TORONTO 2030 DISTRICT

NET-ZERO BUILDINGS PATHWAYS PROJECT AND TOOL

TORONTO 2030 DISTRICT

A Guide for Decision-Makers and Building Owners on How to Use the Net-Zero Buildings Pathways Tool

May 2024

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BACKGROUND

» *The Toronto 2030 District*

The Toronto 2030 District is part of a North American network of building districts and cities, the goal of which is to catalyze transformation in the built environment and the role it plays in mitigating and adapting to climate change.

It is a public–private partnership that is committed to achieving a low-carbon future. Its members include property owners and managers, tenants, utility companies, government, service providers, and civil society actors.

Toronto 2030 District's vision is that:

> Toronto will have net-zero greenhouse gas emissions and be a healthy place for all to thrive. Vibrant cultural, entertainment, business, and residential communities will be underpinned by a sophisticated clean infrastructure for essential resources and services. The energy network will be clean, resilient, and create minimal waste.

» *About Toronto 2030 District's Pathways Project and Net-Zero Buildings Pathways Tool*

Between 2022 and 2023, the Toronto 2030 District's Pathways Project produced a five-part series of reports. Taken together, the reports explore credible pathways to achieving net-zero operational greenhouse gas emissions (GHG) for the built environment in the Toronto core by 2050.

The project's goal is to lay the foundation for practical implementation of its recommendations through pilot programs, experiments, new incentives and programs, and proposals for regulatory reform.

Each report represents a distinct phase of the project:

- **Phase one** was a high-level overview of the Toronto District and the boundaries of our test bed, with a focus on the current state of its buildings, energy systems, sources of GHG, and the challenges of moving to a net-zero GHG-emissions future.
- **Phase two** examined the cost and viability for District building owners of transitioning existing combustion systems to emissions-free energy via six options: electric ground-source heat pumps, electric air-source heat pumps (ASHPs), hybrid systems (natural gas and electric heat pumps), electric boilers, and blue or green hydrogen boilers and furnaces.
- **Phase three** looked at whether heating-load–related building retrofits can help reduce the cost of fuel switching and contribute to the pathway to net zero.
- **Phase four** examined three additional solutions to assess their potential contributions to reaching net zero: building-mounted solar panels, behind-the-meter storage systems, and expanded district heating.
- **Phase five** consolidated the project's findings, presenting the results and conclusions of the first four reports.
- **Phase six** is the public release of the Toronto 2030 District's Net-Zero Buildings Pathways Tool and methodology.

The overall analysis found that the most urgent action required to achieve the 2030 and 2050 carbon emissions targets is to focus on switching from fossil fuels to non-emitting energy for building heating—notably with highly efficient electrification or alternatives, where necessary.

OVERVIEW: WHAT IS THE NET-ZERO BUILDINGS PATHWAYS TOOL?

The Net-Zero Buildings Pathways Tool summarizes a district or region's building-sector heating emissions by building type, presents pathways to net zero, and establishes cost–benefit ranges. This enables users to compare the region- or district-specific contributions, challenges, and opportunities of various building types and pathways.

It was designed to help building owners/operators in the Toronto District and other jurisdictions in Ontario more accurately estimate the cost and feasibility of decarbonizing their building systems. It has since been modified to enable users in other regions, districts, and jurisdictions to similarly evaluate net-zero building pathways.

Although users should be aware that the tool was developed specifically for the Toronto District, the intent is that it can also be used as a template in other jurisdictions that have similar environmental and regulatory conditions to Toronto (both within Ontario and outside of the province), and can be modified for other jurisdictions with different circumstances. By leveraging jurisdiction-specific data—including utility and building-stock data—other regions will be able to customize the tool for their own use.

» *Who the Tool Is For*

The tool is intended to be used primarily by organizational and regional policy-makers—including property owners/operators, municipal governments, researchers, and consultants—that are trying to establish region-wide, cost-effective decarbonization strategies across multiple building occupancies and types.

» *What the Tool Does*

The Net-Zero Buildings Pathways Tool estimates and summarizes the capital investment needed and the operating-cost impact of key building archetypes in Toronto for building owner/operators prior to implementing net-zero carbon technologies and strategies, as well as the District-wide implications.

Specifically, the tool allows users to input data and estimate the costs and benefits of adopting two key approaches to achieving net zero in their jurisdiction:

- **Fuel switching:** Transitioning from using carbon-intensive fuel sources—primarily natural gas —to electrified, low- to zero-carbon or renewable sources via the following routes:
  - ASHPs (including a hybrid option that uses renewable natural gas [RNG] as a backup during colder months);
  - Ground-source heat pumps;
  - Electric-resistance heating; and
  - Blue/green hydrogen (note: because blue/green hydrogen's commercial viability in a building retrofit context is currently unproven, it is included in the tool as a "thought exercise" in the event that it does become viable at some future date).
- **Efficiency upgrades:** Converting building envelopes and heating/cooling systems to more high-performing systems, increasing thermal performance, or reducing demand and reliance on heating systems through:
  - Wall-insulation upgrades
  - Window-insulation upgrades
  - Roof-insulation upgrades
  - Energy-recovery ventilation

» *Why Use the Tool*

Users of the Net-Zero Buildings Pathways Tool will find that it is a key part of their jurisdiction's efforts to reach 2030 and 2050 climate goals, as it allows users to accurately outline the cost-effectiveness of varying decarbonization strategies through:

- Recognizing that different strategies and technologies may be needed to implement change for different kinds of buildings (through considering the differences between, and opportunities and challenges of, various building occupancies and sub-categories);
- Applying assumptions relevant to the user's situation; and
- Developing order-of-magnitude budget guidance across their portfolio or jurisdiction.

HOW TO USE THE TOOL

» *Tool Structure*

The Net-Zero Buildings Pathways Tool is an easy-to-use, colour-coded workbook into which data inputs for a jurisdiction can be entered and analyzed.

The Excel workbook is organized as follows:

1. Input cells are shaded green, output/informational cells are shaded white, and flagged values are shaded yellow:

	Meaning	Colour
Colour Legend for Cells	User-Changeable	
	Non-Changeable:	Calculation Outputs / Information
	Flagged Values:	Includes user notes with explanations as to why the values are flagged

6	**OFFICE**			
7	Class 'A' - gas boiler	12	12	0%
8	Class 'A' - district heating/ cooling	24		
9	Class 'A' - electric	24		
10	Class 'B' & 'C' - rooftop units	16	12	0%
11	Class 'B' & 'C' - electric	27	-	50%

User Note:
District energy conversion is not evaluated by this tool. See methodology. Values assumed for this

2. User notes help users navigate the tool, as they describe the requirements for select inputs:

Construction Cost Item	Units	Percent on Construction	Multiplier
General Conditions (GC)	% of capital expenses	10%	0.10
Contingency Costs (CC)	%	20%	0.20
Project Management (PM)	%	15%	0.15
Tax	% of capital expenses	13%	1.13
		Total Multiplier	1.64

User Note:
Contingency costs should be inclusive of construction, design/scope, and any other relevant contingencies

3. Tabs are organized using groupings and specific colours:

Net-Zero Building Pathways Tool Tabs

TAB GROUPING	TABS	CONTENT
General Tabs	[Intro]	High-level instruction, background, and navigation for the tool
	[Global Inputs]	Input assumption applied to multiple tabs within the tool
	[Building Typology]	Inputs and outputs on building types, baseline energy consumption, and system sizing
	[System Descriptions]	Descriptions of the default inputs used for the tool's electrical, mechanical, and building-envelope calculations
System Retrofit Tabs (Fuel Switching)	[FS – Unitary Capital]	Input tab for unitary capital replacement costs and fixed electrical and equipment capital costs of each fuel-switching option
	[FS – Capital Output]	Output tab for the calculated capital replacement costs of each fuel-switching option
	[FS – Operational]	Input tab for the annual utility cost of each fuel-switching option
	[FS – Business Case]	Output tab calculating the total retrofit cost and comparing each option to the base case
	[FS – Graphical Analyses]	Provides graphical representations of fuel-switching data
Envelope Replacement Tabs (Efficiency)	[Efficiency]	Inputs and outputs on building form, massing, current envelope measures, "business-as-usual" envelope-replacement measures, and deep energy retrofit (DER) replacement measures

4. Rows are grouped into five major occupancy types and then into sub-building types:

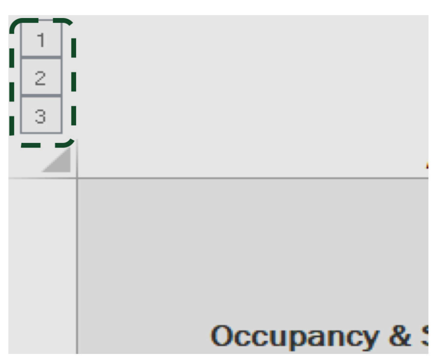
MAJOR OCCUPANCY TYPES	OFFICE	RETAIL AND HOSPITALITY	MULTI-UNIT RESIDENTIAL	RESIDENTIAL	INSTITUTIONAL
Sub-Building Types	Class "A": gas boiler	Restaurant	Pre-2004 apartment: gas boiler	Typical house	High water–use hospital (inpatient)
	Class "A": district energy	High-rise hotel: gas boiler	Pre-2004 apartment: electric		Low water–use hospital (outpatient)
	Class "A": electric	High-rise hotel: electric	Post-2004 condominium		Assembly and educational
	Class "B" + "C": rooftop units	Standalone retail			
	Class "B" + "C": electric	Mall retail			

5. The calculation methodology is applied consistently to each row (i.e., each occupancy and sub-building type). Changing the inputs affects each row in the same way.

6. Default inputs are provided for most occupancies, sub-building types, and net-zero strategies. (Note that each gap in default inputs provided represents a research gap that has not yet been addressed.)

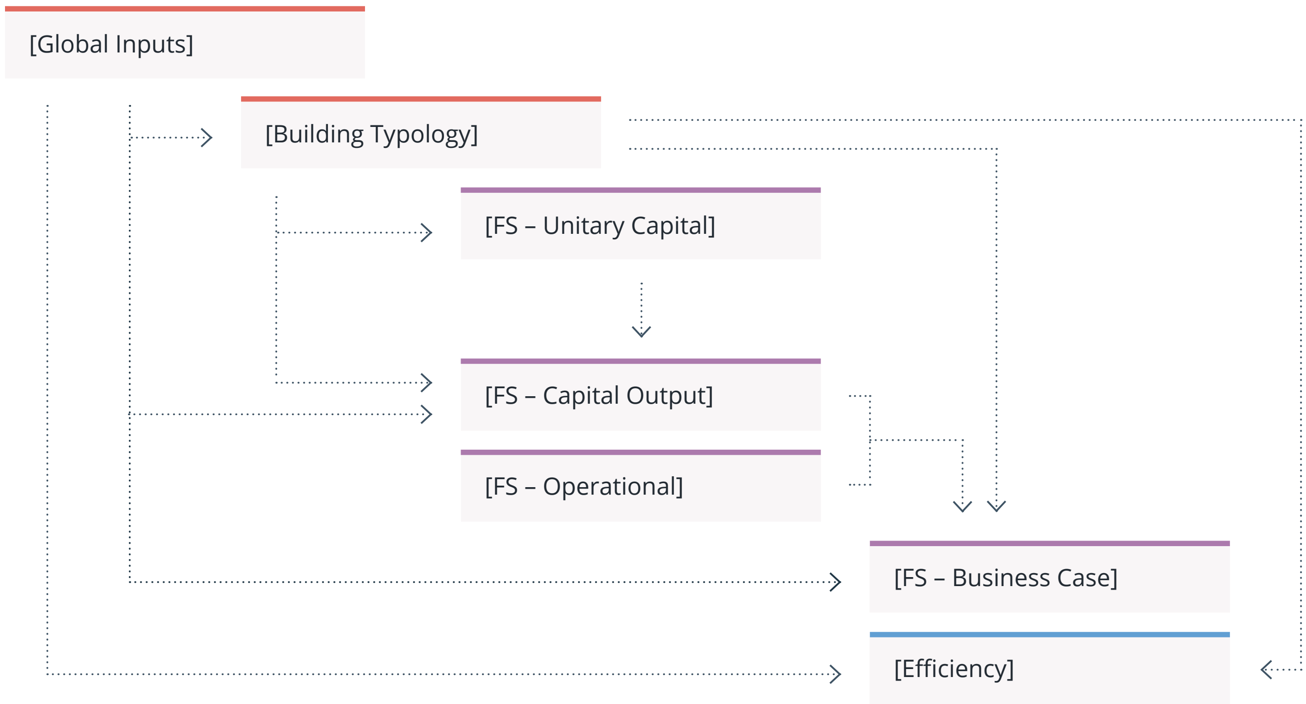
7. Columns are grouped using different levels of visibility:

- To hide all data, select [1] in the left-hand corner of the workbook tab.
- To only see user inputs, select [2] in the left-hand corner of the workbook tab.
- To see all inputs and background calculations, select [3] in the left-hand corner of the workbook tab.



» *Calculations Methodology*

The Net-Zero Buildings Pathways Tool applies the following calculation workflow, in which the order of operations is described using arrows, and tab colours reflect tab groupings (see "Tool Structure," above):



In 2019, Toronto 2030 District built the **Toronto 2030 Platform**, which is an online interactive tool that records and displays the energy, GHG emissions, and water consumption on a map of the District. The data was sourced from Toronto Hydro, Enbridge, Enwave, The City of Toronto, and the Municipal Property Assessment Corporation at the block level in order to maintain privacy.

To estimate capital costs, Toronto 2030 District developed prototype buildings that included the mechanical systems favoured by that building type. Using the energy data from our platform, we estimated energy use and equipment size by each building typology. We then used equipment suppliers or actual projects to obtain the capital costs of a plant retrofit, including equipment, installation, likely building modifications, and soft costs (such as project planning and management).

The resulting costs, when divided by the gross floor of the typology, became the per-square-foot cost for that category of building.

We then estimated amortized annual capital cost, annual fuel cost, and total cost.

ANALYSIS TOOL: PROCEDURE

The Net-Zero Building Pathways Tool provides a common framework that allows users to apply custom assumptions to test scenarios. The user's analysis process involves defining the scenario they wish to test, applying assumptions to represent that scenario, and reviewing the results.

The tool is prepopulated with default assumptions for clarity of use. (These default assumptions should be verified as applicable or replaced with user-applicable values, not relied on "as is.")

The following guidelines should be kept in mind by users:

- Users should confirm or revise [Global Inputs], including default common construction costs, utility rates, heating degree days, and amortization assumptions.
- Users should revise [Building Typology] to reflect the buildings under consideration in their district. This data includes the following information:
    - Building population in the district:
        - Building floor–area distribution within the occupancy group and the district; total gross floor area in the district
    - Buildings' physical characteristics:
        - Average building gross floor area, number of floors, number of suites
    - Baseline energy consumption:
        - Average energy use intensity, baseline primary heating source, predicted and calibrated natural gas use and energy use (calibrated when total district use is known)
    - System sizing:
        - Makeup air unit (MAU) and rooftop unit (RTU) replacement sizes and unitary plant capacity (per square foot of floor area) for space heating, space cooling, and water heating; and corresponding plant capacity for the average building
- Users should review and/or revise [System Descriptions] for insights and narrative details associated with the default inputs throughout the workbook, in both the fuel-switching and efficiency tab groupings.

Building pathways for fuel-switching:

- Data and analysis are independent from the efficiency tab.
- Users should confirm or revise the unitary costs by component in [FS – Unitary Capital] to calculate the capital replacement costs of each component and the total capital retrofit cost per average building shown in [FS – Capital Output].
- Users should confirm or revise [FS – Operational] to reflect the applicable annual utility costs per square foot of building floor area (by occupancy group and fuel-switching option). This cost is inclusive of carbon costs.
- User input data includes:
  - Determining the heating-load basis (similar to the thermal energy demand intensity for heating) by revising:
    - The percentage of heating provided by electricity and/or gas
    - The baseline heating efficiency
  - Each retrofit grouping preceding the baseline inputs calculates the fuel cost to satisfy that heating load.
    - For ASHP with RNG backup, the current analysis assumes that the RNG backup never operates and that the heat pump system is used for 100% of heating annually (an intentional simplification).
- Users should review the conclusions summarized in the following output tabs:
  - [FS – Business Case]
    - Calculates and summarizes the total retrofit capital cost, amortized capital cost, escalating carbon price, total lifecycle cost (including capital, operational, and carbon), and incremental retrofit cost versus the “like-for-like” retrofit cost for an average building.
  - [FS – Graphical Analyses]
    - Graphically represents data such as:
      - > Current energy uses (in energy per gigawatt-hour) per building typology
      - > Relative costs by typology ($ per square foot)

Building pathways for efficiency:

- Data and analysis are independent from fuel switching tabs.
- Users should confirm or revise [Efficiency] to reflect their district, including:
  - Building form and massing
    - — Floor height, number of subgrade floors, window-to-wall ratio, and percentage of the exterior party walls within occupancy groups and the district to output envelope–specific areas and perimeters.
  - Baseline building measures
    - — Thermal resistances of the walls, windows, roof, and foundation for the average associated building type to output-associated heat losses.
  - Business-as-usual (BAU) replacement measures
    - — Updating the default inputs to depict BAU thermal resistances and unitary cost per building-envelope component to output heat loss and associated savings and reduction.
  - Option 1 distributed energy resource measures
    - — Updating the desired thermal resistances and unitary replacement costs for wall-, window-, and roof-insulation upgrades, and energy-recovery ventilators (ERVs). This portion outputs the building-envelope losses and savings for the components and the change versus like-for-like, heating reductions, and the impact to plant size for an ERV.

ANALYSIS PROCESS: ACCURACY, ASSUMPTIONS, AND LIMITATIONS

The process used to analyze the data collected in the first four *Toronto 2030 District* reports—and to create this tool—is based on a number of key assumptions and limitations, including the following:

- The results are a starting point for future replication and investigation—that is, the tool uses a simplified, "top-down" approach to averages across a large, non-homogeneous building population. Actual building situations in different jurisdictions are likely to deviate significantly from this approach.
- Default inputs and assumptions are believed to be relevant to the Toronto District, as they have been informed by subject matter experts and/or based on "best guess" opinions —such as a consensus range garnered from input by cost consultants, building owners, and contractors—focusing on the District.
- The default inputs and assumptions used in the tool were developed for the Toronto District. However, as noted earlier, the tool can be used as a template in other jurisdictions that have similar environmental and regulatory conditions to Toronto (both within Ontario and outside of the province) and can be modified for jurisdictions with other circumstances. By leveraging jurisdiction-specific data—including utility and building-stock data—other regions will be able to customize the tool for their own use.
- Subject matter experts have reviewed the appropriateness of the assumptions used and the results reached in this tool. However, these have not been validated against statistically representative data sets of completed fuel-switching retrofits as very little data currently exists. This is therefore an important area for future research.
- Where assumptions are taken from a publicly accessible reference document, that document is noted at the relevant input location.
- User-specific situations are unlikely to be addressed using the default inputs alone. Subject matter experts should therefore review the data used for inputs and edits to ensure they are appropriate and applicable.

- Although blue/green hydrogen is listed as one fuel-switching option, it is not commercially viable at this time. It is therefore included in the tool as a "thought exercise" only, in the event that it does become viable at some point.
- The assumptions and results used herein attempt to reflect the cost categories we can predict will exist. Until then, however, they should be seen as having very low accuracy.
- The cost methodology used in the tool assumes that capital and operational (utility) cost savings scale linearly with system/building sizing. Accuracy could therefore be improved with additional evidence.
- System sizing is a key component of capital cost estimates. The tool estimates system size by assuming a size and an achievable size reduction (i.e., "right sizing"), and developing cost estimates based on the right-sized system replacement. Default right-sizing assumptions are applied for systems that are likely to achieve right sizing. For all other systems, the current default assumption is that no right sizing is implemented during fuel switching. This is a significant area of focus for future research as it has the potential to reduce capital costs by as much as 30–50% in a number of situations.
- [FS – Business Case] does not consider if or how fuel switching might be implemented for buildings that have district energy or electric as their baseline heating source.
  The rationale for this is as follows:
  - District heating/cooling
    - Assumes that the district supplier converts at their own capital cost with no construction within the building. This scenario likely underrepresents the cost of low-carbon district service (i.e., either the operating cost will increase to absorb the district supplier's costs, or physical changes will be needed to the building to accommodate low-carbon district service, or both); presently, however, no default assumption is available. Buildings that use this heating source currently report a default total conversion cost of $0 per square foot.
  - Electric heating/cooling
    - Electricity is already a low-emission fuel in Ontario (note that this may not be true in other jurisdictions). Converting electric-resistance heating has many other benefits that make it a practical choice, however, as this type of heating is inefficient and costly to operate and unnecessarily burdens the electricity grid with peak demand, thereby preventing other buildings from fuel switching. Buildings that use this heating source currently report a total conversion cost of $0 per square foot for all retrofits.

The methodology used to create the tool assumes the following:

- All buildings within a sub-building category use the same described retrofit pathway (although, in reality, each building's pathway is likely to vary, even within a sub-building category), and assume that the described option is feasible at the indicated building sub-category.
- The sum of occupancies and sub-categories represents all buildings in the jurisdiction.
- All existing energy fuels used are represented reasonably by electricity and natural gas data.
- Inputs are constant over time, with no changes (e.g., to the cost of fuel, fuel-emission rates, construction costs, and borrowing costs).
- No interactivity of costs or savings between fuel switching and efficiency is considered.

FUTURE ITERATIONS OF THE NET-ZERO BUILDINGS PATHWAYS TOOL

There are a number of ways that the tool could be improved in the future to benefit users.

The following improvements are being considered for future iterations of the tool:

- Improving the accuracy or applicability of cost analysis through:
  - Adding annual maintenance cost assumptions for each retrofit type;
  - Linking calculations between the fuel-switching tabs and the efficiency tab;
  - Exploring subgrade conditioned and unconditioned floor areas;
  - Allowing users to calculate the solar potential for select buildings (on the efficiency tab), focusing on single-family homes with a peaked roof facing south;
  - Allowing users to calculate the cost/benefit (efficiency tab) of smart thermostats and identify relevant building archetypes;
  - Conducting research to update the calculations within [FS – Operational] for the ASHP with RNG backup to allocate consumption between heat pump and gas consumption; and
  - Allowing electrical costs to be scalable—i.e., based on building size. The electrical capital costs for ASHPs, ground-soure heat pumps, and electric resistance retrofits within [FS – Unitary Capital] are currently flat, "per-building" assumptions.
- Improving usability and outputs through:
  - Turning the workbook into an interactive, web-based product that increases user accessibility (e.g., through data visualizations);
  - Highlighting relative technology viability in outputs to help users evaluate the viability of their retrofit pathway;
  - Including user-filterable pivot tables to sort and compare data;
  - Creating dropdown menus that generate figures and tables;
  - Adding visuals such as figures, charts, and pivot tables in addition to those already available for fuel switching, and adding others related to efficiency; and
  - Adding the escalating cost of carbon to business-case outputs.

SPECIAL NOTE ON BUILDING-MOUNTED SOLAR AND BEHIND-THE-METER STORAGE CONCLUSIONS

Toronto 2030 District previously explored the possible contributions of building-mounted solar and behind-the-meter storage to achieving net-zero operational GHG emissions for the built environment in the Toronto core by 2050. These are not included in the Net-Zero Buildings Pathways Tool. However, the key findings still remain of interest.

A review of the Toronto 2030 District's *Integrated Pathways to Decarbonization* report was conducted with regard to the key conclusions outlined in Section 2.1: Building Mounted Solar and Section 2.2: Behind the Meter Storage.

The following statements should be considered during the decarbonization pathway decision-making process in terms of changes to technology or the industry since the report was first published:

- Building-mounted solar, even when coupled with battery electricity storage, will not meet today's—let alone future—loads using current technology.
- Building owners will still need to rely on the decarbonized grid to meet electricity demand, especially in winter, when heating demand is high and solar irradiance is lower.
- Building-mounted solar photovoltaic cells are not a necessary element of a pathway to dramatically decarbonize building heating.
- Solar strategies that benefit building owners from a cost perspective should still be pursued where justifiable on the basis of cost–benefit, even if not a precondition to decarbonization.
- The use of thermal storage and battery energy storage systems (BESS) is likely to reduce the required capacity of the grid. The magnitude of this, previously estimated as being a maximum of 10% [4% thermal mass, 6% BESS], was not revalidated since originally established. Therefore, this is a potential area for future investigation.
- Using thermal mass is much less expensive than using BESS or thermal storage but has much more limited impact/benefit.

CONCLUSION

The Toronto 2030 District's Net-Zero Buildings Pathways Tool is a decision-making tool for building owners, building portfolio managers, policy-makers, and key building-sector stakeholders looking to define pathways to net-zero decarbonization.

Although it was designed for the Toronto 2030 District, it is hoped that both this jurisdiction and others will leverage the tool to help make informed decisions about how to prioritize credible pathways to achieving net-zero operational GHG for the built environment.

Ultimately, the goal of open sourcing the Net-Zero Buildings Pathways Tool is so that decision-makers can define the most cost-effective decarbonization pathways for their jurisdictions and then help to lay a foundation for the practical implementation of recommendations through pilot programs, experiments, new incentives and programs, and proposals for regulatory reform.

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CONNECT WITH US

The Toronto 2030 District is a private sector–led initiative supporting District-wide reductions in building-related energy, water, and transportation emissions across Toronto's downtown core. Sponsored by Building Owners and Managers Association Toronto, the Ontario Association of Architects, and Sustainable Buildings Canada, the Toronto 2030 District seeks to convene key stakeholders in the local building sector in support of a more effective culture of building conservation across all building types in the District.

If you would like to learn more about Toronto 2030 District's Pathways Project or collaborate with us, please contact:

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