

CORNELL UNIVERSITY ITHACA CAMPUS UTILITIES RELIABILITY AND ENERGY TRANSITION MASTER PLAN STUDY

Key Terms

Term	Definition
Allocational or Attributional Greenhouse Gas (GHG) Accounting	An emissions accounting system in which an entity (e.g. Cornell's Ithaca campus) uses average factors (e.g. NY grid-average CO_2/kWh) to allocate responsibility for shares of system-wide physical emissions for tracking and accountability within the boundary of the entity's site.
Borehole Thermal Energy Storage (BTES-HEAT)	A serial array of tightly spaced shallow boreholes (500-900 ft depth) designed to work as a "thermal battery." Stored heat is discharged during the heating season and charged off-season with nearby waste heat or renewable solar thermal energy.
Carbon Neutrality	Net-zero GHG emissions; offsets/removals balance all remaining emissions for accounting. Achievable "on paper" independent of fossil fuel free timeline for campus and/or the grid; ongoing expense with few direct benefits.
Coefficient of Performance (COP)	Ratio of the amount of useful heat or cooling delivered by a system to the amount of work or electrical energy required to run it. It measures the energy efficiency of heating, cooling, and refrigeration systems like a heat pump or chiller.
Combined Heat and Power (CHP)	Combined heat and power (CHP) is the simultaneous production of electricity and heat which boosts system efficiency by utilizing waste heat to meet campus heating requirements. Also called co-generation.
Cornell Combined Heat and Power Plant (CCHPP)	In 2009, Cornell installed a Combined Heat and Power (CHP) system consisting of two gas turbine generators at the Central Energy Plant, totaling 30 MW of electrical output with heat recovery steam generators (HRSGs) meeting 85% of annual campus heating needs.
Consequential Greenhouse Gas (GHG) Accounting	Uses marginal factors (e.g., emissions from the generator that responds to Cornell's load change) to quantify GHG impact (avoided or induced) of a specific intervention/decision (e.g., switching heating systems).

Term	Definition
	Consequential GHG accounting attempts to capture the system-wide impact of local changes.
Decarbonization	The process of reducing or eliminating human-caused carbon dioxide (CO2) and other greenhouse gas emissions, primarily by switching from fossil fuels to renewable sources.
District Energy	A centralized system producing electricity, chilled water, hot water, and/or steam to serve a network of nearby buildings.
Earth Source Heat	A research program that investigates the science, engineering, policy community implications and technological feasibility of harvesting renewable thermal energy from deep within the earth.
Energy Savings Performance Contract	A financial or funding opportunity for energy efficiency projects in non-residential buildings – designed to deliver energy savings that are at least equal to the amount of the payments needed to finance the improvement projects.
Enhanced Energy Conservation	Projects identified to avoid capital costs as well as reducing energy use, thermal demand and greenhouse gas emissions.
Fossil Fuel Free	A system that provides campus energy without combustion of coal, oil, or gas by replacement of fossil-fueled systems with electric-powered systems served by renewable energy sources.
Geoexchange	A renewable heating and cooling system that uses the stable, moderate temperature of the earth as a heat source in the winter and a heat sink in the summer to move heat between the ground and buildings.
Marginal Emission Rate	The amount of greenhouse gas emissions (typically in lbs/MWh) produced by the specific, last-activated power plant required to meet an incremental increase in electricity demand.
Master Plan	A comprehensive, long-term framework that outlines a cohesive physical vision, land use, infrastructure, and

Term	Definition
	development strategy for a site or community that is flexible and adaptable to changes in policy and conditions.
Master Plan Study	The investigative and analytical process—or the report documenting that process—that comes *before* or *during* the creation of a master plan to evaluate feasibility, existing conditions, data collection, and options.
Recoverability	The speed and effectiveness of restoring normal operations following a failure.
Reliability	The consistency of a system to operate without failure.
Renewal	Repairs and updates to significantly extend the life of existing equipment and infrastructure without replacement.
Resiliency	The ability to withstand and adapt to disruptions

Acronyms and Abbreviations

Acronym	Full Name
BaU	Business as Usual
BTES	Borehole Thermal Energy Storage
CEP	Central Energy Plant
CCHPP	Cornell Combined Heat and Power Plant
CCS	Carbon Capture and Storage
CETI	Cornell Energy Transition Initiative
CHP	Combined Heat and Power
CLCPA	Climate Leadership and Community Protection Act
CTG	Combustion Turbine Generator
CUB	Cornell Utility Building (East, North and South)
CUBO	Cornell University Borehole Observatory
CWP	Chilled Water Plant
DEFR	Dispatchable Emission-Free Resource
ECI	Energy Conservation Initiative
ESH/EGS	Earth Source Heat or Enhanced Geothermal System
ESPC	Energy Savings Performance Contract
ETS	Energy Transfer Station
GSHP	Ground-Source Heat Pump (i.e. Geo-exchange)
HRSG	Heat Recovery Steam Generator
klbs/hr or kpph	kilopond per hour (units for steam)
LCCA	Life-Cycle Cost Analysis
LSC	Lake Source Cooling
MAS	Maple Avenue Substation (Cornell owned, existing)
MER	Marginal Emission Rate
MMBtu	One million British Thermal Units
MMR	Micro Modular Reactor
NYCI	New York Cap & Invest
NYISO	New York Independent System Operator
NYSEG	New York State Electric and Gas
O&M	Operations and Maintenance
QBL	Quadruple Bottom Line
RNG	Renewable Natural Gas
SMR	Small Modular Reactor
SOFC	Solid Oxide Fuel Cells
STG	Steam Turbine Generator
UR&ET	Utilities Reliability and Energy Transition
WSHP	Water Source Heat Pump

List of Contributors

Cornell Contributors	Role
UR&ET Core Team	UR &ET Vision Statement and Project Charter
Buildings and Properties (B&P) Trustee Energy Subcommittee	QBL criteria, oversight
Brooks Center for Infrastructure (BCI)	Infrastructure oversight
Energy Conservation Controls Operations (ECCO) Team	Energy Conservation Initiative Studies
University Architects and Planning (UAP)	2008 Campus Master Plan Integration and Potential Growth oversight
Cornell Facilities Engineering (FE)	Building Design Standards and Process Steam Loads study
Carbon Neutral Campus Committee	Education and Engagement oversight
Faculty Advisory Committee (FAC)	Evaluation Criteria
Community Advisory Teams (CAT)	QBL criteria - community
Students	MEng and Energy Transition Club Studies

External Consultant Contributors	Role
NYSERDA Flextech Program	Cost-share funding and technical review
Jacobs	UR&ET Master Plan Study
Bond	Cost Estimating
Anderson Lab	Emissions Impact Study
Baringa with MWh	Retail Electric Rate Forecast Study
Ramboll	North & East Campus Geoexchange Study and Steam to HW Master Plan study
CHA	Above-ground ESH Study and Chilled Water Renewal and Expansion Study
KFI	Conditions Assessment Study
Pond	Conditions Assessment Study
GeothermEx	Below-surface ESH Study

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List of Scenarios Used in Report

Number	Short Name	Full Name
Scenario 0	S0_Baseline	Baseline (Lowest Capital Option)
Scenario 01	S1_BaU	Business as Usual with CHP in Perpetuity
Scenario 02	S2_Steam Elec Boiler	Electric Steam Boilers in 2035
Scenario 03	S3_Steam Elec Boiler and chillers	Electric Steam Boilers + Steam Heat Pumps + Heat Recovery Chillers
Scenario 04	S4_Steam Elec Boiler+geoX	Electric Steam Boilers + North Campus Geoexchange
Scenario 05	S5_Steam Elec Boiler, Hourly Matching RE	Electric Steam Boilers with Hourly Matching Renewable Energy
Scenario 06	S6_Earth Source Heat	Earth Source Heat
Scenario 07	S7_BTES, geoX	Core Campus BTES + North & East Campus Geoexchange
Scenario 08	S8_BTES, geoX optimization	Core Campus BTES + North & East Campus Geoexchange + System Optimization
Scenario 09	S9_BTES, geoX, ECI	Core Campus BTES + North & East Campus Geoexchange + Enhanced ECI
Scenario 10	S10_BTES, geoX, ESH	Core Campus BTES + North & East Campus Geoexchange + ESH
Scenario 11	S11_geoX	Geoexchange for Full Campus
Scenario 12	S12_UTEN	Utility Thermal Energy Network (UTENs) with Peak Shaving

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CHAPTER 1: INTRODUCTION

Cornell's Ithaca campus operates an efficient, reliable, and adaptable district energy system that produces and distributes electricity, heating, and cooling through an underground campus-wide network. The Utilities Reliability and Energy Transition (UR&ET) program pursues solutions to eliminate fossil fuels used in the Ithaca campus district energy system, whether originating from electricity generated on-site or purchased from the New York state grid.

UR&ET Vision Statement

Cornell University seeks to build and operate a resilient, reliable, affordable, and efficient energy system that supports a world class teaching and research institution. The Ithaca Campus district energy system will reduce emissions, support state efforts to decarbonize the energy sector, and serve as a research and teaching nexus for energy innovation while enabling regional solutions.

Utilities Reliability & Energy Transition Guiding Principles

The master planning process focuses on energy consumption, distribution, and production facilities of Cornell's Ithaca campus district energy system. Existing conditions and operations and maintenance practices of current assets are evaluated. Recommendations include both short- and long-term opportunities with an emphasis on technology currently deployable and at-scale.

Key priorities for the master planning effort include the following:

- **Resiliency:** For this effort, resiliency encompasses reliability (i.e. utility service is available when needed most), redundancy (i.e. loads are met despite loss of equipment), and recoverability (i.e. loads are met despite equipment or grid outage)

- **Climate:** Reduce *consequential* emissions from on-campus generation and grid purchased electricity. Consequential emissions measure the net, system-wide change as a direct result of a specific action. The goal is to avoid actions that merely shift on-site fossil fuel emissions to a fossil fuel-based grid.

- **Renewal:** The plan will consider existing asset ages and necessary repairs and updates to significantly extend the life of existing equipment and infrastructure without replacement. For example, having chillers over 40 years of age impacts resiliency analysis.

- **Constructability:** Minimize campus disruption by aligning projects. For example, coupling hot water conversion efforts with pavement or stormwater rehabilitation projects.

- **Regulatory Impacts:** The NY Climate Leadership and Community Protection Act (CLCPA) includes the following goals:

    1) 70% electricity from renewable sources (i.e. grid is 70% renewable) by 2030
    2) Zero-emission grid (grid is 100% clean) by 2040
    3) Reduce emissions at least 85% below 1990 levels by 2050

The following principles were established when developing the UR&ET master plan study:

- **Maximize Synergies and Co-Benefits:** Seek to incorporate opportunities to support the University's goals. For example, encouraging living lab opportunities between faculty, staff, and students.

- **Create an Actionable Plan:** The UR&ET master plan study will generate a discrete set of projects with a clear, yet flexible implementation strategy. Risks and opportunities are evaluated.

- **Deploy a Maintainable and Reliable Future System:** Improve long-term maintainability and reliability.

CHAPTER 2: DRIVERS

The Utilities Reliability and Energy Transition (UR&ET) master planning strategy is driven by:

1) Cornell's Quadruple Bottom Line
2) Federal, state, and local regulations
3) Aging infrastructure

Quadruple Bottom Line

Cornell has embraced a sustainability framework that incorporates the three key areas of environment, economy, and equity (which we call planet, prosperity, and people), and adds a fourth area of consideration (purpose) which helps Cornell examine how they can best contribute to a more sustainable world as an educational institution. The Quadruple Bottom Line (QBL) Sustainability Framework is outlined below and is both an "ethos" for how to consider sustainability as part of campus education and operations, but also a tool for decision-making. The UR&ET master plan study's possible solutions were evaluated beyond the traditional "single bottom line" of fiscal cost using the key elements below.

Prosperity - Supports Financial Stability

- **Affordability—Capital Costs.** Measures life-cycle financial performance relative to the baseline scenario with a range of predicted capital costs.
- **Affordability—Operating Costs.** Measures life-cycle financial performance relative to the baseline scenario. NYCI costs were excluded during this analysis because of the cost uncertainty.
- **Maintainability:** Evaluates operational features, including staffing, equipment, and long-term performance.
- **Resilience:** Measures improvement to campus utility resilience metrics, including reliability, redundancy, and recoverability.

Purpose - Supports Cornell's Mission

- **Research and Teaching:** the extent to which the project enables research, teaching, learning, or commercialization opportunities for students, faculty, staff, or community such as training, certification, or workforce development.
- **Land grant mission—scalable solutions**: Impact within the broader community of practice and policy.

People - Supports Community Goals and Potential

- Measures campus and local community perception and direct community impacts (examples include community utility costs, available capacity, disruption to campus operations, pride in achieving emission reductions).

Planet - Supports Environmental Needs

- Level of greenhouse gas emission reduction (Scope 1 and Scope 2)

The Utilities Reliability and Energy Transition program focuses on Cornell's district energy system and is designed to reduce carbon emissions, whether originating from electricity generated on-site or purchased from the New York state grid. Cornell's district energy outlook includes clean grid electricity, Lake Source Cooling, and geothermal heating technologies to reduce greenhouse gas emissions. The UR&ET master plan study recommends an ecosystem of renewably sourced technologies, paced with NY Grid transition, which:

- envisions a fossil fuel-free district energy system,
- makes significant progress towards carbon neutrality goals with a focus on reducing on-site greenhouse gas emissions (Scope 1)

- identifies deployable, high-efficiency electrified heating solutions to minimize NY grid greenhouse gas emissions (Scope 2)

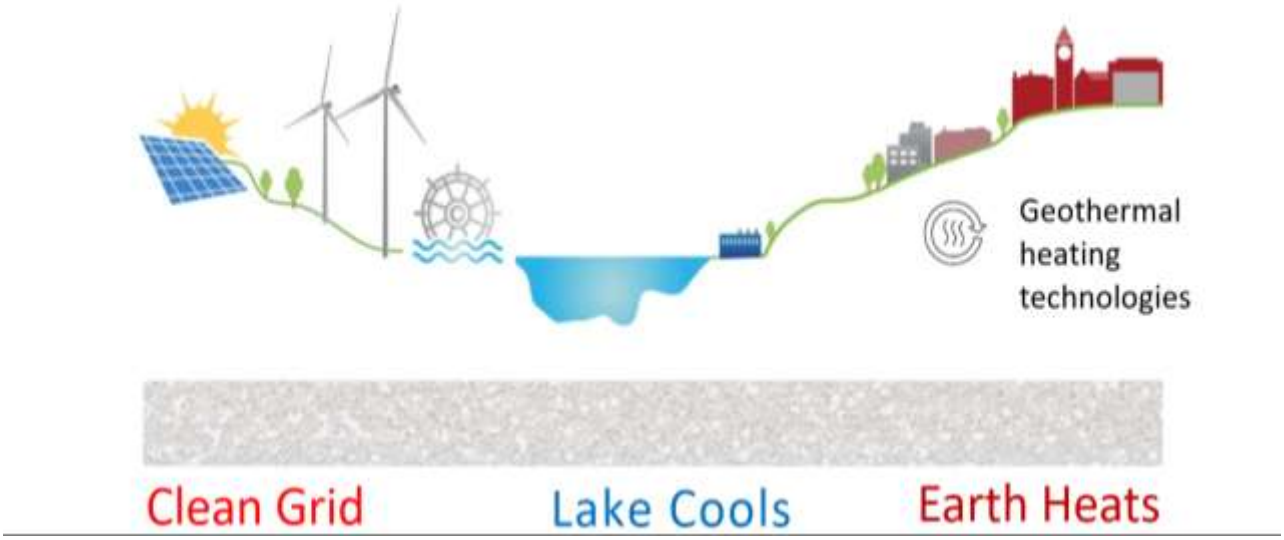


Figure 1: Cornell's District Energy System Outlook

Federal, Local, and State Regulations

New York State, the Town of Ithaca, and the City of Ithaca have enacted various laws, regulations, and codes that directly and indirectly impact Cornell's district energy plant both today and in the future. Many of these regulations are informed by the **New York Climate Leadership and Community Protection Act (CLCPA)**[1] which was signed into law in July 2019. The CLCPA delegates responsibility to the Public Service Commission (PSC), the New York State Department of Energy Conservation (DEC), and other agencies to develop programs and regulations to meet target climate goals. The following regulations are in development:

- **New York Cap & Invest (NYCI)** can be described as a comprehensive carbon price for emissions generation from fuel combustion activities, upstream and out of state activities, Municipal Solid Waste (MSW) landfills, cement production, glass production, and electronics manufacturing. A first step in this program is the development of **Mandatory Greenhouse Gas Reporting**[2] protocols.

[1] Website for NY Climate Law: https://climate.ny.gov/
[2] Website for NY Mandatory Greenhouse Gas Reporting: https://dec.ny.gov/environmental-protection/air-quality/mandatory-greenhouse-gas-reporting

- **New York State Energy Code**[3] has incorporated on-site renewable energy and energy efficiency requirements for new construction, additions, and substantial improvements. The **Ithaca Energy Code Supplement**[4] includes requirements for net-zero new construction. The **All-Electric Buildings Act** requires all-electric cooking and heating for new buildings less than seven stories, followed by taller buildings three years later. Renovations of, or additions to, existing buildings are exempt. However, implementation and enforcement of regulations that prohibit installation of fossil fuel equipment and building systems in new buildings is suspended by Court Order[5] (as of July 2, 2026).
- On the horizon is the proposed **NY HEAT Act** (Home Energy Affordable Transition). A key stipulation is the prohibition of natural gas combustion as the primary source of heating beyond 2050.

The UR&ET master plan study is designed with a flexible, modular approach that enables Cornell to adapt as New York's clean energy transition progresses. Recognizing that achievement of certain CLCPA milestones may occur over a longer timeframe than originally envisioned by the NY 2025 Energy Plan, the UR&ET master plan study positions Cornell to optimize operational, economic, and emissions outcomes as climate policy, grid performance, and regulatory frameworks continue to evolve. In addition, there is an opportunity to amend building-centric codes and regulations to reflect the growing recognition of thermal energy networks and district energy systems as integrated infrastructure that benefits both connected buildings and the broader electric grid.

Aging Infrastructure

Cornell's district energy system has been continuously adapting to campus load growth and regulatory changes since the late 1800s. The supporting infrastructure includes a wide age range of assets from newly installed hot water distribution piping to steam piping installed over 100 years ago. Similarly, production assets for heating, cooling, and electricity vary in their condition, with some assets installed over 80 years ago. While the campus has continued to grow over the past two decades, the district energy system has not installed any new fossil-fuel heating systems. This is directly attributable to campus-wide energy conservation initiatives and high-performance building standards that have reduced heating loads, as well as good operational and maintenance practices of the existing equipment. The Utilities Reliability & Energy Transition master plan continues to focus on improving resiliency and maintainability of the district energy system during the transition process.

[3] NY Building Code website: https://dos.ny.gov/notice-adoption
[4] Town of Ithaca Energy Code Supplement website: https://townithacany.gov/resource_library/town-of-ithacas-energy-code-supplement-iecs/
[5] https://dos.ny.gov/system/files/documents/2026/07/decision-mulhern-gas-v.-mosley-2d-cir.pdf

Improving Resiliency and Maintainability

Resilience includes reliability, redundancy, and recoverability. Maintainability considers operational features, including staffing, equipment, and long-term performance. There are critical energy infrastructure components well beyond end-of-life. In particular:

- The average age of Cornell's chiller fleet is 41 years.
- The steam turbine generators are over 40 years old, have reliability issues, and require significant maintenance.
- Cornell's chilled water system has a major singular failure point without sufficient redundancy.
- Portions of the existing steam distribution systems are over 100 years old and require industry-specific maintenance expertise.

System Resiliency: The UR&ET master plan study integrates the concept of redundancy across critical heating and cooling loops, ensuring that the failure of any single component – such as a geo-exchange borehole or a centralized heat pump – does not disrupt campus operations. By leveraging the existing thermal storage infrastructure and expanding microgrid capabilities, the campus can maintain independent, autonomous operations during regional power grid outages and severe winter storms.

Infrastructure Maintainability: Transitioning away from legacy fossil fuel systems provides a unique opportunity to standardize equipment and simplify maintenance protocols. The plan prioritizes modular system designs and localized utility nodes, allowing technical teams to isolate and service components without wide-scale campus shutdowns. Furthermore, the integration of advanced digital twins and predictive maintenance sensors will shift operations from a reactive state to a proactive life-cycle management model, minimizing long-term operational costs and extending the lifespan of new utilities assets.

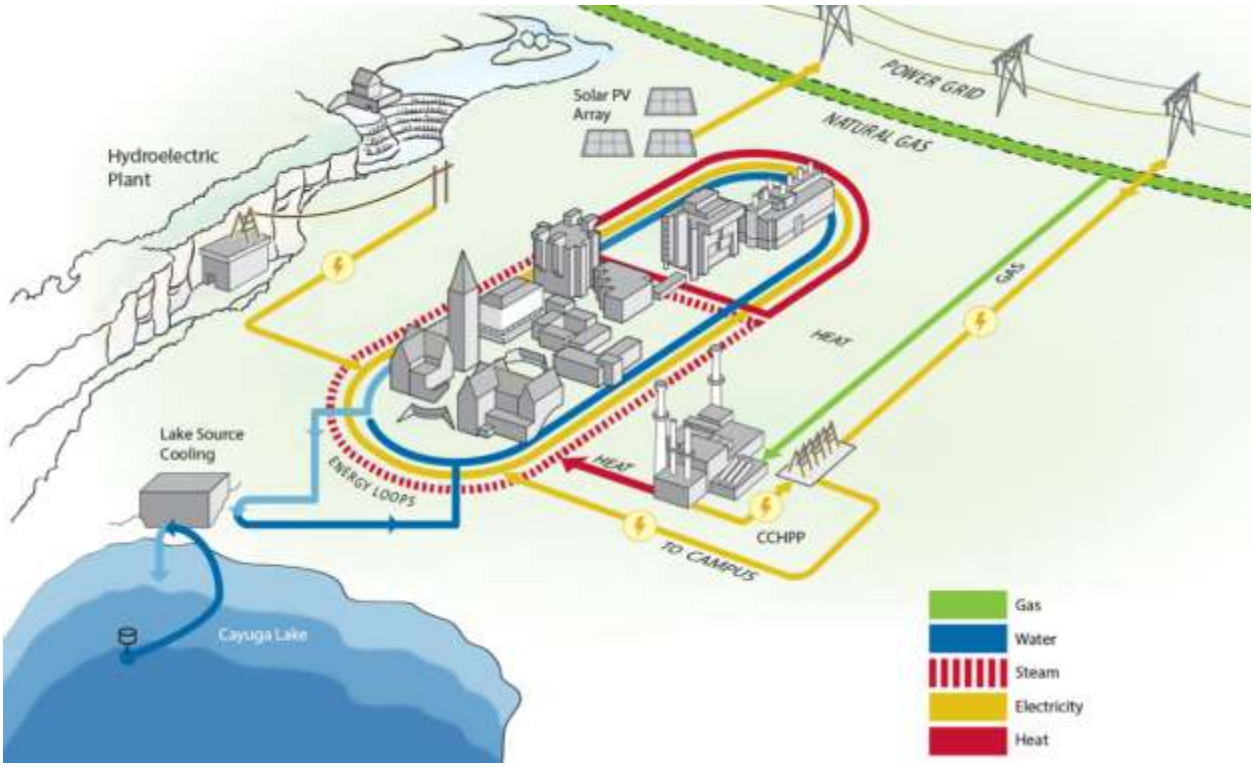


Figure 2: Cornell's Existing District Energy System

District Energy

Cornell's district energy system uses co-generation to provide heating and electricity coupled with Lake Source Cooling to provide cooling to the Ithaca Campus. District energy is a centralized system that generates energy at a central plant and distributes the energy via a piping network to multiple buildings. Advantages of district energy include:

- *Lower maintenance:* Buildings do not need their own individual boilers, cooling towers, or major mechanical equipment
- *Saves space:* Centralized generation means equipment takes up less room inside each building
- *Lower peak capacity:* District energy systems serve diverse building types, enabling shared peak loads for central equipment and reduced equipment capacity requirements.
- *Renewable-ready:* Thermal energy networks can readily incorporate renewables like geothermal, solar thermal, biomass, and large-scale heat pumps for multiple buildings at once – particularly for existing buildings.

- *Reliability and resilience:* Central plants often feature redundant equipment and diverse fuel sources to maintain service during local outages or when equipment fails
- *Efficiency:* Central plants have a more stable load profile and thus can operate more efficiently than individual building equipment.

Consuming over two trillion Btu of energy annually, the Ithaca campus requires a large and complex infrastructure to supply reliable heating, cooling, and power. There are three main district energy infrastructure systems on campus: District Heating, District Cooling, and Electricity Generation.

District Heating

Cornell's district heating system provides steam to the campus community for space heating, humidification, sterilization, hot water, and research along with cogenerated electricity. Centralized district heating has a long and rich history at Cornell, with district steam appearing on campus in the late 1800s and the origination of the current version of the district system starting operation in 1923, which at the time was thought to be the largest distribution system in the world.

In 2009, Cornell's Combined Heat and Power Plant (CCHPP) was installed. By generating electricity and capturing waste heat for campus heating simultaneously, CCHPP is one of the most efficient fossil-fuel electric generators on the NY grid[6]. The CCHPP also enhanced Cornell's resiliency with the ability to isolate from the grid during a regional electrical outage and allow the campus to remain operational.

Steam and electricity production occurs at the Central Energy Plant (CEP) where steam is produced primarily from the two heat recovery steam generators (HRSG) associated with two combustion turbine generators (CTGs) as well as five large boilers. The primary fuel source for steam production is natural gas with #2 fuel oil (ultra-low sulfur diesel fuel) serving as a backup source.

District heating now serves over 150 buildings (14 million+ square feet) and is supplied to the campus via an underground steam distribution system consisting of approximately 12 miles of steam, 10.5 miles of condensate lines, and over 150 vaults or manholes. The campus has started the transition from this steam distribution system to a hot water distribution network. This transition aims to enhance heating performance and distribution efficiency. The steam system is being transitioned in phases, starting at the periphery of the distribution and working backwards toward the point of generation. Energy transfer stations (ETS) are being utilized to establish various hot water districts that convert steam-to-hot

[6] EPA – eGrid website: https://www.epa.gov/egrid

water heat via heat exchangers. In the future, a large ETS is currently planned to be installed at the CEP for complete elimination of steam distribution across campus.

Steam and Hot Water Demand

Steam is provided to the campus year-round except for a short steam shutdown that typically occurs in May to allow for system repairs when steam demand is low. Most of the steam consumption is used for building-level heating and domestic hot water, with additional process uses at labs, greenhouses, and dining facilities.

The district heating plant production fluctuates seasonally with a peak demand of approximately 335,000 lbs of steam/hr (~400 million Btu per hour or 400 MMBtu/hr) in the heating season and a peak demand of 60,000 lbs/hr (~70 MMBtu/hr) in the cooling season, where one pound of steam is equivalent to the weight of one pound of water in vapor phase, and one Btu is the measure of heat energy it takes to raise the temperature of one pound of water by one degree Fahrenheit. The annual average steam production at the plant for 2023 and 2024 was ~118,000 lbs/hr (~140 MMBtu/hr). Figure 3 below shows the hourly steam production trend data from the years 2023 and 2024 as recorded by the central energy plant steam meters.

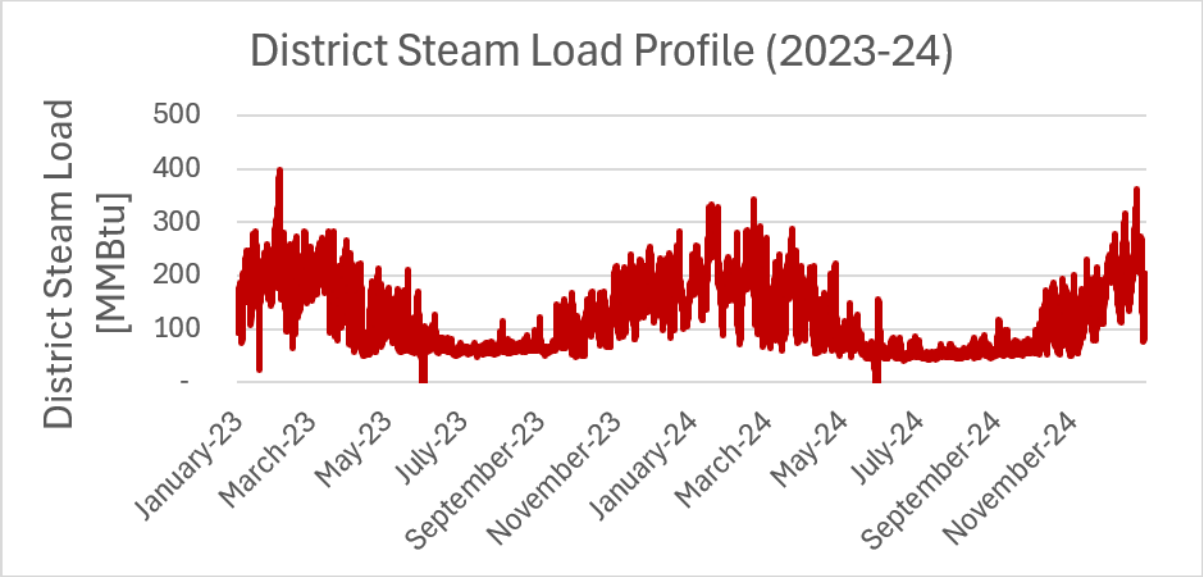


Figure 3: Central Steam Plant Load Profile (2023-24)

An elevated demand for the central energy plant typically persists until April, after which a reduced heating load characteristic of the milder shoulder season continues until the end of May. This period coincides with reduced heating requirements at the end of the academic year and in the summer. The fall shoulder season, with its increasing heating loads, extends from August to October, after which the elevated winter heating loads are observed. The

campus heating peak load is significantly higher than the annual average demand. This highlights a key production challenge faced by the district heating plant – the need for system flexibility to meet peak loads that are short in duration but dramatically larger than average load. The heating peaks observed from December to February typically occur during extreme cold spells that occur fewer than 20 days annually.

A heat load duration curve, below, shows 2024 steam generation hourly average history. The curve ranks hourly steam demand from highest to lowest, beginning at approximately 360 MMBtu/hr and declining steeply before gradually tapering to about 50 MMBtu/hr for most hours and transitioning to zero during the annual maintenance outage. The figure illustrates the distribution of campus heating demand, highlighting the difference between infrequent peak loads and the more common baseline heating requirements. The load duration curve shows the thermal peak is only required for a limited number of hours per year, typically less than 100 hours or 1% of the year. Ithaca experiences very cold periods in winter, but those events are short in duration. Reduction in peak heating demand through steam-to-hot water conversions, enhanced energy conservation measures, and temperature controls improves redundancy of existing production assets and reduces future heating capacity requirements.

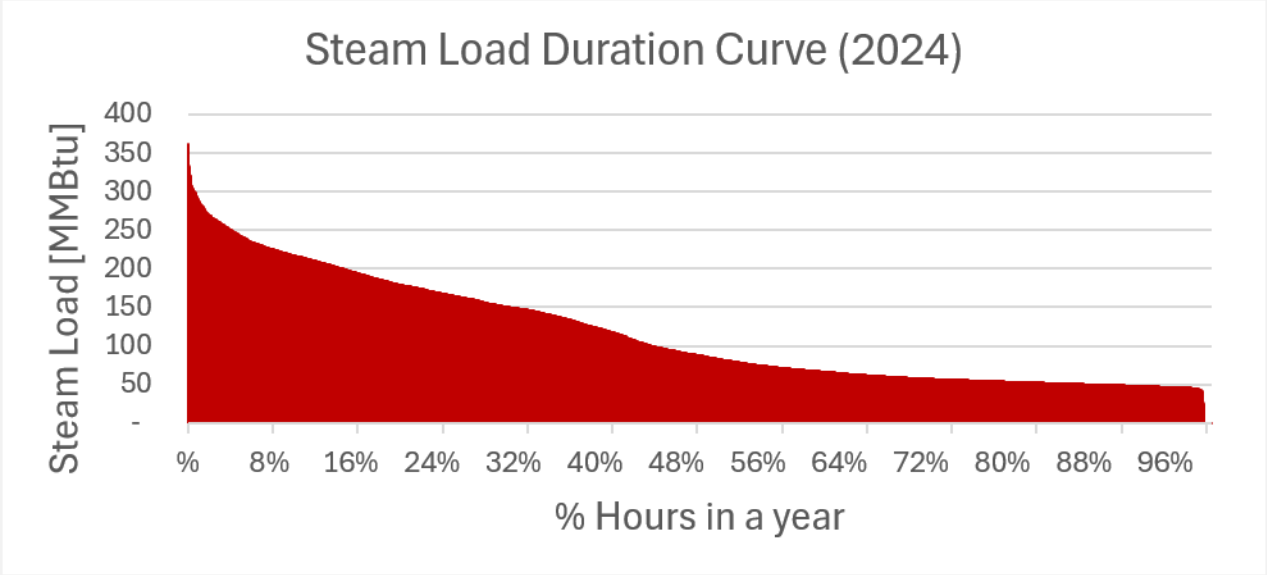


Figure 4: Central Heating Plant Load Duration Curve (2023-24)

District Cooling

The district chilled water system at Cornell provides a centralized cooling system for the campus and is utilized mainly for space cooling needs but also for some process type loads. District cooling serves over 100 facilities, with over 11 million square feet of conditioned area. Chilled water is provided via two production plants and supplied to the campus through an underground piping network.

District cooling on campus has been a continuously evolving system starting with one of the first district chilled water systems in a campus environment. The deployment of central chilled water occurred in the early 1960s when the first chilled water plant was constructed on campus. The chilled water plant began operation in 1963 with two 1,200-ton centrifugal chillers and was considered state of the art. One ton of refrigeration is a unit of power used to measure the heat-extraction capacity of cooling equipment and is defined as the rate of heat removal required to melt or freeze 1 short ton (2,000 lbs) of pure ice (32F) in 24 hours.

Cornell continues to develop and implement industry-leading, innovative district cooling solutions such as the Lake Source Cooling (LSC) system. In 1999, LSC was designed to meet baseline cooling loads at the time of installation, with the pre-existing water-cooled chillers intended to serve peak cooling needs. It was anticipated that additional cooling capacity would be required as early as 2004 to meet Cornell's building growth and peak cooling demand. Through energy conservation initiatives, use of the 1991 thermal storage tank, and use (and maintenance) of chillers from 1974, 1987, and 1998, Cornell has been able to reliably meet campus cooling loads. Projecting into the future, Cornell Utilities has determined a need for expansion of the chilled water plant to maintain the resilience and reliability as campus cooling loads continue to grow and chilled water demand increases.

Chilled Water Demand

The district cooling system serves a large variety of building usages including residential, educational, and research buildings. The variety creates a diversified load on the loop as each building peak is seen at a different time of day. Fig 2-20 shows the chilled water hourly trend data from the year 2023 and 2024, as recorded by the district cooling energy meters. The peak cooling demand observed in the summer is ~25,000 tons. The district cooling plant produces ~51 million ton-hrs of cooling annually. Campus cooling demand peaked in 2019 and has reduced subsequently in the post-COVID years. Elevated summer cooling load levels are typically experienced from June through September. However, some shorter periods of lower cooling demand are also experienced in the summer months, marking the end of the academic year and summer breaks when campus occupancy is low. Reduced cooling demand from spring and fall shoulder seasons is typically experienced from April to June and September to October, respectively. In the winter months, the campus cooling has a minimum base cooling load of 2,500 tons.

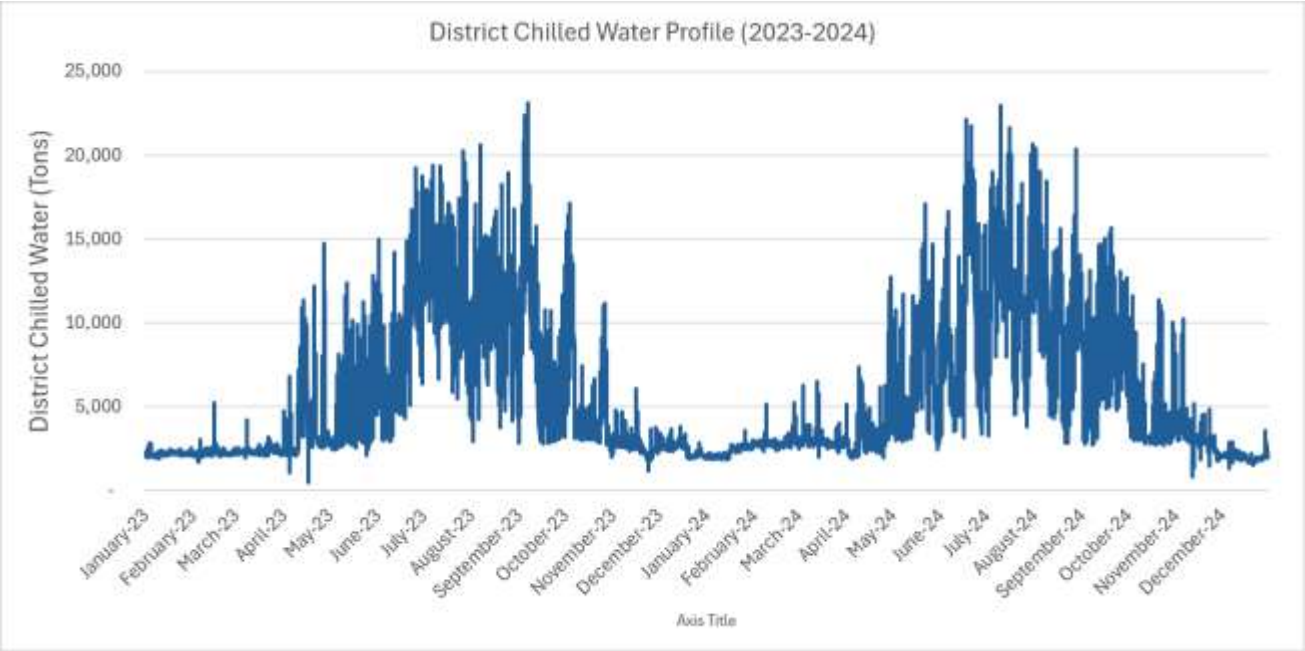


Figure 5: District Chilled Water Load Profile (2023-24)

Throughout the study period, district energy cooling loads are expected to grow through new construction and addition of conditioning during building renovation. Like heating loads, reduction in peak cooling demand through enhanced energy conservation measures improves the equipment redundancy of the existing chilled water production assets and reduces cooling capacity requirements. However, in contrast to heating loads, cooling peak demand is anticipated to increase throughout the 40-year analysis period through the addition of new loads through new construction and renovation of previously unconditioned space, whereas heating loads are anticipated to decrease.

Electricity Generation

Electricity for the main campus is supplied via on-site generation from the CEP and off-site power by New York State Electric & Gas (NYSEG), the local utility provider. Both sources typically operate in parallel to provide the most reliable system. The electrical distribution on campus is mainly via underground feeders owned and operated by the University. The campus consumes approximately 208,000 MWh annually with a peak demand of approximately 35 MW.

Hydroelectric Plant



Figure 6: Cornell Hydroelectric Plant

Originally built in 1904, the hydroelectric dam over Beebe Lake has undergone several upgrades and expansions. During the last major renovation in 1981, the plant was completely rebuilt and all the original machinery removed. Two Ossberger crossflow turbines were installed with a total rated capacity of 1,870 kW. The plant, however, is limited to about 1,100 kW output because of the size of the penstock. This hydroelectric plant is "run of river," which means that no water is stored. On an annual basis, this plant produces approximately 6 million kWh.

Rooftop Solar



Figure 7: Cornell Solar Photovoltaic Installation

Cornell has seven on-campus solar arrays distributed across eleven buildings. The largest installation is over the North Campus residence halls, where the capacity is approximately 1.1 MW and generates about 1,350 MWh annually. The campus also has smaller distributed arrays over the Cornell Campus Store, College of Human Ecology, Fernow Hall, Snee Hall, and Klarman Hall. The current campus on-site rooftop PV generation potential is approximately 1,476 MWh.

PPA Solar Farms



Figure 8: Cornell Power Purchase Agreement for Off-Site Renewable Energy

In addition to rooftop solar, Cornell has developed renewable solar energy projects on university-owned lands with power-purchase agreements. Electricity from these projects flows to the regional grid. Generation of renewable electricity at these sites offsets emissions from campus energy use. Off-site solar generates approximately 35,000 MWh annually.

Electrical Demand

Power generation and usage data at Cornell is recorded by energy meters at the Central Energy Plant (CEP) and around the campus. Campus consumption and peak demand are relatively flat across the year. This is a result of campus heating using natural gas and campus cooling being mostly generated by the highly efficient LSC plant, which is metered separately from Main Campus.

Figure 9 shows the campus peak electrical demand recorded for the year 2023 and 2024. The campus consumes an average of 17,000 MWh per month across this period with no clear indication of increasing consumption year-over-year. In the last two years, peak demand was recorded on February 15th of 2023 at 35.6 MW, and the resulting annual load factors are 66% for 2023 and 72% for 2024.

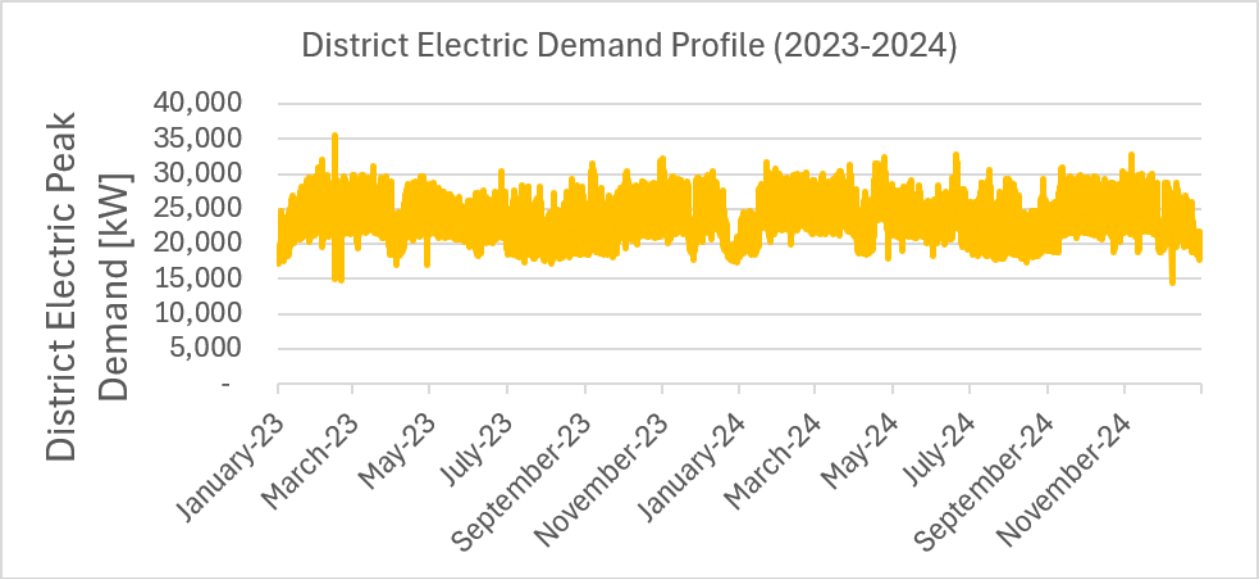


Figure 9: Campus Peak Electrical Demand (2023-24) (excludes LSC peak demand of 2700kW)

CHAPTER 4: CAMPUS GROWTH, RISKS, AND VULNERABILITIES

Campus Growth – Potential Development

The UR&ET master plan study focuses on buildings that are connected to the existing district energy system and are either partially conditioned (electricity and heating) or fully conditioned (electricity, heating, and cooling). Most buildings are fully conditioned; however, some older buildings have not been removed since first constructed and are not connected to district cooling. An advantage of district energy is its ability to support the energy needs of various building types, ages, and changing demand compared to building-specific systems. Incorporating energy conservation measures throughout the campus has permitted the district energy system to continue providing reliable heating, cooling, and electricity to new buildings and renovations, without adding new production assets at the central energy plant since 2008.

With a 40-year analysis period which ends in 2067, it is necessary to not only plan the energy transition for existing facilities and operations, but also for future facility renovations and expansions. This chapter evaluates the impact of growth in the form of new facilities, major renovations, and building energy conservation and analyzes the impact those changes will have on the energy infrastructure.

2008 Campus Master Plan (CMP)

Cornell is a constantly evolving campus, and the University has previously developed and adopted a planning framework with the completion of Cornell's Campus Master Plan (CMP)[7] in 2008 to guide development of the University's land. The CMP provided the university with an integrated framework to guide its long-term physical development efforts. The CMP provides a set of guidelines for decisions about where to locate the university's research, teaching, residential, and recreational priorities and programs. It also offers a campus-wide frame of reference for the university's current capital plan, and links local and precinct plan goals to the broader plan. The CMP also draws upon previous physical planning efforts, including the 1989 campus plan and precinct plans, as well as the Comprehensive Policies for the Physical Planning and Design for the Ithaca Campus, from 1989 and 1972. The UR&ET master plan study uses the CMP and other input from Cornell stakeholders to understand possible growth scenarios and how they might affect the campus district energy equipment and infrastructure.

Potential Identified Major Projects

In addition to new facilities, major changes to existing facilities were captured to quantify long-term energy consumption impacts. There are four categories to consider: active projects, potential major renovations, potential added cooling to a facility, and potential growth. A description of those categories is below.

- **Active Projects:** These are major renovations which are either in progress or in the existing capital plan. These renovations will result in a reduction in existing heating loads by following high-performance design standards. The addition of cooling is planned if the building is not already cooled.

- **Potential Major Renovation:** These are major renovations, which are not currently planned, but are needed during the analysis period based on the understanding of the University's facility goals and/or the condition of the buildings. These renovations will result in a reduction in existing heating loads and the addition of cooling if the building is not already cooled.

- **Potential Added Cooling to a Facility:** The identified buildings are buildings which currently do not have mechanical cooling throughout the building. The renovation of the facilities would focus on adding cooling and converting buildings to lower temperature hot water (130F-150F), if needed.

[7] Cornell's 2008 Campus Master Plan website: https://fcs.cornell.edu/departments/office-university-architect/cornell-campus-master-plan-2008

- **Potential Growth:** Over the last 25 years, the Cornell campus has grown at approximately 100,000 square feet per year. However, with several core zones completely built out on campus, growth is expected to slow down over the next 40 years. Input from Cornell stakeholders has helped identify land parcels that have potential for development. The growth has been split into near-term growth based on the five-year capital plan (active projects) and long-term growth, beyond five years. The identified growth by zones for the UR&ET master plan study should not be interpreted as Cornell's long-term development plan, but rather a consideration of zone constraints and what is possible. These potential growth areas will help shape where supporting infrastructure distribution piping or production systems should be placed to provide the best value to the University. This is particularly important when considering the sizing and configuration of buried infrastructure, such as distribution piping which can have a life span of 100 years. Sizing distribution with future loads in mind can save millions of dollars and reduce disruption to campus. Additionally, it is recommended that production systems utilize an approach that considers long-term growth but is built in a way to allow for phasing of assets so additional generation is constructed when the actual demand increases.

Table 1: Potential Identified Major Projects

Category	Project Bldg. Area (SF) [2028-2067]
Active Projects	500,000
Potential Major Renovation	1,200,000
Potential Added Cooling to a Facility	500,000
Potential Growth	2,000,000
Total	**4,200,0000**

Energy Conservation Initiatives (ECI)

In addition to potential growth and major renovation projects, it is anticipated that most of the buildings on the district energy system can achieve thermal demand reductions and energy savings through energy conservation measures. The UR&ET master plan study, in coordination with Cornell's Energy Conservation Controls Operations team (ECCO), has identified projects to reduce electric, heating and cooling loads through energy recovery, controls upgrades and motor replacements. ECCO is an operations and maintenance team with Cornell Facilities and Campus Services consisting of nine technicians and a general foreman focused on energy conservation and building controls. Cornell has deployed a successful demand side reduction program at the building level called Energy Conservation Initiative (ECI) since 2000. The ECI program is funded by the University to facilitate the deployment of energy conservation measures based on strong financial performance. As part of the future projection, it is planned that the ECI program will continue to be deployed and enhanced to incorporate energy consumption and demand savings.

External Campus Risks & Vulnerabilities

The first step in assessing the Cornell baseline risk conditions is to identify natural and man-made risks to the campus. Risk is a combination of the probability and severity of hazards, as defined below. The tables below show the probability, severity, and risk of hazards to Cornell in the present day and as anticipated in the future. Risks and vulnerabilities identified in this section are based on Tompkins County Resiliency Recovery Plan and Hazard Mitigation Plan, Cornell's vulnerability assessments, and climate adaptation planning data from Northeast Regional Climate Center.

Each identified category of campus risk and vulnerability is first evaluated based on current conditions. This comprehensive evaluation assesses its probability, severity, and overall risk for the next 25 years. Looking beyond this initial period, future conditions are then informed by climate trends and potential impacts of climate change. These projections determine whether the probability, severity, and risk of each category are expected to be increasing, decreasing, or neutral.

Probability

- Unlikely – The event has happened in the past but has not happened in recent history.
- Occasional – The event has happened in recent history but is not an annual occurrence.
- Frequent – The event happens on an annual or more frequent occurrence.

Severity

- Negligible – The event has minimal impact to people, infrastructure, or operations on campus. This category is also applicable to events that are critical in other areas and reduce in impact by the time it reaches campus.
- Moderate – The event has impact to people, infrastructure, or operations on campus without completely eliminating the ability to function.
- Critical – The event completely disrupts people, infrastructure, and/or operations on campus.

Potential Future

- Decreasing – Based on future projections, these types of events will occur less or severity will be reduced.
- Neutral – Based on future projections, no changes to frequency or severity are anticipated.
- Increasing – Based on future projections, these types of events will occur more frequently or severity will be increased.

Based on this assessment, the severe weather and climate projection hazards are shown below.

Table 2: Severe Weather/Climate Phenomenon Categories and Vulnerabilities for Cornell

Hazards	Probability	Severity	Risk	Potential Future Projection
Tornado	Occasional	Critical	High	Neutral
Extreme Cold	Occasional	Moderate	High	Increasing
Extreme Heat	Frequent	Moderate	High	Increasing
Severe Thunderstorms	Occasional	Moderate	High	Increasing
Severe Winter Storms/Snowstorm	Occasional	Moderate	High	Increasing
Non-Storm Surge Flooding	Occasional	Moderate	Medium	Increasing
Drought	Occasional	Moderate	Medium	Increasing
High Winds	Occasional	Moderate	Medium	Increasing
Seismic	Unlikely	Moderate	Medium	Neutral
Hurricane/Typhoon	Unlikely	Moderate	Medium	Neutral
Storm-Surge Flooding	Occasional	Moderate	Medium	Increasing
Wildland Fires/Wildfires	Occasional	Moderate	Low	Increasing
Desertification	Unlikely	Negligible	Low	Neutral
Subsidence/Sinkholes	Occasional	Negligible	Low	Neutral

Table 3: Climate Projection Categories and Vulnerabilities for Cornell

Hazards	Probability	Severity	Risk	Potential Future Projection
Annual Average Temperature Increase	Occasional	Moderate	Low	Increasing
Wet Bulb Increase	Occasional	Moderate	Low	Increasing
Precipitation Changes	Occasional	Moderate	Low	Increasing

CHAPTER 5: MASTER PLANNING METHODOLOGY

Project Approach

The UR&ET master plan study was developed in four phases and was designed to align goals with an understanding of existing systems. The phases are summarized below:

Phase 1: Information Gathering

The intent of this phase was to build alignment for clear goals and a strong understanding of existing systems. This understanding allowed for the development of a baseline scenario utilizing existing production and distribution systems. Interviews with Cornell stakeholders established a deeper understanding of existing campus conditions and challenges. The process included:

- Developing consensus of planning priorities and quantifiable performance metrics.
- Gathering existing data and system information to understand baseline systems and operational procedures.
- Completing additional system assessments to validate and fill gaps.
- Developing a baseline scenario that represents requirements for providing continuous, reliable service to existing and new facilities.

Phase 2: Range of Scenarios

During this phase, a systematic methodology was deployed to evaluate a diverse set of solutions and technologies that could meet the goals of the UR&ET master plan study and fit Cornell's short- and long-term goals, including:

• *Technology Screening:* Evaluated a multitude of options to understand what solutions and technologies are truly viable and what could be ruled out due to qualitative and quantitative goal misalignment. This stage can be found in Chapter 6.

• *Scenario Analysis:* During this stage, a set of viable alternative scenarios for the system were identified. A scenario comparison was completed that considered quantitative and qualitative criteria (Quadruple Bottom Line), including annual utility cost, capital cost, operation & maintenance (O&M) costs, and greenhouse gas emissions. The outputs of this final stage are key scenario metrics that enabled stakeholders to work towards identifying a preferred scenario (aka "Recommended Scenario").

Phase 3: Interim Report

This phase was focused on crafting a robust implementation plan for the Recommended Scenario and identified discrete projects aligned with plan goals, capacity needs, funding constraints, and equipment needs. For this stage, an implementation strategy identified

project drivers, funding potential, and a portfolio of projects to address energy consumption, distribution, and production facilities.

Phase 4: Final Report

The final phase included incorporation of comments from a review of the draft UR&ET master plan study by key stakeholders to finalize the plan and identify short-term (0-5 years) recommendations and implementation strategies. In addition, final reports from outside consultants regarding forecasted utility rates, future grid emissions, financial, and potential external funding opportunities were considered.

Scenario Analysis Approach

The scenario development and analysis stage is a critical component of the plan as the analysis provides crucial information for defining the preferred path forward. A scenario is a complementary combination of applicable technologies built around key campus goals. A scenario can include technologies and solutions addressing different utilities or campus demands that can be implemented at different scales across campus. For example, a scenario can integrate one or multiple technologies that address steam and hot water production, chilled water production, on-site generation, and distribution. It can also include solutions that are implemented across the whole campus or selected for a targeted deployment to a section of the campus.

These developed scenarios were analyzed utilizing an hourly performance analysis of the system with each scenario including capital, operation and maintenance (O&M), and utility costs as well as energy consumption and emissions for the full analysis period. The analysis period is 40 years (2028-2067). Additionally, the analysis included changes and facility growth on campus as outlined in the previous chapter (Chapter 4).

For the UR&ET master plan study, a set of "Core Thermal Scenarios" was developed which combined technologies and solutions tailored to the campus thermal demands, existing infrastructure and operations, growth projections, and broader Cornell decarbonization goals. These core thermal scenarios also incorporated insights from ongoing studies and development at Cornell, such as the campus transition to hot water distribution and heating as well as ongoing research and development of the Cornell University Borehole Observatory[8] (CUBO) regarding direct use geothermal ("Earth Source Heat").

While certain foundational technologies and solutions remained at the core of each scenario, Jacobs worked with Cornell to identify and evaluate "scenario variations." These variations included items such as distribution routing, peak generation, buildings/areas

[8] Cornell CUBO Website: https://sustainable.cornell.edu/living-laboratory/projects/cornell-university-borehole-observatory-cubo

served, production equipment configurations, energy storage, and energy conservation, which can significantly impact the overall life-cycle performance, costs, and implementation strategy of a core thermal scenario.

Assumptions & Clarifications

The following assumptions were held consistently across the development and analysis of each thermal scenario. These assumptions are grouped into the following categories:

- Regulatory Impact
- Operations and Maintenance
- Utility Rate Projections
- Utility Developmental Area
- Building Load Data
- Design Campus Heating and Cooling Capacity
- Critical Heating Load
- Climatic Modeling
- Building Steam-to-Hot Water Conversion
- Basis of Planning of District Hot Water Temperature
- Building Hot Water Temperature Design Standard
- Building Hot Water Supply Temperature Testing
- Building Heating Renovation Costs
- Process Steam Loads
- Mechanical Room Conversions
- District Energy Connection & Phasing
- Piping Materials

Regulatory Impact

Scenario development considered the impact of current and upcoming local and state regulations and laws. Many of the state regulations are informed by the 2019 New York State Climate Leadership & Community Protection Act (CLCPA).

The CLCPA (SB6599) mandates the establishment of a program to require that “by the year two thousand forty (collectively, the ‘targets’) the statewide electrical demand system will be zero emissions” (N.Y. Public Service Law §66-p(2)(b)). Under this provision, the NY DEC would have the authority to develop new rules and regulations to retire fossil fuel generators, such as Cornell’s Combined Heat and Power Plant.

The bill also sets the overarching goal of achieving a net-zero economy by 2050, which coupled with the All-Electric Buildings Act and the proposed NY HEAT Act could prohibit the use of natural gas combustion as the primary source of heating beyond 2050. The CLCPA

contains definitions of what is considered renewable and eligible for Renewable Energy Credits (RECs). For example, biogas and biodiesel may be considered renewable sources under NY State law after recent updates in 2026.

Operations & Maintenance

Operations and maintenance (O&M) costs were calculated based on existing contracts and operations for known operations. For new equipment with no reference information, an equipment-level basis using ASHRAE 180 (Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems) and RS Means maintenance tables were utilized. This approach enables direct maintenance comparisons between scenarios and allows future costs to align with equipment projections. Note that some operational costs remain consistent across the scenarios, such as administrative elements, and were not analyzed to avoid diluting scenario comparisons.

The costs associated with maintenance and repair of electrical systems that exist today (e.g. feeders, switches, and transformers, etc.) are not included in the analysis as there are no system-wide changes anticipated for the electrical system. The capital cost and associated O&M for new equipment, such as a new substation, is included in the scenarios.

Utility Rate Projections

Power delivered to the University is supplied by New York State Electric and Gas (NYSEG), which is regulated by the State of New York. Cornell utilizes the NYSEG "Nonresidential Standby" service, which is often used for customers who generate their own power but require access to the utility grid for backup or supplemental supply. NYSEG's hourly pricing is applicable to Cornell, which means that electricity costs are paid based on the actual hourly market price. Hourly pricing is linked to the NYISO Day-Ahead Market[9] which is influenced by factors such as fuel costs, generation availability, and weather. In addition to hourly price, electric utility charges also reflect varying delivery costs based on the time electricity was used. Seasonally changing charges are applied based on period of consumption, specifically during on-peak, off-peak, and super-peak hour periods. This rate structure aims to encourage shifting electricity consumption to off-peak hours to reduce peak demand.

The electricity utility rate considered for the UR&ET master plan study has been informed by a 25-Year Rate Forecasting Advisory Service study. The study investigated various potential rate scenarios with considerations for generation source and load growth.

[9] NYISO Real Time Dashboard website: https://www.nyiso.com/real-time-dashboard

For future gas utility rate projections, natural gas costs were escalated annually by 3% plus percentage-based adjustments reflecting Henry Hub[10] price projections, which aligns with the electrical rate escalation approach.

Utility Development Area

Throughout the various scenarios, there are solutions presented that illustrate potential areas on campus which could be developed for energy infrastructure. While there has been some stakeholder coordination, these areas are strictly for illustrative purposes only and do not represent the final location of the proposed solution. The locations were identified based on providing the lowest first cost from an engineering study perspective and siting can be adjusted or moved further out with additional piping and infrastructure costs. Moving forward, engaging all land stewards at Cornell will be important to ensure alignment and support for the Recommended Scenario.

Building Load Data

To model the energy consumption and performance of existing buildings, relevant existing data was utilized. This approach focused on the use of available building-level meter data (chilled water, steam, and electricity). After reviewing the data and evaluating the factors that influence energy consumption on campus, 2024 was determined as the most representative data set.

Other years were ruled out because they included occupancy periods associated with COVID-19 or there have been enough changes on campus that the data was no longer relevant. The 2024 data was reviewed and cleansed to remove any potential blips associated with metering error or one-off type of events.

Design Campus Heating and Cooling Capacity

While 2024 serves as the basis of annual system loads, a more extended approach was utilized to identify the initial required firm capacity. Cornell looked back at historical metering and weather to identify the appropriate heating and cooling loads based on existing system configuration. The results of the analysis identified a steam demand peak of 340 klbs/hr and a chilled water demand peak of 23,000 tons. It is important to note that these are starting loads for scenarios and as there are changes on campus to increase demand (e.g. additional facilities) or reduce demand (e.g. ECI or hot water conversion), the peak system demand can be adjusted accordingly.

[10] Henry Hub Natural Gas Spot Price website: https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm

Critical Heating Loads

Quantifying the critical heating loads for campus is a crucial step to ensure emergency backup heating systems have adequate capacity and fuel storage in case of extended outages or disruptions to primary heating systems. The critical heating loads for the campus are composed of two parts:

- Heating load from critical buildings
- Heating load from non-critical buildings

Critical buildings are buildings that house sensitive items that cannot withstand an extended outage, such as animals, plants, assets, equipment, research, and anatomy preservation functions. Critical buildings have been identified based on inputs received from Cornell. All heating loads associated with these buildings are included in campus critical heating loads.

The second component of critical loads comes from non-critical buildings. It consists of the minimum heating load required to protect the building equipment and piping in case of extreme weather events and extended outages. These heating loads have been quantified for different building types on campus through energy modeling based on parameters that mimic building operation during extreme weather or extended outage events.

Climatic Modeling

The system modeling for the UR&ET master plan study was developed using historic weather information and temperature parameters that align with the existing building portfolio and design criteria. This means that during extreme weather events, the building loads would not grow proportionally with temperature, as the installed HVAC equipment is already running at maximum. For loads to grow proportionally, there would need to be major changes in building systems. Similar to potential changes in load growth or utility rates, it is recommended that climatic changes be continuously monitored and the plan be updated accordingly as further clarity is provided in the future.

Building Steam-to-Hot Water Conversion

A significant portion of the building portfolio on campus receives steam from the district system and utilizes steam-to-hot water heat exchangers to generate and distribute hot water within buildings for heating. Hot water conversion involves installing new distribution piping throughout the campus to provide hot water directly to facilities from the generation source. In facilities that require steam, such as humidification for preservation of rare manuscripts and art collections, or autoclaves for research and animal care, a point of use or small local steam system must be deployed.

Basis of Planning District Hot Water Supply Temperature

High-performance heat pumps and electrified heating sources operate more efficiently at lower supply temperatures by minimizing the temperature difference between the heat source (geoexchange, BTES, or chilled water return) and the heat sink (heat transfer equipment – hot water coils and perimeter radiation). Therefore, to maximize efficiency and minimize costs of heating the hot water system, lowering the supply temperature to the greatest extent practical is desired. Lowering the system hot water supply temperature also enables newer technology integration as most commercially available heat pumps have a max output of 140°F-160°F.

As Cornell renews its distribution system, Cornell is converting its existing steam distribution to hot water. Switching to hot water distribution improves thermal efficiency by reducing thermal losses while also improving safety and maintainability. For the purposes of this report, a district hot water supply temperature of 160°F was utilized. Many existing campus buildings could operate at 160°F without a change in performance and some existing facilities already incorporate this lower setpoint.

Building Hot Water Temperature Design Standard

Historically, most of Cornell's buildings operated with a hot water supply temperature range from 180°F - 200°F and return temperature of 140°F - 170°F. A higher supply temperature relative to the return temperature enables a greater temperature difference across the heat transfer equipment (e.g., heating coils within the air handling units and perimeter radiation). This enables heat transfer with lower flow requirements, thereby reducing pumping energy. As a result, increasing the temperature difference between the supply and return increases the overall efficiency of the system.

To prepare buildings for lower supply temperatures from high-performing electrified heating technologies, a campus design standard was implemented in 2019 that established a maximum 130°F supply and maximum 100°F return temperature for any domestic hot water or hydronic heating system serving newly constructed buildings and major renovation projects. A lower hot water supply temperature provides significant improvements in the heat pump's coefficient of performance, enabling higher efficiency equipment which provides greater capacity as well as lower operating costs. The reduced return temperature requirements enable the heat transfer equipment to meet heating loads without introducing a pumping energy penalty. For new systems or major renovations, a low hot water supply temperature is consistently utilized for design.

Building Hot Water Supply Temperature Testing

As part of the UR&ET master plan study development, Cornell conducted a controlled hot water temperature reduction study across 26 campus buildings (~65–70 hydronic systems)

to determine the minimum heating hot water supply temperature required to satisfy space heating demands while maintaining occupant comfort. The objective was to assess the feasibility of operating buildings under low-temperature hot water supply (LTHW, <160°F) conditions and to inform planning and costs for converting from high-temperature systems.

A standardized outdoor air temperature (OAT)-based reset strategy was implemented, reducing hot water supply (HWS) temperature to 150°F at low ambient conditions (≤25°F) and 120°F at mild conditions (≥55°F), with continuous monitoring of system performance through the building automation system. Adjustments were made only where heating deficiencies were observed.

Testing results illustrated a significant reduction in required supply temperatures. While 85% of the test buildings initially operated at ≥180°F, results indicated that 81% could operate at ≤160°F and 73% at ≤150°F, with only 15% requiring 180°F to maintain performance without any physical changes. These outcomes were validated at near-design winter conditions, demonstrating the reliability of lower temperature operation.

System performance varied by heating type. VAV reheat systems demonstrated the greatest tolerance for reduced temperatures, while perimeter/radiation systems showed moderate dependency on envelope performance. Preheat and glycol systems were generally the most temperature-sensitive and often governed minimum supply temperature requirements but are also generally the easiest to replace.

A key finding was that heating limitations were frequently driven by control strategies rather than equipment capacity. Common issues included restricted airflow during heating, improper staging of heating systems, and control logic limiting coil output. Implementation of improved strategies, particularly dual-maximum VAV control, corrected heating staging, and elimination of excessive setback-driven loads, enhanced heat delivery and reduced peak demand, enabling stable operation at lower hot water supply temperatures.

These findings have direct implications for steam-to-hot water conversion. The demonstrated ability of most buildings to operate at ≤160°F indicates that many facilities are effectively LTHW-ready, reducing the need for widespread mechanical upgrades such as coil or heat exchanger replacement. Instead, required improvements are primarily controls-based and targeted toward specific constraints (e.g., preheat systems or envelope deficiencies), significantly lowering capital costs.

Higher temperature hot water production equipment installed to meet local loads may be required in lieu of whole building HVAC replacement in cases where the building cannot operate with 160°F hot water supply. Further evaluation can be developed to understand the full range of benefits and challenges of this approach versus performing required retrofits to

all buildings to operate at lower hot water temperatures. Potential benefits of retrofitting buildings and designing around a lower hot water supply (HWS) temperature may include lower life-cycle costs, in addition to enabling more efficient technologies as part of the overall energy exchange strategy.

Building Heating Renovation Costs

For facilities that will still require modifications to the building heating components (heating coils and perimeter radiation) after the testing and optimization program, building renovation costs include upgrades or replacement of local equipment which might not be compatible with hot water or need additional capacity to utilize lower temperatures associated with hot water. Changes at the building level include upgrades or replacement of air handler heating or pre-heat coils. Changes at a zone level include upgrades or replacements of VAV boxes or local reheat coils, fan-coil units, radiators, and unit heaters.

Buildings with existing steam systems are frequently the highest cost when transitioning to a lower district hot water temperature as they require extensive modifications or renovation throughout the facility.

Process Steam Loads

Cornell currently uses direct steam for lab and research processes, sterilization, humidification, and animal facilities located in various facilities across campus. Converting these facilities to a low-temperature hot-water system will require installation of local steam generation to serve these auxiliary processes. This UR&ET master plan study did not complete a full inventory of steam process equipment in buildings on campus but an initial cost of $5 million was included in full hot water conversion scenarios to provide accounting for some level of the potential process steam conversion cost.

Mechanical Room Conversion

Steam, condensate piping, and associated steam-to-hot water conversion equipment in building mechanical rooms would be removed as part of the building conversion. Buildings typically have one or two shell and tube heat exchangers for heating. Water-to-water plate heat exchangers would be installed in the mechanical rooms to provide heating for each facility. It is assumed that buildings with a demand of 500kBtu and less would have one heat exchanger, and buildings greater than 500kBtu will generally have two 75% capacity heat exchangers.

For domestic hot water, the typical approach is to provide a single heat exchanger. If the building uses a steam-fired domestic water heater with a storage tank, the steam would be disconnected. Removing the system frees up mechanical space in the building to install a plate-to-plate heat exchanger connected to the district low-temperature hot-water system.

District Energy Connection & Phasing

During the transition period, new hot water piping will generally run parallel with the existing steam system. This assumption is based on the expectation that branch line and building hot water conversion construction will take several months to complete. A parallel approach limits extended outages, temporary equipment, or complicated phasing elements which would be required in a reuse scenario. It is assumed that short duration outages (several days) are acceptable and therefore no extra cost for temporary equipment to support a facility during a conversion is accounted for.

Some areas of campus might be able to reuse existing steam distribution pathways or parts of existing steam piping due to system configuration (e.g. areas with multiple diverse pathways). The cost efficiency of this reuse is not accounted for in the scenario analysis to be conservative but should be considered during design to reduce costs.

Piping Materials

Piping materials and installation methods were discussed with stakeholders and considered in the analysis. Direct-buried, trench-installed piping was used at the site-level. Horizontal directional boring may be used in specific areas to minimize surface disruption or cross-congested corridors, but such options are not included within this level of analysis as identifying specific sections is more aligned with a feasibility scope study. Pipe materials used for various thermal utility distributions included carbon steel schedule 40, HDPE DR11, and Carbon Steel EN 253.

Greenhouse Gas Emissions Accounting Methodology

Quantification of Greenhouse Gas (GHG) emissions associated with each scenario is essential to understand the true environmental impact of solutions being selected. While quantifying emissions from on-site fossil fuel combustion is straightforward, estimating emissions associated with grid electricity is considerably more complex. This complexity arises from the interconnected nature of the electric grid and the influence of factors such as additional electricity demand, economic conditions, political considerations, and social impacts. These factors can fundamentally alter grid emissions, potentially resulting in substantial increases or reductions in overall emissions.

The UR&ET master plan study considers Scope 1 emissions (from onsite stationary combustion) and Scope 2 emissions (from purchased electricity) associated with the on-campus energy utilities (electricity, chilled water, and steam) which includes stationary combustion and purchased electricity as it relates to those items. It does not include Scope 1 elements such as company vehicles, back-up generators, or fugitive emissions. Scope 3 emissions are not considered as part of this energy master plan.

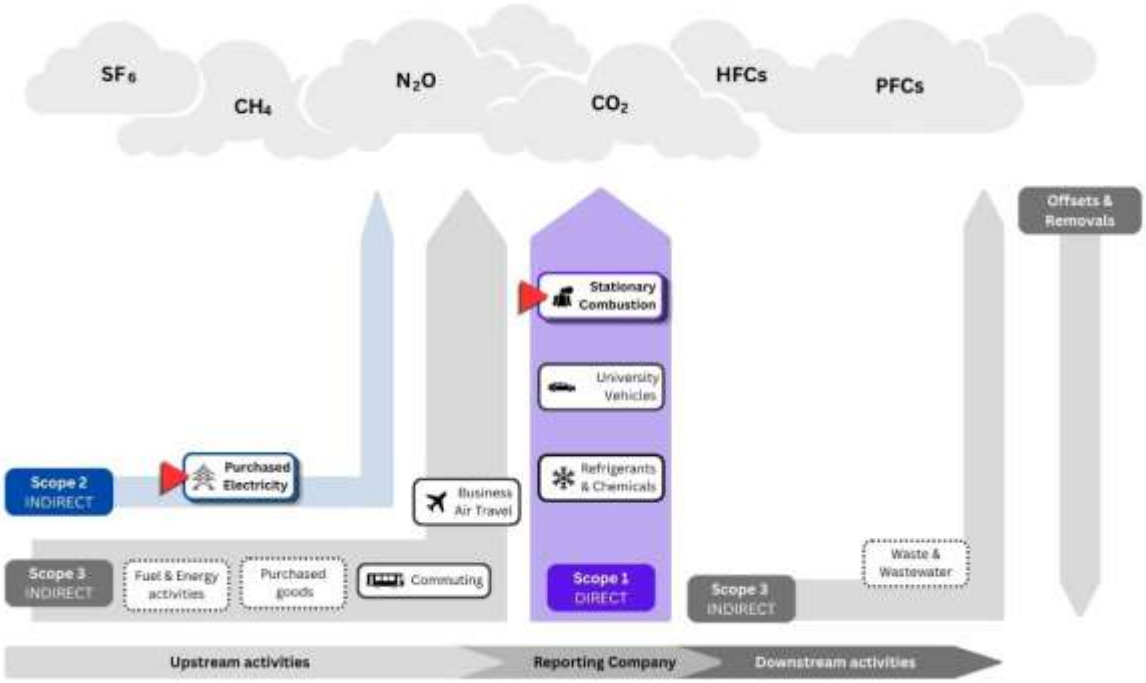


Figure 10: Scopes and Categories for Cornell's GHG Baseline Inventory

Background of Emission Rate Calculation Methodologies

There are several metrics that can be used to quantify grid electric GHG emissions for GHG reporting and inventory as well as to aid decision-making for selection of scenarios. The grid electric emission metrics that can form the basis of the UR&ET master plan study GHG methodology are:

- Annual average emission factor
- Hourly average emission factor
- Marginal emission factor

The type of emission metric being utilized plays a key role in the type of carbon methodology being deployed. Allocational carbon accounting methods use a simplified average emission factor to track emissions over time and help in setting broader reduction targets. Consequential carbon accounting, on the other hand, aims to measure the change in GHG emissions caused by a specific action or decision to understand its real-world impact. This type of carbon methodology is more commonly used in strategic planning exercises when comparing change in emissions across different scenarios.

Annual Average Emissions Factor

An annual average emissions factor represents the average greenhouse gas emissions associated with grid electricity use over a year. It is a single value that represents the overall

carbon intensity of the grid, which is calculated by dividing the total emissions of a grid by the total electricity generated. In this way, the average emissions factor is also the average emissions generated by each generation asset connected to the grid. If a grid has a mix of coal, natural gas, and renewable sources, the average emissions factor reflects the combined carbon intensity of all those sources. However, it does not indicate how emissions will change if the load changes. A drawback of this factor is that it does not capture the daily and seasonal change in the carbon intensity of the grid. This metric is typically used for allocational GHG accounting and carbon inventory reports.

EPA's eGRID[11] divides the U.S electric grid into several subregions. Cornell University falls into the NYUP subregion which represents the cleanest subregion grid in the country, with a large portion of generation coming from nuclear power and hydropower, but there is rarely excess zero-carbon electricity available.

Hourly Average Emissions Factor

Hourly average emission factor is an average emissions factor generated for each hour of the year for a particular grid region. This results in an emissions profile with 8,760 data points that provides a more accurate representation of the actual GHG emissions compared to the annual average emissions factor. An example of this data is found in the Figure 11 heatmap.

The heatmap figure below presents NYISO 2024 hourly Marginal Emission Rate (MER) data[12] in lb/kWh, on a monthly-hour schedule. Green cells indicate lower values and red cells higher values on a 0–1.2 scale. MER is lowest (green) during spring daytime hours, indicating higher levels of renewables on the grid relative to the electric load. MER is highest (red) during the evening hours, peaking during summer, winter, and fall when electric loads are high with fewer renewable resources. MER peaks during July-September, indicating that the NY grid peaks in the summer. As NY electrifies heating loads, the NY grid may shift to a winter peak.

[11] EPA eGRID website: https://www.epa.gov/egrid
[12] NYISO Open Access Same-Time Information System (OASIS) Website: https://oasis.nyiso.com/

Month / Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0.6	0.7	0.4	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7
1	0.6	0.6	0.4	0.4	0.3	0.4	0.6	0.5	0.6	0.7	0.7	0.7
2	0.6	0.6	0.4	0.4	0.2	0.4	0.5	0.5	0.6	0.6	0.7	0.6
3	0.6	0.6	0.4	0.4	0.2	0.3	0.5	0.4	0.6	0.6	0.6	0.6
4	0.6	0.6	0.4	0.4	0.3	0.4	0.5	0.4	0.5	0.6	0.6	0.6
5	0.6	0.6	0.4	0.5	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.6
6	0.7	0.6	0.6	0.6	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7
7	0.7	0.8	0.7	0.6	0.4	0.4	0.5	0.5	0.5	0.7	0.7	0.7
8	0.7	0.6	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.7	0.7	0.7
9	0.6	0.6	0.5	0.4	0.4	0.5	0.6	0.5	0.6	0.6	0.6	0.6
10	0.6	0.6	0.5	0.4	0.4	0.5	0.7	0.5	0.6	0.7	0.7	0.7
11	0.6	0.5	0.4	0.4	0.4	0.5	0.7	0.6	0.7	0.7	0.7	0.7
12	0.6	0.5	0.3	0.3	0.4	0.5	0.7	0.6	0.7	0.7	0.7	0.7
13	0.6	0.5	0.3	0.3	0.3	0.6	0.8	0.7	0.7	0.6	0.6	0.6
14	0.6	0.5	0.3	0.3	0.3	0.6	0.8	0.7	0.7	0.7	0.7	0.7
15	0.6	0.6	0.3	0.3	0.4	0.6	0.8	0.7	0.7	0.6	0.6	0.6
16	0.7	0.6	0.3	0.4	0.4	0.7	0.8	0.8	0.8	0.7	0.7	0.7
17	0.8	0.7	0.5	0.5	0.5	0.8	0.9	0.9	0.8	0.8	0.8	0.8
18	0.7	0.8	0.6	0.6	0.6	0.8	0.9	0.9	0.9	0.8	0.8	0.8
19	0.6	0.8	0.7	0.7	0.6	0.8	0.9	0.9	0.9	0.7	0.7	0.7
20	0.6	0.6	0.6	0.7	0.7	0.8	0.9	0.9	0.8	0.7	0.7	0.7
21	0.6	0.6	0.5	0.6	0.6	0.8	0.9	0.9	0.8	0.6	0.6	0.6
22	0.6	0.6	0.4	0.5	0.5	0.7	0.8	0.8	0.8	0.7	0.7	0.7
23	0.6	0.6	0.4	0.5	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.7



Figure 11: NYISO 2024 Hourly MER Data (lbs/kWh)

The hourly average emissions factor successfully captures the daily and seasonal change in carbon intensity of the grid based on change in load and when different generation assets are coming online. For example, the grid has higher demand during the day compared to the night, which requires more generators to be online during the day compared to the night. If the grid has considerable solar assets, there would be considerable carbon-free generation during the day to meet demand compared to the night which might require dirtier generation assets to be online. Peak electrical consumption currently occurs during hot summer afternoons. As heating is electrified, the New York State grid is expected to experience a shift to a winter peak which will occur in the very early morning.

This metric is useful for measuring the actual impact of measures and solutions that change the electric demand profile or shift the campus load to hours when the grid is cleaner.

Marginal Emissions Factor

Marginal emission factors or non-baseload rates represent the change in emissions that would result from a small change in electricity demand. They focus on the specific power plants (the "marginal" plants) that would respond to shifts in electrical load, rather than considering the average emissions of the entire grid. This makes marginal factors more useful for understanding the real-world impact of actions like energy efficiency or load

shifting and guide long-term decision-making. Similar to hourly average emissions, marginal emissions factors have hourly data points that can be used to estimate the marginal emissions over the course of the year.

New York Cap and Invest (NYCI) or Carbon Price (Average Emissions)

New York State's Cap-and-Invest program[13] was anticipated to launch in 2026 as part of the state's broader efforts to reduce GHG emissions through implementation of a "carbon price" mechanism. The program has been delayed. Unlike a simple carbon price which directly sets a price per ton of carbon emissions, a cap-and-invest program sets a quantity or a maximum emissions cap and allows the market to determine the price of allowances.

Under this program, the maximum limit on overall GHG emissions will be set for specific regions or sectors. The caps are designed to decline over time, progressively reducing the total amount of allowable emissions. Regulated entities are required to obtain allowances for the emissions they produce beyond their emission cap. The program generates revenue by auctioning off or distributing allowances to regulated entities, the revenue is then invested in projects that reduce emissions and promote clean energy. Organizations or companies that can reduce their emissions below their caps can sell their extra allowances to other organizations/companies that are not able to reduce their emissions, creating a market incentive to reduce emissions efficiently. The potential for selling these credits for financial benefit to Cornell was not included in this plan.

To forecast the cost, NYSERDA's projected price ceiling for carbon allowances (updated in March 2024) was utilized with Scenario B serving as the reference case (carbon cost of $15 initial ceiling price and escalating by 6% annually thereafter). The UR&ET master plan study assumed a carbon cost program starting in 2028 and the cost projections from NYSERDA were shifted three years without any escalation. Once beyond the ten-year price projection obtained from NYSERDA, the NYCI costs were escalated 3% annually, accounting for inflation. It is probable that the cost of carbon would escalate faster than the 3%, but due to the number of unknowns in the market, a conservative approach was taken.

Projecting Scenario Emissions

For the purposes of this plan, an emissions projection was developed to reflect the potential GHG emissions of the grid. The emissions estimates were developed based on information from state agencies (NYISO, DPS, NYSERDA) while considering current market conditions, project development timeline, and other critical variables. Utilizing these data points and the current uncertainty of the grid clean energy transition timing (e.g. 2025 NYS Energy Plan

[13] New York Cap & Invest Preliminary Scenario Analysis: https://capandinvest.ny.gov/-/media/Project/CapInvest/Files/2024-01-26-NYCI-Preproposal-Analysis-Webinar.pdf

includes reference to a level of uncertainty), an initial set of milestones were identified and critical for informing the projections that were utilized, these are defined below:

- 2030: Point at which noticeable grid emissions reductions begin to occur.
- 2035: Point at which the grid achieves a 70% reduction in GHG emissions.
- 2045: Point at which the grid achieves a 90% reduction in GHG emissions.
- 2050: Grid reaches true zero emissions.

Utilizing the defined inflection points as the basis, the plan considers two different emissions rate projections. The first is the marginal emissions rate, which was utilized to calculate Cornell's emissions from a sustainability perspective and internal record keeping. The second is a full portfolio mix using hourly average emissions factors, which is used as the basis for calculation to determine potential financial implications with a state-regulated carbon price. The variances in how these calculations are completed are described in their respective sections, but as noted above, they both utilize the same grid greening trajectory.

Cornell's Electrification Emissions Impact based on CLCPA Milestones

For the UR&ET master plan study, it was determined that an hourly marginal emissions rate projection provided the best basis for understanding the Ithaca Campus' potential impact on the environment from emissions from purchased electricity. To develop marginal emissions rates, a historical approach was utilized. Data was retrieved from NYISO website which published Real-Time Implied Marginal Emission Rates (IMER) for the NYISO Central Zone from 2024. It was assumed that this emissions rate remains consistent until the 2030 Milestone when the initial downward trend begins.

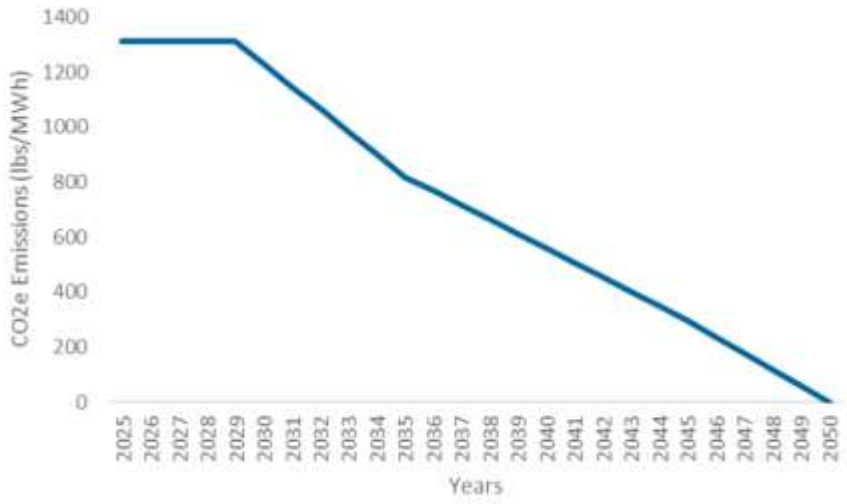


Figure 12: CLCPA Emissions Reduction Milestones

This approach was evaluated against a separate third-party effort conducted by the Cornell University Anderson Lab based on their deep understanding of the NYISO market and future electric grid production and demand scenarios established by the 2025 NY energy plan. The Anderson Lab, led by professor and department chair of the Biological and Environmental Engineering Department at Cornell, analyzed the emissions impact of Cornell's electrification pathways using a capacity expansion model of the New York grid. The team developed a weather-driven and transmission-constrained New York State grid framework and incorporated the NY grid electric generators and renewable (solar and wind) generation at target CLCPA milestones, informed by the 2025 NY Energy Plan[14] to answer the following question:

"What are the grid emissions associated with Cornell's electrification pathways – what is dispatched by the NY Grid for the additional planned hourly electrical load?"

CHAPTER 6: TECHNOLOGY SCREENING

Technology Screening Overview

Jacobs conducted a technology screening review to assess the viability of a range of potential solutions that could be deployed at the Cornell campus. These solutions encompass existing technologies, alternative fuels and new upcoming technologies that can provide a pathway to help Cornell decarbonize their district energy systems.

Each solution analyzed in this section has been rated based on several key performance indicators:

- **Maintainability**
  - Implemented technology can have a large impact on the maintenance effort and cost on campus. Generalized or centralized technology can reduce maintenance burden while highly specialized technology may diminish staff's ability to operate campus systems.

- **Resiliency**
  - At a minimum, all technologies will maintain the existing reliability of a system or utility. This metric considers any elements of the technology that enhances the reliability of a utility beyond current conditions.
- **Sustainability**
  - The impact, large or small, that the technology has on achievement of identified goals for each category. The larger the impact, the better the technology is for this metric.

[14] 2025 NY Energy Plan website: https://energyplan.ny.gov/

- **Implementation Viability**
  - The amount of invasive work required and impact on campus occupants necessary to implement the technology. For example, a technology that requires occupants to be relocated would not be rated well.
- **Financial Performance & Funding Availability**
  - The economic viability of the technology with a focus on the estimated annual savings compared to initial capital investment.The availability and likelihood of funding being available for this through mechanisms such as grants, performance contracts, P3, etc.
- **Research and Education Integration**
  - Considers how the technology supports the integration of research and educational opportunities at the University.

These key performance indicators have been selected based on discussions and collaboration with Cornell stakeholders and provide a comprehensive path to understanding which solutions fit the goals and the vision of the UR&ET master plan study.

Table 4: Technology Screening Criteria Ratings

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Technology Screening Approach

The decarbonization solutions recommended in this section have been screened based on how they integrate with the current district energy system infrastructure at Cornell and future campus goals. Solutions have been analyzed considering factors including but not limited to the following:

- **Existing campus operation:** Campus base loads, peak loads, existing equipment and asset age/renewal.
- **Financial metrics:** Initial capital expenditure, expected operational & maintenance costs, current and future costs of fuel/production.
- **Campus resiliency:** Distribution or generation resiliency, integration into emergency backup systems, challenges and benefits from distributed generation assets.
- **Deployment feasibility:** Mature market with abundant supply chain for solutions for near term adoptions, deployable without extended disruption to campus use and operations.

- **Regulatory hurdles:** Combustion and combustion-free solutions to meet regulatory requirements, assessing effect of decarbonization on local grid.

Based on the analysis conducted, each technology considered has been assigned to the following categories:

- **Full Campus Deployment:** Technologies that appear to be a strong candidate for the Cornell campus with potential application across all or major portions of the campus. This technology should be considered as a foundational part of the scenario development phase.

- **Targeted Solution Deployment:** Technologies that are a borderline fit for the Cornell campus and/or might be a fit for a discrete part of the campus. This technology will be considered as a supporting or opportunistic part of a scenario but not the leading technology.

- **For Future Contemplation:** At present, these solutions do not appear viable for the Cornell campus due to a variety of reasons but should be reconsidered in future years if there are changes in technology, regulations, cost or other variables.

The results of the screening exercise are shown below with more detail for each technology on the following pages.

Table 5: Technology Screening

Full Campus Deployment	Targeted Solution	For Future Contemplation
Hot Water Heat Pumps	Electric Boiler	Landfill Gas
Geo-Exchange	Localized Heating System	Methane Pyrolysis
Energy Conservation	Regional Thermal Plant	Biomass
Back-up CHP	Steam Heat Pump	District Energy Exhaust Heat Recovery
Thermal Energy Storage	Solar Thermal	Fuel Cell
Borehole Thermal Energy Storage	Wastewater Heat Recovery	Nuclear Fusion
Earth Source Heat	Near Ambient Loop	Micro/Small Modular Reactors
Airside Economizer Shutdown	Heat Battery	Alternative Diesel
Not Applicable		Waste-to-Gas
Not Applicable		Biogas
Not Applicable		Hydrogen

Full Campus Deployment

Technologies that appear to be strong candidates for the Cornell campus with potential application across all or major portions of the campus. These technologies should be considered as a foundational part of the alternative scenario development. Technologies that are highlighted blue were considered as part of the scenario development and components that are green are incorporated into the final Recommended Scenario.

Table 6: Full Campus Deployment Technology Screening and Scoring Summary

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Hot Water Heat Pumps	Geo-Exchange	Back-up CHP	Energy Conservation at Buildings	Thermal Energy Storage	Borehole Thermal Energy Storage	Earth Source Heat	Air-Side Econ. Shutdown
Maintainability	YELLOW	GREEN	YELLOW	GREEN	GREEN	GREEN	YELLOW	GREEN
Resiliency	GREEN	GREEN	GREEN	YELLOW	GREEN	GREEN	GREEN	YELLOW
Sustainability	GREEN	GREEN	RED	GREEN	GREEN	GREEN	GREEN	YELLOW
Implementation Viability	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	YELLOW	GREEN
Financial & Funding	GREEN	YELLOW	RED	GREEN	GREEN	RED	RED	GREEN
Research & Education	YELLOW	GREEN	RED	YELLOW	YELLOW	GREEN	GREEN	YELLOW

Hot Water Heat Pumps

Heat pumps (or heat recovery chillers (HRCs)) produce chilled water and hot water simultaneously. They can move heat that is typically rejected from CHW production and turn it into useful heat for building heating hot water. High coefficients of performance for simultaneous heating and cooling in the 5-7 range can be achieved. Typical HRCs generate HW in the 140-160°F supply temperature range, but depending on size HRC temperatures of up to 170-200°F can be achieved. Lower temperature HW (LTHW) supply temperatures increase efficiency, with the most efficient systems operating in the 105-120°F HW supply temperature range. Due to heat of compression, the HW-to-CHW production ratio is typically between ~ 1.25-to-1 and 1.5-to-1.

Advantages

- Very high efficiency

- Electrifies heating loads
- Very similar to traditional cooling-only chillers
- Reduces cooling tower load and boiler load, as well as associated water, electricity and natural gas use

Disadvantages

- Controls primarily a single LTHW temperature, may require flexibility with the other LTHW supplies and loads
- Requires simultaneous heating and cooling loads are present and/or pairing with long-duration storage capacity

Hot Water Heat Pump Application at Cornell

Heat pumps are a viable solution where simultaneous heating and cooling loads exist for significant portions of the year, or where significant long-duration storage can be implemented.

The LSC plant is currently rated at a capacity of ~20k tons and captures 99% of the annual cooling load at an exceptionally efficient COP of ~30. Operation of hot water heat pumps can complement the current operation of LSC, adding more cooling capacity and production resiliency but at a much lower COP.

Heat pumps can also be utilized in conjunction with various heat sources and heat sinks, including connection to thermal energy networks (TENs). There is potential to integrate this solution with other measures such as geothermal heat exchanger, wastewater energy transfer, and various other sources of waste heat recovery (e.g., labs, processes, data centers).

Table 7: Hot Water Heat Pumps Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**GREEN**	Heat pumps have similar maintenance as a standard water-cooled chiller.
Resiliency	**YELLOW**	Solution would put a larger reliance on the electrical system and may require a dedicated back-up power system.
Sustainability	**GREEN**	Operates at high system efficiency and generates both chilled and hot water, thereby reducing emissions associated with producing hot water.

Criteria	Rating	Description
Implementation Viability	GREEN	Plant construction would be relatively straight forward, but hot water conversion is required. Solution can be implemented to provide a base heating/cooling load to complement operation of LSC.
Financial & Funding	GREEN	A heat recovery chiller would have strong economics compared to existing heating production equipment. Depending on overall financials of the system, there may be alternative funding sources such as an Energy Savings Performance Contract (ESPC)
Research & Education	YELLOW	Moderate research and academic involvement opportunities with Cornell's Engineering programs.

Ground Source/Geoexchange & Geoexchange with Mechanical Balancing

Closed loop geothermal exchange systems use a field of vertical boreholes to access the earth's near subsurface, where relatively constant temperatures exist to transfer thermal energy for heating or cooling. Geothermal heat pumps can reduce energy usage by enabling the sharing of energy across the heating and cooling demands of the system. Geothermal exchange systems can only be used to produce chilled and hot water (not steam) and operate at COPs in the range of ~3-6. Multiple types of systems are available, including options to combine one or more types (e.g., open or closed loop, surface water). The efficiency and longevity of the geo-exchange system is enhanced when the net cooling and heating loads across the year are balanced. For systems where the loads are not balanced, mechanical balancing is needed via additional heat injection or extraction to maintain thermal balance in the borefields.

Advantages

- Precludes fossil fuel equipment and removes reliance on gas boilers
- Low operating and maintenance costs with high reliability
- Generates high efficiency heating and cooling

Disadvantages

- Produces only hot water for heating (no steam)
- Requires large available space for initial borefield installation
- In-situ test boreholes recommended across multiple locations
- Heat pumps use refrigerants which can have a global warming potential

Ground-source/Geoexchange Application at Cornell

Ground source/Geoexchange systems are best suited for operations with distinct heating and cooling loads in different seasons. While this solution can be viable as the primary

heating source for the campus, the land required for the well field would be large – approximately 85 acres required to meet 100% peak heating load with a low temperature distribution system. More acreage may be required for higher operating temperature requirements.

Implementation of this solution would take considerable time and planning with extended periods of time required for drilling the large number of geothermal wells. A typical completion time for 650-foot boreholes through clean shales may be 1.75 days or 2.5 days for 800-foot boreholes. Drill rigs with diesel engines of 70 – 350 HP are typically used for drilling boreholes and would need to run during all allowable hours. Electric rigs to drill boreholes are rare.

Cornell is a heating dominated climate and the loads for the potential geo-exchange system will not be balanced across the year. Mechanical balancing will be needed to maintain thermal balance within the borefields, such that additional heat is injected to balance excess heat extracted in winter to meet heating demands. Borefield balancing will also allow building a larger capacity system that meets a greater heating demand. A variety of sources can be used for heat injection. Waste heat sources or heat rejection from the campus are possible low-energy heat injection sources.

Table 8: Geo-Exchange Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**GREEN**	Requires relatively little maintenance with fluids monitoring, flow monitoring, temperature monitoring
Resiliency	**GREEN**	Undergrounding assets can maintain reliability during adverse events or support peaking events
Sustainability	**GREEN**	Active management provides options for electricity consumption timing and passive heating or cooling
Implementation Viability	**GREEN**	Off the shelf technology with few regulatory barriers – boreholes to 656 ft True Vertical Depth (TVD) is possibly enough to reach thousands of tons. Mechanical balancing would improve viability to meet heating dominant system loads at Cornell
Financial & Funding	**YELLOW**	Many funding mechanisms are available for closed loop borehole arrays. This opportunity would likely have interest from potential federal and private donors as well as potential incentives from NYSERDA and IRA.

Criteria	Rating	Description
Research & Educational Integration	**GREEN**	Can be instrumented with distributed fiber optics sensors for active management, heat transfer problems, and fluid chemistry research.

Backup Combined Heat & Power

Combined heat and power (CHP) is the simultaneous production of electricity and useful heat from a single fuel or energy source. A backup CHP system would provide emergency heat and power during extended grid outages. On-site electrical generation from this solution would be used to meet critical loads while recovered heat would be used to generate hot water to provide heating through radiators.

While CHP turbines typically use natural gas, they can be modified to use a variety of renewable/low-carbon fuels such as renewable natural gas, biogas, biomass, hydrogen, etc. - to integrate with other solutions.

Advantages

- Reliable source of electricity and steam/hot water
- Easy startup
- Can utilize existing Cornell equipment, infrastructure, and expertise

Disadvantages

- Typically uses fossil fuels with associated GHG emissions
- Requires periodic maintenance and test running
- Requires extensive fuel storage

Back-up Combined Heat and Power Application at Cornell

Backup CHP systems would add resiliency to campus systems as an emergency source for heat and power. Proposed turbines/reciprocating engines that would be installed in this solution would have a significantly lower output than existing CEP turbines and would only be used for backup power and heat. In the event of extended grid outage, backup systems would be turned on to safeguard and protect campus assets and buildings. Reciprocating engines have lower associated maintenance costs and would be the preferred solution for this kind of application.

The existing natural gas fired CHP system can potentially be retained as emergency backup. If Cornell implements other renewable fuel solutions – biomass, biogas, RNG, hydrogen, etc. – the CHP turbines/reciprocating engines could be modified to use alternate fuel.

Adequate fuel storage would be required to meet resiliency/backup operational requirements.

Table 9: Back-up Combined Heat and Power Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	YELLOW	CHP systems have slightly more complex equipment which requires specialized operations personnel and maintenance contracts Estimated maintenance for this solution may be potentially costly compared to the short durations of useful operations
Resiliency	GREEN	Can serve as a generation asset in the event of a utility failure. A dual fuel system can further improve resiliency
Sustainability	RED	Solution will not add strain to the local grid; however, CHP systems do not align with Cornell's net-zero carbon goal. Potential to modify systems to use renewable/low-carbon fuel can reduce emissions
Implementation Viability	GREEN	Easy to implement with existing systems, CHP can utilize steam or hot water for a thermal medium, allowing for simpler hot water conversion. Conversion to alternate fuels will require modification to existing CHP equipment
Financial & Funding	RED	Higher capital cost associated with backup system which will not have a payback period
Research & Educational Integration	RED	Low research and academic involvement opportunities with Cornell's Engineering programs. Transitioning to renewable or alternative fuel powered CHP (biomass/biogas, hydrogen) can create broad opportunities for academic and research integration

Energy Conservation at Buildings

While the other solutions in this chapter are focused on implementing new technologies at the plant level to increase district heating/cooling/power generation potential, this solution focuses on conservation measures that can be implemented at an individual building level. The goal is to identify and implement high-impact energy conservation measures across the building envelope, lighting/plug loads and HVAC systems that can reduce electrical, heating, cooling energy use and peak demands.

Energy conservation measures can encompass a range of solutions which can be tailored to individual buildings based on their existing performance. Measures to improve building envelopes include enhancing insulation in exterior walls/roof, replacing windows and doors, improving air sealing to reduce infiltration, and adding strategic shading to reduce solar gain in summer months. Load reduction measures include lighting upgrades, integration of lighting and plug load controls that aim to reduce lighting and plug load energy use. HVAC measures and optimization such as recommissioning, replacing older systems, adding heat recovery measures, and integration of demand control mechanisms can be highly effective in reducing building heating and cooling loads.

Advantages

- Helps reduce energy use, peak demand, and GHG emissions
- Requires minimal to no changes to existing district energy equipment and infrastructure
- High-impact measures with good financial paybacks once identified help create a highly replicable implementation plan

Disadvantages

- Individual plans need to be created for every building
- Higher upfront costs
- There may be retrofitting/installation limitations on existing or older buildings

Energy Conservation Application at Cornell

Cornell has a robust plan to implement energy conservation measures at buildings known as the Energy Conservation Initiative[15] (ECI). Through this initiative Cornell has identified and implemented upgrades in building automation & controls, heat recovery, and lighting systems over the past 20 years. Over its lifetime ECI has helped Cornell save ~$86 million and avoid ~254,953 MTCO2e in GHG emissions. Cornell personnel have developed significant expertise, solutions, and priorities for continued building improvements, whose anticipated life-cycle costs could be compared as an alternative to equivalent district energy modifications.

Expansion of this initiative to include more measures and application in more buildings across the campus can further help reduce demand and strain on campus utility infrastructure. It can also increase the immediate and near-term reductions in energy

[15] Cornell's Energy Conservation Initiative Website: https://sustainable.cornell.edu/buildings-energy/energy-conservation-initiative

use/GHG emissions since implementation of building measures require shorter implementation and planning periods than substantial changes to campus energy systems.

While higher upfront costs might be associated with some measures, financial payback or savings extend beyond operational energy savings of individual buildings. Reduced loads on campus central plant allow for campus growth without additional expenditure in adding system capacity or installing new distribution. In addition to energy performance and cost savings, implementation of these measures can also improve occupant experience by enhancing comfort and creating healthy interior environments.

Table 10: Energy Conservation at Buildings Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**GREEN**	Energy conservation measures can be aimed at renewing and replacing existing building systems to reduce maintenance at a building level. Addition of new equipment/controls can increase long-term maintenance
Resiliency	**YELLOW**	While not directly impacting resiliency, reduction in energy consumption and demand reduces strain on energy infrastructure and makes it easier to enhance resiliency at a campus wide level
Sustainability	**GREEN**	Highly effective in reducing energy use on a shorter timeline compared to other solutions with immediate impacts on associated GHG emissions, while also reducing strain on local grid
Implementation Viability	**GREEN**	Easy to implement with existing systems and has good phasing characteristics. Certain measures may have installation limitations in existing buildings. High-impact measures once identified can be implemented across the campus creating a highly replicable and actionable plan.
Financial & Funding	**GREEN**	Higher upfront capital associated with some measures, but high impact measures with strong financial characteristics can be prioritized. Several federal, state, local and utility incentives can be available based on selected measures. Financing from ESCOs/utilities could also be available for certain measures.

Criteria	Rating	Description
Research & Educational Integration	**YELLOW**	Moderate research and academic involvement opportunities with Cornell's Engineering programs. Current ECI initiative data tracking provides a strong base for research and educational integration.

Thermal Energy Storage

Thermal Energy Storage (TES) uses stratified liquid or ice to store chilled/hot water. A typical application of this solution involves charging a chilled/hot water storage tank at night, or a low demand and low electrical cost time, and discharging during the day or periods of higher demand. By shifting production periods, the cost of chilled/hot water production is decreased, and peak demand on the electrical power supply is reduced.

There are several different modes of TES operation including load shifting and peak shaving. Load shifting can also be used to reduce load during periods when the grid is "dirtier" to periods when the grid emissions are lower.

Advantages

- Reduces utility purchase at peak power
- Improves system reliability by adding capacity/redundancy/standby
- Improves system efficiency (increases COP)
- Potential for optimization with a CHW/HW plant
- Opportunities for grid responsiveness

Disadvantages

- Large tank and site required
- Electrical rate influences payback time
- Additional equipment and controls required

Thermal Storage Application at Cornell

Cornell already has prior experience with this solution. CWP 3 includes a large chilled water storage tank with a capacity of 4,000 tons (cooling). This tank can be charged with chilled water at night when electricity rates and campus cooling demand is low – as well as when outside air and condenser water temperatures are low – and utilized during the day to meet peak system loads.

Additional TES tanks could serve an important role in both the short and long-term plans at Cornell. If Cornell transitions to a hot water system, the TES tank(s) could also become a dual hot/chilled water “flip” tank that provides year-round benefits.

In the long term, a TES tank could be a useful asset for reducing system demand, managing utility costs, and reducing emissions from heating/cooling equipment. Significant electrical peak shifting/shaving through TES can also improve cost savings, grid-responsiveness, and electrical production support.

Table 11: Thermal Energy Storage Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**GREEN**	A TES generally requires minimal maintenance and can help with maintenance phasing for active equipment.
Resiliency	**GREEN**	Energy storage can provide short-term load support in the event of a utility outage or CHW production deficit.
Sustainability	**GREEN**	The TES can help with load balancing to allow equipment to operate at ideal load points and can reduce electrical load on the grid during peak hours. TES can also enhance usage of on-site renewable energy production and reduce renewable energy export to grid.
Implementation Viability	**GREEN**	A thermal energy storage tank requires a decent amount of land but is relatively easy to construct.
Financial & Funding	**GREEN**	A cost-effective way of enhancing the chilled/hot water system, lowering operating costs and carbon emissions. There will likely be multiple funding sources, including an IRA tax credit which may be rolled back/subject to change from upcoming and future legislations.
Research & Educational Integration	**YELLOW**	Moderate research and academic involvement opportunities with Cornell's Engineering programs for system operation and optimization for operating efficiency, utility costs, and carbon emissions through peak shaving and load shifting.

Borehole Thermal Energy Storage

Borehole thermal energy storage (BTES) is a specialized geoexchange system that is primarily used for heating. This solution uses the earth as a seasonal energy storage medium by charging boreholes through heat injection and extracting it later for heating. Unlike conventional geoexchange systems, injected heat is not extracted from building cooling loads, but from dedicated heat sources including waste heat recovery or solar thermal.

Closed loop vertical boreholes used for BTES can be drilled in a higher density than boreholes required for a typical balanced geo-exchange system. Storage temperature within boreholes can reach or exceed 160°F and can produce hot water at higher temperatures compared to typical geoexchange systems. Boreholes for such a system are typically arranged with series connections from inside to outside of cylindrical, near sphere, or ellipsoidal borehole arrays.

Advantages

- Higher temperature differentials compared to geo-exchange
- Greater peak capacities per linear foot of vertical ground heat exchanger

Disadvantages

- Limited by volumetric heat capacity and conductivity
- Lower recovery factors than aquifer thermal energy storage

Borehole Thermal Energy Storage Application at Cornell

Borehole thermal energy storage solution couples well with heating-only demands. With LSC providing a highly efficient and sustainable solution for campus cooling, BTES can provide a similar solution that can integrate with existing systems at Cornell. Denser arrays of boreholes for BTES systems significantly reduce borefield area requirements compared to geoexchange systems with a similar peak capacity. This solution can be paired with heat recovery from any source and actively managed with off-peak electricity or waste heat at any time.

Typical borehole depth for this solution is 300 - 650 ft depending on the ground composition. Boreholes are constructed below the frost penetration depth with an insulation layer covering the borefield. This results in a minimal impact on the area above the boreholes which reduces land disturbance and allow for multi-use.

A drawback of BTES solution is that the borehole temperatures and extraction rates from the borehole can take up to five years to stabilize. The borehole performance and extraction rates are low when operations begin, and performance improves over time as the thermal reservoir accumulates heat in the surrounding rock.

Table 12: Borehole Thermal Energy Storage Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	GREEN	Requires relatively little maintenance with fluids monitoring, flow monitoring, temperature monitoring
Resiliency	GREEN	Undergrounding assets can maintain reliability during adverse events or supporting peaking events
Sustainability	GREEN	Active management provides options for electricity consumption timing and passive heating or cooling.
Implementation Viability	GREEN	Off the shelf technology with few regulatory barriers. Integration of BTES would significantly lower space requirement for borefields.
Financial & Funding	YELLOW	Many funding mechanisms are available for closed loop borehole arrays. This opportunity would likely align with potential federal funding opportunities, private donors, incentives from NYSERDA, and tax credits from the IRA.
Research & Educational Integration	GREEN	Can be instrumented with distributed fiber optics sensors for active management, heat transfer problems, and subsurface fluid geochemistry research.

Earth Source Heat

Also known as enhanced geothermal systems, Earth Source Heat (ESH) is an emerging technology that harnesses heat from the Earth's interior. Conventional geothermal systems require pre-existing fluid reservoirs in permeable underground rock to capture heat from deep inside the earth, while ESH allows creation of a human-made reservoir to tap deep heat for use on the surface. To create a reservoir, fluid is injected deep underground at high pressure to create new fractures and increase rock permeability. Water can then be pumped underground via an injection well, where it is then heated while flowing through the network of fractures. The resulting hot water is drawn up into a second well and used for heating and/or generation of electricity.

Advantages

- Precludes fossil fuel equipment and removes reliance on gas boilers
- Consistent baseload energy source
- Can be constructed in areas without traditional geothermal resources

Disadvantages

- High capital costs associated with drilling, construction, O&M
- Technological challenges with development and optimization
- Potential for induced seismic activity

Earth Source Heat as a Research Application at Cornell

Cornell has been exploring an ESH solution to meet campus heating demands through the Cornell University Borehole Observatory (CUBO). As part of Phase 1, an approximately 10,000 ft deep exploratory borehole was drilled to collect a variety of data related to subsurface conditions such as temperature, permeability and rock characteristics to assess ESH viability.

Previous studies have shown that based on the temperature gradients observed, 3-4 well pairs could cover ~90% of Cornell's annual heating demand. Electric generation from ESH while feasible, would be an inefficient application of extracted energy (estimated 5% conversion efficiency).

A single well pair (estimated baseload capacity of 55 MMBtu/hr) can meet peak summer heating load and up to 60% of annual heating load with a smaller capital cost. ESH can be paired with another heating source such as heat pumps, biomass/biogas, or other alternative fuel boilers to meet peak heating loads while minimizing generation of additional emissions.

CUBO Phase 2 is the next step in the exploration for the feasibility of a campus scale ESH system. This phase aims to build upon Phase 1 and acquire new data through deepening the borehole by an additional 2,000 ft, enhanced testing and refining the ESH design. There are currently challenges with securing funds for CUBO Phase 2 through DOE or additional donors, as well as potential legal challenges in NY State regarding permitting and mineral rights associated with ESH.

Table 13: Earth Source Heat Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	ESH systems are projected to have 25-year service life and require continuous maintenance and monitoring to ensure proper operation. Due to the developing nature of ESH technology and extensive research outcomes specialized staff or additional training of operators would be required. Additionally, specialty equipment will be required which increases maintenance costs and hinders maintainability.

Criteria	Rating	Description
Resiliency	**GREEN**	ESH systems are predominantly passive piping systems with long lifespans, minimal maintenance requirements, and are not reliant on external fuel/energy sources
Sustainability	**GREEN**	Uses a renewable source of energy to significantly reduce GHG emissions from heating without adding additional strain on the grid or requiring a different fuel
Implementation Viability	**YELLOW**	ESH is a complex developing technology which can present various challenges from drilling, reservoir management and induced seismic activity. Research activity from CUBO and applied deep geothermal heat can help large scale application.
Financial & Funding	**RED**	High upfront capital costs and high degree of uncertainty with estimated costs for large-scale implementation.
Research & Educational Integration	**GREEN**	Developing technology which presents excellent research and academic integration opportunities with Cornell's various Engineering programs and existing research programs such as the Cornell University Borehole Observatory (CUBO).

Airside Economizer Shutdown

In heating dominated climates, the low base cooling load and high heating loads in winter limit the amount of heat recovery that can be achieved through simultaneous generation of chilled and hot water. This results in lower heating performance and higher required heating energy.

This solution involves inducing an additional cooling load to create an opportunity for heat recovery to improve the heating performance of a system. Building air handling unit (AHU) economizers are disabled in winter months, resulting in reduced free cooling and increased plant cooling loads. This results in increased simultaneous cooling and heating loads where the heat pump chiller can operate, generating hot water at a higher efficiency than typical heating only equipment.

Advantages

- Allows electrification of heating and reduces dependency on natural gas
- Can provide a consistent base heating load
- Low maintenance costs for heat pump chiller

Disadvantages

- Not as efficient as other heating solutions

- Reduces efficiency of cooling systems

Airside Economizer Application at Cornell

This solution integrates well with the current planned campus transition to hot water heating which utilizes low-temperature hot-water. It also takes advantage of the high-performance cooling assets at Cornell such as the LSC by shifting free cooling load at building level AHUs to the district energy plant. Implementation of this solution would require the addition of a heat pump chiller at the campus central plant to generate chilled and hot water.

This solution can be a viable option in buildings with high internal loads such as labs, animal housing/research facilities and dorms. Building level AHU economizers can be disabled in winter months to induce a cooling load on the chilled water system. Economizer shutdowns can be used in winter months when base cooling loads are lower and disabled when there is higher cooling demand from buildings.

Table 14: Airside Economizer Shutdown Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**GREEN**	From a maintainability perspective, the key equipment of heat pump chillers has similar maintenance as a standard water-cooled chiller.
Resiliency	**YELLOW**	This system would put a larger reliance on the electrical system and may require a dedicated back-up power system. Adds backup capacity and resilience to campus chilled water system.
Sustainability	**YELLOW**	This solution would reduce reliance on and emissions from existing natural gas CHP system to generate hot water. While more efficient than CHP systems, other solutions such as HPs and ESH would provide higher efficiencies. Electrification of heating load would result in additional strain placed on grid.
Implementation Viability	**GREEN**	Implementation would require the installation of new central plant equipment, and the planned completion of the campus hot water heating transition. Solution can be implemented to provide a higher base heating load in winter than can be achieved by a typical heat recovery chiller.

Criteria	Rating	Description
Financial & Funding	GREEN	Economizer shutdown would have strong economics with installation of centralized heating/cooling equipment and little to no investment at the building level. Depending on overall financials of the system, there may be alternative funding sources such as an ESPC.
Research & Educational Integration	YELLOW	Moderate research and academic involvement opportunities with Cornell's Engineering programs.

Targeted Solutions

Technologies that are a borderline fit for the Cornell campus and/or might be a fit for a discrete part of the campus. This technology will be considered as a supporting or opportunistic part of the scenario but not the leading technology. Technologies that are highlighted blue were considered as part of the scenario development and components that were green are incorporated into the Recommended Scenario.

Table 15: Targeted Solution Deployment Technology Screening and Scoring Summary

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Electric Boiler	Localized Heating Systems	Regional Thermal Plants	Steam Heat Pumps	Solar Thermal	Waste-water Heat Exchange Systems	Near Ambient Loop	Heat Battery
Maintainability	GREEN	RED	YELLOW	YELLOW	GREEN	YELLOW	YELLOW	YELLOW
Resiliency	RED	RED	YELLOW	YELLOW	GREEN	YELLOW	GREEN	GREEN
Sustainability	YELLOW	YELLOW	YELLOW	YELLOW	GREEN	GREEN	GREEN	GREEN
Implementation Viability	GREEN	YELLOW	YELLOW	GREEN	YELLOW	YELLOW	YELLOW	GREEN
Financial & Funding	RED	RED	YELLOW	RED	YELLOW	YELLOW	YELLOW	YELLOW
Research & Education	RED	YELLOW	YELLOW	YELLOW	GREEN	GREEN	GREEN	YELLOW

Electric Boilers

Electric boilers use electric resistance to generate hot water. Electrode boilers use electricity flowing through streams of water to generate steam. Both types of boilers are highly efficient compared to natural gas boilers (99%+ efficient).

They offer high turn-down ratios that allow safe operations at low outputs without compromising efficiency. Electric boilers also require lower initial costs but have higher life-cycle costs compared to natural gas boilers due to higher cost of electricity.

Advantages

- Quick response time and full turndown capability
- Low maintenance and longer equipment lifespan
- Direct electrification of heating
- "Unfired" boiler, may not require continuous operations staff
- Low energy use in standby mode
- Small footprint compared to comparable size gas-fired boiler

Disadvantages

- Higher operating costs
- Requires changes to electric infrastructure and
- capacity
- Low resiliency

Electric Boiler Application at Cornell

This solution can be implemented to generate high temperature water or high-pressure steam that would integrate easily with the current systems at the CEP. Implementation would require a significant upgrade to the electrical infrastructure to allow for the increased high voltage electrical capacity required to operate electric boilers. Meeting the entire campus peak heating demand would require a peak electrical demand of ~100MW (current campus peak is 25-35 MW).

Electric boilers are also expected to have a significantly higher associated utility cost for operation compared to natural gas boilers. Estimated Levelized Cost Of Heat (LCOH) for electric boilers ranges from $20-$34/MMBtu as compared to LCOH of $5.8-$8.8/MMBtu for a standard natural gas boiler.

Electric boilers can be a viable option as a targeted solution for specific parts of the campus, select buildings and as a low-cost peaking tool, operating for ~100 hrs/yr on extremely cold days when paired with another baseload thermal solution. This solution can be a viable bridge technology to transition to combustion-free heating and significantly reduced carbon emissions in the short-term while other solutions are being explored or implemented.

Table 16: Electric Boiler Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	GREEN	Electric boilers have lower maintenance costs and are relatively easy to maintain.
Resiliency	RED	Electric boilers use a single fuel source and don't always have N+1 capacity.
Sustainability	YELLOW	Solutions can help significantly reduce emissions from heating energy use; however, they lack the higher COPs offered by heat pump solutions and would place a much greater load on the existing grid. Steam heating also has higher distribution losses compared to hot water heating.
Implementation Viability	GREEN	This system would integrate easily with existing campus equipment. Implementation would require significant changes to CEP electrical infrastructure
Financial & Funding	RED	Easier integration with existing heating equipment would result in lower initial costs but increased operational costs would result in higher life-cycle cost. Maintenance cost of existing steam distribution would further increase life-cycle cost.
Research & Educational Integration	RED	Does not align with existing Cornell programs or present new educational, research or outreach opportunities.

Localized Heating System

Equipment deployed is dedicated to heat production for the building it is connected to. The connected equipment could be natural gas boilers, electric boilers, air source heat pumps (ASHPs) or water source heat pumps (WSHPs). Solutions can be tailored to the demands of the building, physical constraints, and existing infrastructure. This approach allows for the utilization of solutions that can produce low-temperature hot-water, high temperature hot water, or steam.

Advantages

- Easier phasing characteristics

Disadvantages

- Lack of redundancy or excess installed capacity
- Increased long-term O&M from large equipment count

- Low future adaptability
- Large equipment footprint local to each building

Localized Heating Systems are Not Included in the Recommended Scenario

Transferring buildings individually may simplify the overall campuswide conversion from steam to hot water in phases, vs. replacing the entire steam distribution with hot water distribution across campus. A local hot water boiler or WSHP/ASHP would be installed in the mechanical room / addition of each building, which would require a hot water conversion within any building still operating with steam.

Depending on the size and configuration of the mechanical rooms, building expansion may be required to house the localized boilers/equipment. A hot water conversion would be required within each mechanical room. With the existing buildings generally being space constrained, this would likely be difficult to fit within the existing footprint and would likely require building expansion. Building-by-building expansions for localized energy system conversion would be difficult to accomplish and likely impact the campus aesthetics or accessibility.

Table 17 : Localized Heating Systems Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**RED**	With localized systems there is a significantly higher quantity of equipment, when compared to central systems, that will require ongoing maintenance.
Resiliency	**RED**	Usually, these systems are built with a single fuel source (natural gas or electricity) and don't have N+1 capacity.
Sustainability	**YELLOW**	Impact on sustainability targets would be highly dependent on the kind of technology chosen for localized heating systems. HPs could significantly reduce heating energy use emissions but would add more strain to local grid in the short term. Natural gas hot water boilers are not aligned with Cornell's sustainability targets.
Implementation Viability	**YELLOW**	System has good phasing characteristics, but there could be concerns about space availability in existing buildings.

Criteria	Rating	Description
Financial & Funding	**RED**	A localized heating system often has the lowest first cost, but due to energy and O&M costs, this system frequently has a higher LCC. While this system would likely not be eligible for grants, the ability to break it into smaller projects can help with funding.
Research & Educational Integration	**YELLOW**	Integration of HPs can present a broad number of applied research opportunities that could be compatible with a number of Engineering College disciplines

Regional Thermal Plants

Regional Thermal Plants deploy equipment dedicated to heat production for several buildings near to each other. The intent is to locate smaller heating plants to serve clustered buildings and supply each building with hot water for heating. The connected equipment could be electric boilers, air source heat pumps or water source heat pumps. Solutions can be tailored to the demands of the building, physical constraints, and existing infrastructure. This approach allows utilization of solutions that can produce low-temperature hot-water, high temperature hot water, or steam.

Advantages

- Easier phasing characteristics
- Reduces campus distribution piping required
- Modifications to mechanical rooms are easier

Disadvantages

- Increased long-term O&M
- Multiple plants need to be located across the campus
- Low future adaptability

Regional Thermal Plants are Not Included in the Recommended Scenario

Transferring buildings in small groups to regional plants may simplify the overall campus-wide conversion from steam to hot water in phases, vs. replacing the entire steam distribution with hot water distribution across campus. Additional electrical infrastructure would need to be supplied to regional thermal plants. This can be a viable solution for satellite campuses or extended sections of the campus which would otherwise need extensive distribution connections to central plants.

Regional plants are more efficient and require less O&M compared to localized heating solutions, but less efficient and require more O&M compared to centralized heating

solutions. They also offer less flexibility with planning future expansion which may require building new regional plants.

Table 18: Regional Thermal Plants Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	**YELLOW**	Regional plants require less equipment than localized solutions, but more equipment than centralized systems.
Resiliency	**YELLOW**	Systems are typically built with a single fuel source (natural gas or electricity).
Sustainability	**YELLOW**	Impact on sustainability targets would be highly dependent on the kind of technology chosen for localized heating systems. HPs could significantly reduce heating energy use emissions but would add more strain to local grid in the short term. Natural gas hot water boilers are not aligned with Cornell's sustainability targets.
Implementation Viability	**YELLOW**	This system has good phasing characteristics, but there could be concerns about space availability in or around existing buildings.
Financial & Funding	**YELLOW**	A regional heating system often has a lower first cost, but due to energy and O&M costs, often has higher LCC. While this system would likely not be eligible for grants, the ability to break it into smaller projects can help with funding.
Research & Educational Integration	**YELLOW**	Integration of HPs can present a broad number of applied research opportunities that could be compatible with a number Engineering College disciplines

Steam Heat Pumps

Unlike traditional chillers, steam heat pumps can produce chilled water and steam simultaneously. Most hot water heat pumps supply HW in the range of 140-160F and are more efficient when generating low-temperature hot-water. Steam heat pumps are specialized to produce high temperature hot water or steam at high efficiencies, that can generate steam up to 330°F.

While not as efficient as hot water heat pumps, steam heat pumps can achieve coefficients of performance up to 2-3.3. Due to higher temperature steam generation, the steam-to-CHW production ratio is typically lower than hot water heat pumps.

Advantages

- Higher efficiency relative to electric boilers
- Reduces boiler and cooling tower loads

Disadvantages

- Controls single temperature
- Requires simultaneous heating and cooling loads

Steam Heat Pumps are Not Included in the Recommended Scenario

Steam heat pumps are a viable solution where simultaneous heating and cooling loads exist for significant portions of the year, or where long-term thermal energy storage exists. This solution integrates well with the existing steam distribution and heating systems on campus and will not require a conversion to hot water systems. Steam heat pumps can also be a targeted solution that can provide a phased solution to hot water conversion while providing a way to electrify steam generation at higher efficiency.

Steam heat pumps can be staged to meet base winter cooling load or base summer heating loads. Its operation can complement the current operation of LSC and add additional capacity and resiliency for growth. The resulting operation would increase energy use from cooling due to shifting of loads to a less efficient cooling source than the LSC but allows the simultaneous generation of steam.

Table 19: Steam Heat Pumps Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	Steam heat pumps require maintenance and inspections compared to hot water heat pumps. Additional maintenance would be required for existing campus steam distribution. Steam heat pumps retain the legacy steam/condensate system maintenance burdens.
Resiliency	**YELLOW**	This system would put a larger reliance on the electrical system and require a dedicated back up power system.
Sustainability	**YELLOW**	This solution would improve system efficiency when compared to an electrode boiler by ~ 50% depending on the low-grade heat source available. This solution is dependent on a low-grade waste heat source.

Criteria	Rating	Description
Implementation Viability	**GREEN**	Implementation would be straight-forward; no hot water conversion will be required. Can be implemented to provide a base heating/cooling load throughout the year and complement operation of LSC.
Financial & Funding	**RED**	A steam heat pump would have strong economics compared to existing heating production equipment. Depending on overall financials of the system, there may be alternative funding sources such as an ESPC.
Research & Educational Integration	**YELLOW**	Moderate research and academic involvement opportunities with Cornell's Engineering programs.

Solar Thermal

Solar thermal systems harness the sun's energy to capture heat. Non-concentrating solar thermal systems use flat plate or evacuated tube collectors to generate hot water. A variety of solar thermal panels designs exist, with a general tradeoff between fluid production temperature and efficiency. Production of hot water allows simple integration with BTES for energy storage.

Advantages

- Renewable energy source, reduces GHG emissions
- Low maintenance costs
- Higher efficiency and versatile for low temperature applications

Disadvantages

- High capital costs
- Large space requirements for panels and storage tanks
- Intermittent generation

Solar Thermal Application at Cornell

Cornell currently operates three different solar thermal systems, primarily using evacuated tube collectors to generate hot water and steam. The key constraint with solar heating is peak generation does not align with peak consumption seasonally or daily, and would require thermal energy storage to be a viable large-scale solution. Large scale application would also require building and maintaining significant backup heating resources which would bring up total costs.

Table 20: Solar Thermal Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	**GREEN**	Require relatively little maintenance - primarily cleaning of collectors and periodic checks for leaks and damages.
Resiliency	**GREEN**	Enhances system resiliency by adding distributed generation of thermal energy and ability to be operational even during utility outages.
Sustainability	**GREEN**	Captures thermal energy from a renewable energy source to reduce GHG emissions from heating and reliance on fossil fuels without adding addition strain on the grid
Implementation Viability	**YELLOW**	Plant construction would be straight forward; however additional heating/storage systems would still be required. Solution would likely not be the primary heating system due to large space requirements, but could provide a low operating cost, carbon-free source of long-term heating of the thermal energy storage solutions (e.g., tanks, geothermal exchange) contributing to meeting the overall campus heating demands.
Financial & Funding	**YELLOW**	Moderate capital costs but low O&M costs would result in strong life-cycle savings. Depending on overall financials of the system, there may be alternative funding sources such as an ESPC, as well as incentives to reduce costs.
Research & Educational Integration	**GREEN**	High research and academic involvement opportunities with Cornell's Engineering programs and integration with existing solar thermal plants. Additional applications and research in downhole thermal balancing and seasonal storage.

Wastewater Exchange Systems

Sanitary sewer flow typically operates at a near constant temperature and with a predictable minimum flow as it travels through the sewer pipe. This presents an opportunity to recover waste heat through wastewater exchange systems. In this solution, a heat exchanger is used to pull heat from (or reject heat to) the wastewater and transfer it to/from the university's clean water distribution pipe (e.g., ambient loop or other TEN system). It is a closed-loop system, with a separator and heat exchanger isolating the wastewater system from the university's district energy system. The wastewater effluent utilized for heat exchange flows

back into the sewer, while the energy is transferred to/from the university's thermal systems and upgraded as necessary with a heat pump on the university side.

Advantages

- Very low annual energy cost (pumping with O&M for separation)
- Carbon free, consistent source of energy
- The wastewater system can serve as a heat source/sink that doesn't require annual balancing as the wastewater system is continuously replenished from a thermal perspective.

Disadvantages

- Requires coordination with local utility and maintaining a given temperature range of the wastewater effluent
- Requires additional maintenance on the wastewater separation equipment

Wastewater Exchange Systems are Not Included in the Recommended Scenario

Cornell is already investigating the potential to add a sewer HX system on West Campus, which would potentially be located upstream of the treatment facility. To implement this solution Cornell would need to coordinate with City of Ithaca to allow the heat exchange to be implemented and to work through operating parameters. Wastewater HX would typically not cover the entire heating/cooling needs but could serve as a valuable part of the load profile.

Wastewater HX could complement LSC and provide additional capacity for peak demand and future expansion. It could also be used to pre-heat hot water or domestic hot water and can be integrated with other heating solutions. Wastewater HX systems can also potentially be integrated with biomass gasification systems if biogas generation solutions are pursued.

Table 21: Wastewater Exchange Systems Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	Requires additional maintenance with wet wells and HX but has minimal moving parts or complex systems.
Resiliency	**YELLOW**	Wastewater HX shouldn't be the only source but as a portion of the solution adds resiliency to campus systems.

Criteria	Rating	Description
Sustainability	**GREEN**	Wastewater HX allows for high operating efficiencies, are often much more efficient than boiler HW systems and cooling tower CW systems resulting in lower GHG emissions and reduced strain on the grid.
Implementation Viability	**YELLOW**	While Cornell owns the sewer mains this solution might need to be extensive coordination with the municipal utility.
Financial & Funding	**YELLOW**	Higher upfront capital cost, but much lower operating costs long term. Likely be funding sources, however current IRA tax credits for this solution may be rolled back/subject to change from upcoming and future legislation.
Research & Educational Integration	**GREEN**	Broad opportunities for research and academic involvement in biomass technologies which couples well with Cornell's Engineering programs

Near Ambient Loop

Near-ambient distribution is used to interconnect multiple heat sources or sinks that operate at different conditions. The loop operates within a drift temperature range dictated by performance requirements; this allows for thermal flywheeling and harnessing of energy that would otherwise be wasted. Other benefits include enhanced resilience and flexibility for future growth by using distributed generation hubs rather than one large central plant. Distribution network for ambient loops requires less piping and insulation compared to hot and chilled water distribution.

This solution also allows integration of other high efficiency solutions such as heat pumps and heat recovery chillers to maximize heat recovery potential. Supplemental heating and cooling sources, such as borefields or boilers, can be added at a district level to offset load imbalances and further improve performance.

Advantages

- High energy sharing capabilities, enable energy resources such as heat sources, heat sinks, or thermal energy storage systems
- Modularity in distribution
- Reduced installation costs due to one or two pipe systems as compared to 2 x 2 - pipe systems for separate heating and cooling supply/return loops
- Reduced energy losses to/from environment, little need for insulation, and in fact may benefit from passive energy exchange with ambient earth along distribution paths

Disadvantages

- Robust controls network required
- Requires distributed equipment with heat pumps located at each individual building which would be a major concern with existing buildings which have congested mechanical rooms.

Near Ambient Loops are Not Included in the Recommended Scenario

An ambient distribution solution integrates well with transition to hot water and integration of heat pumps. This solution offers integration with other solutions such as geothermal exchange and wastewater exchange systems to further enhance efficiency and emissions reduction. Ambient loops are most effective if used both as a heating and cooling solution to maintain a balance of heat rejection and injection. Ambient loops can facilitate phased conversion of campus sections without disrupting adjacent sections. This can also be a viable solution for satellite campus areas which cannot be connected to LSC.

Campus wide implementation would require a new centralized distribution system, which would represent a large construction effort and capital cost. In addition, the localized distribution would need to be installed at each individual building. Similar to the localized equipment solution, this would require space in existing buildings, which is not available in many cases. Additionally, maintenance requirements are increased due to individual equipment installed at the building drastically increasing the equipment quantity.

Table 22: Near Ambient Loops Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	Distribution itself will require similar maintenance to existing campus chilled water distribution but could have extra building/regional equipment requiring maintenance.
Resiliency	**GREEN**	Ambient distribution is often looped and relies on many sources of heat production and rejection.
Sustainability	**GREEN**	Allows integration of solutions such as HPs, wastewater / geo-HX which are often much more efficient than boiler HW systems and cooling tower CW systems resulting in lower GHG emissions and reduced strain on the grid.

Implementation Viability	**YELLOW**	Equipment configuration will dictate the viability of implementation due to space, but underground space is more efficient than a 4-pipe system. Ambient distribution is effective if used for heat rejection and production, and can complement current LSC capacity and allow flexible future growth.
Financial & Funding	**YELLOW**	Capital costs could be higher/lower based on solution configuration, but operating costs would be lower in the long term. There will likely be funding sources, however current IRA tax credits may be rolled back/subject to change from upcoming and future legislations
Research & Educational Integration	**GREEN**	Integration of HPs, geo HX and wastewater HX can present a broad number of applied research opportunities compatible with a number Engineering College disciplines

Heat Battery

Heat batteries offer another form of thermal energy storage (TES) system that can store and release thermal energy. Resistive heaters are embedded within the storage modules which heat the material (crushed rocks/sand/phase change materials) up to 750 °C, providing a heat storage capacity of ~10kWh/ft3. TES modules can have a heat loss of less than 0.1% per hour. With a round-trip efficiency of ~98% efficiency at 1 cycle/day. There are several different modes of TES operation including load shifting and peak shaving. Load shifting can also be used to reduce load during periods when the grid is "dirtier" to periods when the grid emissions are lower.

Advantages

- Reduces utility purchase at peak demand
- Improves system reliability by adding redundancy/standby
- Compatible with steam systems

Disadvantages

- Large site requirements
- Electrical rates dictate payback/viability
- Additional equipment and controls required

Heat Batteries are Not Included in the Recommended Scenario

Application of heat batteries would be similar to thermal energy storage using hot water. In the short term it could become a useful asset to help meet heating demands and managing periods of peak loads as well as support phasing for transitioning to hot water heating.

This solution can also help Cornell reduce carbon emissions by shifting loads away from periods when the grid is "dirtier", allowing for more advanced emissions accounting, enhanced utilization of on-site renewable energy production and reduced need for carbon offsets.

In the long term, a heat battery could be a useful asset for reducing system demand, managing utility costs, and emissions from heating/cooling equipment.

Table 23: Heat Battery Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	Heat batteries generally require minimal maintenance, but may require specialized inspections and maintenance compared to other thermal storage solutions.
Resiliency	**GREEN**	Energy storage will help provide short-term support in the event of a utility outage or HW production deficit.
Sustainability	**GREEN**	Heat batteries can help with load balancing to allow equipment to operate at ideal load points and can reduce electrical load on the grid during peak hours. This solution can also enhance on-site renewable energy production usage and reduce energy export to grid.
Implementation Viability	**GREEN**	Land requirement is highly dependent on selected technology (sand/rocks vs PCMs) and its expected operation (load shifting peak shaving). This solution would require a decent amount of land but is moderately easy to implement.
Financial & Funding	**YELLOW**	Typically, a cost-effective way of enhancing hot water system, lowering operating costs and carbon emissions. Costs can vary based on selected technology. There will likely be multiple funding sources, including an IRA tax credit which may be rolled back/subject to change from upcoming and future legislations.
Research & Education	**YELLOW**	Moderate research and academic involvement opportunities with Cornell's Engineering and Chemical programs for system operation/optimization for operating efficiency, utility costs, and carbon emissions.

Future Contemplation

At present, these solutions do not appear viable for the Cornell campus due to a variety of reasons but should be reconsidered in future years if changes in technology, regulations, cost or other variables occur.

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Table 24: Future Consideration Technology Screening and Scoring Summary Part I

Criteria	Landfill Gas	Biomass	Alt. Fuel Combined Heat and Power	Methane Pyrolysis	District Energy Buildings Exhaust Air Heat Recovery	Fuel Cells
Maintainability	YELLOW	RED	YELLOW	RED	GREEN	YELLOW
Resiliency	RED	GREEN	GREEN	GREEN	YELLOW	GREEN
Sustainability	YELLOW	YELLOW	YELLOW	GREEN	YELLOW	YELLOW
Implementation Viability	YELLOW	RED	GREEN	RED	GREEN	YELLOW
Financial & Funding	RED	YELLOW	YELLOW	RED	YELLOW	YELLOW
Research & Education	RED	YELLOW	GREEN	GREEN	YELLOW	GREEN

Table 25: Future Consideration Technology Screening and Scoring Summary Part II

Criteria	Small Modular Reactor	Micro Modular Reactor	Nuclear Fusion	Alternative Diesel	Waste to Gas	Biogas	Hydrogen
Maintainability	RED	RED	RED	GREEN	RED	RED	RED
Resiliency	GREEN	GREEN	GREEN	GREEN	GREEN	GREEN	RED
Sustainability	GREEN	GREEN	GREEN	YELLOW	YELLOW	GREEN	GREEN
Implementation Viability	RED	RED	RED	YELLOW	RED	YELLOW	RED
Financial & Funding	RED	YELLOW	RED	YELLOW	RED	YELLOW	RED
Research & Education	RED	RED	RED	GREEN	YELLOW	GREEN	GREEN

Landfill Gas

Landfill gas (LFG) is a natural byproduct of the decomposition of organic material within landfills, primarily composed of methane and carbon dioxide. This gas can be effectively captured, cleaned, and then transported via pipeline for use in boilers or gas turbines to generate heat and/or electricity.

When utilizing traditional equipment, a retrofit is typically necessary to accommodate the lower energy density characteristic of landfill gas. The efficiency of LFG utilization is generally lower than that of natural gas and is highly dependent on the extent of cleaning and processing performed after capture. Furthermore, LFG generation rates can fluctuate significantly year-to-year, with peak rates typically occurring 10-20 years before a landfill's closure.

Advantages

- Minimal changes required to existing thermal systems
- Renewable source of energy

Disadvantages

- Large piping project to connect
- Unit pricing is unknown
- Long term resource availability

Outlook for Landfill Gas Application at Cornell

Several landfills in the surrounding region, including those in Ontario, Broome, Chemung, and Cortland Counties, are located within a potentially viable range for supplying Cornell with landfill gas (LFG). However, all potential locations are located at least 30 miles from the campus. This would result in substantial piping costs, estimated at around $100 million in infrastructure for each site. Furthermore, the Ontario County landfill is slated for closure in 2028, meaning its peak LFG capture potential would have passed.

While the Broome, Chemung, and Cortland County landfills either already utilize LFG or are in the process of developing such systems, the overall generation potential is low. The combined annual waste from these three sites totals only 730,000 tons, yielding approximately 315,000 cubic feet of LFG daily. This translates to roughly 158 MMBtu of heat per day, satisfying less than 7% of Cornell's annual heating demand. Even at peak generation, LFG from all potential sites combined would only meet 12% of the summer base heating load and 2% of the winter peak heating load, indicating it would only be a supplementary energy source. The estimated costs for LFG utilization can also vary

significantly, depending on the final application and the level of treatment and processing required.

Table 26: Landfill Gas Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	YELLOW	This would have similar characteristics to natural gas but would likely require additional O&M as this fuel offers lower heating values than natural gas.
Resiliency	RED	Landfill systems can have issues with supply availability and might not have good long reliability.
Sustainability	YELLOW	Landfill gas would represent energy from a renewable source and allow for heating application without adding additional load to existing grid.
Implementation Viability	YELLOW	There is currently no viable resource near campus to be able to deploy this solution.
Financial & Funding	RED	High upfront cost of equipment and construction of LFG pipeline. This system would likely be eligible for grants. Additional costs from material handling and transport.
Research & Educational Integration	RED	Can present some opportunities in education and applied research of landfill gas collection and landfill gas to energy conversion and synergy with Cornell's existing research into biogas and biogas systems.

Biomass

Biomass combustion utilizes local biomass products such as purpose grown crops, woodchips, trimmings, and other biomass material as a direct fuel source. The available biomass material can be combusted with specialized boilers to generate heat or integrated into CHP systems to generate heat and electricity. While less efficient than natural gas systems, biomass-based systems can achieve efficiencies of 70-80%.

Advantages

- Depending on the fuel source it can be considered environmentally friendly
- Alternative fuel source
- Can generate steam or hot water

Disadvantages

- Larger footprint required
- Significant material transport and handling
- Biomass sources can be seasonal, requiring storage

Outlook for Application at Cornell

Biomass heating systems would have significant land requirements (2,000-13,000 ft2/MWhth/yr), and any solution utilizing biomass as the primary heating/electricity source would require an extremely large area. The Cornell campus in Ithaca stretches across ~2,300 acres and Cornell's additional land holdings in Tomkins County include an estimated ~11,000 acres including a 4,300-acre botanical garden. It is estimated from previous studies that ~4,000 acres may be available for biocrop cultivation. The generation potential from such a system is 27,700 MWh of electricity and 157,500 MMBtu of heating (14% and 20% of annual campus electrical and heating energy). While a full biomass heating system would require ~20,500 acres of biocrop land and would only satisfy 73% of annual electrical energy use.

Other potential drawbacks for biomass-based systems include logistical challenges and time required to establish adequate supply of feedstock. Transport, handling and storage of material would be a major logistical challenge requiring further land requirement and manpower. Establishing feedstock supply would take an estimated 3-10 years, putting a significant constraint on implementation timelines.

While not best suited to be the primary heating/power generation solution for Cornell, biomass heating/CHP can be used as a peaking solution to meet peak loads when paired with another thermal solution.

Table 27: Biomass Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**RED**	Material handling, collection and storage along with additional equipment would increase maintenance and operation costs.
Resiliency	**GREEN**	Depending on storage size, biomass can maintain an extended quantity of on-site fuel to enhance system resiliency.

Criteria	Rating	Description
Sustainability	**YELLOW**	Biomass would represent energy from a renewable source and allow for heating and/or power generation without creating additional strain on the grid. Not currently recognized as a renewable energy source under the CLCPA for NY.
Implementation Viability	**RED**	Implementing on campus would be a challenge to maintaining existing operations and would require installation of a new collection, storage and combustion plant. Land requirements for such a system would also be extremely large and require a large amount of feedstock to maintain a significant baseload through the year.
Financial & Funding	**YELLOW**	While overall capital and operational costs will likely be on the higher end compared to other technologies, this system would likely be eligible for grants.
Research & Educational Integration	**YELLOW**	Moderate opportunities for research and academic involvement in biomass technologies with Cornell's Engineering, Chemical and Agricultural programs.

Alternative Fuel Combined Heat and Power

Combined heat and power (CHP) is the simultaneous production of electricity and useful heat from a single fuel or energy source. CHP produces on-site electricity and recovered heat for efficient generation of steam, hot water or other thermal needs. A typical CHP plant has an efficiency of 70-85% compared to conventional operation which has a total efficiency of 50-60%.

While CHP turbines typically use natural gas, they can be modified to use a variety of renewable/low-carbon fuels – renewable natural gas, biogas, biomass, hydrogen, syngas, landfill gas – or can be outfitted with Carbon Capture, Utilization, and Sequestration (CCUS) to reduce net carbon emissions.

Advantages

- Reduces GHG emissions
- High energy efficiency
- Reliable source of electricity and steam
- Can be modified to use alternate fuels

Disadvantages

- Reduced efficiency from using alternate fuels

- Power plant adds O&M to university, vs grid power

Outlook for Application at Cornell

CHP technology is a critical component of the current campus district energy operations at Cornell. Cornell CEP installed twin 15 MW turbines with heat-recovery steam generators in 2009 which generates 80%+ of annual campus electricity requirement. If a new power generation solution is implemented on campus, the current CHP plant can also be transitioned to a backup power source based on equipment condition without requiring any fuel switching.

The existing CHP plant can be modified to generate hot water instead of steam, reducing the impact of transitioning to hot water thermal systems. The CHP turbines can be modified to use renewable fuels such as biogas, biomass, hydrogen, syngas etc., giving Cornell the opportunity to establish some onsite production of fuel.

Based on current biogas/RNG generation potential on campus, Cornell could run a 2.5-3 MW CHP plant (<10% of current CEP capacity). This indicates that the implementation of an alternate fuel CHP solution as the primary heating/electric solution would require a reliable local external fuel supply. An alternative implementation as a peaking solution would also be viable at Cornell. A smaller capacity CHP could be used during winter months to meet peak heating loads and provide electric generation.

Table 28: Alternative Fuel Combined Heat and Power Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	A CHP plant typically has slightly more complex equipment and requires specialized operations personnel and maintenance contracts.
Resiliency	**GREEN**	CHP can serve as a generation asset in the event of a utility failure. Depending on the selected system, this can be dual fuel.
Sustainability	**YELLOW**	While CHP systems do not add additional strain on the local grid, they do not align with Cornell's long-term goal of net-zero carbon. Potential to modify CHP systems to use renewable/low-carbon fuels can reduce emissions from heating and electrical generation.

Criteria	Rating	Description
Implementation Viability	**GREEN**	Cornell already has existing CHP infrastructure that can be utilized. CHP can also utilize steam or hot water for a thermal medium, allowing for a smoother hot water conversion Conversion to alternate fuels will require modification to existing CHP equipment.
Financial & Funding	**YELLOW**	Higher capital cost but will likely provide life-cycle savings. This opportunity would likely have interest from an ESPC or P3, and potential incentives from NYSERDA.
Research & Educational Integration	**GREEN**	Moderate research and academic involvement opportunities with Cornell's Engineering programs. Transitioning to renewable or alternative fuel powered CHP (biomass/biogas, hydrogen) couples well with Cornell's Engineering, Chemical and Agricultural programs and can create broad opportunities for academic and research integration.

Methane Pyrolysis

Methane pyrolysis is an emerging technology that offers a potential pathway for producing clean hydrogen. Also known as “turquoise hydrogen”, it is a process that splits methane (CH4) into hydrogen and solid carbon by applying high heat, without using oxygen. The solid carbon byproduct produced from this process can be a valuable material for various industries.

Steam methane reforming is currently the dominant method for hydrogen production but is a carbon intensive process. It requires additional carbon capture and storage (CCS) to reduce associated carbon emissions from hydrogen production which adds to production costs. Methane pyrolysis can produce hydrogen with minimal or no carbon emissions and stronger financials even when compared to steam methane reforming equipped with CCS. Hydrogen is a versatile, clean burning fuel that can be utilized for generating hot water or steam or integrated into Combined Heat and Power (CHP) systems to produce both electricity and hot water or steam simultaneously. Production of clean hydrogen at improved cost effectiveness, addresses two of the key hurdles faced with utilizing hydrogen as an alternative fuel.

Advantages

- Produces clean hydrogen which reduces net
- emissions
- More cost effective than current hydrogen production methods
- Generates valuable byproduct

Disadvantages

- Requires significant heat energy input
- Development technology, still not commercially ready
- Large initial investment and space requirements
- Byproduct needs additional handling which is crucial for economic viability

Outlook for Application at Cornell

This solution provides a path to producing clean hydrogen and can help Cornell transition to a hydrogen-based district energy system. It can be a viable option to produce a reliable supply of hydrogen with minimal to no carbon emissions.

However, methane pyrolysis technology is relatively new and not completely commercially adapted. Implementation would require providing time to optimize the technology and processes at each stage. Cornell would have to source a large amount of renewable energy to provide heat for the reaction for the process to truly be considered a low-emission fuel.

Significant effort would also be required in training staff and facility maintenance. Additional investment will be required in handling and identifying a way to monetize the carbon byproduct, which is a key part to establishing the economic viability of this solution.

This solution will need to be implemented in conjunction with the use of hydrogen boilers/CHP. A possible phased implementation would need to be developed to support the demands of switching the campus to hydrogen fueled equipment.

Table 29: Methane Pyrolysis Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**RED**	Methane pyrolysis is a new technology with maintenance and training practices that are not well-established
Resiliency	**GREEN**	On-site production of hydrogen would enhance resiliency of any hydrogen powered equipment or processes
Sustainability	**GREEN**	Solution produces hydrogen with minimal to no carbon emissions only if a renewable or a low-carbon energy source is used. Implementation supports the integration and usage of a clean burning fuel.

Criteria	Rating	Description
Implementation Viability	**RED**	Technology development, space constraints and effective usage of byproducts are potential challenges to adoption.
Financial & Funding	**RED**	Overall capital and operational cost will likely be high, though there might be opportunities to be eligible for grants. Implementation of this solution would need to be paired with implementation hydrogen boilers/CHP which also represents a capital-intensive solution.
Research & Educational Integration	**GREEN**	High research and academic involvement opportunities with Cornell's Engineering and Chemical programs in hydrogen generation, distribution and utilization systems including fuel cells, green hydrogen, and hub infrastructure.

District Energy Building Exhaust Air Heat Recovery

In heating dominated climates, the low base cooling load and high heating loads in winter limit the amount of heat recovery that can be achieved through simultaneous generation of chilled and hot water. This results in lower heating performance and higher required heating energy.

This solution involves inducing an additional cooling load to create an opportunity for heat recovery while reducing the heating demand on the district heating system. The key component in this solution is the addition of a heat pump chiller in selected buildings, that can produce chilled and hot water simultaneously. Buildings with high outside air requirements or exhaust requirements such as labs, dorms or even greenhouses are viable implementation options to reduce heating load on central plants. Inducing cooling load allows for higher local generation of hot water even in winters when the base cooling load can be quite low.

Advantages

- Allows electrification of heating and reduces dependency on natural gas
- Can provide a consistent base heating load
- Low maintenance costs

Disadvantages

- Requires installation of smaller equipment across campus
- Not as efficient as other heating solutions

Outlook for Application at Cornell

This solution integrates well with the current planned campus transition to hot water heating which utilizes low-temperature hot-water. Implementation of this solution would require the addition of a heat pump chiller to identified buildings across the campus to meet the local base heating/cooling load. Implementation also requires the addition of an exhaust cooling coil to induce cooling load on heat pump chiller to generate hot water.

Buildings with high ventilation or exhaust rates such as labs, hospitals, animal housing/research, dorms or even greenhouses have a high base heating load and are a viable option for implementation of this solution. False cooling load can be used in winter months when base cooling loads are lower and disabled when there is higher cooling demand from buildings. Building AHUs equipped with heat pipes or other forms of exhaust heat recovery could see a considerable reduction in heating demand similar to the heat output produced from a false cooling load system.

Table 30: District Energy Exhaust Heat Recovery Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**GREEN**	From a maintainability perspective, the key equipment of heat pump chillers has similar maintenance as a standard water-cooled chiller. However, this solution results in an increased equipment count spread across the campus.
Resiliency	**YELLOW**	This system would put a larger reliance on the electrical system and may require a dedicated back-up power system. Adds another local heating source for buildings where this solution is installed.
Sustainability	**YELLOW**	This solution would reduce reliance on and emissions from existing natural gas CHP system to generate hot water. While more efficient that CHP systems, other solutions, such as HPs and ESH, would provide higher efficiencies. Electrification of heating load would result in additional strain placed on grid.
Implementation Viability	**GREEN**	Implementation would require installation of equipment distributed through the campus, with hot water conversion required in installed buildings.

Criteria	Rating	Description
		Can be implemented to provide a higher base heating load in winter than what can be achieved by a typical heat recovery chiller.
Financial & Funding	**YELLOW**	A false cooling load system would have strong economics. Installation of distributed smaller equipment would cost more than large central equipment. Depending on overall financials of the system, there may be alternative funding sources such as an ESPC.
Research & Educational Integration	**YELLOW**	Moderate research and academic involvement opportunities with Cornell's Engineering programs.

Fuel Cells

Solid Oxide Fuel Cells (SOFCs) are advanced electrochemical devices that convert chemical energy into electrical energy. They offer fuel flexibility, allowing input of a variety of fuels such as natural gas, hydrogen, biogas, RNG, or a blend of these fuels. Estimated efficiencies range from 50-60% but they can be paired with heat capture or CHP systems to increase system efficiency.

Their modular design enables scalable power generation by building stacks, making them a good fit for large-scale applications. SOFC systems have no physical limitation to installation size, with systems ranging from 300 kW to hundreds of MW. Associated carbon emissions depend on the system fuel; however, combining SOFCs with carbon capture can provide a path to decarbonizing electricity generation.

SOFCs have estimated CAPEX costs of $7,000-$8,000/kW but require additional operational and fuel costs, unlike solar PV systems. This solution has a similar footprint to BESS, with a land requirement of 2,000 ft^2/MW.

Advantages

- Fuel options: NG, H2, biogas
- Modular architecture

Disadvantages

- High capital costs
- Carbon neutrality requires additional systems and costs

Outlook for Application at Cornell

An SOFC solution can provide a viable transition path to carbon neutral power generation at Cornell. It can be implemented with blended low-carbon fuels such as RNG, biogas, and hydrogen mixed with natural gas, allowing for a phase out of natural gas over time. SOFCs integrate well with existing NG infrastructure with minimal modifications and can be integrated into future RNG and hydrogen systems. Full carbon neutrality can also be achieved through the future implementation of carbon capture technology. Cornell can likely explore partnerships with third parties for funding options (PPA, power as service, capital purchase assistance, etc).

With lower land requirements compared to other electrical generation solutions and the modular nature of fuel cells, such a system could be sited within the main campus area. Cornell would likely need to expand its electrical distribution automation infrastructure for full operation flexibility.

Table 31: Fuel Cells Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**YELLOW**	While SOFC systems require lower maintenance, it is a relatively newer commercial technology with specialized maintenance.
Resiliency	**GREEN**	SOFCs provide a stable and uniform on-site generation that enhances resiliency.
Sustainability	**YELLOW**	While emissions can be similar to only natural gas systems, SOFCs allow the use of blended low-carbon fuels (RNG, biogas, H2) with natural gas, which can significantly reduce emissions and transition away from natural gas. SOFC systems do not add additional strain on the local grid and the use of carbon capture technology allows another path to carbon neutrality.
Implementation Viability	**YELLOW**	Solution integrates well with existing natural infrastructure and allows a phased transition away from natural gas.
Financial & Funding	**YELLOW**	High upfront costs and low system life of 8-10 years. Use of low carbon fuels (RNH, biogas, H2) will add significant cost to initial CAPEX .

Criteria	Rating	Description
		There will likely be funding/incentive sources available; however, current IRA tax credits may be rolled back or are subject to change with upcoming and future legislation.
Research & Educational Integration	**GREEN**	High research and academic involvement opportunities with Cornell's Chemical and Engineering programs. Multiple research opportunities for the development of fuel cells, hydrogen and RNG generation, and hub infrastructure.

Small Modular Reactor (SMR)

Small modular nuclear reactors are smaller versions of utility scale plants. They generate energy from controlled fission reactions, which produce heat absorbed by a working fluid. Potential capacities for SMRs could range 20MW up to 300MW of power production.

SMRs can be used for generation of electricity, heat, or both in a CHP operation. This is a developing technology in its nascent stages, with the likely deployment of pilot projects in the early 2030s. Current R&D and designs are evolving to ensure safe shutdowns are achievable and maintenance costs are reduced.

Advantages

- No GHG emissions
- Reliable fuel source

Disadvantages

- High capital costs
- Technology not currently commercially deployed
- Regulatory concerns

Outlook for Application at Cornell

The state of New York has a sizeable nuclear fleet that generates power to meet over one-fifth of the state's electric demand, showcasing the role of nuclear power in generating clean electricity. A potential SMR at Cornell could be deployed in a power-only or CHP configuration. A smaller plant (20-30 MW) that can maintain baseload operation would likely be a viable implementation option. The potential plant would need to be located away from the existing steam plant and campus buildings.

SMRs can be a viable long-term solution for campus electrical and heating requirements once the technology has matured. Given the current rate of technology development and

the prolonged permitting process that would be required, this technology is at least 8-10 years away but likely longer from being potentially ready to be deployed at Cornell.

Table 32: Small Modular Reactors Screening Assessment (SMR)

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	RED	Maintenance would need to be fully contracted out.
Resiliency	GREEN	Nuclear has significant on-site energy storage and should enhance resiliency.
Sustainability	GREEN	There are no GHG emissions associated with power and/or thermal generation with SMRs, while also being completely independent from the grid.
Implementation Viability	RED	The regulatory, technology, and space constraints, coupled with potential local protests, make adoption very difficult.
Financial & Funding	RED	Overall capital and operational costs will likely be much higher compared to other technologies due to the newness and regulatory requirements, although there might be opportunities to qualify for grants.
Research & Educational Integration	RED	Cornell decommissioned its nuclear research reactor in 2002 and does not currently have a nuclear engineering program, which would limit opportunities for academic and research integration.

Micro Modular Reactor (MMR)

Micro modular nuclear reactors are even smaller versions of small modular reactors and utility scale plants. They generate energy from controlled fission reactions, which produce heat absorbed by a working fluid. Potential capacities for MMRs could range from 1 MW to 20MW of power production. Initial CAPEX estimates for MMRs range from $10,000/kW to$15,000/kW. MMRs can be used to generate electricity, heat, or both through a CHP operation, and is a developing technology in nascent stages with likely deployment of pilot projects in the early 2030s. Current R&D and designs are evolving to ensure safe shutdowns are achievable and maintenance costs are reduced.

Advantages

- No GHG emissions
- Reliable fuel source

Disadvantages

- High capital costs
- Technology not currently commercially deployed
- Regulatory concerns

Outlook for Application at Cornell

A potential MMR would have a similar deployment to a small modular reactor solution. MMR at Cornell could be deployed in a power-only or CHP configuration. A smaller plant (up to 20 MW) that can maintain baseload operation would likely be a viable implementation option. The potential plant would need to be located away from the existing steam plant and campus buildings.

MMRs can be a viable long-term solution for campus electrical and heating requirements once technology has matured. Given the current rate of technology development and prolonged permitting process that would be required, this technology is a at least 8-10 years away but likely longer from being potentially ready to be deployed at Cornell.

It is recommended that this solution is monitored moving forward, as the industry is moving rapidly and heating-only reactors have a potential to move faster than a combined heat and power type of configuration. There are currently companies working on a PPA approach utilizing a design, build, own, operate and maintain model that would allow Cornell to purchase the generated heat without having to manage system operations.

Table 33: Micro Nuclear Reactors Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**RED**	Maintenance would need to be fully contracted out.
Resiliency	**GREEN**	Nuclear has significant on-site energy storage and should enhance resiliency.
Sustainability	**GREEN**	There are no GHG emissions associated with power and/or thermal generation with SMRs, while also being completely independent from the grid.
Implementation Viability	**RED**	The regulatory, technology, and space constraints, coupled with potential local protests, make adoption very difficult.

Criteria	Rating	Description
Financial & Funding	**YELLOW**	Overall capital and operational costs will likely be much higher compared to other technologies due to the newness and regulatory requirements, although there might be opportunities to be eligible for grants.
Research & Educational Integration	**RED**	Cornell decommissioned its nuclear research reactor in 2002 and does not currently have a nuclear engineering program, which would limit opportunities for academic and research integration. If Cornell changes academic mission, this could be a great living lab opportunity.

Nuclear Fusion

Nuclear fusion energy is another developing technology that aims to deliver a clean, long-term, carbon-free energy source. Commonwealth Fusion Systems (CFS) is developing compact fusion power plants through technology centered on high-temperature superconducting magnets. These powerful magnets may enable a significantly smaller and more cost-effective design compared to previous approaches utilizing fusion technology.

CFS is currently developing a demonstration machine employing these magnets with the primary goal of demonstrating net energy gain by 2027, meaning it produces more fusion energy than required to start and sustain the process. The demonstration machine is expected to pave the way for their planned commercial fusion power facility: a 400 MW plant designed for commercial viability and integration into existing energy infrastructure. CFS projects that the commercial facility will be operational in the early 2030s.

Advantages

- No GHG emissions
- Reliable fuel source

Disadvantages

- High capital costs
- Technology not currently commercially deployed
- Regulatory concerns

Outlook for Nuclear Fusion Application at Cornell

While the technology from CFS and the pilot project hold promise for a compact and economically viable fusion power plant, it faces significant hurdles in technological readiness, economic viability, regulatory approval, and public acceptance. Overcoming

these challenges is crucial for the successful deployment of commercial fusion power and realizing its potential.

Successful demonstrations and commercialization of this technology can have a significant impact on Cornell's energy use and associated GHG emissions. While it could provide reliable, carbon-free generation, a 400 MW plant would be too large for implementation at Cornell. Long-term implementation at Cornell would hinge on the reactor size that would be commercially available. This solution is expected to face similar regulatory hurdles as MMRs and SMRs.

Table 34: Nuclear Fusion Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**RED**	Maintenance would need to be fully contracted out.
Resiliency	**GREEN**	Nuclear has significant on-site energy storage and should enhance resiliency.
Sustainability	**GREEN**	There are no GHG emissions associated with power and/or thermal generation with nuclear fusion technology, while also being completely independent from the grid.
Implementation Viability	**RED**	The regulatory, technology, and space constraints, coupled with potential local protests, make adoption very difficult.
Financial & Funding	**RED**	Overall capital and operational cost will likely be much higher when compared to other technologies due to the newness and regulatory requirements, although there might be opportunities to be eligible for grants.
Research & Educational Integration	**RED**	Cornell decommissioned its nuclear research reactor in 2002 and does not currently have a nuclear engineering program, which would limit opportunities for academic and research integration

Alternative Diesel

Alternative diesels are an emerging area of interest with application in the energy sector, offering opportunities to improve sustainability while allowing easier integration with existing technologies. Biodiesel and renewable diesel are two prominent alternative diesel fuels currently in use.

Biodiesel is produced from vegetable oils or animal fats and often requires blending with petroleum diesel for optimal performance. Renewable diesel (also known as hydrogenated vegetable oil) is chemically similar to petroleum diesel and is derived from biomass sources. Both can be used in diesel engines with little or no modification and offer similar performance and significant emissions reduction.

Existing thermal or power plants can use alternative diesel blends without significant modifications, allowing for a gradual transition to more sustainable fuel sources. Alternative diesels can be utilized to generate hot water or steam or integrated into Combined Heat and Power (CHP) systems to produce electricity along with hot water or steam.

While promising, the integration of alternative diesels in power and thermal generation faces challenges such as fuel availability, cost competitiveness, and long-term storage stability.

Advantages

- Carbon-neutral energy source
- Can produce steam or hot water
- Is a “drop in fuel” and can leverage existing infrastructure
- Can leverage existing diesel equipment

Disadvantages

- Local availability of alternative diesel
- Limited proven examples of large-scale deployment
- High cost of operation compared to conventional fuels

Outlook for Application at Cornell

Integration of this alternative as the primary heating and/or power generation source faces significant challenges. The current primary CEP equipment utilizes natural gas and will not be compatible with alternative diesel. There is also a lack of reliable, large-scale sources for alternative diesel available near Cornell. Furthermore, the utility operating costs would be considerable; alternative diesel is estimated to cost between $15-25/MMBtu, a significant increase compared to the current natural gas price of $5-10/MMBtu.

Alternative diesel, however, presents a good fit as a backup emergency fuel source and would integrate well with the existing emergency diesel generators at the CEP and generators distributed across the campus. Blended alternative diesel and petroleum diesel can allow for a phased approach to transitioning to a more sustainable fuel while also utilizing the current storage equipment with little to no modification.

Table 35: Alternative Fuel Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	GREEN	Similar upkeep and maintenance to existing emergency diesel generators and storage systems.
Resiliency	GREEN	Enhances system resiliency as an alternative emergency fuel source. Onsite production could further enhance resiliency.
Sustainability	YELLOW	The solution can help reduce emissions from heating energy use and power generation; however, overall usage as an emergency fuel source would be highly limited.
Implementation Viability	YELLOW	This system would integrate easily with existing diesel generator equipment, but there could be concerns about finding a reliable local supply.
Financial & Funding	YELLOW	Integration into existing infrastructure would require limited investment. Alternative diesel has higher operational costs compared to traditional fuels. However, usage as an emergency fuel source is expected to be highly limited.
Research & Educational Integration	GREEN	Presents significant opportunities for research and academic involvement in biofuel production, which aligns well with Cornell's Engineering, Chemical and Agricultural programs. Additional opportunities exist in distribution infrastructure and alternate applications.

Waste to Gas

A waste-to-gas plasma torch is a technology that uses a plasma torch to convert waste materials into synthesis gas (syngas) and other valuable byproducts. This process, known as plasma gasification, involves subjecting waste to extremely high temperatures (often exceeding 10,800°F) generated by a plasma torch, causing the waste to break down into its constituent elements. The organic components of the waste are converted into syngas, a mixture of hydrogen and carbon monoxide, while inorganic materials are transformed into a glassy, inert substance called slag. Waste material such as municipal solid waste, tires, hazardous waste, and even some types of medical and chemical waste can be utilized for plasma gasification.

The syngas produced can be further processed and used as a direct combustion fuel source to generate electricity or in a Combined Heat and Power (CHP) application to generate heat and electricity. Syngas also has applications in fuel cells and can be used as a precursor in

hydrogen production. The slag produced as a byproduct of this process can be used in construction materials.

Advantages

- Supports a circular economy
- Reduced emissions compared to traditional incineration of waste
- Can utilize a wide range of waste materials

Disadvantages

- Higher capital and operating costs
- Plasma torch requires significant energy use
- Production of potentially harmful byproducts

Outlook for Waste-to-Gas Application at Cornell

This solution generates syngas, which is a versatile fuel and chemical feedstock with a wide array of applications in energy production. It can be integrated with the existing CHP equipment at Cornell, and a natural gas-syngas blend can be utilized, allowing for a phased approach to transitioning to a more sustainable fuel.

However, large-scale application at Cornell would be challenging due to constraints regarding production, performance, and capital expenditure. Syngas also has a lower heating value than natural gas which results in lower system efficiency and reduced system outputs. Additional cleaning to remove impurities and processing facilities are also required before syngas can be utilized. The production and quality of syngas can be highly variable based on the waste material utilized, and the implementation of this solution as the primary heat and electricity generator is unlikely due to the limited amount of waste available on campus.

While this solution can be implemented as a peaking solution in support of another primary thermal/electrical solution, the initial investment required to build and operate a plasma torch and purification facility will be a limiting factor.

Table 36: Waste-to-Gas Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	**RED**	Additional material handling and high equipment maintenance and operation costs from plasma torch, cleaning and purification facilities.
Resiliency	**GREEN**	Depending on storage size, syngas can provide an extended supply of on-site fuel to enhance system resiliency. The addition of a different fuel source also improves resiliency, with the option to be used for backup power and heat in during grid outage.
Sustainability	**YELLOW**	Syngas would reduce net carbon emissions compared to natural gas and allow for heating and/or power generation without creating additional strain on the grid.
Implementation Viability	**RED**	Implementing this solution on campus would be a challenge due to the need to maintain existing operations while installing new distribution lines, plasma torches, and purification plants. Waste availability would also limit plant size.
Financial & Funding	**RED**	Overall capital and operational costs will likely be on the higher end, given large initial investment and energy required to run plasma torch.
Research & Educational Integration	**YELLOW**	Medium opportunities exist for research and academic involvement in alternate fuel technologies, which aligns well with Cornell's Engineering, Chemical and Agricultural programs.

Biogas/Renewable Natural Gas (RNG)

Biogas is a renewable energy source produced through the anaerobic decomposition of biomass and organic materials such as food and animal waste, plant material, or sewage. This process occurs when microorganisms break down organic matter in an oxygen-free environment. A refined version of biogas, known as Renewable Natural Gas (RNG), is chemically identical to conventional natural gas, making it a highly versatile biofuel. Biogas systems offer an environmental advantage due to their significantly lower land and feedstock requirements compared to other biomass energy systems.

Both biogas and RNG have various applications. They can be utilized to generate hot water or steam or integrated into Combined Heat and Power (CHP) systems to produce electricity along with hot water or steam. While RNG offers the same efficiency as natural gas, biogas has slightly lower efficiency due to its lower energy density, which means it requires additional gasification, cleaning, and processing facilities to be upgraded to RNG. RNG also has additional applications such as serving as fuel for vehicles and cooking.

Advantages

- Carbon-neutral energy source
- Can leverage existing natural gas equipment and distribution
- Improves waste management and promotes
- Promotes circular economy

Disadvantages

- High capital costs for gasification and purification
- Requires new distribution lines
- Concerns with odors and safety hazards

Outlook for Biogas/RNG Application at Cornell

Cornell University already possesses smaller research units focused on the gasification of biomass to produce biogas, and the existing Combined Heat and Power (CHP) equipment can be adapted to utilize biogas or Renewable Natural Gas (RNG). An initial study from Cornell projected RNG rates at $30-40/MMBtu.

Biogas yields are highly variable, ranging from 700 to 28,000 cubic feet per ton of waste, with crop residue demonstrating the highest potential. Based on a 2010 report by CURBI (Cornell University Renewable Bioenergy Initiative), Cornell generates an estimated 30,500 tons per year of organic waste from dining halls, dairy farms, greenhouses, crops, and research facilities. This substantial waste stream could potentially generate ~10,000 MWh of electricity and ~42,600 MMBtu of heat annually, satisfying around 5% of the campus's yearly electrical and heating energy demands. Furthermore, this estimated annual waste volume could be supplemented by municipal solid waste to increase output.

Biogas and RNG present a viable solution for generating a consistent baseload of heating and electricity for the campus. When combined with other energy solutions, they can also effectively address peak heating demands. They also offer for integration with other innovative solutions, such as sewer heat exchange systems, to further enhance performance.

Table 37: Biogas/RNG Screening Assessment

Technology Screening Criteria Ratings	RED - Negative or No Impact Low Favorability	YELLOW – Modest Impact Moderate Favorability	GREEN - Positive Impact High Favorability

Criteria	Rating	Description
Maintainability	**RED**	Additional material handling, equipment maintenance, and operation costs from biomass handling, biogas gasification, and purification facilities.
Resiliency	**GREEN**	Depending on storage size, biogas/RNG can provide an extended supply of on-site fuel to enhance system resiliency. The addition of a different fuel source improves resiliency, with the option to be used for backup power and heat during grid outages.
Sustainability	**GREEN**	Biomass represents energy from a renewable source and allows for heating and/or power generation without creating additional strain on the grid.
Implementation Viability	**YELLOW**	Implementation on campus would present challenges in maintaining existing operations and would require the installation of new distribution lines, gasification, and purification plants.
Financial & Funding	**YELLOW**	While overall capital and operational costs will likely be on the higher end compared to other technologies, this system would likely be eligible for grants.
Research & Educational Integration	**GREEN**	Significant opportunities exist for research and academic involvement, and the potential establishment of a living lab. R&D in biomass technologies aligns well with Cornell's Engineering, Chemical, and Agricultural programs. Additional opportunities in distribution infrastructure and alternate applications.

Hydrogen

Hydrogen is a clean-burning fuel, with water as its primary byproduct of combustion, and efficiencies that can reach as high as 90%. This versatility allows it to be effectively utilized for generating hot water or steam or integrated into Combined Heat and Power (CHP) systems to produce both electricity and hot water or steam simultaneously.

A key benefit of "hydrogen-ready" boilers is their capacity to operate on a blend of hydrogen and natural gas, typically containing around 20% hydrogen, which directly contributes to a reduction in natural gas consumption. Furthermore, these boilers offer a future-proof solution, as they can be subsequently adapted to run entirely on 100% hydrogen. While the upfront cost of hydrogen boilers is comparable to that of natural gas boilers, the current expenses associated with the production and storage of hydrogen are considerably higher.

Advantages

- Carbon emissions-free source of energy at point of combustion
- Is a "drop-in fuel" and can leverage existing infrastructure
- Can produce steam or hot water

Disadvantages

- Local availability of hydrogen
- Limited proven examples of deployment
- High operating costs

Outlook for Hydrogen Application at Cornell

The optimal application of hydrogen at Cornell would involve deploying it on the existing steam system and retrofitting the Combined Heat and Power (CHP) system to accept hydrogen. Utilizing a blended hydrogen-natural gas fuel would significantly reduce emissions from natural gas combustion.

While technically possible, this solution faces several hurdles. There are very few existing examples of boilers or generators primarily fired by hydrogen, and currently, no reliable, large-scale sources of hydrogen are available near Cornell. Furthermore, the utility operating cost would be considerable. Hydrogen is estimated to cost between $50-100/MMBtu, a significant increase compared to the current natural gas price of $5-10/MMBtu.

Table 38: Hydrogen Screening Assessment

Technology Screening Criteria Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	Rating	Description
Maintainability	**RED**	Hydrogen is a new technology, and maintenance and training practices are not well-established.
Resiliency	**RED**	Generally, the system would be challenging from a fuel supply standpoint to be considered a resilient source.
Sustainability	**GREEN**	The burning of hydrogen results in zero emissions if renewable energy sources can be used to generate green hydrogen. Use of hydrogen boilers will have no impact on existing grid.
Implementation Viability	**RED**	Constraints related to the availability and storage of hydrogen would make this solution difficult to implement and would limit potential plant size.

Criteria	Rating	Description
Financial & Funding	**RED**	High upfront capital cost and high operational cost mean this is a high-cost technology.
Research & Educational Integration	**GREEN**	Significant opportunities for research and academic involvement, and potential establishment of a living lab. R&D in hydrogen generation, distribution, and utilization systems aligns well with Cornell's Engineering and Chemical programs. Additional opportunities exist in fuel cells, green hydrogen and hub infrastructure.

CHAPTER 7: THERMAL SCENARIOS

The future of Cornell's thermal infrastructure is at a major decision point. To understand the best approach and fit for Cornell's thermal infrastructure, the UR&ET team developed twelve thermal scenarios for further investigation. Each scenario was evaluated against a series of qualitative and quantitative criteria (Quadruple Bottom Line). The highest-rated scenario was selected as the "Recommended Scenario".

The section below provides a summary of each of the 12 scenarios, separated into two classifications: "steam scenarios" and "hot water scenarios" (i.e., whether steam remains the primary distribution medium or whether the distribution system and buildings are converted to hot water). It is important to note that the actual heating technologies (see Chapter 6) occur in multiple scenarios.

Table 39: Heating Technologies by Scenario

Technology	Description	Scenarios
Borehole Thermal Energy Storage (BTES)	BTES is a specialized geoexchange system that uses the earth as a seasonal energy storage medium by charging boreholes through heat injection and extracting it later for heating.	7,8,9,10
Combined Heat and Power (CHP)	CHP is the simultaneous production of electricity and useful heat from a single fuel or energy source.	1
Earth Source Heat (ESH)	Accessing the renewable heat stored in the basement rock below the Earth's surface (~10,000 ft) by circulating water through well sets and heat exchanger equipment located at the surface. This is commonly known as an enhanced geothermal system.	6,10

Technology	Description	Scenarios
Geoexchange with ground source heat pumps (GSHP)	Closed-loop geothermal exchange systems use a field of vertical boreholes (400-900 ft) to transfer thermal energy for heating or cooling between buildings and the ground. Heating and cooling loads must be balanced over the year to ensure long-term functionality.	4, 8, 9, 11
Electric Steam Boilers	Boilers use electricity flowing through streams of water to generate steam.	0, 2, 3, 4, 5
Electric Hot Water Boilers	Boilers rely on electric resistance to generate hot water.	6, 7, 8, 9, 10, 11, 12
Steam Heat Pumps	Steam heat pumps can produce chilled water and steam simultaneously to meet base winter heating load or base summer heating loads.	3
Waste heat recovery	Waste heat from sanitary sewers, combined heat and power, data centers, or other large process loads with a predictable flow and temperature can be recovered to preheat hot water or domestic hot water and integrated into a heat pump solution.	8, 9, 10, 12

Thermal Scenario Evaluation Criteria

To support scenario development and help clarify the preferred scenario moving forward, a set of evaluation criteria was established. The criteria were developed in collaboration with Cornell personnel to align the priorities and goals within this report as well as ensure that proposed infrastructure provides reliable and effective heating, cooling, and electricity.

Evaluation criteria included Maintainability, Resiliency, Sustainability, Constructability, Financial Factors, and Risk Factors. The following designations were used to establish initial ratings on anticipated performance across the scenarios: Red = negative or no change, Yellow = modest positive change, and Green = significant positive change.

Scenario Evaluation Ratings	RED – Negative or No Change Low Favorability	YELLOW – Modest Positive Change Moderate Favorability	GREEN – Significant Positive Change High Favorability

Maintainability

- Improvements in equipment and distribution age, type, and redundancy to minimize maintenance outages
- Reduction of total equipment run hours due to quantity and right-sizing

- Reduction in number and specialization of system types on campus
- Reduction in required shifts or personnel per shift
- Equipment and operation methods are familiar to existing personnel

Resiliency

- Improvements in equipment and distribution age, type, and redundancy to minimize maintenance outages
- Increased ability to isolate smaller areas of service
- Removal of vulnerabilities in the system
- Ability to meet two-week utility outages

Sustainability

- Improvements in equipment and distribution age, type, and redundancy to enhance operational efficiency
- Increase in energy sharing and reduction in waste energy
- Elimination of on-site combustion for normal operations
- Achievement of complete reduction of annual Scope 1 and Scope 2 GHG emissions

Constructability

- Low overall construction impact to day-to-day campus life
- Leveraging existing assets to assist phasing
- Minimal use of technology requires specialized staff

Financial Factors

- Life-cycle cost
- Initial capital cost
- Ability to leverage exterior funding sources such as credits, grants, and third-party funding

Risk Factors

- Utilization of technologies that have a strong track record of performance
- Strong understanding of the natural resources that will be leveraged, if they are being leveraged
- No major potential issues with third party agencies or community personnel that could interrupt project development

Steam Scenarios

- SCENARIO 0: Baseline (Lowest capital option; utilizes electric steam boilers)
- SCENARIO 01: Business as Usual with CHP in Perpetuity
- SCENARIO 02: Electric Steam Boilers in 2035
- SCENARIO 03: Electric Steam Boilers + Steam Heat Pumps + Heat Recovery Chillers
- SCENARIO 04: Electric Steam Boilers + North Geoexchange
- SCENARIO 05: Electric Steam Boilers with Hourly Matching Renewable Energy

Steam Scenarios Results Summary

Each steam thermal scenario was evaluated against the scenario ranking criteria with the results summarized below.

Table 40: Steam Scenarios Assessment Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	SCENARIO 0	SCENARIO 01	SCENARIO 02	SCENARIO 03	SCENARIO 04	SCENARIO 05
Maintainability	**RED**	**RED**	**RED**	**RED**	**RED**	**RED**
Resiliency	**YELLOW**	**YELLOW**	**YELLOW**	**YELLOW**	**YELLOW**	**YELLOW**
Emissions	**YELLOW**	**RED**	**YELLOW**	**YELLOW**	**YELLOW**	**YELLOW**
Constructability	**GREEN**	**GREEN**	**GREEN**	**GREEN**	**YELLOW**	**YELLOW**
Financial	**RED**	**RED**	**RED**	**RED**	**RED**	**RED**
Risk	**YELLOW**	**RED**	**YELLOW**	**YELLOW**	**YELLOW**	**YELLOW**

Hot Water Scenarios

- SCENARIO 06: Earth Source Heat
- SCENARIO 07: Core Campus BTES + North & East Campus Geoexchange
- SCENARIO 08: Core Campus BTES + North & East Campus Geoexchange, System Optimization
- SCENARIO 09: Core Campus BTES + North & East Campus Geoexchange, Enhanced ECI
- SCENARIO 10: Core Campus BTES + North & East Campus Geoexchange + Earth Source Heat
- SCENARIO 11: Geoexchange for Full Campus

- SCENARIO 12: Utility Thermal Energy Networks (UTENs) with Peak Shaving

For Scenarios 6-12, the campus transitions from using steam to hot water as the primary heating medium, requiring a hot water conversion across the campus. Steam distribution is replaced by hot water distribution for this transition to be complete and the new production assets to come online.

Hot Water Scenarios Results Summary

Each hot water thermal scenario was evaluated against the scenario ranking criteria with the results summarized below.

Table 41: Hot Water Scenarios Assessment Summary

Scenario Evaluations Ratings	**RED - Negative or No Impact Low Favorability**	**YELLOW – Modest Impact Moderate Favorability**	**GREEN - Positive Impact High Favorability**

Criteria	SCENARIO 06	SCENARIO 07	SCENARIO 08	SCENARIO 09	SCENARIO 10	SCENARIO 11	SCENARIO 12
Maintainability	YELLOW	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN
Resiliency	GREEN	YELLOW	GREEN	GREEN	GREEN	GREEN	YELLOW
Emissions	GREEN	YELLOW	GREEN	GREEN	GREEN	GREEN	GREEN
Constructability	RED	YELLOW	YELLOW	YELLOW	YELLOW	RED	RED
Financial	RED	RED	YELLOW	YELLOW	YELLOW	RED	YELLOW
Risk	RED	YELLOW	YELLOW	YELLOW	RED	YELLOW	RED

SCENARIO 0: Baseline (Lowest capital option)

The Baseline scenario allows the analysis to benchmark the expected life-cycle performance, GHG emissions, as well as operational and maintenance costs. **This forms the basis of comparison with any developed scenario to aid decision making.**

The Baseline Scenario maintains existing system types and service areas while providing the minimum energy utility investment. This scenario also meets the minimal requirements under the CLCPA with the lowest capital investment. The CCHPP will be taken offline and moved to back-up service starting in 2040. All heating will transition to electrode steam boilers by 2050, and no new natural gas assets will be brought online. Additional resiliency and redundancy projects are not pursued, and efficiency is only gained through replacing existing assets.

Lake Source Cooling remains the primary campus cooling asset and is supplemented by the renewal of the existing chilled water plant and two new production plants to meet future campus growth. CWP #2 on East Campus is returned to being used as a chilled water generation facility. A new North CWP is established to meet North Campus cooling loads. At CWP #3 the existing configuration and capacity is retained, with repair and replacement as needed.

Scenario Cost Drivers

The primary driver of the Baseline life-cycle costs is utility costs, which account for over 50% of the total life-cycle costs. This high utility usage is primarily associated with electrification of campus heating with electrode steam boilers and the higher cost of electricity compared to natural gas.

The replacement of existing natural gas boilers with new electrode boilers, paired with maintaining steam operation through replacing aging sections of the steam distribution and hot water conversion of campus peripheral areas, results in higher capital expenditures in the near term.

Costs associated with NYCI carbon costs are highest in the near term and are projected to reduce starting in 2040 as campus heating is electrified. These costs are projected to reduce to zero by 2050, when the grid has decarbonized and the campus heating is completely electrified.

The O&M costs associated with the Baseline Scenario are primarily driven by maintaining the steam system and boiler equipment at the central steam plant, maintaining the steam distribution system, and maintaining and operating of the chillers and LSC.

Scenario Ratings

This scenario presents the lowest initial capital investment option for complying with the CLCPA. The table below summarizes the ratings for this scenario based on life cycle, energy, and financial performance and its impact on campus operations.

Table 42: Scenario 0 Baseline Ratings Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**RED**	• Minimal changes to distribution system to reduce maintenance outages; steam heating systems have inherently higher associated maintenance. • Increase in number of cooling assets and distributed cooling plants. • Simplification of heating assets and reduced maintenance compared to existing operations. However, as steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.
Resiliency	**YELLOW**	• While cooling production vulnerabilities are reduced by adding distributed resources, there are no major changes to heating production and distribution to impact system resiliency.
Emissions	**YELLOW**	• Electrode steam boilers offer better heating efficiency compared to existing campus natural gas boilers and the CCHPP plant while maintaining LSC. • No energy sharing or harnessing of waste energy sources, making this one of the highest overall energy-consuming scenarios evaluated.
Constructability	**GREEN**	• Low overall construction impact to day-to-day campus life, with large scale construction limited to a couple of existing and new sites. • Leverages existing steam and chilled water distribution and allows for a more gradual, phased completion of steam-to-hot water conversions.
Financial	**RED**	• Lowest capital cost option to comply with the provisions of the CLCPA. • Moderate to poor life-cycle cost performance compared to other scenarios studied in this report. • Low opportunities to leverage exterior funding sources through credits, grants, and third-party funding.
Risk	**YELLOW**	• Campus operations will require minimal changes. • This scenario has one of the highest vulnerabilities to electricity costs, and any changes would significantly impact results. • As steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.

SCENARIO 01: Business as Usual with CHP in Perpetuity

NOTE: Scenario 1 is not compliant with CLCPA.

This scenario maintains existing production and operations on campus throughout its life cycle. Steam remains the primary method of heating the campus, and reliance on \ existing systems continues through the full analysis period. Existing natural gas equipment at the Central Energy Plant, such as the combustion turbines, heat recovery steam generators, and natural gas steam boilers, is replaced at the end of its life to support continued steam production at the existing facility. Additional resiliency and redundancy projects are not pursued, and efficiency is only gained through replacing existing assets.

Chilled water production matches the Baseline Scenario, with maintained capacity at LSC and CWP #3 and added generation capacity at existing CWP #2 and the new North CWP. Steam, hot water, and chilled water distribution sizing and replacement times are the same as the Baseline Scenario.

Scenario Cost Drivers

This scenario has the most evenly distributed costs across the major components. This is due to the system being replaced incrementally, and the campus is still using a high amount of natural gas, which has a low energy unit cost.

The replacement of combustion turbines, steam turbines, HRSGs, and natural gas boilers, paired with maintaining steam operation through replacing aging sections of the steam distribution and hot water conversion of campus peripheral areas, are key drivers of capital expenditures.

This scenario has the highest O&M costs, mainly associated operating the Combined Heat and Power Plant and maintaining and repairing the steam distribution system.

Since this scenario does not comply with CLCPA, a significant component of its life-cycle costs is associated with potential NYCI carbon cost penalties. These penalties increase over time as the NYCI carbon costs are expected to escalate.

Scenario Ratings

This scenario represents minimal changes to campus operations, renewing the steam production assets as required while maintaining natural gas as the primary fuel source for heating and electricity production.

While this scenario is expected to have lower life-cycle utility costs compared to Baseline, it does not decarbonize campus operations and does not comply with CLCPA. It maintains significant annual GHG emissions throughout the study period, resulting in significant NYCI carbon cost penalties.

Table 43: Scenario 01 Business as Usual Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**RED**	• Minimal changes to distribution system to reduce maintenance outages; steam heating systems have inherent higher associated maintenance. • Increase in the number of cooling assets and distributed cooling plants. • Renews exists heating assets, with no major changes to existing O&M procedures and staff.
Resiliency	**YELLOW**	• While cooling production vulnerabilities are reduced by adding distributed resources, there are no major changes to heating production and distribution vulnerabilities.
Emissions	**RED**	• Renewal of existing heating equipment results in no improvement to thermal efficiency of heating production equipment. • Campus heating continues to be powered by natural gas, resulting in significant annual GHG emissions. • Campus systems will not comply with the provisions of the CLCPA. • No energy sharing or harnessing of waste energy sources.
Constructability	**GREEN**	• Low overall construction impact on day-to-day campus life, with large-scale construction limited to a couple of existing and new sites. • Leverages existing steam and chilled water distribution, and allows for a more gradual, phased completion of steam-to-hot water conversions. • Renews existing campus cooling technologies, while new heating technologies simplify campus heating operations.
Financial	**RED**	• Low utility cost option with low initial capital expenditure required.

Criteria	Rating	Assessment
		• While slight life-cycle cost savings are projected over Baseline, significant NYCI carbon cost penalties are associated with this scenario. • Minimal chances to leverage external funding sources through credits, grants, and third-party funding.
Risk	**RED**	• Potential risks and issues with noncompliance with the CLCPA; all new campus buildings will require local heating systems. • Life-cycle costs associated with this solution are heavily exposed to potential changes in NYCI carbon costs. • As steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.

SCENARIO 02: Electric Steam Boilers in 2035

This scenario is similar to Scenario 0 but with an accelerated electrification timeline. The CCHPP and natural gas boilers turn off in 2035, and heating is electrified sooner under this scenario. This scenario maintains a steam-based district heating system while accelerating achievement of a fossil-free heating system by 2035 , compared to 2050 under the Baseline Scenario. Electrode boilers, which are fully operational by 2035, become the primary source of steam production and the CCHPP system is moved to backup service only.

Chilled water production generally matches the Baseline Scenario with maintained capacity at LSC and CWP #3 and additional generation capacity at existing CWP #2 and the new North CWP. The updated capacity at CWP #3 uses an optimized configuration for ease of maintenance and cost. Steam, hot water, and chilled water distribution sizing and replacement timelines are the same as the Baseline Scenario.

Scenario Cost Drivers

The primary driver of life-cycle costs for this scenario are utility costs, which account for the majority of total life-cycle costs. These high utility costs are primarily associated with the rapid electrification of campus heating with electrode steam boilers, which have a lower coefficient of performance compared to other electrification scenarios.

The replacement of existing natural gas boilers with new electrode boilers, paired with maintaining steam operation through the replacement of aging sections of the steam distribution and hot water conversion of campus peripheral areas, results in higher capital expenditures in the near term, although these costs still relatively low compared to other scenarios.

Costs associated with NYCI carbon costs are highest in the near term and reduce when campus heating is electrified. These costs are projected to reduce as the grid decarbonizes.

The O&M costs associated with this scenario are primarily higher compared to other scenarios due to the high cost of maintaining a steam system.

Scenario Ratings

This scenario presents the lowest initial capital investment option, although it will result in higher cumulative GHG emissions compared to the Baseline Scenario.

Since this scenario primarily maintains most of the existing district steam heating system in its current configuration, there are minimal benefits to overall system maintainability, resiliency, or risk. The table below summarizes the ratings for this scenario based on life-cycle, energy, financial performance, and its impact on campus operations.

Table 44: Scenario 02 Electric Steam Boilers in 2035 Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**RED**	• Minimal changes to the distribution system to reduce maintenance outages; steam heating systems have inherent higher associated maintenance. • Increase in the number of cooling assets and distributed cooling plants. • Simplification of heating assets and reduced maintenance compared to existing operations. However, as steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.
Resiliency	**YELLOW**	• While cooling production vulnerabilities are reduced by adding distributed resources, there are no major changes to heating production and distribution to impact system resiliency.
Emissions	**YELLOW**	• Electrode steam boilers offer better on-campus heating efficiency compared to existing campus natural gas boilers and CHP plant but are less efficient than heat pump technologies.

Criteria	Rating	Assessment
		• No energy sharing or harnessing of waste energy sources, making this one of the highest energy consuming scenarios that was evaluated.
Constructability	**GREEN**	• Low overall construction impact on day-to-day campus life, with large scale construction limited to a couple of existing and new sites. • Leverages existing steam and chilled water distribution, and allows for a more gradual, phased completion of District Hot Water Master Plan.
Financial	**RED**	• Lowest capital cost option to comply with provisions of the CLCPA. • Moderate to poor life-cycle cost performance compared to other scenarios studied in this report. • Limited opportunities to leverage exterior funding sources through credits, grants, and third-party funding.
Risk	**YELLOW**	• Campus operations will require minimal changes. • This scenario has one of the highest vulnerabilities to electricity costs, and any changes would significantly impact results. • As steam systems are replaced by hot water systems, finding qualified staff and parts to maintain the system will become more challenging.

SCENARIO 03: Electric Steam Boilers + Steam Heat Pumps + Heat Recovery Chillers

This scenario uses a hybrid approach, maintaining existing district steam-based heating operations for most of the district energy system, with the exception of East Campus, which uses a hot water-based solution primarily fed by heat recovery chillers and supplemented by steam exchangers. For steam generation, electrode boilers are combined with steam heat pumps to increase system efficiency. The use of steam heat pumps (HPs) and electrode boilers allows for higher efficiency steam production compared to only using electrode boilers.

Chilled water production generally matches the Baseline Scenario, with maintained capacity at LSC and CWP #3 and additional generation capacity at existing CWP #2 and the new North CWP. The updated capacity at CWP #3 uses an optimized configuration for ease of maintenance and cost. Steam heat pumps also generate chilled water to meet campus base cooling load through the year.

Scenario Cost Drivers

The primary driver of life-cycle costs for this scenario is utility costs, which account for over half of the total life-cycle costs. This high utility usage is primarily associated with electrification of campus heating and the higher cost of electricity compared to natural gas.

The replacement of existing natural gas boilers with new steam heat pumps and electrode boilers, paired with maintaining steam operation through replacing aging sections of the steam distribution and hot water conversion of campus peripheral areas, results in higher capital expenditures in the near term.

Costs associated with NYCI carbon costs are highest in the near term and reduce as campus heating is electrified. This cost is projected to reduce to zero when the grid is decarbonized.

The O&M costs associated with this scenario are primarily driven by maintaining staffing and heat pump/boiler upkeep at the central steam plant, as well as the maintenance and operation of the chillers and LSC.

Scenario Ratings

This scenario presents an option with higher upfront capital costs due to the implementation of higher efficiency solutions, resulting in a strong cumulative life-cycle cost and greater lifetime GHG emissions reduction relative to the Baseline Scenario. The table below summarizes the ratings for this scenario based on life-cycle, energy, and financial performance, and its impact on campus operations.

Table 45: Scenario 03 Electric Steam Boilers + Steam Heat Pumps + Heat Recovery Chillers Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**RED**	• Minimal changes to distribution system to reduce maintenance outages; steam heating systems have inherent higher associated maintenance. • Increase in the number of cooling assets and distributed cooling plants. • Simplification of heating assets and reduced maintenance compared to existing operations. However, as steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging. • Steam heat pumps will require additional maintenance and operation methods that may not be familiar to personnel.

Criteria	Rating	Assessment
Resiliency	**YELLOW**	• While cooling production vulnerabilities are reduced by adding distributed resources, there are no major changes to heating production and distribution to impact system resiliency.
Emissions	**YELLOW**	• Electrode steam boilers offer better on-campus efficiency, compared to existing campus natural gas boilers and CHP plant. • Heat recovery equipment, such as steam heat pumps and heat recovery chillers, allows for energy sharing and harnessing of waste energy sources. • Potential load balancing for steam heat pumps through LSC modifications will be highly dependent on lake temperature profiles, which can limit utilization.
Constructability	**GREEN**	• Low overall construction impact on day-to-day campus life, with large scale construction limited to a couple of existing and new sites. • Leverages existing steam and chilled water distribution and allows for a more gradual, phased completion of District Hot Water Master Plan.
Financial	**RED**	• Moderate to poor life-cycle cost performance compared to other scenarios studied in this report. • Low chances to leverage exterior funding sources through credits, grants, and third-party funding.
Risk	**YELLOW**	• Campus operations will require minimal changes. • This scenario has one of the highest vulnerabilities to electricity costs, and any changes would significantly impact results. • As steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging. • High-lift steam heat pumps are a relatively new technology with limited field installations. • Finding an additional low-grade heat source could be a challenge and could limit heat pump operation during high-use periods.

SCENARIO 04: Electric Steam Boilers + North Campus Geoexchange

This scenario uses a hybrid approach of maintaining existing production and operations for bulk of the campus while accelerating hot water conversion in North Campus.

The accelerated hot water conversion of North Campus allows for the integration of a ground-source heat pump system to meet all local heating and cooling requirements. The

new plant isolates all North Campus loads from the rest of the campus, and the use of geo-exchange systems enables heat recovery to generate high-efficiency heating and cooling.

Steam remains the primary medium of heating for Core and East Campus, using electrode steam boilers installed at the new steam plant at CEP. These areas continue utilizing Lake Source Cooling (LSC) as the primary cooling asset, supplemented by the renewal of existing chilled water plants. CWP #2 on East Campus is renewed, and existing cooling assets at CWP #3 are refurbished to extend their life and replaced like-for-like as needed. No additional steam loads are added, even after electrification of steam plant, as all new buildings will be designed for hot water heating.

Scenario Cost Drivers

The primary driver of life-cycle costs for this scenario is utility costs, which account for over half of the total life-cycle costs. This high utility usage is primarily associated with electrification of campus heating and the higher cost of electricity compared to natural gas.

The replacement of existing natural gas boilers with electrode boilers, along with a new ground source heat pump plant and associated borefield, results in higher capital expenditures in the near term. Additional high-capital-cost items include maintaining steam operation through replacing aging sections of the steam distribution and hot water conversion of North Campus and other peripheral areas.

Costs associated with NYCI carbon costs are highest in the near term and reduce as campus heating is electrified. This cost is projected to reduce to zero when the grid is decarbonized.

The O&M costs associated with this scenario are primarily driven by maintaining staffing, heat pump/boiler upkeep, and the maintenance and operation of the chillers and LSC.

Scenario Ratings

This scenario integrates technologies such as geo-exchange systems to achieve cumulative energy and GHG emissions savings over the Baseline Scenario. The table below summarizes the ratings for this scenario based on life-cycle, energy, financial performance, and its impact on campus operations.

Table 46: Scenario 04 Electric Steam Boilers + North Geoexchange Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**RED**	• Minimal changes to distribution system to reduce maintenance outages; steam heating systems have inherent higher associated maintenance. • Increase in the number of cooling assets and distributed cooling plants. • Simplification of heating assets and reduced maintenance compared to existing operations. However, as steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.
Resiliency	**YELLOW**	• While cooling production vulnerabilities are reduced by adding distributed resources, there are no major changes to heating production and distribution to impact system resiliency. • North campus resiliency is enhanced with local hot water and chilled water plant, backed up by existing connections to other campus heating and cooling assets.
Emissions	**YELLOW**	• Electrode steam boilers offer better on-campus efficiency compared to existing campus natural gas boilers and the CHP plant. • Geo-exchange systems harness waste heat, generating high efficiency heating and cooling.
Constructability	**GREEN**	• The geo-exchange system on North Campus can disrupt day-to-day campus life from drilling operations. • Low overall construction impact on day-to-day campus life for the rest of campus, with large scale construction limited to a couple of existing and new sites. Leverages existing steam and chilled water distribution and allows for a more gradual, phased completion of steam-to-hot water conversion.
Financial	**RED**	• Medium capital cost option; however, resulting life-cycle utility costs are high, resulting in poor life-cycle cost performance. • Strong life-cycle cost performance compared to other scenarios studied in this report. • Moderate opportunities to leverage exterior funding sources through credits, grants, and third-party funding for some plants/technologies.

Criteria	Rating	Assessment
Risk	**YELLOW**	• Campus operations will require minimal changes. • This scenario has one of the highest vulnerabilities to electricity costs and any changes would significantly impact results. • As steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.

SCENARIO 05: Electric Steam Boilers with Hourly Matching Renewable Energy

This scenario maintains all the thermal production, distribution, and operations as discussed in Scenario 2: *Electric Boilers in 2035*, but aims to meet all campus electricity demand through Cornell-owned solar PV generation and battery energy storage systems (BESS).

Not only does this scenario help Cornell achieve a fossil fuel free campus but it also offsets all campus electricity consumption through solar PV and BESS to achieve net-zero Scope 1 on-site stationary combustion emissions and Scope 2 purchased electricity GHG emissions through hourly matching.

Depending on system configuration and contractual arrangements, this scenario achieves full greenhouse gas emissions reductions for Scope 1 and Scope 2, as it is not reliant on the decarbonization of the grid to achieve carbon neutrality for Scope 2 (purchased electricity) emissions. This scenario puts Cornell in a carbon-negative scenario on an annual basis because of the required overbuilding of solar assets to achieve a 24/7 hourly carbon-free electricity match during the winter months, which have low electrical production but high electrical demands.

Scenario Cost Drivers

The primary driver of life-cycle costs for this scenario is the capital cost associated with installing the solar and BESS systems. All other costs are minimal. The payback on solar is relatively poor compared to other scenarios.

Scenario Ratings

This scenario presents the highest initial capital investment option for achieving a fossil-fuel-free district energy system.

- This is the only scenario which would meet Cornell's voluntary commitments to decarbonize by 2035 without the use of RECs or VPPAs.

- The land necessary to complete this solution would likely be very difficult to acquire and could cause issues with the local community.

The table below summarizes the ratings for this scenario based on life-cycle energy and financial performance and its impact on campus operations.

Table 47: Scenario 05 Electric Steam Boilers with Hourly Matching Renewable Energy Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**RED**	• Minimal changes to distribution system to reduce maintenance outages; steam heating systems have inherent higher associated maintenance. • Increase in the number of cooling assets and distributed cooling plants. • Simplification of heating assets and reduced maintenance compared to existing operations. However, as steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.
Resiliency	**YELLOW**	• While cooling production vulnerabilities are reduced by adding distributed resources, there are no major changes to heating production and distribution to impact system resiliency.
Emissions	**GREEN**	• Electrode steam boilers offer better heating efficiency, compared to existing campus natural gas boilers and CHP plant, but are less efficient than heat pump technologies. • Eliminates all on-site fossil fuel combustion and achieves net-zero Scope 2 emissions through hourly matching.
Constructability	**RED**	• Low overall construction impact on day-to-day campus life with large scale construction limited to a couple of existing and new sites. • Leverages existing steam and chilled water distribution and allows for a more gradual, phased completion of steam-to-hot water conversion.

Criteria	Rating	Assessment
		• PV and BESS systems will require extensive open land that will be difficult to find near Cornell. • Achieving the necessary land and equipment permitting and procurement would be extremely challenging.
Financial	**RED**	• Highest capital and life-cycle cost option; however, the scenario also results in the lowest average utility cost. • Potential for some grants and third-party funding associated with the solar and BESS, but likely not enough to change financial viability of the project.
Risk	**RED**	• Campus operations will require minimal changes. • The scenario has one of the highest vulnerabilities to electricity costs, and any changes would significantly impact results. • As steam systems are replaced by hot water, finding qualified staff and parts to maintain the system will become more challenging.

SCENARIO 06: Earth Source Heat

Scenario 6 evaluates the development of an Earth Source Heat (ESH) system to meet campus heating demand, transitioning away from existing steam production and operations with four production doublets. This emerging technology taps internal heat deep within the earth as a renewable heating source for hot water production.

The Combined Heat and Power Plant will be turned off as a primary energy source and no new natural gas or steam assets will be brought online. The new ESH system will be the primary hot water production asset and will be supplemented by peaking and backup electrode hot water boilers.

Lake Source Cooling remains the primary campus cooling asset and is supplemented by the renewal of the existing chilled water plant and two new production plants to meet future campus growth. CWP #2 on East Campus is restored to a chilled water generation facility. A new North CWP is established to meet North Campus cooling loads. Existing cooling assets at CWP #3 are replaced to provide a similar total plant capacity.

Scenario Cost Drivers

The primary driver of the life-cycle costs for this scenario is capital costs, which account for approximately half of the total life-cycle costs. This capital expenditure is primarily

associated with drilling the ESH doublets and converting the campus to hot water. The ESH doublets will require redrilling after a period in service, estimated here at 25 years of life, which results in a spike in capital costs during the 2057-67 period.

Utility costs account for approximately a third of life-cycle costs and are lower compared to other scenarios in this report. The lower utility costs are driven by the high efficiency of the ESH system, which considerably reduces electricity usage for heating.

Costs associated with NYCI carbon costs are highest in the near term and reduce starting 2035 as campus heating is electrified. These costs are projected to reduce to zero when the grid is decarbonized.

The O&M costs see a reduction compared to a steam system with less maintenance associated with the distribution system. The ESH system will have requirements associated with monitoring system operation and any permitting requirements.

Scenario Ratings

This scenario presents strong energy performance metrics and cost savings over the Baseline with the integration of high-efficiency heating technologies. While this scenario presents strong results, it also has the highest level of risk. Risks are derived from multiple areas including:

- **Resource uncertainty**. Enhanced Geothermal Systems are a new technology, with few production systems in service anywhere and none with an operational history of more than three years. ESH would be the first application east of the Rocky Mountains. Due to this, there is a high level of uncertainty regarding critical system performance metrics, such as reservoir temperature degradation, induced fracture connectivity, matrix permeability, system pressure, and makeup water loss rates. While some of these performance risks could be reduced with further testing utilizing CUBO, performance risks will not be eliminated until a doublet is active.

- **Regulatory Risks**. As this would be a first-of-its-kind system, there are significant risks that community and regulatory challenges could slow or halt ESH development. Cornell currently projects that the permitting process for ESH could require five years, with multiple steps that could create pauses or stops in work. Depending on the system configuration, there will likely be a need to engage with additional community stakeholders, which could dramatically influence the viability of the project.

Table 48: Scenario 06 Earth Source Heat Summary

Scenario Evaluation Ratings	RED – Negative or No Change Low Favorability	YELLOW – Modest Positive Change Moderate Favorability	GREEN – Significant Positive Change High Favorability

Criteria	Rating	Assessment
Maintainability	YELLOW	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems. • While components of the ESH Plant should be relatively simply to maintain, it represents a new technology not familiar to personnel at or outside Cornell
Resiliency	GREEN	• Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus. • Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure of the distribution to critical service areas.
Emissions	GREEN	• ESH offers considerably higher efficiencies compared to electric boilers. • ESH taps into a renewable heating resource which should regenerate over time.
Constructability	RED	• Campus conversion to hot water will have a major impact to day-to-day campus life, with new distribution lines required over most of the campus area. • Exiting CUBO operations have shown drilling is possible without disrupting day-to-day campus life; however, drilling and stimulating rock in this geological area is unproven. There are limited qualified contractors to conduct the drilling and stimulating operations, and the contractor(s) will likely not be local to the region.
Financial	RED	• High capital costs associated with drilling and redrilling ESH doublets. • Poor life-cycle cost performance compared to other scenarios studied in this report, driven by high capital costs.

Criteria	Rating	Assessment
		• Strong opportunities to leverage external funding sources through credits, grants, and third-party funding. However, the extent of funding available may be lower than previously expected.
Risk	**RED**	• ESH represents an emerging technology with no commercial-scale plants of similar configuration in operation. • Viability and efficiency of plant can be severely altered based on the findings of CUBO Phase II, and ultimately, the first production doublet. Permeability creation and connection between the production and injection wells consistent with the design will have a large impact on project costs and performance. • Future drilling and redrilling requirements can present challenges from permitting to land/mineral rights, given the depth and extent of the drilling.

SCENARIO 07: Core Campus BTES + North & East Campus Geoexchange

This scenario transitions away from existing steam production and operations on campus by using a combination of geoexchange and geothermal storage systems for heating and cooling in different parts of campus. North and East Campus would use independent ground-source heat pump plants that generate both heating and cooling for their respective areas using geo-exchange borefields. Core Campus transitions to using a Borehole Thermal Energy Storage (BTES) system for heating, which is seasonally charged in summer months and discharged in winter.

Lake Source Cooling (LSC) remains the primary campus cooling asset for core campus and is supplemented by the refurbishment and replacement of assets at CWP #3. LSC can also be used to supplement cooling provided by the new ground-source heat pump systems in North and East Campus.

Scenario Cost Drivers

The primary driver of life-cycle costs for this scenario is capital costs, which account for 45% of the total life-cycle costs. This capital expenditure is primarily associated with the drilling costs for the BTES modules, GSHP borefields and campus hot water conversion.

Utility costs account for 44% of life-cycle costs and are lower compared to other scenarios in this report. The lower utility costs are driven by the higher efficiency of the GSHP and BTES heat pumps, which reduce electricity usage for heating.

Costs associated with NYCI carbon costs are highest in the near term and reduce as campus heating is electrified. These costs are projected to reduce to zero when the grid decarbonizes.

The O&M costs associated with this scenario are primarily driven by maintaining the staffing and upkeep of various distributed heating plants around the campus, the large number of heat pumps, and the maintenance and operation of the chillers and LSC.

Scenario Ratings

This scenario presents significantly higher capital costs compared to the Baseline Scenario without achieving significant savings in life-cycle utility costs. While this scenario also allows Cornell to comply with CLCPA and reduce potential NYCI carbon cost penalties, the overall system efficiency of the heating and cooling systems is relatively low.

The table below summarizes the ratings for this scenario based on the life-cycle, energy, and financial performance and its impact on campus operations.

Table 49: Scenario 07 Borehole Thermal Energy Storage + North & East Geoexchange Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**YELLOW**	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems. • Increase in the number of heating and cooling assets and distributed heating and cooling plants. • While components of the BTES Plant are not difficult to maintain, the plant operations and charging/discharging represent a new technology not familiar to personnel at or outside Cornell.
Resiliency	**YELLOW**	• Improvement in equipment and distribution age, with enhanced redundancy to minimize maintenance outages. • Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus.

Criteria	Rating	Assessment
		• Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure in the distribution and allowing for service from multiple plants.
Emissions	**YELLOW**	• Geo-exchange systems generate heating and cooling efficiently while recovering waste heat to improve performance. • BTES operations using chilled water return results in a high temperature lift, which results in low overall BTES heating efficiency.
Constructability	**YELLOW**	• Conversion of campus to hot water will have a major impact on day-to-day campus life, with new distribution lines required over most of the campus area. • Geo-exchange system on East and North Campus can disrupt day-to-day campus life from drilling operations. • Drilling required for BTES modules is expected to create significant impact to day-to-day campus life due to its location.
Financial	**RED**	• High capital costs associated with drilling for geo-exchange fields and BTES modules. • Weaker life-cycle cost performance compared to other scenarios studied in this report driven by high life-cycle utility costs. • Strong opportunities to leverage exterior funding sources through credits, grants and third-party funding.
Risk	**YELLOW**	• BTES technology has limited commercial-scale plants in the US. • Charging and discharging operations would need to be managed to ensure adequate capacity during winter. • Ground source heat pumps are established technology with strong track record of application. • Campus operations will require significant changes to operations and integration of multiple plants generating heating and cooling.

SCENARIO 08: Core Campus BTES + North & East Campus Geoexchange + System Optimization

This scenario builds on Scenario 7 by optimizing the BTES charging heat source, equipment utilization, and plant locations. System optimization aims to improve system efficiency and

reduce overall equipment costs. Like Scenario 7, North and East Campus use independent ground-source heat pump plants that generate both heating and cooling for the respective areas using geo-exchange borefields. For Core Campus, the system is fed by three BTES plants, two of which are co-located with the GSHP plants.

The geoexchange borefields are optimized based on plant loads to reduce the number of boreholes through external balancing. The BTES system in this scenario is charged using solar thermal collector arrays. These collectors generate hot water, which are a better heat source for BTES charging operation, resulting in improved system efficiency. Additionally, distributed plant locations and co-location of BTES-GSHP plants help reduce equipment required by promoting the reuse of heat pumps.

Lake Source Cooling (LSC) remains the primary campus cooling asset for Core Campus and is supplemented by refurbishment and replacement of assets at CWP #3, as well as the new ground source heat pumps systems in North and East Campus.

Scenario Cost Drivers

The primary driver of the life-cycle costs for this scenario is utility costs, which account for nearly half of the total costs. While the utility costs are high, they are considerably lower than an electrode boiler-based solution. The lower utility costs are driven by the higher efficiency of the BTES and GSHP heat pumps, which reduces electricity usage for heating.

Capital costs account for a significant portion of the total life-cycle costs. This capital expenditure is primarily associated with the drilling costs for the BTES modules, GSHP borefields, and campus hot water conversion.

Costs associated with NYCI carbon costs are highest in the near term and
reduce as campus heating is electrified. These costs are projected to reduce to zero when the grid is decarbonized. Due to the overall efficiency of the heating and cooling systems, these costs are relatively low.

The O&M costs associated with this scenario are primarily driven by staffing and upkeep of various distributed heating plants around the campus, the large number of heat pumps, and the maintenance and operation of the chillers and LSC. System maintenance costs are generally reduced due to hot water systems being more aligned to chilled water system operations than a more complicated steam system.

Scenario Ratings

This scenario presents strong life-cycle performance, with a competitive net present value and capital costs compared to other scenarios. This scenario allows Cornell to comply with CLCPA provisions and reduce potential NYCI carbon cost penalties, with improved system efficiencies compared to the previous scenario. Additionally, this scenario has a high likelihood of receiving alternative sources of funding, therefore reducing the capital burden on the University.

The table below summarizes the ratings for this scenario based on the life-cycle, energy, and financial performance and its impact on campus operations.

Table 50: Scenario 08 BTES + North & East Geoexchange + System Optimization Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**GREEN**	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems. • Increase in the number of heating and cooling assets and distributed heating and cooling plants. • While components of the BTES plant are not difficult to maintain, the plant operations, and charging/discharging represent a new technology not familiar to personnel at or outside Cornell.
Resiliency	**GREEN**	• Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus. • Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure of the distribution to critical service areas.
Emissions	**GREEN**	• GSHP systems recover waste heat and generate heating and cooling efficiently. • BTES operations using solar thermal collectors utilize a renewable energy source to improve BTES heating efficiency. • LSC remains a significant cooling source for the campus, improving overall cooling performance.

Criteria	Rating	Assessment
Constructability	**YELLOW**	• Conversion of campus to hot water will have a major impact on day-to-day campus life, with new distribution lines required over most of the campus area. • Drilling for BTES modules will occur throughout campus. Modules at CEP and North Campus would cause relatively lesser disruption to campus life. • Geo-exchange system on East and North Campus could disrupt day-to-day campus life from drilling operations.
Financial	**YELLOW**	• Strong life-cycle cost performance compared to other scenarios studied in this report, driven improved system efficiency and reduced equipment costs from heat pump reuse. • High capital costs associated with drilling for geo-exchange fields and BTES modules; however, reduced modules help lower capital costs. • High chances to leverage exterior funding sources through credits, grants, and third-party funding.
Risk	**YELLOW**	• BTES technology has limited commercial-scale plants in the US. • Ground-source heat pumps are established technology with strong track record of application. • Campus operations will require significant changes to operations and integration of multiple plants generating heating and cooling.

SCENARIO 09: Core Campus BTES + North & East Campus Geoexchange + Enhanced ECI

This scenario further builds upon the optimization explored in Scenario 8 by exploring strategies to reduce campus heating demand. Key drivers and areas of heating load are identified, and through Enhanced Energy Conservation and retrofit measures, campus heating load profile is reshaped. Optimization of BTES operations is also explored through reduction of operating temperatures to improve system performance.

This scenario was selected as the Recommended Scenario, for additional details on this scenario, see Chapter 8. For comparison purposes, the scenario cost drivers and ratings are provided below.

Scenario Cost Drivers

The primary driver of life-cycle costs for this scenario is utility costs, which account for around two-thirds of the total costs. While utility costs are high, they are considerably lower than the electrode boiler-based solution in the Baseline Scenario. The lower utility costs are driven by the higher efficiency of the BTES and GSHP heat pumps, which reduces the electricity usage for heating.

Capital costs account for a significant portion of total life-cycle costs. This capital expenditure is primarily associated with the drilling costs for the BTES modules, GSHP borefields, and campus hot water conversion.

Costs associated with NYCI carbon costs are highest in the near term. After the CHP is moved to back up operation, the carbon cost reduce significantly with a cost going to zero once the grid is fully decarbonized.

The O&M costs associated with this scenario are primarily driven by the staffing and upkeep of various distributed heating plants around the campus, the large number of heat pumps, and the maintenance and operation of the chillers and LSC. System maintenance costs are generally reduced due to hot water systems being more aligned to chilled water system operations than a more complicated steam system.

Scenario Ratings

This scenario presents strong life-cycle performance, with a competitive net present value and capital costs compared to other scenarios. This scenario positions Cornell ahead of potential future CLCPA driven regulations and carbon charges with strong system efficiencies.

This scenario is the most efficient from an energy and O&M perspective. This means that once the system is fully deployed, Cornell will be the most protected against volatility in market prices for electricity and associated tariffs and riders. Cornell has seen great success with this type of approach via the LSC. Additionally, it is highly likely that Cornell would receive alternative sources of funding, therefore reducing the capital burden taken on by the University.

The table below summarizes the ratings for this scenario based on the life-cycle, energy, and financial performance and its impact on campus operations.

Table 51: Scenario 09 BTES + North & East Geoexchange + Enhanced ECI Summary

Scenario Evaluation Ratings	RED – Negative or No Change Low Favorability	YELLOW – Modest Positive Change Moderate Favorability	GREEN – Significant Positive Change High Favorability

Criteria	Rating	Assessment
Maintainability	GREEN	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems. • Increase in the number of heating and cooling assets and distributed heating and cooling plants. • While components of the BTES plant are not difficult to maintain, the plant operations and charging/discharging represent a new technology not familiar to personnel at or outside Cornell.
Resiliency	GREEN	• Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus. • Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure of the distribution to critical service areas.
Emissions	GREEN	• GSHP systems recover waste heat and generate heating and cooling efficiently. • BTES operations using solar thermal collectors utilize a renewable energy source to improve BTES heating efficiency. • LSC remains a significant cooling source for the campus, improving overall cooling performance.
Constructability	YELLOW	• Campus conversion to hot water will have a major impact on day-to-day campus life, with new distribution lines required over most of the campus area. • Drilling for BTES modules is spread across campus. Modules at CEP and North Campus would cause relatively less disruption to campus life. • The optimized number of BTES modules improves constructability. • Geo-exchange system on East and North Campus can disrupt day-to-day campus life from drilling operations.
Financial	YELLOW	• Strong life-cycle cost performance compared to other scenarios studied in this report, driven improved system

Criteria	Rating	Assessment
		efficiency and reduced equipment costs from heat pump reuse. • High capital costs associated with drilling for geo-exchange fields and BTES modules; however, reduced modules help lower capital costs. • Strong opportunities to leverage exterior funding sources through credits, grants, and third-party funding.
Risk	**YELLOW**	• BTES technology has limited commercial-scale plants in the US. • Ground source heat pumps are an established technology with a strong track record of application. • Campus operations will require significant changes to operations and integration of multiple plants generating heating and cooling.

SCENARIO 10: Core Campus BTES + North & East Campus Geoexchange + ESH

This scenario is a hybrid approach combining strategies and technologies from Scenario 6 and Scenario 8. Ground-source heat pump systems for North and East Campus, while BTES systems for Core Campus are supplemented by a single ESH doublet. The ESH doublet will serve as a base loaded asset in the system.

Cornell's efforts to develop this emerging technology includes integrating a single Earth Source Heat doublet to provide a base heating load for the campus. The rest of the campus heating is provided by BTES plants for Core Campus and ground source heat pump plants for North and East Campus.

This scenario also integrates the optimized plant layouts and operating strategies laid out in Scenario 8. Utilizing hot water generated by solar thermal collectors as a BTES charging source helps increase heating system efficiency, while reuse of BTES heat pump as ground-source heat pumps by switching operating modes helps reduce initial system costs and improves equipment utilization.

Similar to Scenario 8, Lake Source Cooling (LSC) remains the primary campus cooling asset for core campus and is supplemented by the refurbishment and replacement of assets at CWP #3.

Scenario Cost Drivers

The primary driver of the life-cycle costs for this scenario is utility costs, which account for nearly half of the total costs. While the utility costs are high, they are considerably lower

than a steam electrode boiler-based solution. The lower utility costs are driven by the higher efficiency of the BTES and GSHP heat pumps, which reduces electricity usage for heating.

Capital costs account for a significant portion of the total life-cycle costs. This capital expenditure is primarily associated with the drilling costs for the BTES modules, GSHP borefields, and campus hot water conversion.

Costs associated with NYCI carbon costs are highest in the near term and reduce as campus heating is electrified. This cost is projected to reduce to zero when the grid is decarbonized. Due to the overall system efficiency, this is a relatively low cost.

The O&M costs associated with this scenario are primarily driven by the staffing and upkeep of various distributed heating plants around the campus, the large number of heat pumps, the maintenance and operation of the chillers and LSC. System maintenance costs are generally expected to decrease due to hot water systems being more aligned to chilled water system operations compared to a more complicated steam system.

Scenario Ratings

This scenario presents strong life-cycle performance, with competitive net present value and capital costs compared to other scenarios. This scenario allows Cornell to comply with CLCPA provisions and reduce potential NYCI carbon cost penalties while achieving improved system efficiencies compared to the previous scenario.

Additionally, this scenario has a high likelihood of receiving alternative sources of funding, therefore reducing the capital burden taken on by the University.

While the scale of ESH deployment is not as large compared to the full ESH scenario, there is still considerable risk associated with drilling of even a single doublet. See the full ESH scenario for more details on the potential risks.

The table below summarizes the ratings for this scenario based on the life-cycle, energy, and financial performance and its impact on campus operations.

Table 52: Scenario 11 BTES + North & East Geoexchange + ESH Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**GREEN**	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems. • Geo-exchange and BTES well systems have minimal maintenance requirements and limited exposure to potential damage. • Heat pumps have similar maintenance requirements as typical water-cooled chillers. • While components of the ESH and BTES Plants are not difficult to maintain, operations represent a new technology not familiar to personnel at or outside Cornell.
Resiliency	**GREEN**	• Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus. • Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure of the distribution to critical service areas.
Emissions	**GREEN**	• ESH offers considerably higher efficiencies compared to electric boilers. • GSHP systems generate heating and cooling efficiently. • BTES operations using solar thermal collectors tap a renewable energy source to improve BTES heating efficiency. • LSC remains a significant cooling source for the campus, improving overall cooling performance.
Constructability	**YELLOW**	• Campus conversion to hot water will have a major impact on day-to-day campus life, with new distribution lines required over most of the campus area. • CUBO has shown drilling is possible without disrupting day-to-day campus life; however, drilling and stimulating rock in this geological area is unproven. There are limited qualified contractors to conduct the drilling and stimulating operations and the contractor(s) will likely not be local to the region. • Drilling for BTES modules will be spread across the campus. Modules at CEP and North Campus would cause relatively lesser disruption to campus life.

Criteria	Rating	Assessment
		• Geo-exchange system on East and North Campus may disrupt day-to-day campus life from drilling operations.
Financial	**YELLOW**	• Strong life-cycle cost performance compared to other scenarios studied in this report, driven improved system efficiency and reduced equipment costs from heat pump reuse. • High capital costs associated with drilling for ESH doublet, geo-exchange fields, and BTES modules. • High chances to leverage exterior funding sources through credits, grants, and third-party funding.
Risk	**RED**	• ESH represents an emerging technology, with no commercial scale plants of similar configuration in operation. • Viability and efficiency of ESH plant can be severely altered based findings of CUBO Phase II. Well pressure differentials, rock composition, and groundwater chemistry all have an impact on project costs and performance. • Future drilling and redrilling requirements can present challenges from permitting to land or mineral rights given the depth and extent of the drilling. • Limited commercial-scale BTES plants in US. • Ground source heat pumps are an established technology with strong track record of application.

SCENARIO 11: Geoexchange for Full Campus

Ground source heat pump systems are used as the primary heating and cooling source for the entire campus district energy system. This scenario transitions away from existing steam production and operations on campus by using geo-exchange systems for heating and cooling across campus. Two independent ground source heat pumps plants–one for Core and East Campus and the other for North Campus–generate both heating and cooling for their respective areas using geo-exchange borefields. LSC helps meet summer cooling load for Core and East Campus cooling loads, as well as provide a source of heat rejection for both ground source heat pump plants to support thermal balancing operations. No other cooling assets are required to supplement the ground source heat pump and LSC capacity for this scenario.

This scenario requires construction of two new plants to generate heating and cooling for different parts of the campus. The combustion turbines with heat recovery steam generators will be retained as backup power and steam generation.

Two new GSHP plants are built in Core and North Campus. The Core Campus plant will serve Core and East Campus, while the North Campus plant will serve North Campus. Cornell's LSC facility will provide summer cooling load for Core and East Campus and act as a heat sink for thermal balancing of the geo-exchange fields.

Scenario Cost Drivers

The primary driver of the life-cycle costs for this scenario is capital costs, which account for approximately half of the total life-cycle costs. This capital expenditure is primarily associated with the drilling costs for the GSHP borefields and campus hot water conversion.

Utility costs account for about a third of life-cycle costs and are on the lower compared to other scenarios in this report. The lower utility costs are driven by the higher efficiency of the ground source heat pumps which reduces electricity usage for heating.

Costs associated with NYCI Carbon costs are highest in the near term and reduce as campus heating is electrified. This cost is projected to reduce when the grid is decarbonized. Due to overall system efficiency, this is a relatively low cost.

The O&M associated with this scenario are primarily driven by maintaining the staffing and upkeep of various distributed heating plants around the campus and the large number of heat pumps and the maintenance and operation of the chillers and LSC. System maintenance costs are generally reduced due to hot water systems being more aligned to chilled water system operations than a more complicated steam system.

Scenario Ratings

This scenario presents strong life-cycle performance with a competitive net present value and higher utility cost savings compared to other scenarios. This scenario allows Cornell to comply with CLCPA provisions ahead of compliance requirements and reduce potential NYCI Carbon cost penalties through using ground source heat pumps.

The challenge with this scenario is the extensive drilling require: over 4,000 bores at a depth of 850 ft would need to be completed, or more if shallower depths are selected. Upon completion, the borefield would be one of the largest geoexchange fields in the US.

The table below summarizes the ratings for this scenario based on the life-cycle, energy, and financial performance and its impact on campus operations.

Table 53: Scenario 11 Geoexchange for Full Campus Summary

Scenario Evaluation Ratings	RED – Negative or No Change Low Favorability	YELLOW – Modest Positive Change Moderate Favorability	GREEN – Significant Positive Change High Favorability

Criteria	Rating	Assessment
Maintainability	GREEN	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems. • Geo exchange well systems have minimal maintenance requirements and limited exposure to potential damage. • Heat pumps have similar maintenance requirements as typical water-cooled chillers.
Resiliency	YELLOW	• Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus • Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure of the distribution to critical service areas
Emissions	GREEN	• Mid-range system efficiency of all the scenarios studied. Better than steam scenarios, but less effective than BTES.
Constructability	RED	• Campus conversion to hot water will have a major impact on day-to-day campus life with new distribution lines required over most of the campus area • Drilling the large number of boreholes required for this system (over 4,000 bores) would take a significant amount of time, ranging from several years to a decade • Geo-exchange borefields locations are on campus peripheries, and impact to day-to-day campus life can be limited
Financial	YELLOW	• Strong life-cycle cost performance compared to other scenarios studied in this report driven by improved heating performance and high energy cost savings • High capital costs associated with drilling for geo-exchange fields • High chance to leverage exterior funding sources through credits, grants and third-party funding.

Criteria	Rating	Assessment
Risk	**RED**	• Ground source heat pumps are established technology with strong track record of application • Campus operations will require significant changes to operations and integration of multiple plants generating heating and cooling

SCENARIO 12: Utility Thermal Energy Networks (UTENs) with Peak Shaving

The Utilities Thermal Energy Network and Jobs Act (UTENJA) provides an opportunity for utilities companies to maintain growth in their market as natural gas is phased out. This scenario imagines a thermal solution that incorporates a utilities-owned thermal energy network that could immediately tie into Cornell's district energy system. Strategies such as waste heat pipe size optimization and peak shaving through thermal energy storage are also explored based on the campus heating load profile.

This scenario utilizes waste heat from an offsite low grade heat source for campus heat production. Campus heating systems are transitioned from existing steam production and operations to hot water as the primary heating medium, would require a hot water conversion across all campus buildings. Steam distribution will also need to be replaced by hot water distribution for this transition to be complete and the new production assets to come online.

Distributed plants with water-source heat pumps utilize waste heat from the utilities thermal energy network and would be supplemented by peaking/backup electrode hot water boilers and a thermal energy storage tank.

Lake Source Cooling remains the primary campus cooling asset and is supplemented by renewal of the existing chilled water plant and two new production plants to meet future campus growth. CWP2 on East Campus is restored to a chilled water generation facility. A new North CWP is established to meet North Campus cooling loads. Existing cooling assets at CWP3 are replaced to provide a similar total plant capacity.

Scenario Cost Drivers

The primary driver of the life-cycle costs for this scenario is capital costs, which account for approximately half of the total life-cycle costs. This capital expenditure is primarily associated with building a new utility-scale distribution system to bring waste heat from an offsite source to the campus. The hot water distribution costs and the costs of three new hot water plants require significant capital expenditure in the near term.

Utility costs account for approximately half of life-cycle costs, are lower compared to other scenarios in this report. The lower utility costs are driven by the high efficiency WSHPs which considerably reduce electricity usage for heating.

Costs associated with NYCI Carbon costs are highest in the near term and reduce as campus heating is electrified. This cost is projected to reduce to zero when the grid is decarbonized.

The O&M associated with this scenario are primarily driven by maintaining the staffing and upkeep of equipment at the new hot water plants and the maintenance and operation of the chillers and LSC.

Scenario Ratings

This scenario presents one of the highest energy consumption and cost savings over the baseline by integration of high efficiency heating technologies.

While this scenario also allows Cornell to comply with CLCPA provisions and reduce potential NYCI Carbon cost penalties, it presents considerable risk from relying on the establishment and long term continued operation of an offsite waste heat source with utility-scale permitting and regulations.

The table below summarizes the ratings for this scenario based on the life-cycle, energy, and financial performance and its impact on campus operations.

Table 54: Scenario 12 Utility Thermal Energy Networks (UTENs) with Peak Shaving Summary

Scenario Evaluation Ratings	**RED – Negative or No Change Low Favorability**	**YELLOW – Modest Positive Change Moderate Favorability**	**GREEN – Significant Positive Change High Favorability**

Criteria	Rating	Assessment
Maintainability	**GREEN**	• Hot water heating systems are inherently easier to maintain compared to steam production and distribution systems • Increase in number of cooling and heating production assets with distributed heating and cooling plants around campus • Water-source heat pumps, while currently not used at Cornell are relatively easy to maintain and operate

Criteria	Rating	Assessment
Resiliency	**GREEN**	• Cooling and heating production vulnerabilities are reduced by adding distributed resources around the campus • Cooling and heating distribution vulnerabilities are addressed by eliminating single points of failure of the distribution to critical service areas
Emissions	**GREEN**	• Water Source Heat Pumps (WSHPs) operate at higher efficiencies compared to electric boilers and would recover low grade waste heat from an offsite source to generate hot water.
Constructability	**RED**	• Campus conversion to hot water will have a major impact to day-to-day campus life with new distribution lines required over most of the campus area • New ambient distribution connecting offsite waste heat to campus will be a major challenge considering estimated distribution length. • Building new plants should have a low overall construction impact to day-to-day campus life with large scale construction limited to a couple of existing and new sites
Financial	**YELLOW**	• High capital costs associated with building ambient distribution system connecting to offsite waste heat source. • Strong life-cycle cost performance compared to other scenarios studied in this report driven by lower life-cycle utility costs • High chances to leverage exterior funding sources through credits, grants and third-party funding.
Risk	**RED**	• Campus heating operations will be entirely dependent on the continued operation of the utility thermal energy network. This system would not be operational if the utility thermal energy network is not available and would require building a completely new heating system. • Building new ambient distribution will require permitting as well as coordination with numerous stakeholders. • Likely reliant on a third party to complete the development.

CHAPTER 8: THE RECOMMENDED SCENARIO

Selecting the Recommended Scenario

During a UR&ET master planning workshop, all scenarios were quantitatively evaluated using the Cornell Quadruple Bottom Line (QBL) sustainability evaluation framework. This methodology quantifies the priorities of a project by balancing four areas: people, purpose, prosperity and planet. Starting tools (available online[16]) include an excel spreadsheet and "how-to" guide with sample categories and questions to prompt analysis. Using these starting tools, a QBL matrix was developed for the UR&ET master plan study. QBL analysis often brings up questions we do not have answers to, often identifying areas of uncertainty and risk which are captured in a separate risk register.

The QBL framework is intended to:

1. Systematically evaluate and document carbon neutrality and sustainability impacts
2. Ensure sustainability evaluation criteria are identified, balanced and considered
3. Identify risks or previously unseen benefits early
4. Provide a tool that can quantitatively rank solutions having complex costs and benefits

The UR&ET program combines the knowledge base of many experts: Cornell Utilities, Distribution, Energy Management, EH&S and Facilities Engineering, external engineering and financial consultants, Brooks Center for Infrastructure, Community Advisory team, as well as Cornell faculty and students. These experts used the QBL analysis to downselect to the preferred scenario based on an evaluation of twelve (12) thermal scenarios. The scenario which scored highest in the QBL analysis was selected as the Recommended Scenario (ie the "basis of design" for the energy master plan). This Recommended Scenario provides a decarbonization roadmap for the district energy system--allowing implementation priorities to be identified.

The term "Recommended Scenario" for the chosen thermal solution is used to reflect the flexibility and modularity built into the proposed solution. It is one possible solution, which was optimized and fully costed out, to use for planning. Assumptions and risks need to be revisited at regular intervals to make adjustments to the scenario as dictated by changing conditions. Possible drivers that might lead to scenario updates include changes to predicted retail electric rates, campus load growth from building renovations, energy conservation and new construction, adjustments to consequential carbon associated with the NY grid capacity fuel mix, and NY CLCPA policy updates.

[16] Sustainable Cornell Framework - The Quadruple Bottom Line: https://sustainable.cornell.edu/take-action/get-started

How was QBL applied to the Utilities Reliability & Energy Transition Program?

Initial Rankings

Rankings for capital spend, operating expenses, and cumulative carbon emissions were calculated from the initial analysis of each thermal scenario.

Screening for dealbreakers

Each thermal scenario was screened for dealbreakers:

- It will not reduce Cornell's consequential GHG emissions over the analysis period
- Significant cost premium that is not mitigated by other project benefits
- It is not constructable
- It does not have a viable permitting path
- It has insufficient information available (i.e., unmitigated risk exposure)

The following thermal scenarios were removed from further consideration because they were identified as a dealbreaker. These included:

- Scenario 01: Business as Usual. *Will not reduce Cornell's consequential GHG emissions over the analysis period*
- Scenario 02: Steam Electric Boilers in 2035. *Will not reduce Cornell's consequential GHG emissions over the analysis period*
- Scenario 03: Steam Electric Boilers + Steam Heat Pumps + Heat Recovery Chillers *Not constructable – requires another LSC intake*
- Scenario 04: Electric Steam Boilers + North Geoexchange. *Will not reduce Cornell's consequential GHG emissions over the analysis period*
- Scenario 05: Steam Electric Boilers with Hourly Matching Renewable Energy. *Significant cost premium that is not mitigated by other project benefits*. *Due to land required, is not constructable*.
- Scenario 06: Earth Source Heat. *Insufficient information currently available*
- Scenario 07: Core Campus BTES + North & East Geoexchange. *Will not reduce Cornell's consequential GHG emissions over the analysis period*
- Scenario 10: Core Campus BTES + North & East Geoexchange + ESH. *Insufficient information currently available*
- Scenario 12: Utility Thermal Energy Network (UTENs) with Peak Shaving. *No viable permitting path*

U*sing the QBL matrix*

The following scenarios were evaluated further, with Scenario 9 resulting in the highest QBL ranking when evaluated over a 40-year timeline:

- Scenario 0 – Baseline

- Scenario 08 – BTES charged with Solar Thermal
- **Scenario 09 – BTES with Enhanced ECI**
- Scenario 11 – Full Campus Geoexchange

The QBL matrix is summarized in the following table.

Table 55: Sustainability Evaluation Criteria

QBL Category	Sub Category	Description
Planet	*Carbon Emissions*	What is the reduction in consequential carbon emissions over the 40-year analysis period
Purpose	*Research/Teaching*	Measures the extent to which the project enables research, teaching/learning or commercialization opportunity for students, faculty, staff or community (e.g. certification or workforce development).
Purpose	*Land Grant Mission*	Potential impact within the broader community of engineering practice and environmental public policy
People	*Community Impact*	Measures campus and local community perception, and direct community impacts (e.g. utility costs, available capacity, disruption to campus operations, community support in achieving emission reductions, etc.).
Prosperity	*Affordability*	Measures life-cycle financial performance relative to the Baseline scenario.
Prosperity	*Maintainability*	Measures operational features, including staffing, materials and long-term performance predictability.
Prosperity	*Resiliency*	Measures improvement to campus utility resilience, including reliability, redundancy, and recoverability.

The following quantitative analysis was performed with a 1 being the lowest rank and 5 the highest:

Table 56: QBL Cumulative Capital (CAPEX) and Annual Utility (OPEX) Rankings

SCENARIOS	40 YEAR CUMULATIVE CAPITAL SPEND (CAPEX)	CAPITAL SPEND RANK	2067 ANNUAL UTILITY SPEND (OPEX)	UTILITY SPEND RANK
0_Baseline	$ 686,000,000	4.83	$ 59,575,000	1.05
1_BaU	$ 752,000,000	4.61	$ 30,948,000	5.00
2_Steam Elec Boiler	$ 637,000,000	5.00	$ 59,919,000	1.00

SCENARIOS	40 YEAR CUMULATIVE CAPITAL SPEND (CAPEX)	CAPITAL SPEND RANK	2067 ANNUAL UTILITY SPEND (OPEX)	UTILITY SPEND RANK
S3_Steam Elec Boiler and chillers	$ 868,000,000	4.21	$ 58,178,000	1.24
S4_Steam Elec Boiler+geoX	$ 731,000,000	4.68	$ 57,112,000	1.39
S6_Earth Source Heat	$ 1,809,000,000	1.00	$ 31,462,000	4.93
S7_BTES, geoX	$ 1,241,000,000	2.94	$ 47,018,000	2.78
S8_BTES, geoX optimization	$ 956,000,000	3.91	$ 41,921,000	3.48
S9_BTES, geoX, ECI	$ 965,000,000	3.88	$ 39,424,000	3.83
S10_BTES, geoX, ESH	$ 1,299,000,000	2.74	$ 36,190,000	4.28
S11_geoX	$ 1,168,000,000	3.19	$ 44,841,000	3.08
S12_UTEN	$ 814,000,000	4.40	$ 37,556,000	4.09

Table 57: QBL Cumulative Carbon Rankings

SCENARIOS	CUMULATIVE CARBON	CARBON RANK
S0_Baseline	2,280,068	4.19
S1_BaU	4,995,815	1.00
S2_Steam Elec Boiler	2,037,370	4.48
S3_Steam Elec Boiler and chillers	2,011,214	4.51
S4_Steam Elec Boiler+geoX	1,986,572	4.54
S6_Earth Source Heat	1,594,369	5.00
S7_BTES, geoX	1,934,071	4.60
S8_BTES, geoX optimization	1,731,089	4.84
S9_BTES, geoX, ECI	1,693,022	4.88
S10_BTES, geoX, ESH	1,660,497	4.92
S11_geoX	1,810,319	4.75
S12_UTEN	1,677,252	4.90

Table 58: QBL Results Summary

Scenario	Carbon	Research; Teaching	Land Grant	Community	CapEx	OpEx	Maintain-ability	Resilience	Total
S0_Baseline	0.73	0.05	0.10	0.05	0.92	0.20	0.40	0.30	**2.75**
S1_BaU	0.73	0.15	0.00	0.00	0.97	1.00	0.30	0.30	**3.44**
S8_BTES, geoX, Optimization	0.70	0.23	0.40	0.20	0.78	0.70	0.20	0.20	**3.40**
S9_BTES, geoX, ECI	0.79	0.23	0.40	0.20	0.78	0.20	0.20	0.25	**3.04**
S11_geoX	0.61	0.15	0.20	0.20	0.64	0.62	0.30	0.20	**2.91**

Details about the Recommended Scenario - Overview

The UR&ET master plan study envisions a transition to an ecosystem of electrified heating and cooling systems, paced with the NY Grid transition. The Recommended Scenario buildings on existing cornerstone solutions such as Cornell's Energy Conservation Initiative (ECI) and Lake Source Cooling (LSC) and incorporates strategies identified from other evaluated scenarios to reduce campus heating demand and consumption. Areas which provide the best opportunity for cost effective reduction of heating loads were identified through Enhanced Energy Conservation measures, thereby reshaping the district energy thermal load profile, reducing annual utility costs, lowering capital costs, and directly reducing Scope 1 GHG emissions. Additionally, system optimization for heating and cooling dispatch and thermal energy storage were identified as opportunities to improve system efficiency, reduce overall equipment costs and lower impact on the NY grid as campus heating is electrified.

The Recommended Scenario proposes a phased transition to a hot water-based district energy system anchored by three distributed utility production hubs (North, East, South), leveraging primarily borehole thermal energy storage (BTES), geo-exchange, and Lake Source Cooling. This would eliminate on-campus fossil fuel combustion associated with the district energy system, except during an electric grid outage.

The Recommended Scenario transitions from a centralized, fossil fuel-based system to a distributed, electrified thermal network with the following characteristics:

- **Results in lowest total cost (constructing, operating, maintaining) among viable decarbonization options** when evaluated over the 40-year analysis period.

- **Maintains and improves reliability** through distributed production and renewed assets.
- **Adapts to change with scalable and modular solutions**, allowing for changes in funding, regulation, and technology and variations in district energy loads associated with building level growth, renovations, and space utilization changes.

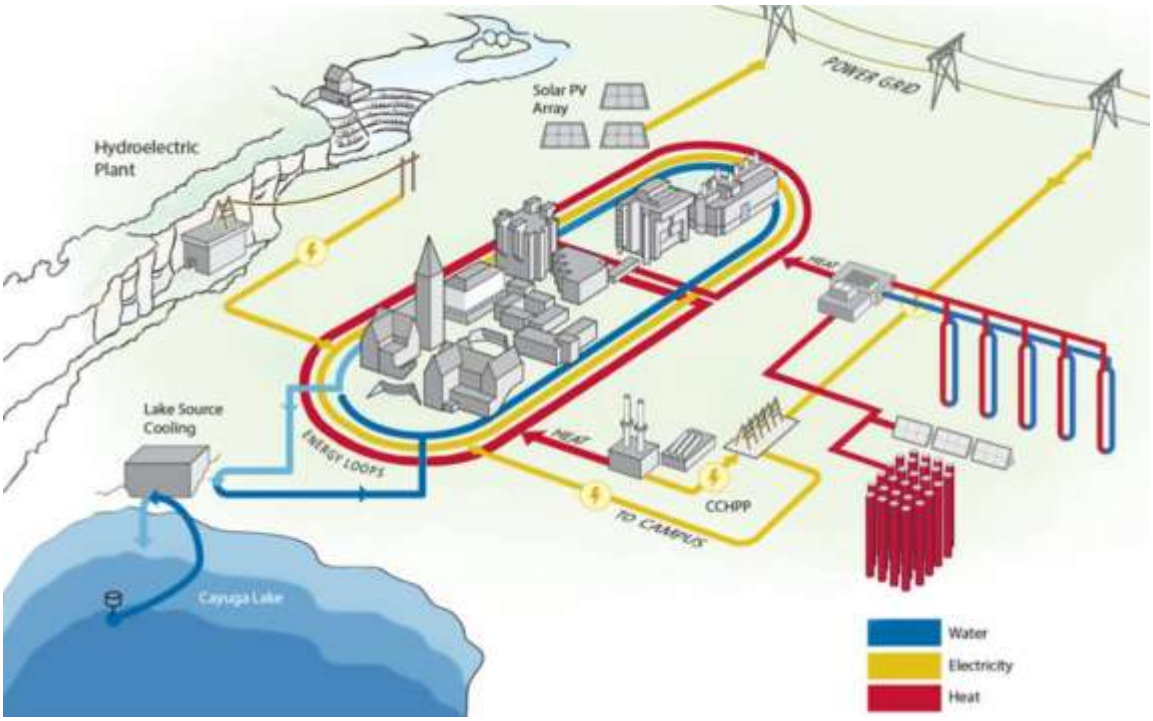


Figure 13: Cornell's Recommended Scenario

The Recommended Scenario fundamentally reshapes the campus energy infrastructure:

- Purchased electricity instead of self-produced.
- Transition from steam to a hot water distribution system
- Construction of 3 Cornell Utility Buildings (CUBs) across campus to house assets to produce hot water and chilled water.
- Installation of heat pumps in the CUBs to produce useful heat and capture waste heat year-round.
- Installation of vertical, closed loop geothermal boreholes (BTES + geo-exchange) that when coupled to heat pumps will provide efficient baseload heating.
- Continued use and renewal of Lake Source Cooling as primary cooling asset.
- Retention of existing Cornell Combined Heat and Power Plant (CCHPP) as emergency backup with the option for natural gas and/or diesel fuel firing (or renewable natural gas or biofuel if those fuels become available).

The Recommended Scenario pathway is intentionally programmatic and adaptive. It is not a lump-funded, fixed buildout. The execution plan seeks to accomplish the following:

- Phased deployment aligned with asset renewal cycles as much as possible.
- Foundational projects in the first 5 years to boost efficiency and mitigate regulatory uncertainty.
- Decision gates along the implementation timeline which allow for incorporation of updated cost, new technologies, grid transition and policy conditions.
- Modular design and execution that can scale or pause. All assets would be put into use as they are built.

This approach reduces long-term risk by avoiding over-reliance on any single technology or regulatory outcome, while preserving optionality through modular deployment and continued use of existing assets during the transition. **It allows Cornell to decarbonize with controlled cost, with preserved reliability, and remaining adaptable to highly uncertain external conditions.**

Production

The thermal production solution for this pathway utilizes an approach that is slightly different than typical higher education environments due to necessary load balancing considerations required to accommodate the load profile when considering the benefits of Lake Source Cooling. Before providing details on each plant configuration, this section provides a brief overview of the cornerstone technologies deployed for this solution. For the portions of the load which can be thermally balanced across the year, a traditional geoexchange system is deployed. For the portion of the load that is unbalanced due to higher heating demand, a BTES system is utilized. BTES modules, which are designed to discharge heat only, utilize various charging sources such as waste heat from CHP and solar thermal, and serve to store energy over the course of the year and allow the system to be discharged during the heating season.

By the end of the transition, most heat is generated renewably (via solar thermal arrays), stored for seasonal usage via Borehole Thermal Energy Storage (BTES) and supplemented with heat pumps. In addition, geo-exchange borefields integrated with high efficiency heat pumps provide heating and cooling; and improve system balancing. The unparalleled efficiency of Lake Source Cooling (LSC) continues to anchor the district cooling system with support from the geo-exchange systems along with heat pumps.

Geoexchange (GeoX) – Balanced Seasonal Thermal Energy Storage

Geo exchange systems utilize a set of borehole heat exchangers from 400-1,000ft to seasonally store thermal energy in the ground via closed loop grouted closed loop piping system. Based on the limited space available on campus as well as high level

considerations for the characteristics of the geology in the region, an initial layout was completed with wells sized to be 850 ft deep with a 25-foot center-to-center spacing. Each 5-inch diameter bore will have a single U-bend loop. The 25 ft spacing was chosen to reduce the thermal creep potential over the system life. Exact depth and spacing will need to be further investigated based on testing and further discussion with the industry.

Given an 850-foot target depth, the borehole arrays themselves are configured in rows of no more than seven boreholes per row and will utilize reverse return piping arrangement to provide better flow balancing for system pressure loss. Various rows of boreholes are arranged with submanifold field vaulting. Submanifolds are then connected to their respective plant.

Geoexchange uses the existing subsurface ground temperature (typically a constant ~50 degrees F) integrated with ground source heat pumps to provide heating and cooling. The key operating parameter is thermal balancing. The heat removed from the borefield during heating season should equal the heat rejected into the borefield during cooling. Otherwise, the subsurface temperature can become too cold and the heat pump loses efficiency, or worst case the borefield can be damaged with freezing temperatures. The Recommended Scenario considers traditional borefields for North and East Campus.

Borehole Thermal Energy Storage (BTES) - Unbalanced Seasonal Thermal Energy Storage

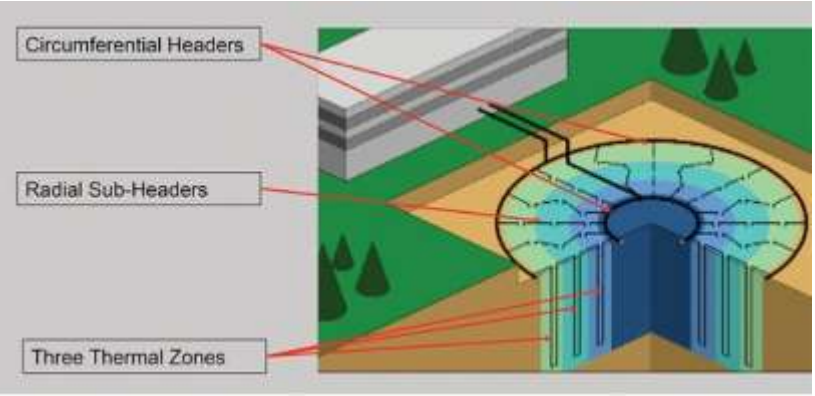


Figure 14: Borehole Thermal Energy Storage

The figure above shows a representation of a single BTES module with a concentrated circular cluster of bores with different thermal zones and placement of inlet and outlet headers. To build a BTES system as a scalable solution to generate campus heating, the system is divided into multiple “modules.” Each BTES module is a concentrated set of boreholes that can be charged and discharged independently. This modular approach allows discharge from multiple modules to be stacked to meet heating demand while simplifying associated equipment layout such as pumps and heat pumps. Modules are

serially arranged boreholes with connecting rows allowing radial outward flow. Borehole depth and inter-bore spacing will be matched to geological constraints and performance needs.

BTES acts as an underground battery that is charged during the summer (via solar thermal, a heat pump and/or waste heat sources) and discharged during the winter. For the Recommended Scenario, multiple BTES modules are installed. For planning purposes, the modules were assumed to contain 150 bores with each bore drilled to 850 feet deep with a 13 ft spacing in a geometrically offset circular configuration. This concentrates heat towards the center of the module, with a reversible flow to maximize temperature differentials. Drilling depths are above average for typical BTES (usually between 150 – 300 feet) due to the space constraints and heat storage quantities required. This is a potential area of optimization for a future detailed design effort, with a goal of reducing heat losses from the rock volume. Flow design for the BTES modules must undergo careful parametric analysis during detailed design to optimize for various metrics, including annual stored energy, turbulent flow limits, and pressure drops, among others. Each module is expected to have a footprint of approximately 45,000 ft^2 or close to 1 acre. With proper planning, the area of the BTES can still be utilized for other development.

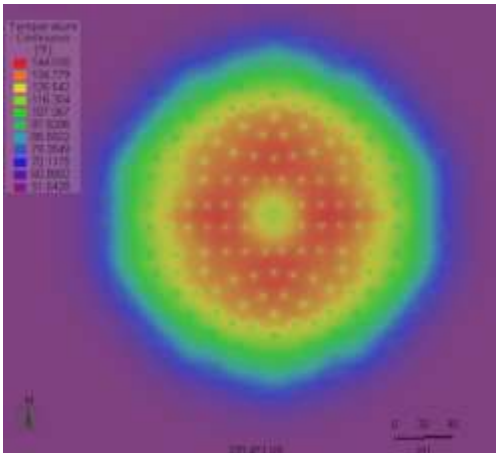


Figure 15: BTES Modeling Temperature Graphical Output

Charging Source Approach

Two different heat sources are used for charging, an initial charging and a sustainment state which are discussed below.

Initial Charging: The current central energy plant operations result in excess steam generation during the summer. This excess heat is condensed and not used for campus heating. For the first three years excess heat generated from the CCHPP is used for BTES charging to improve operational efficiency prior to being brought online. This efficiency is achieved due to the operating temperatures of BTES system being hot enough to allow the

heat to be utilized directly without the need for heat pumps to boost temperatures. The BTES modules are not discharged during this time.

Sustainment State: After the initial, multi-year charging period, BTES charging requires ~6 months (May to October) to reach the required internal temperature (170F) before discharging begins. The stored heat in the BTES modules is discharged to meet heating demand for an approximately 6-month discharge period (October to May). The charge/discharge period will vary by module as not all modules will be required immediately at the start of the discharge period. The discharge temperature at the start of the discharging period is 170F. This temperature progressively declines to ~90F as the BTES modules are depleted. Heat pumps are utilized to boost discharge temperatures to the hot water temperature required for usage in buildings.

When excess waste heat is no longer available after the CCHPP is shutdown (except for emergency backup), the BTES modules charging switches to using solar thermal collector arrays. Each BTES module is equipped with solar thermal collectors which can be installed near the BTES plants – on existing buildings roofs, over parking lots, or on empty fields. The solar collectors absorb solar radiation to heat water, generating a low-grade heat source which is converted with heat pumps to a high-grade heat source for BTES charging. This improves the operating efficiency of the charging heat pumps. Solar thermal is the optimal heat source due to the reduction in required lift by the heat pump compared to chilled water return, geoexchange or wastewater heat recovery. The efficiency of the solar thermal system is based on local conditions--on the solar irradiance and the temperature differential between the output temperature and the ambient air temperature. Based on the anticipated operational period and temperature requirements it is anticipated that the system will operate with a temperature differential of 20-40°F which allows the solar thermal system to turn the sun's energy into usable energy at an efficiency rate of 50-70%. This efficiency is significantly higher than a solar photovoltaic system which produces electricity at a typical efficiency of 10-20%.

Charge Source Evaluation

The BTES modules require a heat source to generate heat for charging. Any waste heat source can be utilized by supplementing lower-grade heat with a heat pump for BTES charging but the efficiency of the heat pump is directly tied to the temperature of the source entering water temperature. The higher the temperature, the more efficient the heat pump is able to generate hot water. To identify the most cost-effective source of heat, a variety of potential sources were evaluated including:

- **CHW Return:** Tie into the CHW return to decrease CHW return temperature before returning to the lake.

- **Wastewater Heat Recovery:** Based on data provided by Cornell, there are two major opportunities for wastewater heat recovery on campus. There is no wastewater heat recovery from large scale resources outside of Cornell.
- **Geoexchange**: Traditional shallow borefield located throughout campus. For this analysis it only includes benefits as it relates to BTES and doesn't consider the full benefit which is evaluated elsewhere in the recommended scenario.
- **Solar Thermal:** Utilize solar thermal to heat water paired with a thermal energy storage (TES) tank to allow for maximum use of output and charging time.

A rough order of magnitude (ROM) analysis was completed for different charging technologies which considered the capacity limitations at Cornell, expected entering water temperatures, rough order of magnitude capital costs, and estimated production costs based on the approximate round-trip efficiency of a BTES system and an average electric rate of $0.10/kWh. The figure below illustrates the approximate average coefficient of performance (COP) of the different technologies based on their supply temperature.

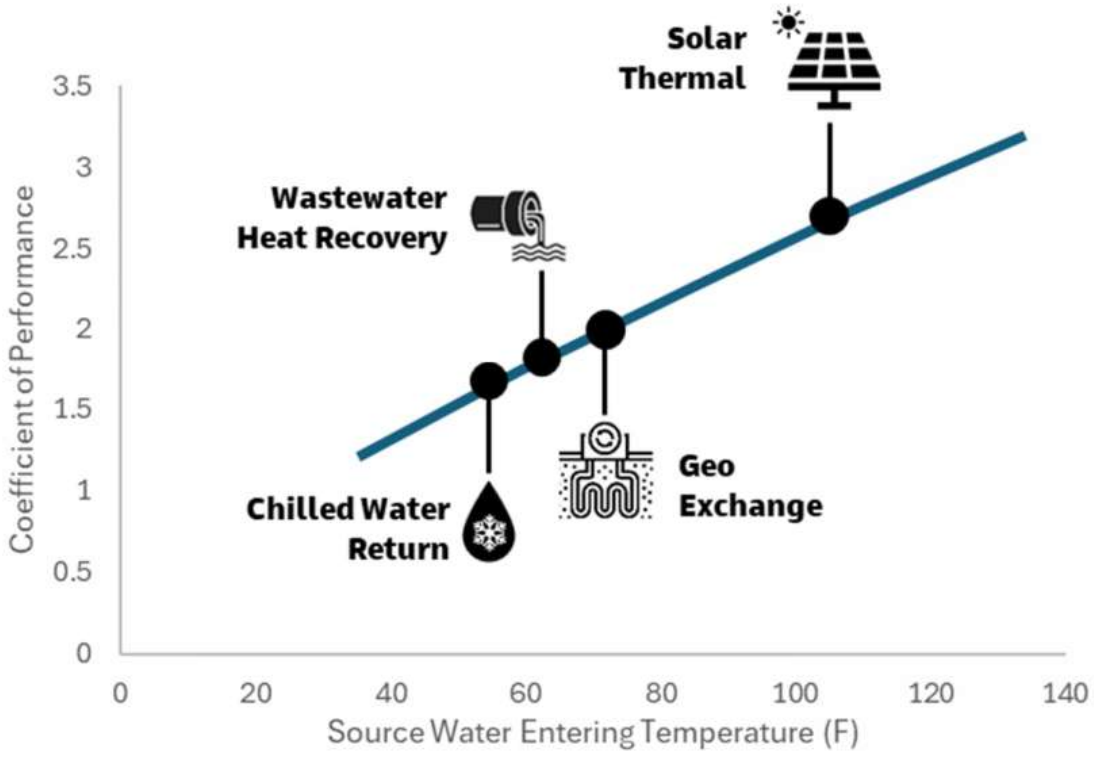


Figure 16: BTES Charging Technologies COP vs Source Water Entering Temperature (F)

BTES-Geoexchange Plant Operations

The BTES-GeoX configuration uses heat pumps to support the operation of the BTES modules and the geoexchange systems, allowing heat pumps to switch between different operations based on the time of year, system start up and load requirements.

Charging BTES with CCHPP Excess Heat

When available, the BTES modules use excess heat that is produced during operation of the combustion turbines (heat above what is needed to meet campus demand) for the first 3 years of charging, after which the study assumes it switches to solar thermal collectors for charging. During charging mode, the condenser water is converted to approximately 180F hot water which is then directly sent to the BTES. The CCHPP will remain a charging source for as long as it's allowed to operate, including operating for testing.

Charge BTES with Solar Thermal and Heat Pumps

Solar thermal was chosen as the primary source of low-grade heat for the BTES as it provides a highly efficient source of on-site energy renewably with long-term and consistent charging available across the 40-year analysis period. Depending on operating characteristics, system efficiencies, and load requirements the solar thermal will provide between 80-140F hot water. Two heat pumps will convert the low-grade heat from the solar thermal to the high-grade heat required for charging the BTES modules.

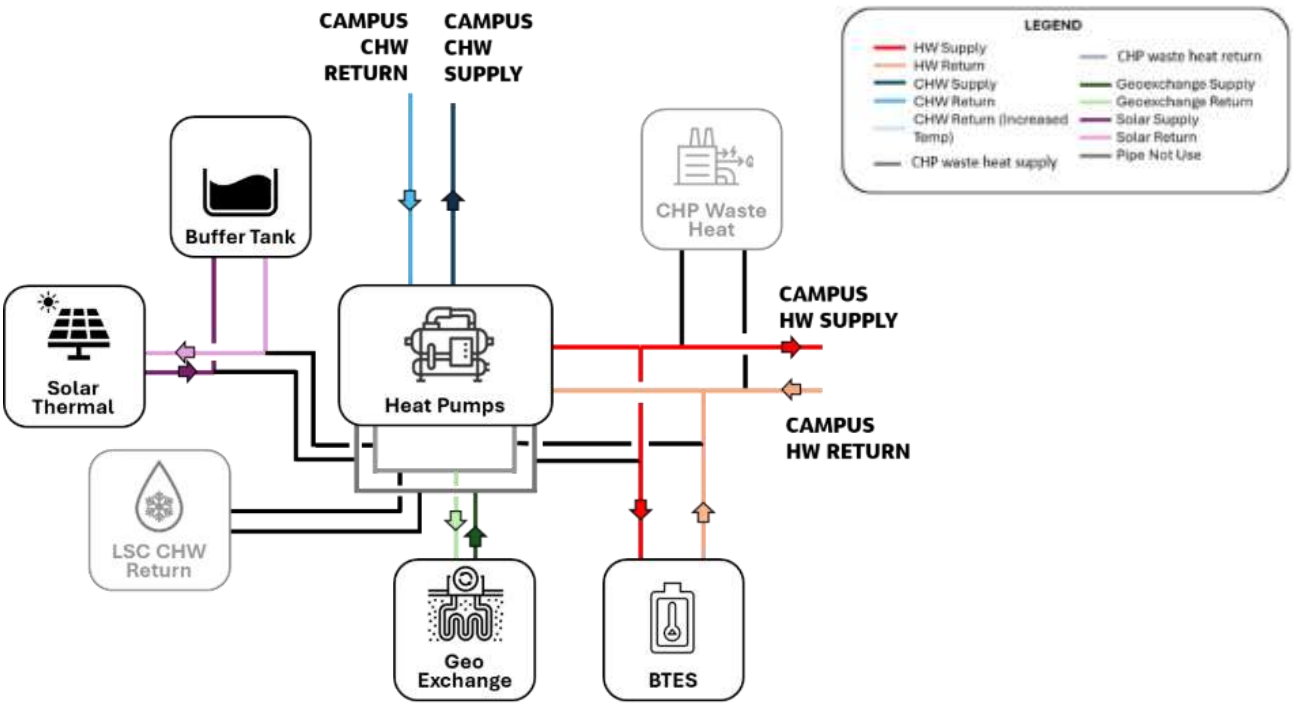


Figure 17: BTES Charging with Solar Thermal and Heat Pumps Illustrative Flow Diagram

Discharging BTES

Once the BTES reaches the targeted charge temperature, it is ready for discharge mode. In discharge mode, the system extracts heat from the BTES and depending on the supply temperature, the hot water is either directly injected into the hot water loop (at initial charged state) or run through a single heat pump to bring the hot water temperature up to the hot water supply temperature. A single heat pump is only needed when compared to charge mode because of the reduced lift in this operational mode. This results in an additional heat pump required per BTES module which remains idle in winter.

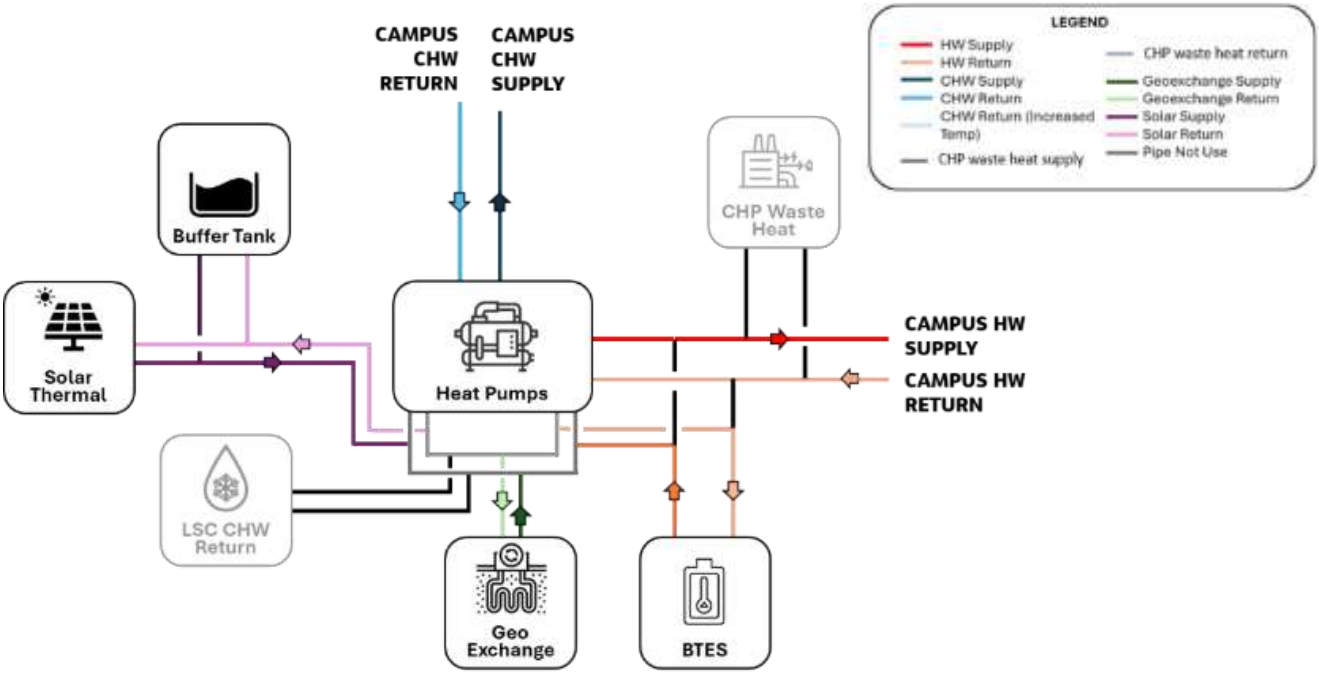


Figure 18: BTES Discharge Below Supply Temperature Illustrative Flow Diagram

Heat Pump Optimization

The BTES-GeoX Plant operation aims to stage heat pump operations to reduce the number of heat pumps required by using the idle heat pump during heating period. The idle heat pump not used for BTES operations in winter, is instead used as a ground-source heat pump and extracting heat from the East Campus geo-exchange borefield.

During summer months, the charging heat pumps switch from charging operations to ground-source heat pump operation. In this mode, they use the Geo-exchange borefield as a heat sink to generate cooling for East Campus. However, when operating in this mode the charging heat pump is not available to charge the BTES module. To allow BTES charging levels to remain unchanged, a hot water thermal energy storage (TES) system will be

installed to store hot water generated by the solar thermal collectors. This allows the heat generated by the collectors during the day to be stored when the charging heat pumps may be operating as ground source heat pumps in cooling mode. At night, when East Campus cooling loads are reduced by 50-70%, the heat pumps are available to switch back to charging operations by utilizing the heat stored in the hot water TES. This switching operation allows maximum utilization of installed heat pumps by eliminating four additional dedicated ground source heat pumps while maintaining the same charging levels to support Core Campus heating demand in winter.

Lake Source Cooling

Lake Source Cooling continues to be the workhorse for district cooling and continues to operate much more efficiently than traditional geo-exchange cooling. This system is four (4) times more efficient than traditional water-cooled chillers. In addition, the existing 4million gallon chilled water thermal storage tank will be utilized for peak electric usage reduction and to boost system reliability.

Electric Boilers

Electric boilers use electric resistance to generate hot water or steam. Electric boilers are highly efficient compared to currently installed natural gas boilers (close to 100% versus 84%). They offer high turndown ratios that allow safe operations at low outputs without compromising efficiency. Electric boilers have lower initial costs but have significantly higher life-cycle costs compared to natural gas boilers due to the higher cost of electricity. These electrode boilers are designed to meet short-duration peak heating demand above design performance of the BTES-GeoX system, so they will operate for a limited amount of time on the coldest days of the year.

Solar Thermal Collectors

The solar thermal collector area for each BTES module was estimated based on the campus heating load profile, number of proposed modules and use of CCHPP waste heat as a charging source for an initial three years. Each module requires approximately 75,000 ft^2 of solar thermal collector area along with an approximately 75,000-gallon buffer tank, and pump to assist the charging operation. The collectors are typically located above or adjacent to the BTES.

Auxiliary Equipment

Electrical upgrades to the substation handle the increase in campus electric demand, heat pumps, electric boilers and other pumping and supporting equipment needed for reliable operations. To support the worst-case load requirements of 70MW, the Maple Avenue

Substation will require expansion to 100MVA. The expansion will use two additional 20MVA transformers which match the exiting substation configuration to simplify maintenance.

Cornell Utility Buildings (CUB)

The Recommended Scenario distributes the electrified heating and cooling production assets to three (3) new Cornell utility buildings (called CUB's). Each CUB will house the heat pumps and associated equipment/controls required for operation of the heating and cooling systems. For example, the North CUB will be approximately 18,000 GSF and house 2 BTES pumps, 2 Ground Source Heat Pumps, and multiple other pumps associated with chilled water, hot water, solar thermal and geo-exchange systems.

Emergency Backup Power and Heat

The existing Combined Heat and Power Plant will provide emergency back-up power and heat. The combustion turbines can generate a total of ~30MW which can meet existing building electrical demand, and the heat recovery steam generators with duct burner firing can generate over 300 MMBtu/hr of heat, thus able to meet expected campus heating needs. The steam would be converted to hot water at the plant and distribution through the hot water network. To be available for emergencies, the combustion turbines would have to be routinely tested. Any waste heat generated through testing would be stored in the BTES.

Distribution

The Recommended Scenario requires full conversion to a hot water distribution system with more focus on low-temperature hot-water (where buildings use 160F or lower temperature hot water). This effort is significant but necessary. Hot water allows for superior utilization of renewable energy sources compared to steam (heat pumps can effectively generate 160F water; however, efficiency is reduced when lifting supply temperatures as high as 210F). Hot water distribution systems are significantly more efficient (less losses at the plant, distribution and buildings) and easier from a maintenance perspective relative to steam. Steam pipe expertise is "aging out" as the workforce with that expertise retires and steam system maintenance and operation is not taught to the newer generation.

However, Cornell has plenty of steam pipe in excellent condition, and this impacts the distribution strategy. The implementation strategy divides the campus into different areas. The emphasis is aligning the buildout of the hot water production assets as best as possible with the distribution. For example, hot water conversion recently completed for Vet Medical Center and East Campus Research Facility (ECRF) will be expanded to the rest of East Campus to align with the planned production assets and new Cornell Utility Building. This approach reduces the need for temporary equipment and reliance on aging assets. The Plan takes an "outside in" approach, with conversion working from "outer" campus (East and North) first, then moving towards Central Campus / Engineering Quad with the final

conversion at the Central Energy Plant. A mix of plastic and metal pipe will be utilized to accommodate those facilities which require higher temperature hot water (180F+). In addition, existing steam or condensate lines will be repurposed when/where appropriate.

Consumption

Enhanced energy conservation builds upon the great success Cornell has seen with the energy conservation program but utilizes a more aggressive approach that is better aligned with the new district energy production strategy. The enhanced energy conservation projects have been evaluated on both simple payback (capital cost versus operational savings) and future capital avoidance. Energy conservation provides near-term reduction in emissions, reduced operating expenses and reduced energy transition capital cost (as there is less heating load to convert).

Hot Water Readiness in Buildings

Similar to the distribution system conversion, the Recommended Scenario requires full conversion of existing buildings on the district energy system to be hot water ready with focus on low-temperature hot-water (where buildings can use 130F-150F supply hot water temperatures based on a district supply temperature of 140-160F). This effort is significant and this master planning process recognizes the difficult conversion of buildings that still rely on steam radiators.

Cornell's Energy Conservation Initiative (ECI)

Launched in 2000, ECI[17] has significantly reduced costs and greenhouse gas emissions, supporting the university's sustainability goals. Past projects are recorded in GRITS public dashboard, showing $92M financial savings as of April 2026 with a total investment of $48M. These projects have resulted in over 270,000 MTCO2e of abated emissions and over 4 million MMBtu (Trillion Btu) of total energy savings. Typical energy conservation initiatives focus on reducing annual consumption versus reduction in peak demand, as benefit accounting including incentives are generally consumption based. However, as the entire campus energy system is being transformed, attention to reduction of peak demand allows significant savings in capacity of energy production and distribution infrastructure.

Core Components Summary

While the new infrastructure provides a more efficient way to generate and distribute thermal energy, reducing the overall load through building-level conservation allows the entire system to be right-sized. By lowering peak demand, Cornell can install smaller, less expensive plant equipment. A summary of the core components for the Recommended

[17] Cornell Energy Conservation Initiative website: https://sustainable.cornell.edu/buildings-energy/energy-conservation-initiatives

Scenario and a map of the production assets are shown below. The sites for production assets are shown below for study purposes only. BTES, Geoexchange, solar thermal and thermal plants have not been sited.

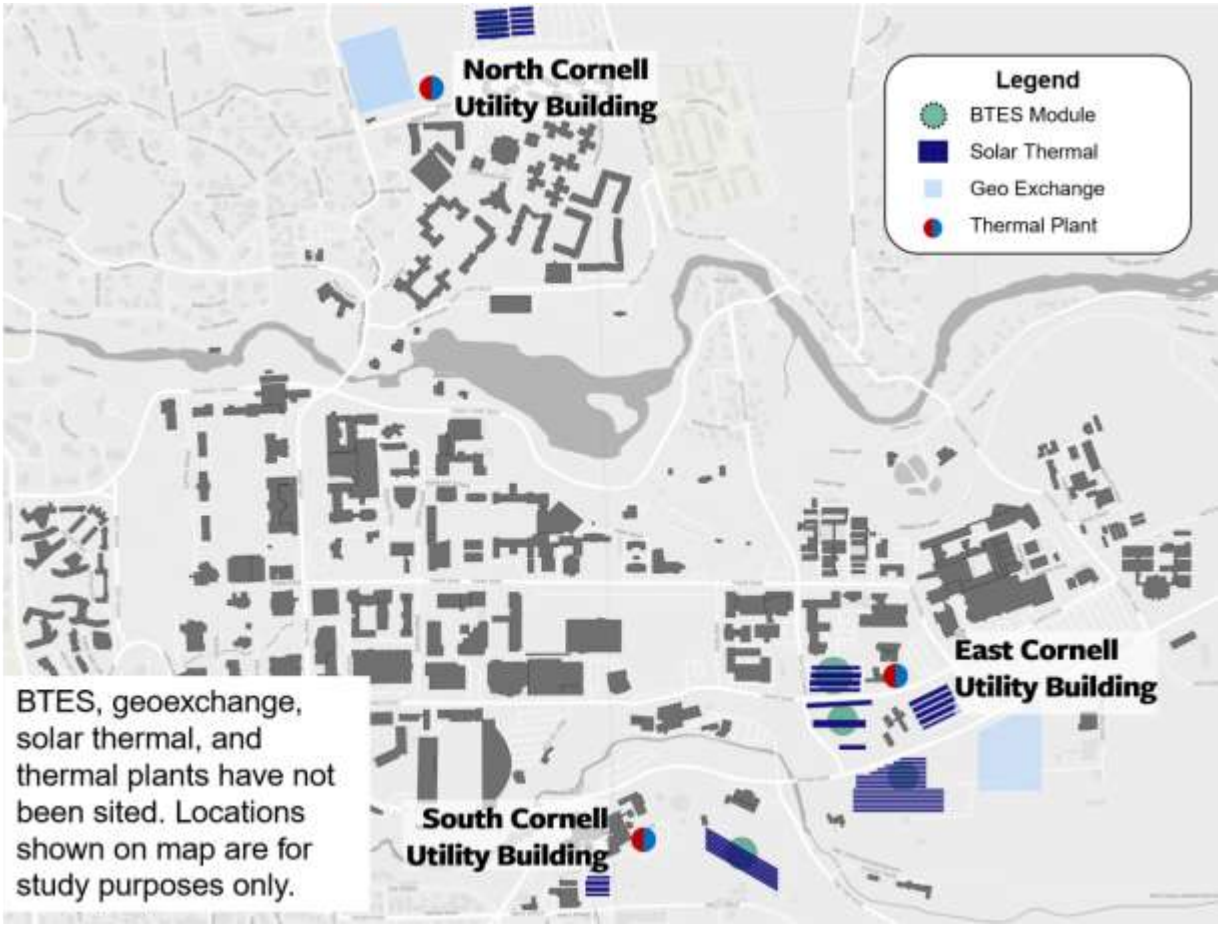


Figure 19: Recommended Scenario Production Assets for UR&ET Master Plan Study

Table 59: Core Components Summary for Recommended Scenario

Component	Role
Cornell Utility Building: CUB(s)	House heat pumps and auxiliary equipment required for operation of heating and cooling systems. For purposes of the study, located on North, East and South Campus.
Borehole Thermal Energy Storage	BTES provides most of campus heating (with heat pump integration). BTES is a very large subsurface battery which is discharged during the heating season and charged during off-season. Five modules are proposed across campus. Each module consists of 150 boreholes at a planned depth of 850ft*. Discharge directly from the BTES will vary seasonally between 90-160F and supplemented with heat pumps for

Component	Role
	a planned hot water supply temperature of 160F for the distribution system. Each module is approximately 1 acre in size. *Borehole number and depth may be adjusted to suit specific site geology during design and construction phase.
Solar Thermal Array	Solar thermal energy provides renewable hot water to charge the BTES models and is supplemented with a heat pump; however, any source of waste heat can be utilized for charging purposes (for example chilled water return). Each BTES module requires approximately 75,000SF of collector area. The collectors are typically located above (canopy) or adjacent to the BTES.
Building Hot Water Conversion	Some of the existing buildings will require conversion to utilize a minimum temperature of 150/160F hot water. In addition, enhanced energy conservation will reduce demand and lower capital spending due to fewer boreholes required and fewer heat pumps.
Distribution System Hot Water Conversion	Replace existing steam system with 160F district hot water supply temperature for space heating. Hot water systems are more efficient, easier to maintain and allow better utilization of renewable energy and low-grade heat.
Geo-Exchange	Geoexchange borefields for North and East Campus and associated piping
Heat Pumps and Other	Heat pumps for geo-exchange and BTES operation and supplemental heat pumps for peaking.
Electric Boilers	Electric boilers for peaking
Lake Source Cooling Renewal	Replace heat exchangers and pumps for renewal of Lake Source Cooling.
Electric Infrastructure	Installation of new electric transformers and renewal of existing electric transformers.

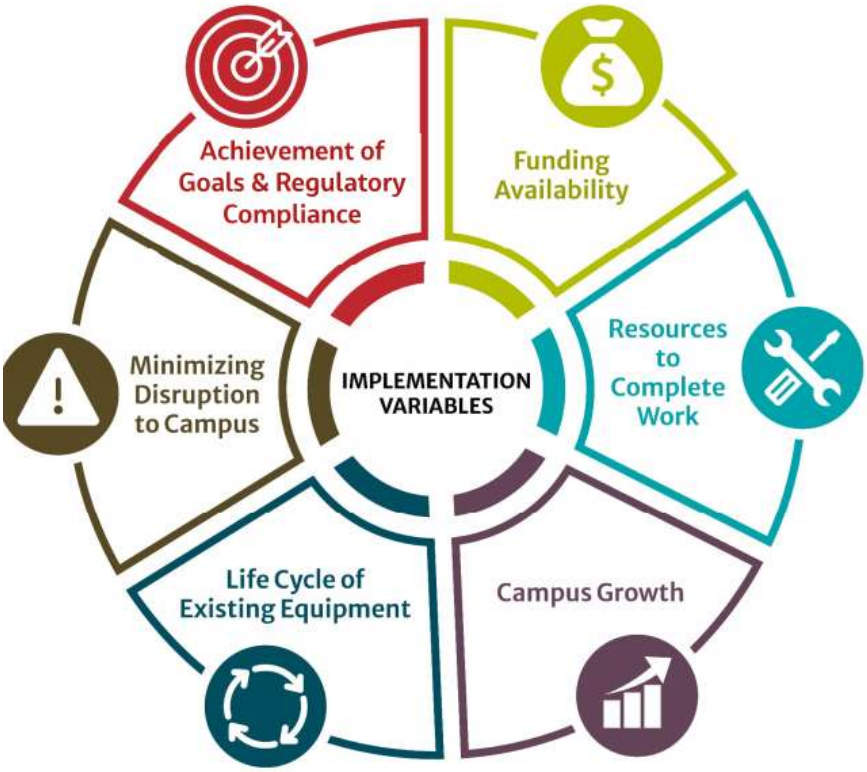


Figure 20: Implementation Framework Variables

Implementation Framework

There are various opportunities, limitations, and demands to consider during implementation to maximize financial investment. It is important to note that throughout the implementation plan, each variable will change based on needs at the time.

Below is a summary of these variables:

Achievement of Goals & Regulatory Compliance

The implementation plan needs to align with compliance with regulatory requirements as well as consider existing voluntary commitments. This includes Scope 1 and Scope 2 for emissions associated with the on-campus energy utilities (electricity, chilled water, and steam). It includes stationary combustion and purchased electricity as it relates to those utilities. It doesn't include Scope 1 elements such as company vehicles, backup

generators, or fugitive emissions. Scope 3 emissions are not considered as part of this energy master plan (they are considered within Cornell's Climate Action Plan[18]).

Funding Availability

There is no single funding source with the available capacity to meet the project implementation demands. A variety of funding sources will be leveraged as they are available.

Resources to Complete Work

As this represents a large amount of work that is not the standard for Cornell or the Ithaca area, the available resources to support the work both internally and externally are important to consider.

Campus Growth

Ideally, when new facilities come online these buildings will be connected to the existing district energy system to reap the benefits inherent in district energy systems.

Life-cycle of Existing Equipment

Over the implementation period, existing equipment will reach the end of its useful life. Ideally, when equipment reaches the end of the useful life, it is replaced with equipment or service that is part of the new district system plan.

Minimizing Disruption to Campus

These scenarios will lead to widespread work across campus. Where possible, these projects should be completed in a manner that limits the number and/or length of disruptions to areas.

Implementation Strategy

Utilizing the previously described framework, an implementation strategy was developed. This strategy is focused on maximizing the value for Cornell. This includes the ability to leverage third party funding as well as carefully balancing the workload to minimize disruption to campus operations as well as ensure a level of consistency for construction operations which drives quality and cost effectiveness.

The strategy aims to establish alternative production points throughout the campus to provide strong phasing pathways as well as provide flexibility to work in different areas of campus depending on other campus constraints and opportunities.

[18] Climate Action Plan website: https://sustainable.cornell.edu/climate-action/climate-action-plan

The approach provides a general phasing plan by production system and distribution service area. The master plan proposes major work to be completed over the transition period. It is important to note that the developed implementation strategy provides a feasible potential pathway. This is one of many ways to approach implementation and if there are changes to opportunities or constraints, the plan can easily adapt to those changes. More detailed information on the phasing of each production system and distribution service area can be found on the following pages.

Foundational First Five Years

The UR&ET master plan study recommends immediately undertaking projects and living lab opportunities that are compatible with any version of the future. Cornell's decarbonization path is heavily influenced by external factors such as the rate that new clean energy sources are added to the New York electric grid relative to load growth, state and federal regulations and available technologies. Due to the risk and uncertainties identified, the initial recommendations are incremental in nature, maximize synergies with Cornell's academic and research mission, and build the foundation for the full transition to electrified heat and New York grid-supplied electricity. The initial projects reduce campus emissions.

Below are key first steps which allow Cornell to move forward effectively:

Foundational Projects ($71M from 2028-2032)

The Foundational Projects represent the equipment renewal, energy conservation and expansion activities required to ensure reliable heating and cooling for campus. These projects are required in all of the scenarios. Prioritizing these projects allows the University to make meaningful progress on findings from the UR&ET master plan study while navigating uncertainty and preserving flexibility.

Expansion and Renewal of Chilled Water ($22M)

Install a heat pump at an expanded Chilled Water Plant 2 (renamed the "East Cornell Utility Building") to meet campus chilled water load growth while enhancing reliability for critical east campus cooling loads serving the College of Veterinary Medicine. This heat pump will also produce hot water for campus both during and after the transition to electrified heat.

The existing chillers in Cornell's Chilled Water Plant 3 will be renewed to extend their life for another 15 years until new geothermal assets are in service.

Distribution System Steam-to-Hot Water Conversion ($19M)

Convert end-of-life steam distribution lines dating back to 1910 on North and Central Campus'. Complete the conversion on East Campus within the Center for Veterinary Medicine complex.

Enhanced Energy Conservation and Building Hot Water Conversion ($34M)

Energy conservation reduces both annual energy consumption and peak energy demand on the coldest and hottest days of the year. These projects immediately reduce operating costs and the required capacity of new electrified heating systems.

In concert with distribution system steam-to-hot water conversions, buildings must be upgraded to receive hot water and to operate at lower temperatures. Where possible, these efforts will be combined with energy conservation to minimize the disruption to building occupants.

Pilot Borehole Thermal Energy System ($22M in 2029)

Borehole Thermal Energy Storage (BTES) is the primary heating technology in the master plan Recommended Scenario. This is leading edge technology and is an ideal solution for a heating-dominated system like Cornell's. A BTES system will be constructed on East Campus, the first of five BTES' laid out in the master plan. This project is important to complete in the first capital program for the following reasons:

- Cornell's existing system efficiency is improved immediately. The system will capture unutilized waste heat during the summer months, store it in the well-field, and put it to use in the winter to heat buildings on East Campus.
- Enables critical learning in design, construction and operations.
- Enables improved cost estimates and ramp-up of drilling contractors.
- Powerful living lab opportunities and technology demonstration for New York.
- Eligible for state and federal grants and tax incentives.

Revisit the Master Plan (2028)

The master plan will be reviewed in 2028 to ensure the critical inputs and assumptions are still valid. This process is intended to repeat at some regular frequency over the next 10 years. Uncertainty in NYS grid emissions reductions, regulations, and technology require revisiting the master plan regularly to ensure the direction is still congruent with state and University goals. Jacobs' Virtual Infrastructure (VI) software tool simulates the Cornell district energy system, enabling adjustments to the Recommended Scenario and measuring progress towards goals.

Major Milestones

Flexibility is key for a project of this magnitude when considering funding, campus disturbance, status of the grid and the NY Climate Law. The UR&ET master plan study implementation strategy utilizes three (3) CLCPA trigger points, including:

1) 70% renewable target goals for the NY grid (Milestone: 203x)
2) no fossil fuel for on-site electric generation (Milestone: 204x)
3) no fossil fuel for heating (Milestone: 205x)

Geographic Zones

Additional dependencies for the implementation are spatial--aligning distribution, production and building changes by region or zone. Major capital programs include drilling (BTES and geo-exchange), building new production facilities (ie Cornell Utility Buildings – CUBs), distribution, and buildings. A key phasing consideration is initial BTES charging. The initial charging to "steady state" conditions is anticipated to take ~3 to 5 years and will utilize waste heat from the existing Central Energy Plant. The UR&ET master plan study phasing strategy can be described as an "outside in" approach, with focus on outer parts of campus and aligns distribution work with production work, shown below.

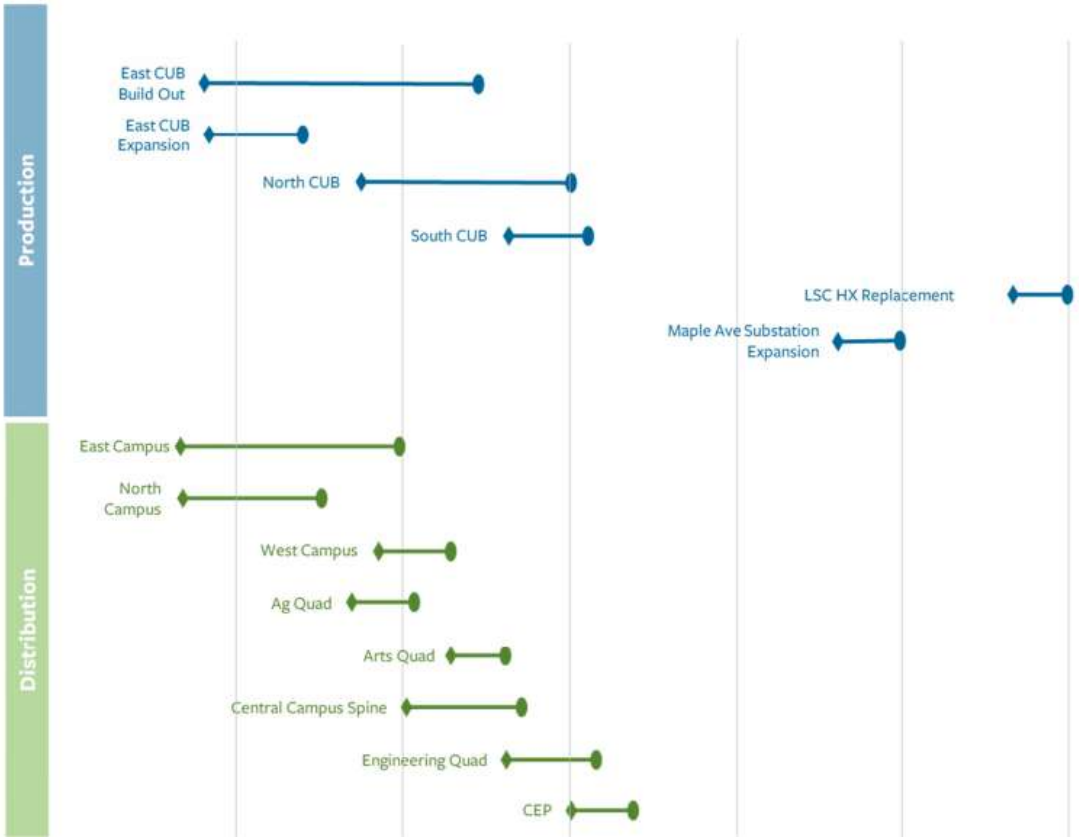


Figure 21: Geographic phasing of production, distribution, and buildings

CHAPTER 10: SUMMARY AND UR&ET MASTER PLAN STUDY UNCERTAINTIES

Each thermal scenario was evaluated against the qualitative and quantitative scenario criteria (Quadruple Bottom Line) to identify the Recommended Scenario. The Recommended Scenario will serve as the guide for Cornell to move forward given the current planning information and assumptions and allows Cornell to set direction and create a shared vision of the future for the mission-critical utilities system. It is intended to be dynamic and flexible so that as variables such as technologies, costs, and demands change, appropriate updates to the path forward can be made to ensure Cornell is making the best decision given the most current set of information.

Technical Overview

The recommended scenario fundamentally reshapes how energy is produced and delivered.

Notable components include:

- Purchased electricity instead of self-produced (i.e. electrification)
- Transition from steam to a hot water distribution system
- Installation of heat pumps in three (3) Cornell Utility Buildings across campus to produce useful heat and capture waste heat year round
- Extensive use of thermal energy storage from solar thermal
- Large-scale geothermal technologies

Annual Production

By the end of the transition, energy production is no longer provided by a fossil-fuel based combined heat and power plant (except as emergency backup for grid outages). Borehole thermal energy storage utilizing solar thermal charging will provide ~63% of campus heat. During the winter, the BTES output declines while discharging, and heat pumps are utilized to maintain hot water distribution temperatures. Geo-exchange borefields with heat pumps provide ~34% of campus heating and ~26% of cooling needs. Lake Source Cooling remains the primary cooling asset, providing ~50% of campus cooling needs. Annual energy production for heating and cooling is summarized in Table 9.1 based on the final analysis year of the master plan (2067).

Table 60: Recommended Scenario Annual Production

Component	Heat Production (MMBtu)	Heating (%)	Cooling Production (MMBtu)	Cooling (%)
BTES with Heat Pumps	454,000	63	55,800	0
Geoexchange with Heat Pumps	241,000	34	169,000	26
Lake Source Cooling	0	0	192,000	48
Other Heat Pumps	23,000	3	169,000	26
Total	**718,000**	**100**	**644,000**	**100**

Annual Electric Consumption

The transition from on-site power generation to electrification will dramatically increase annual electric purchases. Calendar year (CY) 2067 electric *purchases (i.e. grid)* are forecasted at ~305 million kWh, and includes building usage (i.e. plug load, lights, equipment) and electricity required for all new plant equipment. For comparison, current grid purchases are very small (~15 million kWh) and are associated with periods when on-site generation is low or down (i.e. turbine maintenance). Currently, metered building electric usage is ~200 million kWh.

Peak Capacity

The recommended scenario will provide a total heating capacity of 410MMBtu/hr and total cooling capacity of 31,000 tons (exclusive of the thermal storage tank) with sufficient redundancy and resiliency to meet peak loads. Peak heating needs are projected at 260MMBtu/hr, which represents a significant reduction compared to the current peak (~340MMBtu/hr). Peak cooling is kept stable at ~25,000 tons despite 40 years of growth.

Table 61: Recommended Scenario Heating and Cooling Capacity

Cornell Utility Building (CUB)	Heating Capacity (MMBtu/hr)	Cooling Capacity (tons)
East CUB	143	6,200
North CUB	86	5,800
South CUB	181	3,000
Lake Source Cooling (LSC)	0	16,000
TOTALS	**410**	**31,000**
Projected Peak	**260**	**25,000**

Electric Demand

Full electrification of heating and cooling will more than double the campus electric peak demand from ~30MW currently to ~70MW in 2067. Electrical upgrades will be required to handle the additional load.

Backup

The existing Combined Heat and Power Plant will provide emergency back-up power and heat. The combustion turbines can generate a total of ~30MW and the heat recovery steam generators with duct burner firing can generate over 300 MMBtu/hr of heat, thus able to meet expected campus heating needs. The steam will be converted to hot water at the plant and distributed through the hot water network. To be available for emergencies, the combustion turbines would have to be routinely tested. Any waste heat generated through testing would be stored in the BTES.

Financial Overview

The financial results of the different scenarios were each driven by different key factors. The information below summarizes the main drivers for the financial results for the Recommended Scenario compared to the baseline and business as usual cases:

Recommended Scenario: The scenario has front loaded capital cost associated with the steam-to-hot water conversion and new, long term production assets. Operational costs are reduced due to the energy and maintenance efficiency associated with a hot water based system and by completing enhanced energy conservation projects.

Baseline: This scenario has a low capital cost due to the general strategy of replacing assets only as needed. The low capital is offset by the high operational cost associated with the inefficient steam system and the low efficiency of electric boilers (as compared to geothermal systems). This leads to consumption of a large amount of high cost electricity.

Business as Usual: Similar to baseline, the lower initial capital cost is due to the as-needed replacement. This scenario does have slightly higher capital and O&M costs due to the continued prime operation of the CTGs. The efficiency of the CHP drives utility cost down but the financial benefits are reduced because of the impact of carbon costs.

The financial analysis by Jacobs is based on the following assumptions:

- **Net Present Cost (NPC)** in this report represents the present value of all construction, operations and maintenance (O&M), utility and carbon-related costs for a given scenario over the analysis period, discounted back to 2025 dollar using

the University's discount rate of 4.50%. NPC does not include financing costs such as interest expense or debt repayments, etc.

- **Life-cycle Cost (LCC)** in this report represents the sum of all construction, O&M, utility, and carbon-related costs for a given scenario over the analysis period, expressed in nominal (escalated) dollars. LCC excludes financing costs such as interest expense or debt repayments, etc.

- **Financial Values.** Values throughout this chapter will typically be shown in nominal dollars (2026 dollars plus inflation). Real dollars (2026 dollars) are used to show net present costs. Dollar denominations will be identified per table or figure.

Life-cycle Assumptions

- Analysis assumes a 40-year life-cycle analysis with a start date of 2028
- An annual average of 3% inflation for capital, and O&M costs
- Discount Rate: 4.5%

Capital Costs

The capital cost criterion refers to the first cost to install the equipment or infrastructure. This includes all equipment, piping, supporting accessories and appurtenances, supporting discipline components, and labor. The cost of equipment and installation labor was calculated from sources such as RSMeans Construction Cost Estimate data, equipment manufacturers, and design and construction projects. The cost estimate that is included in the life-cycle cost analysis is developed and used specifically for the evaluation of scenarios and represents an Association for Advancement of Cost Engineering (AACE) Class V cost estimate which is the earliest and least-defined cost estimate, typically used for initial screening and feasibility studies and provides a wide accuracy range **(low side: -20% to -50% and high side: +30% to +100%)**. Based on Jacobs previous experience and engagement, the estimates are expected to fall within the tighter bands of the accuracy range.

At a planning level, there are numerous variables which cannot be fully investigated that can impact capital cost. While contingencies such as the Undeveloped Design Details financial markup are included in the estimate, it is recommended that capital cost estimates are further vetted prior to moving to a detailed design or construction phase. Capital costs have been marked up as per input received from Cornell University. The markups included are listed below:

Capital Cost Mark Ups by Component

- CM Permits & Insurance 3%
- CM General Contractor 8%
- Undeveloped Design Details 15%
- CM Fee 3%
- CM Contingency 5%
- Insurance/Bond 3.5%
- Cornell Internal PM 3.5%
- Design 8%
- Owner's Construction Contingency 15%

Life-cycle Cost Analysis (LCCA) Comparison with Baseline and Business as Usual

For LCCA comparison purposes, the Recommended Scenario is matched against 1) Business as Usual, and 2) Baseline.

Business as Usual assumes the following: we continue operating the Central Energy Plant using combined heat and power, boilers and steam turbine generators for campus electric and heating needs. We continue to burn fossil fuels for this energy and maintain our Regional Greenhouse Gas Initiative (RGGI) compliance strategy by limiting electric export to less than 10% of Cornell's annual electric generation. This operating strategy prevents Cornell's generator from triggering RGGI requirements. While not directly incorporated into the Jacobs engineering analysis of the Business as Usual (BaU) scenario, future changes to RGGI compliance as well as proposed New York Cap & Invest (NYCI) regulations may impact how Cornell operates the Combined Heat and Power Plant. The distribution system remains steam and is gradually converted to hot water distribution through deferred maintenance, aging chilled water assets are replaced in kind, and energy conservation initiatives are kept at current levels. Existing Combined Heat and Power Plant is renewed within the analysis period. New buildings would be required to install their own building specific non-fossil fuel heating systems in order to meet local building energy code.

The Business as Usual scenario has the lowest LCCA but does not satisfy the core criterion of decarbonization. Large spends associated with building and distribution system conversion are avoided. However, steam piping is replaced with hot water distribution over the analysis period as the steam piping reaches end of life. Cornell continues to own and operate the natural gas line which allows for wholesale gas purchasing and keeps utility costs low. Business as usual does not reduce on-site carbon emissions, Cornell's voluntary goals are delayed or abandoned, and the university has maximum exposure to any future "carbon tax". With the proposed CLCPA regulatory restrictions regarding natural gas combustion, a potential risk of continuing business as usual and delaying decarbonization

may result in a future accelerated "decarbonization" compared with the recommended path.

Baseline takes a compliance approach to the CLCPA and is the simplest way to meet the CLCPA 2040 (zero-emissions electricity and Cornell's Combined Heat and Power plant is used for emergency back-up power and heat) and 2050 goals (no fossil fuel combustion for heating and natural gas boilers are retired). Electrode boilers are utilized for heat and **all** electric is purchased from the grid. Our capital costs and campus disruption are lower: with spend limited to electric boilers, electric transformers and renewal of existing assets at the central plant; utility costs dramatically increase as we are now paying retail electric prices. Hot water distribution conversion continues in response to steam pipe failure and in support of building renovation/growth.

The Life-cycle Costs over the 40-year analysis period (2028-2067) is ~ $3 billion. The capital projects are ~ 20% of the spend. Utilities spend is ~ 58% and Operations and Maintenance spend is ~ 9%. The LCCA is based on the Jacobs implementation strategy, which is effectively a 15-year construction window beginning in 2028 and completing in 2043. Schedule sliding will likely result in higher life-cycle costs. The Jacobs analysis does not consider any potential incentives or grants. Implementation and timing of the recommended scenario is highly dependent on sensitivities to the financial analysis including regulations, energy markets, and capital costs.

Table 62: Recommended Scenario vs Alternatives Capital Costs

Buildings & Properties Program	RECOMMENDED SCENARIO (Nominal $M)	BASELINE (Nominal $M)	BUSINESS AS USUAL (Nominal $M)
BUILDING Energy conservation and hot water conversion	169	192	192
DISTRIBUTION Hot Water conversion	216	258	258
PRODUCTION assets and electrical Infrastructure	621	334	387
RENEWAL	1	110	110
TOTAL	**$1,007**	**$894**	**$947**

Table 63: Recommended Scenario vs Alternatives Executive Summary

Scenario		Recommended Scenario	Baseline	Business as Usual[1]
Description		Hot water distribution with shallow geothermal and demand reduction	Steam distribution with electrode boilers	Combined heat and power in perpetuity
40 Year Cumulative Cost (Nominal $)	Capital	$1,007 M	$894 M	$947 M
	O&M	$264 M	$383 M	$527 M
	Utility	$2,164 M	$3,014 M	$1,230 M
	Carbon Cost [3]	$87 M	$113 M	$461 M
	Total	**$3,522 M**	**$4,404 M**	**$3,165 M**
40 Year Net Present Cost (2025 $)	Capital Only	$603 M	$339 M	$328 M
	Total [2,3]	**$1,450 M**	**$1,411 M**	**$1,090 M**
Peak Campus Electrical Load (MW)		67	105	40
40 Year Cumulative GHG Emissions (MTCO2e) [4]		2,170,000	2,485,000	5,700,000

(1) Not compliant with CLCPA regulations
(2) Represents construction, operations and maintenance, utility and carbon-related costs 2028-2067, discounted to 2025 using rate of 4.50%. Does not include financing costs or grants and incentives.
(3) New York Cap & Invest carbon cost assumptions are informed by NYSERDA cost projections.
(4) GHG Emissions are cumulative over the 40-year analysis period (2028-2067) and assumes a 70% reduction in grid emissions by 2035 and zero-emissions electric grid by 2043. Includes both Scope 1 emissions from onsite combustion and Scope 2 emissions from grid power generation

Key Points

- The Recommended Scenario relies on lowering campus energy consumption and using efficient geothermal heating solutions to lower costs and emissions.
- Business as Usual is not a zero-cost option and does not comply with CLCPA. During the analysis period, both system renewal and expansion are necessary.
- The Recommended Scenario is the lowest operation and maintenance cost (O&M) because of system renewal and highly efficient operations.
- The baseline scenario has 25% higher cumulative costs due to highest electrical demand; although discounting of future costs results in lower Net Present Cost (NPC) than the Recommended Scenario.
- Current and future incentives and grants have not been included in any scenario. The Recommended Scenario is most likely to capture the greatest volume of project related state and federal funds.

Emissions Overview

A core evaluation criterion of the quadruple bottom line analysis is the degree by which the Recommended Scenario reduces consequential emissions.

Consequential vs Allocational Emissions

The UR&ET master plan study focuses on **consequential** emissions versus allocational. Consequential emissions quantify the system-wide change in emissions caused by a specific action, decision, or technology shift. Allocational emissions refer to the physical greenhouse gas (GHG) emissions allocated to a specific entity for a standard time period.

Allocational emissions are often those associated with annual accounting. For example, GHG reporting for accounting purposes uses *annual grid emission factors* to calculate the emissions associated with grid purchased electric. These annual emission factors assume that system wide grid dispatch does not vary for added demand. Consequential emissions are looking at the actual consequences from added demand.

The UR&ET master plan study evaluates GHG emissions over the 40-year analysis period (2028-2067) and assumes a 70% reduction in grid emissions by 2035 and zero emissions electric grid by 2043 (i.e. CLCPA goals). Both Scope 1 (on-site combustion) and Scope 2 (purchased electric) emissions are included. The Recommended Scenario emissions are ~2,200,000 Metric ons CO_2e, which are lower than Business As Usual by 3,500,000 Metric Tons CO_2e. From a fossil fuel perspective, 3,500,000 Metric Tons CO_2e is what the current Central Energy Plant would emit over 23 years. The Recommended Scenario is also better than the Baseline Scenario. The Baseline is ~2,500,000 Metric Tons CO_2e which is ~300,000 Metric Tons CO_2e more than the Recommended Scenario.

Table 64: 40-year Cumulative Emissions of Business as Usual compared to Baseline and Recommended Scenario

COMPONENT	BUSINESS AS USUAL	BASELINE	RECOMMENDED
40 YEAR TOTAL GHG EMISSIONS [Metric Tons CO_2e]	5,700,000	2,500,000	2,200,000
DIFFERENCE FROM BUSINESS AS USUAL [Metric Tons CO_2e]		3,200,000 LESS	3,500,000 LESS

The emissions impact of the Recommended scenario depends on the ***unit generators responding to the planned load*** of the power system rather than annual average carbon intensity. The distinction is critical because the suite of generators dispatched to meet the

incremental hourly electricity demand may be different from the annual generation dispatch reflected in system-average emission factors. This concept is the essence of consequential versus allocational emissions.

Grid Response to Cornell's Electrification:

Cornell Energy & Sustainability engaged with the Anderson Lab to answer the following questions:

1) ***What are the consequential grid emissions associated with the Baseline Scenario? (i.e. electrification increases grid usage annually by ~ 450,000 MWh with a specific hourly profile – what is dispatched for each hour)***

2) ***What are the consequential grid emissions associated with the Recommended Scenario? (i.e. electrification increases grid usage annually by ~ 304,000 MWh with a specific hourly profile – what is dispatched for each hour)***

These questions are framed under two future grid configurations (203X and 204X):

- 203X: New York meets CLCPA target goals of 70% renewable energy
- 204X: New York meets CLCPA target goals of a 100% zero-emissions grid without a known "dispatchable emissions free resource" (DEFR)

The answers to these questions are summarized as follows:

Results show that while average emission factors decline substantially with grid decarbonization, hourly incremental emissions decrease only modestly and remain strongly influenced by residual thermal generation, transmission constraints, and chronological storage operation. This divergence indicates that **average emission metrics can misrepresent** the operational emissions consequences of new electrification loads, whereas **incremental emissions provide a more accurate representation of system response under realistic constraints.**

1) Baseline Scenario: Under the 70% Renewable NY Grid configuration ("203X"), incremental emissions are higher due to greater reliance on thermal generation. The Baseline Scenario results in approximately 0.15–0.16 million Metric Tons CO_2/yr (150,000 – 160,000 Metric Tons CO_2). Under the Zero-emissions grid configuration without DEFRs ("204X"), emissions decrease to approximately 0.13–0.14 million Metric Tons CO_2/yr (140,000 – 160,000 Metric Tons CO_2).

2) Recommended Scenario: Under the 70% Renewable NY Grid configuration ("203X"), incremental emissions are approximately 0.10–0.11 million Metric Tons CO_2/yr (100,000 – 110,000 metric tons). Under the Zero-emissions grid configuration ("204X") without DEFRs, incremental emissions are 0.09–0.10 million Metric Tons CO_2/yr (90,000 – 100,000 metric tons), reflecting a cleaner generation mix. However, fossil fuel generators are still operating on the grid to maintain reliable electric service if no Dispatchable Emissions Free Resource (DEFR) is established before the zero-emissions grid milestone.

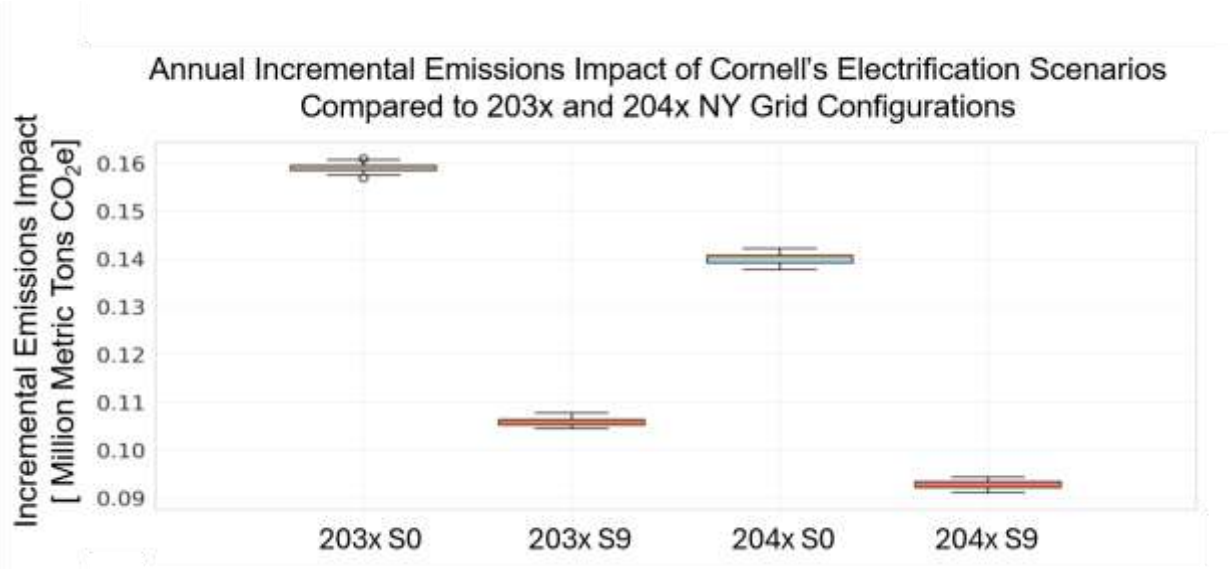


Figure 22: Incremental Emissions Impact from S0_Baseline (abbreviated "S0") and S9_Recommended Scenario ("S9") under CLCPA Milestones compared to 203x and 204x NY Grid Configurations.

Aligning the Energy Transition

The timing of the shift of Cornell's heating system to electrification is integrally tied to the transition of the NY Grid. A transition where Cornell eliminates on-site fossil fuel consumption when the electric grid is still fossil fuel driven (i.e. natural gas generators increase operation to meet Cornell's planned electric load) is unacceptable. Such an action would shift Scope 1 emissions to Scope 2 emissions and timed poorly would actually increase emissions. The emissions impact study indicates that the timing of heating electrification relative to grid decarbonization is a dominant driver of emissions outcomes, while the scenario selection plays a secondary but consistent role.

Annual GHG emissions associated with the future operation of a grid-powered campus energy system are dependent on the carbon intensity of electricity available for purchase on an hourly basis throughout the year – a factor outside the control of the University. Based on the results of the analysis, it was clear that due to the efficiency of Cornell's existing district energy system (with an annual natural gas GHG footprint of ~0.15 million Metric Tons CO_2),

a measured approach focused on existing system efficiency in the near term can have immediate impacts on emissions reductions which are not reliant on the timing of the grid transition. Aggressive energy reduction through enhanced energy conservation and steam-to-hot water conversions within the current system (S1) would outperform the performance of the baseline scenario (S0) while operating with the 203x grid configuration and make significant progress towards the recommended scenario (S9) implementation plan. These actions reduce on-site energy consumption and thermal losses, boost system efficiency, and prepare Cornell to align the timing of Cornell's heating electrification as the grid becomes greener.

UR&ET Master Plan Study Uncertainties

The term "Recommended Scenario" is used to reflect the flexibility and modularity built into the solution. It is one possible solution, optimized and fully costed out, to use for planning. Part of the master planning process is ensuring that assumptions and risks are revisited at regular intervals so adjustments to the Recommended Scenario can be made. Adjustments may include retail electric rates, campus load changes including building renovations, added cooling and new construction, adjustments to consequential carbon associated with the NY grid capacity fuel mix, and NY CLCPA policy updates, with over 50% of the LCCA cost impact resulting from the anticipated utility rates.

In addition to the timing of the NY grid transition to clean power, there are significant near and long-term uncertainties and nuances that require judicious planning, including regulatory policies, technology markets and costs.



Figure 23: UR&ET Master Plan Study Regulatory and Energy Market Uncertainties

Regulatory Uncertainty

New York is currently developing a "carbon price" mechanism called New York Cap and Invest (i.e. NYCI). NYCI is currently stalled in state government and represents an unknown

cost exposure. Jacobs has applied a carbon cost as a placeholder for NYCI and/or any other carbon cost recovery mechanism. There are also partially approved laws in the legislature which ***could*** impact the long-term ability of the CEP to continue burning fossil fuels; specifically, the NY HEAT Act, which is still in deliberation. A key of the NY HEAT Act is a stipulation prohibiting natural gas combustion as the primary source of heating beyond 2050.

Energy Market Uncertainty

What will energy costs be in 40 years? It's highly variable, especially as thermal generators are aging assets set for retirement, renewables are being added to the grid, and new regulations are being established for large load integration. For this effort, the consulting firm Baringa was engaged to develop estimates for electric pricing over the 40-year analysis period. The estimate included forecasting supply, and delivery charges for both kWh and kW. In addition, the analysis considers the myriads of other tariff charges (i.e. System Benefit, Merchant Function, etc.)

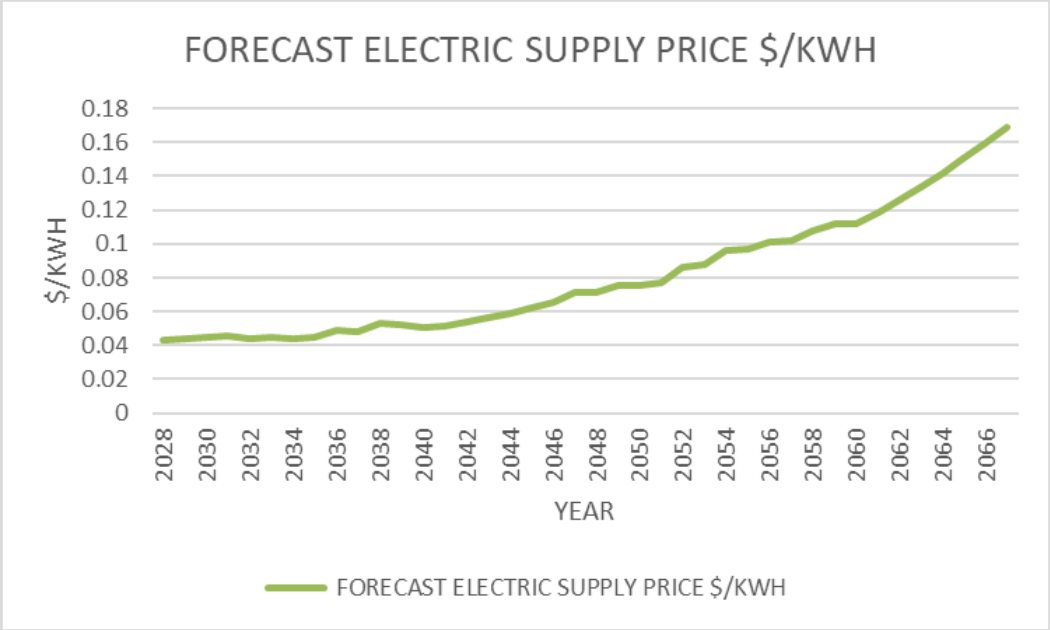


Figure 24: Baringa Forecast Electric Supply Price with 3% Annual Escalation

Capital Cost Uncertainty

Labor and material costs may change, significant unknowns for below-ground properties, drilling methods, markets and capabilities.

Clean Technology Uncertainty

The program is intentionally flexible to incorporate new technologies as they become available and demonstrate advantages over the existing planned technologies.

CHAPTER 11: EDUCATION AND ENGAGEMENT

While the solution and long-term implementation plan are important, the near-term deployment and success of the plan is the most critical element. With this criticality in mind, this section outlines key actions and elements which need to be considered in the near term. Next steps are focused on setting up of the framework of the plan with an aim on integrating the plan within the Cornell and greater community ecosystem as well as taking steps to continue to derisk the path forward.

Advocacy & Integration into Capital Planning

As the projects will require a large capital infusion compared to current operating conditions, the implementation strategy must be integrated into the capital planning across the University. This means ensuring the plan is integrated with capital plans for utilities, Cornell University, SUNY system, and other relevant plans.

In addition to capital plan integration, it is critical that there is strong advocacy for the plan deployment across various stakeholder groups. Plan advocacy helps to ensure that the plan remains a priority from the various funding sources and that as new funding opportunities come about, there is a champion in place working to explore how the funding could be obtained and/or used.

University Design Standards and Guidelines

University Design Standards and Guidelines are intended to be the minimum requirements to which each new construction and renovation project must conform. Based on the recommendations throughout the UR&ET master plan study, several modifications or additions should be made to the University Design Guidelines in partnership with Facilities Engineering to ensure that all projects support the decarbonization plans of the University's utility systems.

Staffing and Procurement Strategies

The construction work outlined over the front end of the analysis period represents a significant effort above and beyond the typical utility projects executed by the University. Additionally, the full set of required projects will result in major work across campus and needing to be completed over a 10 to 15-year period. These unique aspects mean that

Cornell needs to explore potential strategies beyond the standard approach and staffing to ensure efficient, high quality, and timely delivery of the various projects.

Geoexchange Testing

The identified solution leverages various shallow (less than 1,000 ft) geoexchange energy storage systems to store thermal energy and efficiently deliver thermal energy to the campus. During the planning phase, assumptions were made associated with the ground characteristics, but these assumptions must be vetted as the properties could differ from assumption resulting in a cost impact (positively and negatively) on the proposed solution.

Test bores help provide better quantification of the thermal properties as well as allowing understanding of existing risks and what strategies could cost effectively mitigate these risks. The more test bores that can be constructed and tested, the better position Cornell is in. At minimum it is recommended that two (2) test bores be completed and tested.

Community Engagement

Engaging both the Cornell campus community and the surrounding local community is essential for building trust, support, and shared ownership of the energy transition strategy. On-campus engagement should include students, faculty, researchers, and staff, leveraging Cornell's academic strengths to incorporate research, teaching, and experiential learning into the plan. This can help position the campus as a living laboratory while ensuring that operational changes are well understood and supported.

Externally, engagement with local residents, municipalities, and regional stakeholders is particularly important given Cornell's influence in the Ithaca area. Energy infrastructure projects, especially those involving land use, geothermal resources, or new facilities—can raise local concerns. Early and transparent communication, public forums, and partnership opportunities help to address these concerns and identify co-benefits, such as local job creation, improved air quality, and shared opportunities.

Einhorn Center for Community Engagement

Aligning the UR&ET master plan study with the Einhorn Center can bring wide benefit. Building on Cornell's founding DNA as a land-grant institution and the success of existing public service and engagement initiatives across the university, the Einhorn Center for Community Engagement was endowed in 2021. This center creates a permanent hub of community engagement at Cornell – one that supports a university culture where students, faculty, staff and partners work together to create a better world.

"When we really understand each other's point of view, and show up with more curiosity and less certainty, we often discover we share more common ground than we might think. And it's that common ground that is necessary to find solutions to our most intractable problems."
— David M. Einhorn

Figure 25: David Einhorn Center for Engagement Vision Statement

Community-engaged learning at Cornell[19] is just what it sounds like: learning that takes place in and with communities. By combining their diverse expertise and skills, teams of faculty, staff, students and community members address global issues and help build a more sustainable, just and collaborative future. These powerful partnerships – the very heart of community-engaged learning – create opportunities to research, teach and learn at home and around the world.

Policy Advocacy

Cornell must actively engage in shaping state and regional policy frameworks that directly impact project feasibility. This includes advocating for favorable regulatory conditions for geothermal systems, district energy, electrification, and carbon reduction policies, while monitoring evolving requirements under New York's CLCPA and other programs.

Cornell Atkinson Center--Accelerating Energy Transitions[20]

Cornell Atkinson supports research and builds vital connections among researchers, students, staff, and external partners to innovate technology, engage communities, inform policy change, and advance leadership to accelerate the transition to clean energy in a just and equitable way. Specific challenges addressed by the Atkinson Center are also present in the UR&ET master plan study and include renewable fuel sources, smart technologies, demand-response programs, distributed controls, issues of fairness and accessibility, co-optimized systems, and education.

Third Party Endorsement & Engagement

Independent validation from recognized experts, industry groups, or certification bodies can enhance credibility and stakeholder confidence. Third-party reviews approach, and projected outcomes help ensure robustness and transparency.

[19] Einhorn Center for Community Engagement website: https://einhorn.cornell.edu/about/what-is-community-engaged-learning/
[20] Cornell Atkinson website: https://www.atkinson.cornell.edu/research/energytrans/

Engagement with external partners such as peer institutions, utilities, technology providers, financial partners, and research organizations, also brings additional expertise and innovation. These strategic partnerships can accelerate deployment and open opportunities for pilot projects, grants, or co-funded initiatives.

CHAPTER 12: ACKNOWLEDGEMENTS

We would like to acknowledge the NYSERDA Flextech Program which provided external review and cost-share funding for the development of the UR&ET master plan study.

In addition to the UR&ET core team (listed below), the UR&ET master planning study included a multi-disciplinary team of staff, students, faculty, financial and engineering consultants. The UR&ET master plan study incorporated inputs from a variety of experts, layered with peer review for oversight of the process, technical calculations and results, and selection of the Recommended Scenario.

Table 65: UR&ET Core Team Members

Name	Title
Cole Tucker	Associate Vice President, E&S
Stacey Edwards	Utilities Reliability & Energy Transition Program Manager
Sarah Carson	Director CSO
Cheryl Brown	Director Environmental Compliance
Josh LaPenna	Director of Utilities Production
Wayne Bezner Kerr	Utilities Planning and Renewal Project Manager
Kimberly Anderson	Assistant Director CSO
Meredith Rutherford	Sustainability Manager
Jaimee Wilson	Senior Energy and Sustainability Engineer
David Frostclapp	Engineer
David Perrine	Senior Environmental I&C Technician

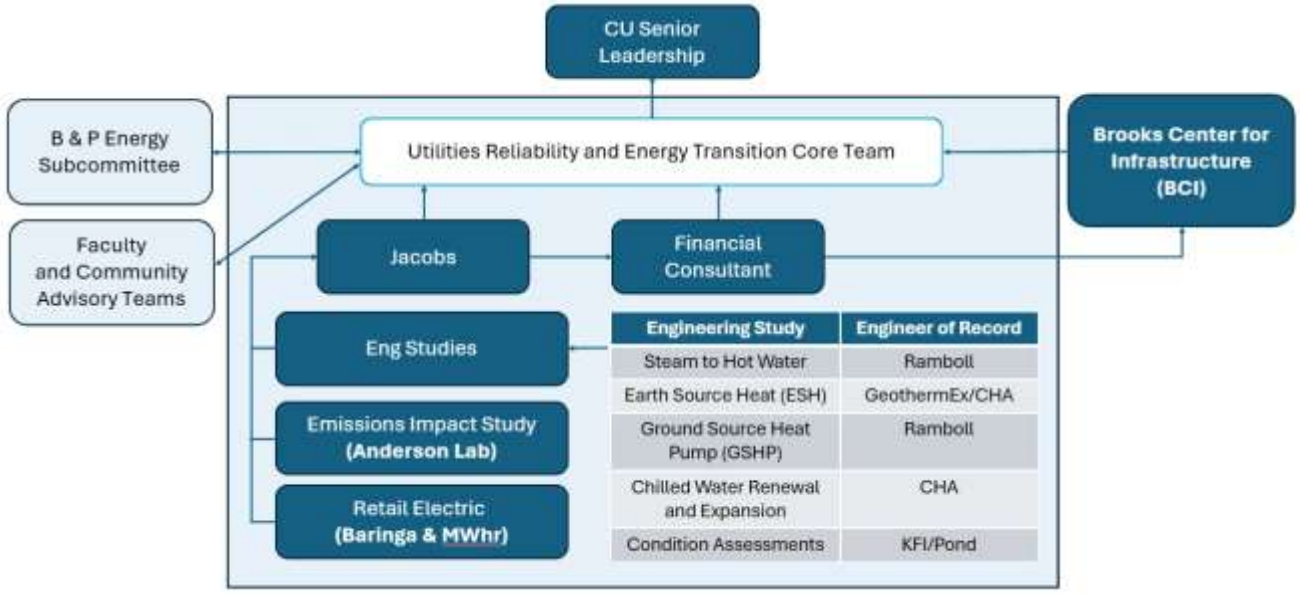


Figure 26: UR&ET Master Planning Study Contributor Flow Diagram

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