Welcome to this week's presentation & conversation hosted by the **Canadian Association for the Club of Rome**, a Club dedicated to intelligent debate & action on global issues.

Welcome to CACOR Live

The views and opinions expressed in this presentation are those of the speaker & do not necessarily reflect the views or positions of CACOR.

Thermal Networks and Nuclear Energy —A Pathway to Decarbonizing Building Heating.

Description: In Canada, as much energy is used to heat buildings as is used for electricity. Current plans for achieving net-zero buildings include retrofitting millions of buildings with electric heat pumps. While work is underway to mitigate the risks for building-electrification, there's another complementary pathway—Thermal Networks as large-scale utilities. An opportunity for synergies between electricity grids & TNs occurs when they share non-emitting Combined Heat & Power generators. Among the largest of clean CHP generators is nuclear energy. Canada intends to increase its nuclear energy capacity by 2050. Harnessing the CHP capabilities of nuclear energy to also service TNs would reduce the need for additional clean heat generation while contributing to grid modernization that enables greater use of variable renewables.

Biography: Dr. Robert Walker is a retired public sector scientist & science executive who acts now as an independent advisor. Past leadership roles have included President & CEO of Atomic Energy of Canada Limited & Canadian Nuclear Laboratories, ADM (S&T) at National Defence, & CEO of Defence R&D Canada. He is presently a Senior Fellow at the U Ottawa's Institute for Science, Society, and Policy, and a member of McMaster U's Board of Governors.

The presentation will be followed by a conversation, questions, & observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, & Inuit in Canada) and their descendants.

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2024 Jul 24 Zoom #207

Thermal Networks and Nuclear Energy – a Pathway to Decarbonizing Building Heating

Presentation to
the Canadian Association for the Club of Rome
July 24, 2024

Robert Walker, PhD, FCAE
Senior Fellow
Institute for Science, Society and Policy
University of Ottawa

Related Past CACOR Presentations

- **Reimagining Nuclear Energy**, Robert Walker
  - December 2, 2020
  - https://youtu.be/VvDZNxB6QJE
- **District Energy Systems: Canada's Missing Infrastructure**, Jamie Stephen
  - February 17, 2021
  - https://www.youtube.com/watch?v=ciHo8jYdlrQ
- **Reimagining Nuclear Energy – an Update**, Robert Walker
  - November 10, 2021
  - https://canadiancor.com/bob-walker-reimagining-nuclear-energy-an-update-2021-11-10/

This presentation draws on a recent Position Paper

Thermal Networks and Nuclear Energy – Advancing the Dialogue towards Clean Heat Infrastructure for Canada

A Position Paper

An Initiative of McMaster University's Institute for Energy Studies, the Boltzmann Institute and the Canadian Nuclear Association

McMaster University

Boltzmann Institute
Institut Boltzmann

cna canadian nuclear association

Released February 28, 2024

About the Authors

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- Michael Lynch, Canadian Nuclear Association
- Paul Spekkens, Senior Technical Consultant
- Robert Walker, Institute for Science, Society and Policy
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- Paul Acchione, Ontario Society of Professional Engineers
- John Barrett, Portolan Global Inc
- Peter MacKinnon, Synergy Management
- Robin Manley, Paradymshyft Nuclear Advisory Ltd
- David Novog, McMaster University
- John Stephenson, Boltzmann Institute

Representatives from the following organizations have been consulted in the development of the Paper. Their listing does not infer their endorsement of the Paper's finding and recommendations.

Government	Associations/Think Tanks	Thermal Network Industries	Nuclear Energy Sector
Canadian Nuclear Safety Commission	Canadian Academy of Engineers	Enbridge	Atomic Energy of Canada Limited
Natural Resources Canada	McMaster Senior Administration	Enwave	Canadian Nuclear Laboratories
Ontario IESO	Ontario Society of Professional Engineers	FVB Energy	CANDU Owners Group
Public Services and Procurement Canada	Transition Accelerator	Hamilton Community Enterprises	Organization of Canadian Nuclear Industries

Measures of Energy

1 J = Joule (is a measure of energy)
1 Wh = Watt-hour (a different measure of energy)
1 W = Power (1 Joule / second)

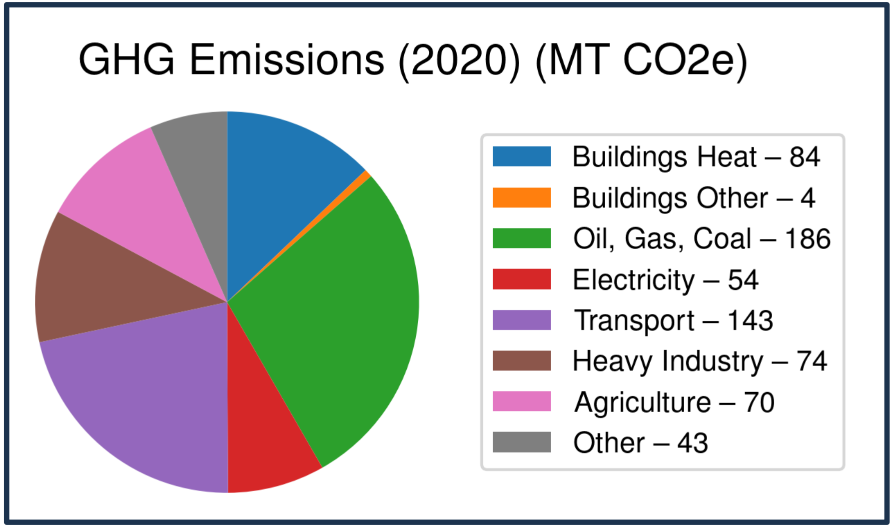
K as prefix – kilo, times 10^3
M as prefix – mega, times 10^6
G as prefix – giga, times 10^9
T as prefix – tera, times 10^{12}
P as prefix – peta, times 10^{15}

A pizza oven uses about ~300 kWh/day
McMaster uses about ~10MW on average
Scale of peak power used in Ontario ~23GW
Heat energy needed for buildings in a city is about ~1 TWh
Total energy needed in Ontario ~3600PJ /year

Suffix e – electrical
Suffix t – thermal
CHP – Combined Heat and Power

Decarbonizing Building Heating:
Up Front Facts and Assumptions

Canada's GHG emissions

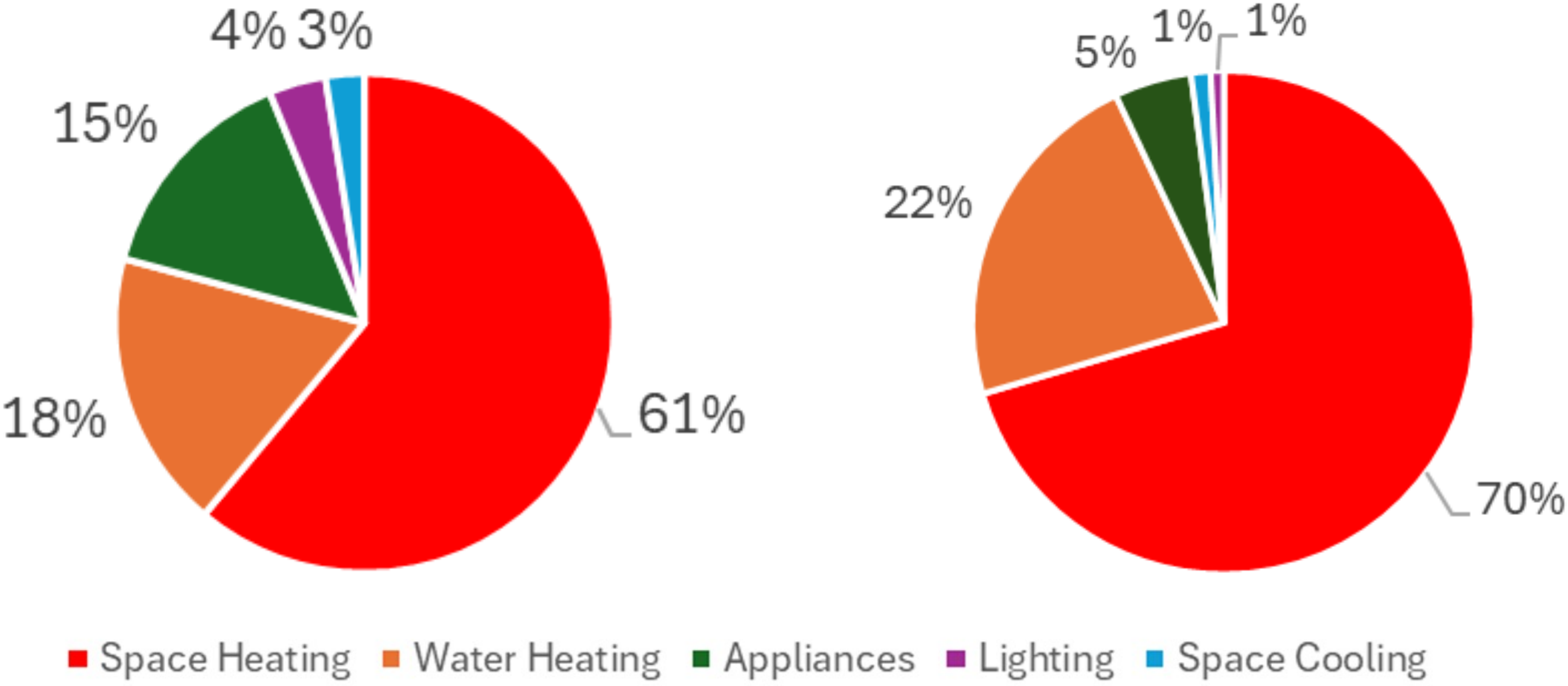


Building heating emitted 84 MT of GHG in 2020, or about 13% of total emissions…

but building heating accounted for >50% of Toronto's GHG emissions

Where do Ontario’s Building GHGs come from?

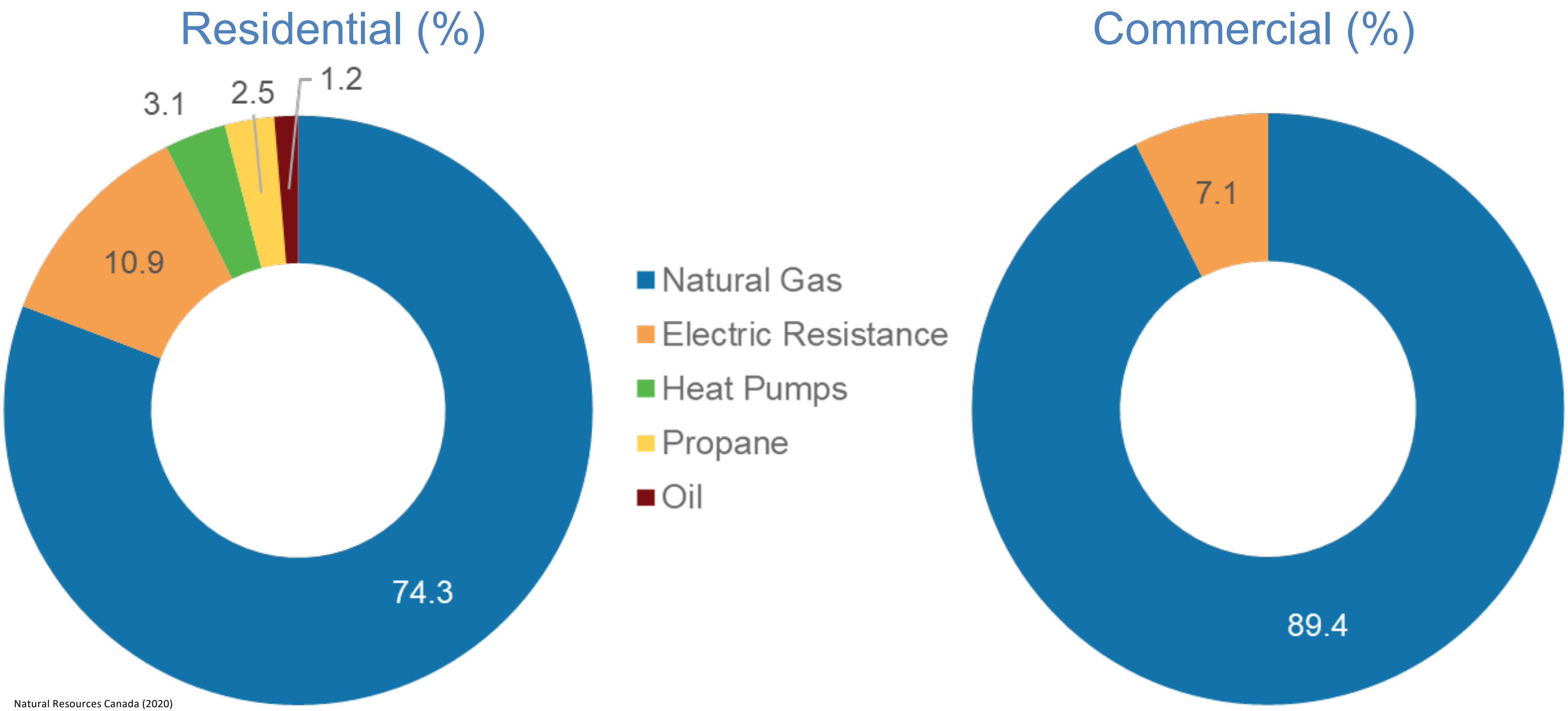
Residential Energy | Residential GHGs



Canada - Natural Resources Canada - Energy Use Data Handbook Tables (2020)

Courtesy MIES

How Do We Heat our Buildings in Ontario?

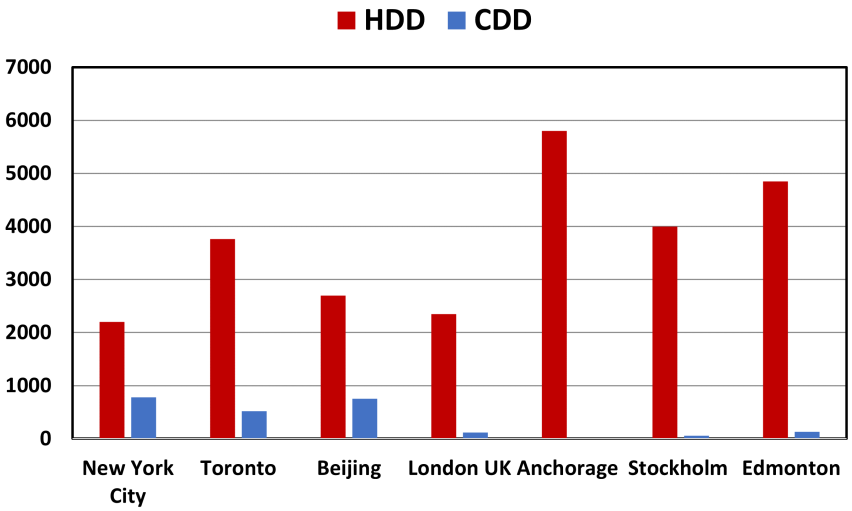


Natural Resources Canada (2020)

Courtesy MIES

How much Heating Energy Do we Need?

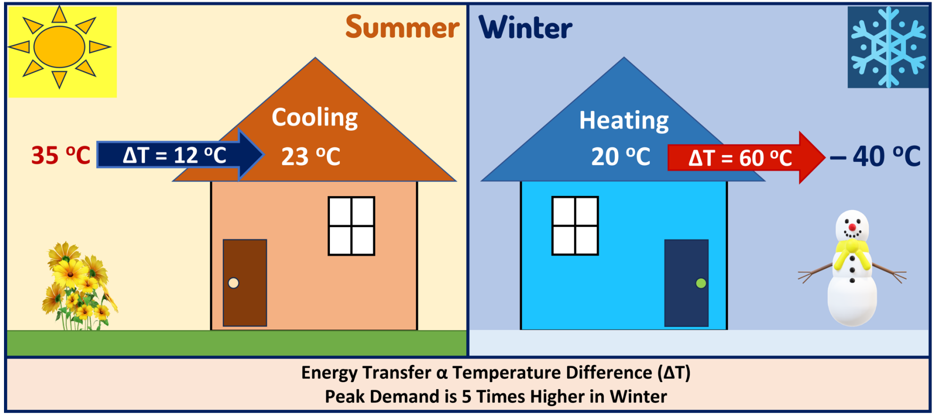
We Live in a Cold Climate



A measure of cold climate cities' building energy quantity demand.

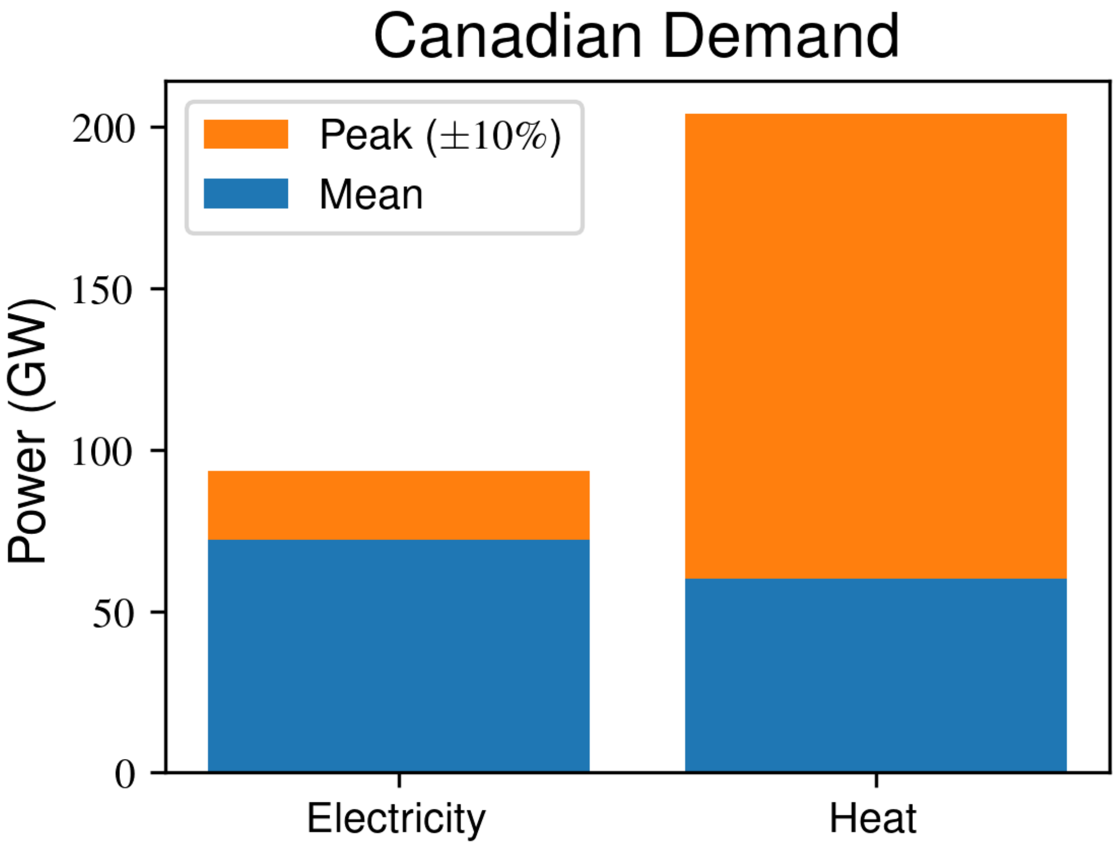
H/CDD – Heating/Cooling Degree Days

The Peak Heating is 5x Peak Cooling



Courtesy MIES

Canada's building heating demand is very large and very peaky



Climate change Impacts?

- **increases average winter temperatures**

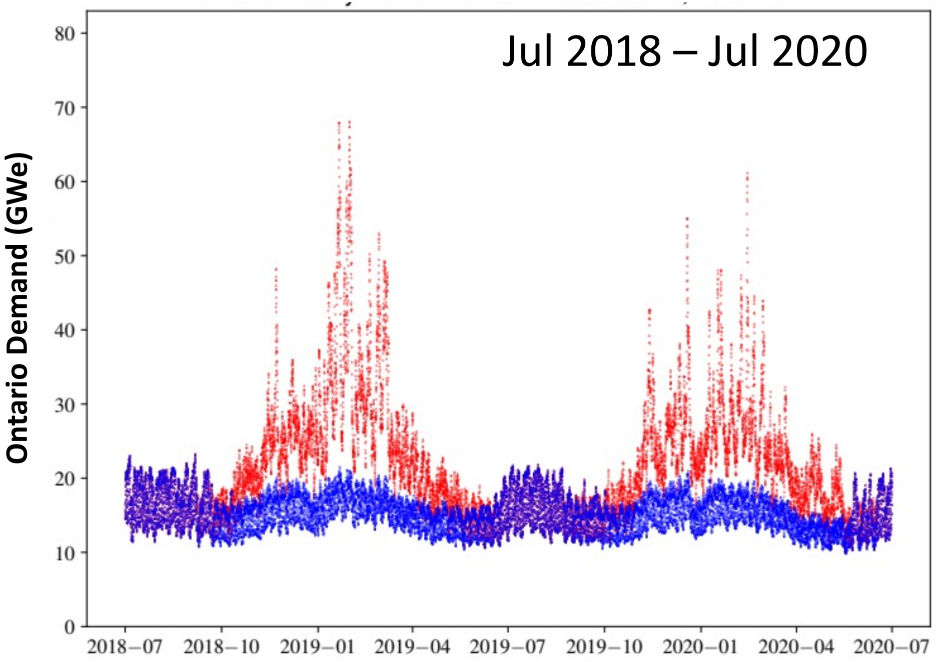
But also …

- **increases the risk of extreme cold spells of large geographic area and multi-day durations through polar vortex disruptions.**

Energy system designers need to build capacity to meet peak demand

Electrification of building heating must account for the impacts on the grid (1 of 2)

Ontario Hourly Power Demand – 30% GSHP, 70% ASHP

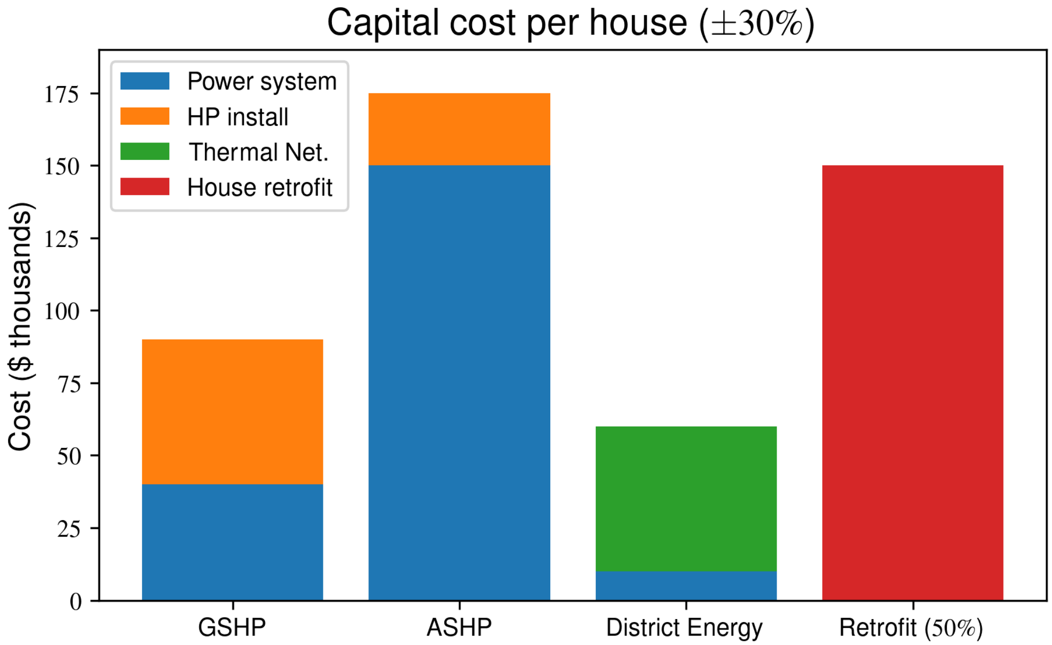


ASHP – Air Source Heat Pump
GSHP = Ground Source Heat Pump

Actual electricity demand (blue), plus modelled demand (red) if natural gas heating had been replaced by 30% ground source heat pumps (GSHP) and 70% air source heat pumps (ASHP).

Source: Boltzmann Institute

Electrification of building heating must account for the impacts on the grid (2 of 2)



ASHP – Air Source Heat Pump
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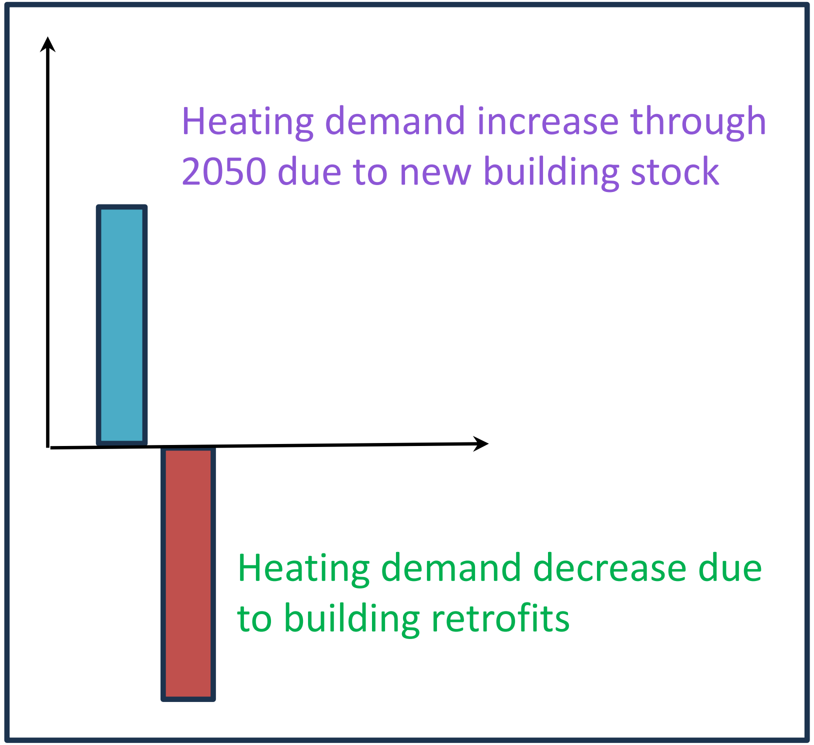
At-scale capital costs per house of heating options need to include power system expansion for peak demand increase and building retrofit costs.

Source: Boltzmann Institute

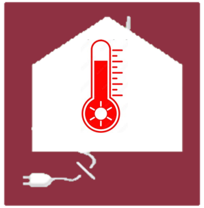
Building heating demand – today and outlook

Heating demand through 2050 is assumed to remain ~ flat

This may be optimistic; need for options if so



Climate Action: Requires us to address these problems



24% of Ontario’s carbon emissions from building heat system

+60% is lost to environment

~5-9 TWh (6-9%) curtailed

Electrification: demand increase 2-5 times

Ontario's Natural Gas (NG) heating demand is 191 TWh

The Potential: Ontario's Total Unutilized Heat Energy Resources

+380 TWh

64 TWh_t Industry End Use Losses

30 TWh_t Commercial/institutional End Use Losses

10 TWh_t Centralized NG Peaking Power Plants

9 TWh_e Curtailed Electricity

21 TWh_t Cooling Process Energy

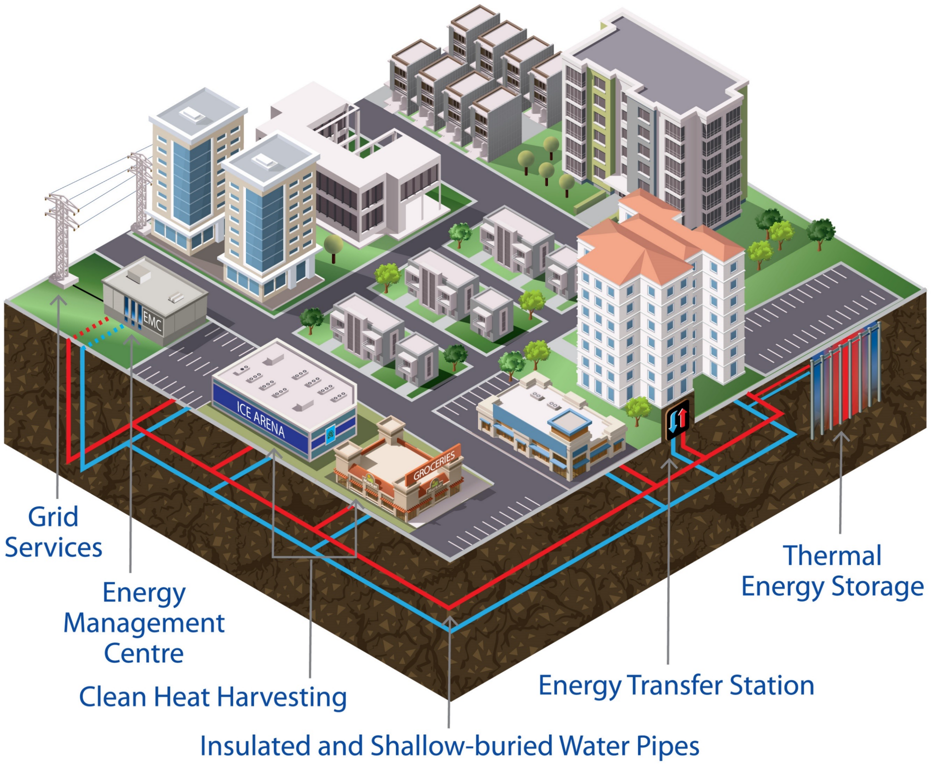
250 TWh_t Nuclear

Thermal Networks

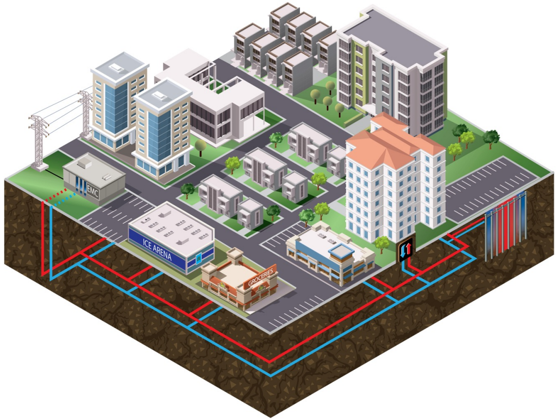
What are Thermal Networks?

Thermal Networks (TNs) **are a class of energy infrastructure with growing importance for Canada.**

- District Energy systems as public utilities
- A network of shallow-buried water pipes
- Buildings are both consumers and prosumers of heat
- Thermal Energy Storage, with peak and seasonal capacities comparable to natural gas storage
- 200+ district systems in Canada, about 2% of Canada's heat demand and growing



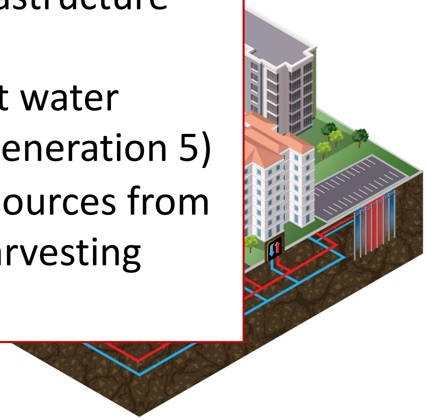
What are Thermal Networks? (6 big ideas)



What are Thermal Networks? (6 big ideas)

1. District Energy Systems:

- Deliver heat to new and existing non-rural buildings through networks of (insulated, shallow buried) water pipes
- Operated as public utilities, paying for infrastructure through rates
- Originally steam (Generation 1-3), now hot water (Generation 4) or ambient temperature (Generation 5)
- Achieve net zero GHGs by migrating heat sources from fossil fuels to clean heat sources and by harvesting existing clean heat



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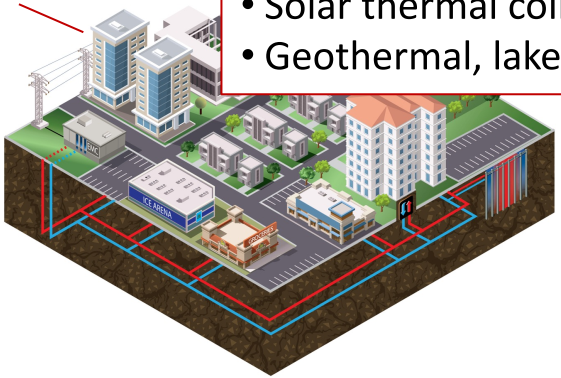
2. Clean Heat Harvesting:

- Community-based low-grade heat sources, e.g. building AC, waste water, data centres, supermarkets, ice rinks, subways, industrial heat
- Nuclear and biomass Combined Heat and Power (CHP)
- Solar thermal collectors
- Geothermal, lakes & oceans, mines



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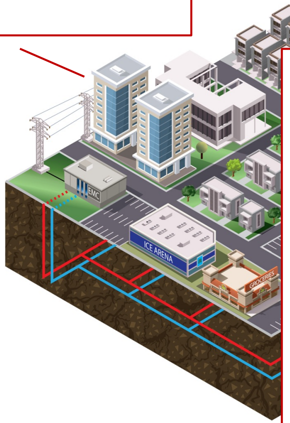

3. Thermal Energy Storage (TES):
- TES at a variety of capacities to address short-term to seasonal variations in heat demand
- Cost is a small fraction of electrical storage – seasonal TES can economically store summer heat for use in winter for whole communities
- Smaller, fast responding TES buffers between steady heat supply and diurnal demand fluctuations

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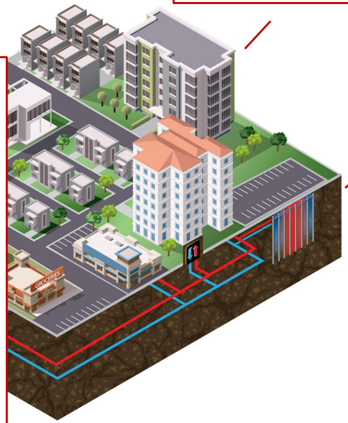
4. Grid Services:

- Coupling with TNs (and their TES) enables (nuclear) CHP plants to provide dispatchable power for electricity grid
- TNs with TES can provide low-cost grid demand response services
- Storing CHP heat in TES, on-demand, can reduce curtailment, improve utilization of variable renewables (wind, solar PV)



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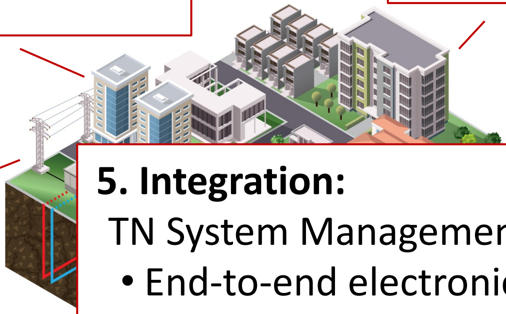

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5. Integration:

TN System Management
- End-to-end electronic monitoring and control
- Use TES, adjust water temperatures to optimize performance, use of available heat

Thermal Corridors
- City-wide DES/TES interconnections
- Connections to large Heat Harvesting - e.g., Nuclear CHP
- Distances up to 100 km or more

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6. Building HVAC:
- Most connections to hot-water DES require modest investments in building HVAC (e.g. heat exchangers, air handling units)
- Retrofit of steam-based building HVAC is much more challenging – addressed through interim solutions that manage changes over the HVAC and building life-cycle

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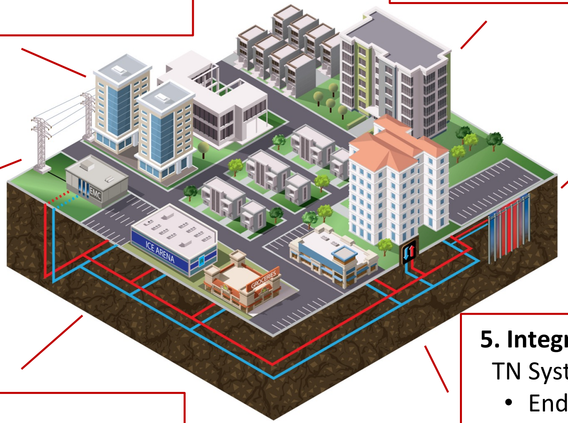

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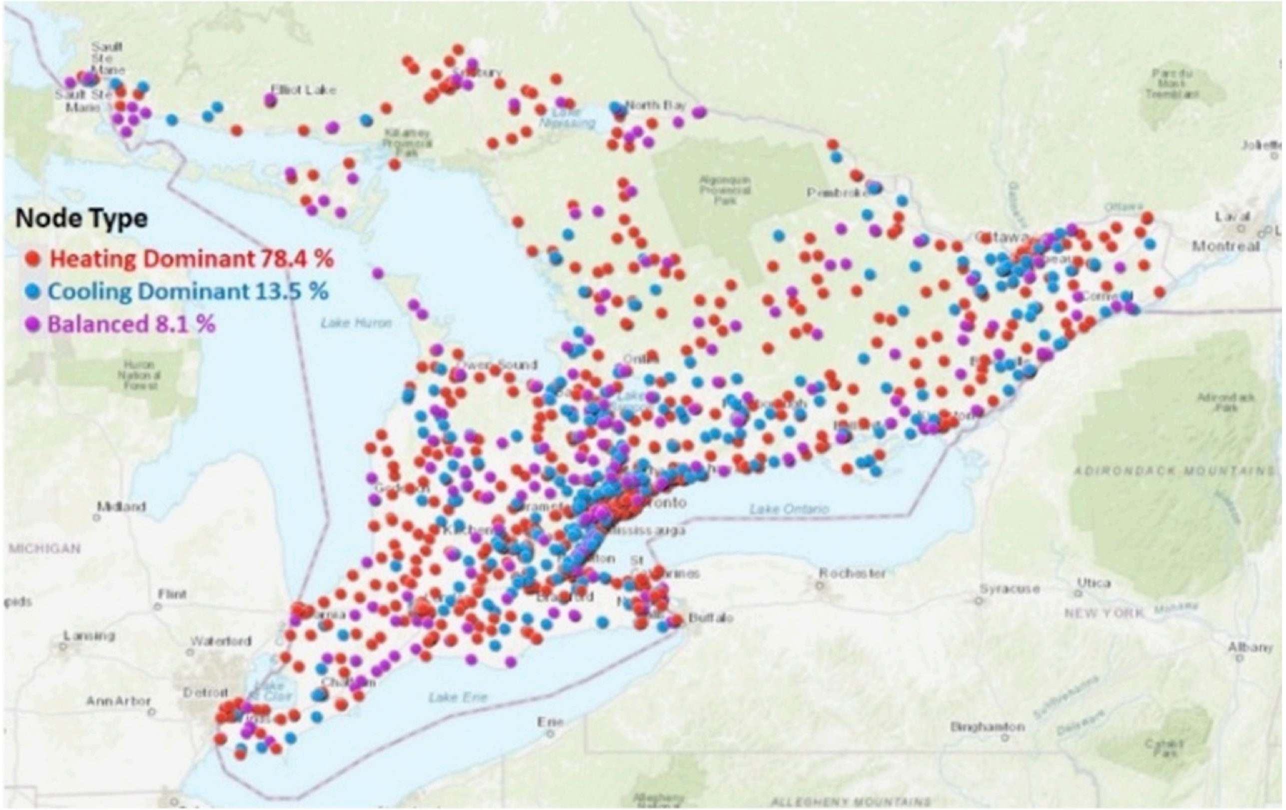
TN planning begins with Heat Mapping

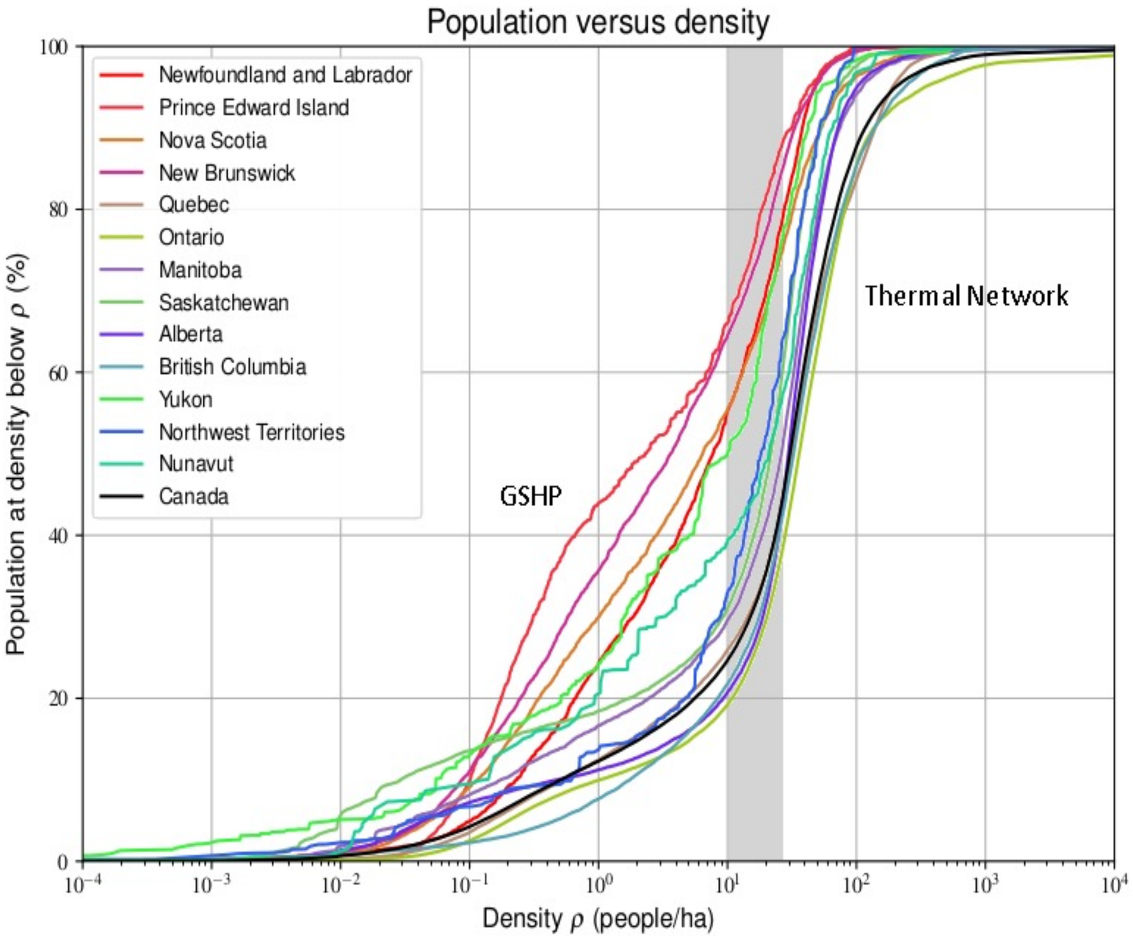
Mapping of heat sources and heat demand, with magnitudes and temporal characteristics, is necessary to guide planning and prioritization of Thermal Networks.



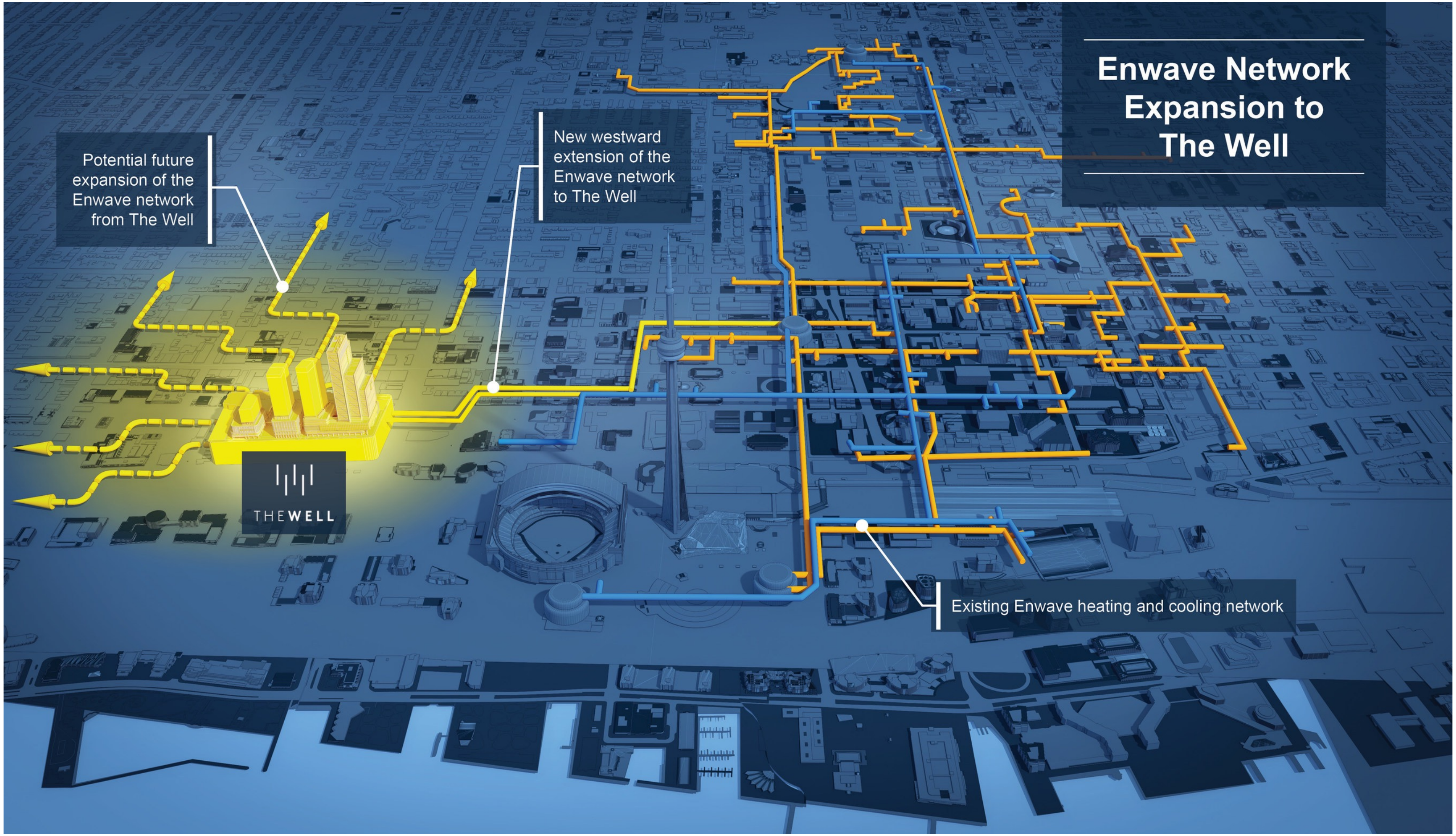
Courtesy MIES

Thermal Network economics work best for urban areas

Up to ~70% of Canada's population Is estimated to have sufficient density to be considered for connecting to TNs.



Thermal Networks Exist and Work



Source: www.enwave.com

Thermal Networks in practice

- Shallow-buried, pre-insulated pipes.
- Disruption not unlike other municipal infrastructure.
- Installed above other infrastructure with minimal cover – freezing not a problem.
- Widely used in Canada since about 1982.
- Cost for TN distribution systems ***and*** building connections is ~ $1000/kW to $3000/kW - comparable to costs for electricity distribution system capacity increases.

- Technology is evolving.
- Smaller diameter PEX pipes come in rolls.
- Can be routed around other utilities, trees etc.
- Municipal cooperation on Right-of-Ways is important.

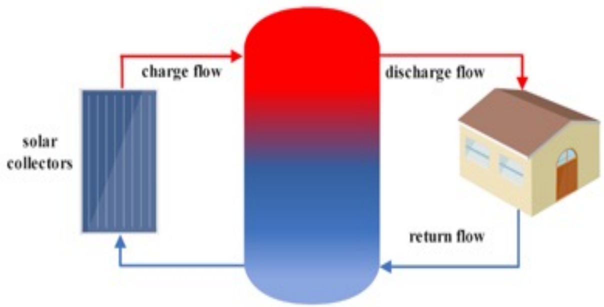
Building requirements for connecting to Thermal Networks

Typical Energy Transfer Station – Courtesy of FVB Energy

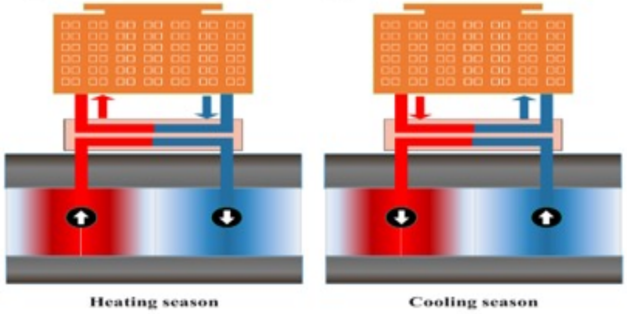
- Energy Transfer Stations (ETS) are installed within the building to replace existing heating equipment.
- Through heat exchangers, both space and domestic hot water heating is provided.
- For small buildings or residences, gas furnaces can be replaced with hydronic air handling units with control valves and meters. Usually, the hydronic air handling units are smaller than a furnace and can directly replace them - just like getting a new furnace.
- Heat exchangers for on-demand domestic hot water eliminate the need for hot water tanks.
- These in-building components, which cost less than a gas furnace and hot water tank, would normally be installed and maintained as part of the TN service and covered by monthly charges.

Thermal Energy Storage Technologies

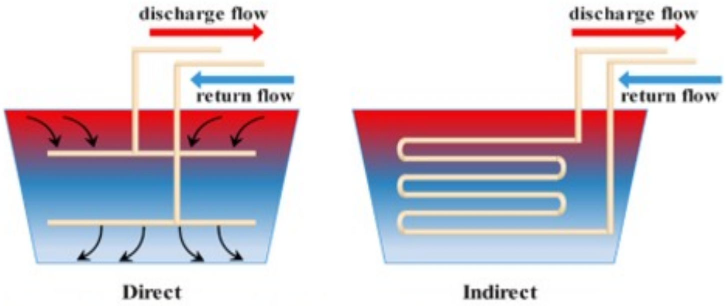
Tank Thermal Energy Storage



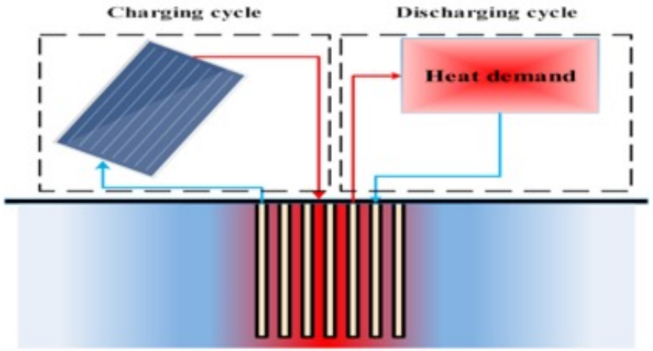
Aquifer Thermal Energy Storage



Pit Thermal Energy Storage



Borehole Thermal Energy Storage



Source: A. Pourahmadiyan, M. Sadi, and A. Arabkoohsar, Seasonal thermal energy storage. INC, 2023

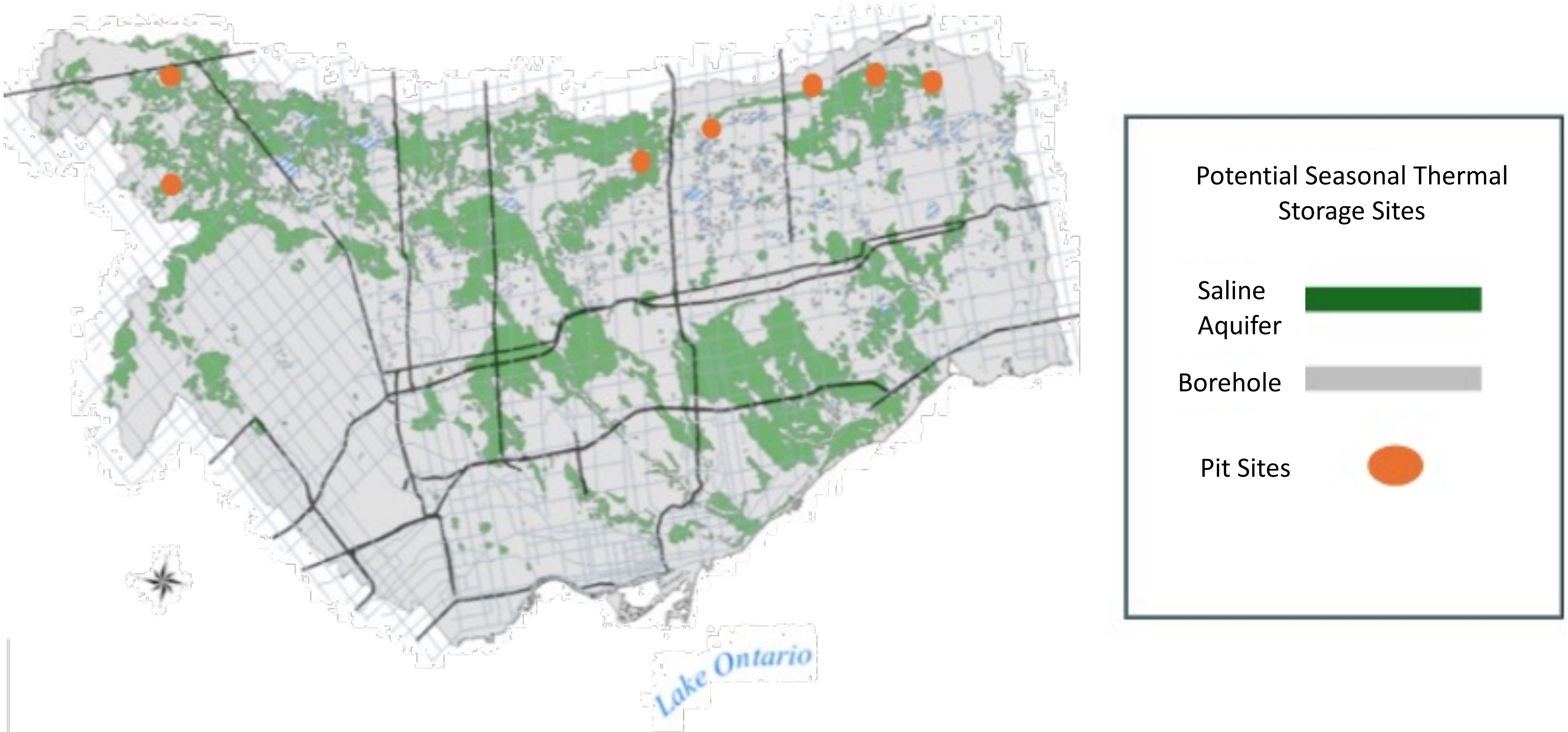
Tank Thermal Energy Storage

Markham District Energy – can provide 40 MW of heating capacity using excess heat from gas fired CHP plant and from heat pumps.

Enwave's "The Well"

Sourcehttps://group.vattenfall.com/press-and-media/newsroom/2022/germanys-largest-heat-storage-in-the-starting-blocks
www.enwave.com

Aquifer and Pit Thermal Storage Opportunities Exist in Ontario



Source: D. Ford and B. Wong, "Use of a Regional Hydrogeologic Model to Identify Candidate Areas for Borehole and Aquifer Thermal Energy Storage," GeoCanada 2010 - Work. with the Earth, pp. 1–4, 2010.
https://www.lioapplications.lrc.gov.on.ca/Pits_And_Quarries/index.html?viewer=Pits_and_Quarries.Pits_and_Quarries&locale=en-CA

Electrification of building heating must account for the impacts on the grid - *revisited*

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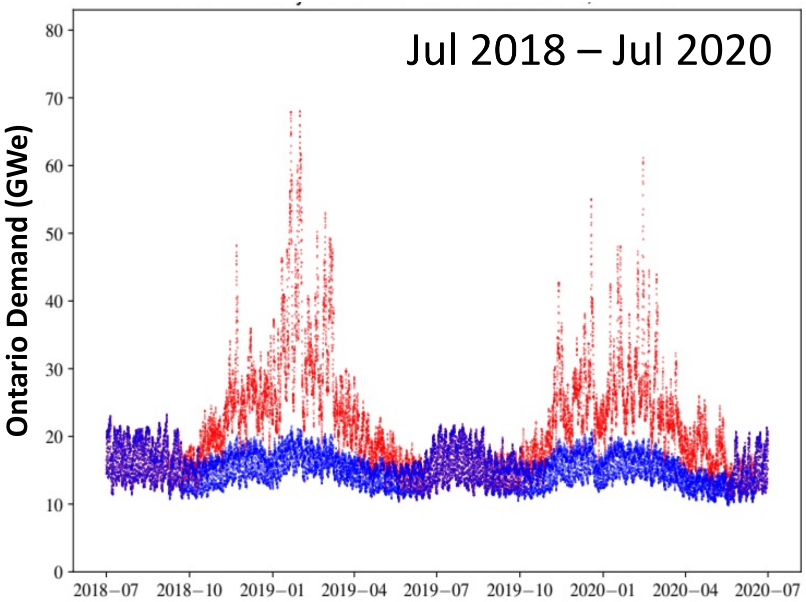
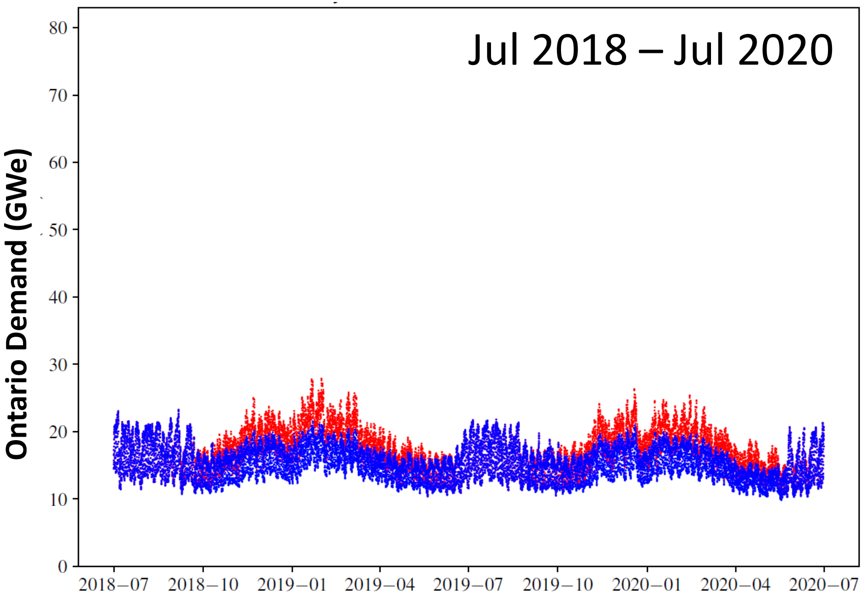


Actual electricity demand (blue), plus modelled demand (red) if natural gas heating had been replaced by 30% ground source heat pumps (GSHP) and ***70% air source heat pumps (ASHP)***.

Ontario Hourly Power Demand – 30% GSHP, 70% Thermal Networks



Actual electricity demand (blue), plus modelled demand (red) if natural gas heating had been replaced by 30% ground source heat pumps (GSHP) and ***70% Thermal Networks.***

Source: Boltzmann Institute

Thermal Networks – Potential Benefits

- harvest clean residual heat
- utility models finance building connectivity (build into rate base – a monthly meter bill & amortize over long time)
- short-term and seasonal heat storage economical today
- market-ready solutions that help grid modernization
- leverage other strategic clean energy investments (e.g. nuclear)

Thermal Networks in Summary

The Opportunity

- a decarbonization pathway with many environmental, social and economic benefits
- a *backbone* solution for Canada's transitioned clean heat infrastructure
- heat up to ~50-70% of Canada's buildings by 2050, while saving hundreds of billions of dollars compared to the alternative electrification pathway

The Challenges

- Need for supporting policy and regulatory frameworks
- Scale up by ~20-30 x today
- Connect and serve over 10M buildings
- Mitigate urban infrastructure disruptions

Thermal Networks and Nuclear Energy

Canada is on a path to increase its nuclear energy supply

- Canada is a Tier 1 nuclear nation.
- Canada is on a path to increase its nuclear energy supply by ~3x, or ~50 GWe.
- The path will see deployments of both large and small new nuclear.
- New nuclear has the potential to both service TNs (large nuclear) and be integrated into TNs (small nuclear).

Darlington NGS

Note: Other Pathways to decarbonize TNs (e.g. variable renewables, biomass, hydrogen) are both possible and necessary.

Generation III+ Large Reactors: Examples

MONARK

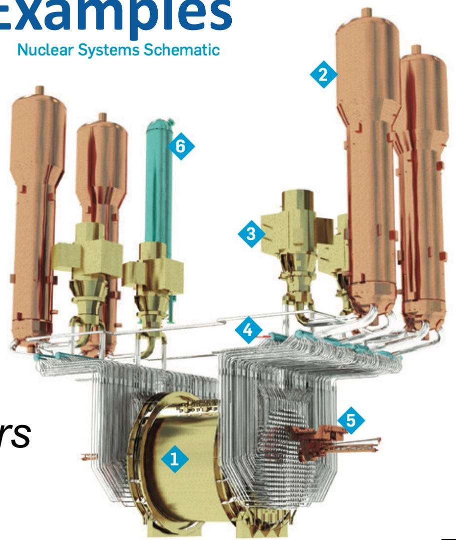
~~Enhanced CANDU 6 (EC 6)~~

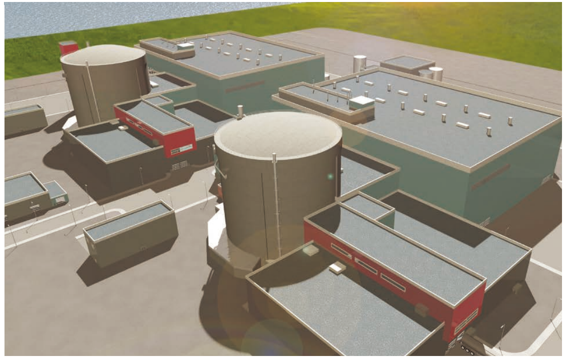
PHWR – ~~740 MWe,~~ 2084 MWt

1000 MWe

- *Generation III+ (passive safety)* 70+
- *Capacity Factor > 92%, Lifetime ~~60+~~ years*
- *Load Following capability*
- *Combined Heat and Power (CHP) option*

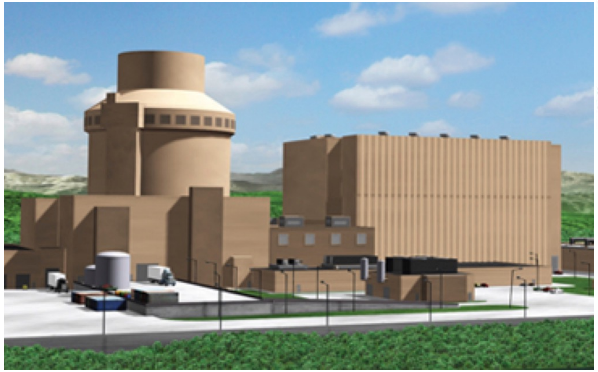
Nuclear Systems Schematic

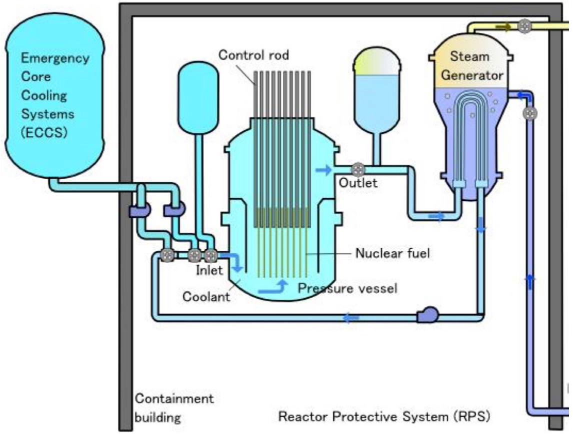




Westinghouse AP1000

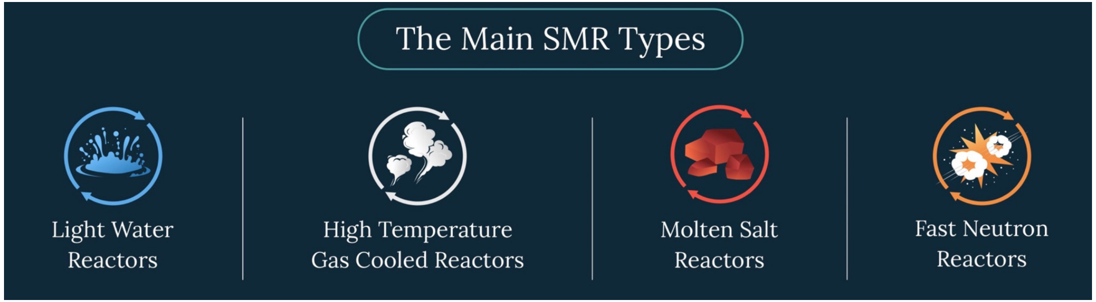
PWR – 1110 MWe, 3415 WMt





Adapted from: AtkinsRealis, Westinghouse

SMRs - Many Designs



Water Cooled Reactors
- PWRs, BWRs, PHWRs*
- Gen III+
- 300-400°C

High Temperature Gas Cooled Reactors
- Gen IV
- Helium cooled
- 600-900°C

Molten Salt Reactors
- Gen IV
- Atmospheric pressure
- 600-700°C
- Moderated or fast neutrons

Fast Neutron Reactors
- Gen IV
- Liquid metal/sodium cooled, no moderator
- 400-600°C

* Can operate with no fuel enrichment

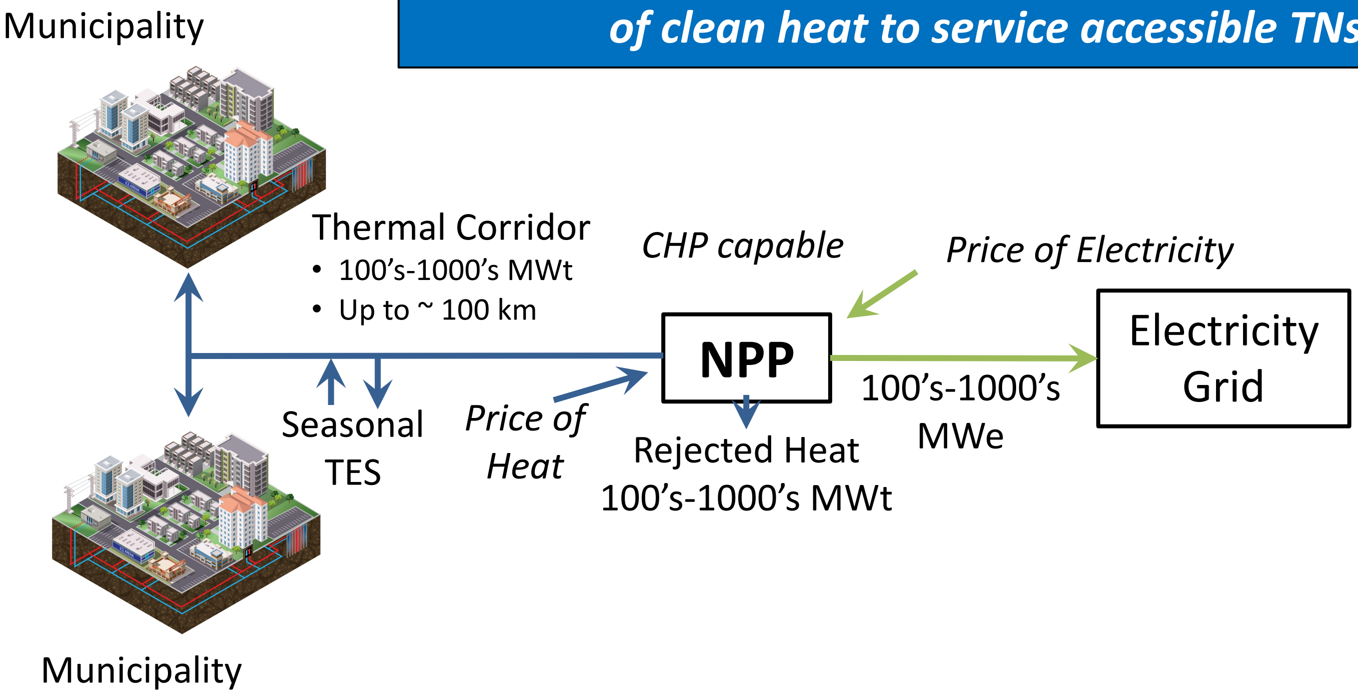
Low-Enriched Uranium Fuel - ~5-20% enrichment

Designs from each of the main SMR types are in play in Canada for multiple energy markets: electricity (grid and micro-grid), hydrogen, industrial and building heat

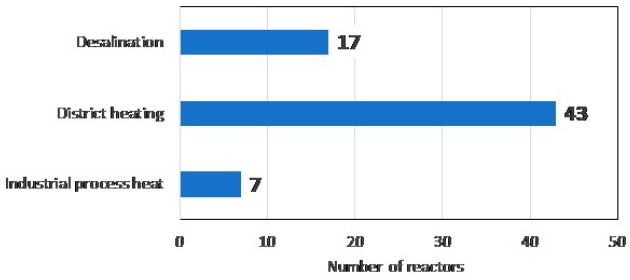
Large (Grid-Scale) Nuclear servicing TNs.

The Scenario Described

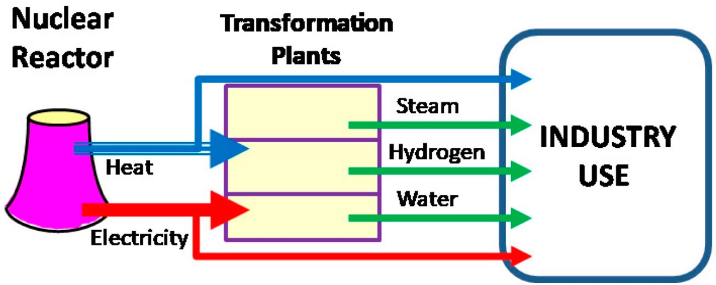
Ambition: by 2050, ~ 3-5 NPPs provide up to ~ 5-10 GWt of clean heat to service accessible TNs



There is extensive operating experience with NPPs and District Heating (1 of 2)

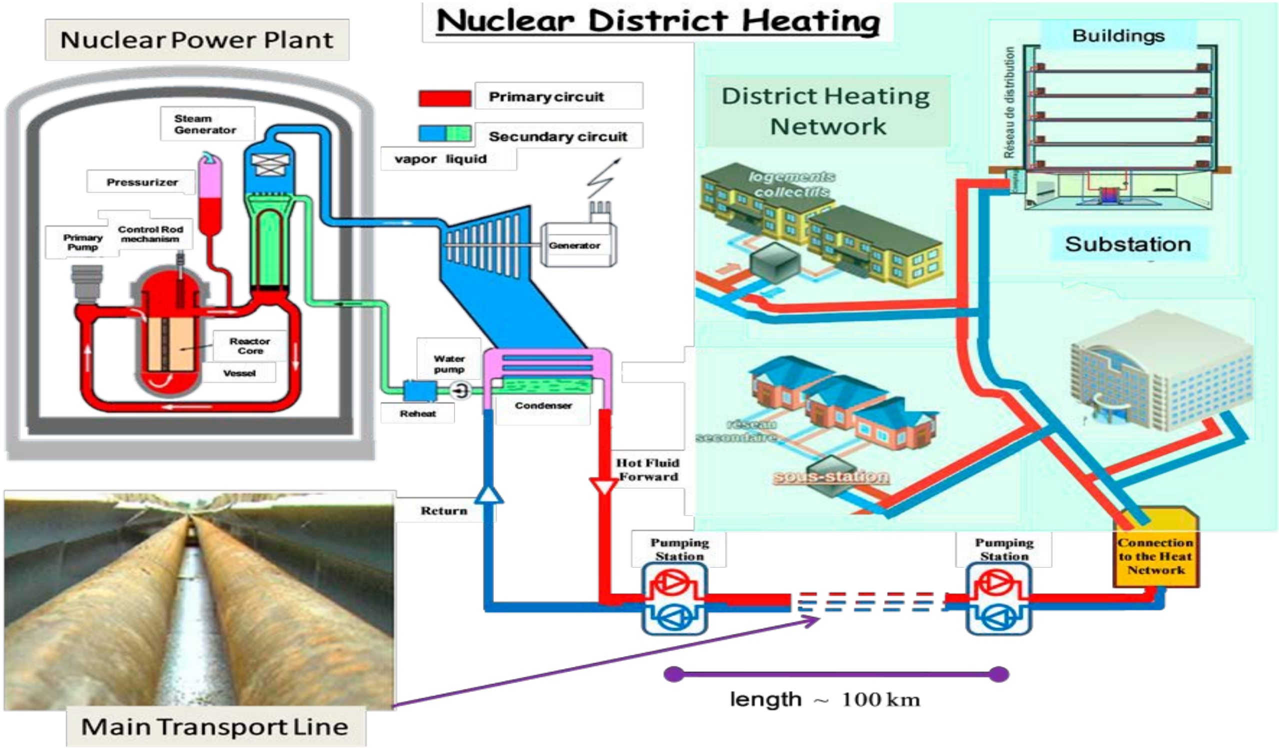


About 10% of the global nuclear fleet has been configured to successfully supply CHP for District Heating. >500 reactor years of experience. [IAEA 2019]



NPPs operating in CHP utilize a “Transformation Plant” to isolate the Nuclear Island from the downstream heat application and to prevent possible downstream radioactive contamination. [IAEA 2019]

There is extensive operating experience with NPPs and District Heating (2 of 2)



NPPs operating in CHP connect to the District Heating system through a heat transportation system. [Oliker 2022]

NPPs can service TNs at long distances

Source: REFUNA AG (2015b).

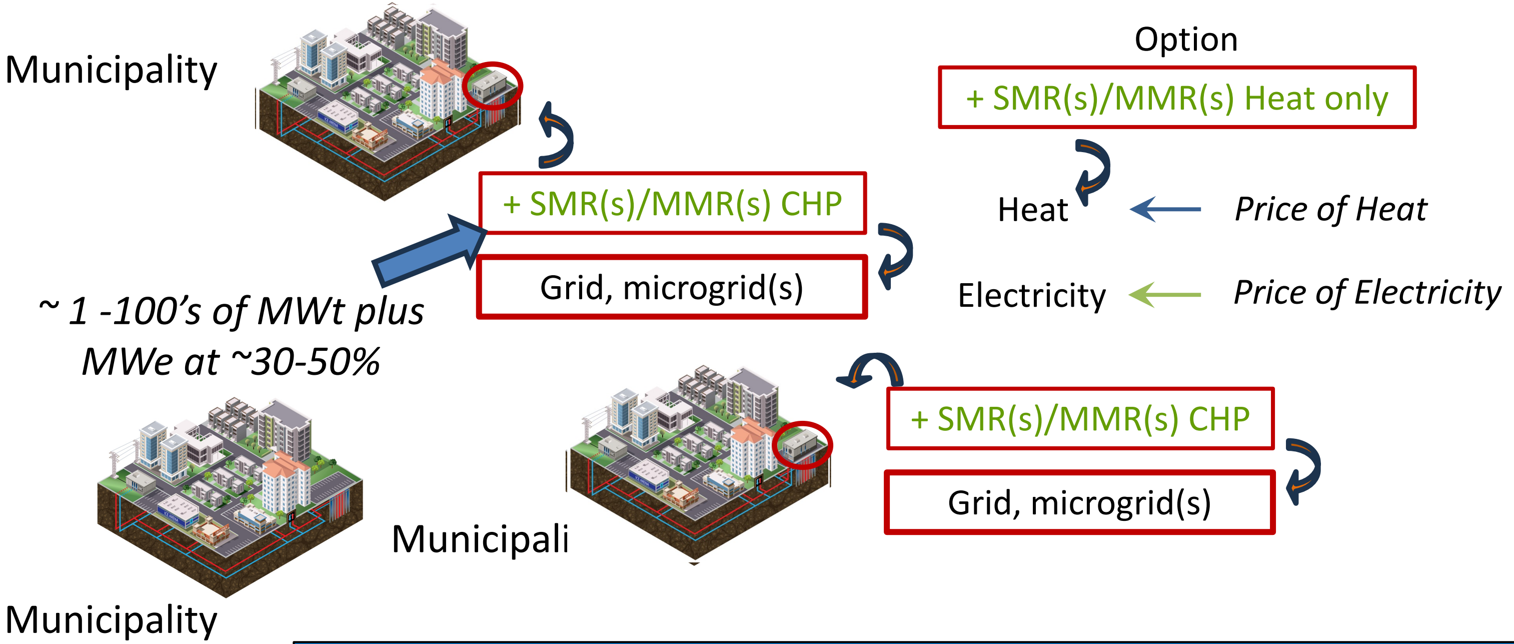
District heating network at the Beznau Nuclear Power Plant, Switzerland. [NEA, 2022]

Proposed heat corridor for NPP District Heating in China. [Chen et al. 2020]

Large (Grid-scale) Nuclear servicing TNs

- Nuclear planning is underway for grid-scale new nuclear in multiple provinces.
- There is extensive global operating experience with NPPs servicing District Heating.
- NPPs can supply clean heat to TNs at long distances.
- Most modern grid-scale reactor designs offer CHP as an option.
- The economics of nuclear CHP require a modest price for heat (1:6 rule-of-thumb)
- There are multiple ways that resiliency of heat supply from NPPs to TNs can be achieved.
- The capital costs for NPPs to service TNs are incremental.

Small Nuclear integrated into Thermal Networks.
The Scenario Described



Ambition: by 2050, ~ hundreds of SMRs/MMRs provide up to ~5-10 GWt of clean heat integrated into TNs across Canada

MMR – Micro Modular Reactor
(SMR with output < 5MWe)

Small/Micro Modular Reactors integrated into Thermal Networks

- Canada’s nuclear energy sector is moving forward with small/micro nuclear deployments.
- Each small/micro nuclear design offers improvements in safety and performance.
- Small/micro nuclear has a very small emergency planning zone.
- A fleet-of-fleets approach offers opportunities to reduce costs.

Recommendations

Recommendations

1 Towards a Canadian Thermal Network Strategy – Policy Recommendations

2 A Short Term Action Plan - beginning the journey

3 What might success look like - guiding the journey

4 A Notional Roadmap for TN deployments - sequencing the journey

Policy Recommendations

1. Launch public education and consultation to expand public understanding of Thermal Networks and acceptance of distributed energy resources and nuclear CHP

2. Recognize (waste) residual heat, as a strategically important form of energy. Promote the conservation and re-use of heat as a key enabler of Canada's net zero transition.

3. Formally recognize Thermal Networks as part of Canada's energy critical infrastructure, Deploy Thermal Networks at scale to make residual and renewable heat resources affordable, reliable and accessible.

4. Adopt a utility approach for Thermal Networks to eliminate barriers and provide options to support equitable, rapid decarbonization of building heating. Fund amortization of infrastructure and of building conversions through usage charges.

5. Integrate governance, planning and operation of Electricity, Gas, and Thermal Network infrastructures to create and leverage opportunities for synergies, greater efficiency and societal good in the energy sector transition in Canada by 2050.

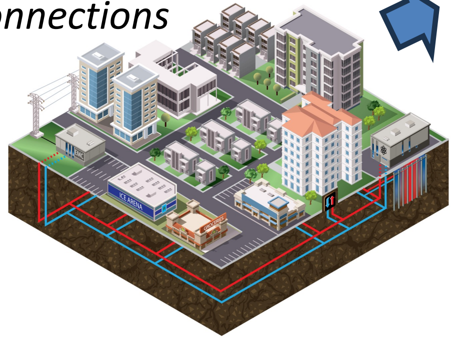
6. Assess the business case to configure nuclear power plants, at all scales, for Combined Heat and Power (CHP) , where they can provide economic heat to Thermal Networks, maximize the benefits of nuclear power

A Notional Roadmap

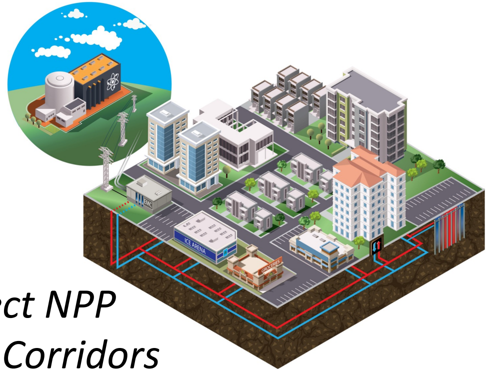
Decarbonize energy sources, harvest rejected heat, add SMRs/MMR CHP, add grid services

Create/expand DES, add TES

Build city-wide TN interconnections



Expand building connections to TNs



Connect NPP Thermal Corridors

***Ambition: by 2050, TNs* provide up to ~40 GWt (140 GWt peak) of Canada's building heating demand**

Questions?

To read the Position Paper:

https://www.eng.mcmaster.ca/mcmaster-institute-for-energy-studies/featured-publications/#thermal-networks-position-paper