University of Toronto

Carbon and Energy Reduction Master Plan

Version 1

REP 001

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Reference: ARUP Job number P999-18-195

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Executive Summary

Arup was engaged by the University of Toronto St George Campus per RFP 999-18-195 to develop the Site Utility Master Plan. The University has three primary objectives for the Site Utility Master Plan:

1. Develop a **RENEWAL** strategy for the existing and aged utility assets to support the future performance of the campus;
2. Address the campus' considerable **GROWTH** needs tied in with the University's master plan and secondary plan, and addressing reliability, redundancy and resiliency in the face of this growth and;
3. Develop a plan that is in line with the university's commitment to reduce **GREEN** house gas emissions (37% below 1990s by 2030) and campus carbon neutrality by 2050.

At the inception of the Site Utility Master Plan, a benchmarking exercise of peer universities was carried out and nearly all peer universities have some form of campus carbon neutrality targets. As world class institution leading in research and academic excellence, the University of Toronto Site Utility Master Plan Team recognizes that achieving campus carbon neutrality requires transformative and complex changes to the existing campus site utilities. At the same time, the University of Toronto Master Plan Team recognizes that the underlying and compounding challenges of renewing the aged utility infrastructure and meeting the considerable campus future growth are also opportunities for major transformation of the site utility infrastructure. From that point on, the Master Plan team proceeded with the aspirational target of achieving campus carbon neutrality by 2050 for the site utility master plan. The target includes a clear definition of carbon neutrality that requires at least 80% reduction of emission reduction relative to 1990 levels, with the remaining carbon emission to be offset using some form of offsite renewable generation.

The development of the Site Utilities Master Plan was a diverse collaborative effort inclusive of major campus and external stakeholders. Throughout the project, key stakeholders were brought together where their cross-disciplinary inputs were synthesized to objectively evaluate, balance options and priorities. The outcome is a holistic, actionable, low-carbon road map for the campus utility infrastructure that responds to the three primary objectives of the master plan. It will strategically guide the University to transform its utility infrastructure and be recognized leader as a sustainable, world class institution.

Key Stakeholders included:

UT Site Utility Masterplan Team - Ron Saporta, Gordon Robins, Paul Alves, Jelena Vulovic- Basic, Paul Leitch, Keith Foster, Gurmel Multani

UT Steering Committee Team – Gilbert Delgado, Christine Burke, Devendra Chopra, John Robinson, Kenneth Corts, Kim McLean, Paul Handley, Bryan Karney, Carrie Greenop

External stakeholders - including Toronto Hydro, City of Toronto

Other key university stakeholders indirectly engaged via the UT Site Utility Master Plan team

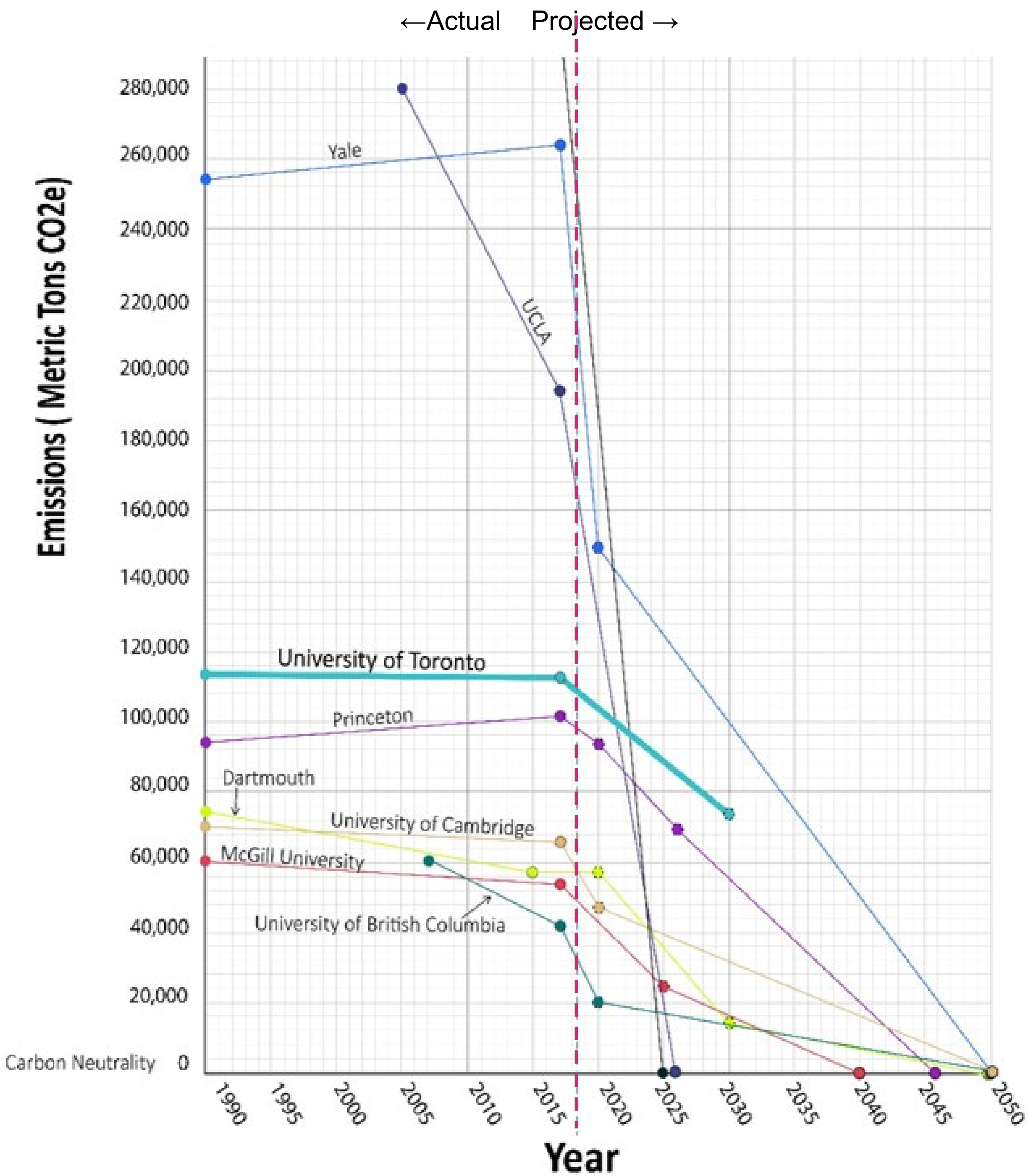


Figure 1 - Peer Universities Carbon Targets Benchmarking

Master Plan Process

To develop the Site Utilities Master Plan a clearly defined eight-steps process was used which included the stakeholder engagement running in parallel of the process.

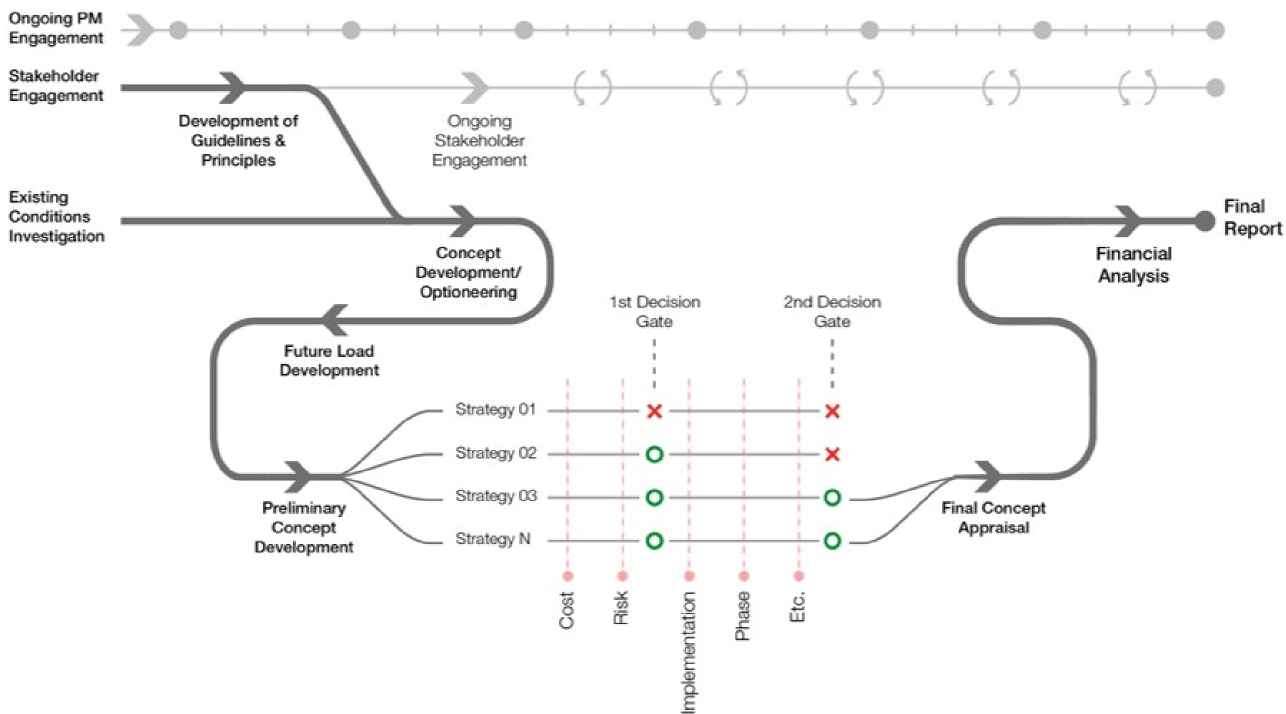


Figure 2 - Masterplan Process Roadmap

The master plan process is shown above. It included an examination of existing conditions, understanding future loads, identifying energy conservation features, identification and prioritization of options then developing and costing a preferred option.

Existing Conditions Investigation

An existing conditions investigation was undertaken to summarize the existing conditions of the site utility infrastructure and to assess utility infrastructure renewal needs. The information used for this assessment is based on the best available documentation such as drawings, audit reports, snapshots from the BAS, site walkthroughs, and from discussions with the University's Utilities and Building Operations team.

Based on the assessment, some key findings include:

1. In general, various system and components of the utility infrastructure are old and are operating close to or beyond their expected service life.
2. Specific sections of the campus' extensive **steam distribution system** require immediate attention and/or the development of an action plan due to their current conditions, chronical/past failure issues, and/or the very high degree of consequence to a large number of campus buildings in case of a failure.

3. The **main steam header** at the central steam plant is a single point of failure to the entire campus steam system. It is recommended that a second line to distribute steam from the plant be implemented.
4. More than half of the campus' existing emergency generators, the existing central electrical distribution substation, and downstream feeder and equipment (4.16 kV and 13.8 kV) are operating beyond their expected service life and require renewal.

Other main equipment requiring immediate renewal needs are further described in Section 3. The existing condition assessment report can be found under Appendix A.

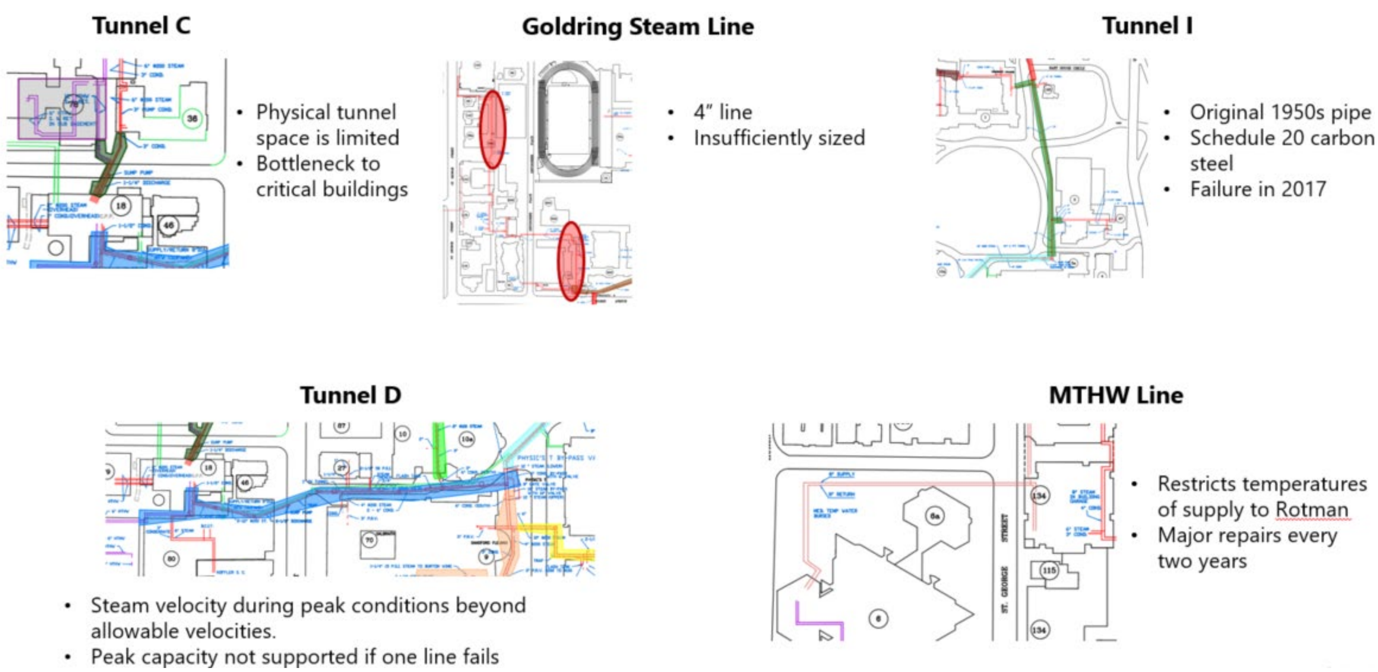


Figure 3 - Existing Conditions - Distribution Renewal

Existing Building Improvement

As part of the Master Plan, ten representative buildings were selected based on the inputs from the Master Plan team for basic walk-through audit. The objective of the exercise was to determine the potential level of thermal and electrical energy reduction for existing buildings across the campus. Based on the existing building site walk, the following was will be assumed

A weighted average of

- 15% reduction in heating,
- 28% reduction in cooling, and
- 10% reduction in electricity.

Future Campus Load Modelling

Based on the information provided by the University of Toronto St. George Campus Capital Planning team, the total building floor area of the campus is anticipated to increase by approximately 650,000 m^2 by 2035 (60% relative to 2020), and potentially by 1,030,000 m^2 by 2050 (95% relative to 2020). Using interim results from the tri-campus energy performance standards for new development, combined with the projected growth of the campus, the future thermal and electrical load of the campus is estimated to serve as the basis of calculation for the master plan.

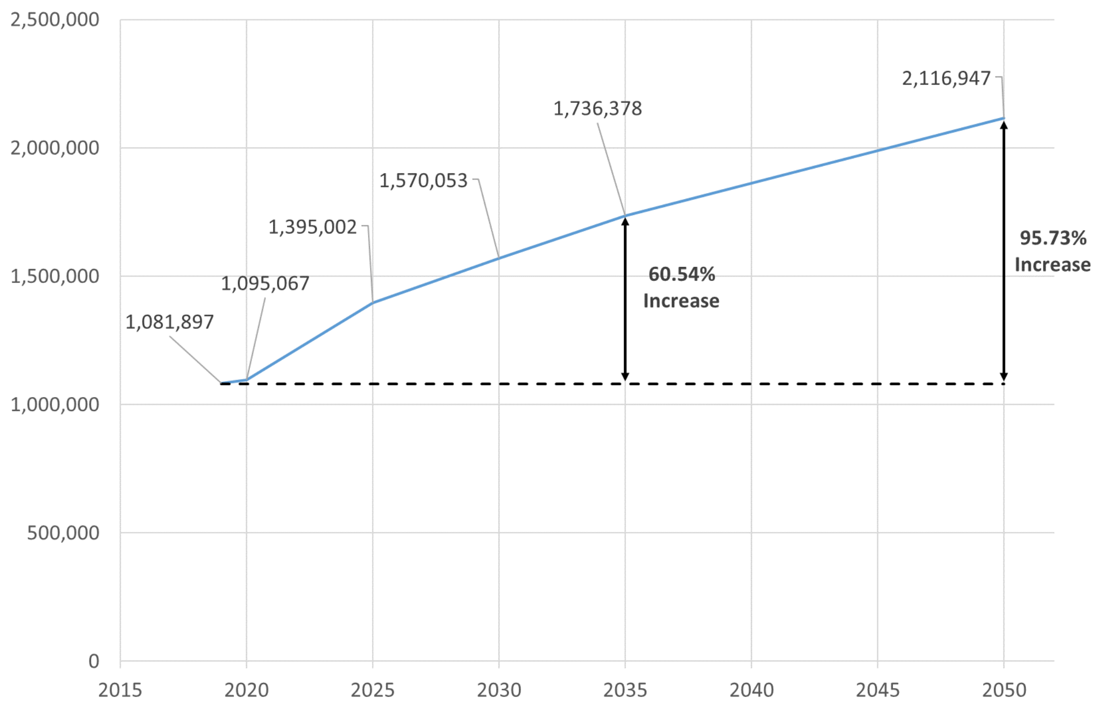


Figure 4 - Future Demand and Consumption Report – Projected Campus New Development

Due to existing building improvement and progressive energy performance requirements for new development, the total heating demand at the campus level is not expected to increase significantly. The total cooling demand at the campus level is expected to increase more in-line with the future campus area growth. Electric demand would increase from future growth and if the campus were to be fully electrify (including all heating and cooling), it could increase by over 150MW.

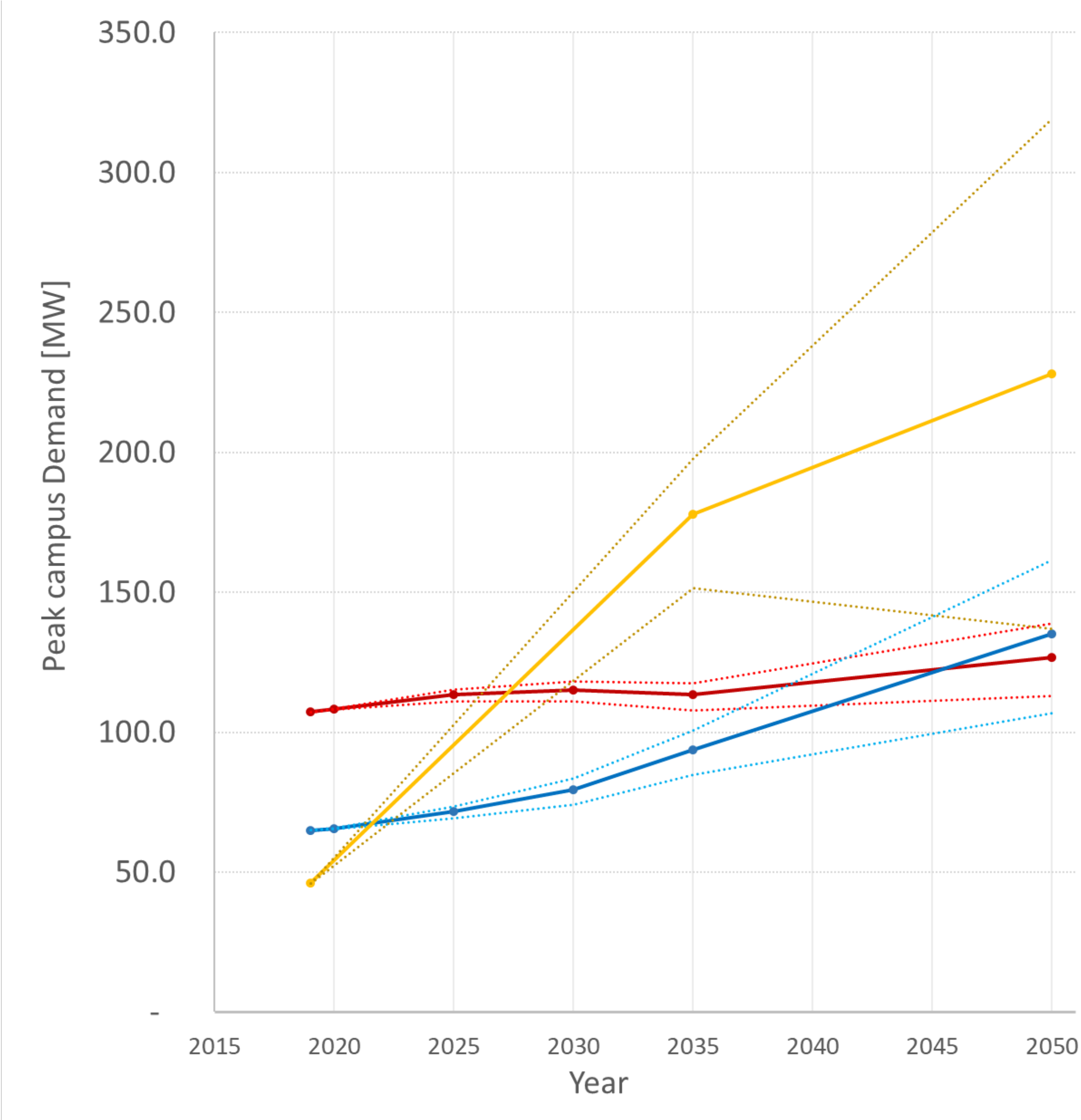


Figure 5 - Campus Future Annual Energy Demand

Preliminary Concepts Development and Concept Screening

To develop the site utility master plan for the campus, the team looked forward into the year 2050 and contemplated what the campus site utilities infrastructure would look like. The development of future site utility options includes a look into possible energy supply mix, with a primary focus on energy supply technologies that are low-carbon and substitute natural gas as a means to create thermal (heating) energy. Through discussion with the university, the strength, weakness, opportunities, and risks of different supply technologies were explored. Based on the technical and commercial maturity, spatial requirement, operation complexity, and efficiency of different technologies discussed, campus electrification was agreed to be the best option forward.

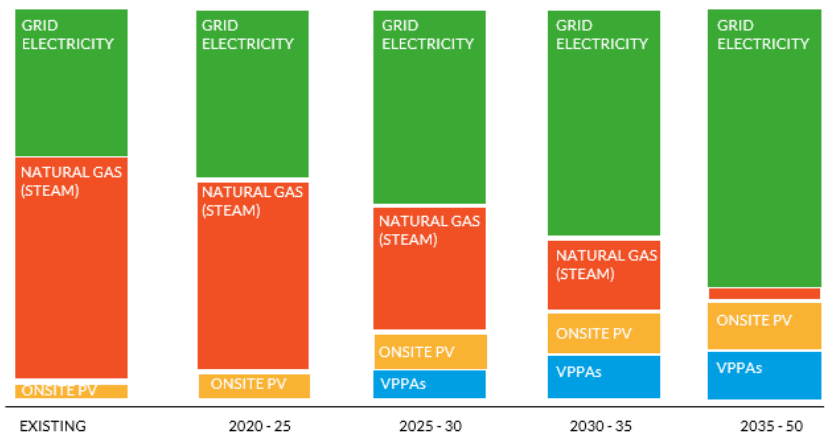


Figure 6 - Potential Energy Supply Strategies

Results

Different enabling technologies for campus electrification as well as different distribution modes were further explored, and a long list of utility strategies were developed and iteratively screened using the performance evaluation for quantitative assessment, including capital cost, operating cost, equivalent carbon emission, and total cost of ownership.

A base case was also designed for comparison and assumes a business-as-usual (BAU) scenario where existing carbon emission commitment (37% emission reduction from 1990) is achieved via continual improvement of existing building energy performance and necessary renewal of existing utility infrastructure.

The three final alternatives and BAU scenario are shown in the following diagrams comparing them against multiple criteria and then a deeper dive on operating total cost of ownership and carbon tax. An important consideration when looking at the following cost results is that although the costs of the BAU scenario are lower, this scenario cannot be compared equally to the other three alternatives as it does not achieve 80% reduction of carbon emissions.

Category Weighting	Category	Criteria	Weighted Score Alternative #1	Alternative #2	Alternative #3
30%	Environmental	Decarbonization, efficiency, environmental impact	18	21	15
15%	Resiliency	Flexibility, and future proofing, space	12	9	9
20%	Operational	Digitization, operation, compatibility	18	14	15
5%	Social	Human impact , campus, culture	3	3	3
30%	Economic	Capital, O&M, Risk	19	15	15
		Total	69	62	56

Figure 7 - Evaluation Matrix Alternative Results

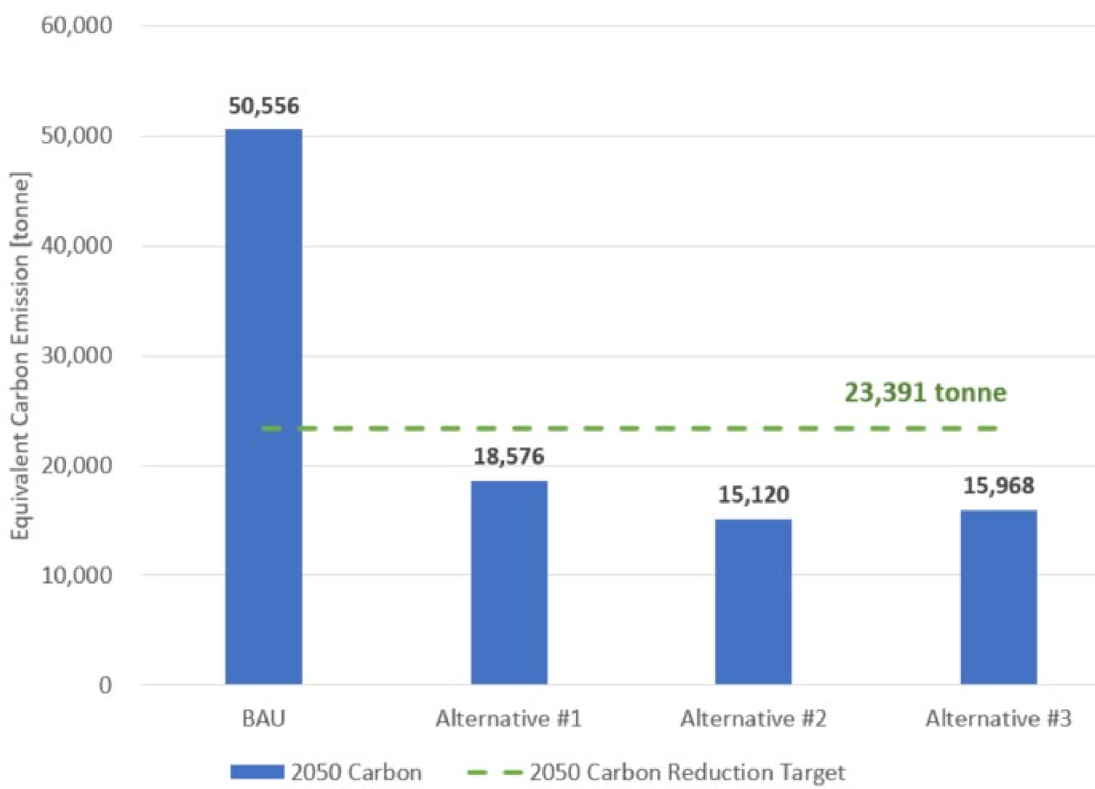
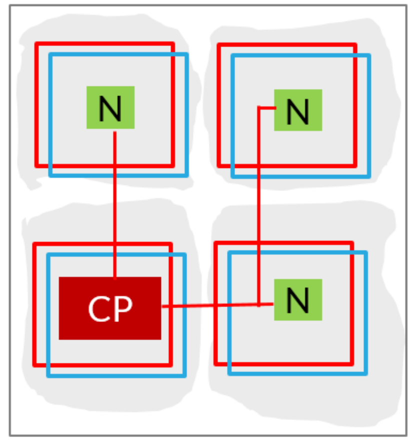


Figure 8 - Alternatives Carbon Emissions Summary

Final Concept and Implementation



Alt. 1
Central Plant Focused

University of Toronto's commitment to achieve Carbon Neutrality could be pursued simply through purchasing carbon offsets, however University of Toronto believe that reducing existing demand, transforming to a low carbon generation strategy, and ultimately reducing utility demand is how true carbon reduction will be accomplished in response to the global climate emergency. Achieving campus carbon neutrality in this way requires transformative changes of the campus's utility infrastructure & buildings.

The current economic system does not adequately assign costs to externalities including greenhouse gas emissions in buildings and utility networks designed today and therefore comparing only the financial costs of the final design to the BAU was not sufficient to evaluate which option should be pursued. Alternative #1 became the final design to be pursued when economics and environmental impact are both considered significantly valuable.

Alternative #1 includes the creation of dispersed nodal plants that thermally and electrically support the surrounding buildings, with the central plant providing supplementary capacity for the nodal plants. This approach is a hybrid combination between a centralized and decentralized system. It reduces the size of distribution infrastructure compared to a completely centralized system, while maintaining a similar level of operation and maintenance to a centralized option. This option is also the most flexible for integrating future low-carbon generation technology at the central steam plant that is not currently technically and/or commercially viable.

The main enabling technologies linked to the nodal plants are ground source heat pumps (GSHP), which would incorporate geo-exchange borefield across the campus wherever possible. Gas-fired steam boilers at the central steam plant will be phased out and substituted with electric resistance boilers.to supplement the nodal plants. The GSHP system would supply chilled water (CHW) and low-temperature hot water (LTHW) to surrounding new and to most existing buildings. Existing buildings operating on steam or higher temperature hot water are required to undergo retrofit to convert to LTHW operation by 2040, or implement standalone electrification building system such as air-source heat pumps, variable refrigerant flow system or local electric resistance boilers.

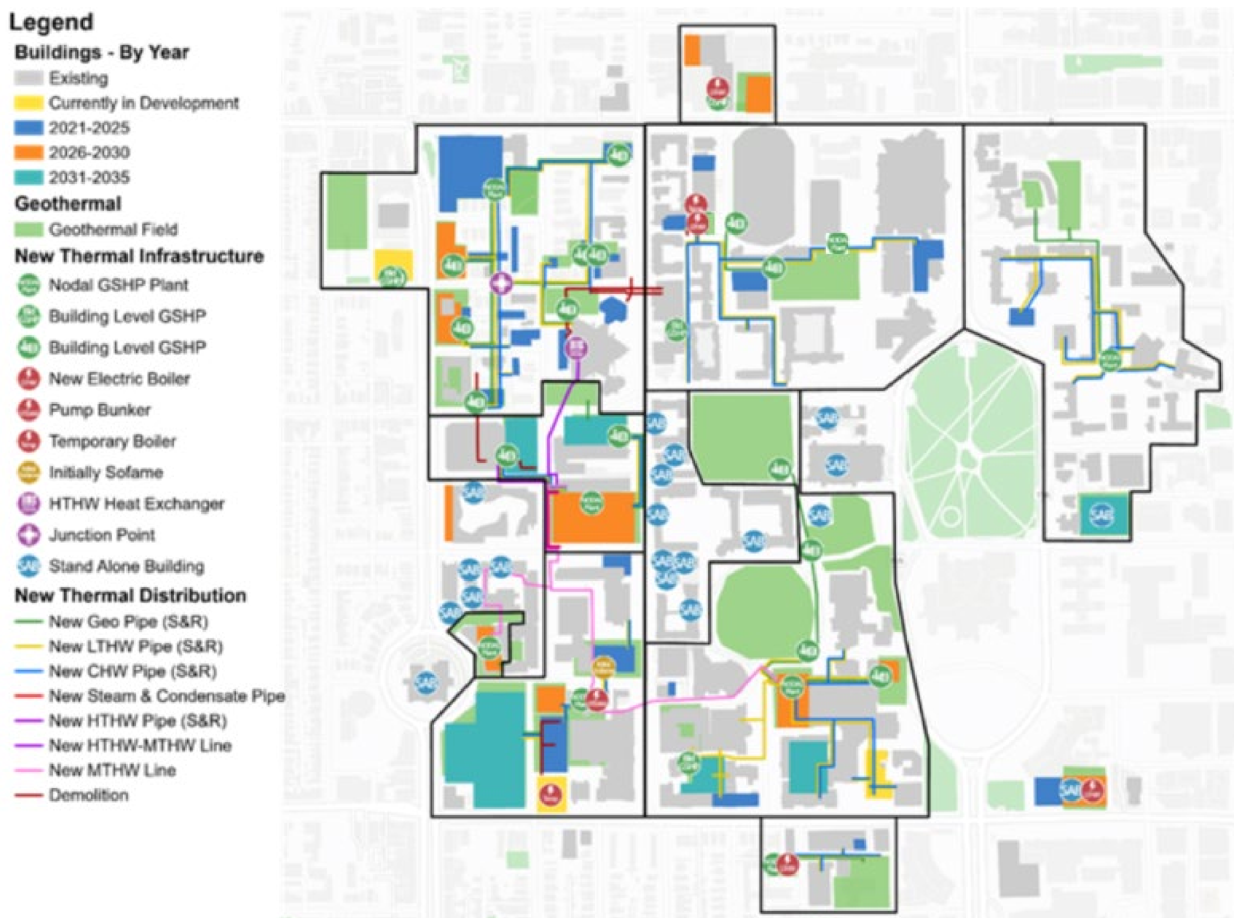


Figure 9 - Thermal Design 30-Year Overview

The electrical strategy utilizes the existing HV switching station (also referred to as the "CED") and adds three new HV switching stations; the new HV switching stations will be collocated with the large mechanical plant rooms planned for the Medical Sciences, Sydney Smith, and Gateway renovations / new buildings, and are planned to come online in 2030, 2026, and 2024, respectively. Once a new CED is online, loads from existing and new buildings will be migrated or added to the CED based on criteria outlined in the phasing strategy. The goal of the strategy is to transform the campus electrical infrastructure from what exists today, into something that will have the capacity to accommodate the ambitious power requirements from the final preferred thermal strategy, while achieving a level of flexibility to allow the campus to adapt to new and growing technologies.

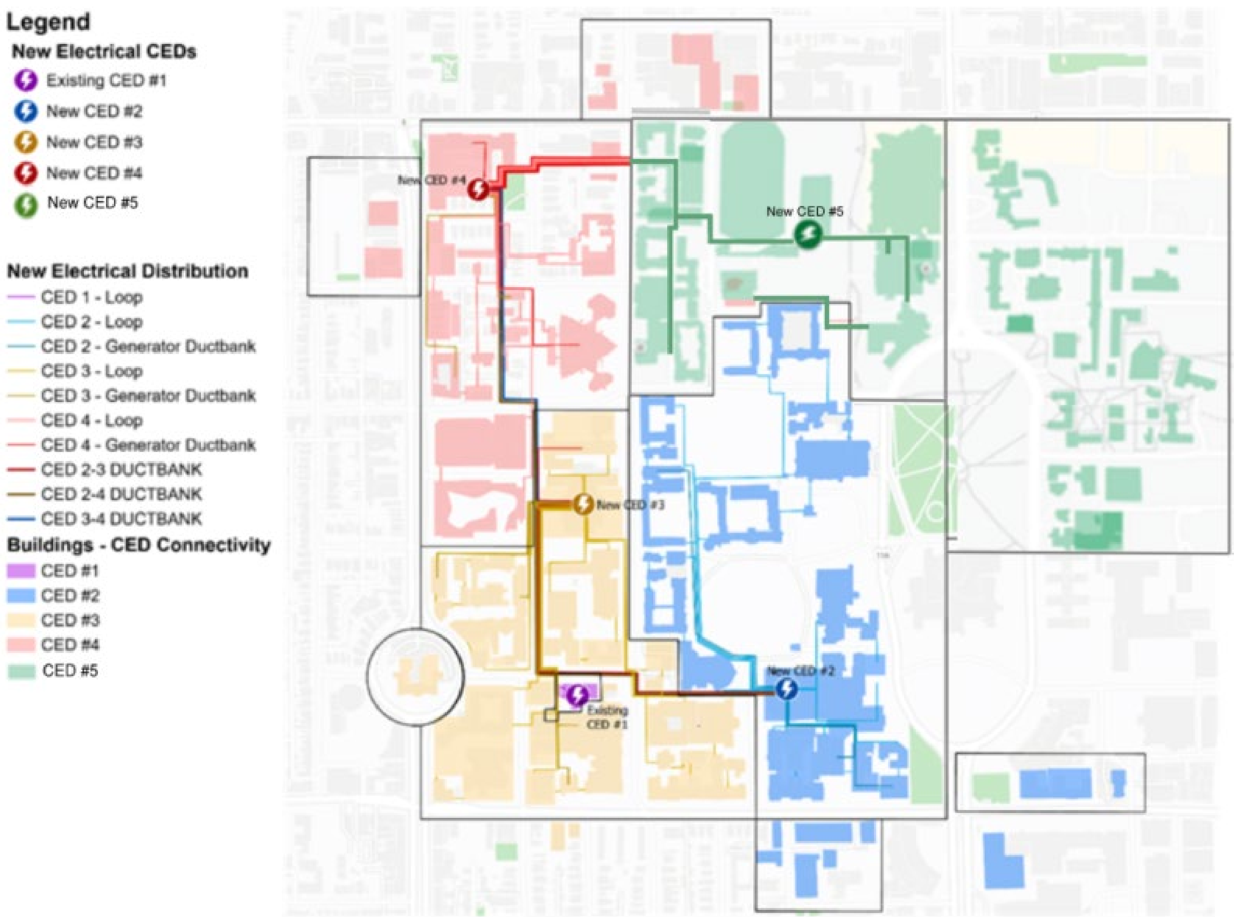


Figure 10 – CED Design 30-Year Overview

A detailed plan of the final preferred option and its implementation has been developed with an accompanying digitally map that can be viewed over a web interface.

The figure below shows a timeline calendar of major capital projects as well as renewal items.

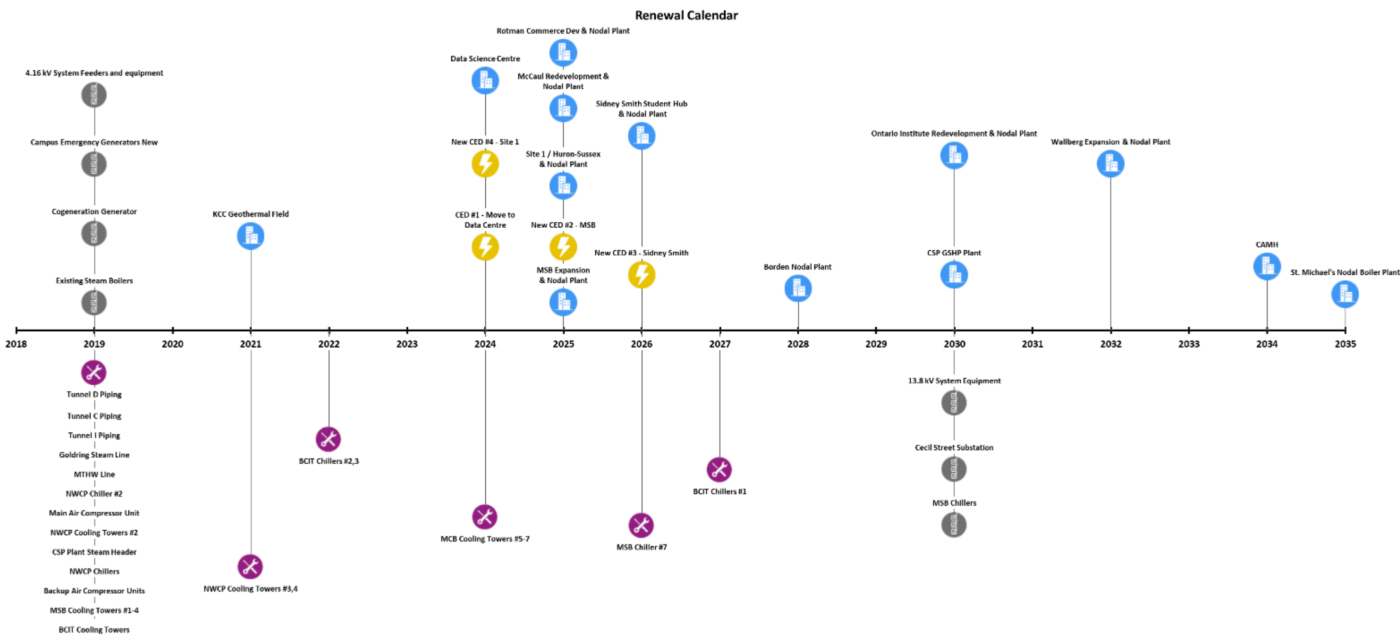


Figure 11 - Development and Renewal Schedule

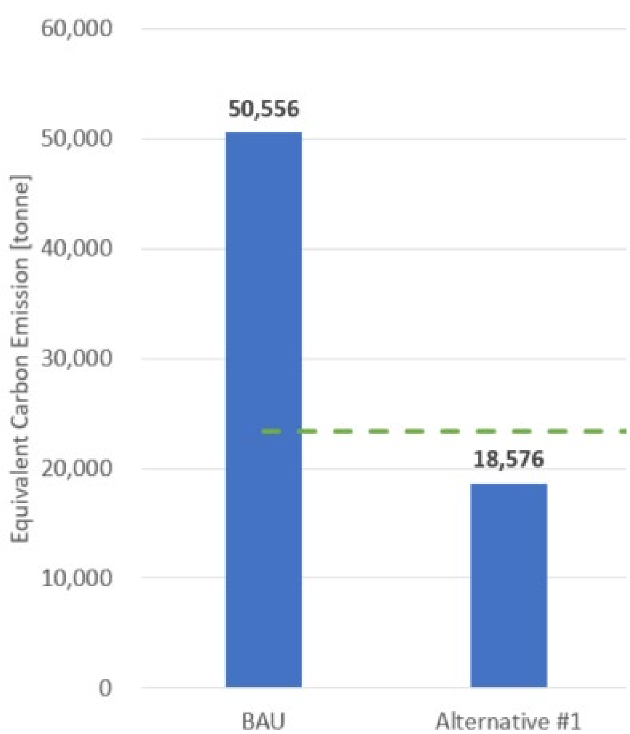


Figure 12 - Total Carbon Emissions of BAU vs. Final Design

Recommendations and Next Steps

The Master Plan includes an implementation schedule that further outlines the description of the strategy, key milestone dates of major projects and key requirements of the strategy for the next 30 years.

Preliminary design and cost estimation were developed at a master plan level to facilitate decision making and to compare different options that meets the University's objectives.

The Master Plan is developed based on a set of assumptions and best information available provide by the University. It is not intended to predict the future. Events frequently do not occur as expected, and changes are constant. The Site Utility Master Plan should be treated as a living document that needs to be refreshed periodically to the constant changes happening to the campus. Design and cost estimation are expected to evolve as the design and planning of the campus and its component are further developed. Bridging feasibility studies for smaller components of the Master Plan (i.e. a nodal network or a nodal plant) is recommended prior to design and construction. The bridging feasibility study can be done independently from the design and construction team, or as part of the design and construction scope.

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Acronyms and Terms

ASHP	Air Source Heat Pump
CSHP	Central Steam Plant
ECM	Energy Conservation Measure
GHG	Greenhouse Gases
GSHP	Ground Source Heat Pump
HTHW	High Temperature Hot Water
LTHW	Low Temperature Hot Water
MTHW	Medium Temperature Hot Water
UofT	University of Toronto
UTMP	University of Toronto Master Plan
VRF	Variable Refrigerant Flow

1 Introduction

This report documents the collaborative effort that the University of Toronto St. George campus and the Arup team have carried out under the "Site Utilities Master Plan". Arup was commissioned by University of Toronto on April 16, 2019 to complete a Site Utility Masterplan as per RFP 999-18-195. The goal of the Site Utilities Master Plan is to depict the existing utility infrastructure conditions and to act as a guide for the future utility infrastructure. It is developed based on inputs from key stakeholders of the University's diverse entities and based on fundamental information provided by the University including but not limited to existing drawings, manuals, utility data, and site investigation of existing utility assets and infrastructure, existing campus master plan, expected campus growth over the next 15 to 30 years, future building energy performance, and more. This report captures the site utility master planning process and the various discussions, decisions, data and processes that the University of Toronto and Arup team has encountered throughout the master planning project. Results and outcomes are also summarized.

1.1 University of Toronto Project Objectives

The University of Toronto St. George campus was established more than 190 years ago (as King's College circa 1927). Since the campus' inception, the campus' existing utility assets have been providing services, with past and planned renewal and expansion, to a vast number of buildings, including the university's own and external entities. Coupled with anticipated considerable growth of the campus over the next decade and a strong mandate to reduce the campus carbon emissions as per the University Climate Change Coalition (UC3), the University's objectives for this study are threefold:

4. Develop a **RENEWAL** strategy to help ensure utility assets can support the future performance of the campus;
5. Address the campus' **GROWTH** needs tied in with the University's master plan and secondary plan, and addressing reliability, redundancy and resiliency in the face of this growth and;
6. Develop a plan that is in line with the university's commitment to reduce **GREEN** house gas emissions (37% below 1990 by 2030) and campus carbon neutrality by 2050.

1.2 Peer Benchmarking

A peer benchmarking exercise was performed to understand the carbon reduction commitment of peer universities. Nearly all universities have committed to a form of campus carbon neutrality in the future. Inclusion is focused on Scope 1 and Scope 2 emissions and targeting for 2030 or 2050 in alignment with the Paris agreement.

	Harvard	Princeton	Dartmouth	McGill	U of British Columbia	U of Cambridge	UCLA
Scope 1	●	●	●	●	●	●	●
Scope 2	●	●	●	●	●	●	●
Scope 3				●			●
Carbon Neutrality	●			●	●	●	●

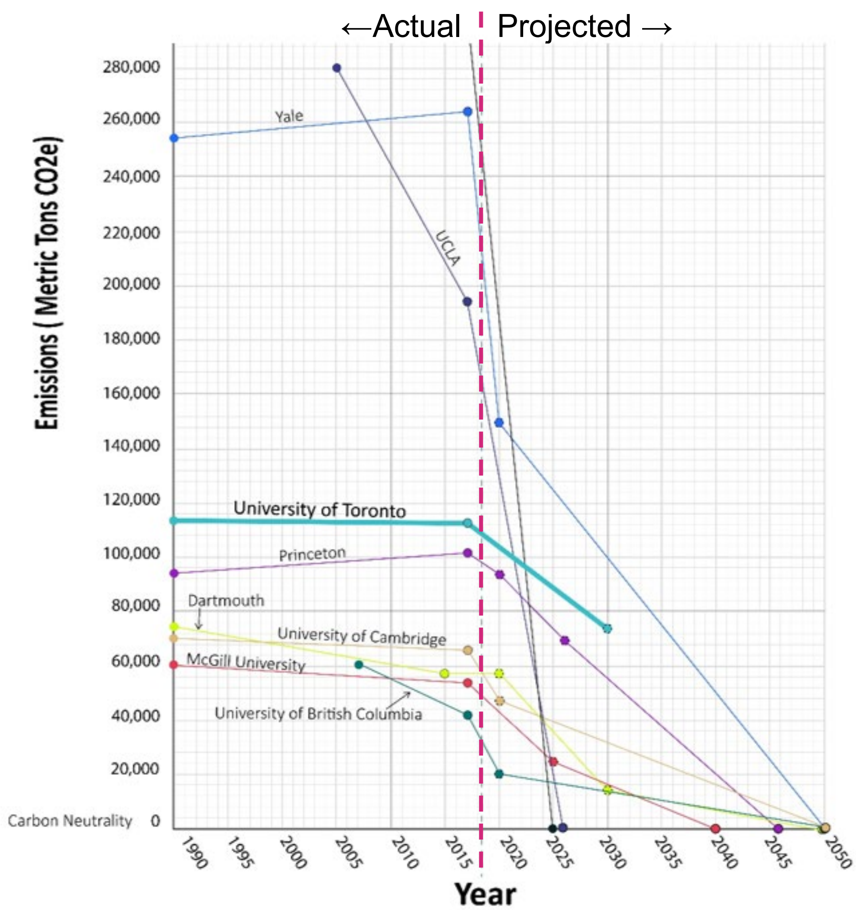


Figure 13 - Peer Universities Carbon Targets Benchmarking

1.2.1 Carbon Neutrality Goal Definition

Based on the peer benchmarking study and discussion with the University of Toronto, the master plan has established a definition of carbon neutrality as the following:

- At least 80% reduction in scope 1 and 2 absolute carbon emissions relative to 1990 level, and
- 20% offset from University owned onsite or offsite renewables.

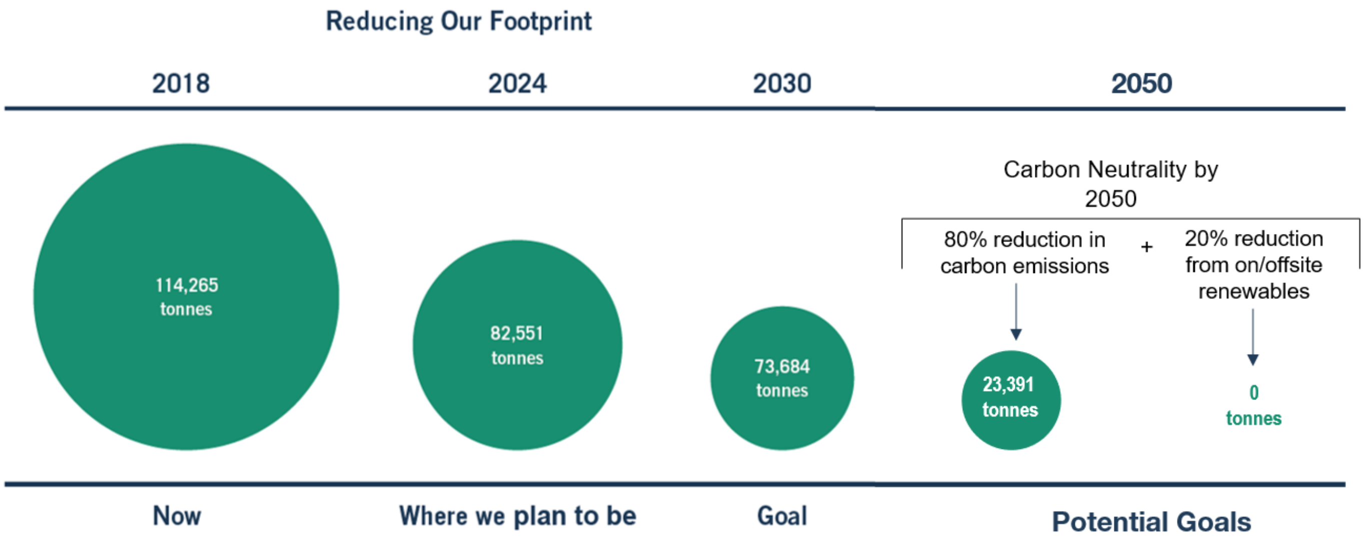


Figure 14 - University of Toronto Carbon Emission Goals

The campus scope 1 and 2 carbon emissions include the direct and indirect emission associated with the consumption of electricity and natural gas. For the utility master plan, emissions associated with the University's own transportation fleet are not included. Scope 3 emissions and embodied carbon associated with building constructions and renovations are also not included.

Reduction associated with scope 1 and 2 emissions will be based on a combination effort of existing building improvement, new buildings performance standard, system efficiency improvement, fuel switching and onsite/offsite renewable generation. University of Toronto has decided against purchasing carbon offsets or renewable credits for utility consumption.

1.3 Project Boundary

The St. George Campus is generally bounded by Bloor Street to the North, Queen's Park to the East, Spadina Avenue to the West, and College Street to the South. St Michael's College and Victoria College are situated east of Queen's Park and their buildings are mostly supported by the main campus district steam network. Figure 15 shows the boundary of buildings included in the scope of the Utility Master Plan. Buildings considered a part of the St. George campus but lies outside of these bounds were not included in the utility master plan.

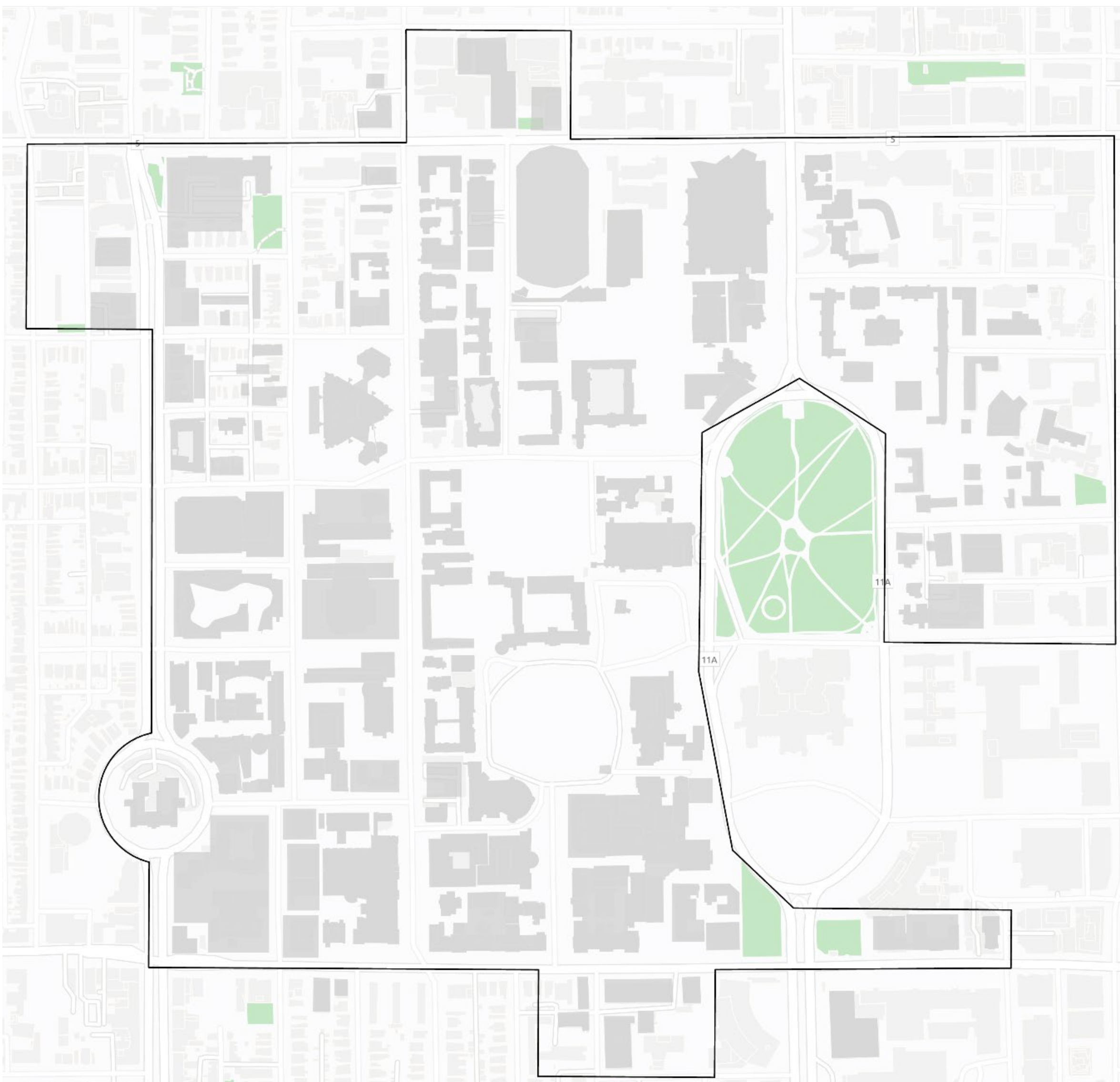


Figure 15 - Utility Masterplan Scope Boundary

1.4 Project Team

Collaboration with the University of Toronto Utility Masterplan Team and all stakeholders was prioritized throughout the entirety of the project. Arup and the UT Utility Masterplan team worked closely on ideation, decision making, and content revision for the development of the masterplan.

Key Stakeholders included:

UT Site Utility Masterplan Team - Ron Saporta, Gordon Robins, Paul Alves, Jelena Vulovic- Basic, Paul Leitch, Keith Foster, Gurmel Multani

UT Steering Committee Team – Gilbert Delgado, Christine Burke, Devendra Chopra, John Robinson, Kenneth Corts, Kim McLean, Paul Handley, Bryan Karney, Carrie Greenop

External stakeholders - Toronto Hydro, City of Toronto

Other key university stakeholders indirectly engaged via the UT Site Utility Master Plan Team

1.5 Masterplan Report

This report outlines the process in determining the Masterplan strategy and further details the strategy that will be pursued.

Chapters 2-6 focuses on the steps in developing the design strategies and provides the considerations and assumptions that were incorporated. Supporting reports, Existing Conditions, Existing Building Energy Strategy, Future Demand and Consumption Analysis Report, created by Arup for the masterplan are summarized in chapters 2-4 and full reports are provided in the appendixes. The main content of this Masterplan report does not contain all information and these supporting reports must be used in conjunction with a comprehensive understanding of the masterplan project. Chapters 5 and 6 focus on the formulation of three strategies that were developed from a long list of potential utility design options and the evaluation and quantitative analysis used to determine the strategy selected to be pursued. Chapter 9 then details the selected strategy including considerations for implementation and design requirements.

2 Approach and Methodology

2.1 Masterplan Project Process

The University of Toronto St. George Campus Utilities Master Plan is to be used to depict current conditions, act as a guide to meet the future demand from the considerable anticipated growth and provide a roadmap for the University to meet its carbon reduction commitment.

The zero carbon campus approach outlines the main steps to achieve UofT's carbon neutrality goal. It begins by reducing the campus energy demand through improving the energy performance of existing buildings. For new development, new building energy preformance targets are set to limit additional emissions being added. Further emission reduction will be achieved through enhancing generation and distribution systems efficiency and investigation into implementing low carbon energy supply and technology. Remaining emission reduction will be achieved with renewable energy generation on or off-site the St.George Campus.

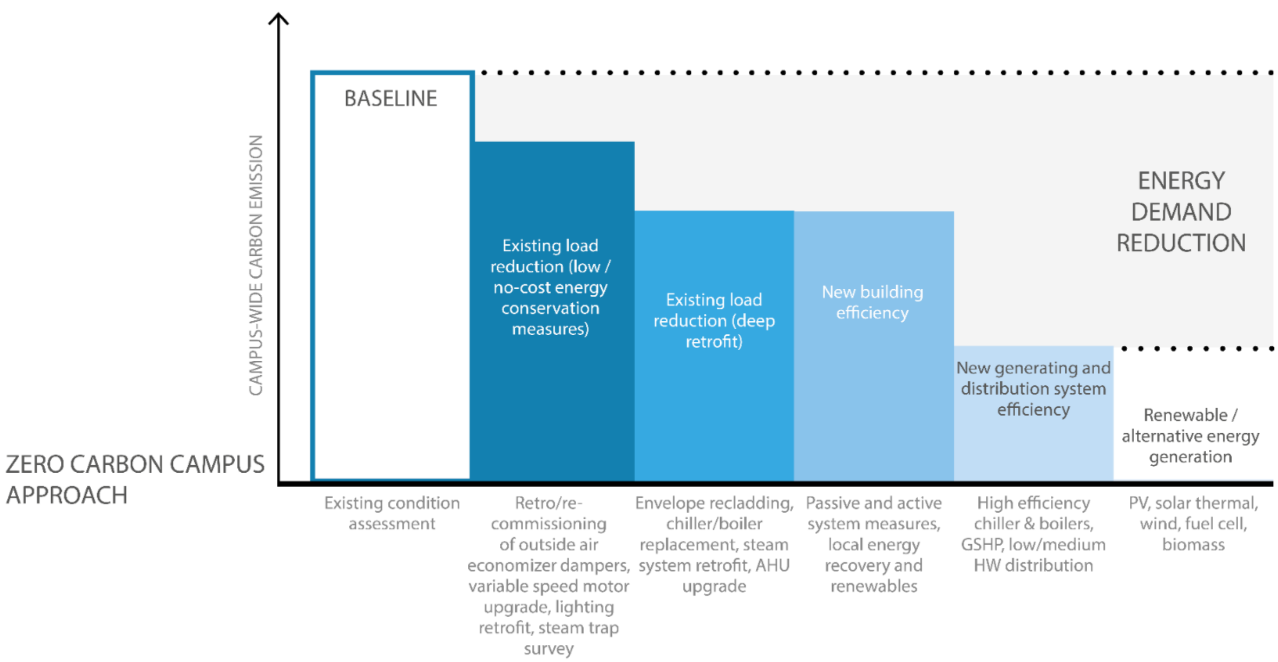


Figure 16 - Zero Carbon Campus Approach

The Utility Master Plan began with the development of performance evaluation guidelines and principles. The framework allows the team to objectively evaluate and compare options based on key performance metrics and was used throughout the master planning process. At the same time, an existing site conditions investigation were conducted to better understand the general conditions and the renewal needs of the major utility infrastructure assets. Ten different buildings were also selected as representative buildings across the campus for ASHRAE level 1 walkthrough audits to evaluate the potential energy conservation savings of all existing buildings on campus.

Once a better understanding developed from the existing site condition investigation and existing building walkthrough audits, the Master Plan team held multiple workshops and brainstorming sessions to develop a long list of potential thermal and electrical supply and distribution options. These options were further screened and refined using the performance evaluation framework, and three final options were selected for technical analysis to evaluate the capital cost, operational cost, equivalent carbon emission, etc of each option. These results of the three final options were also compared against a business-as-usual baseline. One final strategy was selected as the roadmap for the future of the campus utility infrastructure.

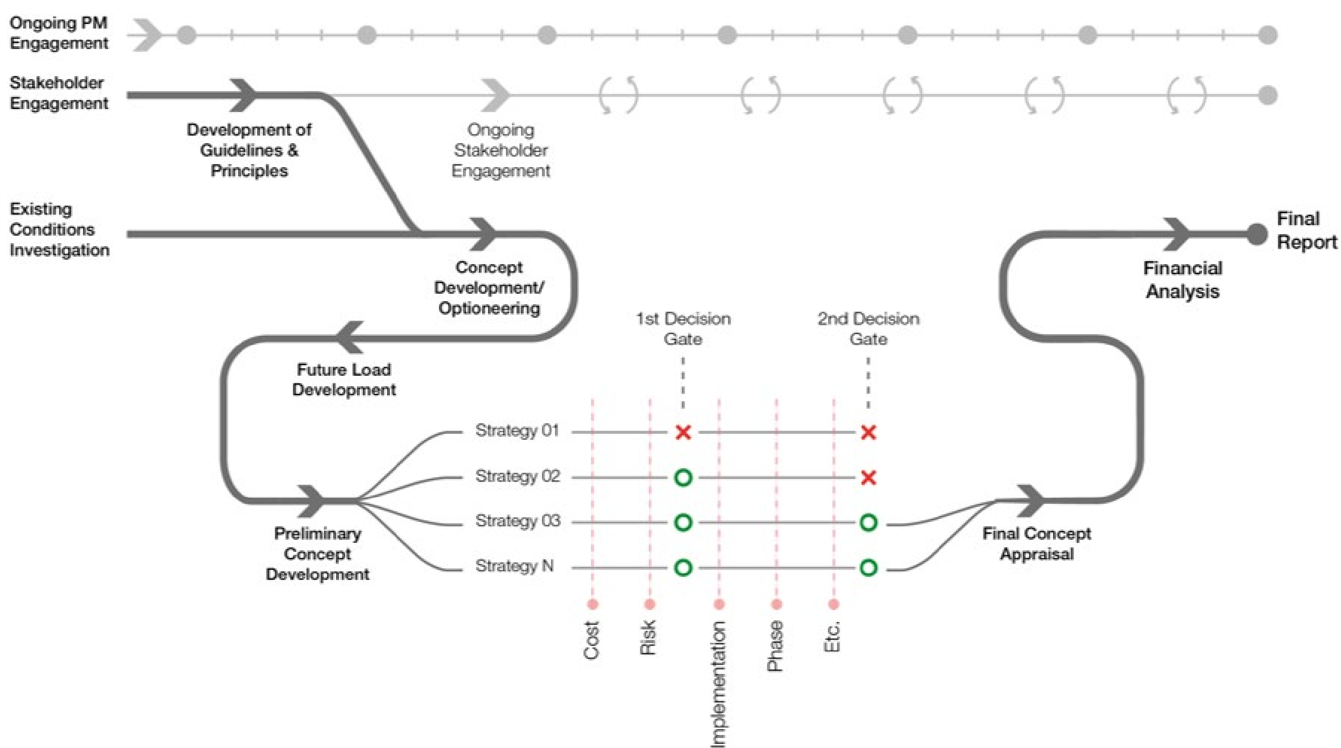


Figure 17 - Masterplan Process Roadmap

Inputs and assumptions are based on information gathered from University of Toronto, collaborative workshops, desktop research, local product manufacturers, prior experience, and the use of engineering calculations. Main sources of information received include:

- Utility Distribution Drawings – electricity, natural gas, heating network, cooling network
- Building Utility Demand and Consumption Data – electricity, natural gas, steam, chilled water
- Capital Plan – containing planned future developments and their associated building functions, areas, and year of construction

2.2 Evaluation Matrix Framework

To support the evaluation process of different campus utility options, a multi-criteria evaluation matrix was developed. Each strategy was evaluated against five categories encompassing values most important to the University of Toronto. – Environmental, Resiliency, Operational, Social, Economic. Category weighting, shown in figure 7, were assigned weights based on feedback from participants at a workshop with the Utility Masterplan Team. These categories were broken down into specific criteria with impact on the Masterplan and scored individually. Criteria scores were multiplied by the category weighting and summed to produce a total score.

The evaluation process was used throughout the Masterplan process to facilitate decision making by University of Toronto Masterplan Team in which strategy to pursue.

Evaluation matrix results are found in later sections of report and full scoring of each category criteria found in Appendix D.

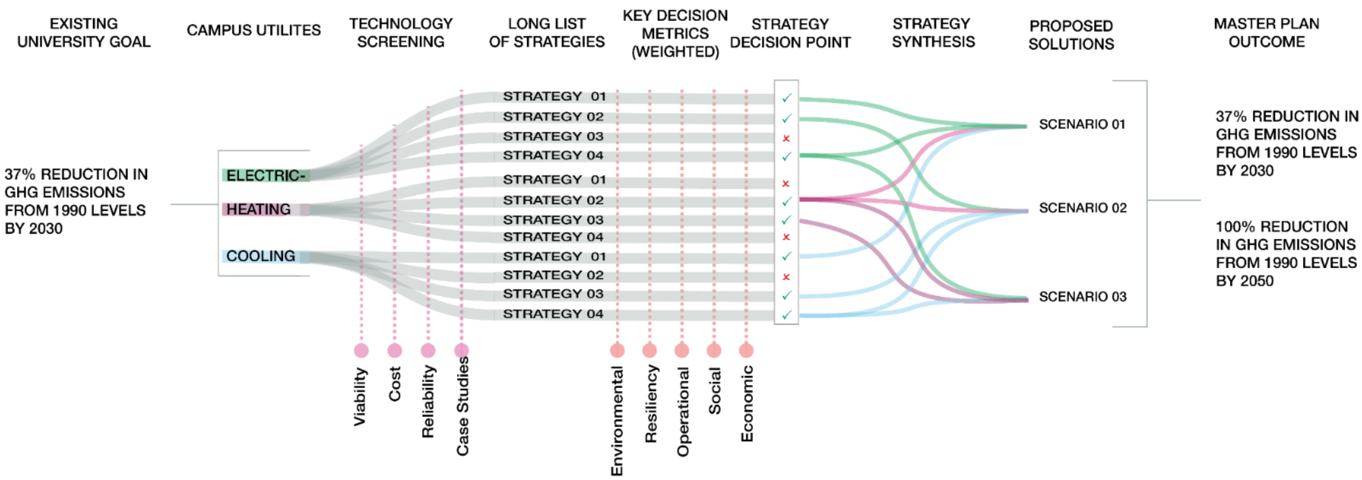


Figure 18 – Long List Strategy Evaluation Process

Scoring	4	3	2	1	0
Description	Excellent performance	Good performance	Average/little impact	Poor performance	Unacceptable performance

Category Weighting	Category	Description	Metrics	Criteria Weighting	Scores: Strategy 1	Scores: Strategy 2	Scores: Strategy 3
30%	Environmental	Decarbonization, efficiency, environmental impact	mt CO2e				
15%	Resiliency	Flexibility, and future proofing, space	Y/N				
20%	Operational	Digitization, operation, compatibility	%				
5%	Social	Human impact , campus, culture	Y/N				
30%	Economic	Capital, O&M, Risk	$				

Weighting

Weight each criteria based on importance. Weighting scale of 1-4 where:

4 = high importance
3 = medium importance
2 = low importance
1 = negligible

Scoring

Score all strategies for each criteria and then multiply with weighting. Scoring scale of 0-4 where:

4 = excellent
3 = good
2 = average/little impact
1 = poor
0 = unacceptable

Figure 19 – Strategy Evaluation Matrix Framework

3 Existing Conditions Assessment

A copy of the completed Existing Conditions Report is in Appendix A for reference.

3.1 Report Summary

The purpose of the Existing Conditions report was to summarize the current condition of the campus utility systems and to assess utility infrastructure renewal needs. The findings in this assessment inform the development of the campus' future utility strategy. The information used for this assessment was based on the best available documentation such as drawings, audit reports, snapshots from the BAS, site walkthroughs, and from discussions with the University's Utilities and Building Operations team. From this aggregated information (refer to Appendix A Equipment Logs), the various systems and individual components of these systems were assigned a risk factor pertaining to redundancy, resiliency and reliability and will be evaluated accordingly.

Equipment analyzed include major thermal and electrical generation and distribution systems, such as boilers, chillers, cooling towers, and pumps. Collected information details the capacity, conditions, and estimated economic life of all the major equipment analyzed. Maintenance replacement of major equipment were discussed based on the current year (2019) and for the year 2030.

The following summarizes the major findings of the assessment:

5. The campus has an extensive **steam distribution system** of varying ages and conditions, and specific sections of the steam distribution system has a composite risk factor of 4 (High). A composite risk factor of 4 (High) is given since it represents a very high degree of consequence to a large percentage of campus buildings in case of a failure. Immediate attention / action plan is recommended for sections of the steam distribution system, specifically the distribution system originating from the plant, tunnel C, Tunnel D, and Tunnel I.
    a. Lines originating from Tunnel C and Tunnel D support the entire west (Tunnel C) and east (Tunnel D) campus and have certain portions with undersized piping and no redundancy.
    b. Tunnel I supplies the entire north side of the campus and has no redundancy if this pipe were to fail. A section of this piping was replaced in 2017 due to a failure and the remaining portion is from the 1950s with piping material suspected to be schedule 20 carbon steel which is below the current standard for a steam system based on wall thickness and stress tolerance.
    c. The existing 100mm (4 in) **steam line serving the Goldring Centre for High Performance Sport** (Building #42) is undersized and should be upgraded to 150mm (6 in) immediately.
    d. The existing buried 200 mm (8 in) **MTHW piping from Robarts Library** (not a steam distribution line) to the Rotman and Innis College Residence has had chronic failure issues and should be replaced immediately.

6. The **main steam header** at the central steam plant is a single point of failure to the entire campus steam system. It is recommended that a second line to distribute steam from the plant be implemented. The main steam header is currently located in a constricted space and will be a challenge to replace the isolation valves if required.
7. The **cogeneration gas turbine** had one failure of the turbine recently and was rectified. There was sufficient steam generation and backup power (from Toronto Hydro) capacity at the central utility plant when the failure occurred, so thermal and electrical supplied to buildings was satisfied. However, the turbine failure resulted in a considerable financial penalty to the campus due to increased electrical costs. The generator and the control panel are also beyond its economic life and replacement parts are obsolete. Current location of the generator is not accessible for major overhaul / replacement. A replacement plan of the cogeneration gas turbine is recommended.
8. The **existing steam boilers** at the central steam plant are operating beyond their economic life expectancy, but parts of the boilers have been replaced and the boilers are in overall good condition. There are no generation capacity issues for the steam boilers to meet current demand and long-term heating demand growth. As a result, they score a low composite risk factor. Considering the increasing age of the equipment and the equivalent carbon intensity of the steam system, a replacement plan by 2030 should be considered.
9. The three, main nodal chilled water plants have sufficient capacity for the current demand. At present, **NWCP chiller #2** has an re-occurring issue with leaking refrigerant, and poses challenge for the plant to meet its shoulder season load as it is the only chiller with variable speed drive. Replacement of the chiller is recommended. **MSBCP chiller #7 (AUX)** support critical process load in winter at the MSB and is operating beyond its economic life. Despite its dual compressor configuration, replacement of the chiller is recommended.
10. Records show that 15 out of 29 of **the campus' existing emergency generators** are now operating beyond their Expected Service Life. It is recommended that an overall review of the campus emergency power distribution be conducted and to develop a replacement plan for the aging generators.
11. The **utility tunnel** is congested and has inadequate space for maintenance. High temperature in the tunnel is also a concern for the cables routed in the tunnels and will reduce the life expectancy of the conductors. A plan should be developed to replace and reroute these conductors as soon as possible to mitigate the risk of failure.
12. The **existing Central Electrical Distribution (CED) substation** is over 30 years old and is at the end of its expected service life. It is a key infrastructure to the campus electrical distribution system and a plan should be developed to allow the substation equipment to be renewed over the next 5 years.

13. Existing **4.16kV system feeders and equipment** have exceeded the end of their useful life, with some feeders operating beyond their capacity at peak demand. Spare parts that are required for the continued maintenance of this equipment are no longer available due to equipment obsolescence. A significant proportion of the aging 4.16kV feeders are of the PILC type, which presents an environmental risk due to their lead and PCB content. Projects related to upgrading the 4.16kV system to 13.8kV should be prioritized.
14. A majority of the campus buildings south of Bloor Street that are supplied directly by Toronto Hydro are also fed from the **Cecil Street Transformer Station**. Therefore, an outage at the Cecil Street Transformer Station would result in major operational disruption throughout the whole St. George Campus. It is recommended that the university conducts an internal review of the campus' emergency power plan, as well as discusses with Toronto Hydro regarding possible contingency measures.
15. The campus' **13.8kV equipment** are generally of advanced age. The university is experiencing difficulty with the basic operation and general maintenance of these equipment in a number of buildings – in particular: MSB (#5), Robarts (#6), Sandford Fleming (#9), NE Substation (#30), North Borden (#61A), Warren Stevens (#68A), and Northwest Chiller Plant (#122).
16. While the **maintenance cycle** for HV equipment is typically every two years, the university has only been able to perform maintenance on 6 of its 72 substations each year. At the current rate, the maintenance cycle seen by the equipment exceeds 10 years. It is recommended that the University considers implementing a predictive maintenance system with the replacement of these equipment.
17. The **main and backup air compressor units** at MSB have experienced multiple operational issues. In addition, the backup compressors are operating beyond their economic life. It is recommended the compressed air units are replaced upon determining the system load. The 3" carbon steel compressed air distribution lines are showing signs of corrosion and it is recommended the connected buildings are converted to the new 4" stainless steel compressed air line.
18. The **equipment controls** for the heating, cooling and electrical systems on campus is dominated by pneumatic controls and manual operation. The process of integrating equipment controls systems into EMRS has begun, however much of the three systems' equipment has controls systems that are not technically capable of monitoring and outputting what's required for the EMRS. It is recommended equipment control systems are upgraded for integration to EMRS to ensure all equipment can be monitored and controlled remotely. This will provide data consistency and availability, as well as visibility of the building loads to help load management and identify inefficiencies.

4 Existing Building Energy Conservation Potential

A copy of the completed Existing Building Energy Conservation Potential report is in Appendix B reference.

4.1 Report Summary

The Existing Building Site Walk Assessment was performed as part of the Site Utility Master Plan to inform the campus future utility demand and consumption analysis. Despite considerable future growth of the campus, the existing campus buildings will continue to make up a significant portion of the campus future utility requirement.

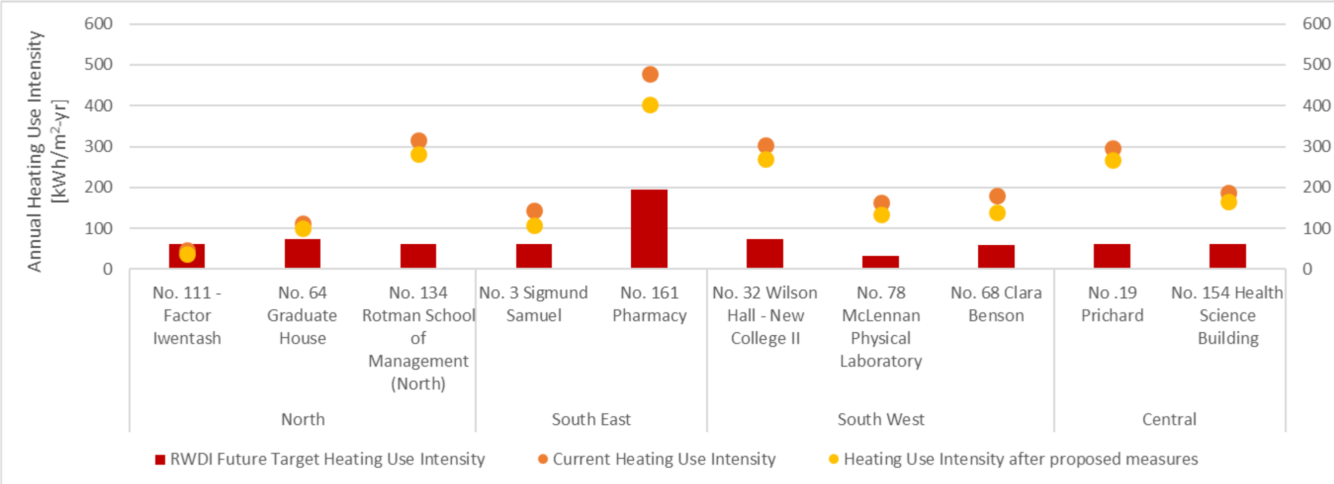
Ten buildings representing different building archetypes were selected by the Master Plan team to determine the approximate thermal electrical load reduction levels. The potential reduction of the representative building archetypes were then extrapolated to estimate the potential utility reduction of existing buildings on campus. The ten buildings representing different building archetypes selected is listed below.

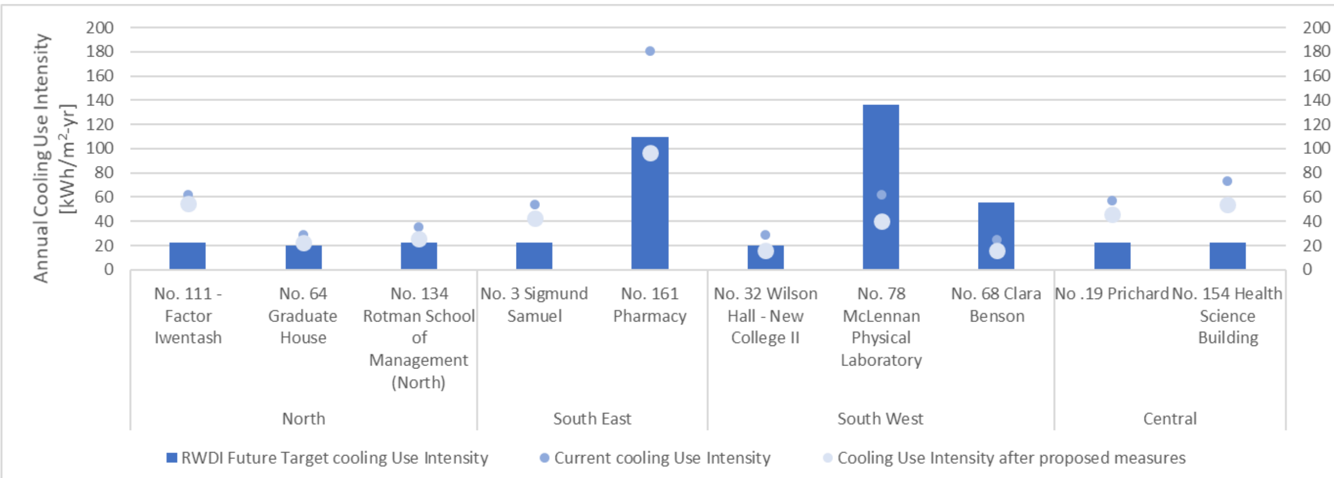
Table 1 – Existing Buildings Report – Site Walk Buildings

No.	Building	Function	Area
68	Clara Benson Building	Athletic Facility	SW
32.1	Wilson Hall-New College II	Residence	SW
78	McLennan Physical Laboratories (78A)	Academic and Research Lab	SW
19	J. Robert S. Prichard Alumni House	Administrative	Central
154	Health Sciences Building	Administrative	Central
161	Leslie L. Dan Pharmacy Building	Academic and Research Lab (Wet Lab)	SE
3	Gerstein Science Information Centre in the Sigmund Samuel Library Bldg	Library	SE
64	Graduate House	Residence	North
111	Factor-Inwentash Faculty of Social Work	Academic	North
134	Rotman School of Management – North Building	Academic	North

The Existing Building Site Walks resemble ASHRAE Level 1 energy audits. ASHRAE Level 1 Audit (or Walk-Through Analysis) is a basic walk-through audit that identify corrective measures, describe the potential implementation of the measure, and identify potential operating energy savings using preliminary energy analysis. Capital intensive projects such as deep retrofit / major renovations were not considered in this report; capital planning projects are considered to achieve future energy performance targets based on the analysis performed by RWDI in the future campus thermal load analysis as outlined by the campus' Capital Planning team.

The ten buildings' current energy consumption, energy consumption after proposed retrofit, and future building performance targets are presented in the following diagram. The average reduction of annual heating, cooling, and electricity use are estimated to be 17%, 28% and 10%.





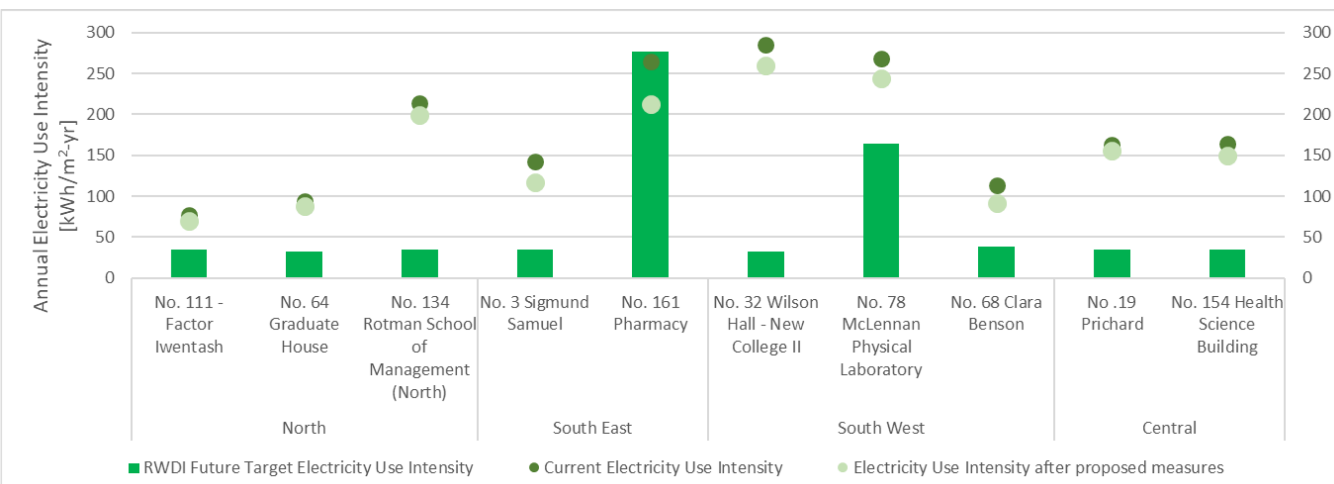


Figure 20 – Existing Buildings Report – Proposed Retrofit Energy Consumption and Demand of Site Walk Buildings

Table 2 – Existing Buildings Report – Proposed Energy Reduction of Site Walk Buildings

Area	North			South East		South West			Central	
Building	No. 111 – Factor Iwentash	No. 64 Graduate House	No. 134 Rotman School of Management (North)	No. 3 Sigmund Samuel	No. 161 Pharmacy	No. 32 Wilson Hall – New College II	No. 78 McLennan Physical Laboratory	No. 68 Clara Benson	No .19 Prichard	No. 154 Health Science Building
Heating Reduction	22%	10%	11%	15%	15%	8%	18%	23%	9%	13%
Cooling Reduction	12%	20%	28%	15%	46%	45%	36%	33%	18%	30%
Electricity Reduction	9%	7%	7%	17%	20%	9%	9%	20%	4%	10%

Table 3 – Existing Buildings Report – Proposed Energy Reduction of Campus Building Types

	Heating Reduction	**Cooling Reduction**	**Electricity Reduction**
Office/Admin	15%	15%	7%
Academic	12%	29%	9%
Athletic	23%	33%	20%
Residential	9%	33%	8%
Lab	17%	41%	14%
Library	15%	46%	20%
Weighted Average	**15%**	**28%**	**10%**

Among the building visited, Leslie Dan Pharmacy (Bldg ID #161) shows the highest energy savings potential due to reduction in ventilation/exhaust air requirement associated with wet lab spaces. On heating, 124 Bloor (Bldg ID #111) and Clara Benson (Bldg ID#68) shows higher than 20% heating use reduction due to potential AHU upgrade and air heat recovery opportunities.

The heating, cooling, and electricity use reduction is calculated based on the building annual utility consumption data provided, equipment nameplate information collected during the site walk or from available drawings, and estimated equipment runtime. The results are dependent on the accuracy of these inputs. Annual CHW consumption data is not available for all buildings visited and required extrapolation based on the best available data to determine. There is a level of inaccuracy associated existing annual CHW consumption shown in the report, thus affect the accuracy of calculated building cooling use reduction. It is recommended that the building cooling use reduction to be re-assessed when annual building CHW trend data are available.

The results from the basic site walk is intended to support part of the master plan's effort to evaluate future campus utility load, and is adequate to identify order of magnitude potential energy reduction opportunities associated with existing buildings and the need for a more detailed audit. It is not at a sufficient level of detail to reach a final decision on implementing proposed measures.

5 Future Demand and Consumption Analysis

A copy of complete Future Demand and Consumption Analysis Report is in Appendix C for reference.

5.1 Report Summary

The objective of the Campus Utility Demand and Consumption Analysis was to estimate the increase in the overall campus energy and demand resulting from new capital development at the University of Toronto between the years 2019 and 2050. Starting from the current existing campus condition, projected increases in annual consumption [MWh/yr] and peak demand [MW] were calculated for heating, cooling, and electricity across the campus based on existing utility consumption and trend data, building performance target analysis by RWDI, and other future building energy performance benchmarks from publications such as the Toronto Green Standard and Zero Emission Building Framework. This result of this study was to serve as the basis of analysis for the campus utility master plan and to support future utility strategies development. These results are presented in graphical and tabular form below.

Building and infrastructure built today will experience different weather patterns over the course of the 21st century due to the impact of climate change. In this analysis, the impact on campus building thermal load due to changing future climate conditions was evaluated using shoebox energy models of residential and commercial buildings with future weather files morphed by WeatherShift, a proprietary tool developed by Arup and Argos Analytics that adjusts typical meteorological weather file based on global emission scenario (assumed RCP 8.5 – business-as-usual). By 2050, the modelled building peak heating and cooling demand is estimated to change by -7% and +10%, respectively, and the modelled building annual total heating and cooling consumption is estimated to change by -1% and +23%, respectively.

It should be noted that the increase in annual electricity consumption and demand presented in this report does not include the electricity that is required to provide the additional heating and cooling load of the campus.
The growth of electrical demand including the plant heating and cooling demand has been calculated for the design strategy being pursued and is shown in section 8.3.1 Energy Summary.

Finally, existing building demand and consumption values within this analysis are based on best available received data and any missing existing data was estimated using building function specific demand factors. The estimated future campus building heating, cooling and electricity demand and annual consumption are based on a range of assumptions and parameters. The actual future campus utility demand and consumption will vary depending on parameters, including but not limited to the actual building area developed and associated space programming, actual building performance level, future climate change conditions, load reduction achieved on existing buildings, and more. See Future Demand and Consumption Analysis report Appendices for a full detailed list of assumptions and data files used within this report. Most notably, annual CHW consumption data is not available for all buildings and required extrapolation based on the best available data to determine. There is a level of inaccuracy associated existing annual CHW consumption shown in the report, thus affect the accuracy of calculated future building cooling demand and consumption. The calculated campus cooling demand and consumption should be verified when annual building CHW trend data are available.

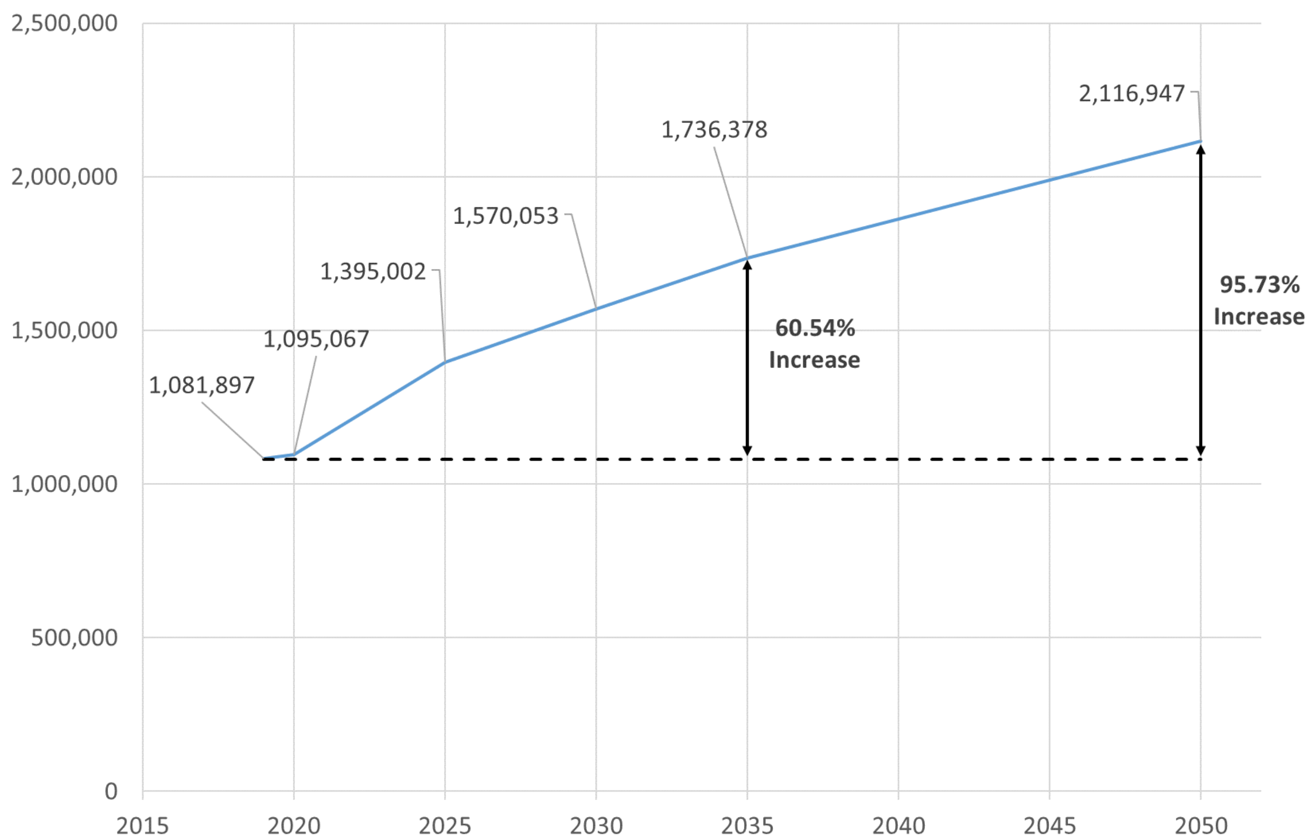


Figure 21 - Future Demand and Consumption Report – Projected Campus New Development

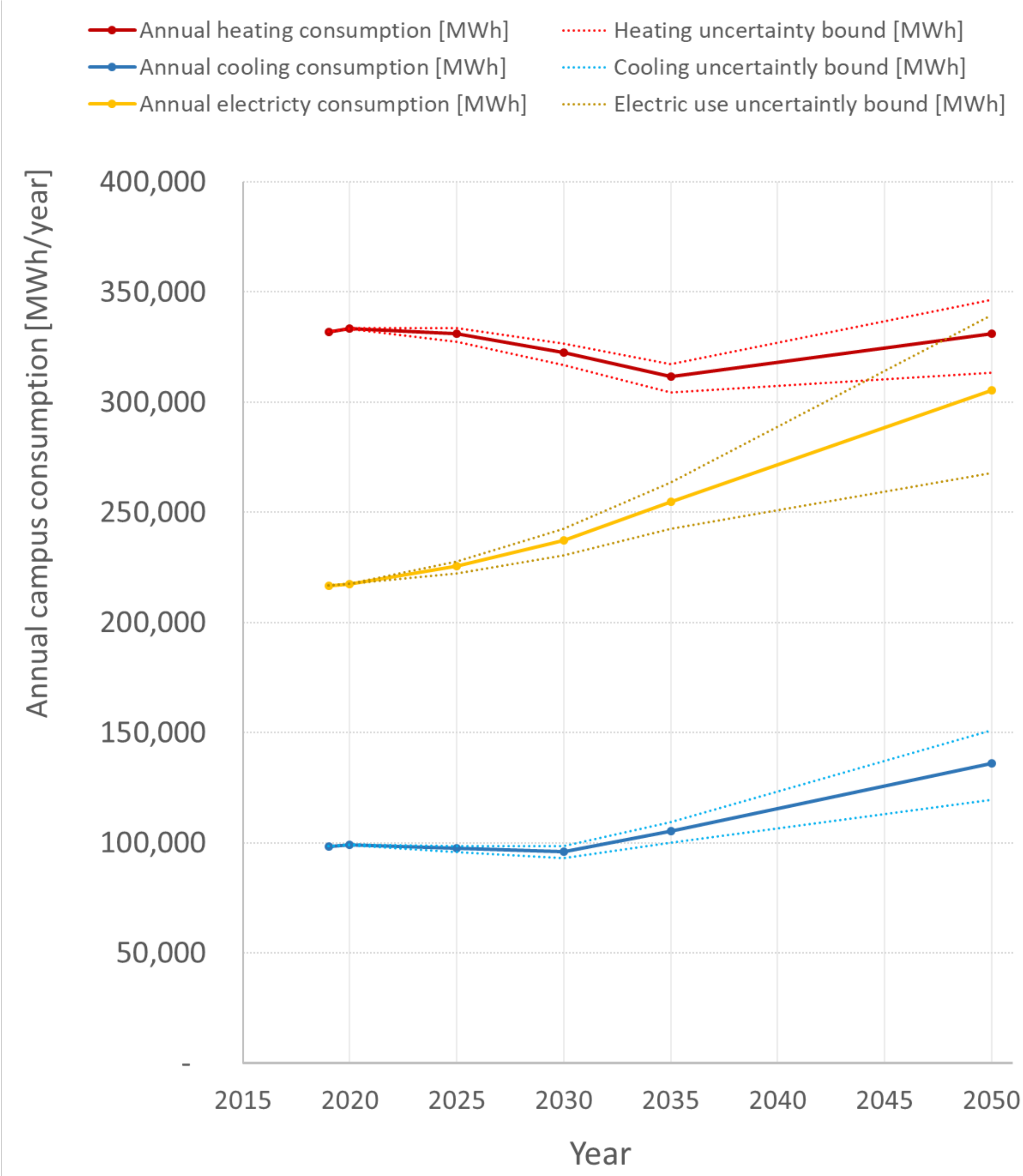


Figure 22 - Future Demand and Consumption Report – Campus Future Annual Energy Consumptions

Note: Annual electricity consumption and demand presented in this report does not include the electricity that is required to provide the additional heating and cooling load of the campus

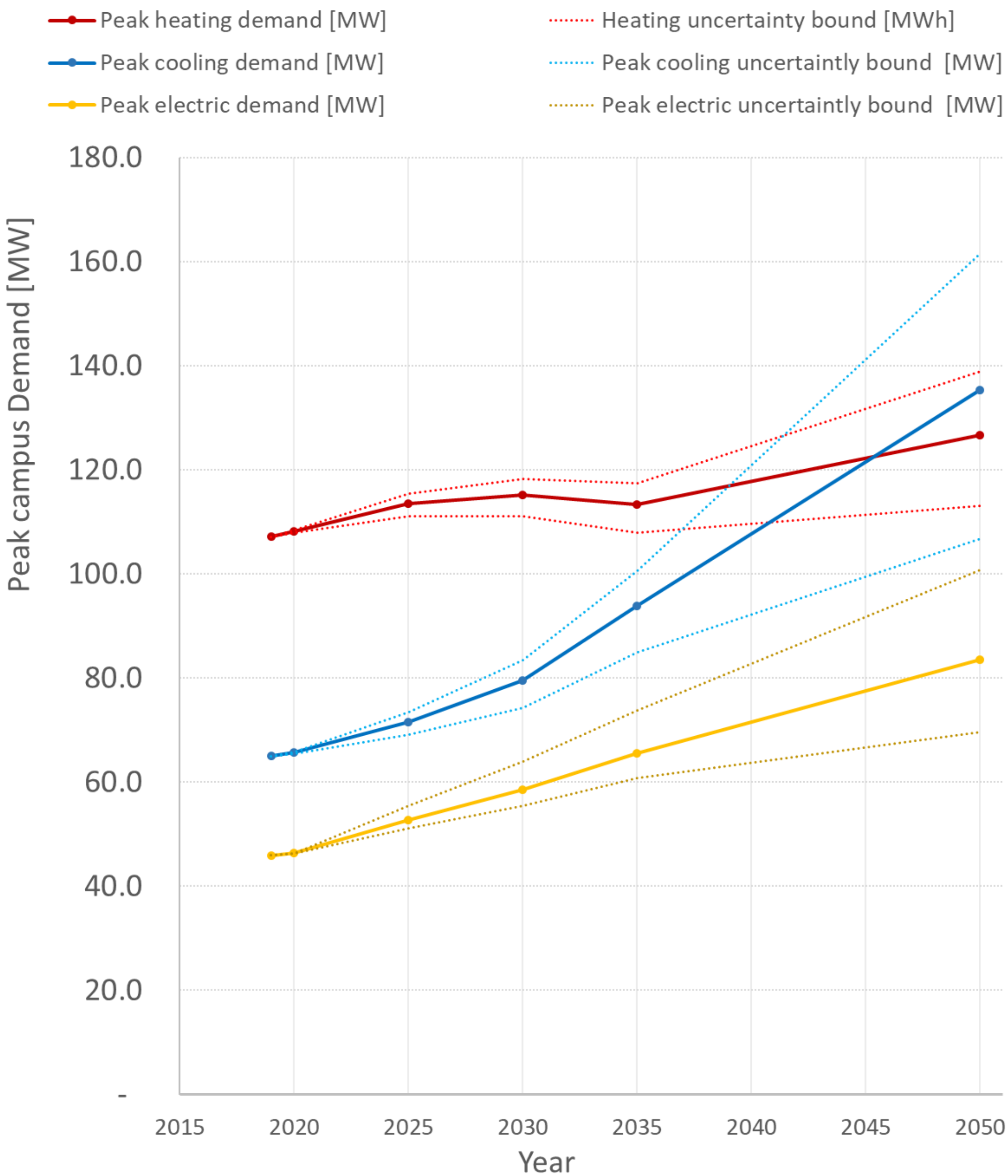


Figure 23 - Future Demand and Consumption Report – Campus Future Annual Energy Demand

Table 4 – Future Demand and Consumption Report – Future Campus Demand and Consumption Summary

		2019	2020	2025	2030	2035	2050
Heating Energy	Annual heating energy [MWh]	331,990	333,547	331,155	322,440	311,708	330,961
Heating Demand	Peak heating demand [MW]	107	108	114	115	113	127
Cooling Energy	Annual cooling energy [MWh]	98,350	99,135	97,371	96,089	105,357	135,932
Cooling Demand	Peak cooling demand [MW]	65	66	72	80	94	135
Electric Energy	Annual electric use [MWh]	216,726	217,642	225,531	237,490	254,675	305,262
Electric Energy	Peak electric demand [MW]	46	46	53	59	66	84

Table 5 – Future Demand and Consumption Report – Net Increased (or Decrease) relative to 2019 in Demand and Consumption Summary

		2019	2020	2025	2030	2035	2050
Heating Energy	Increase in annual heating energy [MWh]	-	1,557	-881	-9,642	-20,422	-1,171
Heating Demand	Increase in peak heating demand [MW]	-	1.00	6.30	7.90	5.90	19.20
Cooling Energy	Increase in annual cooling energy [MWh]	-	785	-1,098	-2,499	6,755	37,439
Cooling Demand	Increase in peak cooling demand [MW]	-	0.60	6.50	14.30	28.60	70.00
Electric Energy	Increase in annual electric use [MWh]	-	916	8,805	20,764	37,949	88,536
Electric Energy	Increase in peak electric demand [MW]	-	0.40	6.80	12.50	19.60	37.50

6 Preliminary Concept Development

To develop the site utility master plan for the campus, the team looked forward into the year 2050 and contemplated what the campus site utilities infrastructure would look like. The goal was to develop a long list of site utility options for the future of the campus, narrow down to a short list of options and eventually one preferred option, and then work backward to determine how the campus will transition from existing conditions to the anticipated future state.

6.1 Energy Supply Strategies

The development of future site utility options includes a look into possible energy supply mix, with a primary focus on energy supply technologies that are low-carbon and substitute natural gas as a means to create thermal (heating) energy. Through discussions with the university, the strength, weakness, opportunities, and risks of different supply technologies were explored.

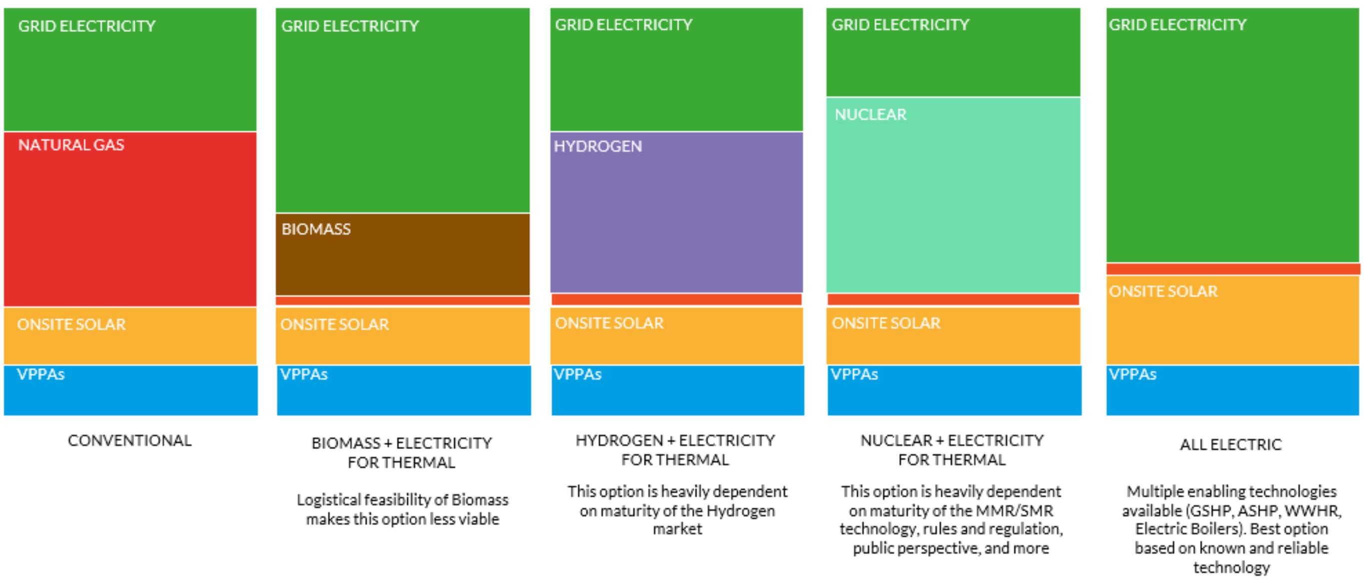


Figure 24 - Potential Energy Supply Strategies

Based on the technical and commercial maturity, spatial requirement, operation complexity, and efficiency of different technologies discussed, campus electrification was agreed to be the best option forward.

Electricity will be used as the base energy supply to the campus and enables the ability to add-in new developed technologies into the energy supply in the future. The campus will undergo electrification through a phased approach, seen in Figure 25, gradually reducing the reliance on natural gas and increasing onsite renewable technology. Virtual purchased power agreements, which includes some form of offsite renewable power generation owned by the University, will also need to be implemented to achieve the last 20% emission reduction for carbon neutrality.

It is recognized that natural gas will not be eliminated completely on campus, as backup heating systems and process equipment may still require it. The focus of the Utility Master Plan in achieving Carbon Neutrality by 2050 is focused on reducing/replacing the natural gas used for heating at the central steam plant and local boilers/rooftop units.

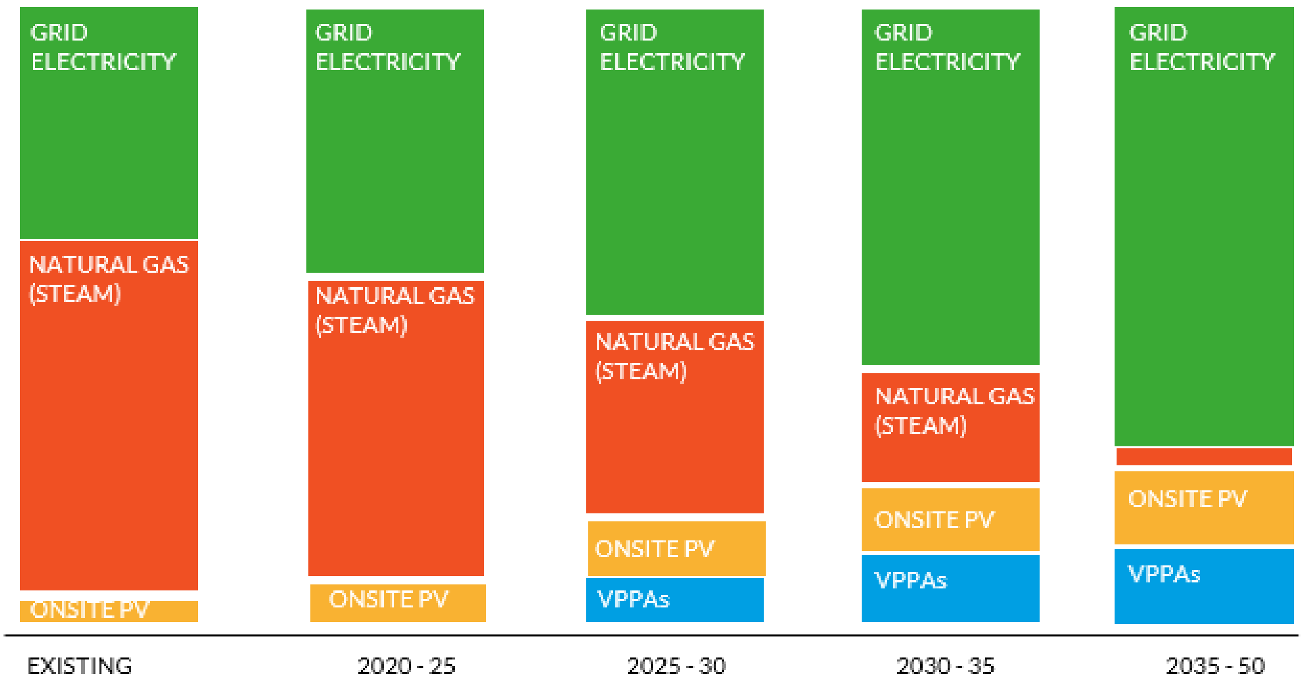


Figure 25 - Phased Campus Electrification Strategy

6.2 Campus Electrification Toolkits

Campus electrification can be achieved using a combination of different mechanical system, distribution schemes and renewable and storage system. The team went through an exercise to develop a list of different combination of possible campus electrification system configurations and discuss the advances and disadvantages of each. A long list of possible campus electrification system configurations was investigated in workshops and then narrowed down to three options which were further developed and applied to the campus for quantitative analysis.

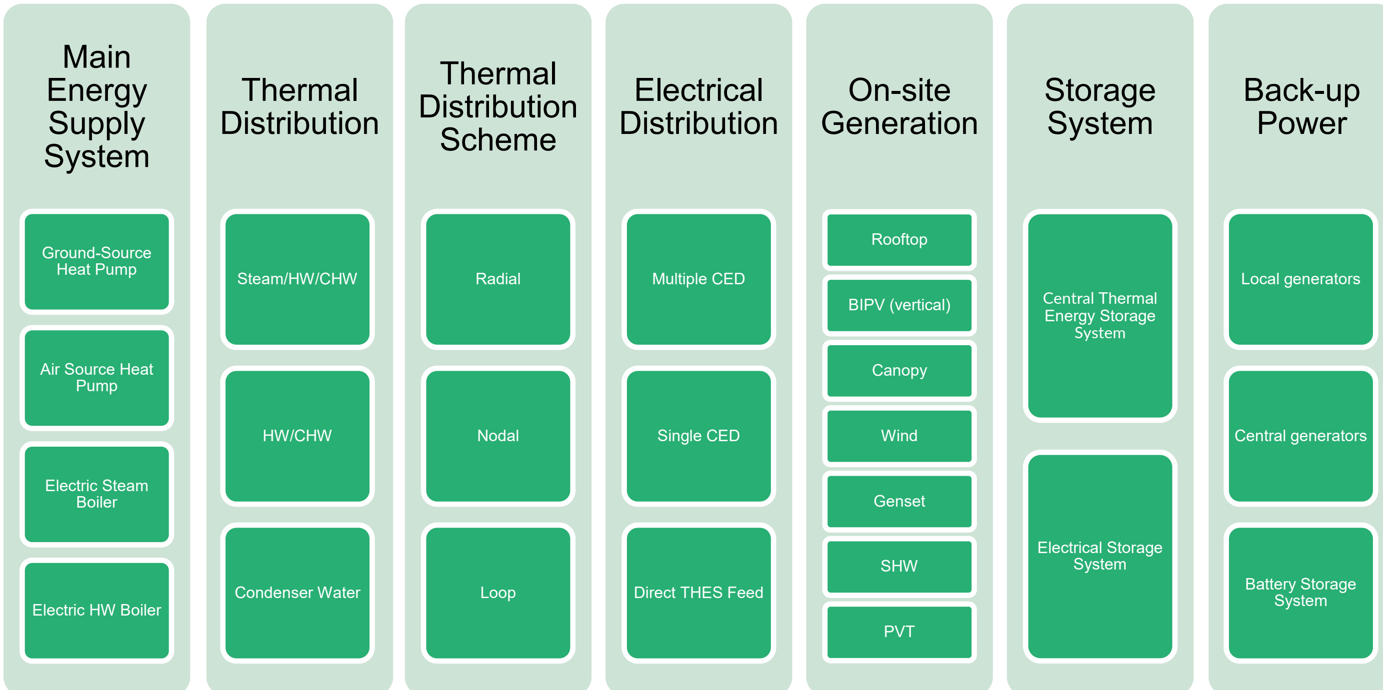


Figure 26 - Electrification system configuration options

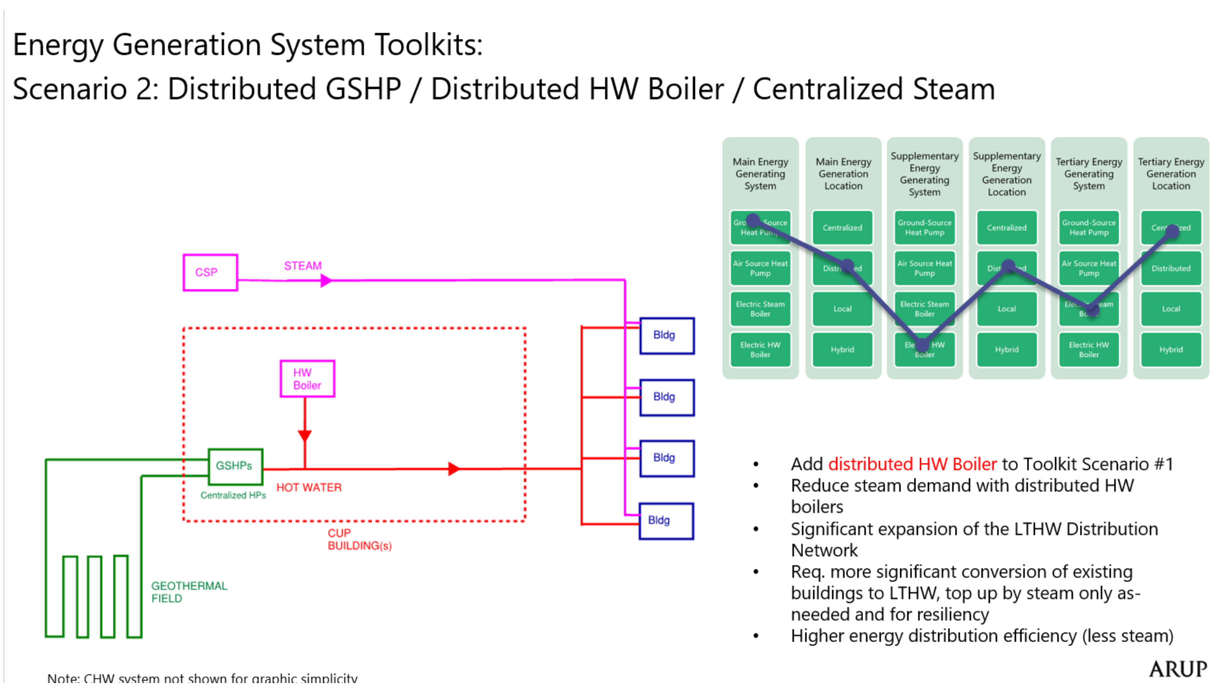
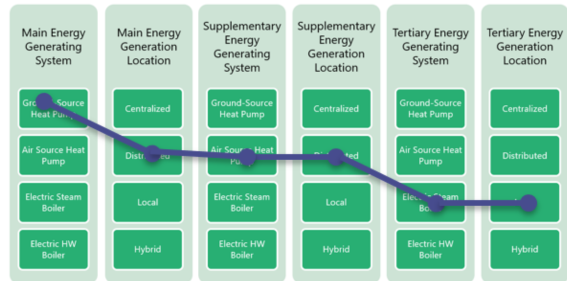
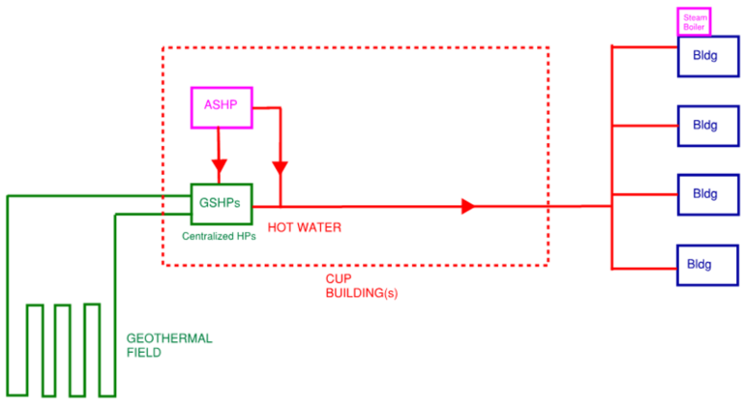


Figure 27 – Considered Configuration: Distributed GSHP / Distributed HW Boiler / Centralized Steam

Energy Generation System Toolkits:
Scenario 5: Distributed GSHP / Distributed ASHP/ Local Steam





- Similar to Scenario 4 but higher operating efficiency
- Roof/outdoor requirement can be a challenge
- Required storage tank as buffer
- Complete removal of steam distribution in the future
- Very significant expansion of the LTHW Distribution Network
- Highest energy distribution efficiency (no steam)
- Req. more significant conversion of existing buildings to LTHW, top up by steam locally only as-needed
- Deploy temporary HW boilers as needed for resiliency (despite lack of central steam)

Figure 28 - Considered Configuration: Distributed GSHP / Distributed ASHP/ Local Steam

6.3 Site Utility Design Alternatives

6.3.1 Campus Area Designation Approach

The downtown campus encompasses a vast area and large number of buildings; therefore, the campus was broken down into smaller areas, nodes pertaining to the thermal design and blocks pertaining to the electrical design.

Thermal Nodes are based on existing and planned infrastructure capacities and building areas loads. Each Node has its own utility system serving the buildings within the area. Potential to connect nodal utility systems across area boundaries was also considered during strategy design.

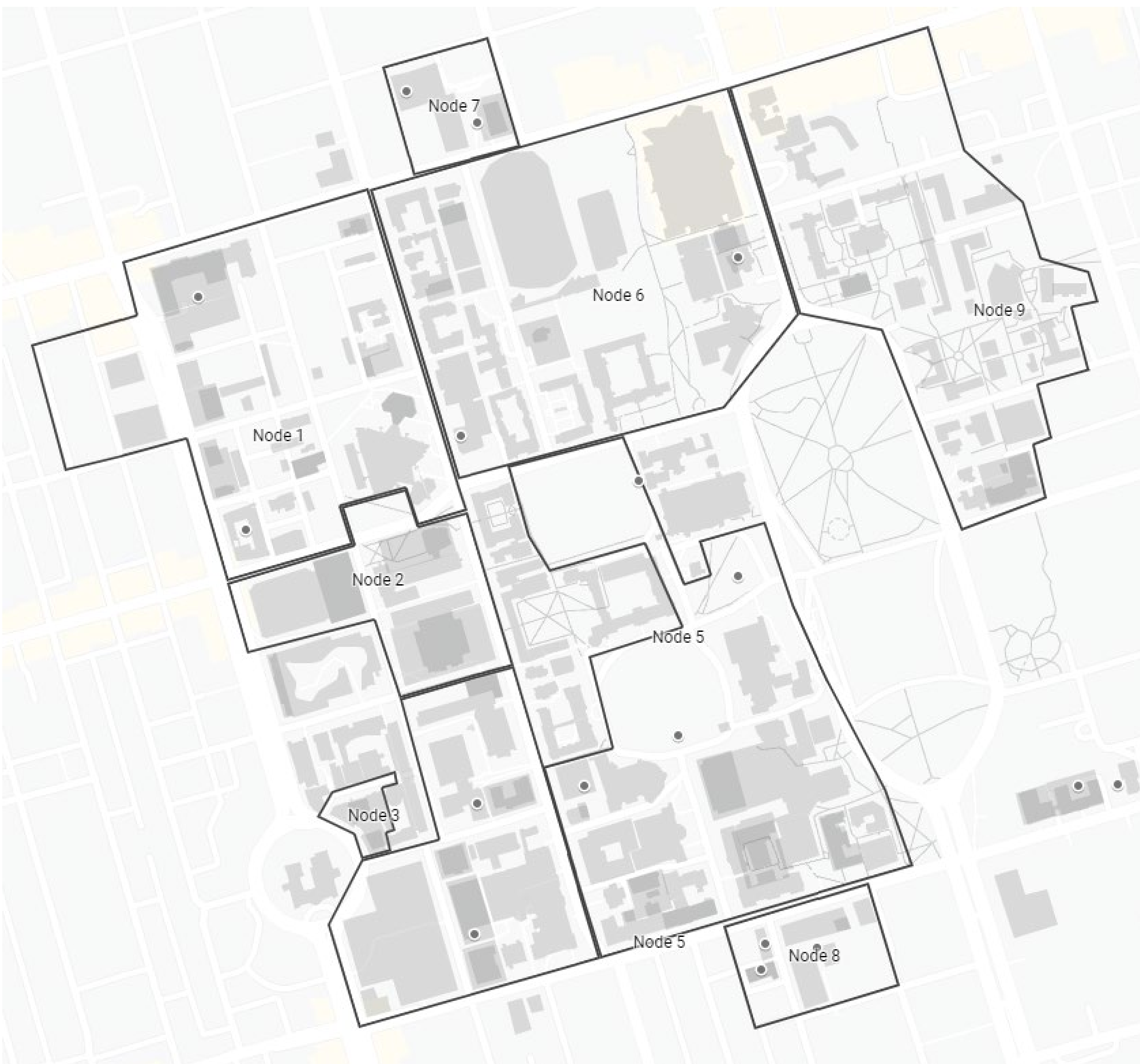


Figure 29 - Thermal Nodes

Electrical design blocks correspond to existing and proposed new high voltage switching stations (referred to here as "CED") locations and their connected buildings. New CEDs are collocated where the density of electrical demand is the highest, and follows closely the thermal strategy, such that new CED plant rooms will be built at the same time and in close proximity to the new thermal plant rooms.

Figure 30 - Electrical Blocks

6.3.2 Siting and Spatial Requirements

The historic nature of the campus and location in downtown Toronto limits space available for construction activities and new/modification of mechanical and electrical infrastructure. Aside from site utilities infrastructure owned and operated by the University, consideration for other public utilities distributed across the campus must also be taken into consideration when new utility infrastructure designed and implemented. In addition to permit and approval by the City of Toronto, installing new distribution piping under/crossing public right-of-way require coordination with and review by the Toronto Public Utilities Coordinating Committee (TPUCC), a consortium established by the City of Toronto and utility companies who own and operate facilities in the public road. TPUCC includes utilities companies such as Enbridge, Toronto Hydro, Rogers Communication, and Toronto Transit Commission (TTC) to name a few. Traffic must also be coordinated and approved by permit from the City of Toronto’s Transportation Services related to traffic management. Construction within private property but close to TTC’s asset (generally within 60 m of “zone of influence”) will also require coordination with TTC subway structures.

6.3.3 Geothermal Fields

The campus was analysed for potential geothermal fields with feedback from the Master Plan team. Each new development assumes a geothermal field underneath the building footprint and any additional open space on the new development’s site. Additional areas targeted include sports fields, parks, open courtyards, and existing underground parking lots.

The following rule-of-thumb metrics were assumed in calculating geothermal fields thermal capacity. These metrics were based on thermal conductivity tests performed at King’s College Circle and Robert Street Field. Actual thermal conductivity and ground conditions of specific locations can vary. Feasibility study, including test borefield for each field must be conducted to better understand site specific ground conditions (geology, ground water conditions, thermal conductivity, etc) before design and construction of a borefield.

- Borehole Density: 0.0278 boreholes/sq.m
- Area Utilization factor: 75%
- Thermal Output: 14kW / borehole

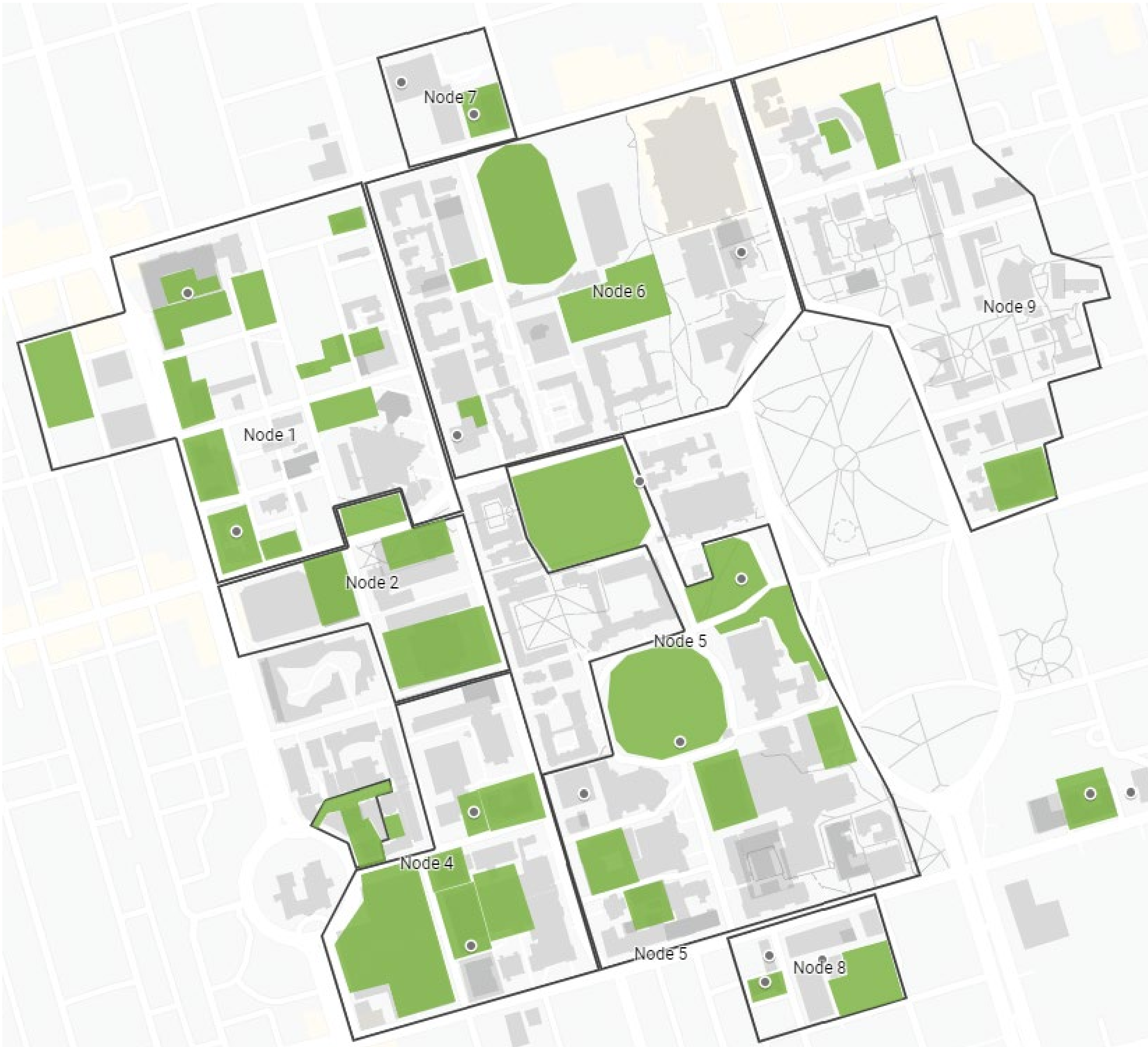


Figure 31 - Potential Geothermal Borehole Fields

Constructing the exact location and size of each geothermal field shown is not critical for the success of the masterplan as the nodal plant design accounts for the geothermal fields uncertainty and is equipped with a backup thermal source such as the central steam plant or local boilers if such geothermal energy is not met. However, geothermal fields should be maximized at all possible locations to maximize system efficiency (relative to electric resistance) and hence reducing carbon emissions and utility costs.

6.3.4 East of Queens Park

St. Michael's College and St. Victoria's college buildings reside east of Queen's Park.

There is a single underground connection across Queen's Park Street, slightly north of Charles Street, through an underground utility tunnel. This utility tunnel contains a steam pipe and condensate pipe and supplies steam to connected buildings shown in Figure 32. This area has been classified as Node 9 in the thermal design and apart of CED X – Block Z in the electrical design.

These colleges will be offered connection to the University of Toronto utility distribution system with agreeance they will align with the Masterplan Design Requirements, including new building performance, existing building conversion, and maximizing geothermal fields areas.

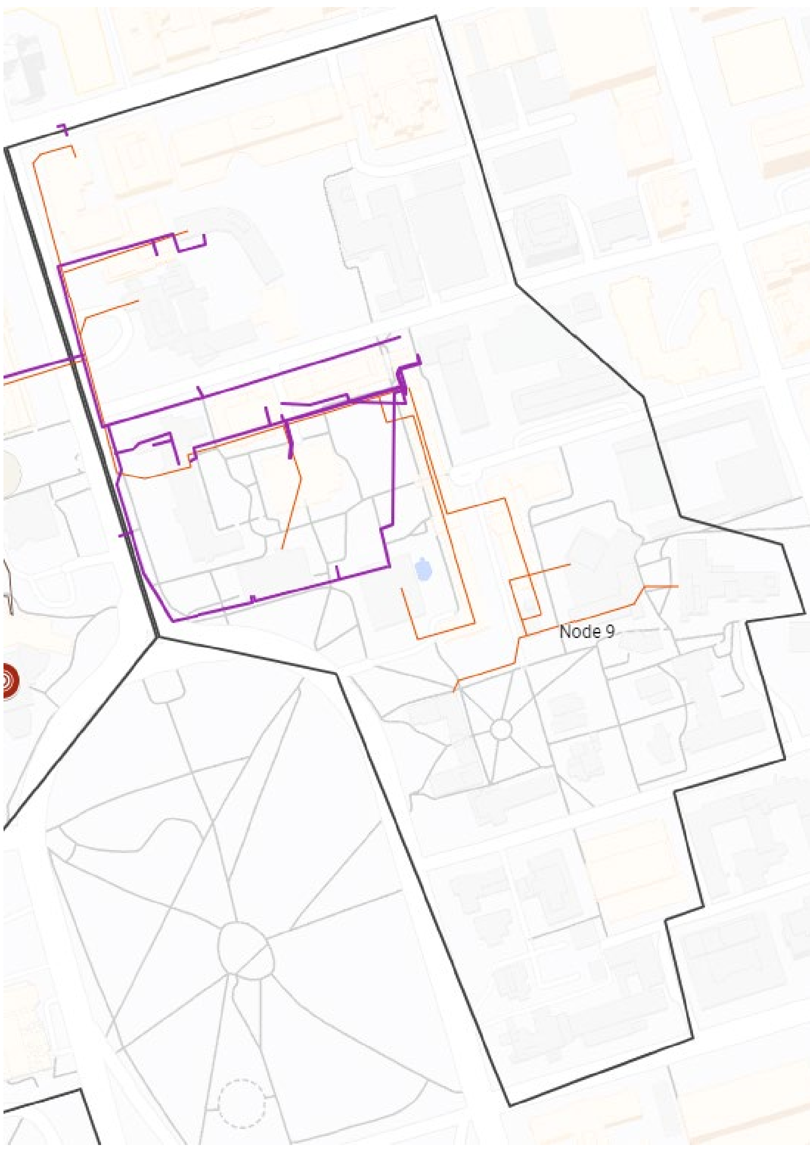


Figure 32 - Existing Steam(red) and electrical (purple) distribution feeding buildings east of Queen's Park

6.4 Resiliency considerations

Resilience consideration were given to the utility infrastructure based on standby and back-up power requirement. The electrical strategy outlined in Section 8.5 is based on a desire for a more resilient campus distribution system. The addition of new high voltage switching stations (or “CEDs”) supplied from Toronto Hydro feeders originating from different Transformer Stations is the backbone of a system whose intention is to reduce outages due to various utility failures. Various measures have been accommodated at each CED including load shedding. Approach to emergency power and generators are also discussed in section 8.5.9.

During workshops and discussion with the Master Plan team, it is recognized that a campus resiliency plan is required to be developed outside of the scope of the utility master plan to better inform the resiliency requirement for the utility infrastructure and the campus at large. These includes emergency response to unexpected event such as civil events (public protest or sports event celebration), natural disasters, disease outbreak, terrorist events, cyber attack, to name a few.

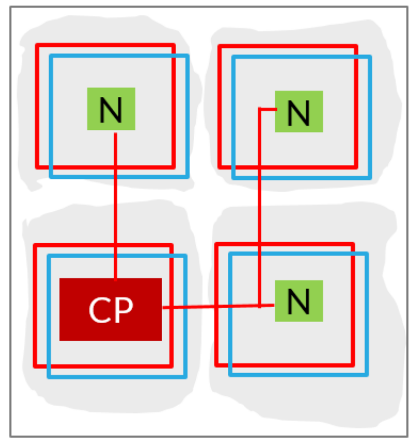
7 Concepts Overview

7.1 Three Shortlisted Strategies

After a series of workshops and iterations, three site utilities strategies were chosen that involve different combination of generation technologies and different approach to utility distribution across campus. These three options were taken further for quantitative analysis to calculate their capital cost, utility cost and equivalent carbon emissions. Details of the three design alternatives were captured in the Design Narrative submission dated December 10th, 2019.

7.1.1 Alternative #1 – Central Generation Focused

This option utilizes a hybrid distribution arrangement, making nodal plant and distribution with the Central Steam Plant and existing distribution for back up. Nodal plants can contain ground source heat pumps, cooling towers, and if needed, chillers and electric resistance boilers.

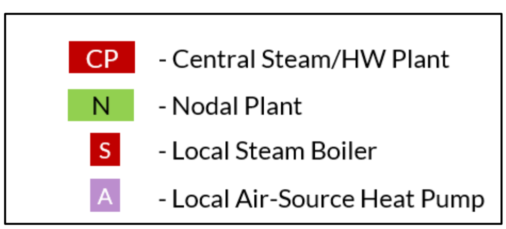


Alt. 1
Central Plant Focused

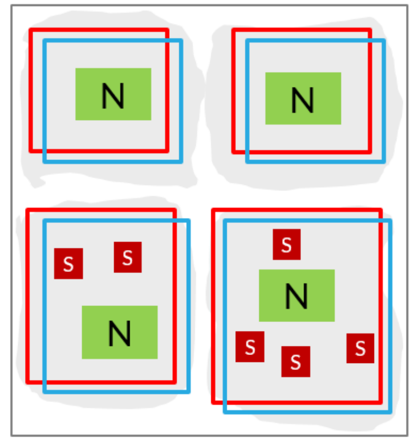
Geothermal fields within each node are fed back to nodal plants and then low temperature hot water and chilled water is distributed to buildings. Where the thermal load is larger than the geothermal capacity in a nodal, the connection from the central steam plant provides top-up heating as required. Central steam distribution will remain until existing buildings undergo conversion to operate on low temperature hot water rather than steam. Most existing buildings operating on steam have the flexibility in being converted to hot water operation up until 2040.

This option is the most flexible for integrating future low-carbon generation technology at the central steam plant that is not currently technically and/or commercially viable. While the nodal plants are the primary means to support buildings within their nodes, the nodal plants will be backed-up by the central steam plant. This arrangement maintains the concept of centralization of the campus utilities while enhancing the redundancy of the system. Significant site utility distribution infrastructure is required to connect existing and new development buildings to nodal plants with 6-pipe distribution.

Legend



7.1.2 Alternative #2 – Nodal Generation Focused



Alt. 2
Nodal Plant Focused

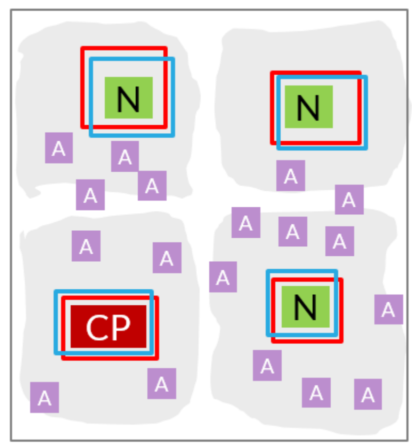
Alternative #2 focuses on generation within each nodal plant and reliance on the central steam plant is gradually eliminated.

Nodal plants receive supply from surrounding geothermal fields and make use of combination of ground-source and air-source. Remaining demand is supplied from chillers and electric hot water boilers within each nodal plant.

This option is the most operational efficient due to ground source heat pumps and air source heat pumps being relatively higher efficiency (relative to electric resistance) and can be integrated with heat recovery operation. It also reduces heat loses with faster elimination of steam distribution.

Extensive building conversion is required for buildings to receive hot water rather than steam as the central steam plant will be eliminated. Buildings that cannot be converted to low temperature hot water economically will receive local electric steam or high temperature hot water boilers.

7.1.3 Alternative #3 – Local Generation Focused



Alt. 3
Local Generation Focused

The third alternative maximizes local generation, utilizing roof area on existing and new buildings for air-to-water heat pumps/ variable refrigerant flow systems where possible.

Nodal geothermal plants are still deployed using a hybrid distribution arrangement where central distribution from the existing Central Steam plant to provide top-up to nodal plants and standalone buildings without sufficient capacity from ASHP/VRF system.

7.1.4 Electrical Strategy

The electrical strategy was designed such that the high-level concepts are agnostic to the decision of the final alternative selection. While details such as the size of each high voltage switch station (or "CED"), and the boundaries of each corresponding node vary between alternatives, locations and quantities of CEDs was set early on.

8 Final Concept Overview

8.1 Introduction

The selected option was developed into the preferred site utility strategy for the future of the campus. It depicts what the future campus thermal and electrical infrastructure would look like by year 2050 that address the master plan's primary objectives of renewal, growth, and green. The final concept strategy was developed and screened based on close collaboration effort with the Master Plan Team through workshops and discussions.

Development and Renewal Schedule:

The Development and Renewal Schedule in the following section provides an overview of all existing equipment renewal, major nodal development, and infrastructure requirements throughout the next 30 years. This is a key driver for design and phasing of the Masterplan.

Thermal Requirements Section:

The thermal strategy for the campus is broken down by thermal nodes. Details of each thermal nodal strategy are captured through a narrative, design map, and phasing strategy table. All three components must be used concurrently for a comprehensive understanding of the masterplan project.

The narrative describes major new developments and critical infrastructure elements that must be implemented for success of the masterplan design and achieving the university's emission goals.

The design map shows an overview of the 2035 thermal design projected onto a map of the campus. It shows all heating and cooling infrastructure equipment and distribution required and proposed geothermal fields with their connectivity to each nodal plant. A full interactive version of this map is provided as a supporting tool to this document and found online as the UofT Masterplan Webmap using the online link. The Webmap was developed to show all details on existing and new buildings, thermal infrastructure, and electrical infrastructure and can be filtered for different phases and types of equipment.

The Nodal Phasing Strategy summarizes which phase all major infrastructure and building conversion needs to be implemented. The implementation phases span 5-year periods until 2035 and then 15 year period till 2050. All required building conversion is to be completed in a 20-year time-period, each year requiring equal amount of building conversion area until 2040.

The following definitions for thermal distribution are used and is consistent with the current terminology and definitions used by the University.

CSP – Central Steam Plant

HTHW – High Temperature Hot Water, with a supply temperature at 250 to 260 F, created from central steam via heat exchangers located at the central steam plant.

MTHW – Medium Temperature Hot Water, with a supply temperature at ~180F. Currently, there is only one MTHW line, connecting Robarts Library to Rotman and Innis College. It is “powered” by a HTHW line from the CSP.

LTHW – Low temperature Hot Water, with a supply temperature at 140F. Currently this is mostly dependent on the Sofame System which recovers heat from the exhaust stack at the CSP. Ground-source heat pump is expected to supply hot water at this temperature.

Electrical Design Section:

The electrical strategy for the campus is broken down by electrical blocks (or nodes). The electrical strategy is captured through a narrative, design map, and phasing strategy algorithms. All three components must be used concurrently for a comprehensive understanding of the masterplan project. The narrative describes the general technical and demand capacity requirements at each node, and is broken down into demand power, emergency power, redundancy, as well as renewable energy strategies. The map is divided into subsets of 5-year intervals from present to 2035, and one interval for 2050. Each interval will show information such as electrical demand at each node, migrations of existing buildings to the new high voltage switch station (or “CED”), and connections of new buildings/projects. The phasing algorithm is reliant on the phasing of thermal projects, as well as the schedule of major new developments, and each project should be evaluated individually against the algorithm.

The following figures show the 2035 overview of the thermal and electrical design, respectively.

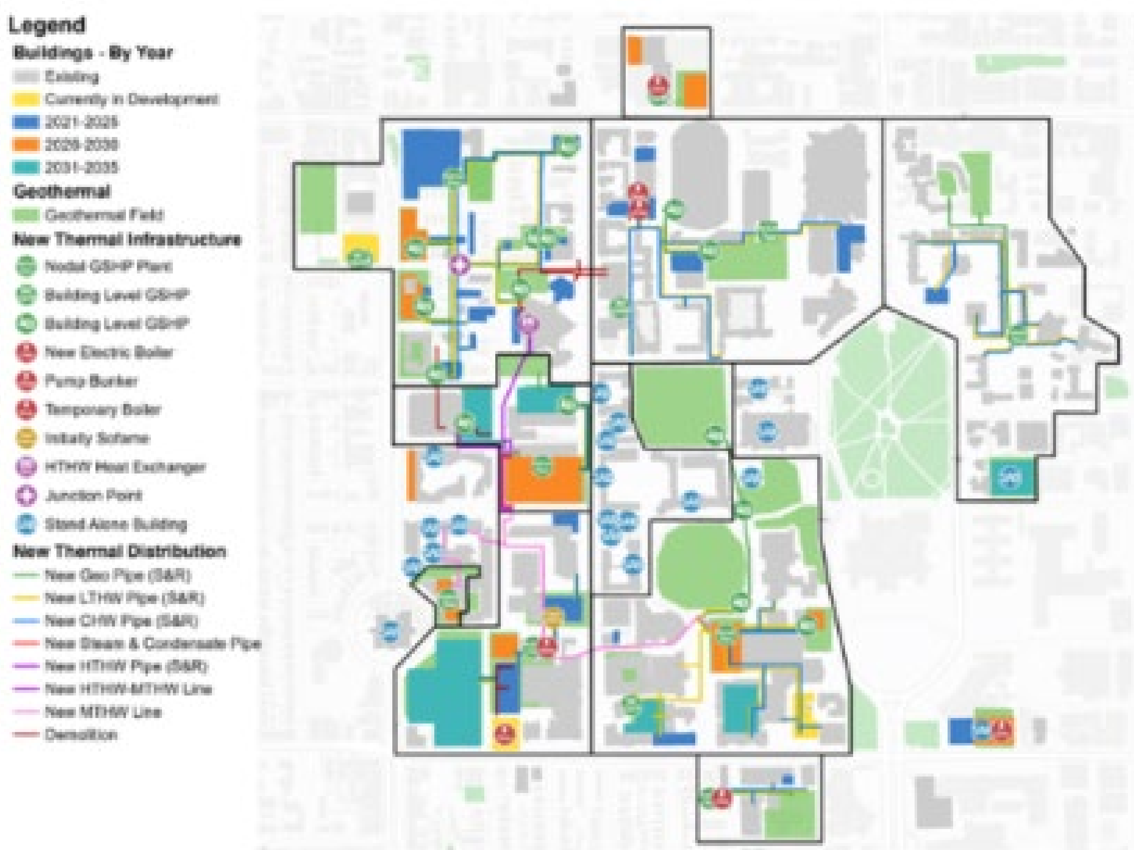


Figure 33 - Thermal 2035 Design Overview

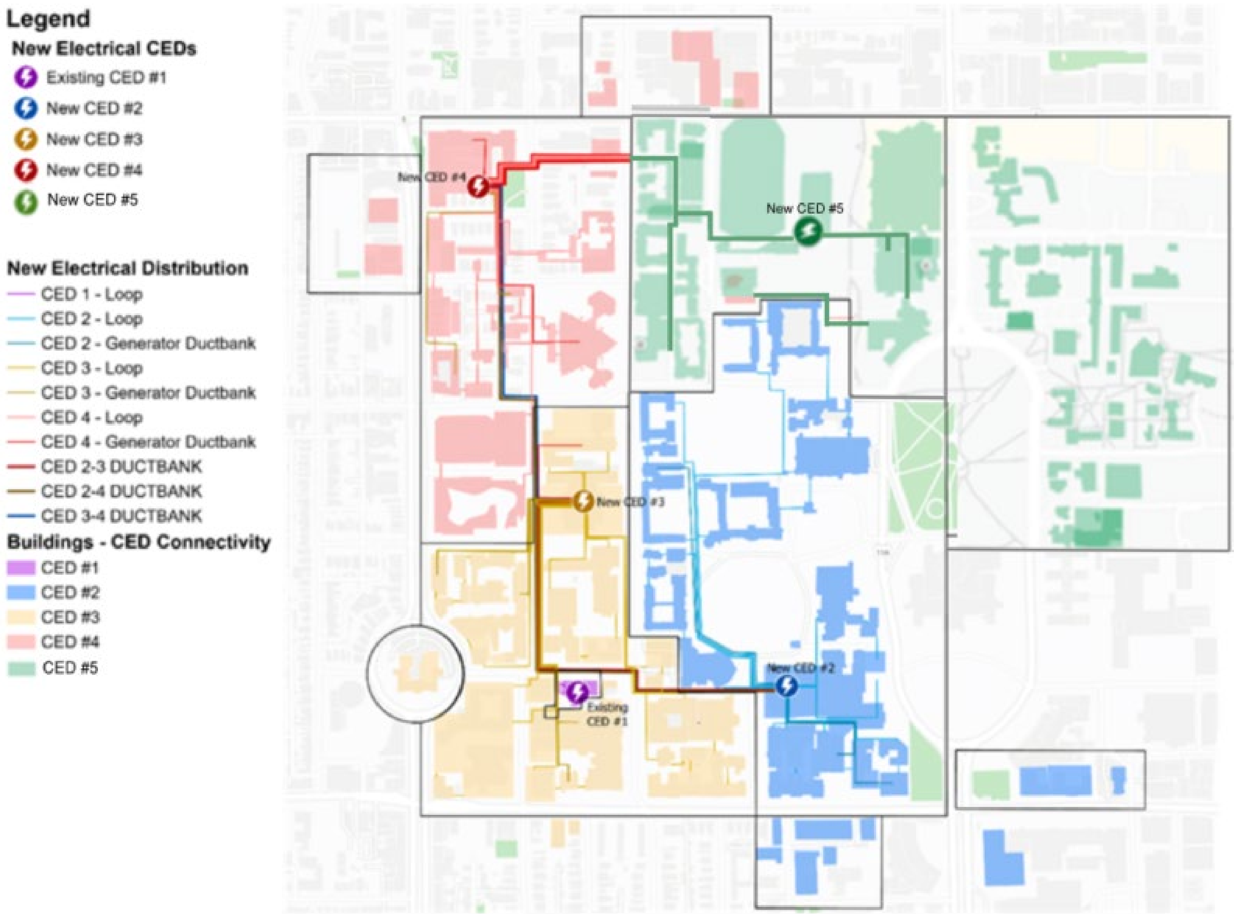


Figure 34 - Electrical 2035 Design Overview

8.2 Development and Renewal Schedule

The timeline shows existing equipment, renewal plans, and major new development construction over the next 30 years. This has been used to inform the design of each node and phasing.

See supporting document Renewal Calendar Spreadsheet File for interactive and dynamic version of timeline.

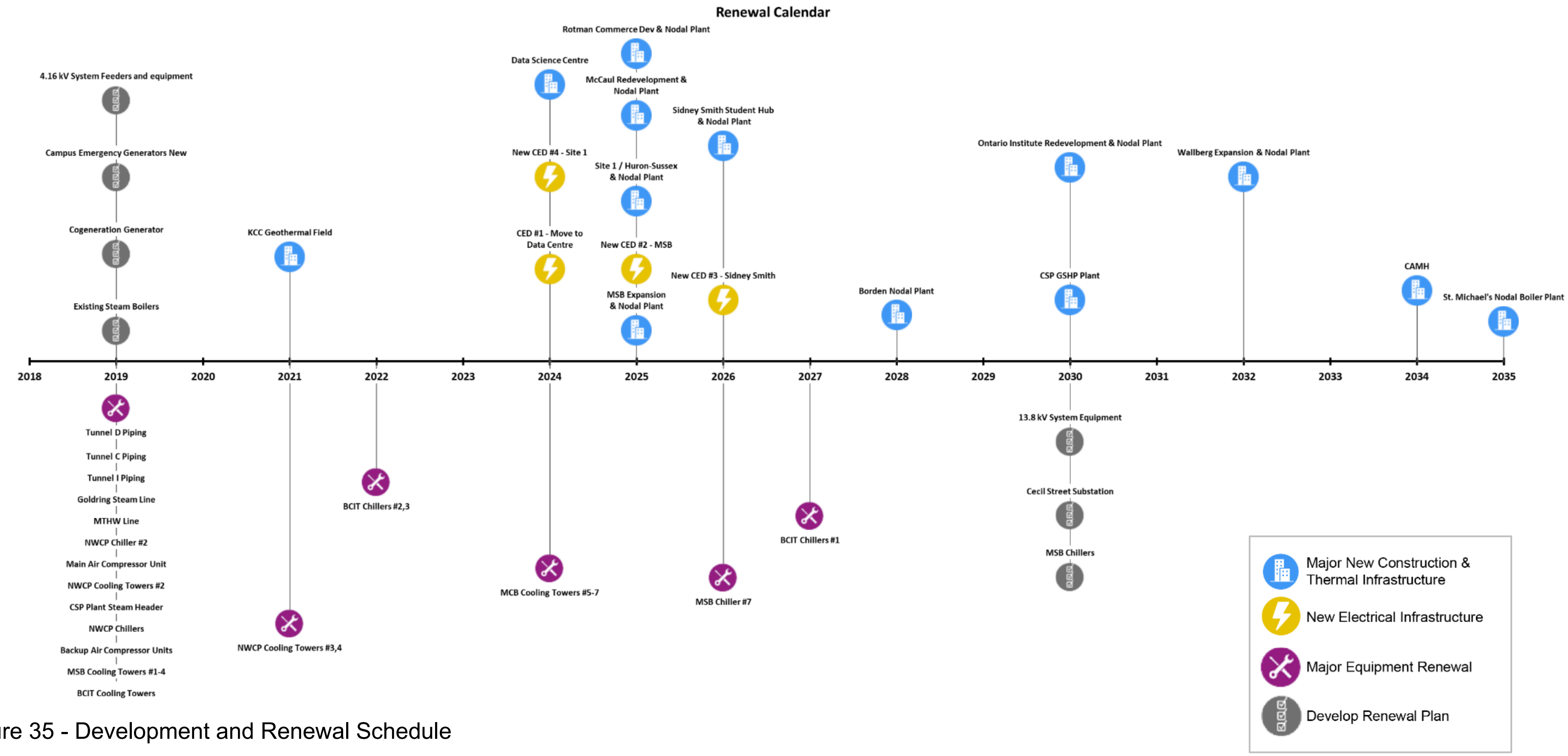


Figure 35 - Development and Renewal Schedule

8.3 Final Concept Quantitative Summary

8.3.1 Energy Summary

The following charts display the campus' energy demand and consumption for the final design presented in this section. This is updated from the Future Demand and Consumption Analysis Report to include electricity required for heating and cooling equipment.

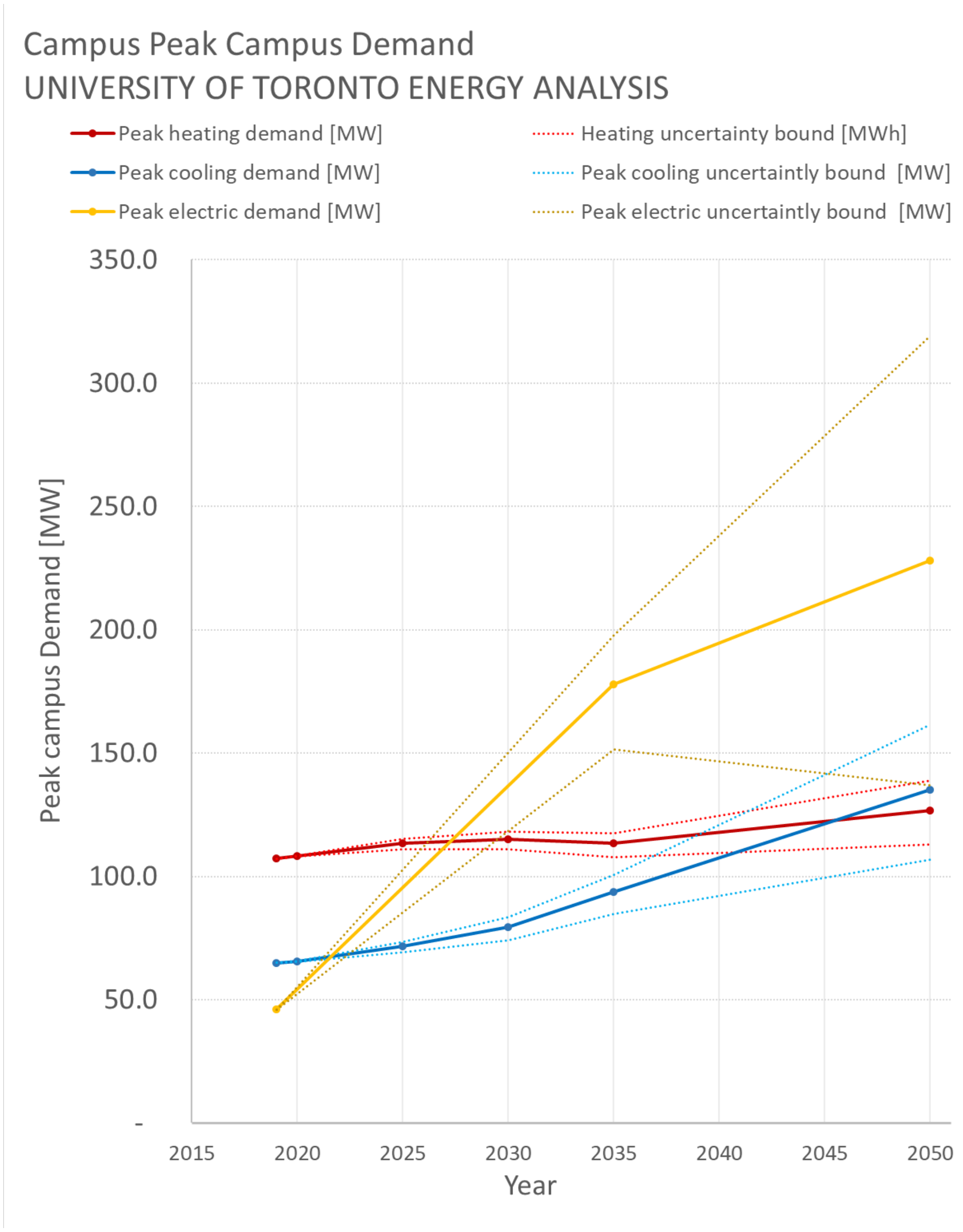


Figure 36 – Campus Total Annual Demand of Final Design

Table 6 – Campus Total Annual Demand and Consumption

	Demand (MW)		
	Electricity	Heating	Cooling
2019	46	107	65
2025	-	113	72
2030	-	115	80
2035	178	113	94
2050	228	127	135

	Consumption (MWh)		
	Electricity	Heating	Cooling
2019	216,726	331,990	98,350
2025		331,155	97,371
2030		322,439	96,089
2035	363,416	311,708	105,357
2050	653,015	330,961	135,932

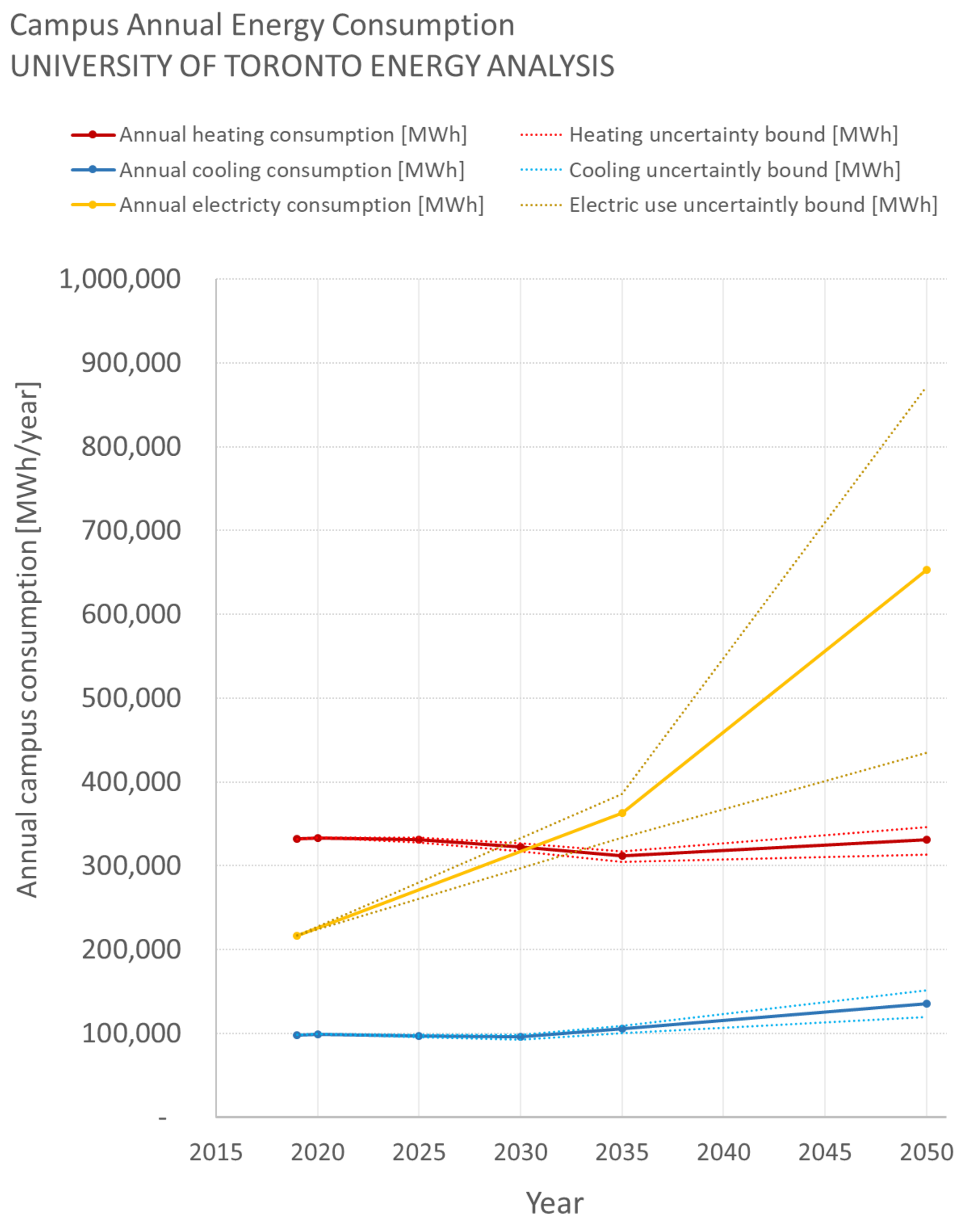


Figure 37 - Campus Total Annual Consumption of Final Design

8.4 Thermal Requirements Briefing by Nodes

8.4.1 Node 1 - North-West (Huron-Sussex Neighbourhood)

There are 9 new developments being added in 2025 (Site 1 on the North west corner of the node, Site E on the north east corner of the node, and various neighborhood residence infills).

A new nodal plant located at Site 1 will replace the existing Northwest Chiller Plant and support the surrounding buildings in not only chilled water (CHW) but also with low-temperature hot water (LTHW). The existing Northwest Chiller Plant will be demolished for new residential development. The nodal plant at Site 1 will house ground-source heat pumps (GSHP), and be connected to surrounding geoexchange borefield . The nodal plant will also include chillers and cooling towers for peaking / back-up capacity. Geothermal from Robert Street Field is currently shown to be connected to the nodal plant by 2025. Main CHW and LTHW piping will be distributed from this plant down south through the living lane and east to support gate E. This distribution must be completed by 2025 to support the new developments being built by 2025. All branches to buildings from the main piping will need to be installed and operational prior to new developments are built in the future.

The Huron Sussex Spadina Mid-Rise - Washington and Glen Morris developments are planned to be completed by 2030. Distribution for these two developments will be constructed by 2025 along with the other distribution and ready to be connected when the buildings come online.

A new 10” HTHW line is added from the central steam plant and fed up to Robarts. New heat exchangers in Robarts will take the new HTHW line and the existing HTHW and provide additional capacity into the nodal LTHW network. The two HTHW line approach is chosen in lieu of one bigger main because of the good existing conditions of the HTHW line and for better redundancy. The HTHW line is expected to re-adapt as MTHW when central steam distribution is phased out.

Existing chilled water distribution connecting existing buildings to the North-west chiller will be used where possible. It will be connected to the new CHW main and support existing building and other building not previously connected to the chilled water network. There will be no stand-alone heated or cooled buildings in this node. All buildings will be fed from the Nodal Plant in site 1. The CHW connections to Rotman, Massey College and Innis College are maintained but it is expected that these buildings will primarily be supported by chilled water from their nodal plant.

The existing MTHW line from Robarts to Rotman and Innis College will be abandoned in-place. These buildings will be fed LTHW from within their node and the infrastructure must be in-placed prior to the decommissioning of the MTHW line from Robarts to Rotman.

The HTHW line from Warren Stevens building will be demolished (or abandoned in placed) in year 2025. This building will receive LTHW and Chilled water from the Nodal plant in site 1 by year 2025. The building will need to be retrofitted in year 2025 to utilize the LTHW. The building conversion can be delayed if needed and thus delay the cut off from the HTHW.

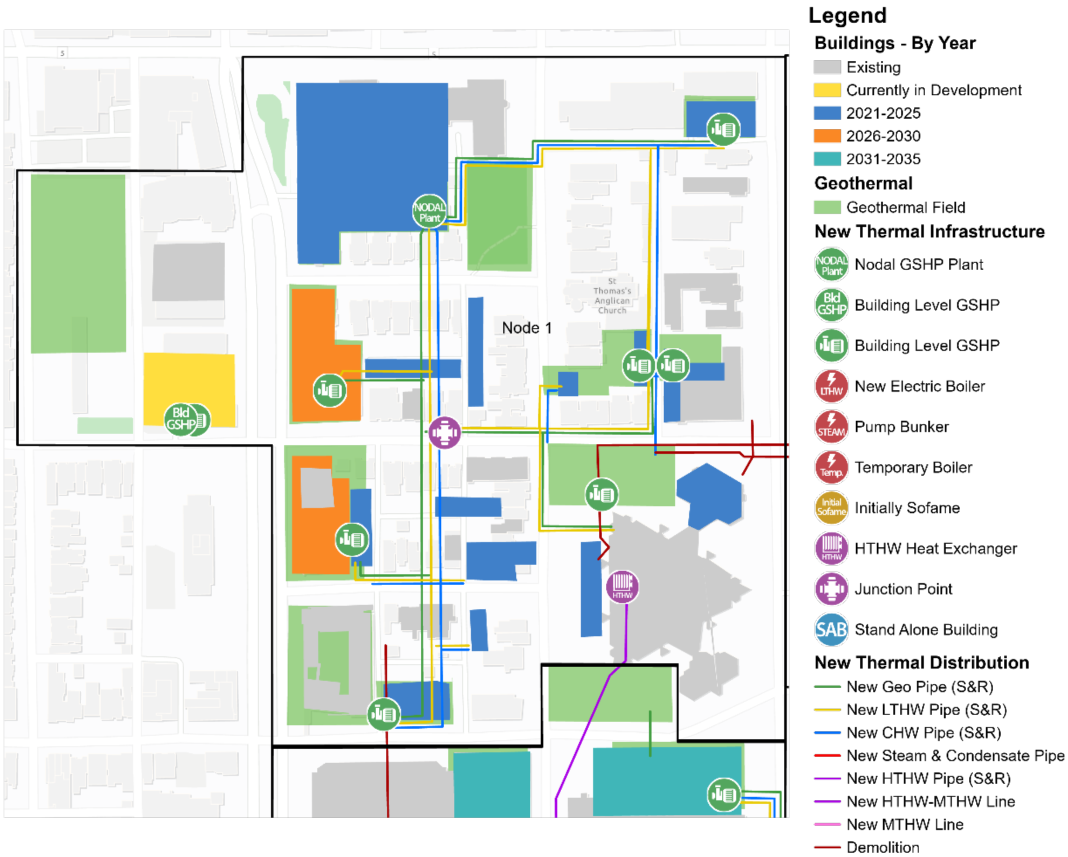


Figure 38 - Node 1 Thermal Design

Table 7 - Node 1 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	17.6 MW from NWCP (shared with Node 6)	12 MW Total: • 9.5 MW GSHP • 2.5 MW Chiller	15 MW Total: • 9.5 MW GSHP • 5.5 MW Chiller
Connected Cooling Load	5.8 MW	9.2 MW	12.1 MW
Heating			
Total Heating Capacity	From CSP & local boilers	20.7 MW Total: • 9.5 MW GSHP • 11.2 MW from CSP	20.7 MW Total: • 9.5 MW GSHP • 11.2 MW from CSP
Total Connected Heating Load	9 MW	13.0 MW	14.9 MW

Table 8 - Node 1 Phasing Summary Table

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants		- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric BOS			- GSHP - Chiller - Cooling Towers - Electric BOS
Geothermal Fields	1 Geothermal field	5 Geothermal fields (including underneath site 1)	2 Geothermal Fields (underneath Mid-rise Washington and Glen Morris development)		
Demolition		Demolition of NW Chiller Plant to new Residential Development			
Distribution Piping		- Trench Main - Trench Branch - Existing Demolition			
Building Conversion Upgrade building Steam to LTHW		32,900 m^2 of existing buildings	32,900 m^2 of existing buildings	32,900 m^2 of existing buildings	32,900 m^2 of existing buildings **To be completed by 2040*

8.4.2 Node 2 – East Central

Sidney Smith redevelopment is planned to be completed by 2030 with geoexchange borefield underneath. A new nodal GSHP plant with supplementary chillers and cooling towers will be added into Sidney Smith during the construction. The concept is to connect the geoexchange borefield south of Robarts, underneath the redevelopment of Ramsay Wright and Clara Benson to the nodal GSHP plant.

Existing HTHW and steam distribution that run below the Sidney Smith redevelopment will need to be re-routed to the west of the redevelopment to continue feeding buildings to the north and west in 2030. The piping re-route work will need to be completed before construction is started on Sidney Smith re-development. While the steam and HTHW are re-routed, the already built new HTHW line from the central plant to Robarts Library can be used to support all buildings in node 2. This is to prevent any disruption of service. The need to re-route the steam line underneath Sidney Smith is not required if Ramsay Wright can undergo building conversion from steam to HW prior to the redevelopment of Sidney Smith.

Clara Benson and Ramsay Wright redevelopment will be constructed by 2035 with geoexchange borefield underneath and pump bunkers. The geoexchange fields will be fed back to the nodal plant in Sidney Smith via geothermal pipes. Ramsay will receive LTHW and Chilled water from the nodal plant at Sidney Smith.

Warrant Stevens and Clara Benson will no longer be fed from the existing HTHW line and receive LTHW from the Sidney Smith nodal plant. If all the underground pipes to Clara Benson become too congested, then an alternate local GSHP plant is needed at the Clara Benson Redevelopment.

The existing HTHW line that goes through Warren Stevens to feed New College and Grad House will stay connected to the buildings for back-up. New College will undergo building retrofit and have its standalone building system, and Grad House is expected to supported by its own nodal network.

Table 9 - Node 2 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	Local Chillers	12.0 MW Total: • 5.3 MW GSHP • 6.7 MW Chiller	20.0 MW Total: • 5.3 MW GSHP • 14.7 MW Chiller
Connected Cooling Load	4.7 MW	9.7 MW	16.6 MW
Heating			
Total Heating Capacity	From CSP & local boilers	17.5 MW Total: • 5.3 MW GSHP • 12.2 MW from CSP	17.5 MW Total: • 5.3 MW GSHP • 12.2 MW from CSP
Total Connected Heating Load	7.4 MW	8.8 MW	14.3 MW

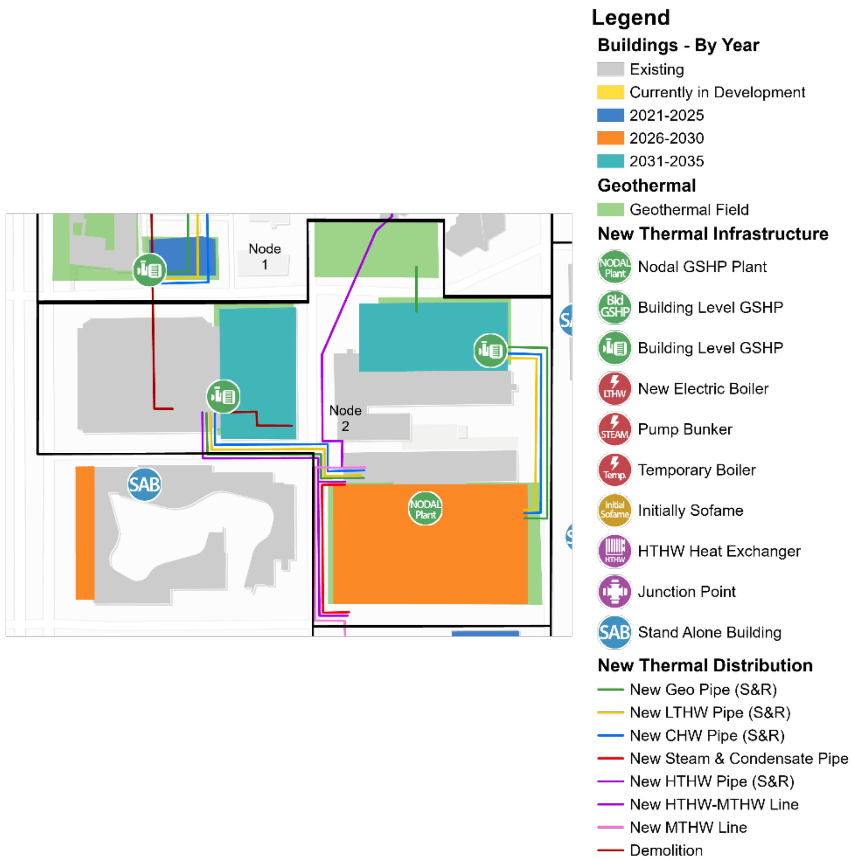


Figure 39 - Node 2 Thermal Design

Table 10 – Node 2 Phasing Summary Table

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants			- Mechanical Room Area - GSHP - Chiller - Cooling TowersElectric BOS		- Chiller - Cooling Tower - Electric BOS
Geothermal Fields			1 Geothermal Field	3 Geothermal Fields	
Demolition					
Distribution Piping			- Trench Main - Trench Branch Existing Demolition		
Building Conversion Upgrade building Steam to LTHW		16,300 m2 of existing buildings	16,300 m2 of existing buildings	16,300 m2 of existing buildings	16,300 m2 of existing buildings **To be completed by 2040*

8.4.3 Node 3 – Borden Building

Node 3 is a relatively small node due to its density and limited space available for geoexchange borefield. Borden building will be revitalized by 2035. A new nodal plant will be added into the new development. The area under this building and in the court yard in Earth Sciences and Bancroft street will have a geoexchange field installed and these will be connected back to the new nodal plant. Only Borden building is expected to be connected to the nodal plant and will contain GSHP, and supplementary chillers and cooling towers. The new MTHW line that extends from the new HTHW near Lash Miller will run through the existing HTHW lines in earth sciences will be connected to the nodal plant as backup. Existing steam distribution will stay in-place supporting the existing buildings until the existing buildings are converted with standalone system (All buildings marked as SAB on the map) If area for geoexchange borefield is available underneath or near the buildings, they are to include local GSHP and utilize the geothermal energy locally. The buildings using geothermal energy will require conversion from Steam to LTHW. Otherwise, they are to be retrofitted with ASHP/VRF or local electric boilers. Each will contain their own supplementary chillers and cooling towers.

Table 11 Node 3 Thermal Load and Capacity Table

	Existing	**2035**	**2050**
Cooling			
Total Cooling Capacity	Local Chillers	5.5 MW Total: • 1.1 MW GSHP • 4.5 MW Chiller	5.5 MW Total: • 1.1 MW GSHP • 4.5 MW Chiller
Connected Cooling Load	0.1 MW	4.5 MW	4.5 MW
Heating			
Total Heating Capacity	From CSP & local boilers	2.8 MW Total: • 1.1 MW GSHP • 1.7 MW from CSP	2.8 MW Total: • 1.1 MW GSHP • 1.7 MW from CSP
Total Connected Heating Load	0.4 MW	2.1 MW	2.1 MW

Figure 40 - Node 2 Thermal Design

Table 12 - Node 2 Phasing Summary

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants			- Mechanical Room - GSHP - Chiller - Cooling Towers - Electric BOS		-Electric BOS
Geothermal Fields			2 Geothermal Fields		
Demolition					
Distribution Piping			- Trench Main		
Building Conversion Upgrade building Steam to LTHW		500 m2 of existing buildings	500 m2 of existing buildings	500 m2 of existing buildings	500 m2 of existing buildings **To be completed by 2040*

8.4.4 Node 4 - South-West

The central steam plant (CSP) will serve as a nodal plant to support the surrounding buildings and as a central plant to provide supplemental heating to other nodal plants. This arrangement, as described in previous sections, leverage existing infrastructure to provide enhanced thermal resiliency. It also provides a higher degree of flexibility to integrate future low-carbon technologies at the CSP.

There are two new development by year 2025 in this node – the new Data Centre Building Phase 1 and the new Astronomy building. Geoexchange borefield will be installed underneath the buildings with 6-pipe connection to the CSP where new GSHP will be located. LTHW and HW are distributed from the CSP to the new development and existing development as they undergo building conversion to LTHW. Instead of having supplementary chillers and cooling towers at the CSP, the CSP will utilize the existing CHW connections and equipment at the BCIT chiller plant for supplemental cooling capacity. Future connection to CAMH redevelopment should be considered and be taken into account during the development of the New Data Centre Building Phase 1. CAMH will be redeveloped by 2035 with a geothermal borefield installed underneath the building.

A single Electrode Steam Boiler (i.e. CEJS 4200) is to be installed at the CSP by 2035 for peaking and back-up capacity. This allows for two 120,000 lb/hr boilers to be removed by 2035. The plant will operate mainly on natural gas fired boilers. By 2050, all remaining natural gas fired boilers are to be phased out and replaced with electrode steam boilers by 2050 and provide the remaining of the overall peak demand. The existing BCIT chillers 2 and 3 (total capacity of 10.5 MW or 3,000 ton) will needed to be renewed in the near future. 9 MW is expected to be required at a minimum in conjunction with the new 9 MW of GSHP.

Table 13 - Node 4 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	17.6 MW from BCIT	18.0 MW Total: • 9.0 MW GSHP • 9.0 MW Chiller at BCIT (renewed)	25.0 MW Total: • 9.0 MW GSHP • 16.0 MW Chiller at BCIT
Connected Cooling Load	11.7 MW	14.0 MW	20.9 MW
Heating			
Total Heating Capacity	From CSP & local boilers	23.5 MW Total: • 9.0 MW GSHP • 14.5 MW from CSP	23.5 MW Total: • 9.0 MW GSHP • 14.5 MW from CSP
Total Connected Heating Load	15.4 MW	16.8 MW	19.4 MW

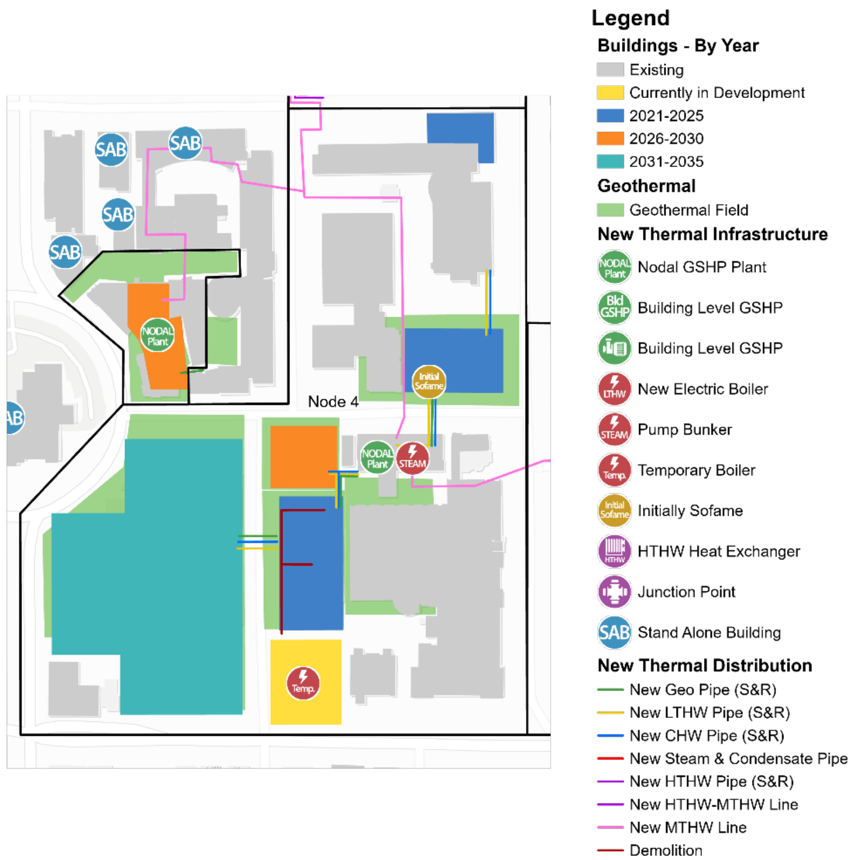


Figure 41 - Node 4 Thermal Design

Table 14 - Node 4 Phasing Summary

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants		- BCIT #2 and 3 chillers (renewal) - BCIT Cooling Towers	- GSHP at CSP	- Central Steam Boiler Plant Electric Boiler	- Chillers, cooling towers, and electric boilers expansion
Geothermal Fields		3 Geothermal Fields	2 Geothermal Fields	1 Geothermal Field	
Demolition				- Portion of CSP gas-fired boilers	- Remaining Central Steam Plant gas-fired boilers
Distribution Piping			- Trench Main - Trench Branch - Existing Demolition		
Building Conversion Upgrade building Steam to LTHW		27,800 m^2 of existing buildings	27,800 m^2 of existing buildings	27,800 m^2 of existing buildings	27,800 m^2 of existing buildings **To be completed by 2040*

8.4.5 Node 5 - South (King's College Circle)

There is no new major development by year 2025 except the Wallberg Sustainability Lab addition on top of the existing building. By 2030, node 5 will utilize the basement of the new Medical Science Building (MSB) West Wing Expansion as the nodal energy plant to provide heating and cooling to the MSB expansion as well as surrounding buildings via low-temperature hot-water (LTHW) and chilled water (CHW) piping. The nodal plant will house ground-source heat pumps, cooling towers and ancillary equipment, and will connect to geoexchange borefields within and adjacent to the node using new condenser water piping, including the Back Campus Field.

The new nodal plant at MSB West Wing Expansion is expected to connect to the existing MSB nodal chiller plant and the central heating system to provide peak capacity as well as transitional heating and cooling capacity to support unexpected changes to the future development phasing plan. For cooling, new control will be required to integrate the new nodal plant with the existing MSB nodal chiller plant. For heating, the nodal plant will utilize steam-to-hot-water heat exchangers to provide supplemental heating capacity for the new LTHW network.

The new nodal plant will also require infrastructure of Ground Water (GW), Low-Temp Hot Water (LTHW), Chilled Water (CHW). The required infrastructure should utility the existing chilled water network as much as possible, as well as the new LTHW infrastructure based on the new Landmark geothermal system. New Ground Water Piping infrastructure will need to be constructed for the new nodal plant. The new geo-exchange borefield are expected to be constructed incrementally over time, and the ground-source heat pumps and cooling towers at the new nodal plant are also expected to be built-out incrementally according to the construction of new geo-exchange borefields, with their construction anticipated between 2020 and 2030.

There will be a building-level GSHP plant at the Wallberg building and its infill expansion. It is served by a new geothermal field beneath the new Wallberg expansion. Low temperature hot water pipes will be provided to the buildings in the SW of the node by the MSB node plant as well.

It is expected that the central heating plant will be electrified or transitioned to a low-carbon technology in the future where there may not have exhaust heat to be recovered by the Sofame system. The Landmark geothermal plant will need to be modified with its geothermal capacity integrated with the MSB nodal plant.

All buildings marked as SAB on the map surrounding Node 5 will not be connected to a new nodal plant. These buildings have a relatively lower thermal demand and consumption density. They will be served by the existing central steam until they undergo building retrofit with standalone system such as ASHP/VRF or electric boilers. If geoexchange is available under/near the buildings, they are to include a GSHP and be self-sufficient locally. The buildings using geothermal energy will require conversion from Steam to LTHW. Each will contain their own Chillers and Cooling towers.

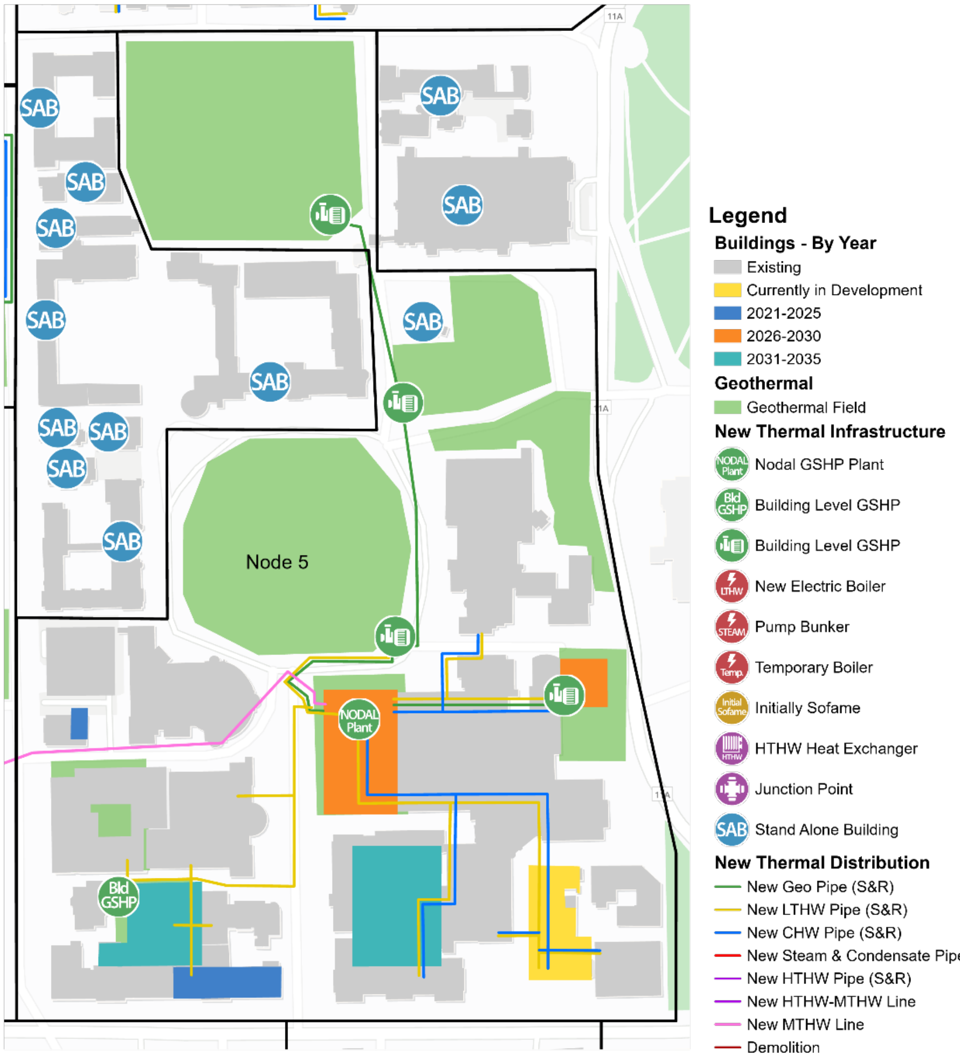


Figure 42 - Node 5 Thermal Design

Table 15 – Node 5 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	37.0 MW from MSB Chiller Plant	30.4 MW Total: • 15.4 MW GSHP • 15 MW Chiller	45.4 MW Total: • 15.4 MW GSHP • 30 MW Chiller
Connected Cooling Load	19.4 MW	24.1 MW	38.1 MW
Heating			
Total Heating Capacity	From CSP & local boilers	49.3 MW Total: • 15.4 MW GSHP • 33.9 MW from CSP	49.3 MW Total: • 15.4 MW GSHP • 33.9 MW from CSP
Total Connected Heating Load	35.0 MW	33.0 MW	40.2 MW

Table 16 - Node 5 Phasing Summary Table

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants			- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric BOS		- Chillers - Cooling Towers - Electric BOS
Geothermal Fields	1 Geothermal Field		5 Geothermal Fields	1 Geothermal Field	
Demolition			MSB Chiller Plant		
Distribution Piping	-		- Trench Main - Trench Branch - Existing Demolition		
Building Conversion Upgrade building Steam to LTHW	-	49,600 m^2 of existing buildings	49,600 m^2 of existing buildings	49,600 m^2 of existing buildings	49,600 m^2 of existing buildings **To be completed by 2040*

8.4.6 Node 6 – North

There are five new development in this node expected to be completed in conjunction with the Varsity arena master plan which is expected to begin in 2035. A nodal plant is proposed at the southeast corner of Varsity Arena. The new nodal plant will provide heating/cooling to the new and surrounding building with new ground-water (GW), chilled water (CHW), and low-temperature hot water (LTHW) piping infrastructure. New ground-source heat pump, chillers, cooling towers, and electric boilers are required at the nodal plant. The plant will connect to surrounding geo-exchange borefields to be constructed between 2020 and 2030. A connection to the existing central heating system is expected at the new nodal plant using steam-to-hot-water heat exchangers for supplemental and transitional heating capacity. Due to capacity limitations of the central heating distribution, local electric boiler(s) are required to provide peaking heating capacity of the nodal system. Underground piping for geothermal, chilled water, and low temp hot water are built by 2025. All buildings in this node are served by the nodal plant, including Rotman School of Management buildings and Innis College, which received CHW and partial heating from the west.

Table 17 - Node 6 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	From local cooling equipment	9 MW Total: • 7.0 MW GSHP • 2 MW Chiller	22.6 MW Total: • 7.0 MW GSHP • 15.6 MW Chiller
Connected Cooling Load	5.7 MW	8.2 MW	19 MW
Heating			
Total Heating Capacity	From CSP & local boilers	21.5 MW Total: • 7.0 MW GSHP • 14.5 MW from CSP	21.5 MW Total: • 7.0 MW GSHP • 14.5 MW from CSP
Total Connected Heating Load	10.5 MW	11.8 MW	16.3 MW

Figure 43 - Node 6 Thermal Design

Table 18 - Node 6 Phasing Summary

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants				- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric Resistance Boiler - Electric BOS	- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric Resistance Boiler - Electric BOS
Geothermal Fields		2 Geothermal Fields	2 Geothermal Fields		
Demolition					
Distribution Piping			- Trench Main - Trench Branch Existing Demolition		
Building Conversion Upgrade building Steam to LTHW		31,600 m^2 of existing buildings	31,600 m^2 of existing buildings	31,600 m^2 of existing buildings	31,600 m^2 of existing buildings *To be completed by 2040

8.4.7 Node 7 - North of Bloor

Nodal plant will be built by 2030 in the Ontario Institute. Node plant will contain GSHPs, chillers , and cooling towers for heat rejection backup. New 6 pipe underground loops will be built to all buildings in node by 2030.

Table 19 – Node 7 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	From local cooling equipment	3.6 MW Total: • 1.1 MW GSHP • 2.6 MW Chiller	3.6 MW Total: • 1.1 MW GSHP • 2.6 MW Chiller
Connected Cooling Load	2.3 MW	3.0 MW	3.0 MW
Heating			
Total Heating Capacity	From CSP & local boilers	3.7 MW Total: • 1.1 MW GSHP • 2.6 MW from CSP	3.7 MW Total: • 1.1 MW GSHP • 2.6 MW from CSP
Total Connected Heating Load	2.2 MW	2.9 MW	2.9 MW

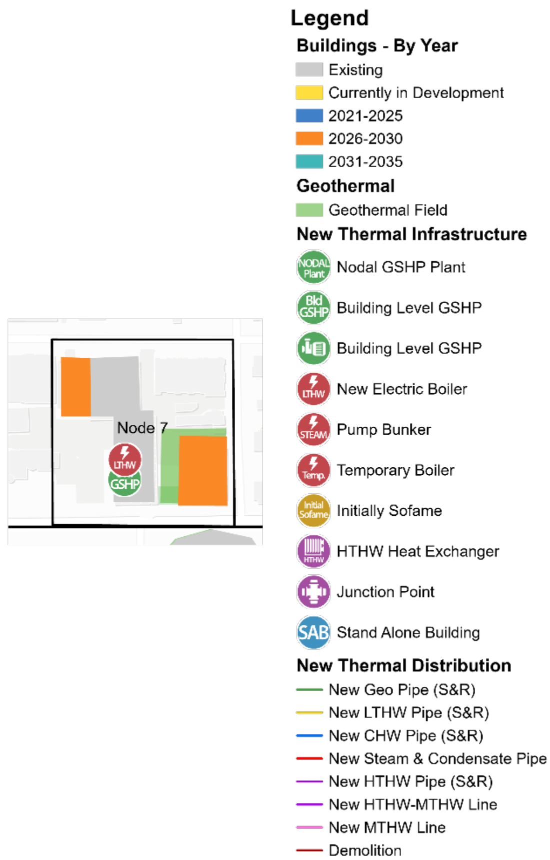


Figure 44 - Node 7 Thermal Design

Table 20 - Node 7 Phasing Summary Table

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants			- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric BOS		- Electric BOS
Geothermal Fields			1 Geothermal Fields		
Demolition					
Distribution Piping			- Trench Main		
Building Conversion Upgrade building Steam to LTHW		8,700 m^2 of existing buildings	8,700 m^2 of existing buildings	8,700 m^2 of existing buildings	8,700 m^2 of existing buildings *To be completed by 2040

8.4.8 Node 8 - South of College

Node plant will be built by 2025 in 167 College / 256 McCaul Redevelopment. Node plant will contain GSHPs, chillers, and cooling towers for heat rejection backup. New 6-pipe underground loops will be built to all buildings in node by 2025.

Table 21 – Node 8 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	From local cooling equipment	4.4 MW Total: • 1.8 MW GSHP • 2.6 MW Chiller	4.4 MW Total: • 1.8 MW GSHP • 2.6 MW Chiller
Connected Cooling Load	1.7 MW	3.8 MW	3.8 MW
Heating			
Total Heating Capacity	From CSP & local boilers	6.0 MW Total: • 1.8 MW GSHP • 4.2 MW from CSP	6.0 MW Total: • 1.8 MW GSHP • 4.2 MW from CSP
Total Connected Heating Load	3.3 MW	5.2 MW	5.2 MW

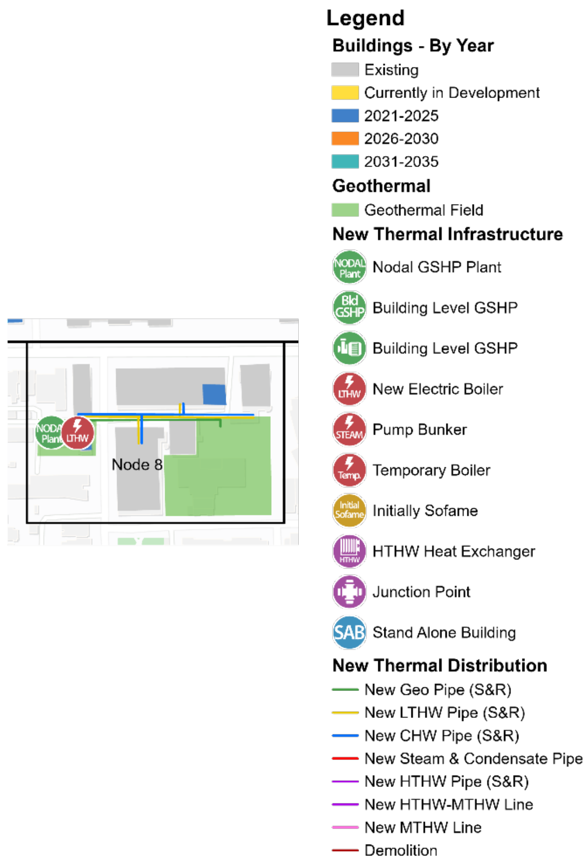


Figure 45 - Node 8 Thermal Design

Table 22 - Node 8 Phasing Summary Table

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants		- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric Resistance Boilers - Electric BOS			- Electric BOS
Geothermal Fields		1 Geothermal Fields		1 Geothermal Fields	
Demolition					
Distribution Piping		- Trench Main - Trench Branch - Existing Demolition			
Building Conversion Upgrade building Steam to LTHW		7,300 m^2 of existing buildings	7,300 m^2 of existing buildings	7,300 m^2 of existing buildings	7,300 m^2 of existing buildings *To be completed by 2040

8.4.9 Node 9 - East (East of Queen's Park)

Node 9 will be a fully independent stand-alone node, with existing steam distribution infrastructure to assist its transition. A nodal plant will be developed at the St. Michael's Boiler Plant by 2035. This plant contains GSHP and electric boilers to supply the HW and CHW needs for the node. Based on the available area for Geothermal Boreholes only a select number of buildings have been transitioned to utilize the nodal plant. The remaining building will be retrofitted to use ASHP/VRF or local boilers where possible.

The new development on Wellesley with be a Stand Alone Building (SAB) due to its relative isolation within the node.

Table 23 – Node 9 Thermal Load and Capacity Table

	Existing	2035	2050
Cooling			
Total Cooling Capacity	From local cooling equipment	3.9 MW Total: • 1.4 MW GSHP • 2.5 MW Chiller	5.9 MW Total: • 1.4 MW GSHP • 4.5 MW Chiller
Connected Cooling Load	4.4 MW	3.3 MW	4.8 MW
Heating			
Total Heating Capacity	From CSP & local boilers	7.7 MW Total: • 1.4 MW GSHP • 6.3 MW from CSP	7.7 MW Total: • 1.4 MW GSHP • 6.3 MW from CSP
Total Connected Heating Load	7.1 MW	6.0 MW	6.0 MW

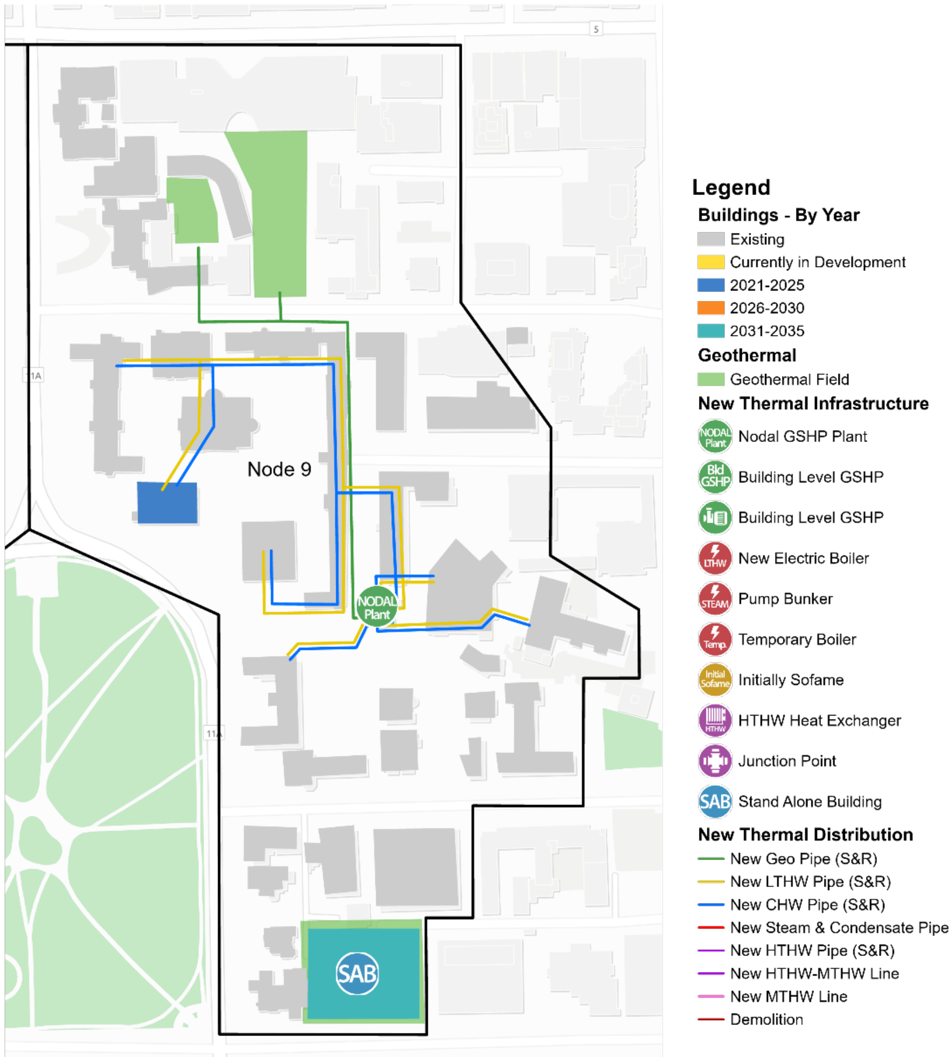


Figure 46 - Node 9 Thermal Design

Table 24 - Node 9 Phasing Summary Table

	Current Developments	2021-2025	2026-2030	2031-2035	2036-2050
Generating Plants			- Mechanical Room Area - GSHP - Chillers - Cooling Towers - Electric BOS	- Chillers - Cooling Towers - Electric BOS	
Geothermal Fields				3 Geothermal Fields	
Demolition					
Distribution Piping				- Trench Main - Trench Branch - Existing Demolition	
Building Conversion Upgrade building Steam to LTHW		23,900 m^2 of existing buildings	23,900 m^2 of existing buildings	23,900 m^2 of existing buildings	23,900 m^2 of existing buildings **To be completed by 2040*

8.5 Electrical Distribution Strategy

8.5.1 Introduction

The electrical distribution strategy takes its inspiration from the campus' existing high voltage (HV) loop structure. The strategy utilizes the existing HV switching station (also referred to as the "CED") and add three new HV switching stations; the new HV switching stations will be collocated with the large mechanical plant rooms planned for the Medical Sciences, Sydney Smith, Gateway, and Varsity renovations / new buildings, and are planned to come online in 2035, 2030, 2026, and 2024, respectively. The HV switching stations are labelled CED 1 through 5, where:

- Existing CED – CED 1;
- Medical Sciences Building - CED 2;
- Sydney Smith - CED 3;
- The Gateway - CED 4;
- Node 6 – CED 5

The University has advised that there are plans to relocate the existing CED (CED 1) from its current location in the central steam plant to the basement of the data center at the adjacent property. The current strategy is based on the assumption that the existing CED will be renewed and expanded in its current location as necessary to meet the demand outlined in this master plan. However, should the CED require to be relocated to the data center, the relocation can be accommodated with no material impact to the schedule and cost forecast.

CED #1, 2 , 4, and 5 will be serviced from one of the nearby available Toronto Hydro Transformer Stations (Cecil, Charles, and Bridgemen, respectively) and the five CEDs will be interconnected to provide multiple source redundancy. Toronto Hydro currently has three Transformer Stations located in close proximity to the campus: Cecil Transformer Station (which currently supplies CED 1) located south of College St., Bridgeman Transformer Station located north of the campus, and Charles Transformer Station located east of the campus. Exactly which Transformer Station each of the new CEDs will receive their feeders from is to be discussed and confirmed with Toronto Hydro. This configuration will provide redundancy for the campus in the event of a utility power loss at one of the Toronto Hydro Transformer Stations.

Once a new CED is online, loads from existing and new buildings will be migrated or added to the CED based on criteria outlined in the phasing strategy. The goal of the strategy is to transform the campus electrical infrastructure from what exists today, into something that will have the capacity to accommodate the ambitious power requirements from the final preferred thermal strategy, while achieving a level of flexibility to allow the campus to adapt to new and growing technologies. In order to achieve this, a set of criteria has been developed to evaluate when and where loads will be redistributed to the newly created CED.

The size (both physical and electrical capacity) of each CED is primarily dependent on the thermal strategy. As detailed in the resiliency section of this report, the current design accounts for backup power of 20% of the CED's capacity, where 10% of the backup loads would be taken from each adjacent CED. The physical sizes of the CEDs shown in the following table carry this assumption.

Table 25 - CED Electrical Room Size

CED #	Electrical Room Size (sqm)
CED1	1200
CED2	650
CED3	650
CED4	650
CED5	700

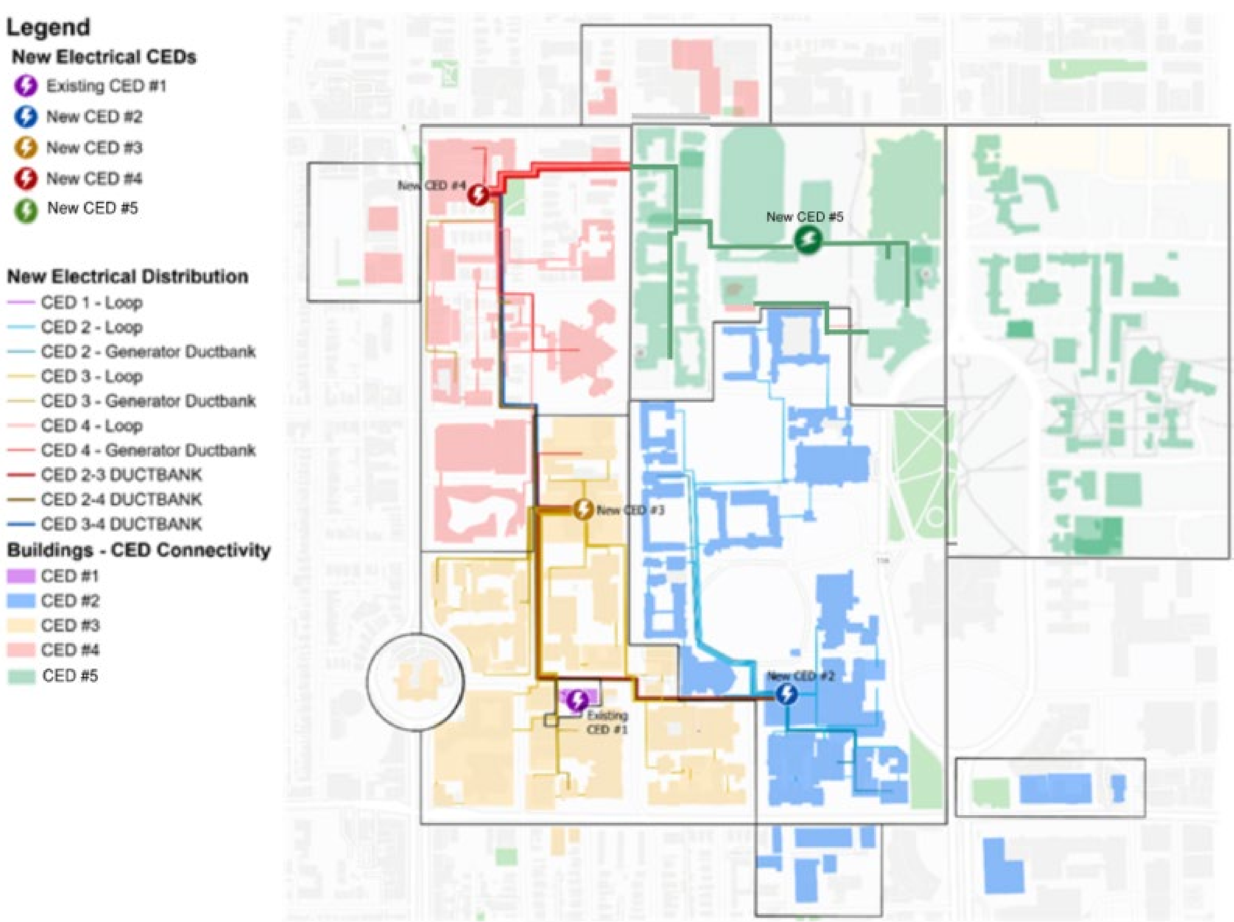


Figure 47 - Electrical Infrastructure Design by year 2050 Overview

8.5.2 High Voltage Loops

The master plan takes its inspiration from the existing CED loop structure found on campus. Buildings will be connected to a CED via a High Voltage closed loop network. Each loop is assumed to be using 750MCM cables (current University's standard), routed between buildings in concrete encased ductbanks. The number of buildings per loop may vary based on the demand load of each building.

8.5.3 Toronto Hydro

Toronto Hydro currently has three 13.8kV Transformer Stations located in close proximity to the campus. Each CED will receive redundant feeders (i.e. each feeder capable of supplying 100% of the demand load). The preference is for each CED's incoming feeders to come from different Toronto Hydro Transformer Stations.

8.5.4 Legislative Constraints

Based on recent discussions with Toronto Hydro, the University's current HV loop structure is a grandfathered system that could be difficult to emulate for newer projects. At issue is the ability to route new ductbanks across city-owned roadways to connect the various campus buildings. As a result of legislative changes over the years, only LDCs (local distribution companies) are now able to construct and own infrastructure that extends into the public right-of-way. The University is aware of the issue and is in discussion with Toronto Hydro on a potential solution.

Discussions have touched on arrangements ranging from building a new dedicated Toronto Hydro Transformer Station on (or under) campus, to Toronto Hydro providing power from existing Transformer Stations to the CEDs, where the CEDs are utility owned, but University operated. Coming to agreements with Toronto Hydro is crucial to final arrangement of electrical infrastructure on campus; however the Toronto Hydro have been collaborative to work together with the University, and no major risks are anticipated at this time.

The legislative constraints are outside of the scope of this study. The strategy and associated costs are developed based on the assumption that the infrastructure will be owned and operated by the University of Toronto.

8.5.5 CED demand

Demand load at each CED at 5-year intervals (values for each year are provided in MW, and represent the total anticipated demand load at each CED at that time):

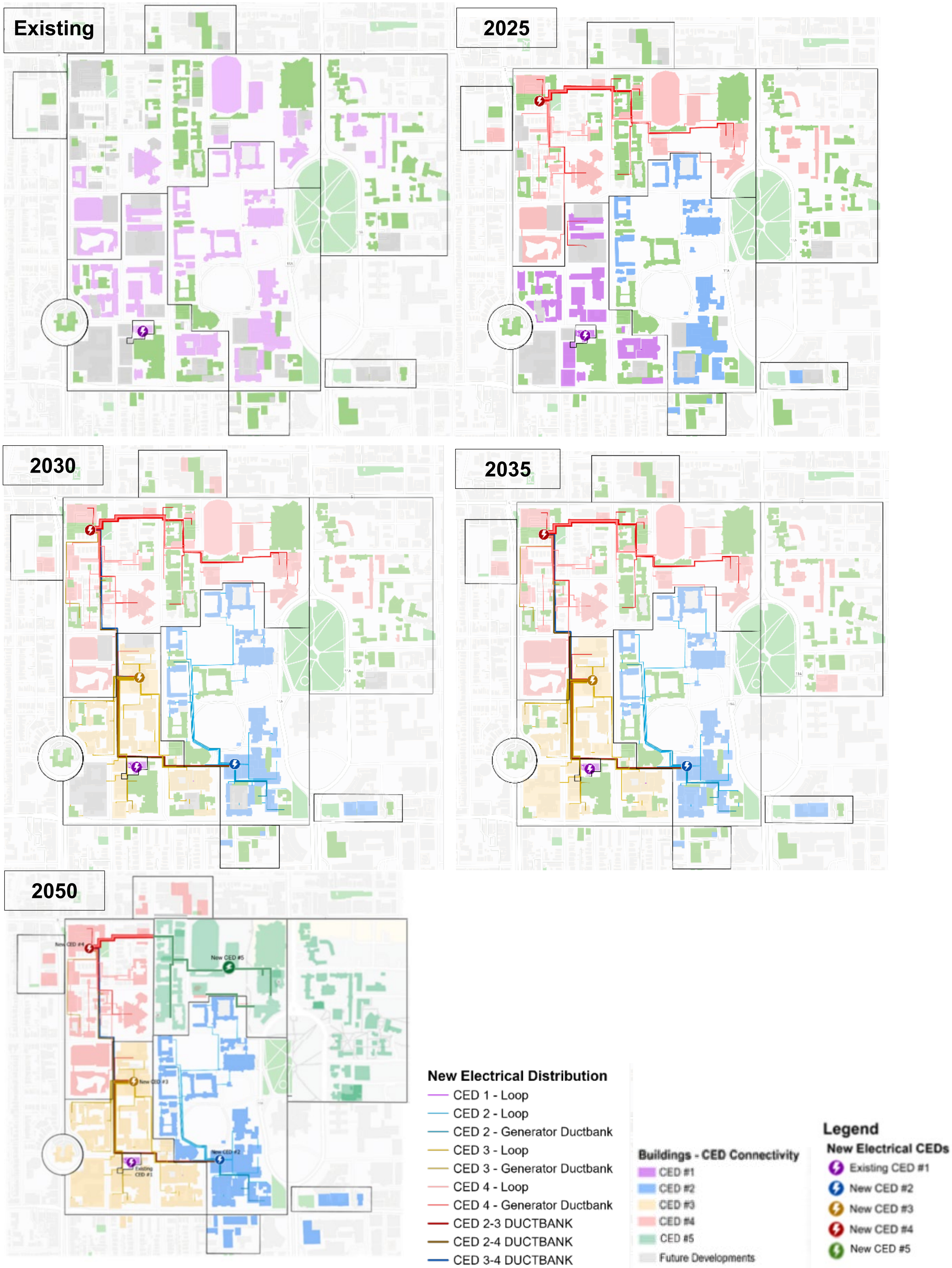
Table 26 – Estimated CED demand load by years

CED	Year Online	2019	2025	2030	2035	2050
1	Existing	40.24	30.01	0.00[(2)]	70.13	89.43
2	2030	n/a	n/a	19.06	24.34	35.52
3	2026	n/a	n/a	26.12	29.55	39.36
4[(3)]	2024	n/a	15.09	28.04	28.99	45.71
5[(3)]	2035	Tbd	Tbd	Tbd	Tbd	tbd
OTHER[(1)]	-	6.32	14.04	18.40	21.58	13.93
Grand Total (MW)		**52.18**	**59.14**	**91.62**	**174.59**	**223.95**

Notes:

1. Buildings outside of the Bloor-Spadina-College-University boundaries are assumed generally to not be connected to a CED.
2. CED 1 may not reach exactly zero load in 2030; however the intent is to show the migration of existing loops to the other CEDs in preparation for the coming of the steam electrification at around year 2035. This also provides a window of opportunity to renew / relocate the existing CED.
3. A demand load update will be provided for CED 4 and CED 5 once the concept design is complete.

Campus overview of buildings connected to each CED at 5-year intervals:



8.5.6 Phasing Algorithm

The electrical strategy considers the process for adding and migrating building power supplies between CEDs for new and existing developments. Some of the existing buildings on campus are fed directly by Toronto Hydro, while others are supplied by the CED.

The goal is to renew and transform the campus electrical infrastructure from what exists today, into a system that will have the capacity and flexibility to accommodate the changing world of the future. In order to achieve this, a set of criteria is evaluated to determine when and where loads will be redistributed among the newly created CEDs.

Is Building New or existing?	Existing incoming supply	Is desired CED online?	Action
New	N/A	No	a) Provide Direct Toronto Hydro Feed or b) Connect to existing loop infrastructure
New	N/A	Yes	Connect to desired CED
Existing	Toronto Hydro Fed	No	Continue using Toronto Hydro Feed
Existing	Loop Fed (Existing CED)	No	Continue using existing loop feed
Existing	Toronto Hydro Fed	Yes	Connect to CED – exact timeline to be determined by UofT*
Existing	Loop Fed (Existing CED)	Yes	Once target CED is online, phase construction of new ductbanks to migrate existing loops to new CED

* One of the more challenging scenarios are new / existing buildings that have dedicated feeders from Toronto Hydro. In this case the recommendation for when to transfer a building from dedicated feeders to loop fed will depend on the resiliency needs of the building, and whether other aspects of the infrastructure design (namely centralized batteries and generators) are operational. The main motivations for utilizing a loop distribution structure are to take advantage of benefits such as increased resiliency, access to central batteries to facilitate peak shaving, and to power the building in the future from centralized on-site power generation (once the system becomes available). The University will need to evaluate these existing buildings on a case by case basis, and decide when the best time is to migrate buildings based on

their mission criticality, availability of battery or other centralized renewable power, as well other consideration of neighbouring new construction projects where costs of new ductbanks can be consolidated.

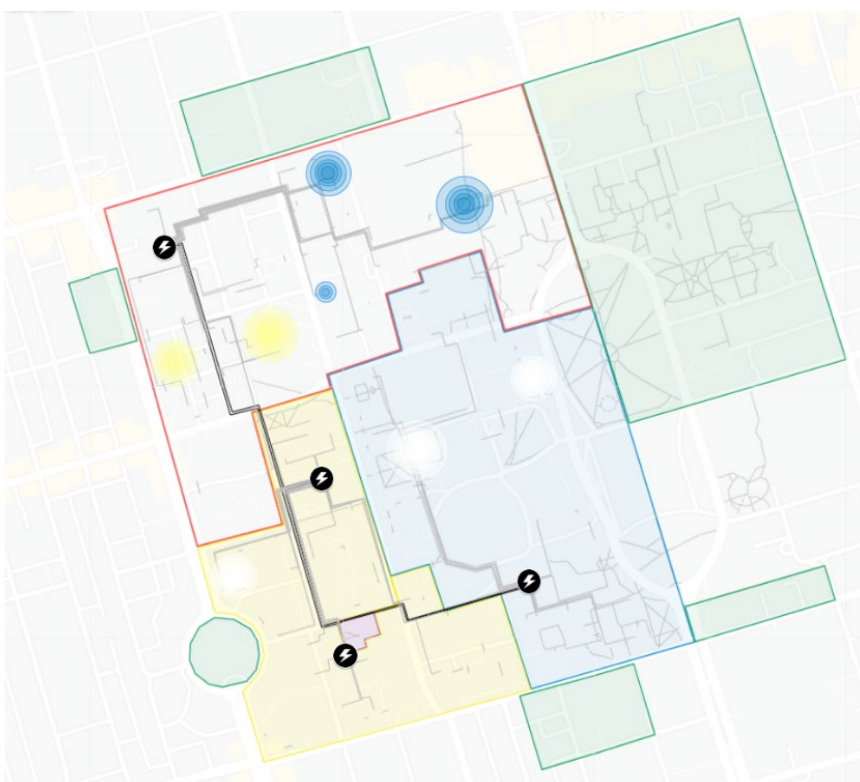
8.5.7 Redundancy and Resiliency

Regarding backup power, the University has previously expressed concerns over the reliability of the existing electrical system. The addition of multiple CEDs provides an opportunity to improve the resiliency of the campus infrastructure. By providing connections between the CEDs in the form of interconnecting ductbanks, downtime due to main equipment and utility failures can be minimized.

The backup power strategy is based on a type of “load shedding,” where adjacent CEDs can drop non-critical loads in order to redirect power to more critical loads. In order to achieve this, certain controls upgrades will need to be implemented; the costing analysis currently accounts for some form of a campus-wide SCADA system).

The current strategy considers that 10% of loads at each CED may be shed in the event of a failure at an adjacent CED. This in turn will provide power for approximately 20% of the demand load at the affected CED. This level of backup will be accomplished by providing ductbanks which connect one CED with two others, in a type of overall loop configuration not dissimilar from the HV loop network described earlier.

Representation of 20% Redundancy for an example scenario of CED #4 going offline (Take note, this example will be updated to include CED #5 upon completion of the concept design):



The master plan currently has CED 1 dedicated to the electrification of the existing steam plant. It has been determined that providing a fractional level of backup for this load type is not necessary, therefore no interconnecting ductbank is required between CED 1 and any other CEDs. Therefore, connections are only required between CED 2 and 3, CED 2 and 4, and CED 3 and 4.

The worst-case scenario being considered for the master plan is when one CED is brought offline due to a single point of failure. In this case, loads will be shed from adjacent CEDs, and the capacity can be diverted to the affected CED, where it can then be directed downstream to more critical buildings.

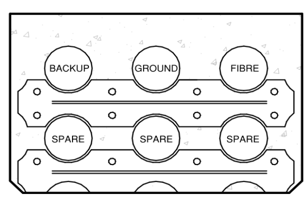
As an illustrative example: CED 2, 3, and 4 are 50MW each. In the event that CED 4 is offline, CED 2 and 3 will each free up 5 MW of power (through load shedding) to provide a total of 10MW of power to CED 4 to power critical loads.

Since only a small fraction of the overall demand load is being shed, extra reserved capacity is not required from Toronto Hydro to provide this level of backup capability. This strategy allows CEDs to continue to supply power to a limited number of buildings, while also supporting a small percentage of loads typically connected to an adjacent CED that is experiencing an outage.

For large scale utility power failures (i.e. full grid outages), the loss of power would be unavoidable, regardless of the infrastructure configuration. Provision for mobile generator connection at each CED has been included such that the University can maintain power to desired buildings for prolonged full utility outages.

Based on the 20% spare backup provision described above, the ductbanks interconnecting CEDs 2, 3, and 4 will be in a 3x2 duct configuration (900mm x 600mm). By comparison, the option of providing 100% backup to one CED would result in a 3x3 ductbank configuration (900mmx900mm). For an incremental cost increase, the University can consider building the ductbanks for 100% backup, even though the plan does not require it. The current cost analysis carries provision for 3x2 duct configuration.

20% Redundancy Ductbanks Configuration:



8.5.8 Flexibility

The University places a high degree of importance on the flexibility of an infrastructure design, specifically as it relates to the system's ability to accommodate new and growing technologies. By providing a centralized power distribution system, there is an opportunity to switch to localized power generation when the technology and cost becomes viable with minimal impact to the campus' electrical infrastructure.

8.5.9 Centralized High Voltage Generators

Of the existing emergency generators on the U of T campus, all will require replacement over the course of the Master Plan lifetime. Approximately 50% of the generators active on campus have already reached their lifetime expectancy and should be replaced as soon as an opportunity presents itself.

The two general design options to be considered are the current system (decentralized) versus a centralized system. The advantages and disadvantages of each are described here:

Table 27 - Centralized Life Safety System (HV Generators) vs. Decentralized Life Safety System

Centralized Life Safety System (HV Generators)		**Decentralized Life Safety System (Business as Usual)**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Decreased quantity of generators to maintain	HV authorised personnel required for maintenance	No HV maintenance requirements	Increased quantity of generators to maintain
Can achieve N+1 redundancy with less units	Failure of bus will have significant impact	Failures will have a smaller impact (affect less buildings)	Zero redundancy where single generator units utilized
Increased ability to take advantage of economies of scale (e.g. flexibility of configuration for 5MW demand)	Lower range of products for HV units.	Greater range of products for LV units.	Reduced ability to take advantage of economies of scale (e.g. Cost of single 500kW unit vs. multiple units summing to 500kW)
Installed capacity can follow load growth	Adding future generator plant requires integration into existing system	No need for complicated centralized controls No synchronisation required	-

	Requires synchronisation control		

Though both schemes are viable, a centralized approach with either diesel or natural gas emergency generators is recommended. The requirements outlined below assume natural gas (typically 1MW units); natural gas has greater benefits from a maintenance perspective when compared with equivalent diesel units.

Space has been allocated in each CED to allow for centralized high voltage emergency generators. The power provided by these will cover life safety and critical loads, and is meant to provide power for short durations only (2 hours). Requirements for emergency power are governed by code. Sizing of generator rooms is based on 10% of total demand load at the corresponding HV switch station (for life safety and critical loads). Unlike the backup power strategy for interconnected CEDs, the HV emergency distribution system is not currently interconnected between CEDs (the generators presently selected are not sized such that load shedding can be accommodated).

CED #	Generator Room (sqm)
CED 1	350
CED 2	200
CED 3	200
CED 4	200
CED 5	150

8.5.10 Phasing Algorithm

The phasing strategy for emergency generators will follow a similar approach to that of the HV loop infrastructure.

Is Building New or existing?	Is desired CED online?	Action
New	No	a) Provide standalone generator or Connect to existing generator distribution
New	Yes	Connect to HV generator distribution network at desired CED location
Existing	No	Continue utilizing existing emergency power infrastructure
Existing	Yes	Connect to CED when existing generator is at end of life

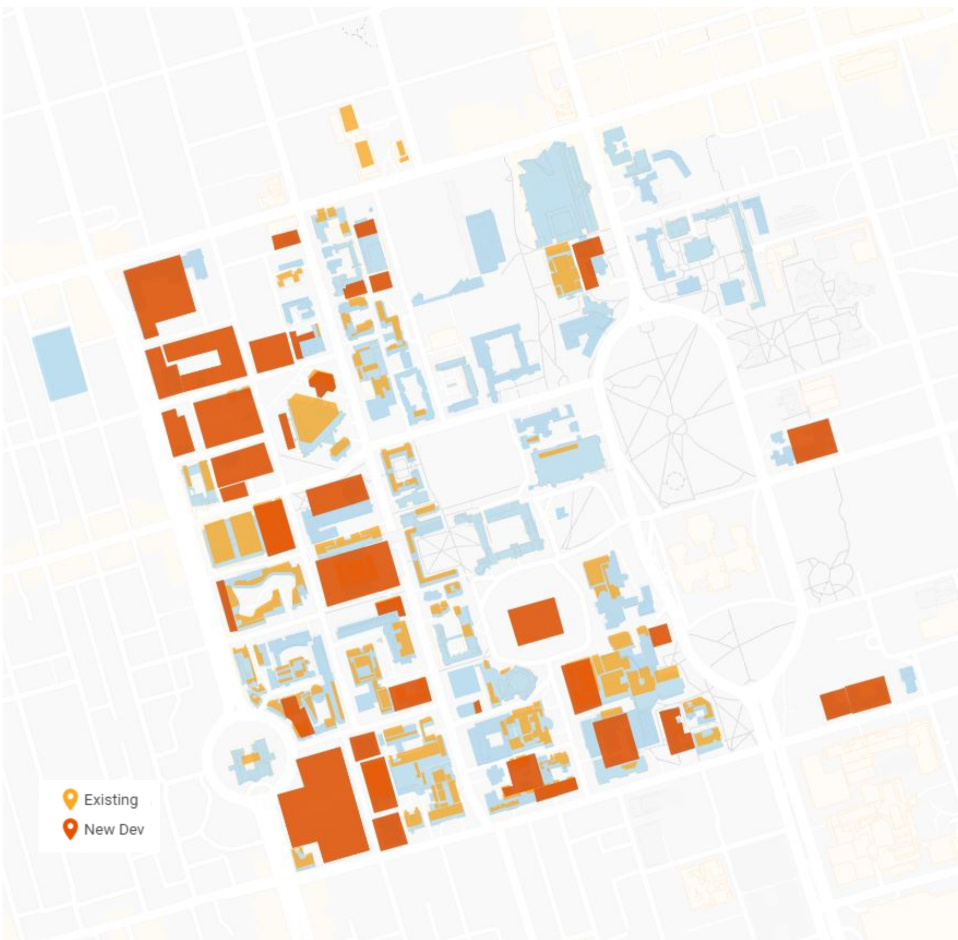
8.5.11 Renewable Energy Strategy

While onsite renewable energy generation can be incorporated in the campus strategy, the technology currently available does not allow for complete onsite power generation for the size of the demand load being proposed. The technologies outlined below are expected to supplement power provided by the local utility.

8.5.12 Rooftop Solar PV Integration

Rooftop solar PV is planned to be provided at the building level. Any PV systems would be metered and tied in to the building's main switchboard, which can be used to offset local power use. A number of existing buildings on the campus have been identified to have rooftop space to accommodate new solar PV panels. Studies will need to be conducted to determine feasibility of such spaces, including a structural load analysis, as well as additional space for electrical equipment and upgrades to the building switchboard. For new buildings, the default will be to provide rooftop solar PV and maximize the amount of usable space available. Current estimates indicate for rooftop solar PV to account for a total of maximum 6 MW of the campus' on-site electrical energy production. It is noted again that this assume all new buildings will include rooftop solar PV and, where possible, all existing buildings will be retrofit with rooftop solar PV. Through discussion with the University, it is noted that a 2 MW of solar PV system deployment over the next 10 years is more realistic.

On-site Rooftop Solar PV Utilization (Campus Map):



8.5.13 Batteries

As the thermal strategies shift the campus towards electrification, we can expect to see large changes in peak demand within the campus' electrical profiles. For example, the summertime peak due to high amounts of cooling are expected to be surpassed by the wintertime peaks due to the switch to electric heating.

With the outlook of electric profiles changing over the coming years, provision for some degree of battery storage systems becomes more viable. The forecast of a shift to renewable energy generation also provides a critical point where the market will support the need for batteries.

Space provisions for batteries have been made within each CED. The use case being considered is for peak shaving purposes (i.e. not currently supporting energy storage for back-up or redundancy from on-site generation or emergency systems). As technologies and campus conditions evolve the possible use cases for a centralized battery system may change. The current battery room provision is sized to support 10% of each CED's capacity for a maximum of 6 hours.

CED #	Battery Room (sqm)
CED1	900
CED2	450
CED3	450
CED4	450
CED5	400

8.5.14 Additional CED for Thermal Node #6

Following the Site Utility Master Plan, based on a feasibility study was provided by G Architects to finalize the location for the thermal nodal plant #6 (refer to Appendix I) . It was determined that nodal plant #6 shall be located on the Southeast corner of Varsity Arena. As part of that thermal node, an additional CED (CED#5) will be required to support the buildings within thermal node 6 and thermal node 9 (St Michael's college and Victoria College).. The new CED shall be fed from the Toronto Hydro Charles Street Transformer Station. The figure and table below shows a revised breakdown of the CEDs.

Figure 48 – Potential Alternative Electrical Infrastructure Design by year 2050

Table 28 – Estimated CED demand load by years

CED	Year Online	Load Type	Existing	2025	2030	2035	2050
1	Existing	Total	43.3	32.3	0.0 (2)	70.1	89.4
		Thermal Electrical Load of Total	0.0	0.0	0.0	70.1	89.4

2	2030	Total	n/a	n/a	20.4	24.9	33.6
		Thermal Electrical Load of Total	n/a	n/a	6.7	10.0	12.6
3	2026	Total	n/a	n/a	26.1	29.5	39.4
		Thermal Electrical Load of Total	n/a	n/a	6.8	7.4	10.0
4(3)	2024	Total	n/a	12.9	13.6	14.4	18.7
		Thermal Electrical Load of Total	n/a	4.1	4.1	4.4	5.2
5(3)	2035	Total	n/a	8.8	21.0	21.7	31.4
		Thermal Electrical Load of Total	n/a	12.2	12.2	13.3	19.0
Other (1) (Fed from Toronto Hydro)	-	Total	3.3	8.8	13.1	16.6	17.3
		Thermal Electrical Load of Total	0.0	5.1	8.5	8.7	8.7
	Grand Total (MW)		46.6	75.0	94.2	177.3	229.8

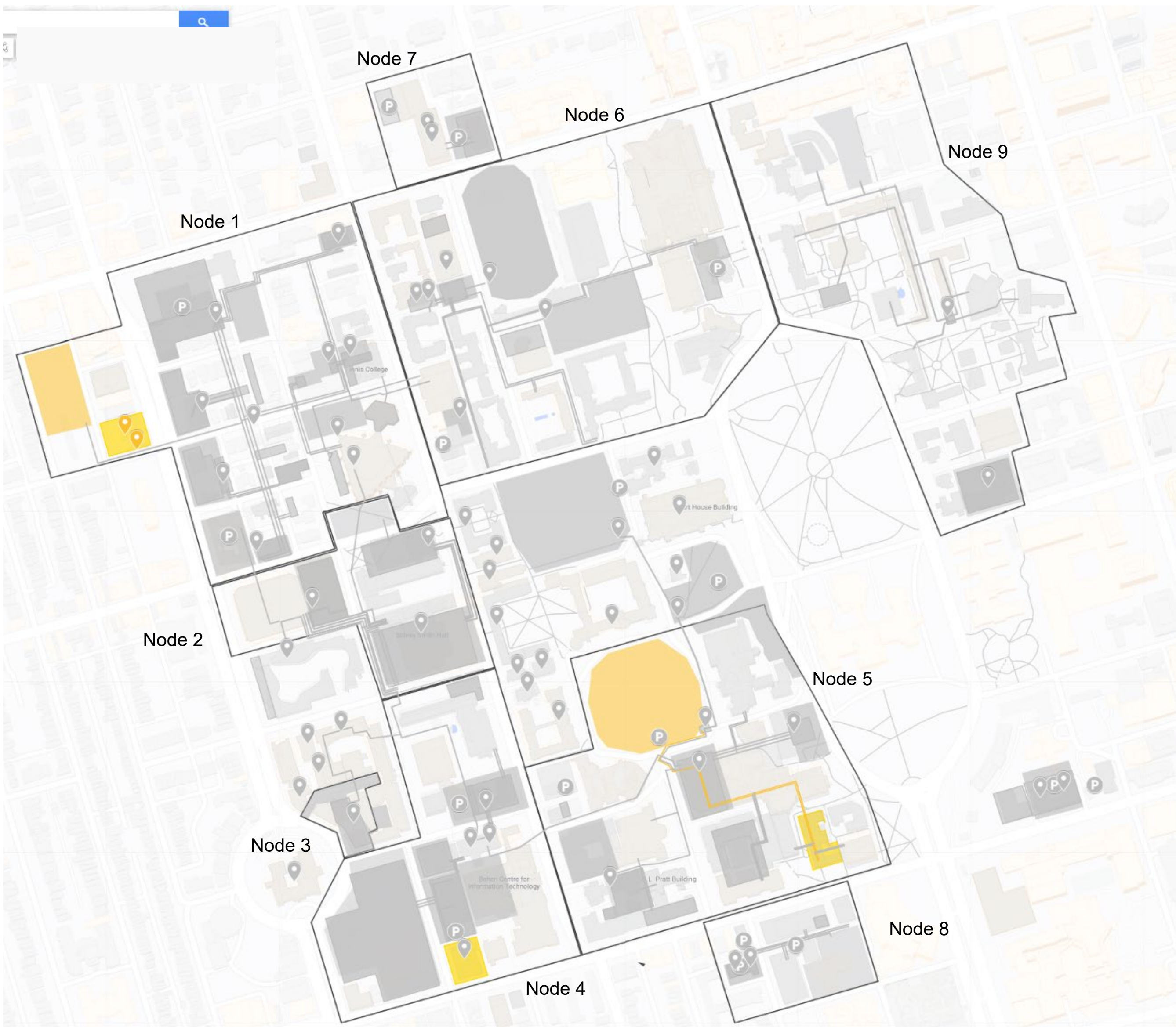
Notes:

1. Buildings outside of the Bloor-Spadina-College-University boundaries are assumed generally to not be connected to a CED.
2. CED 1 may not reach exactly zero load in 2030; however the intent is to show the migration of existing loops to the other CEDs in preparation for the coming of the steam electrification at around year 2035. This also provides a window of opportunity to renew / relocate the existing CED.
3. A demand load phasing update will be provided for CED 4 and CED 5 once the concept design is complete.

8.6 Nodal Phasing Strategy summarizes

8.6.1 Currently Ongoing Phase

Node	Description
Node 1	Robarts Street Geothermal Field and Spadina Sussex Residence development will be completed. A pump bunker and Building level GSHP will be added into Spadina Sussex Residence to connect to Robert Street Field.
Node 2	N/A
Node 3	N/A
Node 4	Student Commons development will be completed.
Node 5	KCC Geothermal field and Fitzgerald Revitalization will be completed. A new LTHW pipe will be added to expand the existing Sofame system and connect the geothermal field future pump bunker to the Fitzgerald Revitalization. A new chilled water pipe will be constructed from the Fitzgerald Revitalization to MSB for connection to MSB’s future nodal plant.
Node 6	N/A
Node 7	N/A
Node 8	N/A
Node 9	N/A

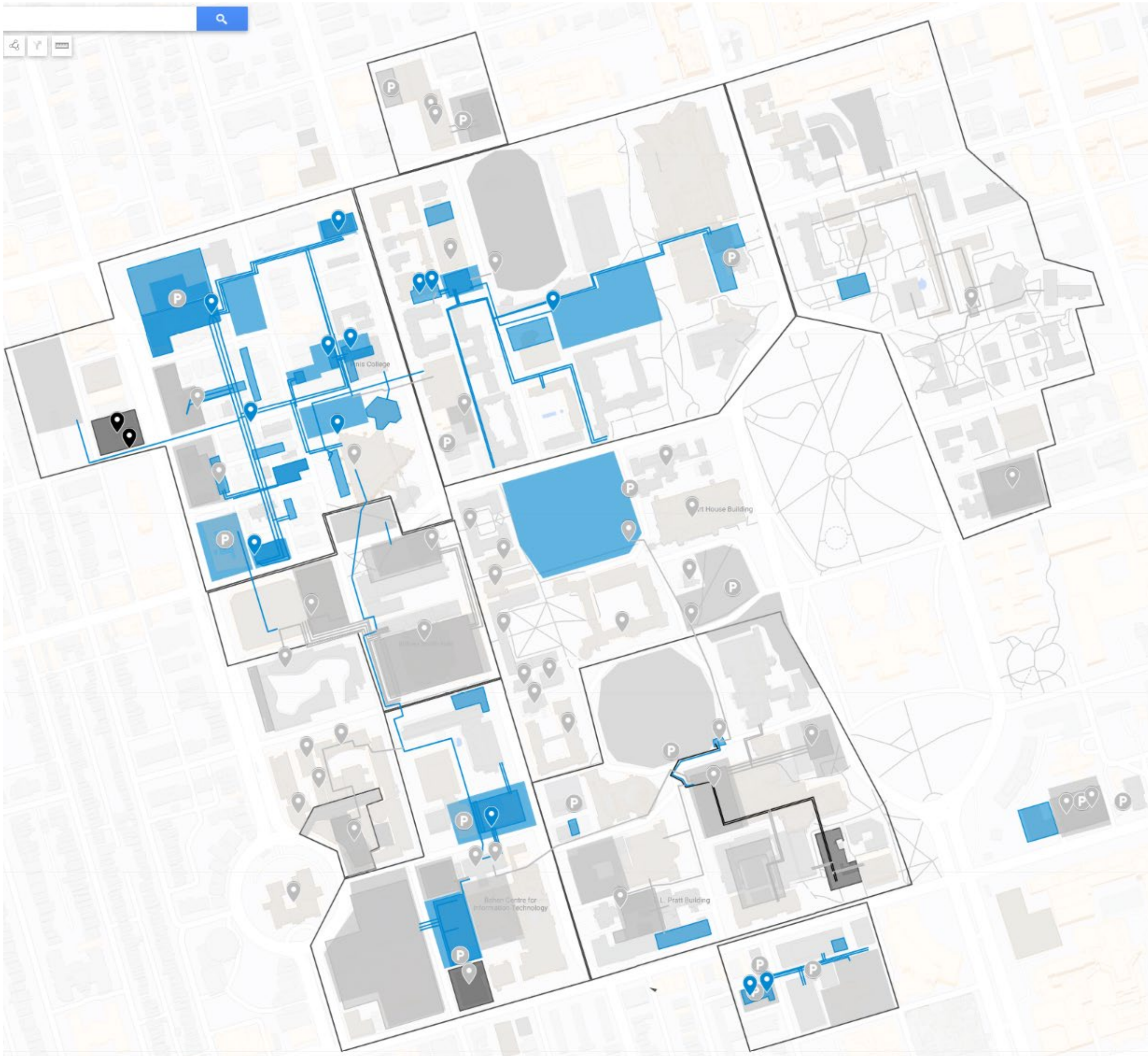


Map Legend

- New Geothermal Fields
- New Buildings, distribution, equipment
- Completed past phase work
- N/A to phase

8.6.2 Phase 2021-2025

Node	Description
Node 1	There are 9 new developments being added in 2025. A nodal plant at Site 1 will replace the northwest chiller plant. Within the Site 1 nodal plant, it will contain GSHP, chillers and cooling towers, CED(#4) and piping connections to the new surrounding geothermal field. New main piping will need to be installed along the Living Lane and Sussex Mews Ave to connect the geothermal field with Site 1 and for the distribution of LTHW and CHW from Site 1 to surrounding buildings. The heat transfer station at Robart Library will needs to be renewed, including new MTHW line connecting Robarts Library with Innis College and Rotman will need to be renewed. A new HTHW connection from CSP to Robarts Library is also proposed to supplement the new LTHW network.
Node 2	The new HTHW line from the CSP to Robarts will run across this node to backup the Huron Sussex LTHW network. The existing HTHW line running from Warren Stevens to Graduate House can be demolished and abandoned after Graduate House is connected to the Huron Sussex network.
Node 3	N/A
Node 4	Three new buildings are anticipated with geothermal system installed underneath the new Astrophysics and the Data Centre Phase 1 building. New GSHP will be installed at the CSP to provide new LTHW and CHW to the new buildings, with existing Sofame system and BCIT chillers for top-up. A new HTHW line will be added from the central steam plant and feed up to Robarts Library. This line does not replace the existing HTHW line.
Node 5	N/A
Node 6	N/A
Node 7	N/A
Node 8	Nodal plant will be built by 2025 in 167 College / 256 McCaul Redevelopment. Nodal plant will contain GSHPs, electric boilers, and cooling towers for heat rejection backup and 6-pipe underground loops will be built to feed all buildings in node. Geothermal field underneath the building and at the Orde St School.
Node 9	Northrop Frye development will be built.
Building Steam Conversion	By 2040, all buildings on campus are converted from internal steam/MTHW distribution for heating to LTHW distribution for heating (40,000 sqm per year). Key buildings to be converted before 2025 are buildings in node 6 connecting to the nodal plant as well as buildings that will be connecting to the CSP Sofame in Node 5.

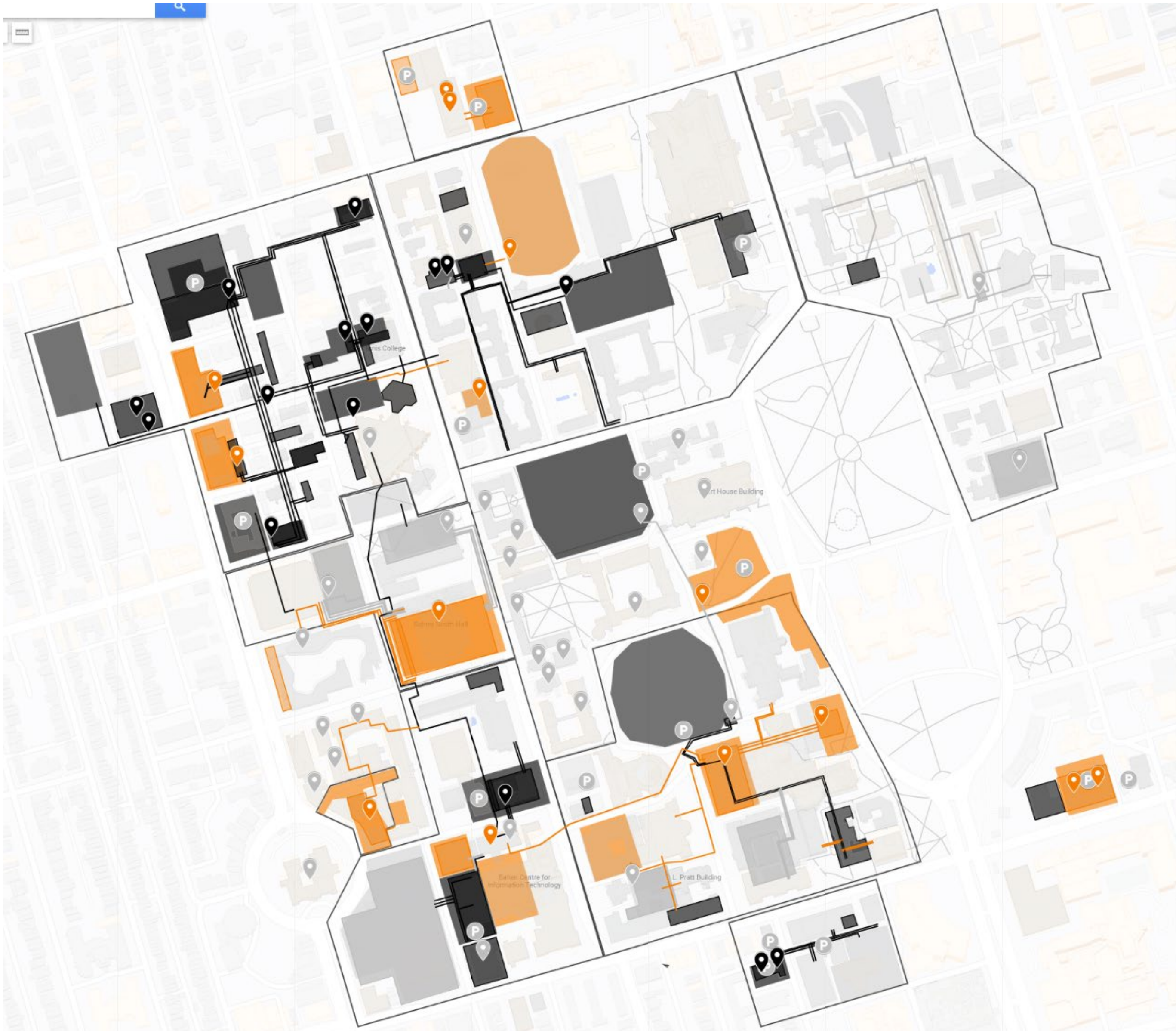


Map Legend

- New Geothermal Fields
- New Buildings, distribution, equipment
- Completed past phase work
- N/A to phase

8.6.3 Phase 2026-2030

Node	Description
Node 1	The Huron Sussex Spadina Mid-Rise - Washington and Glen Morris developments will be completed by 2030. Both developments will have a geothermal field underneath the building and a pump bunker for connection from the field to site 1 through already constructed geothermal piping.
Node 2	The Sidney Smith expansion will have a geothermal field underneath and house the Nodal plant with GSHP, chillers, cooling towers, and new CED #3. The nodal plant will only serve the Sidney Smith building itself by 2030, and support the redevelopment of Clara Benson and Ramsay Wright by 2035. The steam and HTHW will be rerouted to the west of the redevelopment of Sidney Smith to continue feeding buildings to the north and west. Rerouting of the existing steam line is not necessary if Ramsay Wright is converted from Steam. The 6-pipe connection between Clara Benson and Sidney Smith may not be feasible due to congestion and Clara Benson's geothermal system will need to be standalone. The existing HTHW line from Ramsay Wright to Warren Stevens will need to be rerouted to prepare for the redevelopment of Clara Benson.
Node 3	Borden will have a revitalization by 2030 and a geothermal field and nodal plant will be added. The nodal plant size will contain GSHP, chillers, cooling towers.
Node 4	Two geothermal fields will be added and connected to a new nodal plant within the existing steam plant building. GSHP nodal plant will provide chilled water and low temp hot water to all buildings in this node by 2035.
Node 5	A new nodal plant will built in the Medical Sciences Building Expansion and serve heating and cooling to the high-density-loads buildings in the eastern half of the node. Low temperature hot water pipes will be provided to the buildings in the SW of the node by the MSB node plant as well. Geothermal fields in the northern part of the node will be completed for future connection to the nodal plant. CED #2 will also be housed at the MSB nodal plant.
Node 6	N/A
Node 7	Node plant will be built by 2030 in the Ontario Institute and contain GSHPs, chillers , and cooling towers for heat rejection backup.
Node 8	N/A to phase
Node 9	N/A to phase
Building Steam Conversion	By 2040, all buildings on campus are converted from internal steam/MTHW distribution for heating to LTHW distribution for heating (40,000 sqm per year). All buildings connecting to the MSB nodal plant in node 5 should be converted by 2030.

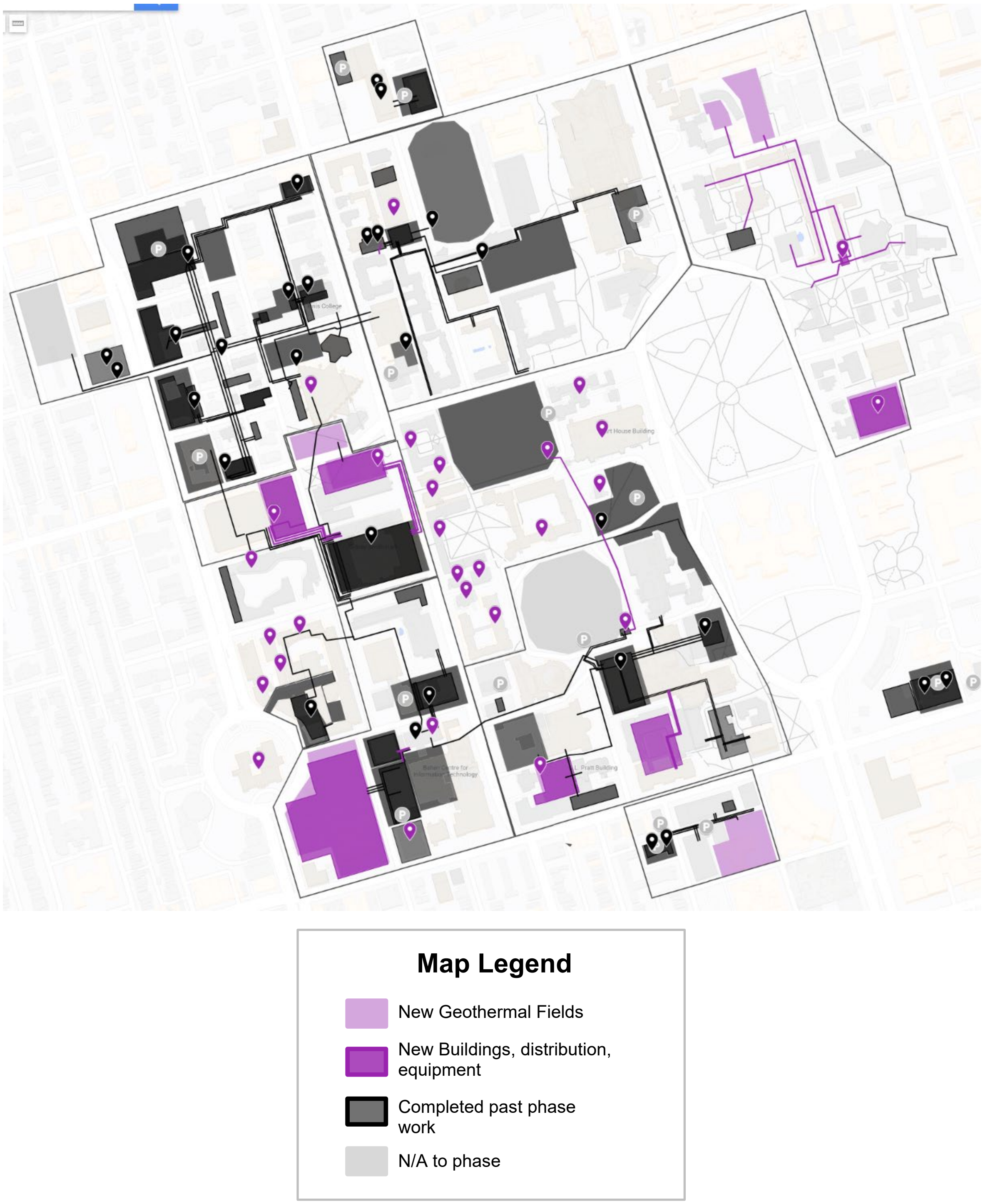


Map Legend

- New Geothermal Fields
- New Buildings, distribution, equipment
- Completed past phase work
- N/A to phase

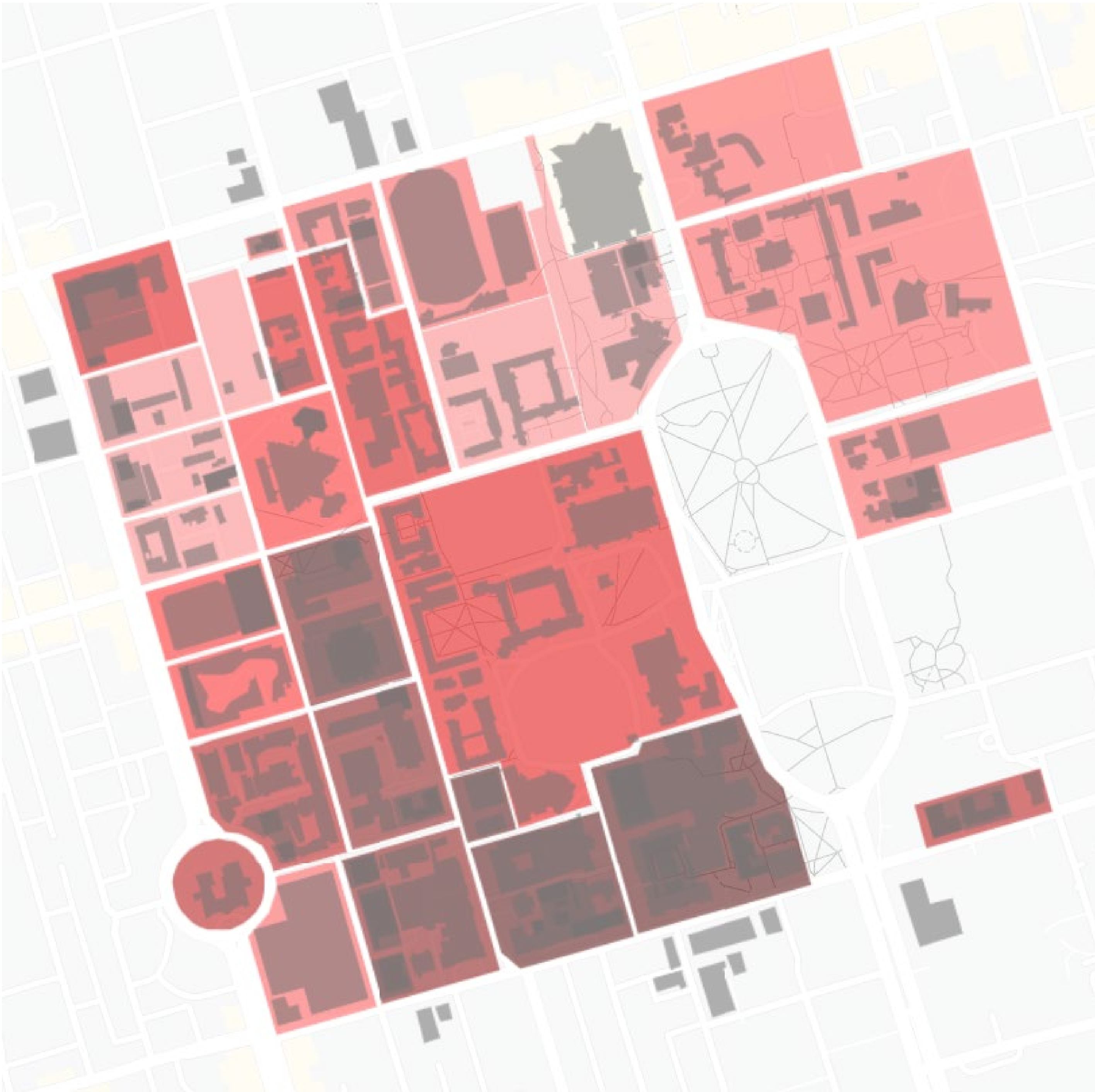
8.6.4 Phase 2031-2035

Node	Description
Node 1	N/A to phase
Node 2	Clara Benson & Ramsay Wright redevelopment will be constructed by 2035 with geothermal underneath and pump bunkers. The geothermal fields will be fed back to the Nodal plant in Sidney Smith via geothermal pipes. The 6-pipe connection between Clara Benson and Sidney Smith may not be feasible due to congestion and Clara Benson's geothermal system will need to be standalone.
Node 3	N/A to phase
Node 4	Two existing natural gas boilers are removed and a new electric steam boiler is added to the Central Steam Plant. CED #1 will need to be expanded accordingly. CAMH Development will be constructed with geothermal underneath.
Node 5	There will be a building-level GSHP plant at the Wallberg building expansion served by a new geothermal field beneath it. The geothermal fields in the northern part of the node will have geothermal pipes built and connected to the nodal plant by 2035.
Node 6	The new nodal plant will be built in the southeast corner of Varsity Arena, with GSHPs, electric boiler, chillers, and cooling towers for heat rejection backup. Steam connection from CSP are also kept for heating backup. Underground piping for geothermal, chilled water, and low temp hot water are built by 2035 to feed all buildings in node.
Node 7	N/A to phase
Node 8	A geothermal field will be added below the existing elementary school if the school gets demolished.
Node 9	A new nodal plant will be constructed at the St. Michael's Boiler Plant. This plant contains GSHP and Electric boilers to supply the HW and CHW needs for the node.
Stand Alone Buildings	All buildings marked as SAB on the map surrounding node 3 will not be connected to a new nodal plant. They will be equipped with local electric boilers. If geothermal is available under the buildings, they are to include a GSHP and utilize the geothermal energy locally.
Building Steam Conversion	By 2040, all buildings on campus are converted from internal steam/MTHW distribution for heating to LTHW distribution for heating (40,000 sqm per year). Key buildings to be converted are buildings connecting to the Sydney Smith nodal plant in node 2


Map Legend
New Geothermal Fields
New Buildings, distribution, equipment
Completed past phase work
N/A to phase

8.6.5 2036-2050

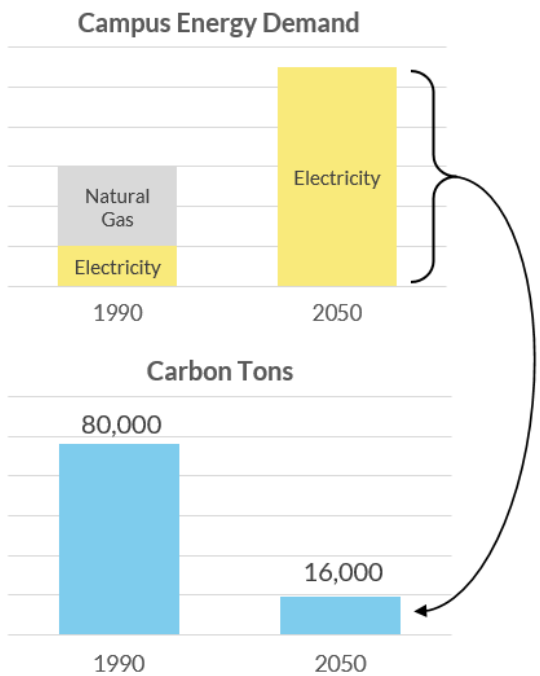
Node	Description
Node 1	Additional improvement of nodal plant equipment to increase capacity for nodal development built-out
Node 2	Additional improvement of nodal plant equipment to increase capacity for nodal development built-out
Node 3	N/A
Node 4	Additional improvement of nodal plant equipment to increase capacity for nodal development built-out. Remaining capacity at the CSP to be converted to electric based.
Node 5	There will be a building-level GSHP plant at the Wallberg building expansion served by a new geothermal field beneath it. The geothermal fields in the northern part of the node will have geothermal pipes built and connected to the nodal plant by 2035.
Node 6	Additional improvement of nodal plant equipment to increase capacity for nodal development built-out.
Node 7	N/A
Node 8	N/A
Node 9	Additional improvement of nodal plant equipment to increase capacity for nodal development built-out.
Building Steam Conversion	By 2040, all buildings on campus are converted from internal steam/MTHW distribution for heating to LTHW distribution for heating.



Note: Darker shade indicates a higher maximum area development potential, and vice versa

8.7 Offsite Renewable Systems

The Masterplan design achieves an 80% reduction of emissions from 1990. The remaining 20% of emissions, 16,000 tons, is due to the electricity grid emissions. To meet carbon neutrality additional measures must be considered. University of Toronto's mandate includes offsetting the remaining carbon emissions with university owned renewable energy systems and do not want to particulate in purchasing carbon offsets.



One feasible renewable energy system that could be procured is an offsite Photovoltaic Farm on university owned land. The system capacity is estimated at 350 to 450MW.

University of Toronto's must determine the carbon offset system to meet their Carbon Neutrality goal. The grid emissions factor, carbon tax cost, carbon offset cost, and grid electricity cost should all be examined when evaluating the most economical and future proof carbon offset strategy.

9 Conclusions and Next Steps

Through a closely collaborative effort with the University of Toronto with a diverse, cross-disciplinary inputs from major campus and external stakeholder, the Site Utility Master Plan assessed the existing site utility conditions, future campus thermal and electric load, and explored a range of potential energy supply and distribution options and technologies. One final strategy was selected to be the strategic direction for the St George Campus Site Utility Infrastructure to achieve campus carbon neutrality by 2050. The Master Plan includes an implementation schedule that further outline the description of the strategy, key milestone dates of major projects and key requirements of the strategy for the next 30 years.

The Master Plan's goal is to guide the stakeholders decision-making process to develop a long-term strategy for the campus site utility infrastructure. Preliminary design and cost estimation are developed at a master plan level to facilitate decision making and to compare different options that meets the University's objectives. The Master Plan is developed based on a set of assumptions and best information available provide by the University. It is not intended to predict the future. Events frequently do not occur as expected, and changes are constant. The Site Utility Master Plan should be treated as a living document that needs to be refreshed periodically to the constant changes happening to the campus. Design and cost estimation are expected to evolve as the design and planning of the campus and its component are further developed. Bridging feasibility studies for smaller components of the Master Plan (i.e. a nodal network or a nodal plant) is recommended prior to design and construction. The bridging feasibility study can be done independently from the design and construction team, or as part of the design and construction scope.

Appendix A. Existing Conditions Report

Appendix B. Existing Building Energy Conservation Potential Report

Appendix C. Future Demand and Consumption Analysis Report

Appendix D. Evaluation Matrix

Univesity of Toronto St George Campus

Utility Master Plan - Evaluation Matrix

Date: Dec-17-2019

Scoring	4	3	2	1	0
Description	Excellent performance	Good performance	Average/little impact	Poor performance	Unacceptable performance

Category Weighting	Category	Criteria	Description	Metric	Criteria Weighting (1-4)	Strategy 1	Strategy 2	Strategy 3	Strategy 1	Strategy 2	Strategy 3
30%	Environmental	Operational carbon intensity	CO_2e emissions during in-use phase	tCO_2e/kWh	4	2	4	3	8	16	12
		Embodied carbon intensity	CO_2e emitted during the manufacture, transport and construction, together with end of life emissions.	tCO_2e/kW	1	1	1	2	1	1	2
		Harmful emissions (N_2O. NOX, SO_2, O_3, VOCs, PM, refrigerants)	Emissions detrimental to human and environmental health	g/kWh g/kBtu	3	1	2	1	3	6	3
		Adaptability to Future Grid Emission Factor	Adapted to future utility market (clean/dirty grid)	Y/N	4	4	3	1	16	12	4
		New water use/demand	Demand for new water consumption (open loop systems)	Gallons per year	2	3	3	3	6	6	6
		Residual product requiring disposal	Management of by-products such as waste from nuclear micro-reactor or ashes from biofuel	qualitative score	2	2	2	2	4	4	4
15%	Resilience	Adaptable and Future Proofed	Adaptability to future technologies and changes in thermal demand due to climate change	Y/N	4	4	2	1	16	8	4
		Service Reliability - Electric	Degree of impact due to equipment outage and ability to provide backup (power supply)	Hours downtime or CAIDI	4	4	4	4	16	16	16
		Service Reliability - Thermal	Degree of impact due to equipment outage and ability to provide backup (thermal)	Hours downtime or unserved kWh	4	3	1	2	12	4	8
		Degrees of redundancy	Degree of backup when there is an equipment/system outage	#	4	4	2	3	16	8	12
		Islanding capability	Ability for entire system to be powered without connection to electricity grid.	Y/N	3	3	2	2	9	6	6
		Black start capability	Ability to recover from total power shutdown by an axillary power source.	Y/N	3	2	1	1	6	3	3
		Load shedding capability	Ability to deliberatly and selectivly drop specific electrical loads within system	%	3	2	3	2	6	9	6
		Backup generation - portion of critical load met	Providing emergency power to meet (portion of) critical load	%	4	3	3	3	12	12	12
		Electric/thermal energy storage - load duration available	Ability to incorporate battery or thermal energy storage system	Hours	2	2	3	2	4	6	4
20%	Operational	Staff Requirements	Quantity of operation staff required.	Y/N	4	4	4	2	16	16	8
		On-site spatial footprint requirements	Spatial requirements required for rooftop equipment and plant equipment within buildings.	m2	4	3	2	2	12	8	8
		Demand side management compatibility	The ability for buildings/system to adjust the energy demand in response to better match energy supply/generation under expected/unexpected events and operation.	%	4	4	4	4	16	16	16
		IoT technology (remotely controllable)	Intelligence for improved asset utilization and performance (remote controllability, design custom rules, analytics and monitoring)	Y/N	2	4	4	4	8	8	8
		O&M complexity	Complexity to operate and maintain the implemented technologies and systems	qualitative score	4	4	3	2	16	12	8
		Scheduled maintenance downtime	Presence of backup electrical and thermal systems to facilitate scheduled system downtime for maintenance	Hours downtime	4	4	2	4	16	8	16
		Technology maturity	Implemented technology is well established in the industry	qualitative score	2	4	2	4	8	4	8
		Complexity risk - permitting/regulatory	Complexity to implement technologies due to regulatory / permitting (i.e nuclear operation, waste removal, licenses)	qualitative score	1	3	3	3	3	3	3
		Complexity risk - interconnection	Complexity and quantity of existing buildings requiring thermal system conversion.	qualitative score	3	3	2	3	9	6	9
		Modularity / Phase-ability	Flexibility to implementation phase of planned infrastrure and reduced impact if changes required.	qualitative score	4	2	2	3	8	8	12
5%	Social	Ambient air quality	Exhaust air from combustion technologies and its impact on surrounding air quality	ppm	2	1	2	1	2	4	2
		Alignments with goals from the University of Toronto's committee on the Environment, Climate Change and Sustainability (CECCS)	Community engagement, teaching & education, research & innovation, University as an agent of change in the community, raising the profile of University's contributions toward climate change within and outside the academic community	qualitative score	4	3	3	3	12	12	12
30%	Economic	CAPEX	Costs for generation plants, building efficieny upgrade, distribution piping, building conversion, and electrical infrastructure.	$	4	3	1	1	12	4	4
		OPEX	Operating costs of Energy (electricity and natural gas), Operation & Maintenance and Carbon Tax.	$	4	2	3	3	8	12	12

Subtotals		Strategy 1	Strategy 2	Strategy 3
Environmental	Unweighted	38	45	31
	Weighted	18	21	15
Resilience	Unweighted	97	72	71
	Weighted	12	9	9
Operational	Unweighted	112	89	96
	Weighted	18	14	15
Social	Unweighted	14	16	14
	Weighted	3	3	3
Economic	Unweighted	20	16	16
	Weighted	19	15	15
	TOTAL	69	62	56

Appendix E. Development and Renewal Schedule

Appendix F.Equipment Capacity Table

Appendix G. Cost Summary of Design

Appendix H. Workshop Presentations

Appendix I. Energy Node 6 – Feasibility Study Report