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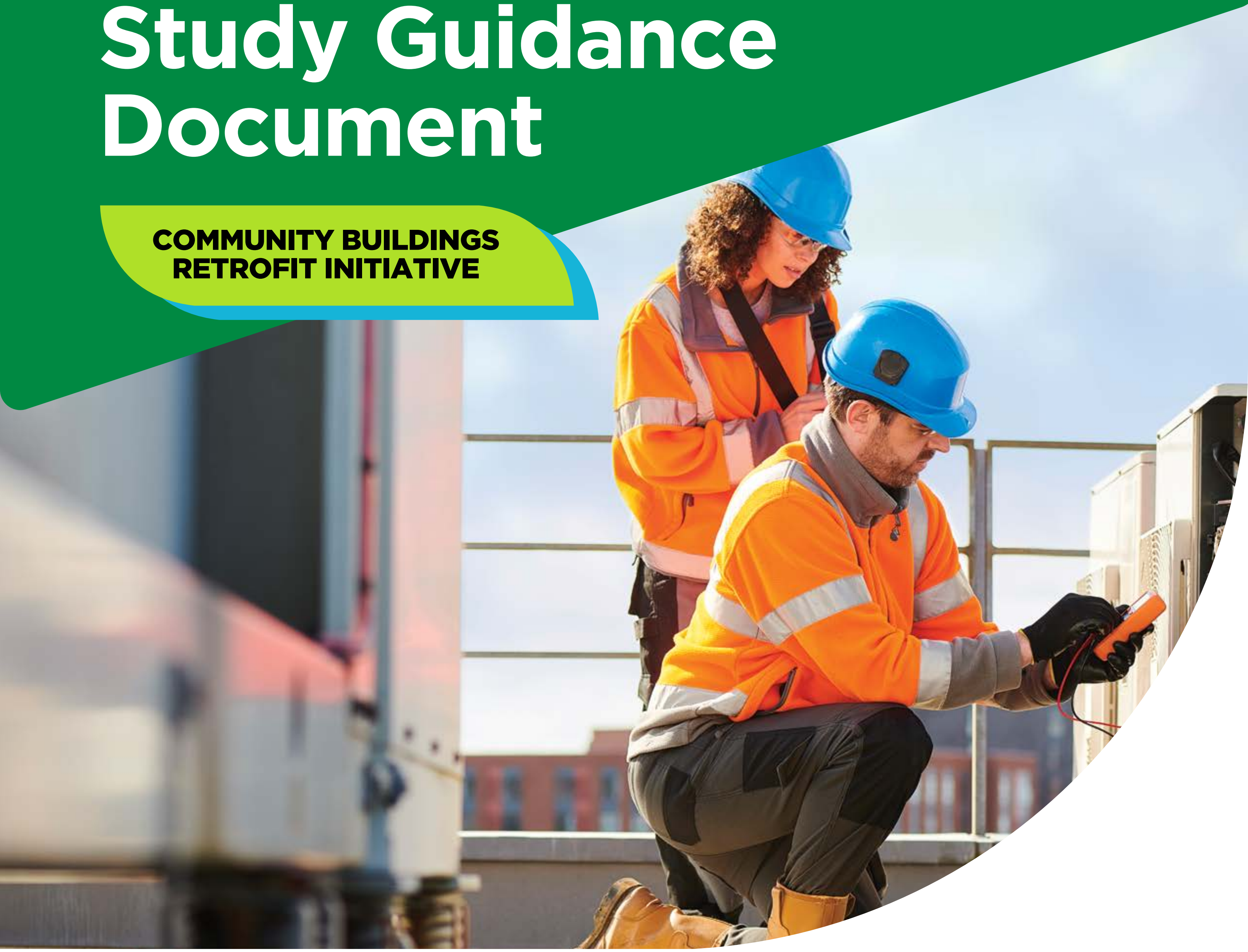
GHG Reduction Pathway Feasibility Study Guidance Document

COMMUNITY BUILDINGS RETROFIT INITIATIVE



A program of/ Un programme de la FCM

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INTRODUCTION

Program definition

The Federation of Canadian Municipalities (FCM) Community Buildings Retrofit (CBR) initiative helps to optimize the energy performance and reduce greenhouse gas (GHG) emissions of community buildings owned by municipalities and not-for-profit organizations. The CBR initiative is administered through FCM's Green Municipal Fund (GMF).

FCM's Community Buildings Retrofit initiative is a $167 million initiative that was made possible through a federal government contribution of $950 million in its 2019 budget. Applicants can stack CBR funding with funding from other programs, including programs available through provincial and territorial governments.

Grants for GHG reduction pathway feasibility studies help to integrate energy and GHG reductions into longer-term plans for managing community buildings. These studies will enable municipalities to identify a sequence of GHG reduction measures—the "GHG reduction pathway"—that will help to reduce GHG emissions for community buildings by at least 50% within 10 years and by at least 80% (i.e. near net-zero GHG emissions) within 20 years while managing capital costs and reducing operating costs. For a full list of eligibility requirements for the CBR initiative and GHG reduction pathway feasibility studies, see the application guide.

The completion of a GHG reduction pathway feasibility study through the CBR initiative, or an equivalent study, is a prerequisite for applying for a CBR GHG reduction pathway capital project. Equivalent studies must meet the minimum requirements laid out in this document but do not need to have been funded by the CBR initiative. If you have conducted a feasibility study and are uncertain if it meets the minimum requirements, you may contact FCM for guidance.

For additional information, please visit our website.

For northern municipalities, contact FCM for additional guidance.[1]

1 The North is defined as the three territories and the northern extent of seven provinces. This includes portions of the following provinces defined by Statistics Canada codes: Newfoundland and Labrador (10), Québec (24), Ontario (35), Manitoba (46), Saskatchewan (47), Alberta (48) and British Columbia (59).

About this guidance document

This document has been developed to provide guidance for the preparation of a GHG reduction pathway feasibility study ("study") for the GMF Community Buildings Retrofit (CBR) initiative.

The document is organized in two important ways:

Purpose, process, details: Part 1 summarizes the overall purpose of the study. Part 2 discusses process and delivery details and quality of work. Part 3 includes a glossary of important terms and technical references.

Requirements vs. recommendations: In parts 1 and 2, each section includes both FCM's requirements for the study and recommendations or best practices. Typically, there are fewer requirements than recommendations/best practices, and the requirements are often qualitative in nature. The recommendations or best practices go into more detail on industry norms for similar work and offer useful starting points for analysis.

Part 1:
STUDY PURPOSE AND OUTCOMES

The purpose of a GHG reduction pathway feasibility study (“study”) is to support municipal and not-for-profit decision-makers in making early, informed decisions on capital planning for their assets in alignment with their GHG reduction and other organizational goals (e.g. financial, sustainability, operational, etc.). The study will enable the project proponent[2] to explore alternative GHG reduction measures and capital investment timing to meet these goals.

Studies will consider:

a) the uniqueness of the site and current organizational and jurisdictional constraints and opportunities for the project proponent

b) a wide variety of measures of GHG reduction suitable to the site

c) the systemic nature of deep carbon retrofit projects (looking beyond isolated retrofits of single systems, considering interactions and inter-relations of building systems as a whole)

d) the life cycle cost implications considering upfront capital requirements, facility operations and equipment maintenance

e) the broader importance of the facility to critical operations for the project proponent (i.e. operational constraints for measure implementation[3])

Given the complexities of deep retrofits—especially their implementation in existing facilities in operation and with traditionally fixed capital and maintenance budgets—the study includes additional focus on operational engagement and capital planning alignment.

Required outcome of the study

The study must articulate at least one “GHG reduction pathway” selected through a comparison of at least two GHG reduction pathway scenarios. A GHG reduction pathway describes a set of GHG reduction measures (“package”) and a capital plan to reduce GHG emissions by at least 50% within 10 years and by at least 80% within 20 years compared to baseline performance.[4]

2 “Project proponent” refers to the entity that is undertaking the study (e.g. municipal or not-for-profit facility owners).

3 See the Measure-Level Study section for more details on study measures.

4 A GHG reduction pathway scenario may differ from a GHG reduction pathway by the level of detail and effort put into the capital plan.

GHG reduction pathway scenarios

The project proponent may choose the outcome of the study to be two or more GHG reduction pathways articulated for key decision-makers, or the project proponent may choose to incorporate the selection of a GHG reduction pathway for implementation into the study process. Regardless of whether the study presents one or more GHG reduction pathways, the study must include the development of at least two GHG reduction pathway scenarios as indicated below.

The study must include the following GHG reduction pathway scenario:

- A "minimum performance" scenario with the following components:
  - A 10-year plan that achieves a minimum 50% reduction in on-site GHG emissions vs. current performance
  - A 20-year plan that achieves a minimum 80% reduction in on-site GHG emissions vs. current performance

The study must also include at least one of the following GHG reduction pathway scenarios:

- A "short-term deep retrofit" scenario: This includes the same GHG reduction measures as the "minimum performance" scenario except that all measures are implemented in the first five years (possibly through inclusion of additional funding and financing options).

OR

- An "aggressive decarbonization" scenario: This delivers a similar life cycle cost result over the study period as the "minimum performance" scenario, but maximizes cumulative GHG reductions over the same period.

The study may also include additional GHG reduction pathway scenarios, such as:

- A "targeted life cycle cost per tCO_2e" scenario: This includes measures targeting a maximum life cycle cost per tonne GHG reduced.[5]
- A "maximum site potential" scenario: This targets the greatest reduction potential possible, independent of capital considerations.
- An "optimized outcome" scenario: This considers cost-per-tCO_2e targets, GHG reduction targets, and other qualitative and quantitative impacts optimized according to project proponent objectives.

In addition to GHG reduction pathway scenarios that reduce GHG emissions by at least 50% within 10 years and at least 80% within 20 years, the study team and project proponent may also consider the inclusion of a "like-for-similar" scenario for comparison purposes.[6] This is a business-as-usual (BAU) scenario based on planned or required maintenance and equipment replacement (as determined from the site assessment) in combination with traditional energy audit recommendations from previous studies of the facility.

5 Federal buildings as part of the Greening Government strategy are required to target $300/$tCO_2e$ over 40 years.

6 A "like-for-similar" scenario is unlikely to meet the required GHG reduction targets and does not count towards the minimum two GHG reduction pathway scenarios required for inclusion in the study.

Other considerations

The following are additional items to be considered as part of the study.

Alignment with funding opportunities

It is recommended that the final study document identify prospective national and regional incentives and funding programs for capital projects, including CBR GHG reduction pathway capital projects. Funding opportunities can inform capital planning for the GHG reduction pathway, and consideration should be given to any requirements or prerequisites for these incentives and programs that could be integrated into the scope of work for this study.

Future work preparation

Depending on the urgency of execution, the study could include additional activities which will allow for acceleration of the next phase of work. Examples include the preparation of a measurement and verification (M&V) plan for the recommended design, individual equipment and site testing (e.g. thermal conductivity testing), and more detailed schematic design work.

Broader sustainability and resilience analysis

It is understood that GHG reduction pathway scenarios will have other qualitative benefits (e.g. occupant comfort) or non-energy/GHG benefits (e.g. water savings) that may be important to the project proponent and other key stakeholders. Study teams are encouraged to integrate these considerations into a broader decision-making process.

The project proponent may also consider aligning the study outcomes with climate resilience planning (e.g. by applying a Climate Lens[7]). This could include examining future weather and climate impacts (e.g. rising temperatures or flood risks) and assigning qualitative or quantitative value to measures that improve resilience.

Education and collaboration

Given the highly integrated nature of decarbonization planning, many stakeholders are often involved in the study process, creating a great opportunity to educate stakeholders about the process of decarbonization in general and the unique challenges and opportunities that buildings present. Likewise, there may be the opportunity to collaborate or partner with other organizations (equipment manufacturers, NGOs, other municipalities etc.), particularly where innovative technologies or processes are being explored that are outside the normal operating expectations for the project proponent.

7 The Climate Lens is an assessment framework developed by the federal government of Canada. It is intended to assess infrastructure projects with a focus on GHG mitigation and climate change resilience.

Future change considerations

Given the long time frame considered in the study, the project proponent should consider whether there will be a need to revisit results and calculations in the future. Potential triggers that may impact the study results and motivate an update in the future include:

- new technologies or significant improvements in existing technologies
- significant changes to emission factors (especially for electricity grids) and the cost of carbon
- new/additional incentives or funding opportunities
- facility use changes or major renovations

Therefore, it is recommended that the project proponent ensure the required analysis and study components be provided in a form that can be updated as required with relative ease—for example, by requesting that service providers provide electronic versions of calibrated energy models and use energy analysis software that is not expected to be obsolete (or deprecated) in the short or medium term.

Part 2:
STUDY PROCESS AND REQUIREMENTS

Figure 1 provides an overview of the steps involved in completing the study. Part 2 provides expected deliverables and other requirements for each step, along with best practice recommendations. References to other standards or guidelines have been highlighted where appropriate and links to those references are included in Part 3.

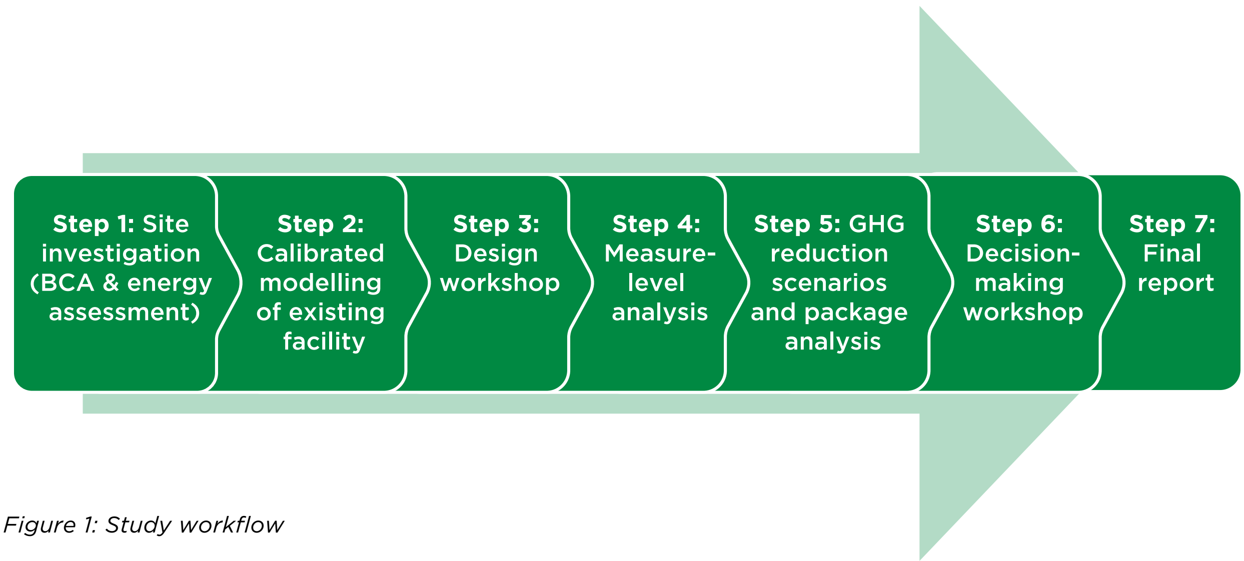

Figure 1: Study workflow

Step 1: Site investigation

To begin the study, the "study team"[8] conducts a review of all available documentation (e.g. previous studies completed, existing drawings, etc.) followed by a site walkthrough and operator interviews to gain an understanding of the existing facility and its operations.

Additional site investigation work may also be required to finalize measures and (occasionally) to collect temporary metering data that is needed in order to better understand and calibrate the energy model of the facility.

In almost all situations, the operator interview is the most important component of the site investigation, since operators have the greatest insight into the current state of repair and operating conditions of the energy-using equipment in the facility and often have significant insight into how to improve these systems and address deficiencies.

8 "Study team" refers to the service provider team engaged by the proponent to deliver the pathway study (e.g. engineers, architects, energy modellers, building scientists, cost consultants, etc.).

Minimum requirements

The study team should use the site investigation to gather data consistent with, at minimum, the requirements defined for an ASHRAE Level 2 energy audit—but with enough detail to support a robust data-driven financial analysis and accurate estimates of energy consumption, cost and savings as well as GHG emissions and emission reductions. The study team does not have to prepare a report that meets the ASHRAE requirements, and the ASHRAE 211 standard should be used as a guideline only.

The site investigation is required to have, at minimum, the following components:

- A review of available documents such as drawings, O&M records and manuals, equipment specifications/cutsheets, previous relevant audits/reports/condition assessments, etc.
- Analysis of utility bills or past energy use for a minimum of 12 months (preferably 36 months) and benchmarking performance.
- A facility site survey to review key building systems and fill in gaps in knowledge that may have been identified during the documentation review, as well as interviews with operations and/or property management staff.
- An interview or other form of engagement with operational staff, to allow for operational implications to be captured and to start a fulsome conversation with these critical team members.

The energy assessment portion of the feasibility study must be completed by a qualified professional, either P.Eng, CEM or CEA.

Best practices/recommendations

A robust site investigation will help the study team identify site-specific opportunities, constraints and barriers in relation to potential measures to be considered in the study.

If a building condition assessment (BCA) has not been conducted in the past three to five years, or the study team feels that a recent BCA does not provide adequate information to inform a 20-year capital plan for the current facility's energy systems, it is recommended that the study team conduct a BCA (or alternatively, a property condition assessment (PCA)) in accordance with ASTM E2018-15, *Standard Guide for Property Condition Assessments: Baseline Property Condition Assessment Process*.

For the energy systems investigation, it is recommended that the study team generally follow the ASHRAE Level 3 requirements; but the team is not expected to strictly comply with Level 3 reporting requirements. **Table 1** below summarizes key differences between the ASHRAE Level 2 and Level 3 requirements (refer to ASHRAE Standard 211 for full requirements). Since the project is considered capital-intensive and both detailed energy modelling and robust data-driven financial analysis are expected, the level of site investigation at a systems level will fall somewhere between a Level 2 and Level 3 audit depending on the depth of system change and the importance of a given measure to the overall decarbonization plan.

A formal Level 3 audit would include a higher degree of data collection than is required for this study, but would help to improve the overall results (since higher-quality data would need to be collected). In general, a Level 3 audit would align with this study, but may add to potential study costs.

Destructive investigation of enclosure, and occasionally HVAC systems, may be valuable where there are gaps in information that could significantly impact the results of the study, such as uncertainty surrounding the existing construction and condition of the enclosure or structure. Whether destructive investigation is warranted should be weighted carefully (e.g. it may help to identify possible measures, performance impacts and associated costs) but generally it is recommended that the study rely on existing documentation and visual review.

Table 1: ASHRAE audit requirements comparison

ASHRAE Level 2 Audit (i.e. quick wins) **Minimum requirement**	**ASHRAE Level 3 Audit (i.e. investment)** **Best practice/recommendations**
• Basic site review and operations staff interview • Utility review • Basic energy end-use breakdown • No/low-cost and/or simple measures • Basic energy and financial analysis • Identification of measures that have complex interactions or require large investment for further study (i.e. ASHRAE Level 3)	• ASHRAE Level 2 + higher quality and accuracy • Capital-intensive project focus • Detailed field analysis (e.g. sub-metering) • Detailed energy use modelling • Robust engineering data-driven financial analysis for the most accurate estimates of cost savings

Step 2: Calibrated modelling of existing facility

Following the completion of the site investigation, a calibrated energy model of the existing building should be prepared. This energy model will be used to determine measure-level and facility-level energy and GHG results and will inform analyses of life cycle costs (e.g. energy cost savings).

Minimum requirements

To ensure best results for what are likely to be more systemic (i.e. complex and interrelated) facility-level GHG reduction measure packages, the model should be calibrated in accordance with the requirements established in the current revision of ASHRAE 14 and a calibration report should be provided.

All facility energy use should be included in the model, including process loads, even when the buildings studied have significant process loads or include system types not typically handled natively by the hourly modelling tool chosen by the team. Where a process load (or any system) has not been modeled natively in the hourly analysis software, additional documentation and calculations should be provided and the results of external calculations should be combined with natively modeled results seamlessly within the report. Include any other documentation of overall results.

Accounting for significant baseline variation

Sometimes facilities are anticipated to undergo significant changes in independent operating parameters such as peak occupancy, schedule of use, temperature set-points or user-driven equipment usage. In cases where such variation is expected to be significant, the calibrated model should be adjusted to account for these factors before measure-level and facility-level analysis begins.

Where variation is considered substantial (e.g. when the facility has an entirely new functional program) then a case can be made to ignore the need for a calibrated model of the existing facility and to use the results of a model reflective of the new facility usage as the baseline. In this case, however, more work may be required in the future to understand how to properly capture the GHG savings of implemented measures. Consideration for these implications should be included in the study.

Best practices/recommendations

Total envelope performance: A best practice for modelling building enclosures—consistent with the most recent version of the National Energy Code for Buildings (NECB)—includes the holistic analysis of thermal bridging, including point and linear heat loss. This analysis can provide insight into potential existing enclosure issues, especially at system intersections (e.g. wall and window, parapet, etc.) and can more accurately reflect the benefit of best practice approaches for enclosure improvements. This work will typically require more detailed site investigation as well as the input of a façade expert. BC Hydro and the City of Toronto have published guidance and spreadsheet tools to support the work and quantify whole facility and system-specific heat loss. Links to these and other resources are included in Part 3.

Electricity demand impact modelling: It is recommended that, in cases where fuel-switching to electricity (e.g. air-source heat pumps) is expected to be a critical component of the final decarbonization solution, enough detail be included in the analysis to reflect the impact on site electricity demand. Such demand modelling requires an accurate understanding of: (i) building schedules of use, and (ii) the combined part-load and temperature-sensitive performance curves for major equipment. This additional information can take more time to collect during site investigation and measure analysis, but can yield important (critical) insights where there are project feasibility concerns related to electrical service.

Embodied impact analysis: Embodied emissions are those generated at points in the building's life cycle other than during operation, such as from the material supply chain (i.e. raw material extraction, materials processing, transportation or manufacturing), from construction, and during building end of life (i.e. demolition and disposal). Careful selection of different material/ products for potential upgrades may help to significantly reduce life cycle emissions, or even offer carbon storing opportunities (e.g. bio-based enclosure materials have a carbon storage benefit). The Canada Green Building Council's *Zero Carbon Building Performance Standard* has requirements for embodied carbon (including reporting and offset requirements) including an embodied carbon reporting template.

Future weather: Accounting for changes in weather caused by climate change is considered a best practice for long-term studies. Typically, study teams can rely on local conservation authorities and other provincial government sources of climate projections for estimates of weather changes over 25- and 50-year time horizons.[9] Note that, while future weather impacts should be considered, the typical best practice is to treat the impacts to equipment size in a purely pessimistic manner (e.g. ignoring potential benefits to heating equipment sizing while including increased cooling equipment requirements).

Step 3: Design workshop

The purpose of the design workshop is to confirm the overall direction of the study, identify key study team members and identify and screen measures for further analysis, given the information generated in the site investigation and baseline calibrated modelling steps. Discussion should address site-specific opportunities, constraints and barriers to implementation of potential measures, and alignment of measures with the facility and broader goals of the project proponent.

Minimum requirements

Conduct and document a workshop with the study team and key project stakeholders.

Best practices/recommendations

Important steps in the design workshop include:

- Confirmation of the project proponent's goals for the building, including GHG reduction, sustainability, operational, financial etc. and specific goals for the study (e.g. how the study will be used to inform council decision-making).
- Discussion of available funding, financing and financial and capital planning constraints.
- Discussion of scheduling, key milestones, potential conflicts/ concerns, etc.

9 For more information on future weather trends, see the Climate Atlas of Canada website and the Government of Canada website.

- Review of the study process, including roles and responsibilities for the study team and project proponent representatives (i.e. key stakeholders and decision-makers, such as asset managers or capital planners, operations and maintenance staff, and energy management staff).
- Basic facility decarbonization education, including an explanation of how GHG emissions are calculated and why results are expected to vary over time as a function of various regulatory factors and grid emission factors.
- Review of the building maintenance and equipment replacement requirements uncovered during the site investigation and a discussion of the existing capital plan for the building and/or planned maintenance, repairs, replacements and upgrades.
- Brainstorming, describing and qualitatively screening GHG reduction measures for further analysis.
- Identification of non-energy or qualitative benefits (e.g. thermal comfort improvements, future-proofing, showcase/educational opportunities, etc.) that should support decision making.
- Promotion of preferred measures and ruling out of undesired measures from consideration based on feasibility and compatibility with the site and client needs.

Though it can be useful for some measure-level analysis to be completed prior to the first study workshop, this is not required.

Step 4: Measure-level analysis

The study team will need to determine the GHG reduction potential and capital cost of each measure identified during the design workshop (or otherwise required to be studied) using appropriate energy analysis techniques and quantity surveying procedures. Refer to Part 3, which provides a list of potential information sources.

Other non-energy or qualitative benefits identified in the workshop should also be documented for each measure and used to support decision-making.

Minimum requirements

At a minimum, the following measures must be analyzed:

- Full facility fuel switch from fossil fuels (including process loads)
- Renewable electricity generation (e.g. photovoltaic panels[10])

10 For renewable energy systems where excess energy is generated relative to energy used (on an hourly basis) and exported to the grid, the avoided emissions may be calculated using a marginal electricity grid emission factor instead of an average grid emission factor. Refer to the Canada Green Building Council's ZCB-Design v2 Workbook for current regional marginal emission factors (link provided in Part 3). Additional information on marginal emission factors can be found in The Atmospheric Fund's *A Clearer View on Ontario's Emissions*, available here.

- For any facility components requiring replacement during the study period (identified during the site investigation or in the building condition assessment) at least one improved alternate must be studied, where feasible. For example, if windows will require replacement within the study period, at least one window improvement measure must be explored.

The description and documentation of each measure explored should discuss:

- Scope/high-level design of the measure, including major equipment included in the measure and sufficient detail to understand the systemic complexity of the measure (e.g. high-level schematics)
- Assumptions used to analyze the measure
- Annual GHG reduction potential of the measure
- Capital cost to implement the measure in year zero of the study (adjusted for inflation)[11]
- Identification of measures or systems that are interrelated or dependent on each other for successful operation
- Implementation strategy (including limitations, if any) applicable to the specific measure
- Potential commissioning, measurement and verification, and other relevant implementation considerations

The accuracy (and associated design detail prepared) of the capital costing in the measure-level analysis should generally be in the range of +/- 20–25%, resulting in a CIQS Class C level capital estimate.

Analysis techniques for measures often require additional tools beyond what is natively available in hourly analysis software programs. For example, closed-loop geo-exchange systems are not easily analyzed in the most commonly used modelling tools (e.g. eQUEST, IES, Energy Plus) often necessitating analysis in other tools (e.g. GLD or TRNSYS). Where separate software or analysis tools are determined to be required to achieve the level of accuracy desired from the study, they should be used and appropriately documented.

Best practices/recommendations

Studied measures

A list of measures that are likely to be explored as part of a robust decarbonization analysis is provided in **Table 2** next page. Note that this is **not an exhaustive list** and the study team may identify measures beyond those listed below.

11 For measures that are expected to require a construction period greater than one year, the study team may use an average yearly cost (i.e. the total cost divided by the number of years in the construction period) as opposed to an exact cost for each year of the construction period, for simplicity of determining the year zero cost.

Table 2: List of potential measures to be studied

Building system	Potential measures to be explored
User-driven loads (e.g. lighting)	LED technology—interior and exterior Daylighting and dimming control Task lighting and/or addressable lighting for occupant-customized lighting needs Energy Star® appliances and computer system equipment Enhanced server room design (e.g. hot-aisle/cold-aisle)
Envelope/ enclosure	Re-cladding or over-cladding walls (increasing effective insulation level) Roof insulation upgrades, including options involving modifications to roof/wall intersections (e.g. parapets) to allow for additional insulation to be installed beyond current amounts High-performance glazing and framing systems for doors, windows and skylights, especially windows with low-emissivity coatings, triple-glazing, noble gas fills and framing systems with enhanced thermal breaks or using non-metal materials (e.g. fibreglass) Air sealing at both the interior and exterior of façades Below-grade foundation wall insulation upgrades (especially where adjacent landscape will be disturbed anyway)
HVAC—delivery	Revised building zoning—space planning, fundamental changes to the HVAC strategy Natural ventilation, operable windows, atrium/stack effect Labyrinth or earth tube to pre-condition ventilation make-up air Demand control ventilation (e.g. CO_2 sensors) Underfloor/displacement delivery of ventilation Dedicated outdoor air systems with variable-air volume Energy recovery using multiple technologies including heat/enthalpy wheels, reverse-flow systems, energy recovery chillers, waste heat from electrical vault, heat pump energy redistribution, etc. Near-temperature and low-power heating/cooling delivery approaches (e.g. chilled beams, VRF, "oversized" ECM fan-coils) Solar thermal pre-heat of ventilation systems (e.g. transpired solar collectors) and thermal system (e.g. solar hot water)

Building system	Potential measures to be explored
HVAC—plant	Multi-stage, condensing furnaces and boiler[12] Advanced air-source heat pumps (e.g. those suitable for cold climate) Geo-exchange heat pumps (e.g. closed- and open-loop, where applicable)
On-site renewable energy systems	Solar power (i.e. photovoltaic panels) in roof-mounted, parking awning and building integrated arrangements Biofuel and/or biomass boilers or combined heat and power (CHP) systems Hydrogen/fuel cell (in traditional or CHP configurations) Battery energy storage systems (BESS) to take advantage of variation in grid emissions Wind power and micro-hydro, where appropriate
Process loads[13]	Ice plant improvements (for rinks) Customized process heat recovery (for pools) Drain-water heat recovery (for large, collected domestic hot water loads) Variable-speed fans and ecology unit heat recovery units (kitchens)
Carbon storage/ sequestration	Bio-based/carbon storing insulation materials (e.g. cellulose) FSC-certified wood structural materials and finishes Large-scale carbon sequestration equipment (e.g. POND technologies)

A strong study also considers a range of alternatives within each measure (e.g. more than just one approach for low-power HVAC delivery) and increasing levels of performance for the same general measure (e.g. a dedicated outdoor air system (DOAS) with two or three approaches to heat/energy recovery, yielding increasing effectiveness).

12 Generally, given the long-term goal of an 80% GHG emissions reduction within 20 years, study teams should avoid recommending like-for-like or like-for-similar replacements for existing fossil fuel burning systems resulting in those systems being in good repair at the end of the study period. That said, condensing gas-burning equipment may still be the most cost-effective and robust option, especially where grids are not expected to aggressively decarbonize or where renewable natural gas or a similar alternative is viable in the long term.

13 See links for modelling guidance resources for ice plant and pool process loads.

Measure analysis

The best practice for measure analysis is to employ a broadly experienced study team that can inform the proper financial and energy analysis of the identified measures. The team should include experts who understand design constraints and opportunities as well as building science concerns and can offer appropriate assumptions for modelling and costing work sufficient to achieve the level of accuracy expected for the study.

Where possible, energy/GHG metrics studied at the measure level should include:

- total and percentage emissions reduction compared to baseline year[14] (tCO_2e or %)
- Greenhouse Gas Intensity (GHGI) (tCO_2e/m^2)
- Energy Use Intensity (EUI) (kWh/m^2)
- Thermal Energy Demand Intensity (TEDI) (kWh/m^2)

Financial metrics at this stage to be used as part of measure analysis should include:

- capital cost (both absolute and incremental capital cost)
- operating savings (energy/carbon savings, maintenance savings)
- simple payback and NPV (where relevant to the project proponent)
- alternative funding sources for specific measures

Computer-aided optimization and results visualization techniques (e.g. parallel coordinates plot) are often used to explore and summarize the results of many or all combinations of measures as an interim step toward making full facility-level recommendations. These techniques can be very useful to help study teams hone in on key parameters and measures required to achieve energy- and GHG-reduction targets. Such techniques, where employed, should be explained clearly to the project proponent, and there should be discussion of their value to the overall process.

Step 5: GHG reduction pathway scenarios and package analysis

In this phase, the design team will assemble measures into packages for each GHG reduction pathway scenario and conduct a technical and financial analysis to determine the effectiveness of each package. The analysis should include an incremental capital and life cycle costs comparison for alternative packages to the "minimum performance" GHG reduction pathway scenario (see Part 1).

Minimum requirements

At a minimum, the scenario and package analysis documentation should include:

- The full list of the measures that make up the scenario(s) and the reasoning for including them in the

14 Baseline year is defined as at least 12 consecutive months of data. It is recommended to use the most recent 12 months for comparison purposes.

package. Include descriptions of measures or systems that are interrelated or dependent on each other for successful operation.

- A comparison and discussion of critical GHG reduction and financial metrics (as discussed below).
- A summary of the non-energy or qualitative benefits of the package, building on the measure-level analysis (e.g. SWOT analysis).
- Results from an analysis of the sensitivity of the scenarios(s) explored to the following factors:
    - **Price of carbon:** The study team should clearly state and justify future carbon pricing assumptions used in the sensitivity analysis. The current information on the projected price of carbon is different in each province. See Part 3 for useful references for the anticipated price of carbon at least up to 2030.
    - **Projected grid emission factors:** The sensitivity analysis to grid emission factors should look at the target years and assess the impact of grid emissions on achieving the targets.

Given the long time frame of the study, changes in the provincial electricity grids may have a material impact on prospective emission reductions. It is expected that the study team use projected grid emission factors (at least at a provincial/territory/regional level).

The study team should clearly document and provide assumptions for the basis of the projected grid emission factors. See Part 3 for potential sources of information on projected grid emission factors.

In analyzing the performance of different packages that achieve the 50% and 80% GHG reduction thresholds outlined above, the study team is required to document the following energy and GHG metrics using an energy model:

- Total and percentage reduction in operational GHG emissions[15] vs. baseline year[16] (including from on-site energy generation)
- Greenhouse Gas Intensity (GHGI) (tCO_2e/m^2)

The study team is required to document the following financial metrics for each package:

- An absolute and incremental capital cost comparison of the “minimum performance” package with any other recommended packages over a straight 20-year capital planning horizon (all $ adjusted back to study baseline year)
- Operating costs (including maintenance, energy and carbon costs)
- Incremental life cycle cost (ILCC) vs. “minimum performance” package ($) over at least 20 years
- Cost per tonne of carbon abated over the study period ($\$ILCC/tCO_2e$)

15 Emission factors should be appropriately referenced (including any assumptions relating to grid emission projections).

16 This should be the same baseline year used in the measure-level analysis.

Life cycle cost analysis process

The purpose of life cycle cost analysis is to determine the cost-effectiveness of the packages presented in the study. As such, the following should be completed when conducting an LCCA for each option:

- The analysis should start at the anticipated year of completion of the first major project and extend at least 20 years beyond that point.
- Life cycle costing should consider:
    - capital costs—including hard and soft costs (i.e. design, engineering and construction costs)
    - operation and maintenance costs (including anticipated repairs and replacement of equipment)
    - anticipated cost of energy and carbon
    - available external funding (incentives, grants, etc.)[17]
    - residual value at last year of study period using (at least) a straight-line depreciation
    - time value of money assumptions (e.g. interest, inflation, discount rate) reviewed and approved for the purpose of the study by the project proponent
- The sources and calculation rationale for energy conversions, utility rates, LCCA rates and carbon pricing assumptions should be clearly documented and should be aligned with industry best practices. Further guidance is included in Part 3.

Best practices/recommendations

The following is a list of additional energy/GHG metrics that can be used to inform decision-making:

- Thermal Energy Demand Intensity (TEDI) (kWh/m^2)
- Energy Use Intensity (EUI) (kWh/m^2)
- on-site annual zero carbon balance
- change in peak electricity demand for the facility (kW-peak, summer and winter)
- embodied carbon impacts of deep retrofit activities (tCO_2e)
- upstream GHG impacts of fossil fuel usage (tCO_2e)

Additionally, the project proponent may benefit from sensitivity analyses of package performance in relation to other factors such as:

- capital cost
- cost of energy
- construction/utility escalation rates
- variation in time-value of money assumptions (e.g. inflation, discount rate)
- 20-year global warming potential (GWP) emission factors

Multi-parameter financial sensitivity methods, such as a Monte Carlo analysis, can be a suitable means of testing the sensitivity of measure packages to variations in financial parameters. The study team should fully explain the conclusions and benefits of such an analysis to the project proponent.

17 This should be for confirmed external funding if deemed necessary by the project proponent to be shown separately. Prospective funding should be incorporated as a sensitivity analysis (if desired).

Though unlikely, if there are no recommendable options that achieve an 80% reduction within the study period, an additional narrative can be included in the study report explaining why and outlining the key factors preventing achievement of the minimum target.

Step 6: Decision-making workshop

The purpose of the decision-making workshop is to review the measure- and facility-level analysis results and reach a consensus on the GHG reduction pathways to be included in the final report. Once the GHG reduction pathway, or pathways, is/are agreed upon, the participants in the workshop can discuss how the package(s) would be rolled out in the short, medium and long term to balance capital considerations with goals for GHG reduction and long-term financial performance.

Minimum requirements

- Conduct and document a workshop with the study team and key project stakeholders addressing the intent outlined above.

Best practices/recommendations

Important steps in the workshop include:

- Present GHG and financial analyses for each scenario package along with preliminary options and analyses for bundling measures within each package.
- Review non-energy and qualitative benefits of each scenario.
- Ensure agreement with the project proponent and study team on key assumptions and decision-making metrics.
- Reach consensus on the analysis and agree on the GHG reduction pathways to be fully articulated in the final report.
- Review potential roll-out scenarios for the package(s) associated with the selected GHG reduction pathway scenarios and discuss feasibility issues and financial constraints that impact timelines for GHG reduction measure implementation.

Step 7: Final report

The output of this study should be in the form of a final report. The report should outline the GHG reduction pathway scenarios that allow the facility to achieve the necessary reduction targets within the required time frame. It should also discuss how alternative measures and facility-level options were explored and discussed with the broader stakeholders as part of the process that led to the identification of the preferred pathway(s).

Minimum requirements

At a minimum, the study team should prepare a decarbonized capital plan and comparison matrix made up of a table of cash flows and capital investments and aligned with the study period (e.g. 20-year, 40-year, etc.) and granularity (e.g. annual, 5-year, 10-year) desired by the project proponent for each GHG reduction pathway.

As well, the study team should prepare a final summary of each of the study steps above, including design, energy modelling, capital planning and costing results. The report should be organized in a logical manner that addresses each of the requirements listed within the anticipated workflow presented in this document. The final report should include all assumptions and limitations associated with each stage of work and contain an appendix with the following information:

- site assessment reports—building condition assessment and energy systems investigation
- model calibration summary report
- measure descriptions, including any basis of design information (quantity take-offs, equipment selection information, system diagrams, etc.)
- energy, GHG and cost analyses at the measure and facility scale not suitable for inclusion in the main report body
- capital cost estimate—cost consultant report
- other reference material

Best practices/recommendations:

Part 3 of this guide includes an example table of contents (outline) for a final summary report.

The project proponent should consider using the report as a deliverable for other potential funding streams (i.e. the final report should align with other incentive, grant or other funding programs, such that the project proponent can directly use the study to meet the requirements of those programs).

A final presentation of the results to the broader stakeholders is recommended to bring closure to the process and transition to the next phase of work (e.g. funding/financing applications, schematic design, etc.).

Part 3:
DEFINITIONS AND REFERENCES

Table 3: Key terms and definitions

Key Term	Definition	Link/reference
Cumulative GHG reductions	Also known as accumulated emissions, this is the sum of GHG emissions over a particular time period. Cumulative emissions are an important concept, as two reduction scenarios with the same reduction (e.g. an 80% reduction within 20 years) can have different cumulative emissions depending on the implementation time frame for specific measures.	–
ASHRAE 211	The *Standard for Commercial Building Energy Audits* addresses Standard 211, which establishes consistent practices for conducting and reporting energy audits for commercial buildings.	Standard 211-2018, available here.
ASTM E2018—15	The *Standard Guide for Property Condition Assessments: Baseline Property Condition Assessment Process*, is intended for use on a voluntary basis by parties who desire to obtain a baseline property condition assessment of commercial real estate.	ASTM E2018—15, available here.
ASHRAE 14	Establishes energy model calibration requirements	Guideline 14-2014—Measurement of Energy, Demand, and Water Savings.
NECB	National Energy Code for Buildings	National Energy Code of Canada for Buildings 2017 The energy code in your province or territory (nrcan.gc.ca)

Key Term	Definition	Link/reference
BC Hydro	BC Hydro: Building envelope thermal bridging	Commercial new construction (bchydro.com)
City of Toronto	TGS Energy Modelling Guidelines	Energy Modelling Guidelines Version 3—City of Toronto
Ice plant improvements	Facilities with ice plants must consider this critical process load. To ensure accurate results, the ice plant and associate improvements should be modelled. The references to the right provide guidance on modelling and ice plants.	ASHRAE Journal, "Improving Efficiency In Ice Hockey Arenas" The International Building Performance Simulation Association (IBPSA) case study on modelling a community centre, including a pool and ice rink, covers all major loads to consider.
Customized process heat recovery	Like ice plants, swimming pools must also be considered when modelling process loads. The reference to the right provides guidance on modelling pools.	Modelling indoor swimming pools
Greenhouse Gas Intensity (GHGI)	The total greenhouse gas emissions associated with energy use on the building site. It is reported in kilograms of CO_2-equivalent per square metre ($kgCO_2e/m^2$) and includes onsite emissions sources as well as those associated with provincial electricity generation.	Defined as per the Canada Green Building Council's *Making the Case for Building to Zero Carbon*
Energy use intensity (EUI)	The sum of all site energy (not source energy) consumed on site (e.g. electricity, natural gas, district heat) including all process loads, divided by the floor area of the building.	Defined as per the Canada Green Building Council's *Zero Carbon Building Performance Standard*
Thermal energy demand intensity (TEDI)	The annual heat loss from a building's envelope and ventilation after accounting for all passive heat gains and losses, per unit of modelled floor area.	Defined as per the Canada Green Building Council's *Zero Carbon Building Performance Standard*

Key Term	Definition	Link/reference
Absolute capital cost	The baseline cost plus the incremental cost of achieving the energy benefit of the measure or package. The baseline cost should be informed by the building condition assessment (BCA).	–
Incremental capital cost	The increase or decrease in the cost of construction, relative to the baseline costs outline by the facility BCA.	–
Operational carbon	The emissions associated with the energy used to operate the building.	Defined as per the Canada Green Building Council's *Zero Carbon Building Performance Standard*
Incremental Life cycle cost (ILCC)	The net present value (NPV) of the increase or decrease in total costs per square metre for construction, operation and maintenance over the study period, relative to the "minimum performance" package (or other reference package).	Definition adapted from the Canada Green Building Council's *Making the Case for Building to Zero Carbon*
Cost per tonne of carbon abated ($ILCC/tCO2e)	The net present value (NPV) of the increase or decrease in total costs per tonne of CO_2-equivalent saved, relative to the "minimum performance" package.	Definition adapted from the Canada Green Building Council's *Making the Case for Building to Zero Carbon*
Residual value	The residual value of a system (or component) is its remaining value at the end of the study period, or at the time it is replaced during the study period.	For more information on residual value, see this resource.
On-site annual zero carbon balance	The net emissions of the sum of embodied carbon, operational carbon and avoided emissions.	Defined as per the Canada Green Building Council's *Zero Carbon Building Performance Standard*

Key Term	Definition	Link/reference
Embodied carbon	Carbon emissions associated with materials and construction processes throughout the whole life cycle of a building. These are additional to operational carbon emissions.	Defined as per the Canada Green Building Council's *Zero Carbon Building Performance Standard*
Upstream GHG impacts	An additional consideration can be made for natural gas consumption in relation to methane leakage from the extraction, processing and distribution of natural gas. Methane, while short-lived, has a higher global warming potential than carbon dioxide. Therefore, the potential impact to upstream GHG emissions could be an important consideration for a holistic analysis (i.e. a consideration when calculating life cycle emissions).	A recent study further outlined potential life cycle emission factors that include consideration for life cycle electricity grid emission factors and upstream natural gas emissions: "Lifecycle greenhouse gas emissions from electricity in the province of Ontario at different temporal resolutions," L. Pereira and D. Posen, *Journal of Cleaner Production*, October 2020.

Table 4: Factors and assumptions

Energy and GHG factors	Possible sources/guidelines
Energy conversion factors	Canada Energy Regulator conversion tables The Canada Energy Regulator provides a comprehensive list of conversion factors.
GHG emission factors	The Canada Green Building Council's Zero Carbon Building Workbook (ZCB-Design v2 Workbook) is available here. The Canada Green Building Council has released an Excel workbook that summarizes current emission factors for provincial grids (including average and marginal factors) as well as common fossil fuels. The calculator primarily draws factors from two sources: Canada's National Inventory Report (2018), available here. *Energy Star Portfolio Manager Technical Reference: Greenhouse Gas Emissions*, available here.

Energy and GHG factors	Possible sources/guidelines
Future grid emissions	Canada Energy Regulator, *Canada's Energy Future 2016: Energy Supply and Demand Projections to 2040*, data appendices, available here. The Canada Energy Regulator annually publishes projections for future grid mix nationally and by provincial/territory year over year.
Marginal emission factors	The Canada Green Building Council's Zero Carbon Building Workbook (ZCB-Design v2 Workbook) is available here. The workbook summarizes current emission factors for provincial grids (including average and marginal factors) as well as common fossil fuels.
Time value of carbon	The Time Value of Carbon: Smart Strategies to Accelerate Emission Reductions Produced by CPA (Chartered Professional Accountants) Canada, this publication examines how to accelerate GHG reductions by addressing near-term climate forcers (NTCFs), the short-lived GHGs that significantly contribute to climate change.

Table 5: Utility and carbon pricing

Utility and carbon pricing	Possible sources/guidelines
Electricity—consumption	Utility provider or energy authority
Electricity—demand	If provided as separate rate schedule
Natural gas	Utility provider or energy authority
Water	Utility provider or energy authority
Propane	Utility provider or energy authority
Diesel	Utility provider or energy authority
Carbon shadow pricing	It is recommended that studies align with Canada's "greening government" carbon shadow pricing, available here.

Utility and carbon pricing	Possible sources/guidelines
Carbon pricing (to 2030)	Studies should factor in the federal government's anticipated increase to the carbon price of $15 per tonne starting in 2023, rising to $170 per tonne by 2030. The details are available here.
Carbon pricing (after 2030)	Currently, the federal government has not provided guidance on potential carbon tax escalation after 2030. The project proponent should make reasonable assumptions as to any carbon pricing after 2030 and clearly document any assumptions. It is required to conduct a carbon pricing sensitivity analysis, so different scenarios for carbon pricing after 2030 should be considered. Examples of different carbon pricing schemes that could be considered: • Flat carbon pricing after 2030 (i.e. no increases) • Continued $15/tonne increases every year to the end of the study period

Table 6: Life cycle costing and resources

Life cycle costing	Possible sources/guidelines
LCCA methodology	*2019 ASHRAE Handbook—HVAC Applications*, Chapter 38, available here. National Institute of Standards and Technology, NIST Handbook 135, *Life Cycle Costing Manual for the Federal Energy Management Program*, 2020 edition, available here. Whole Building Design Guide "Life-Cycle Cost Analysis (LCCA)", available here.
Escalation rate—capital	Consistent with project proponent's portfolio rates for capital projects or federal government life cycle cost analyses (BGIS Scope of Work for Carbon Neutral Study Services—Life Cycle Costing Analysis)
Escalation rate—utilities	Consistent with project proponent's portfolio rates for capital projects or federal government life cycle cost analyses (BGIS Scope of Work for Carbon Neutral Study Services—Life Cycle Costing Analysis)

Life cycle costing	Possible sources/guidelines
Inflation/price escalation	Consistent with project proponent's portfolio rates for capital projects or the the Canadian Consumer Price Index, available here.
Discount rate	Consistent with project proponent's portfolio rates for capital projects or federal government life cycle cost analyses. It is expected that GHG reduction pathways in applications for CBR GHG reduction pathway capital projects will use a discount rate of their preference—but this discount rate should be no greater than 5% (5% is aligned with the federal government's discount rate outlined in its Greening Government Strategy: Real Property Guidance document). Proponents wishing to use a discount rate higher than 5% should contact FCM. Treasury Board of Canada Secretariat's (TBS's) *Canadian Cost-Benefit Analysis Guide* also provides a discount rate for the opportunity cost of capital for the federal government. Additional information on the TBS *Canadian Cost-Benefit Analysis Guide*, available here.

Table 7: Cost estimates and resources

Cost estimates	Possible sources/guidelines
Capital estimates	*Elemental Cost Analysis, Format, Method of Measurement, Pricing: Measurement of Buildings by Area and Volume*, available here.
Maintenance	Supplied by operator "Maintenance Costs," *2019 ASHRAE Handbook—HVAC Applications*, Chapter 38, available here. Building Owners and Managers Association International, *Preventative Maintenance Guidebook: Best Practices to Maintain Efficient and Sustainable Buildings*, available here.
Residual	Straight line depreciation Canada Revenue Agency, Depreciable Properties and Their Rates, available here.

Sample report outline

A sample report outline has been presented below (adapted from ASHRAE Standard 211-2018):

Executive summary

a) Overall assessment of energy benchmarking and performance

b) Aggregated savings and costs of recommended measures

c) Table of recommended measures and options, with savings and costs

d) Life cycle cost analysis (LCCA)

Introduction

a) Study scope

Facility description

a) Building information

b) Building envelope

c) HVAC

d) SHW/DHW

e) Lighting

f) Process and plug loads

Historical utility data

a) Data summary

b) Utility rate structures

c) Benchmarking

d) Target and savings estimate

e) End-use breakdown

Measures and options analysis

a) Energy modelling approach

b) Measure interactions

c) Measurement and analysis

d) LCCA

e) Schematic diagrams (as applicable)

f) Workshop summary

g) Measures considered but not recommended

GHG reduction pathway capital plan

a) GHG reduction pathway(s) summary and capital plan(s)

b) Comparison matrix

Appendices

Appendix A:
EXAMPLE GHG REDUCTION PATHWAY SCENARIOS

Figure 2 shows essential quantitative features of the "minimum performance", "aggressive decarbonization" and "like-for-similar" GHG reduction pathway scenarios for a community building in Ontario.

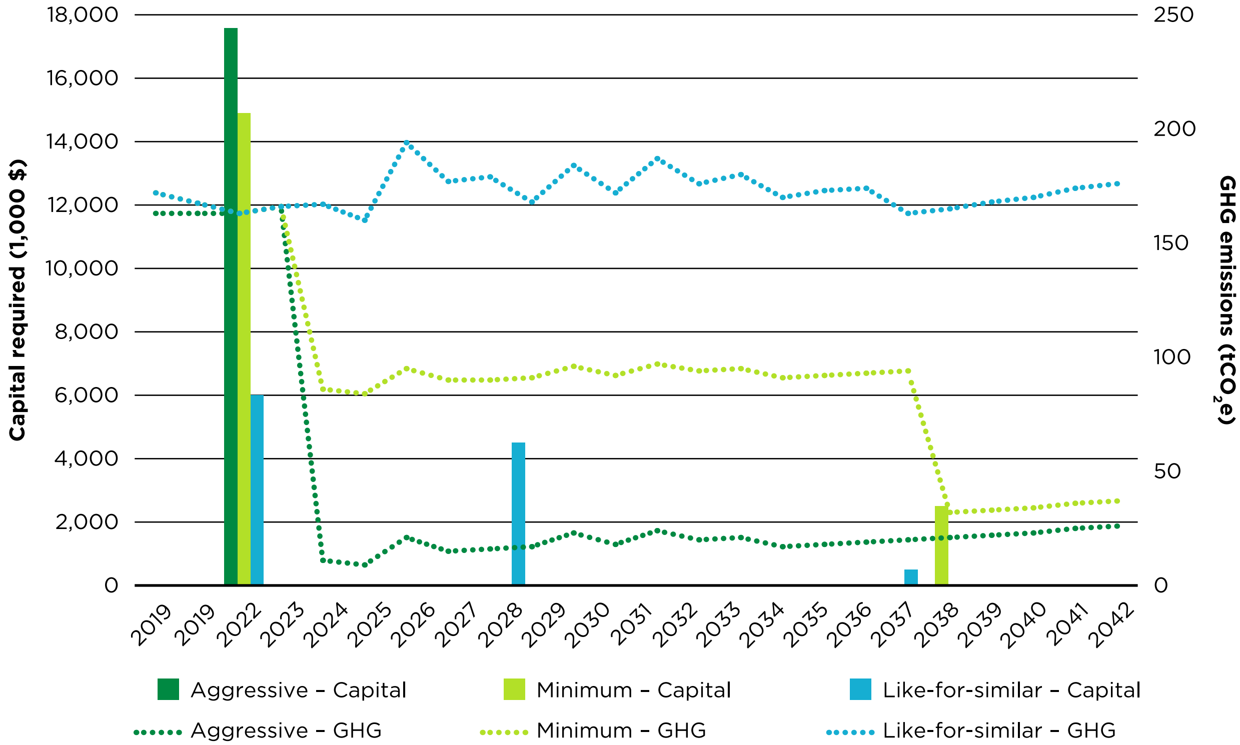

Figure 2: Example capital investment and annual GHG emissions—minimum performance compared to like-for-similar over 20 year period

In this example, the GHG emissions for the baseline year are calculated as an average of the building's GHG emissions in 2018 and 2019. The "like-for-similar" scenario is based on three pre-planned capital projects to address critical maintenance and to replace the HVAC system at end of life. GHG emissions in the "like-for-similar" scenario are not expected to decrease, due to current projections that the grid emission factor in Ontario will increase. The sensitivity of the GHG reductions to the grid emission factor projection is explored as part of the study (but not shown here).

In the "minimum performance" scenario, the first large project includes work originally planned for 2028 in the "like-for-similar" scenario to minimize disruption and facility downtime while ensuring that load reduction efforts are not done after HVAC upgrades (thus keeping overall capital costs down).

The situation could also have been reversed—where the optimal and least disruptive roll-out of the "minimum performance" scenario was to split the work between 2022 and 2028 in a similar manner to the "like-for-similar" scenario. The remainder of the "minimum performance plan" work is completed in 2038 (when rooftop units will be fuel-switched to air-source heat pumps).

In the "aggressive decarbonization" scenario, all work is completed in a single project.