Carleton University

Carleton Energy Master Plan

Final Report

Job number 274250

Arup Canada Inc.
121 Bloor Street East
Suite 900
Toronto ON M4W 3M5
Canada
www.arup.com

ARUP

1 Executive Summary

The new Energy Master Plan is a strategic plan that depicts a roadmap for Carleton University to become a carbon neutral campus by 2050. The strategic plan is the outcome of an iterative, collaborative process between the University's stakeholders, including but not limited to, members from Energy and Sustainability Services, Facilities Management and Planning, researchers and professors from the University's academia and external consultants. It is a holistic, multi-pronged approach that considers and responds to the University's existing infrastructure and assets, policies and standards, future development plans, and past project experiences. The Energy Master Plan is estimated to significantly reduce the campus' equivalent carbon emission by 80% relative to 2005 levels, with the remaining 20% emission to be offset via purchasing carbon offsets, procuring renewable power purchase agreements, or developing offsite renewable system(s). Approximately 25,600 metric tonnes of CO_2 will need to be reduced to achieve 80% reduction from 2005 levels. The Energy Master Plan takes into consideration the campus' direct and indirect equivalent carbon emissions (Scope 1 and 2) related to utility consumption; it does not include carbon emissions related to transportation and other areas (scope 3) including waste, food and materials.

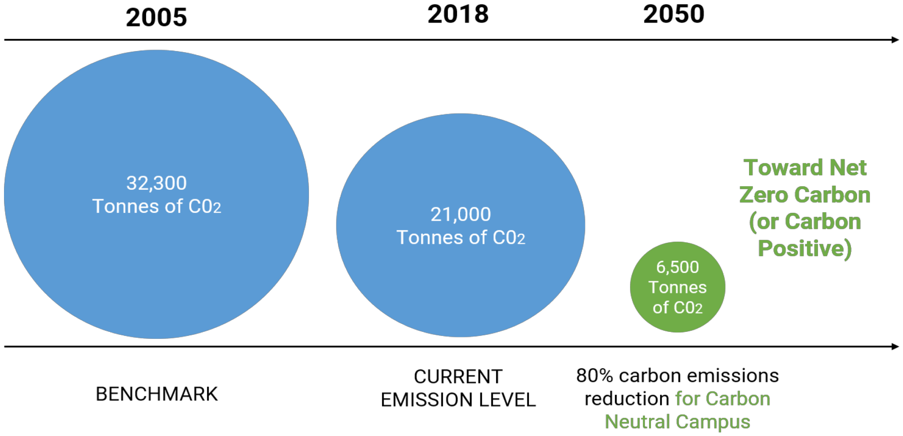


Figure 1 - Campus Carbon Emission Reduction Goals

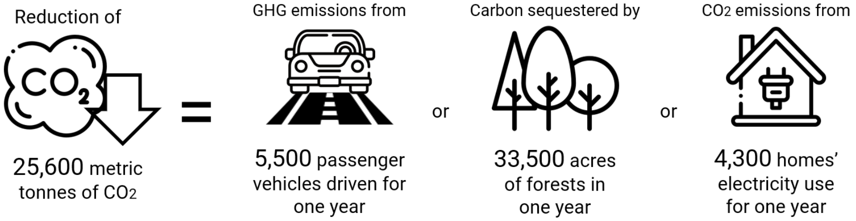


Figure 2 - Campus Strategy Carbon Emission Reduction Results Equivalency

Carleton University's carbon neutrality goal is an ambitious step forward that is in alignment with federal and local government policies and strategies toward climate change and its threat to our environment, health, economy and collective future. It demonstrates the University's leadership and commitment to our collective effort to mitigate and reduce the impact of climate change. The University's carbon reduction target is also in alignment with the carbon reduction targets of other major Canadian universities and leading institutions in North America.

As the consumption of natural gas on campus represents over 85% of its carbon emissions, the Energy Master Plan primarily focuses on a utility strategy that completely transforms the existing utility infrastructure on campus to a new low-carbon energy supply system. The utility strategy is to transition the campus away from its legacy gas-based district steam heating system to a low-temperature electric hot water system using electric boilers housed in three new nodal plants across the campus. In addition to resulting in deep reduction in carbon emission, the utility strategy will also provide renewal to the aging existing utility infrastructure, enhancing the system's redundancy and resiliency to support the campus' operations. The nodal plant approach provides greater flexibility in phasing in construction and building transitions. The new low-temperature hot water system also enables greater design flexibility for the University to incorporate a wide range of efficient and renewable energy systems such as geothermal, sewage heat recovery and air-source heat pump systems.

The proposed utility strategy was selected after an extensive evaluation process which screened then analyzed a long list of technologies and strategies, see Figure 3. The process included the use of a performance evaluation framework incorporating criteria such as carbon emission reduction, costs, and technology integration, see Figure 4. This was all done in collaboration with the University's stakeholders.

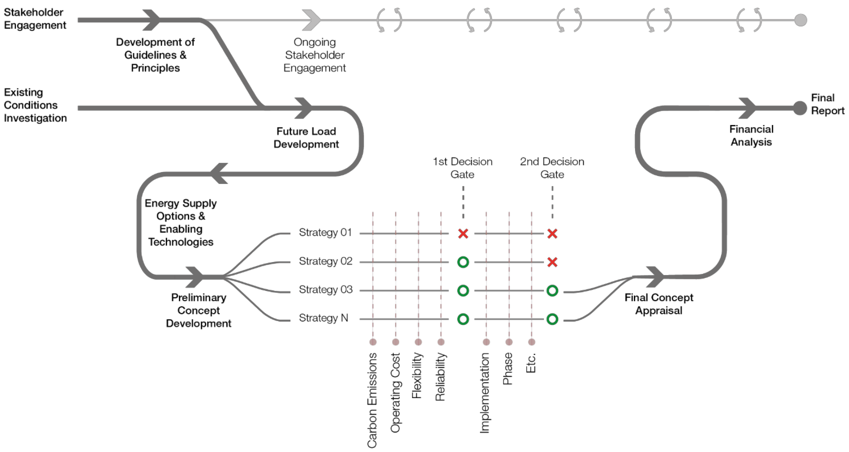


Figure 3 - Master Plan Process

Figure 4 - Key Performance Drivers

To achieve carbon neutrality, the campus will also require significant energy performance improvements to its existing building assets. In addition to building and infrastructure retrofits, the University will also need to develop more aggressive energy performance standards for future development and onsite renewable system integration. The Energy Master Plan includes considerations and indicative performance requirement levels for building retrofit and new construction, but further analyses are required to set out definitive targets in these areas.

As part of the Energy Master Plan, an implementation framework, Figure 5, has been developed to outline a list of short and long-term action items required to implement the carbon neutral strategy. Other key project milestone dates such as new development or major equipment renewal can be added to the framework to identify design and construction synergies. The implementation framework also serves as a way to track progress of the implementation of the carbon neutral strategy. The implementation framework is intended to be a working document that require periodic review and update in order to respond to the future changes and uncertainties, technological advancement, and changes in government policies and regulations. The outbreak of the COVID-19 pandemic is an example of disruption that could alter the plan and has already had a significant impact on the forecast included in this plan.

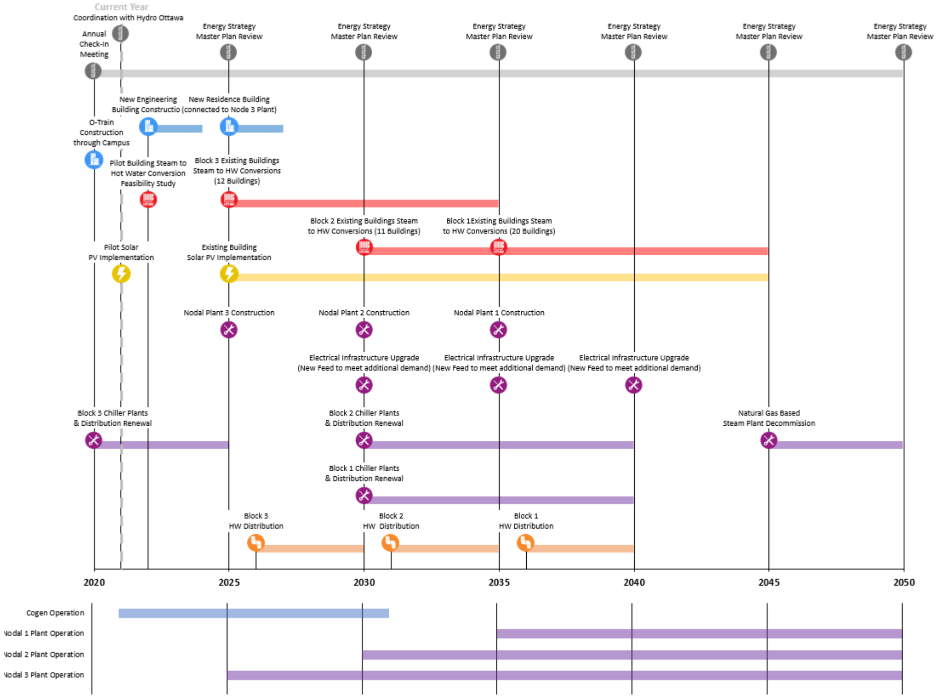


Figure 5 - Campus Strategy Implementation Framework

Currently, the business case for the proposed carbon neutral strategy is not financially attractive. This is partially due to the considerable excess capacity in the existing heating system that could be used for future growth which lowers the capital cost in the business-as-usual scenario. However, it should be noted that low-carbon technologies are advancing at an accelerated pace, increasing their system efficiency, reliability, and lowering their capital cost every year. Examples include battery energy storage system and solar photovoltaic system, which have seen their first cost reduced and efficiency increased considerably in the past decade. Other emerging low-carbon energy supply options such as hydrogen and deep geothermal are also showing potential as viable future technologies. These emerging technologies have the potential to be incorporated into the proposed carbon neutral strategy and optimize the economics as the technologies mature.

In today's continuously changing world with rapid technological breakthrough and advancement, changing business and economic landscape, and social and geopolitical uncertainties, a long-term strategic plan such as the Energy Master Plan will need to be updated periodically in the future in response to the unpredictable and inevitable changes. The Energy Master Plan and the proposed climate neutral strategy is developed based on a holistic evaluation of key performance drivers, benefits, cost and risks. It is a pragmatic, bold step forward for the University and the academic community at-large paving the way for other similar institutions to respond to the climate emergency and providing a leading academic environment for students and research.

Contents

2 Introduction

2.1 Overview of Energy Master Plan

The Carleton University's Energy Master Plan started with a clear vision and objective – to develop a utility strategy for the campus to become carbon neutral by 2050. Building upon the previous energy master plans and the successful results of the initiatives implemented at various levels of the campus, this Energy Master Plan takes a holistic view of developing a strategic plan that would transform the campus' existing utility infrastructure to a low-carbon system. The master planning process considers and responds to the campus' existing utility infrastructure conditions, future capital development plan (2016 Campus Master Plan), policies, programs, other strategic plans, and key performance drivers; it was an iterative, collaborative process with key inputs from the University's Facilities Management and Planning team, as well as professors and researchers from the academia. This report summarizes a carbon neutral strategy for the campus, action items in the short and long-term, and an implementation framework that reinforce performance reporting, all to support the campus in transforming its utility infrastructure system and provide increased reliability and safety to its operation, to continue its academic and research excellence and achieve the University's carbon reduction goals to become a carbon neutral campus by 2050.

2.2 Objectives and Goals

Carleton University has a strong commitment to embedding continuous environmental and sustainable improvement in its operation. To further the success of these commitments, the University's objectives and purpose for this Master Plan encompass the following:

1. Reduce Carleton University's Environmental Footprint:
    - Develop a phased plan to reduce our GHG emissions and to meet the Government of Canada reduction targets by 2030 and to become a carbon neutral campus by 2050 [1];
    - Develop a plan to expand our current district energy infrastructure to support flexible campus growth;
    - Utilize innovative generation, distribution and delivery technology to increase our efficiency and lower our environmental impacts
2. Reduce Utility Operational Costs:
    - Optimize utility operation costs;
    - Maximize the net economic benefit to Carleton by looking at renewable energy generation;
    - Propose methods for substantial gains in building efficiency and thermal efficiencies within the production and distribution of building heating and cooling loads;
3. Increase Reliability and Safety:
    - Increase the system redundancy and resiliency;
    - Mitigate the impact of operational failures and interruptions.

The University has committed to reduce its carbon emissions 50% by 2030 below 2005 levels and is now developing this plan to become a carbon neutral campus by 2050. Based on the previous Energy Master Plan (2018-2021), the University has been continuously reducing its energy and carbon footprint from 2015 to 2017 as shown in Figure 6.

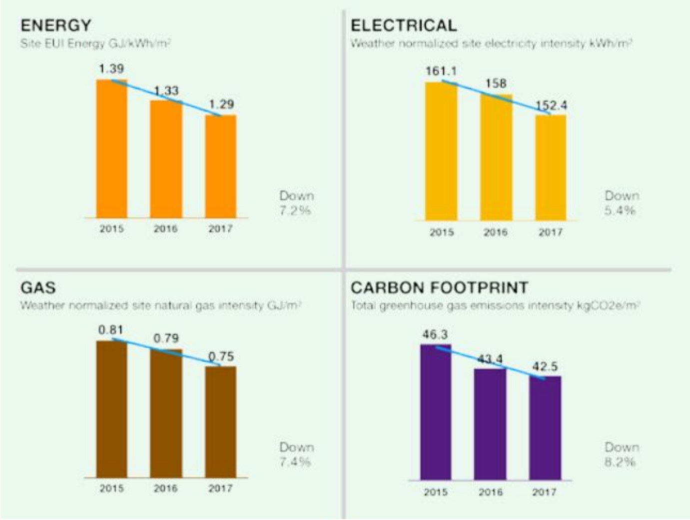


Figure 6 - Carleton University Energy and Carbon Footprint Reduction

Countries and cities, including Canada and the City of Ottawa, have declared a Climate Emergency in response to climate change and its threat to our environment, our healthy, our economy, and our future. At both the local and global scale, the next decades are critical to contribute meaningfully to tackle climate change and reduce our carbon footprints. Carleton is committed to its climate action goals, to challenging current industry practices and transitioning from its carbon-intensive energy systems into more sustainable operational practices that drive significant positive change for the community and the environment .

---

[1] Original objective was net-zero energy consumption campus. This objective was refined during the Master Planning process

2.2.1 Alignment to Carleton's Existing Strategies

Carleton University's Energy Master Plan has been developed with consideration and recognition of Carleton's other campus-wide strategies and plans. Some of these strategies include the 2020 Strategic Integrated Plan, 2018-2019 Sustainability Annual Report, 2018-2021 Energy Master Plan, and the 2016 Campus Master Plan Update.

The 2020 Strategic Integrated Plan showcases three landmarks, the Rideau Canal, Bronson Avenue, and the Pasapkedjinawong (Rideau River) that converge around the campus and are used to frame Carleton University's aspirations: Share Knowledge, Shape the Future, Serve Ottawa, Serve the World, Strive for Wellness, and Strive for Sustainability, see Figure 7. The Energy Master Plan supports the third strategic direction to promote and implement sustainable practices around the campus. In alignment with the Strategic Integrated Plan, the Energy Master Plan is inspired by the Rideau River as a symbol to represent the resiliency and the responsibility required to curb climate change.

The 2018-2019 Sustainability Annual Report highlights commitments and accomplishments from Carleton University which shaped this Energy Master Plan. Some notable achievements from the University include 11 Green Globes certified buildings and a 35% reduction in emissions intensity (since 2009) among others shown in Figure 7. Further information regarding sustainable initiatives from the University can be found in the annual sustainability reports.

The previous 2018-2021 Energy Master Plan was released with initiatives regarding the future use of buildings located on the campus and existing building upgrades. Building on top of this work and to align with Carleton's goals, this new Energy Master Plan provides a holistic and strategic direction to reduce the overall campus carbon emissions and targets a 2050 carbon neutrality goal.

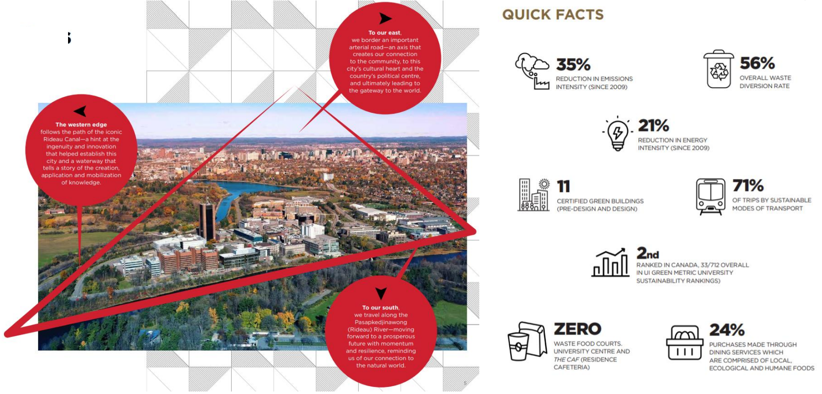


Figure 7 - (Left) Carleton's 2020 Strategic Integration Plan, (Right) University's Accomplishments Reported

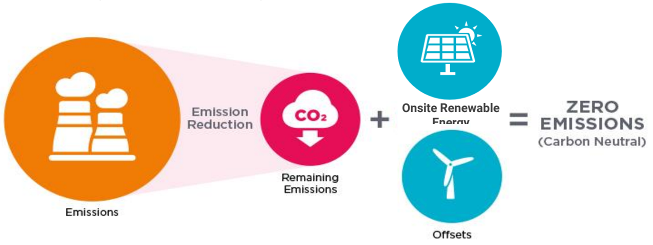
2.2.2 Carbon Neutral Goal Definition

A total carbon footprint of an organization is a measure of the direct and indirect greenhouse gas (GHG) emissions associated with its activities as defined in the following categories.

- Scope 1: Direct GHG Emissions - From sources that are owned or controlled equipment on site
- Scope 2: Electricity and heat indirect GHG Emissions - From the generation of purchased electricity and heat consumed
- Scope 3: Other Indirect GHG Emissions - Extraction and production of purchased materials, transportation of fuels and the use of sold goods and services

Carbon neutrality is defined as having no net greenhouse gas (GHG) emissions which is achieved by either;

a. Eliminating net GHG emissions, or
b. By minimizing GHG emissions as much as possible and using carbon offsets or other measures to mitigate the remaining emissions[1].



Carleton's carbon emissions goals of a 50% reduction by 2030 (from 2005 levels) and carbon neutrality by 2050 includes scope 1 and scope 2 emissions only. It will achieve this following strategy b. discussed above i.e. a mixture of emission reduction and offsets.

Due to the challenging nature of calculating scope 3 emissions, also referred to as embodied carbon, pertaining to indirect emissions, such as food, waste, construction, transportation, that are not created from assets owned or controlled by the University, this Master Plan does not account for these emissions. Carleton recognizes Scope 3 emissions are becoming increasingly valuable in understanding the entire scope of their environmental impacts and future additions to the Master Plan will consider the inclusion of indirect emissions.

---

[1] Second Nature – The Presidents' Climate Leadership Commitments https://secondnature.org/signatory-handbook/frequently-asked-questions/

2.2.3 Benchmarking

A benchmarking exercise was completed against local, provincial, and federal policies, as well as peer universities. The exercise focused only on Scope 1 and Scope 2 emissions and target 2030 or 2050 which is in alignment with the Paris Agreement. Carleton University's commitment to be carbon neutral by 2050 is in alignment with nearly all other policies and universities investigated.

Carleton
Program:
Baseline: 2005
Goals: 50% reduction by 2030, energy neutrality by 2050

Ottawa
Program: Climate Change Master Plan
Baseline: 2012
Goals: 43% by 2025, 68% by 2030, 96% by 2040, 100% by 2050

Ontario
Program: A Made-in-Ontario Environment Plan
Baseline: 2005
Goals: 30% below 2005 levels by 2030

Canada
Program: Pan-Canadian Framework on Clean Growth and Climate Change
Baseline: 2005
Goals: 30% below 2005 levels by 2030

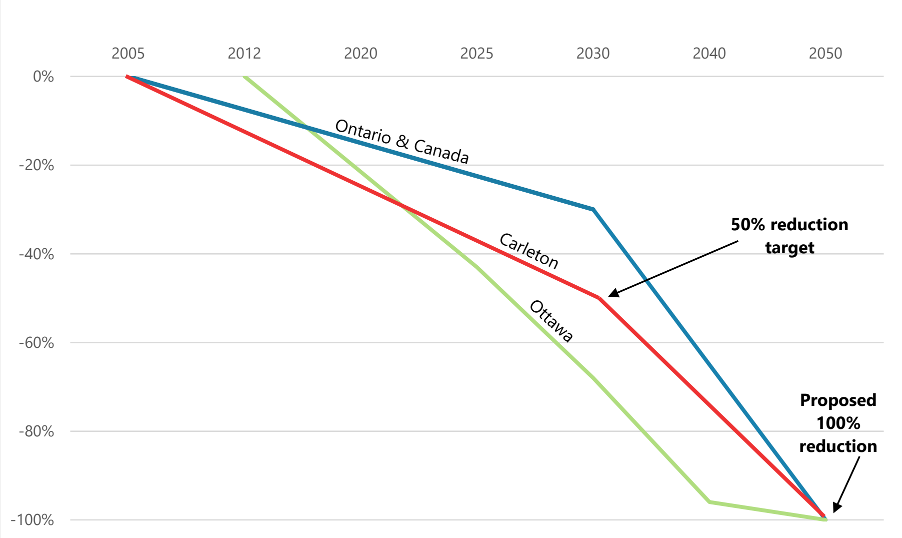


Figure 8 - Local, Provincial, and Federal Policies Carbon Reduction Goals from Baseline

Table 1 - Peer Universities Carbon Reduction Goals

	Carleton	UBC	McGill	Queens	U of Waterloo	Brock	U of Toronto
BASE YEAR	2005	2007	2005	2008	(not released)	2013	1990
2020 Goal		Reduce emissions by 67%		Reduce emissions by 35%			
2030 Goal	Reduce emissions by 50%			Reduce emissions by 70%		Reduce emissions by 20%	Reduce emissions by 37%
2040 Goal			**CARBON NEUTRAL**	**CARBON NEUTRAL**		Reduce emissions by 80%	
2050 Goal	**CARBON NEUTRAL**	**CARBON NEUTRAL**			**CARBON NEUTRAL**		**CARBON NEUTRAL**

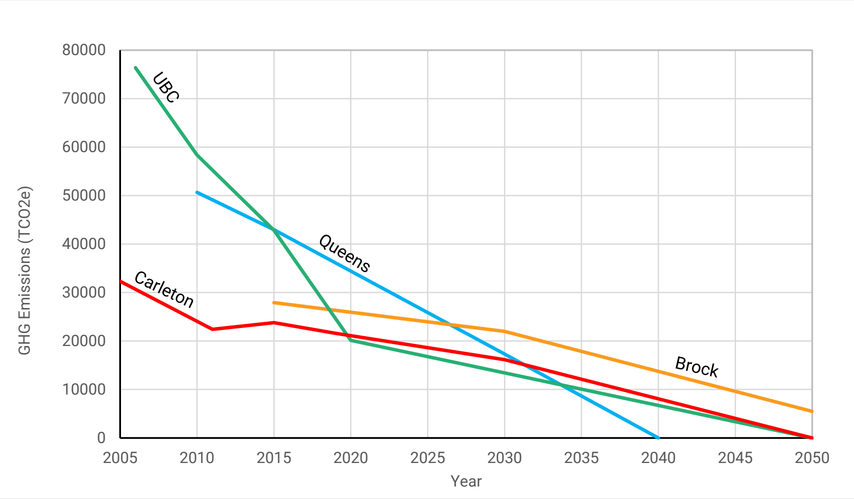


Figure 9 - Peer Universities Carbon Reduction Goals

2.3 Approach & Master Plan Development Considerations

2.3.1 Zero-Carbon Campus Approach

Carleton University’s Energy Master Plan is to be used to provide a roadmap for the University to meet its carbon reduction commitment. The approach to achieve campus carbon neutrality is based on the following main steps, see also Figure 10.

1. Identifying a baseline reference emission level for the campus
2. Reducing load from existing buildings using energy conservation measures
3. Further reducing load from existing buildings using deep energy retrofits
4. Adopting high building energy performance standards for new building development/renovation
5. Implementing new generation and/or distribution system to increase system efficiency and/or switch fuel supply to significantly reduce operational carbon emission level
6. Offsetting remaining carbon emissions using renewable generation, power purchase agreement and/or purchasing carbon credit

This Energy Master Plan focuses on step 5, through investigating low carbon energy supplies and technologies to formulate a new generation and distribution strategy related to heating, cooling, electricity supply to all of Carleton’s campus buildings.

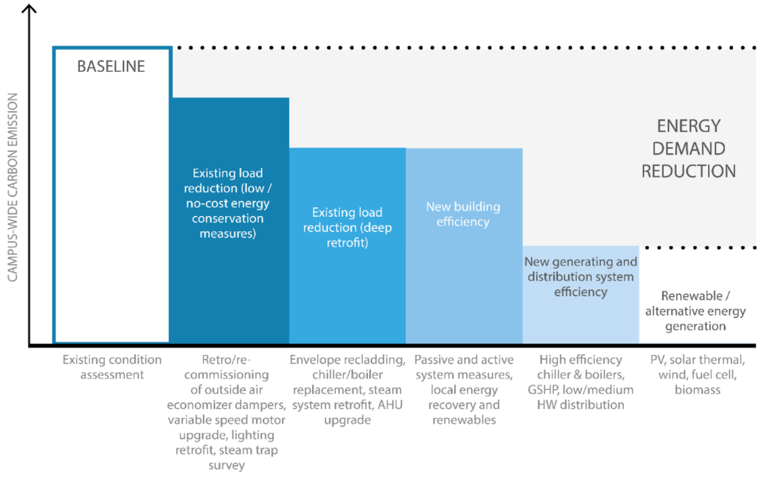


Figure 10 - Zero Caron Campus Approach

2.3.2 Master Plan Project Process

The process used to develop the Master Plan, as shown in the roadmap in Figure 11, began by identifying the existing infrastructure and operating conditions on campus, establishing a baseline to build upon. A campus site walk was conducted to gain a more thorough understanding of operation and general condition of campus buildings and facilities. Future campus energy load was then developed through modelling analysis, incorporating campus growth and expected future building performance.

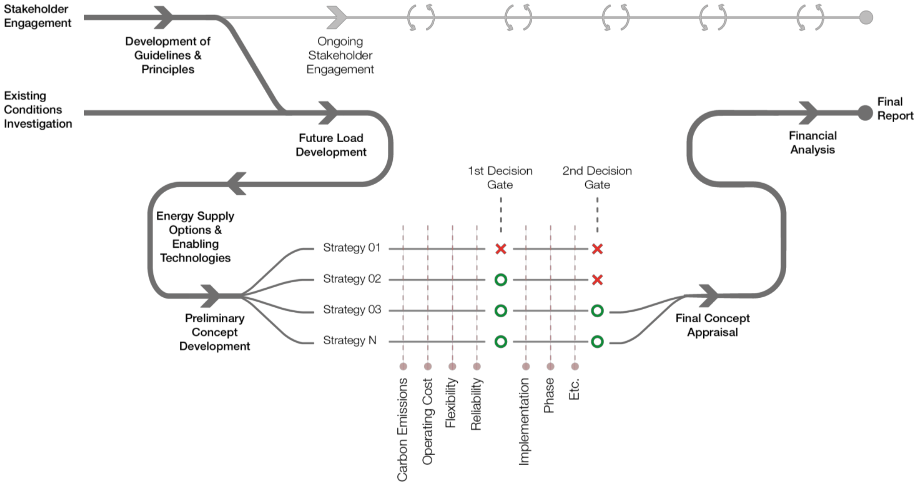


Figure 11 - Master Plan Process Roadmap

Concurrently, key performance metrics for the campus were established and were used throughout the Master Plan process to evaluate proposed technologies and strategies to ultimately identify a preferred strategy on campus. The top 4 criteria identified were carbon emissions, operating cost, reliability, and flexibility, as seen as seen in Figure 12.

Figure 12 - Key Performance Metrics and Weightings

To develop future site utility options, Carleton looked into possible energy supply mixes, with a primary focus on energy supply technologies that are low-carbon and can substitute natural gas as a means to create thermal (heating) energy. A series of energy supply technologies were explored and evaluated through multiple workshop and brainstorming sessions with the University. A summary of the quantitative analysis of each energy supply that was considered is included in Appendix B.

These options were further screened and refined iteratively using the performance evaluation framework. Three shortlisted options were selected for technical analysis to evaluate the capital cost, operational cost, equivalent carbon emission, etc of each option. The results of the three final options were also compared against a business-as-usual baseline, outcome and results of the quantitative analysis of the three options are included Appendix E.

The preferred option, the Carbon Neutral Campus Strategy, was selected from the three shortlisted options as the roadmap for the future of the campus utility infrastructure. The strategy was further refined and outlined the design approach at the plant, distribution and building level interventions. Optimization technologies were also investigated as well as defining short-term and long-term actions tailored to Carleton's current campus. The subsequent sections of this report and the appendices contain the details and analysis of the final Carbon Neural Strategy and the associated Low Carbon Utility Strategy for the campus which are captured in this Energy Master Plan document.

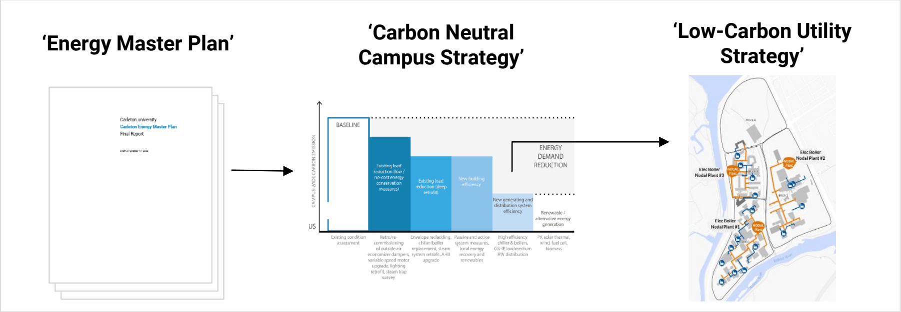


Figure 13 – Definitions of Energy Master Plan, Carbon Neutral Campus Strategy, and Low-Carbon Utility Strategy in this report

3 Campus Context

3.1 Site Context

Situated beside the historic Rideau Canal to the west and Pasapkedjinawong (Rideau) River to the south, Carleton University was founded in 1942 with the intent to serve returning World War II veterans. The University has grown to over 30,000 full time students sitting within Ottawa City on a 150-acre campus. Some of the general land regulations applicable to Carleton's campus area are summarized following and taken into consideration during development of the Master Plan.

Feature	Details
Territorial Acknowledgement	"Carleton University acknowledges the location of its campus on the traditional, unceded territories of the Algonquin nation."
Ottawa Greenbelt	A 20,000-hectare conservation area surrounding Ottawa's downtown core. Features agricultural farms, sand dunes, wetland areas
Rideau Valley Conservation Authority	The southern part of Carleton's campus is located on the Rideau River Flood Plain riparian zone. Developments on the Rideau River Flood Plain are controlled by the Rideau Valley Conservation Authority, shown in Figure 14.
O-Train Regulations	The O-Train track is centrally located on campus. The City of Ottawa plans to twin the tracks located on campus, closing the O-Train Trillium Line for construction from May 2020 to Sept 2022. Construction on Carleton Station will potentially include: - Adding a pedestrian underpass north of Carleton Station to support Carleton's development plans; and - A pedestrian tunnel segment below the tracks connected to Carleton's tunnels. Construction near the track (building and utility work) is expected to require review/approval by the City of Ottawa / Authority Having Jurisdiction (AHJ). It is currently unclear what is the "zone of influence" required by the City of Ottawa / AHJ.

Table 2 - Land Regulations in Ottawa, Ontario applicable to Carleton University

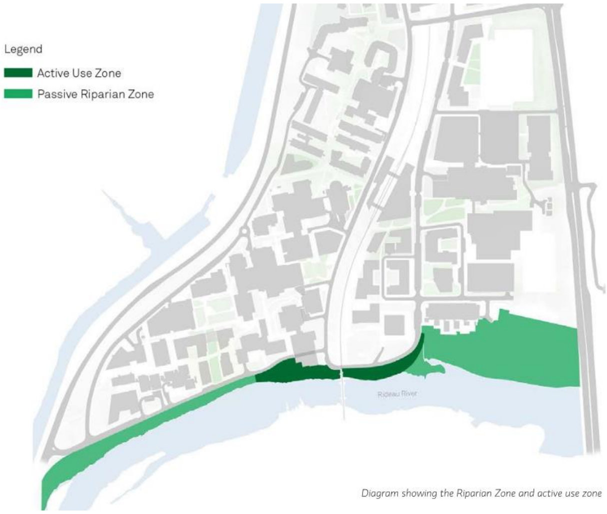


Figure 14 - Developments on the Rideau River Flood Plain are controlled by the Rideau Valley Conservation Authority

Water Table and Flood Report

The Rideau Valley Conservation Authority (RVCA) identifies Carleton campus area as flood-prone. During a 1:100-year flood event, Rideau River will flood up the existing ditch west of Bronson Avenue and spread west into a few spots within Carleton's campus. Floodwaters are managed by the dyke-flood wall system in the Carleton area. Through discussion with the University, flooding has also occurred on the northwest side of the campus from Colonel By Drive.

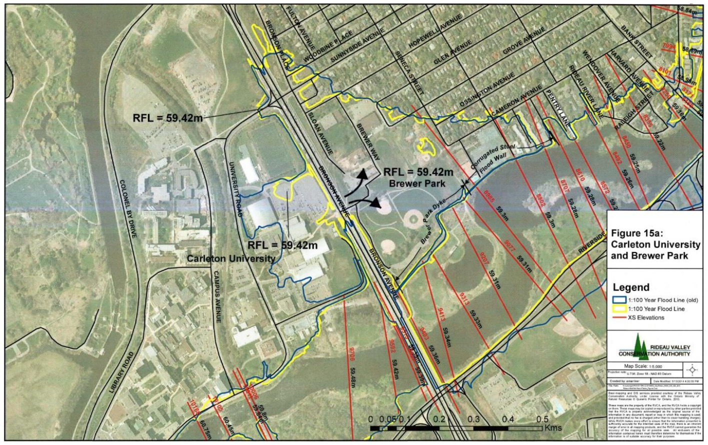


Figure 15: Rideau Valley Conservation Authority's projected 1:100-year flood event

Based on site walks and discussion with the University, there are areas on campus that are known to have high water tables, specifically the area north of Leeds House and the area south of Robertson Hall. The high-water table has also led to groundwater penetration in the pedestrian tunnel, causing seasonal flooding.

3.2 Existing Campus

Since the campus' inception, the campus' existing utility assets have expanded and been providing services, to a vast number of University-owned buildings. A campus site walk observed the central plant, chiller plants, tunnel system and 10 existing buildings of varying types and size to better inform operation and general condition of the campus. The Carleton 10-Year Asset Management Plan 2019/2020 also used to inform general conditions of campus assets.

3.2.1 Utility Networks & Energy Use

The current campus utility networks include a central electrical distribution, a central heating network, and a distributed chilled water network. Best available drawings, utility billing and trend data of utility demand and consumption were provided by the University and attached in Appendix A Phase 1 Memo Report document.

Electricity Network

The electricity network includes four 13.2 kV 8MW feeds from Hydro Ottawa from the east side of the campus. Based on building data, the peak electricity demand is 14MW, and annual consumption is 68.6MWh. There are two backup generators (1MW and 300kW) located at the central heating plant, and several other backup generators distributed across the campus located at the building level.

There are 5 closed loops (Loop A, B, C, D, and E) that feed campus buildings on the electricity network. These loops are generally sized 350MCM and come from one or two switchboards (both on Bronson Avenue). Buildings fed directly from the loop generally transform down to 600V. See Appendix A for Electrical Distribution Drawing included within the Phase 1 Memo Report document.

Natural Gas Network

The campus' natural gas network is supplied by Enbridge Gas and has two incoming gas supply feeds to campus. The natural gas used at the maintenance building (central heating plant) by the central steam boilers are purchased using direct access and through Comsatec. Natural gas is also used at the buildings level to supply local hot water boilers and rooftop air-handling units (furnace). Total campus natural gas consumption is approximately 9.2 million m^3 annually, with 90% of the total natural gas used the central heating plant. See Appendix A for Natural Gas Network Distribution Drawing included within the Phase 1 Memo Report document.

Heating Network

The installed heating capacity at the plant is 200,000 lbs of steam/hr and observed peak steam demand is 95,000 lbs of steam/hr. Annual steam generation is approximately 238,000,000 lbs of steam/year. The central heating plant consumes approximately 9,150,000 m3 of natural gas annually, resulting in average efficiency of 70%. The campus steam system has two 6" steam pipe mains that extend from the maintenance building to feed buildings on campus.

A new 5 MW co-generation system has been installed at the maintenance building and is expected to begin operation in 2021. The gas turbine will add a steam capacity of 40,000 lbs of steam/hr, or with duct burners 100,000 lbs of steam/hr. Combined with the existing capacity of the central steam boilers and the new co-generation system, the total heating capacity is approximately 300,000 lbs of steam/hr. The co-generation system is required to operate a minimum of 6,500 hours per year for 10 years, based on an agreement with Ottawa Hydro.

Table 3 - Annual steam generation and natural gas metered at the Central Heating Plant, 2018

2018 Annual Steam Generation at Central Plant		2018 Natural Gas metered for Central Plant	
238,075,955	Lb of steam/yr	9,155,699	m3/yr
230,933,676	kbtu/yr*	329,605,164	kbtu/yr
		Annual Average Steam Production Efficiency	70%

* Based on 970 btu per lb of steam

Cooling Network

There are 14 cooling plants distributed across campus that are not interconnected. An approximate sum of the chiller capacities is approximately 6,500 tonnes, including a 1000-tonne absorption chiller located at the Steacie Building. In the summer months, when campus heating demand is low but the co-generation system is required to operate, the absorption chiller can utilize the excess heat generated by the co-generation system. See Appendix A for Cooling Network Distribution Drawing and chiller capacity included within the Phase 1 Memo Report document.

Sanitary Network

The sanitary network on campus are separate from the stormwater system. All sewage from buildings on campus are gravity drained to a common point east of Alumni Hall, where the campus' main electrical substation is located. Sewage from nearby townhouses east of the campus are also drained to the campus, where all sewage drains to a wet well that is pumped into a force main to the city municipal system. The wet well and pumping station are owned and operated by the City of Ottawa. See Appendix A for Sanitary Network Drawing included within the Phase 1 Memo Report document.

Tunnels

A vast tunnel network connecting nearly all buildings on campus provide sheltered walkways for faculty and students to traverse campus. Service tunnels run along-side these pedestrian tunnels carrying distribution piping for steam, condensate, high temp hot water, and chilled water. The service tunnels were observed to be in good condition, however, have limited capacity for additional thermal distribution.

3.2.2 Existing Building Inventory

The campus currently has 48 buildings and approximately 481,000 square meters in floor area. Building's age varying from 1959 - 2018, with over half of the campus GFA constructed in the 1960s, as seen in Figure 16.

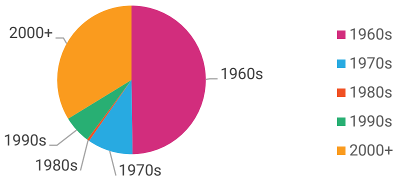


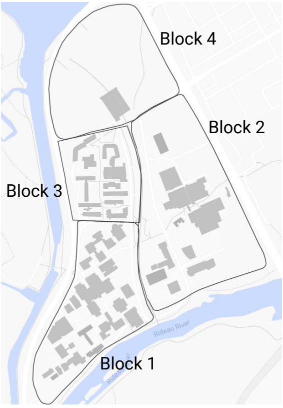
Figure 16 - Existing Buildings Age Breakdown

Within the Carbon Neutral Strategy, the campus is divided into smaller blocks and broken down by existing building types, see Table 4 and Figure 17. Blocks are based on existing and planned infrastructure capacities, building type similarity, and major geographical elements ie. roadways, O-Train tracks. Each block has its own nodal utility system serving the buildings within the area, however, connecting nodal utility systems across block boundaries is also possible to incorporate into the utility strategy design.

Table 4 - Existing campus building areas and types within blocks

	Number of Buildings	Building Area (m^2)	Building Area (% of total campus and % of block)
Block 1 Total	20	217,870	55% of total Campus
Academic	12	118,029	52%
Lab	7	92,421	41%
Ancillary	1	16,460	7%
Block 2 Total	10	57,825	15% of Campus
Lab	2	14,979	26%
Ancillary	2	6,891	12%
Athletics	6	35,955	62%
Block 3 Total	12	118,827	30% of Campus
Academic	1	7,013	6%
Residence	11	111,814	94%
Block 4 Total	1	249	0.06% of Campus
Academic	1	249	100%
Campus Total	44	403,811	100%

Figure 17 - Campus Blocks



Heating
Most campus buildings are heated by the central heating plant with high pressure steam distributed throughout the campus at 125 to 150 psi. Nearly all of buildings on campus have local steam converter(s) with medium temperature hot water (MTHW) distribution at 180ºF within the buildings; only a few buildings still use local, direct steam. The central steam system also supports a smaller MTHW distribution system that serves the Architecture building, Minto building, and Mackenzie building. Remaining buildings not connected to the central heating plant have either local hot water boilers or a rooftop furnace. It was observed that plant rooms and equipment are generally well maintained and accessibility in only some buildings is limited due to their location below grade. See Appendix A for Heating Network Distribution Drawings included within the Phase 1 Memo Report document.

Cooling
Cooling for buildings is mainly served by the nodal chiller plants, with the exceptions when local air-cooled chillers provided and local packaged rooftop DX cooling. Recently residence buildings completed retrofits projects to receive cooling, with cooling systems now in all campus buildings.

Ventilation
Most buildings on campus operate on a schedule with the exception of lab buildings that run 24/7. Some of the lab buildings have been recently retrofitted with glycol wrap-around coil(s) for energy recovery within their general exhaust and fume hood exhaust. Labs are believed to be constant volume and VFDs have been provided on most AHUs (Air Handling Units) and pumps. Dormitory buildings mainly contain 2-pipe fan coil systems with roof mounted air-cooled chillers. There is an opportunity for air-side economizers to recover energy from exhaust air within residence buildings. Mixed use buildings such as the University Centre have a mix of mechanical ventilation systems, such as VAV air-handling units, dual-duct air-handling units, and packaged rooftop units.

Energy Use
Building level energy use intensity benchmarking identified high energy consuming buildings and overall performance of Carleton's buildings. Carleton has historically trended energy performance of different buildings as a means to evaluate energy performance relative to each other. The buildings with the highest EUI indicates the building with the lowest building performance and should be targeted as priorities for building energy retrofit. Buildings with the highest absolute energy consumption should also be considered for building energy retrofit.

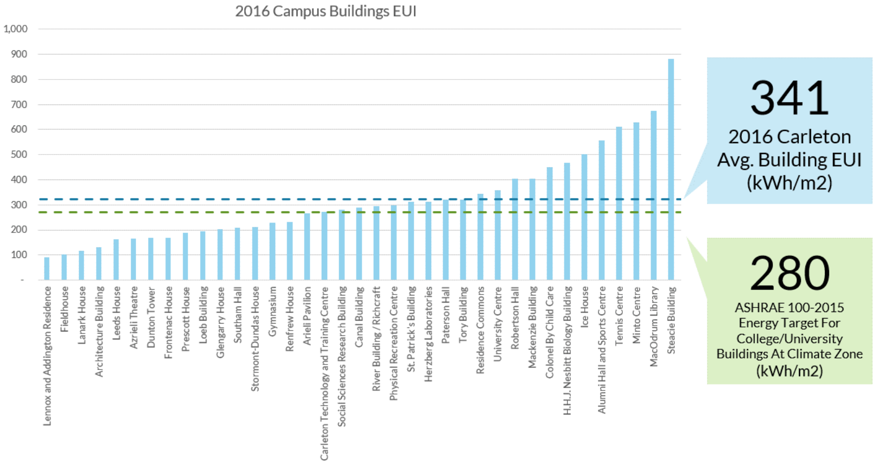


Figure 18 - 2016 Campus Buildings Energy Use Intensity

3.2.3 Emissions

Carleton has also historically tracked utility consumption for performance monitoring and carbon emissions emitted on campus. Carleton's 2030 and 2050 carbon emissions targets utilize 2005 as baseline emission levels. Through previously implemented carbon reduction measures, emissions in 2018 were reduced by 35% below 2005 levels.

On-campus building heating from natural gas contributes the highest amount of emitted emissions in comparison to the campus's other main energy end uses, contributing over 79% of the total campus' emissions, Figure 20. Lowering existing building energy demand will lead to significant carbon emission reductions as it will lower gas consumption, however, carbon emission reduction will become increasingly challenging if the campus remains on gas supplied energy sources.

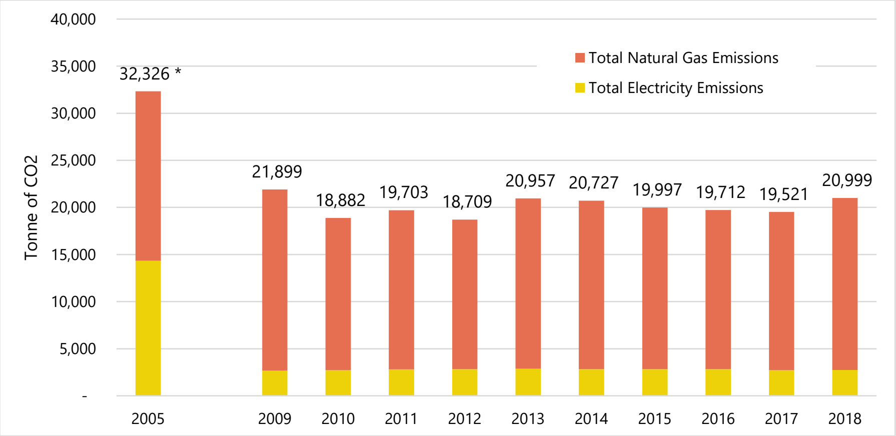


Figure 19 - Carleton's Historical Carbon Emissions

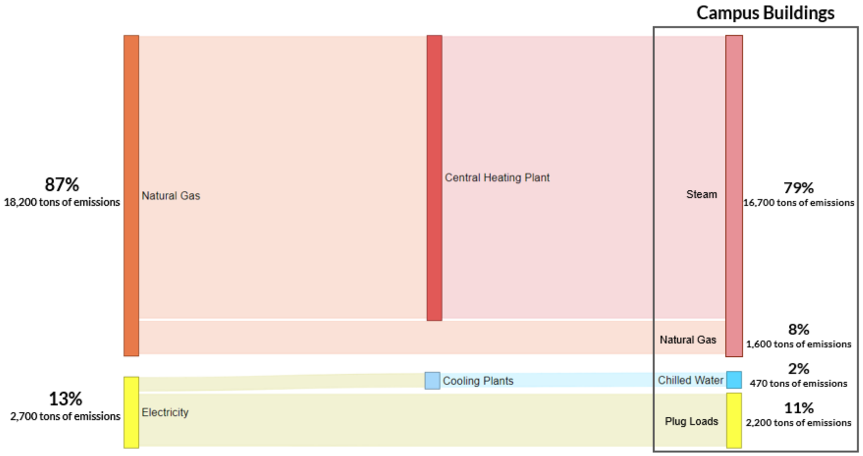


Figure 20 - Carleton's Energy End Use Carbon Emission Breakdown based on 2018 Utility Demand

3.3 Future Growth

For the Energy Master Plan, the campus' future utility demand was initially based on the Carleton University's 2016 Campus Master Plan and its projected campus growth. Building type breakdown of existing buildings are shown in Table 5 were assumed for future growth and then interpolated in 10-year increments until 2050. All future developments were expected to be completed by 2050. Parking, tunnels, and utility buildings were not included in area totals.

		2030 Campus Area m²	**2040 Campus Area m²**	**2050 Campus Area m²**
Block 1 Total	56% of Campus	24,856	24,856	24,856
Academic	52% of block 1	13,465	13,465	13,465
Lab	41% of block 1	1,878	1,878	1,878
Ancillary	7% of block 1	9,513	9,513	9,513
Block 2 Total	14% of Campus	36,598	36,598	36,598
Lab	26% of block 2	4,361	4,361	4,361
Ancillary	12% of block 2	22,757	22,757	22,757
Athletics	62% of block 2	9,480	9,480	9,480
Block 3 Total	29% of Campus	20,470	20,470	20,470
Academic	6% of block 3	1,208	1,208	1,208
Residence	94% of block 3	19,262	19,262	19,262
Block 4 Total	0.06% of Campus	36,249	36,249	36,249
Academic	100% of block 4	36,249	36,249	36,249
Campus Total	**100%**	**532,204**	**650,378**	**768,552**

Table 5 - Expected Campus Growth per Block

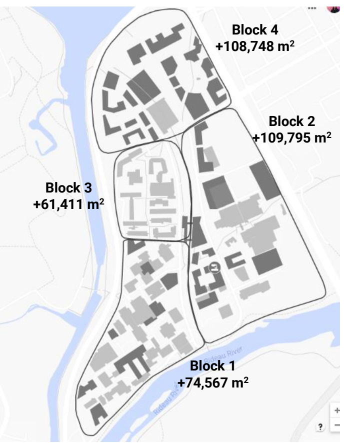
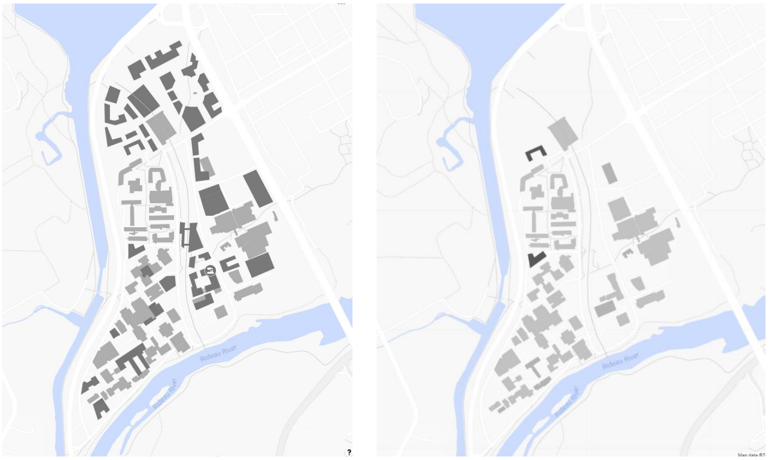


Figure 21 - Assumed Campus Growth by 2050 (Future Developments shown in dark grey)

Due to the Covid-19 Pandemic, Carleton's future growth plan was re-evaluated and the expected new development area on campus was revised over the course of developing the Energy Master Plan. Currently, the Energy Master Plan campus growth was revised to only include the development of the new Sustainability Research Centre near the Mackenzie Building (23,225 sqm, 250,000 sqf) and the new residence building north of the Leeds House (18,580 sqm, 200,000 sqf), seen in Figure 22. All other future developments described in the 2016 Campus Master Plan were removed for the Carbon Neutral Strategy for the time being. The Carbon Neutral Strategy is designed to support flexible campus growth and has the ability to adapt the expansion of utility infrastructure accordingly.

	Existing Campus Area	2050 Campus Area
2016 Campus Master Plan	403,800 m^2	768,500 m^2 (+364,700 m^2)
Covid-19 Revision	403,800 m^2	**445,600 m2** (+41,800 m^2)



Note: Darker Shaded Buildings Represents New Capital Development

Figure 22 - (Left) 2019 Campus Growth Plan, (Right) Covid-19 Reduced Growth

3.4 Future Campus Load

3.4.1 Future Demand and Consumption Analysis

To inform the utility strategy development and analysis, the campus' future utility demand and consumption were estimated based on the proposed new campus developments. It also included building performance energy improvements to existing buildings which were based on building retrofit results in Carleton's previous energy master plans. Starting from the existing campus utility demand and consumption level, the associated increases in annual consumption [MWh/yr] and peak demand [MW] for heating, cooling, and electricity across the campus were calculated. This analysis is based on existing utility consumption and trend data, Carleton building performance targets, and other future building energy performance benchmarks from publications such as the Toronto Green Standard and Zero Emission Building Framework.

The campus' future utility demand and consumption were developed by taking the breakdown of building type area and applying the applicable energy factors based on building type and expected year of construction, see Future Utility Requirements in Table 6 and Figure 23 and 24. It should be noted that the increase in annual electricity consumption and demand presented in Table 6 does not yet include the electricity that is required to provide electrified heating and cooling loads of the campus, as the increase in electricity consumption and demand is dependent on the Low-Carbon Utility Strategy and technologies. The increase of electrical demand due to plant heating and cooling demand for the Carbon Neutral Campus Strategy is presented in Section 0.

Table 6 - Future utility requirement

	Heating Demand (MW)	Heating Consumption (MWH)	Cooling Demand (MW)	Cooling Consumption (MWH)	Electricity Demand (MW)	Electricity Consumption (MWH)
Existing Total	37	81,200	27	35,000	13	68,547
2021-2030 Total	41	82,100	29	31,000	14	64,700
2031-2040 Total	41	77,000	29	28,500	14	60,600
2041-2050 Total	41	71,800	29	26,600	14	56,500

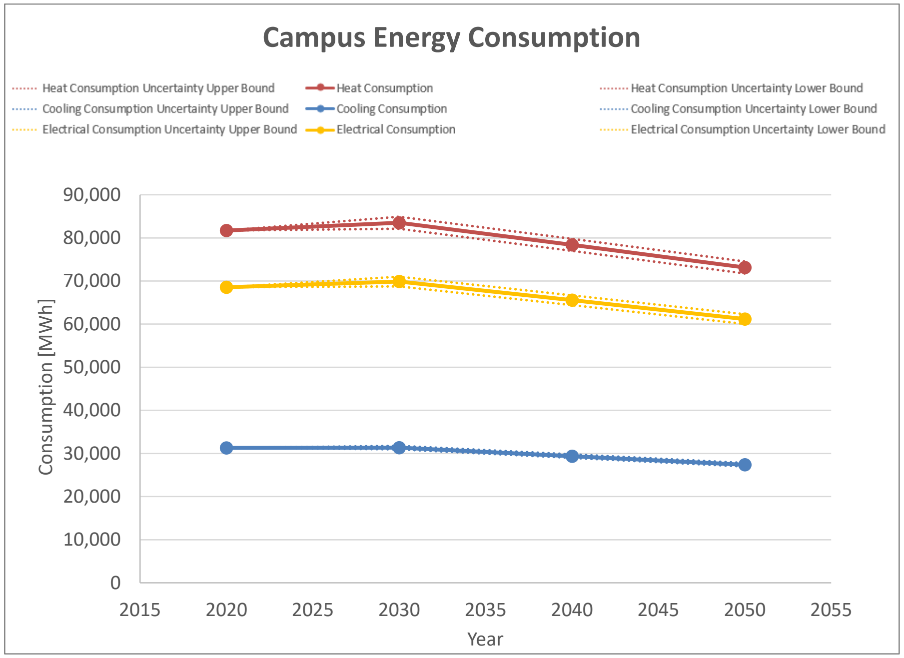


Figure 23 - Campus future thermal demand analysis, 2020 to 2050 energy consumption

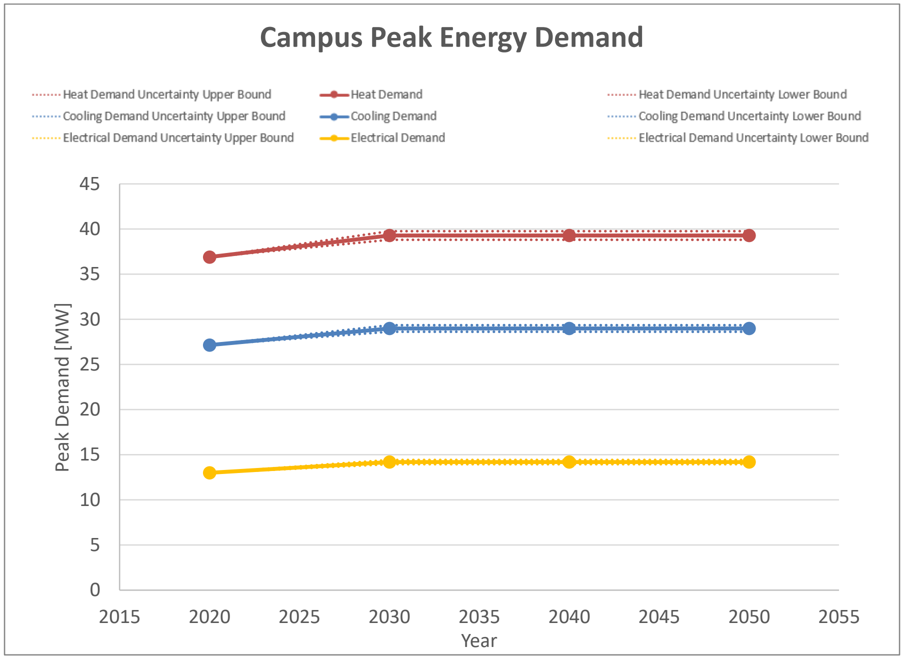
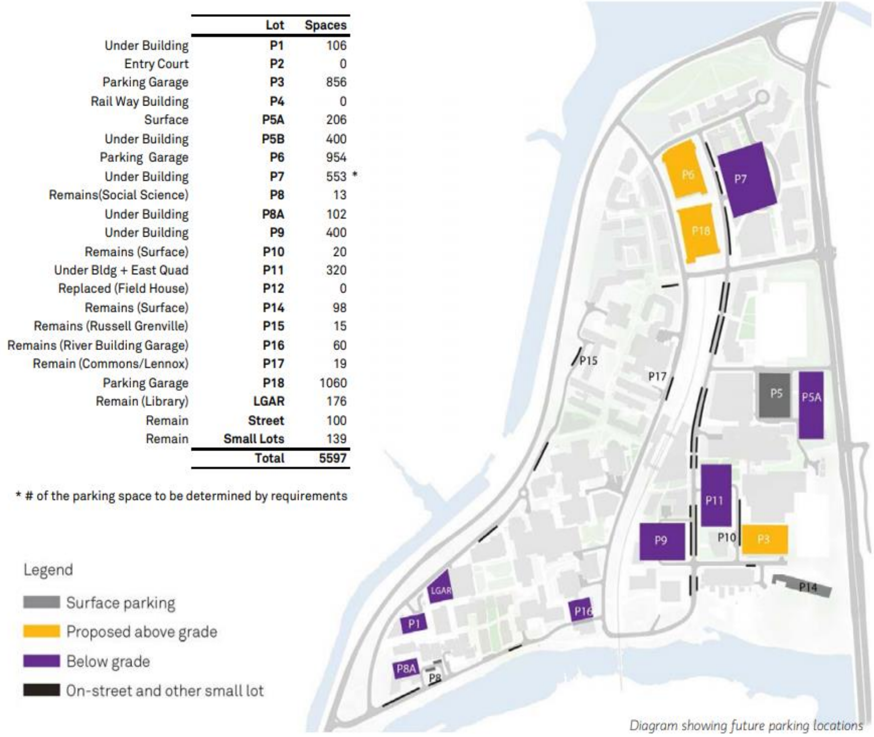


Figure 24 - Campus future thermal demand analysis, 2020 to 2050 campus peak energy demand

3.4.2 Electric Vehicle Charging

Carleton University currently has eight electric vehicle charging stations on campus and plans to adopt additional charging stations to meet the future demand of electric vehicles. Carleton University's 2016 Capital Master Plan presented potential future parking locations, which were used for the analyses generated.



	Lot	Spaces
Under Building	P1	106
Entry Court	P2	0
Parking Garage	P3	856
Rail Way Building	P4	0
Surface	P5A	206
Under Building	P5B	400
Parking Garage	P6	954
Under Building	P7	553 *
Remains(Social Science)	P8	13
Under Building	P8A	102
Under Building	P9	400
Remains (Surface)	P10	20
Under Bldg + East Quad	P11	320
Replaced (Field House)	P12	0
Remains (Surface)	P14	98
Remains (Russell Grenville)	P15	15
Remains (River Building Garage)	P16	60
Remain (Commons/Lennox)	P17	19
Parking Garage	P18	1060
Remain (Library)	LGAR	176
Remain	Street	100
Remain	Small Lots	139
	Total	5597

* # of the parking space to be determined by requirements

Diagram showing future parking locations

Figure 25 - Potential future parking lots

All existing and new parking lots can include electric vehicle charging stations, achieved by retrofitting existing parking lots and constructing new parking lots to include charging stations.

Charging stations are assumed to be installed for 20% of the parking capacity on campus by 2050, which will be phased-up accordingly (10% in 2030, 15% in 2040, etc.). Estimates for the energy required to meet the demand and consumption of electric vehicle charging stations on campus are included in Table 7.

Assumptions per parking spot charging station:

- 7.2 kW demand
- 6 hours per day of use for 365 days a year

Table 7 - Electric vehicle charging stations

	Existing	2030	2040	2050
Total Parking Spots on Campus	1,800	3,065	4,330	5,595
% of Parking Lot Spaces to be EV Charging Stations	-	10%	15%	20%
# of EV Charging Stations in Campus Parking lots	8	560	840	1,119
Electric Demand [MW]	-	3.2	4.8	6.4
Electric Consumption [MWh]	-	7,060	10,590	14,121

3.5 Utility Rates

Historical utility rates are obtained from the University as the basis of analysis for the utility strategy development. The historical blended average rate of electricity is observed to be \$0.116/kWh. Starting in November 2020, Arup understands that Carleton University will no longer receive a \$0.040 /kWh rebate on electricity rates. For the purposes of this Energy Master Plan, the blended average rate of electricity that will be used to evaluate the campus energy strategies is assumed as \$0.116 / kWh + \$0.040 / kWh = \$0.156 / kWh starting in 2021. The rate for natural gas will be based on historical average rate of \$0.246/m3 starting in 2021.

Table 8 - Natural gas and electricity rates used for planning purposes

Utility	Rate
Natural Gas Rate	$0.246/m3
Electricity Rate	$0.156/kWh

The historical average natural gas and electricity cost are shown below:

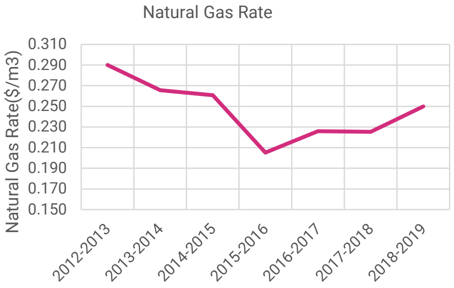


Figure 26 - Natural gas rate, 2012 to present (source: Enbridge Gas)

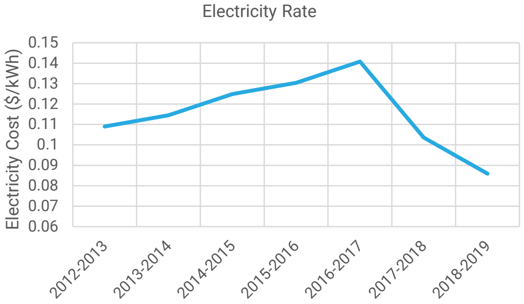


Figure 27 - Electricity rate, 2012 to present

4 Carbon Neutral Campus Strategy

4.1 A Holistic Approach

The Carbon Neutral Campus Strategy took an emphasis on the campus utility strategy. It started with looking to 2050 and envisioning what the future campus would look like. The utility strategy then worked backwards from 2050 to the present to understand what the transition might look like while considering Carleton's key performance metrics.

After a series of option evaluations and screenings, an all-electrically powered campus was selected as the main low-carbon energy supply strategy, replacing the dependence on natural gas for heating. Grid electricity in Ontario is mostly generated from nuclear power and the equivalent carbon emission factor of grid electricity in Ontario is considerably lower than fossil fuel (natural gas). Heating and cooling technologies using electricity only are reliable and industry proven technologies that will allow for safe and reliable campus operation. The utility strategy uses a nodal approach that allows the strategy to adapt to changing campus growth and increase flexibilities in implementation timelines. Strategy optimization technologies are also included that aim to lower annual operating costs.

A low-carbon utility strategy is a major component of the Carbon Neutral Campus Strategy as the campus is currently dependent on fossil fuel (natural gas); the use of natural gas currently accounts for over 80% of its equivalent carbon emissions. However, the transformation to a low-carbon utility infrastructure is only one critical part of the puzzle for the University to achieve carbon neutrality. Therefore, the strategy includes a holistic, multi-pronged approach that includes deep retrofit for existing buildings to reduce its utility demand and setting high efficiency performance requirements for future developments, transformation to a low-carbon utility infrastructure and augmented by utilizing offsite renewables or carbon offsets to mitigate remaining carbon emissions, outlined in Figure 28 - Zero Carbon Campus Approach.

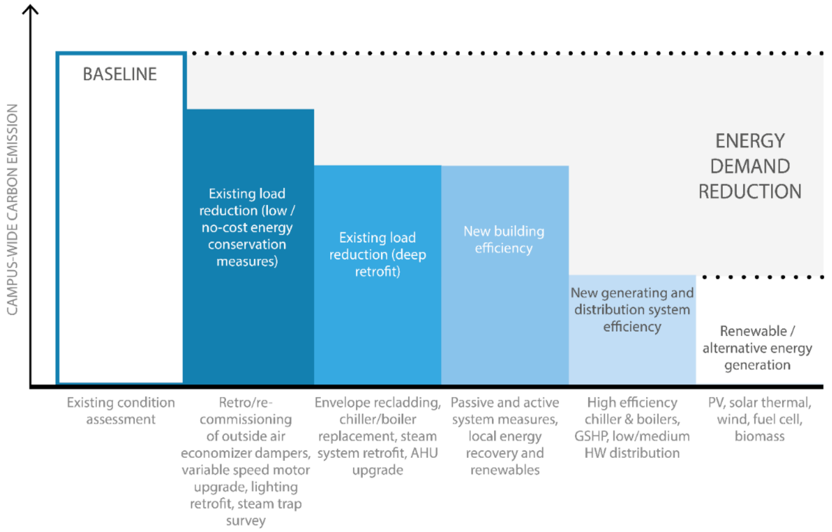


Figure 28 - Zero Carbon Campus Approach

4.1.1 Existing Buildings

Carleton University has successfully retrofitted several existing buildings to reduce their overall heating, cooling, and electrical consumption. To support the campus carbon neutral strategy, improvements to existing building performance are required to continue over the next 30 years as existing campus buildings will continue to make up a significant portion of the campus future utility requirement. Reducing Carleton's existing building utility requirement not only directly reduce overall campus emission reductions and operational cost-savings, but also reduces the capacity requirement of the new campus utility infrastructure and the associated capital cost. The

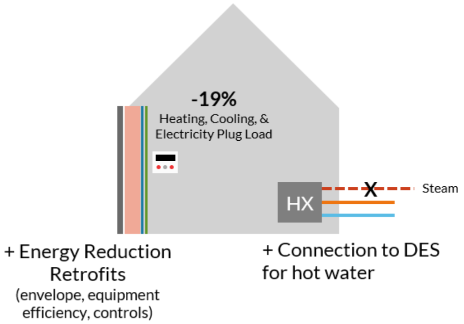


Figure 29 – Existing Building Retrofit Sketch

Energy Master Plan currently sets a indicative minimum of 19% improvement for annual heating, cooling, and electricity consumption for existing building performance improvement over the next 30 years to 2050, outlined in Table 9 below. The estimated potential building performance improvements are considered in calculating the campus' future carbon emission levels but not included to preliminary system sizing in the utility strategy.

Table 9 - Existing building reductions

Phase	Phased Reduction to Heating, Cooling, & Electricity Existing Building Load
2021-2030	6.3%
2031-2040	12.6%
2041-2050	19.0%

Additionally, existing buildings served by the existing central heating plant (CHP) via direct steam will be required to undergo retrofit to hot water distribution in the building. Where possible, existing buildings with local gas-fired boilers should be retrofitted with district hot water connections as existing equipment reaches life expectancy. Each building will have specific requirements and retrofit to low/medium temperature hot water distribution within the building may require retrofit/replacement of the building's air-handling units and terminal/perimeter heating systems (i.e. terminal reheat boxes, perimeter radiators).

The buildings' steam-to-HW conversion retrofits should follow a phased approach in alignment with the phasing of the new campus utility infrastructure. By 2050 it's expected that all existing buildings will be connected to the new low-carbon utility infrastructure.

4.1.2 New Developments

The previous Energy Master Plan included estimates of energy performance for new developments. To achieve Carleton's 2050 carbon neutrality goal, further improvement is required on the energy performance of new buildings.

This Energy Master Plan and the current carbon neutral strategy do not set a definitive energy performance target or standard for future development on campus. It looks to industry standards, existing research and policies, as well as industrial best practices to inform the basis of analysis for the utility strategy development. The plan does reference the current and future building energy efficiency requirements in Toronto Green Standard (TGS) and City of Toronto's Zero Emission Building Framework as a benchmark of building performance improvement for future developments at Carleton University. The City of Toronto's Zero Emission Building Framework (ZEBF) is one of the City's key climate action strategies to achieve zero-carbon by 2050. The ZEBF outlines future improvement requirements for common building archetypes and percentage improvements above Ontario Building Code Supplementary Standard SB-10, 2017.

To support the campus carbon neutrality target, the Energy Master Plan assumes that campus developments built between 2020 and 2030 are expected to achieve a 25% improvement in building performance relative to current local code minimum requirement (SB-10, 2017). Developments between 2031 and 2040 will target 35% improvement above current local code minimum requirement (SB-10, 2017), and developments beyond 2040 will target 45% improvement above current local code minimum requirement (SB-10, 2017).

Table 10 - Building performance assumptions for new developments

Phase	Building Performance Assumption
2019	Local Code Minimum Requirement (SB-10, 2017)
2021-2030	25% improvement above SB-10, 2017
2031-2040	35% improvement above SB-10, 2017
2041-2050	45% improvement above SB-10, 2017

All new developments will be designed to be connected to the new low-carbon utility infrastructure and utilize hot water distribution. The first new developments that are constructed within each node will have the opportunity to house a utility infrastructure for the node and should be designed with appropriate plant space, see Figure 30. Utilizing new developments for new nodal plants maximizes campus space and takes advantage of construction synergies.

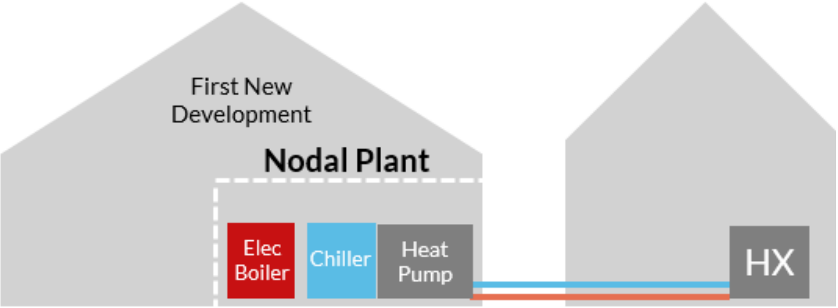


Figure 30 - Zero Carbon Campus Approach

4.1.3 Utility Strategy Overview

The thermal heating strategy is based on campus electrification through the addition of three new nodal heating plants that house electric boilers to generate low temperature hot water. This low temperature hot water will be distributed throughout the campus to supply heating to all new and existing buildings, see Figure 31.

Existing nodal campus cooling plants containing chillers and cooling towers will remain and be expanded accordingly to supply cooling to connected existing and new buildings.

By 2040, the three nodal plants will be constructed so that all campus buildings can be connected in a phased manner and no longer reliant on the central plant existing steam network by 2050.

Further details on the Low-Carbon Utility Strategy are included with section 4.2.

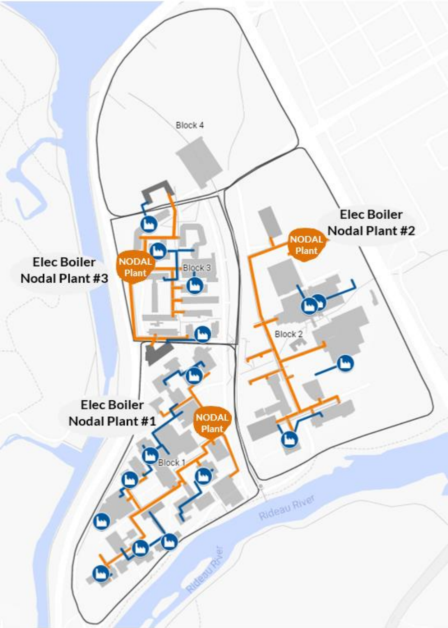


Figure 31 – Schematic of the New Campus Utility Strategy

4.1.4 Renewable System

Onsite renewable energy generation is a part of the campus carbon neutral strategy. However, onsite renewable energy generation is not expected to completely offset the campus utility demand and the majority of the power will still come the external utility grid.

Potential sites for solar photovoltaic system have been identified across the campus, mainly targeting existing parking and existing buildings as seen in Figure 32. For new buildings, maximum roof area should be utilized for solar PV system or equivalent solar renewable system. At a minimum, rooftops for new construction should be designed to be solar-ready with the necessary electrical and structure infrastructure for future solar PV system deployment.

Current estimates indicate the maximum rooftop solar PV system size to be 2.3 MW. The carbon neutral strategy included a phased deployment of the Solar PV system across the campus by 2050. Solar PV capital investment and electricity savings are included within the quantitative analysis results in section 4.4.3.

Figure 32 - Campus Solar Potential Areas

4.1.5 Carbon Offset

The pathway identified for the Carleton campus is to minimize existing emissions as significantly as possible, install onsite renewables then utilize offsite renewables, carbon offsets, etc. to mitigate remaining emissions. This is discussed more in this section.

Campus grid electricity consumption in 2050 is expected to be 135,300 MWh, producing approximately 6,700 tons of equivalent carbon emissions, see Figure 33. As a results of campus electrification (and building performance improvement and renewable generation), campus carbon emissions would be reduced by 80% reduction from 2005 carbon emissions levels. However, to achieve carbon neutrality, additional efforts must be put into place to offset the emissions generated through grid electricity use, as identified by the following:

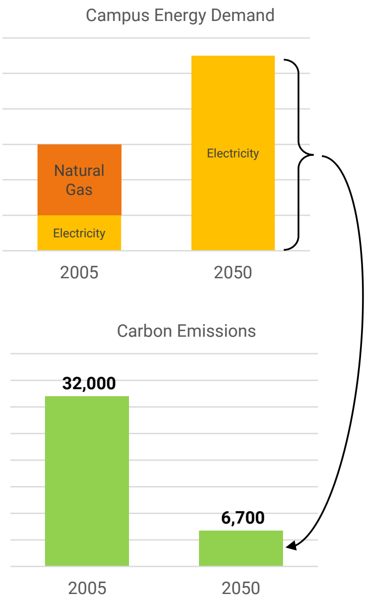


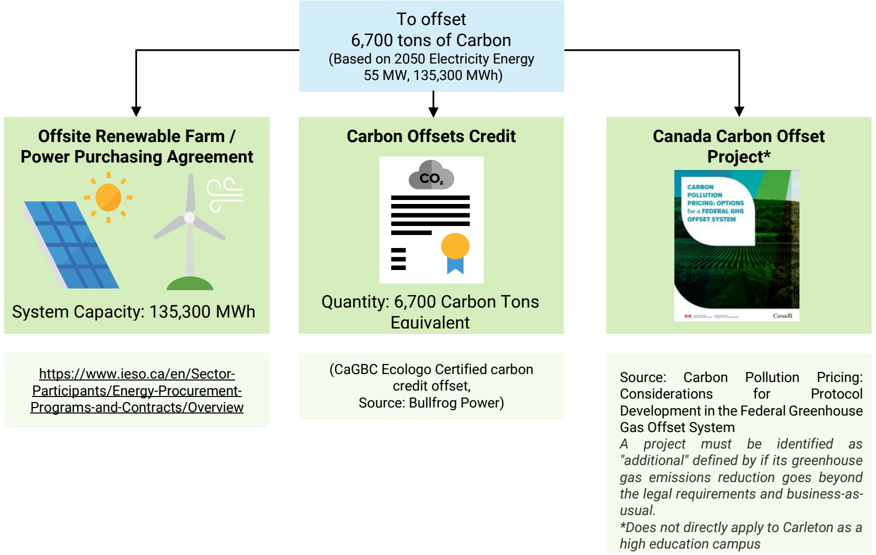
Figure 33 - Carbon Emissions from Electricity

1. **Offsite Renewable Farm or Power Purchasing Agreement**
   Power is generated offsite using renewable technologies and connected directly or virtually to the campus through purchasing agreements. Equivalent grid emissions are assumed for renewable power generated and supplied back to the grid. Therefore, to achieve carbon neutrality equal or greater renewable generation to campus electricity consumption is required to offset remaining carbon emissions.

2. **Carbon Offset Credits**
   Offset credits can be purchased, equivalent to tons of emissions generated, to contribute to offsite carbon emission reduction projects.

3. **Carbon Offset System Project**
   Canada is developing a carbon offset protocol[1] for carbon emission trading programs. To be eligible projects seeking to trade emissions must reduce their emissions over and above what would be considered business as usual. Climate Change Canada has identified the following shortlisted carbon development strategies for offsetting:
   - Aerobic composting of organic waste,
   - Afforestation/restoration, anaerobic digestion,
   - Improved forest management,
   - Landfill methane management,
   - Livestock manure management,
   - Soil organic carbon

   It's important to note that these have not been identified as directly applicable to Carleton as a higher education campus. Figure 34 below summarizes the current potential carbon offset options for Carleton University.



To offset
6,700 tons of Carbon
(Based on 2050 Electricity Energy
55 MW, 135,300 MWh)

Offsite Renewable Farm / Power Purchasing Agreement

System Capacity: 135,300 MWh

https://www.ieso.ca/en/Sector-Participants/Energy-Procurement-Programs-and-Contracts/Overview

Carbon Offsets Credit

Quantity: 6,700 Carbon Tons Equivalent

(CaGBC Ecologo Certified carbon credit offset,
Source: Bullfrog Power)

Canada Carbon Offset Project*

Source: Carbon Pollution Pricing: Considerations for Protocol Development in the Federal Greenhouse Gas Offset System

A project must be identified as "additional" defined by if its greenhouse gas emissions reduction goes beyond the legal requirements and business-as-usual.

**Does not directly apply to Carleton as a high education campus*

Figure 34 – Current Potential Carbon Offset Options for Carleton University.

Note 1: https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/federal-offset-system.html

4.2 Low-Carbon Utility Strategy

The development of Carleton's Carbon Neutral Campus Strategy has a large emphasis on campus utility infrastructure as its dependence on fossil fuel (natural gas) accounts for a considerable amount of the campus equivalent carbon emission. The campus' utility infrastructure and its dependence on fossil fuel (natural gas) accounts for a considerable amount of the campus equivalent carbon emissions.

4.2.1 Nodal Plant

Three nodal heating plants will house electric boilers to supply low-temperature hot water (140ºF) via 2-pipe distribution to all existing and new buildings on campus. Electric boilers do not burn fossil fuels and if coupled with a non-fossil electricity supply can offer a zero carbon heating supply. They are assumed to operate at 99% efficiency based on current manufacturer's product data. Distributed low-temperature hot water will connect directly to building fan coil units or air-handling units via optional heat exchangers, as seen in Figure 35. However, it is recognized that natural gas may not be eliminated completely on campus, as backup heating systems and process equipment may still require it. Nonetheless, the focus is placed on reducing/replacing the natural gas used for day-to-day heating at the central steam plant and local boilers/rooftop units.

Existing nodal chilled water plants distributed at different campus buildings will remain and serve chilled water to all campus buildings, including all new developments. Existing nodal chiller plants will be expanded in capacity or new nodal plant locations can be constructed to meet the expected increased cooling demand of new development. Distributed chilled water will connect directly to building fan coil units or air-handling units, as seen in Figure 35.

Estimated equipment capacities required at each nodal plant for the heating and cooling systems are summarized in Appendix F. The values noted in Appendix F are estimated based on building peak thermal demand and current campus growth plan for the purpose of utility strategy evaluation. The estimated building thermal demand, plant and equipment sizes, and associated technical requirements need to be further designed and calculated based on the latest campus plan and anticipated building programs with nodal plants feasibility studies. These numbers should not be used to inform basis of design and construction budgets.

The campus' heating and cooling plants and distribution network are essentially isolated from each other. If the nodal heating and cooling plants can be co-located, then electric heat recovery chiller(s) can be used to support simultaneous heating and cooling load. It should be noted that most of the campus' cooling system is shut off during winter season.

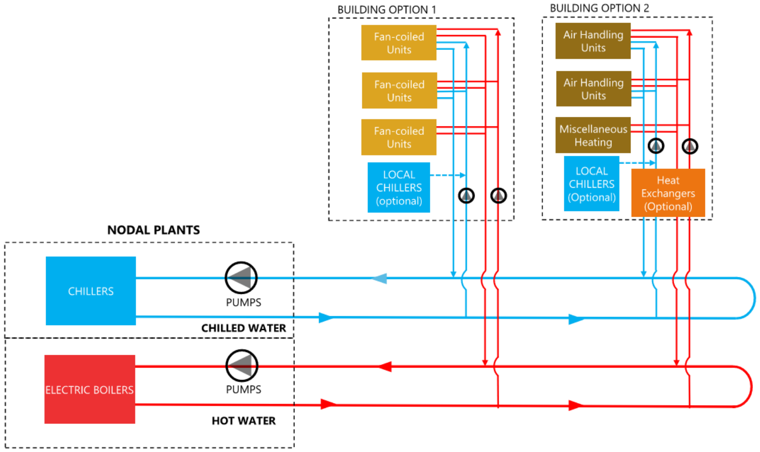


Figure 35 - Utility Strategy Thermal Schematic

The utility strategy will be implemented in a phased approach, as shown in Figure 36, gradually reducing the reliance on the central plant and local equipment and increasing connection to each nodal plant. The co-generator needs to operate from 2020 to 2030 and will then be taken offline as it increases carbon emissions and is not in alignment with the goal of the Carbon Neutral Campus Strategy. Once nodal plant operations begin, electric boilers can begin to supply existing buildings with heating hot water to existing and new buildings and reduce the load of the natural gas boilers. It is assumed that all new and existing buildings will be connected to a nodal plant by 2050 and the central plant can then be phased out. Existing buildings reliant on local cooling will also follow a phase approach in connecting to existing or new nodal chiller plants. The phasing diagram in Figure 36 demonstrates a linear connection of existing buildings to the nodal plant as for simplicity and is only indicative of how the strategy could be implemented on campus.

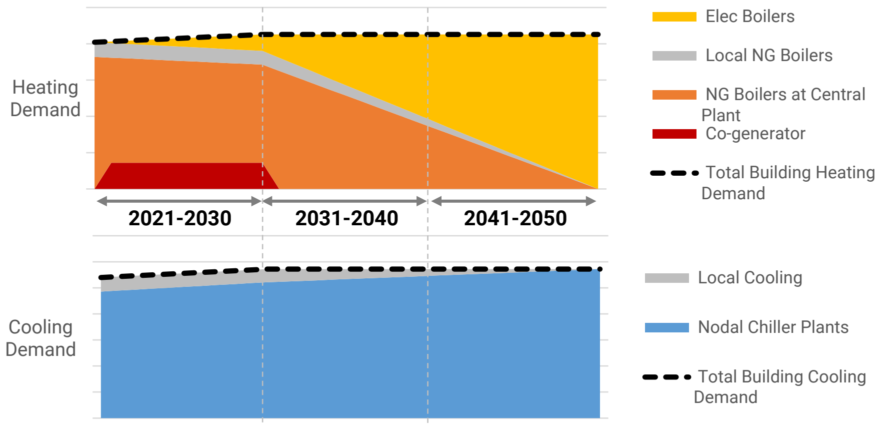


Figure 36 - Utility Strategy Phased Approach

The nodal heating plants are estimated to require a 44 MW of electricity demand when all nodal plants are operational i.e. winter. Figure 37 shows the different demand loads for each node broken out for heating and cooling. It should be noted that the 44 MW demand is greater than the campus' current peak electricity demand, as the current campus' peak electricity is in summer and is primarily driven by the campus' cooling demand. By switching to electricity as the main energy source for heating, the annual campus peak demand is expected to shift to winter. Therefore, the new nodal plants will require new electrical feed from either the campus main substation with expanded capacity near Bronson Avenue, a new campus substation, or direct feed from Ottawa Hydro.

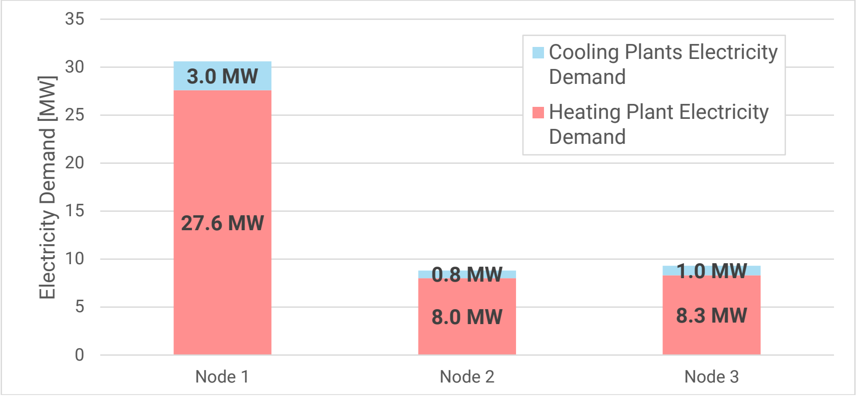
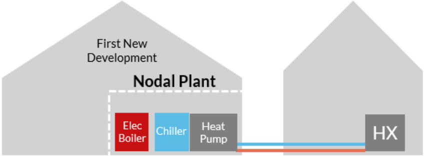


Figure 37 - Nodal Plant Thermal Electricity Demand

As new development phasing is not known, indicative nodal plant locations, shown in Figure 38 were assumed for the planning and quantitative distribution analysis. Additional aspects to consider when evaluating nodal plant locations are as follows:

- Locate nodal plants near the core of each node to reduce distribution piping capacity and routing to lower CAPEX. Potentially sub-divide nodal plant within nodes if there is considerable spatial and/or logistical challenges.
- Potentially integrate new nodal plant into future development in lieu of retrofitting existing spaces to maximize design and construction synergies.



- Connection to existing and new electrical loops - As nodal plants will be require significant electrical infrastructure, reducing new duct bank routing can minimize capital costs
- Proximity to other nodal plants or align distribution main trunks so that nodes can be interconnected for additional system redundancy and resiliency

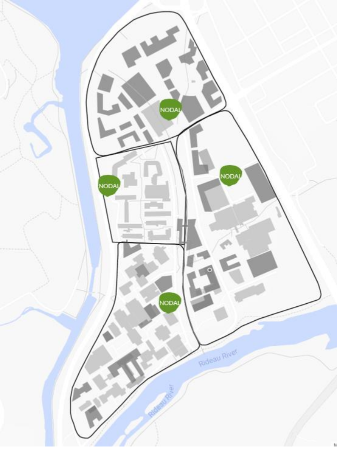


Figure 38 - Indicative Nodal Plant Locations

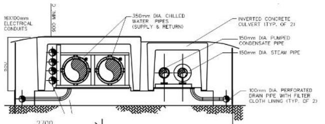
4.2.2 Distribution

The campus utility strategy requires new two-pipe heating hot water to be installed throughout campus to connect nodal plants to buildings. The cooling network distribution will also be expanded organically to serve existing buildings reliant on local cooling and new developments.

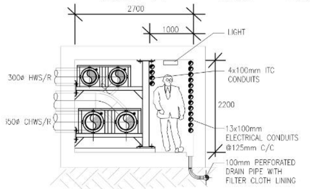
Distribution options for campus include the following:

- **Direct-buried pre-insulated pipes** are a low-cost option and require simple installation. However, they are limited in durability and lifespan as they are exposed to the ground condition. They also may pose a challenge in determining a new direct path as existing distribution and tunnels are present.
- **Inverted Trench piping** have a higher capital cost, compared to direct buried, however are far easier to access and maintain. They also pose a challenge in determining a new direct path as existing distribution and tunnels are present.
- **Piping within Existing Tunnels** will have the highest cost and longest construction timeline but are the easiest to monitor and maintain. It must be determined if existing utility areas within tunnels have sufficient area for new distribution pipe sizes.

DIRECT BURRIED



INVERTED TRENCH



TUNNEL

Two distribution strategies were considered for the implementation of the new hot water network:

Thermal Distribution Strategy 1: Distribution within Existing Tunnels

Existing tunnels contain public walkways and service areas which incorporate existing steam and chilled water distribution. Three options have been identified to include new distribution within existing tunnels, the feasibility of all options is dependent on existing tunnel dimensions, depths, and structural details which requires further assessment and analysis.

1. **Through Existing Utility Area -** Deploy temporary thermal distribution pipes while removing existing distribution in sections and installing with new piping sections. This option will be accompanied with phasing complications as it will be difficult to continue service buildings while removing and adding distribution. The public walkway tunnel will also not be operational during construction. As previously mentioned, existing utility areas within the tunnels may not have sufficient space for new distribution pipe sizes as hot water piping will be larger than steam piping. There are also potential design complications if distribution piping needs to cross public walkway areas to connect to a new building.

2. **Add New Distribution Piping Under the Top of Tunnels** - Lay distribution under the top of the tunnels and retrofit tunnel to allow access from within public walkway and utility tunnel area. This eliminates the concern of having to cross perpendicularly through an existing tunnel to connect distribution to a new building. If tunnels are not deep enough then tunnel ceilings must be lowered to accommodate distribution. The public walkway areas may not be operational during construction. Certain sections of the tunnels may not have enough head room to add distribution piping.
3. **Add new distribution below tunnels concrete slab** - Install new piping underneath the slab of the pedestrian tunnel. Cost and length of time of construction may be significant, especially in congested areas. It is also unknown if there is an existing electrical duct bank underneath section of tunnels that would not allow for this option. Public walkways will not be operational during construction.

Thermal Distribution Strategy 2: Distribution avoiding Tunnels
Direct buried or inverted trench distribution to be utilized for distribution throughout open areas on campus. Routing of distribution will be less efficient and costly as existing underground utilities and tunnels must be avoided. Inverts of existing utilities and tunnels must be located in order to determine paths for new distribution piping.

Existing utility and tunnel invert measurement and distribution network feasibility study is recommended as a short-term action to determine the best distribution strategy to pursue on campus, further details in section 5.2.

4.2.3 Existing and New Buildings

Existing buildings served by the CHP via steam or high temperature hot water heat exchangers will undergo retrofit to receive low temperature hot water distributed from electric boilers within nodal plants. Existing buildings with local heating boilers can be retrofitted for low temperature hot water as equipment reaches life expectancy and connected to a nodal plant. Retrofit to low temp hot water may require systematic retrofit of AHU (coil replacements) and perimeter heating systems (i.e., low temperature radiators). Most buildings on campus have steam converters and hot water internal distribution, however, retrofit to the buildings AHU and perimeter system may still be required. Particularly, retrofit of the perimeter heating systems can pose a greater challenge for retrofit. The current utility strategy does not assume local boilers at the building level for backup heating but supplementary heating can be added if deemed necessary.

All new developments will be designed and constructed to utilize the district low temperature hot water of 60°C (140°F) from new nodal plants and low-temperature hot water distribution. As new developments begin design, however, other local low carbon heating and cooling technologies such as those shown in Figure 39 can be considered and evaluated. Utilizing these local low-carbon heating and cooling technologies can potentially yield a considerable operational efficiency improvement over the use of the nodal plants. Conversely, they may increase maintenance cost and reduce system redundancy due to decentralization. Local low-carbon systems should be evaluated as an optimization strategy on a case-by-case basis against the district nodal system approach.

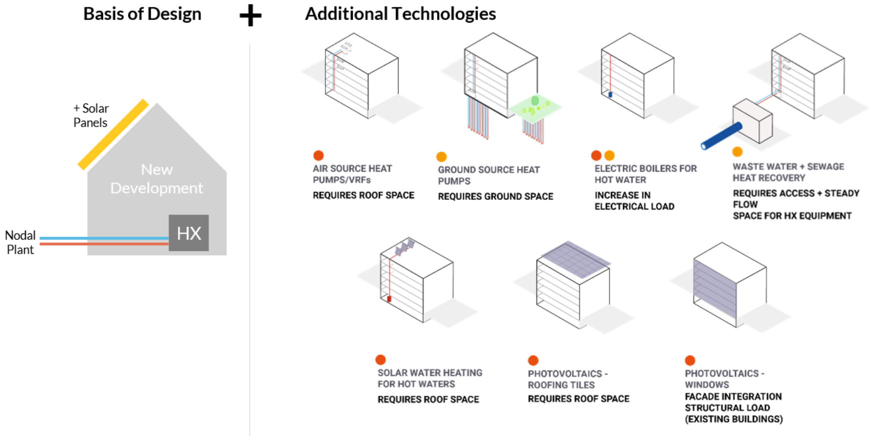


Figure 39 - New Development Technology Toolkit

4.3 Quantitative Analysis Summary

A quantitative analysis was performed to estimate capital investment, operational costs, equivalent carbon emissions, and 50-year total cost of ownership to inform economic feasibility and resulting carbon reduction of the Carbon Neutral Campus Strategy. A carbon tax sensitivity analysis was also performed to determine the effects of an escalated future carbon tax costs.

Assumptions in relation to the cost analysis included in the quantitative results are as follows:

- Utility Escalation per annum
  - 3% on natural gas
  - 2% on electricity
- Carbon tax at $20 per tonne (2019), increasing $10 per tonne every year up to $50 per tonne
  - 3% Cost Escalation on Carbon Tax per annum
- Emission Factors
  - Electricity 40g per kWh_e
  - Natural gas 1900g per m^3

Additional factors that were considered too detailed for this Energy Master Plan and not included were:

- Design Contingency
- General Conditions
- Construction Soft Cost – engineering, finance, legal, insurance, etc
- CAPEX Escalation per annum
- Maintenance and labor escalation per annum

4.3.1 Business-as-Usual Scenario Development

A business-as-usual (BAU) scenario was developed to compare capital and operational costs of the proposed design alternatives for Carleton University's future campus. It assumed existing campus system will continue to operate and existing utility infrastructure will only be renewed as necessary. Renewal costs associated with the BAU scenario are shown in Figure 40.

The BAU scenario assumes the following consistent with the campus' current operations:

Heating System:

- Campus will rely on the natural gas-based district heating infrastructure
  - Existing Boilers are maintained but not replaced as they are within anticipated life expectancy and in good working condition
- The existing central steam network will be expanded to serve new developments on campus
- All existing steam and condensate distribution will be renewed
  - Pipes are replaced with same size & capacity as existing (where information is available)

Cooling System:

- All existing nodal chillers will be renewed (approximately 6,500 tons of chiller equipment)
- All existing local building cooling equipment (local chillers or DX equipment) will be renewed
  - Local cooling load is assumed to be 13% as existing cooling load is not known
- All existing chilled water distribution will be renewed
  - Pipes are replaced with same size & capacity as existing (where information is available)
- New developments will have localized chillers and/or DX units for cooling;
  - Chilled water distribution is not expanded beyond what is existing

Buildings Level:

- Energy efficiency improvement projects will be implemented for existing buildings to achieve 19% reduction in heating, cooling, and electricity energy use
- New developments will perform at the level of existing buildings

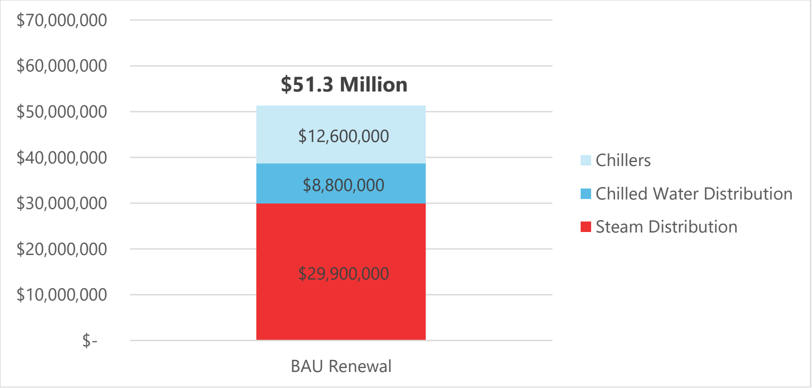


Figure 40 - BAU Renewal Cost Breakdown

Equivalent Greenhouse Gas Emissions

The Carbon Neutral Campus Strategy emissions in 2050 will be 6,700 tonnes, which equates to a 79% reduction from 2005 Emissions levels and is slight below the 80% target. As the strategy assumes the existing central plant natural gas boilers will be decommissioned by 2050, only emissions due to electricity remain. The remaining equivalent emissions are to be offset using offsite renewable systems or carbon offsets that are further discussed at section 4.1.5. The Master Plan assumes an emission factor of 1.9kg/m3 for natural gas and 0.04kg/kWh for electricity.

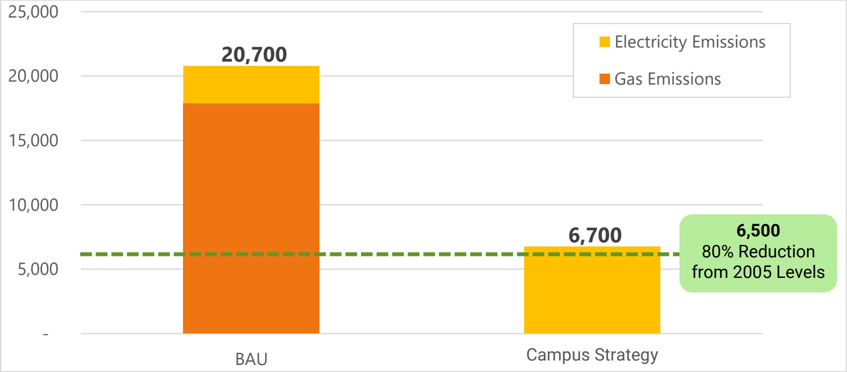


Figure 41 - Equivalent Carbon Emissions

Total Cost of Ownership per tonne of carbon emission reduced from 2018 Carbon emission levels is shown in Figure 42 . This figure demonstrates that if the costs over 50 years are associated with tonnes of carbon emitted then the carbon neutral strategy is better by orders of magnitude.

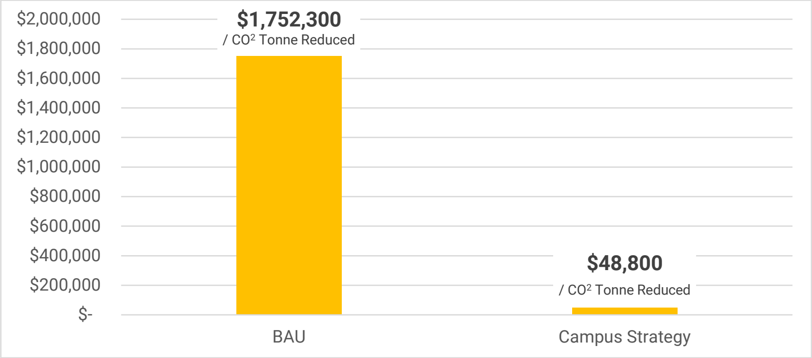


Figure 42 - CAPEX per Emission Reduced from 2018 Emission Levels

4.3.6 Sensitivity Analysis on Carbon Tax

Carbon tax rates represent a significant future uncertainty in the total cost of ownership for each design. The calculations above take a conservative approach following the current carbon pricing strategy set by the Federal Government.

Reports from the Fiscal Commission of Canada revealed that the price of carbon would need to increase to $210 per tonne by 2030 in order to achieve Canada's 2030 emission goals of 30% reduction. An additional analysis was conducted on the Carbon Neutral Campus Strategy to test the impacts of increased carbon tax by increasing carbon tax to $210 per tonne. Figure 43 shows a comparison of carbon tax costs in 2050, demonstrating the BAU scenario's vulnerability to increased carbon tax requiring additional $3.0 million annually with an elevated carbon tax price.

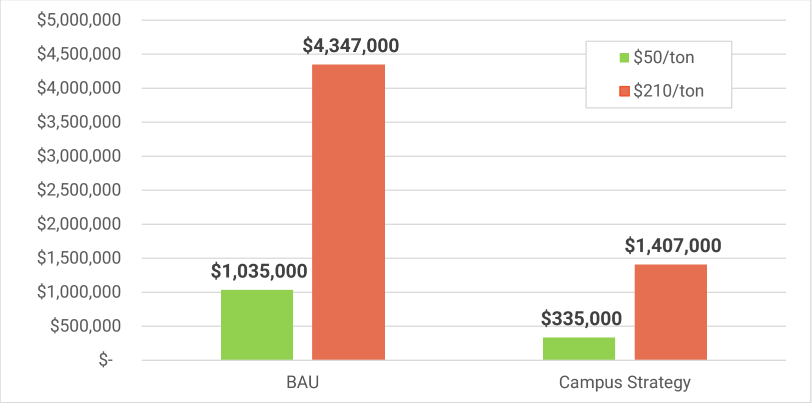


Figure 43 - 2050 Annual Carbon Tax

4.4 Strategy Optimization

This section discusses potentially strategies that may optimize the Carbon Neutral Campus Strategy in the future.

As the thermal strategies shift the campus towards electrification, the campus is expected to see large changes in demand peaks within the campus' electrical profiles. Current summertime peaks due to high amounts of cooling will be surpassed by the wintertime peaks from electric heating demands, see Figure 44 - . The estimated campus electrical profile in 2050 shows annual electrical peaks in January and February due to electric boilers, contributing up to 78% of the electrical peak demand. With the outlook of electric profiles changing over the upcoming years and the increase in reliance on grid-electricity, provision for onsite electrical or thermal storage systems can contribute to reducing electricity demand and operating cost.

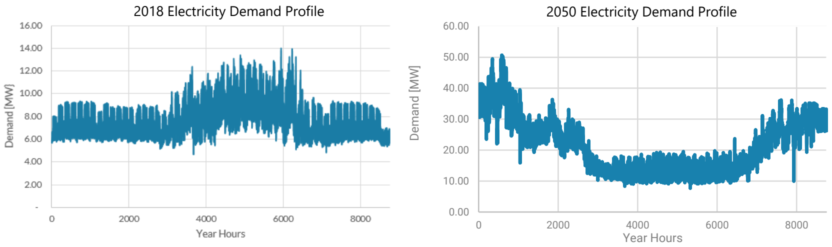


Figure 44 - Carleton's 2018 and Estimated Future 2050 Electricity Demand Profile

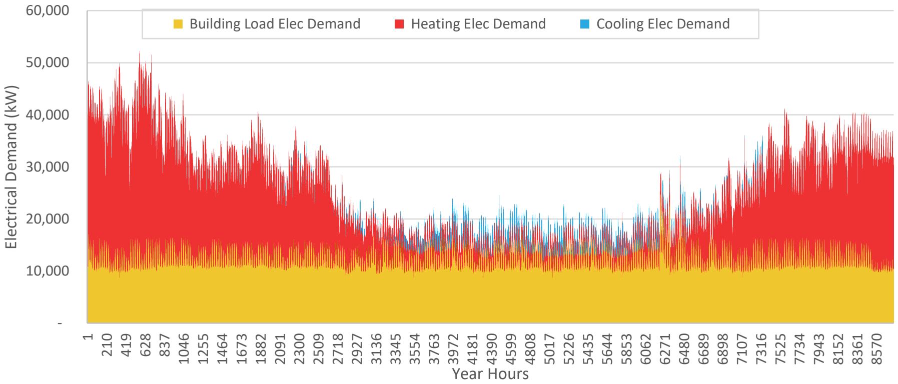


Figure 45 – 2050 Electrical Demand Breakdown

Currently, Global Adjustment (GA) charges contribute to on average 66% of Carleton's total annual electrical bill. Under the assumption that the Global Adjustment Rate structure remains until 2050, GA charges could exceed $13.5 million per year due to the increase in campus electrical demand.

The cost savings analysis of the following optimization technologies is based on the existing global adjustment rate structure. It's important to note that it's not known how long the GA rate structure will be in place and there is uncertainty on how the future utility rate will be structured. Detailed economic analysis should be performed at the time of investment consideration.

It should be noted that these high-level estimates are based on current rule-of-thumb utility and capital cost benchmarks and will potentially change considerably in the future. Current regulation, utility infrastructure and technology maturity may also pose considerable barriers for the University to proceed these concepts further.

4.4.1 Thermal Storage

A thermal energy storage (TES) system was investigated to provide energy cost savings by reducing peak electrical demand under the current Class-A global adjustment electricity tariff structure. The economic feasibility of a TES system was investigated for the chilled and hot water systems to be charged during off-peak hours and discharged during times of peak electric use. TES are advantageous as they allow high temperature differentials in hot water system for much higher energy storage, operate with a high round trip efficiency, and have a long lifespan.

A TES system dedicated to hot water for heating was found to be most economically feasible application of thermal energy storage. Chilled water TES system is not deemed viable due to low cooling demand on campus distributed existing chilled water plants.

The proposed tank for optimization analysis was sized to deliver 10MW over an eight hour period with a total storage capacity of 80 MWHt. The tank storage capacity is 2.5 million litres requiring the tank to be 16m high and 14m in diameter based on a height to diameter ratio of > 2.0 found to result in the highest thermal efficiency for stratification[2]. Campus electricity demand can be reduced by an estimated 29% with the proposed storage tank, reducing the campus energy costs by $1.5 million annually. Preliminary cost analysis estimates simple payback of the TES tank is 4.2 years.

A centralized TES tank offers flexibility and increased heating efficiency. It would require distribution to each nodal plant and is recommended if plant interconnectivity for redundancy benefits is also desired.

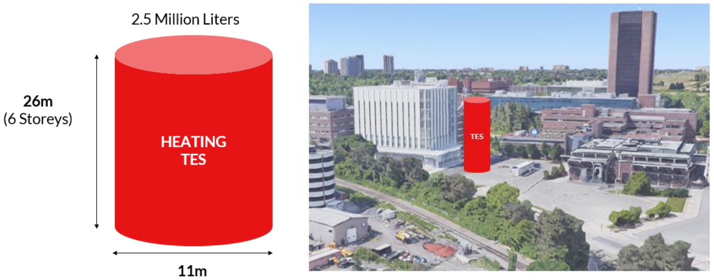


Figure 46 - (Left) Proposed TES Tank Dimensions, (Right) TES tank depicted beside Health Science Building

A TES tank at each nodal plant would eliminate the need for additional distribution and reduce size required of each tank. As Block 1 represents over 60% of the campus heating demand, installing a 10MW TES tank at Nodal Plant 1 can reduce total campus electricity demand by 29%.

It is not expected that the TES will be required until the nodal plants are designed and constructed and the campus has converted to an electrification strategy. Further analysis of its economic feasibility, location, connection and hydronic design of the TES is recommended at the concept design of the nodal plant.

Figure 47 - (Left) Central TES with connection to each nodal plant, (Right) TES Tank at each nodal plant
(TES Tanks are shown are for visualization purposes and do not represent required tank sizes. Distribution pipe routing shown is also indicative)

---

[2] https://www.mendeley.com/catalogue/0f7d5621-46fd-3abe-a5f5-bd88b155d4ca/

4.4.2 Battery Energy Storage System (BESS)

With the outlook of electric profiles changing over the coming years and the forecast of a shift to renewable energy generation, battery storage system becomes increasingly beneficial to integrate into the campus.

Battery storage systems provide the ability to charge and store electricity while electrical demand is low, or demand charges are low. During peak demand period, the battery storage system can discharge to the campus electrical network and reduce system demand and associated demand charges. Various Battery types and systems configurations are available, with lithium batteries as the most common technology currently.

Proposed battery storage systems for optimization analysis on campus assume a lithium battery system of various capacities to meet different percentages of the campus peak demand, as summarized in Table 11 below. Estimated annual savings are applied to the Global Adjustment costs for 2050 Electrical demand. Analysis presented is not be used for battery system design - detailed analysis of peak shaving capacity, and feasibility testing of connection to electrical infrastructure is required.

Table 11 - Proposed Battery Systems

	Battery Power	**Estimated Annual Savings in 2050**	**Battery System CAPEX**	**Area Required** (Area for Battery & Power Inverter, required transformer area not Included)
2% of Peak Demand	1 MW 4 MWh	$290,000	$0.6M - $1.52M	40m2
4% of Peak Demand	2 MW 8 MWh	$570,000	$1.2M - $3.04M	80m2
6% of Peak Demand	3 MW 12 MWh	$860,000	$1.8M - $4.56M	120m2
7% of Peak Demand	3.5 MW 14 MWh	$1,000,000	$2.1M - $5.32M	140m2

Connecting a battery storage system to the switchgear where all four campus feeds are incoming to the campus is the most feasible application of a battery on campus for peak shaving controls and minimizing infrastructure upgrades. Distributed batteries could require electrical loops capacity upgrades or restrict the ability to back feed battery power to other loops.

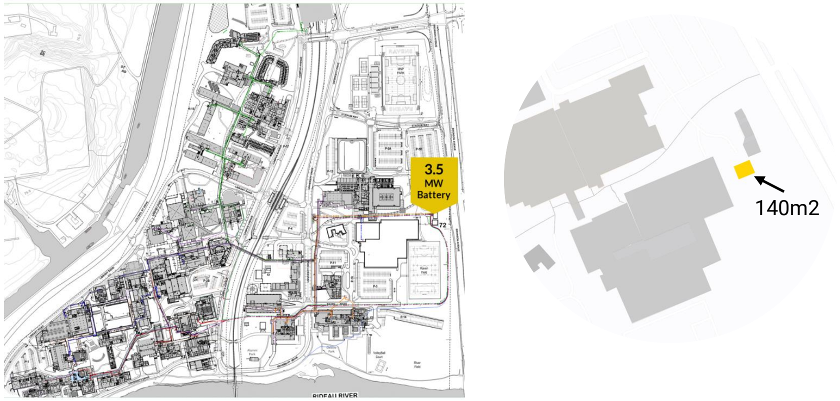


Figure 48 - Possible Application of centralized 3.5MW Battery on Campus

Investment costs of battery systems are expected to decrease in the future, as estimated by NREL's research study Cost Projections for Utility-Scale Battery Storage 2019, Figure 49 . As technologies and campus conditions evolve, the possible use cases for a centralized battery system, such as energy storage for back-up or redundancy, onsite generation, and emergency systems, may change and cost benefit analysis will need to be revised.

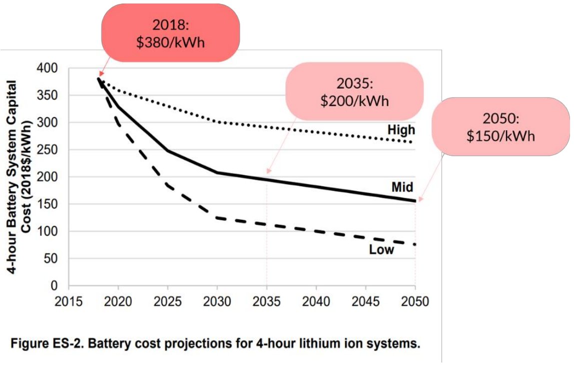


Figure ES-2. Battery cost projections for 4-hour lithium ion systems.

Figure 49 - Estimated Future Battery Costs (Source: NREL - Cost Projections for Utility-Scale Battery Storage, 2019)

4.4.3 Solar Photovoltaic

As described in Section 4.1.4, renewable solar energy will be integrated into the Carbon Neutral Campus Strategy through the addition of solar photo-voltaic (PV) panels on existing buildings, new developments, and above available parking areas.

Areas applicable for PV installation, Figure 32, were identified through satellite/google maps, looking for flat empty rooftop areas and parking lots that will not be converted to a new development in the 30-year campus growth plan. The entire rooftop or parking lot area was taken and a utilization factor was applied to account for areas not applicable for PV panels. The analysis performed assumed solar output calculated based on south facing panels with a 20-degree tilt and sun-path projections for Ottawa locations. It was also assumed that only existing buildings and the two new developments, were included due to the Covid-19 growth plan revisions. PV systems would be metered and tied into the building's main switchboard, which can be used to offset local power use.

Preliminary calculations estimate the campus' onsite electrical energy production by solar PV is 2.3 MW/ 2,760 MWh, resulting in estimated $431,000 in electricity savings annually.

Estimated Usable Area for PV Panels:	22,700 m^2
Total Solar Capacity:	2,270 kW
Total Annual Electricity Generation:	2,760,000 kWh
Total Annual Electricity Savings:	$431,000
GHG Emission Reduction:	138,000 kg of Carbon
Capital Cost:	$9.0 million

Further studies will need to be conducted to determine feasibility of the PV areas, including a structural load analysis, as well as additional space for electrical equipment and upgrades to the building switchboard. PV panel generation and costs calculations are based on industry standards and past project estimations, actual construction cost may vary due. Each project will have specific circumstances and conditions that will need to considered; capacity and cost estimation are expected to evolve as the design and planning of each PV installation are further developed.

4.4.4 Sewage Heat Recovery

Sewage systems offer the opportunity to recovery low grade heat from raw sewage or treated sewage effluent with the use of heat pumps. These systems do pose a risk for operation complexity due to fouling and odour from sewage handling.

A proposed sewage heat recovery system takes advantage of dual 300mm sewage force-mains leaving campus. Preliminary calculations estimate 2 x 1.5MW heating output based on pipe size and industry sewage flow assumptions, supplying roughly 5% of the campus required heating demand.

Further research and investigation being conducted by Carleton research teams have already begun to refine system implementation feasibility.

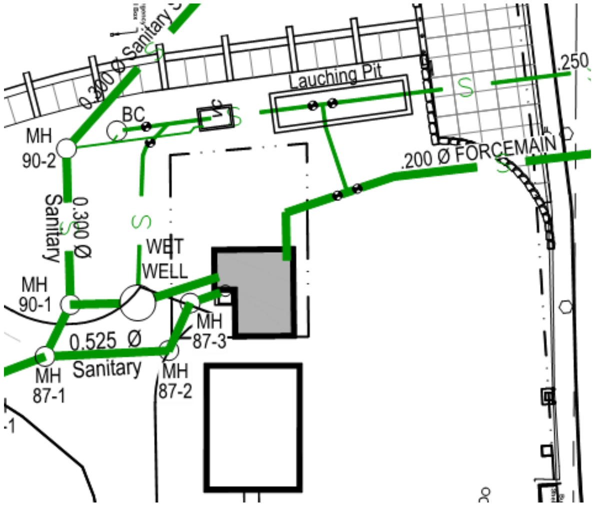


Figure 50 - Campus Wet Well and Force-mains

4.4.5 Optimization Technology Summary

The proposed optimization of thermal heating storage and electric battery storage systems are evaluated and the total cost of ownership results are summarized in the figure below. The thermal heating storage and electric battery storage systems were estimated to generate a 14% savings to annual electrical costs. Results are summarized in Figure 51.

Assumptions for the above include:

- Thermal Tank: 10MW, installed in 2030, CAPEX $6.5 million
- Electric Battery: 3.5 MW 14 MWH, installed in 2030, CAPEX $2.9 million ($205/kWh)
- Cost savings for TES Tank & Battery are based on current Global Adjustment Class A Rate Structure assuming batteries can reduce campus peak during five peak events from previous year
- Equipment life expectancy and renewal of technologies is not considered

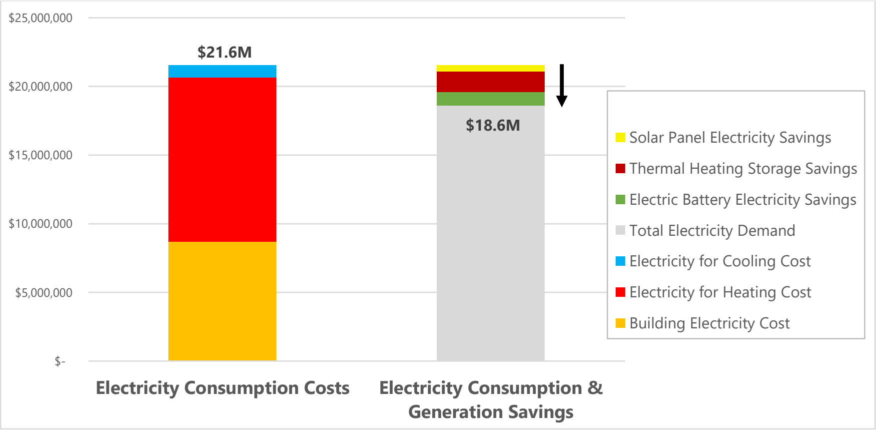


Figure 51 - Optimization Technology Annual Electricity Savings (2050)

5 Next Steps

5.1 Implementation Framework

The implementation framework, Figure 56, summarizes indicative project milestones including an overview of the existing equipment renewal plan, major new development construction, nodal development, and infrastructure requirements over the next 30 years for the Carbon Neutral Campus Strategy. This has been used to inform the design/phasing timeline of each node.

The Carbon Neutral Campus Strategy should be thoroughly reviewed every five years as technology and campus conditions evolve.

A supporting document of the renewal calendar includes an interactive and dynamic version of timeline and ability to track progress of milestone completion. Refer to Appendix H for supporting document spreadsheet.

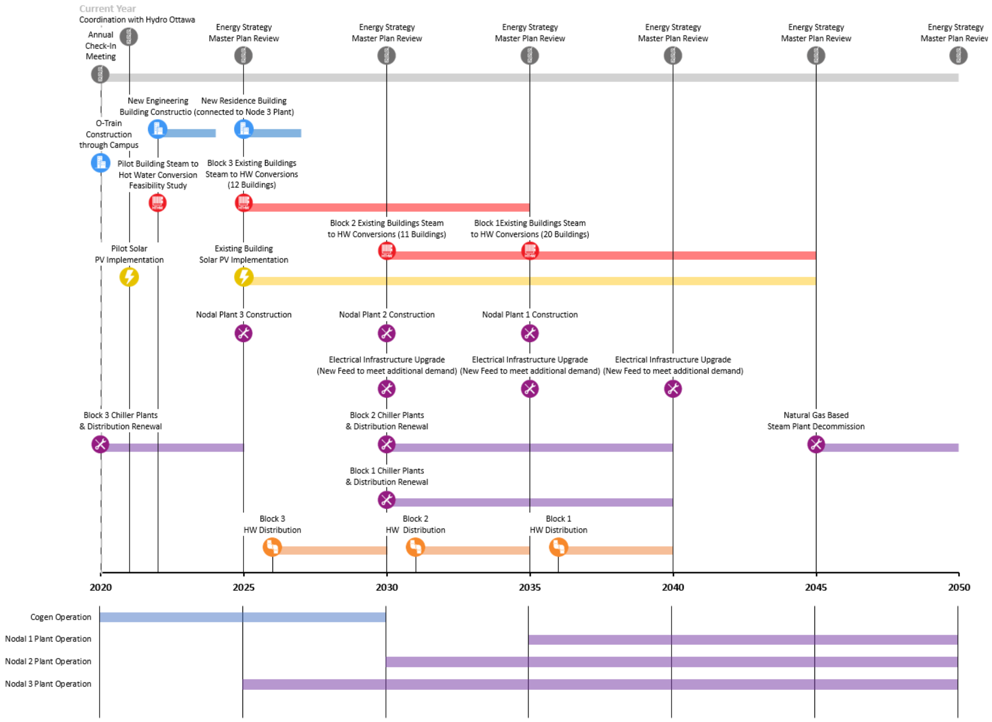


Figure 52 - Implementation Framework

5.2 Short-Term Actions

Conducting pilot studies or feasibility studies are mechanisms to evaluate technical and economic feasibility of the energy efficiency / carbon reduction projects at a small scale and provide a phased approach to scale-up to campus-wide implementation. As the Carbon Neutral Campus Strategy is based on the combination of different projects incorporating new utility infrastructure, thermal energy generating technologies, existing building retrofits, and renewable system integration, pilot studies can be carried out to work towards achieving zero-carbon. Short-term actions also present an opportunity for collaboration with Carleton academia and students. The following pilot studies and short-term actions are recommended to be completed on campus within the next five years:

5.2.1 Existing Building Energy Retrofit

. Existing buildings will require signification effort and capital investment but are a vital step in Carleton's goal of carbon neutrality. Upgrades such as improvement/ renewal of building envelope, controls, HVAC equipment, ventilation, etc will make a big impact on reducing energy use. To retrofit nearly the entire campus, a number of building retrofits will need to take place each year for the next 30 years. Investigation of buildings with high heating and cooling consumption can help identify buildings to prioritize for energy retrofit as these buildings will have a greater impact on lowering emissions and reducing load on central plant and equipment sizing for new plants. Buildings such as labs, may pose a challenge for energy reduction and steam conversion retrofit projects. Deep retrofit feasibility studies should also be conducted to evaluate and determine an energy performance target for different campus buildings types.

Next Steps:

- Identify buildings suitable for energy retrofit
  - Buildings without planned major redevelopment
  - Buildings with high heating and cooling load
- Perform Building Energy Audit to identify and quantify potential energy conservation measures
- Determine building level cooling demands and consumption
- Establish energy reduction targets for different campus building archetypes

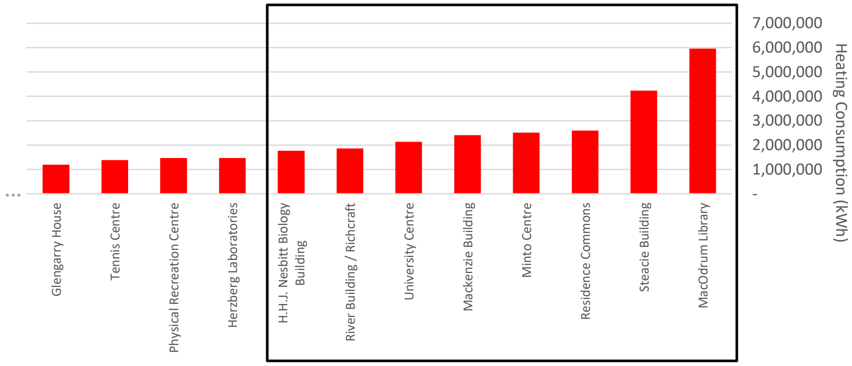


Figure 53 - High Heating Consumption Campus Buildings - Averaged 2016-2018 Steam & Natural Gas Consumption data provided by Carleton

5.2.2 Steam to Hot Water Conversion Retrofit

Existing buildings should be retrofitted to connect to a new district heating system which utilizes centrally supplied low temperature hot water. Most buildings on campus are on high temperature hot water distribution within the building (180ºF) but need to be converted for a lower supply temperature and/or lower delta T. Building heat exchangers, as well as steam fed AHU and fan coil units should be retrofitted/replaced to receive LTHW. A steam conversion feasibility test can be performed on a few campus buildings to identify technical requirements and economics.

Next Steps:

- Identify all existing buildings heating systems configuration
- Select buildings suitable for steam conversion feasibility study, considering:
  - Buildings without planned major renovation or redevelopment
  - Typical heating system configuration
  - High annual heating consumption, Figure 53
- Integrate feasibility study with energy auditing scope

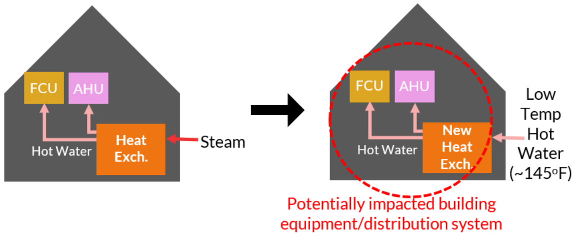


Figure 54 – Existing Building Steam to Hot Water Conversion Retrofit Schematic

5.2.3 Renewable System (PV)

Renewable solar energy will be integrated into the Carbon Neutral Campus Strategy through the addition of solar photo-voltaic panels on existing buildings, new developments, and canopies above available parking areas.

Within the areas identified as applicable for PV installation, the University further identified specific sites most suitable for initial PV installations. A new parking garage is being designed for construction within the next three years and will be designed to structurally support PV panels for the future. Another parking lot without any upcoming major renovations planned is P18 Parking garage, located within the north end of campus spanning the O-Train track. Canel and Ritchcraft were also identified as potential buildings for rooftop PV panel installation due to their open roof designs. This list is not exhaustive of suitable sites and further analysis is required to determine initial solar projects. See Appendix G for further analysis of existing areas on campus identified for PV installation.

Next Steps:

- Perform site specific feasibility analysis to evaluate:
  - Structural capacity on existing structure
  - Integration with existing electrical infrastructure
  - Concept design of the PV system (sizing, spatial requirement, annual outputs and economics)
- Other considerations:
  - Select existing parking lots or buildings without planned major renovation or redevelopment

5.2.4 New Building Performance Standard Development

A new energy performance standard with performance targets for new developments to be put into place, such that new development can reduce the burden on the campus carbon emissions and support the University's vision to achieve carbon neutrality in the future.

Future cost/benefit studies are recommended to determine a definitive energy performance targets for new buildings.

Next Steps:

- Research into established Building Performance standards within the industry e.g. Figure 55
- Develop list of performance metrics and targets for new development and specific building archetypes

Year constructed	Toronto Green Standard certification level	EUI
2019-2020	V3 Tier 1	170
2021-2025	V3 Tier 2	130
2026-2030	V3 Tier 3	100
2031-2050	V3 Tier 4	65

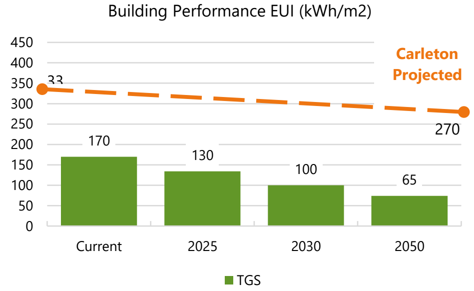


Figure 55 – Indicative Toronto Green Standard Performance EUI for future campus development
(Note: TGS targets shown are for commercial buildings)

5.2.5 Electrical Infrastructure

The Carbon Neutral Campus Strategy and associated costs were developed based on the assumption that electrical infrastructure will be available. The Strategy will result in nearly doubling the existing electricity demand, surpassing existing capacity before 2050. Investigation into electrical upgrade and renewal feasibility and costs should be performed.

Next Steps:

- Engage in discussion with Ottawa Hydro to determine electrical upgrade feasibility
- Perform a detailed electrical infrastructure audit and renewal plan
- Investigate interconnectivity for renewal systems ie. Solar PV

5.2.6 Nodal Plant Detailed Feasibility Study

A feasibility study should be performed to better understand building thermal demand requirement, equipment sizing and estimated spatial requirements of new nodal plants for the Carbon Neutral Strategy. The study should also investigate potential locations to house the nodal plant incorporating considerations listed in section 4.2.1. Upcoming new developments should consider including nodal plant within building footprint and be designed with necessary spatial and technical requirements. As the first nodal plant should be constructed within the next 5 years, a nodal plant feasibility study should begin promptly.

5.2.7 Distribution Network Detailed Feasibility Study

Given the urban density of Carleton and extensive network of existing utility systems, adding new distribution routing may pose challenges that requires further detailed survey and assessment. Distribution configurations available on campus are within and around existing tunnels, and direct or inverted trenches to avoiding existing tunnels. Figure 56 shows potential intersections/conflicts with existing utility systems from a distribution scenario that avoids using existing tunnels.

A distribution network feasibility study can help determine the best distribution strategy to pursue on campus by indemnifying the following.

Next Steps:

- Existing tunnel dimensions, depths, and structural details
- Elevation of existing stormwater and sanitary lines
- Feasibility of removing existing distribution from service tunnels

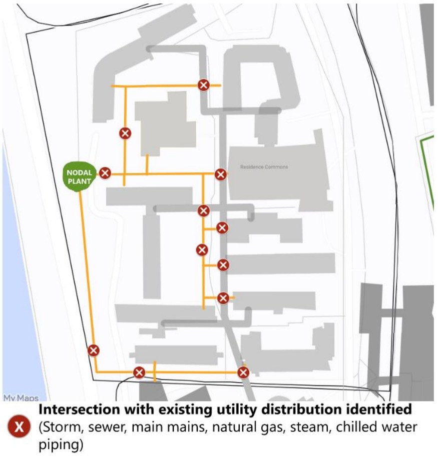


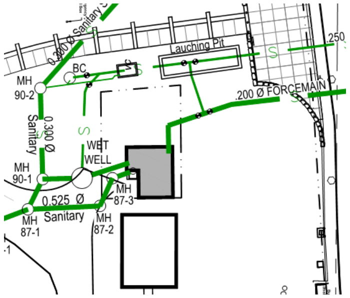
Figure 56 – Potential Intersections with Existing Utility Distribution

5.2.8 Sewage Heat Recovery Study

A sewage heat recovery system can provide supplementary thermal supply for design options that utilize LTHW. Heat pump technology can be used to transfer/recover heat from sewage main. Research teams at Carleton have begun investigation into sewage heat recovery potential on campus and should further investigation of the physical infrastructure and connection to surrounding buildings.

Next Steps:

- Feasibility testing of the physical sewage infrastructure to confirm the following
  - Sewage flow
  - Pipe sizes
  - Sewage heat recovery capacity
  - Concept design of interconnection with sewage pipe/wet well and heat exchanger
  - Mechanical plant location in nearby building for heat pumps
  - Ownership/access pf sewage pipes and wet well
  - Approval from city for implementation
  - Odor and maintenance considerations



5.3 Long-Term Actions

5.3.1 Nodal Plants and Distribution Design and Construction

After a nodal plant feasibility study is complete, design and construction for three nodal plants should begin. The first nodal plant is proposed to begin design construction in the next five years as shown in the implementation framework in Figure 56. The nodal plant is anticipated to initially only serve the building that it is housed in, with room for future equipment and capacity expansion. Within the following 5-10 years, distribution to each building within the node will be constructed and all buildings will be converted to operate using hot water supplied by the nodal plant. The remaining nodal plants should follow a similar phased approach and all buildings should to be connected to nodal plants receive heating via low carbon generation by 2050.

All dates within the implementation framework have been set as targets, however, dates are subject to change as campus projects progress. Carleton University should track progress and update the timeline of all milestones in the Master Plan accordingly.

5.3.2 Electrical infrastructure upgrade

Electrical infrastructure upgrades will be required to support the Carbon Neutral Campus Strategy. Detailed design and construction of electrical infrastructure upgrades should align with the timeline for Nodal plants. Development of an electrical infrastructure redundancy standard can help inform to inform these electrical system upgrades.

Detailed design is required for the interconnectivity for optimization systems, including batteries and solar PV systems.

Increased dependence on campus electrical infrastructure also requires a reliable emergency and maintenance plan for the electrical system. Development of the plan should consider:

- Winter Peak demands
- Connected campus heating equipment
- On campus electrical infrastructure failures
- Off-campus hydro provider failures/blackouts
- Emergency generator and life safety system

5.3.3 Existing Central Plant Phase Out

New nodal plants will gradually supply all campus heating needs and by 2050 all existing and new developments will be connected to the nodal plants and will be no longer reliant on the existing central heating plant. As heating demand on the central plant decreases, boilers can be taken offline when possible. The central heating plant building can be repurposed into a heating or cooling nodal plant, utilized for different program use or re-developed into a new building on campus.

The existing natural gas utility network on campus should remain as non-heating natural gas usage may continue. Significant reduction to campus natural gas consumption is expected once the cogeneration system and existing steam boilers are offline. A phasing plan for the central heating plant should be developed to address these elements including a timeline of necessary actions.

5.3.4 Block 4 Development - Geo-Exchange Technology

Geo-exchange technology was not pursued as part of the campus strategy due to previously unsuccessful geo-exchange installation on campus. Carleton University is considering testing a closed loop geothermal technology at an upcoming new development. Through success of a small project, interest in larger geo-exchange projects may return. Potential future development at Block 4, northern campus is an area where large-scale geo-exchange system can be deployed to provide efficiency low-carbon heating and cooling to new developments in the area. Figure 57 highlights potential geo-exchange borehole fields locations on campus.

Figure 57 - Potential Geo-exchange Borehole Fields on Campus

6 Conclusions

The Carbon Neutral Campus Strategy was developed to provide an optimized solution for campus carbon neutrality across Carleton University's key performance indicators. Its goal is to provide a guide to the stakeholders decision-making process to develop a long-term strategy for the campus site utility infrastructure. The Carbon Neutral Campus Strategy reduces emissions on campus by 80% by reducing campus demand reduced from existing buildings, new developments, and transformation of the existing utility generation system to a low-carbon energy source. Remaining carbon emissions will be offset with renewables or carbon offsets.

By adopting campus electrification, low carbon technology will supply campus building thermal demands. The strategy uses a nodal approach to transform the campus utility system, providing implementation flexibility and a balance between complete centralization and decentralization. The Master Plan includes an implementation framework that further outlines key milestone dates of major projects and key requirements of the strategy for the next 30 years. It's important to note, existing buildings are a vital step in reducing carbon emissions to achieve Carleton University's goal of carbon neutrality and will require signification effort and capital investment. Focus should be placed on completing retrofits in a number of buildings each year for the next 30 years; nearly the entire existing campus will require energy reduction and steam to hot water conversion retrofits.

This approach does not include Scope three emissions, however, Carleton recognizes accounting for these emissions is valuable in understanding full scale of environmental impacts and scope three emissions will be considered in future revisions of the Campus Energy Master Plan.

Design and cost estimates within the Master Plan were used for comparison and decision-making purposes to formulate the Carbon Neutral Campus Strategy. The Master Plan is developed based on a set of assumptions and best information available provide by the University. It's expected that events will not occur as expected therefore the Energy Master Plan should be treated as a living document and is expected to evolve with the constant changes of the campus.

Finally, the Energy Master Plan should be reviewed with the consideration in the latest advancement in low-carbon technologies, changes in regulatory policies and programs, physical impacts due to climate changes, and other political and social-economic factors. Design and cost estimation are expected to be updated as the design and planning of the campus and its components continuously evolved and refined. Feasibility studies bridging the Carbon Neutral Campus Strategy and indicative campus strategy phasing timeline in section 5.1 and 5.2 are necessary components for the success rollout of Master Plan.

Appendix A. **Phase 1 Memo Report**

Memorandum

ARUP

Arup Canada Inc.

To	Carleton University	Date March 9, 2020
Copies		Reference number 0101
From	Arup	File reference
Subject	Carleton University Energy Neutral Campus Plan - Phase 1 Memo Report	

1 Introduction

This technical memorandum summarizes the basis of calculation (model inputs) for Carleton University's Energy Neutral Master Plan. The analysis includes a summary of the current campus peak demand and annual consumption for heating, cooling, and electrical energy and the anticipated increase based on future campus growth and building energy performance.

The main objective of the Energy Neutral Master Plan is to develop a roadmap for Carleton University to achieve its environmental goals while increasing system reliability and safety and reducing utility operational costs. Carleton University has a strong commitment to embedding continuous environmental and sustainable improvement in its operation. The University has committed to reduce its carbon emissions by 30% below 2005 levels by 2030 and is now developing a plan to become a carbon neutral campus by 2050. Based on the previous Energy Master Plan (2016), the University's 2018 carbon emissions are 35% below 2005 levels. This basis of calculation memo describes the assumptions and methodology for the quantitative evaluation of different energy strategies for the campus.

2 Site Context

2.1 Campus Size and Population

Carleton University is located in Ottawa, Ontario. The campus is bordered by Colonel By Drive to the West, Bronson Avenue to the East, and the Rideau River to the South. The campus currently has 48 buildings and approximately 481,000 square meters in floor area. Table 1 summarizes the past and current campus total floor area, student population, utility consumption and equivalent carbon emission. The campus is expected to increase its total floor area by 300,000 m^2 by 2050.

	Total Floor Area (m^2)	Total student population	Electricity (GWh)	Natural gas (m^3 x 10^6)	Carbon (x 10^4 tonnes)
2005	310,000	21,917	65	9.8	3.2
2018	481,000	31,202	68	10	2.1
Planned Development	301,476				

Table 1: Past and Current campus total floor area, student population, utility consumption and equivalent carbon emission (Source: Request for Proposal for Carleton University's Energy Neutral Master Plan, 2019)

2.2 Existing Site Context

2.2.1 Land Regulations

Table 2 summarizes some general land regulations applicable to Carleton's campus area.

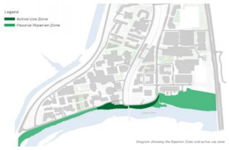
<table>
<tr><th>Feature</th><th>Details</th></tr>
<tr><td>Territorial Acknowledgement</td><td>- "Carleton University acknowledges the location of its campus on the traditional, unceded territories of the Algonquin nation."</td></tr>
<tr><td>Ottawa Greenbelt</td><td>- A 20,000-hectare conservation area surrounding Ottawa's downtown core
- Features agricultural farms, sand dunes, wetland areas</td></tr>
<tr><td>Rideau Valley Conservation Authority</td><td>- Carleton's south campus is located on the Rideau River Flood Plain riparian zone
- Developments on the Rideau River Flood Plain are controlled by the Rideau Valley Conservation Authority

</td></tr>
<tr><td>O-Train Regulations</td><td>- The O-Train track is centrally located on campus. The City of Ottawa plans to twin the tracks located on campus, closing the O-Train Trillium Line for construction from May 2020 to Sept 2022.
- Construction on Carleton Station will potentially include:
○ Adding a pedestrian underpass north of Carleton Station to support Carleton's development plans; and
○ A pedestrian tunnel segment below the tracks connected to Carleton's tunnels.
- Construction near the track (building and utility work) is expected to require review/approval by the City of Ottawa / Authority Having Jurisdiction (AHJ). It is currently unclear what is the "zone of influence" required by the City of Ottawa / AHJ.</td></tr>
</table>

Table 2: Land Regulations in Ottawa, Ontario applicable to Carleton University

Memorandum

2.2.2 Water Table and Flood Report

The Rideau Valley Conservation Authority (RVCA) identifies the Carleton University area as flood-prone. During a 1:100-year flood event, Rideau River will flood up the existing ditch west of Bronson Avenue and spread west into a few spots within Carleton's campus. Floodwaters are managed by the dyke-flood wall system in the Carleton area. Through discussion with the University, flooding has also occurred on the northwest side of the campus from Colonel By Drive.

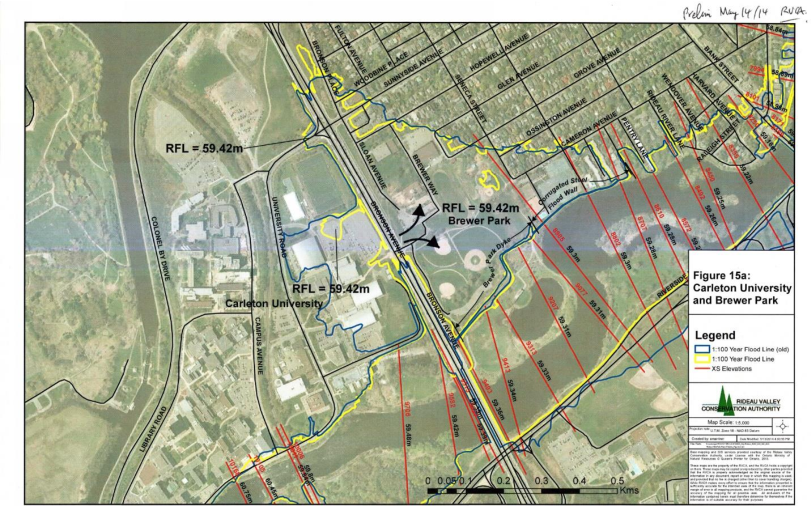


Figure 1: Rideau Valley Conservation Authority's projected 1:100-year flood event

Based on site walks and discussion with the University, there are areas on campus that are known to have high water tables, specifically the area north of Leeds House and the area south of Robertson Hall. The high water table has also led to groundwater penetration in the pedestrian tunnel, causing seasonal flooding.

2.3 Campus Utility Networks

The current campus utility networks include a central electrical distribution, a central heating network and a distributed chilled water network. Best available drawings, utility billing and trend data of utility demand and consumption were provided by the University and attached in Appendix A.

2.3.1 Electricity Network

The electricity network includes four 13.2 kV 8MW feeds from Hydro Ottawa from the East side of the campus. Based on building data, the peak electricity demand is 14.0MW, and annual consumption is 68.6MWh. There is one 1 MW and one 300 kW backup generators located at the central heating plant, and a few other backup generators distributed across the campus located at the building level.

There are 5 closed loops (Loop A, B, C, D, and E) that feed campus buildings on the electricity network. These loops are generally sized 350 MCM and come from one or two switchboards (both on Bronson Avenue). Buildings fed directly from the loop generally transform down to 600V. See Appendix A for Electrical Distribution Drawing.

2.3.2 Natural Gas Network

The campus' natural gas network is supplied by Enbridge Gas and has two incoming gas supply feeds to campus. The University has procured natural gas in two ways. The natural gas used at the maintenance building (central heating plant) by the central steam boilers are purchased using direct access and through Comsatec. Natural gas is also used at the buildings level to supply local hot water boilers and rooftop air handling units (furnace). Total campus natural gas consumption is approximately 9.2 million m^3 annually, with 90% of the total natural gas used the central heating plant. See Appendix A for Natural Gas Network Distribution Drawing.

2.3.3 Heating Network

The buildings on campus are mainly heated by the central heating plant with high pressure steam distributed throughout the campus at 125 to 150 psi. Most buildings on campus have local steam converter(s) with medium temperature hot water (MTHW) distribution at 180ºF within the buildings. Most of the buildings on campus have undergone building conversion from steam to MTHW; only a few buildings still use local, direct steam. The central steam system also supports a smaller MTHW distribution system that serves the residential buildings. Other buildings have either local hot water boilers or a rooftop furnace. See Appendix A for Heating Network Distribution Drawings.

The campus steam system has two 6" steam pipe mains that extend from the maintenance building. The installed heating capacity at the plant is 200,000 lbs of steam/hr and observed peak steam demand is 95,000 lbs of steam/hr. Annual steam generation is approximately 238,000,000 lbs of steam/year. The central heating plant consumes approximately 9,150,000 m3 of natural gas annually, resulting in average efficiency of 70%.

Table 3: Annual steam generation and natural gas metered at the Central Heating Plant, 2018

2018 Annual Steam Generation at Central Plant (From SP2018.xlsx)		**2018 Natural Gas metered for Central Plant** (from Monthly Utility Rates Verification.xlsx)	
238,075,955	lb of steam/yr	9,155,699	m3/yr
230,933,676	kbtu/yr*	329,605,164	kbtu/yr
		Annual Average Steam Production Efficiency	**70%**

*Based on 970 btu per lb of steam

A new 5 MW cogeneration system has been installed at the maintenance building and is expected to begin operation in 2020. The gas turbine will add a steam capacity of 40,000 lbs of steam/hr, or with duct burners 100,000 lbs of steam/hr. Combining with the existing capacity of the central steam boilers and the new cogeneration system, the total heating capacity is approximately 300,000 lbs of steam/hr. The cogeneration system is required to operate a minimum of 6,500 hours per year for 10 years, based on an agreement with Ottawa Hydro.

2.3.4 Cooling Network

There are 14 cooling plants distributed across campus. These cooling plants are not interconnected. A basic sum of the chiller capacities is approximately 6,500 Tons. A 1000-ton absorption chiller is located at the Steacie Building. In the summer months, when campus heating demand is low but the cogeneration system is required to operate, the absorption chiller can utilize the excess heat generated by the cogeneration system. See Appendix A for Cooling Network Distribution Drawing and chiller capacity.

2.3.5 Sanitary Network

The sanitary network on campus are separate from the stormwater system. All sewage from buildings on campus are gravity drained to a common point east of Alumni Hall, where the campus' main electrical substation is located. Sewage from nearby townhouses east of the campus are also drained to the campus, where all sewage drains to a wet well that is pumped into a forced main to the City municipal system. The wet well and pumping station are owned and operated by the City of Ottawa. See Appendix A for Sanitary Network Drawing.

3 Annual Consumption and Peak Demand

3.1 Approach and Methodology

The approach to achieve campus carbon neutrality is based on following main steps (see Figure 2):

1. Identifying a baseline reference emission level for the campus
2. Reducing load from existing buildings using energy conservation measures
3. Further reducing load from existing buildings using deep energy retrofits
4. Adopting high building energy performance standards for new building development/renovation
5. Implementing new generation and/or distribution system to increase system efficiency and/or switch fuel supply to significantly reduce operational carbon emission level
6. Offsetting remaining carbon emission using renewable generation, power purchase agreement and/or purchasing carbon credit

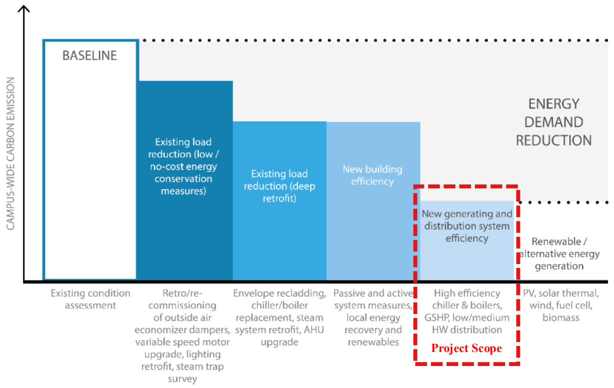


Figure 2: Zero Carbon Campus Approach

The project scope is focused on Step #5 of the Zero Carbon Campus Approach – new generating and distribution system. The emissions associated with existing building improvement and future building development were considered and discussed with the University, and assumptions are made to determine their associated impacts and further described in subsequent sections of this report. The campus' future thermal and electricity demand and consumption is calculated as follows:

1. Existing heating, cooling, and electricity demand and consumption were determined for existing buildings using utility and building trend data received from Carleton. Where utility/trend data are not available, Arup utilized performance benchmarks from previous projects and energy models.
2. Potential performance improvements for existing buildings were established based on previous energy master plan reports. The potential energy reduction identified with building retrofit projects is 19%. This number is applied when the campus' future energy consumption and associated greenhouse gas emission levels are calculated, but this number is not considered when the campus' future thermal demand is calculated (for preliminary system sizing).
3. Campus growth and new developments were projected based on Carleton's 2016 Campus Master Plan.
4. For new development, energy demand and consumption were calculated based on existing utility data, analyses conducted on building performance targets, and utilizing future building energy performance benchmarks from publications from the Toronto Green Standards and the Zero Emission Building Framework.
5. Electric vehicle charging stations in new and existing parking lots were included in future electrical demand and consumption calculations. Future parking lots projection are based on Carleton's 2016 Campus Master Plan.

Values provided in this report are used for calculation purposes for the Energy Neutral Campus Plan only to compare options. Actual future campus utility demand and consumption will vary depending on multiple parameters. These include but not limited to the actual building area developed and associated space programming, actual building performance level, future climate change conditions, and load reduction achieved on existing buildings.

3.2 Existing Demand and Consumption

The current peak heating demand from the campus steam network is based on utility data provided by the University, which is approximately 95,000 lbs of steam per hour (27,000 kW_t). Extrapolating the peak thermal demand based on building area, summarized in Table 4, the total campus current peak heating demand is approximately 104,500 lbs of steam per hour (29,500 kW_t).

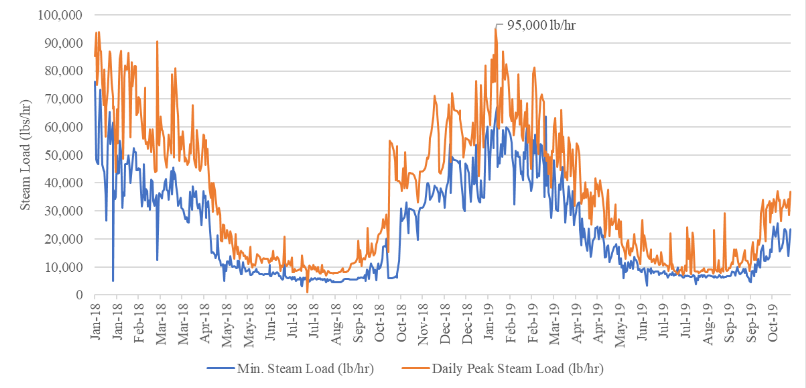


Figure 3: Daily Average Steam Load

Table 4: Total campus heating extrapolation for buildings with local boilers

	% of Buildings Area Connected	**Peak Demand**	**Source**
Steam Network	90%	95,000 lb/hr (27,000 kW_t)	Metered Data
Local Boilers	10%	9,500 lb/hr (2,698 kW_t)	Calculated
Total Heating Demand		**104,500 lb/hr** (29,678 kW_t)	

The current annual heating consumption for the campus is based on utility spreadsheets provided by Carleton University, which contains utility consumption data for year 2016, 2017 and 2018. The annual heating consumption of the campus steam network is 238,000,000 lbs of steam per year.

At the building level, hourly trend data of steam consumption for twelve buildings was provided by the University. The thermal demand and consumption of these twelve buildings were used as the representative buildings based on their archetypes to generate the heating consumption factors shown in

Table 5. The thermal demand and consumption of the twelve buildings determined from the building trend data have been increased by 50% in a calibration process such that the sum of buildings' total matches the campus total heating consumption.

Building-level cooling demand and consumption data was not available, so the campus' chilled water demand is based on industry energy performance benchmarking for different building types. These factors and the estimated campus total cooling demand and consumption is presented in Table 5.

The campus' current electricity demand and consumption figures have been modified to remove electricity used for cooling equipment, including chilled water plants and local building cooling equipment. Chilled water demand and consumption were estimated for each building using the factors in Table 5. The cooling electricity energy used per building assumed COP of 4 and has been subtracted from the electricity metered data per building. The electrical demand data factors were also increased by 50% to match the campus total electrical demand, as done with the heating consumption data.

Table 5: Existing building demand and consumption factors by building type

	Heating Consumption (kWh/m^2)	**Heating Demand** (W/m^2)	**Cooling Consumption** (kWh/m^2)	**Cooling Demand** (W/m^2)	**Electrical Consumption** (kWh/m^2)	**Electrical Demand** (W/m^2)
Source	**Building Meter Data**	**Building Meter Data**	**Industry Factors & Building Meter Data***	**Industry Factors**	**Building Meter Data**	**Building Meter Data**
Academic	222	76	65	59	149	35
Ancillary	172	23	28*	73	172	33
Athletics	195	124	26	73	181	34
Lab	218	185	178	98	134	26
Residence	158	59	25*	43	89	20
Campus Total	**81,700,000 kWh$_t$**	**36,900,000 W$_t$**	**35,00,000 kWh$_t$**	**25,900,000 W$_t$**	**68,547,000 kWh**	**13,000,000 W**

3.3 Existing Building Performance Improvement

Carleton University has successfully retrofitted a few existing buildings to reduce overall heating, cooling, and electrical consumption. Improvements to existing building performance are assumed to continue over the next 30 years. The estimated potential building performance improvements will be applied to future utility consumption and carbon emission levels but will not influence future utility demand (for preliminary system sizing).

The Energy Neutral Campus Plan will assume a 19% improvement from heating, cooling and electricity across existing buildings. Improvements to existing buildings are assumed to be performed over a 30-year time period to achieve the total percentage improvement outlined in Table 6 below.

Table 6: Existing building reductions

Phase	Heating, Cooling, & Electricity Reduction
2021-2030	6.3%
2031-2040	12.6%
2041-2050	19.0%

3.4 Future Campus Development

The campus' future development is mainly based on the Carleton University's 2016 Campus Master Plan. The campus is divided into 4 blocks and broken down by building types. For example, Block 3 is primarily residential (see Figure 4 and Table 7).

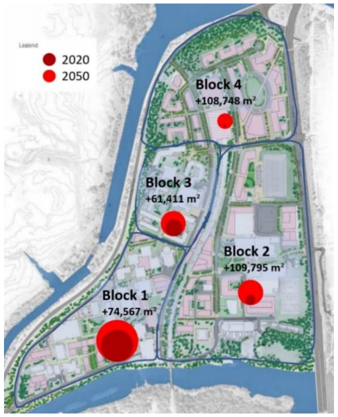


Figure 4 - Campus Future Development & Blocks

Table 7: Existing campus building areas and types within blocks

	Number of Buildings	Building Area (m^2)	Building Area (% of total campus and % of block)
Block 1 Total	**20**	**217,870**	**55% of total Campus**
Academic	12	118,029	52%
Lab	7	92,421	41%
Ancillary	1	16,460	7%
Block 2 Total	**10**	**57,825**	**15% of Campus**
Lab	2	14,979	26%
Ancillary	2	6,891	12%
Athletics	6	35,955	62%
Block 3 Total	**12**	**118,827**	**30% of Campus**
Academic	1	7,013	6%
Residence	11	111,814	94%
Block 4 Total	**1**	**249**	**0.06% of Campus**
Academic	1	249	100%
Campus Total	**44**	**403,811**	**100%**

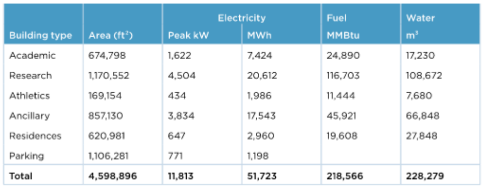
All future developments are projected to be complete by 2050 as stated in the Carleton Energy Neutral Request for Proposal. The total future growth area was then interpolated in 10-year increments until 2050 (Table 8). Parking, tunnels, and utility buildings were not included in area totals. For campus growth area per building type in each future phase, see Appendix B.

Table 8: Assumed campus growth

	2030 Total Campus Area m^2	**2040 Total Campus Area m^2**	**2050 Total Campus Area m^2**
Block 1	251,765	276,621	301,476
Block 2	104,643	141,241	177,839
Block 3	139,297	159,767	180,237
Block 4	36,498	72,747	108,996
Campus Total	**532,204**	**650,379**	**768,552**

3.5 Future Building Performance

Carleton University's 2018 Energy Master Plan estimates energy performance of new developments at an EUI of 270 kW/m^2, Figure 5 and Figure 6. This represents approximately a 23% reduction from existing building EUI. We have assumed that all new buildings developed in the next 10 years will achieve at least a 23% reduction in energy performance compare from their existing performance. We have assumed that further improvements to new building performance standards will be in-place to support Carleton University's 2050 carbon neutrality goal.



		Electricity		Fuel	Water
Building type	**Area (ft^2)**	**Peak kW**	**MWh**	**MMBtu**	**m^3**
Academic	674,798	1,622	7,424	24,890	17,230
Research	1,170,552	4,504	20,612	116,703	108,672
Athletics	169,154	434	1,986	11,444	7,680
Ancillary	857,130	3,834	17,543	45,921	66,848
Residences	620,981	647	2,960	19,608	27,848
Parking	1,106,281	771	1,198		
Total	**4,598,896**	**11,813**	**51,723**	**218,566**	**228,279**

Figure 5: Projected energy and water consumption in new buildings (source: Carleton's 2018 Sustainability Master Plan; Table 4.6)

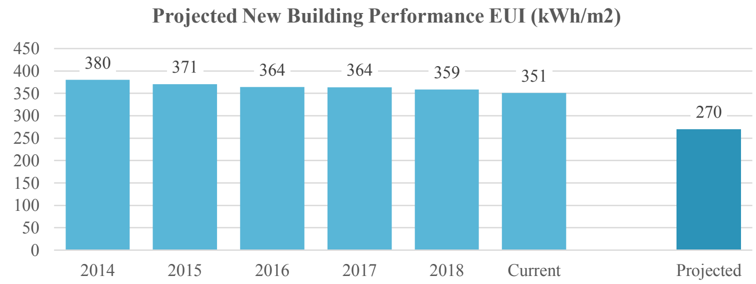


Figure 6: Projected New Building Performance EUI

The Toronto Green Standard (TGS) will be used as a basis to determine the building performance of future developments at Carleton University. TGS promotes sustainable site and building design, using a four-tier system to assess building performance for residential, industrial, commercial, and institutional building types. To apply TGS standards to consumption and demand factors for Carleton University's buildings, industry standards and energy models were used.

Table 9: Toronto Green Standard V3 tiers

Year constructed	TGS Certification level	EUI
2019-2020	V3 Tier 1	170
2021-2025	V3 Tier 2	134
2026-2030	V3 Tier 3	100
2031-2050	V3 Tier 4	74

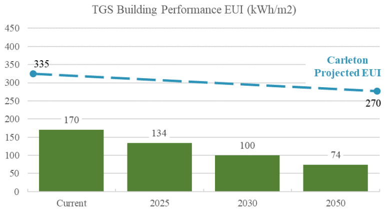


Figure 7: Toronto Green Standard Building Performance EUI

Campus developments built between 2020 and 2030 are expected to achieve a 25% improvement in building performance relative to existing buildings. Developments between 2031 and 2040 will target TGS v3 Tier 3, and developments beyond 2040 will target TGS v3 Tier 4.

Table 10: Building performance assumptions for new developments

Phase	Building Performance Assumption
2019	Existing
2021-2030	Existing with 25% improvement
2031-2040	T3 v3 Tier 3
2041-2050	T4 v3 Tier 4

Using the parametric model results published in the Zero Emissions Building Framework (Table 11), the heating, cooling, and electricity use for a building meeting each Tier of TGS v3 were extracted for a typical commercial office and mid-rise residential building. These figures were then applied to Carleton University's building types using shoebox energy models developed by Arup. *See* Table 12 *for resulting demand factors for each phase and building typology*.

Table 11: Zero Emissions Building Framework parametric model

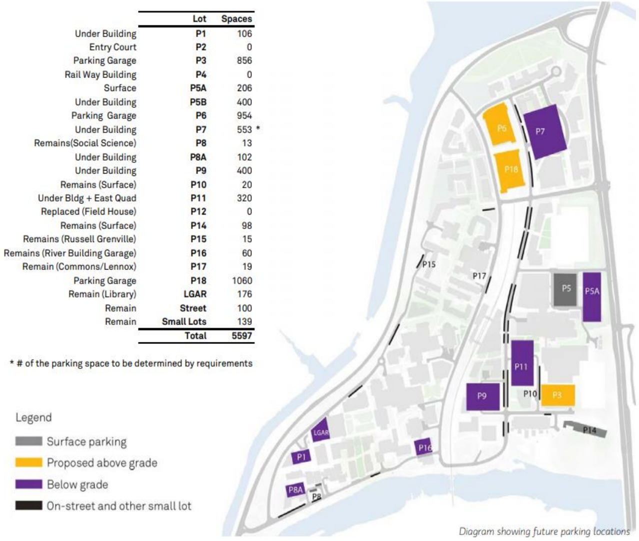
		TGS v3 T1	TGS v3 T2	TGS v3 T3	TGS v3 T4
Commercial Office	Anticipated Future Performance Improvement % (relative to previous cycle) on Annual Total Consumption [kWh/m^2/yr]				
	Cooling	n/a	136%	107%	107%
	Heating	n/a	51%	73%	75%
	Electric	n/a	92%	80%	70%
	Anticipated Future Performance Improvement % (relative to previous cycle) on Peak Demand [W/m^2/yr]				
	Cooling	n/a	103%	108%	105%
	Heating	n/a	69%	84%	75%
	Electric	n/a	92%	80%	70%
Mid-rise Residential Building	Anticipated Future Performance Improvement % (relative to previous cycle) on Annual Total Consumption [kWh/m^2/yr]				
		TGS v3 T1	**TGS v3 T2**	**TGS v3 T3**	**TGS v3 T4**
	Cooling	n/a	103%	108%	105%
	Heating	n/a	69%	84%	75%
	Electric	n/a	92%	80%	70%
	Anticipated Future Performance Improvement % (relative to previous cycle) on Peak Demand [W/m^2/yr]				
	Cooling	n/a	101%	110%	106%
	Heating	n/a	64%	79%	74%
	Electric	n/a	94%	94%	95%

Table 12: Building factors by type

Academic	**Existing**	**2021-2030**	**2031-2040**	**2041-2050**
Heating Consumption (kWh/m^2-yr)	225.57	110.78	80.87	60.65
Heating Demand (W/m^2)	76.40	57.30	48.13	36.10
Cooling Consumption (kWh/m^2-yr)	64.86	48.65	52.05	55.69
Cooling Demand (W/m^2)	58.57	43.93	47.44	49.81
Elec Consumption (kWh/m^2-yr)	148.67	111.50	89.20	62.44
Elec Demand (W/m^2)	34.69	17.35	13.88	9.71
Ancillary	**Existing**	**2021-2030**	**2031-2040**	**2041-2050**
Heating Consumption (kWh/m^2-yr)	172.09	86.05	62.81	47.11
Heating Demand (W/m^2)	22.63	16.97	14.26	10.69
Cooling Consumption (kWh/m^2-yr)	27.59	20.69	22.14	23.69
Cooling Demand (W/m^2)	73.10	54.83	59.21	62.17
Elec Consumption (kWh/m^2-yr)	172.04	129.03	103.22	72.26
Elec Demand (W/m^2)	32.78	16.39	13.11	9.18
Athletics	**Existing**	**2021-2030**	**2031-2040**	**2041-2050**
Heating Consumption (kWh/m^2-yr)	195.06	97.53	71.20	53.40
Heating Demand (W/m^2)	123.54	92.66	64.49	58.37
Cooling Consumption (kWh/m^2-yr)	26.43	19.82	21.21	22.69
Cooling Demand (W/m^2)	73.10	54.83	59.21	62.17
Elec Consumption (kWh/m^2-yr)	180.91	135.68	108.55	75.98
Elec Demand (W/m^2)	34.37	17.19	13.75	9.63
Lab (Wet/Dry)	**Existing**	**2021-2030**	**2031-2040**	**2041-2050**
Heating Consumption (kWh/m^2-yr)	218.17	109.09	79.63	59.73
Heating Demand (W/m^2)	184.84	138.63	116.45	87.34
Cooling Consumption (kWh/m^2-yr)	178.40	133.80	143.17	153.19
Cooling Demand (W/m^2)	98.18	73.64	79.53	83.50
Elec Consumption (kWh/m^2-yr)	134.26	100.70	80.56	56.39
Elec Demand (W/m^2)	25.91	12.95	10.36	7.25
Residential	**Existing**	**2021-2030**	**2031-2040**	**2041-2050**
Heating Consumption (kWh/m^2-yr)	157.83	78.92	54.45	34.85
Heating Demand (W/m^2)	58.61	43.96	34.73	25.70
Cooling Consumption (kWh/m^2-yr)	24.82	18.62	21.97	23.94
Cooling Demand (W/m^2)	42.90	21.45	23.60	25.01
Elec Consumption (kWh/m^2-yr)	89.49	67.12	63.09	59.94
Elec Demand (W/m^2)	19.80	9.90	93.10	8.84

3.6 Electric Vehicle Charging Stations

Carleton University currently has one electric vehicle charging station on campus. The University plans to adopt more charging stations in parking lots to meet the future demand of electric vehicles. Carleton University's 2016 Capital Master Plan presented potential future parking locations, which was used for the analyses generated in this report. It is assumed that these parking spaces will all be built by 2050, and equally over each phase.



	Lot	Spaces
Under Building	P1	106
Entry Court	P2	0
Parking Garage	P3	856
Rail Way Building	P4	0
Surface	P5A	206
Under Building	P5B	400
Parking Garage	P6	954
Under Building	P7	553 *
Remains(Social Science)	P8	13
Under Building	P8A	102
Under Building	P9	400
Remains (Surface)	P10	20
Under Bldg + East Quad	P11	320
Replaced (Field House)	P12	0
Remains (Surface)	P14	98
Remains (Russell Grenville)	P15	15
Remains (River Building Garage)	P16	60
Remain (Commons/Lennox)	P17	19
Parking Garage	P18	1060
Remain (Library)	LGAR	176
Remain	Street	100
Remain	Small Lots	139
	Total	5597

* # of the parking space to be determined by requirements

Figure 8: Potential future parking lots

Additionally, it is assumed that all existing and new parking lots will include electric vehicle charging stations, achieved by retrofitting existing parking lots and constructing new parking lots to include charging stations. Charging stations will comprise of an assumed 20% of parking on campus by 2050, which will be phased-up accordingly (10% in 2030, 15% in 2040, etc.). Estimates for the energy required to meet the demand and consumption of electric vehicle charging stations are included in the future campus total electric demand and consumption (see Table 13).

Assumptions per parking spot charging station:

- 7.2 kW demand
- 6 hours per day of use for 365 days a year

Table 13: Electric vehicle charging stations

	Existing	2030	2040	2050
Total Parking Spots on Campus	1,800	3,065	4,330	5,595
% of Parking Lot Spaces to be EV Charging Stations	-	10%	15%	20%
# of EV Charging Stations in Campus Parking lots	1	560	840	1,119
Electric Demand [MW]	**-**	**3.2**	**4.8**	**6.4**
Electric Consumption [MWh]	**-**	**7,060**	**10,590**	**14,121**

3.7 Thermal and Electrical Demand and Consumption Summary

Demand and consumption forecasts were developed by taking the breakdown of each of the four Block's building type area and applying the applicable factors based on building type and phase to calculate total demand and consumption (see Table 14).

Upper and lower sensitivity bounds of 20% are applied to the changes in each phase. Applying these factors generates a range of projected demand and consumption values, which are summarized in Table 14 and presented in Figure 9 and Figure 10.

Table 14: Future utility requirement

	Heating Demand (MW)	**Heating Consumption (MWH)**	**Cooling Demand (MW)**	**Cooling Consumption (MWH)**	**Electricity Demand (MW)**	**Electricity Consumption (MWH)**
Existing Total	37	81,704	26	35,000	13	68,547
2021-2030 Total	46	94,541	32	38,752	16	77,004
2031-2040 Total	53	102,431	38	42,961	18	91,724
2041-2050 Total	58	106,807	45	47,591	20	99,309

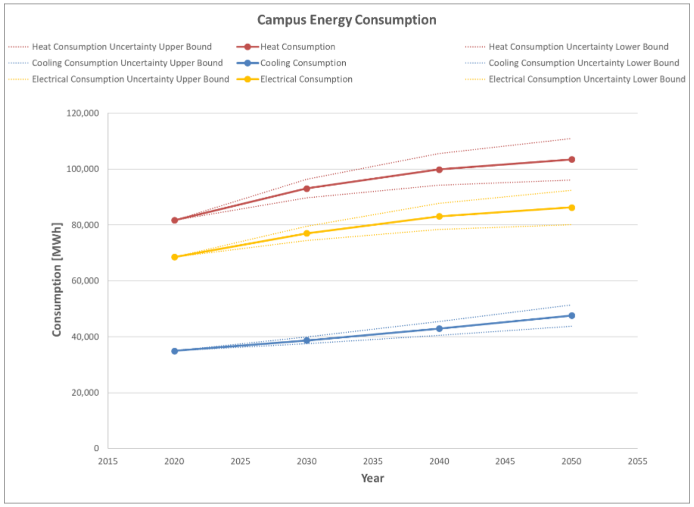


Figure 9: Campus energy consumption, 2020 to 2050

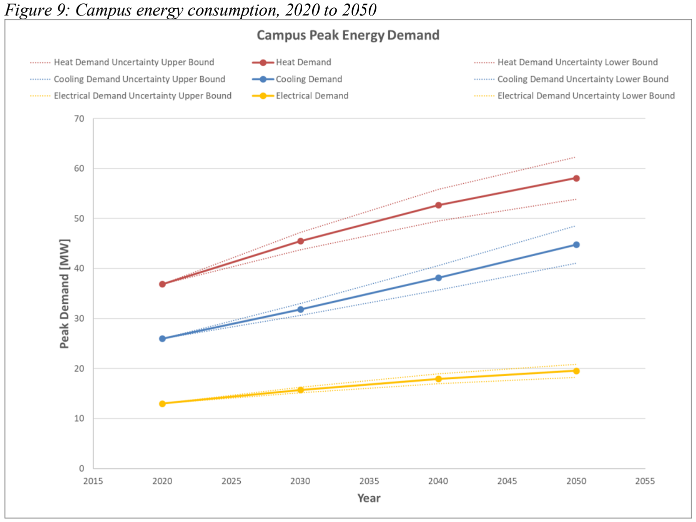


Figure 10: Campus peak energy demand, 2020 to 2050

4 Utility Rate

Historical utility rates are obtained from Monthly Utility Verifications Rate spreadsheets provided by Carleton University. The historical average natural gas and electricity cost are shown below:

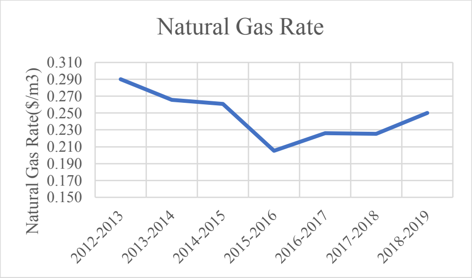


Figure 11: Natural gas rate, 2012 to present (source: Enbridge Gas)

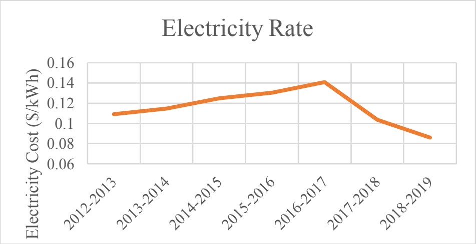


Figure 12: Electricity rate, 2012 to present

The historical blended average rate of electricity is observed to be $0.116/kWh. Starting in November 2020, Arup understands that Carleton University will no longer receive a $0.040 /kWh rebate. For the purposes of the Energy Neutral Master Plan, the blended average rate of electricity that will be used to evaluate the campus energy strategies is assumed as $0.116 / kWh + $0.040 / kWh = $0.156 / kWh. The rate for natural gas will be based on historical average rate of $0.246/m3.

Table 15: Natural gas and electricity rates

Utility	Rate
Natural Gas Rate	$0.246/m3
Electricity Rate	$0.156/kWh

5 Equivalent Carbon Emission Factor

The equivalent carbon emissions factors are obtained from the *Canada 2019 National Inventory Report*. As such, this report assumes an emission factor of 1.9kg/m3 for natural gas and 0.04kg/kWh for electricity.

Table 16: Natural gas and electricity emission factors

	Emission factor
Natural Gas	1.9 kg/m3
Electricity	*0.04 kg*/kWh

Carbon tax is assumed to be \$30 / tonne CO$_2$e, scaling linearly to 2022 to \$50 / tonne CO$_2$e..

6 Business-as-Usual Scenario

A business-as-usual (BAU) scenario will be designed to compare capital and operational costs of the proposed design alternatives for Carleton University's future campus. The BAU scenario will be designed throughout the next project phase and OPEX, CAPEX emissions calculations will follow.

The BAU scenario assumes the following in alignment with the campus' current operations:

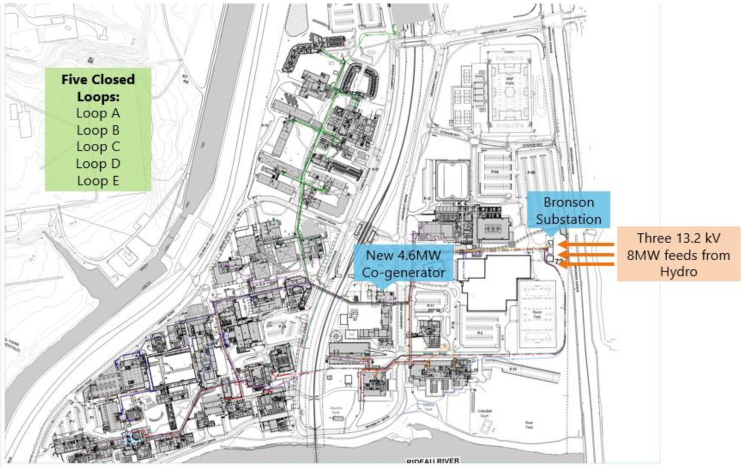
- Existing buildings on campus will continue to rely on the natural gas-based district heating infrastructure;
- The existing central steam network will be expanded to serve new developments on campus; New developments will have localized chillers and/or DX units for cooling;
- Energy efficiency improvement projects will be implemented to existing buildings; and
- New developments will perform at the level of existing buildings.

7 General Limits

These analyses are based on the best available information provided by Carleton University at the time of this report's preparation and the assumptions listed in this report. The calculated future campus peak demand and annual consumption should be used only as the basis of assumption for the Energy Master Plan purposes. Any use of this report or decisions based on this report are at the user's discretion. Arup does not accept responsibility for the accuracy of information provided by others and does not accept responsibility for damages, if any, suffered by any other party as a result of decisions made or actions based upon this report.

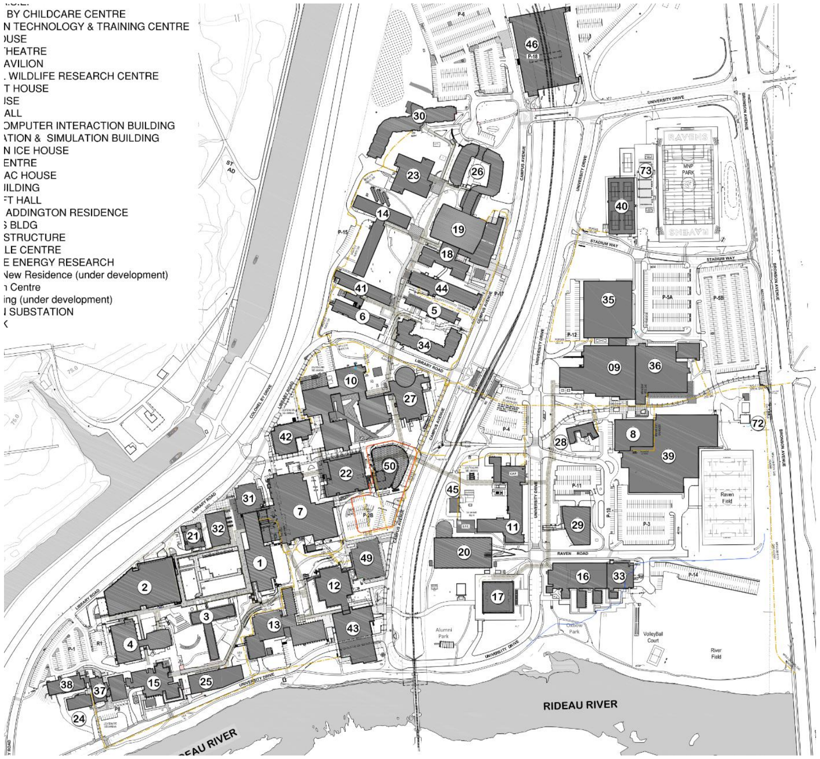
Memorandum

A. Appendix – Campus Utility Distribution Drawings

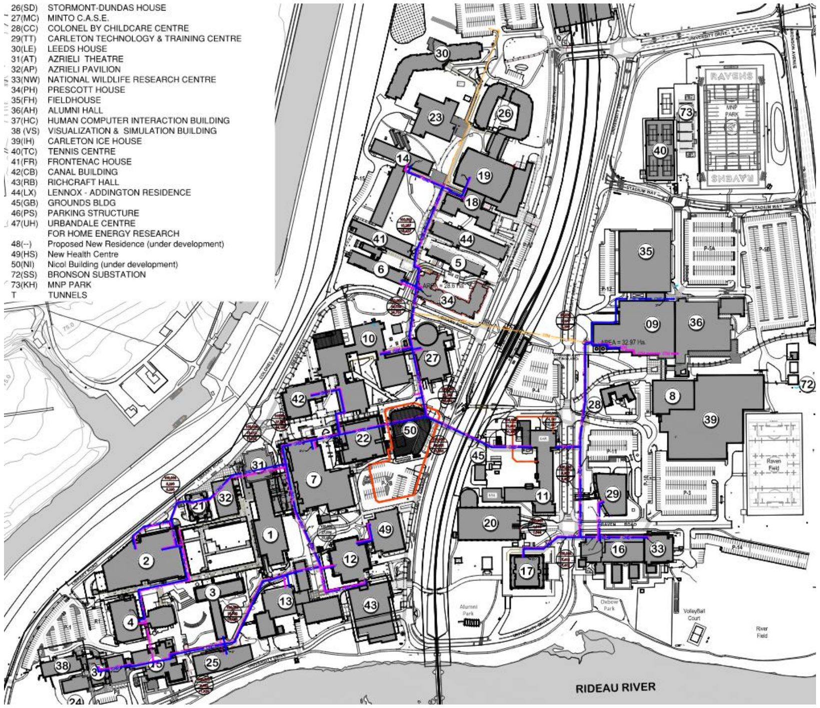


Drawing 1: Campus electricity network

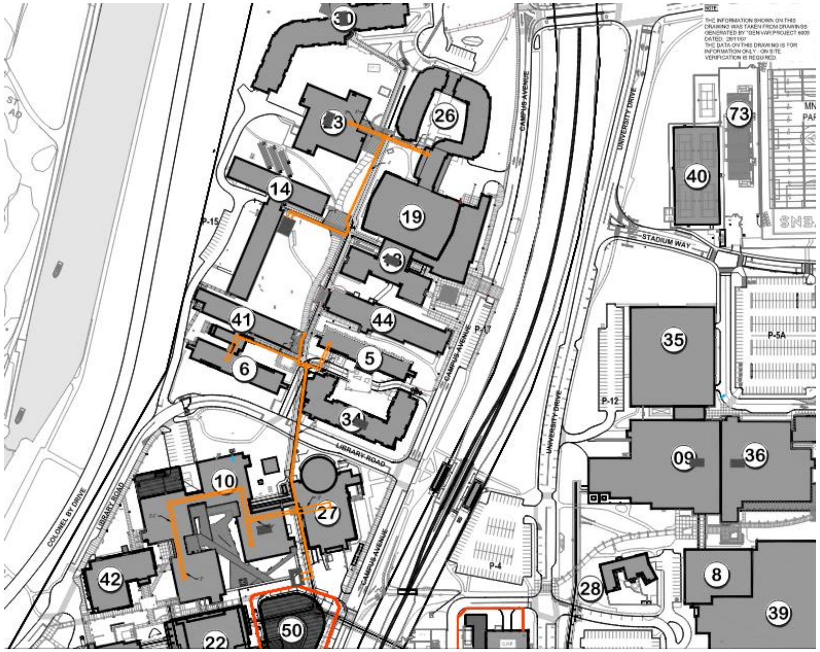
Memorandum



Drawing 2: Natural gas network

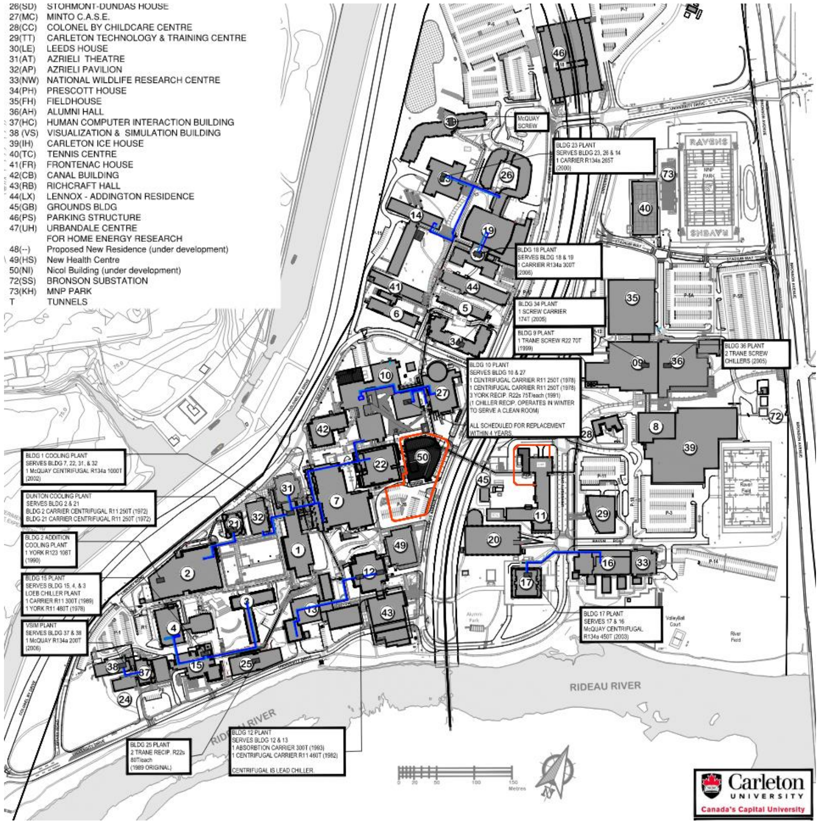


Drawing 3: Steam distribution

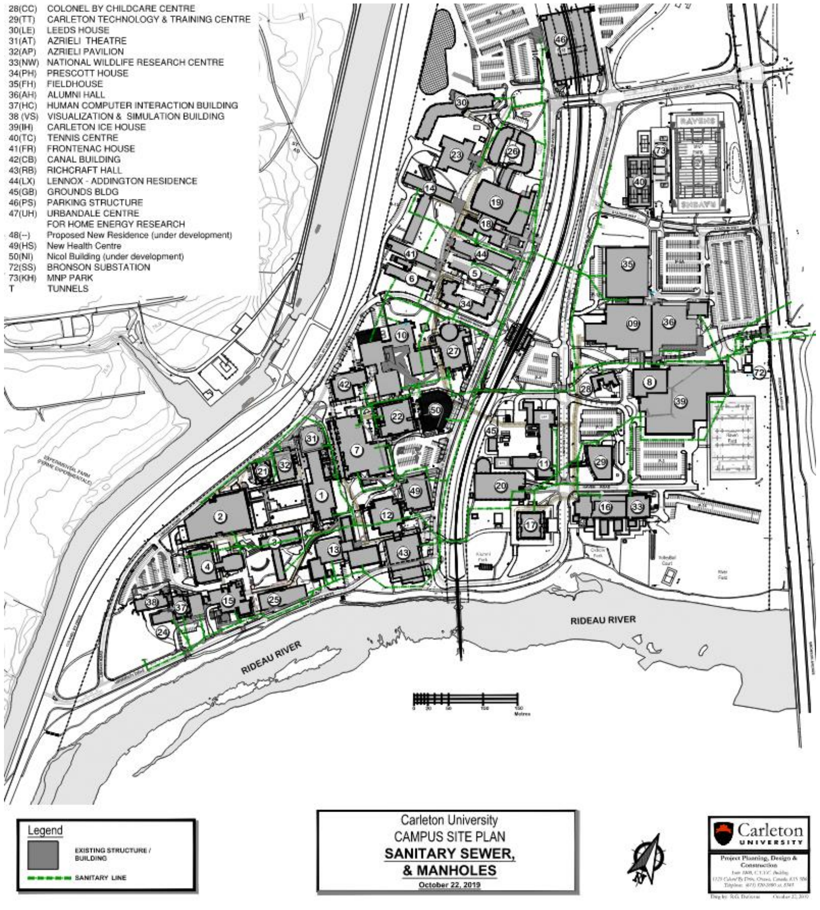


Drawing 4: MTHW distribution

Memorandum



Drawing 5: Chilled Water Distribution



Drawing 6: Sanitary Sewer Distribution

Memorandum

B. Campus Growth

		2030 Campus Area m^2	**2040 Campus Area m^2**	**2050 Campus Area m^2**
Block 1 Total	**56% of total Campus**	24,856	24,856	24,856
Academic	52% of block 1	13,465	13,465	13,465
Lab	41% of block 1	1,878	1,878	1,878
Ancillary	7% of block 1	9,513	9,513	9,513
Block 2 Total	**14% of Campus**	36,598	36,598	36,598
Lab	26% of block 2	4,361	4,361	4,361
Ancillary	12% of block 2	22,757	22,757	22,757
Athletics	62% of block 2	9,480	9,480	9,480
Block 3 Total	**29% of Campus**	20,470	20,470	20,470
Academic	6% of block 3	1,208	1,208	1,208
Residence	94% of block 3	19,262	19,262	19,262
Block 4 Total	**0.06% of Campus**	36,249	36,249	36,249
Academic	100% of block 4	36,249	36,249	36,249
Campus Total	**100%**	**532,204**	**650,378**	**768,552**

▨ Not Recommended

Appendix B. **Energy Supply Options Evaluation**

	Conventional System (BAU)	**Cogeneration System**	**Renewable Natural Gas**	**Hydrogen**	**Micro Nuclear**	**Sewage Heat Recovery**	**Biomass (heating only or cogeneration)**	**Electric Boilers**	**GSHP**	**Confederation Heights District Energy (8)**
	Main Supply	Main Supply	Main Supply	Supplementary	Supplementary	Supplementary	Main Supply	Main Supply	Main Supply	Main Supply
New Capacity	-	Heat: 7MW(2) Elec: 4.6 MW	N/A	Elec: 14 MW	Elec: 14 MW Heat: 18.6 MW	Heat: 3 MW (4)	Heat: 30 MW Elec: 8.7 MW(5)	Heat: 40 MW	Heat: 40 MW	Heat: 40 MW
CAPEX	$0	$0	$0	$100-$210 Million	$140-$280 Million	$3-8 Million	$78-$102 Million	$20-40 Million	$80-$120 Million(7)	$16-25 Million
Annual Carbon Emission (tons CO2)	22,000	29,000	3,400 reported (21,000 emitted)	0- 30,000	11,000	18,000	2,600-3,400 reported (27,000-33,000 emitted)	7,000	4,000	7,000-23,000
Total Annual Energy Cost(1)	$13 Million	$10 Million	$20-21.5 Million(3)	$10-90 Million	N/A	$13 Million	$11-14 Million(6)	$22 Million	$13 Million	$16-20 Million

(1) To supply 40MW heat & 14MW elec demand

(2) Without duct burner

(3) Dependent on contract terms

(4) Capacity based on further investigation

(5) Heat to power ratio depends on technology deployed

(6) Only includes energy cost - excludes other O&M costs that may be significant for biomass plant

(7) Cost excludes ground water distribution piping

(8) All values to be further explored with ESAP

All technologies are assumed without cogeneration unless noted
All values are high level estimates

Appendix C. Preliminary Campus Utility Strategies

1.0 Business as Usual

2.1 Electric HW Boilers in Existing Central Plant

2.2 Electric HW Boilers – Nodal Plants

3.1 GSHP Plant 4 Pipe – Central Plant

3.2 GSHP Plant 4 Pipe – Central Plant Backup

3.3 GSHP Plant 4 Pipe - Nodal

4.1 Ground Water Dist. - Radial

4.2 Ground Water Dist. - Nodal

4.3 Ground Water Dist. Loop

5.1 Sewage Heat Recovery with LTHW Elec Boilers

5.2 Sewage Heat Recovery – Local Building

6.0 Renewable Natural Gas Boilers

Appendix D. **Energy Strategies Evaluation Matrix**

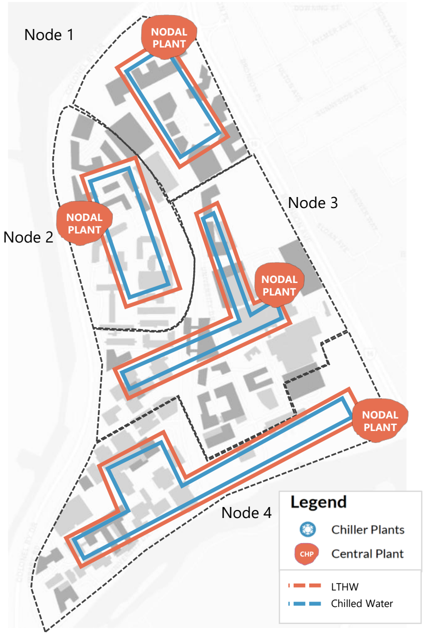
Criteria	Description	0 - BAU	1.0 - Electric Steam Boilers in Central Plant	2.1 - Electric HW Boilers in Central Plant	2.2 - Electric Boilers in Nodal Plants	3.1 – Central GSHP Plant	3.2 – Central GSHP Plant + CHP Backup	3.3 - Nodal GSHP Plants	4.1 – Radial GW Distribution	4.2 – Nodal GW Distribution	4.3 - Loop GW Distribution	5.1 HW Electric Boilers + SHR	5.2 – Central GSHP Plant + SHR	6.1 Steam Boilers with RNG	WEIG
Carbon Reduction	Equivalent carbon emission (reduction) of the strategy, potential to integrate with other renewable technologies	1	4	4	4	5	4	5	5	5	5	4	5	4	5
Reliability	Service continuity, post-outage service, ability to resume service/black start, islanding capacity	3	3	4	5	4	5	5	4	4	4	3	3	3	4
nual Operating Cost	Ongoing cost for tenants related to fuel commodity, water, chemical, operation and maintenance	5	1	1	1	4	5	4	4	4	2	2	5	2	3
Flexiblity	The ability for the technology to expand, adapt and/or supplement other technologies and infrastructure	4	4	4	3	4	4	3	3	3	3	5	4	2	3
Logistices	Spatial requirement (plant/distributions system), logistics, permitting, technology maturity	5	5	5	4	4	4	3	2	2	3	2	2	3	3
Initial Cost	Capital cost, of the strategy, potential of external funding, phase-ability	5	5	3	3	2	2	3	2	3	1	3	2	5	3
mmunity Integration	Ease to integrate with the community (appearance, odor, noise)	2	4	4	4	4	4	4	4	4	4	3	3	2	2
Political Risk	Impact to the design and operation of the system due to political changes/uncertainties, government support, fuel volatility	5	5	4	4	3	4	3	3	3	3	4	3	3	2
ublic Accpetance/ Engagement	Public acceptance (or rejection) of the technologies	2	2	4	4	3	3	3	3	3	3	4	4	2	2
inability Rating System Integration	Potential of the technologies to support other sustainability rating system such as LEED, Eco-district, etc	2	2	4	4	4	4	4	4	4	4	4	4	2	2
WEIGHTED SCORE (out of 100)		**67.2**	**70.3**	**73.5**	**72.0**	**76.3**	**80.0**	**76.6**	**70.1**	**71.8**	**65.8**	**67.4**	**71.5**	**57.5**	

1	Unacceptable Performance
2	Poor Performance
3	Average / Little Impact
4	Good Performance
5	Excellent Preformance

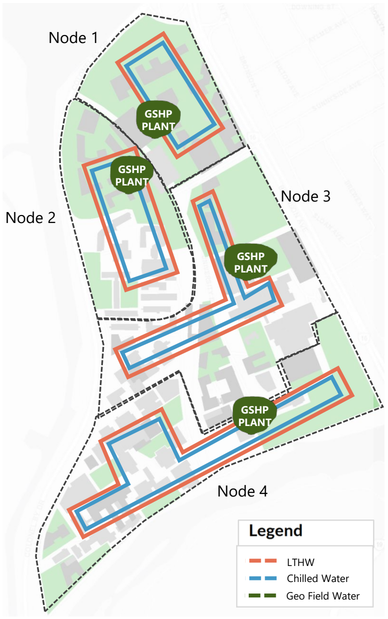
Appendix E. Three Shortlisted Strategies Analysis Results

THREE SELECTED CAMPUS ENERGY STRATEGIES

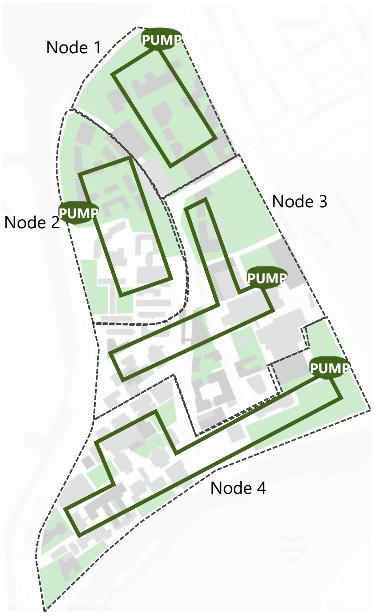
Strategy #1 – Electric Hot Water Boilers, Nodal Distribution
(previously Option 2.2)



Strategy #2 – GSHP Plants, Nodal Distribution
(previously Option 3.3)



Strategy #3 – Ground Water, Nodal Distribution
(previously Option 4.2)

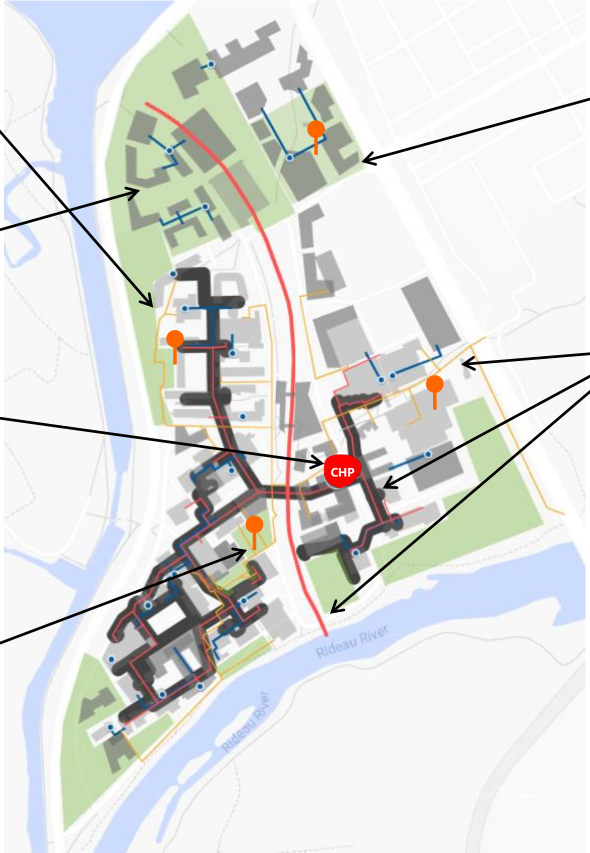


ARUP

Energy Strategy Assumptions & Considerations

ARUP

SUMMARY OF ELEMENTS CONSIDERED



Existing Buildings

New Developments

Existing Central Plant

Nodal Plant Locations

Geo-exchange fields

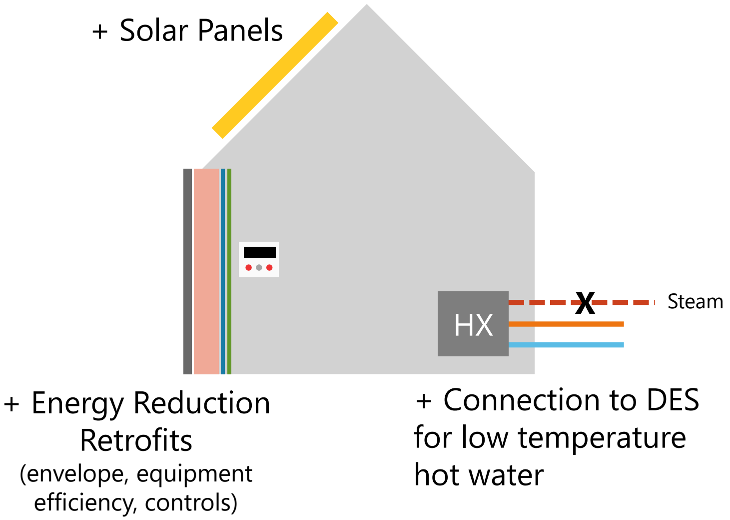
Distribution Routes

- Existing distribution piping
- Tunnels
- O-Train Tracks

EXISTING BUILDINGS

Assumptions:

1. Building retrofit for energy savings and steam to LTHW conversion
    - Assumed $215/sqm to retrofit all existing buildings to reduced heating, cooling, and electrical consumption by 19%
    - Assumed $350/sqm to retrofitted all existing buildings to receive low temperature hot water and connect to nodal plant
2. Solar Panels
    - Preliminary analysis estimates 2,000 kW of solar PV capacity available on existing buildings and parking lot areas without new developments planned on the areas in the future
    - Estimated CAPEX Cost of solar PV panels: $8 Million, 0.4 $ Million electricity cost savings
3. Existing Buildings with Chiller plants
    - Existing building chiller plants within BAU and Strategy #1 to remain and increase in capacity to meet demand
    - Existing chiller plants within Strategy #2 & #3 to be removed as buildings will receive cooling from nodal plants



+ Solar Panels

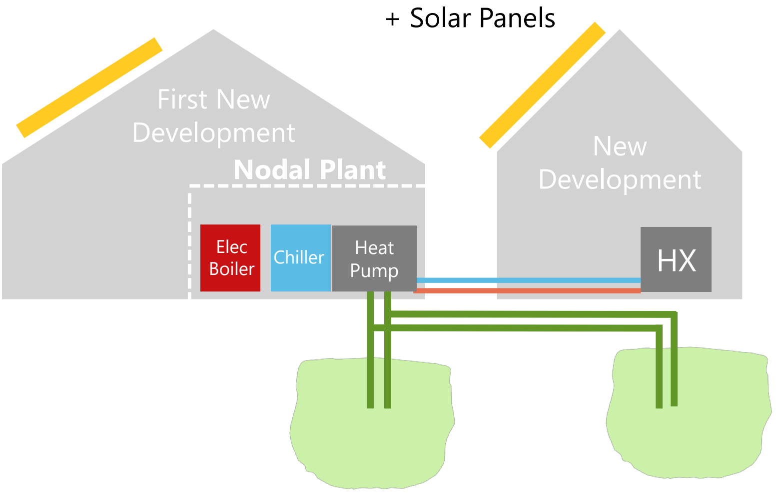
+ Energy Reduction Retrofits
(envelope, equipment efficiency, controls)

+ Connection to DES for low temperature hot water

NEW DEVELOPMENTS

Assumptions

1. Heating and Cooling
    - The first new development built within each node will house the new nodal plant. New Developments to be designed with necessary spatial requirements for nodal plant.
    - All following new developments to be connected to the nodal plant and receive heating hot water and chilled water.
2. Solar Design
    - All new developments to include photovoltaic panels on rooftop for distributed local generation.
    - Preliminary analysis estimates a maximum 7,000 kW of solar PV capacity available on new developments over the next 30 years
    - Estimated CAPEX of solar PV panels: $28.5 Million, 1.3 $ Million electricity cost savings



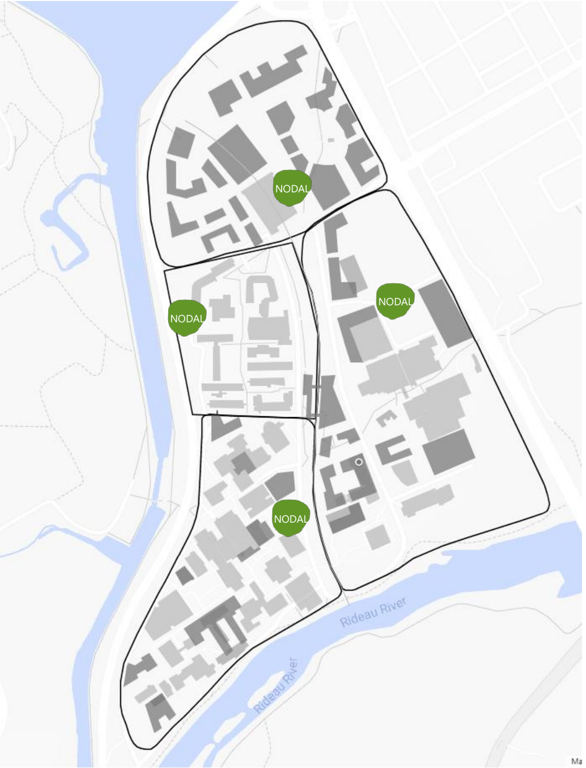
4. NEW NODAL PLANTS

As new development phasing is not known, nodal plant locations assumptions were made for the basis of design based on the following

- Close proximity to geo-fields to reduce geo-pipe lengths
- Within unoccupied space

Nodal plants will be located within the first new development built within each block. Further analysis is required to determine required space for each nodal plant and which new planned developments would be optimal to house a nodal plant.

Indicative Location of Nodal Plants



4. NODAL PLANT MECHANICAL SYSTEMS

Heat Pumps (modular scroll/centrifugal)

- Take ground water from the field and produce hot or chilled water
- Modular units allow for easy expansion and redundancy as well as heat recovery operation for simultaneous heating and cooling
- Centrifugal units can achieve higher HW supply temperature

Cooling Towers or Dry Cooler

- Used to reject excess heat in during peak cooling demand (when/if geo-borefields are tapped)
- Reduced maintenance compared to typical cooling tower
- Adds resilience to system

Peaking/Supplementary Electric Boiler

- Used to provide additional heating capacity during peak heating demand
- Can utilize peaking electric boiler for 100% low-carbon operation
- Reduced capital cost compared to high efficiency gas fired boiler, but higher operating cost

		Nodal Plant (Strategy #1 & #2)	**In Building (Strategy #3)**
Assumed Equipment Efficiencies			
GSHP COP in heating	COP	5.0	4.5
GSHP COP in cooling	COP	3.7	3.4
Assumed Mechanical Plant Space Requirements			
Electric Steam Boiler Plant	m2/kW	0.0024	0.0042
Chiller plant	m2/kW	0.0238	0.0238
GSHP plant	m2/kW	0.1227	0.1227

MODULAR SCROLL

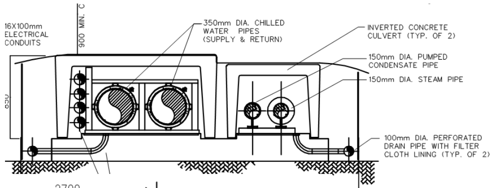
CENTRIFUGAL SCROLL

ARUP

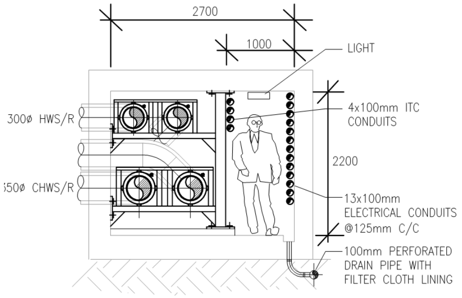
DISTRIBUTION PIPING

- All options will be run by default 5 - 7 ft below grade
- **Direct-buried pre-insulated pipes**
  - Lowest cost, simple installation
  - Limited durability and lifespan
  - Determining path for new direct buried pipe through existing distribution and tunnels poses complications and risks
- **Inverted Trench**
  - Higher capital cost
  - Easier to access and maintenance
  - Determining path for new direct buried pipe through existing distribution and tunnels poses complications and risks
- **Within Existing Tunnels**
  - Highest cost and construction timeline
  - Easiest to monitoring and maintenance
  - Existing utility area within tunnels may not be sufficient for new distribution pipe sizes

DIRECT BURRIED



INVERTED TRENCH



TUNNEL

ARUP

DISTRIBUTION

Distribution within Existing Tunnels

- Existing tunnels contain public walkways and utility area with existing steam distribution.
- Feasibility of all options dependent on existing tunnel dimensions, depths, and structural details

Options to run new distribution within existing tunnels

1. **Through existing utility area**
    - Remove existing distribution and replace with new piping .
    - Existing utility area may not be sufficient space for new distribution pipe sizes
    - Phasing complications - it will be difficult to continue service to buildings while removing and adding distribution
2. **Add new distribution to top of tunnels**
    - Lay distribution on top of tunnels and retrofit tunnel to allow access from within public walkway and utility tunnel area
    - Avoids intersections with passenger walkthrough tunnel
    - Tunnels may not be deep enough underground to add distribution piping on top
3. **Add new distribution below tunnels**
    - Break up existing tunnel flooring and lay new piping underneath public walkway and utility area of tunnel
    - Avoids intersections with passenger walkthrough tunnel
    - Cost and length of time of construction may be immense
    - Passenger walkways will not be operational during construction

ARUP

DISTRIBUTION

Distribution avoiding Tunnels

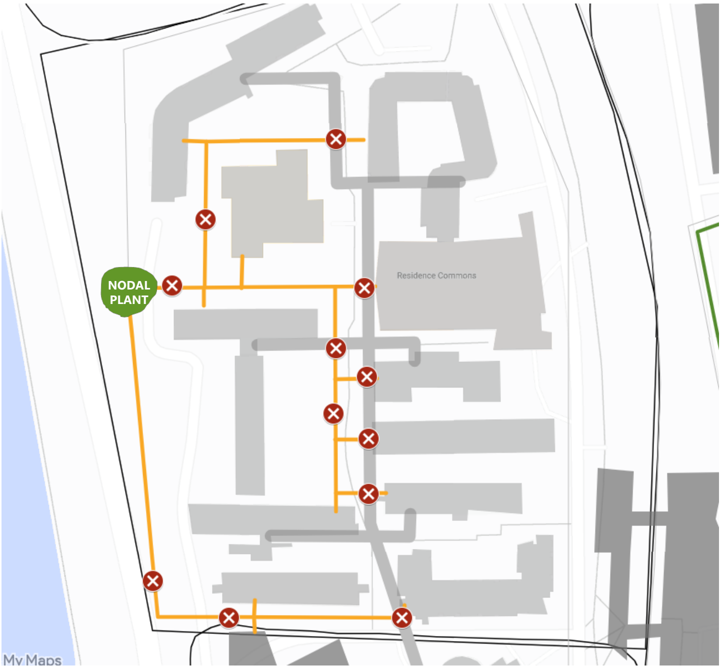
- Direct buried or inverted trench distribution

- Routing of distribution will be less efficient as existing tunnels and distribution must be avoided – piping paths attempt to avoid running parallel with existing distribution

- Risks associated with determining path for new direct buried or inverted trench piping through existing distribution and tunnels. Further analysis on depths of existing distribution.

Avoiding Tunnels is the distribution configuration used as the basis of design within all strategy calculations

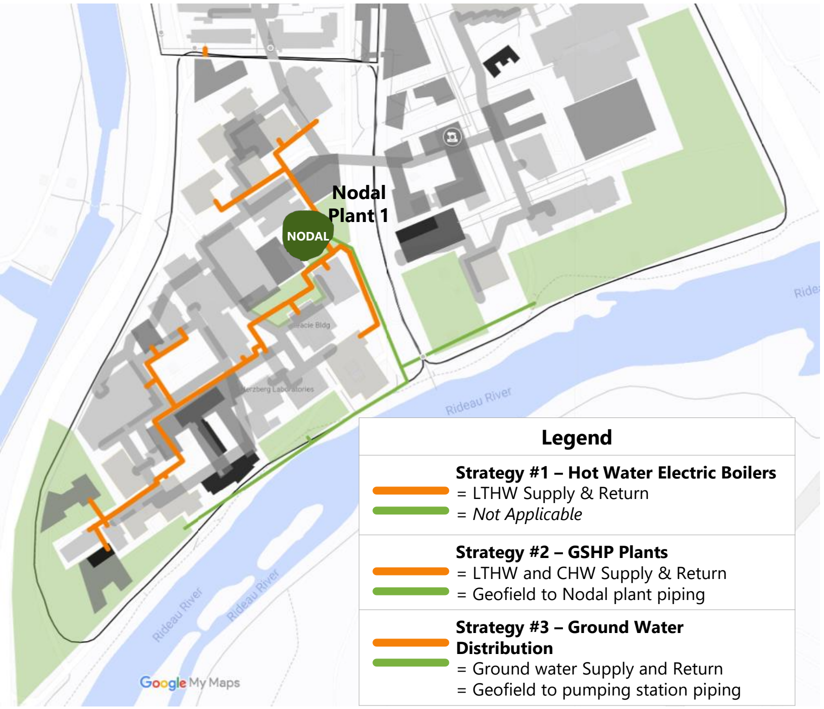
DISTRIBUTION INVESTIGATION



X **Intersection with existing utility distribution identified** (Storm, sewer, main mains, natural gas, steam, chilled water piping)

Note: There may be other potential conflicts / challenges with new distribution routing that requires further detailed survey and assessment

BLOCK 1 DISTRIBUTION OPTIONS

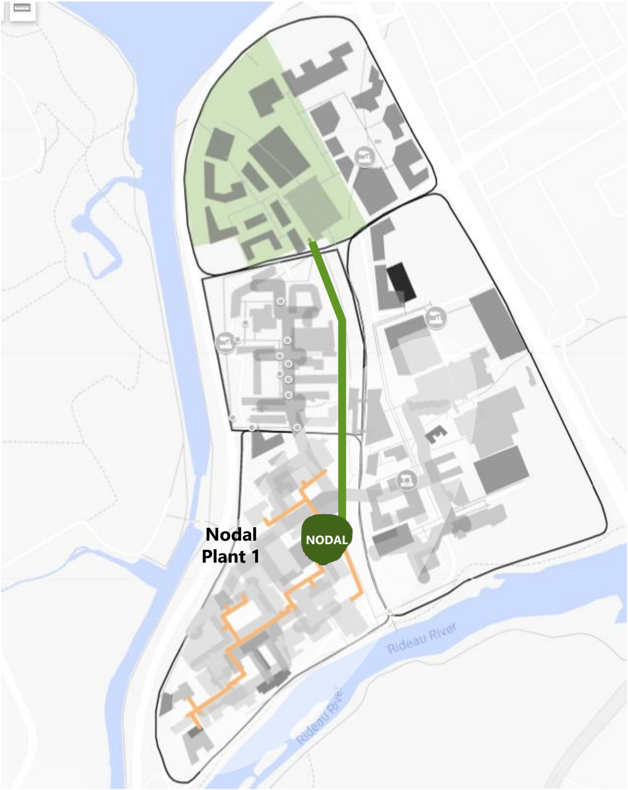


#1 - Block 1 served by nearby geo-fields

- Easier maintenance and maximum heat recovery with one nodal plant.
- Geo-field pipe has to cross under O-Train Tracks. Increased costs and complications for construction.
- Disruptive construction for distribution and geo-exchange fields surrounding academic buildings

'Block 1 Served By Nearby Geo-fields' is the Block 1 distribution configuration used as the basis of design within all strategy calculations

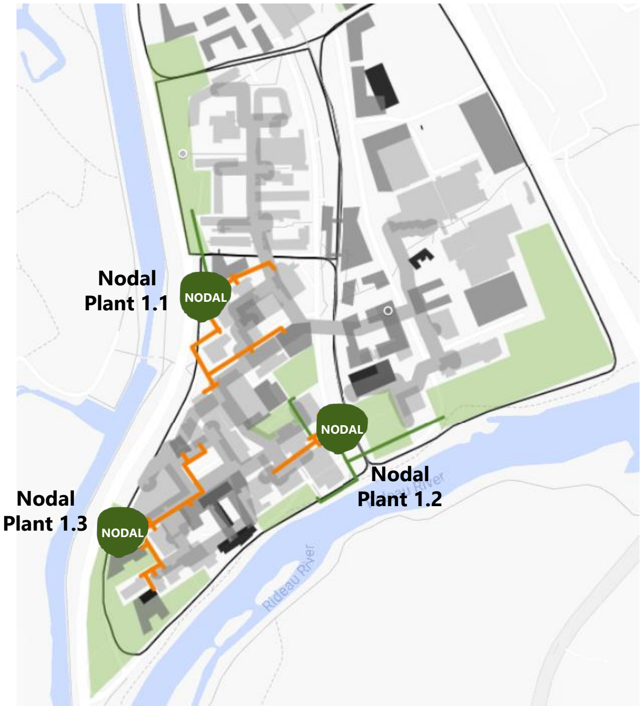
BLOCK 1 DISTRIBUTION OPTIONS (CONT.)



#2 - Block 1 served by northern geo-exchange field

- Most expensive distribution configuration due to the size and length of the geo-field pipe
- Least intrusive construction in areas with campus buildings
- Risk associated with spatial requirements for geo-field pipe due to proximity to O-Train tracks and existing utility distribution

BLOCK 1 DISTRIBUTION OPTIONS (CONT.)

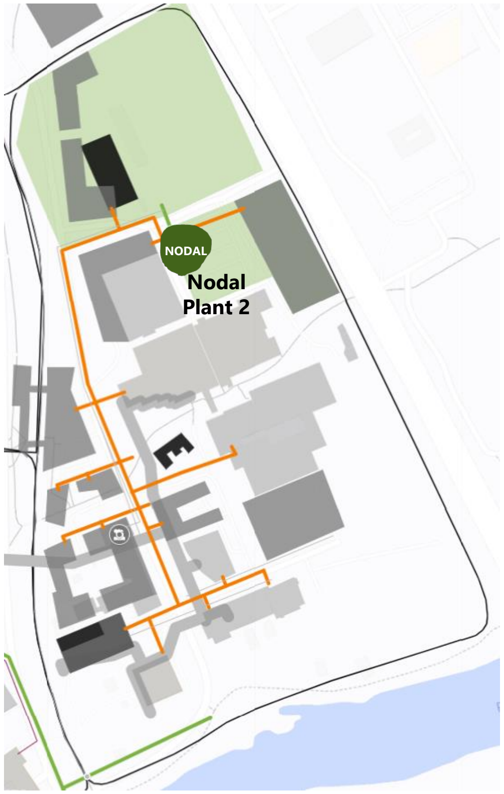


Nodal plant locations and selection of buildings connected to each plant is indicative. Further analysis will be required to determine optimized distribution strategy for three nodal plants

#3 – Three Nodal Plants

- Nodal plants are served by closest geo-exchange fields available.
- Increased CAPEX for nodal plant equipment
- Increased maintenance for three nodal plants and decreased heat recovery between the heating and cooling systems
- Decreased geo-field and building distribution piping costs due to smaller load and shorter lengths

BLOCK 2 DISTRIBUTION CONFIGURATION



Legend

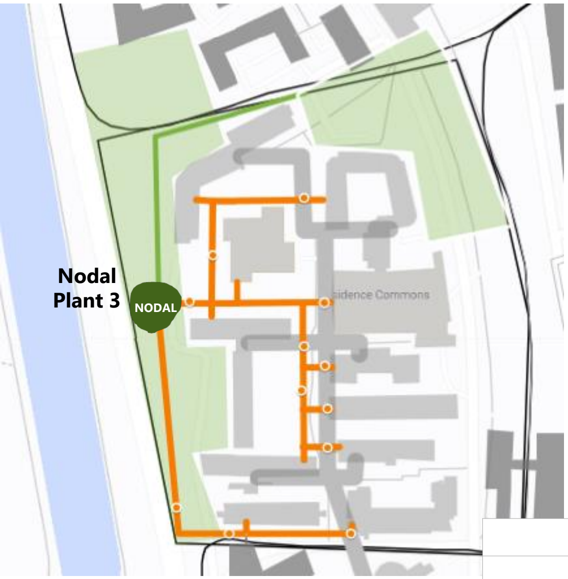
Strategy #1 – Hot Water Electric Boilers
🟧 = LTHW Supply & Return
🟩 = *Not Applicable*

Strategy #2 – GSHP Plants
🟧 = LTHW and CHW Supply & Return
🟩 = Geofield to Nodal plant piping

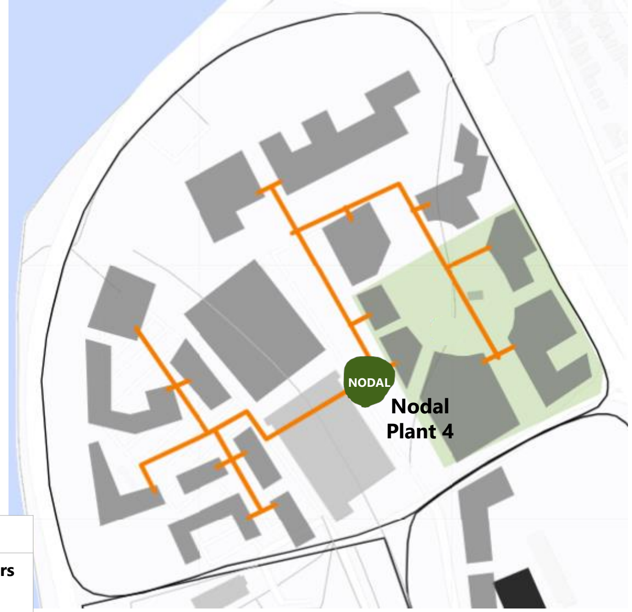
Strategy #3 – Ground Water Distribution
🟧 = Ground water Supply and Return
🟩 = Geofield to pumping station piping

BLOCK 3 & 4 DISTRIBUTION CONFIGURATION

Block 3



Block 4



Legend

Strategy #1 – Hot Water Electric Boilers
🟧 = LTHW Supply & Return
🟩 = *Not Applicable*

Strategy #2 – GSHP Plants
🟧 = LTHW and CHW Supply & Return
🟩 = Geofield to Nodal plant piping

Strategy #3 – Ground Water Distribution
🟧 = Ground water Supply and Return
🟩 = Geofield to pumping station piping

ARUP

GEO-EXCHANGE FIELD STRATEGY

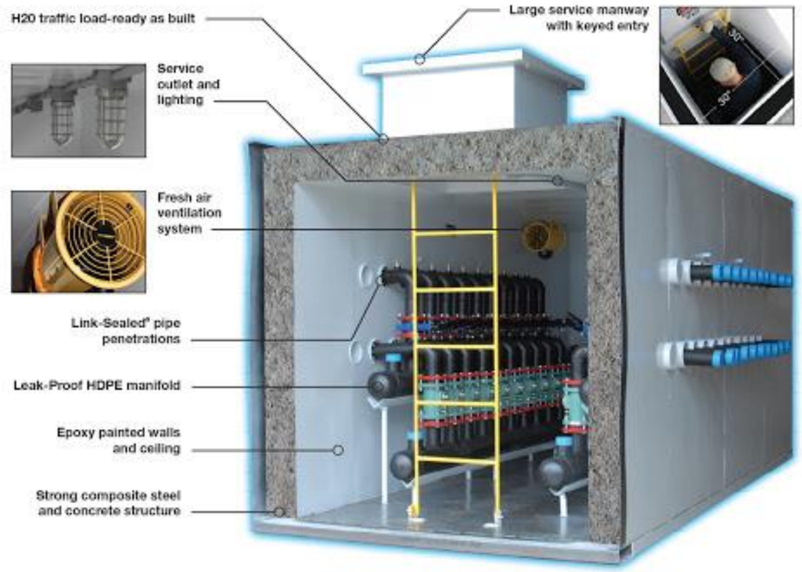
Primary

- Central ground water pump heat package within Nodal Plant for Strategy #2 and within building mechanical plants for Strategy #3

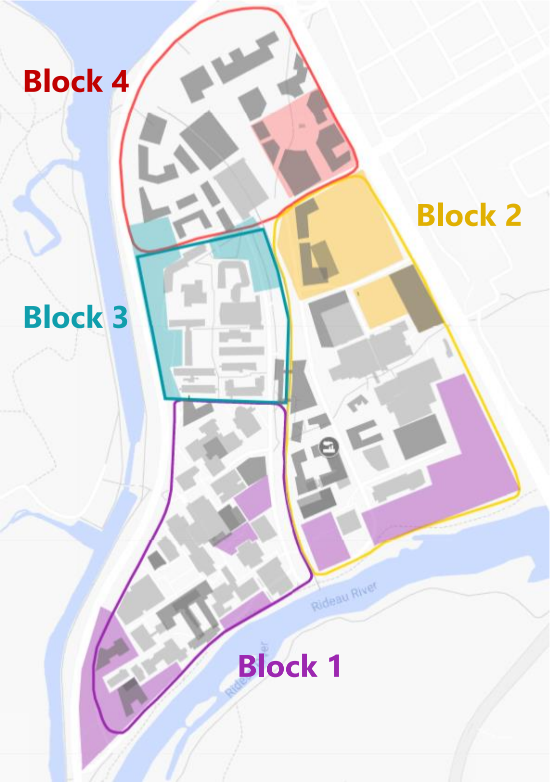
Secondary

- Ground Water loop for each new borefield constructed
- Local ground water manifold, dedicated circulation pumps, and heat exchangers
  - Standalone pump bunker or integrated into basement mechanical room nodal plant or nearby building

Ground Water Manifold



GEO-EXCHANGE FIELDS



- This geo-field configuration is used within the basis of design within all three strategies
- Geo-exchange fields' size and location were selected to maximize the ground source potential for each block
- Nodal plant locations correlate with the configuration of the geo-exchange fields to decrease the length of geo-field pipes

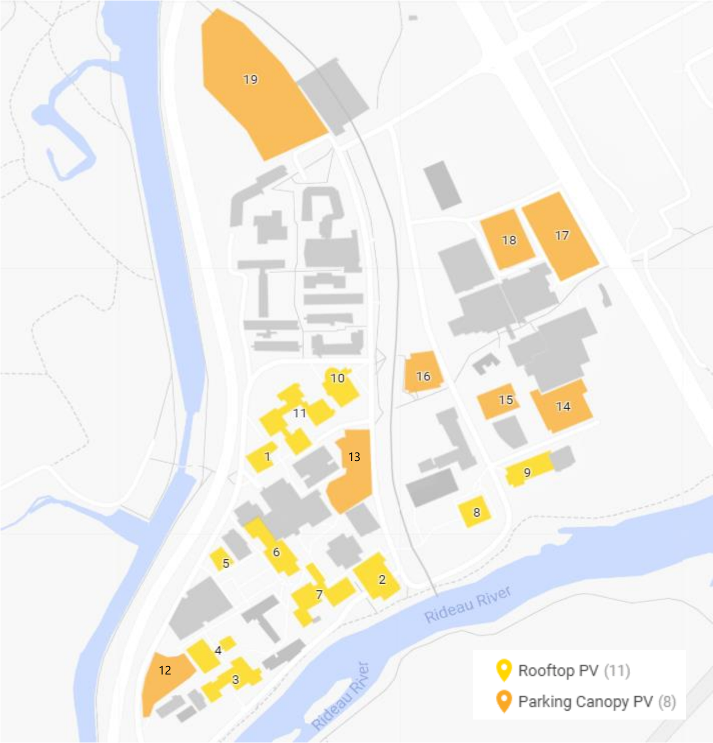
Note:

- Additional geothermal fields (not shown) can be constructed under all new developments and used locally within the new building for peaking to reduce demand on the nodal plant and capacity required of distribution
  Local geothermal fields have not been included in costs and capacity calculations for Strategies.

CAMPUS SOLAR CAPACITY

- Existing and new buildings and parking areas assumed to receive solar PV panels to reduce electrical demand of campus.
- The area measurements are estimated based on Satellite image/Google map. The entire rooftop or parking lot area is taken and a utilization factor is applied to account for areas not applicable for PV panels. Further analysis will be required to determine exact areas applicable for PV panels.
- PV panel generation and costs calculations are based on industry standards and past project estimations. Actual construction cost may vary due to unforeseen circumstances.
- Each project will have specific circumstances and conditions that will need to considered - capacity and cost estimation are expected to evolve as the design and planning of each PV installation are further developed.

Estimated Usable Area for PV Panels:	91,800 m2
Total Solar Panel Capacity (kW):	9,200 kW
Total Annual Electricity Generation:	11,200,000 kWh
Annual Electricity Cost Savings:	$1.7 Million
GHG Emission Reduction:	558,000 kg of CO2
Capital Cost:	$36.7 million

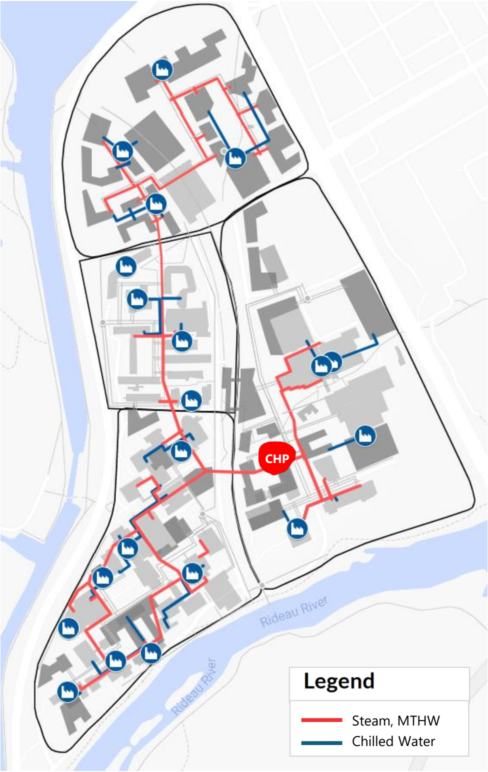


ARUP

ENERGY STRATEGY EVALUATION

ARUP

BUSINESS AS USUAL



OVERVIEW

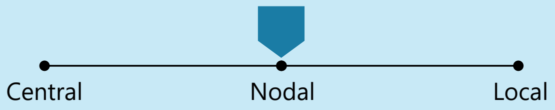
- CUP continue to operate using **natural gas** to serve existing buildings
- Existing district steam/HW infrastructure will be expanded to serve new buildings on campus
- CHW will continued to be operated locally/nodally and will be expanded serve new buildings on campus as required. New CHW equipment will be added to meet demand as existing capacity is at maximum capacity.

- **Distribution:** Existing (Steam, MTHW, chilled water)

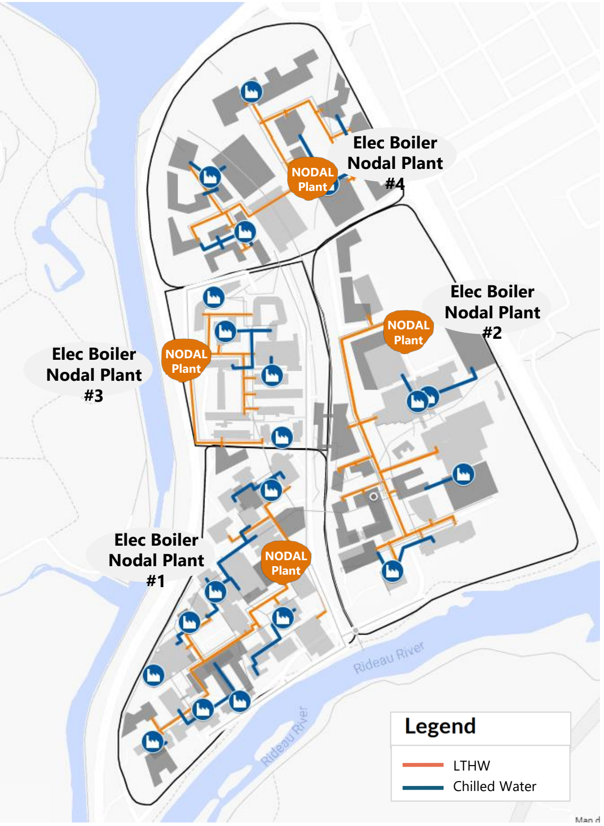
Future campus main energy supply technology:

Electric Boilers (Steam/Hot Water)

ENERGY SUPPLY SCHEME



STRATEGY #1 – NODAL ELECTRIC HOT WATER BOILERS



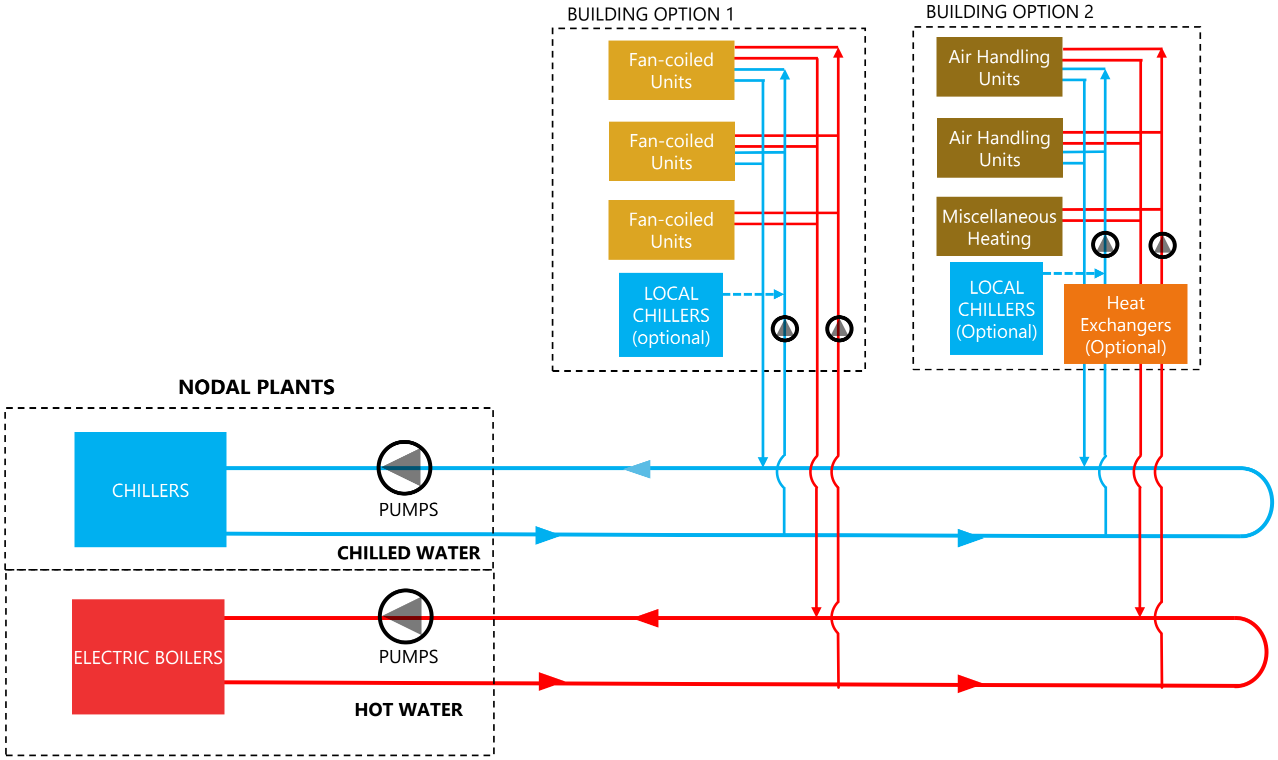
OVERVIEW

- Hot water electric boilers will be added to nodal plants and replace the gas-fired boilers and Cogen system as the main source of heating at the central plant.
- Once all equipment within the existing central plant is phased out, the central plant building can be repurposed for a new development or become the new nodal plant.
- New LTHW distribution will connect nodal plants to all buildings within each block. Existing steam distribution to be phased out with hot water distribution (~180F).
- Existing buildings will be retrofitted to use LTHW and be served from the nearby nodal plant. Upgrades are needed at the building level, but the level of impact will be different among different buildings, i.e. coils replacements vs AHU replacement
- New developments will connect directly to the nearby nodal plant for heating hot water and CHW. If a new development is constructed prior to the nodal plant being operational, the development will connect temporarily to the existing steam network or receive temporary electric boilers.
- CHW will continued to be operated locally/nodally and will be expanded serve new buildings on campus as required. New CHW equipment will be added to meet demand as existing capacity is at maximum capacity.

Distribution:

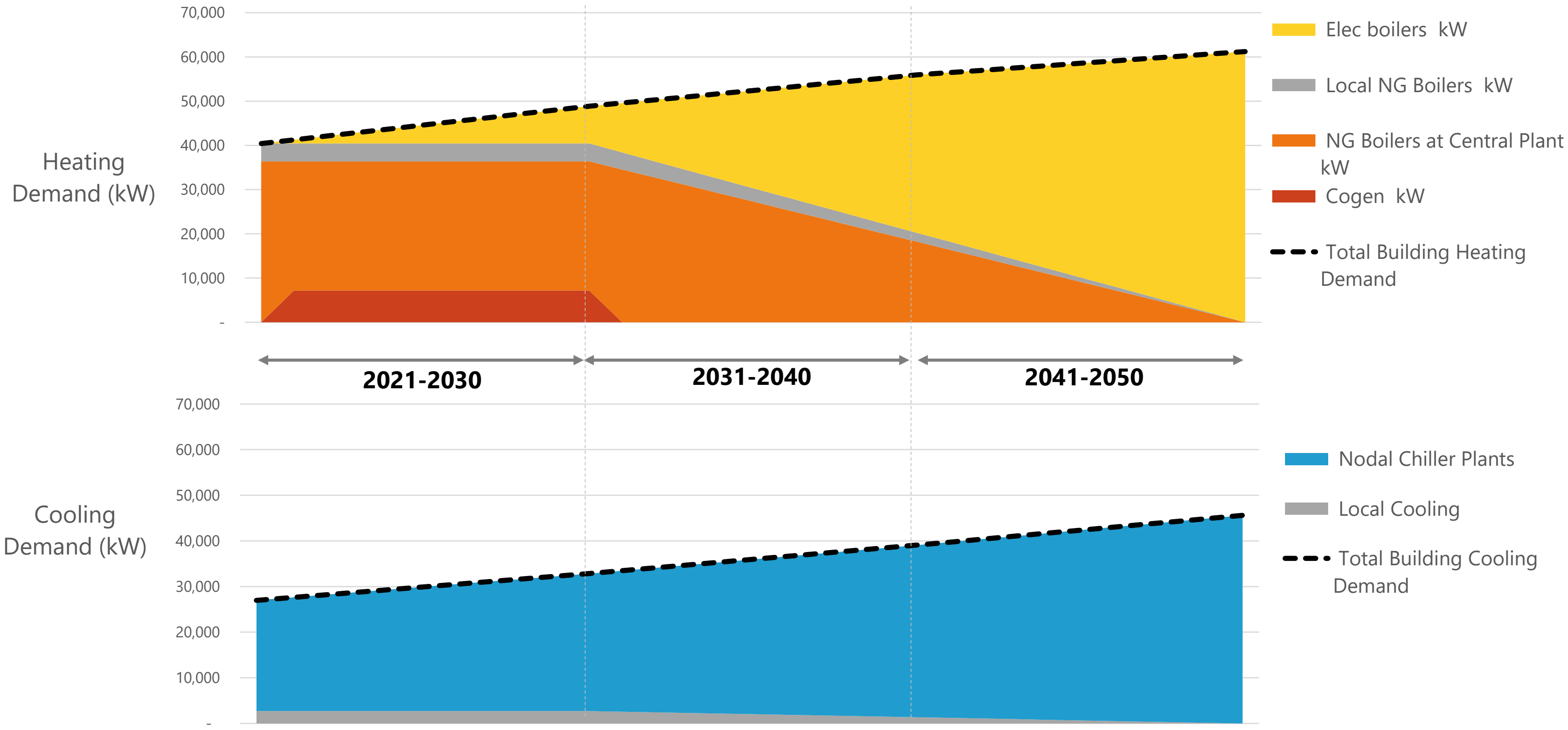
- New LTHW to buildings
- Existing chilled water distribution to remain (remains decoupled with heating)

STRATEGY #1 – THERMAL SCHEMATIC

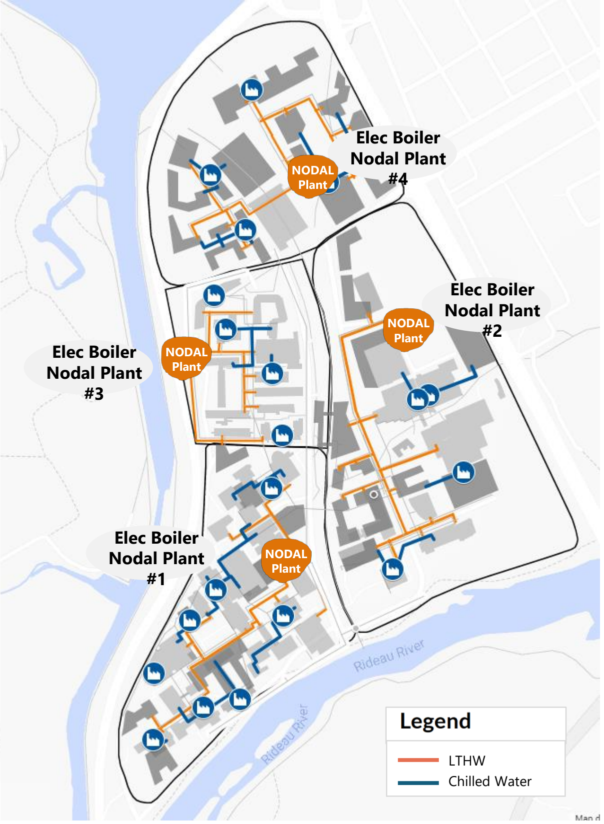


ARUP

STRATEGY #1 – THERMAL GENERATION PHASING



STRATEGY #1 – PROS & CONS



PROS

- Lower spatial requirement at the nodal plants (only heating is req.)
- Minimal mechanical space needed in new buildings and minimal existing building retrofits (most buildings are not directly steam-fed and electric HW boiler can supply at a higher HW temperature)
- Reduced CAPEX without geoexchange and reduced CHW distribution (reused)

CONS

- CAPEX for new heating distribution across the campus and new nodal plants
- High OPEX due to low efficiency of electric boilers
- CAPEX associated with electrical infrastructure upgrade; higher complexity to bring new heavy electrical feed to nodal plant and cost uncertainty associated with Hydro Ottawa infrastructure upgrade requirement
- Higher dependency on electricity of all three strategies, risks on resiliency due to dependency on electricity
- No change to cooling system redundancy

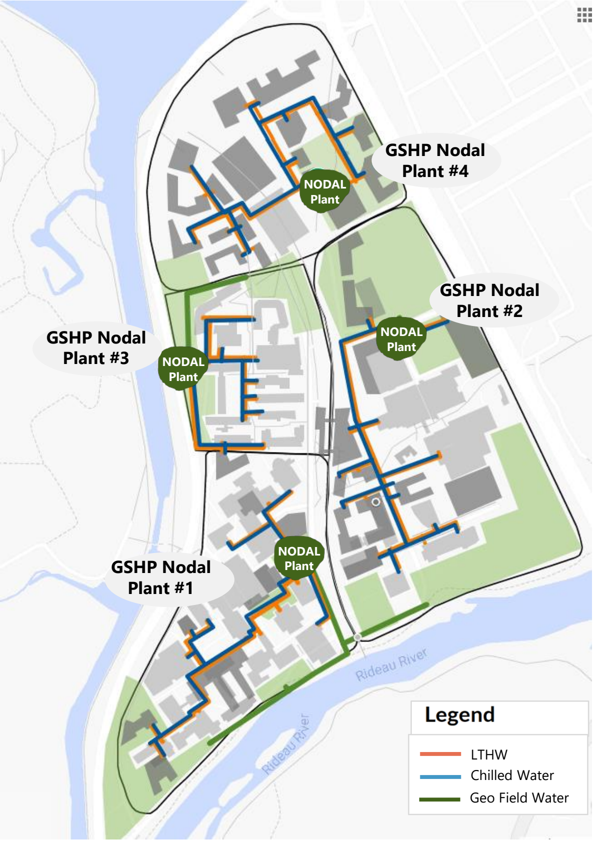
Future campus main energy supply technology:

Geo-exchange Heat Pumps

ENERGY SUPPLY SCHEME

Central Nodal Local

STRATEGY #2 – NODAL GSHP PLANT WITH 4 PIPE DISTRIBUTION



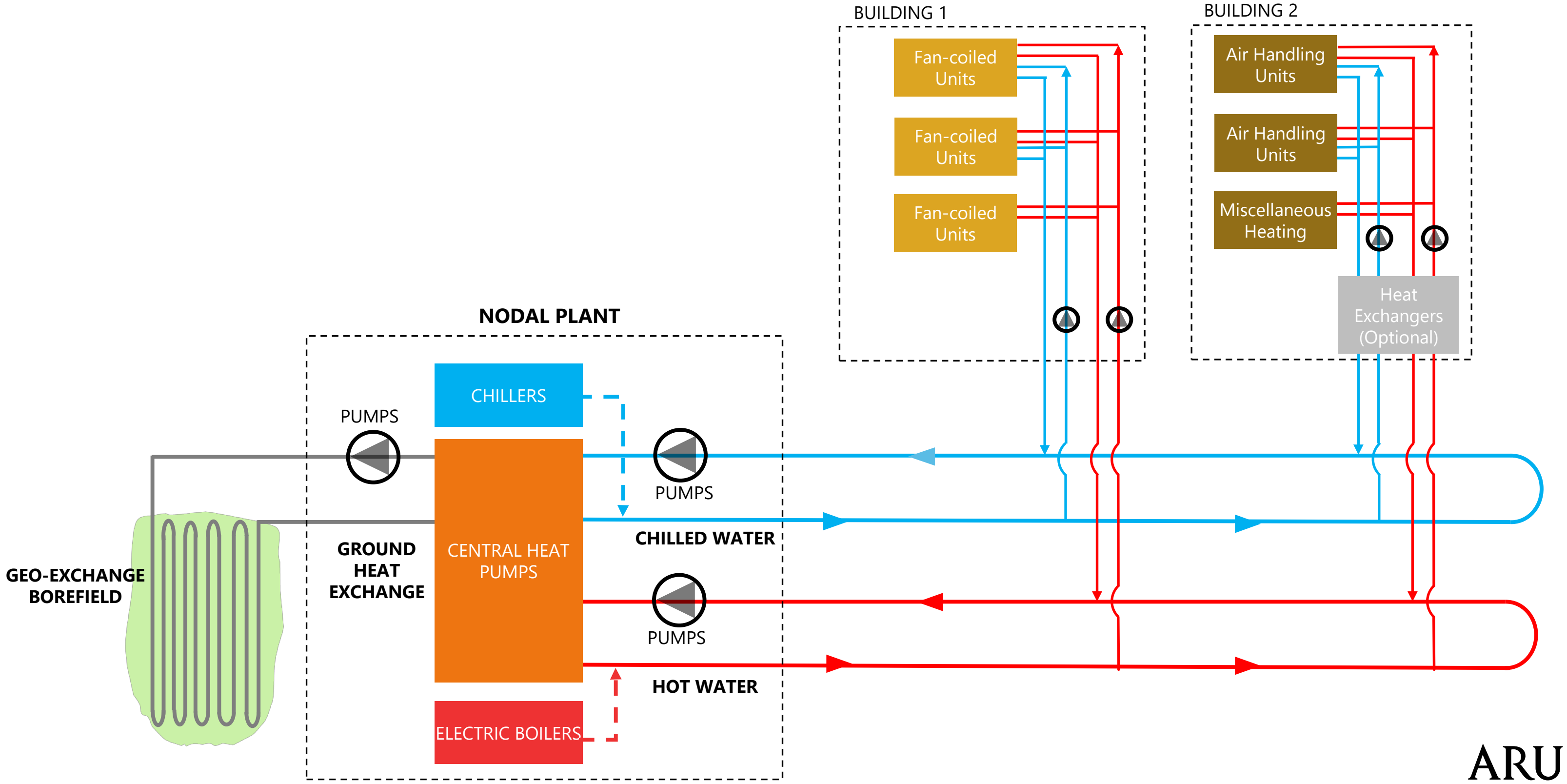
OVERVIEW

- Geo-exchange fields will be connected to new nodal GSHP plants and utilize heat pumps to provide CHW/LTHW to buildings. Nodal plants will also include peaking cooling towers and electric resistance boilers
- New LTHW and CHW distribution will connect nodal plants to all buildings within each block. Existing steam, high temperature hot water (180F), and part of the chilled water distribution to eventually be phased out.
- Once all buildings are connected to new nodal plants, the existing central plant and existing chilled water plants will be phased out and the central plant building can be repurposed for a new development or become the new nodal plant.
- Existing buildings will be retrofitted to use LTHW (140F) and be served from the nearby nodal plant. Relatively minor updates are needed at the building level, unless steam is fed directly to the AHU or fan coil units within the building.
- New developments will connect directly to the nearby nodal plant for heating hot water and CHW. If a new development is constructed prior to the nodal plant being operational, the development will connect temporarily to the existing steam network or receive temporary electric boilers and temporary chillers

Distribution:

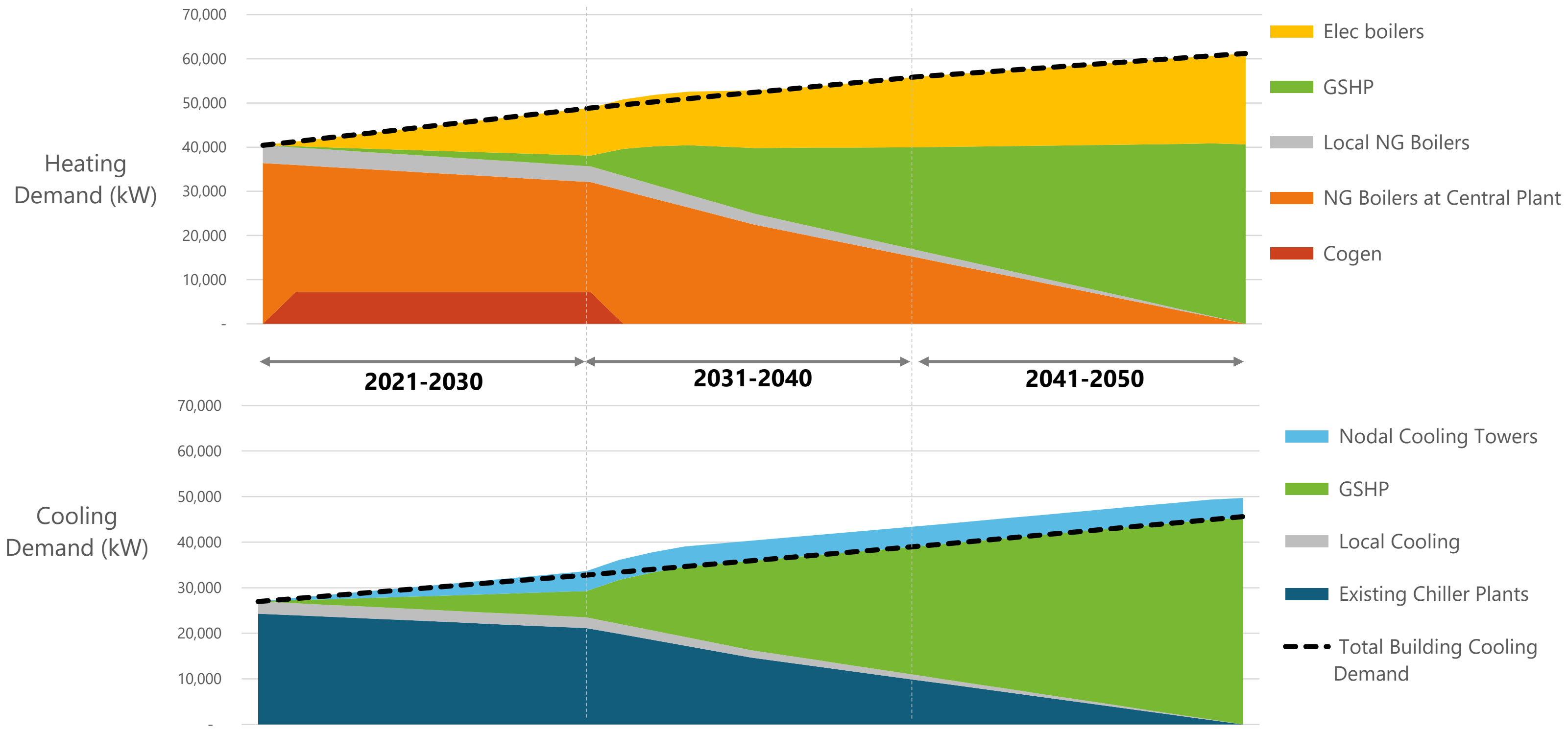
- New 4-pipe to all buildings (Chilled water, LTHW)
- New 2-pipe Geo Pipe to connect geo fields to plant

STRATEGY #2 – THERMAL SCHEMATIC



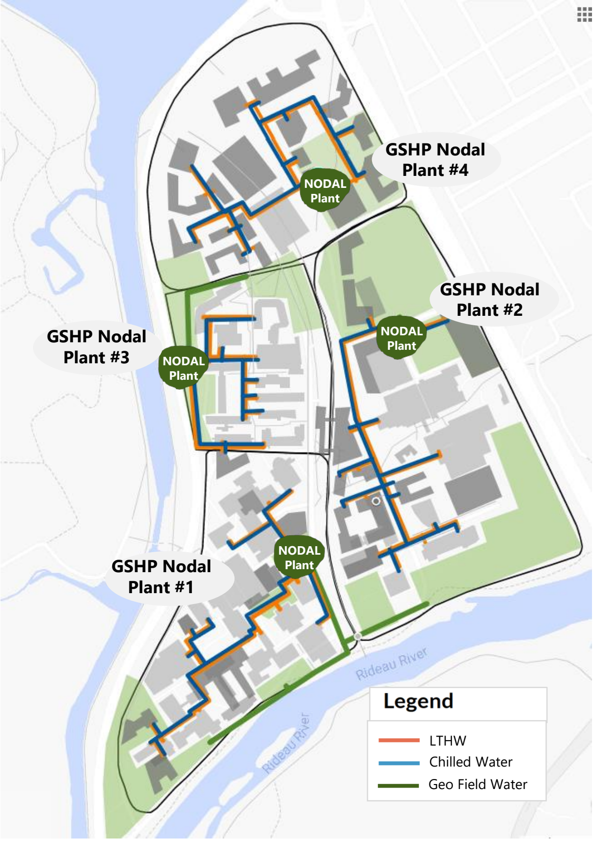
ARUP

STRATEGY #2 – THERMAL GENERATION PHASING



ARUP

STRATEGY #2 – NODAL GSHP PLANT WITH 4 PIPE DISTRIBUTION



PROS

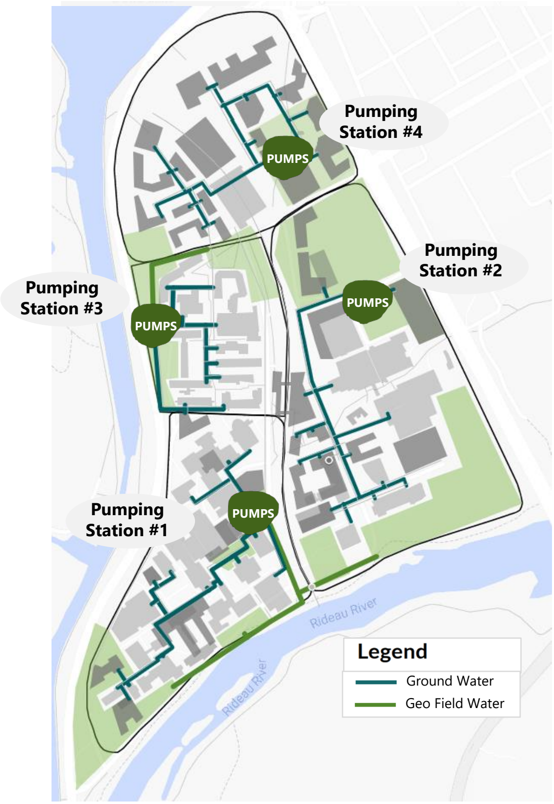
- Highest operation efficiency and lowest OPEX out of all three strategies
- Nodalized approach for GSHP is more realistic in terms of distribution piping if geothermal fields within a node are not close to each other. Can further sub-nodalize the system.
- Higher flexibility to integrate with other centralized/nodalize technologies (relative to a 2-pipe distribution system)
- Northern part of the campus with higher geothermal capacity potential. Phasing will be simpler for new development on the North side of the campus.
- Borefields at different nodes can be connected for higher redundancy and load diversification

CONS

- Req. deeper retrofit / building conversion relative to Strategy #1 – Electric Hot Water Boiler Option
- Reducing centralization requires a overall higher system capacity for system redundancy (more plant equipment AND geoexchange borefield)
- Slightly higher maintenance and lower energy efficiency comparing to centralized approach.
- High CAPEX due to geothermal system

ARUP

STRATEGY #3 – NODAL GROUND WATER DISTRIBUTION



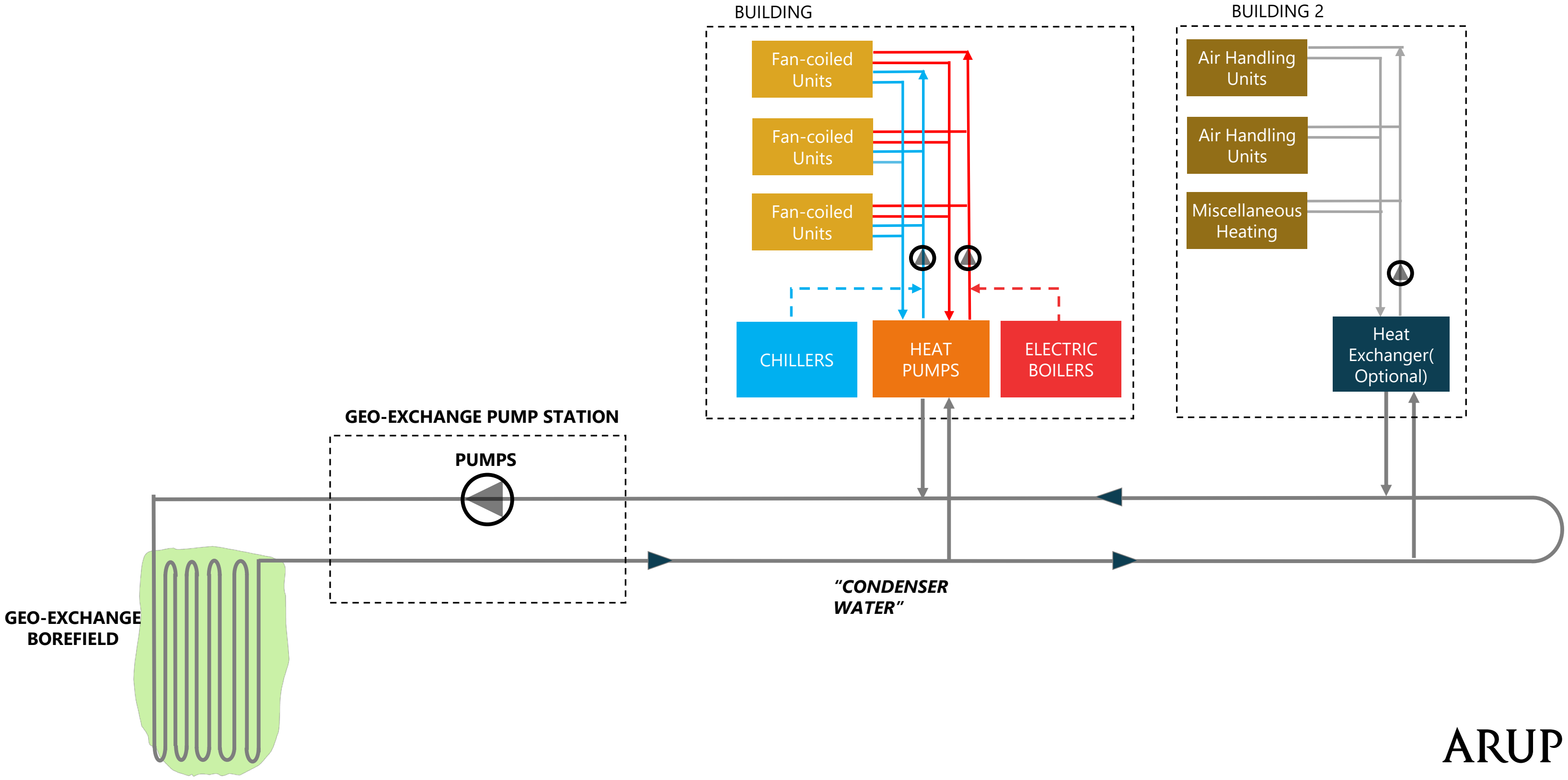
OVERVIEW

- Geo-exchange fields will connect to nodal pumping stations and then distribute ground water to all buildings on campus
- Nodal pumping stations will be standalone pump bunker or integrated into basement mechanical room nodal plant or nearby building. Pumping stations to include local ground water manifold, dedicated circulation pumps, and heat exchangers.
- Buildings will utilize local ground source heat pumps to provide CHW/LTHW throughout the building. Buildings will also include peaking cooling towers and electric resistance boilers.
- Existing buildings will be retrofitted to use LTHW (140F) to utilize local heat pump. Relatively minor updates are needed at the building level, unless steam is used directly to the AHU or fan coil units within the building.
- Once all buildings are connected to new nodal plants, the existing central plant and existing chilled water plants will be phased out and the central plant building can be repurposed for a new development or become the new nodal plant.
- New developments will connect directly the ground water distribution. If a new development is constructed prior to the nodal ground water distribution being available, the new development will connect temporarily to the existing steam network or receive temporary electric boilers and temporary chillers.

Distribution:

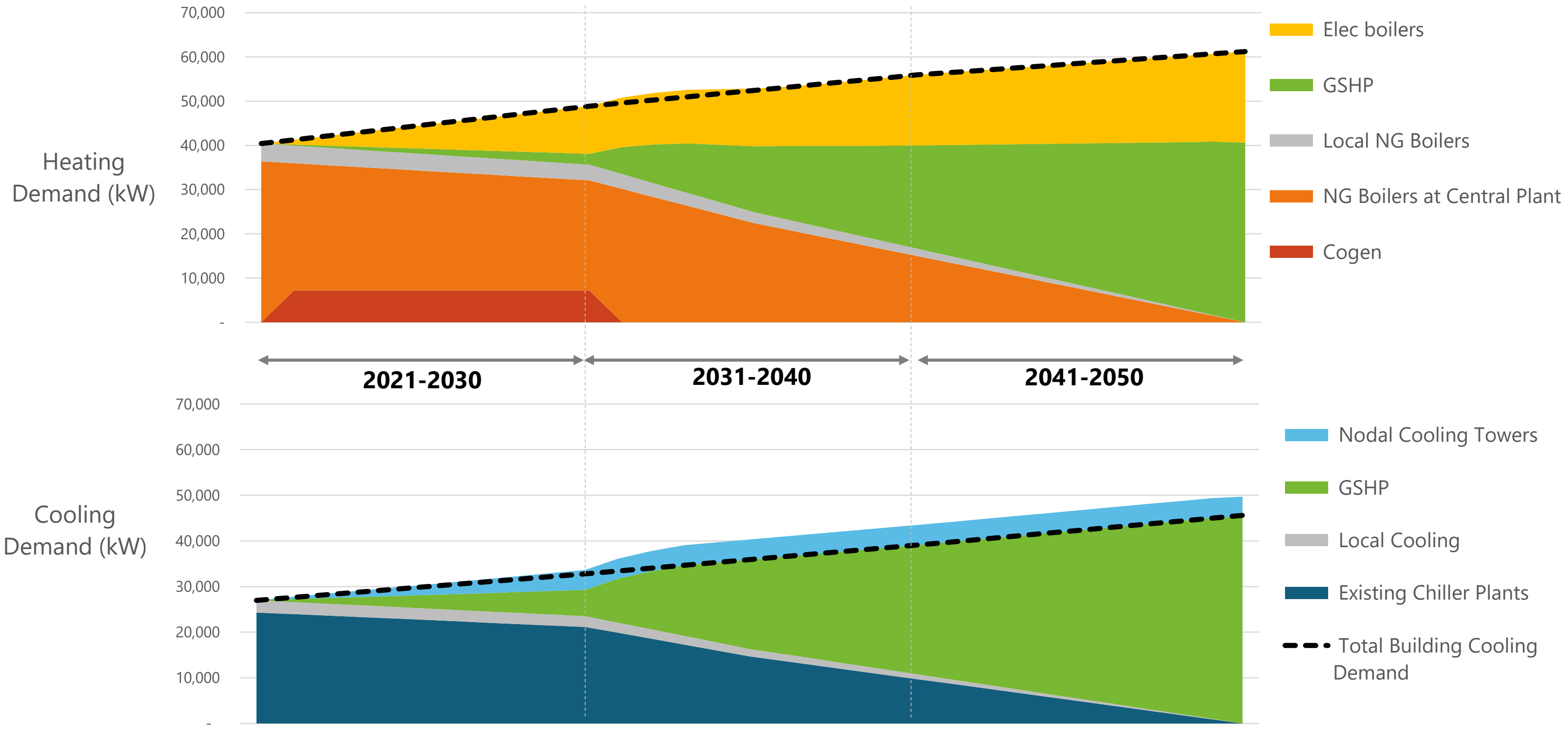
- New 2-pipe Geo Pipe to connect geo fields to Pumping station
- 2-pipe ground water distribution to all buildings
- Local GSHP at building for LTHW & chilled water

STRATEGY #3 – THERMAL SCHEMATIC

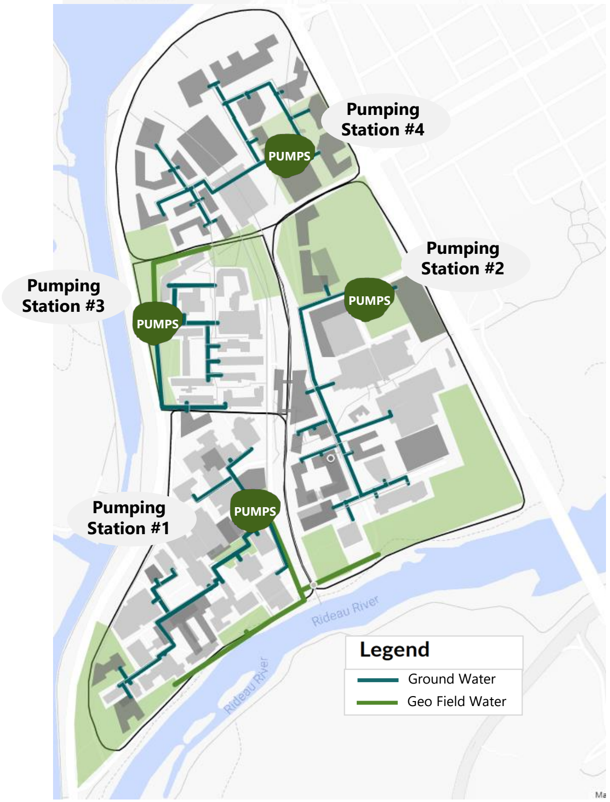


ARUP

STRATEGY #3 – THERMAL GENERATION PHASING



4.2 – NODAL GROUND WATER DISTRIBUTION



PROS

- Higher energy efficiency and lower OPEX comparing to electric hot water option.
- GW pipe sizes due to nodalization
- Phasing of the strategy can be relatively easier with a nodal approach
- Capital for new plant equipment can be phased based on new development / existing building upgrade.
- Mild temperature for distribution implies lower thermal losses;

CONS

- Reduced energy efficiency due to relatively lower load diversification (only happens on CW side)
- Decentralized equipment for maintenance
- Space requirement for GSHP's at the building level; can be difficult to achieve in existing buildings
- Potential new electrical feed (upgrade) required to existing buildings.
- CAPEX for LTHW conversion for existing buildings (or terminal heat pump)
- Geothermal capacity can be limited on the South-west portion of the campus (infill)

Appendix F. Utility Strategy Nodal Capacities

Capacities in table show equipment capacities at each Nodal plant within each phase of the Master Plan. Values are based on existing and new development loads connected to nodal plants following the implementation timeline in Section 5.1. It's important to note the capacities in the table do not represent the required heating and cooling capacity of the entire campus, they only represent what's required at each nodal plant to serve connected buildings. Remaining heating and cooling demand of the campus will be served by the existing central heating plant and existing nodal cooling plants. Incremental capacities (bolded values) do not consider equipment renewal which will be required as necessary when equipment reaches end of life.

Heating electricity demand assumes electric boilers to have 99% efficiency and cooling electricity demand assumes a COP 7 for chillers. Heating electricity demand includes demand for pumps and cooling electricity demand includes demand for cooling towers and pumps.

It should be noted that the values in the table are calculated based on building peak thermal demand and current campus growth plan for the purpose of utility strategy evaluation. The estimated building thermal demand, plant and equipment sizes and associated technical requirements need to be further designed and calculated based on the latest campus plan and anticipated building programs with nodal plants feasibility studies. These numbers should not be used to inform basis of design and construction budgets.

		Current	By End of 2030	By End of 2040	By End of 2050
Nodal Plant 1 Nodal Heating Plant 1 is expected to be in operation by 2035 as shown in the implementation framework. Following the nodal plant beginning operation, all buildings within the node are planned to be connected to the nodal plant by 2045. ‡Equipment capacities shown in the table before the nodal plant is in operation in 2035 correspond with the new Sustainability Research Centre being built and will be required locally within the new development if the nodal plant is not operation at the time.					
Heating	Electric Boiler Capacity	0 MW	**+ 1.3 MW** Total: 1.3 MW‡	**+ 12.7 MW** Total: 14 MW	**+ 12.8 MW** Total: 26.8 MW
Cooling	New Chiller Capacity	0 MW	**+ 1.0 MW** Total: 1.0 MW‡	Total: 1.0 MW	Total: 1.0 MW
	New Cooling Tower Capacity	0 MW	**+ 1.0 MW** Total: 1.0 MW‡	Total: 1.0 MW	Total: 1.0 MW
Electricity	Heating Electricity Demand	0 MW	**+ 1.4 MW** Total: 1.4 MW‡	**+ 13.1 MW** Total: 14.5 MW	**+ 13.1 MW** Total: 27.6 MW
	Cooling Electricity Demand	0 MW	**+ 0.1 MW** Total: 0.1 MW	Total: 0.1 MW	Total: 0.1 MW
Nodal Plant 2 Nodal Plant 2 is expected to be in operation by 2030 as shown in the implementation framework. Following the nodal plan beginning operation, all buildings within the node are planned to be connected to the nodal plant by 2040.					
Heating	Electric Boiler Capacity	Total: 0 MW	Total: 0 MW	**+ 7.8 MW** Total: 7.8 MW	Total: 7.8 MW
Cooling	New Chiller Capacity	Total: 0 MW	Total: 0 MW	Total: 0 MW	Total: 0 MW
	New Cooling Tower Capacity	Total: 0 MW	Total: 0 MW	Total: 0 MW	Total: 0 MW
Electricity	Heating Electricity Demand	Total: 0 MW	Total: 0 MW	**+ 8.0 MW** Total: 8.0 MW	Total: 8.0 MW
	Cooling Electricity Demand	Total: 0 MW	Total: 0 MW	Total: 0 MW	Total: 0 MW

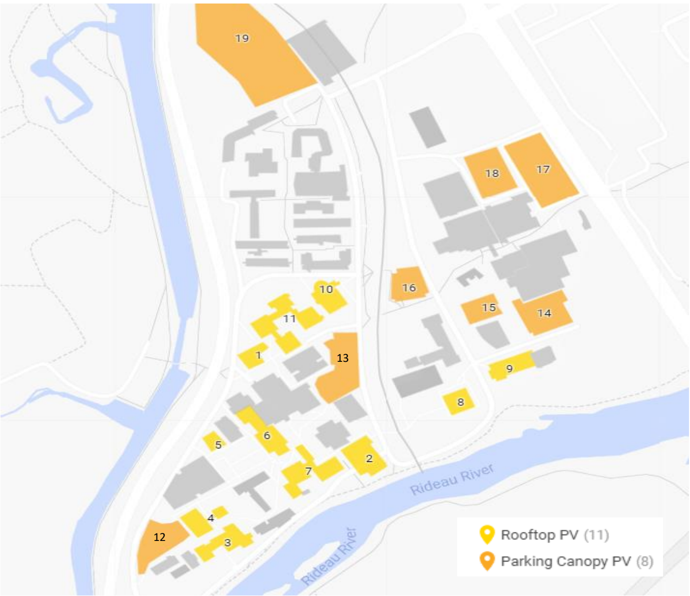
		Current	By End of 2030	By End of 2040	By End of 2050
Node 3 Nodal Plant 3 is expected to be in operation by 2025 as shown in the implementation framework. Following the nodal plant beginning operation, all buildings within the node are planned to be connected to the nodal plant by 2035.					
Heating	Installed Electric Boiler Capacity	Total: 0 MW	**+ 4.4 MW** Total: 4.4 MW	**+ 3.5 MW** Total: 7.9 MW	Total: 7.9 MW
Cooling	New Chiller Capacity	Total: 0 MW	**+ 0.6 MW** Total: 0.6 MW	Total: 0.6 MW	Total: 0.6 MW
	New Cooling Tower Capacity	Total: 0 MW	**+ 0.6 MW** Total: 0.6 MW	Total: 0.6 MW	Total: 0.6 MW
Electricity	Heating Electricity Demand	Total: 0 MW	**+ 4.5 MW** Total: 4.5 MW	**+ 3.8 MW** Total: 8.3 MW	Total: 8.3 MW
	Cooling Electricity Demand	Total: 0 MW	**+ 0.09 MW** Total: 0.09 MW	Total: 0.09 MW	Total: 0.09 MW
Total Campus THD = Total Heating Demand Remaining percentage of THD is supplied by existing central plant steam network.					
Heating	Installed Electric Boiler Capacity	0 MW (0% of THD)	**+ 5 MW** Total: 5 MW (13% of THD)	**+ 19 MW** Total: 24 MW (70% of THD)	**+19 MW** Total: 43 MW (100% of THD)
Cooling	New Chiller Capacity	Total: 0 MW	**+ 1.6 MW** Total: 1.6 MW	Total: 1.6 MW	Total: 1.6 MW
	New Cooling Tower Capacity	Total: 0 MW	**+ 1.6 MW** Total: 1.6 MW	Total: 1.6 MW	Total: 1.6 MW
Electricity	Heating Electricity Demand	Total: 0 MW	**+ 5.9 MW** Total: 5.9 MW	**+ 24.9 MW** Total: 30.8 MW	**+ 13.1 MW** Total: 43.9 MW
	Cooling Electricity Demand	Total: 0 MW	**+ 0.2 MW** Total: 0.2 MW	Total: 0.2 MW	Total: 0.2 MW

Appendix G. **Solar PV Analysis Existing Campus**

ysis is high level calculation to determine potential area savings for PV installations on the Carleton campus, and associated potential
st and reduction in energy, energy cost and carbon. The following should be noted.
a measurements are estimated based on Satellite image/Google map. The entire rooftop or parking lot area is taken and a utilization
ıpplied to account for areas not appliacble for PV panels. Further anaylysis will be required to determine exact areas applicable for PV

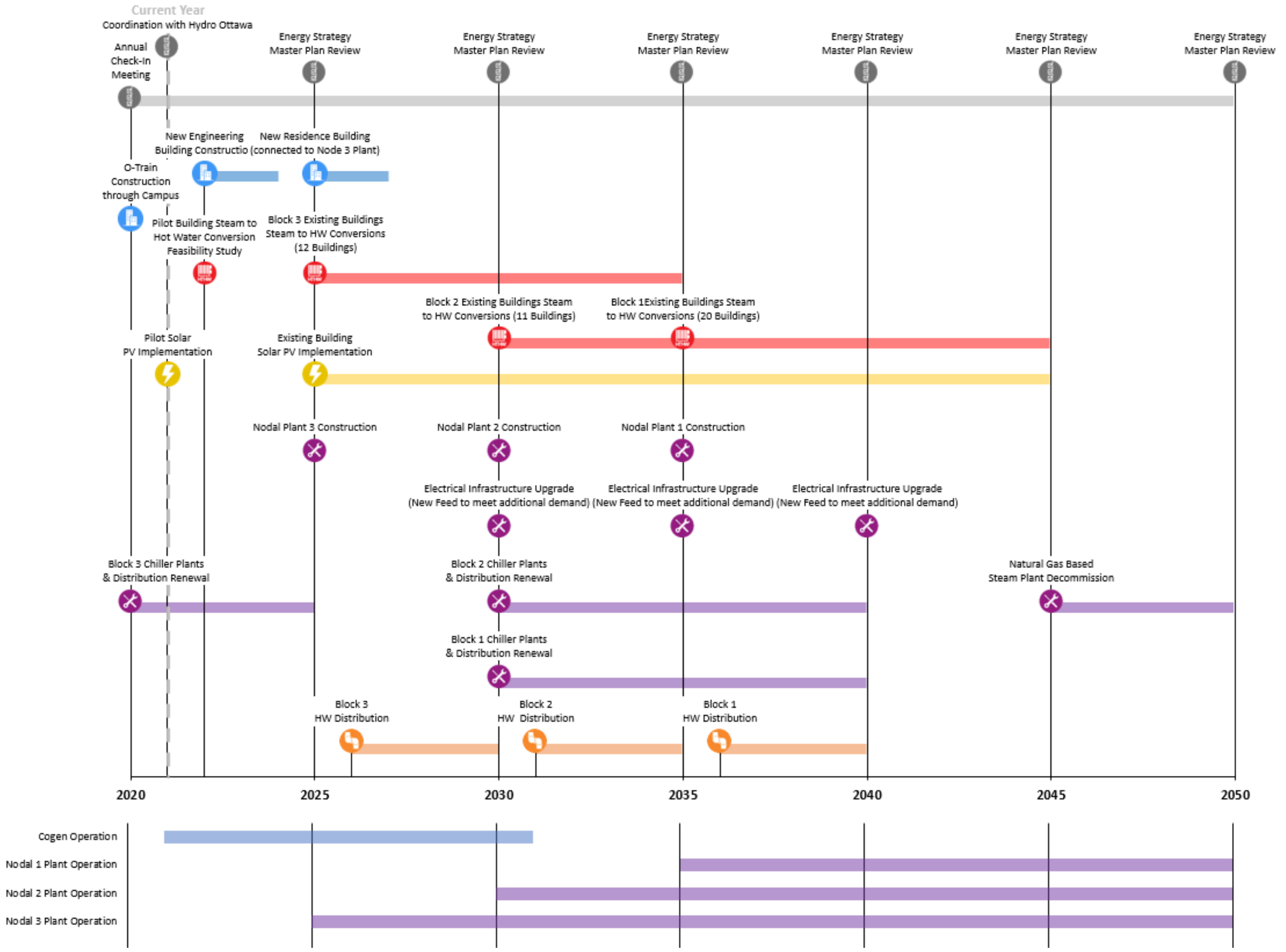
l generation and costs calculations are based on industry standards and past project estimations. Capital cost shown do not include any
ion soft cost, contractor OH&P, and design contingency. Actual construction cost may vary due to circumstance related to COVID-19 and
orseen cirsumstance. No cost escalation is included in the calculation.
oject will have specfic circumstances and conditions that will need to condsidered - capacity and cost estimation are expected to evolve
sign and planning of each PV installation are further developed.

ons:			Notes
zation Factor (Building rooftop)	50%		
zation Factor (Parking Structure)	70%		
out Demand	0.1	kW/m2	Assuming south facing with spacing between rows of panels to minimize self shading. Panel density can be optimized with different panel arrangement
put Energy	1217	kWh/kW	Solar Output calculated on PVWatt by NREL, assumes roof mounted panels, south facing at 20deg tilt, Ottawa location.
Cost	0.156	$/kWh	
Cost	4000	$/kW	
Emissions	0.05	kg CO2/kWh	



Building	Type	Area (m2)	Usable Area for PV (m2)	Solar Capacity (kW)	Annual Electricity Generation (kWh)	Capital Cost ($)	Electricity Cost Savings ($)	Payback Period ($)	GHG Emission Reduction (kg)
	Building Rooftop	1,290	645	65	78,497	258,000	$ 12,245	21.1	3,925
	Building Rooftop	3,180	1,590	159	193,503	636,000	$ 30,186	21.1	9,675
	Building Rooftop	2,750	1,375	138	167,338	550,000	$ 26,105	21.1	8,367
	Building Rooftop	1,970	985	99	119,875	394,000	$ 18,700	21.1	5,994
ower	Building Rooftop	780	390	39	47,463	156,000	$ 7,404	21.1	2,373
	Building Rooftop	3,150	1,575	158	191,678	630,000	$ 29,902	21.1	9,584
	Building Rooftop	3,750	1,875	188	228,188	750,000	$ 35,597	21.1	11,409
	Building Rooftop	1,610	805	81	97,969	322,000	$ 15,283	21.1	4,898
	Building Rooftop	2,210	1,105	111	134,479	442,000	$ 20,979	21.1	6,724
	Building Rooftop	2,250	1,125	113	136,913	450,000	$ 21,358	21.1	6,846
e Building									
	Parking	4,510	3,157	316	384,207	1,262,800	$ 59,936	21.1	19,210
	Parking	6,200	4,340	434	528,178	1,736,000	$ 82,396	21.1	26,409
	Parking	4,850	3,395	340	413,172	1,358,000	$ 64,455	21.1	20,659
	Parking	2,310	1,617	162	196,789	646,800	$ 30,699	21.1	9,839
	Parking	3,070	2,149	215	261,533	859,600	$ 40,799	21.1	13,077
	Parking	8,810	6,167	617	750,524	2,466,800	$ 117,082	21.1	37,526
	Parking	4,850	3,395	340	413,172	1,358,000	$ 64,455	21.1	20,659
	Parking	24,300	17,010	1,701	2,070,117	6,804,000	$ 322,938	21.1	103,506
		81,840	52,700	5,270	6,413,590	21,080,000	1,000,520		320,680

Appendix H. **Strategy Implementation Framework**


Current Year
Coordination with Hydro Ottawa
Annual Check-In Meeting
Energy Strategy Master Plan Review
Energy Strategy Master Plan Review
Energy Strategy Master Plan Review
Energy Strategy Master Plan Review
Energy Strategy Master Plan Review
Energy Strategy Master Plan Review
New Engineering Building Constructio
New Residence Building (connected to Node 3 Plant)
O-Train Construction through Campus
Pilot Building Steam to Hot Water Conversion Feasibility Study
Block 3 Existing Buildings Steam to HW Conversions (12 Buildings)
Block 2 Existing Buildings Steam to HW Conversions (11 Buildings)
Block 1Existing Buildings Steam to HW Conversions (20 Buildings)
Pilot Solar PV Implementation
Existing Building Solar PV Implementation
Nodal Plant 3 Construction
Nodal Plant 2 Construction
Nodal Plant 1 Construction
Electrical Infrastructure Upgrade (New Feed to meet additional demand)
Electrical Infrastructure Upgrade (New Feed to meet additional demand)
Electrical Infrastructure Upgrade (New Feed to meet additional demand)
Block 3 Chiller Plants & Distribution Renewal
Block 2 Chiller Plants & Distribution Renewal
Natural Gas Based Steam Plant Decommission
Block 1 Chiller Plants & Distribution Renewal
Block 3 HW Distribution
Block 2 HW Distribution
Block 1 HW Distribution
2020
2025
2030
2035
2040
2045
2050
Cogen Operation
Nodal 1 Plant Operation
Nodal 2 Plant Operation
Nodal 3 Plant Operation