GHG Modelling 2021/2022

Results and Reference Document

April 20, 2022

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Section 1: 2021 Modelling Results

The Greenhouse Gas (GHG) Modelling 2021/2022 Results and Reference Document is a supporting document for The City of Calgary Climate Mitigation Action Plan. This document describes the Low Carbon Economy (LCE) model version 2021, an integrated emissions and economic model for Calgary's key emission areas of buildings and transportation. Section 1 of this report provides a detailed overview of the net zero scenario modelling results that informed the development of the Mitigation Action Plan. The modelling results shown here represent the maximum technical GHG reduction potential within the LCE 2021 this is referred to as the "Net Zero" scenario. The purpose of the LCE is to forecast the emission reduction and financial impact of GHG reduction scenarios for comparison with defined emissions reduction targets.

The LCE was originally developed in 2018 in collaboration with the University of Calgary and the University of Leeds. Section 2 of this report describes the updates and changes that were made in 2021 – 2022 as part of the update to the Climate MItigation Action Plan., including updates to demographic data, energy price data, financial metrics, addition of stretch measures (including the greening of district energy systems, hydrogen blending and commercial building electrification) and the addition of sensitivity analysis for energy prices, carbon prices and emission factors.

Net Zero Scenario

The following section details the results of the Net Zero scenario when run through the LCE 2021 model. For the purposes of this document, an 'intervention' is defined as a single action that has GHG reduction potential (e.g., retrofitting a home with efficient lights and appliances) and a series of interventions grouped together is defined as a 'scenario'.

The Net Zero scenario is the scenario that achieves the maximum GHG reductions that could be modelled in the LCE, and operates under some key design assumptions:

- All interventions initiate in 2022 and continue to 2050.
- For all units across all sectors interventions are implemented linearly and phased so that the final remaining units are converted by the year 2050.
- For new units, all interventions are immediately active and 100% of units are converted.

These assumptions were put in place to demonstrate the pace and scale required to align with a Net Zero by 2050 decarbonization target.

Modelling baseline emissions

All emission scenarios take away from an emissions baseline, figure 1 above demonstrates Calgary's forecasted emissions baseline from 2019 to 2050. Emissions decline from just over 14 Megatons (Mt) in 2019 to just over 12 Mt by 2050. There are two key driving factors to the trend observed above. The first is a rapidly cleaning electric grid that leads to significant GHG emission reductions in the near future. The second is a steadily increasing population which leads our forecasted emissions to grow once gains from cleaning of the electric grid slow. This emissions profile demonstrates a worst-case scenario for Calgary to 2050 where no progress is made in the fields of renewable energy generation, energy efficiency and electric vehicle deployment. From this baseline we can subtract carbon savings from the Net Zero scenario.

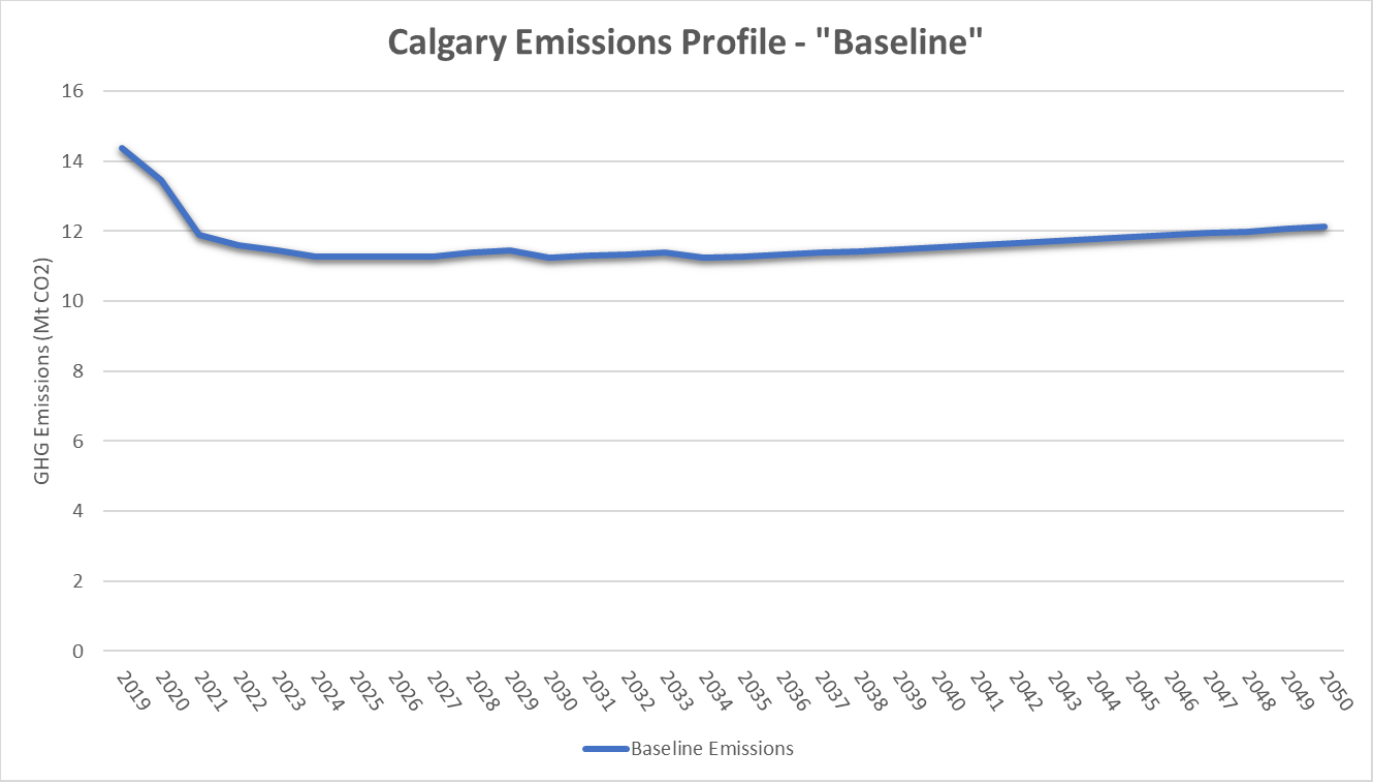


Figure 1 Calgary Emissions Profile – Baseline

Please see Appendices for the data and assumptions made to calculate the modelled baseline.

Calgary's modelled pathway to net zero

The net zero scenario was designed to maximize GHG emissions savings with current technology and available data. It is important to note that this modelling exercise does not lock Calgary into implementing any specific technology implementation pathway. It will be important to revisit this modelling and trajectory to net zero as new information and data become available. Each scenario is comprised of a series of

interventions, GHG reductions are achieved in the Net Zero scenario through the implementation of the following actions in Table 1. For a full list of available interventions in the LCE please see Appendices.

Net Zero Scenario						
Residential		Commercial and Industrial		Transportation		
Existing	New	Existing	New	Personal	Public	Commercial
R7.20.33 - All existing residential classed buildings are retrofit to Net Zero Energy by 2050	R13.26.39 - All new residential buildings are Net Zero Energy as of 2022	CI3 - All existing office space is deep retrofit and fully electrified by 2050	CI6 - All new office space is deep retrofit and fully electrified	VT7.8.9.13.14.15 - All personal vehicles are fully electrified by 2050	VT2 - All public and commercial transit vehicles are fully electrified by 2050	VT18.21.23 - All commercial vehicles are fully electrified by 2050
		CI8.12 - All existing retail and warehouse space is deep retrofit by 2050	CI10.14 - All new retail and warehouse space is deep retrofit			

Table 1 List of Interventions Net Zero Scenario

The combined emissions reduction potential from the interventions in Table 1 are shown in Figure 2 below. Figure 2 shows Calgary could achieve a 66% reduction in modelled emissions (yellow solid line) compared to our expected baseline emissions (blue line) by 2050. If we assume that the natural gas system includes 20% hydrogen blending, the reduction potential could increase to a 68% reduction, and if the electricity grid gets cleaner faster than currently expected and is net zero emissions by 2045, the reduction could increase to 92% reduction in emissions by 2050 (orange dotted line). Of the 66% total reduction, nearly half of those reductions are seen in the residential sector (49%), a third come from the transportation sector (33%) and smallest proportion of the savings come from the commercial and industrial sectors (18%) (figure 3).

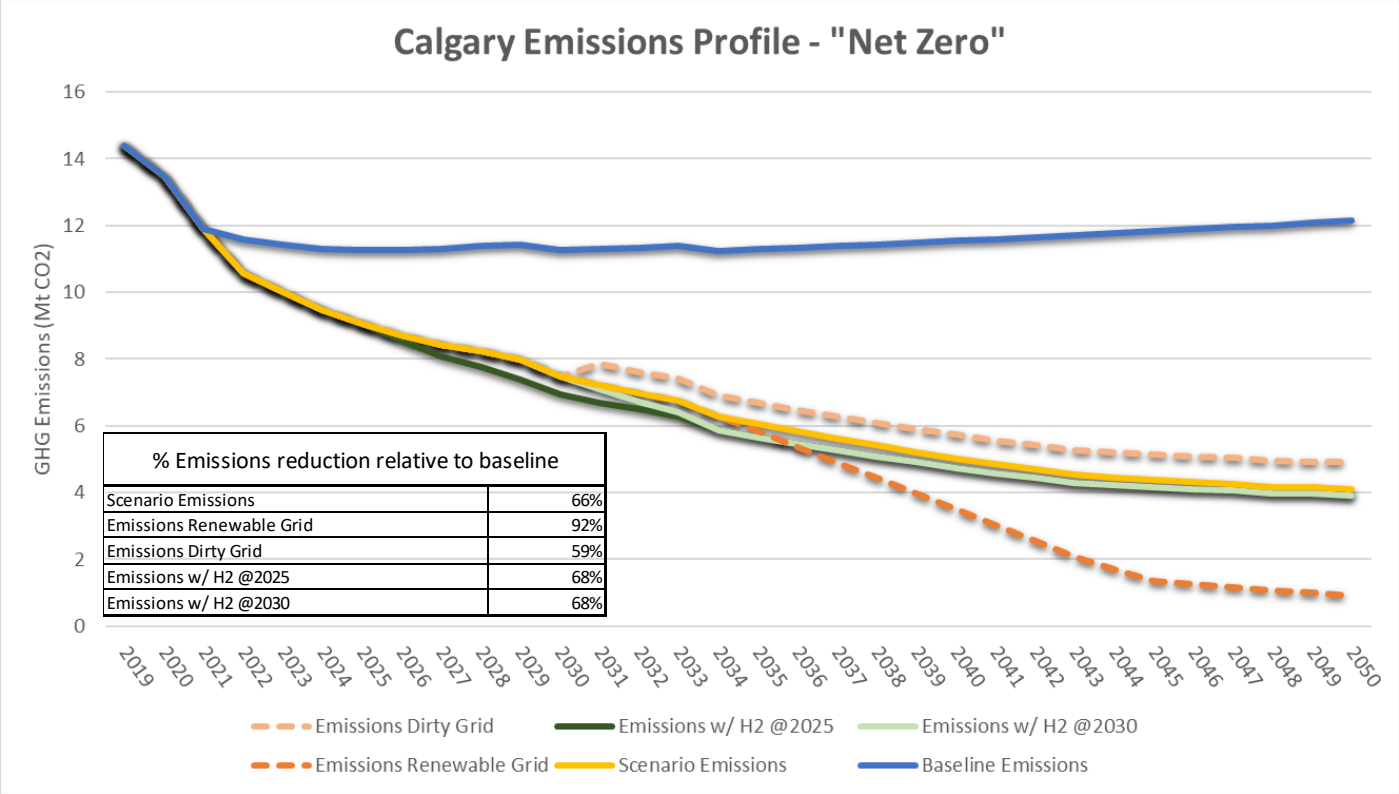
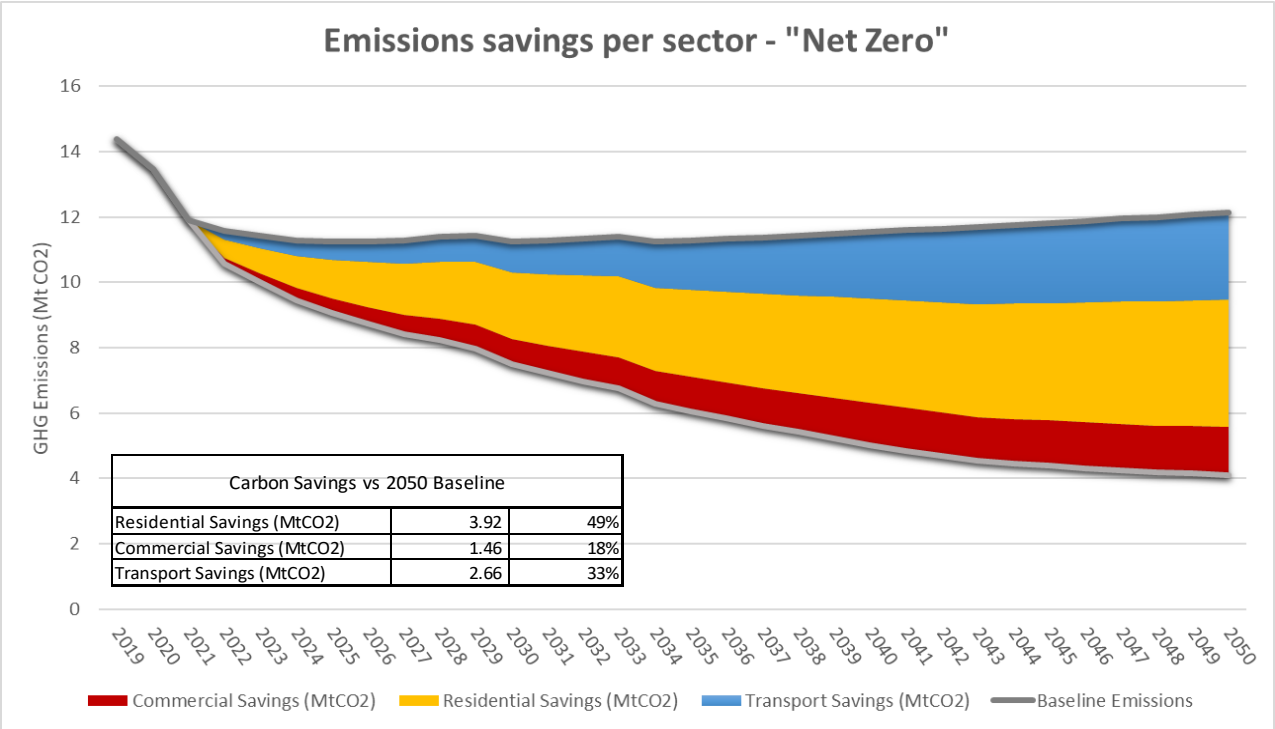


Figure 2 Calgary Emissions Profile - Net Zero Scenario



Carbon Savings vs 2050 Baseline		
Residential Savings (MtCO2)	3.92	49%
Commercial Savings (MtCO2)	1.46	18%
Transport Savings (MtCO2)	2.66	33%

Figure 3 Net Zero Scenario - Emission reduction per sector

The pace and scale of action required across all sectors to achieve these reductions is significant. In the residential sector, an annual retrofit rate of 3% is required, which equates to 19,000 retrofits annually or 52 daily retrofits. In the commercial and industrial sector that retrofit rate is 5% and would require an average number of 317 retrofits annually from now until 2050. It would also require an annual electric vehicle adoption rate of 6.2% representing 82,000 annual EV conversions. Developing the capacity to meet these targets is key and is undoubtedly one of the greatest challenges that Calgary faces to achieve a a net zero future. These values are a direct result of the scenario assumptions detailed at the start of this section and are required if Calgary is going to achieve Net Zero by 2050. Every year of inaction means the pace and scale of action must intensify.

Even given the significant investment and ambitious pace and scale of implementation required to achieve the net zero scenario, the modelling shows there is a gap between the estimated reductions and achieving net zero. Calgary's ability to achieve net zero emissions is dependent on our ability to encourage and require the implementation of zero and low carbon technologies within Calgary city boundaries. It is also dependent on several factors that are less within our control. For example, how quickly and to what extent the Alberta electricity grid decarbonizes, the pace and scale of federal carbon price increases and the implementation of other provincial and federal net zero policies, regulations, programs, and funding.

The variable that affects Calgary's emissions the most significantly in the net zero scenario is the provincial electricity emissions factor. If the Alberta electricity grid decarbonizes at the rate currently predicted by the Alberta Energy System Operator (AESO), Calgary will only achieve a 66% reduction with the Net Zero scenario compared to baseline. In contrast, if the Alberta electricity grid decarbonizes more quickly and achieves a net zero electricity grid by 2045, then Calgary's emissions could achieve a 92% reduction by 2050.

In either case, additional ways to reduce emissions will need to be identified to achieve our emissions targets. By indicating the gaps in our reduction efforts, The City invites other partners to help create, invest in, and support the energy transition. The City of Calgary will continue to work with our industry and research partners to understand new and innovative ways to reach our emissions goals.

Net Zero Scenario		Unit Metrics				Scenario Metrics
Intervention code	Intervention description	Marginal capital cost (2022 dollars)	Carbon savings lifetime (tonnes)	$/tonne	NPV	Carbon savings 2022-2050 (Mt)
R13	Single family Net Zero New	55,500.00	228.21	68.07	(15,534.68)	126.99
R39	Apartment Net Zero New	20,500.00	94.19	32.09	(3,022.93)	49.85
R26	Townhome Net Zero New	42,180.00	166.98	73.56	(12,283.85)	33.66
CI6	Electrification 50% AEDG Office New	368.55	0.40	(419.97)	167.67	27.02
R7	Single family Net Zero Retrofit	135,000.00	358.02	200.29	(71,709.05)	25.15
VT15	Gasoline vehicles (medium) to electric	8,512.50	48.35	(197.20)	9,533.75	21.33
VT14	Gasoline vehicles (light) to electric	6,262.50	41.64	(222.86)	9,279.31	20.04
CI14	Retail AEDG 50% New	56.49	1.12	(95.96)	107.77	13.66
CI10	Warehouse AEDG 50% New	56.49	0.59	(32.67)	19.41	11.06
CI3	Electrification Deep Office Retrofit	526.50	1.08	456.21	(494.87)	7.84
R20	Townhome Net Zero Retrofit	102,600.00	303.25	162.81	(49,373.33)	7.06
CI8	Warehouse Moderate/Deep Retrofit	64.52	1.22	(85.40)	104.50	5.99
VT16	Gasoline vehicles (heavy) to electric	11,512.50	73.97	(217.63)	16,097.37	5.93
CI12	Retail Moderate/Deep Retrofit	64.52	1.71	(143.34)	244.75	5.44
R33	Apartment Net Zero Retrofit	51,300.00	153.08	149.01	(22,810.33)	4.45
VT21	Diesel Light Goods Vehicle to electric	30,262.50	933.15	(360.27)	336,188.44	1.18
VT18	Heavy Goods Vehicles to electric	37,762.50	1,515.50	(352.25)	528,405.29	1.00
VT8	Diesel vehicles (medium) to electric	5,887.50	43.38	(206.55)	8,959.88	0.65
VT2	Buses to electric	34,012.50	1,276.84	(366.06)	467,404.06	0.48
VT23	Gasoline Light Goods Vehicles to electric	30,262.50	919.50	(359.79)	330,828.66	0.45
VT9	Diesel vehicles (heavy) to electric	7,012.50	57.55	(220.42)	12,685.23	0.37
VT7	Diesel vehicles (light) to electric	4,012.50	37.11	(234.13)	8,687.62	0.30

Table 2 Net Zero Scenario - Carbon and economic metrics by intervention

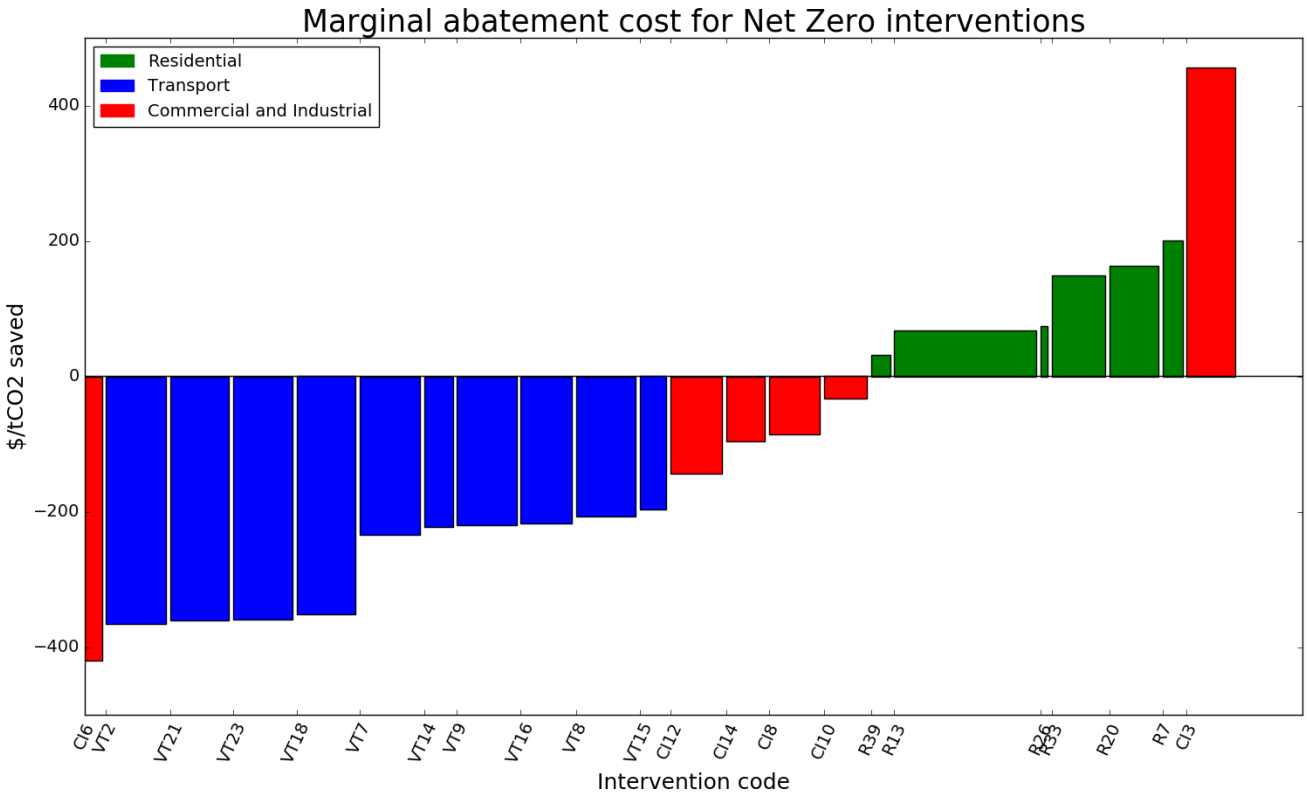


Figure 4 Net Zero Scenario - Marginal abatement cost by intervention

Table 2 shows economic and carbon summary metrics generated by the LCE for the Net Zero scenario. Figure 4 shows the marginal abatement cost per intervention for the Net Zero scenario – ordered left to right from lowest to highest cost. The width of the bars represents the scenario carbon savings shown in the right-hand column of table 2.

The estimated investment cost required to achieve the Net Zero scenario is $87.89 billion between now and 2050. This cost reflects the incremental cost of investment relative to baseline to implement all the interventions shown in Table 2. The investment calculated in the model is measured in 2022 dollars as a cost to all stakeholders across the economy broadly. The investment total does not represent the cost to The City of Calgary directly, nor does it provide an estimation of the required program costs to implement specific policies or programs. Instead, it represents the capital investment that needs to be mobilized in each sector including from governments, businesses, organizations, and individuals. Clearly, the investment required to realize the 2050 net zero future is significant, and this is due to the high retrofit cost of net zero homes and the pace and scale of retrofits that are required over a fairly short period of time.

Please see “Section 2 – Technical Documentation” for more information on how these metrics were calculated.

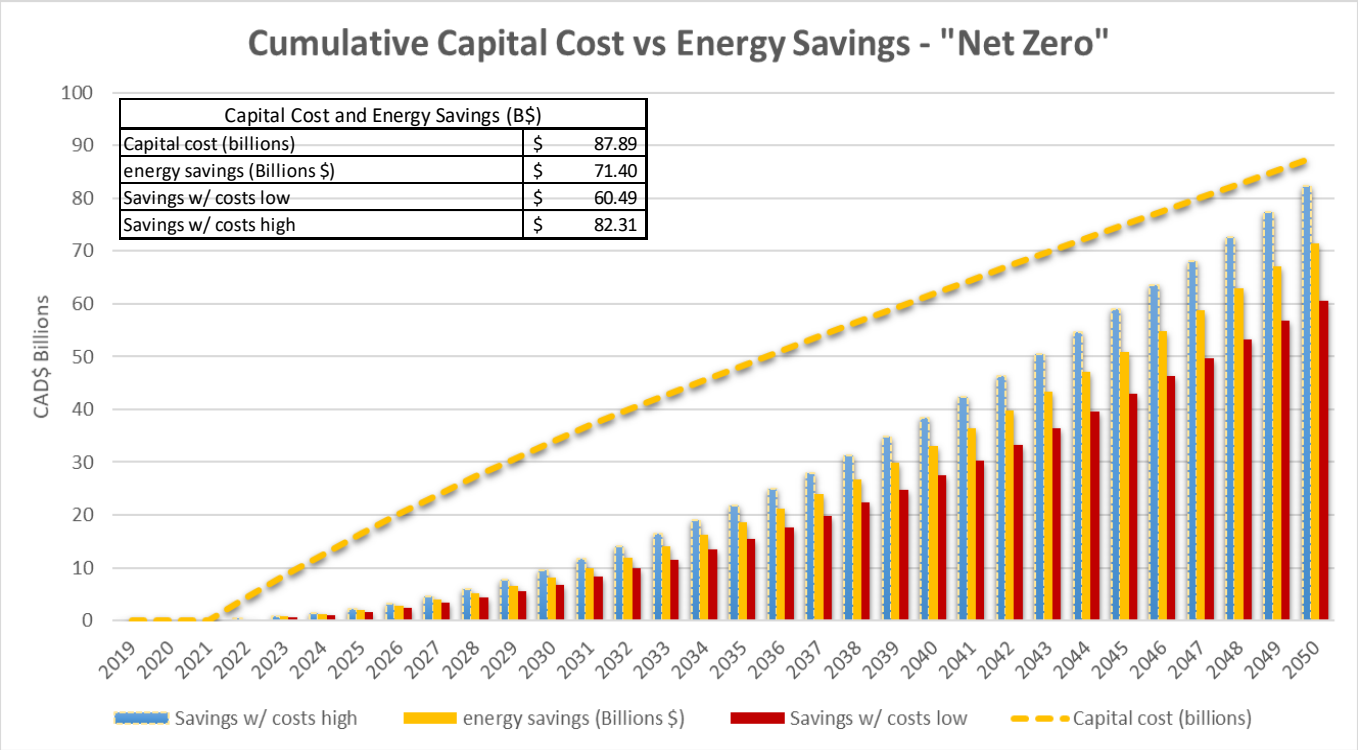


Figure 5 Net Zero Scenario - Capital cost vs energy savings

Section 2: Technical documentation

This section of the document outlines the key objectives, updates areas, assumptions and methodology changes made to the Low Carbon Economy model version 2018. This 2021 model uses a very similar methodology to the 2018 model, and as such, readers should refer to the original Low Carbon Economy report for further detail. This document will give a broad overview of the modelling framework and further detail the major changes between the 2018 and 2021 models.

Objectives

The objectives of the 2021 update to the Low Carbon Economy model are to provide updated model outputs for the creation of the 2022 Climate Mitigation Action Plan. On November 16, 2021, Calgary City Council approved the Declaration of Climate Emergency and Call to Action and made a clear commitment to taking local action on a global crisis. As part of the Declaration of Climate Emergency and Call to Action, the target of Net Zero by 2050 became a part of our public mandate. Council directed administration to update the city-wide and corporate greenhouse gas reduction target to net-zero emissions by 2050 and set sector specific interim targets to ensure accountability and benchmarking. Given that the previous modelling iteration was designed with a less ambitious emissions reduction target in mind (80% reduction below 2005 levels by 2050), a new model was required to quantify the ambition and investment required for a Net Zero future.

Key Update Areas

The key update areas for the 2021 revision include:

- model integration and process improvement,
- energy prices and emissions factors,
- demographic data,
- sensitivity analysis for energy prices and emission factors,
- Gap analysis for outstanding interventions (stretch measures).

The paragraphs below provide additional details on each of these updates. The original 2018 Low Carbon Economy work was split into six separate models: residential buildings, commercial buildings, private transportation, public transportation, land-use, and waste. In the 2021 revision, five of the models (excluding waste) were integrated into one single model. This combined model has the benefit of having core inputs for all 5 models that reduces duplication and removes a potential source of error when editing for scenario generation. Energy prices, emissions factors and carbon pricing were also updated to incorporate the historic data gathered between 2018 and 2021. In a similar fashion, demographic data relating to population trends, residential and commercial building stocks were also updated to inform the base case scenario. Model integration allows all models to use the same inputs and assumptions, which means all demographic data, financial data, emission factors, and energy prices are contained within a single model and can all be modified simultaneously.

Aside from updates to existing data there were two new areas of development: sensitivity analysis for emissions factors and energy pricing and the inclusion of stretch measures. The sensitivity analysis applies to emissions factors of natural gas and electricity, as well as energy pricing for natural gas, electricity, gasoline, and diesel. It enables the construction of error bars around the value for any given year for these

assumptions. The City of Calgary consulted with Delphi Group on the 2021 model update. Delphi completed a gap analysis within the existing 2018 model to determine whether any additional measures should be added to the model. These were termed 'stretch measures' and were designed to reflect the adjusted ambition to a net zero future by 2050.

2018 Model Review and Integration

This section describes step-by-step the methodology for all key update areas.

Step 1: Combine the six separate models from 2018 into a single integrated model

In 2018, the Low Carbon Economy model was split into 6 different individual models – Residential buildings, Commercial and Industrial buildings, Private Transportation, Public Transportation, Land Use and Waste. Of the six models five were combined into a single integrated model, with waste modelling being moved to the corporate emissions modelling process.

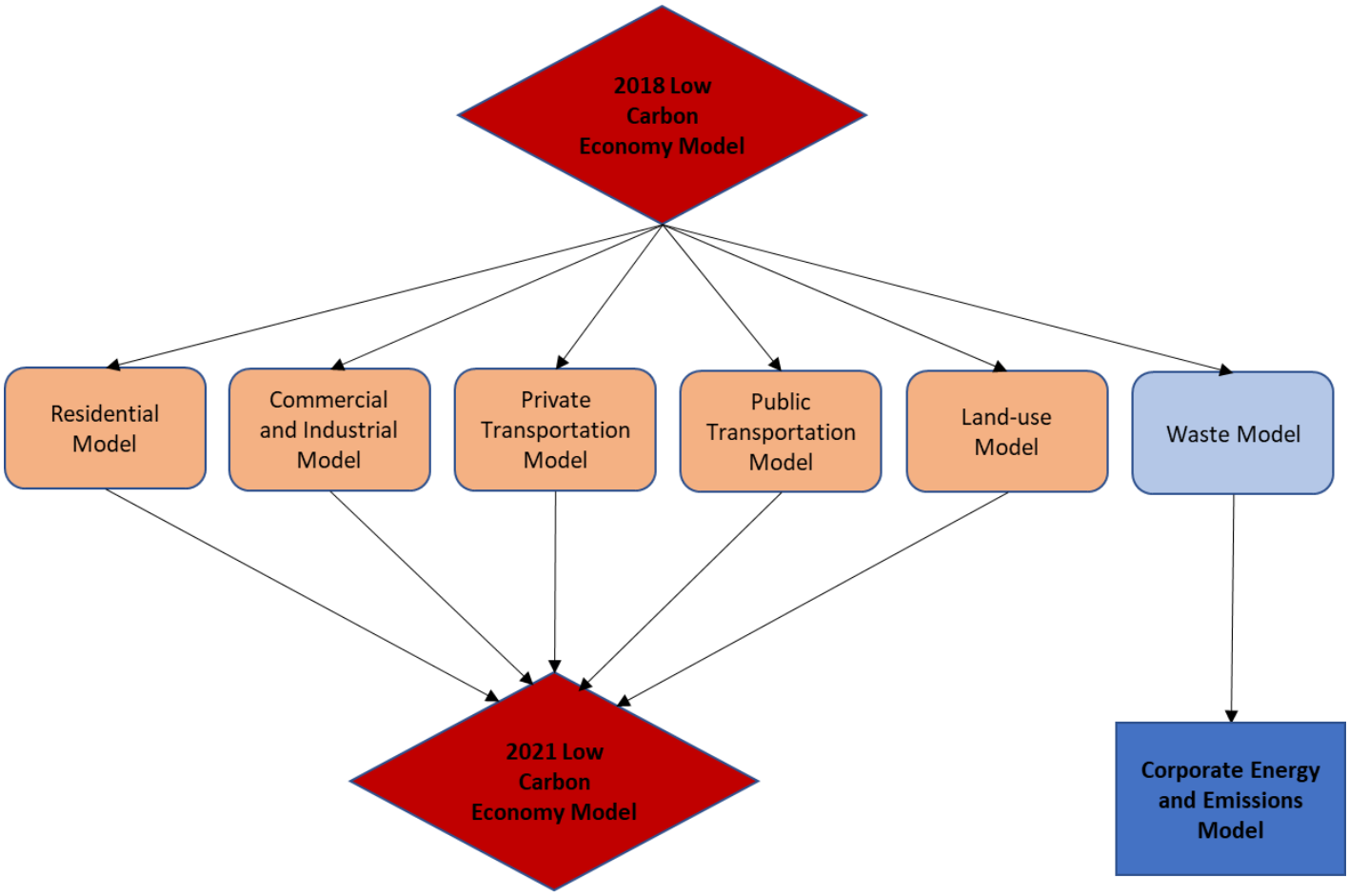


Figure 6 Process diagram Low Carbon Economy revision

Step 2: Cross-check

Once combined, a quality control process ensured the new 2021 combined model was functioning in the same manner as the prior 2018 models. Several different scenarios were trialed, and the model results were cross checked to ensure they returned the same value.

Step 3: Inputs updated

The next step was to identify the fields from the 2018 models that needed to be updated in the 2021 model. The table below lists the main update fields, the forecast method, and their source data.

Variable	Forecast method to 2050	Source
Electricity price	Rolling average forecasting with high low sensitivity	Alberta Utilities Commision (https://www.auc.ab.ca/current-electricity-rates-and-terms-and-conditions/)
Natural gas price	Rolling average forecasting with high low sensitivity	Alberta Utilities Commision (https://www.auc.ab.ca/current-gas-rates-and-terms-and-conditions/)
Carbon price	Aligned with source forecast, kept constant after 2030.	Pan Canadian Approach to Carbon Pollution Pricing 2023-2030
Gasoline price	Rolling average forecasting with high low sensitivity	Delphi Consulting Group
CNG price	Rolling average forecasting with high low sensitivity	Delphi Consulting Group
Diesel price	Rolling average forecasting with high low sensitivity	Delphi Consulting Group
Population	Interpolation based on source data up to 2040	2019 Federal Census and The City of Calgary Scenario Series
Building stock growth projections	Interpolation based on 2019 and 2040 source data points	The City of Calgary 2019-2050, Scenario Series Forecast
Electricity emissions factor	Aligned with AESO LTO reference case, kept constant after 2040. With high low sensitivity	AESO Long term Outlook 2019

Table 3 Variables updated, forecast method and source data LCE revision

Step 4: Interventions and functionality added

A gap analysis revealed several pieces of new functionality and interventions were missing and could be added to improve the flexibility and breadth of modelling capability. The additions are listed below, with further detail in subsequent headings.

- Sensitivity for emission factors and commodity pricing of electricity, natural gas and fuels,
- Hydrogen fuel blending,

- District Energy,
- Stretch interventions.

Sensitivity for emission factors and commodity pricing of electricity, natural gas and fuels

An emissions factor and commodity pricing sensitivity was added to the 2021 LCE model. For all electricity, natural gas, and all fuels there is an option to select “low”, “baseline” or “high” forecasts to use within scenario generation. This gives the flexibility of multiple forecasts and allows the user to see the impact of macro drivers on emissions reduction or energy savings. Pricing and emission factor sensitivites were defined using statistical techniques and the extrapolation of historic data. In the case of the electric grid emissions factor, the long-term outlook of the AESO was taken into close consideration.

Hydrogen fuel blending

Hydrogen fuel blending into the natural gas network has been gaining traction as a building heating solution in Alberta. As a result, two hydrogen fuel blending options were added to the model. Both options assume hydrogen will be blended into the natural gas network to a maximum blend mix of 20% over the course of 4 years. Option 1 assumes this process will begin in 2025, whereas option 2 assumes 2030. These are applied to the entirety of natural gas consumed within city limits. A value of 20% for the maximum blend rate was chosen, as this is supposed to be the maximum value that can be combusted by existing natural gas fired appliances[1]. Additional hydrogen scenarios will be built out as data becomes available.

District Energy

The 2021 LCE model now also contains interventions related to the development and greening of Calgary’s current District Energy (DE) system. Four interventions are modelled: greening the existing system to 20% hydrogen, a doubling of system capacity, a doubling of system capacity and greening to 20% Hydrogen, a doubling of system capacity and greening 100%. Data for these scenarios was developed in consultation with Atlantica Energy.

Stretch interventions

Other “stretch” measures were also added to the 2021 LCE model. Overall, the original list of interventions was very comprehensive, however; the review found seven interventions that were missing from the original list that were added to 2021 LCE model (table 4 below).

Intervention Class	Intervention Title	Description
Stretch	Water Conservation	Water conservation packs for residences
Stretch	Telework	2 days of remote work per week

[1] https://www.atco.com/en-ca/about-us/news/2021/122920-suncor-and-atco-partner-on-a-potential-world-scale-clean-hydroge.html

Stretch	Solar Water Heating	Solar water heating in the residential sector
Stretch	Commercial Building Smart Controls	Fitting all office buildings with building smart controls
Commercial and Industrial	Electrification of Office Heating	Fully electrifying all current and future office buildings
District Energy	District Energy Greening	Greening our current DE system with a 20% Hydrogen blend
District Energy	District Energy Expansion	Expanding our current DE system to a contract demand of 110MW

Table 4 List of stretch meausres added to the 2021 LCE model

For more detail on the stretch measures added please see “Stretch Measures Key Data” within Appendices.

Step 5: Variables added

Several new variables were also added to the 2021 model to account for the addition of new interventions. New field additions and their source data are listed in the table below.

Variable	Data source	Link
Green hydrogen cost	Pembina Institute	https://www.pembina.org/reports/hydrogen-climate-primer-2020.pdf
Green hydrogen emissions factor	Pembina Institute	https://www.pembina.org/reports/hydrogen-climate-primer-2020.pdf
District Energy operation costs	Atlantica District Heating	Consultation
District Energy construction costs	Atlantica District Heating	Consultation
Energy savings and cost data for commercial building smart controls	American Council for an Energy Efficient Economy	https://www.aceee.org/sites/default/files/publications/researchreports/a1703.pdf
Energy savings and cost data for deep retrofit and electrification of office buildings	Canada Green Building Council	https://portal.cagbc.org/cagbcdocs/advocacy/2021_CaGBC_Decarbonization-Retrofit-Costing-Study_2DEC21_EN.pdf

Table 5 Variables added 2021 LCE model revision, data source

Step 6: Outputs added

The final step was to develop new outputs and graphing for the 2021 model.This was conducted using a dashboard style approach that allows increased time saving when running multiple scenarios and consistent graphing. See figure 7 below for example output data.

Emissions (kt) LIVE												
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Baseline Emissions	14,385.18	13,470.40	11,910.18	11,593.03	11,439.58	11,284.98	11,261.23	11,262.06	11,288.04	11,401.96	11,441.82	11,255.19
Scenario			11,910.18	9,581.77	9,139.16	8,708.00	8,399.90	8,126.01	7,888.17	7,748.60	7,543.93	7,147.55
2050 target	0	0	0	0	0	0	0	0	0	0	0	0
Cost (billions)												
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Baseline	1.447867416	1.512274697	1.655257574	2.227053878	2.268859992	2.288890843	2.336620981	2.364768693	2.385935252	2.403839615	2.395172809	2.496896839
Scenario	1.447867416	1.512274697	1.655257574	4.629933151	4.590190972	4.527381037	4.488791715	4.428465844	4.359266204	4.28226722	4.174906803	4.11650805
NET	0	0	0	2.685348739	2.496531831	2.298002196	2.08947901	1.871676906	1.645288492	1.408251747	1.163126469	0.911717266
Expenditure in scenario	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Capital cost (billions)	0	0	0	3.438702026	3.3269122	3.2148793	3.1024336					
Energy savings (Billions $)	0	0	0	0.301202272	0.432199866	0.575964774	0.732608334					
Scenario carbon savings	0	0	0	2.011257726	2.300422518	2.576979996	2.86133031					
mt												

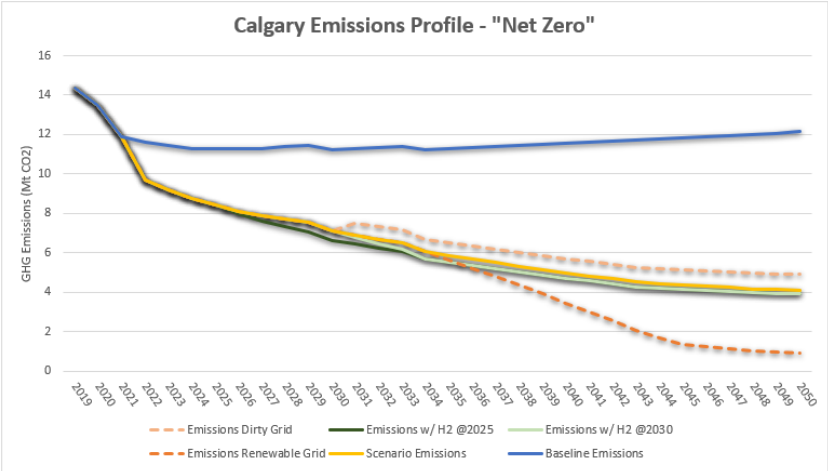


Figure 7 Example of dashboard outputs from 2021 LCE update

Inputs not changed

The key elements that were not changed since the 2018 LCE model were the design and costing of the original intervention packages. Across the residential, commercial, industrial and transportation sectors there were 87 different interventions ranging from net zero retrofits of single-family homes to moderate retrofits of warehouses. The actions within each of these interventions and the associated costs were not updated. These interventions and their costing were originally developed through a rigorous review process with the University of Calgary and the University of Leeds in the UK. High level review of each of these interventions deemed all were still relevant and costs were in line with expectation for 2022.

Model Design and Operation

The following section details how the 2021 Low Carbon Economy model functions, what the basic operating principles are, financial metrics calculated, how to interpret the outputs, andwhat is not included in the model.

Basic Principles

The 2021 Low Carbon Economy model is a series of integrated sector specific relational models that subtract from a common baseline. There are a series of models each one representing a sector, these models store data in a fixed format record in tables of rows and columns. The combined effect of these models is then compared against a pre-determined baseline to analyze the impact of the changes. This is a time series model and runs from our current year 2022 to 2050. The purpose of GHG emissions modelling is to project future emissions if we continue business-as-usual and to identify the effect of different emissions reduction technologies. The model focuses on energy efficiency and low carbon energy technologies that could be implemented in residential buildings, commercial buildings (offices and retail), industrial buildings (warehouses), and personal and public transportation within Calgary city boundaries. The model is focused on energy efficiency and low carbon energy technologies that could be implemented across the residential, commercial, industrial and transportation sectors. Only energy consumed within the city boundary is considered – including both fuels and electricity. Emissions from fuels and electricity are known as ‘Scope 1’ and ‘Scope 2’ emissions. ‘Scope 3’ emissions that are embedded in goods and services are excluded from this analysis.

Financial and emissions calculations are unit based. they are first calculated at the single unit level and then rolled up to a citywide scale based on the number of units - this method applies across all sectors. There are three primary metrics that form the backbone of the model: investment cost, energy savings and carbon savings. Simplified equations for each metric are displayed below:

Investment Cost:

$$Investment\ cost = (total\ units * implementation\ rate) * unit\ cost$$

Equation 1 Investment cost over analysis period

Energy Savings:

$$\begin{aligned} Energy\ savings \\ &= (total\ units * implementation\ rate) * ((natural\ gas\ savings * natural\ gas\ price) \\ &+ (electricity\ savings * electricity\ price)) \end{aligned}$$

Equation 2 Energy savings over analysis period

Carbon Savings:

$$\begin{aligned} Carbon\ savings \\ &= (total\ units * implementation\ rate) \\ &* ((natural\ gas\ savings * natural\ gas\ emission\ factor) \\ &+ (electricity\ savings * electricity\ emission\ factor)) \end{aligned}$$

Equation 3 Carbon savings over analysis period

All cashflows are displayed in 2022 dollars without inflation to 2050. The value of energy savings is based on energy price data that reflect carbon price assumptions shown in table 9. A discount rate of 3% is applied for NPV and IRR metrics. Learning rates are also progammable for all interventions, however, thus far have only been included where it is deemed, they will occur with a high degree of certainty. For instance, in markets with a historical trend of declining/increasing prices, such as electric vehicles. For electric vehicles a learning rate of 12.5% was applied, meaning EV's achieve cost parity in 2029. For other interventions, where the scale and direction of the learning rate is highly uncertain, inclusion of a learning rate would introduce bias to the model

Metrics

Financial and environmental metrics are central to the low carbon economy model. They allow us to rank individual interventions to see which provide the best return and they also allow us to further analyze the full impact of different scenarios. The main metrics used in the 2021 LCE model are listed below with their representative equations.

Net Present Value (NPV): The difference between cash inflows through energy savings and outflows from investment cost calculated from 2022 – 2050.

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

Equation 4 Net Present Value

Where:

Rt=Net cash inflow-outflows during a single period

i=Discount rate or return that could be earned in alternative investments

t=Number of time periods

Internal Rate of Return (IRR): IRR aims to estimate the profitability of an investment. It is the discount rate required to make the NPV of all cash flows equal to zero. The IRR calculation used here is taken without hurdle rate – no Weighted Average Cost of Capital (WACC) is applied.

$$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1 + IRR)^t} - C_0$$

Equation 5 Internal Rate of Return

Where:

Ct=Net cash inflow during the period

tC0=Total initial investment costs

t=The number of time periods

Payback period (PP): The length of time that it takes to recover the cost of an investment in years.

$$PP = \frac{Capital\ cost}{Average\ annual\ energy\ savings}$$

Equation 6 Payback period

Dollars invested per tonnes of carbon saved ($/tonne): The dollar value that needs to be invested to save 1 tonne of Carbon Dioxide.

$$\$\ per\ tonne = \frac{NPV}{Tonnes\ of\ CO_2\ saved}$$

Equation 7 Dollars invested per tonnes of carbon dioxide saved

What's not included

The 2021 LCE model does not represent all emissions city-wide. Instead, the model focuses on the core sectors of residential buildings, commercial buildings (offices and retail), industrial buildings (warehouses), and personal and public transportation. Other emissions sources such as heavy industrial, high pressure natural gas users, waste and provincial fuel volumes are not included. This is because The City does not have adequate information to properly assess the emissions. In some instances, these emissions are captured elsewhere (e.g., waste is modelled using the Corporate Greenhouse Gas and Emissions Programming). The unmodelled emissions make up ~3.5Mt of CO2e annually at 2019 base year, with by far the largest portion coming from provincial fuel volume of ~2Mt. The provincial fuel volume is a balance of fuel that the province applies to Calgary's emission inventory based on fuel usage outside of the city limits. The effect of these unmodelled emissions is misalignment of the baseline emissions of the model with our true baseline emissions for the whole city. For instance, our citywide emissions in 2019 were ~18Mt whereas the baseline within the LCE has total emisions of ~14.5Mt for 2019. Further refinement of the modelling process is ongoing to better account for these unmodelled emissions.

Scenario generation

Scenario generation is the process of selecting from the ~90 available interventions to understand their emissions impact in a combined scenario. The 2021 LCE model has two methods for conducting scenario analysis, the first is an automated method based on selection criteria in three tranches and the second is a customized manual method wherein the user selects each individual intervention. The automated method allows users to select from three predefined scenarios; cost effective, cost neutral and technical potential. Cost effective scenarios select the interventions that when combined produced the highest NPV. Cost neutral scenarios select interventions with the highest GHG reduction for equal investment cost to energy savings over the analysis period. Technical potential selects the interventions that produce the greatest overall GHG reduction regardless of cost. The second method of selection is manual, and it allows the user to select whichever interventions they wish without the constraints of financial or emissions related criteria. For the purposes of the update to the 2022 Climate Mitigation Action Plan, a technical potential scenario was selected as this represents the greatest emissions reduction that could be modelled using available data.

Model results and interpretation

A key distinction to make in the interpretation of the 2021 Low Carbon Economy model is that this is not a forecast, it is a model. A model is a simplified description, especially a mathematical one, of a system or process to assist calculations and predictions[2]. The model can help assist in the process of predictions; however, it is not one in itself. The 2021 LCE model allows us to synthesize a large amount of information quickly to inform decisions, and its flexibility and utility also allows us to consider multiple scenarios at once. When we examine the results of our modelled scenarios, we should be aware we can only compare them to the baseline we have set. The LCE is a simplification of reality wherein we compare the energy and emissions of a fictional baseline in 2050 with the energy and emissions in 2050 of our designed scenarios. We do have to be aware that this interpretation leaves out other considerations, most notably; social, economic, and/or political changes that impact model results.

The LCE baseline assumes that the energy systems and modes of transport of today remain constant; the only things that change are population, energy costs and emissions factors of current energy sources (e.g., the electric grid). The baseline then represents Calgary taking no concerted action to address emissions and instead continues with business-as-usual. It is modelling practice to keep as many elements constant in the baseline as possible, to avoid introducing bias into the baseline that will otherwise skew the results of other scenarios you model. A key component of the baseline data is the city growth trajectory to 2050. The LCE uses an annual population/unit growth projection of 1.5% per year. This is in line with other City lead forecasts, however, is generally deemed to be an aggressive growth scenario. A revision of this growth scenario is underway, however, for now this value is retained to align with other City groups. Clearly a less aggressive growth scenario would have a significant impact on baseline emissions and the investment cost required in the Net Zero scenario.

Another key point of clarification surrounds the cost data supplied by the model. Investment cost and energy savings are calculated for the economy at large. Therefore, these costs and savings are not borne by any one party. As an example, the expansion of electric vehicles entails two separate costs, charging infrastructure costs and vehicle purchase costs. Those costs could be shared by vehicle owners,

[2] https://www.thefreedictionary.com/Mathematical+model

municipalities who develop charging infrastructure and privately owned instutitions/workplaces that provide charging for their customers/workers. However, this value is provided as a single value of investment cost required for an EV in any given year. The investment costs seen in these models do not represent The City's obligation but nor do they represent the obligation of citizens.

Appendices

Baseline data

Demographic data is taken from 2019, aligned with the 2019 civic census. Note, transport vehicle stock is based on traffic volume data taken from the Regional Travel Model (RTM) and may not align completely with vehicle registration data – for more information on the RTM and other transport related forecasting please visit the webpage. Population and unit data is based on an average annual population growth of 1.5%. This value aligns with other City groups but is under revision – please see “Model results and interpretation” for discussion on this assumption.

Baseline data	
2019 population	1,283,177
Average annual population growth rate	1.50%
2019 residential dwellings	520,564
2019 commercial and instututional space (m2)	30,742,074.17
Building survivorship	96.40%

Table 6 Baseline data

Residential baseline units				
Year	2020	2030	2040	2050
Single family	299,862	333,353	366,843	400,334
Townhome	99,627	113,597	127,566	141,536
Apartment	129,832	192,337	254,842	317,347
Commercial & Industrial baseline				
Office (m2)	13,130,999.11	16,246,540.90	19,362,082.69	22,477,624.49
Warehouse (m2)	11,052,711.48	13,675,145.94	16,297,580.40	18,920,014.85
Retail (m2)	7,305,495.91	9,038,842.90	10,772,189.89	12,505,536.88
Transport vehicle stock				
Buses	802	899	996	1,093

Cars	1,228,856	1,562,056	1,895,256	2,228,455
Motorcycles	12,649	16,079	19,509	22,939
HGV	1,362	1,597	1,832	2,067
LGV	3,144	4,153	5,162	6,171

Table 7 Baseline unit data

Emission Factors	**Units**	**2010**	**2020**	**2030**	**2040**	**2050**
CNG	t CO2e/GJ	0.05743	0.05743	0.05743	0.05743	0.05743
Diesel	t CO2e/L	0.00275	0.00268	0.00235	0.00235	0.00235
District Energy	t CO2e/GJ	0.04473	0.04473	0.04473	0.04473	0.04473
Gasoline	t CO2e/L	0.00246	0.00231	0.00193	0.00193	0.00193
Grid Electricity	t CO2e/kWh	0.00087	0.00062	0.00028	0.00026	0.00026
Hydrogen	t CO2e/kg	0.00100	0.00100	0.00100	0.00100	0.00100
Natural Gas	t CO2e/GJ	0.05610	0.05610	0.05610	0.05610	0.05610
Biodiesel	t CO2e/L	0.00000	0.00000	0.00000	0.00000	0.00000

Table 8 Baseline emission factors

Cost with Carbon Tax	**Units**	**2010**	**2020**	**2030**	**2040**	**2050**
Carbon price	$/tCO2	-	30	170	170	170
Biodiesel	$/L	1.26	1.16	1.28	1.41	1.56
CNG	$/GJ	21.64	23.36	31.40	31.40	31.40
Diesel	$/L	1.03	1.03	1.44	1.55	1.68
District Energy	$/GJ	9.84	13.68	21.23	22.66	24.23
Gasoline	$/L	1.08	1.07	1.44	1.55	1.68
Grid Electricity	$/kWh	0.07	0.10	0.15	0.16	0.19
Hydrogen	$/kg	-	23.85	23.85	23.85	23.85
Natural Gas	$/GJ	7.37	5.40	14.47	15.31	15.92

Table 9 Baseline energy and fuel cost

Residential Key Data

Intervention Code	Sector	Sub-sector	Intervention	Description
R1	Residential	Single family house	Retrofit 1	Efficient lights and appliances
R2	Residential		Retrofit 2	Upgrade to code
R3	Residential		Retrofit 3	Upgrade to code + Heat pump
R4	Residential		Retrofit 4	Upgrade to R2000
R5	Residential		Retrofit 5	Passive House
R6	Residential		Retrofit 6	Passive House + Heat pump
R7	Residential		Retrofit 7	Net Zero Energy Building
R8	Residential		New 1	Code + Efficient lights and appliances
R9	Residential		New 2	Heat pump
R10	Residential		New 3	R-2000
R11	Residential		New 4	Passive House
R12	Residential		New 5	Passive House + Heat pump
R13	Residential		New 6	Net Zero Energy Building
R14	Residential	Townhouse	Retrofit 1	Efficient lights and appliances
R15	Residential		Retrofit 2	Upgrade to code
R16	Residential		Retrofit 3	Upgrade to code + Heat pump
R17	Residential		Retrofit 4	Upgrade to R2000
R18	Residential		Retrofit 5	Passive House
R19	Residential		Retrofit 6	Passive House + Heat pump
R20	Residential		Retrofit 7	Net Zero Energy Building
R21	Residential		New 1	Code + Efficient lights and appliances
R22	Residential		New 2	Heat pump
R23	Residential		New 3	R-2000
R24	Residential		New 4	Passive House
R25	Residential		New 5	Passive House + Heat pump
R26	Residential		New 6	Net Zero Energy Building
R27	Residential	Apartment	Retrofit 1	Efficient lights and appliances
R28	Residential		Retrofit 2	Upgrade to code
R29	Residential		Retrofit 3	Upgrade to code + Heat pump
R30	Residential		Retrofit 4	Upgrade to R2000
R31	Residential		Retrofit 5	Passive House
R32	Residential		Retrofit 6	Passive House + Heat pump
R33	Residential		Retrofit 7	Net Zero Energy Building
R34	Residential		New 1	Code + Efficient lights and appliances
R35	Residential		New 2	Heat pump
R36	Residential		New 3	R-2000
R37	Residential		New 4	Passive House
R38	Residential		New 5	Passive House + Heat pump
R39	Residential		New 6	Net Zero Energy Building

Table 10 Full list residential interventions

Residential Retrofit

Residential – Retrofit Baseline

Baseline residential buildings to show potential of available upgrades. Buildings assumed to be up to previous codes and meeting the characteristics listed below.

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit:

- No activities or costs associated with this scenario, just establishes baseline

Building types and characteristics

This baseline will be applied to 3 building types (single family, townhome, and apartment) with the characteristics shown below. These characteristics will be held constant for all of the upgrade scenarios.

	Floor area (m^2)	# Floors	Façade area, windows included (m^2)	Window area (m^2)
Single family	208.7	2	286	51
Townhome	159.1	2	125	22
Apartment	70.5	1	44	13

Table 11 Residential building types and characteristics

Residential – Retrofit 1: Install efficient lightbulbs and appliances

Simplest available retrofit. No renovation or construction required, just installation of upgraded lightbulbs and appliances with higher efficiencies.

Baseline Characteristics (unchanged)

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit

- Purchase and installation of high efficiency lightbulbs and appliances. Suggested ratings are as follows:

- A rated ovens
- A+ Wet Appliances
- A++ Cold Appliances

Residential - Retrofit 2: Upgrade to code

Renovation of an existing building to meet current code requirements in Alberta -> the cost is NOT for a new construction, but for a RETROFIT of an existing structure with the baseline characteristics listed.

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit

- Upgrade wall insulation to **U = 0.21 W/m2-K**
- Upgrade ceiling/roof insulation to **U = 0.162 W/m2-K**
- Replace windows, **U = 2.2 W/m2-K**
- Replace NG furnace to **AFUE 92%**
- Replace NG water heater to **67% efficiency**

Other notes

The updates to Alberta building code, while stricter in most respects, has become more lenient in terms of windows, moving from a U-value of 1.9 to 2.2 W/m²*K. In the case a building was up to previous code, no retrofit would be needed as far as windows goes. As we cannot confirm old buildings would be up to code, assume retrofit is needed to bring to 2.2 standard.

Residential – Retrofit 3: Upgrade to code and install heat pump

Similar to Retrofit 2 with the addition of purchase and installation of heat pump with COPh 3.1

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit

- Upgrade wall insulation to **U = 0.21 W/m^2-K**
- Upgrade ceiling/roof insulation to **U = 0.162 W/m^2-K**
- Replace windows, **U = 2.2 W/m^2-K**
- Replace NG furnace and water heater with **heat pump, COPh 3.1**

-

Residential - Retrofit 4: Upgrade to mid Performance-based standard

Renovation of an existing building to meet a performance based standard that falls in the mid-range of standards available. The insulation and energy use of the standard are based on, but not specifically tied to, the R-2000 standard. Note that this does not necessitate a home to be certified R-2000, but to meet the requirements the standard dictates. The measure outlines a RETROFIT of an existing structure with the baseline characteristics listed.

As there are a number of ways to meet the standard, it may be more practical to suggest a series of possible renovations or steps that could move towards the goal, with individual pricing for each of the steps that could then be combined.

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit:

The standard is performance based – hence, there are multiple combinations of wall/roof insulation, window performance, and HVAC equipment efficiency that could be used to meet the energy performance requirements. We are looking for a ballpark figure for the cost of the most standard “upgrade package” that would bring a home to similar standards listed in the R-2000 requirements.

Other notes

Is there a “standard upgrade package” for this standard and, if so, how was it chosen? Could this upgrade package change for each building type or in the event of a large-scale retrofitting project? A potential example of a series of retrofits to bring up to R-2000 standard can be found here http://buildingknowledge.ca/projects/r2000-net-zero-energy-home/

Residential - Retrofit 5: Upgrade to high Performance-based Standard

Renovation of an existing building to meet a high standard for limited energy use. i.e. A heating load of under 15kWh/m² per year and total energy use 60 kWh/m² per year. The goal of this retrofit is to meet the energy requirements set forward by the passive house institute, however this only applies to the energy use requirements, not the entire passive house brand. -> the cost is NOT for a new construction, but for a RETROFIT of an existing structure with the baseline characteristics listed.

Similar to the mid-performance case, it may be practical to break this scenario down into a series of steps that could be taken towards the energy use standard that could then be added together in the study. This could be particularly useful in the case that a full upgrade to the standard would not be possible.

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K

- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit:

Similar to the mid performance case, this standard is performance based – hence, there are multiple combinations of wall/roof insulation, window performance, and HVAC equipment efficiency that could be used to meet the energy performance requirements. We are looking for a ballpark figure for the cost of the most standard "upgrade package" that meets the passive house requirements:

- Heating Load: < 15kWh/m² per year
- Total primary energy use: < 60 kWh/m² per year

Residential - Retrofit 6: Upgrade to high Performance-based Standard and install heat pump

Similar to retrofit 5 with the addition of purchase and install of heat pump with COPh 3.1.

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit:

Similar to the mid-performance case, this standard is performance based – hence, there are multiple combinations of wall/roof insulation, window performance, and HVAC equipment efficiency that could be used to meet the energy performance requirements. We are looking for a ballpark figure for the cost of the most standard "upgrade package" that meets the passive house requirements:

- Heating Load: < 15kWh/m² per year
- Total primary energy use: < 60 kWh/m² per year
- Replace NG furnace and water heater with **heat pump, COPh 3.1**

Residential - Retrofit 7: Upgrade to Net Zero Energy Building (ZEB)

Renovation of an existing building to meet the Net ZEB standard. This would apply to net zero ENERGY use, not net zero emissions. So, the retrofit will include an upgrade for minimal energy use as well as the addition of on-site power generation in the form of solar panels. -> the cost is NOT for a new construction, but for a RETROFIT of an existing structure with the baseline characteristics listed.

Baseline Characteristics

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K

- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

Activities included in the retrofit:

Similar to previous, multiple combinations are possible to upgrade the house to the Net ZEB standard. Would be looking into possible and most cost-effective ways of accomplishing this standard. Meeting this standard would include similar upgrades to Retrofit 6 with the addition of onsite energy generation. In the case of on-site generation, solar PV will be used:

- Based on solar PV from southern Calgary to account for 60kWh per m² of floor space will take roughly 40 * 255W solar panels using 65m² of roof space along with 30 kWh storage.
- In the case that a 40-panel installation is impractical, a minimum of 12 panels would be needed to support a 3kWp load so this could be used as an estimate for cost

Other Notes

Above solar PV estimates are based on ReneSola JC255M-24/Bb, 255 Watt Panel.

Residential New Building

Residential – New Building Baseline

For this section based on new building construction, cost comparisons will be based on the cost associated with the construction of a new building to code and the premium cost for the additions or upgrades in each of the scenarios. The new building baseline will be assumed to meet the following standards:

Baseline Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m^2-K
- Windows: U = 2.2 W/m^2-K
- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

- This scenario will not feature any upgrades. It will set the baseline cost for the construction of a new building that is up to code. This cost will be used for comparison of other premium constructions.

Building types and characteristics

This baseline will be applied to 3 building types (single family, townhome, and apartment) as detailed in table 11 above.

Residential – New Building 1: Baseline (code) plus efficient lightbulbs and appliances

Simplest available upgrade. No change to normal construction, just installation of lightbulbs and appliances with higher efficiencies.

Baseline (code) Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m2-K
- Windows: U = 2.2 W/m^2-K
- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

- Purchase and installation of high efficiency lightbulbs and appliances. Suggested ratings are as follows:
    - A rated ovens
    - A+ Wet Appliances
    - A++ Cold Appliances

Residential – New Building 2: Heat pump

Construction of new building up to code with the addition of purchase and installation of heat pump with COPh 3.1 in place of NG heaters.

Baseline (code) Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m^2-K
- Windows: U = 2.2 W/m^2-K
- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

- Purchase and installation of **heat pump, COPh 3.1** in place of NG heaters

Residential – New Building 3: mid Performance-based Standard

Construction of new building to meet a performance based standard that falls in the mid-range of standards available. The insulation and energy use of the standard are based on, but not specifically tied to, the R-2000 standard. Note that this does not necessitate a home to be certified R-2000, but to meet the requirements the standard dictates.

As there are a number of ways to meet this standard, it may be more practical to suggest a series of possible options or steps that could be added to a new construction towards the goal, with individual pricing for each of the steps that could then be combined.

Baseline (code) Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m^2-K
- Windows: U = 2.2 W/m^2-K

- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

- The standard is performance based – hence, there are multiple combinations of wall/roof insulation, window performance, and HVAC equipment efficiency that could be used to meet the energy performance requirements. We are looking for a ballpark figure for the cost of the most standard "upgrade package" that can be applied to a new construction that meets the R-2000 requirements.

Residential – New Building 4: High Performance-based Standard

Construction of a new building to meet a high standard for limited energy use, i.e. A heating load of under 15kWh/m² per year and total energy use 60 kWh/m² per year. The goal of this retrofit is to meet the energy requirements set forward by the passive house institute, however this construction only applies to the energy use requirements, not the entire passive house brand.

Baseline (code) Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m^2-K
- Windows: U = 2.2 W/m^2-K
- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

Similar to the mid performance case, this standard is performance based – hence, there are multiple combinations of wall/roof insulation, window performance, and HVAC equipment efficiency that could be used to meet the energy performance requirements. We are looking for a ballpark figure for the cost of the most standard "upgrade package" that could be applied to construction of a new building that meets the passive house requirements:

- Heating Load: < 15kWh/m² per year
- Total primary energy use: < 60 kWh/m² per year

Residential – New Building 5: High Performance-based Standard with addition of heat pump

Construction of new building up to the standard of new building 4 with the addition of a heat pump with COPh 3.1. In essence, a combination of New building 2 and New building 4 upgrades.

Baseline (code) Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m^2-K
- Windows: U = 2.2 W/m^2-K
- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

Similar to the mid-performance case, this standard is performance based – hence, there are multiple combinations of wall/roof insulation, window performance, and HVAC equipment efficiency that could be used to meet the energy performance requirements. We are looking for a ballpark figure for the cost of the most standard "upgrade package" that could be applied to construction of a new building that meets the passive house requirements:

- Heating Load: < 15kWh/m² per year
- Total primary energy use: < 60 kWh/m² per year
- Replace NG furnace and water heater with **heat pump, COPh 3.1**

Other notes

As there are a number of ways to meet the passive house requirements a heat pump may already be included in New Building 4 scenario.

Residential – New Building 6: Net Zero Energy Building (ZEB)

Construction of new building that is net zero energy. This would apply to net zero ENERGY use, not net zero emissions. So, the build will include an upgrade for limited energy use as well as the addition of on-site power generation in the form of solar panels.

Baseline (code) Characteristics

- Wall insulation: U = 0.21 W/m^2-K
- Ceiling/roof insulation: U = 0.162 W/m^2-K
- Windows: U = 2.2 W/m^2-K
- NG furnace at AFUE 92%
- NG water heater at 67% efficiency

Additional upgrades during construction

Similar to previous, multiple combinations are possible to upgrade the house to the Net ZEB standard. Would be looking into possible and most cost effective ways of accomplishing this standard. Meeting this standard would include similar upgrades to Retrofit 6 with the addition of onsite energy generation. In the case of on-site generation, solar PV will be used:

- Based on solar PV from southern Calgary, to account for 60kWh per m² of floor space will take roughly 40 * 255W solar panels using 65m² of roof space along with 30 kWh storage.
- In the case that a 40 panel installation is impractical, a minimum of 12 panels would be needed to support a 3kWp load so this could be used as an estimate for cost
- Main ask would be for installation costs of these systems over costs of systems themselves, unless there are any standard installation package for solar PV retrofits often used

Other Notes

In the case of a multi-unit complex, solar of 3kW would be desired for each individual unit. At what quantity of units/roof space might this become unfeasible? Above solar PV estimates are based on ReneSola JC255M-24/Bb, 255 Watt Panel.

Commercial and Industrial Key Data

Intervention Code	Sector	Sub-sector	Intervention	Description
CI1	Commercial and Industrial	Office	Retrofit 1	Shallow Retrofit
CI2	Commercial and Industrial	Office	Retrofit 2	Moderate-Deep Retrofit
CI3	Commercial and Industrial	Office	Retrofit 3	Deep Retrofit
CI4	Commercial and Industrial	Office	New 2	AEDG 30%
CI5	Commercial and Industrial	Office	New 3	AEDG 50%
CI6	Commercial and Industrial	Office	New 4	AEDG 50% + GSHP
CI7	Commercial and Industrial	Warehouse	Retrofit 1	Shallow Retrofit
CI8	Commercial and Industrial	Warehouse	Retrofit 2	Moderate-Deep Retrofit
CI9	Commercial and Industrial	Warehouse	New 2	AEDG 30%
CI10	Commercial and Industrial	Warehouse	New 3	AEDG 50%
CI11	Commercial and Industrial	Retail	Retrofit 1	Shallow Retrofit
CI12	Commercial and Industrial	Retail	Retrofit 2	Moderate-Deep Retrofit
CI13	Commercial and Industrial	Retail	New 2	AEDG 30%
CI14	Commercial and Industrial	Retail	New 3	AEDG 50%
CI15	Commercial and Industrial	DE	Baseline	District Energy standard spec
CI16	Commercial and Industrial	DE	Greening asset	District energy 20% H2
CI17	Commercial and Industrial	DE	Greeening + Expansion	District energy double size & 20% H2
CI18	Commercial and Industrial	DE	Greening 2 + Expansion	District energy double size & 100% H2

Table 12 Full list commercial and industrial interventions

Technical Information

Shallow Retrofit

This measure involves actions that would maximize the efficiency of electrical appliances and their use with minimal intrusive renovations being required. This will result in a roughly 40% decrease in electricity consumption.

Moderate-Deep Retrofit

This measure includes the steps of the shallow retrofit but also more intrusive renovations to insulation, HVAC, and heating methods. This results in slight electricity savings from the shallow retrofit along with heating energy reductions of roughly 30%.

Deep Office Retrofit

This measure includes the steps of shallow and moderate-deep retrofits but also includes the installation of an appropriately sized Ground Source Heat Pump (GSHP) that replace Natural Gas systems. Energy saving[3] and cost data[4] was taken from the Canada Green Building Council. This intervention only applied to offices, GSHP usage in retail and industry settings is an area of future research.

AEDG 30%

ASHRAE publishes the Advanced Energy Design Guides (AEDG), which layout a number of possible building improvements that will result in a decrease in energy consumption and emissions. The AEDG 30% standard provides a list of improvements that lower energy consumption 30% above the previous 1999 standards set out by ASHRAE, which equates to a 10% energy reductions compared to the current National Energy Code of Canada for Buildings (NECB) set out in 2011.

AEDG 50%

Similar to the previous, the AEDG 50% standard lays-out a number of possible improvements to decrease energy consumption and emissions. The 50% standard is name for being a 50% decrease relative to the AHRAE standards of 2004, which equates to a 30% energy reduction compared to NECB 2011.

AEDG 50% + GSHP

The same as AEDG 50% above but also includes installation of appropriately sized GSHP. For new construction 30% cost discount[5] is given over retrofit installation.

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[3] https://www.cagbc.org/cagbcdocs/advocacy/Making_the_Case_for_Building_to_Zero_Carbon_2019_EN.pdf

[4] 2021_CaGBC_Decarbonization-Retrofit-Costing-Study_2DEC21_EN.pdf

[5] https://homeguide.com/costs/geothermal-heat-pump-cost#new

	Item	Component	Recommendation	How-To's in Chapter 4
Envelope	Roof	Insulation entirely above deck	R-20 c.i.	EN2, 17, 20-21
		Metal building	R-13 + R-19	EN3, 17, 20-21
		Attic and other	R-60	EN4, 17-18, 20-21
		Single rafter	R-38 + R-10 c.i.	EN5, 17, 20-21
		Surface reflectance/emittance	No recommendation	
	Walls	Mass (HC > 7 Btu/ft^2)	R-15.2 c.i.	EN6, 17, 20-21
		Metal building	R-13 + R-13	EN7, 17, 20-21
		Steel framed	R-13 + R-7.5 c.i.	EN8, 17, 20-21
		Wood framed and other	R-13 + R-7.5 c.i.	EN9, 17, 20-21
		Below grade walls	R-7.5 c.i.	EN10, 17, 20-21
	Floors	Mass	R-12.5 c.i.	EN11, 17, 20-21
		Steel framed	R-38	EN12, 17, 20-21
		Wood framed and other	R-30	EN12, 17, 20-21
	Slabs	Unheated	R-15 for 24 in	EN13, 17, 19-21
		Heated	R-15 Full slab	EN14, 17, 19-21
	Doors	Swinging	U-0.50	EN15, 20-21
		Non-swinging	U-0.50	EN16, 20-21
	Vertical Glazing	Window to wall ratio (WWR)	20% to 40% maximum	EN23, 36-37
		Thermal transmittance	U-0.33	EN25, 31
		Solar heat gain coefficient (SHGC)	N, S, E, W N only	
			No recommendation	
		Window orientation	No recommendation	EN29-30
		Exterior sun control (S, E, W only)	No recommendation	EN24, 28, 30, 36, 40, 42 DL5-6
	Skylights	Maximum percent of roof area	3%	DL5-7, DL8, DL13
		Thermal transmittance	U-0.69	DL7, DL8, DL13
		Solar heat gain coefficient (SHGC)	0.64	DL8, DL13
Lighting	Interior Lighting	Lighting power density (LPD)	0.9 W/ft^2	EL1-2, 4, 8, 10-16
		Light source (linear fluorescent)	90 mean lumens/watt	EL4, 9, 17
		Ballast	Electronic ballast	EL4
		Dimming controls for daylight harvesting for WWR 25% or higher	Dim fixtures within 12 ft of N/S window wall or within 8 ft of skylight edge	DL1, 9-11, EL6-7
		Occupancy controls	Auto-off all unoccupied rooms	DL2, EL5, 6
		Interior room surface reflectances	80%+ on ceilings, 70%+ on walls and vertical partitions	DL3-4, EL3
HVAC	HVAC	Air conditioner (0-65 KBtuh)	13.0 SEER	HV1- 2, 4, 6, 12, 16-17, 20
		Air conditioner (>65-135 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Air conditioner (>135-240 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Air conditioner (>240 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Gas furnace (0-225 KBtuh - SP)	80% AFUE or E_t	HV1- 2, 6, 16, 20
		Gas furnace (0-225 KBtuh - Split)	90% AFUE or E_t	HV1- 2, 6, 16, 20
		Gas furnace (>225 KBtuh)	80% E_c	HV1- 2, 6, 16, 20
		Heat pump (0-65 KBtuh)	13.0 SEER/7.7 HSPF	HV1- 2, 4, 6, 12, 16-17, 20
		Heat pump (>65-135 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Heat pump (>135 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
	Economizer	Air conditioners & heat pumps - SP	No recommendation	HV23
	Ventilation	Outdoor air damper	Motorized control	HV7-8
		Demand control	CO_2 sensors	HV7, 22
	Ducts	Friction rate	0.08 in. w.c./100 feet	HV9, 18
		Sealing	Seal class B	HV11
		Location	Interior only	HV9
		Insulation level	R-6	HV10
SWH	SWH	Gas storage	90% E_t	WH1-4
		Gas instantaneous	0.81 EF or 81% E_t	WH1-4
		Electric storage 12 kW	EF > 0.99 – 0.0012xVolume	WH1-4
		Pipe insulation (d<1½ in./ d≥1½ in.)	1 in./ 1½ in.	WH6

Table 13 AEDG 30 - Office Buildings

	Item	Component	Recommendation	How-To's in Chapter 4
Envelope	Roof	Insulation entirely above deck	R-20 c.i.	EN2, 17, 20-21
		Metal building	R-13 + R-19	EN3, 17, 20-21
		Attic and other	R-60	EN4, 17-18, 20-21
		Single rafter	R-38 + R-10 c.i.	EN5, 17, 20-21
		Surface reflectance/emittance	No recommendation	
	Walls	Mass (HC > 7 Btu/ft^2)	R-15.2 c.i.	EN6, 17, 20-21
		Metal building	R-13 + R-13	EN7, 17, 20-21
		Steel framed	R-13 + R-7.5 c.i.	EN8, 17, 20-21
		Wood framed and other	R-13 + R-7.5 c.i.	EN9, 17, 20-21
		Below grade walls	R-7.5 c.i.	EN10, 17, 20-21
	Floors	Mass	R-12.5 c.i.	EN11, 17, 20-21
		Steel framed	R-38	EN12, 17, 20-21
		Wood framed and other	R-30	EN12, 17, 20-21
	Slabs	Unheated	R-15 for 24 in	EN13, 17, 19-21
		Heated	R-15 Full slab	EN14, 17, 19-21
	Doors	Swinging	U-0.50	EN15, 20-21
		Non-swinging	U-0.50	EN16, 20-21
	Vertical Glazing	Window to wall ratio (WWR)	20% to 40% maximum	EN23, 36-37
		Thermal transmittance	U-0.33	EN25, 31
		Solar heat gain coefficient (SHGC)	N, S, E, W N only	
			No recommendation	
		Window orientation	No recommendation	EN29-30
		Exterior sun control (S, E, W only)	No recommendation	EN24, 28, 30, 36, 40, 42 DL5-6
	Skylights	Maximum percent of roof area	3%	DL5-7, DL8, DL13
		Thermal transmittance	U-0.69	DL7, DL8, DL13
		Solar heat gain coefficient (SHGC)	0.64	DL8, DL13
Lighting	Interior Lighting	Lighting power density (LPD)	0.9 W/ft^2	EL1-2, 4, 8, 10-16
		Light source (linear fluorescent)	90 mean lumens/watt	EL4, 9, 17
		Ballast	Electronic ballast	EL4
		Dimming controls for daylight harvesting for WWR 25% or higher	Dim fixtures within 12 ft of N/S window wall or within 8 ft of skylight edge	DL1, 9-11, EL6-7
		Occupancy controls	Auto-off all unoccupied rooms	DL2, EL5, 6
		Interior room surface reflectances	80%+ on ceilings, 70%+ on walls and vertical partitions	DL3-4, EL3
HVAC	HVAC	Air conditioner (0-65 KBtuh)	13.0 SEER	HV1- 2, 4, 6, 12, 16-17, 20
		Air conditioner (>65-135 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Air conditioner (>135-240 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Air conditioner (>240 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Gas furnace (0-225 KBtuh - SP)	80% AFUE or E_t	HV1- 2, 6, 16, 20
		Gas furnace (0-225 KBtuh - Split)	90% AFUE or E_t	HV1- 2, 6, 16, 20
		Gas furnace (>225 KBtuh)	80% E_c	HV1- 2, 6, 16, 20
		Heat pump (0-65 KBtuh)	13.0 SEER/7.7 HSPF	HV1- 2, 4, 6, 12, 16-17, 20
		Heat pump (>65-135 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
		Heat pump (>135 KBtuh)	No recommendation	HV1- 2, 4, 6, 12, 16-17, 20
	Economizer	Air conditioners & heat pumps - SP	No recommendation	HV23
	Ventilation	Outdoor air damper	Motorized control	HV7-8
		Demand control	CO_2 sensors	HV7, 22
	Ducts	Friction rate	0.08 in. w.c./100 feet	HV9, 18
		Sealing	Seal class B	HV11
		Location	Interior only	HV9
		Insulation level	R-6	HV10
SWH	SWH	Gas storage	90% E_t	WH1-4
		Gas instantaneous	0.81 EF or 81% E_t	WH1-4
		Electric storage 12 kW	EF > 0.99 – 0.0012xVolume	WH1-4
		Pipe insulation (d<1½ in./ d≥1½ in.)	1 in./ 1½ in.	WH6

Table 14 AEDG 30 - Retail Building

Climate Zone 7 Recommendation Table for Warehouses and Self-Storage Buildings

	Item	Component	Conditioned	Semi-heated	How-To Tips in Chapter 5	✓
Envelope	Roof	Insulation entirely above deck	R-20.0 c.i.	R-10.0 c.i.	EN1–3	
		Metal building	R-13.0 + R-19.0	R-16.0	EN1, 4	
		Single rafter	R-38.0 + R-10.0 c.i.	R-38.0	EN1, 5	
		Solar reflectance index (SRI)	No recommendation	No recommendation	EN2	
	Walls—Exterior	Mass (HC > 7 Btu/ft^2)	R-15.2 c.i.	R-7.6 c.i.	EN1, 6, 15–16	
		Metal building	R-19.0 + R-11.2 c.i.	R-13.0	EN1, 7, 15–16	
		Steel framed	R-13.0 + R-7.5 c.i.	R-13.0	EN1, 8, 15–16	
		Wood framed and other	R-13.0 + R-7.5 c.i.	R-13.0	EN1, 9, 15–16	
	Walls—Interior	Partition walls (between semi-heated and conditioned spaces)	R-13.0	R-13.0	EN1	
	Slabs	Unheated	R-15.0 for 24 in.	No recommendation	EN1, 10, 14	
	Doors—Opaque	Swinging	U-0.500	U-0.700	EN1, 11	
		Vehicular/dock thermal transmittance	U-0.500	U-0.500	EN1, 12	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	EN1	
		Vehicular/dock infiltration—door open with truck in place	Weatherseals for dock levelers and trailer hinges	Weatherseals for dock levelers and trailer hinges	EN1, 13	
	Vertical Glazing (Including Doors)	Thermal transmittance	U-0.33	U-0.60	EN1, 17, 20, 22	
		Solar heat gain coefficient (SHGC)	N, S, E, W – 0.45	No recommendation	EN1, 17, 20, 22, 27	
		Exterior sun control (S, E, W only)	PF > 0.5	No recommendation	EN1, 20–21, 23, 25	
	Skylights	Area (percent of gross roof)	5%–7% prismatic diffusing skylights required in warehouse areas (except in self-storage areas)		EN1, 18–20	
		Thermal transmittance	U-0.69	U-1.36	EN1, 19	
		Solar heat gain coefficient (SHGC)	0.64	No recommendation	EN1, 19	
		Visible light transmittance (VLT)	0.59		EN1, 19	
Lighting	Interior Lighting	Lighting power density (LPD)	Warehouse (bulky and self storage) = 0.6 W/ft^2 Warehouse (fine storage) = 0.85 W/ft^2 Office area = 0.9 W/ft^2		EL12–18	
		Linear fluorescent lamps	T-5HO or T-8 high-performance with high-performance electronic ballast		EL3–7	
		Controls for daylight harvesting	Automatic dimming or switching of all luminaires in daylighted areas		DL1–10, EL9–10	
		Occupancy controls	Auto-on/off for all luminaires in the warehouse and self-storage areas, manual-on/auto-off for all office areas		EL8	
		Ceiling surface reflectances	80%		EL2	
	Exterior Lighting	Canopied areas	0.5 W/ft^2		EL19–21	
HVAC	HVAC	Cooling system (conditioned storage, all sizes)	No recommendation			
		Air conditioner (0–65 KBtuh)	13.0 SEER		HV1–4, 8, 16, 18–19, 22	
		Air conditioner (>65–135 KBtuh)	No recommendation		HV1–4, 6, 16, 18–19, 22	
		Air conditioner (>135–240 KBtuh)	No recommendation		HV1–4, 6, 16, 18–19, 22	
		Air conditioner (>240 KBtuh)	No recommendation		HV1–4, 6, 16, 18–19, 22	
		Gas furnace (0–225 KBtuh—SP)	80% AFUE or 81% E_t		HV1–2, 6, 16, 22	
		Gas furnace (0–225 KBtuh—Split)	90% AFUE or E_t		HV1–2, 6, 16, 22	
		Gas furnace (>225 KBtuh)	82% E_c or 81% E_t		HV1–2, 6, 16, 22	
		Heat pump (0–65 KBtuh)	13.0 SEER/7.7 HSPF		HV1–4, 6, 16, 18–19, 22	
		Heat pump (>65–135 KBtuh)	No recommendation		HV1–4, 6, 16, 18–19, 22	
		Heat pump (>135 KBtuh)	No recommendation		HV1–4, 6, 16, 18–19, 22	
		Destratification	Destratifying fans for high bay spaces		HV7	
	Economizer	Air conditioners and heat pumps—SP	No recommendation		HV24	
	Ventilation	Outdoor air damper	Motorized control		HV9–10	
		Air leakage through relief dampers	3 cfm/ft^2 at 1 in. wg			
	Ducts	Friction rate	0.08 in. w.c./100 ft		HV11, 20	
		Sealing	Seal class B		HV13	
		Location	Interior only		HV11	
		Insulation level	R-6		HV12	
SWH	Service Water Heating	Gas water heater efficiency	Storage—90% E_t, Instantaneous—0.81 EF or 81% E_t		WH1–2, 4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × Volume		WH1–2, 4	
		Point of use heater selection	Avoid pumped return for distributed light loads		WH5	
		Water heater sizing	Avoid oversizing and excessive supply temperatures		WH3	
		Pipe insulation (d < 1½ in./ d ≥ 1½ in.)	1 in./ 1½ in.		WH6	

Table 15 AEDG 30 - Warehouses

Climate Zone 7 Recommendation Table for Small to Medium Office Buildings

	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-35.0 c.i.	EN2, 17, 19, 21–22	
		Attic and other	R-60.0	EN3, 17, 19, 20–21	
		Metal building	R-30.0 + R-11.0 Ls	EN4, 17, 19, 21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-19.0 c.i.	EN5, 17, 19, 21	
		Steel framed	R-13.0 + R-18.8 c.i.	EN6, 17, 19, 21	
		Wood framed and other	R-13.0 + R-15.0 c.i.	EN7, 17,19, 21	
		Metal building	R-0.0 + R-22.1 c.i.	EN8, 17, 19, 21	
		Below-grade walls	R-15.0 c.i.	EN9, 17, 19, 21–22	
	Floors	Mass	R-20.9 c.i.	EN10, 17, 19, 21	
		Steel joint	R-49.0	EN11, 17, 19, 21	
		Wood framed and other	R-49.0	EN11, 17, 19, 21	
	Slabs	Unheated	R-20.0 for 24 in.	EN12, 14, 17, 19, 21–22	
		Heated	R-25.0 for 48 in.	EN13,14, 17, 19, 21–22	
	Doors	Swinging	U-0.50	EN15, 17–18	
		Nonswinging	U-0.50	EN16–17	
	Vestibules	At building entrance	Yes	EN18	
	Continuous Air Barriers	Continuous air barrier	Entire building envelope	EN17	
	Vertical Fenestration	WWR	20% to 40%	EN25; DL6	
		Window orientation	Area of W and E windows each less than area of S windows (N in southern hemisphere)	EN30–31	
		Exterior sun control (S, E, and W only)	No recommendation	None	
		Thermal transmittance	Nonmetal framing windows = U-0.33 Metal framing windows = U-0.34	EN23–24	
		SHGC	Nonmetal framing windows = 0.40 Metal framing windows = 0.40	EN24, 32–33; DL12	
Daylighting / Lighting	Daylighting	Light-to-solar-gain ratio	Minimum VT/SHGC = 1.10	EN34–40	
		Vertical fenestration EA	0.12	DL7–11	
	Interior Finishes	Interior surface average reflectance	Ceilings = 80% Wall surfaces = 70% Open office partitions = 50%	DL14–15; EL4	
		Open office partitions parallel to window walls	Total partition height = 36 in. maximum - or - Partition above desk height = min 50% translucent	DL4, 10; EL2, 4	
	Interior Lighting	LPD	0.75 W/ft^2	DL1–5; EL2–3, 5, 12–19	
		24-hour lighting LPD	0.075 W/ft^2	EL20	
		Light source lamp efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92 T8 and T5 lamps ≤ 2 ft = 85 All other > 50	EL6–8	
		Ballasts	4 ft T8 lamp nondimming applications = NEMA Premium instant start 4 ft T8 lamp dimming applications = NEMA Premium program start Fluorescent and HID sources = electronic	EL8	
		Controls for daylight harvesting in open offices—locate on N and S sides of bldg	Dim all general fluorescent lights within primary and secondary daylight zones of open offices	DL16–20; EL1, 11	
		Automatic controls	Auto ON to 50% = private offices, conference and meeting rooms, lounge and break rooms, copy rooms, storage rooms Auto ON occupancy sensors = restrooms, electrical/mechanical rooms, open and private office task lighting Time switch control = all other spaces	DL13; EL1, 5, 9–10	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 am and 6 am	EL23	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 am to 6 am)	EL21, 24–25	
		Walkways, plazas, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 am to 6 am)	EL22, 24–25	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 am to 6 am)	EL24–25	
Plug Loads	Equipment Choices	Laptop computers	Minimum 2/3 of total computers	PL1–2	
		ENERGY STAR equipment	For all computers, equipment, and appliances	PL1–2	
		Equipment power density	For all computers, equipment, and appliances	PL1–2, 4–6	
	Controls	Computer power control	Network control with power saving modes and control OFF during unoccupied hours	PL3	
		Occupancy sensors	Desk plug strip occupancy sensors	PL3	
		Timer switches	Water coolers and coffee makers control OFF during unoccupied hours	PL3	
		Vending machine control	Yes	PL3	

Table 16 AEDG 50 - Office Buildings

Climate Zone 7 Recommendation Table for Small to Medium Office Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 90% efficiency	WH1–5	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume (see Table 5-7)	WH1–5	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH1–5	
		Electric heat pump water heater efficiency	COP 3.0 (interior heat source)	WH1–5	
		Pipe insulation (d < 1½ in. / d ≥ 1½ in.)	1 in. / 1 ½ in.	WH6	
HVAC	Packaged Single-Zone Air-Source Heat Pumps	Cooling and heating efficiency	See Table 5-8 for efficiency	HV3	
		ESP	0.7 in. w.c.	HV3	
		DOAS air-source heat pump	Yes	HV10	
		DOAS heating and cooling efficiency	See Table 5-10 for efficiency	HV10–11	
		DOAS energy recovery	Yes, see Table 5-11 for effectiveness	HV12	
		DOAS fan—ESP	1.5 in. w.c. maximum	HV20	
	WSHPs with DOAS	Unit size	5 tons or less	None	
		Single-stage cooling and heating efficiency	Cooling = 16.4 EER Heating = 5.2 COP	HV4	
		Two-stage cooling and heating efficiency	Cooling part load = 17.6 EER Cooling full load = 15.0 EER Heating part load = 5.7 COP Heating full load = 5.0 COP	HV4	
		WSHP fan—ESP	0.5 in. w.c.	HV4, 20	
		Condensing boiler efficiency	90%	HV14, 30	
		DOAS water-to-water heat pump	See Table 5-10 for efficiency	HV10–11	
		DOAS variable airflow with DCV	Yes	HV17–18	
		DOAS energy recovery	Yes, see Table 5-11 for effectiveness	HV12	
		DOAS fan and motor	65% mechanical efficiency Motor efficiency per Standard 90.1-2010, Table 10.8B VSD efficiency = 95%	HV23	
	VAV DX with Gas-Fired Hydronic Heating	DX efficiency	See Table 5-9 for efficiency	HV6	
		Low-temperature air supply and SAT reset	50°F to 61°F	HV6, 11, 25, 31	
		Perimeter convector heat source	Hot water	None	
		Condensing boiler efficiency	90%	HV14, 30	
		Economizer	≥54,000 Btu/h, differential dry-bulb control	HV6, 16	
		Energy recovery	Yes, see Table 5-11 for effectiveness	HV12	
		Indirect evaporative cooling	No recommendation	None	
		Demand control and ventilation reset	Yes	HV17–18	
		ESP	2.0 in. w.c.	HV7, 20	
	VAV CHW (same as VAV DX except...)	Air-cooled chiller efficiency	10 EER	HV14, 29	
		Air-cooled chiller IPLV	12.5 IPLV < 150 tons, 12.75 IPLV ≥ 150 tons	HV14	
		Variable-speed pumping	Yes	HV29	
		Maximum fan power	0.72 W/cfm	HV7, 23, 31	
	Fan-Coils with DOAS	Air-cooled chiller efficiency	10 EER	HV14, 29	
		Air-cooled chiller IPLV	12.5 IPLV < 150 tons 12.75 IPLV ≥ 150 tons	HV14	
		Condensing boiler efficiency	90%	HV14, 30	
		Variable-speed pumping	Yes	HV29–30	
		VAV fan-coil units	Yes	HV8	
		Fan-coil unit fan power	0.30 W/cfm	HV8	
		DOAS chilled-water and hot-water coils served by same plant as fan-coils	Yes	HV10	
		DOAS variable airflow with DCV	Yes	HV10–11, 17	
		DOAS energy recovery	Yes, see Table 5-11 for effectiveness	HV12	
		DOAS fan and motor	65% mechanical efficiency, motor efficiency Standard 90.1-2010, Table 10.8B	HV23	
	Radiant Systems with DOAS	Air-cooled chiller full-load efficiency	10 EER	HV14	
		Air-cooled chiller IPLV	12.5 IPLV < 150 tons, 12.75 IPLV ≥ 150 tons	HV14	
		Condensing boiler efficiency	90%	HV14, 30	
		DOAS heating and cooling efficiency	See Table 5-10 for efficiency	HV10–11	
		DOAS variable airflow with DCV	Yes	HV10–11, 17–18	
		DOAS energy recovery	Yes, see Table 5-11 for effectiveness	HV12	
		DOAS fan—ESP	1.5 in. w.c.	HV20	
	Ducts and Dampers	OA damper	Motorized damper	HV16	
		Friction rate	0.08 in./100 ft	HV20	
		Sealing	Seal Class B	HV22	
		Location	Interior only	HV20	
		Insulation level	R-6.0	HV21	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Table 17 AEDG 50 - Office Buildings (cont'd)

Climate Zone 7 Recommendation Table for Medium to Big Box Retail Buildings

	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-35.0 c.i.	EN1–2, 18–21	
		Metal building	R-30.0 + R-11.0 Ls	EN1, 3, 18–21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-17.0 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-22.1 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-18.8 c.i.	EN6, 18–20	
	Floors	Mass	R-20.9 c.i.	EN7, 18–20	
		Steel framed	R-49.0	EN8, 18–20	
	Slabs	Unheated	R-20 for 24 in.	EN9, 18–21	
		Heated	R-25 for 48 in.	EN10, 18–21	
	Doors	Swinging	U-0.50	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.40	EN22–23	
		SHGC	0.45	EN23–24, 27	
		VT	0.45	EN23	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Table 18 AEDG 50 - Retail Building

Vehicular Transportation Key Data

Intervention Code	Sector	Sub-sector	Intervention	Description
VT1	Vehicular Transport	Buses	Diesel to Hybrid	All current and future diesel buses to hybrid
VT2	Vehicular Transport	Buses	Diesel to Electric	All current and future diesel buses to electric
VT3	Vehicular Transport	Buses	Diesel to CNG	All current and future diesel buses to CNG
VT4	Vehicular Transport	Diesel cars light	Diesel to Hybrid	All current and future light duty diesel cars to hydrid
VT5	Vehicular Transport	Diesel cars medium	Diesel to Hydrib	All current and future medium duty diesel cars to hydrid
VT6	Vehicular Transport	Diesel cars heavy	Diesel to Hybrid	All current and future heavy duty diesel cars to hydrid
VT7	Vehicular Transport	Diesel cars light	Diesel to electric	All current and future light duty diesel cars to electric
VT8	Vehicular Transport	Diesel cars medium	Diesel to electric	All current and future medium duty diesel cars to electric
VT9	Vehicular Transport	Diesel cars heavy	Diesel to electric	All current and future heavy duty diesel cars to electric
VT10	Vehicular Transport	Petrol cars light	Gasoline to hybrid	All current and future light duty gasoline cars to hydrid
VT11	Vehicular Transport	Petrol cars medium	Gasoline to hybrid	All current and future medium duty gasoline cars to hydrid
VT12	Vehicular Transport	Petrol cars heavy	Gasoline to hybrid	All current and future heavy duty gasoline cars to hydrid
VT13	Vehicular Transport	Petrol cars light	Gasoline to electric	All current and future light duty gasoline cars to electric
VT14	Vehicular Transport	Petrol cars medium	Gasoline to electric	All current and future medium duty gasoline cars to electric
VT15	Vehicular Transport	Petrol cars heavy	Gasoline to electric	All current and future heavy duty gasoline cars to electric
VT16	Vehicular Transport	Motorcycles	Gasoline to electric	All current and future motorcycle to electric
VT17	Vehicular Transport	HGV	Diesel to hybrid	All current and future diesel HGV's to hybrid
VT18	Vehicular Transport	HGV	Diesel to electric	All current and future diesel HGV's to electric
VT19	Vehicular Transport	HGV	Diesel to CNG	All current and future diesel HGV's to CNG
VT20	Vehicular Transport	LGV	Diesel to hydrid	All current and future diesel LGV's to hybrid
VT21	Vehicular Transport	LGV	Diesel to electric	All current and future diesel LGV's to electric
VT22	Vehicular Transport	LGV	Gasoline to hydrid	All current and future gasoline LGV's to hybrid
VT23	Vehicular Transport	LGV	Gasoline to electric	All current and future gasoline LGV's to electric

Table 19 Full list vehicular transportation interventions

Baseline data, and analysis of all public mitigation measures considered in this analysis, is conducted using the Calgary Regional Transportation Model (RTM). This trip-based mathematical model that draws survey data to complete a 4-stage process:

- Generating demand for travel;
- Distributing trips between zones;
- Splitting trips according to mode of travel; and
- Assigning trips to the road and transit networks.

The software used for this model is currently emme/2 software. The current RTM covers the geographic area of the city and some additional lands around the city limits. It is an a.m. peak hour model that represents the major trip purposes and modes of travel occurring in that time period. It deals primarily with personal travel and does not include a representation of trucks.

Factors That are included in the Regional Transportation Model (RTM):

- Transportation Network ie. Road Capacity, Truck Routes, HOV lanes, Transit Options (The Baseline horizon is as is on the ground, Future Horizons are Based On Current Plans)
- Distribution of Jobs and Population (Baseline is Current Land use, Future horizons based on expected development)
- Travel Dollar Costs (this is where the fuel cost value is included)
- Travel Distance
- Travel Time (For vehicle travel, factoring in network congestion)
- Household Characteristics
    - Household Income
    - Household Size
    - Auto Ownership
- Person Characteristics
    - Gender
    - Age
- Transit Pass Ownership
- Work Location
- Home Location
- Occupation
- Work Status: Employed vs Unemployed
- Student Status: Post Secondary, High School, vs Grade School
- Vehicle needed during work

The Calgary RTM is used to generate impacts on carbon emissions and energy use from the majority of measures in this analysis and all public measures. For private measures, where individuals choose to switch to hybrid or electric vehicles, is completed using excel based models at the University of Leeds. These models use baseline data from Calgary RTM and data inputs listed below to calculate aggregate impacts on carbon emissions and energy use.

For further information on the RTM, including key data and figures, please consult:
http://www.calgary.ca/Transportation/TP/Pages/Planning/Forecasting/Forecasting-Toolbox.aspx

Vehicle class	Gross vehicle weight pounds (kg)
Motorcycle	≤793 (1,749)
Light-Duty Vehicle	≤3,856 (8,500)
Medium-Duty Passenger Vehicle	3,856 to <4,536 (8,500 to 10,000)
Heavy-Duty Vehicle (diesel)	3,856 to 6,350 (8,500 to 14,000)
Goods vehicles	>3,856 (8,500)
– light	<8,847 (19,500)
– medium	8,847 to 14,971 (19,500 to 33,000)
– heavy	>14,971 (33,000)

Table 20 Vehicle class information

Public Transit Key Data

Intervention Code	Sector	Intervention	Description
PT1	Public Transit	Increased biking and w	Expanded non-motorized transport (biking and walking)
PT2	Public Transit	Parking levies 1	Increasing parking levies ($3/hr - $12/d)
PT3	Public Transit	Parking levies 2	Increasing parking levies ($8/hr - $32/d)
PT4	Public Transit	Carbon tax	100$ carbon tax
PT5	Public Transit	Car ownership 1	Reduced car ownership (20%)
PT6	Public Transit	Car ownership 2	Reduced car ownership (40%)
PT7	Public Transit	Free transit	Free transit
PT8	Public Transit	Expand transit 1	Expansion of transit coverage (25%)
PT9	Public Transit	Expand transit 2	Expansion of transit capacity (50% increase)
PT10	Public Transit	Carpooling	Carpooling
PT11	Public Transit	Biofuel	Biofuel (B20)

Table 21 Full list public transit interventions

Increased biking and walking: Programs encouraging commutes to cycle or take other non-motorised forms of transport to work are common in a number of large cities. This measure estimates the potential for a shift from motorized transportation options to walking and cycling using Calgary's regional transportation model. Costs were estimate by the RTM model.

Parking levies: A large proportion of weekday traffic is single-occupancy commuters travelling to and from the downtown core. Current parking rates are an average of approximately $20/day. This measure proposes additional parking charges to major commuter routes and major streets in the city. Elasticity of parking demand to changes in parking prices built into Calgary RTM model and based on transit surveys. No costs are attributed to implementing this policy.

Carbon tax: Both the Provincial and Federal governments have committed to carbon pricing, with the cost per tonne of CO2 rising from $20 today to $50 by 2022. This measure assesses the impact on motorised vehicle use from the change in fuel prices this policy will have. For reference, every $10 increase in the carbon tax adds approximately 2.3 cents/litre to the cost of gasoline. Price elasticity of demand built into Calgary RTM model and based on transit surveys. Results are included in the baseline reflecting the impact of existing and planned policies up to a price of $50/tonne in 2022 and held constant from there forward.

Car ownership: This measure assumes that car ownership declines over the period to 2050 against the baseline scenario. Importantly, no specific policies are considered as the means for bringing about this outcome. No costs were estimated for this measure, and it is not included in scenarios, as the costs are highly dependent on the policy approach taken. This mitigation measure is not included in any of the scenarios.

Exapnd transit: These measures assume that fleet of public transport vehicles is increased in order to reduce walk times 25% (the distance individuals need to walk to reach transit options), or wait times 50%. The impact on transportation choices and emissions are based on surveys conducted by the City of Calgary and included in the regional transportation model. Costs are estimated using data on the City's public transportation network[6]. Fares are assumed to maintain 49% of transport costs.

Carpooling: In this measure occupancy of private vehicles is increased 10%. Costs are estimated at $2 million per year based on previous programs at the City of Calgary and a review of Canadian programs.

Biofuel: In this measure biofuels are added to gasoline and diesel fuel to make up 20% of the total volume of fuel. Due to the reduced energy density of ethanol and biodiesel vehicle performance is estimated to decline 2%. The price of biofuel is estimated to be 5% higher than regular gasoline or diesel.

6City of Calgary (2014). Transit Fare review Strategy. https://www.calgarytransit.com/sites/default/file

s/content/PDF/transit-fare-strategy-review-final-report-feb-2014.pdf

Land Use Key Data

Intervention Code	Sector	Intervention	Description
LU1	Land use	MDP	Increased densification of residential units
LU2	Land use	MDP+	further increased densification of residential units

Table 22 Full list land use interventions

Urban form plays a fundamental role shaping urban processes, from travel patterns to employment decisions and housing choices[7,8,9]. Critically, in contrast with many other options for addressing GHG emission considered by the Climate Smart Cities team, land-use decisions are very hard to change, or 'un-do', in the future. While personal vehicles are replaced every 15-20 years and houses are rebuilt every 50-100 years, the structures of neighbourhoods and business districts can persist for far longer. How we build a growing city may therefore be one of the most important decisions we make towards meeting long-term goals like our climate change targets.

In Calgary, the cities' long-term commitment to sustainable development is guided by the Municipal Development Plan (MDP), and Calgary Transportation Plan (CTP). These documents, supported by successive City Councils and written with support from a large set of urban stakeholders, establishes a 60-year strategy for urban growth.

Using the MDP and CTP to provide a baseline for what the City of Calgary will look like in 2050, this analysis considers two scenarios to understand the impact of urban form on urban GHG emissions and energy use. The first of these, the "MDP Plan", assesses the impact of existing policies as compared with a 'dispersed' scenario where the footprint of Calgary, and the number of single family detached homes, are not affected by the MDP and CTP. This scenario provides an assessment of the impact of policies the City has already implemented, and plans to implement, in order to achieve the targets of the MDP and CTP.

A second scenario considers the climate and economic impacts of an increase in the ambition of the MDP and CTP. Specifically, the "MDP+" scenario has the City of Calgary achieve the 2050 targeted split between single family, townhouses, and apartments, one decade earlier, in 2040. This scenario assesses whether a case can be made for the City to push beyond its existing targets for sustainable urban development.

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8 Todd Litman, Evaluating Transportation Land Use Impacts: considering the impacts, benefits and costs of different land use development patterns (Victoria Transport Policy Institute, 2009), http://www.vtpi.org/landuse.pdf

9 Greg Dierkers et al., CCAP Transportation Emissions Guidebook. Part One: Land Use, Transit and Travel Demand Management (Center for Clean Air Policy, 2005), http://www.ccap.org/guidebook.

Land-use decisions have large, and potentially uncertain impacts on the economic structure of a city considering a timeline to 2050. To provide a high-level estimate of the overall GHG and economic impact, analysis is broken into three components:

Transportation

Higher urban densities can reduce travel times and distances and can also allow for investment in non-motorized transport options, like cycle and walking routes, and public transport options. Unique aspects of cities will influence how emissions and energy use change with density, however, a large body of research across North American cities finds strong patterns between changes in urban population density and changes in energy use. Using an elasticity of transportation energy use with respect to density of 0.118[10] and estimates of Calgary's total density under each scenario impacts on urban energy expenditure and emissions are calculated. An elasticity of 0.118 implies that a 10% increase in density leads to a 1.18% decline in transport energy use. Calculations in the transportation sector do not include the economic savings from individuals not purchasing vehicles, or the additional cost individuals may incur from public transport.

The change in density between the Dispersed and MDP scenario is available from City of Calgary geodemographic analysis (Calgary, 2009). The change in density associated with the MDP+ scenario is calculated using urban densities by neighbourhood data applied to the change in the housing stock between scenarios. These numbers were collected via a consultation with stakeholders and City of Calgary staff.

Values used to determine changes in urban density:

Person per hectare in single family dominated neighbourhood	20
Person per hectare in townhouse dominated neighbourhood	35
Person per hectare in apartment dominated neighbourhood	90

Table 23 Values used to calculate changes in urban density

Buildings

Meeting a scenario (MDP or MDP+) is predicated on a Calgarians living in a greater diversity of housing types. The impact on carbon emissions and energy use from this change is calculated using representative houses built to code and modelled using Hot2000. Carbon savings and energy expenditure savings are achieved when fewer of any given housing type are built, or when there are relatively fewer houses that have a relatively higher energy/carbon footprint and more houses of a relatively lower energy/carbon footprint.

Changes in housing types also lead to changes in the cost of homes and the amount individuals spend on housing. Analysis uses median housing prices for single family, townhouses and apartments in 2017, and

10 Karathodorou, N., Graham, D. J., & Noland, R. B. (2010). Estimating the effect of urban density on fuel demand. Energy Economics, 32(1), 86-92.

assumes prices increase 3% annually (in real terms), through 2050. Changes to assumptions around the cost of homes in 2017 and the change in prices through 2050 have a large effect on the economic impacts. Two points are important to note. First, as long as single-family homes are more expensive than townhomes or apartments, any shift to higher density reduces net expenditure on new homes in the City of Calgary and is therefore an economic 'savings'. The scale of economic savings is therefore uncertain, but the direction of the economic impact is not.

Second, changes in urban land-use policy will affect the prices of existing homes. In particular, building fewer single-family homes is likely to increase the price of existing single-family homes, and housing affordability. Policies that affect density will therefore need to be implemented in a considered and gradual manner. Impacts on housing affordability are not considered in these calculations.

Characteristics of new homes (based on code):

- Wall insulation: U = 0.47 W/m²*K
- Ceiling/roof insulation: U = 0.17 W/m²*K
- Windows: U = 1.9 W/m²*K
- Natural Gas (NG) Furnace at 78% efficiency
- NG water heater at 61% efficiency

City infrastructure

Basic urban infrastructure, including roads, sewers, new schools, and public amenities, must be provided as the city grows. Analysis completed by the City of Calgary in 2009 provides estimates of the changes in the costs to the City of Calgary under the 'Dispersed' and 'MDP' scenarios through 2070. To calculate savings under the MDP and MDP+ scenarios, savings are assumed to be proportional to the change in the urban footprint of the city.

Stretch Measures Key Data

Intervention Code	Sector	Intervention	Description
S1	Commercial and Industrial	Stretch 1	Install smart controls to all office buildings
S2	Residential	Stretch 2	Water conservation, install low flow faucets all residential
S3	Transportation	Stretch 3	2 days of telework a week
S4	Residential	Stretch 4	Solar water heating on all single family residences

Table 24 Full list stretch interventions

Office

Table 25 Full list stretch interventions

Building Smart controls

Stretch one involves installing smart controls into all current and future office buildings within Calgary. Both smart controls allow for greater levels of control and analysis on building lighting, plug loads, heating, and cooling systems. Operated effectively they can significantly reduce energy usage through optimization. The

American Council for an Energy-Efficient Economy has conducted a lot of work on this area, and their research was taken and adapted here to Canadian dollars[11].

Residential water conservation

Stretch two involves installing low flow faucets and shower heads to all current and future residential builds. This has a low upfront cost and has been shown to reduce water heater energy consumption by up to 20%[12][13][14][15].

Telework

Stretch three models a 3-day work week for all downtown workers. Data from the RTM and pandemic conditions suggests that two days of remote work equates to 2.62% less trips throughout the week.

Solar water heating

Stretch four explores solar water heating for residential and assumes the same power generation available to the city for solar PV is put toward solar thermal instead[16][17].

Three other stretch interventions were also identified and integrated during the gap analysis. Those measures (table 4) relating to electrification of office space and district energy and now integrated into commercial and industrial interventions (table 12).

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[11] https://www.aceee.org/sites/default/files/publications/researchreports/a1703.pdf

[12] https://www.eia.gov/energyexplained/use-of-energy/homes.php

[13] https://www.frontiersin.org/articles/10.3389/frsc.2021.630973/full

[14] https://www.hydroquebec.com/residential/energy-wise/hot-water/energy-saving-products.html#trousses

[15] https://www.energy.gov/energysaver/articles/new-infographic-and-projects-keep-your-energy-bills-out-hot-water

[16] https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/canmetenergy/files/pubs/SOLAR-BuyersGuide-SolarWaterHeatingSystems_ENG.pdf

[17] https://newenergyeconomy.ca/our-stories-1/calgary-company-uses-solar-solutions-to-heat-homes