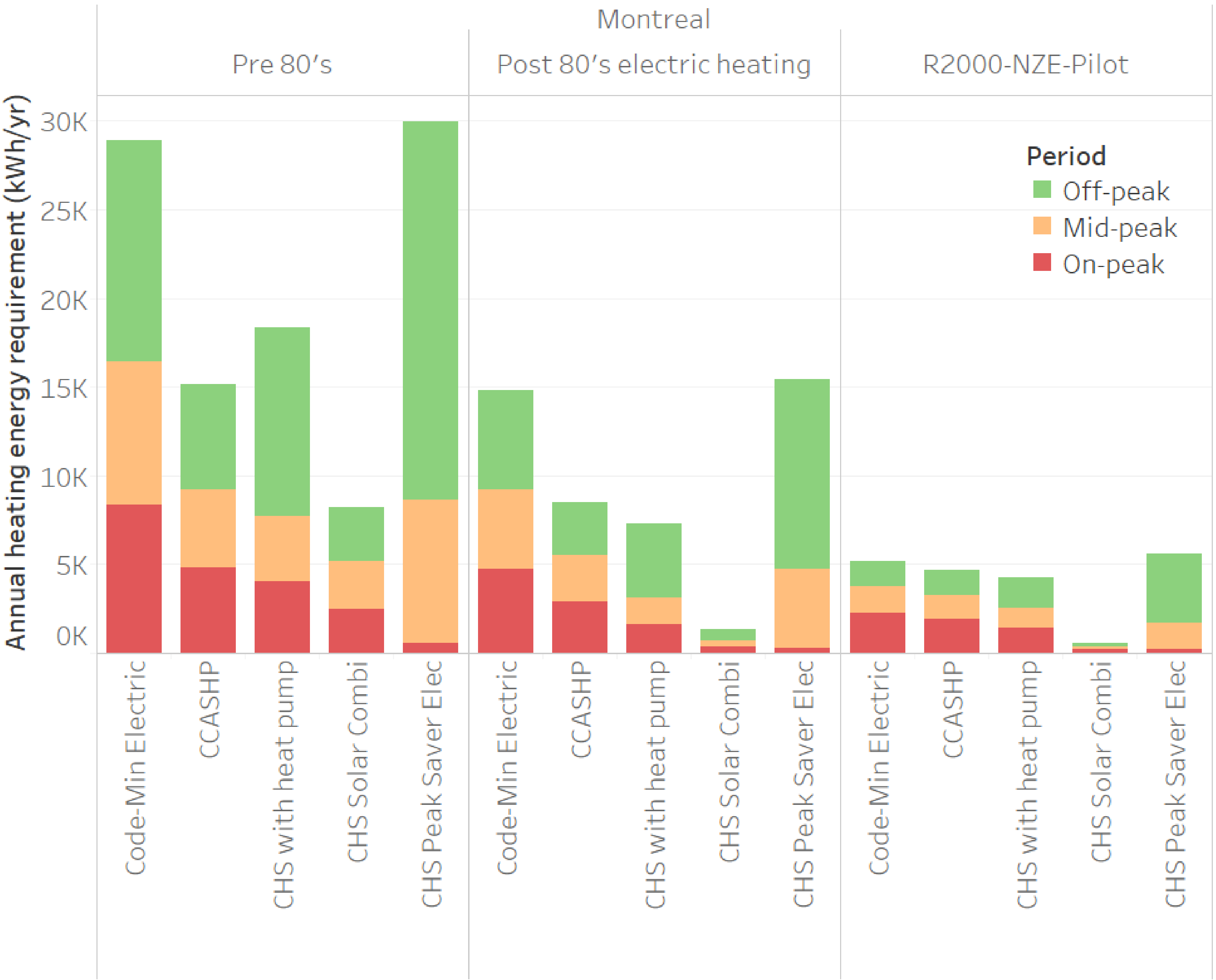
- Systems with HPs and solar save the most energy.
- Standalone CHS systems charged by electric resistance may not provide total energy savings on an annual basis.



Energy Savings: Impact of Archetype & Location

- Archetype & Location affect how much energy can be saved: technology has more savings potential in colder regions and in older, less efficient housing.

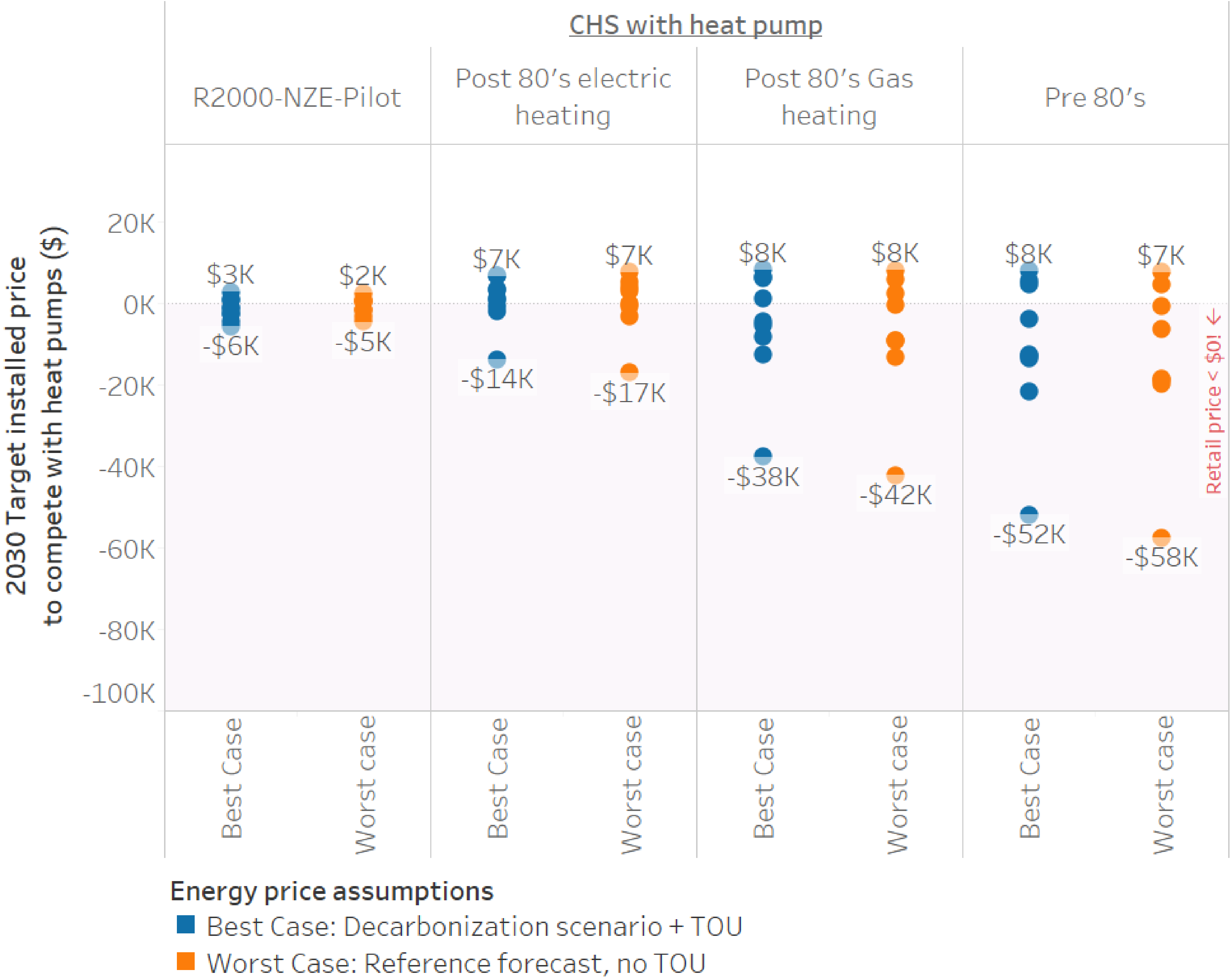
Load Shifting



- For hypothetical night-time TOU regime, CHS technology consumes less on-peak electricity.
- When controlled to minimize on-peak use, simple CHS + electric resistance systems could reduce on-peak demand by up to 90%.

Compact Heat Storage Integration Strategies

	+Solar	+Heat Pump	+Elec. Resistance
Savings Potential	**High**	**Medium**	**Nil**
Load Shifting Potential	**Very High**	**Very High**	**Very High**
Target Markets	**Atlantic Canada**	**ON, MB, BC Interior**	**QC, BC lower mainland, NZE-Ready housing**

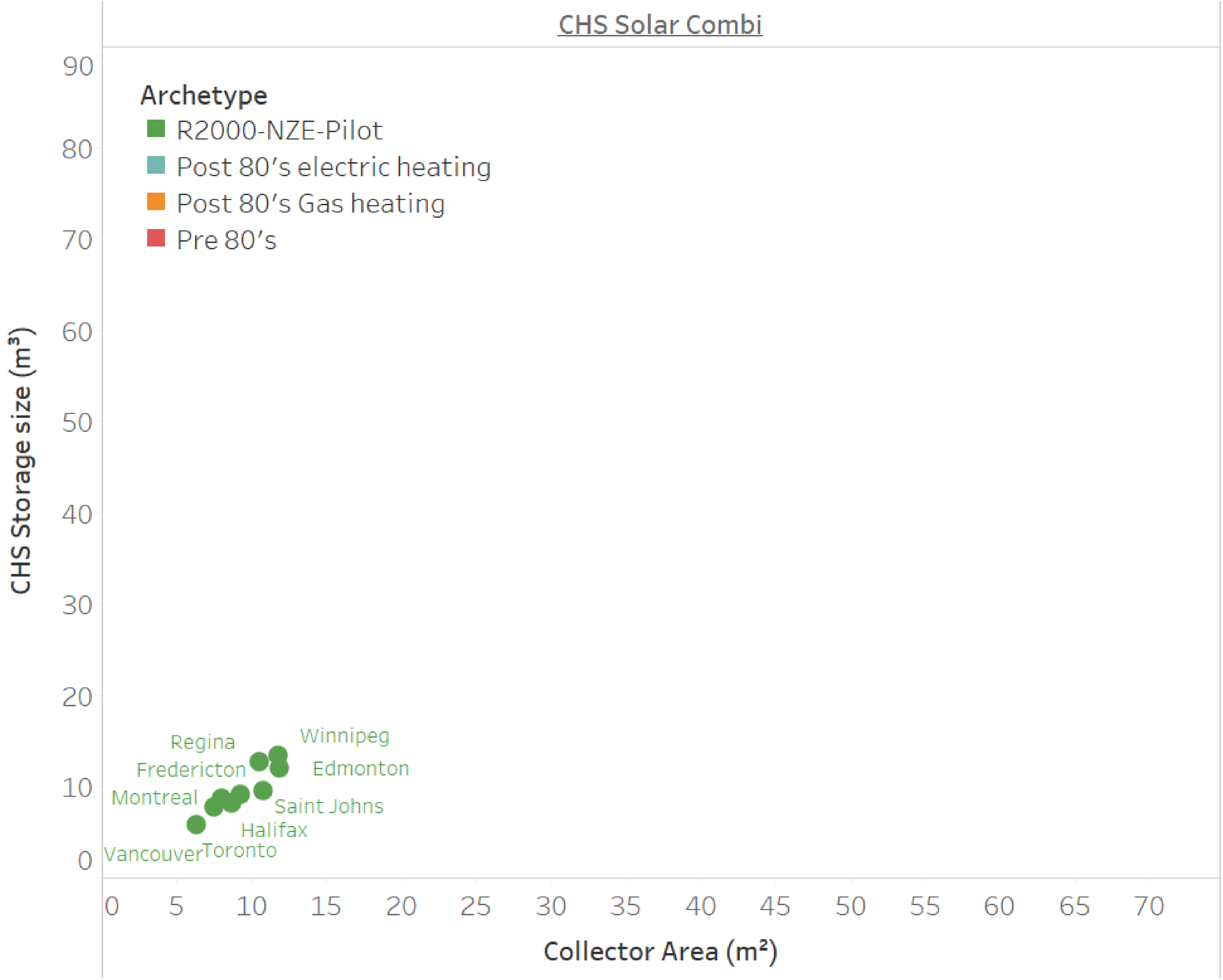


CHS + Heat Pump

Scope:	COSTED IN BOP:
CHS	Heat Pump
	Indoor unit
	Aux. heater
	Water heater
	HRV
	200A service

- If a 1 m³ CHS system can be installed alongside a heat pump for $5-8k it will compete with stand-alone heat pumps in Atlantic Canada and QC.

CHS + Solar Combi System Sizes



NZE-Ready:

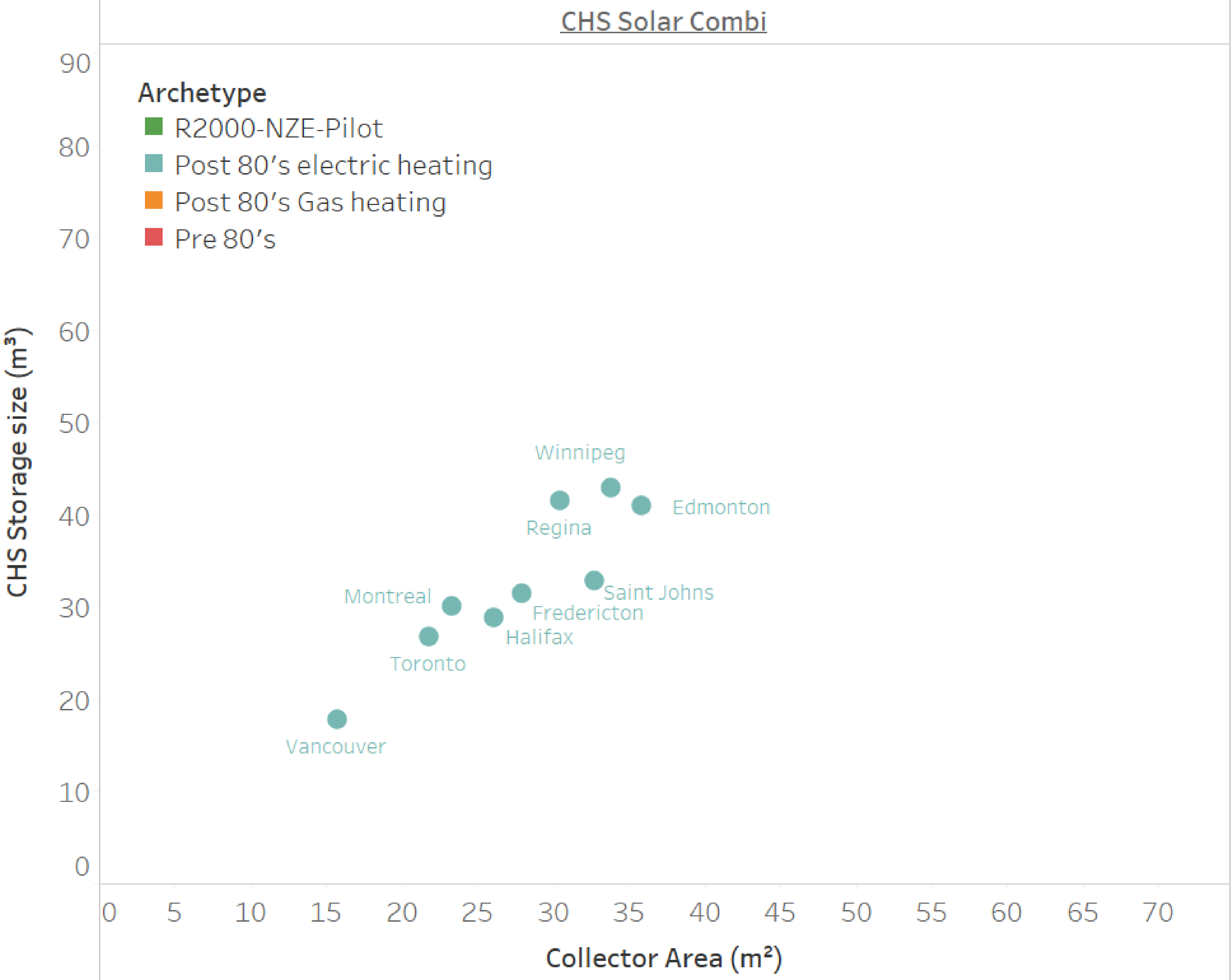
Sizes are likely practical in new NZE-R homes:

- Collectors: 6-12 m^2
- CHS: 6-13 m^3

(Cost target: $14-18k CAD)

- These systems are smaller than some of the solar combi units installed in the EQuilibrium NZE pilots.

CHS + Solar Combi System Sizes



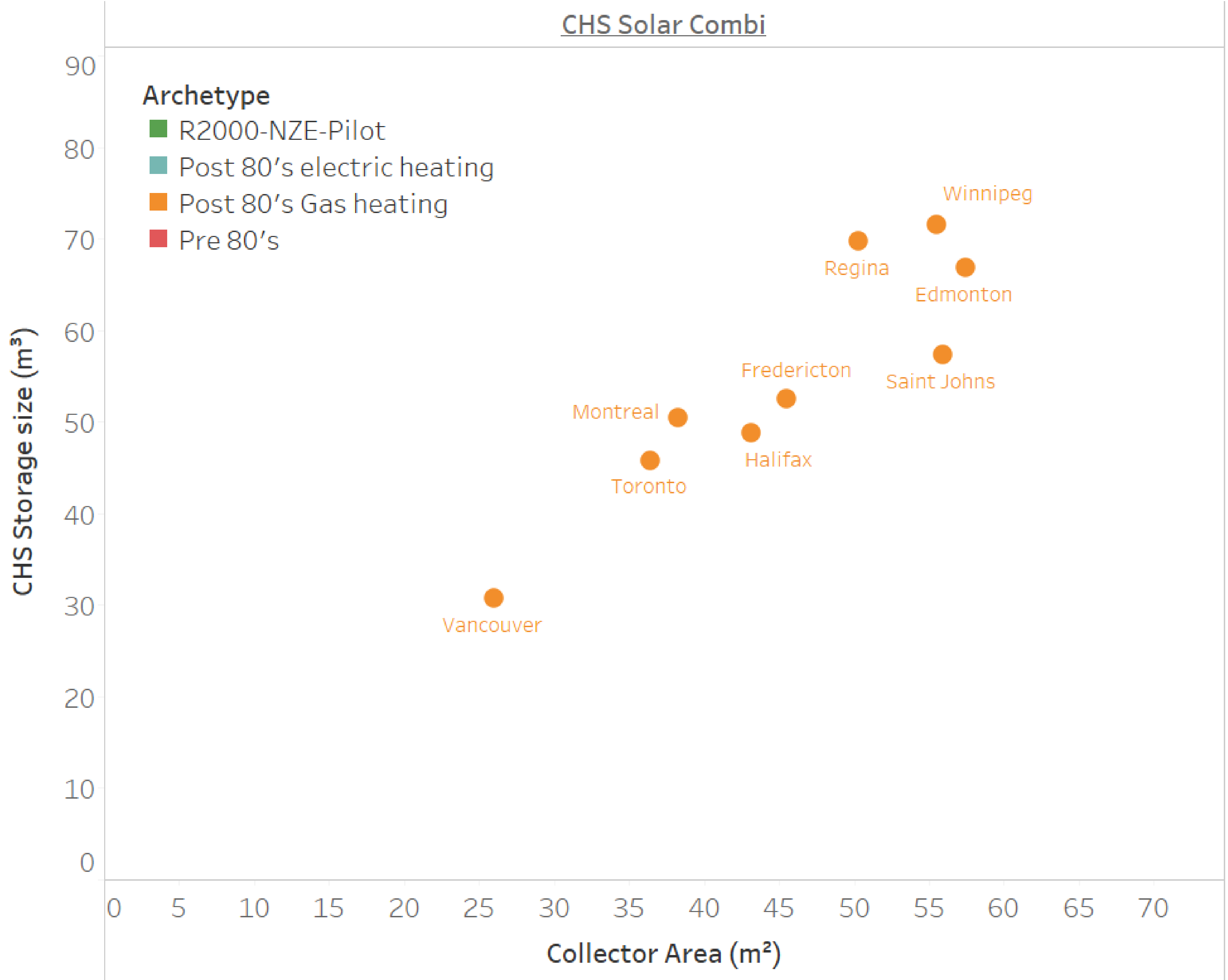
Post-80's electric:
Sizes are unwieldy in smaller, code-built homes

- Collectors: 15-35 m^2
- CHS: 18-42 m^3

(Cost target: $17-28K)

These systems are larger than combi-systems used in prior NZE demos, and are probably only practical in new construction.

CHS + Solar Combi System Sizes



Post 80's Gas:

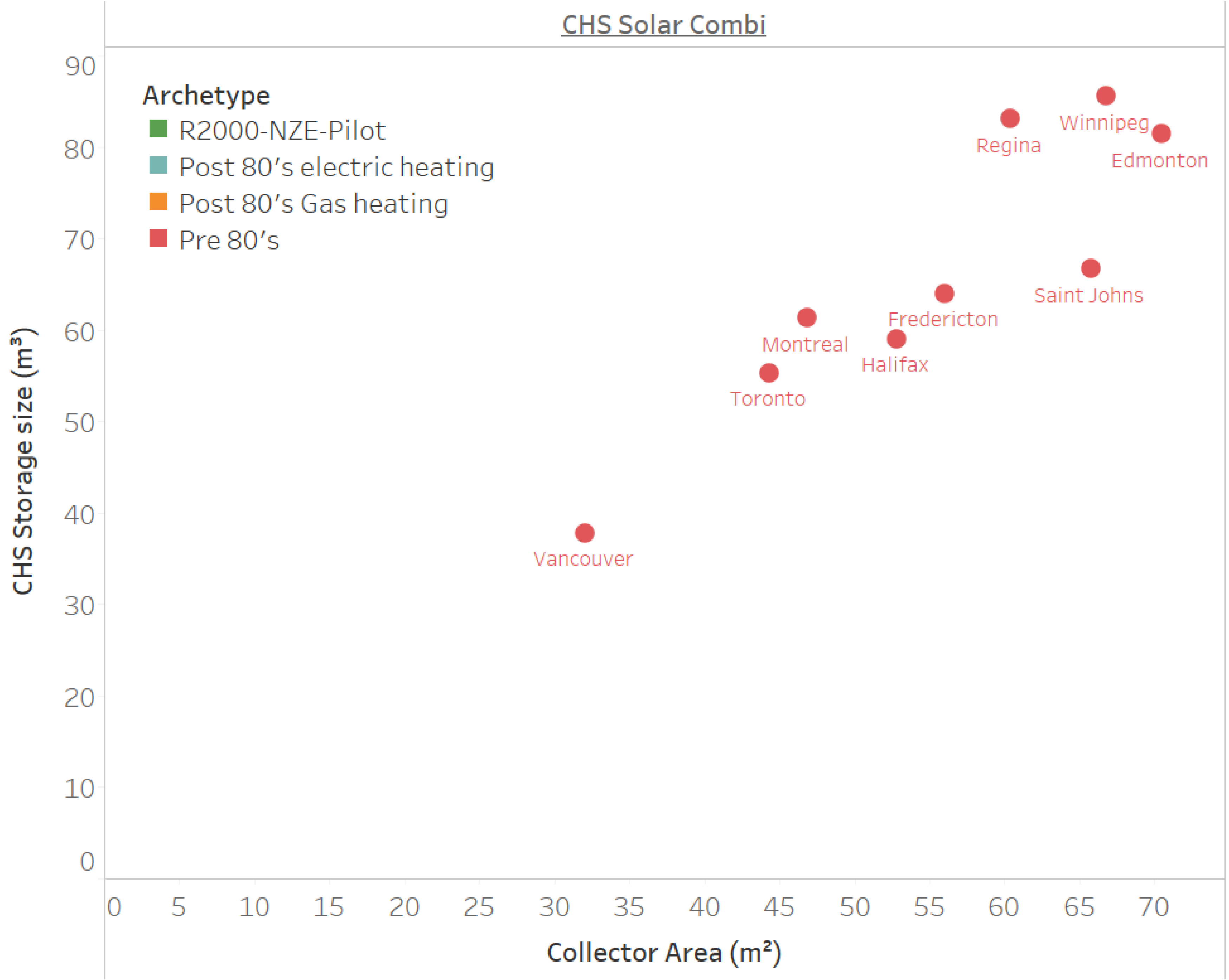
Sizes are likely impractical in new construction, unachievable in retrofit.

- Collectors: 26-57 m^2
- CHS: 30-71 m^3

(Cost target: $4-25K)

Collectors are now covering 50+% of available roof area; CHS occupies 10% of home volume.

CHS + Solar Combi System Sizes



Pre-80's:

Sizes are implausible in any application – especially retrofit.

- Collectors: 32-70 m^2
- CHS: 37-85 m^3

(Cost target: up to $25K)

Conclusions

- Compact heat storage technology promises **significant energy and utility bill savings**. GHG impacts will be region-dependant.
- CHS shows **good potential for shifting loads** to from high-demand to low-demand periods, and could be a **useful tool for clean electrification**.
- **Low-energy homes** and new NZE-R construction are good applications for **CHS** when integrated with **electric resistance** and **solar collectors**.
- **CHS** technology is attractive in **older homes** when integrated alongside **heat pumps**.
- Cost targets for 1m^3 stand-alone CHS: **$4-8k CAD**.
- **Next steps:** laboratory & field trials to validate dynamic performance models and confirm above results.

Thank you!
Merci!

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