DISTRICT ENERGY DIGEST

No. 7, February 2024

DISTRICT ENERGY DIGESTS are produced every four months by the **Boltzmann Institute**, **described here on Page 6.** They provide brief accounts of recent items relevant to the deployment of district energy, many with a focus on the Greater Toronto and Hamilton Area (GTHA). An annex is dedicated to the Boltzmann Institute's major ongoing project (see Pages 7 and 8 below). Back issues of the *Digest* are at link. To subscribe, please write to link.

News from the GTHA and Ontario

Boltzmann Institute director Michael Wiggin authored two items in the December 2023 issue of *The Voice*, produced by the Ontario Society for Professional Engineers. They are "Time to support our forestry communities" and "Networks for decarbonization." Both are available at link.

The second item may be of special interest because it reproduces several remarkable charts developed by another Boltzmann director, Martin Green, illustrating what could happen if space heating in Ontario is electrified. The most significant of these charts – Figure 4 in Michael Wiggin's article – was reproduced on Page 8 of the October 2023 issue of this *Digest*, but the whole suite of seven charts is certainly worth careful attention. An upcoming report will describe the technical basis for the charts.

Together, the charts help make two powerful cases: (1) The current direction of governments to replace natural gas heating with heat pumps will likely incur extraordinary and unaffordable capital costs on the electrical system. (2) The best alternative – certainly the most affordable – could be to deploy widespread district heating (note particularly the article's Figure 7 and associated text).

The progress of the City of Guelph towards district energy has been unreasonably ignored in these *Digests*, perhaps because Guelph (population 156,000) is just outside the GTHA. In 2013, a subsidiary of the then Guelph Hydro Inc. produced the *District Energy Strategic Plan for the City of Guelph* (link). It followed the *Community Energy Plan* approved by Guelph City Council in 2007 (link). The 2013 plan began by describing district energy as "The foundation for a cleaner, healthier and prosperous community." It continued, "A network of district energy piping and small thermal energy plants supplying at least 50 per cent of the heating needs of the City would substantially reduce the community's carbon footprint."

In 2014, Guelph Hydro and the City described Guelph "as the first community in North America with a plan for an interconnected thermal grid to serve industrial, commercial and residential buildings across an entire city" (link).

However, by 2016, it was clear Guelph's first forays into district energy hadn't worked out. An investment of $8.7 million had to be written off – the result said one councillor of "what was probably a lack of competence" in the management of the forays (link). In December 2023, an observer wrote about the downtown part of Guelph's district energy plans, just sold for a pittance, "The whole thing went ass-backwards. Instead of establishing a market, determining the cost effectiveness and ability to meet that demand, the city moved forward creating a system that too few even wanted"(link).

An additional challenge may have been the recently evolved byzantine complexity of some of the municipal arrangements for energy management, Guelph Hydro is now part of Alectra Inc., which is 97% owned by the Cities of Barrie, Guelph, Hamilton, Markham, Mississauga, St. Catherines, and Vaughan. Alectra has a dozen or so subsidiaries (link).

The above necessarily brief account of a truly bewildering saga highlights the need for better planning for space heating, among Canada's biggest decarbonization challenges. Each municipality should be required to have a heat plan, setting out how buildings are heated and how they could or even should be heated for decades to come. One reason for founding the Boltzmann Institute in 2022 was to help foster the expertise required for heat planning – and also to help secure a provincial framework that encourages district energy to flourish, the need for which may be illustrated by the next item.

Enbridge and the Ontario Energy Board. The OEB has ruled that Enbridge must charge developers the cost of natural gas connections – averaging $4,400 for a single family home (link) – rather than amortizing the cost over decades to be paid down through monthly energy charges. "The energy board said the utility's long-term plan is unreasonable because it assumes that every new housing development will include gas servicing and that homebuyers will remain on gas for 40 years, despite an energy transition toward electrification" (link). Environmental groups have applauded the OEB's ruling because it will encourage new homes to be built with heat pumps (e.g., link). Enbridge is appealing the decision. Ontario's energy minister is to introduce legislation overruling the OEB because the upfront costs "would slow or halt the construction of new homes, including affordable housing" (link).

Previous *Digest* issues have noted that such massive electrification will eventually incur unbearable costs for governments, utilities, developers, and end users. Initially, until the grid becomes overloaded, electrification could appear to be a low-cost option. But, before long, as soon as the early 2030s, electricity costs could become unmanageable, with devasting consequences for Ontario residents and businesses, and for the economy in general.

There is a potentially lower-cost and more reliable alternative for space heating than natural gas and electrification – an alternative that the Ministry of Energy and environmental groups may need to become more aware of. It is district energy, district heating in particular – as is being widely embraced in Europe (see the section below on the study tour). Ontario's first steps towards bringing rationality to this urgent topic should include developing a province-wide framework for heat planning in (say) 2050 to guide the OEB, the IESO (Independent Electricity System Operator), and municipalities.

Elsewhere in Canada

Edmonton's troubles. Guelph is not the only Canadian city to have had challenges with its forays into district energy. The very first item in these *Digests*, in February 2022, highlighted Edmonton's progress. It noted a city-owned system under development in the downtown. The newly elected mayor urged "more investment in district energy systems to help meet the City's climate goals." Now, the downtown facility has been in trouble on account of a substantial increase in its estimated cost.

Mayor Amarjeet Sohi has noted that the City's administration is trying to get the private sector on board to make it more financially feasible. (link)


Edmonton's downtown district energy facility is in the Winspear Centre, shown here.

Canada's impoverished municipalities may no longer have the means to engage in what for them can be expensive forays into relatively new capital responsibilities. (This wasn't always the case. Early in the last century, the City of Toronto, which had wider taxing powers than now, had a capital budget larger than that of the Ontario government [Pp. 11-13 of link]). Things may be done on the cheap, with less management attention than required. Later in this issue of the *Digest* is mention of a study tour of facilities in northern Europe. Even there, where cities generally have much more in the way of responsibilities, income, and power, the private sector can be a strong actor in district energy development and operation.

The experience of Saint John (New Brunswick) shows that not all district energy stories are gloomy. That city's first foray into district energy cost "way below" the budgeted amount and is already returning enough to recover the city's contribution in less than four years (link). The report continues, "Meanwhile, the city is also working on a longer-term feasibility study, which is expected to cost around $900,000. It includes developing a city-wide map and preliminary pipe network to identify and establish 20 to 30 zones for possible district energy system development."

A few more words (and recent sources) on energy storage

Among the most important features of district heating systems is the low capital cost of storing thermal energy when compared with the cost of storing electrical energy – both at grid scale. The table on the next page indicates the unit capital costs of three hot water storage facilities (including the Høje Taastrup pit storage facility, linked to Copenhagen's district energy system, to be visited in the study tour noted on Page 6). Two kinds of unit cost are shown. One is per kilowatt-hour (kWh) of the maximum amount of *energy* that can be stored. The other is per kilowatt (kW) of the highest rate of energy deliverable from the storage – also known as the maximum *power* or discharge rate.

The table shows comparable data for three grid-scale storage facilities for electricity: the world's largest, at Moss Landing near Monterey, California; one at Waratah, near Newcastle, Australia; and one near Manchester, UK (Carlton Power). All cost US$330-400 per kWh of energy storage, compared with the indicated range of US$0.80-20.27/kWh for hot-water storage.

Comparison of the capital cost of grid-scale storage of thermal energy with that of electrical energy

Facility (locations in text)	Capacity (MWh)	Discharge rate (MW)	Cost in 2022US$		Source
			Per kWh	Per kW	
Hot water storage					
Vojens pit storage	12,180	39	0.56	177.70	link
Høje Taastrup pit storage	3,300	30	3.61	396.70	link
Berlin tank storage	2,600	200	20.27	263.50	link
Battery storage					
Moss Landing BESS project	3,000	750	333.00	1,333.00	link
Waratah Super Battery	1,680	850	385.00	762.00	link
Carlton Power (battery)	250	250	397.00	397.00	link
NREL 2023 (4-hour battery)	60	15	446.00	1,785.00	link
NREL 2050 (4-hour battery)	60	15	220.00	880.00	link
Pumped hydro storage					
GTM			153.00		link
Thunder Said Energy	6,000	500	187.50	2,250.00	link
NREL				2,737.52	link

Also shown in the table is a recent overview of the capital costs of grid-scale lithium-ion batteries by the U.S. government's National Renewable Energy Laboratory. NREL's estimates are higher than those for the three specific batteries in the table, in part because they may include costs not represented in information about these facilities. Even if, as NREL suggests, there'll be a real 50% fall in batteries' capital costs by 2050, storing electrical energy could still be at least 50 times more costly than storing thermal energy in the unlikely event hot-water storage costs do not fall (link).

The table includes information about two examples of pumped hydro storage – worldwide the main form of energy storage (link), as well as in both Canada (link) and the U.S. (link) – together with NREL's estimate of the typical capital cost per power unit of this method of storing electricity.

The table suggests that, per unit of *energy*, battery storage is currently about 100 times the capital cost of hot water storage, with pumped hydro storage being almost 50 times higher. Per unit of *power*, battery storage may be only three times as costly as hot-water storage, and less expensive than pumped hydro storage. Batteries may be able to cover brief interruptions and peaks quite well but be of little use providing back-up for the days and even weeks of low wind speeds that occur during Ontario winters. (Data on operating costs are less available. Because of batteries' relative complexity, their operating costs are likely to be higher.)

Battery and pumped hydro facilities effectively store electrical energy, energy with a higher *exergy* than the thermal energy stored as hot water – i.e., electricity is a higher grade of energy, useful for many more purposes. However, the two kinds of energy can be validly compared when the stored electrical energy is used only for producing hot water or hot air for space heating.

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The relatively low cost of thermal energy storage makes it practicable to, for example, harvest solar thermal energy in summer and use it in winter, thereby much extending available energy sources.

Moreover, hot water storage – again, appropriate for comparison when the end use of the energy is for space heating – may also be more reliable and less dangerous than storing electricity (e.g., link).

District energy study tour, northern Europe, May 24 to June 8, 2024

The Boltzmann Institute is to conduct a study tour of district energy facilities in northern Europe. Details are at link. The study tour will focus on the management and capital funding of district energy, particularly as they involve municipalities, and on engineering and other technicalities. To participate or seek more information, write to link. Facilities of the cities and towns below will be examined in detail. [Square brackets for each location give a rough estimate of the population servable by district energy – 14,000 to 4.5 million – usually similar to today's urbanized population and in some cases similar to the population already served.] *Partial travel and accommodation subsidies are available for graduate students working in the area and for junior staff persons in municipalities and utilities.*

Amsterdam, The Netherlands [1.5 million] Much like the GTHA in that most space heating is now by natural gas. They plan to switch almost all of it to low-carbon district heating by 2040.

Kristiansand, Norway [125,000] Distributes heat from bioenergy and otherwise unused heat from industry and a waste-to-energy plant. District cooling is based on cold seawater.

Aarhus, Denmark [360,000] Almost all buildings are connected to the district heating system, soon to be served by Europe's largest deep-geothermal facility, drawing 70^{o}C water from 2.5-km depths.

Berlin, Germany [4.5 million] District heating serves half of this city-state's buildings. Features include ongoing massive expansion, much fossil-fuel avoidance, and Europe's largest above-ground hot-water storage. Berlin is buying the system back from Swedish company Vattenfall for Can$2.3 billion.

Tallin, Estonia [450,000] A leading IT centre, evident in the management details of its widespread district energy systems, soon to include the city centre's large stock of historic buildings.

Helsinki, Finland [1.4 million] The most northerly, coldest place to be visited, with a high market penetration of district energy, all from combined heat-and-power plants, soon to include nuclear.

Stockholm, Sweden [2.1 million] has some 90% of its floor space served by district heating, and a rapidly growing share served by district cooling. Features include two-way trading in hot and cold water between the 3,000-km-long heat network – 50% city-owned – and over 30 data centres.

Visby, Sweden [58,000] This island town's sources for its heat network include locally produced forest bio-energy and bio-oil, bio-gas from a landfill site, and waste heat from sewage treatment.

Rønne, Denmark [14,000] is the main town on the famously "green" island of Bornholm, on target to have all carbon-neutral energy production by 2025, with district heating as a key factor in attainment.

Hamburg, Germany [2.5 million] This city-state has had district heating for 130 years, but not yet serving more than 25% of floor space. Its heat is mostly from coal-fired electricity generation – to be replaced with heat from nine sources including solar, deep geothermal, biomass, and storage.

Copenhagen, Denmark [1.4 million] Said to be the world leader in district energy. A 160-km trunk system (≤120^{o}C water) links to distribution systems – municipally owned or consumer co-ops – in 22 municipalities in the region, as well as to new hot-water pit storage for addressing peak demand.

Also of interest (on using nuclear energy for district heating)

There's much ongoing work, particularly in China, on the use of nuclear energy for district heating. Note in particular a September 2023 academic paper by Haichen Liu and colleagues, "Simultaneous transport of freshwater and heat: An application to Chinese northern coastal regions" (summary at link, full version behind a paywall). This paper is the latest in a series on a novel method for supplying much-needed heat and freshwater in north-east China.

Output from the Haiyang Nuclear Generating Station, on the coast of the Yellow Sea, is used to desalinate and heat seawater, as well as produce 2.5 GW of electricity. The resulting hot freshwater is then transmitted about 100 km north to Yantai (urban population about 2.5 million). There, heat is extracted for space heating and the water is further cooled and added to the water supply, eventually passing through Yantai's wastewater system to the sea. Cooling is achieved using lithium-bromide absorption chillers powered by the hot water. Capital costs are reduced substantially by using a single pipe to transmit both heat and freshwater without requiring a return pipe.

There are plans to triple the amount of nuclear generation in Ontario. If done, it would make much sense to use for space heating some of the colossal amounts of thermal energy produced by the reactors, instead of merely warming Lakes Ontario and Huron. The Boltzmann Institute is collaborating with nuclear colleagues to explore how nuclear reactors in Canada could supply hot-water networks with heat, including heat that could be stored, at large scale, until needed for distribution to buildings.

About the Boltzmann Institute

We're a federally incorporated, not-for-profit organization founded in 2022, seeking to help eliminate harmful emissions from human energy use, named for Ludwig Boltzmann, a 19th-century Austrian founder of the science of thermodynamics.

We aim to contribute research and education towards securing carbon neutrality by 2050, initially focusing on thermal energy use in buildings (heating and cooling).

Our website at www.bi-ib.ca is a growing resource – now partially bilingual – on district energy and related matters including electricity generation.

Our early funding came from generous private contributions. The Government of Canada is now contributing $750,000 to the work of the Boltzmann Institute described in the annex to this *Digest* on the next two pages.

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WHAT WE'LL SEE DOWN TWO PATHWAYS

Project update, February 5, 2024

"The best laid schemes o' Mice an' Men Gang aft agley" [often go awry] write Scots poet Robert Burns in his 1785 ode *To a Mouse, On Turning Her Up in Her Nest With the Plough*. That's been our experi-ence over long and eventful careers. And so it has been with this project. There've been delays in lining up the several McMaster University graduate students involved – just a series of unfortunate events. But now they're (almost all) on board and raring to go. Here's a list of their tentative thesis titles:

- Development of heating energy usage profile for electrification of space heating scenarios focused on air-source and ground-source heat pumps
- Comparison of peak power demand impacts accounting for annual energy requirements with hybrid air-source heat pumps with renewable natural gas or hydrogen furnaces to manage peak demand
- Peak power demand impacts on grid and annual energy requirements for clean heat sources including solar thermal, bio-based fuels, and grid-wide renewable electricity curtailment
- Peak power demand impacts on grid and annual energy requirements for residual heat sources including cooling process heat and electricity generation residual heat
- Impact and efficiency of mass deployment of pit thermal energy storage based on architype buildings and clean heat sources to manage electrification of heating peak power demand
- Impact and efficiency of borehole thermal energy storage based on architype buildings and clean heat sources to manage electrification of heating peak power demand
- Thermal and electrical network grid-wide infrastructure investment strategies based on planned provincial-grid generation-mix options by 2050.

There's been little delay by FVB Energy Inc. in their part of the project: to develop a low-carbon district heating system for an illustrative community. This hypothetical community is a composite of typical urban landscapes found in Ontario, endowed with a typical array of clean heat resources. Several technologies are being examined and costed. The completed pre-feasibility report will shed light on development issues and costs commonly encountered by communities tackling the worth-while but often difficult challenge of decarbonizing buildings through offering consumers a low-carbon district heating service.

Taken together the above work will help communities across Ontario and Canada think about deve-loping heat plans – much as they now develop land-use plans. And we hope it will provide the rationale for senior levels of government to encourage such heat planning. Each community's heat planning process could begin by answering these three questions:

1. What is the community's peak heating demand (space and water heating), and in which part(s) of the community does it occur?
2. What are the available sources of heat in and near the community, particularly heat that would otherwise be unused (including for the moment heat from fossil-fuel-based co-generation) and heat that is not based on fossil-fuel use?
3. What will it cost utilities and property owners to decarbonize the heating of all the buildings in the community, on the one hand chiefly with widespread electrification (heat pumps), and on the other hand chiefly with thermal networks (for district heating – and district cooling)?

Question 3 asks about the most popular or feasible pathways to decarbonization, but communities could also consider other proposed pathways such as widespread use of use of equipment fuelled with hydrogen or renewable natural gas. The utilities in mind for Question 3 are existing provincial and local electrical utilities as well as utilities, existing and proposed, that operate thermal networks.

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This project is supported by a contribution from federal government agencies (see the logos below) awarded to the Boltzmann Institute after a competition among universities and think tanks. The project is to be completed by March 31, 2025. We'll be disseminating results as we get them through future editions of this *Digest* and other means. Please e-mail the project manager John Stephenson (link) with questions, comments or in-kind contributions to the project.

This project was undertaken with the financial support of the Government of Canada
Ce projet a été realisé avec l'appui financier du gouvernement du Canada

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