PEMBINA institute

Canada's Renovation Wave

A plan for jobs and climate

Madi Kennedy and Tom-Pierre Frappé-Sénéclauze

July 2021

photo: Roberta Franchuk, Pembina Institute

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Executive summary

To meet climate targets, we need to eliminate carbon pollution from Canadian homes and buildings before mid-century by phasing out on-site combustion of fossil fuels and powering buildings with clean energy. Fuel switching to clean electricity (from wind, solar, and hydro) is the most scalable and market ready way to provide low-carbon energy to buildings. Fuel-switching should be paired with additional measures to reduce overall energy use, improve air quality and thermal comfort, and increase resilience to extreme weather events and earthquakes.

Addressing this climate liability will require an additional investment of about $400 billion, and will unleash a Canada-wide 20-year retrofit wave that will yield generous economic, social, and environmental returns. Investments in the retrofit economy are very effective means to accelerate economic recovery. This is because the actions needed to decarbonize buildings — manufacturing and installing windows, installing air-source heat pumps, adding insulation, etc. — are labour-intensive, and create jobs where people live: in big cities, suburbs, and small towns. These are well-paid jobs in the trades, in manufacturing, and in professional services, for small-scale contractors and larger firms.

To provide an estimate of the scale of this opportunity, and of the public investments needed to realize it, this paper presents a heuristic model of how Canada's buildings can be retrofitted over the next 20 years. Priming the pump for this transformation will require public investments at an order of magnitude above funds allocated to date. We estimate the public investments needed to meet these objectives at about $10 to $15 billion per year, every year between now and 2040 (or until appropriate regulatory drivers are in place).

These investments will create up to 200,000 long-lasting well-paid jobs, generate more than $48 billion in economic development each year, and pay for themselves twice over through increased tax revenue. Paired with a rapid decarbonization of our electricity grids, these retrofits will allow us to decarbonize most of our buildings by 2040. Because of the energy efficiency gains of deep retrofits, electrification of the residential sector can be achieved without increasing the total electricity use, leaving headroom for further electrification of transport and industry.

1. Introduction

To meet climate targets, we need to eliminate carbon pollution from Canadian homes and buildings before mid-century by phasing out on-site combustion of fossil fuels and powering buildings with clean energy. Fuel switching to clean electricity (from wind, solar, and hydro) is the most scalable and market-ready way to provide low-carbon energy to buildings. Fuel-switching should be paired with upgrades to envelope and ventilation systems to reduce overall energy use, improve air quality, ensure thermal comfort, and increase resilience to extreme weather events and earthquakes.

To provide an estimate of the scale of this opportunity, and of the public investments needed to realize it, this paper presents a heuristic model of how Canada's buildings can be retrofitted through a 20-year retrofit wave.[1]

This paper is in three parts:

- We review how investments in the energy efficiency sector can accelerate economic recovery, support community resilience, and address the climate crisis while creating long-lasting well-paying jobs across Canada.
- We present a simplified scenario outlining how we could renovate all of Canada's buildings over the next 20 years.
  - We quantify the impacts of this retrofit wave in each province: economic growth, jobs created, and resulting reductions in carbon pollution, electricity demand and energy costs.
  - We estimate the public subsidies needed to meet these objectives and compare these to historical and announced investments.
- We close with recommendations to address this funding gap and show how these can be paired with regulations to enable a 20-year nation-wide retrofit wave.

[1] The 'Retrofit Wave' was coined by the European Commission in 2020. European Commission, "Renovation Wave: doubling the renovation rate to cut emissions, boost recovery and reduce energy poverty." https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835

1.1 The role of electrification and low-carbon fuels

To meet climate targets, we need to eliminate carbon pollution from buildings before 2050. Achieving a zero-carbon building sector by 2050 relies primarily on fuel-switching the 63% of Canadian buildings heated with natural gas or oil to electricity, with the rapid decarbonization of the electricity grid.

Low-carbon gaseous heating fuels, such as biomethane and some forms of hydrogen,[2] might also have a role to play in decarbonizing the building sector, though this role is constrained by limited supply. Even as new supplies are developed, their best uses might not be in buildings, but rather for end-uses requiring high energy density such as industrial processes and transportation. There might be a need for tactical deployment of biogas in some heritage building complexes with centralized heat plants and high heat loads, such as large hospitals and academic campuses. A major technological breakthrough enabling the rapid commercial production of cellulosic (wood-based) biomethane at scale could increase the potential use for peak heating in buildings, but this remains a wild card and might compete with other uses for these forestry by-products. Therefore, the use of heat pumps powered by clean electricity remains the most likely path for decarbonization of most building.

Heat pumps combine high efficiency with the capacity to provide both heating and cooling.[3] Because furnaces and boilers last on average 20 to 25 years, we need all replacements after 2025 to be low-carbon systems to achieve a zero-carbon building sector by 2050 without having to force the early replacement of functioning equipment.

This decarbonization pathway can be front-loaded, particularly in provinces with clean electricity grids. For example, B.C. sectoral targets for 2030 feature a minimum 59% carbon reduction in buildings, in contrast to 27% for transportation and 33% for oil and gas.[4] In provinces that still rely heavily on coal and natural gas for electricity generation, high-efficiency electrical heating will result in net carbon savings as coal-phase-outs take effect. According to our calculation, a cold climate heat pump will be

[2] Maddy Ewing et al., *Hydrogen on the path to net-zero emissions: Costs and climate benefits* (Pembina Institute, 2020). https://www.pembina.org/pub/hydrogen-primer

[3] See upcoming Pembina Institute report on climate impacts and health in multi-unit residential buildings and long-term care facilities.

[4] Government of British Columbia, "B.C. sets sectoral targets, supports for industry and clean tech" https://news.gov.bc.ca/releases/2021ENV0022-000561

able to provide heating at a lower carbon footprint than a high-performance natural gas furnace as early as 2023 for Alberta and 2022 for Saskatchewan.[5]

1.2 Beyond fuel-switching: meeting multiple objectives through deep retrofits

Beyond decarbonization, there are multiple objectives that can be met through energy renovation: efficiency, health, safety, resilience, and durability. Considering the holistic long-term needs of a building allows retrofits to meet multiples objectives with the least disturbance and in the most cost-effective way.

We generally qualify as ‘deep retrofits’ renovations that upgrade several systems of the building (HVAC, envelope, lighting, etc) to meet multiple objectives (Figure 1). For example, upgrades to the building envelope and mechanical equipment present unique opportunities to improve its resilience to extreme weather events like heat waves, floods, and forest fires, to improve seismic resilience in earthquake zones, and to improve indoor health by reducing infiltration of pathogens and pollutants. New electrical heating equipment and appliances offer opportunities to integrate demand-response technologies that can reduce or delay loads when the systems is near peak, thus avoiding unnecessary upgrades to distribution and transmission lines and facilitating the integration of more intermittent renewables in the grid.

[5] Based on grid emissions intensity projections from CER Evolving Scenario, and average cold climate heat pump performance by province (see Appendix A for more details on grid emissions intensity and heat pump performance). Detailed analysis pending publication.

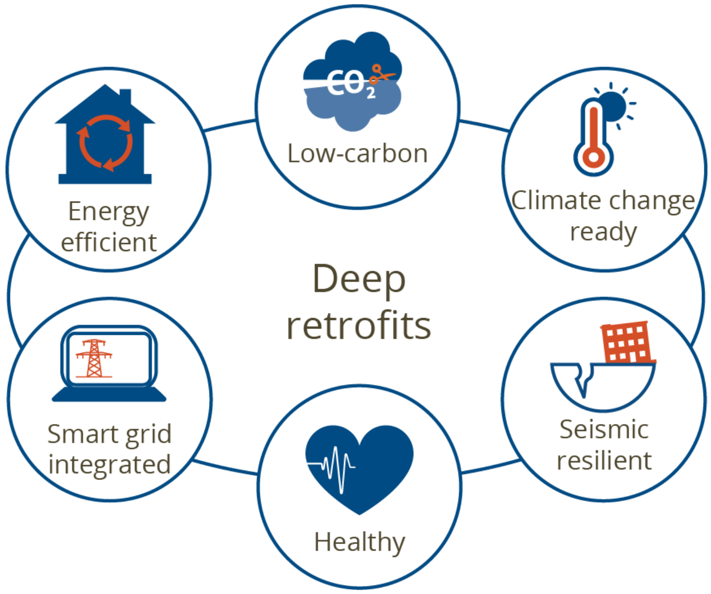

Figure 1. Characteristics of deep retrofits

These interventions are most affordable at two key moments in the life of a building: (1) when the heating equipment is replaced, or (2) when key components of the building envelope are replaced (re-cladding, re-roofing, major replacement of windows, etc.). Pairing these heating equipment replacements with envelope efficiency enables right-sizing of this equipment and its most efficient use. These multi-system upgrades can happen concurrently or over time, but should be designed jointly. Whether phased or implemented in one major renovation, deep retrofits can provide energy savings of 30–50%, electrifying heating load such that the building can be fully decarbonized as the electricity grid converts to zero-carbon renewables.

1.3 Job creation and economic stimulus

Retrofits also have immense potential to create jobs and grow the economy. In 2018, the energy efficiency sector employed 436,000 workers across six key industries: construction, manufacturing, wholesale trade, professional and business services, utilities, and other services. That's about 2.3% of all jobs in Canada.[6] Energy efficiency

[6] Eco Canada, *Energy Efficiency Employment in Canada* (Natural Resources Canada, 2019), 8. https://www.eco.ca/research/report/energy-efficiency-canada/

employment grew by almost 2.8% in Canada from 2017 to 2018, compared to 1.0% for all jobs nationally.[7,8]

Across these six key industries, 51,000 Canadian businesses generated an estimated $82.6 billion in energy efficiency operating revenues.[9] The energy efficiency workforce generated $14.9 billion in income revenue in 2018 — and this is only direct and permanent employment.[10]

Creates more jobs per dollar invested than other industries

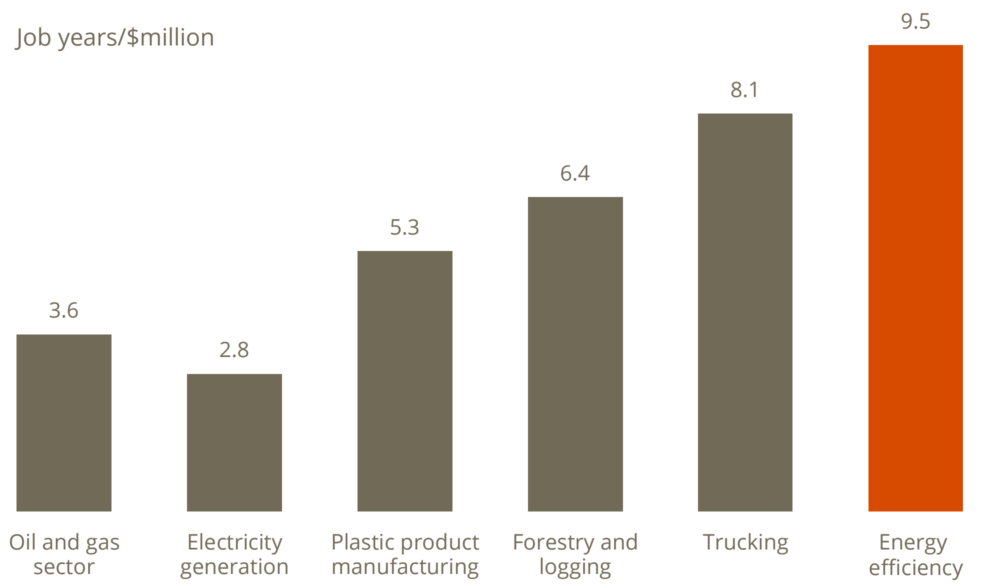

Figure 2. Jobs multipliers by industry

Data sources: Statistics Canada and Efficiency Canada.[11]

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[7] *Energy Efficiency Employment in Canada. 23.*

[8] ACEEE, *How does energy efficiency create jobs?* , 1. https://www.aceee.org/files/pdf/fact-sheet/ee-job-creation.pdf

[9] *Energy Efficiency Employment in Canada,* 8.

[10] *Energy Efficiency Employment in Canada*, 22.

[11] Statistics Canada, "Input-output multipliers" https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610059401&pickMembers%5B0%5D=2.3&pickMembers%5B1%5D=4.6&cubeTimeFrame.startYear=2013&cubeTimeFrame.endYear=2017&referencePeriods=20130101%2C20170101

Efficiency Canada, *Written Submission for the Pre-Budget Consultation in Advance of the Upcoming Federal Budget* (2020). https://www.efficiencycanada.org/wp-content/uploads/2020/09/EffCan-2020-Advocacy-federal-Pre-budget-submission.pdf

Energy efficiency jobs are inherently labour intensive and create a higher number of jobs than other industries (Figure 2). Whole building retrofits are estimated to create an average of 9.5 gross direct and indirect[12] jobs for every $1 million invested.[13]

Creates good jobs

Wages and quality of work are as important as the number of jobs created. Energy efficiency jobs are in communities where people live, so they don't have to relocate to find work. There is also evidence that these jobs are higher paying. In the U.S., energy efficiency jobs pay 28% above the national median.[14] Canada does not collect salary data specific to energy efficiency jobs; however, we know that construction jobs pay 25% more than the national average.[15]

Energy efficiency jobs present an attractive mix of higher pay and lower barriers to entry.[16] The disappearance of good-paying jobs for workers without college or advanced degrees — or the loss of middle-skill jobs — has been a growing concern and is a factor leading to income inequality across the country.[17] This happens as the relative shares of low- and high-skilled occupations grow and the share of mid-skilled employment shrinks. However, energy efficiency offers competitive wages even to those workers earning the lowest relative pay within their given occupation. Workers in the energy efficiency sector have less formal education than the national average,[18] but their pay is higher than the national average.

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[12] Direct jobs: Jobs generated from a change in spending patterns resulting from an expenditure or effort (e.g. construction jobs for a retrofit project). Indirect jobs: includes employment in upstream industries that supply and support the core activities of energy retrofits. Workers in such positions may produce mechanical equipment, cement, timber or other materials, or provide financial and other services.

[13] Clean Energy Canada, *The Economic Impact of Improved Energy Efficiency in Canada (*2018). https://cleanenergycanada.org/wp-content/uploads/2018/04/TechnicalReport_EnergyEfficiency_20180403_FINAL.pdf; and Efficiency Canada, *Written Submission for the Pre-Budget Consultation in Advance of the Upcoming Federal Budget*.

[14] Joseph Kane and Ranjitha Shivaram, "How clean energy jobs can power and equitable COVID-19 recovery, *Brookings,* September 10, 2020. https://www.brookings.edu/blog/the-avenue/2020/09/10/how-clean-energy-jobs-can-power-an-equitable-covid-19-recovery/

[15] Global Opportunities, "What is the average Salary in Canada." https://www.globalopp.ca/news-blog/2020/5/25/what-is-the-average-salary-in-canada

[16] Mark Munro, Adie Tomer, Ranjitha Shivaram and Joseph Kane, *Advancing inclusion through clean energy jobs* (Brookings, 2019), 16. https://www.brookings.edu/wp-content/uploads/2019/04/2019.04_metro_Clean-Energy-Jobs_Report_Muro-Tomer-Shivaran-Kane.pdf

[17] Creig Lamb and Sarah Doyle, *Future-proof: Preparing young Canadians for the future of work.* (Brookfield Institute, 2017), 4. https://brookfieldinstitute.ca/wp-content/uploads/FINAL-FP-report-Onlinev3.pdf

[18] *Energy Efficiency Employment in Canada,* 21.

Needs targeted intervention to increase equity and diversity

The Canadian energy efficiency workforce is, however, less diverse than the national average. Just under one-fifth (18%) of workers were reported to be female and 2% were reported to be Indigenous; both figures are lower than national workforce averages.[19] Likewise, in the construction trades sector, female workers tend to have proportionately lower wages than their male counterparts (Figure 3).

Figure 3. Workers in construction by wage and gender

Data source: Statistics Canada.[20]

Access to jobs in the energy efficiency sector for all Canadians, including racialized people, women, and persons with disabilities, is limited by significant and often hidden barriers to entry. Understanding what might stop vulnerable and marginalized populations from accessing and retaining employment in the energy efficiency sector is a critical first step to breaking down these barriers (for example, see Figure 4 for a summary of barriers women face in entering trades).[21] Investments to address these barriers are needed to provide equitable access to these economic opportunity;

[19] *Energy Efficiency Employment in Canada*, 20.

[20] Statistics Canada. "Table 14-10-0307-01 Employee wages by occupation, annual, inactive." https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1410030701

[21] Mike Moffatt and John McNally, *Making a Green Recovery Inclusive for All Canadians* (IISD, 2020). https://www.iisd.org/sustainable-recovery/making-a-green-recovery-inclusive-for-all-canadians/

furthermore, training and hiring workers from under-represented groups will increase uptake of energy efficiency programs within these communities by increasing trust.[22]

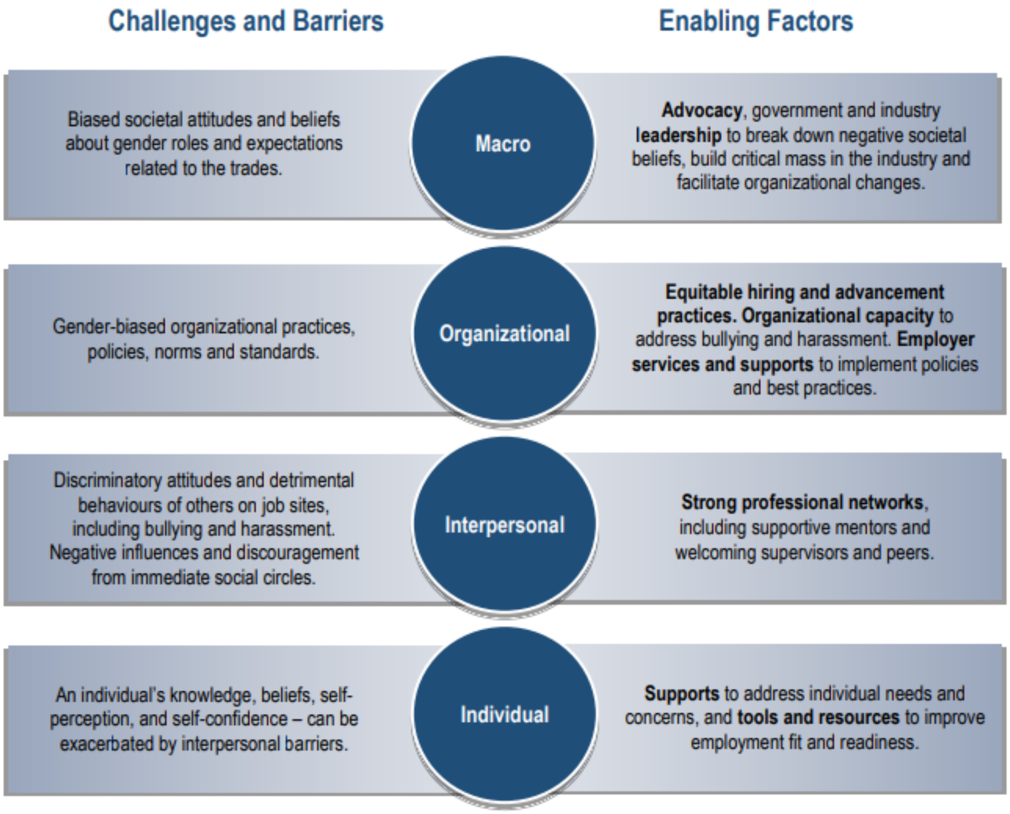

Figure 4. Challenges and barriers for women entering trades

Source: Skillplan.[23]

[22] Brendan Haley, "Low-income households should be a priority for federal energy efficiency funding," *Policy Options,* February 23, 2021. https://policyoptions.irpp.org/magazines/february-2021/low-income-households-should-be-a-priority-for-federal-energy-efficiency-funding/

[23] Skillplan, *Enhancing the Retention and Advancement of Women in Trades in British Columbia: Final Report* (SRDC, 2017), 2. https://www.workbc.ca/getmedia/08872319-a2db-45bc-935e-a4d44f8a3ac0/Construction_Retention_and_Advancement_of_Women_in_Trades_Feb-2017.pdf.aspx

1.4 Public support needed to scale up retrofits

Economic failures of energy efficiency

Fuel-switching and other upgrades increase the energy efficiency of buildings, thus reducing future energy costs. Because electricity is more expensive than natural gas, these fuel-switches can reduce energy costs only marginally or may even result in slightly higher bills if no other efficiency upgrades are implemented. High upfront costs and Canada's low energy prices mean that comprehensive retrofits including heating equipment and envelope upgrades often do not have a great payback through energy savings alone, even for buildings that were previously heated with electricity.

This does not mean that these investments are not economically rational; in fact, they are necessary to protect the housing infrastructure that is critical for a functioning economy. There is already a large body of literature discussing the economic failures limiting the adoption of cost-effective energy efficiency measures: split incentives between tenants and landlords, lack of validated data on energy performance, lack of competition due to labour shortages, lack of transparency on contractor qualifications, etc. To these we must add barriers to the full valuation of non-energy benefits: lack of data on indoor air quality and resulting health care costs, difficult-to-quantify climate risks, lack of reward for proactive adaptation measures, lack of transparency on carbon liabilities and regulatory risks, etc.

In the medium term, some of these economic failures will need to be addressed through price signals and regulations: carbon pricing, performance disclosure requirements, equipment performance standards, and whole-building emission limits. Providing early signals and timelines for phasing regulations will also be critical to help build market capacity and incentivize early adoption. But in the short-term, these economic failures need to be corrected through subsidies.

The need for subsidies

We need to socialize a significant portion of the incremental costs to implement measures above 'business-as-usual' replacements for three reasons. First, this will avoid locking in inefficient and non-resilient technologies, where owners replace failing systems with equipment that meets minimum performance standards but is not compatible with a low-carbon future. Second, this will facilitate the growth of supply chains and upskilling or re-skilling of the labour force ahead of the implementation of regulations. And third, this will help reduce inequity and support the 20% of Canadians who are in energy poverty.[24]

Energy poverty and equity impacts of electrification

Energy poverty refers to households that are unable to access and afford adequate energy for necessities, such as heating and cooling. Any household that spends more than 6% of their after-tax income on home energy services (or roughly twice the national median) is experiencing energy poverty.[25] According to analysis done by CUSP, approximately 20% of households in Canada experience energy poverty. The Maritimes have the highest rates of energy poverty in Canada, with 41% of the households in Prince Edward Island experiencing high home energy cost burdens.[26]

Addressing energy poverty will require utility bill assistance programs, policies protected homeowners from disconnection, and programs that fund and facilitate energy efficiency improvements to help permanently lower utility bills.[27] Creating targeted policies and support fuel switching and efficiency improvements for those who are currently facing, or at risk of, energy poverty will help meet the dual equity and climate objectives.[28, 29]

Estimating the level of subsidy needed to stimulate the desired investments while minimizing free-ridership[30] is both a science and an art. However, current practice

[24] Energy poverty is defined as spending more than twice the Canadian median on home energy needs as a percentage of income. Canadian Urban Sustainability Practitioners, "Energy Poverty." https://energypoverty.ca/

[25] This is one of the commonly used metrics used to measure energy poverty; however, there is no formal definition. CUSP, *Energy Poverty in Canada: A CUSP Backgrounder* (2019), 3. https://energypoverty.ca/backgrounder.pdf

[26] *Energy Poverty in Canada: A CUSP Backgrounder,* 4.

[27] Rachel Cluett, Jennifer Amann, and Sodavy Ou, *Building Better Energy Efficiency Programs for Low-Income Households,* (ACEEE, 2016), 8. https://www.aceee.org/sites/default/files/publications/researchreports/a1601.pdf

[28] Greenlining, *Equitable Building Electrification: A Framework for Powering Resilient Communities,* (2019), 6. https://greenlining.org/wp-content/uploads/2019/10/Greenlining_EquitableElectrification_Report_2019_WEB.pdf

[29] Ecotrust Canada. *Moving Toward Energy Security in British Columbia's Rural, Remote and Indigenous Communities,* (2020), 4. https://ecotrust.ca/wp-content/uploads/2020/03/2019-Policy-Report_EC_lowres.pdf

[30] A free-rider is someone who would install an energy-efficiency measure even without any program incentives because of the return on investment of the measure, but receives a financial incentive or rebate anyway.

shows that for more complex multi-system retrofits to proceed, subsidies of half to three-quarters of the incremental costs are needed.[31]

1.5 Market development and innovation strategy

Significant costs savings can be achieved through vertical integration and process innovation such as lean construction practices and pre-fabrication. But for these innovations to come to market, supply and demand must grow in tandem, and financing[32,33] and regulatory[34] barriers must be addressed. This will require all key players in the real estate sector — owners, financiers, insurers, regulators and service providers — to change aspects of how they do business. Each owns a part of the puzzle but they operate based on their own priorities and success metrics; none have the responsibility of changing market conditions to enable new outcomes. This role is best played by third-party entities, which can form market development teams to collaboratively address these barriers and build the case for these investments. Across North America, various such market development initiatives are underway, including the Pembina Institute's Reframed Initiative.[35]

[31] Acadia Center, *Energy Efficiency: Engine of Economic Growth in Canada* (2014), 34, Table A2-1. https://acadiacenter.org/wp-content/uploads/2014/11/ENEAcadiaCenter_EnergyEfficiencyEngineofEconomicGrowthinCanada_EN_FINAL_2014_1114.pdf

[32] Devon Calder, *The Case for Deep Retrofits: Improved business case evaluation and financing options for deep retrofits in multi-unit residential building* (The Atmospheric Fund, 2020) https://taf.ca/wp-content/uploads/2020/09/TAF-Business-Case-Deep-retrofits_2020.pdf

[33] Pembina Institute, *Affordable Housing Renewal: Retrofits at Scale* (2018). https://www.pembina.org/reports/affordable-retrofits-workshop-2018.pdf

[34] Betsy Agar, *Barriers to deep retrofits: Regulatory solutions from across Canada,* (Pembina Institute, 2020), 1. https://www.pembina.org/pub/regulatory-retrofit-solutions

[35] Reframed Initiative, https://reframedinitiative.org. Also see this solution providers map for a list of other incubators: https://tinyurl.com/DeepRetrofitMap

2. Canada's renovation wave

To quantify the economic activity that could be generated by a wave of climate-focused renovations and estimate the scale of public investment needed to unlock this opportunity, we must answer four questions: What upgrades are needed? By when do we need to get them done? How much will it cost? And what fraction of this cost should be subsidized?

Retrofit measures and programs must be adapted to different market segments in response to different building forms, occupancies, climates, and low-carbon energy options. While representing this complexity in full is outside of our scope, general trends and principles can be used to paint a portrait of a clean transition and provide estimates of the investments needed in each province.

2.1 Depth, pace, and cost of upgrades required: a heuristic model

To provide a more intuitive sense of the transformation needed to meet our climate targets, we developed a heuristic model of the retrofit wave needed in the residential sector. This is not meant as a prescriptive policy recommendation, but as a rule of thumb to characterize the depth of investments needed and the speed required to stay on track.

Pace of retrofits

To decarbonize the existing residential and institutional, commercial and industrial buildings (ICI) building stock by 2050, we propose a nation-wide wave of renovation with a four year ramp up period, fifteen-year sustained effort, and a decade of wind-down:

2021-2025 **Ramp up:** capacity building and incentives lead to a rapid ramp-up in fuel-switching from current levels to ~ 4.5% of stock per year.[36]

[36] For simplicity, we express all retrofit rates as a percentage of today's stock, ie pre-2021 (hereafter labelled 'vintage' stock), and NOT a percent of the evolving stock (which grows over time with population growth).

2025-2040 **Steady state:** all heating equipment replacements are with low-carbon systems, combined with efficiency and resiliency upgrades. 4 to 5% of vintage stock is retrofitted each year.

2040-2050 **Ramp down:** retrofitting of the 'contemporary' stock, buildings built between 2020 and 2030 that were not built to a zero-carbon standard.

Accounting for an average demolition rate of 1% per year, this scenario would see about 40% of the vintage stock be retrofitted by 2030, with all remaining vintage stock retrofitted by 2040 (Figure 5).

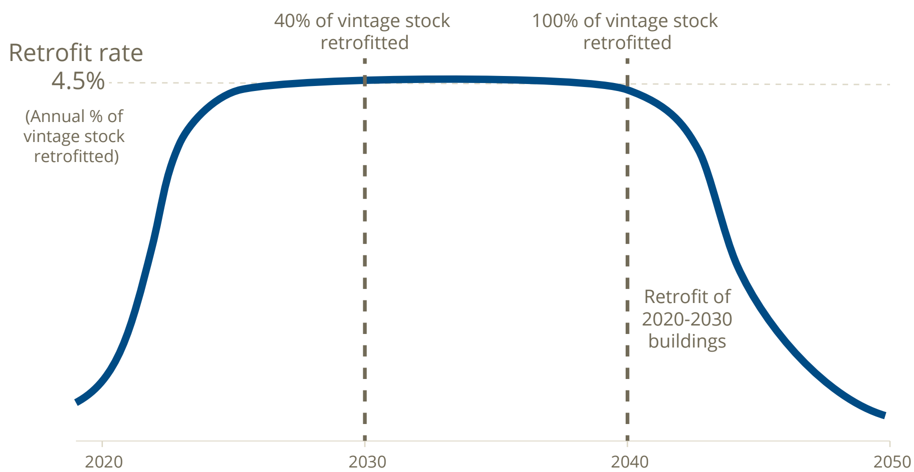

Figure 5. Conceptual model of retrofit wave: fraction of vintage building stock fuel-switched each year, 2020 to 2050

To minimize demand on the grid and maximize economic return and welfare, we figure that about half of these fuel-switches will be accompanied by envelope upgrade measures, and that this effort be front-loaded so that one in four existing buildings will have undergone a deep retrofit by 2030.

Cost of and savings from retrofits

To estimate the carbon reductions, energy savings, and economic impacts of our scenario for residential buildings, we used a residential retrofit calculator developed by Ralph Torrie for Efficiency Canada and shared with us for this report (see Appendix A for more details). This tool represents the evolution of the current Canadian residential building stock and the cost and impacts of different retrofit measures, capturing provincial differences in building stock, fuel uses, energy costs, and grid carbon intensity (both current and projected). The calculator is still in development, and costing assumptions need to be reviewed and refined, but nevertheless it provides an effective tool to estimate the overall impacts of the proposed retrofit scenario.

Investments needed in institutional, commercial and industrial buildings (ICI) buildings are more complex to estimate, as they are very diverse in form and uses. Case studies of ICI deep retrofits report average costs ranging from $75 to $275 per square metre ($m^2$).[37] Applying $200/$m^2$ as plausible cost to the 754 million square metres of ICI in Canada gives us a rough measure of the investments that might be needed in this space. We have not estimated the energy, carbon, or utility bill savings for this building stock for this paper; this is the subject of future research.

Parameters of heuristic model for residential retrofits

Depth of retrofits

We assume every residential building touched be put on a high-efficiency electric path:

- Oil and gas-fired space heating systems are replaced with electric heat pumps
- Domestic hot water systems are replaced with electric heat pumps
- Lighting and appliances are converted to high efficiency
- Half of electric-baseboard heated buildings are also converted to heat pump

We assume that half of buildings touched will also get a major building envelope upgrade featuring added insulation and improved air tightness.[38]

Future carbon intensity of electricity supply is specified by province and assumed to follow the 'Evolving Scenario' published in the Canada Energy Regulator's (CER) Canada Energy Future 2020 report. This scenario assumes coal phase-out is completed in Canada by 2028.

Cost of retrofits

Cost estimates for fuel-switching and envelope measures are summarized in Appendix A. These were assumed constant over the economic modelling period (2020-2040).

Not included in these estimates:

- Base cost of repairs (i.e. assuming these upgrades happen at or near component end-of-life, we include only the incremental cost above the base cost of business-as-usual replacement)
- Lighting, appliances upgrades, and demand-response technologies
- Upgrade of electrical panel or electrical hookup to accommodate additional load
- Climate adaptation measures (e.g. protection against floods or forest fires)

[37] This is range is based on incremental cost data collected from nine case studies in from Canada (primarily B.C.) and various locations in the U.S. The case studies are based on actual and modelled retrofits, and result in energy savings from 50% to 80%. See Appendix A for summary table of case studies. Full publication and results pending.

[38] We also expect that lighting and appliance upgrades will be part of this scenario, but these were not included in this analysis.

- Seismic upgrades
- Remediation for moisture damage, mould, and/or asbestos

These costs can be substantial and will vary by site. Thus, the total cost estimates here are conservative. The cost of upgrades of 'contemporary' buildings in the ramp-down phase (2040-2050) were not estimated and not included in our economic analysis.

Level of incentives

To estimate the level of public investment needed, we assumed that incentives and grants would on average cover:[39]

- 50% of the costs of switching from oil or gas to heat pumps
- 25% of the cost of converting electrical baseboards to heat pumps
- 75% of the cost of envelope upgrades.

2.2 Model results: investments needed, dollars saved, jobs created

Table 1 summarizes the investment needed and economic benefits of the renovation wave. Meeting our climate objectives in the residential and commercial sector will r**equire an investment of approximately $20 billion per year between now and 2040, contribute an additional $48 billion to GDP each year, and create up to 200,000 jobs across Canada.**[40] These are new good-paying jobs in the trades, manufacturing, and professional services, distributed in all regions of Canada, lasting for the next 20 years. Table 2 breaks down the investment needed and economic benefits for residential and commercial[41] buildings by province.

[39] We also calculated the cumulative negative net-present values from interventions across each province. This represents the gap between the costs of the measures necessary to meet targets and the investment that a perfect economic optimizer would deem justifiable over the lifetime of the measures if there was no competition for capital or human resources. This method gives us a conservative lower bound on the level of public subsidies needed in absence of regulations. Preliminary analysis shows these results to be comparable to those resulting from the above estimate. Final results from this analysis will be published in a subsequent update.

[40] The retrofit needs of the territories were not included in this analysis due to data limitation, and some unique challenges that the territories face in decarbonizing the existing building stock (e.g. remoteness, energy sources including remote diesel grids, and extremely cold weather).

[41] Commercial results are estimates calculated by applying a retrofit cost of $\$200/m^2$ to the total building stock (see Appendix A for details). As with the residential scenario, we've assumed that 80% of the buildings (or m^2) standing today will need to be retrofitted by 2040, and 20% will be demolished and redeveloped (1% demolition rate per year over 20 years). Redevelopment costs are not included in these calculations.

Table 1. Key impacts of proposed retrofit scenario plus commercial retrofits

	Residential			Commercial
	Detached homes	Attached homes	Apartments	
Retrofits per year	340,000	71,000	188,000	32 million m^2
	Total: 598,000 dwellings			
Investment needed	$277 billion by 2040			$120 billion by 2040
Electricity demand	-10%			n/a*
Carbon reductions from sector achieved by 2050	89%[42]			n/a*
Annual energy bill savings in 2050	$10.8 billion			n/a*
GDP growth per year[43]	$33.6 billion			$14.6 billion
Jobs created[44]	138,000			60,000

Note: annual investments, GDP and jobs are based on the average spend between 2020 and 2040 (ie adjusted downward to reflect the 2020-2025 ramp up period).
* Energy and carbon outcomes of renovation of commercial and institutional buildings are the subject of future research.

[42] The remaining 11% of carbon emissions result from electricity use in Alberta, Saskatchewan, and Nova Scotia; in the 'Evolving' scenario from the CER used in this model, these provinces don't reach a decarbonized grid in 2050. The CER notes that grid emissions will need to be reduced beyond the projections made in their scenario if Canada is to meet its net-zero goal (see footnote below).

[43] Gross GDP growth from a $15 billion annual investment in retrofits. Using the estimate of $2.30 in GDP growth for every dollar spent. *Written Submission for the Pre-Budget Consultation in Advance of the Upcoming Federal Budget.*

[44] 138,000 gross jobs per year means that 138,000 jobs are created each year, with each job lasting for 12-months; equivalently, 138,000 people would be employed continuously between now and 2040.

Table 2. Economic growth and job creation for residential and commercial retrofits, by province

	Total Investment ($ billion/year)			Gross GDP growth ($ billion/year)			Gross jobs per year		
	Residential	Commercial	**TOTAL**	Residential	Commercial	**TOTAL**	Residential	Commercial	**TOTAL**
CANADA	$14.6	$6.3	**$20.9**	$33.6	$14.6	**$48.2**	138,700	60,200	**198,900**
BC	$1.9	$0.9	**$2.8**	$4.3	$2.1	**$6.4**	17,800	8,500	**26,300**
AB	$1.6	$0.9	**$2.5**	$3.7	$2.1	**$5.8**	15,200	8,800	**24,000**
SK	$0.5	$0.2	**$0.7**	$1.1	$0.5	**$1.6**	4,400	2,000	**6,400**
MB	$0.5	$0.2	**$0.8**	$1.2	$0.5	**$1.7**	4,900	2,200	**7,100**
ON	$5.6	$2.4	**$8.0**	$12.8	$5.6	**$18.4**	52,900	23,100	**76,000**
QC	$3.5	$1.2	**$4.7**	$8.1	$2.8	**$10.9**	33,500	11,500	**45,000**
NB	$0.3	$0.1	**$0.5**	$0.8	$0.3	**$1.1**	3,200	1,300	**4,500**
NS	$0.4	$0.2	**$0.6**	$1.0	$0.4	**$1.4**	4,000	1,600	**5,600**
PE	$0.1	$0.0	**$0.1**	$0.1	$0.1	**$0.2**	600	300	**900**
NF	$0.2	$0.1	**$0.3**	$0.6	$0.2	**$0.8**	2,300	800	**3,100**

Note: Totals may not be exact due to rounding

Energy and carbon impacts in the residential sector

The retrofit wave paired with reductions in the carbon intensity of Canada's electricity grids will result in an 89% reduction in carbon emissions from residential buildings in 2050. The remaining 11% of emissions, in this model, result from the incomplete decarbonization of the electricity grid in Alberta, Saskatchewan and Nova Scotia. The grid decarbonization projections used here come from the CER's Canada Energy Futures 2020. The report notes the need to reduce grid emissions beyond the projections made in their scenario if Canada is to meet its net-zero goal.[45] Transitioning to net-zero electricity is a

[45] "For Canada to meet its 2050 goals, the rate of energy transition will need to increase beyond levels shown in the Evolving Scenario. [...] To substantially decrease energy system emissions, several complementary dynamics will likely play a large role. Increasing the share of zero and low carbon energy sources, such as low carbon electricity, used across the entire economy will be key, as will the contributions from existing trends in energy efficiency. Even with considerable improvements in energy conservation and efficiency, research suggests shifting away from burning fossil fuels for energy and replacing them with low carbon alternatives will be crucial to long-term deep decarbonization of the Canadian economy." Canada Energy Regulator, *Canada Energy Future 2020: Executive Summary*. https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/net-zero/index.html See also the Pembina Institute's original response

goal Canada can strive for and achieve well before 2050, enabling additional emission reductions in the building sector.

Notably, this carbon reduction can be achieved without increasing the total demand for electricity. The greater electric efficiency resulting from envelope upgrades (assumed to be included in half of all retrofits) and from switching baseboard heaters to heat pumps can lead to a net decrease in electrical demand of 10%. Investments in efficiency may not have carbon benefits in provinces with clean electricity, but the surplus can be used for electrification of other sectors of the economy, from transportation to industry.

Table 3. Economic and carbon impacts of the renovation wave in the residential sector, by province

	# of buildings retrofitted per year			Electricity load	Carbon reductions	Energy bill savings
	Detached homes	Attached homes	Apartments	% of 2017 load in 2050	% below 2017 by 2050	Savings per year in 2050 ($ billion)
CANADA	339,800	70,700	188,200	89%	89%	$10.8
BC	40,400	10,200	27,700	88%	95%	$1.4
AB	42,800	7,600	13,100	181%	70%	-$0.2
SK	13,500	1,200	3,300	161%	78%	-$0.03
MB	13,800	1,300	5,100	86%	99%	$0.3
ON	128,300	33,900	64,700	126%	99%	$2.5
QC	70,900	13,500	66,500	53%	98%	$5.1
NB	9,700	800	2,300	63%	99%	$0.6
NS	11,500	1,200	3,800	97%	86%	$0.5
PE	1,800	200	500	154%	100%	$0.1
NL	7,100	900	1,300	57%	98%	$0.5

2.3 Public investments needed

We estimate the public investment needed to achieve this level of residential retrofits to be on the order of $9 billion per year. ICI sector buildings probably require a lower level

after publication of the CER Canada Energy Future report: Nichole Dusyk, "Why Canada's Energy Future report leads us astray," *Pembina Institute*, January 9, 2020. https://www.pembina.org/blog/why-canadas-energy-future-report-leads-us-astray of public support to pay for these incremental capital costs, likely in the $2 to $4 billion per year range. This is because they are professionally managed, already access institutional private lenders, and are often managed under triple-net-lease agreements that allow owners to pass-on some of these costs to tenants (particularly if financed through loans on tax or utility bills[46]). Together, the residential and ICI sector therefore require public investments of the order of $10 to $15 billion per year.[47] This is comparable to the $12 billion annual program spending estimated in 2018 by the study commissioned from Dunsky Energy by Efficiency Canada.[48]

This level of subsidies will need to be maintained at least over the next ten years, or until regulations are in place and the cost of these measures become integrated in business-as-usual real estate transactions (and absorbed in the value of properties and land). Note that this is likely a conservative estimate, because only the costs of energy measures are represented here. Additional costs for measures aimed at improving the climate or seismic resilience of homes and buildings are not included and will also require incentives. Appendix B summarizes the main types of incentive programs that could be used to maximize the market transformation potential of these investments.[49]

The levels of subsidies we are recommending are significantly more than the current programs in place or announced. Current investments include:

- ~$821 million annually invested by utility demand-side management programs (residential and ICI)[50]
- $470 million annual investment for social housing refurbishment through the National Housing Strategy co-investment fund ($2.26 billion over 10 years)[51]

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[46] Madi Kennedy, Tom-Pierre Frappé-Sénéclauze, and Betsy Agar, *Property Assessed Clean Energy in Canada: Design considerations for PACE programs and enabling legislation* (Pembina Institute, 2020), 5. https://www.pembina.org/pub/pace-financing-canada

[47] This expanded range account for the possibility of cost reductions for retrofits as they are scaled, or higher cost retrofits with the inclusion of adaptation measures.

[48] From their PCF+ scenario: Dunsky Energy Consulting, *The economic impact of improved energy efficiency in Canada* (2018), Table 16. Available at https://cleanenergycanada.org/wp-content/uploads/2018/04/TechnicalReport_EnergyEfficiency_20180403_FINAL.pdf

[49] See also program recommendations in Tom-Pierre Frappé-Sénéclauze. *Achieving Canada's climate and housing goals through building retrofits: Recommendations on green stimulus and platform commitments* (Pembina Institute, 2020). https://www.pembina.org/reports/federal-buildings-recs-2020.pdf

[50] James Gaede, Brendan Haley, and Madeleine Chauvin, *2020 Canadian Provincial Energy Efficiency Scorecard,* (Efficiency Canada, 2020), 281. https://www.scorecard.efficiencycanada.org/wp-content/uploads/2020/11/2020-Provincial-Energy-Efficiency-Scorecard.pdf

[51] Note that the NHS investment primarily support the base cost of bringing social housing to a state of good repair, including modest energy upgrades (a minimum of 25% savings). The investments we discuss

- $371 million annual investment the federal government committed to residential retrofits in 2020 ($2.6 billion over seven years)[52]
- $880 million in interest free financing through CMHC ($4.4 billion in interest-free financing over five years)[53]
- $1.01 billion allocated to FCM's Green Municipal fund in 2019[54]
- $2 billion provided to the Canada Infrastructure Bank for investment in the commercial building sector (some of which might be invested in professionally managed residential buildings).[55]

Even accounting for these investments, **there remains a funding gap of the order of $8-13 billion per year across Canada** (Table 4).

here are incremental costs above these base upgrades. CMHC, *Canada's National Housing Strategy* (2018), 10. https://eppdscrmssa01.blob.core.windows.net/cmhcprodcontainer/sf/project/placetocallhome/pdfs/canada-national-housing-strategy.pdf; and AUMA, "Federal government launches the National Housing Co-Investment Fund." media release, May 9, 2018. https://www.auma.ca/news/federal-government-%E2%80%8Elaunches-national-housing-co-investment-fund

[52] Government of Canada, "Building Back Better: A Plan to Fight the COVID-19 Recession." https://www.budget.gc.ca/fes-eea/2020/themes/building-back-better-rebatir-mieux-en.html

[53] Government of Canada. *Budget 2021: A Recovery Plan for Jobs, Growth, And Resilience*, (2021), 177. https://www.budget.gc.ca/2021/pdf/budget-2021-en.pdf

[54] Government of Canada, *Backgrounder: Strong Communities, Affordable Electricity and a Clean Economy,* (2019), 2. https://www.budget.gc.ca/2019/docs/nrc/infrastructure-infrastructures-electricity-electricite-en.pdf

[55] Canadian Infrastructure Bank, "Prime Minister announces infrastructure plan to create jobs and grow the economy," media release, October 1, 2020. https://cib-bic.ca/en/the-canada-infrastructure-bank-announces-a-plan-to-create-jobs-and-grow-the-economy/

Table 4. Funding gap, by province ($ billion/year)

	Projected retrofit investment needed		Baseline federal and provincial investment			Funding gap (incentive needed minus baseline investment)
	Estimated cost of retrofits per year	Estimate of Incentives needed per year[56]	Existing utility programs (2019)[57]	Existing provincial programs (2019)	Federal commit-ment[58]	
CANADA	$20.9	$12.3	$0.84	$0.23	$1.4	$9.8
BC	$2.8	$1.6	$0.17[59]	$0.028[60]	$0.11	$1.3
AB	$2.5	$1.5	-	$0.04	$0.11	$1.4
SK	$0.67	$0.4	$0.0070	-	$0.11	$0.30
MB	$0.75	$0.4	$0.063	-	$0.11	$0.30
ON	$8.0	$4.8	$0.41[61]	-	$0.21[62]	$4.1
QC	$4.7	$2.7	$0.078	$0.17	$0.11	$2.3
NB	$0.46	$0.30	$0.025	-	$0.11	$0.10
NS	$0.59	$0.30	$0.063	-	$0.11	$0.20
PE	$0.09	$0.06	$0.013	-	$0.11	-$0.071
NL	$0.33	$0.20	$0.016	-	$0.11	$0.06

Bridging this funding gap requires a shift in how retrofit incentive programs are perceived — from a short-term stimulus meant to provide limited support to many Canadians, to a long-term investment in the resilience and affordability of the housing

[56] For this analysis we assumed that public funding would be needed for 50% of ICI investment. However, in the discussion we apply a range of $10-15 for investment to account for the possibility of cost reductions for retrofits as they are scaled, or higher cost retrofits with the inclusion of adaptation measures.

[57] *2020 Canadian Provincial Energy Efficiency Scorecard,* 281.

[58] Funding includes CMHC co-investment fund of $4.7 billion over 10 years; $2.6 billion over seven years for the Canada Green Home Program; FCM $1.01 billion assumed to be delivered over five years; the estimated value of the interest for the $4.4 billion in interest free financing (2% interest rate over 10 years, loan term $40,000); and the $2 billion for commercial retrofits from the Canadian Infrastructure Bank.

[59] BC Hydro utility data for 2020 was not available, so 2019 data was used.

[60] For fiscal year 2022 for incentives, marketing and administration of the Better Homes and Better Buildings BC program. Nat Gosman, personal communication July 2021.

[61] Enbridge Gas utility data for 2019 was not available, so 2018 data was used.

[62] Including the $200 million over two year for point-of-sale rebates available to Ontario retailers offered through the federal Energy Savings Rebate program (ended March 31, 2021) https://www.canada.ca/en/environment-climate-change/services/climate-change/low-carbon-economy-fund/energy-savings-rebate.html

infrastructure of this country. We need to recognize that these are fiscally sound investments:

- They more than pay for themselves through public revenues generated by taxation, returning $2 to $5 to public coffers per program dollar spent.[63, 64]
- They have been shown to create significant health benefits that could lead to savings in health care costs. A 2015 study found that retrofitting residential buildings in Toronto to comply with minimum building code regulations can save US$2.3 billion/year in health care.[65]
- They are an effective avenue for economic stimulus, through immediate spending on upgrades, long-term returns from real estate, and energy bill savings that are re-invested locally in economic sectors that typically create more jobs than the energy sector.
- Every dollar invested in climate change adaptation for our infrastructure is estimated to save $3 to $6 in recovery costs.[66]

To use these funds efficiently to quickly transform markets and enable the phasing in of regulations requiring these upgrades, a shift is needed in how federal funds for retrofits are typically disbursed. An effective approach should prioritize leveraging provincial market transformation strategies (where they exist) and coordinating innovation across all levels of government (see upcoming paper from Efficiency Canada on this topic).

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[63] Modelling by Dunsky and the Center for Spatial Economics in 2018 estimates the spending cost for the PCF+ scenario at $154.7 billion over 13 years, and the resulting net additional provincial and federal tax revenue to be $348.7 billion over that period: 2.3 times the program spending. *The economic impact of improved energy efficiency in Canada,* Table 15, Table 27, Table 28.

[64] A 2011 study compared the costs of the program to the public revenues generated by Germany's KfW development bank's "energy efficiency renovation" program through taxes concluded that the program returned nearly four times more to the public coffers than it costs; more than five times if reduction in unemployment benefits were included. KfW Bankengruppe, *Impact on Public Budgets of KfW Promotional Programmes in the Field of 'Energy-Efficient Building and Rehabilitation,'* 2011, 8. Available at https://www.actu-environnement.com/media/pdf/news-22153-etude-kfw.pdf

[65] M.S. Zuraimi and Z. Tan, "Impact of residential building regulations on reducing indoor exposures to outdoor $PM_{2.5}$ in Toronto," *Building and Environment* (2015), 89. https://www.sciencedirect.com/science/article/abs/pii/S0360132315001171

[66] Federation of Canadian Municipalities, *Investing In Canada's Future: The Cost of Climate Adaptation at the Local Level* (2020), 13. https://data.fcm.ca/documents/reports/investing-in-canadas-future-the-cost-of-climate-adaptation.pdf

3. Recommendations

Decarbonizing the Canadian building stock to meet climate targets, will require government to quickly scale up investment, and implement policies in four key areas: target setting, financing and incentives, regulation, and the federal government to advance building retrofits. These recommendations should be implemented in partnership and collaboration with provinces, territories, and local governments.

Target setting

- The federal government should create a vision for a nation-wide renovation wave aiming at decarbonizing the vintage stock by 2040.

Financing and incentives

- The federal government, in partnership with the provinces, should commit public investments on the order of ~**$10-15 billion per year over the next ten years** to enable this renovation wave, including:
  - ~$10 billion per year to fund deep retrofits for residential and commercial buildings, with programs covering 50-75% of retrofit costs.
  - $2 billion per year to fund no-cost deep retrofits for low-income households[66] and top-up for the renovation of social housing through the National Housing Strategy.[67]
  - $300 million per year in skill development, capacity building and recruitment to grow the energy efficiency and green building workforce,[68] with funds earmarked to increasing its diversity (see Figure 4). [69]

[66] Efficiency Canada, "Funding for Low Income Energy Efficiency." https://www.efficiencycanada.org/low-income-energy-efficiency/

[67] Currently, renovations funded through the NHS must only reach a 25% reduction in carbon emissions, making it difficult for cash-strapped housing societies to justify spending more to achieve deeper emissions reductions and integrate climate adaptation measures.

[68] This mirrors the recommendations from the Canada Green Building Council, "Ready, set, grow: CaGBC tables recommendations for Canada's post-COVID-19 economic recovery," media release, May 5, 2020, https://www.cagbc.org/News/EN/2020/20200513_News_Release.aspx ; and Efficiency Canada, *Written Submission for the Pre-Budget Consultation in Advance of the Upcoming Federal Budget* .

[69] This echo's The Atmospheric Funds 2021 Budget recommendations (TAF). TAF, *2021 Federal Budget Recommendations*, (2021). https://taf.ca/wp-content/uploads/2021/02/TAF-fedbudgetsubmission-2021-02-19.pdf

- $100 million per year to fund market development initiatives to resolve systemic barriers to deep retrofits and facilitate large-scale roll out of new integrated retrofit offerings[70]
- $100 million per year to fund research, development and demonstration of key retrofit technologies.[71]

- Retrofit funding should be disbursed through a small number of large programs, to minimize market confusion and ensure efficacy of public investments. This could include channelling funds through established programs (municipal, provincial, utility).
- Access to federal funds for the renovation wave should be made contingent on provinces committing and implementing regulatory roadmaps for a zero-carbon building sector.
- The federal government should capitalize a loan guarantee program to reduce the risk to private financing of building retrofits[72] and CMHC should support the roll out and harmonization of PACE financing across Canada.[73]

Regulation

- The federal government should partner with provinces to align the following regulatory commitments towards a zero-carbon building sector. Governments should provide early signals and timelines for implementing these policies to allow capacity building, and incentivize early adoption.

[70] In the Netherlands, the "Energiesprong" (energy leap) is a successful example of such a market development approach (David Dodge, "Energiesprong: a leap forward for net-zero building retrofits," *Pembina Institute,* February 8, 2017. https://www.pembina.org/blog/gef-energiesprong), which is now being incorporated in initiatives across Canada, including Pembina's Reframed Initiative (Reframed deep retrofit supply chain, https://tinyurl.com/DeepRetrofitMap). See also the paper by Efficiency Canada on mission-driven innovation: https://www.efficiencycanada.org/retrofit-mission/

[71] Calculations by Efficiency Canada based on funding envelope for codes and standard related activities by BC Hydro and Fortis BC and pro-rated on a per capita basis. See also: Efficiency Canada, *Tiered Energy Codes: Best Practices for Code Compliance (*2020). https://www.efficiencycanada.org/wp-content/uploads/2020/09/Tiered-Energy-Code-Best-Practices-for-Code-Compliance.pdf

[72] Given the significant learning curve in understanding the risks and value of PACE financing for building owners, portfolio managers, underwriters, and CFOs, it is critical that eligibility criteria and terms be harmonized across the country to justify mobilization of resources. Canada is a small market as it is, and further fragmentation will not allow the structural changes needed for PACE to succeed.

[73] Équiterre and the Pembina Institute, *Federal Policies for Low-Carbon Buildings: A blueprint to implement the PanCanadian Framework buildings strategy* (2017), 22. https://www.pembina.org/pub/federal-buildings-blueprint

- Carbon intensity limits for new and existing buildings.[74]
- Energy performance standards requiring all heating equipment to have a coefficient of performance greater than 100% sometime between 2025 and 2030 (i.e. ahead of the 'aspirational' target set for 2035).[75, 76]
- Benchmarking, labelling, and public disclosure policies to inform real estate market assessment of performance, comfort, climate risks, and carbon risks.

Data and transparency

- Open-data policies, data quality standards, and data exchange protocols to enable data-driven user-centered decision tools for energy investment and market potential analysis.

[74] Steven Nadel and Adam Hinge, *Mandatory Building Performance Standards: A Key Policy for Achieving Climate Goals* (ACEEE, 2020), 1. https://www.aceee.org/sites/default/files/pdfs/buildings_standards_6.22.2020_0.pdf

[75] Energy and Mines Ministers' Conference, *Market Transformation Strategies for Energy-Using Equipment in the Building Sector* (2017), 3. http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/Market-Transformation-Strategies_en.pdf

[76] International Energy Agency is calling for a ban on installation of all fossil fuel boilers starting in 2025. International Energy Agency, *Net Zero by 2050: A Roadmap for the Global Energy Sector,* (2021), 19-20. https://iea.blob.core.windows.net/assets/4482cac7-edd6-4c03-b6a2-8e79792d16d9/NetZeroby2050-ARoadmapfortheGlobalEnergySector.pdf

Appendix A. Modelling assumptions

The model was commissioned by Efficiency Canada and developed by Ralph Torrie in 2020/2021. The Excel-based model provides high-level assessment of the impacts of retrofitting the residential building stock including the costs, energy impacts, and GHG impacts. The following outlines key data sources and assumptions.

A.1 Residential buildings

Building stock

- National energy use database results from 2017 were used for building stock characteristics (such as heating source, building type and vintage), energy use and GHG emissions.
- The model does not account for growth of the building stock, or demolition of existing buildings. We estimated the impact of demolition rates by assuming demolished stock was replaced with an electrically heated building with equivalent total energy use (with the simplifying assumption that the increase in square footage is offset by an increase in efficiency). The costs from these projects are not included in the total investment, and therefore this does not impact GDP or jobs estimates. But it does represent (although imperfectly) the energy use and resulting carbon reductions from these replacements. Greenfield developments are not represented.

Cost of retrofits

- The analysis uses average incremental cost of retrofit measures by building type and by vintage (Table 5).
- The analysis does not account for potential decrease in capital cost and labour costs for retrofits over time.

Table 5. Incremental cost of retrofits

Building type	Vintage	Retrofit	Heat pump	Domestic hot water heat pump
Detached homes	Pre 1996	$35,000	$8,000	$3,000
	Post 1995	$30,000	$8,000	$3,000
Attached home	Pre 1996	$25,000	$8,000	$3,000
	Post 1995	$20,000	$8,000	$3,000
Apartments	Pre 1996	$20,000	$5,000	$3,000
	Post 1995	$20,000	$5,000	$3,000

Utility rates and carbon pricing

The Canada Energy Regulator evolving scenario was used to project utility rates to 2050 for this analysis. This includes increase in carbon pricing using the assumption that carbon prices continue to rise to $60/t in 2030 and $125/t by 2050 (in 2019 real terms).[77] This rate is below the federal government's recent commitment to a $170/t carbon tax by 2030. Future analysis will include the impact on cost of a $170/t carbon tax in 2030.

Grid emissions intensity

We used projections of electricity generation broken down by fuel source for every province and territory for 2021-2050 based on Canada Energy Regulator's evolving scenario from their 2020 Canada's Energy Future report. We then calculated the emissions intensity of the electricity grid by applying the emissions intensity of each generation source, using historical data from Canada's National Inventory Report, to its proportion of total generation in a given year.

Note: According to CER: "The Evolving Energy System Scenario… considers the impact of continuing the historical trend of increasing global action on climate change throughout the projection period. Globally, this implies lower demand for fossil fuels, which reduces international market prices. Advancements in low carbon technologies lead to improved efficiencies and lower costs. Within Canada, we assume a hypothetical suite of future domestic policy developments that build upon current climate and energy policies."[78] However, this scenario does not meet Canada's target of net-zero

[77] Canada Energy Regulator, *Canada Energy Future 2020*, (2020), 27. https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2020/canada-energy-futures-2020.pdf

[78] *Canada Energy Future 2020: Executive Summary.*

emissions by 2050, and as mentioned above does not consider the impact of a carbon tax increase to $170/t by 2030.

Thermal retrofits

The model includes assumptions about energy reductions from envelope improvements. The model assumes an average energy reduction of ~50% from baseline; however, this varies by building type vintage and province (Table 6).

Table 6. Post-retrofit gross thermal output (kWh/m^2)

Building type	Vintage	AB	BC	MB	NB	NF	NS	ON	PE	QU	SK
Detached homes	Pre 1996	73	45	65	63	65	61	70	62	74	72
	Post 1996	69	43	59	55	60	54	60	52	66	60
Attached homes	Pre 1996	48	39	62	59	63	56	65	56	63	63
	Post 1996	43	39	52	49	55	49	55	47	61	54
Apartments	Pre 1996	55	32	50	47	45	43	55	43	58	51
	Post 1996	46	29	40	37	41	36	40	35	44	40

Heat pumps

Space heating

- The heat pump performance in Table 7 accounts for the impacts of both climate and technology (hence the difference in values from one city to another and between ASHP / CCASHP). When it’s too cold, the heat pump switches to resistance heating, which decreases the efficiency. This trade-off between performance and heating load is shown in Figure 6.
- The analysis does not include emissions from heat pump refrigerant leakage.
- The economy-wide modelling uses the performance for cold climate heat pumps because cold climate heat pumps have a better performance and business case in the vast majority of Canada.

Table 7. Annual system heating efficiency, including back-up energy

	Annual system heating efficiency (J/J)	
	ASHP	CC-ASHP
Vancouver	2.89	3.19
Calgary	1.88	2.33
Regina	1.64	2.00
Winnipeg	1.56	1.97
Toronto	2.17	2.71
Montreal	1.87	2.50
Charlottetown	2.05	2.67
Fredericton	1.96	2.54
Halifax	2.11	2.76
Saint Johns	2.36	2.85

Data source: Canmet ENERGY, Heat Pump model

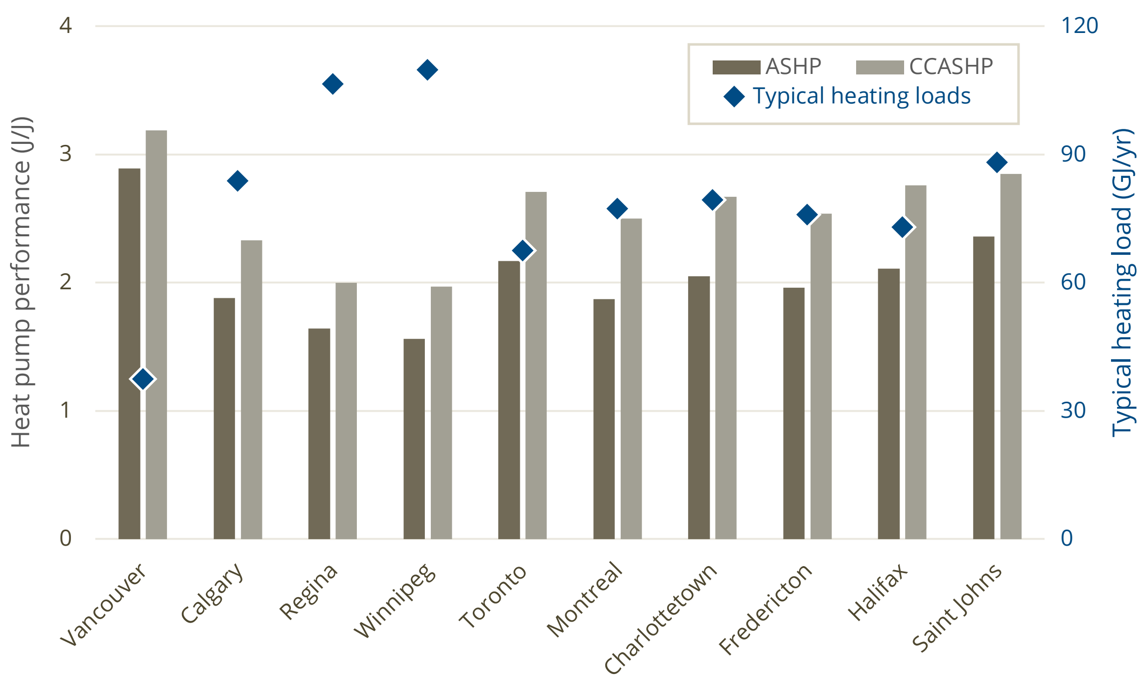

Figure 6. Heat pump performance and typical heating load for selected cities

Heat pump performance includes back-up (resistance) heating

Domestic hot water

- Domestic hot water heat pumps are assumed to have an efficiency of 290%.
- Using electric heat pumps for both domestic hot water and space heating slightly increases the energy use from space heating. This is not accounted for in this analysis.

Air conditioning

This analysis does not include projections for increased energy use as a result of air conditioning (AC), and makes the simplifying assumption that AC use will stay the same. In reality, installing heat pumps will increase access to AC, and as temperatures rise there will be an increase in AC use.

A.2 Institutional, commercial and industrial buildings

Cost of retrofits

To estimate the cost of ICI retrofits we used an average incremental cost by m^2 and the total size of ICI building stock by province. Table 7 summarizes the range of incremental costs for commercial building retrofits found in a number of case studies, and Table 8 summarizes the commercial building stock by province.

Table 7. Incremental costs of retrofits of commercial buildings in case study locations

Location	Energy Reduction	GHG Reduction	Incremental Cost ($/m^2)
Vancouver, BC	78%	93%	$211.00
Vancouver, BC	52%	86%	$75.00
Vancouver, BC		75%	$215.00
Burnaby, BC	31%		$233.33
Terrace, BC	31%		$233.33
Florida	46%		$75.34
New York, NY	46%		$107.64
New York, NY	38%		$67.19
Kyoto, Japan	46%		$165.47

Table 8. Floor area of commercial and institutional buildings, by province

Location	Total building stock (million m^2).[79]
Canada	754.3
BC	107.0
AB	110.5
SK	25.3
MB	28.0
ON	290.0
QC	144.2
NS	19.8
NB	15.8
NFLD	10.5
PEI	3.2

[79] Commercial building stock data is aggregated for Atlantic provinces, so estimates for the size of commercial building stock (by m^2) in these provinces were prorated by population size. Source: National energy use database results from 2017.

Appendix B. Summary of retrofit costing literature review

Tables 9 and 10 summarize the range of incremental costs for single family and multi-unit residential building retrofits found in a number of case studies.

B.1 Single family homes

Table 9. Summary of total and incremental retrofits costs for single family homes based on modelled and actual case studies

Study Name	Building type	Building size (m^2)	Total cost ($/unit)	Incremental cost ($/unit)	Energy savings
Berkeley National Lab - A Meta-Analysis of Single-Family Deep Energy Retrofit Performance in the U.S.	SFD	195		$40,000	45%
ACEEE- Residential Deep Energy Retrofits	SFD		$50,000 - $100,000	$40,000	50%
Sacramento Municipal Utility District (SMUD) and National Renewable Energy Laboratory (NREL) Research and Development Program on Deep Energy Retrofits	SFD		$66,500 - $141,000	$16,957- $40,800	
New York State Energy Research and Development Authority (NYSERDA)	SFD		$67,000 - $144,000		
National Grid Deep Energy Retrofit Pilot Homes	SFD		$50,000 - $180,000		50%
Evaluating Exterior Insulation and Finish Systems for Deep Energy Retrofits	SFD			$56,000	
Utica, NY- Pembina	SFD		$100,000 - $145,000		65%
Arlington, MA (duplex)- Pembina	Duplex		$100,000		67% Heating only

Deep Energy Retrofits—Eleven California Case Studies	SFD			$25,910	70%
NYSERDA Pilots				$32,000	
A process for developing deep energy retrofit strategies for single family housing typologies: Three Toronto case studies	SFD	250	$45,353		65%
A process for developing deep energy retrofit strategies for single family housing typologies: Three Toronto case studies Cost Assessment of Selection of Energy Efficiency Strategies	SFD	131	$ 29,504		67%
	SFD	166	$35,422		72%
	Semi detached	250	$77,080		90%
	SFD	131	$53,250		89%
	Semi detached	166	$56,257		90%
Building America Efficient Solutions for Existing Homes		226	$38,300		
Cost Assessment of Selection of Energy Efficiency Strategies	SFD	242		$15,166	
	SFD	242		$12,873	
KB Home Double ZeroHouse 3.0 with PV	SFD	243	$48,524		
KB Home Double ZeroHouse 3.0 with PV	SFD	243	$24,262		
Sundance - with air source heatpump and ASHP water heaters	Townhouse		$105,000		70-80%
Sundance - without air source heatpump and ASHP water heaters	Townhouse		$ 92,000		70-80%

B.2 Multi-unit residential buildings

Table 10. Summary of total and incremental retrofits costs for MURBS based on modelled and actual case studies

Study Name	Building type	Building size (m^2)	Total cost ($/unit)	Incremental cost ($/unit)	Energy Savings
RDH- Market Rental Revitalization Study	Low-Rise Walk-Up	1,207		$13,600	50%
	Low-Rise Walk-Up	1,207		$13,800	50%

	Low-Rise with Elevator	4,180		$8,800	37%
	Low-Rise with Elevator	4,180		$9,200	48%
	High-Rise	13,935		$8,800	36%
Fortis BC - DER without Fuel switching	High Rise Rental	6,512			
CoV - Exploring Options for 80% GHG Reductions in Downtown Buildings	High Rise Condo	5,200			39%
	High Rise Rental	5,200			96%
Castle Square, MA	MURB	16,204		$18,023	72%
Greenbrook Case study with solar	MURB	18,840	$171,653	$38,583	50%
Greenbrook Case study without solar	MURB	18,840		$28,779	44%
RDH modelled approach	MURB	3,372		$5,465	32%
	MURB	3,372		$6,666	33%
	MURB	3,372		$9,573	35%
Comprehensive Retrofit of an Existing Multi-Unit Residential Building: Impacts on Energy Performance and GHG emissions	MURB	9,513	$14,392	$2,571	
Rocky Mountain Institute – San Francisco retrofit	MURB			$23,000	60%
RDH Vancouver - Affordable Retrofits Workshop	MURB			$7,000	75%
	MURB			$13,000	75%
Surrey Retrofit	MURB			$47,000	
Strategies for a High Comfort, Low Energy Retrofit in NYC - Pursuing Passive	MURB	11,427	$ 79,420	$51,066	63%
RDH Strata Energy Study	MURB	5,176.00		$5,962	28%
	MURB	5,176		$5,962	26%
	MURB	3,525		$5,583	17%
	MURB	4,369		$5,504	47%
Mutual Housing at Spring Lake, California with PV	MURB	6,002		$10,537	
Mutual Housing at Spring Lake, California without PV	MURB	6,002		$24,686	

B.3 Comparison of residential energy retrofit costs

Efficiency Canada's report 'Canada's Climate Retrofit Mission' released in June 2021, uses the same modelling tool produced by Ralph Torrie. Efficiency Canada's report also speaks to the scale of the effort needed to retrofit our building stock before 2050, however, the cost figures vary between the two studies because of different scenarios and costing data. Efficiency Canada uses a range of total retrofit costs (base cost + incremental cost) and assumes cost decrease over time, whereas this report uses incremental retrofit costs without decreasing the cost over time. See tables below for summary of costs used in both reports, and literature review findings.

Table 11 Summary of costing assumptions

Building type	Efficiency Canada	Pembina Institute	Literature Review	
	Total cost	Incremental cost	Incremental cost	Total cost
Detached homes ($/unit)	$56,000-$96,000	$46,000	$13,000-$56,000 *Average: $30,000*	$30,000-$180,0000 *Average: $80,000*
Attached homes ($/unit)	$46,000-$66,000	$36,000		
Apartments ($/unit)	$33,000-$43,000	$28,000	$6,000-$50,000 *Average: $17,000*	$15,000-$170,000 *Average: $90,000*.[80]

[80] Note: this figure is based only based on three data points.

Appendix C. Types of incentive programs

Targeting the incentives to populations, building types, and regions that have the greatest need will provide the greatest impact. This targeting will require a variety of mechanisms, including (but not limited to):

- **Rebates —** Rebates ease the up-front cost burden for building owners, and are commonly used by utilities and all levels of government to incentivize targeted technologies and retrofit measures. They are best paired with outcome-based incentives, used to top up specific technologies and to support resilience and measures that do not return direct cost or carbon savings but have other social benefits.
- **Outcome-based grants** — Amount is based on amount of CO_2 abated and may be set to increase as a higher percentage of emissions reductions is achieved. The grant per tonne can be adjusted to different electricity situations by province, and is ideally paired with utility-based incentives for peak reduction to ensure effective use of clean electricity resources, and function as a resilient grid capable of integrating more renewables.
- **Tax credits** — Used to incentivize building owners to invest in energy efficiency.[81] From 2007-2010, the federal government used the Home Renovation Tax Fund in combination with the ecoEnergy rebate program to incentivize a range of home energy improvements.[82]
- **Fully funded measures —** Low-income households may have trouble accessing incentives such as rebates because these require upfront payment before incentives are received. Programs that instead provide fully funded upgrades (including capital and installation costs) to low-income homes will ensure this population can access funding and the benefits of retrofits.[83]

[81] Steven Nadel, *Energy Efficiency Tax Incentives in the context of Tax Reform*, (2012, ACEEE), iv. https://www.aceee.org/files/pdf/white-paper/energy-efficiency-tax-incentives.pdf

[82] Building, "Federal Government suspends Eco-Energy Retrofit Homes Program," April 1, 2010. https://building.ca/federal-government-suspends-eco-energy-retrofit-homes-program/

[83] *Building Better Energy Efficiency Programs for Low-Income Households*, 11.

- **Financing with interest rate buy-down —** Financing will be a critical for scaling up retrofits. Public and private sources of capital need to be mobilized using a variety of financial instruments designed for building to achieve deep carbon and energy reductions.[84] Financing programs can be complemented by federal or provincial interest rate buy-down programs to increase access and incentivize investment.

Incentives for energy efficiency have traditionally been piecemeal, targeting single measures. Creating flexible funding streams that are allocated based on performance targets and coordinated with electric utility incentives will make it easier for industry and building owners to focus on achieving meaningful carbon and energy reductions through whole building interventions.

[84] *Property Assessed Clean Energy in Canada*, 3.