# Canada's Climate Retrofit Mission

## Why the climate emergency demands an innovation-oriented policy for building retrofits

Brendan Haley and Ralph Torrie

June 2021

Efficiency Canada
Carleton University

# Canada’s Climate Retrofit Mission

*Why the climate emergency demands an innovation-oriented policy for building retrofits*

Brendan Haley, Ralph Torrie

c/o Carleton University
1125 Colonel By Drive
Ottawa, ON K1S 5B6
https://efficiencycanada.org

Facebook: https://facebook.com/EfficiencyCanada
Twitter: https://twitter.com/EfficiencyCAN
LinkedIn: https://linkedin.com/company/efficiency-canada
Instagram: https://instagram.com/efficiencycanada

# Table of Contents

# About the Authors

**Brendan Haley** has been Efficiency Canada's policy director since the organization's launch in 2018. Brendan oversees research and advocacy efforts and led the development of Canada's first provincial energy efficiency policy scorecard and database. His advocacy for energy efficiency in Nova Scotia while energy coordinator at the Ecology Action Centre led to the creation of Canada's first energy efficiency utility. Brendan has a PhD in public policy from Carleton University where his research combined insights from Canadian policy economy and technological innovation system frameworks to examine complementary interactions between traditional natural resource sectors and low-carbon technologies. He has written on sustainability transitions, innovation and industrial policy for several organizations, including the Smart Prosperity Institute, the Canadian Centre for Policy Alternatives, the Pembina Institute, the Broadbent Institute. He was awarded the prestigious Banting Post-Doctoral Fellowship from 2016-2018 and holds a master's in environmental studies from York University and a BSc in economics from Dalhousie University.

**Ralph Torrie** is President of Torrie Smith Associates and the Director of Research at Corporate Knights since April 2021. Ralph has been working in the area of sustainable energy futures since the late 1970's and his low carbon scenario analysis for Canada was the first such study in the world. He is the inventor of strategic planning software for local government climate mitigation that was used by hundreds of cities on five continents. In addition to his consulting practice, he served as Assistant Coordinator of the Energy Research Group of the United Nations University and the International Development Research Centre, as a senior executive of two publicly-traded management consulting firms, and as Managing Director of the Trottier Energy Futures project. He has numerous publications, is a frequent keynote speaker, and is a recipient of the Canadian Environment Silver Award for his work on climate change.

# Acknowledgments

This report was made possible through the support of the Sitka Foundation, Ivey Foundation, Trottier Foundation, and the J.W. McConnell Foundation. The idea for the report originated in the spring of 2020 when discussions on recovery from the pandemic spurred big thinking. Initial retrofit program modeling was conducted as part of the Build Back Better series of reports and conversations sponsored by Corporate Knights. Early policy proposals were also developed for the Task Force for a Resilient Recovery.

The authors gratefully acknowledge reviewers who gave generously of their time to review draft versions of the report. Their constructive feedback resulted in significant revisions and, we hope, improvements. We hope that the conversations started during the review process will continue as we work together to reframe our approach to building retrofits in response to the climate emergency. Any errors or omissions are the responsibility of the authors. The following reviewers acted in their personal capacities, and we list organizational affiliations for identification purposes. Peter Amerongen (Butterwick Building Company and Retrofit Canada); Mitchell Beer (The Energy Mix); Adam Cohen (Passive Buildings Canada & Human Nest Project); Jen Hancock & Tim Coldwell (Chandos Construction); Fatima Crerar & Bryan Purcell (The Atmospheric Fund); Jason Dion (Canadian Institute for Climate Choices); Chuck Faulker & Ryan Kelly (EfficiencyOne); Tom-Pierre Frappé-Sénéclauze, Betsy Agar, Madi Kennedy (Pembina Institute), James Meadowcroft (Carleton University & The Transition Accelerator), Sheldon Mendonca (Rocky Mountain Institute), Steve Nadel (American Council for an Energy Efficient Economy), Emma Norton (ReCover Initiative), Mike Singleton (Sustainable Buildings Canada), Mark Carver & Philippe St-Jean (Natural Resources Canada), Donna Vakalis (Sustainability Solutions Group), George Benson (Vancouver Economic Commission), Roger Peters (CoEnergy Ontario Co-operative), James Gaede, Kevin Lockhart, Corey Diamond (Efficiency Canada).

**Suggested Citation**

Haley, Brendan & Ralph Torrie. 2021. *Canada's Climate Retrofit Mission.* Ottawa: Efficiency Canada.

# Introduction

The climate emergency requires the deployment of zero-carbon solutions at an unprecedented scale, speed, and level of performance. This is particularly urgent in the existing buildings where we live, work, play, and convene. The urgency lies in the need to eliminate fossil fuel use in buildings themselves, while also achieving energy savings to free up Canada's existing renewable energy resources to decarbonize other sectors, such as transportation, industry, and heating in new buildings.

We will not achieve the required greenhouse gas (GHG) and energy efficiency performance from our existing building stock by working within current market structures and policy approaches. Rather than making each retrofit a single project and the responsibility of individual building owners, policymakers must understand the energy efficiency and GHG savings potential from treating buildings as public infrastructure. This perspective invites us to value the national level systemic and societal benefits of retrofitting buildings on a scale and at a pace that is responsive to the climate emergency.

Deploying retrofits at infrastructure scale requires a mission-oriented policy approach, which establishes ambitious goals and invites a bottom-up search for replicable emission reducing retrofit solutions. These solutions will require reshaping the structure of existing retrofit markets to create economies of scale and learning. They will involve the use of new technologies such as prefabricated building façades and all-in-one HVAC systems.

However, new business models and organizational systems are likely to be most important. The new technological and organizational combinations in these retrofit solutions need to achieve larger GHG and energy savings, faster, at lower cost, while increasing the services buildings provide to occupants.

In this report, we define the contours of a climate retrofit mission for Canada. We quantify the retrofit potential and demonstrate the scale required to confront the climate emergency. We consider why the current market and policy structures for building retrofits must be transformed and review promising models and innovation pathways. We then apply a "mission oriented" policy framework to the building retrofit challenge. We define the mission and then propose a way to organize the public sector to achieve it.

## Buildings retrofits and the net-zero challenge

There is no pathway for Canada to achieve its greenhouse gas emission targets that does not include deep and widespread energy efficiency improvements to the residential and commercial building stock, combined with phasing out its fossil fuel use.

In this report, we look at the potential for improving the efficiency and electrifying the entire stock of some 10 million buildings in Canada – the “total reserves” of retrofit potential. Using standard databases that characterize the building stock by province, by type, and by energy end use intensities, we develop two scenarios that follow s-curve distributions in the rate of building retrofits accomplished per year, starting with slower growth to allow time for learning and experimentation, followed by a rapid acceleration or take-off. One scenario reflects an emergency response that retrofits the entire building stock by 2035. A second scenario reflects a slower implementation rate with retrofits completed by 2050. Both scenarios include efficiency improvements in lighting and other electricity devices, thermal energy intensity reductions of 40-60% through building envelope upgrades, and conversion of space and water heating to electric heat pumps. Both scenarios assume retrofit costs decline as scale increases, as experienced in other sectors such as solar and wind energy. Further cost sensitives are included to emphasize that the ultimate costs are uncertain and will be determined by the success of a policy approach aiming to increase economies of scale and trigger learning.

In the scenarios, nominal program costs could range from $580 billion to $972 billion, breaking down to $39 to $62 billion annually over 15 years, or $20 to $32 billion annually over 30 years. These are significant capital expenditures, but they are of the same order of magnitude as the $80 billion Canadians spend annually on building renovation or the $57 billion spent on fuel and electricity.

Critically, the scenarios show that a comprehensive national building retrofit program enables electrification and decarbonization in other sectors. A retrofit strategy that includes the replacement of fossil fuel heating with electric heat pumps can actually result in net annual electricity savings of 50 TWh. Combining electrification with thermal envelope upgrades decreases heating demand. In addition, several provinces rely heavily on electric baseboards and resistance heating technologies, which can be converted to more efficient heat pumps.

Thus, the full decarbonization of the building stock could increase the supply of clean electricity in Canada rather than drain it. The clean electricity freed up by building retrofits could reduce 60 Mt CO2eq per year if used to power 10 million electric vehicles. The release of clean electricity potential also reinforces the strategic role of greater east-west electricity trade, as retrofits enable hydroelectricity rich provinces to make better use of their existing resources to decarbonize sectors outside their borders with high-value opportunities for electrification.

The potential for buildings to enable emission reductions in other sectors reinforces the rationale for undertaking comprehensive building retrofits at large scale and as rapidly as possible. Yet, this level of retrofit performance is far from what is being achieved under current market structures and policy environments. Our scenarios ramp up to retrofitting 12% of the building stock per year in our emergency response scenario, and 5% per year in the slower scenario. Current rates are below 1% for low-rise residential buildings and 1.4% of commercial building floor area, with retrofits achieving shallow rather than deep energy savings. To achieve better results, we need to transform the way we deliver building retrofits.

## A mission to transform building retrofits

Clean technologies like wind, solar, and batteries have witnessed dramatic cost reductions because of policies and business models that promoted and exploited technological innovation and economies of scale. There are significant opportunities to trigger learning by doing, producing, interacting, and using to see similar dynamics in high-performance building retrofits.

The energiesprong model pioneered in the Netherlands is an approach with the potential to transform building retrofits. This model combines many buildings into large-scale retrofit projects, coordinates the supply chain, uses mass-produced and standardized wall assemblies and mechanical pods, and provides long-term financing and performance guarantees for building owners. The model contrasts with the dominant approach which treats each retrofit project as separate, leaving building owners responsible for managing and financing complex projects.

There are a variety of innovation pathways that could increase the performance of building retrofits. These include the use of integrated design and project delivery, prefabrication of building facades and HVAC systems, mass customization tools that manage distinct building characteristics with greater ease, aggregation of retrofit projects into single portfolios, the increased use of digital technologies, and better ways to meet building user needs.

Exploring these innovation pathways and new models demands a new policy approach. Our current policy frameworks emphasize static cost-benefit analyses to select retrofit solutions, and then provide rebates and financing within the confines of existing market structures. This has locked building retrofits into a level of performance that either achieves shallow energy savings or makes deep energy saving achievements high-cost, niche projects.

We suggest framing retrofit policy as a mission, following the approach popularized by innovation theorist Mariana Mazzucato. This framework calls for defining a mission that is societally relevant, bold and inspirational, with clear direction and ambitious goals. Achieving the mission requires reshaping markets, encouraged by inviting multiple bottom-up solutions and engaging diverse disciplines and sectors to promote learning and dynamic efficiencies.

Our current policy frameworks emphasize static cost-benefit analyses to select retrofit solutions, and then provide rebates and financing within the confines of existing market structures.

An ambitious mission, consistent with the urgency of the climate emergency, would aim for a mass retrofit of the building sector by 2035. It would involve eliminating all direct fossil fuel use from the existing building stock, making buildings highly energy efficient so they are ready to convert to zero-carbon energy sources, and contributing to the decarbonization of other sectors by freeing up clean energy resources. Organizing such a mission will require public sector institutions capable of accepting risks, being flexible, and avoiding secrecy to enable ongoing interaction with market participants. The absence of an active strategy to reshape the ways existing retrofit markets work is a policy gap in Canada. We can fill this gap by creating “market development teams” throughout the country, inspired by the energiesprong model. These teams will produce replicable retrofit solutions involving innovations in areas such as contracting, procurement, and demand aggregation. A policy system should then be ready to rapidly

The absence of an active strategy to reshape the ways existing retrofit markets work is a policy gap in Canada. We can fill this gap by creating "market development teams" throughout the country

accelerate the retrofit solutions that work, mobilizing public investments from entities like the Canada Infrastructure Bank, initiating reforms to policy and regulatory environments, and facilitating knowledge exchange through quantitative data and social networks. A new public sector organization acting as the "retrofit mission leader" will coordinate this retrofit innovation policy system.

Taking on an ambitious climate retrofit mission has significant potential to empower Canada's larger net-zero emission vision, and to create Canadian industrial advantages. Such a mission fits the Canadian need to develop systems for the use of technologies in harsh geographic environments, which previously motivated leadership in long-distance electricity transmission and the extraction of oil from sand. Achieving this mission will build Canadian expertise and enable higher-value deployment of our nation's existing clean energy resources.

To confront the climate emergency, it is time to launch an innovation-oriented building retrofit mission.

# Quantifying the retrofit potential

This section outlines the total reserves of retrofit potential in Canada and presents a broad picture of the potential costs and impacts of undertaking comprehensive retrofits of all the country's existing buildings. Scenarios consider the implications of higher costs and faster implementation. The results estimate GHG reductions and lead to the intriguing conclusion that a program to both improve energy efficiency and electrify buildings ultimately frees up more of Canada's electricity resources.

## Existing Buildings

There are 9-10 million buildings in Canada, comprising 2,000 million square metres of residential and 750 million square metres of commercial and institutional building floor area, as illustrated in Figure 1 and Figure 2. Table A shows the distribution of households by dwelling type.[1] There are an estimated 9 million residential buildings in Canada and 480,000 commercial and institutional buildings.[2]

---

[1] The scope of this paper is restricted to the ten provinces, and mobile homes are also excluded from the analysis.

[2] The profile is presented in square metres here as that is the one metric for which we have estimates for both residential and commercial/institutional buildings, by type and by province. Our C/I analysis is floor area-based, and for the residential sector, our analysis is based on occupied floor area for space heating and on occupied dwellings for other end uses. The inventory defined for this study is based on data from the NRCan Comprehensive Energy Use Database for 2017, Natural Resources Canada, *Comprehensive Energy Use Database* (Government of Canada, n.d.), https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm. the most recent year available when the analysis was undertaken.

*Table A*

| Canadian Households by Dwelling Type and Vintage (2017 data) (all figures in thousands) | | | |
|---|---|---|---|
| | Old (built before 1996) | New (built after 1995) | Total |
| Households in single detached dwellings | 5,378 | 2,692 | 8,070 |
| Households in single attached dwellings | 917 | 763 | 1,679 |
| Households in apartment dwellings* | 2,866 | 1,604 | 4,471 |
| Total no. of occupied dwellings | 9,161 | 5,059 | 14,220 |
| Total no. of residential buildings (est.) | | | 9,000 |

* There is no comprehensive database of residential buildings in Canada. The number of residential buildings is sometimes erroneously conflated with the number of dwellings, but single family attached, and apartment buildings contain multiple dwellings. While there are nearly 15 million residential dwellings, we estimate there are about 9 million residential buildings. In addition to single-family detached buildings this includes 400,000 in the single family attached category, 10,000 high rise apartment buildings (>5 storeys), 70,000 low rise apartment buildings, and 250,000 buildings comprised of duplexes and flats).

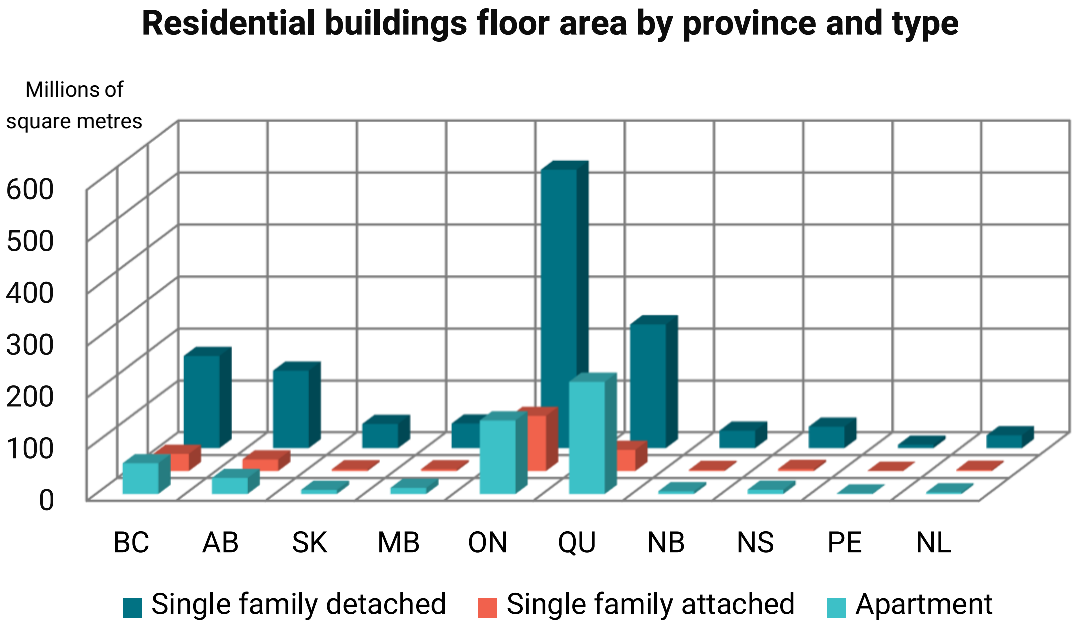


*Figure 1*

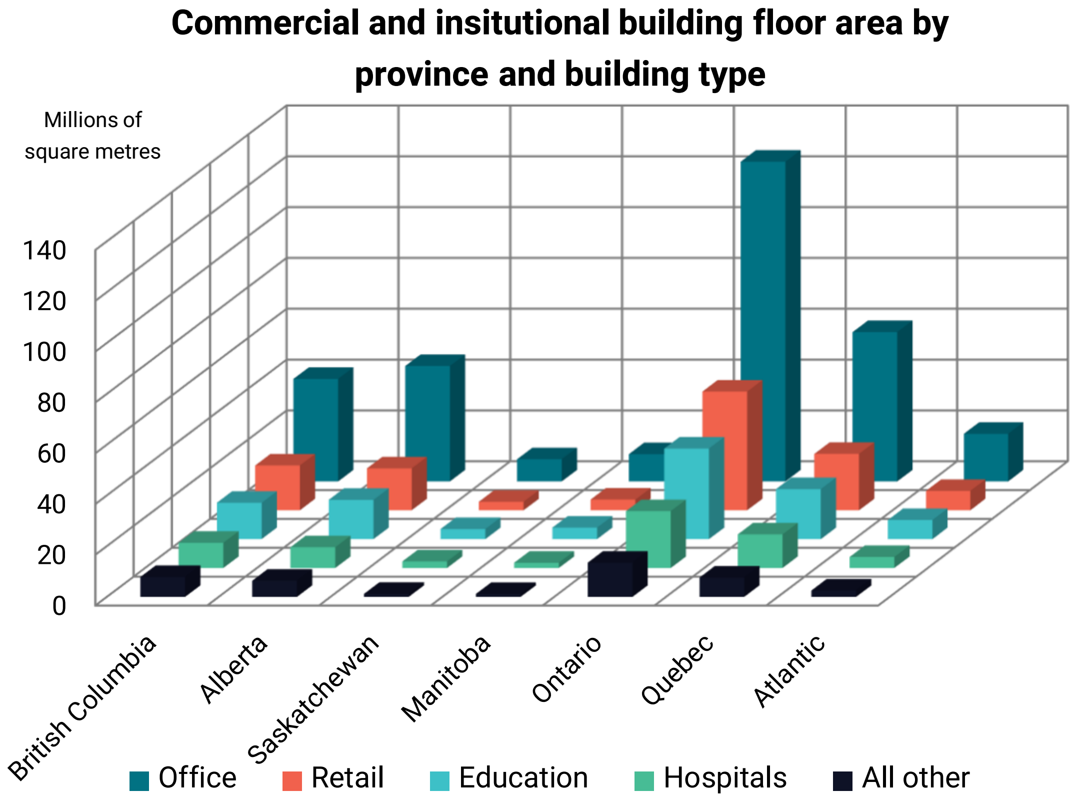


*Figure 2*

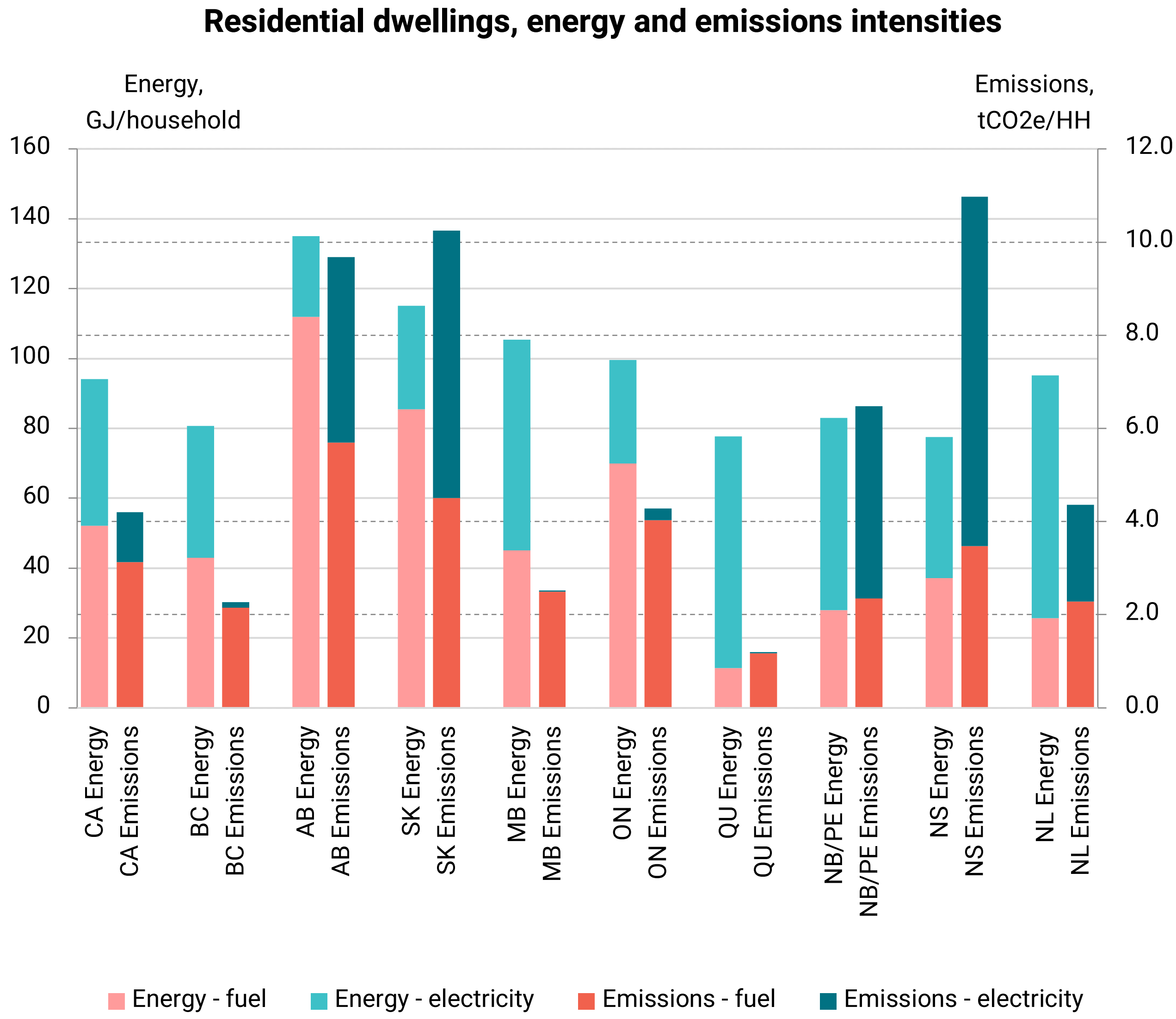
Greenhouse gas emissions from fossil fuel consumption for space and water heating of the existing building stock totaled 108 Mt $CO_2e$ in 2017, the reference year for this analysis. Figure 3 and Figure 4 show how energy and greenhouse intensities vary by province for residential and commercial buildings,[3] respectively, and Table B summarizes some building energy use and emissions patterns that are important to understanding the retrofit potential.[4]

- In Alberta and Saskatchewan, electricity's share of space heating is relatively small, as reflected by the low contribution that electricity makes to total building energy use. At the same time, these provinces have relatively carbon-intensive grids, so notwithstanding the relatively small share of building energy it provides, electricity nevertheless contributes a relatively large share of total building GHG emissions.
- In the hydro-rich provinces of B.C., Manitoba, and Quebec, electric space and water heating is common, reflected by the relatively large share of electricity in total building energy use. But because of the near-zero carbon intensity of the grids, the contribution of electricity to building emissions is small.
- In Atlantic Canada, electric space heating is prevalent, and the carbon intensity of the electric grids is relatively high. As a result, buildings account for a high share of total emissions, particularly in Nova Scotia, where the combination of carbon-intensive electricity, extensive use of electric space and water heating, and a relatively high contribution to total energy use from buildings results in the sector's highest contribution to greenhouse gas emissions in any province.
- In Ontario, building energy use is high and the electricity intensity of the buildings is medium, but the low-carbon grid keeps electricity's share of building emissions low.

---

[3] Our data is consistent with and based on NRCan's Canadian Energy Use database, but totals by sector and fuel are not in exact agreement with CEUD because of our method and scope for compiling the data. Our sector totals include the direct emissions from fuel consumption in the buildings and a pro-rated share of power plant emissions. Also, as noted above, the simulation includes only the ten southern provinces, excludes mobile homes, and tracks fossil fuel consumption in two categories only – natural gas and petroleum. More than 50% of PEI's electricity supply comes from New Brunswick, and therefore they are combined for purposes of considering the role of electricity-related emissions and the contribution of building related emissions.

[4] As previously noted, throughout this report, GHG emissions from buildings include the emissions from the grid electricity used by the buildings, estimated as the product of the building electricity use and the average annual carbon intensity of the provincial grid in which the building is located.



Residential dwellings, energy and emissions intensities
Energy, GJ/household
Emissions, tCO2e/HH
160
140
120
100
80
60
40
20
0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
CA Energy
CA Emissions
BC Energy
BC Emissions
AB Energy
AB Emissions
SK Energy
SK Emissions
MB Energy
MB Emissions
ON Energy
ON Emissions
QU Energy
QU Emissions
NB/PE Energy
NB/PE Emissions
NS Energy
NS Emissions
NL Energy
NL Emissions
Energy - fuel
Energy - electricity
Emissions - fuel
Emissions - electricity

*Figure 3*

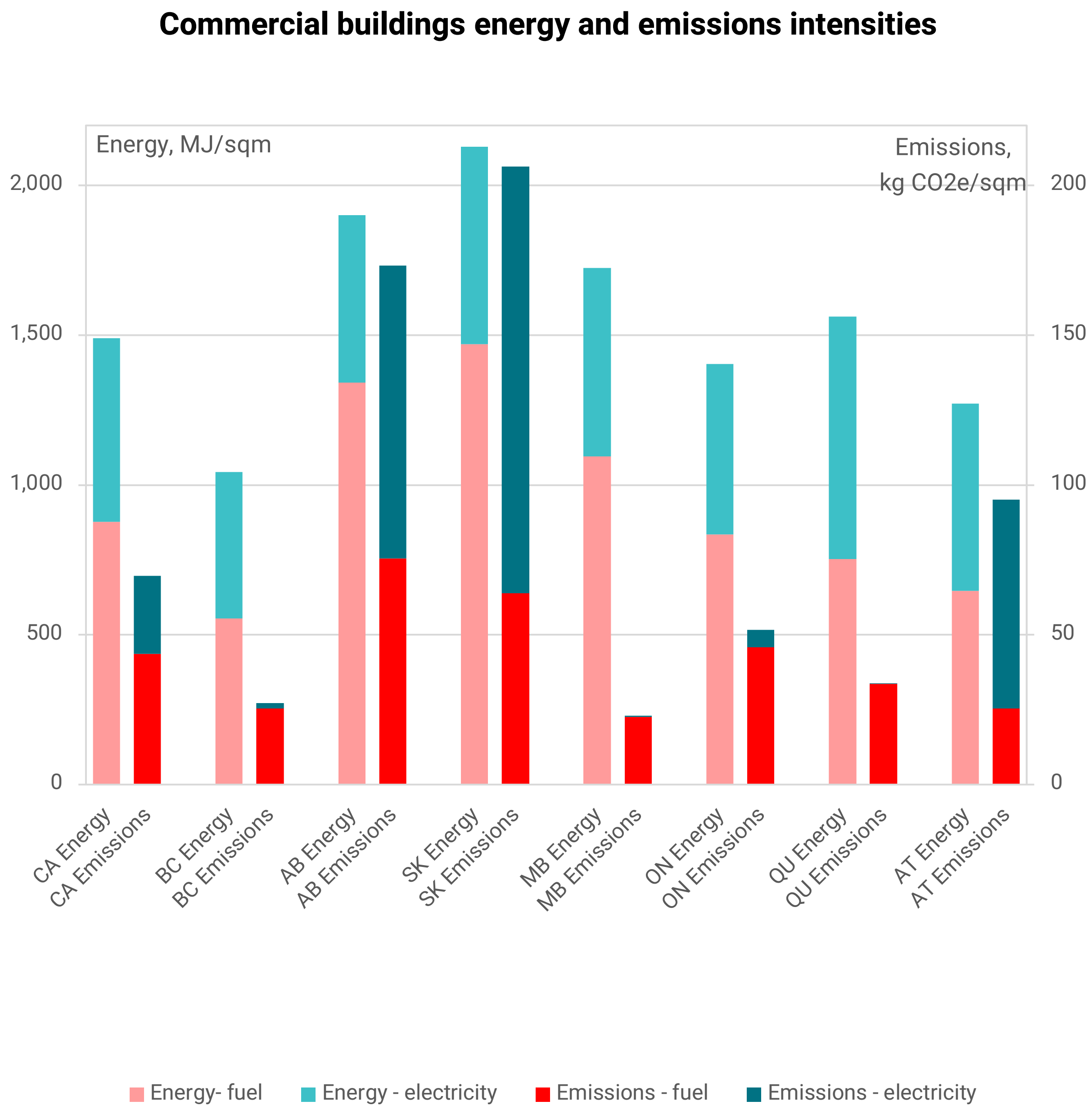

Commercial buildings energy and emissions intensities
Energy, MJ/sqm
Emissions, kg CO2e/sqm
2,000
1,500
1,000
500
0
200
150
100
50
0
CA Energy
CA Emissions
BC Energy
BC Emissions
AB Energy
AB Emissions
SK Energy
SK Emissions
MB Energy
MB Emissions
ON Energy
ON Emissions
QU Energy
QU Emissions
AT Energy
AT Emissions
Energy- fuel
Energy - electricity
Emissions - fuel
Emissions - electricity

*Figure 4*

*Table B*

| Buildings energy and emissions analysis – some indicators | | | | | |
|---|---|---|---|---|---|
| | Buildings contribution to GHG emissions (including pro-rated electricity emissions) | Average no. of hours/year below -20 C in largest city (2015-2020)[5] | Grid carbon intensity | Electricity share of buildings energy use | Electricity share of buildings emissions |
| British Columbia | 14% | 0 | Extremely low, stable | 47% | 4% |
| Alberta | 16% | 189 | High, declining | 24% | 58% |
| Saskatchewan | 15% | 580 | High, declining | 29% | 65% |
| Manitoba | 14% | 543 | Extremely low, stable | 47% | 2% |
| Ontario | 28% | 33 | Low, rising | 35% | 5% |
| Quebec | 16% | 84 | Extremely low, stable | 69% | 1% |
| New Brunswick & PEI | 25% | 74 | Medium, stable | 65% | 63% |
| Nova Scotia | 47% | 1.3 | High, declining | 49% | 73% |
| Newfoundland and Labrador | 20% | 0 | Low, declining | 57% | 50% |

---

[5] The -20 C temperature benchmark is included in reference to the performance of cold climate, air source heat pumps. The Coefficient of Performance (COP) of current cold weather ASHP's declines with temperature from about 3.5 at +5C to 2.0 at -20 C. The number of hours the temperature drops to -20C or lower is therefore a rough indication of the seasonal performance of heat pumps. The seasonal performance of ASHP's in southern Canada varies from nearly 3.5 in the Lower Mainland for British Columbia to just over 2.0 on the Prairies.

Canada's buildings represent an enormous sunk investment made over a period of many decades – their replacement value exceeds $8 trillion at today's construction costs. As shown in Table C, capital improvements in the existing building stock total $80 billion per year, and another $100 billion per year is spent on building maintenance, repairs, fuel and electricity.

*Table C*

| Buildings in the economy, by the numbers ($ billions) | | | |
|---|---|---|---|
| | Residential | Commercial and institutional | Total |
| Replacement cost valuation[6] | $6,000 | $2,000 | $8,000 |
| Annual renovation and capital improvements[7] | $60 | $20 | $80 |
| Annual routine maintenance and repair[8] | $20 | $20 | $40 |
| Annual expenditures on electricity,[9] | $26 | $14 | $40 |
| Annual expenditures on fuel[10] | $11 | $7 | $18 |
| Canadian GDP (expenditure based)[11]: | $1,800 | | |

---

[6] Altus Group, "2021 Canadian Cost Guide," 2021, https://go.altusgroup.com/e/575253/cost-guide-2021-pdf-download/2653b5/618989972?h=iUdxYb1w9aaU0up0n6r9_2C5yflck1gsbqStvCRGWec.

[7] Statistics Canada, "Table 34-10-0175-01 Investment in Building Construction" (Statistics Canada, n.d.), https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410017501.

[8] Statistics Canada Government of Canada, "Household Spending, Canada, Regions and Provinces," April 25, 2012, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1110022201.

[9] Fuel and electricity expenditures derived from NRCan national energy use database (http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/data_e/databases.cfm) and Hydro Quebec electricity price database (https://www.hydroquebec.com/residential/customer-space/rates/comparison-electricity-prices.html).

[10] Statistics Canada, "Table 11-10-0222-01 Household Spending, Canada, Regions and Provinces" (Statistics Canada, n.d.), https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1110022201.

[11] Statistics Canada. Table 36-10-0104-01 Gross domestic product, expenditure-based, Canada, quarterly (x 1,000,000)

## Methods and input assumptions

To explore different pathways to the decarbonization of existing buildings in Canada we apply separate, linked models of the existing residential and commercial building stock. The models use disaggregated, bottom-up, end-use based simulations of building fuel and electricity to explore comprehensive building retrofit strategies. The modeling approach is deliberately broad brush and scenario-based to facilitate consideration of the "big picture" transition to emission-free buildings. The primary objective of the modeling is to examine large-scale GHG reduction-focused retrofit programs; cost analysis is included in order to compare decarbonization pathways and to consider the role of cost reductions brought about by industrialization of mass retrofits in accelerating the low carbon transition.

The interdependence of high-efficiency buildings and electrification is a defining characteristic of the retrofits included here, which combine upgrades to the thermal efficiency of the building envelopes, efficiency improvements in lighting and other internal loads, and electrification of space and water heating via heat pumps. Heat pump technology is instrumental to the low carbon transition to buildings. A scenario combining heat pumps with thermally inefficient buildings would result in poor performance of the heat pumps and electricity consumption levels that would be challenging if not impossible for most jurisdictions to meet with carbon-free sources.

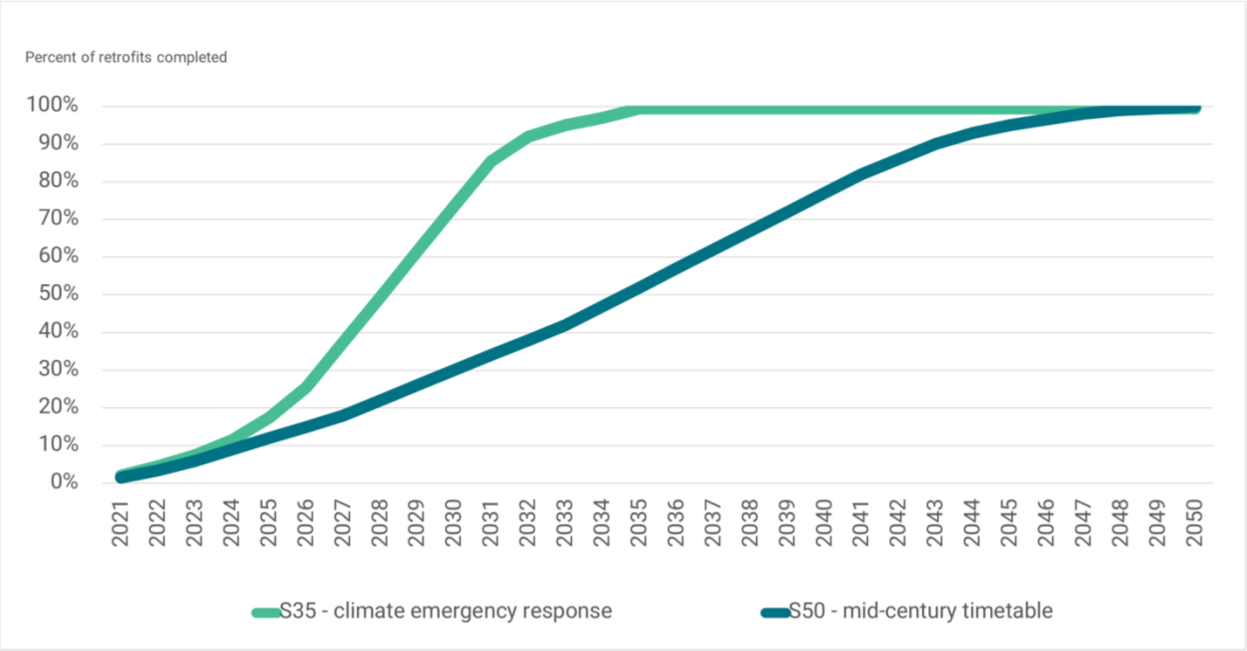
### Common assumptions and features

Both models utilize the same assumptions about grid carbon intensities, future fuel and electricity prices, carbon prices, heat pump performance curves, and program scheduling.

For the period to 2030, the carbon intensities of provincial electricity grids are either held constant (BC, MB, QC, PE, NB) or change according to specific assumptions for a particular province (to 450 g/kwh in AB, 500 g/kwh in SK and NS, 15 g/kW in NL, and 70 g/kwh in ON). After 2030, the GHG intensity of electricity supply in all provinces is held at 2030 levels for purposes of quantifying the emission impact of building retrofits.

Seasonal coefficients of performance (COP) for heat pumps vary from 2.2 in Manitoba to 3.2 in B.C to 2.6-2.7 in eastern Canada (southern Ontario to Atlantic Canada). The seasonal COPs are estimated by applying hourly temperature records (over the last six years for the largest city in each province) and standard space heat load shapes to COP vs. temperature curves for cold weather heat pumps, and then reduced by 0.2 across the board to reflect suboptimal building retrofit design, installation, and operation. It is important to note that achieving the full potential of heat pump technology requires that only cold climate heat pumps are deployed and that they are installed as part of an integrated, whole building retrofit strategy for improved efficiency, comfort and air quality.

Buildings are modeled in annual time steps and the timing of the retrofit program is specified by province and building cohort. The two scenarios presented here – S35 and S50 – are based on S-curve implementation schedules that run their course by 2035 and 2050, respectively, as illustrated in Figure 5.



**Implementation schedules for retrofit scenarios**

*Figure 5*

Scenario S35 reflects an emergency response timetable for addressing climate change, with retrofits accelerating rapidly in the 2020’s and implementation complete by 2035. S50 adopts a slower, almost linear implementation rate, with completion taking until 2050. Both schedules reflect unprecedented rates of building retrofit activity, as discussed in later sections of this report.

The valuation of future fuel and electricity savings is based on the end use price projections in the Canadian Energy Regulator's most recent long-term energy outlook for Canada.[12] Projected real price increases are generally well under 1% per year in this projection (lower than the 3% discount rate used for the analysis) and decline slightly for natural gas. For purposes of present value economic analysis, the energy and carbon savings are presumed to last for 30 years from the date of the retrofit, so that savings taper off by 2065 in the S35 scenario and by 2080 in the S50 scenario. The assumed price of carbon rises to $170/tonne CO2e by 2030 according to the federal government's current schedule and is held constant after that. The carbon price is parameterized separately in the models used in this analysis so that avoided costs of carbon can be compared to and assessed independently of avoided fuel and electricity costs.

## Residential retrofits

Residential buildings are modeled by floor area and by household in 30 cohorts for each province – three types (single family detached, single family attached and apartments), two vintages (pre-1996 and post-1995), and five space heating systems (gas, electric resistance, electric heat pumps, oil, and wood). Lighting, appliances, and air conditioning are modeled by dwelling type for each province. For these end uses, both the S35 and S50 scenarios include a common set of assumptions: a doubling in the percent of residential housing that is air conditioned (to a maximum of 85%), a 25% increase in cooling degree days offset by a 20% improvement in A/C efficiency, and a 40% reduction in per-household electricity used for lighting. For household electronics and other appliances, we assume efficiency improvements are offset by growth in the number and intensity of end uses. By the end of the retrofit program domestic hot water heating is converted to heat pump technology with a COP of 2.9 (estimated this low to allow for the offsetting impact on building heating load).

For space heating, gross thermal output intensity (energy per square metre) is defined by province, by housing type and by vintage; and heating source shares and corresponding efficiencies are applied to compute secondary energy consumption by fuel type and electricity. The building envelope upgrades are defined by their end point thermal intensities, which vary by province, dwelling type and vintage as shown in Table D. These intensities are well above best practice standards for individual retrofits: For

---

[12] The Canadian Energy Regulator, "Canada's Energy Future 2020," November 2020.

example, the Passive House retrofit standard for heating demand is 30 kWh/sqm.[13] The targets represent average thermal performance of the entire post-retrofit housing stock and correspond to 40-60% reductions from current average intensities.

*Table D*

| Average post-retrofit gross thermal output intensities (TEDI), residential dwellings (kWh/sqm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Housing type | Vintage | BC | AB | SK | MB | ON | QU | NB | NS | PE | NL |
| SFD | Pre 1996 | 45 | 73 | 72 | 65 | 70 | 74 | 63 | 61 | 62 | 65 |
| SFD | Post 1995 | 43 | 69 | 60 | 59 | 60 | 66 | 55 | 54 | 52 | 60 |
| SFA | Pre 1996 | 39 | 48 | 63 | 62 | 65 | 63 | 59 | 56 | 56 | 63 |
| SFA | Post 1995 | 39 | 43 | 54 | 52 | 55 | 61 | 49 | 49 | 47 | 55 |
| APT | Pre 1996 | 32 | 55 | 51 | 50 | 55 | 58 | 47 | 43 | 43 | 45 |
| APT | Post 1995 | 29 | 46 | 40 | 40 | 40 | 44 | 37 | 36 | 35 | 41 |

Estimating the costs of the program proposed here is challenging (although arguably not so difficult as estimating the costs of runaway climate change). There is a dearth of good data on the costs of retrofits and almost no quantitative analysis yet on the cost reductions from the learning and experience curves that go along with mass, archetype-based, retrofit missions involving millions of buildings.

The size and the pace of the retrofit program necessary to decarbonize buildings on a timeline consistent with current emission reduction targets represents a complete departure from the one-at-a-time, bespoke nature of historical retrofit practice. Reported costs for innovative pilot projects and bespoke deep retrofit cover a very wide range, with project costs not strongly correlated with energy savings.[14] A study of older, inefficient homes in Chicago found 50% energy savings from investments of about

---

[13] "Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard" (Passive House Institute, September 9, 2015), https://www.passivehousecanada.com/wp-content/uploads/2017/02/Passive-House-and-EnerPHit_building_criteria.pdf.

[14] Brennan Less and Iain Walker, "A Meta-Analysis of Single-Family Deep Energy Retrofit Performance in the U.S.," 2014, https://eta.lbl.gov/publications/meta-analysis-single-family-deep.

$18,000 per dwelling, with conventional efficiency, airtightness and ventilation improvements that did not include window replacements or air source heat pumps.[15] A group of five multi-family retrofits in Toronto produced 40-58% energy savings from envelope improvements and heat pumps for space and some water heating, at costs ranging from $34-$58,000 (average $47,000) per suite.[16] In other literature and in communications with retrofit project managers, cost estimates as high as $100,000-$120,000 per dwelling are not uncommon,[17,18] and the unit costs are highest for the deepest retrofits that achieve thermal energy intensities in the range of 30 kWh/m$^2$ (the Passive House enerPhit standard[19]) and lower.[20]

One of the difficulties in evaluating retrofit cost data is the lack of conventions for what level of efficiency improvement qualifies as a "deep" retrofit. Efficiency gains are often expressed as percent reductions from the pre-retrofit energy intensity. Deep retrofits typically imply an energy intensity reduction of 50% or more, but definitions vary from as little as a 20% reduction in thermal intensity[21] to 80% or more. The effort and related cost will vary with the starting condition of the building, and the actual energy intensity of the building is often omitted from the reports.

Some definitions of deep retrofits are expressed in terms of the physical energy intensity of the post-retrofit building (e.g. kWh/m$^2$), but there is no consistent measurement conventions. Some include only the thermal output of the building (TEDI), while others factor in secondary energy consumption. Some net out contributions from building-connected photovoltaics, while some are restricted to the energy efficiency of the building itself.

There are also different conventions for what is included in the cost of energy efficiency upgrades. Retrofits, and particularly deep retrofits, often include upgrades or replacements of building components. Some analysts attribute only the incremental difference between the cost of a "business-as-usual" replacement with the more energy-

---

[15] Honnie Leinartas and Brent Stephens, "Optimizing Whole House Deep Energy Retrofit Packages: A Case Study of Existing Chicago-Area Homes," *Buildings* 5, no. 2 (May 4, 2015): 323–53, https://doi.org/10.3390/buildings5020323.

[16] Bryan Purcell, "Building Retrofit Costs, Personal Communication" (The Atmospheric Fund, April 29, 2021).

17 Peter Amerongen, "Sundance Housing Co-Op Deep Energy Retrofit."

18 R. Osser, K. Neuhauser, and K. Ueno, "Proven Performance of Seven Cold Climate Deep Retrofit Homes" (Golden, CO (United States): National Renewable Energy Lab. (NREL), June 1, 2012), https://doi.org/10.2172/1047922.

19 "Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard."

20 Purcell, "Building Retrofit Costs, Personal Communication."

21 Sharad Bharadwaj et al., "Deep Decarbonization in Nova Scotia: Phase 1 Report" (San Francisco, CA: Energy and Environmental Economics, for Nova Scotia Power, February 2020).

efficient component, while others include the total cost of the component, a choice that can affect the cost estimate by an order of magnitude.  An intermediate approach includes the undepreciated cost of the equipment being replaced in the cost of the retrofit.[22]

Finally, there are variations in the observed costs of retrofits, even with comparisons that use identical conventions for scope and costing. The energy efficiency of new residential dwellings in Canada has improved several-fold over the past 50 years and there is also a large variation in the improvements that have been made to the older stock, all of which translates into large variations in what is required for a deep retrofit, however defined. In addition, this is a field that is currently subject to a high level of innovation and experimentation with both technologies and techniques, another source of variation in observed retrofit costs.

The retrofits assumed in the scenarios presented here (Table D) go further than most current practice but stop well short of current best-practice “deep retrofits”. The decision to model a program of relatively modest but still “deep enough” energy retrofits (rather than the state-of-the-art building conversions available on today’s market) was driven by the fundamental purpose of this paper: to identify the average level of improvement that would be sufficient for a mission to mass-retrofit Canadian housing as part of the nation’s larger response to the climate emergency.

The scenarios assume current national average costs for thermal efficiency upgrades and heat pumps, with variations by housing type and vintage. The retrofits are defined by their end point thermal intensities (Table D). Both the S35 and S50 scenarios were analyzed with two sets of cost assumptions intended to bracket most of the range of estimates we found in our review. Economies of scale in supply chains and learning curve impacts are assumed to result in a 50% reduction in retrofit costs by 2030 in the S35 scenario, and by 2040 in the S50 scenario.

The average low and high costs assumed for current residential retrofits in our scenarios are $56,000/$96,000 per single family detached house, $46,000/$66,000 per dwelling unit for single family attached housing, and $33,000/$43,000 per unit for apartment buildings. These prices include the materials and labour for shell upgrades,

---

22 Kai Nino Streicher et al., “Cost-Effectiveness of Large-Scale Deep Energy Retrofit Packages for Residential Buildings under Different Economic Assessment Approaches,” Energy and Buildings 215 (May 2020): 109870, https://doi.org/10.1016/j.enbuild.2020.109870.

heat recovery ventilation systems, and heat pumps for space and domestic hot water. They are averages across the entire building stock. Thus, some buildings will incur higher costs and achieve ultra-low-energy, best-practice performance, while other buildings undergo less expensive upgrades to intensities above the target averages.

## Commercial and institutional buildings

Commercial and institutional buildings are modeled by floor area, with energy use intensities quantified for ten different building categories (office, retail, education, hospitals, warehousing, hotels and restaurants, and four others), five end uses (heating, cooling, lighting, auxiliary motors, and plug load), and five energy supply categories (natural gas, electricity, electric heat pumps, oil, and other). As with the residential model, calibration is based on NRCan's CEUD[23]. Secondary intensities are defined for each end use (MJ/m$^2$), and efficiencies for each energy supply source.

The retrofits and heat pump conversions for commercial and institutional buildings include upgrading the efficiency of the individual technologies, but also the overall efficiency of the building as a system. Relative to the current average, our retrofit scenarios include a 40% reduction in the electricity intensity of light, a 35% reduction in building heating requirements, a 50% reduction in the electricity required by auxiliary motors (partly from efficiency and partly the result of electrification and modernization of HVAC systems), a 20% decrease in the intensity of plug load electricity use, and a 10% reduction in the intensity of air conditioning electricity use.

Electric resistance heating is not as widespread in commercial buildings as it is in the residential sector, but there is still significant potential for electricity savings from the conversion to heat pumps from electric resistance heating. Lighting, plug loads, and the fans and pumps associated with legacy HVAC systems in the aging building stock present large opportunities for efficiency improvements that can offset the impact of electrification of heating systems. In natural gas heated buildings, a systems approach that combines improvements in the building envelope, upgrades to lighting and other electrical loads, and modernization of HVAC systems offsets the impact of electrification on total building electricity consumption.[24]

---

[23] Natural Resources Canada, *Comprehensive Energy Use Database*.

[24] Ralph Torrie and Yuill Herbert, "The Implications of Deep Decarbonization Pathways for Electricity Grids," March 2021, https://emi-ime.ca/wp-content/uploads/2021/03/EMI-2020-Herbert_report_The-Implications-of-Deep-Decarbonization-Pathways-for-Electricity-Grids.pdf.

The national averages for pre- and post-retrofit secondary energy use intensities for different building types are summarized in Table E. Without the efficiency impact of heat pumps, the overall 60% drop in building energy intensity would be reduced to about 40%, underscoring the pivotal role this technology will play in decarbonization of the building stock. As with the residential sector, a whole building, systems approach is the key to successful deep retrofits in commercial buildings.[25]

---

[25] Cindy Regnier et al., “System Retrofit Trends in Commercial Buildings: Opening Up Opportunities for Deeper Savings” (Lawrence Berkeley National Laboratory, February 2020).

*Table E*

| Energy use intensities by building type (national averages) | | |
|---|---|---|
| Building type | Pre-retrofit | Post-retrofit |
| | MJ/m2 | MJ/m2 |
| Office | 1,170 | 474 |
| Retail | 1,365 | 535 |
| Healthcare | 2,194 | 886 |
| Education | 1,295 | 505 |
| Hotels & restaurants | 1,959 | 759 |
| Arts | 1,390 | 537 |
| Culture | 1,420 | 555 |
| Wholesale | 1,202 | 463 |
| Warehouse | 1,140 | 410 |
| Other | 1,217 | 466 |

There is a wide variation in the literature on the capital costs of commercial building retrofits, partly because they are very often done simultaneously with other building improvements, making it difficult to isolate those costs uniquely associated with energy efficiency improvements. We have used a similar approach to that described above for the residential sector, with both a low- and high-cost assumption for each building type, and with the same assumed percent cost reductions from the learning curve effect and economies of scale. The low-cost assumptions range from \$250-\$350/m$^2$ for most building types (\$500/m$^2$ for hospitals) and the high-cost assumptions range from \$400-\$500/m$^2$.

# Scenario results

## The direct emission reductions from building retrofits

As explained earlier in this report, the analysis is based on two reference scenarios. In S35, the retrofit program is fully implemented by 2035 and cost reductions from economies of scale are fully realized by 2030. In S50, the retrofits are not completed until 2050 and the gains from economies of scale are not fully realized until 2040. The impact of the retrofits on the fuel and electricity consumption of Canadian buildings is illustrated in Figure 6.

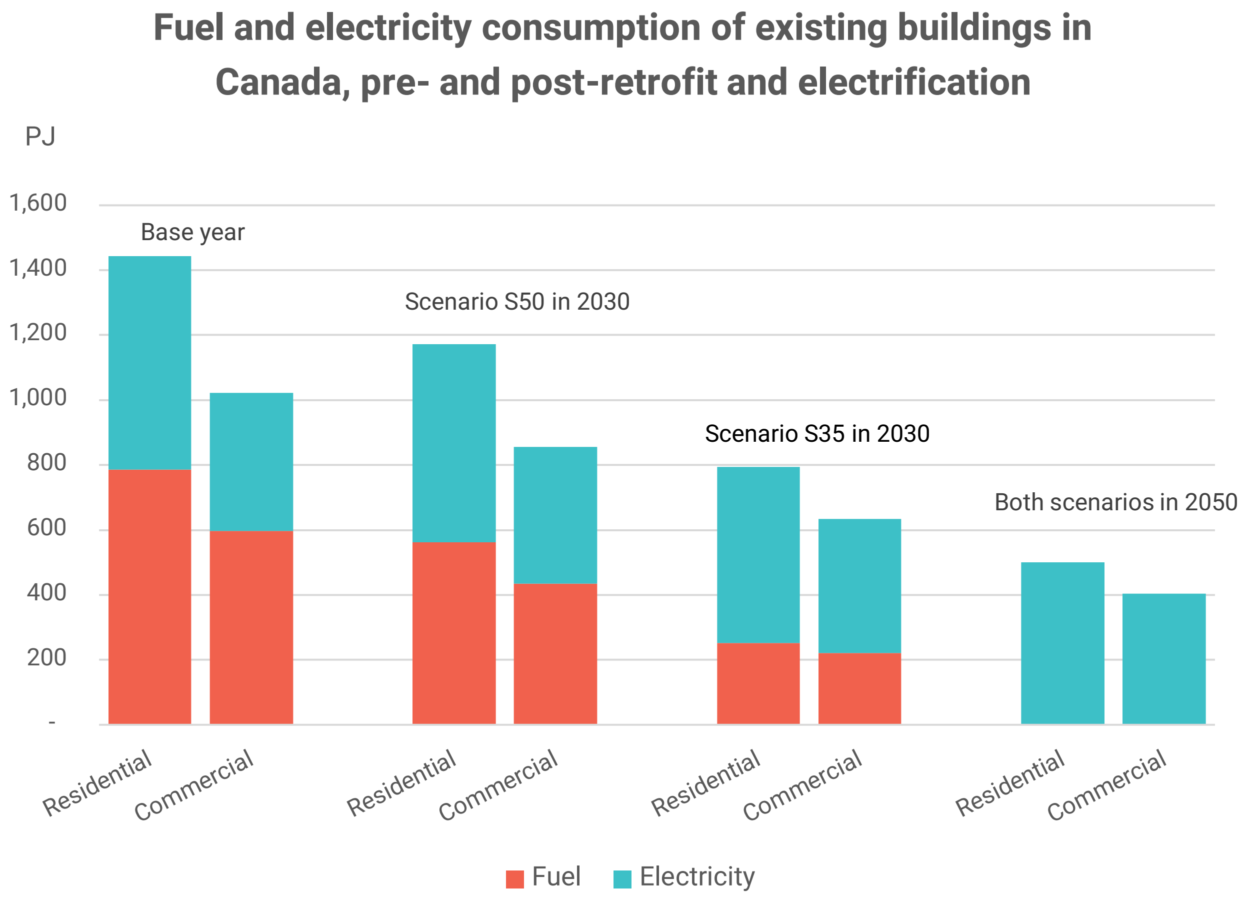


*Figure 6*

When the retrofits are complete, fossil fuel consumption (represented by the red bars) is eliminated in all residential and commercial buildings and the aggregate electricity consumption of the buildings is lower than it was at the outset of the efficiency and electrification program. Before retrofitting, the buildings consume 1,382 PJ of fossil fuels and 1,085 PJ of electricity; after retrofitting and electrification, the fossil fuel consumption is eliminated, and electricity consumption is reduced to 905 PJ. The 180 PJ (50 TWh) drop in building electricity consumption is concentrated in Quebec, but aggregate building electricity consumption declines in every province except Alberta and Saskatchewan, and the moderation of electricity growth made possible by deep retrofits increases the feasibility of achieving and maintaining a carbon-free electricity grid.

The direct emission reduction impacts of the retrofit scenarios are summarized in Table F. The completed retrofit program reduces greenhouse gas emissions from building energy use in Canada by 76%, from 104 Mt CO2e to 25 Mt CO2e. This includes the elimination of emissions from fossil fuel use in buildings and deep cuts in electricity-related emissions.

In provinces with low grid carbon intensities, the electrification and retrofit of buildings achieves a high percentage reduction in emissions. For provinces or regions with grids that are projected to still have significant fossil generation in 2030[26], the direct impacts of the program are smaller. Achieving complete decarbonization of building energy use in those regions would require phasing out fossil fuel electricity generation, a goal that will be more easily achieved if the retrofits described here are realized. Note that even in Alberta and Saskatchewan, where the retrofits result in higher aggregate building electricity consumption, the increase is more than offset by the reduction in fossil fuel emissions.

---

[26] The Atlantic provinces are consolidated as one region for purposes of this table because commercial and institutional building data in the national energy use database is only available at this aggregated level for the Atlantic provinces.

*Table F*

| All buildings, direct GHG impacts of retrofit scenarios (kt CO2e) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Province /region | Base year emissions | Emissions in 2030 | | Emissions in 2050 | | Cumulative reductions by 2050 | |
| | | S50 | S35 | 2050 | % reduction from base | S50 | S35 |
| BC | 6,516 | 4,763 | 2,360 | 822 | 87% | 96,257 | 136,657 |
| AB | 30,691 | 28,463 | 25,372 | 10,222 | 67% | 127,303 | 179,855 |
| SK | 8,084 | 7,457 | 6,601 | 2,921 | 64% | 35,194 | 49,967 |
| MB | 2,535 | 1,844 | 909 | 409 | 84% | 37,869 | 54,071 |
| ON | 35,327 | 26,295 | 13,939 | 5,141 | 85% | 496,933 | 705,631 |
| QU | 9,128 | 6,588 | 3,097 | 1,392 | 85% | 137,776 | 196,175 |
| AT | 11,910 | 10,286 | 8,092 | 4,164 | 65% | 89,401 | 127,306 |
| CA | 104,189 | 85,695 | 60,372 | 25,071 | 76% | 1,020,733 | 1,449,662 |

While both the S35 and S50 scenarios achieve the same annual reduction in emissions by 2050, the cumulative reductions by 2050 are much higher in the S35 scenario. Cumulative emission reductions under S35 reach 1,450 Mt $CO_2$e by 2050, but only 1,020 Mt $CO_2$e under S50, reflecting the climate mitigation benefits of early action.

## Costs

A retrofit program of this magnitude proceeding at this pace has never been undertaken, and there is no precedent for estimating what it would cost. Similarly, while some of the benefits can be quantified (e.g. fuel and electricity cost savings, avoided carbon costs), there are many intangible or difficult-to-quantify benefits from making buildings more comfortable, productive, and healthier environments.[27] Finally, notwithstanding the pricing of GHG emissions, the value of maintaining a healthy global atmosphere is too big to measure.

Like most aspects of the low carbon transition, decarbonizing the building stock requires relatively large capital expenditures in the short term. With the range of capital costs and gradual economies of scale assumed, S35 has total program costs over the 15 years of $580-$925 billion, with a present value of $456-$727 billion.  The S50 scenario, which achieves cost reductions from economies of scale and learning at a slower rate, has capital costs spread out over 30 years of $607-$972 billion, with a present value range of $409-$756 billion.  These costs are shown with some additional detail in Table G.

*Table G*

**Low and high-cost variations of capital costs for S35 and S50 ($ billion)**

| | Residential | | Commercial | | Total | | Annual averages | |
|---|---|---|---|---|---|---|---|---|
| 5-year period | **S35** | **S50** | **S35** | **S50** | **S35** | **S50** | **S35** | **S50** |
| 2021-2025 | 93-150 | 65-106 | 31-49 | 22-34 | 125-200 | 87-140 | 25-40 | 17-28 |
| 2026-2030 | 203-324 | 89-145 | 83-129 | 38-60 | 286-453 | 123-198 | 57-91 | 25-40 |
| 2031-2035 | 109-179 | 92-149 | 60-93 | 38-60 | 169-272 | 130-209 | 34-54 | 26-42 |
| 2036-2040 | | 93-150 | | 42-65 | | 135-215 | | 27-43 |
| 2041-2045 | | 66-106 | | 32-50 | | 98-156 | | 20-31 |
| 2046-2050 | | 22-35 | | 11-18 | | 33-53 | | 7-11 |
| Total, 2021-2050 | 406-653 | 427-690 | 174-271 | 180-281 | 580-925 | 607-972 | | |
| Present value | 321-517 | 290-470 | 135-211 | 119-186 | 456-727 | 409-656 | | |

---

[27] Devon Calder, “The Case for Deep Retrofits” (The Atmospheric Fund, 2020), https://taf.ca/publications/the-case-for-deep-retrofits/.

While these are large expenditures, they are on the same order of magnitude as the amounts Canadian households and firms routinely spend on building renovations, repairs, and fuel and electricity, as shown in Table H.

*Table H*

| Comparison of annual building improvement and energy costs with capital cost of building decarbonization retrofit program | |
|---|---|
| | $ billions |
| Capital expenditures on building renovations in 2019 (from Table C) | 80 |
| Building fuel and electricity costs in 2019 (from Table C) | 57 |
| Range of average annual cost of 15-year S35 program (from Table G) | 39-62 |
| Range of average annual cost of 30-year S50 program (from Table G) | 20-32 |

Without including any credit for savings in fuel and electricity costs, avoided costs of carbon, or any of the other economic, social, and public health benefits of a modernized and improved built environment, the average capital costs assumed for the scenarios described here equate to an average cost of reduced greenhouse gas emissions of \$260-\$470/tonne $CO_2e$ (present value).

When the value of fuel and electricity savings is included in the calculation, the national average costs are in the range of \$50 to about \$220/tonne $CO_2e$. When the avoided costs of carbon are added to the calculation (using the government's proposed carbon price), the retrofits have a neutral present value (using a 3% discount rate) for the low-cost scenario, with variations across provinces. In general, the retrofit program included in the scenarios is more cost-effective in Ontario, Quebec, and Atlantic Canada than in B.C., Alberta, Saskatchewan, and Manitoba.

While these are large expenditures, they are on the same order of magnitude as the amounts Canadian households and firms routinely spend on building renovations, repairs, and fuel and electricity

For the high-cost variations, even with the avoided cost of carbon included, the national average emission reduction cost from the retrofits is about $140/tonne $CO_2e$. Notably, the accelerated emission response scenario – S35 – yields a lower cost per tonne of emission reductions. Again, these calculations include only the value of the direct fuel and electricity savings and the avoided carbon costs, without any credit for the health and productivity gains that come with better indoor environments. These "non-energy benefits" are often the principal motivator for undertaking deep retrofits in today's market, and they are often estimated to have a higher value than energy cost savings.[28] Benefits can include reduction in water and sewer costs, increased home durability, higher comfort levels, improved safety, reduction in sick days, and increased property values. In addition, as discussed more fully below, the electricity savings from the building retrofits represent a large indirect benefit of particular importance to the hydro-rich provinces.

## Indirect impacts

As noted above, the building retrofit program presented here reduces total electricity consumption of existing buildings by up to 17%, thus freeing up 50 TWh/year of electricity supply.

The decline in total electricity consumption even after the conversion to electricity of all building fossil fuel consumption for space and water heating is the result of three interdependent factors. First, there is a significant amount of resistance heating in Canada for both space and water heating; when this is converted to advanced, cold climate heat pump technology, there is a 2-3-fold increase in energy efficiency (lower in cold climates, higher in milder climates). Second, upgrading the thermal efficiency of the building stock amplifies the electricity savings from the conversion of resistance

---

[28] Christopher Russell et al., "Recognizing the Value of Energy Efficiency's Multiple Benefits," *American Council for an Energy-Efficient Economy, Washington, DC*, 2015.

heating to heat pumps and minimizes electricity requirements of the buildings being converted from fossil fuel consumption. Third, the electricity intensity of lighting and HVAC equipment is reduced through a combination of technological efficiency and the reduced fan and pump energy that results from well designed and executed whole building retrofit strategies.

The strength of these contributing factors varies widely between provinces, as shown in Table I, with the advantage going to provinces with higher existing levels of resistance heating and/or milder climates that enhance heat pump performance. These electricity savings represent a large and strategic resource for supporting decarbonization of other sectors, and greatly improve the prospects for achieving and maintaining a low carbon supply of electricity throughout Canada. The electricity savings are unevenly distributed among the provinces, being particularly large in Quebec. This geographic distribution reinforces the potential role that greater east-west trade in electricity could play in achieving a carbon-free supply of electricity throughout Canada.

These electricity savings represent a large and strategic resource for supporting decarbonization of other sectors, and greatly improve the prospects for achieving and maintaining a low carbon supply of electricity throughout Canada.

*Table I*

| Impact of deep retrofits on building electricity use, by province/region | | | | |
|---|---|---|---|---|
| Prov/region | Net reduction in annual building electricity consumption after retrofits, TWh | | | Percent change relative to base year |
| | Residential | Commercial | Total | |
| BC | 4.1 | 2.4 | 6.5 | -20% |
| AB | -4.9 | -2.9 | -7.8 | 28% |
| SK | -1.1 | -0.5 | -1.6 | 20% |
| MB | 1.9 | 0.1 | 2.0 | -16% |
| ON | -2.6 | 1.9 | -0.7 | 1% |
| QU | 41.6 | 3.0 | 44.7 | -45% |
| AT | 4.9 | 1.9 | 6.8 | -30% |
| CA | 44.0 | 5.9 | 49.9 | -17% |

To put these electricity savings in context, it would take 7,500 large wind turbines to produce 50 TWh per year. Applied to electric vehicle charging, 50 TWh could supply 10 million EV's, displacing gasoline engines emitting 60 Mt $CO_2e$ per year.[29] The examples illustrate both the enabling, foundational role of energy efficiency in the transition to a low carbon economy and the importance of taking a whole systems approach to evaluating the role of building retrofits in climate emergency response strategies.

---

[29] With today's technology and driving patterns, a typical electric vehicle requires about 5,000 kWh per year (25,000 km at 20 kWh/100 km) and displaces 5.9 tonnes CO2eq in tailpipe emissions. At that rate 1 TWh of electricity can supply 200,000 EVs, and 50 TWh 10 million EVs, with corresponding GHG emission reductions of 60 Mt CO2eq.

## Conclusion

The mass retrofit of Canada’s building stock is a significant endeavour. It is capital intensive, but comparable to the magnitude of routine expenditures on building renovations, repairs, and energy. Retrofits at the level of performance and scale required to confront climate change cannot be described as “low hanging fruit” – a metaphor often used for energy efficiencies from lighting and shallow building improvements. Indeed, the cost of deep retrofits is not standardized and the current method of performing retrofits can produce relatively high costs using conventional policy metrics. Achieving the take-off in the scale of retrofits that will achieve decarbonization requires lower costs combined with a wider understanding of the value the retrofits will deliver.

Other sectors have achieved dynamic efficiencies by developing economies of scale and learning. Innovative financing and new business models have minimized upfront investment, and reduced inconvenience and risk. In climate policy, wind, solar, and batteries have achieved significant cost reductions as policymakers focused on dynamic opportunities rather than static cost-effectiveness. A similar approach is needed for GHG reduction-focused energy retrofits, requiring new thinking and taking an integrated whole system approach to design, policy, business strategies and management systems that results in high-quality retrofits, carried out thousands at a time and starting soon.

Large-scale building retrofits can play a foundational role in Canada’s energy transition. The scenarios show it is possible to electrify the building sector while reducing total electricity consumption. This means Canada’s renewable energy resources can be redirected to higher-value purposes, such as the decarbonization of industry and transportation. Building retrofits will also have systemic impacts outside the energy system by improving health outcomes through better indoor environmental quality, reducing poverty, and creating resilience against climate impacts.

The quantitative scenarios point to the need for a qualitative transformation in building retrofit markets and policies in order to achieve higher performance at lower cost. The rest of this report is defined by the recognition of this need.

The quantitative scenarios point to the need for a qualitative transformation in building retrofit markets and policies in order to achieve higher performance at lower cost

# What are we achieving now?

The current pace and performance of building retrofits is far below the scenarios considered above to confront the climate emergency. The market for building retrofits is not structured to achieve economies of scale and promote learning dynamics. Much of the responsibility for project management and quality assurance is left to the customer, and the contractors who do the work and the supply chains that provide materials are not integrated.

Most policies and programs available operate within the existing market structure and are not focused on transforming the ways those markets function to enable higher performance. This is not surprising, because building retrofits have traditionally received support in policy institutions where energy and GHG reductions are a secondary benefit rather than the primary objective.

This section recaps the performance of the current building retrofit system and discusses existing market structures and policy institutions, so we can understand how they might be changed.

## Building retrofit performance

There is no comprehensive data tracking of building energy system upgrades. We can gain some insights from the national EnerGuide program, which focuses on low-rise residential building retrofits, as well as a national survey of commercial buildings.

### Residential retrofits

Natural Resources Canada administers the EnerGuide program, which includes a labeling system, a home evaluation service offered by a network of service organizations, and software for energy simulation and design.[30] The program tracks the number of post-retrofit evaluations conducted and the energy savings achieved. However, this does not provide an exhaustive picture because not all efficiency program administrators use the EnerGuide system. This could be due to the cost of the audit to either customers or administrators, or to program strategies focused on installing

---

[30] Natural Resources Canada, “Energuide” (Natural Resources Canada, November 19, 2013), https://www.nrcan.gc.ca/energy-efficiency/energuide/12523.

individual measures (e.g. windows or furnaces) rather than the whole-home approach supported by EnerGuide. This information also does not capture improvements occurring outside of program participation, through regular building maintenance and renovation. Despite these limitations, the EnerGuide data is the best national indicator of comprehensive retrofits taking place because the program is designed to take a whole-home approach to improve energy efficiency.

As shown in Figure 7, 0.7% of the relevant building stock was retrofitted in 2019-2020. This is estimated by taking the number of post-retrofit audits divided by the total single attached and single detached homes.[31] Post-retrofit audits increased significantly when the federal government offered incentives through the ecoEnergy retrofit program, which operated from April 2007 to March 2012. This led to a peak "retrofit rate" of 2.8% in 2010-2011. This peak was likely due to a rush to claim the incentives after the government announced the program would be cancelled.[32]

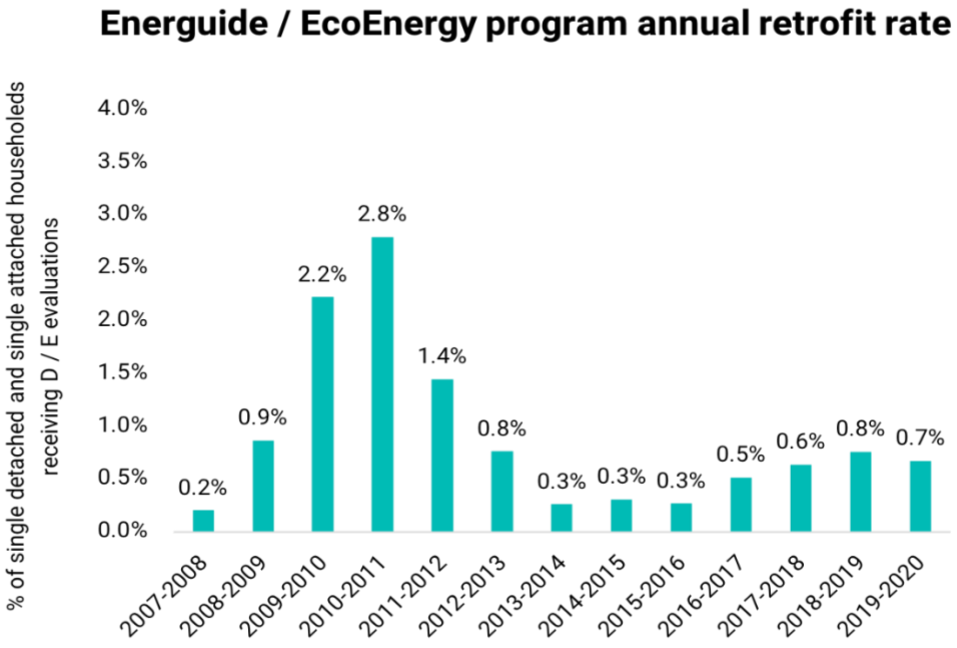


*Figure 7*

---

[31] Post-retrofit audits from EcoEnergy Retrofit report from 2007-2008 to 2013-2014 and the Energuide monthly report dated 2020-06-01. Housing stock figures taken from National Energy Use Database, Residential Sector, Table 20: Total Households by Building Type and Principal Heating Energy Source.

[32] Roma Luciw, "End of EcoENERGY Riles Home Owners," *The Globe and Mail*, April 1, 2010, https://www.theglobeandmail.com/globe-investor/personal-finance/end-of-ecoenergy-riles-home-owners/article1372678/.

From 2011-2012 to 2019-2020, the average annual energy savings per home were estimated to be 38 GJ, or 20% savings from estimated baseline.[33]

It will take 142 years to retrofit all low-rise residential buildings if the annual retrofit rate remains at its current three-year average of 0.7%. The S35 “emergency response” scenario seeks to retrofit these buildings in 15 years, starting with retrofitting 2% of single-family dwellings in the first year, increasing 0.5% per year over the first five years, and then taking off to retrofit 12% per year. The S50 scenario ramps up to a peak annual retrofit rate of 5% per year. Both scenarios also call for dramatically increasing the depth of savings, achieving 68% total energy use intensity reductions in single-family dwellings as a national average (38% reductions without energy savings from heat pump conversions).

## Commercial retrofits

It would take 142 years to retrofit all low-rise residential buildings and 71 years to retrofit all commercial floor area, at current annual rates

Natural Resources Canada analysis of the 2014 Survey of Commercial and Institutional Energy Use (SCIEU) provides a picture of commercial retrofits. The SCIEU is a survey that samples Statistics Canada’s Business Register.[34] The most recent version samples buildings from January 1, 2010 to December 31, 2014. The survey provides information on buildings that undertook 1 to 5 (or more) energy efficiency measures over this period, which could include updates to lighting, heating/cooling equipment, energy management systems, insulation, windows, etc. It does not provide information on the energy savings achieved, and thus the success of these measures or the depth of energy retrofits.

In Table J, we list the percentage of buildings in the survey undertaking more than 4 or 5 energy efficiency measures over the 5 years, on an annual average basis. Using 5 or more measures as a proxy for comprehensive retrofits, 0.6% of buildings and 1.4% of

---

[33] We note that Energuide might overestimate energy consumption as the model’s “normal operating conditions” includes assumptions such as a constant temperature, which does not include behavioural changes or other energy saving measures such as the use of smart thermostats and controls.

[34] https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/scieu/2014/tables.cfm

floor area was retrofitted per year. A 1.4% retrofit rate means it would take 71 years to retrofit all commercial floor area.

The scenarios in the previous section include overall energy intensity performance improvements of 60%. The emergency response scenario starts with retrofitting 2% of the building stock, rising to 12% by 2029, while the 2050 scenario ramps up to retrofitting 5% of the building stock by 2035.

*Table J*

| **Commercial-institutional Buildings energy retrofits** | | |
|---|---|---|
| Number of energy efficiency measures (2010-2014) | % of buildings (annual average) | % of floor space (annual average) |
| 4 or more efficiency measures | 1.4% | 2.5% |
| 5 or more efficiency measures | 0.6% | 1.4% |

*Source: Natural Resources Canada request from 2014 SCIEU*

## The “atomised” building retrofit market and policy structure

A building retrofit is a complex task. It involves different contractors in areas such as insulation, HVAC, and plumbing, as well as financing to cover up-front costs. Thus, particular models or systems develop to accomplish a retrofit. The model that dominates is not necessarily optimal or the best fitted to climate policy objectives.

Donal Brown describes the dominant approach to retrofits as the “atomised market model”.[35] Under this approach, each building is treated as a unique project, and the customer is in charge of selecting contractors, finding financing, and taking on the risks associated with issues like construction delays and long-term underperformance.

---

[35] Donal Brown, “Business Models for Residential Retrofit in the UK: A Critical Assessment of Five Key Archetypes,” *Energy Efficiency* 11, no. 6 (2018): 1497–1517.

This status quo market model has a number of drawbacks. Deeper energy savings and GHG reductions are likely to go unrealized as customers have limited financing and knowledge of what is possible.

The separation between the different trades fails to consider the whole-home energy savings that can occur with an integrated design approach, such as the ability to significantly downsize heating systems after thermal envelope upgrades to improve function and comfort. Contractors are limited to installing technologies that are currently available on the market, and business models based on providing free quotes incent contractors to undertake simple equipment installations of the technologies they know rather work with others to provide whole-building solutions.

It is difficult to attract financing at beneficial rates because high transaction costs occur when individually financing small projects. Under the limitations of this model, the business case for the building upgrade relies on what has been achieved before rather than on the performance that could be achieved if things were done differently, under different market and policy environments.

Programs that offer customer rebates and loans do little to change an atomised market model structure. Building professionals that do retrofit work have experienced several booms and busts in customer incentive programs, rather than a long-term signal. The fleeting nature of these policies provides little incentive for market actors to change the dominant retrofit model in order to achieve better energy efficiency and climate performance.

The policy environments that have traditionally supported building retrofits do not have an explicit decarbonization or market transformation mission.

This situation should not be surprising because the policy environments that have traditionally supported building retrofits do not have an explicit decarbonization or market transformation mission. In North America, the bulk of building retrofit funding is provided by energy efficiency or demand side management programs, where energy savings are considered as a resource for electricity and natural gas utility system planning and operation. The primary policy objective is to reduce utility system costs such as new power plants, fuel purchases, or transmission lines. This governance model can lead to more stable program funding, and an evidence-based program design and evaluation process.[36] However, these regulatory institutional environments also fail to consider many important benefits of energy efficiency, such as improved indoor environmental quality, building durability, resilience against extreme weather, energy poverty reduction, and GHG reductions. The cost-effectiveness tests used for ex-ante evaluation tend to be restricted to customer costs and the cost-benefit to the utility system.[37] This situation produces a bias towards traditional techniques, short-term, measurable results over dynamic efficiencies, and risk aversion under a regulatory mandate to prudently use ratepayer funds. Within existing energy efficiency portfolios there is little room for experimentation with system-changing innovations, other than limited budget carve-outs for small pilot projects.

This dominant model not only crowds out innovation and systemic solutions - it could also lock in too many carbon emissions by promoting shallow over “deep” retrofits. A shallow retrofit that is not part of a longer-term plan can make the implementation of additional solutions needed to achieve larger savings less cost-effective and will result in another round of disruption to the building owner. Given the need to retrofit nearly the entire building stock in the next 15-30 years, each retrofit must be consistent with climate policy objectives.

---

[36] For a discussion on the strengths and limitations of utility demand side management see Brendan Haley et al., “From Utility Demand Side Management to Low-Carbon Transitions: Opportunities and Challenges for Energy Efficiency Governance in a New Era,” *Energy Research & Social Science* 59 (January 2020).

[37] Chris Neme and Marty Kushler, “Is It Time to Ditch the TRC? Examining Concerns with Current Practice in Benefit-Cost Analysis,” in *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings*, 2010; Tim Woolf et al., “National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources” (National Efficiency Screening Project, May 18, 2017).

## New approaches to achieve new results

A mission should strive to “stretch and transform” existing markets and regulatory environments so building retrofits can achieve climate policy objectives.

The building retrofit results achieved thus far should be understood as the outcome of a particular market and policy structure. The retrofit market is not structured to achieve dramatic efficiency and GHG reduction improvements, and few policy initiatives have taken on improving the performance of GHG emission-reducing retrofits as an explicit mission. Rather, retrofits have been forced to “fit and conform” into existing market and political structures.

This has been politically successful because energy savings produce numerous benefits that enable advocates to present compelling business cases to particular constituencies, in different institutional environments. Environmental activists at utility regulatory boards have argued that energy efficiency acts as a “cost-effective” resource in electricity and natural gas systems, even without considering environmental and other societal benefits. However, this strategy constrains energy retrofit assessment to a static cost-benefit calculation. Policymakers have also launched energy efficiency programs in reaction to energy price spikes, or as economic stimulus because they create jobs and cut costs for households and firms. However, these crisis responses are often short-lived, leading to short-term and uneven policy support.

Clever political strategies to fit energy efficiency benefits into current policy priorities or into a discrete policy environment have advanced energy efficiency and climate change progress and have delivered market transformations in technologies such as lighting and equipment. However, these strategies have also likely failed to present a true picture of the potential performance of building retrofits. Instead of fitting and conforming building retrofits to the way things work today, a retrofit mission should strive to “stretch and transform” existing markets and regulatory environments so building retrofits can achieve climate policy objectives.[38]

---

[38] “Fit and conform” and “stretch and transform” strategies are discussed in the context of low-carbon innovation in Adrian Smith and Rob Raven, “What Is Protective Space? Reconsidering Niches in Transitions to Sustainability,” *Research Policy* 41, no. 6 (2012): 1025–36, http://resolver.scholarsportal.info/resolve/00487333/v41i0006/1025_wipsrnitts.

# Transforming building retrofits

The previous section showed that the current rate and energy saving performance of retrofits are inadequate to confront the climate emergency, and that existing market and policy structures were not designed to meet climate change goals.

Our quantitative scenarios present significant increases in scale and performance, which will require significant decreases in retrofit costs. We do not yet know if it is possible to achieve these results. However, the climate emergency calls on us to achieve them, and there are significant benefits to be gained from trying.

In this section, we discuss why we see the potential to achieve the dramatic scale-up of retrofits outlined in our scenarios. At present, we can identify numerous opportunities for learning, new retrofit process configurations or models that show promise, and several avenues for innovation along organizational, technological, and social dimensions. The ability to identify opportunities from change should give us confidence that different results are possible, and that policy should target dynamic performance improvements through innovation.

## S-curve pattern of change

Sustainable transition theories present an S-curve pattern to change[39], which we can categorize into four phases:

- A pre-development stage where rapid change might not be visible, yet new structures are put into place and learning from experimentation occurs;
- A take-off or acceleration stage where new ways of doing things start to demonstrate increased scale;
- A breakthrough phase where follow-on innovations complement and coalesce, producing noticeable changes in physical and social infrastructure;

---

[39] Jan Rotmans, Rene Kemp, and Marjolein Van Asselt, “More Evolution than Revolution: Transition Management in Public Policy,” *Foresight* 3 (2001): 15–31.

- A final phase in which the innovation is maintained and incrementally improved upon and the new ways of doing things are diffused to the most difficult markets, albeit at a slower rate.

This is the pattern that defines the scale-up of retrofits in our scenarios. Virtuous circles of learning and improvement make such dramatic change possible. Thus, if we can foresee opportunities for learning, an S-curve pattern of change might be possible in the building retrofit space.

**S-curve pattern of change**

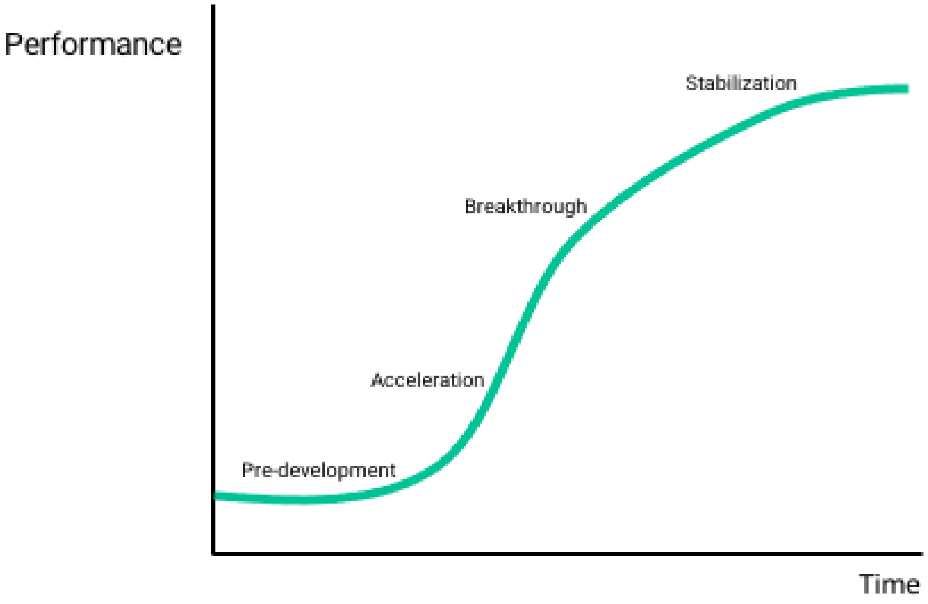


*Figure 8*

## Types of learning

Energy efficiency is often described as a proven, low-cost solution, and thus is evaluated using static cost-benefit analysis rather than considering opportunities for innovation. However, there is not a well-developed market for large-scale and comprehensive energy- and GHG-saving building retrofits, and we could see dynamic performance improvements if there are unrealized opportunities to learn.

Evolutionary theories see *learning* as the most important economic activity.[40] If a sector or national economy has opportunities to learn it can improve its performance over time. Notably, laboratory R&D and classroom study are only capable of promoting a narrow form of information exchange and discovery. Learning that ushers in significant economic change occurs alongside the development of new systems of production and consumption. These changes are triggered when efforts are focused on particular problems, as system imbalances are revealed, when scale increases, and as new technologies are deployed.[41]

Table K presents five types of learning found in the academic literature on innovation and industrial policy. These forms of learning have produced significant changes in other sectors. Learning by doing, producing, using, and interacting each occur alongside the deployment of technology. Social learning recognizes the need for policies and markets to "stretch and transform" to accommodate climate retrofit objectives. This requires new regulatory and governance systems capable of releasing the technological and organizational changes induced by the other forms of learning.

There are opportunities to make dynamic performance improvements to building retrofits with a concerted focus and production scale-up.

The right-hand column of the table lists examples of learning relevant to building retrofits. This is not an exclusive list. We could identify many other examples of learning relevant to building retrofits. Our ability to develop a simple and preliminary list that covers all types of learning suggests there are opportunities to make dynamic performance improvements to building retrofits with a concerted focus and production scale-up.

---

[40] This contrasts with neoclassical economic theories that prioritize exchange and allocation. See Richard R. Nelson and Sidney G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge: Belknap Press, 1982).

[41] Nathan Rosenberg, "The Direction of Technological Change: Inducement Mechanisms and Focusing Devices," *Economic Development and Cultural Change* 18, no. 1, Part 1 (October 1969): 1–24, http://www.jstor.org.proxy.library.carleton.ca/stable/1152198.

*Table K*

**Types of learning and retrofit innovations**

| Type of learning | Theoretical description | Examples of relevance to retrofit mission |
|---|---|---|
| Learning by doing [A] | Labour productivity increases due to improved skill, tacit knowledge, and problem-solving abilities gained through repetition and experience. | Scale up will transition those who work casually in high-performance retrofits towards specialist teams with experience in areas such as air sealing, insulation and heat pump installation, where quality of work significantly impacts performance. |
| Learning in production [B] | Continuous and interdependent changes in capabilities, organizations, material assets, machinery and infrastructure that occur in production. | |
| Technology adoption [C] | Similar technical and organizational solutions are adopted from other sectors and firms, or used to solve similar problems | Retrofit actors adopt general technologies such as LiDAR, drones, robotics, and 3D printing, as well as techniques currently used in new and large buildings. Adoption of organizational solutions from logistics, performance contracting, marketing. |
| Removing scale bottlenecks [D] | Expanded production volumes induce new innovations across the value chain | Specialized facades and cold-climate heat pumps to meet large scale demands of highly efficient building envelopes. |
| Complementary innovations [E] | Changes to production processes induce complementary products and processes | Increased use of prefabrication to develop wall panels enables mechanization and ability to customize based on digital capture information. |
| Intermediate producer specialization [F] | Development of specialized suppliers of intermediate goods follows from increased specialization in a new area of production | Increased retrofit volume induces specialized equipment in areas such as small-scale diggers and self-erecting cranes; scaffolding; coring machines; hydro vac; digital capture techniques; airtightness improvements; diagnostic tools to assess structural and moisture problems. |
| Learning by using [G] | Performance improvements are discovered as technology is used. This can include operations and maintenance solutions, new conceptions of product value, and increased knowledge of specific market needs. | Marketing of complementary products; increased energy saving spillover from positive customer experience; recognition of non-energy and total cost of ownership benefits; persistence of energy savings through energy monitoring and feedback. |
| Learning by interacting [H] | Increased competence is created via routine interaction and knowledge sharing between actors in production process, as well as user-producer interactions. | Integrated project management and design encourages interaction between multiple trades and building users to develop well designed, less costly, and higher performing building solutions. |
| Social learning [I] | Adaptation of policy systems and local public and private sector networks fosters economic performance and manage technological change. | Development of new policies to enable large-scale retrofits, including minimum building performance standards, removal of regulatory barriers, training and recruitment, and creation of intermediary organizations[J] to govern supply chains and innovation. |

---

[A] Kenneth J. Arrow, “The Economic Implications of Learning by Doing,” *The Review of Economic Studies* 29, no. 3 (1962): 155–73.

[B] Ha-Joon Chang and Antonio Andreoni, “Industrial Policy in the 21st Century,” *Development and Change* 51, no. 2 (2020): 324–51.

[C] Nathan Rosenberg, “Technological Change in the Machine Tool Industry, 1840-1910,” *The Journal of Economic History* 23, no. 4 (December 1963): 414–43.

[D] Nicholas Kaldor, “The Irrelevance of Equilibrium Economics,” *The Economic Journal* 82, no. 328 (1972): 1237–55; Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore: Johns Hopkins University Press, 1983).

[E] Nathan Rosenberg, “Technological Interdependence in the American Economy,” *Technology and Culture* 20, no. 1 (1979): 25–50; Erik Dahmén, “Development Blocks in Industrial Economics,” ed. Bo Carlsson, Industrial Dynamics : Technological, Organizational, and Structural Changes in Industries and Firms (Boston: Kluwer Academic Publishers, 1989), 109–21.

[F] Antonio Andreoni, “The Architecture and Dynamics of Industrial Ecosystems: Diversification and Innovative Industrial Renewal in Emilia Romagna,” *Cambridge Journal of Economics* 42, no. 6 (November 9, 2018): 1613–42, https://doi.org/10.1093/cje/bey037.

[G] Nathan Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge [Cambridgeshire], New York: Cambridge University Press, 1982).

[H] Bengt-Ake Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (London: Pinter Publishers, 1992).

[I] David A. Wolfe and Meric S. Gertler, “Innovation and Social Learning: An Introduction,” in *Innovation and Social Learning* (Springer, 2002), 1–24; Peter A. Hall, “Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in Britain,” *Comparative Politics* 25, no. 3 (April 1993): 275–96.

[J] Paula Kivimaa, “Government-Affiliated Intermediary Organisations as Actors in System-Level Transitions,” *Research Policy* 43, no. 8 (October 2014): 1370–80, https://doi.org/10.1016/j.respol.2014.02.007; Paula Kivimaa and Mari Martiskainen, “Dynamics of Policy Change and Intermediation: The Arduous Transition towards Low-Energy Homes in the United Kingdom,” *Energy Research & Social Science* 44 (October 1, 2018): 83–99, https://doi.org/10.1016/j.erss.2018.04.032.

## The energiesprong model

The concept of social learning noted above involves the creation of new development models or configurations of technological, financial, and organizational elements. Energiesprong (energy leap) is an alternative model which aims to transform the building retrofit process. It was first developed in the Netherlands to achieve net-zero energy buildings.[42] It started in the social housing sector, which has two particular advantages as a lead market: building owners with an ability to internalize energy cost reductions, and a large portfolio of similarly constructed buildings. The model is expanding into other building types, such as commercial offices, schools, and care homes.

The project demonstrates the economies of scale and related changes in markets and supply chains that can occur when a large number of buildings are retrofitted together. Table L contrasts the different elements of the energiesprong model with the atomised market model.

---

[42] See Donal Brown, Paula Kivimaa, and Steven Sorrell, “An Energy Leap? Business Model Innovation and Intermediation in the ‘Energiesprong’Retrofit Initiative,” *Energy Research & Social Science* 58 (2019): 101253; European Commission, “Netherlands Energiesprong (Energy Leap),” Policy Measure Fact Sheet (European Construction Sector Observatory, March 2017).

*Table L*

| Comparing retrofit models | | |
|---|---|---|
| | 'Atomised' market model | Energiesprong model |
| Governance | Project management **left to customer**, with little coordination between suppliers | **Single organization** takes responsibility and engages all suppliers in integrated design and project implementation |
| Value proposition | **Estimated** energy savings | **Guaranteed** home improvement and comfort through long-term service contract with retrofit solutions provider |
| User experience | **Separate** marketing and engagement for audit, retrofits, finance etc. | **One-stop-shop** for retrofit service<br>Face-to-face workshops with community |
| Supply chain | Separate trades install measures **available on market** | **Market is shaped** via high-volume orders for integrated measures, with manufacturing off-site |
| Financing | Finance provided by **third party** with little involvement in retrofit with building or owner securing loan | Lender and developer use **energy performance contract** to repay costs with realized energy savings<br>Tenant energy bill converted to "energy plan" that pays for retrofit and maintenance. |

*Adapted from Brown et al 2019.*

The governance of a retrofit project under energiesprong involves a single organization taking on responsibility for the retrofit. This enables coordination of suppliers and contractors with different expertise, working as a team. An initial focus on design can deliver significant energy savings through simple changes such as right-sizing heat pumps and distribution systems. This governance method contrasts with the atomised model where project management is left to the customer, who must navigate a bewildering network of contractors and service providers. Unless the customer has the expertise to take on the role of integrated designer, there is likely to be little coordination between suppliers, resulting in lost opportunities to achieve energy savings and related benefits by making building components work together as a system.

The primary value proposition in the atomised model rests on estimated energy savings. Software estimates the energy savings resulting from specific measures installed, without a system in place post-retrofit to ensure targeted savings are achieved. This leaves the building owner with the consequences of poor work quality or poorly installed equipment. The energiesprong model brings performance contracts to the residential sector, where a retrofit solution provider takes responsibility for energy savings through a 30-year, insurance-backed guarantee. The benefits marketed to the customer and integrated within the performance guarantee can go beyond energy cost savings, including home health and comfort services such as a consistent temperature and better indoor air quality. Performance monitoring after the retrofit provides information to continually maintain equipment, make operational adjustments to save energy, and engage building users in energy-saving behaviours.

The user experience or customer interface moves to a turnkey, one-stop-shop retrofit service. Engagement can occur at community scale. This contrasts with the atomised market model, with different retrofit service providers providing separate marketing and engagement with the customer.

Under the atomised model, the materials and technologies currently available in local markets determine the upgrades that are possible. Under energiesprong, supply chains are reshaped to meet the level of performance required to achieve a net-zero retrofit. This is made possible by demand aggregation - increasing the scale of demand by pooling a large number of similar buildings into a single project. It has resulted in the manufacture of all-in-one HVAC systems and of insulated and air-sealed wall panels that can be quickly installed during the construction phase.

In the energiesprong model, financing is linked to realized energy savings through the energy performance contract. This couples repayment of the loan to retrofit performance, rather than physical assets or building owners' ability to access credit. The financial risks associated with a single retrofit project are distributed over a larger number of projects. Project aggregation also creates the potential to attract the interest of large institutional investors who are deterred by high transaction costs associated with small loan amounts for single projects.

Different financing arrangements can also change the nature of the consumer contract, transforming the typical volumetric energy bill towards an energy plan that acts more like a cell phone bill. An energy plan service charge pays for the retrofit costs and ongoing maintenance over time. Individual households receive a guaranteed level of heat and hot water, with additional per use charges for consumption above a certain amount.[43]

## The market development role

The introduction of the energiesprong model is led by a market development team. In the Netherlands, the government issued a call to explore different approaches to energy efficiency to realize a long-term vision to decarbonize the building stock.[44] This led to the creation of a market development team that hosted forums for market actors (building owners, contractors, manufacturers) to consider how to transform the retrofit process.

Market development teams reshape the way retrofit market actors interact on both the demand and supply side

These teams play a role in reshaping the way retrofit actors interact on both the demand and supply side, leading to new contracting and delivery processes. The teams coordinate building owners with similar building types into a large-scale portfolio, and then develop performance criteria for contracts with suppliers. By putting a challenge out to industry, this approach changed the nature of the typical competitive process. Before suppliers were asked to compete for contracts, they engaged in public forums that facilitated a common understanding of net-zero performance objectives and the vision of delivering net-zero retrofit performance at lower costs via economies of scale. The large-scale demand spurred manufacturing innovations such as prefabricated panels, and the

---

[43] Piet Jacobs et al., "Transition Zero," Funded by EU Horizon 2020 (Energiesprong / Platform31, 2015).

[44] Brown, Kivimaa, and Sorrell, "An Energy Leap?," 6.

creation of new businesses. When the initiative in the Netherlands struggled to find HVAC manufacturers, it led to the creation of a new company called factoryzero.[45]

The market development teams learn from each project and create resources for the model to be replicated. Teams develop standardized templates for procurement and performance criteria. Suggesting complementary changes to regulatory and policy frameworks is also part of their mandate. This can include context-specific issues such as availability of consumer data; incorporating energy efficiency into mortgage assessments; planning permissions for higher roofs and exterior cladding extending off property lines; streamlined permitting to upgrade electrical panels; longer-term utility energy efficiency programs to match the multi-year development and delivery timeline of mass retrofits; and boosting renewable energy incentives when projects are on highly efficient buildings to increase GHG reductions.[46]

## Retrofit innovation pathways

Energiesprong provides an example of a new retrofit model, incorporating technical innovations, new business models, and the reshaping of market structures and policy environments. It has had considerable success in social housing as a lead market. However, it is not necessarily the perfect model for all building types and regional circumstances.

> There are many technological as well as social changes with potential to transform building retrofits.

The need to reshape markets and explore new retrofit models is the most important lesson. There are many technological as well as social changes with potential to transform building retrofits. Below, we present a list of promising areas for innovation to illustrate the multiple pathways that need to be explored.

---

[45] See https://www.nweurope.eu/projects/project-search/mustbe0-multi-storey-building-e-0-refurbishment/partners/factory-zero-bv/

[46] Transition Zero, “Make Net Zero Energy Refurbishments for Houses a Mass Market Reality. National Regional and Local Regulatory Context for E=0 Refurbishments,” Deliverable 3.1 (EU Horizon 2020, February 27, 2017).

## Integrated design and project delivery

A dramatic scale-up in energy savings and cost reductions is likely to occur through the path of better design processes, and not solely through improvements to technological components. As Lovins argues, “the efficiency resource vastly exceeds the sum of individual technologies because artfully choosing, combining, sequencing, and timing fewer and simpler technologies can save more energy at lower cost.”[47]

For instance, proper air sealing of buildings enables smaller, more responsive HVAC systems, which provide greater efficiency and comfort. The potential of better design is often neglected due to hard technology bias, and measurement of savings from individual measures rather than their interaction as a system. Major shifts in techno-economic paradigms come with a new “engineering common sense”[48], and integrated design is likely one of the new ways of thinking and doing required for a net-zero emissions economy.

Integrated project delivery is a related organizational innovation that involves a consortium taking on the responsibility for delivering a retrofit from end to end. This contrasts with a “design-bid-build” model, which is designer-led and siloed. The more collaborative integrated project delivery approach creates potential for learning by interacting. Problems are identified early, and innovative solutions sought through feedback between actors involved in design, construction, and operations and maintenance. Financial risks are shared across the consortium, which makes all team members accountable for building-level performance. This encourages everyone to solve problems and support each other’s innovations, rather than pushing risks onto someone else or implementing a design that makes no sense. This is an organizational approach focused on achieving higher performance at lower cost.

These design and organizational innovations will place new demands on manufacturers and supply chains (e.g. for smaller and more responsive equipment), as well as training systems. They can be encouraged through complementary policy changes. For instance, public sector construction initiatives such as the Rapid Housing Initiative can incent an integrated project delivery approach. Government and utility incentive programs can count savings from systems rather than individual measures and provide

---

[47] Amory B. Lovins, “How Big Is the Energy Efficiency Resource?,” *Environmental Research Letters* 13, no. 9 (2018): 090401.

[48] Chris Freeman and Carlota Perez, “Structural Crisis and Adjustment, Business Cycles and Investment Behaviour,” in *Technical Change and Economic Theory*, ed. Giovanni Dosi (London, New York: Pinter Publishers, 1988), 38–66.

up-front support for design processes (e.g. charrettes and community energy plans) rather than prescriptive rebates on individual measures.

## Prefabrication

Traditional retrofit techniques involve significant on-site construction work to add insulation, remove siding, etc. It comes with risk of damage from exposure to weather conditions, and uncertain installation quality. Manufacturing building envelopes in a factory holds promise to improve quality and airtightness, reduce time and costs on-site, and reduce construction waste, and it means fewer disturbances to building occupants. In Canada, the CanmetENERGY research centre is developing, testing, and validating prefabricated building envelope technologies through the PEER project.[49]

Prefabrication of HVAC systems also groups previously separate functions (space heating and cooling, water heating, ventilation, dehumidification, heat/energy recovery, solar, home monitoring) into one package. This reduces redundant components and space requirements and can ease transport, installation, and maintenance. Smaller units can also provide more services to smaller homes and apartments. CanmetENERGY has an Integrated Energy Systems Lab that explores these technologies.

## Mass customization

The idea that every building is like a “snowflake”, with its own unique configurations and problems, would seem to hinder innovation pathways that rely on a standardized retrofit approach. However, a mass customization model could enable building-specific retrofit solutions to be coupled with large-scale production by using technologies that enable site-specific insights with greater ease.[50] 3D laser scans of a building identify irregularities and analyze them in a building information model. This information can then be used to create customized prefabricated panels. 3D printers can also be used

---

[49] Natural Resources Canada, “PEER – Prefabricated Exterior Energy Retrofit” (Natural Resources Canada, March 2, 2017), https://www.nrcan.gc.ca/energy/efficiency/data-research-and-insights-energy-efficiency/housing-innovation/peer-prefabricated-exterior-energy-retrofit/19406.

[50] see Andrés F. Barco et al., “Building Renovation Adopts Mass Customization,” *Journal of Intelligent Information Systems* 49, no. 1 (2017): 119–46.

on-site to manage irregular surfaces and/or provide customized shapes and aesthetics.[51]

Custom solutions will also be necessary before energy retrofits can take place in buildings with structural or safety issues such as mold. Relevant innovations in this area can include indoor air quality monitoring, use of radar to analyze structural issues[52], and checklists and decision aids on how to find problems early in a project and put these buildings on a separate path.

Customization can also include building-specific add-ons to a retrofit solutions package. For instance, a customer can choose amongst different building aesthetics packages. In the Netherlands, energiesprong projects create the option for "age in place" additions that provide first floor accessibility to the bedroom and bathroom,[53] as well as upgrades to kitchens and bathrooms.

### Place-specific retrofit aggregation

Economies of scale can be achieved through strategies that focus retrofits in the same geographic area. These strategies can deploy replicable solutions across similar building types and lower costs and induce relevant product changes through bulk purchase. Work crews can undertake specialized tasks (siding, air barrier, insulation, etc.), working from building to building in a "retrofit train".[54] Area-based strategies can also create high program participation and engagement. This was demonstrated in Canada decades ago. In 1991-2, The Espanola Power Savers Project achieved an 87% audit participation rate and 72% uptake in energy saving measures by focusing strategies in one geographic area.[55]

Place-specific strategies could initially focus on similar building typologies that lend themselves to replicable solutions. The energiesprong approach has tended to focus on

---

[51] Office of energy efficiency and renewable energy, "Advanced Manufacturing for Building Envelope Retrofits," Energy.gov, accessed April 12, 2021, https://www.energy.gov/eere/buildings/articles/advanced-manufacturing-building-envelope-retrofits; P2ENDURE, "State-of-the-Art Report on Innovations for Deep Renovation," Deliverable Report: 6.5 (EU Horizon 2020, February 28, 2017).

[52] M. Sofi et al., "Determining Dynamic Characteristics of High Rise Buildings Using Interferometric Radar System," *Engineering Structures* 164 (June 1, 2018): 230–42, https://doi.org/10.1016/j.engstruct.2018.02.084.

[53] Ian Shapiro, "Energiesprong A Dutch Approach to Deep Energy Retrofits and Its Applicability to the New York Market" (NYSERDA, March 2018).

[54] Ronald Rovers, "New Energy Retrofit Concept:'Renovation Trains' for Mass Housing," *Building Research & Information* 42, no. 6 (2014): 757–67.

[55] Ontario Hydro, "Espanola Power Savers Project," 1992.

row houses or multi-unit residential buildings. Canada has a diverse building stock, yet there are opportunities to define advanced markets with similar building typologies. These could include “strawberry box”, or victory houses built in the post-Second World War period, 3-storey walk-up apartments, military housing, and tract-built homes in the suburbs. Municipalities with community energy plans and/or declaration of climate emergencies are natural places to implement transformative retrofit approaches.

## Time-specific retrofit aggregation

There are moments in time or “trigger points” that create opportunities for retrofit, such as schedules for equipment replacement, building maintenance and rehabilitation, and tenant or occupant turnover. By coordinating similar upgrades expected to occur at the same time, demand can be aggregated and then coordinated to deliver new and lower-cost supplies, at larger scale. The US Rocky Mountain Institute’s Zero over Time project is implementing this strategy by working with several building owners to create an investment roadmap calendar, and then matching the demand for similar solutions across these calendars.[56]

## Digital technologies

The incorporation of digital technologies enables several retrofit solutions at each stage of the process. Digital pre-production models support integrated design by estimating performance of different retrofit configurations and enable learning through scenarios. 3D scanning and building information systems enable prefabrication.

Detailed data on building characteristics and energy usage that is available across geographies will foster better space- and time-based aggregation strategies. For example, after Portland, Oregon required sellers of single-family homes to disclose a home energy score, the US Pacific Northwest National Laboratory used the data to target geographic clusters for specific upgrades.[57]

Digital technologies are also important post-retrofit, as real-time monitoring of energy usage and building amenities will enable energy performance contracts. Monitoring energy usage and providing feedback encourages behaviours that ensure energy

---

[56] Cara Carmichael, Matt Jungclaus, and Alisa Petersen, “Guide: Best Practices for Achieving Zero Over Time for Building Portfolios” (Rocky Mountain Institute, n.d.), https://rmi.org/insight/zero-over-time-for-building-portfolios/.

[57] Chrissi Antonopoulos et al., “Pushing Green: Leveraging Home Energy Score to Promote Deep-Energy Retrofits in Portland, Oregon,” 2020.

savings persist, and significant savings can be achieved by applying automation and machine learning to energy systems.[58]

## User experience

Perhaps the most important area for innovation is in making the retrofit experience simple, affordable, and desirable for building users. The technical, design, and process innovations noted above all promise to enhance user experience by providing quick, lower-cost, and aesthetically unique retrofits. Further changes could include business models and marketing approaches that place a value on comfort, health, and resilience to weather events. This could trigger learning by using, as customers understand the whole cost of ownership benefits and tell their neighbours about their experience. Technologies such as virtual reality and before-after visualizations can be used to demonstrate the final product and engage consumers. Performance guarantees that take the risks of construction and financing away from the consumer can make buying a retrofit as simple and safe as buying a car or an internet subscription.

Coupling energy and GHG reducing retrofits with other services and solutions to societal problems is another important area for innovation, enabling customers to see energy retrofits as a path to the improvements they already know they need and want in their lives. This can include enhancing buy-in by coupling neighbourhood retrofits with landscaping and community gardens. Adding a new unit or secondary suite to a building during retrofit could bring a homeowner extra revenue to cover the capital costs of the upgrade, help reduce economy-wide energy usage, and contribute to housing affordability. Allowing building retrofits to stretch and transform their larger environment could entail new forms of building ownership, such as conversion of buildings that fail to meet health and safety standards (and/or minimum energy performance standards) to affordable or co-operative housing.

---

[58] Jennifer King and Christopher Perry, “Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings” (American Council for an Energy Efficiency Economy, February 27, 2017), https://www.aceee.org/research-report/a1701.

## Defining the climate retrofit mission

We have established that achieving net-zero economy objectives for the building sector and the wider economy means undertaking high performance building retrofits at an unprecedented scale. There is reason for optimism that such a scale can be achieved by transforming the dominant model used to retrofit buildings and exploring multiple innovation pathways that are possible. Achieving these results also requires a new policy approach that avoids constraining retrofit strategies within existing market and policy environments.

> Achieving these results also requires a new policy approach that avoids constraining retrofit strategies within existing market and policy environments.

A mission-oriented approach, as articulated and popularized by innovation theorist Mariana Mazzucato[59], is a promising way to organize a climate retrofit policy agenda. Human experience with objectives such as going to the moon, and - more recently - creating a vaccine against the coronavirus, demonstrates that societies have the ability to spur major changes, along relatively advanced timelines. In sustainable energy, focused missions such as the US SunShot Initiative and the German energiewende have contributed to dramatic cost reductions in solar and wind technologies.

This policy orientation focuses on finding and deploying technologically feasible solutions to societally relevant problems. It directs processes of economic change by defining a grand challenge, in contrast to a particular technological breakthrough or a strategic sector.[60] Canadian policy thinkers have also recently called for economic policy to be defined by challenges and missions.[61]

---

[59] Mariana Mazzucato, *Mission Economy: A Moonshot Guide to Changing Capitalism* (Penguin Books Limited, 2021).

[60] Mariana Mazzucato, Rainer Kattel, and Josh Ryan-Collins, “Challenge-Driven Innovation Policy: Towards a New Policy Toolkit,” *Journal of Industry, Competition and Trade* 20, no. 2 (2020): 421–37.

[61] Robert Asselin, Sean Speer, and Royce Mendes, “New North Star II : A Challenge-Driven Industrial Strategy for Canada” (Public Policy Forum, April 2020).

Mazzucato presents five criteria for a relevant mission[62]:

1. **It must be societally relevant, bold, and inspirational.**
2. **It must set a clear, targeted, measurable, and time-bound direction.**
3. **It must be ambitious but realistic, audacious enough to trigger what would otherwise not be attempted, but feasible in theory.**
4. **It must operate across disciplines and sectors and involve multiple actors.**
5. **It must invite multiple bottom-up solutions.**

The climate emergency presents a “grand challenge” for Canada and the world, requiring a climate retrofit mission. Our scenario models demonstrate that we can prepare the building stock for decarbonization by eliminating fossil fuels, enhancing energy efficiency, and freeing up enough clean electricity to further reduce emissions in other sectors. This constitutes a Mass Climate Retrofit vision to shoot for. Here is how we can articulate such a mission using Mazzucato’s criteria.

## Mass Climate Retrofits by 2035

### Societally relevant, bold, and inspirational

By 2035, we will have retrofitted all of Canada’s existing building stock to eliminate the direct use of fossil fuels and made our buildings zero-carbon ready, via a high level of energy efficiency and use of a decarbonized energy supply.[63] Building retrofits will also contribute to the decarbonization of transportation and industry by redirecting existing clean energy resources away from energy waste.

Our buildings will be better prepared for extreme weather events brought on by climate change and become more comfortable, healthy, and productive places to be. In the process, Canada will have eliminated energy poverty and created high-quality housing conditions for Indigenous Peoples.

---

[62] Mariana Mazzucato, “Mission-Oriented Research & Innovation in the European Union,” *European Commission*, 2018.

[63] See International Energy Agency, “Net Zero by 2050: A Roadmap for the Global Energy Sector,” May 2021.

Climate impacts will be further reduced by considering the carbon emissions embodied in building materials and equipment - creating demand for supply chains to become zero-carbon and use materials that sequester carbon.

## Clear direction, targeted, measurable, and time-bound

National-level mission targets include:

- Undertaking deep retrofits of all buildings to achieve high levels of energy efficiency and to eliminate direct fossil fuel use;
- Freeing up 50 TWh of clean electricity to enable Canada's net-zero transition in sectors like transportation and industry.

Further direction is required with respect to energy and GHG performance by region and building type. These should be expressed as specific intensity standards, providing a clear target for energy efficiency performance for each building type. Defining more specific targets by building typology can be developed iteratively through further research and data collection. The intensity targets used for residential buildings in our scenarios are found in

Table *D*, and energy intensity reductions for commercial buildings are found in Table E.

Achieving the mission targets will also require performance monitoring against specific retrofit process goals. These performance metrics can include:

- **Cost reduction:** Reduce total retrofit costs by at least 50%;
- **Retrofit speed:** Reduce time to undertake retrofit to 2-5 days;
- **Value:** Retrofits should achieve standards for thermal comfort (ASHRAE 55), durability, ability to maintain heat in emergency situations, and indoor environmental quality through monitoring of indoor environment conditions and occupant experience.

## Ambitious but realistic

Decarbonization scenarios frequently note that the buildings sector can achieve zero emissions without the use of offsets.[64] Real-world examples demonstrate that deep energy savings are being achieved right now.[65] Large-scale retrofits, through approaches such as energiesprong, also demonstrate the potential to reduce costs by 50% or more.[66] Thus the mission is both technically feasible and realistic.

The ambition is introduced by dramatically increasing the scale of retrofits and making large energy and GHG savings a market norm. The mission is to reach the acceleration phase in an S-curve pattern. This scale and speed of retrofits is audacious enough to require experimentation with solutions that would otherwise not be attempted.

## Cross-disciplinary, cross-sector, cross-actor

The mix of actors that must come together for large-scale retrofits includes municipalities, architects, contractors, community organizations, investors, and manufacturers. To achieve new levels of performance, the mission should invite insights from new disciplines and sectors, such as data science, logistics, and marketing.

## Inviting multiple bottom-up solutions

Multiple retrofit models are likely required to achieve the mission. A single policy solution - such as a prescriptive grant or loan program for shallow retrofits - could lock building retrofits into a trajectory unable to meet climate emergency goals. Thus, the mission must invite experimentation and learning from the bottom up. Different solutions are likely to connect with particular building archetypes, regions, and communities.

---

[64] Jason Dion et al., "Canada's Net Zero Future" (Institute for Climate Choices, February 2021), https://climatechoices.ca/reports/canadas-net-zero-future/; Arnulf Grubler et al., "A Low Energy Demand Scenario for Meeting the 1.5 C Target and Sustainable Development Goals without Negative Emission Technologies," *Nature Energy* 3, no. 6 (2018): 515–27.

[65] R. Osser, K. Neuhauser, and K. Ueno, "Proven Performance of Seven Cold Climate Deep Retrofit Homes" (Golden, CO (United States): National Renewable Energy Lab. (NREL), June 1, 2012), https://doi.org/10.2172/1047922.

[66] BPIE, "Think Deep: Boosting Renovation through Innovation & Industrialisation," I24c Memo, November 2016. Economies of scale have reduced retrofit costs by 50% compared to initial pilot project, with goal to achieve 69% cost reduction.

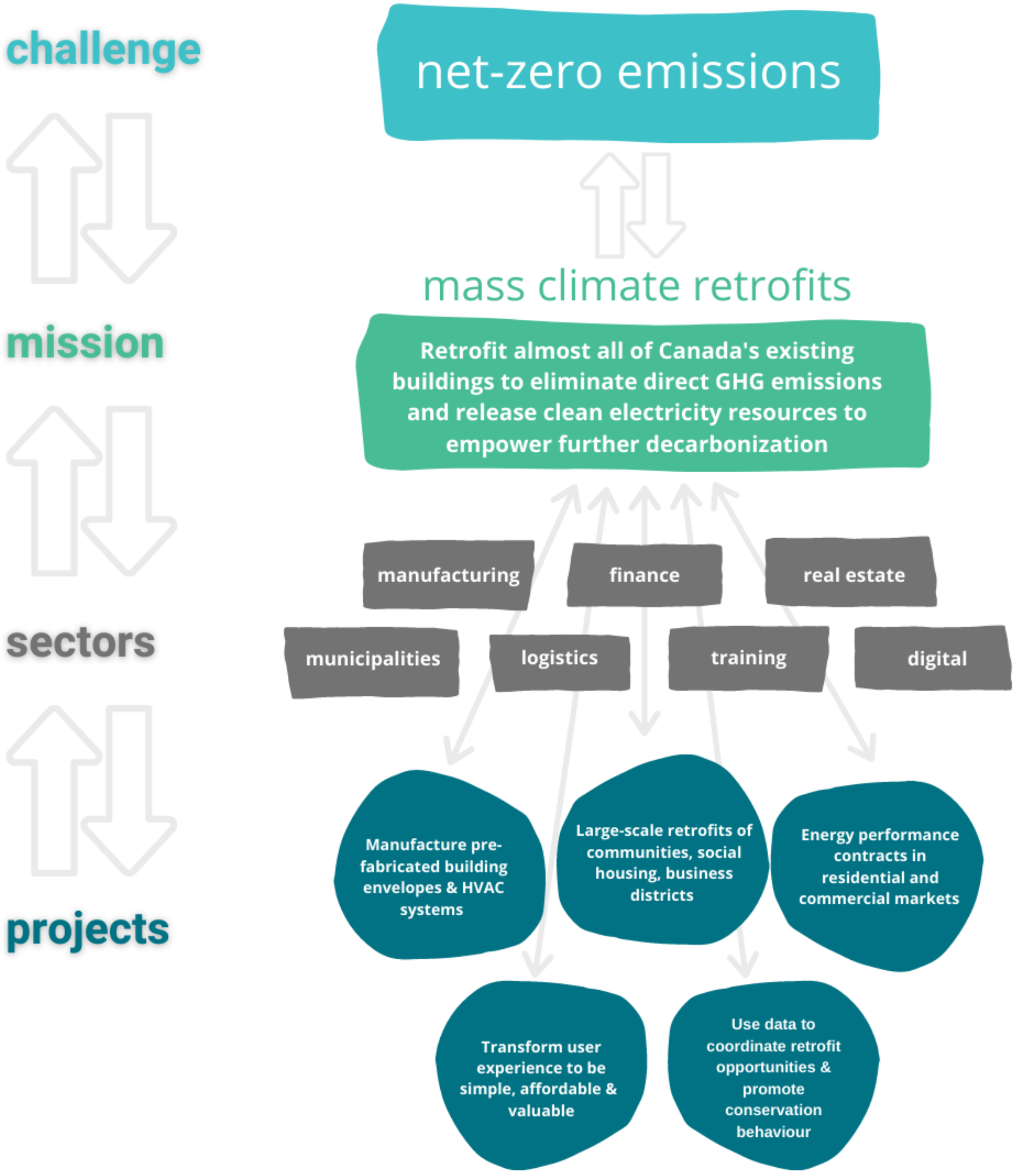

challenge
mission
sectors
projects
net-zero emissions
mass climate retrofits
Retrofit almost all of Canada's existing buildings to eliminate direct GHG emissions and release clean electricity resources to empower further decarbonization
manufacturing
finance
real estate
municipalities
logistics
training
digital
Manufacture pre-fabricated building envelopes & HVAC systems
Large-scale retrofits of communities, social housing, business districts
Energy performance contracts in residential and commercial markets
Transform user experience to be simple, affordable & valuable
Use data to coordinate retrofit opportunities & promote conservation behaviour

*Figure 9*

Figure 9 is one illustration of Mazzucato's mission-oriented template. The national net-zero emissions challenge calls for a mass retrofit mission. This will involve multiple sectors, such as training, manufacturing, and utilities, and can involve a large number of specific projects. The graphic lists examples such as prefabrication, mass retrofits, and data strategies; however, the major point is to have a portfolio of approaches promoting experimentation and an iterative learning process, which will then inform future projects.

The mission can involve projects across the entire innovation chain, from research and development to commercialization. This could include laboratory experiments with new materials or manufacturing techniques. Yet, to trigger the types of learning that are required, efforts must focus on deployment. This includes methods to achieve economies of scale, as well as new contracting and insurance systems after the construction work is complete, such as long-term performance guarantees. Finally, the projects must be evaluated on their systemic impacts or ability to transform existing markets and policy structures. Some projects will fail, yet contribute to learning. Other projects will find new techniques that will need to be adapted for replication across different building types and geographies.

## Why Canadians should take on this mission

A mission focused on the deployment of holistic retrofit solutions is different from the "big science" examples of recent history, such as the Apollo or Manhattan projects. The latter, in particular, involved a closed group of scientific experts and focused on technological achievements.

By contrast, building retrofits are similar to other sustainability transition challenges that involve a network of different actors, the involvement of building occupants, a diversity of building archetypes and regional considerations, and a primary focus on scaling up or deployment. These characteristics dictate a diversity of solutions through a portfolio of projects, and involvement by a variety of potential solution providers.[67]

---

[67] see David C. Mowery, Richard R. Nelson, and Ben R. Martin, "Technology Policy and Global Warming: Why New Policy Models Are Needed (or Why Putting New Wine in Old Bottles Won't Work)," *Research Policy* 39, no. 8 (2010): 1011–23; Brendan Haley, Stewart Elgie, and Geoff McCarney, "Accelerating Clean Innovation in Canada's Energy and Natural Resource Sectors – The Role of Public Policy and Institutions," Report to the Social Sciences and Humanities Research Council for Knowledge Synthesis Grant, May 2016.

An Apollo-type mission fits with the US industrial legacy, with strength in early-stage R&D and invention.[68] In contrast, Canadian innovations such as marquis wheat, oil sands, and long-distance transmission and communications technologies stem from the need to manage the logistics of extensive value chains and adapt to the country's geographic challenges. Discussions of Canadian innovation opportunities have previously cited a potential specialization in buildings that perform in harsh Canadian climates.[69] This suggests Canada can develop advantages in creating systems for the widespread use of sustainable technology,[70] which is exactly the challenge we face in the first part of the 21st century to confront the climate emergency.

> Canada can develop advantages in creating systems for the widespread use of sustainable technology, which is exactly the challenge we face in the first part of the 21st century to confront the climate emergency.

---

[68] Jonas Nahm, "Renewable Futures and Industrial Legacies: Wind and Solar Sectors in China, Germany, and the United States," *Business and Politics* 19, no. 1 (March 2017): 68–106, https://doi.org/10.1017/bap.2016.5.

[69] Mastering technologies essential for survival in the Canadian physical environment with respect to housing and energy waste the first priority in a *technological sovereignty* industrial policy, as outlined by the Science Council of Canada in the 1970s. See John N. H. Britton and James M. Gilmour, *The Weakest Link: A Technological Perspective on Canadian Industrial Underdevelopment* (Ottawa: Science Council of Canada, 1978).

[70] see Richard Hawkins, "Looking at Innovation from a Uniquely Canadian Perspective" (Institute for Science, Society and Policy, 2012).

# Governing the Mission

Fulfilling this ambitious and societally relevant building retrofit mission will require new policy systems. Canada already has many of the building blocks in place, such as the R&D led by CanmetENERGY and financing through the Canada Infrastructure Bank. However, the impact of these existing institutions could be more powerful if complemented by a long-term mission and an organized strategy to reshape the nature of retrofit markets. A mission-oriented approach also requires public sector institutions capable of focusing on the goal, accepting risks, being flexible, and avoiding secrecy to enable ongoing interaction with market participants.

Below, we propose a governance system consisting of a new national organization playing the role of retrofit mission leader, which supports local market development teams. These teams will be tasked with producing replicable retrofit solutions that meet performance goals. The policy system will then aim to rapidly accelerate the retrofit solutions that work to meet a mass retrofit national goal.

## Policy building blocks

Various elements of Canada's policy system are already exploring new ways to retrofit buildings. This includes the Prefabricated Exterior Energy Retrofit (PEER) project at CanmetENERGY that led to a collaborative demonstration project with Ottawa Community Housing to retrofit four Ottawa townhomes from the outside. CanmetENERGY also conducts research and testing in housing innovations, including HVAC systems and net-zero housing in different regions.

The Canada Infrastructure Bank included energy efficient buildings as part of its mandate at the end of 2020 and has now launched a Commercial Building Retrofit Initiative. The financing program sends a signal for market transformation through its criteria. It promotes aggregation of buildings through a minimum $25 million investment threshold and incents deeper retrofits than the market norm through a minimum 30% GHG reduction target combined with preferential interest rates tied to further reductions.

The Energy Efficient Buildings RD&D Program funds research, development and demonstration projects. One of the projects supported thus far is the Sundance Housing Rehabilitation project in Edmonton, which seeks to achieve net-zero performance levels in a 15-building townhouse complex through a “repeatable, modular retrofit process” inspired by the energiesprong approach. The Local Energy Efficiency Partnership (LEEP) program aims to reduce the time and risk builders face implementing innovative solutions through technology forums involving manufacturers, field trials, and knowledge sharing.

## The market development gap

These initiatives make valuable contributions, but they also leave gaps and bottlenecks in the policy system. If those gaps are left unfilled, we are unlikely to achieve take-off in building retrofits.

In its R&D and testing work, CanmetENERGY does not have a partner actively creating large-scale markets for the new technologies they are developing and validating. This also restricts the learning by using and interacting that could feed back into the R&D and field demonstrations.

The Canada Infrastructure Bank has an investment mandate. It can create demand for certain types of retrofit solutions by offering preferential terms linked to performance criteria. However, it is not the Bank’s role to undertake the on-the-ground task of bringing supply chain actors and building owners and users together to re-vision and re-shape the retrofit delivery processes. The Bank is also unlikely to finance experimental initiatives with high initial costs that could achieve dramatic cost reductions. As an institution, its role is to ramp-up solutions that are market ready, which leaves out innovative solutions that have promise to transform markets if given an opportunity to evolve by triggering learning.

In the residential market, federal programs are focused on offering traditional grants and loans to individual homeowners within existing market structures. The transformation of the retrofit process is not an objective, nor is there clear guidance to supply chain actors (auditors, contractors) to meet building specific performance criteria.

Each of the existing programs and policy initiatives has its place in the policy mix. Missing are policy strategies intended to reshape and develop new retrofit markets.

The Energy Efficient Buildings RD&D Program has largely focused on single-building demonstrations (see appendix). This approach can show that it is possible to build or retrofit to high standards (e.g. Passive House or net-zero energy-ready), but it does not lead toward reshaping the technology and market environments to make high-performance buildings the market norm. Projects are selected via time-limited expressions of interest, and preference is given to “shovel-ready” projects with a demonstration component scaled to specific buildings. This program criterion tends to shorten the time and resources allotted for up-front work to design new retrofit systems and business models, such as engaging users about their needs, aggregating demand, developing performance criteria, engaging supply chain actors, and taking integrated project management approaches. While the program currently supports stand-alone front-end engineering design studies, a proponent that seeks support for this initial step runs the risk of not receiving funding for physical construction projects, especially if the proposed solution does not fit program criteria for budget cut-offs and payback periods.

Each of the existing programs and policy initiatives has its place in the policy mix. Missing are policy strategies intended to reshape and develop new retrofit markets.

First, there is no policy agenda that aims to actively reshape the demand and supply side of retrofit markets. The programs and policies noted above are all constrained by current market structures and technologies. By aggregating retrofits to a certain scale, it is possible to require new products and better performance from manufacturers, who will be able to cover fixed costs associated with new product development and retooling production processes. The creation of bulk demand and clear performance criteria will facilitate scale-up and trigger production-based learning.

The second, inter-related missing strategy involves experimentation with new retrofit models. Energiesprong presents an example of a business model or system that incorporates technologies such as prefabrication as well as new organizational systems such as 30-year performance guarantees, replacing energy bills with energy plans, specialized one-stop-shop retrofit services, and new ways to engage user communities. There is currently no policy to adapt the energiesprong approach to

Canada, or to experiment with other multi-dimensional retrofit solutions that fit different geographies and building architypes.

Despite the lack of clear policies to support these functions or strategies, there are several initiatives in Canada inspired by the energiesprong model. These include:

- The Pembina Institute Reframed Lab;
- The Toronto Atmospheric Fund Retrofit Delivery Centre concept;
- Sustainable Buildings Canada's net-zero energy program platform;
- The ReCover Initiative in Nova Scotia;
- The Whole Housing Energy Retrofit Envelope – Nova Scotia (WHERE-NS) project;
- Sundance Housing Rehabilitation Project and Retrofit Canada;
- Ottawa Community Housing's and the NRC's PEER project.

There is no obvious policy program to support these projects. Some have been awarded funding, while others have had trouble navigating funding opportunities in often volatile political environments – needing to fit and conform to program criteria geared towards technology demonstration. Their true potential lies in their ability to stretch and transform the current market and policy environment to do retrofits in a new way, but there is currently no mission to support this outcome. We next turn towards how we might fill the market development gap and direct these activities to achieve an ambitious retrofit mission.

## Organizing the mission

A mission-oriented perspective provides long-term support and a clear objective, with a recognition that achieving transformative changes will require novel approaches combined with a readiness to rapidly scale up solutions that work.

Key functions that public policy must set in motion include experimentation with replicable retrofit solutions; accelerating solutions that work; and guiding the mission at a national scale by providing financial resources, knowledge exchange, and coordination.

Figure 10 provides a picture of how a retrofit mission could be organized.

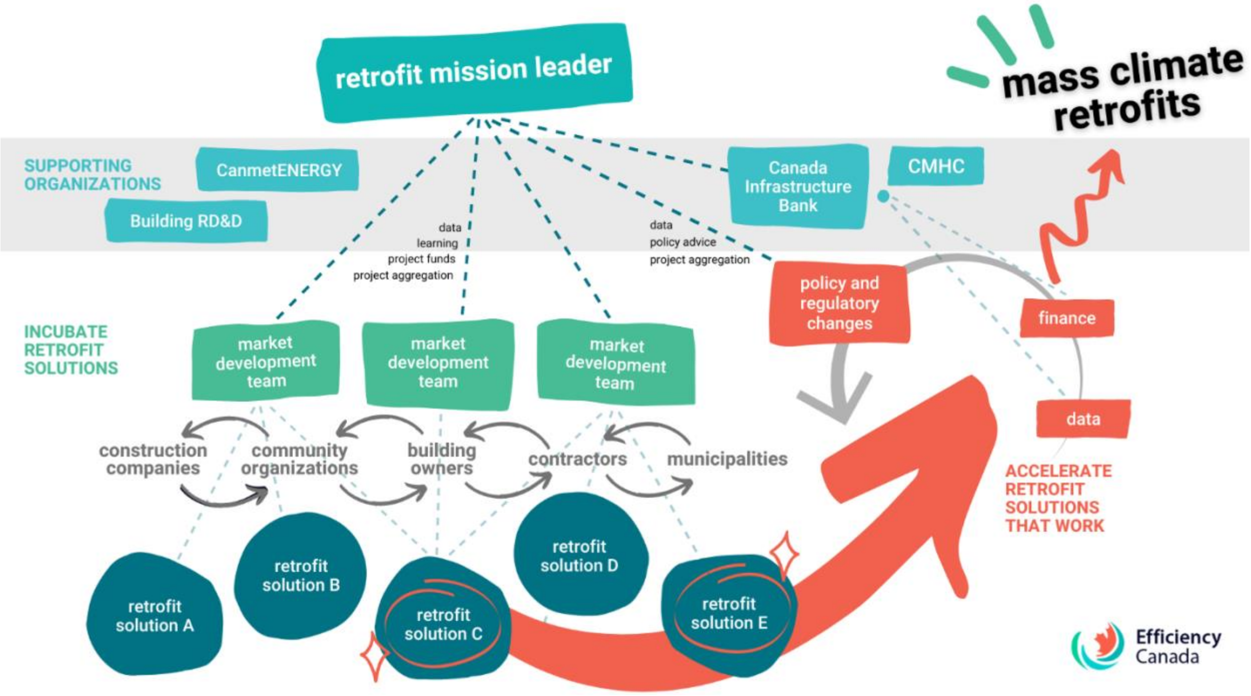


*Figure 10*

## Incubating retrofit solutions through market development teams

> A retrofit solution that works should be replicable, presenting a clear product or approach for a particular building type and/or region that can be easily redeployed to reduce complexity.

A retrofit mission will seek multiple bottom-up solutions from market development teams throughout the country. A solution that works should be replicable, presenting a clear product or approach for a particular building type and/or region that can be easily redeployed to reduce complexity. This converts the retrofit mission from 10 million unique challenges for each building in Canada to a smaller subset of challenges segmented by building characteristics. A viable solution will include physical technologies, as well as new social and organizational systems to govern project management, design, supply chains, financing, and community engagement.

Market development teams will act as intermediary organizations responsible for experimenting with new retrofit solutions. They will bring together actors on the demand and supply side of retrofit markets, as well as relevant policymakers, to achieve mission performance objectives related to speed, cost, and value.

These teams may be organized around regional and building archetype boundaries, recognizing that different solutions will exist for distinct types of buildings, climate zones, and user communities, with the potential to aggregate retrofit demand across both space and time. The legal and organizational structure of each team can vary by circumstance, but non-profit civil society organizations are likely to be a good fit. Teams should include subject matter specialists with expertise in areas such as building science, market transformation, construction, and public engagement.

Members of the teams should be independent and have no material interest in the contracts between users and suppliers or the ultimate success of particular business models. Their task is to reshape markets to meet mission objectives, rather than promoting business interests connected to a particular retrofit model. The teams will be able to capture important on-the-ground and tacit information by being embedded within local markets. They should also have access to knowledge from the retrofit mission leader and a network of similar teams on the global state of the art, so they understand what capabilities must be developed locally.

A team's mandate will include analyzing how existing policy structures can be changed to better enable retrofit solutions. This will require reforms across multiple levels of government, which is why the teams should act as politically independent organizations with the ability to advocate for relevant changes to municipal, provincial, and federal policymakers. This is similar to technology cluster development, where local associations are best positioned to clearly articulate how different levels of government can support innovation strategies.[71]

---

[71] Tijs Creutzberg, "Canada's Innovation Underperformance: Whose Policy Problem Is It?" (Mowat Centre, 2011).

Organizing retrofit projects through market development teams will enable greater flexibility than is possible under current government programs based on time-bound requests for proposals and bureaucratic qualification criteria. To deliver transformative solutions, teams can work with the national mission leader under an active project management approach followed by other mission-oriented innovation organizations.[72] The stable structure and ongoing relationship between the teams, the national mission leader, and local market actors will produce a steady pipeline of innovative retrofit projects. Each project will have sufficient time and security for teams to implement up-front integrated design and project management methods. They can have more discretion to undertake relevant activities at the right stage of development - from smaller-scale demonstrations to active engagement with manufacturers. Finally, they will have the flexibility to cancel projects at the exploration and design stages with no penalty for proponents because of their ability to continue working with the teams on new solutions.

Organizing retrofit projects through market development teams will enable greater flexibility than current government programs based on time-bound requests for proposals and bureaucratic qualification criteria.

The teams must have access to sufficient funding to encourage market actors to initiate projects at a large enough scale to trigger learning by doing and producing. While they might undertake smaller-scale demonstrations, the primary aim is to discover what new solutions become possible when retrofitting at large scale (e.g. 500 homes).

A diversity of retrofit solutions will be the market development teams major output. Some of these solutions will fail to meet performance criteria and will be useful failures that facilitate learning about what works and what does not. The solutions that can meet performance criteria and demonstrate potential to trigger even more learning and transformations will be selected for acceleration.

---

[72] For role of active project management and public administration principles for low-carbon innovation that inform the suggested approach see Brendan Haley, "Designing the Public Sector to Promote Sustainability Transitions: Institutional Principles and a Case Study of ARPA-E," *Environmental Innovation and Societal Transitions*, January 2017, https://doi.org/10.1016/j.eist.2017.01.002.

## Accelerating retrofit solutions that work

The policy system must have the capability to smoothly and rapidly accelerate retrofit solutions that work – meaning they have demonstrated high performance based on mission criteria. We anticipate that acceleration will likely require some combination of policy and regulatory changes, data provision, and finance.

### *Policy and regulatory changes*

As emphasized throughout this paper, retrofit solutions will not necessarily be "market-ready" because the structure of retrofit markets might need to be changed. Thus, solutions that demonstrate high performance in particular market niches might require complementary policy and regulatory changes to accelerate and expand. When a market development team proposes a workable solution, it will also define the complementary regulatory and market changes required for that model to grow in new environments. This underscores the importance of a perspective open to stretching and transforming existing market and policy environments to complement the retrofit mission, rather than fitting and conforming to existing structures, which can lock building retrofits into low performance.

Relevant changes will span all levels of government, likely including changes to municipal by-laws, provincial utility regulations, and federal model retrofit codes. The shift could also include promoting or requiring new practices within existing markets, such as measurement and disclosure of energy performance, retooling manufacturing for mass production, and creation of new professional credentials, such as building performance specialists.

### *Data and Information*

A functioning market requires the right information. Data on the performance of workable business models should be transparent and open source. This information should be tailored to consumers through mandatory labeling and energy reporting. Contractors that have participated in high-quality projects and demonstrated high performance in areas such as airtightness should be able to market their skills. Data should also be tailored to investor needs, so they can properly assess risk and return on investment.[73]

The retrofit mission leader must monitor retrofit technologies and business models around the world and raise their visibility in Canadian markets, as a way of stretching existing conceptions of what is possible.[74] To accelerate workable solutions, market development team members might find themselves mentoring those working to replicate a given retrofit solution. Thus, as a new retrofit model expands, so should the social networks that facilitate knowledge exchange.

### *Finance*

Retrofitting the building stock is a substantial capital investment. Providing the consistent, long-term, public investment required and directing private capital towards this investment opportunity will require government leadership.

The Canada Infrastructure Bank (CIB) recently added building retrofits to its mandate, and its initial Commercial Building Retrofit Program pulls the market towards project aggregation and deeper GHG emission reductions. As market development teams produce new retrofit solutions, the CIB can adapt its financing criteria to continue to pull the market towards higher performance.

To deliver on the retrofit mission, we also need to find solutions for residential buildings, including single-family dwellings. The federal government currently supports Property Assessed Clean Energy (PACE) and on-bill financing through the Federation of Canadian Municipalities, and will offer $40,000, interest-free loans through the Canada Mortgage and Housing Corporation.

New retrofit solutions will likely involve different residential financing models to remove homeowner risk, and/or project finance arrangements that link repayment to aggregate energy savings from large bundles of projects. Existing financing policy frameworks should be encouraged to accommodate high-performance retrofit solutions, and if

---

[73] Katherine Monahan and Barb Zvan, "Bridging the Transparency Gap in Sustainable Finance" (Smart Prosperity Institute, August 2020), https://institute.smartprosperity.ca/bridging-transparency-gap.

[74] Termed "field manipulation" in industrial policy theory. See Bo Carlsson and Staffan Jacobsson, "In Search of Useful Public Policies — Key Lessons and Issues for Policy Makers," in *Technological Systems and Industrial Dynamics*, ed. Bo Carlsson (Springer US, 1997), 299–315.

significant residential project aggregation is achieved, the Canada Infrastructure Bank could incorporate residential retrofits within its portfolio.

## The role of a national retrofit mission leader

The retrofit mission leader must monitor retrofit technologies and business models around the world and raise their visibility in Canadian markets, as a way of stretching existing conceptions of what is possible

A national organization should be tasked with guiding the mission. It will monitor, coordinate, and link together the incubation and acceleration of retrofit solutions to ensure no break in their evolutionary trajectory.

The national organization will have responsibility for creating the market development teams and funding the projects they originate. It will use an active project management approach, as discussed above, to enable a flexible evaluation of projects based on their transformative potential and ability to meet mission performance objectives.

A national mission leader will also play an important role in enabling retrofit solutions by aggregating them at a national scale. This could include working with market development teams to coordinate demand for equipment and materials from buildings across the country. This demand-shaping and coordination role should be coupled with a manufacturing industrial strategy that aims to develop Canadian expertise in retrofit supply chains.

The retrofit mission leader will facilitate information sharing and joint projects between the market development teams. It must have analytical capabilities to monitor global building retrofit innovations, and to disseminate information to wider market actors to rapidly introduce retrofit solutions into markets.

Collecting and maintaining high-quality data on the building stock must also be a high priority. Better data quality is important for understanding the size of the energy and GHG reduction resource in Canada’s buildings and monitoring the success of different retrofit approaches. The organization can work closely with the National Research Council, Natural Resources Canada, CMHC, and provincial entities such as utilities to collect high-quality data on the Canadian building stock.

Such an organization must be independent from day-to-day politics to maintain focus on the mission. It should be staffed by subject matter experts capable of critically examining different retrofit solutions. To create both independence and flexibility, the mission leader can be constituted as a Crown corporation or not-for-profit organization such as Sustainable Development Technology Canada. The organization's leadership should play close attention to following institutional principles of successful innovation-oriented public sector organizations.[75]

The mission leader will need to work in partnership with market development teams to reshape existing policy environments to enable the scale-up of retrofit solutions. This could be disruptive to status quo bureaucracies. A clear link to a high-level political champion in the Prime Minister's Office, Cabinet, or larger climate strategy governance institutions will facilitate policy changes at the federal level, while market development teams will act as prudent advocates to all levels of government.

## The mission can start now

As noted above, Canada has many of the building blocks to organize a building retrofit mission through existing institutions, and willing participants are already on the ground forming market development teams. While the mission can be structured around a mission-leading organization and market development teams, it is also possible to support aligned initiatives immediately while a longer-term organizational system is under development. Given the tight timelines of the retrofit mission we propose, it is appropriate to start learning lessons from the bottom-up solutions that are readily available today.

---

[75] Haley, "Designing the Public Sector to Promote Sustainability Transitions"; Brendan Haley, "Getting the Institutions Right: Designing the Public Sector to Promote Clean Innovation," *Canadian Public Policy* 42, no. S1 (November 1, 2016): S54–66, http://www.utpjournals.press/doi/abs/10.3138/cpp.2016-051.

# Conclusion

The primary message of this report is the need to think about building retrofit policy differently to confront the climate emergency. The scenarios demonstrate a level of performance and scale not yet accomplished. However, such performance is technically feasible. If retrofits can be organized at such a scale, Canada can not only make the existing building stock zero-carbon, but also empower the larger net-zero emission challenge by freeing up a substantial amount of clean electricity.

A mission-oriented policy approach is suited to realizing an ambitious, yet technically feasible, challenge. Such an approach would see building retrofits learn lessons from how innovations evolve and reshape markets. This is a departure from traditional energy efficiency policy environments which evaluate projects using static cost-benefit analyses rather than their potential to achieve dynamic efficiencies and transform existing markets.

Canada's policy system already has many of the building blocks to implement a mission-oriented approach. Missing elements include an independent and innovation-focused organization to guide the mission, coupled with on-the-ground teams exploring ways to reshape how retrofit markets function.

Retrofitting our buildings to eliminate emissions and to perform better in Canada's harsh environments and the future disruptions that will be caused by a changing climate is a worthy challenge. Policymakers need to define the mission, create the right policy structures, and set the stage for Canadians to find transformative solutions.

# References

Altus Group. “2021 Canadian Cost Guide,” 2021. https://go.altusgroup.com/e/575253/cost-guide-2021-pdf-download/2653b5/618989972?h=iUdxYb1w9aaU0up0n6r9_2C5yflck1gsbqStvCRGWec.

Amerongen, Peter. “Sundance Housing Co-Op Deep Energy Retrofit.” Presented at the Retrofit Canada Conference, May 2021.

Andreoni, Antonio. “The Architecture and Dynamics of Industrial Ecosystems: Diversification and Innovative Industrial Renewal in Emilia Romagna.” *Cambridge Journal of Economics* 42, no. 6 (November 9, 2018): 1613–42. https://doi.org/10.1093/cje/bey037.

Antonopoulos, Chrissi, Heather Dillon, Rachel Dzombak, David Heslam, and Samuel Rosenberg. “Pushing Green: Leveraging Home Energy Score to Promote Deep-Energy Retrofits in Portland, Oregon,” 2020.

Arrow, Kenneth J. “The Economic Implications of Learning by Doing.” *The Review of Economic Studies* 29, no. 3 (1962): 155–73.

Asselin, Robert, Sean Speer, and Royce Mendes. “New North Star II : A Challenge-Driven Industrial Strategy for Canada.” Public Policy Forum, April 2020.

Barco, Andrés F., Élise Vareilles, Paul Gaborit, and Michel Aldanondo. “Building Renovation Adopts Mass Customization.” *Journal of Intelligent Information Systems* 49, no. 1 (2017): 119–46.

Bharadwaj, Sharad, Charles Li, Liz Mettetal, and Arne Olson. “Deep Decarbonization in Nova Scotia: Phase 1 Report.” San Francisco, CA: Energy and Environmental Economics, for Nova Scotia Power, February 2020.

BPIE. “Think Deep: Boosting Renovation through Innovation & Industrialisation.” I24c Memo, November 2016.

Britton, John N. H., and James M. Gilmour. *The Weakest Link: A Technological Perspective on Canadian Industrial Underdevelopment*. Ottawa: Science Council of Canada, 1978.

Brown, Donal. “Business Models for Residential Retrofit in the UK: A Critical Assessment of Five Key Archetypes.” *Energy Efficiency* 11, no. 6 (2018): 1497–1517.

Brown, Donal, Paula Kivimaa, and Steven Sorrell. “An Energy Leap? Business Model Innovation and Intermediation in the ‘Energiesprong’Retrofit Initiative.” *Energy Research & Social Science* 58 (2019): 101253.

Calder, Devon. “The Case for Deep Retrofits.” The Atmospheric Fund, 2020. https://taf.ca/publications/the-case-for-deep-retrofits/.

Carlsson, Bo, and Staffan Jacobsson. “In Search of Useful Public Policies — Key Lessons and Issues for Policy Makers.” In *Technological Systems and Industrial Dynamics*, edited by Bo Carlsson, 299–315. Springer US, 1997.

Carmichael, Cara, Matt Jungclaus, and Alisa Petersen. “Guide: Best Practices for Achieving Zero Over Time for Building Portfolios.” Rocky Mountain Institute, n.d. https://rmi.org/insight/zero-over-time-for-building-portfolios/.

Chang, Ha-Joon, and Antonio Andreoni. “Industrial Policy in the 21st Century.” *Development and Change* 51, no. 2 (2020): 324–51.

Creutzberg, Tijs. “Canada’s Innovation Underperformance: Whose Policy Problem Is It?” Mowat Centre, 2011.

“Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard.” Passive House Institute, September 9, 2015. https://www.passivehousecanada.com/wp-content/uploads/2017/02/Passive-House-and-EnerPHit_building_criteria.pdf.

Dahmén, Erik. “Development Blocks in Industrial Economics.” edited by Bo Carlsson, 109–21. Industrial Dynamics : Technological, Organizational, and Structural Changes in Industries and Firms. Boston: Kluwer Academic Publishers, 1989.

Dion, Jason, Anna Kanduth, Jeremy Moorhouse, and Dale Beugin. “Canada’s Net Zero Future.” Institute for Climate Choices, February 2021. https://climatechoices.ca/reports/canadas-net-zero-future/.

European Commission. “Netherlands Energiesprong (Energy Leap).” Policy Measure Fact Sheet. European Construction Sector Observatory, March 2017.

Freeman, Chris, and Carlota Perez. “Structural Crisis and Adjustment, Business Cycles and Investment Behaviour.” In *Technical Change and Economic Theory*, edited by Giovanni Dosi, 38–66. London, New York: Pinter Publishers, 1988.

Government of Canada, Statistics Canada. “Household Spending, Canada, Regions and Provinces,” April 25, 2012. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1110022201.

Grubler, Arnulf, Charlie Wilson, Nuno Bento, Benigna Boza-Kiss, Volker Krey, David L. McCollum, Narasimha D. Rao, Keywan Riahi, Joeri Rogelj, and Simon De Stercke. “A Low Energy Demand Scenario for Meeting the 1.5 C Target and Sustainable Development Goals without Negative Emission Technologies.” *Nature Energy* 3, no. 6 (2018): 515–27.

Haley, Brendan. “Designing the Public Sector to Promote Sustainability Transitions: Institutional Principles and a Case Study of ARPA-E.” *Environmental Innovation and Societal Transitions*, January 2017. https://doi.org/10.1016/j.eist.2017.01.002.

———. “Getting the Institutions Right: Designing the Public Sector to Promote Clean Innovation.” *Canadian Public Policy* 42, no. S1 (November 1, 2016): S54–66. http://www.utpjournals.press/doi/abs/10.3138/cpp.2016-051.

Haley, Brendan, Stewart Elgie, and Geoff McCarney. “Accelerating Clean Innovation in Canada’s Energy and Natural Resource Sectors – The Role of Public Policy and Institutions.” Report to the Social Sciences and Humanities Research Council for Knowledge Synthesis Grant, May 2016.

Haley, Brendan, James Gaede, Mark Winfield, and Peter Love. “From Utility Demand Side Management to Low-Carbon Transitions: Opportunities and Challenges for Energy Efficiency Governance in a New Era.” *Energy Research & Social Science* 59 (January 2020).

Hall, Peter A. “Policy Paradigms, Social Learning, and the State: The Case of Economic Policymaking in Britain.” *Comparative Politics* 25, no. 3 (April 1993): 275–96.

Hawkins, Richard. “Looking at Innovation from a Uniquely Canadian Perspective.” Institute for Science, Society and Policy, 2012.

Hughes, Thomas Parke. *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore: Johns Hopkins University Press, 1983.

International Energy Agency. “Net Zero by 2050: A Roadmap for the Global Energy Sector,” May 2021.

Jacobs, Piet, Kees Leidelmeijer, Wouter Borsboom, Marcel van Vliet, and Peter De Jong. “Transition Zero.” Funded by EU Horizon 2020. Energiesprong / Platform31, 2015.

Kaldor, Nicholas. “The Irrelevance of Equilibrium Economics.” *The Economic Journal* 82, no. 328 (1972): 1237–55.

King, Jennifer, and Christopher Perry. “Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings.” American Council for an Energy Efficiency Economy, February 27, 2017. https://www.aceee.org/research-report/a1701.

Kivimaa, Paula. “Government-Affiliated Intermediary Organisations as Actors in System-Level Transitions.” *Research Policy* 43, no. 8 (October 2014): 1370–80. https://doi.org/10.1016/j.respol.2014.02.007.

Kivimaa, Paula, and Mari Martiskainen. “Dynamics of Policy Change and Intermediation: The Arduous Transition towards Low-Energy Homes in the United Kingdom.” *Energy Research & Social Science* 44 (October 1, 2018): 83–99. https://doi.org/10.1016/j.erss.2018.04.032.

Leinartas, Honnie, and Brent Stephens. “Optimizing Whole House Deep Energy Retrofit Packages: A Case Study of Existing Chicago-Area Homes.” *Buildings* 5, no. 2 (May 4, 2015): 323–53. https://doi.org/10.3390/buildings5020323.

Less, Brennan, and Iain Walker. “A Meta-Analysis of Single-Family Deep Energy Retrofit Performance in the U.S.,” 2014. https://eta.lbl.gov/publications/meta-analysis-single-family-deep.

Lovins, Amory B. “How Big Is the Energy Efficiency Resource?” *Environmental Research Letters* 13, no. 9 (2018): 090401.

Luciw, Roma. “End of EcoENERGY Riles Home Owners.” *The Globe and Mail*, April 1, 2010. https://www.theglobeandmail.com/globe-investor/personal-finance/end-of-ecoenergy-riles-home-owners/article1372678/.

Lundvall, Bengt-Ake. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers, 1992.

Mazzucato, Mariana. *Mission Economy: A Moonshot Guide to Changing Capitalism*. Penguin Books Limited, 2021.

———. “Mission-Oriented Research & Innovation in the European Union.” *European Commission*, 2018.

Mazzucato, Mariana, Rainer Kattel, and Josh Ryan-Collins. “Challenge-Driven Innovation Policy: Towards a New Policy Toolkit.” *Journal of Industry, Competition and Trade* 20, no. 2 (2020): 421–37.

Monahan, Katherine, and Barb Zvan. “Bridging the Transparency Gap in Sustainable Finance.” Smart Prosperity Institute, August 2020. https://institute.smartprosperity.ca/bridging-transparency-gap.

Mowery, David C., Richard R. Nelson, and Ben R. Martin. “Technology Policy and Global Warming: Why New Policy Models Are Needed (or Why Putting New Wine in Old Bottles Won’t Work).” *Research Policy* 39, no. 8 (2010): 1011–23.

Nahm, Jonas. “Renewable Futures and Industrial Legacies: Wind and Solar Sectors in China, Germany, and the United States.” *Business and Politics* 19, no. 1 (March 2017): 68–106. https://doi.org/10.1017/bap.2016.5.

Natural Resources Canada. *Comprehensive Energy Use Database*. Government of Canada, n.d. https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm.

———. “Energuide.” Natural Resources Canada, November 19, 2013. https://www.nrcan.gc.ca/energy-efficiency/energuide/12523.

———. “Funding Opportunities - Current Investments.” Natural Resources Canada, May 31, 2018. https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/21146.

———. “PEER – Prefabricated Exterior Energy Retrofit.” Natural Resources Canada, March 2, 2017. https://www.nrcan.gc.ca/energy/efficiency/data-research-and-insights-energy-efficiency/housing-innovation/peer-prefabricated-exterior-energy-retrofit/19406.

Nelson, Richard R., and Sidney G. Winter. *An Evolutionary Theory of Economic Change*. Cambridge: Belknap Press, 1982.

Neme, Chris, and Marty Kushler. “Is It Time to Ditch the TRC? Examining Concerns with Current Practice in Benefit-Cost Analysis.” In *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Buildings*, 2010.

Office of energy efficiency and renewable energy. “Advanced Manufacturing for Building Envelope Retrofits.” Energy.gov. Accessed April 12, 2021. https://www.energy.gov/eere/buildings/articles/advanced-manufacturing-building-envelope-retrofits.

Ontario Hydro. “Espanola Power Savers Project,” 1992.

Osser, R., K. Neuhauser, and K. Ueno. “Proven Performance of Seven Cold Climate Deep Retrofit Homes.” Golden, CO (United States): National Renewable Energy Lab. (NREL), June 1, 2012. https://doi.org/10.2172/1047922.

P2ENDURE. “State-of-the-Art Report on Innovations for Deep Renovation.” Deliverable Report: 6.5. EU Horizon 2020, February 28, 2017.

Purcell, Bryan. “Building Retrofit Costs, Personal Communication.” The Atmospheric Fund, April 29, 2021.

Regnier, Cindy, Paul Mathew, Alastair Robinson, Jordan Shackleford, and Travis Walter. “System Retrofit Trends in Commercial Buildings: Opening Up Opportunities for Deeper Savings.” Lawrence Berkeley National Laboratory, February 2020.

Rosenberg, Nathan. *Inside the Black Box: Technology and Economics*. Cambridge [Cambridgeshire], New York: Cambridge University Press, 1982.

———. “Technological Change in the Machine Tool Industry, 1840-1910.” *The Journal of Economic History* 23, no. 4 (December 1963): 414–43.

———. “Technological Interdependence in the American Economy.” *Technology and Culture* 20, no. 1 (1979): 25–50.

———. “The Direction of Technological Change: Inducement Mechanisms and Focusing Devices.” *Economic Development and Cultural Change* 18, no. 1, Part 1 (October 1969): 1–24. http://www.jstor.org.proxy.library.carleton.ca/stable/1152198.

Rotmans, Jan, Rene Kemp, and Marjolein Van Asselt. “More Evolution than Revolution: Transition Management in Public Policy.” *Foresight* 3 (2001): 15–31.

Rovers, Ronald. “New Energy Retrofit Concept:‘Renovation Trains’ for Mass Housing.” *Building Research & Information* 42, no. 6 (2014): 757–67.

Russell, Christopher, Brendon Baatz, Rachel Cluett, and Jennifer Amann. “Recognizing the Value of Energy Efficiency’s Multiple Benefits.” *American Council for an Energy-Efficient Economy, Washington, DC*, 2015.

Shapiro, Ian. “Energiesprong A Dutch Approach to Deep Energy Retrofits and Its Applicability to the New York Market.” NYSERDA, March 2018.

Smith, Adrian, and Rob Raven. “What Is Protective Space? Reconsidering Niches in Transitions to Sustainability.” *Research Policy* 41, no. 6 (2012): 1025–36. http://resolver.scholarsportal.info/resolve/00487333/v41i0006/1025_wipsrnitts.

Sofi, M., E. Lumantarna, A. Zhong, P. A. Mendis, C. Duffield, and R. Barnes. “Determining Dynamic Characteristics of High Rise Buildings Using Interferometric Radar System.” *Engineering Structures* 164 (June 1, 2018): 230–42. https://doi.org/10.1016/j.engstruct.2018.02.084.

Statistics Canada. “Table 11-10-0222-01 Household Spending, Canada, Regions and Provinces.” Statistics Canada, n.d. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1110022201.

———. “Table 34-10-0175-01 Investment in Building Construction.” Statistics Canada, n.d. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3410017501.

Streicher, Kai Nino, Stefan Mennel, Jonathan Chambers, David Parra, and Martin K. Patel. “Cost-Effectiveness of Large-Scale Deep Energy Retrofit Packages for Residential Buildings under Different Economic Assessment Approaches.” *Energy and Buildings* 215 (May 2020): 109870. https://doi.org/10.1016/j.enbuild.2020.109870.

The Canadian Energy Regulator. “Canada’s Energy Future 2020,” November 2020.

Torrie, Ralph, and Yuill Herbert. “The Implications of Deep Decarbonization Pathways for Electricity Grids,” March 2021. https://emi-ime.ca/wp-content/uploads/2021/03/EMI-2020-Herbert_report_The-Implications-of-Deep-Decarbonization-Pathways-for-Electricity-Grids.pdf.

Transition Zero. “Make Net Zero Energy Refurbishments for Houses a Mass Market Reality. National Regional and Local Regulatory Context for E=0 Refurbishments.” Deliverable 3.1. EU Horizon 2020, February 27, 2017.

Wolfe, David A., and Meric S. Gertler. “Innovation and Social Learning: An Introduction.” In *Innovation and Social Learning*, 1–24. Springer, 2002.

Woolf, Tim, Chris Neme, Marty Kushler, Steven R. Schiller, Tom Echman, and Julie Michals. “National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources.” National Efficiency Screening Project, May 18, 2017.

# Appendix: Energy Efficient Buildings and Communities RD&D Projects

The table below lists and characterizes projects funded awarded under the “energy efficient buildings and communities” technology area between 2018 and 2020 in the Government of Canada research development and demonstration projects database.[76] The authors used judgment to characterize projects as relating to new building, existing building, building technology, and/or if they involve an element of multi-building demand aggregation or efforts to achieve economies of scale. Most projects, thus far, have focused on new buildings and few involve demand aggregation or economies of scale.

---

[76] Natural Resources Canada, “Funding Opportunities - Current Investments” (Natural Resources Canada, May 31, 2018), https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/current-investments/21146.

| Project | Year Announced | NRCan Funding ($M) | Project Characteristics | | | |
|---|---|---|---|---|---|---|
| | | | New Building | Existing Building | Building technology | Multi-building aggregation / economies of scale |
| Affordable, Replicable and Marketable Net Zero Ready Multiple Unit Residential Buildings | 2020 | $2.4 | ☑ | | | |
| Energy-efficient graphene-based membrane cooling systems | 2020 | $0.9 | | | ☑ | |
| Platforms for life | 2020 | $3.0 | ☑ | | | |
| Building Envelope Technologies for Net-Zero Construction and Retrofit in Canada's Residential and Commercial Sectors | 2019 | $3.0 | ☑ | ☑ | ☑ | |
| Next generation actionable building energy performance metrics, data analytics, and visualization: an open-source platform | 2019 | $0.5 | | | ☑ | |
| Design, construction, demonstration, evaluation, and optimization of a mid-rise "Net-Zero Energy" MURB in Western Canada | 2019 | $3.5 | ☑ | | | |
| Nunavut Arctic College Student Residence Deep Energy Retrofit | 2019 | $2.1 | | ☑ | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Sundance Housing Rehabilitation Project | 2019 | $2.5 | | ☑ | | ☑ |
| Engineering Design for Net Zero Communities in Toronto | 2019 | $0.4 | | ☑ | | ☑ |
| Net-Zero Energy Mixed Use High-Rise Building | 2019 | $3.9 | ☑ | | | |
| 3 300 Saint-Jacques NET ZERO+ | 2018 | $1.0 | ☑ | | | |
| Near Net Zero Energy Supermarket | 2018 | $1.4 | ☑ | | | |
| Occupant modelling for building design and energy codes: roadmap, feasibility study, best practices guidebook, and tested case study | 2018 | $0.4 | | | ☑ | |
| Clayton Heights Passive House Community Centre | 2018 | $1.3 | ☑ | | | |
| Total | | $26.2 | 8 | 4 | 4 | 2 |
| Median | | $1.7 | | | | |