HEATING AND COOLING GTHA BUILDINGS IN 2050

DRAFT 1

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(Author and contact information is on Page 5)

This pre-proposal and its purposes

This document concerns how buildings in the Greater Toronto and Hamilton Area (GTHA) can be heated and cooled so as help meet targets for greenhouse gas (GHG) emissions in 2050.[1*] It is a prelude to a proposal to update a 1995 study entitled *The Potential for District Energy in Metropolitan Toronto*.[2] That 309-page report was prepared by team of representatives of the study's sponsors, including two of the three authors of this pre-proposal (MW and JS).[3] Why the proposed update would concern the larger area of the GTHA is explained below.

The main purpose of the present stage of this pre-proposal is to elicit interest among potential participants in the proposed update. A later stage will be a step towards securing the collaboration of senior governments and developing requests for funding of the update, particularly to the federal government.

Net-zero targets and GTHA buildings

The timeliness of an early-2020s update of the 1995 study is highlighted by the federal government's recent adoption of a Canada-wide target of net-zero GHG emissions by 2050.[4] This adoption matches similar target-setting by GTHA municipalities.[5]

The major challenge in meeting the net-zero target in the GTHA concerns GHG emissions from buildings. These emissions arise overwhelmingly from the winter heating of interior space. GHG emissions also result from cooling, provision of domestic hot water, and other in-building activities involving use of electricity.

In the present City of Toronto, almost all winter space heating is by natural gas, accounting for just over half of annual GHG emissions.[6] In the rest of the GTHA, winter heating by natural gas contributes about 35% of all GHG emissions, just behind transportation as the largest source. Overall in the GTHA, winter heating is the major source of GHG emissions, responsible for about 42% of the total from all sources.[7] To bring GHG emissions in the GTHA to zero or near zero by 2050, priority should be given to reducing fossil fuel use for winter space heating.

Most GTHA buildings to be in use in 2050 likely exist today. For these, much could be achieved through a massive program of "deep retrofitting," which could reduce energy use for heating existing buildings by an average of about 40% by 2050.[8] Deep retrofitting would thus leave about 60% of today's heating requirement by natural gas to be replaced with heating from non-GHG-emitting sources.

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[*]Superscript numbers point to 25 source and other notes on Pages 9 and 10 of this document.

About 30% of buildings to be in use in 2050 could be built between now and then. They will be responsible for increasingly less GHG emissions as relevant regulations are toughened. Nevertheless, many new buildings, particularly those completed before 2035, will have winter heating systems that contribute directly to GHG emissions. It may be prudent to expect that these new buildings contribute to raising the total heat requirement to be replaced by 2050 from 60% of the current level for existing buildings to about two thirds of the current level.[9]

Energy and peak load

How to replace roughly two thirds of today's winter heating *energy* with non-GHG-emitting sources is only part of the challenge posed by the net-zero target. More important could be the *peak load* to be met during the coldest hours of the winter.[10] A heating system may appear to be able to supply enough heat when demand for the heat is averaged across a winter, but unless the system can provide sufficient heat during the coldest hours, it could be inadequate and even life-threatening.

The 1995 study found that the peak heating load rose above 50% of its maximum only about 5% of the time. Thus, providing for the peak periods was to be an expensive business – as it is for any service for which demand varies sharply such as highways, transit and electricity supply. Two ways of dealing with peaks in energy use are to have much underused capacity and to store energy in off-peak periods to be used during peaks. A key feature of the proposed update would be to estimate for each part of the GTHA and for the GTHA as a whole the best way of ensuring that sufficient amounts of heat will be available when needed.[*]

The 1995 study

The basic finding of the 1995 study was that deployment of a district heating network[11] *across what is now the City of Toronto could reduce Toronto's GHG emissions from space heating by between about 55% and 75%.*[12] Heat sources in each building were to be replaced by unused heat from electricity generating stations[13] piped as hot water throughout the study area, with peaking plants providing additional hot water when needed.

This was all to happen over five phases, working out from the downtown – where mostly large buildings would be served in Phase 1, to begin soon after 1995 – and reaching the jurisdiction's limits in Phase 5, to be completed in 2032. By then, several isolated distribution networks could have become integrated into the main system.

Application of the 1995 study to present challenges

The basic finding of the 1995 study – that area-wide district heating could substantially reduce what was then and is now the main source of GHG emissions in the study area – suggests that a

[*]Appendix 1 on Page 6 lists tasks that could be undertaken during the proposed update of the 1995 study.

comparable strategy could be used over the next few decades to achieve a major reduction in GHG emissions across the GTHA. The proposed update could assess why the 1995 study was not implemented for heating buildings, although the main reasons already seem obvious: a relative lack of urgency then about reducing GHG emissions together with absence of a suitable source of capital investment – touched on further below. The 1995 study seems to have had more impact on the cooling of buildings, also touched on below.

The main thrust of the proposed update would be to assess the extent to which deployment of district heating in the GTHA could help meet the net-zero target for 2050. It would be compared with what may be the main alternatives: (i) using gaseous heating sources – fed through existing natural gas pipes – that do not result in GHG emissions, such as green or white hydrogen[14] and what is known as “renewable natural gas”[15]; (ii) using gaseous heating sources that result in GHG emissions and capturing or offsetting these emissions; and (iii) using electricity to heat buildings.[16]

These alternatives and district heating are not mutually exclusive: a net-zero strategy could involve a combination of them and the proposed update would consider such combinations. Indeed, district energy systems – elaborated further below and in Appendix 2 – now usually accommodate several inputs, each raising or lowering the temperature of distributed hot or cold water, as may be appropriate. District energy systems are analogous to electrical grids, which facilitate the use of several inputs whose range can contribute to system resilience.

Heat sources for a GTHA district heating system

The main heat sources identified in the 1995 study are no longer available. The electricity generating stations from which unused heat would be taken have been or are shortly to be closed. Nevertheless, numerous potential heat sources remain in the GTHA, to be assessed in detail during the proposed update. They include unused heat from industry and from continuing generating stations, as well as heat from solar thermal systems, deep and not-so-deep geothermal sources, wastewater treatment plants, and several other sources. One of the authors of this pre-proposal (JS) is preparing an overview of potential GTHA heat sources, to be available soon from jstephenson806@gmail.com.

District energy systems have undergone substantial development since 1995. Then, what are known as second-generation systems prevailed, suitable for making use of unused heat from electricity generating stations. Now, much more sophisticated and efficient fourth-generation systems are installed, capable of exploiting a wide range of what are often surprising sources of thermal energy.[*]

The parts of the GTHA inside and outside the City of Toronto could have a synergistic relationship regarding the development of district heating. Development of the inside part may initially be more feasible on account of its greater densities of population and buildings. It could develop supply chains and experience that would benefit the outside part. The outside part

[*] Appendix 2 on Pages 7 and 8 describes the evolution of district energy systems.

could benefit from the economies of scale achievable through connecting with the inside part. The inside part could benefit from access to available and developable non-GHG-emitting heat sources in the outside part. Moreover, a larger system, with a greater number of inputs and distribution routes, can be made more resilient in the face of unexpected challenges – just as a large electrical grid can be more reliable and resilient than a smaller one.

District cooling for the GTHA

The 1995 study concerned both district cooling and district heating. It provided a major impetus for the development of Deep Lake Water Cooling (DLWC) to serve downtown Toronto buildings.[17] DLWC makes use of the year-round 4°C-water found below about 80 metres depth in Lake Ontario, i.e., about 5 kilometres from Toronto's shoreline. This huge resource of cold water is renewed each winter when the lake's surface water sinks as its temperature falls to and below 4°C. A task of the update could be to assess the extent to which this cold water could provide summer air conditioning for GTHA buildings without causing long-term depletion of the resource.

Except in the area served by DLWC, the cooling of interior space in the GTHA is provided by electric air conditioners and chillers. Because Ontario generates almost all its electricity from non-GHG-emitting sources,[18] the impact of cooling on GHG emissions is relatively small. Indeed, in the emissions inventories touched on above, cooling hardly rates a mention.

Nevertheless, cooling is significant for electricity generation in that it causes the GTHA to have its highest electricity consumption in the summer.[19] Also, as consumption increases with population growth and transport electrification, and as the Pickering Generating Station closes in 2025 and is replaced by natural-gas generation,[20] the imperative to avoid electricity use for cooling could become strong. If a GTHA-wide district heating system is developed, its distribution network could be designed to provide cold water too. An important task of the proposed update could be to assess whether and how this could be done, and to explore synergies between heating and cooling systems.[21]

Implementing district energy for the GTHA

Implementation of widespread district energy in the GTHA by 2050 could need a strong focus on development of district energy in nodes outside Toronto, e.g., in Hamilton, Mississauga (downtown and around Pearson Airport), Oshawa, and many more – according to building densities, thermal energy availability, and the location of existing systems such as in Markham,[22] perhaps with the aim of eventually linking each node to a single expanding system.

The 1995 study looked to embracing just about all buildings in its area with district energy services. This will be less feasible for the GTHA where much of the land remains in agricultural use or with very low-density development. Sophisticated methodology exists for determining the feasibility of servicing particular buildings and groups of buildings. The update would apply the best current versions of this methodology to the GTHA. For the moment it can be said that as the imperatives for avoiding fossil fuel use grow stronger and as district energy technology evolves,[23] the prospect of district energy becomes more attractive in more places.

Funding district energy

District energy systems are mostly characterized by high upfront costs and relatively low operating costs. Deployment of them is usually beyond the resources of municipalities, whose involvement is nevertheless essential for the implementation of these systems, and which are generally well placed to lead their development. Once established, district energy systems can be very attractive to private-sector investors, enabling governments to readily recoup investments in their development.

A case in point could be the history of the Toronto District Heating Corporation, now Enwave Energy Corporation, briefly stated here. The then City of Toronto began TDHC with investments of $68 million by it and Metropolitan Toronto over the 1970s-1990s. The Ontario Municipal Employees Retirement System took a 57% stake in TDHC in 1998, making further investments as the system was renamed. In 2012, Enwave was sold to Brookfield Asset Management for $480 million, from which the City of Toronto received about $170 million. In 2021, after considerable further investment in Toronto and elsewhere, Brookfield sold Enwave for more than $5 billion, of which the Toronto system likely represented about half of the total value.

An important task of the update of the 1995 study could be development of a long-term funding model for programs to achieve net-zero GHG emissions in connection with buildings across Canada. As well as district energy, the model could embrace the funding of deep retrofitting, searches for non-GHG-emitting energy sources, and other relevant matters.

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APPENDIX 1

Tasks suggested here for an update of the 1995 study
(likely to be much revised as a fully fledged proposal is developed)

1. Develop a fine-grained heating and cooling demand map for the GTAH,[24] estimating both energy and load requirements for each of a large number of areas and sub-areas for the present and for each of 2035 and 2050.

2. Identify heating and cooling sources available to the GTHA for district energy, their amounts, deliverability, and costs – including, for example, deep and not-so-deep geothermal heat and deep lake water cooling.

3. Use the results of the above tasks to assess the opportunities for local and area-wide thermal storage and the trade-offs between storage and provision of energy for peak heating and cooling hours.

4. Based on the above, estimate the costs and benefits of each of several phases of development of a district energy system for the GTHA, including development of energy sources, distribution networks, and in-building modifications.

5. Identify all alternatives for heating and cooling buildings in the GTHA, comparing their feasibility and utility point-for-point with the district energy approach, including direct and indirect GHG and other emissions associated with each alternative as well as local, regional, provincial and national economic development benefits.

6. Assess which alternatives could be used in combination with a district energy approach, suggesting several strategic options.

7. Develop a long-term funding model for programs to achieve net-zero GHG emissions in connection with buildings across Canada.

APPENDIX 2

Notes on the evolution of district energy systems

The diagram on the next page shows four generations of *district heating systems* as they have evolved over the last 140 years.[25] The evolution is characterized by much increased efficiency of operation, reduced temperature of the heating medium, and heating sources that have been increasingly diversified and decentralized.

Provision of district cooling has generally been a recent phenomenon – it features in the diagram only in the fourth generation but may now often be considered an essential feature of what are known increasingly as district energy systems.

The first three generations of district heating featured a growing range of centralized heat sources that served larger and larger distribution networks. Steam was the usual heating medium for first generation systems, and pressurized water (above 100^{o}C) for the second generation. Third generation systems distributed water between about 65^{o}C and 95^{o}C, allowing for a wider range of inputs, e.g., solar thermal collectors.

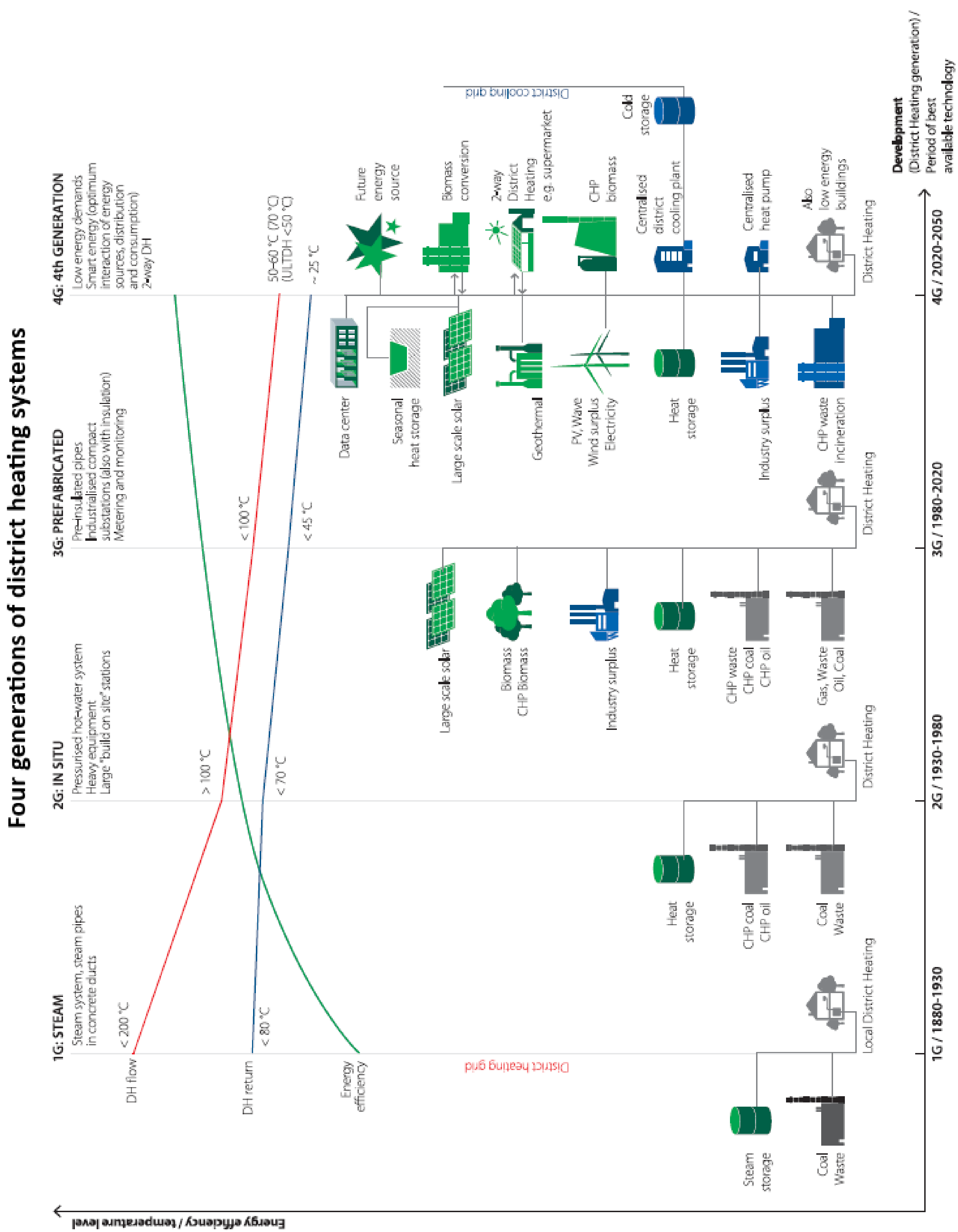
Fourth generation systems distribute cooler water, typically 50-60^{o}C but up to 70^{o}C in very cold weather. Pilot systems are being used in which water with a temperature as low as 35-40^{o}C is distributed, allowing for an even broader range of inputs, as shown in the diagram. (Such low distribution temperatures require appropriate building designs as well as innovative designs of distribution networks and building interfaces.)

Fourth generation systems often incorporate several new features, taking advantage of progress in remote sensing, control mechanisms and even artificial intelligence. Sophisticated controls allow buildings to be both users of heat from a distribution system and suppliers of heat to it, as is shown for the supermarket represented in the diagram, which can have overnight excess heat rejected by its chilling arrangements but need heat at other times.

Storage has been a feature of district heating systems since the first generation but has become increasingly sophisticated and necessary to avoid expensive provision for adding heat during the coldest weather.

Further evolution is likely to include increasing involvement of cooling functions, because rising temperatures are expected, but also because buildings in any case may require more cooling. As they grow larger, their cores can become overheated – even in winter – from the heat from human bodies and proliferating electronic devices.

Cooling services can be delivered separately, but it can be advantageous to consider heating and cooling together – as a district energy system – not the least because chilling usually produces heat and, properly managed, heat can be a source of chilling.


Four generations of district heating systems
1G: STEAM
Steam system, steam pipes in concrete ducts
2G: IN SITU
Pressurised hot-water system
Heavy equipment
Large "build on site" stations
3G: PREFABRICATED
Pre-insulated pipes
Industrialised compact substations (also with insulation)
Metering and monitoring
4G: 4th GENERATION
Low energy demands
Smart energy (optimum interaction of energy sources, distribution and consumption)
2-way DH
DH flow
DH return
Energy efficiency
< 200 °C
< 80 °C
> 100 °C
< 70 °C
< 100 °C
< 45 °C
50-60 °C (70 °C)
(ULTDH <50 °C)
~ 25 °C
District heating grid
District cooling grid
Steam storage
Coal
Waste
Local District Heating
Heat storage
CHP coal
CHP oil
Coal
Waste
District Heating
Large scale solar
Biomass
CHP Biomass
Industry surplus
Heat storage
CHP waste
CHP coal
CHP oil
Gas, Waste
Oil, Coal
District Heating
Data center
Seasonal heat storage
Large scale solar
Geothermal
PV, Wave
Wind surplus
Electricity
Heat storage
Industry surplus
CHP waste incineration
District Heating
Future energy source
Biomass conversion
2-way District Heating e.g. supermarket
CHP biomass
Centralised district cooling plant
Cold storage
Centralised heat pump
Also low energy buildings
District Heating
1G / 1880-1930
2G / 1930-1980
3G / 1980-2020
4G / 2020-2050
Development
(District Heating generation) /
Period of best available technology
Energy efficiency / temperature level

NOTES

1 The GTHA includes the present Cities of Hamilton and Toronto, and the regional municipalities of Durham, Halton, Peel, and York and the 24 local municipalities embraced by these four regions.

2 The *Potential for District Energy in Metropolitan Toronto* is available at https://tinyurl.com/8954mjtt. In 1998, the area of what was then the regional government of Metropolitan Toronto became that of the current City of Toronto on amalgamation of the region's six local municipalities, which included the former City of Toronto.

3 The 1995 study's sponsors were the Municipality of Metropolitan Toronto, Ontario Hydro (since split into three public corporations), and Natural Resources Canada.

4 According to the Government of Canada's website at https://tinyurl.com/fxemd97c, "Achieving net-zero emissions means our economy either emits no greenhouse gas emissions or offsets its emissions, for example, through actions such as tree planting or employing technologies that can capture carbon before it is released into the air." It says too, "Canada has joined over 120 countries in committing to be net-zero emissions by 2050, including all other G7 nations … ."

5 Only Hamilton and Toronto may have formally adopted net-zero targets, but other GTHA municipalities appear to be on the way to doing so.

6 For recent data that most of Toronto's GHG emissions result from winter heating by natural gas, see Page 5 of *City of Toronto 2018 Greenhouse Gas Emissions Inventory* at https://tinyurl.com/2untzhrt.

7 The data for GHG emissions in the GTHA are from the profiles for 2018 at https://tinyurl.com/fsbc63tp. Winter heating and transportation are the main sources of GHG emissions, except in Hamilton, where industry is the main source, then winter heating and then transportation.

8\. There's a range of estimates of the average reduction in energy requirement achievable with a program of deep retrofitting. We've used the City of Toronto's estimate of 40% at https://tinyurl.com/66d788n4.

9\. Ontario government projections for 2046 suggest that the population of the GTHA will increase by close to 40% from its 2021 estimate of 7.7 million (see https://tinyurl.com/4a8dt6zb). Interior space needing winter heat may also increase by about 40% to accommodate this population growth. New buildings to be completed by the late 2040s may require on average only about 20% of the thermal energy now used by existing buildings, i.e., about 8% of total current use. Trends since the mid-19th century suggest that by 2050 winters could average about 0.6^{o}C warmer than now. Thus, estimating an overall heat requirement for interior space in 2050 of about two-thirds of current use may be reasonable.

10\. Peak load is known technically as *power* or *rate of energy conversion*. Estimating power requirements – for electricity or heat – and how they could change can be a challenging task. The 1995 study used available information about building size and type for each of that study area's 400 traffic zones. From these data, estimates were made of energy and maximum power requirements for each zone.

11\. District heating is a system for distributing heat generated in a central location – in the form of hot water or steam – in insulated pipes to individual buildings. In district cooling, cold water is similarly distributed from a central source. District energy is a generic term for district heating and cooling. District energy systems are sometimes known as community energy systems.

12\. The 1995 study found that winter heating resulted in annual emissions of 11.0 megatonnes (MT) of carbon dioxide. A district heating network serving the whole study area could reduce such emissions by 6.3 MT (57% of the total) to 8.5 MT (77% of the total) – see Tables 6.3, 6.6, and 6.7 of the source detailed in Note 2. The lower reduction would apply if only coal were used for peaking and for compensating for reduced output at electricity generating stations resulting from heat extraction (see Note 13) and the higher reduction if only natural gas were used – with an intermediate value if both were used.

13\. The district heating system envisaged in the 1995 study was to depend mostly on heat from electricity generating stations: natural-gas-fuelled Hearn (38%), coal-fuelled Lakeview (41%) and nuclear-fuelled Pickering (31%) – the percentages in brackets show the usual thermal efficiency of each station as indicated in the study report. The low percentages suggest that for each generating station well over half of the energy input was not converted to electricity. For the most part, it was ejected as heat into Lake Ontario. The plan was to convert the three generating stations to what are known as "combined heat and power" (CHP) plants or cogeneration plants, in which some of the heat would be used for district heating. Extraction of this heat would reduce the efficiency of electricity generation, hence the need for the "make-up" generation referred to in Note 12.

14. Green hydrogen is produced by electrolysis and can result in no GHG emissions if none results from generation of the electricity used. White hydrogen occurs naturally in underground deposits that are just beginning to be exploited (see, for example, the program for the H-NAT2021 conference at https://tinyurl.com/v6j28kh).

15. Renewable natural gas (RNG) – like natural gas almost entirely methane – consists of upgraded emissions from organic waste, landfills, and sewage treatment plants. See https://tinyurl.com/dmx6fs6u.

16. Using electricity to produce heat directly – as in a baseboard heater – is an inefficient (and usually costly) use of high-quality energy. Electric heat pumps can be relatively efficient because they can produce many units of thermal energy from each unit of electrical energy. Air-source heat pumps, which extract heat from air, are inefficient at much below 0^{o}C. Ground-source heat pumps, which rely on the relatively constant temperature found a few metres below ground, function well in the coldest weather, but they are expensive to install.

17 Toronto's DLWC system is operated by Enwave Energy Corporation, which provides 75 buildings with cold water as well as 180 buildings with steam heat (see https://tinyurl.com/4w9443wb). Conversion to a hot-water distribution system could allow Enwave's system to be a nucleus of an emerging system.

18. According to the Canada Energy Regulator, at https://tinyurl.com/5cpn9sf6, "In 2018, about 96% of electricity in Ontario is produced from zero-carbon emitting sources: 60% from nuclear, 26% from hydroelectricity, 7% from wind, and 2% from solar. The remainder is primarily from natural gas, with some biomass."

19. Forecasts for 2022 by Ontario's Independent Electricity System Operator for 2022, based on past activity and projected conditions, can be accessed from https://tinyurl.com/f84kdm9s. They suggest that IESO's Toronto Zone (similar to the GTHA without Hamilton) will peak more in the summer for both power and energy, but the rest of Ontario will peak more in the summer for power and more in the winter for energy.

20. IESO's *2020 Annual Planning Outlook*, at https://tinyurl.com/3j3wddkv, concludes: "Ontario is expected to have adequate energy, provided … production from gas-fired generators increases to meet growing demand."

21. There are several potential synergies between heating and cooling. One is that a heat source can provide cooling through adsorption chilling (see https://tinyurl.com/kae5rebk).

22. The City of Markham's Markham District Energy Inc., in its 18th year of operation, provides heating and cooling to buildings with floor area of more than a million square metres (see https://tinyurl.com/p22x9s26).

23. A European analysis suggested for district heating systems the following categories of heat demand per unit land area (in MJ/m^2): <30, almost impossible; 30-100, possible for fourth generation systems; 100-300, possible for earlier systems; >300 highly feasible (see https://tinyurl.com/46kkfd72). A recent exercise by the City of Toronto to map suitable areas for district heating used an admittedly conservative criterion of 140 MJ/m^2. (see https://tinyurl.com/b7nc7zm8). With further evolution, installation of district energy systems may become feasible at below 30 MJ/m^2, especially if the imperative to meet net-zero targets is strong.

24 Creating what is usually known as a "heat map" for a study area is an essential though expensive step in the design of a district energy system. A good resource is at https://tinyurl.com/9td4rauh, which includes examples from 14 countries. A useful Canadian resource on heat-map development, co-authored by a current City of Toronto councillor, is the International District Energy Association's *Community Energy: Planning, Development & Delivery – Strategies for Thermal Networks* at https://tinyurl.com/c5es67w2.

25. The diagram on district energy generations in Appendix 2 is from the source at https://tinyurl.com/4zpvhzkx. Appendix 2 depends heavily on this article and on another by the same team at https://tinyurl.com/yucxpj3v.