Large-Scale Energy System Transformation – From Old School to Clean Energy Campus

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ABSTRACT

Higher education and public sector institutions are in an excellent position to lead the transition from fossil-based energy to a clean energy microgrid. After several years of study, a 150-year old campus is embarking on a once-in-a-generation project that will replace its existing, end-of-life natural gas-powered cogeneration plant and district steam system and transform the campus into a 100 percent electrified and clean energy microgrid that reduces campus greenhouse gas (GHG) emissions by 85 percent. This infrastructure renewal program will include a new electrified heating and cooling plant with integrated geothermal system; distribution of hot/cold water to over 12 million square feet of space in approximately 100 campus buildings; thermal energy storage; distributed energy resources including solar photovoltaics, and battery storage and fuel cells for on-site clean energy generation and critical load backup; and upgrades to the campus electrical infrastructure to support increased power needs. This paper will describe the evaluation of efficiency and supply technologies and their impact on existing infrastructure and buildings. The paper will also discuss the required phasing and specific physical considerations of a conversion to a clean energy microgrid, while improving operational resilience throughout the campus building network. This paper will also provide capital and lifecycle costing scenarios for technical, engineering, commodity, operations and maintenance while addressing resilience and demand management solutions, demonstrating a compelling case for the clean energy conversion. Study findings include equipment requirements, plant build-out phasing, building operation and efficiency improvements, land-use, security, building and advanced microgrid controls, energy storage, large equipment efficiency measures and best-fit renewable technologies.

Introduction

As part of the “Clean Energy Campus” initiative, the University of California, Berkeley (Berkeley) campus proposes to replace its existing, 37-year-old fossil fuel cogeneration plant and steam system and transform the Berkeley campus into a 100 percent electrified and clean energy microgrid that reduces campus GHG emissions by 85 percent. The goal is to have significant portions of the new system operational by 2028 and be substantially complete by 2031. In addition to addressing campus GHG emissions, the project enables the campus to address substantial restoration and renewal needs across its energy infrastructure.

In 2015 the campus initiated a study to determine how to position its utilities infrastructure to serve existing and future needs and to reduce campus greenhouse gas emissions. Through these analyses, the campus determined that replacing the existing cogeneration plant and steam system with a new, centralized electrified heating and cooling plant (EHCP) providing heating and cooling to the campus through new hot and chilled water distribution piping was the optimal solution. The studies also identified a set of new on-site distributed energy resources (DERs) that would provide efficiency and energy resilience for critical loads.

Background

Berkeley is the flagship institution of the ten research universities that comprise the University of California system. Founded in 1868, Berkeley has over 40,000 undergraduate and graduate students on its main campus and more than 10,000 employees. The core campus is 176 acres, consists of approximately 100 buildings with a range of ages, sizes and purposes totaling about 11 million square feet of occupied space. The current campus energy system is a mix of power and steam generated by a 37-year-old natural gas cogeneration plant and utility provided electricity. This system serves the core campus as well as some of the housing and dining facilities adjacent to the campus, some of the athletic facilities and the buildings on the Hill Campus above. The utility power is provided by Pacific Gas & Electric (PG&E) which also provides natural gas. Water and sewer are provided by the East Bay Municipal Utility District (EBMUD). The Berkeley campus manages and provides several of its own utilities. The campus works with a third-party operator for the cogeneration plant and directly maintains and supports all other utilities, including underground steam and high voltage lines, seven switch stations, and a 12KV substation on the Hill Campus. When the campus needs more power than can be provided by this plant, power is drawn from PG&E through a campus-owned substation.

In 2013, the University of California (UC) announced its Carbon Neutrality Initiative, under which all UC campuses are required to eliminate greenhouse gas emissions from their buildings and vehicle fleets by 2025.

Three studies completed in 2015, 2019, and 2020 assessed a total of 33 different system configurations to upgrade or replace the cogeneration plant. An Integrated Resource & Activation Plan (IRAP) was a year-long process completed in late 2023 moving the campus from high-level discovery to the design and construction of a decarbonized energy system for the campus. The plan includes financial and energy system studies, deep stakeholder and expert consultation, and results in a technical, legal, policy, living-lab, and financing blueprint.

Current System

The campus currently receives heat from a 70-plus-year-old steam system in the form of high-pressure steam. This central plant also contains three auxiliary steam boilers that are owned by Berkeley but operated by a third party. The 37-year-old cogeneration and boiler system are fueled by natural gas and sees significant distribution losses (on the order of 20% water losses and 37% thermal energy losses). Ongoing repairs are difficult due to a low maintenance budget and poor manhole conditions. The energy and resource inefficiency of the system also results in a high GHG emission intensity compared to modern day natural gas district systems. The system is responsible for 90% of Berkeley's Scope 1 GHG emissions. Significant deferred maintenance must be addressed, including replacing major plant equipment and seismic upgrade to the plant building. The auxiliary boilers are not in compliance with air quality standards and can only be run 10% of the year. The system is also unable to meet current campus needs. During peak conditions, excess electricity must be purchased from PG&E at a high utility rate. This issue will be exacerbated as the campus grows and comfort cooling is expanded. Thermal utilities on campus are centralized steam and distributed (building by building) chilled water. Campus buildings currently receive all heating from the cogeneration plant.

Not all buildings on campus are provided with cooling, typically only academic, research and lab buildings are provided with decentralized cooling systems. Where provided, cooling is by one of, or a combination of 1) Absorption chillers (served with campus steam) and cooling towers, 2) Water-cooled chillers and cooling towers, and 3) Air cooled chillers.

The central plant provides power to the campus as a by-product of steam generation. The current high voltage electric system is comprised of seven switching stations on the central campus which distribute power through a double loop arrangement. The system provides redundancy through dual feeds to the campus and campus buildings (Figure 1).

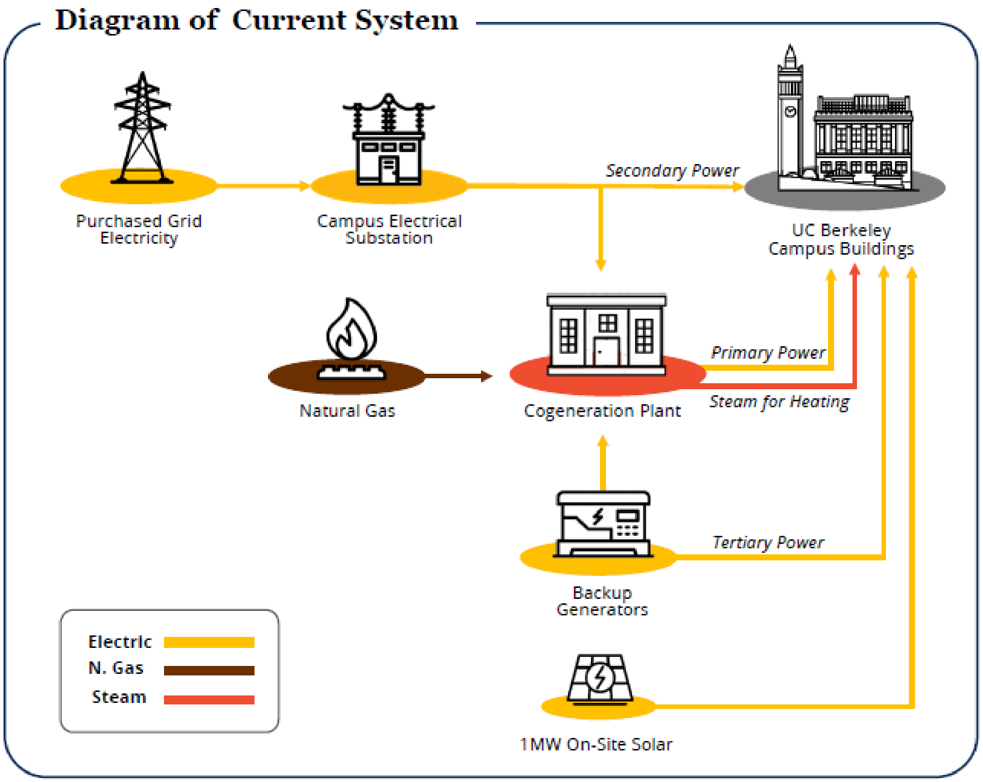


Figure 1. Diagram of Berkeley's Current Energy System.

Initial Studies

Berkeley commissioned several studies between 2015 and 2020, each one building upon the findings, analysis and technical advancements from the previous one. As a result of the 2019 assessment, core options were derived from the systems recommended for further study in the 2015 analysis, as well as low-carbon technologies like heat pumps that had since become more feasible. They also accounted for future expansion of comfort cooling to existing buildings throughout the campus. Each core option consisted of different combinations of a menu of systems that provide heating, cooling, and electricity.

- ***Heating*** - heat pumps, electric boilers, gas boilers, or cogeneration. Central or nodal configuration. Hot water or steam distribution.
- ***Cooling*** - electric chillers, heat recovery chillers, packaged units. Central, nodal, or distributed at the individual building level.

- ***Electricity*** - cogeneration or PG&E grid electricity. Central configuration. These systems can follow three configurations:
  - ***Central*** - one system serves the whole campus.
  - ***Nodal*** - campus is divided into four quadrants, each served by its own system.
  - ***Distributed*** - each building has its own system.

The options were considered with and without "enhancements" that improved performance. The enhancements considered for further study included thermal energy storage, battery storage, solar photovoltaics, solar hot water, and carbon capture.

Originally, carbon capture and sequestration were applied only to options that consumed natural gas and all other enhancements were applied only to the all-electric options. As analysis progressed, four items became clear. 1) Carbon capture and sequestration systems were not currently available at the campus equipment scale. 2) Solar photovoltaic (PV) and solar hot water compete for roof space, and solar PV is a superior technology for this application in terms of first cost, usability, integration with wider campus systems, and impact on infrastructure resilience. 3) The all-electric core options exceeded the maximum capacity of the sole substation that served campus electricity (Hill Substation), triggering expensive and disruptive upgrades. 4) Thermal storage presents an excellent opportunity to reduce campus loads, reduce size of mechanical and electrical equipment, reduce electrical rate through peak demand shaving, and increase heat recovery potential.

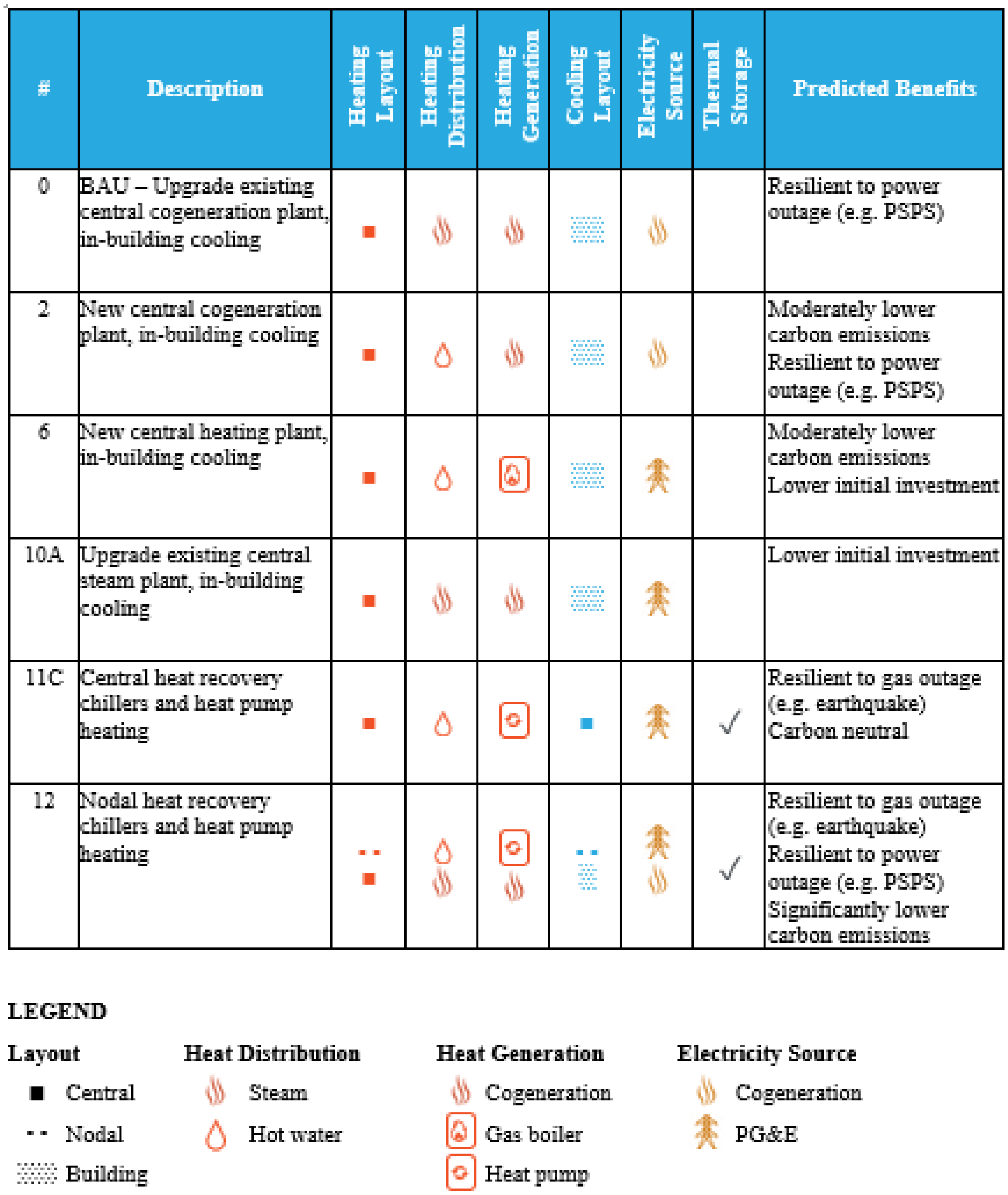
With this information in mind, the approach to enhancements was modified: thermal storage was applied to all electric options and solar PV was added to the options as needed to reduce the peak load below the maximum capacity of the Hill Substation. Three options, with and without enhancements, were carried forward for life cycle cost analysis.

- **Option 0 | business as usual** *Cogeneration and steam distribution*. Lowest capital cost.
- **Options 2 | new cogeneration** *Cogeneration and hot water distribution*. Lowest life cycle cost.
- **Option 11C | central heat recovery** *Electric heat pump and heat recovery chiller plant with thermal storage*. Lowest life cycle cost of carbon neutral options.

Building upon the previous analysis, the 2020 study moved up the construction phasing of the systems and considered financial costs associated with UC requirements of carbon offsets (in addition to regulation), biogas, and clean electricity purchases. This analysis evaluated additional options that could require lower investment than similar options, provide some GHG benefit in the near term, and allow for future decarbonization using technologies that may not be currently feasible. One of the additional options was

- **Option 12 | hybrid nodal heat recovery** *Two heat recovery plants with thermal storage serve the north half of campus only. South half of campus remains on existing system*. A lower cost alternative to Option 11C (central heat recovery) that moves most of the campus load to an efficient, GHG-free, all-electric system but keeps some load on the existing cogeneration plant.

Major characteristics of each option are shown in Figure 2.



#	Description	Heating Layout	Heating Distribution	Heating Generation	Cooling Layout	Electricity Source	Thermal Storage	Predicted Benefits
0	BAU – Upgrade existing central cogeneration plant, in-building cooling	■	♨	♨	░	♨		Resilient to power outage (e.g. PSPS)
2	New central cogeneration plant, in-building cooling	■	💧	♨	░	♨		Moderately lower carbon emissions Resilient to power outage (e.g. PSPS)
6	New central heating plant, in-building cooling	■	💧	🔥	░	⚡		Moderately lower carbon emissions Lower initial investment
10A	Upgrade existing central steam plant, in-building cooling	■	♨	♨	░	⚡		Lower initial investment
11C	Central heat recovery chillers and heat pump heating	■	💧	⟳	■	⚡	✓	Resilient to gas outage (e.g. earthquake) Carbon neutral
12	Nodal heat recovery chillers and heat pump heating	▪ ▪ ■	💧 ♨	⟳ ♨	▪ ▪ ░	⚡ ♨	✓	Resilient to gas outage (e.g. earthquake) Resilient to power outage (e.g. PSPS) Significantly lower carbon emissions

LEGEND

Layout	**Heat Distribution**	**Heat Generation**	**Electricity Source**
■ Central	♨ Steam	♨ Cogeneration	♨ Cogeneration
▪ ▪ Nodal	💧 Hot water	🔥 Gas boiler	⚡ PG&E
░ Building		⟳ Heat pump	

Figure 2. Major characteristics of different options to replace or improve the cogeneration plant.

Integrated Resource and Activation Plan (IRAP)

Between 2021 and 2023, Berkeley engaged Affiliated Engineers, Inc (AEI) to continue to evaluate options and develop an Integrated Resource Activation Plan (IRAP) based on a central heat recovery option (11c). Specific goals for the clean energy plan include: 1) Eliminate fossil fuel use and on-site combustion, 2) Reduce scope 1 and 2 GHG emissions, 3) Renew and upgrade aging infrastructure, 4) Provide a resilient microgrid and on-site renewable energy, 5) Optimize the plan for life-cycle costs, leverage state and federal funding and apply innovative financing, 6) Optimize land use and provide community benefits including research and learning opportunities.

At the heart of the clean energy campus will be a new EHCP. The EHCP will be a state-of-the-art facility accommodating advanced, energy efficient technologies including geothermal heating and cooling, heat recovery chillers, and thermal energy storage. A new campus thermal distribution system will connect the EHCP with existing and new buildings facilitating campus scale heat recovery and decommissioning inefficient and maintenance-intensive steam systems. Distributed Energy Resources (DERs) including energy storage systems, fuel cells and solar photovoltaics will provide clean, resilient power to the campus. DERs and the campus electrical distribution system will constitute a microgrid by definition - a group of interconnected loads and DERs capable of operating in island mode or interconnected with the utility (PG&E).

The project will be phased to allow for effective capital planning while maximizing the long-term benefits of reduced operation and maintenance costs. Phase 1 will convert 75% of campus steam load across 40% of the campus square footage to the new EHCP. Phase 2 will convert the remaining existing campus buildings from steam over to the EHCP. Upon completion of Phase 1 the existing cogeneration facility will be decommissioned and with the new highly efficient EHCP, the campus will see an estimated 70% reduction in scope 1 GHG emissions from fossil fuel combustion (Figure 3).

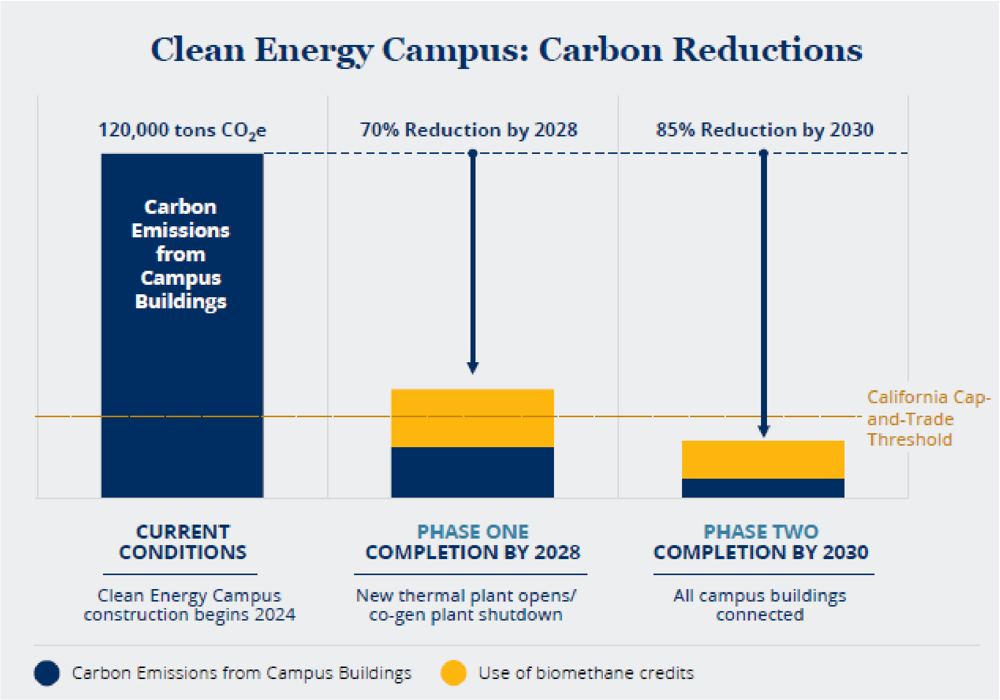


Figure 3. Clean Energy Plan GHG Reductions

The project is split into component parts including 1) EHCP, 2) Piping Distribution, 3) Building Conversions, 4) Existing Cogen, 5) DERs, and 5) Electrical infrastructure (Figure 4).

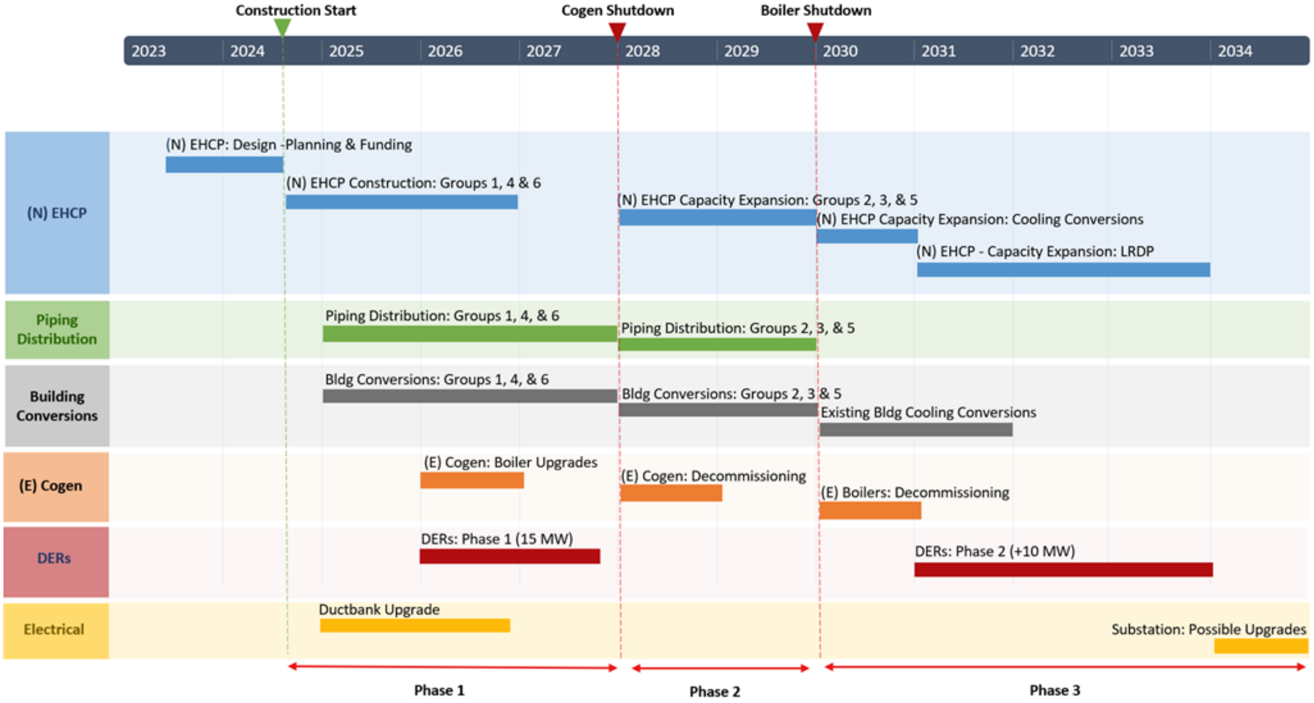


Figure 4. Clean Energy Plan Schedule

Electrified Heating and Cooling Plant (EHCP)

The EHCP will be the new central hub for the generation and distribution of thermal utilities to serve the campus (Figure 5). All equipment will be powered by electricity procured from clean and renewable energy sources. The latest heat recovery technologies will be installed at the plant to generate heating and cooling, supplemented by a geothermal bore-field below the footprint of an existing playfield. The plant will be modular in design, allowing for capacity expansion to facilitate phased conversion and future growth as part of the long-range development plan. Six million gallons of hot and chilled water thermal energy storage (TES) integrated within the footprint of the central plant building will balance supply and demand, optimize efficiency and maximize the ability to reuse waste heat. It is estimated that more than 80% of the annual heating energy, currently provided by steam, can be recovered from existing sources of waste heat across the campus. The roof of the EHCP will be designed to preserve and enhance the existing playfield site with a replacement recreation field while the plant itself will serve as a living lab, providing educational benefits. Creating design standards for new buildings being built on campus so they are compatible with the EHCP is in progress at this time.

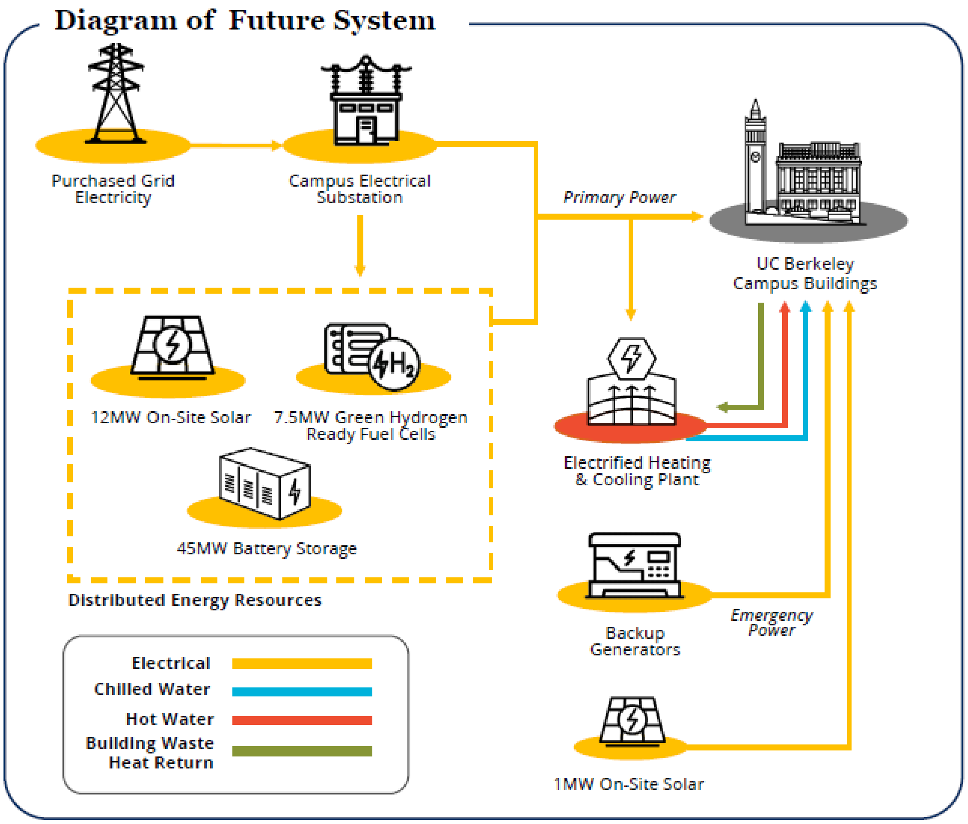


Figure 5. Diagram of Berkeley's Future Energy System

Analysis

Implementation of an all-electric heating and cooling system requires a clear understanding of the annual thermal utility load profile. AEI received building thermal utility trending information and compiled it to form a composite thermal utility load for the campus (Figure 6).

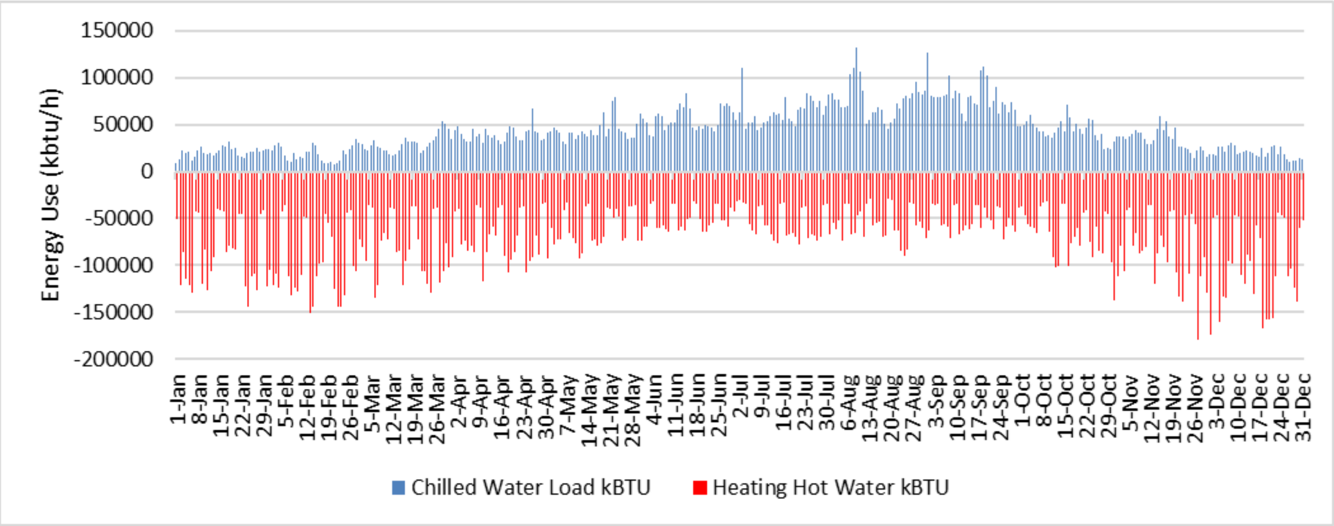


Figure 6. Current Campus Thermal Utility Load Profile

Many buildings on campus do not currently have chilled water cooling. Berkeley requested calculations for future thermal loads include the addition of chilled water cooling in existing buildings that do not currently have cooling. Future load calculations also incorporated Berkeley's Long Range Development Plan (LRDP) to include future additions and renovations on campus (Figure 7.)

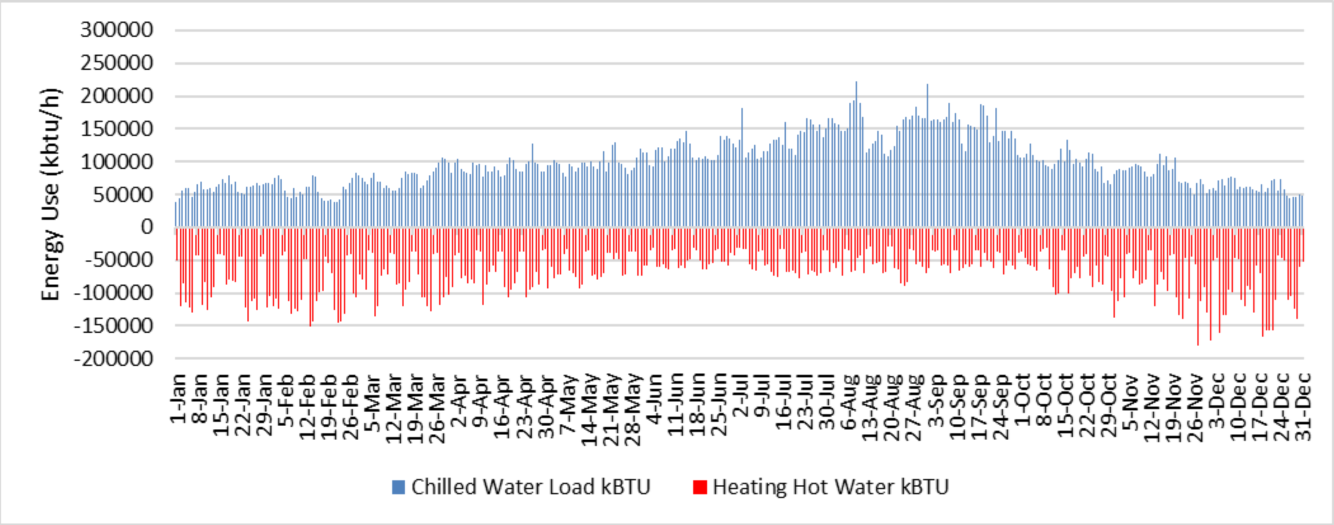


Figure 7. Projected Future Campus Thermal Utility Load Profile

Existing Utilities – Steam

The future load profile serves as a target for the new EHCP and thermal systems therein. Existing thermal utility profiles help to understand how existing systems can be phased out and decommissioned. High pressure steam is currently generated through a heat recovery steam generator (HRSG) and natural gas boilers located at the existing cogeneration and steam boiler plant. Buildings that are transitioned to the new EHCP will be provided with heating hot water via a new heat pump system located at the EHCP. Switching heat sources to an all-electric heating system will reduce the steam demand on the cogeneration system throughout the phased implementation. Reducing the steam demand on the existing cogeneration plant will provide operational challenges. It is recommended that the cogeneration plant be shut-down and decommissioned as soon as the first group of buildings (Phase 1) are transitioned off steam and on to the new EHCP. Remaining steam demand will be provided by existing boilers in the existing plant. Once all the buildings on campus have been converted from steam to heating hot water, the existing boilers in the Cogeneration Building can be decommissioned.

Existing Utilities – Chilled Water

The Berkeley campus currently has approximately 53 water-cooled chillers distributed around campus, with capacities ranging from 25 to 1,400 tons, serving process and comfort cooling loads. This equipment still has useful service life remaining, the extent to which should be determined through an existing condition survey. To maximize use of existing assets and to prolong the need to add central cooling towers for heat rejection, the project will incorporate existing distributed equipment from several buildings which have/will have sizeable chiller plant installations (>500 tons) with remaining useful life. The existing water-cooled chillers (and associated cooling towers) will integrate with the new campus chilled water distribution, operating as satellite peaking-plants. Base load chilled water will be provided by the heat recovery chillers at the EHCP. The cost to integrate this existing equipment into a new chilled water distribution is less than the cost of new water-cooled chillers in the EHCP. Once the existing equipment has reached the end of its useful service life, it should be replaced with new equipment in the EHCP.

New Utilities – EHCP

The recommended primary method for heating water at the EHCP is through the use of water-to-water heat pumps. These heat pumps simultaneously heat and chill water for the campus to use. Any supplemental heating required can be supplied by an electric boiler. Supplemental cooling required can be supplied by a conventional water-cooled chiller. Because heat pumps generate heating and cooling simultaneously, proper equipment operation depends on a correct ratio of load to always exist. Incorporating TES in the EHCP will allow for stable, steady operation of the heat pumps while capturing any excess heat in the system during periods of low demand and storing it for periods of higher demand. Figure 8 shows how heat pumps used in conjunction with TES operate to meet the winter heating and cooling loads without the need for a supplemental boiler.

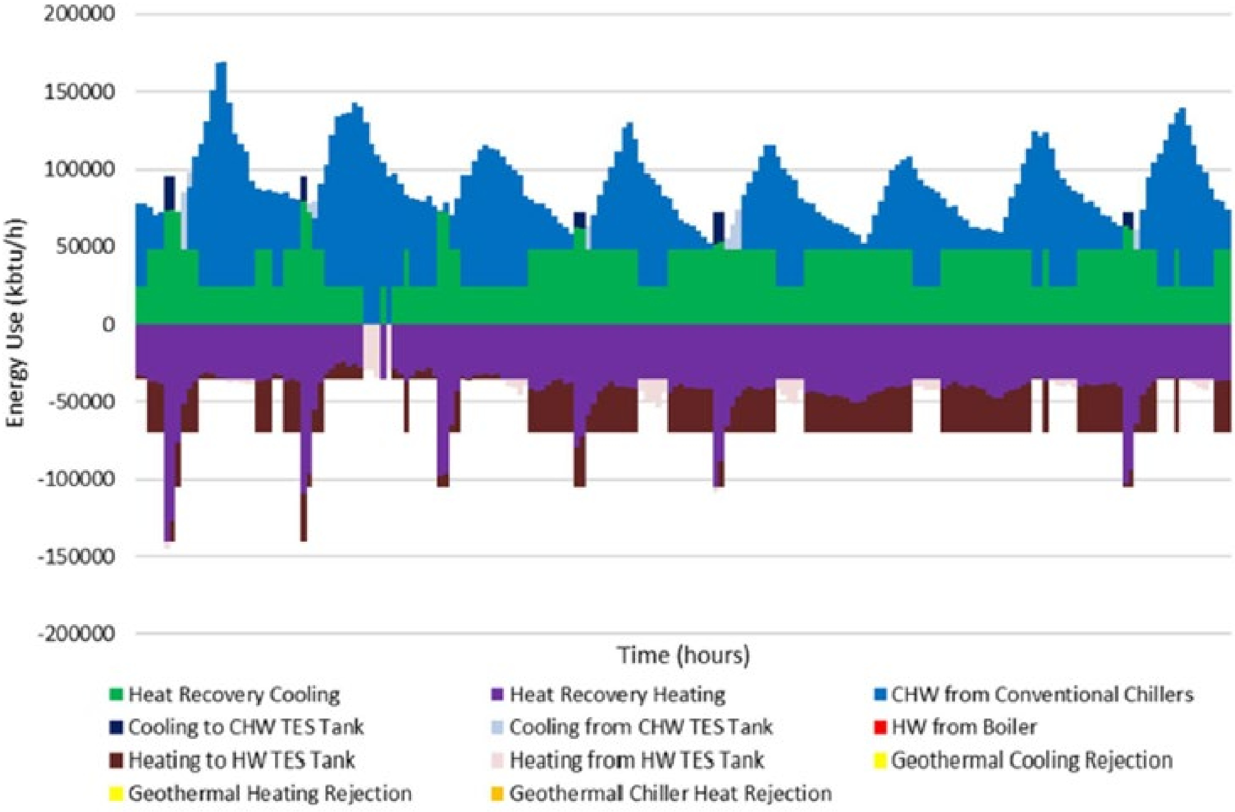


Figure 8. Typical Winter Week of Thermal Utility Dispatch

In the summer, due to a reduced heating demand, a different operational strategy can be implemented to reduce energy cost. Figure 9 shows heat pumps operating for 5 hours each day to charge the heating hot water TES tank. Once the tank is charged, the heat pumps turn off and the heating load is satisfied through TES tank discharge. During the hot water TES tank charge, conventional chillers are used to charge the chilled water TES tank. The chilled water TES tank is allowed to discharge during PG&E on-peak hours to minimize electricity cost.

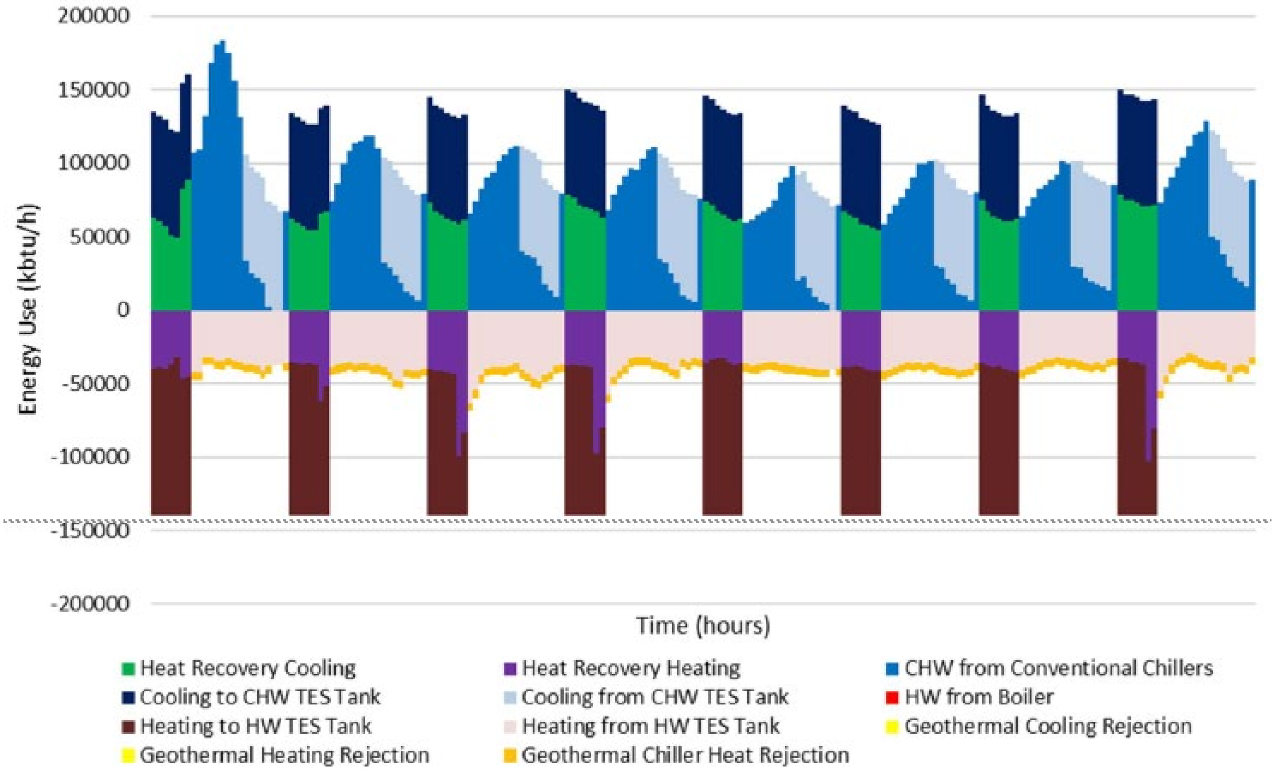


Figure 9. Typical Summer Week of Thermal Utility Dispatch

When existing water-cooled chillers reach their end of useful service life, or additional chilled water load is added to the system, new water-cooled chillers should be installed at or near the new EHCP. This allows for centralized pumping, access to the chilled water TES tank, and common location for equipment maintenance. Water-cooled chillers require supplemental heat rejection to operate. AEI recommends the use of evaporative cooling towers for chiller heat rejection.

Geothermal Heating and Cooling

A closed loop vertical borehole geothermal heating and cooling system will serve as a supplemental heat source and heat sink with direct integration with the EHCP thermal equipment. The proposed solution will utilize the footprint below the EHCP to accommodate approximately 150 (400 ft deep) bore-holes. The UCB Soga Research Group analyzed a 400-foot borehole on campus and determined that the underground thermal properties are well suited for implementing a geothermal system on campus. A thermal response test at a campus site indicated an average thermal conductivity of 1.365 Btu/hr-ft°F. Using this information in conjunction with a desktop study performed by ENGEO, indicating similar geotechnical conditions at the proposed site, AEI assessed the available capacity and determined that the proposed geothermal system will contribute to approximately 6% of the annual heating requirements during Phase 1 of the project. Additionally, in conjunction with the thermal energy storage tanks, the geothermal system will help significantly reduce the peak electrical demand for the EHCP. During the cooling season, the geothermal system will return heat to the ground, reducing water consumption associated with cooling towers and helping restore the heat balance in the ground, effectively acting as a seasonal thermal store.

Piping Distribution and Building Conversions

The campus distribution and building conversions scope is divided into groups of buildings that consider 1) Mix of academic/non-academic buildings, 2) Buildings with existing steam cooling, 3) Proximity to EHCP, 4) Alignment with existing steam infrastructure mains.

Three building groups collectively represent 75% of the campus steam load and have significant repair and maintenance costs. These groups also have the largest cooling loads and associated equipment which can be used to defer equipment at the EHCP. For these reasons, Groups 1, 4 and 6 are preferred for Phase 1 conversions (Figure 10). Building conversions scope will align with the phasing of the piping distribution and will include:

- Steam to hot water conversions and transition to campus heating hot water distribution.
- Transition of process steam loads to building electric steam generators.
- Conversion and transition of distributed cooling systems to campus chilled water distribution.
- Provision of chilled water to existing buildings without cooling for future cooling additions.

Figure 10. New central plant (yellow) and Groups 1 (maroon), 4 (dark & light green), and 6 (bright green)

The maximum HHW temperature available from the EHCP will be 170°F and 165°F on the building side of the heat exchangers (HX). There are a number of buildings operating at temperatures higher than 165°F today. Berkeley conducts an annual winter curtailment where the heating hot water supply temperature is reset in a group of buildings. In the winter of 2022-2023 these setback temperatures were maintained after the winter curtailment period. The buildings were monitored for performance in occupied conditions with the lower heating hot water supply temperatures. For the most part these 36 buildings were reset from 180°F to 160°F, and in some instances to as low as 140°F. This program showed that the majority of the buildings successfully handled the lower heating hot water (HHW) supply temperature without cold complaints from the occupants. The return water temperatures of both chilled water (CHW) and HHW are keys to the performance of the EHCP. In many of the buildings during the site surveys, AEI observed that the “delta-T” (temperature difference between the supply & return temperatures) needed improvement. This will require ongoing focus as the design progresses and changing 3-way valve, constant volume systems into 2-way valve variable volume systems, and eliminating by-pass of the thermal coils of water from the supply side to the return side.

Distributed Energy Resources (DERs) and Campus Electrical Upgrades

Campus electrical distribution upgrades are required to support the new EHCP, DERs and future projected growth as part of the LRDP. DERs will provide on-site, clean, resilient power generation to replace the existing cogeneration plant. Phase 1 proposes 15 MW of generation capacity to serve campus critical loads for a duration of (5) days with the following technologies:

- 8 MW of fuel cell installed in the vicinity of the existing cogeneration plant. Energy sources include biomethane (short-term) and green hydrogen (long-term).
- 10-12 MW of solar photovoltaic installed across several sites on Hill Campus and main campus.
- 45 MWH of energy storage systems (pumped hydro and / or batteries) up a nearby canyon.

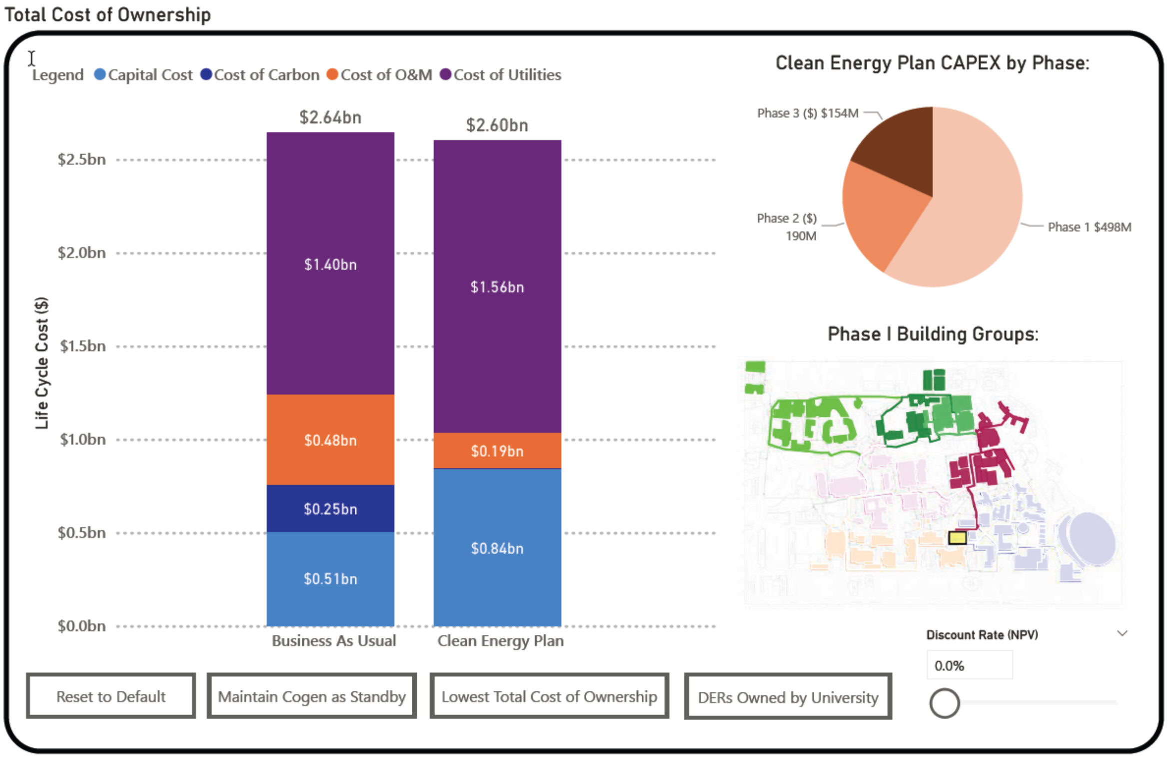
Using an optimization tool and evaluating other qualitative benefits, AEI determined a preferred approach combining a mix of technologies which includes hydrogen future-ready fuel cells, solar photovoltaics (PV) and battery energy storage (BESS). Fuel cells will run continuously and provide baseload power to the campus. Transitional biomethane Renewable Energy Certificates (RECs) will provide a net-zero carbon fuel source for the fuel cells for an interim period. During a power outage, battery energy storage will buffer the generation from PV and fuel cells. Pumped hydro storage is also considered as an alternative/supplemental to battery energy storage. Fuel cells will initially be supplied with natural gas offset by biomethane procured by the university with the longer-term goal of transitioning to green hydrogen or replacing the fuel cells with future energy storage technologies that have a higher energy density and are more cost effective than current technologies.

Energy and Carbon Analysis

A Clean Energy Plan model integrated the analyses performed for the EHCP, building conversions, mechanical distribution, electrical distribution, and DERs. Included in the analysis were the following life cycle costs: 1) Campus utility cost (electricity, natural/biogas and water), 2) Operation and Maintenance (O&M) costs, 3) GHG emissions costs (regulatory, voluntary, and social costs), 4) Capital Expenditure costs (including deferred maintenance and avoided costs).

With each of these analyses the results were compared against the Business-as-Usual (BAU) case, which was defined as the campus remaining on the existing Cogen and steam distribution system and making the repairs to the system for it to remain operational. The analysis was based on a phasing strategy including Phase 1 (2025-2028), Phase 2 (2028-2032), and Phase 3 (2030-2040): LRDP.

The total cost of ownership over a 25-year (2025-2045) life cycle resulted in a cost of $2.6 Billion for the new Clean Energy Plan compared to the cost of $2.64 Billion for the BAU case (excluding social cost of carbon). Figure 11 illustrates the breakdown of the Total Cost of Ownership and the summary of capital expenditure for each of the three phases of implementation of the clean energy plan. The inclusion of social cost of carbon increases the cost of the BAU case to $3.27 Billion.



Discount Rate (NPV) 0.0%

Figure 11. Total Cost of Ownership between BAU and Clean Energy Plan over 25 years

After the annual energy consumption and the sources from which the energy is coming from were calculated, annual utility costs were analyzed. The life cycle utility costs for the clean energy plan as modeled resulted in $1,559M compared to $1,405M for Business-As-Usual (Figure 12). Utility costs used for the model are based on near term market data and projected longer term increases and assume that the University will purchase 100% renewable energy from 2025 onwards.

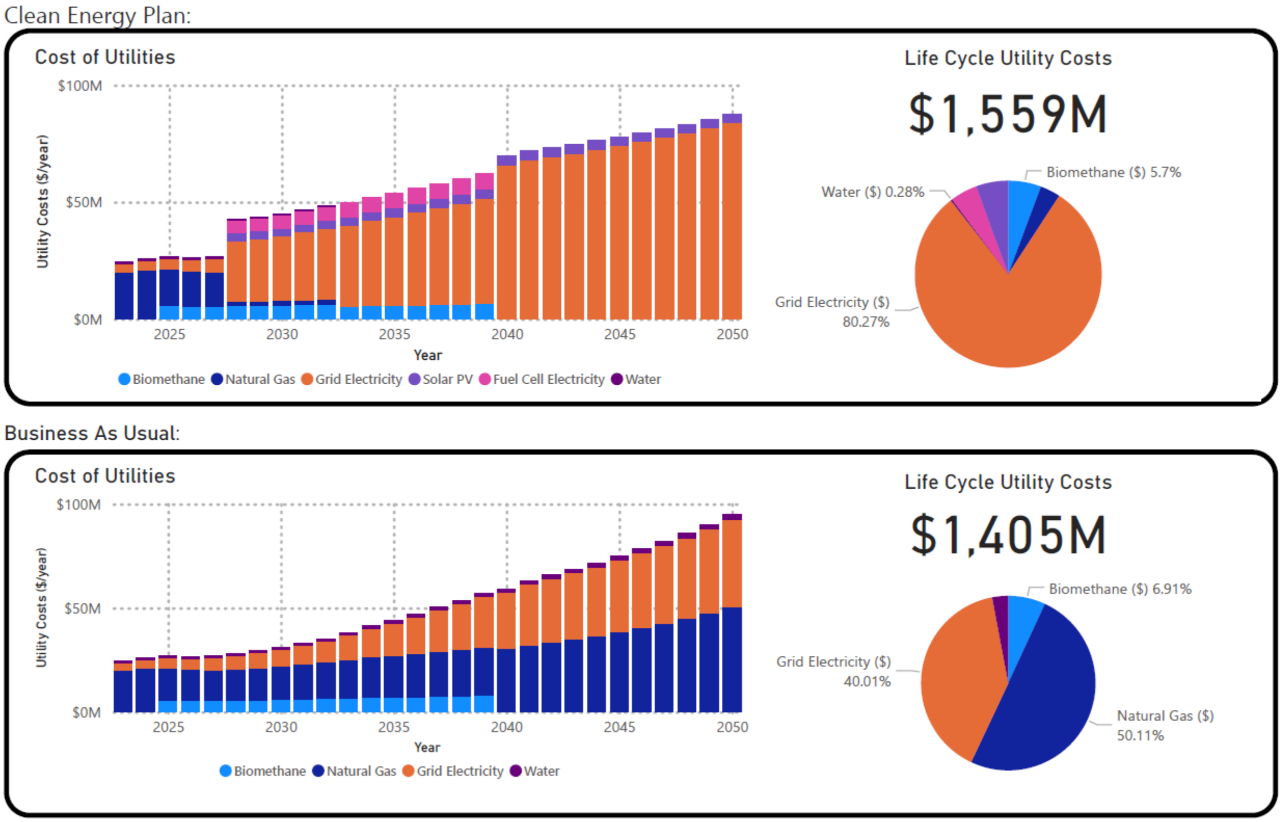


Figure 12. Total Cost of Utilities between Clean Energy Plan and BAU over 25 years

A crucial part of the total analysis was determining when the campus would be able to achieve its GHG reduction goals, which was influenced by the phased implementation of the project. The AEI team determined a timeline that would have the greatest impact in the first phase by 2028, when the existing Cogen plant could be taken offline, and meet significant GHG reduction by 2030 after phases 1 and 2 of the project were implemented. Figure 13 indicates the projected GHG emissions for the main campus for the clean energy plan (326,000 tCO2e) and BAU case (2.5 million tCO2e). A significant reduction in GHG emissions is realized just through implementation of Phase 1 conversions and the subsequent decommissioning of the cogen plant coupled with the University's purchase of renewable energy and transitional biomethane RECs. Figure 14 indicates the projected cost of GHG emissions for the clean energy plan ($96 million) and BAU case ($1.156 Billion) including voluntary and social costs of carbon.

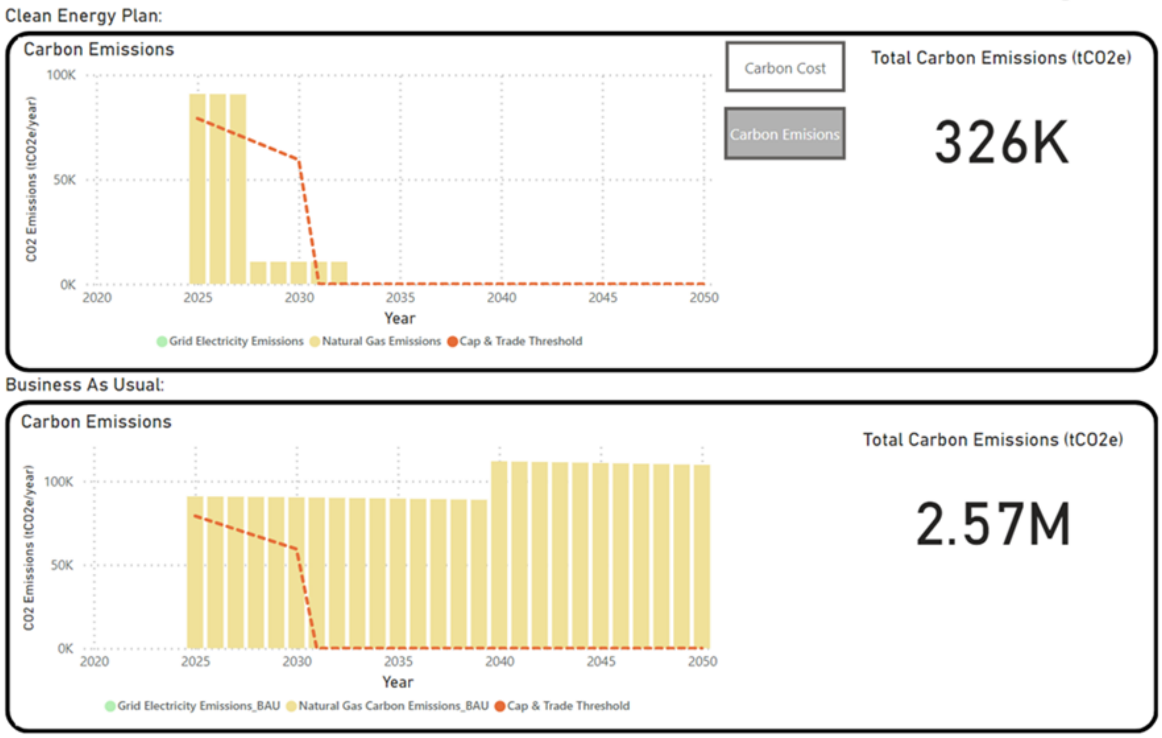


Figure 13. GHG Emissions between Clean Energy Plan and BAU

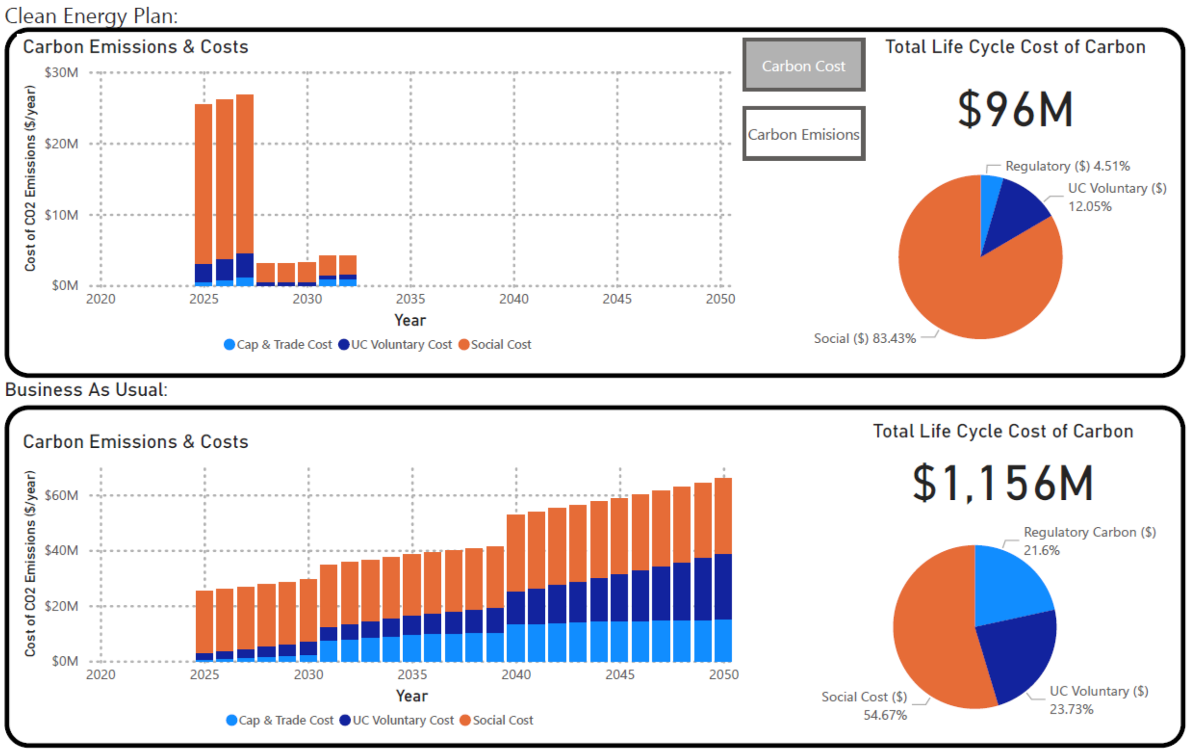
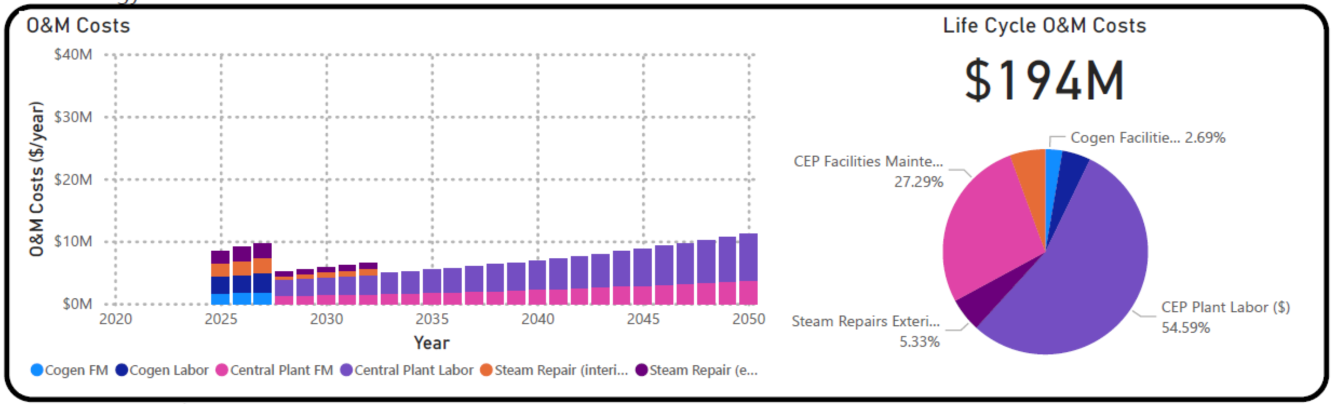


Figure 14. Cost of GHG Emissions between Clean Energy Plan and BAU

The total 25-year O&M costs for the clean energy plan resulted in $194M compared to $483M for BAU, demonstrating the high ongoing maintenance and repair costs associated with the aging steam infrastructure (Figure 15).

Clean Energy Plan:



Business as Usual:

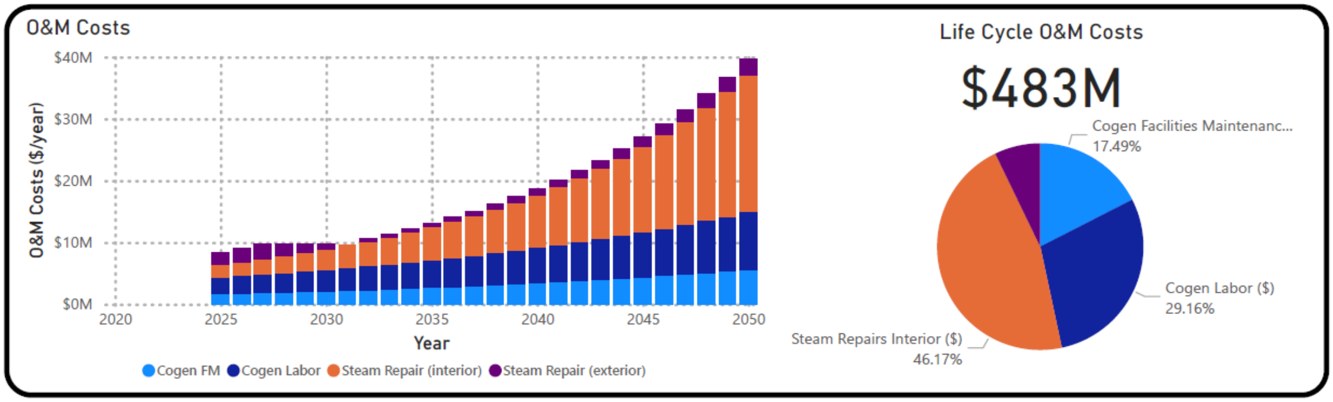


Figure 15. Annual Operations & Maintenance Costs between Clean Energy Plan and BAU (25 years)

Conclusions

The Berkeley Clean Energy Campus initiative consolidates the recommendations of several studies to align the capital, restoration, and renewal requirements of the campus energy system with other campus goals. The approach achieves multiple objectives:

- <u>Infrastructure Restoration and Renewal</u>: The initiative provides over $300 million in avoided restoration and renewal costs by replacing failing in-building equipment with new centralized equipment. It will achieve a reduction of over $110 million in operating expenses over the system's life through improved reliability and avoided costs of carbon. The proposed DERs will provide sufficient power and backup capacity to support campus critical loads, such as life safety provisions and research protection during an extended outage.
- <u>Sustainability and GHG Reduction</u>: The initiative achieves an approximately 70 percent reduction in GHG emissions when the existing cogeneration plant is decommissioned, and the initial set of the most energy-intensive buildings are connected to the new EHCP;

this, along with future biomethane supplies will move the campus below the regulated threshold of California's Cap and Trade program. The new system would provide an 85 percent reduction in building-related energy GHG emissions at full build-out.

- Planning for Future Campus Resilience and Growth: The initiative creates a reliable and resilient utility system with a sufficient electrical and thermal capacity to support future campus operations, enrollment, and new development consistent with the Berkeley LRDP.

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