Berkeley
UNIVERSITY OF CALIFORNIA

UC Berkeley Clean Energy Campus

Integrated Resource & Activation Plan

May 2024

Prepared by the Administration Division's Facilities Services
Department and the Office of Sustainability & Carbon Solutions

The UC Berkeley Clean Energy Campus

UC Berkeley is on course to decarbonize its energy system.

This document, the **Integrated Resource & Activation Plan**, provides an overview of why Berkeley is taking action now, the engagements undertaken to identify the clean energy and carbon reductions strategy required and a rapid implementation scheme to realize a full utility infrastructure transformation.

Over the next decade the Berkeley Clean Energy Campus effort includes the design and construction of a set of solutions that will transform Berkeley's current campus heating, cooling, and power system into an electrified and renewable energy microgrid. This 21st century system will largely eliminate fossil fuel combustion and related on-campus carbon emissions. The new system will enable reliable and resilient energy capacity that will support campus operations, research and enrollment into the future.

The Berkeley Clean Energy Campus supports the State of California and the University of California's priority to address the climate crisis and will demonstrate how rapid, large-scale reduction of greenhouse gas emissions is possible. Berkeley's longstanding leadership in climate-solution technology and policy research positions it to pioneer this transition to a benchmark-setting energy system characterized by sustainability and resilience, setting a precedent for public institutions worldwide.

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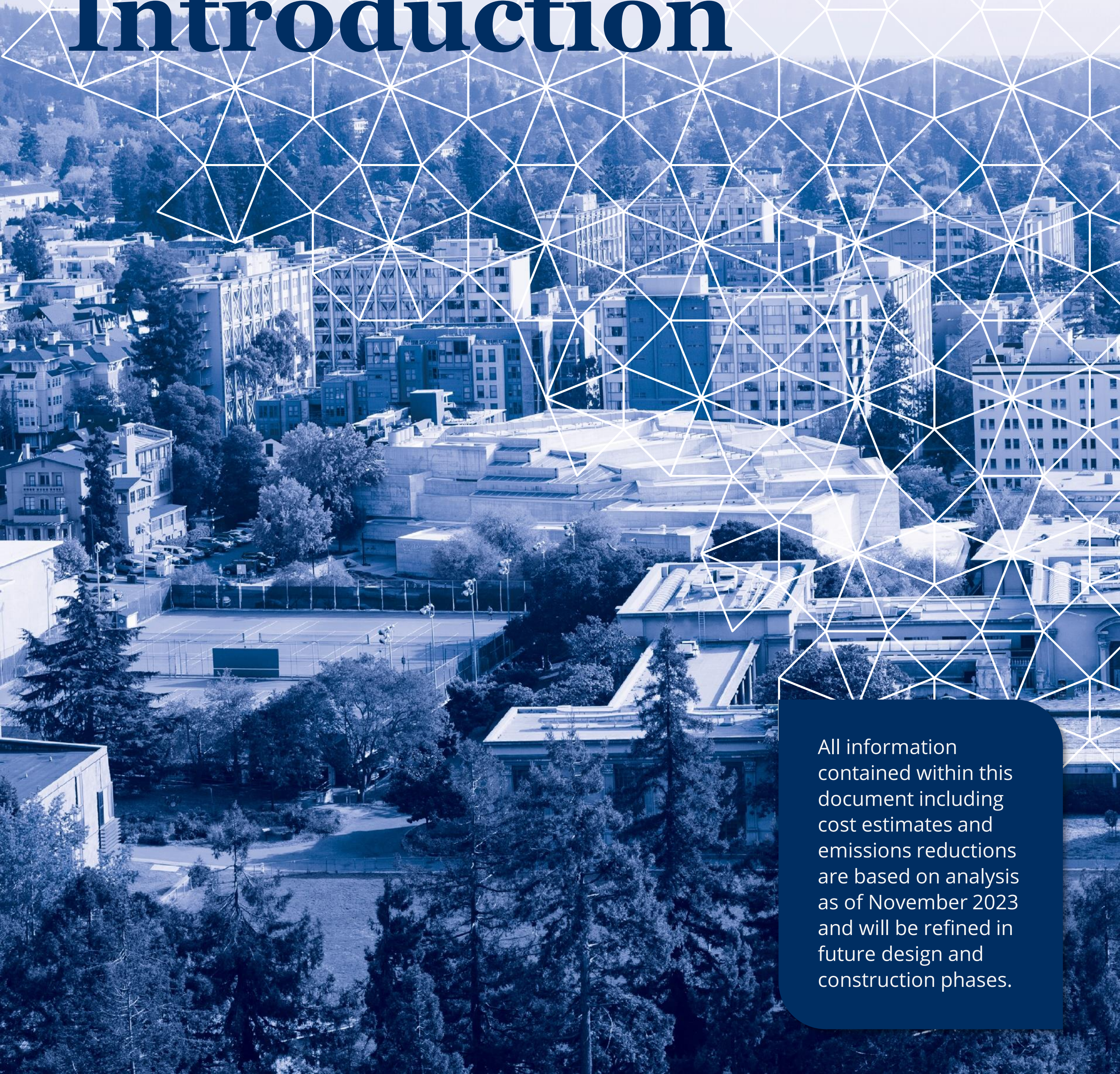


All information contained within this document including cost estimates and emissions reductions are based on analysis as of November 2023 and will be refined in future design and construction phases.

Introduction

The University of California (UC) is fighting climate change and implementing various initiatives and policies with the goal of reducing its carbon emissions by 90 percent before the year 2045.

UC Berkeley has a plan to **reduce its building energy carbon emissions by 85 percent by 2035.** With this reduction in emissions the campus will have achieved an overall operational carbon reduction of 60% or more – well on course to meet the UC 2045 target.

Climate Action Targets

2045

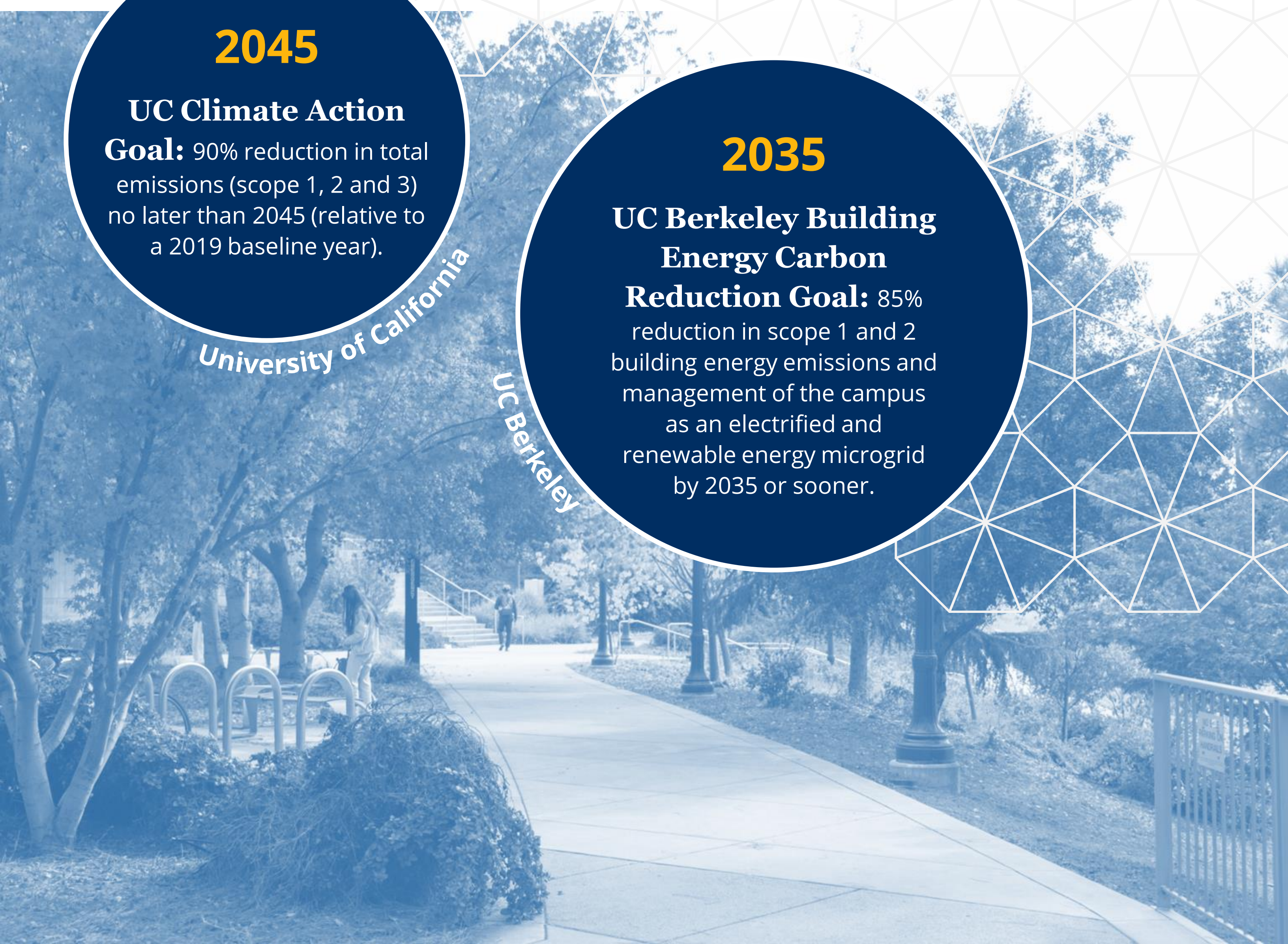
UC Climate Action Goal: 90% reduction in total emissions (scope 1, 2 and 3) no later than 2045 (relative to a 2019 baseline year).

University of California

2035

UC Berkeley Building Energy Carbon Reduction Goal: 85% reduction in scope 1 and 2 building energy emissions and management of the campus as an electrified and renewable energy microgrid by 2035 or sooner.

UC Berkeley



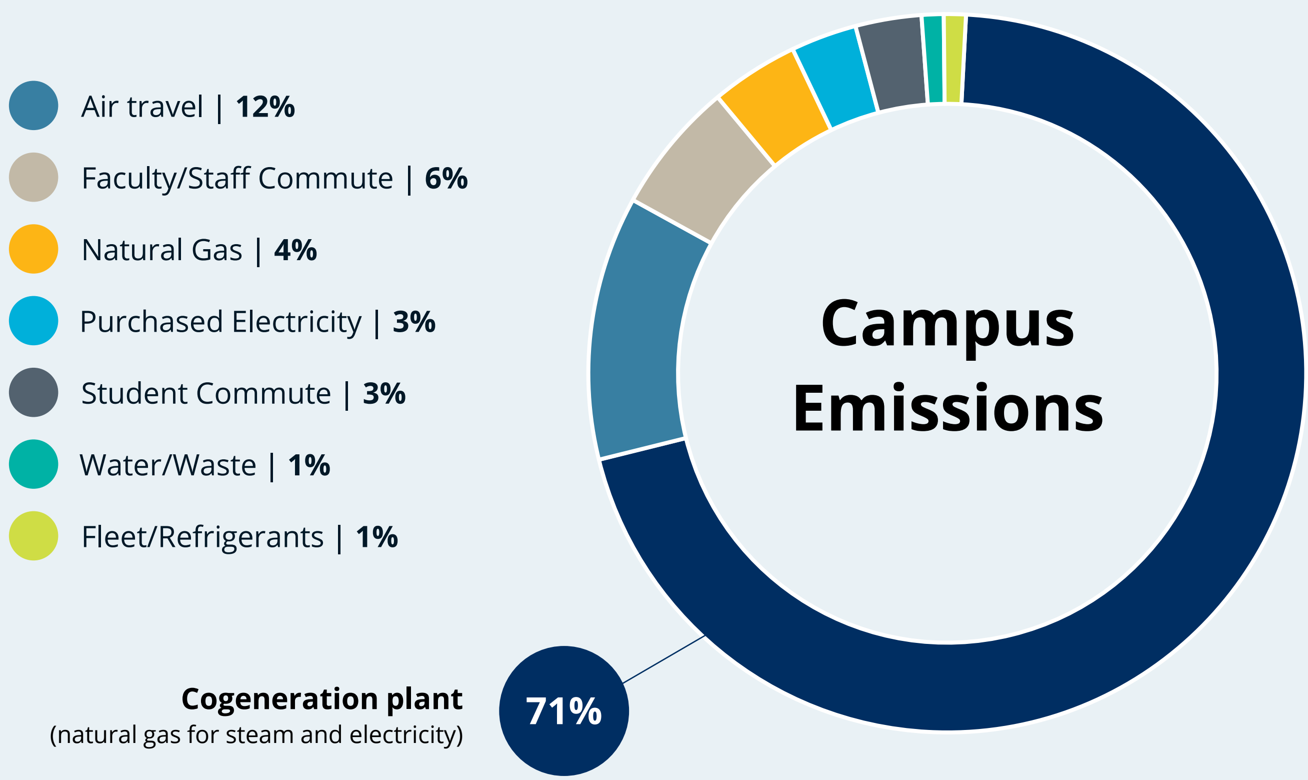
Introduction

Combatting the dire threat of **climate change** means addressing its primary cause—the burning of fossil fuels.

At UC Berkeley, the majority of operational **scope 1, 2, and 3**[1] **greenhouse gas/carbon (GHG) emissions** are associated with building energy consumption. In 2019 the campus emissions were 190,000 metric tons with 71 percent of these emissions coming from the natural gas combusted in the campus **cogeneration plant**. This plant provides most of the main campus electricity and the steam for heating. The plant and steam distribution system to buildings is nearing the end of its lifecycle and replacement with a low carbon solution is imperative to meeting campus needs.

Achieving rapid carbon reduction at UC Berkeley necessitates decisive action and a radical transition from fossil fuels to all-electric solutions supported by clean energy sources. As such the campus is implementing the Berkeley Clean Energy Campus initiative focused on a rapid transformation of the energy system.

UC Berkeley Greenhouse Gas/Carbon Profile Today



[1] Emissions tracked by UC Berkeley include scope 1 (e.g. natural gas combustion on campus), scope 2 (e.g. purchased electricity), and scope 3 (e.g. emissions from commuting and business air travel).

Introduction

Berkeley Clean Energy Campus (BCEC)

The campus has completed numerous studies to determine the most ecologically responsible and financially prudent path forward. The latest, the Integrated Resource and Activation Plan (IRAP), defines the technical, financial, learning and research opportunities for campus decarbonization. Now called the Berkeley Clean Energy Campus (BCEC) initiative, this transformative effort will phase out fossil fuel use for powering, heating and cooling campus buildings by 2035 or sooner. The natural gas-powered cogeneration plant will be decommissioned by 2030 and replaced with a new clean, efficient and resilient energy system that will demonstrate state-of-the-art technologies. It will also exemplify creative financing as a model for other cities and institutions to replicate.

The BCEC Initiative

puts the campus on track to meet its climate reduction goals as well as **provides multifaceted benefits for the campus and beyond, including:**

1

85% Reduction in Carbon Emissions: By replacing the aging and inefficient cogeneration plant with an all-electric system supplied with clean energy, the campus will achieve an 85 percent reduction in building energy GHG emissions while also improving local air quality and contributing to UC Berkeley's environmental commitments.

2

Increase Energy Resilience:
The campus will enhance its ability to operate continuously and support campus growth, even in the face of changing conditions such as extreme heat events, wildfires, and power outages.

3

Millions of Dollars in Long-Term Cost Savings:
The fully realized Berkeley Clean Energy Campus initiative is estimated to save the campus hundreds of millions of dollars. These savings are generated by lower maintenance and operational costs as compared to the existing energy system.

4

Living Lab:
This project will create valuable learning and research opportunities, activating UC Berkeley's brain-trust and fostering collaborative partnerships with government and industry stakeholders.

Introduction

5

Accessibility and Landscape Improvements: The new underground energy distribution network will provide for a generational opportunity for campus-wide renovations of walkways and landscape, including the addition of non-potable (recycled) water piping for irrigation and other uses.

6

Restore and Activate Campus Space: The new plant will be built on the current North Field, an underused recreation field in the central campus. The plant will be one-story, placing most of its core thermal energy systems underground, and will replace the playing field on the roof.

7

Just Transition: Decarbonizing the campus energy systems will require upskilling of existing jobs and will create new positions and opportunities for workers. UC Berkeley is dedicated to ensuring that there is a net gain for employment opportunities resulting from the implementation of the BCEC and that those opportunities are equitably distributed.

8

Stimulates the Regional Economy: The initiative will create and retain full-time jobs, generate hundreds of regional construction jobs, and stimulate tens of millions of dollars into the California economy, bolstering economic growth.

9

Leading Edge Example: The BCEC will serve as a replicable and scalable clean energy model not only for public institutions but also for other sectors. It will demonstrate that meeting University, State, and Federal energy and carbon goals is both achievable and sustainable.

For decades, UC Berkeley has led the world in climate solution technology and policy research. **Now, the campus will build an energy system that sets a standard in sustainable, resilient building energy infrastructure.**

Background

Background

Climate Action to Date

UC Berkeley has made extensive efforts to reduce its greenhouse gas emissions by expanding procurement of green power, reducing energy use through building level energy efficiency, curbing growth-related emissions through electrification and green building practices, and increasing green fleet vehicles. However, most of the reductions in emissions have only just kept pace with campus growth. Emissions from the fossil fuel used in the cogeneration plant system contribute to the majority of the campus' scope 1 greenhouse gas emissions and remain the biggest challenge to achieving the university's 2045 goal of reducing emissions by 90 percent.

Originally designed to power the entire campus and constructed over 30 years ago, the cogeneration system is now inadequate to meet the campus' growing energy needs and incurs increasing operating costs under California's **cap-and-trade** regulatory framework. As a result, the campus has increasingly relied on the local utility for additional power to keep up with growth. With the cogeneration plant and steam distribution system nearing the end of its useful life, maintenance and needed upgrades have become increasingly disruptive and cost prohibitive.

UC Berkeley will meet California state carbon reduction targets

California Cap-and-Trade

In a similar manner to UC Berkeley's efforts, the State of California has been implementing various initiatives and policies to combat climate change. The state has set ambitious emission reduction targets, aiming to reach 40 percent below 1990 levels by 2030 and achieve carbon neutrality by 2045. As part of these efforts, California implemented a cap-and-trade program, managed by the California Air Resources Board, establishing a market-based approach to put a price on carbon to motivate the reduction of greenhouse gas emissions from major industries, including emissions from cogeneration plants like UC Berkeley's. The costs of California's cap-and-trade program are expected to increase over time, representing a financial and reputational risk to UC Berkeley if the cogeneration plant continues to operate. It is estimated that between 2025 and 2050, UC Berkeley could spend $250 million on Cap & Trade carbon costs.

Background

Integrated Resource and Activation Plan Overview

The combination of aging infrastructure, increasing maintenance and operations costs, limited low carbon alternatives to natural gas, and the imperative to achieve climate goals led to the development of the Integrated Resource and Activation Plan (IRAP) to implement the Berkeley Clean Energy Campus Initiative.

Launched in 2021, the two-year Integrated Resource and Activation Plan (IRAP) study included comprehensive engineering and financial studies to create a roadmap for the design of a new campus energy system to replace the aging cogeneration and steam system. Multiple studies involved collaborative partnerships with consultants, campus government relations, researchers, donor services, faculty experts, students and the UC Office of the President.

As a major part of the IRAP, Affiliated Engineers, Inc. (AEI) conducted a comprehensive review of alternatives for retiring the cogeneration plant, ultimately selecting a centralized Electric Heating and Cooling Plant (EHCP) paired with onsite clean energy systems (otherwise known as distributed energy resources) as the optimal solution. The EHCP will incorporate advanced technologies, including geothermal and thermal energy storage, powered by 100 percent clean electricity. Distributed energy resources (DERs) such as fuel cells, solar photovoltaics, and battery energy storage systems will provide onsite clean energy production and power resilience to manage the campus microgrid. A microgrid can operate independently or in coordination with the main power grid, allowing the campus to power critical systems in a blackout.

Key Milestones in the Development of the Berkeley Clean Energy Campus

2015 – 2020

Campus conducts several studies to identify options for upgrading the campus energy infrastructure and reducing energy related emissions.

July 2021

UC Berkeley launches the Berkeley Clean Energy Campus (BCEC) Initiative and initiates the Integrated Resource & Activation Plan (IRAP).

June 2022

The State of California commits $249 million to the Clean Energy Campus.

July 2023

The University of California Board of Regents approves the initiative for pre-construction designs.

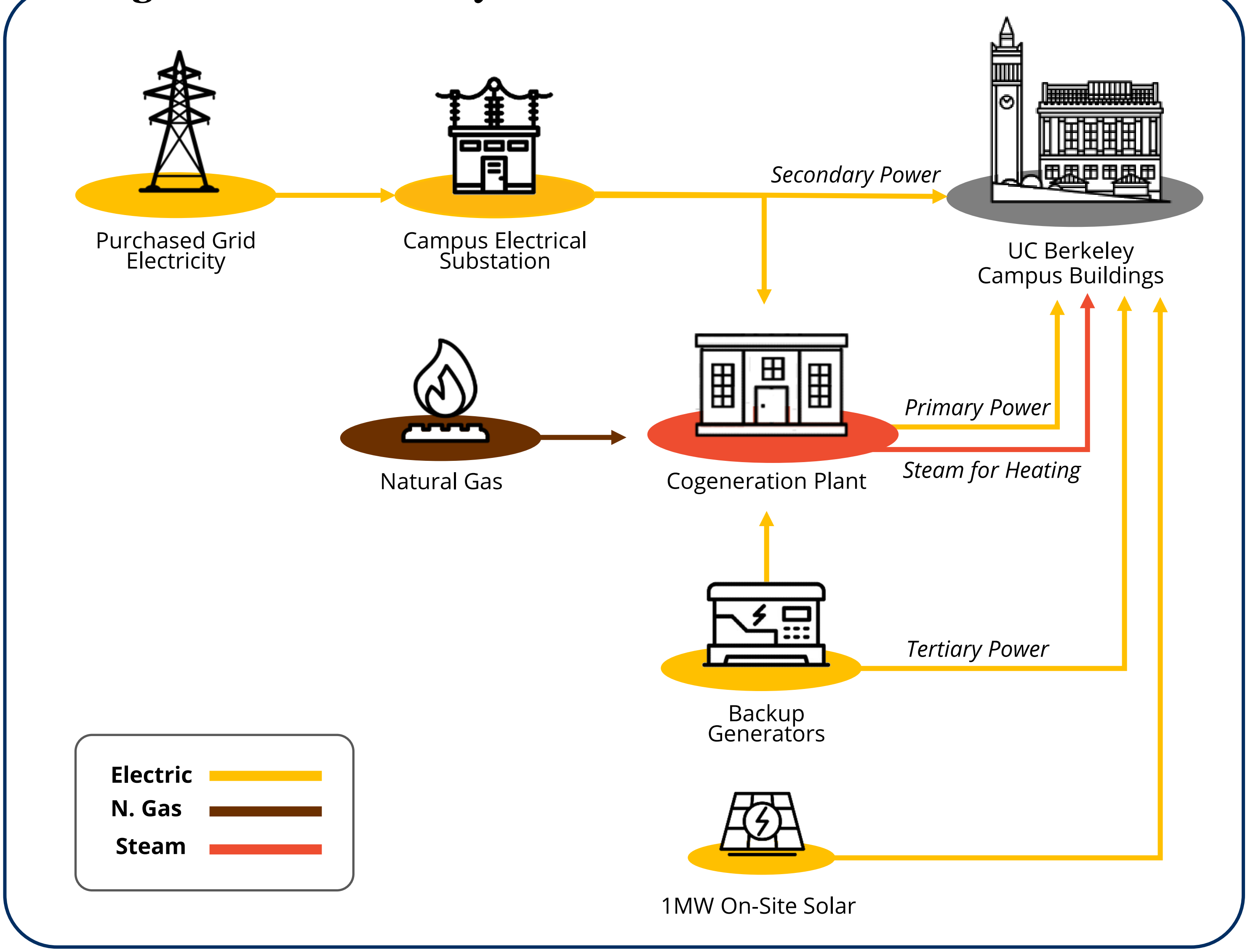
Background

Current System

At the center of Berkeley's current energy system is a gas-fired cogeneration plant, which is the primary source for electricity and heating for campus buildings. When it was first built in 1987, the cogeneration plant was state of the art facility, efficiently producing both electricity and steam. However, 36 years later, the aging and inefficient plant and steam distribution system is nearing the end of its life cycle and unable to keep up with the demands of a rapidly growing campus.

Berkeley's Cogeneration plant

Diagram of Current System



Background

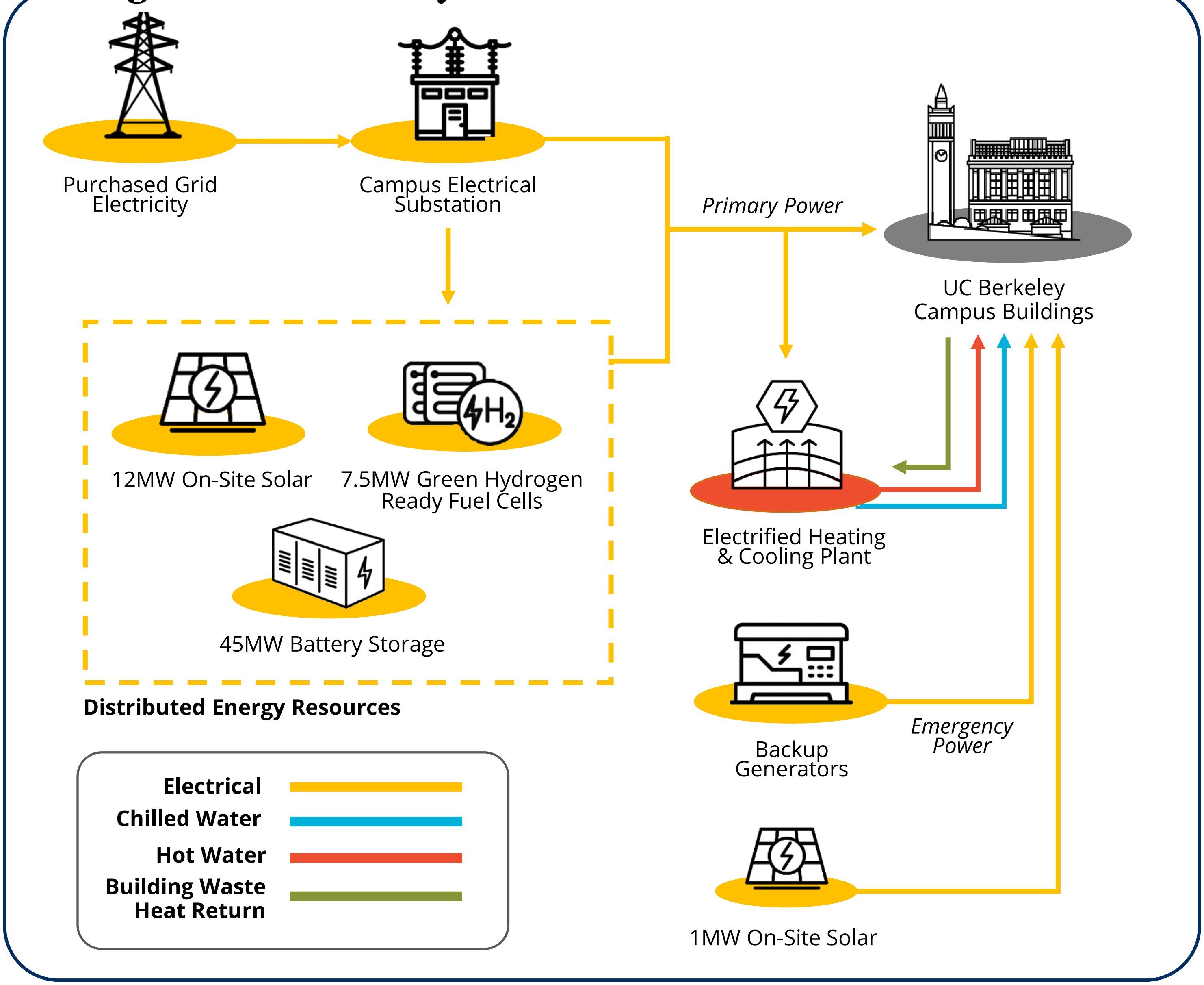
Future System

The new clean energy microgrid will be a localized energy system that integrates multiple distributed energy resources (DERs) such as solar photovoltaics, fuel cells and battery energy storage. Distributed energy resources will help with demand management, generate clean energy, and provide resilient power in emergencies. The microgrid will operate independently or in connection with the main utility electrical grid providing 100% clean power. The system will be controlled and monitored through a central management system. Microgrids provide a more resilient and sustainable energy solution by optimizing the use of renewable energy sources, reducing reliance on the main grid, and providing backup power during grid outages.

What is a microgrid?

A localized and independent electrical system that can operate autonomously or connect to the larger power grid, incorporating renewable energy sources, energy storage, and advanced control technologies to provide reliable and efficient power.

Diagram of Future System



Background

The project will be implemented in two primary phases. The strategic phasing and timing of the project studied in the IRAP results in efficient cost savings and long-term operability.

Phase 1 2028

- Design and build the centralized electric heating and cooling plant (EHCP).
- Construct the heating and cooling distribution piping to north side of campus.
- Convert 50% of campus buildings, with a primary focus on academic buildings that have high steam and power consumption, such as engineering and science buildings on the north side of campus. This will lay the foundation for increasing energy efficiency of the plant as well as those buildings connected to it.
- Install 15 megawatts (MW) of Distributed Energy Resources.
- Shutdown and decommission the cogeneration plant.

Phase 2 by 2035

- Connect remaining campus buildings to the new thermal system, gradually transitioning them from steam to the EHCP.
- Build out equipment system capacity at the electric heating and cooling plant.
- Expand campus electrical capacity.

2028

Berkeley Clean Energy Campus (BCEC)

PHASE 1 GOAL: Develop an efficient, electrified campus heating and cooling system, increase use of clean electricity in campus buildings resulting in a 70% reduction in building energy carbon emissions as early as 2028.

Phase 1 Benefits

Realized in 2028

70%
Reduction in carbon emissions from campus buildings

75%
Campus building thermal needs facilitated by the new central plant

100%
Fully-operational central plant with capacity for all buildings

$200M
In avoided costs from upkeep of existing systems

BY 2035

Berkeley Clean Energy Campus (BCEC)

PHASE TWO GOAL: Achieve 85% carbon-free building energy use

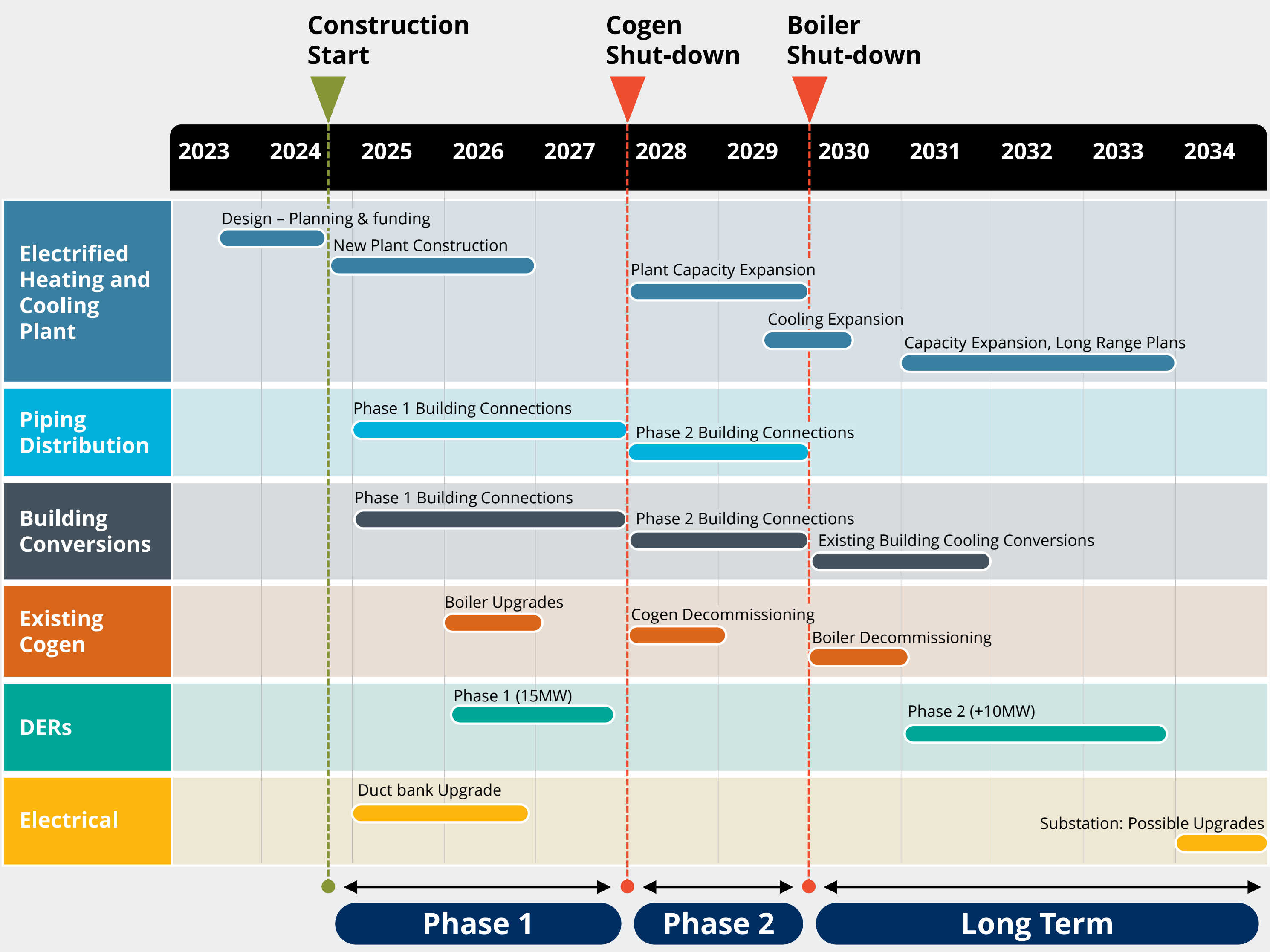
Long Term

- Add an additional 10 megawatts (MW) of clean on-site Distributed Energy Resources.
- Connect new buildings planned for in the campus Long Range Development Plan/ Master Plan and electrical system upgrades.

Background

Collectively, the engineering, financial, and renewable energy studies included in the IRAP have served as key pillars in the development of the Berkeley Clean Energy Campus roadmap and played a pivotal role in defining the project scope for this complex endeavor. With the initial blueprint development completed, the project has moved into preliminary design with a target to begin construction in 2025.

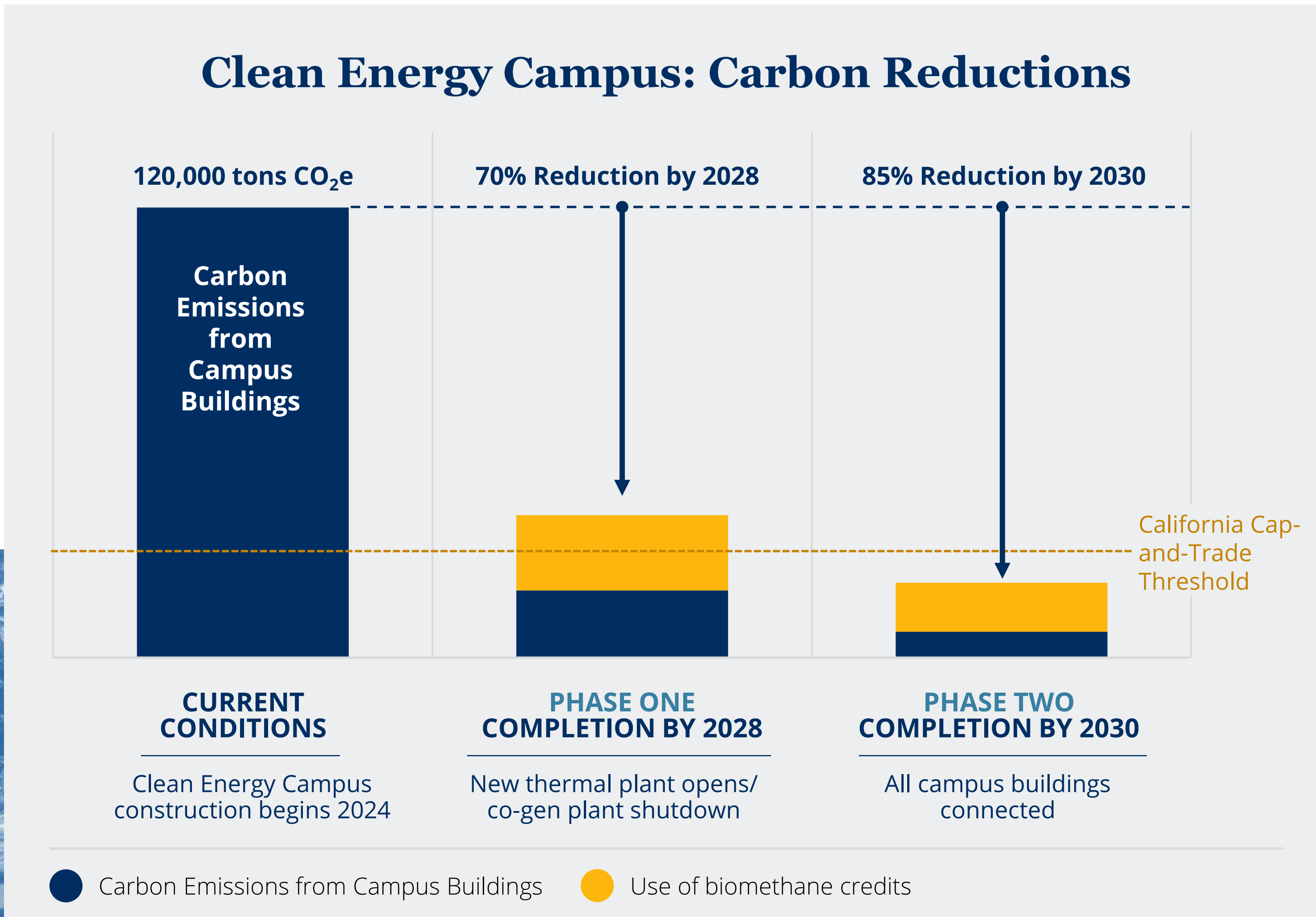
While this plan addresses the majority of UC Berkeley's scope 1 and 2 emissions, additional carbon reduction strategies will be required. The campus will be drafting a revised climate action plan by 2026 outlining its plans to further reduce emissions from buildings not on the new energy system as well as other emissions sources such as fleet vehicles, commuting and business air travel.

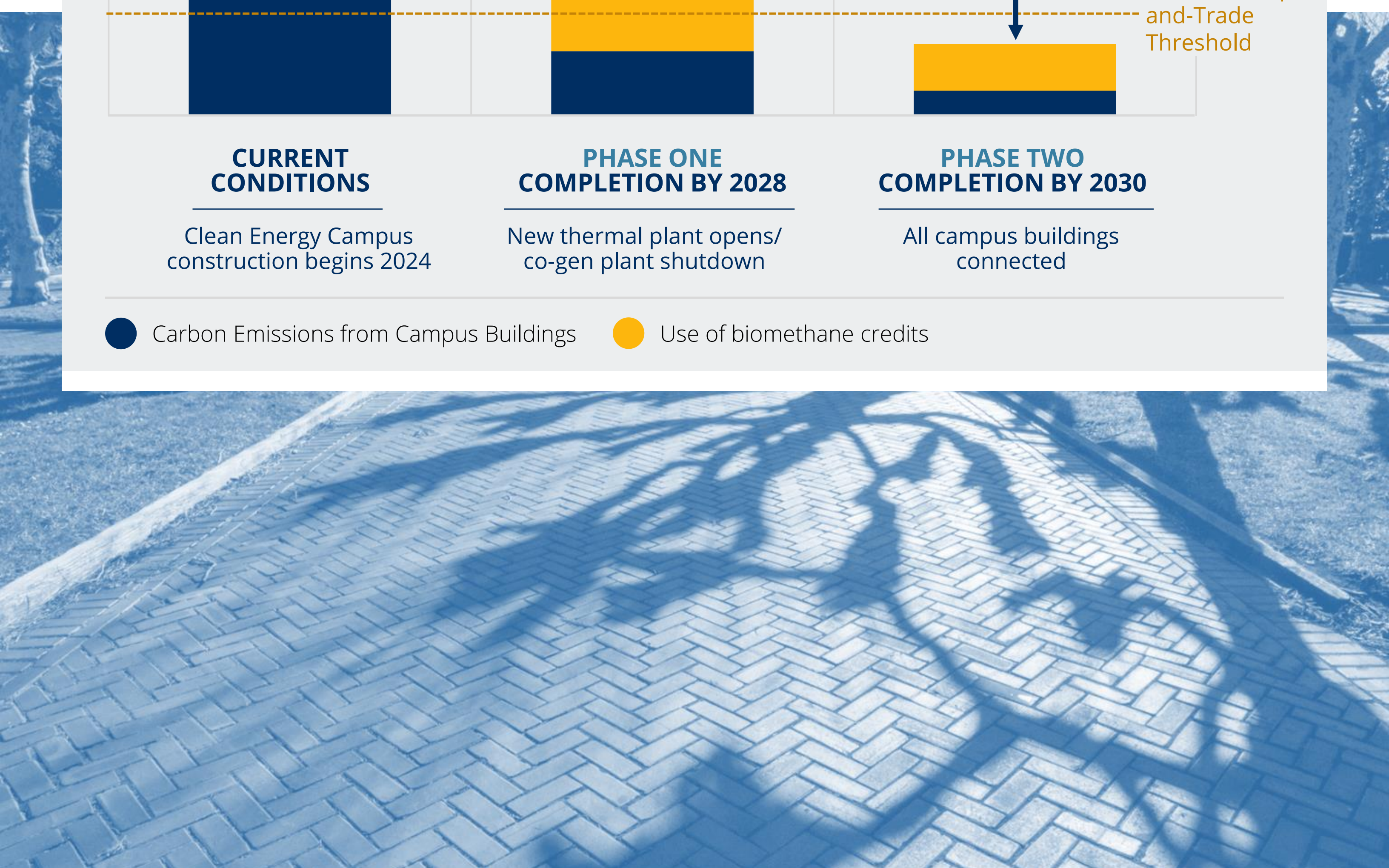


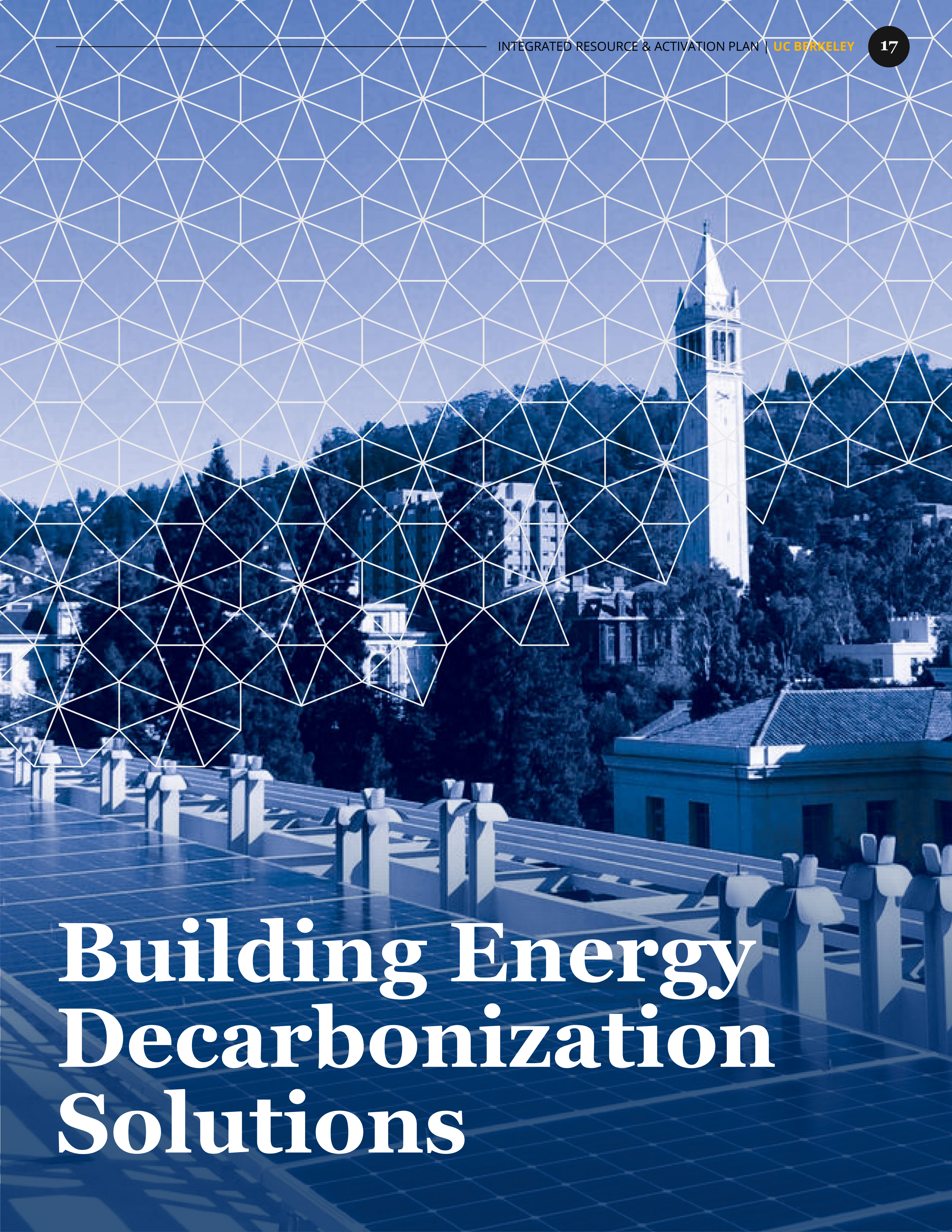
See AEI Berkeley Clean Energy Campus Integrated Resource & Activation Plan (IRAP) in the appendix for more detail.

Background

The Berkeley Clean Energy Campus is estimated to reduce emissions by 70% in the first phase. With the additional procurement of biomethane credits, represented by the yellow bars, to offset natural gas, UC Berkeley will be able to lower its emissions sufficiently enough to be under California's Cap-and-Trade requirements (>25K tons of carbon) in Phase 1. Phase 2 will eliminate additional fossil use achieving an 85% reduction in carbon emissions. The biomethane contract expires in 2039.







Building Energy Decarbonization Solutions

Building Energy Decarbonization Solutions

The technical solutions developed in the **Integrated Resource and Activation Plan (IRAP)** address two primary campus needs:

1

How to deliver decarbonized and energy efficient heating and cooling to buildings

2

How to provide onsite clean energy backup systems to increase resilience

The specific goals of the IRAP include:

- Greatly reduce fossil fuels use and carbon emissions and achieve University, State and Federal climate change goals.
- Renew and upgrade aging infrastructure.
- Transition to a resilient microgrid fed by on-site renewable energy.
- Optimize life-cycle costs, leveraging state funding and federal tax credits as well as innovative financing.
- Optimize land-use and contribution to community benefits.
- Leverage UC Berkeley's brain-trust and provide unique **living lab** opportunities within the university, building collaborative relationships with government and industry.

Building Energy Decarbonization Solutions

Affiliated Engineers, Inc. (AEI) built on previous studies that looked at different central plant and distributed (nodal) plant solutions. The optimal solution was determined to be a centralized Electric Heating and Cooling Plant (EHCP) and a new thermal distribution system paired with onsite clean energy systems (called Distributed Energy Resources or DERs).

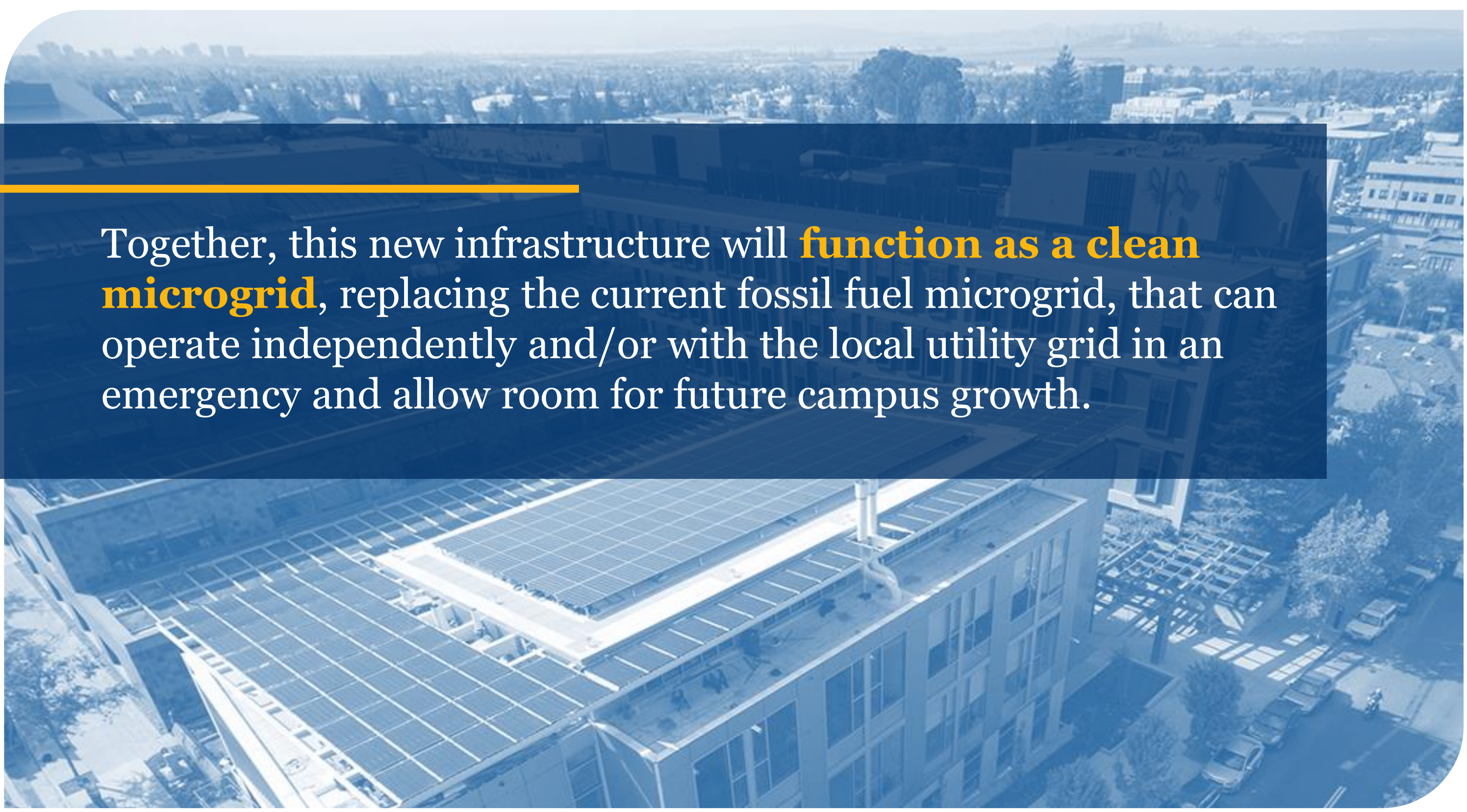
The Electrified Heating and Cooling Plant will be a state-of-the-art facility accommodating advanced, energy efficient technologies including **heat recovery chillers** and thermal energy storage supported by an underground **geothermal heat exchange** system. This plant will provide heating and cooling to existing and new campus buildings through efficient hot and chilled water distribution piping and will be powered by 100 percent clean electricity.

Distributed Energy Resources (DERs) include **green hydrogen** ready fuel cells, **solar photovoltaics** and battery energy storage systems to provide onsite clean energy production efficiently that will also provide resilience for **critical loads** in emergencies and power outages.

Together, this new infrastructure will function as a clean microgrid, replacing the current fossil fuel microgrid, that can operate independently and/or with the local utility grid in an emergency and allow room for future campus growth. The DERs will also greatly reduce carbon emissions in a way that current infrastructure cannot.

The project will be strategically divided into phases to ensure efficient capital planning and to maximize long-term cost savings associated with operation and maintenance.

The following section provides more technical details on each of the solutions identified as part of the IRAP and more information can be found in the appendix.



Together, this new infrastructure will **function as a clean microgrid**, replacing the current fossil fuel microgrid, that can operate independently and/or with the local utility grid in an emergency and allow room for future campus growth.

Building Energy Decarbonization Solutions

Decarbonizing Heating, Expanding Cooling

UC Berkeley currently operates a steam distribution system that provides most campus buildings with heating and hot water as well as supporting some lab processes. Steam is generated at the cogeneration plant and distributed through an increasingly deteriorating piping and tunnel network to buildings. Cooling is provided for a portion of primarily academic buildings by distributed stand-alone equipment (i.e. rooftop air conditioners). As climate change increases the number and severity of extreme heat days, the demand for cooling in all campus buildings is likely to increase. As such, the IRAP sought to identify solutions that would not only decarbonize heating but also provide opportunities to expand cooling to increase campus resilience and occupant comfort in an efficient manner.

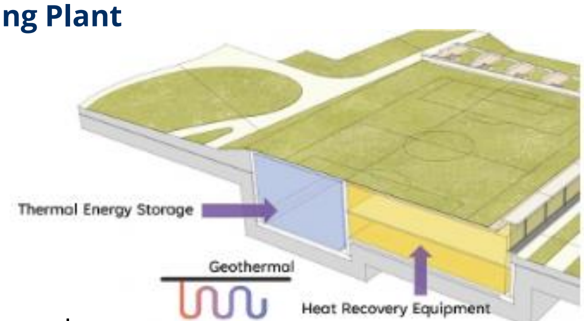
Redesigning the entire campus thermal system is a complex undertaking involving many interrelated systems. The following describes the proposed solutions for five key components of the new system: the new Electrified Heating and Cooling Plant (EHCP), thermal distribution systems, building conversions, advanced utility controls, and electrical upgrades.

Electrified Heating and Cooling Plant (EHCP)

Located on North Field, the new Electrified Heating and Cooling Plant (EHCP) will incorporate innovative technologies to optimize heating and cooling processes while increasing efficiency for campus buildings. The EHCP will capture waste heat from across the campus and from the ground (geothermal) and store and distribute this heat to meet the campus heating and hot water demands. Using advanced heat recovery technologies coupled with thermal energy storage, the EHCP will operate with a combined overall heating efficiency greater than 300 percent. By comparison, the existing steam heating and distribution system operates with an estimated overall heating efficiency less than 60 percent when accounting for distribution losses from the aging steam pipes.

The geothermal system will consist of boreholes drilled below the North Field site to store heat seasonally. Phase 1 will include about 150 boreholes drilled 400 feet deep beneath the plant building. **Water-to-water heat pumps** specifically designed to utilize this underground resource will provide simultaneous heating and cooling capabilities by pulling heat from or rejecting heat to the ground. By tapping into the relatively constant underground temperature and leveraging this with thermal energy storage, the EHCP can harness free and lower cost heating and cooling for buildings.

Concept of the new Centralized Heating & Cooling Plant



The new plant will utilize an underused field in the central campus and a majority of the core energy systems will be underground, including plant equipment, thermal energy storage tanks, and geothermal systems. A new recreation field will be installed on the roof

The new plant will provide views into the inner workings of the facility and offer community learning

Provided by AEI

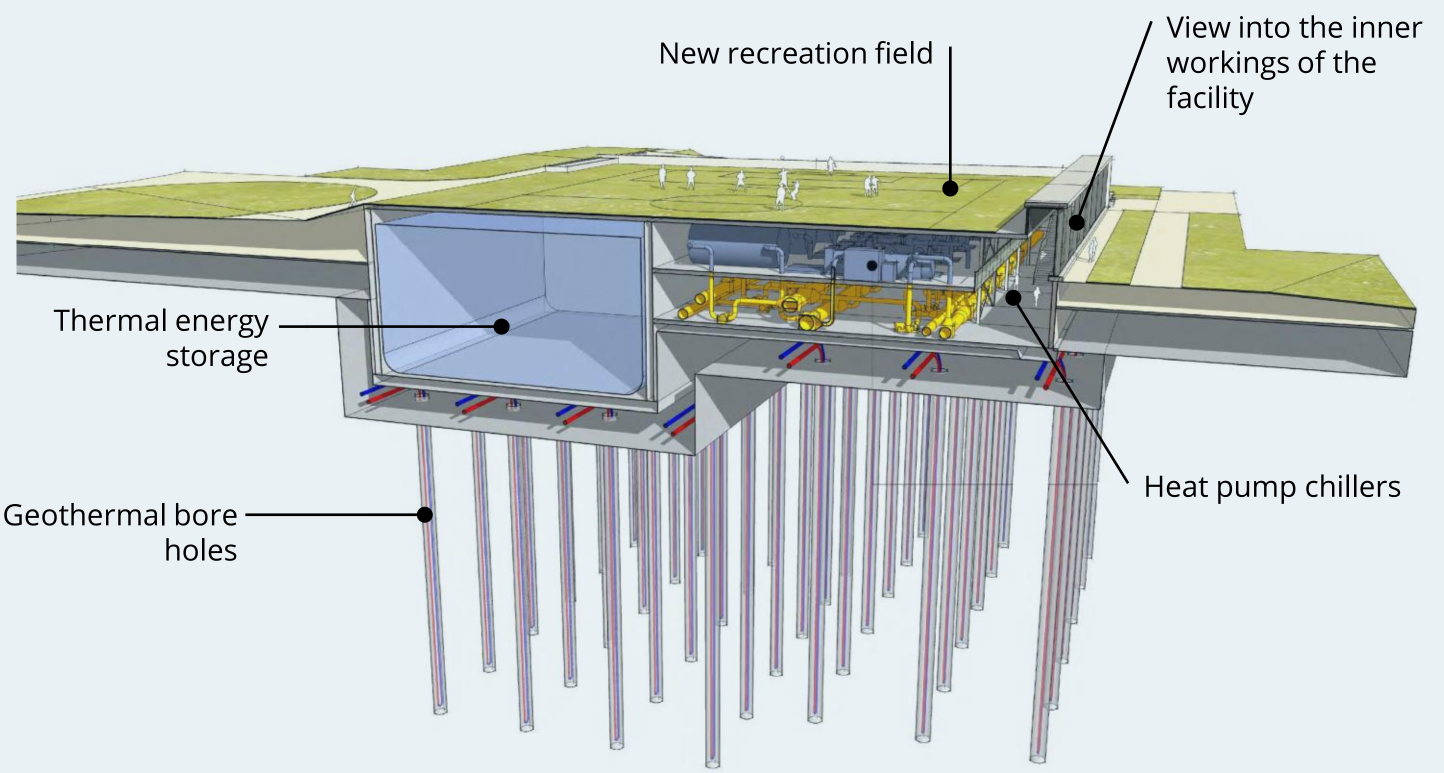
Building Energy Decarbonization Solutions

The thermal energy storage (TES) system consists of two large water tanks totaling over 6 million gallons that will capture excess heat during periods of low demand and store it for periods of high demand. By incorporating TES, the EHCP can satisfy 80 percent of the campus heating energy currently provided by steam, by capturing and reusing waste heat from across the campus. As demand grows and space becomes available, expansion can be accommodated.

When the cogeneration plant is decommissioned at the latter part of phase 1 construction, the electrified heating and cooling plant will take over for about 75 percent of campus heating and cooling needs. Electricity will be provided by the local utility and the distributed energy resources. The remaining buildings to be added in phase 2 will continue to operate on steam until transitioned to the EHCP.

The new plant will not only serve as a centralized energy hub but also a living laboratory. Campus affiliates and visitors will have the opportunity to study and experience sustainable energy solutions firsthand.

Concept diagram of the new Electrified Heating and Cooling Plant



Provided by AEI

Building Energy Decarbonization Solutions

Thermal Distribution Systems

The implementation of the new state-of-the-art thermal distribution system will revolutionize the heating and cooling capabilities of the campus, replacing the inefficient high-maintenance steam system. The new network of heating hot water and chilled water supply and return pipes will be connected to the electrified heating and cooling plant, forming a series of loops that will efficiently serve all campus buildings.

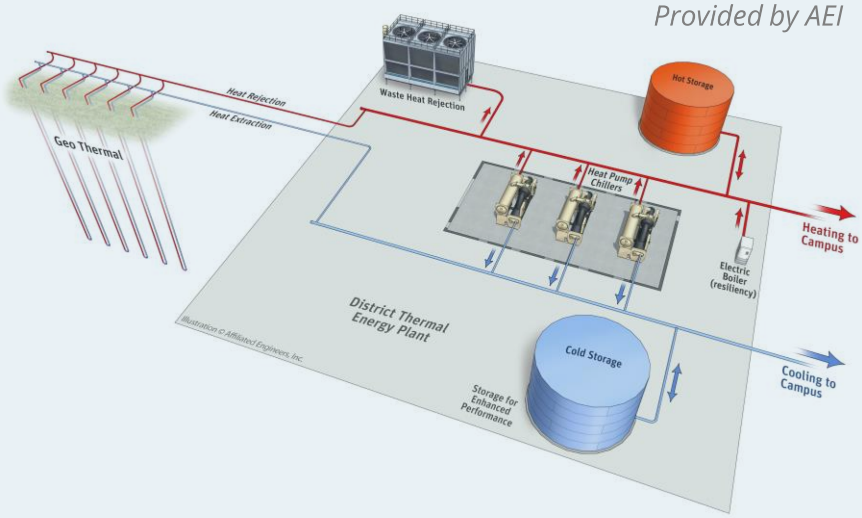
The upgraded system will significantly improve the distribution of thermal energy to buildings as compared to the current steam system, minimizing energy losses during distribution and enhancing the system's redundancy. This will result in greater overall efficiency and cost savings. Moreover, the new system will eventually eliminate the need for distributed cooling equipment units (e.g. rooftop air conditioners), reducing maintenance requirements. As a result of the new system, more campus buildings will have access to cooling capabilities, providing a more comfortable environment for occupants.

The distribution and phasing plan developed by AEI for the campus takes into account steam system deferred maintenance priorities to avoid significant costs by replacing those areas of campus most in need of repair first. To initiate the project, the campus will prioritize connecting the most energy-intensive buildings (about half of the campus) to the new system, effectively shifting approximately 75 percent of the thermal energy load to the electrified heating and cooling plant. Subsequently, other campus facilities will be sequentially connected to the distribution network as it expands in phase 2.

In addition, the first phase will leverage existing cooling assets distributed around campus to supplement the cooling provided by the Electrified Heating and Cooling Plant (EHCP) and reduce the need for additional centralized cooling towers at the beginning. These existing water-cooled chillers still have useful service life and will be integrated into the new chilled water distribution, effectively operating as satellite peaking-plants. Integrating the existing equipment into a new chilled water distribution system is a cost-effective solution compared to installing new water-cooled chillers in the EHCP at the outset. The existing equipment will continue to operate until it reaches the end of its useful service life, at which point it will be replaced with new centralized cooling equipment in the EHCP. This phased approach will allow for a seamless transition while optimizing cost-efficiency.

Diagram of the Electrified Heating and Cooling Plant

The EHCP will capture waste heat from across the campus and from the ground (geothermal) and store and distribute this heat to meet the campus heating and hot water demands.



Provided by AEI

Building Energy Decarbonization Solutions

Building Conversions

The conversion of existing buildings from steam to hot and chilled water will align with the phasing of the distribution plan. There are four primary ways in which buildings will be adapted to the new system:

- Existing buildings connected to steam will be retrofitted to accept hot water instead of steam for heating through the addition of new and emerging **heat pump** and **heat recovery technologies**.
- Process steam loads (e.g. for sterilization processes) will be shifted to building-based electric steam generators.
- Existing distributed cooling systems (e.g. rooftop air conditioning units) will be converted and transitioned to the new centralized chilled water system.
- Existing buildings that currently do not have cooling will be provided with a connection to the central chilled water system for future use.

This upgrade will enhance energy efficiency and reduce reliance on outdated steam systems. Furthermore, both existing buildings with cooling requirements and those without will be connected to the new chilled water system, bolstering the campus' ability to adapt to climate change and provide optimal comfort. Significantly, most of the heat needed for campus buildings will come from the buildings themselves, by recapturing heat currently thrown away via existing building level **cooling towers**.

Most of the buildings to be converted are on the core campus or immediately adjacent and already connected to the existing steam system. Other university buildings located further from the core campus and unconnected to the existing cogeneration and steam system, will be addressed through future decarbonization planning. These other university buildings represent a much smaller energy use and carbon footprint than the buildings that are part of the new campus system. To facilitate a smooth transition, all new facilities planned and constructed prior to the full operation of the electrified heating and cooling plant or distribution network will be designed to seamlessly integrate with the new system.

Advanced Utility Controls

Advanced utility controls will guide the campus-wide flow of heating, cooling, and electricity through the new energy distribution network–what is known as a microgrid. These controls will include sensors, software, and monitoring equipment that ensure sufficient energy is available and shared among campus buildings. Each building is essentially "tuned for maximum efficiency." The advanced utility controls will also be vital when responding to future unplanned outages, as they will allow the campus to specifically direct energy resources to the buildings where it is most needed to maintain critical operations. The microgrid system will monitor both the Distributed Energy Resources and the campus electrical distribution system and provide intelligent monitoring and controls based on campus usage and available DERs. Availability of power from DERs varies with time of day, season, weather, battery capacity and other factors. To assure the system operates smoothly, the microgrid system's programming will consider all incoming, historical, and forecasted data while providing automated control and streamlined monitoring to all systems on campus.

Electrical Upgrades

UC Berkeley currently relies on the existing cogeneration system for 90 percent of its electricity needs, with the rest being supplied by the local utility. Diesel generators are installed in strategic locations throughout campus to provide backup power in the case of an outage. As the campus transitions from the natural gas cogeneration facility and onto to the Electrified Heating and Cooling Plant (EHCP), it will rely on the local utility and newly installed onsite clean energy installations (see Clean Energy: Distributed Energy Resources

Building Energy Decarbonization Solutions

section) to provide power. The new systems, such as electric heat pumps, will increase the overall electrical load of campus and will require upgrades to existing infrastructure. While this can be a significant cost barrier for electrification, the design team determined a flexible approach that could be phased over time to reduce the immediate need for expensive upgrades.

Electrical infrastructure upgrades will be phased to align with the projected electrical load growth from the EHCP as well as the installation of distributed energy resources. Upgrade of the existing utility service capacity serving the campus (Hill **Substation**) is not anticipated to be required during phases 1 and 2 implementation but is likely required to support future campus growth. Supplemental on-site clean Distributed Energy Resources will also be required to support growth.

Currently, the campus distribution system is limited to 48 Mega Volt Amp (MVA) due to existing feeders to the Hill substation. To expand capacity, the campus plans to implement various electrical system upgrades including additional switchgear and conductors from the Hill Substation. These upgrades will increase the system capacity to 55 MVA, allowing for the accommodation of the Phase 1 and Phase 2 heating and cooling distribution without the need for immediate electrical utility service improvements at the Hill Substation. This solution ensures that the campus can effectively meet its electrical needs while optimizing resources and minimizing near-term expenditures. An eventual expansion of electrical capacity at the Hill Substation will be needed to accommodate future growth, unless the campus can keep loads below 55 MVA; as this type of expansion has long lead-times. The planning for this is already underway.

Electrification is Energy and Water Efficient

The electrification of thermal systems at UC Berkeley requires an additional 30,000 megawatt-hours (MWh) of power per year, which amounts to a 16 percent increase compared to the current campus energy usage. According to the IRAP analysis, the anticipated annual energy consumption at the new Electrified Heating can Cooling Plant (EHCP), once fully built, will be 72,000 MWh. However, due to the removal of cooling building level equipment and other measures, the building electrical loads will decrease by 47,000 MWh. The incredible efficiency gains are in part due to the capture of waste heat, which is currently being discarded across campus. The new heat recovery equipment and thermal energy storage tanks at the EHCP will be able to capture 90 percent of the annual campus heating requirements from waste heat.

In addition to being highly energy efficient, capturing waste heat through systems like geothermal and thermal energy storage (TES) results in significant water savings due to the reduction in the number of cooling towers needed to reject waste heat. Moreover, geothermal systems are eligible for rebates through the federal Inflation Reduction Act, providing further incentives for its implementation (see Financial Analysis section).

47,000 MWh **decrease in building electrical loads** according to the study analysis with the new Electrified Heating and Cooling Plant

Water Savings & Recycled Water

The implementation of the Berkeley Clean Energy Campus presents an opportune moment to save water and to leverage the trenching activities required for the new hot and cold water distribution system to connect to the regional recycled water supply when it becomes available. By planning for this future connection, central cooling towers for the electrified heating and cooling plant and future buildings can benefit from the use of recycled water as well as for irrigation purposes. Whether recycled water is used or not, the BCEC is projected to reduce campus water use by 20 percent in the energy use system with the efficiencies gained from the new thermal systems.

20% Reduction BCEC to reduce campus water use in the energy use system by 20% and the option to use recycled water

On-Site: Distributed Energy Resources (DERs)

After the decommissioning of the existing cogeneration plant at the end of Phase 1, the campus will rely on electricity from the utility and onsite clean energy resources. One of the significant challenges of transitioning to an all-electric system is ensuring energy resiliency during utility outages and other events such as high winds, wildfires, and potential earthquakes.

The campus recognizes the importance of maintaining and improving reliable energy sources to meet critical campus safety needs and safeguard sensitive laboratory research.

Implementing Distributed Energy Resources **(DERs) can enhance energy resiliency**, providing a reliable backup of clean energy during utility outages.

Building Energy Decarbonization Solutions

Identifying Critical Loads

A key objective of the project was to provide on-site sources of power to support critical campus operations during a utility outage. Identifying those critical operations and their associated loads is a complex process. To identify critical operations, UC Berkeley assembled a group of campus stakeholders who represented key functions such as research and student life. The group identified and prioritized particular functions to be supported with an emphasis on student safety and research. These included specific research needs, residential housing and dining, security (including lighting, health services, emergency operations center, and the campus police department), and essential data. The evaluation assumed managing critical loads in an outage would include shutting down buildings without critical functions, having non-essential employees work remotely and, depending on circumstances, move classes to a remote format and cancel events. The engineers then identified the needed load to support those functions which provided the basis for the design of resiliency measures. Aligning operations to those loads during an outage will be an ongoing challenge and will require sophisticated controls to maintain.

DERs: Solar, Batteries and Fuel Cells

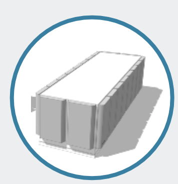
AEI studied a range of Distributed Energy Resource (DER) options that can power the campus for up to five days as well as supplement utility-provided energy during normal operational times. Factors considered included:

- Cost competitiveness
- Feasibility of funding and constructability
- Ability to connect to UC Berkeley's electrical grid
- Ability to provide clean, low-carbon energy
- Ability to provide resilient power for up to 5 days of utility outage
- Phasing and growth potential
- Attractiveness for potential partners and external funding opportunities

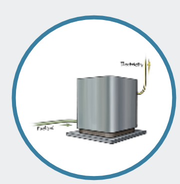
Technical maturity and ability to meet demand DER technology assessed included solar photovoltaic, fuel cells, modular nuclear, deep geothermal power, wind turbines, and pumped hydro power. Using AEI's optimization tool and evaluating other qualitative benefits, the team determined a preferred approach combining a mix of technologies which includes fuel cells, solar photovoltaics and battery energy storage.

Ultimately, AEI recommended a three-part system of DERs: 7.5 megawatts (MW) of fuel cells capable of operating on green hydrogen; 10-12 megawatts (MW) of solar generation on campus rooftops and parking garages; and, 45 megawatt-hours (MWh) of battery energy storage.

Three-part system of DERs

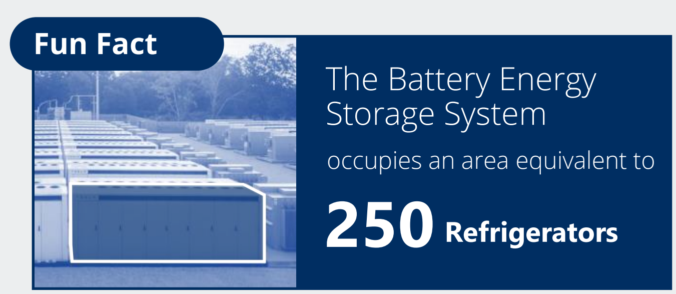


45 MWh Battery Energy Storage



7.5 MW Fuel Cells

10-12 MW Solar PV



Building Energy Decarbonization Solutions

Distributed Energy Resources Profile

Campus Critical Loads

- Research
- Student Residential Housing
- Data
- Safety

Recommended Technology Mix

- Solar Photovoltaics
- Solid Oxide Fuel Cell
- Battery Energy Storage

Energy Sources

- Solar (renewable energy)
- Biomethane for fuel cell (short-term)
- Green Hydrogen for fuel cell (long-term)

AEI also estimated that an additional 10 MW of additional DERs would need to be added in subsequent years to meet growing campus energy resiliency needs.

The University of California (UC) has explored other strategies to reduce emissions while maintaining existing infrastructure including the procurement of biomethane to replace natural gas. Biomethane, also known as renewable natural gas (RNG), is a type of biogas produced from organic waste materials, such as agricultural waste, food waste, wastewater, and landfill waste. Considered a carbon neutral alternative to natural gas, the UC system has invested in biomethane as a transition fuel to aid campuses in reducing emissions through 2040. UC Berkeley plans to use its biomethane allocation from the UC system to reduce the Cap-and-Trade emissions associated with the fuel cells through this time period. This allows UC Berkeley to ramp down natural gas use emissions while more DERs are implemented as well as avoid Cap-and-Trade costs.

Possibility for Solar PV and Storage for Future Growth

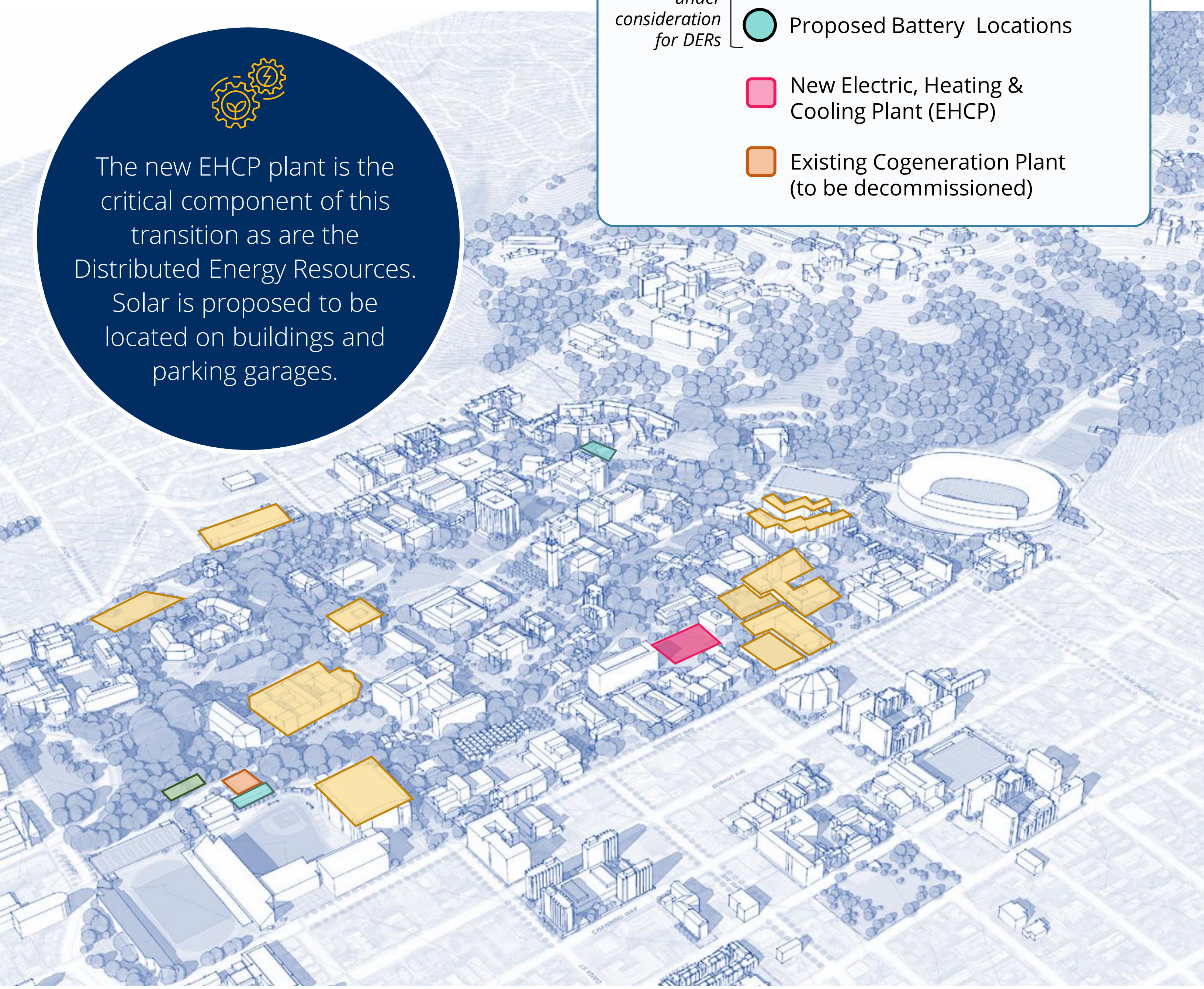
A study conducted by Burns & McDonnell in 2022 assessed the potential for clean energy generation on UC Berkeley's Hillside Campus through solar PV and battery energy storage systems. Despite challenges such as steep slopes, extensive vegetation, existing buildings, and limited infrastructure accessibility, five clusters of sites were identified for potential solar development. Of those five, three sites on the campus hillside totaling 12-15 MW were identified as the most feasible installation options for maximizing solar while minimizing the impact on existing trees, structures and other obstacles. The three sites identified as most feasible for solar will continue to be evaluated for installation during later phases of the energy system construction. The campus will first focus on rooftop and carport solar PV installations on the main campus.

Introduction

Overview of Berkeley Clean Energy Campus Plan

UC Berkeley's new campus energy infrastructure will be distributed throughout campus and be a visible demonstration of the university's commitment to climate action.

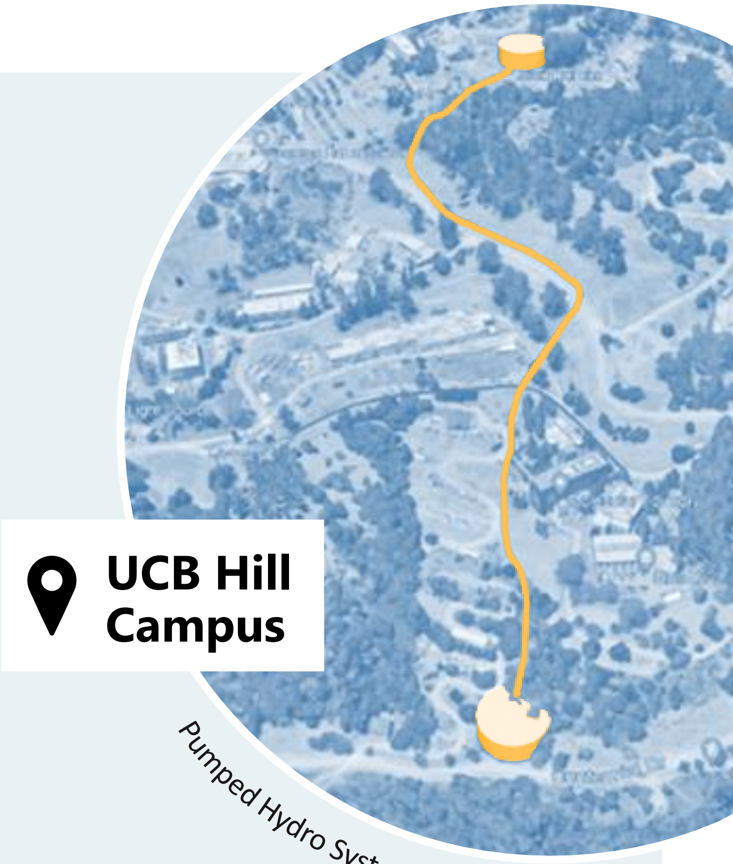
The new EHCP plant is the critical component of this transition as are the Distributed Energy Resources. Solar is proposed to be located on buildings and parking garages.



Building Energy Decarbonization Solutions

Exploring Pumped Storage Hydropower

Prompted by input from UC Berkeley Mechanical Engineering faculty, AEI conducted a study on the potential of closed-loop pumped storage hydropower on campus. Leveraging UC Berkeley's unique geography and steep slope on the hill campus, the IRAP explored the possibility of a closed-loop pumped storage hydropower system as an alternative or supplement to electrochemical batteries that rely on rare earth metals. This innovative approach involves pumping water to an upper storage tank during periods of abundant and clean power, and then utilizing a hydropower turbine and gravity to generate additional power as needed during outages or peak hours, while reducing dependence on the utility.



Pumped Hydro System Concept

A pumped storage hydropower scheme could have a lifespan of

60+ years

Compared to lithium-ion batteries that require replacement every

7-10 years

making pumped storage hydropower a more sustainable and lower embodied carbon solution

By identifying feasible sites with 20 million gallons of upper and lower storage volumes, this system can provide up to 15 megawatt-hours (MWh) of energy, with a turbine output of around 3.5 megawatts (MW), for a duration of 4.75 hours. An additional 30 MWh of battery storage would still be needed to supplement pumped storage hydropower in meeting the critical loads of the campus.

Initially, the capital cost of implementing the pumped storage hydropower system far surpasses that of a battery system of similar size. However, over the system's lifespan, the replacement costs for batteries make the battery capital costs more expensive.

Financial Evaluation

Financial Evaluation

The State of California has committed $249 million towards the project and the funding for the Integrated Resource Activation Plan (IRAP) itself was made possible by the support of generous donors;

however, the total capital cost of the BCEC project is estimated to be **$700 to $800 million,** requiring strategic financial planning. Under the IRAP, consulting firm Ernst & Young (EY) conducted a financial analysis that examined various financing options and developed a financial roadmap for the project's first phase under these funding scenarios. The analysis considered potential funding sources such as the federal **Inflation Reduction Act (IRA)** tax credits, **power purchase agreements (PPA)**, short- and long-term financing, green bonds, grants, and state and federal grants. State funds are envisioned to be used to design the BCEC and cover some of the construction costs of the thermal system transformation. The Distributed Energy Resources (DERs) have been modeled to be delivered through public-private energy service contracts (i.e. power purchase agreements). delivered through public-private energy service contracts (i.e. power purchase agreements).

Ernst & Young developed a flexible financial modeling tool that incorporated cost estimates developed by AEI. The inputs included the state-sponsored funding coverage and debt to fill the financial gap for design and construction of phase 1 of the project. Ernst & Young's discounted cash flow analysis assumed a 4.25 percent tax-exempt financing interest rate with the guidance of the UC system Capital Markets Finance. EY also determined that the campus could take advantage of new "direct pay" provisions under the federal Inflation Reduction Act (IRA), which for the first time can directly transfer clean energy tax credits to non-profit institutions such as universities.

Financial Evaluation

Leveraging funds for the first phase of the Clean Energy Campus

The $249 million in State Funds not only provide significant investment in the BCEC implementation,
it is a funding and saving catalyst. It is offering the BCEC numerous opportunities, including:

- Completion of designs and technical schematics for the entire new system, including new plant, distribution, and distributed energy resources.
- Funds a portion of the Phase 1 construction.
- Implements essential make-ready projects to accommodate increased campus-wide electrical demand and central cooling towers.

The Inflation Reduction Act (IRA)

The IRA will play an important role in funding the Berkeley Clean Energy Campus. The campus is identifying how the IRA can significantly leverage funding allocated by the State.

Catalyst for Savings

The faster the Clean Energy Campus can be completed, the greater the savings that will be realized, and the quicker UC Berkeley can move significantly away from fossil fuel combustion and demonstrate for others rapid large-scale decarbonization.

Green Bonds

Green bonds and green bank financing instruments provide discounted interest rates for eligible “green” projects. The availability, financing rates and size of any potential loan vary by project type and issuer. Green bonds offer potentially 10-45 basis points (bps) lower than traditional bonds. Green banks such as California IBank provide infrastructure loans at rates lower than the market and up to $60 million. As UC Berkeley roles out specific projects, these financing mechanisms may prove to be a viable solution.

What is a PPA?

- PPAs (power purchase agreements) offer UCB the ability to receive energy from resources such as solar and battery storage from a third-party developer without capital costs.
- In a typical direct PPA structure,
  a project developer owns and operates the renewable energy provided to UCB, who receives and takes legal title to the energy based on a negotiated contract at a fixed price.

Tax Credits in a PPA

- Tax ownership of the DER assets (solar, battery storage and fuel cell) transfers to developer, therefore UCB will not be eligible for the associated tax credits.
- Although the developer retains the credit, the benefits of the credit should be shared with UCB and reflected in a reduced fixed price (“strike price”).

Provided by EY

Financial Evaluation

Phase 1 | Tax Credit Estimates

$54 million
Low Case

$71 million
High Case

The financial model estimated eligible tax credits to be $47 million to $71 million from clean energy resources such as battery storage, fuel cells, geothermal energy, piping, and the EHCP for Phase 1. EY's findings reveal that under the IRA, the Federal government could provide rebates ranging from 10 percent to 20 percent of the total project costs upon completion. As an example, including a geothermal heat exchange system beneath the main plant enhances the campus' thermal infrastructure while also increasing the likelihood of securing higher rebates.

Inflation Reduction Act (IRA) Tax Credits

Mitigating Risks

UC Berkeley has the unique opportunity to leverage the Inflation Reduction Act (IRA) tax credits for implementation of the Berkeley Clean Energy Campus (BCEC). While there is a risk that a new administration could undermine the tax benefits, historical trends suggest that these credits have generally been extended rather than revoked. The current Clean Energy Tax Credit program, provided under the IRA, is authorized until 2032. To mitigate this risk, UC Berkeley can complete its project and secure the tax credits prior to the expiry of the current authorization in 2032.

Another potential challenge with leveraging the IRA is the reliability of the tax credit amount. Initially projected based on cost estimates and interpretation of the tax credit applicability, the final determination of the credit amount will be made by the IRS after project completion. This risk is common for renewable energy projects, but insurance products are available in the marketplace to underwrite this risk and provide some certainty to the university for a premium.

Another consideration is the direct pay process, which is newly established under the IRA. While tax credits for renewable energy are not new, the full process and requirements for the direct pay process are still being clarified through federal administrative guidance. However, initial federal guidance has been issued, confirming the eligibility of public universities for the direct pay process. It is essential for UC Berkeley to remain up to date with federal guidance to ensure compliance with the requirements.

Overall, by strategically planning and taking advantage of the IRA tax credits, UC Berkeley can benefit from financial incentives to enable the BCEC. While there are potential risks, various measures can be taken to mitigate them and ensure a successful utilization of the tax credits.

Financial Evaluation

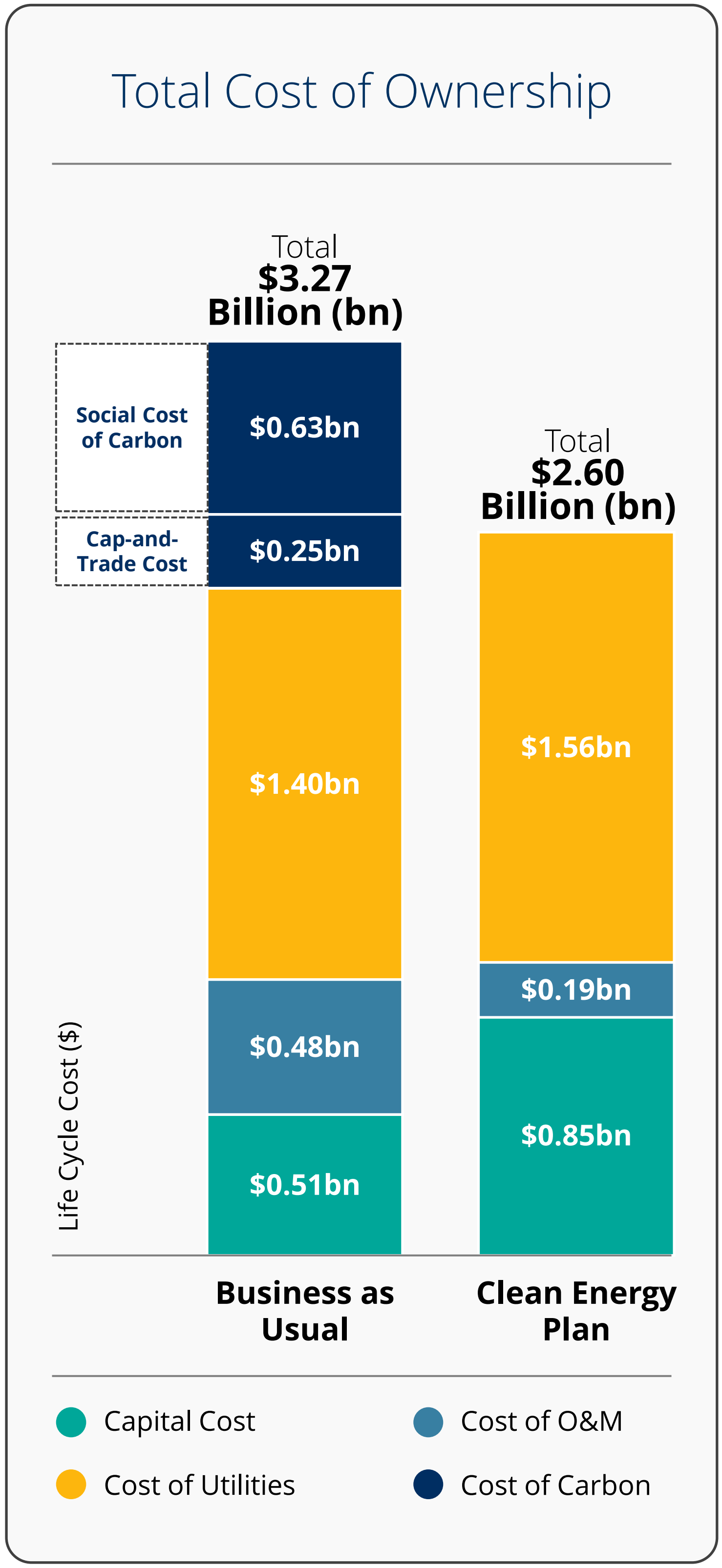
Total Cost of Ownership

A large infrastructure transformation that will serve the campus for many years cannot be considered just in terms of upfront capital cost but in terms of total cost of ownership.

For the IRAP, the life cycle cost analysis included the following considerations over a 25-year period:

- Campus utility costs (electricity, natural / biomethane gas and water)
- Operation and Maintenance (O&M) costs
- Carbon emissions costs (cap & trade and **social costs**)
- Capital Expenditure costs (including deferred maintenance and avoided costs)

The new decarbonized system costs have been compared against the Business-as-Usual case, which is defined as the campus refurbishment of the cogeneration plant and steam distribution system and making the repairs to the system for it to be functional and operational. **The total cost of ownership over a 25-year life cycle resulted in a cost of $2.6 billion for the new Clean Energy Plan** compared to the cost of $2.63 billion for the Business-as-Usual case (excluding social cost of carbon). The inclusion of the social cost of carbon increases the cost of the Business-As-Usual case to $3.31 billion.



Financial Evaluation

Social Cost of Carbon

The social cost of carbon is the monetary value of the net harm to society from climate change associated with adding carbon to the atmosphere each year.

The impacts of climate change include but are not limited to net agricultural impacts, human health effects, increased flood risk damages, environmental migrations, and changes in the value of ecosystem services. The social cost of carbon is a value of the future cost of climate change and can be used to weigh the benefits of reduced consequences against the costs of cutting emissions. UC Berkeley experts have been consulted and have estimated the equity weighted social cost of carbon for the UC system to be approximately $246 per ton of greenhouse gas emissions. This cost will continue to escalate over time.

The financial analysis (shown in the graph on the previous page) provides a conceptual cost and revenue foundation for completing the project's first phase. Moving forward, project financing is largely dependent upon variables such as potential future state investments, partnerships with private entities and philanthropic interest, all of which the university continues to explore. Despite the significant initial investment, the long-term financial savings illustrate the financial viability of a clean energy transition.

UC System equity weighted

Social Cost of Carbon

$246

Per ton of greenhouse gas emissions

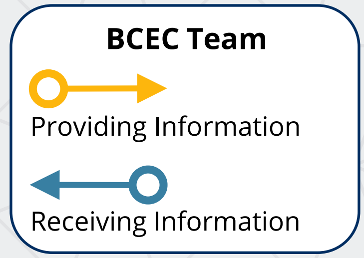
State Advocacy and Funding Outcome

UC Berkeley's campus leaders prioritized the BCEC and collaborated with the campus Office of Government, Community Relations, the Office of Sustainability, and Facilities Services to advocate for the Berkeley Clean Energy Campus, elevating it as its top capital funding request to the state in 2022. Their advocacy efforts encompassed engagements with state legislators, the Governor's Office, the UC Board of Regents, and other decision-makers. To present the project as a model decarbonization capital investment, Chief Sustainability Officer Kira Stoll and Director of Advocacy and Institutional Relations Michelle Moskowitz personally traveled to Sacramento multiple times in 2022 and 2023. In over 30 presentations, they emphasized the project's potential to reduce campus greenhouse gas building energy emissions by 85 percent , which would support the state's ambitious greenhouse gas reduction goals and serve as a prominent demonstration project for other campuses and small cities.

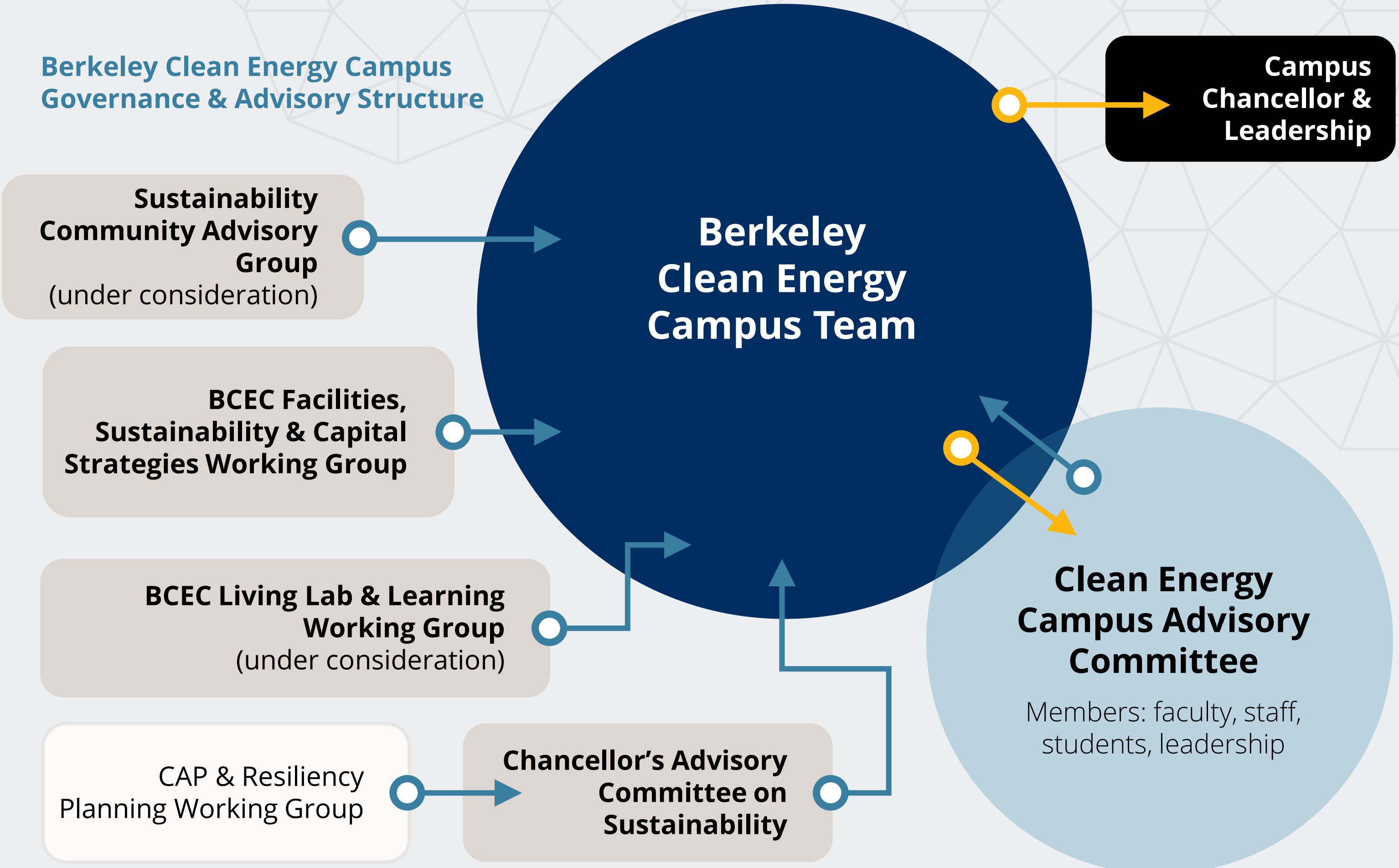
To increase project visibility, over 100 students also reached out to lawmakers, urging immediate action on climate change and advocating for the state's financial investment. These collective efforts yielded incredible results, with the **state approving $249 million in state-backed debt for the Berkeley Clean Energy Campus**, acknowledging its significance and potential impact.

Community Engagement

Community Engagement



Berkeley Clean Energy Campus Governance & Advisory Structure



The Berkeley Clean Energy Campus (BCEC) project has prioritized engaging various stakeholders, including administrators, faculty, researchers, and students, in an inclusive and campus-wide conversation.

To facilitate effective guidance, activities and structures have been developed to provide recommendations on the initiative to the Chancellor and other campus leadership that factor in a diverse set of stakeholder input.

One avenue for this engagement has been the establishment of a BCEC Advisory Committee. The Advisory Committee includes faculty, staff, students, and campus administrators who provide a broad range of expertise and perspectives. This committee has actively reviewed the financial and engineering study outcomes, while also exploring research opportunities associated with the project. Moreover, the project has sought the expertise of student groups like BEACN, an undergraduate consulting firm affiliated with the Haas School of Business, to assess the feasibility of using renewable hydrogen for backup power. The project leads have been in close contact with the UC Berkeley Green New Deal

Community Engagement

student advocates, who have voiced their support for the expedited closure of the cogeneration plant. The group holds student representatives on the advisory committee and several members have been instrumental in project advocacy with the State.

Attention to faculty and researcher engagement has been front and center. This has included presentations and discussions with the Academic Senate and about 80 faculty members have been invited to meetings updating them on the initiative and soliciting their feedback. The breadth of engagement from expert faculty has been impressive. For example, Serverin Borenstein and Nancy Wallace - faculty with the Haas School of Business - advised on marginal costs and financial structures; Dan Kammen faculty with the Energy and Resources Group/Goldman School of Public Policy has suggested resources to examine technologies including geothermal, hydrogen, and long-duration batteries; and Ramamoorthy Ramesh faculty with Physics and Materials Science and Engineering and founding director of DOE's SunShot initiative has identified the value and purposes of the data that could be generated by the project.

Strategic meetings are also on-going with leaders and staff of regional and state agencies, to both inform and explore potential partnerships. Meetings with the General Managers of Bay Area Rapid Transit (BART) and water utility, East Bay Municipal Utility District and the CEO of Pacific Gas & Electric (PG&E) have highlighted mutual interests and potential shared opportunities.

Finally, the energy system team has created a dedicated website for the project that will be continually updated as design and construction progresses.

Community Engagement

Living Lab

From the outset, it has been recognized that the Berkeley Clean Energy Campus initiative is not only a transformative infrastructure project but also a profound opportunity for research and learning

Berkeley's new clean energy system presents a unique opportunity for students, faculty, and other researchers to both contribute and advance their knowledge in renewable energy, project finance, and other fields. The initiative is focused on including the campus brain-trust in the system design and continued discovery during the entire lifespan its operations. The intention of a BCEC living lab is to build mutually beneficial project partnerships between the energy operations and the research and teaching enterprises.

During the spring of 2024, UC Berkeley will continue exploring other research and learning opportunities through a series of stakeholder engagement efforts with faculty, staff and students. These initial ideas will be integrated into the design of the infrastructure and plant to help enable future collaborations.

In 2022, a UC Berkeley team led by Civil Engineering professor Kenichi Soga in partnership with the Office of Sustainability applied for U.S. Department of Energy funds to develop campus geothermal energy storage potential that would support the Berkeley Clean Energy Campus project’s heating system. While UC Berkeley did not receive the funding, the campus application process developed equity-focused partnerships with campus groups such as the Labor Center Green Economy Program, the Building Efficiency for a Sustainable Tomorrow (BEST) Center, along with scientists and engineers from Lawrence Berkeley National Laboratory that will be utilized in future grant applications.

The thermal properties below campus are well-suited for implementing a Ground Source Heat Pump system

UC Berkeley Civil and Environmental Engineering Professor Kenichi Soga led a research project digging a 400-foot borehole near University House on campus and found that the thermal properties below campus are well-suited for implementing a Ground Source Heat Pump system. The research also found that conducting deep borehole drilling on campus is a relatively straightforward process due to the soil profile.

This research helped lead to the BCEC to include geothermal heat exchange into the design of the new energy system.

Link to Berkeley News article

Community Engagement

Just Transition

UC Berkeley is committed to a **just transition** for the BCEC project, which entails ensuring that the shift to a low-carbon economy is **fair**, **inclusive**, and **equitable** for workers and communities impacted by the transition.

The university recognizes that as certain industries or technologies contributing to climate change are phased out, workers in those sectors may face job displacement. Additionally, communities dependent on these industries may encounter economic hardships.

A just transition approach aims to support affected workers and communities by providing retraining, reskilling, and job placement assistance. It also focuses on creating new economic opportunities in clean energy sectors. This approach ensures that workers and communities can actively participate in and benefit from the emerging green economy. UC Berkeley recognizes decarbonizing the campus energy systems will require upskilling and changes to existing jobs and will create new positions and opportunities for staff. The university is dedicated to ensuring that there is a net gain for employment opportunities resulting from the implementation of the BCEC and that those opportunities are equitably distributed.

Throughout the winter and spring of 2024, UC Berkeley will be assessing the labor and equity impacts of the BCEC through research and stakeholder engagement. Listening sessions and focus groups will be held to hear from staff on the ground most impacted by the transition as well as leaders across the campus engaged in climate and environmental justice issues. Lessons learned from this process will inform equity indicators that will be used to track implementation and ensure goals are met for job creation and community **co-benefits**.

The campus is also committed to promoting and increasing participation of Small Business Enterprises (SBEs) and Disabled Veteran Business Enterprises (DVBEs) in purchasing and contract business, subject to any applicable obligations under state and federal law, collective bargaining agreements, and university policies. The campus regularly communicates with interested contractors and consultants to provide information about finding opportunities to work at the campus and encourages them to respond to the annual announcement soliciting interest to perform services. Providing qualified SBEs with the maximum opportunity to participate will be encouraged with the selected design professionals and contractors to meet 25 percent participation. Additionally, as part of the Inflation Reduction Act tax credit program, construction contracts will include prevailing wage (something the UC system already requires) and contracting with firms that offer apprenticeship programs.

UC Berkeley's commitment to a just transition further reinforces the university's dedication to social responsibility, environmental stewardship, and sustainability. By prioritizing fairness and inclusivity, the project can set an example for other initiatives and contribute to a more equitable and sustainable future for all.

Next Steps

Next Steps

The next steps for the Berkeley Clean Energy Campus initiative will include the following:

- Finalize project design
- Secure funding
- Begin construction on Phase 1
- Install distributed energy resources
- Decommission existing cogeneration plant

Multiple make-ready projects will be undertaken during Phase 1 to accommodate increased electrical demand and eventual central cooling towers. In 2024, the project will enter design to develop a detailed plan for the initial build-out of the BCEC, with construction expected to begin in 2025.

The Berkeley Clean Energy Campus initiative puts the campus on track to meet its carbon reduction goals, while also renewing and increasing the resilience, consistency and efficiency of the energy infrastructure. The multifaceted benefits and solutions of the initiative also include expansion of research and learning opportunities and support for the green labor transition.

Benefits

The benefits of the Berkeley Clean Energy Campus can extend beyond campus:

the initiative will serve as a model, demonstrating the transition to a clean energy system on the scale of a medium-sized city.

In addition, the BCEC will generate hundreds of regional construction jobs at the prevailing wage. The project will also facilitate training programs and apprenticeships for those who are interested in transitioning from traditional infrastructure and building-related trades to segue into skilled green-energy jobs. UC Berkeley intends to share its BCEC journey with others seeking to rapidly decarbonize and to demonstrate to the world that meaningful, large-scale solutions to climate change are doable when a community is committed to the task.

Acknowledgements

Acknowledgements

UC Berkeley would like to recognize the following groups and people for their contribution to the Integrated Resource & Activation Plan (IRAP) for the Berkeley Clean Energy Campus initiative.

With a special thanks to three generous donors who funded the IRAP – in the interest of helping UC Berkeley find the pathways to implement deep and transformational carbon reduction solutions. And to Chancellor Carol T. Christ for her leadership and prioritization of Berkeley's decarbonization efforts.

UC Berkeley

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- Ben Hermalin, Executive Vice Chancellor and Provost
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- David Robinson, Chief Campus Counsel
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- Holly Doremus, Chair of CAPRA, Academic Senate
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UC Berkeley Chancellor's Advisory Committee on Sustainability - CACS (2022-2024) Link to more info

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This report was prepared by JLL for UC Berkeley as a synthesis of prior reports, research and work that has been put into the Berkeley Clean Energy Campus Integrated Resource & Activation Plan (IRAP)

Appendix

- Glossary
- Affiliated Engineers, Inc. - Berkeley Clean Energy Campus Integrated Resource & Activation Plan (IRAP)

Glossary

Advanced Utility Controls – sophisticated systems that enable precise monitoring and optimization of various utility functions within a building, leading to improved energy efficiency, cost reduction, and occupant comfort.

Battery Energy Storage Systems – the technology of storing electrical energy in batteries, allowing it to be used later and providing backup power during outages or peak demand periods.

Cap-and-Trade – market-based mechanism that aims to reduce greenhouse gas emissions by establishing a cap on the total emissions allowed and enabling the trading of emission allowances between companies to incentivize emission reductions. This is a key component of California's approach to greenhouse gas reduction, which limits emissions from certain industries.

Climate Change – change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and natural climate variability over time.

Co-Benefits – additional positive outcomes that result from implementing actions related to decarbonization planning.

Cogeneration Plant – facility that simultaneously generates electricity and steam for the UC Berkeley community by using natural gas as its fuel source.

Cooling Towers – large structures used in industrial and commercial settings to extract heat from process or HVAC (heating, ventilation, and air conditioning) systems by allowing water to evaporate, thereby cooling the circulating fluid and facilitating efficient heat transfer.

Critical Loads – essential electrical equipment and systems within a facility that must be continuously powered.

Distributed Energy Resources (DERs) – small-scale power generation and storage technologies, such as solar panels, wind turbines, fuel cells, and batteries, that are deployed close to the point of consumption, providing alternative energy sources and a more decentralized and resilient energy system.

Fuel Cells – electrochemical devices that convert the chemical energy from a fuel, such as hydrogen, into electricity through a reaction with oxygen, offering a clean and efficient alternative to traditional combustion-based power generation.

Geothermal – relating to or utilizing the heat of the earth’s interior.

Geothermal Heat Exchange – system that utilizes the consistent temperature of the ground or water beneath the Earth's surface to provide heating and cooling for buildings.

Greenhouse Gas (GHG) Emissions – gases in the atmosphere that absorb radiation causing the planet’s surface to warm to a temperature above what it would be without its atmosphere. The primary greenhouse gases in Earth’s atmosphere are water vapor, carbon dioxide, methane, nitrous oxide, and ozone.

Green Hydrogen – hydrogen produced through the process of electrolysis using renewable energy sources.

Glossary

Heat Pump – device that transfers heat energy from one location to another by utilizing energy input, typically electricity, to move heat from a colder environment to a warmer one.

Heat Recovery Chillers – HVAC systems that simultaneously provide cooling and utilize waste heat generated from the cooling process for supplemental heating or other applications, improving energy efficiency by recovering and repurposing heat.

Heat Recovery Technologies – systems and processes that capture and reuse waste heat generated by industrial processes, HVAC systems, or other sources, converting it back into useful energy for heating, cooling.

Inflation Reduction Act (IRA) – significant piece of climate legislation, introduced in 2022, offering funding, programs, and incentives to drive and accelerate the clean energy transition.

Just Transition – equitable approach towards greening the economy in a way that is as fair and inclusive to everyone involved, ensuring fair treatment and opportunities for affected workers and communities.

Living Lab – the use of campus as a living laboratory which integrates the academic and operational spheres of the university. This philosophical approach benefits the research and educational mission of the University of California and creates experiential learning and applied research opportunities, while enhancing the campuses' ability to address real world sustainability challenges.

Microgrid – localized and independent electrical system that can operate autonomously or connect to the larger power grid, incorporating renewable energy sources, energy storage, and advanced control technologies to provide reliable and efficient power.

Power Purchase Agreement (PPA) – long-term electricity supply agreement between the power producer and customer in which a third-party developer installs, owns, and operates an energy system on the customer's property.

Scope 1 Emissions – direct emissions generated from the campus cogeneration plant, purchased natural gas, emergency generators, campus fleet, and emissions from refrigerants.

Scope 2 Emissions – indirect emissions, such as purchased electricity.

Scope 3 Emissions – indirect emissions from sources not owned or directly controlled by an institution, but related to the institution's activities, such as business travel and commuting.

Social Cost – comprehensive economic and societal impacts arising from a particular activity or decision, considering not only direct financial costs but also broader considerations such as environmental degradation, public health effects, and social inequalities.

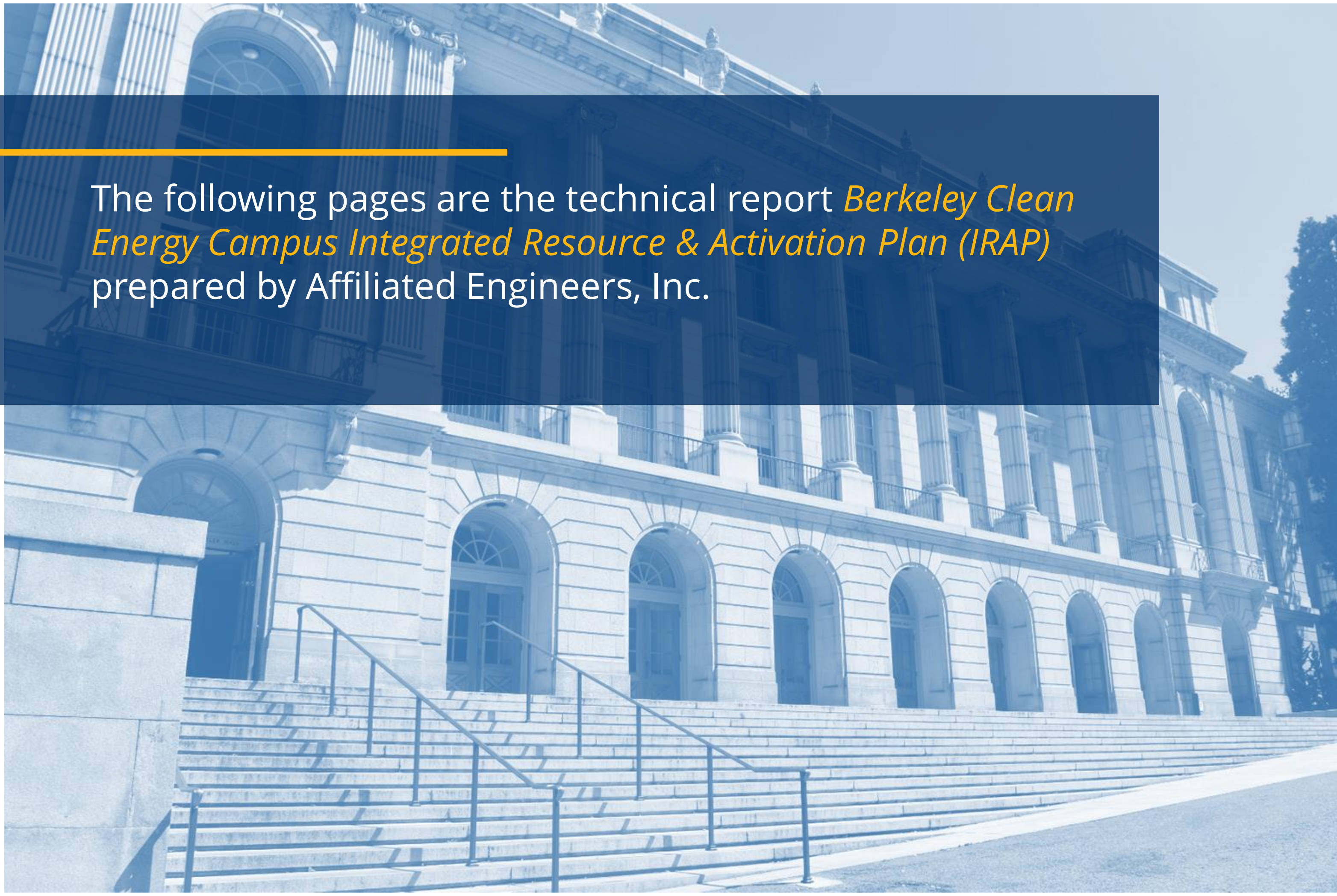
Solar Photovoltaics (PV) – clean energy technology that converts sunlight directly into electricity, commonly in the form of solar panels.

Substation – component of electrical power systems that transforms high-voltage electricity from a transmission system into lower voltages suitable for distribution to consumers.

Thermal Energy Storage – process of capturing and storing thermal energy during times of excess or low demand, and then releasing it when needed for heating, cooling, or other thermal applications.

Water-to-Water Heat Pumps – HVAC systems that transfer heat energy from a water source and use it to provide heating and cooling for buildings or to supply hot water.

Affiliated Engineers, Inc. Report



The following pages are the technical report *Berkeley Clean Energy Campus Integrated Resource & Activation Plan (IRAP)* prepared by Affiliated Engineers, Inc.

Berkeley
UNIVERSITY OF CALIFORNIA

Berkeley Clean Energy Campus Integrated Resource & Activation Plan (IRAP)

NOVEMBER 3, 2023 (public version for distribution)

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1.1 CLEAN ENERGY CAMPUS VISION

Overview:

The clean energy plan campus vision is to provide UC Berkeley with clean, resilient power and thermal utilities to replace the existing fossil-fuel powered cogeneration plant and aging steam distribution system.

Specific goals for the clean energy plan include;

- Eliminate fossil fuel use and on-site combustion
- Reduce scope 1 and 2 carbon emissions
- Renew and upgrade aging infrastructure
- Provide a resilient microgrid and on-site renewable energy
- Optimize the plan for life-cycle costs, leverage state funding and apply innovative financing
- Optimize land use and provide community benefits including research and learning opportunities

At the heart of the clean energy campus will be a new Electrified Heating and Cooling Plant (EHCP) located at the North Field site. 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 microgrid as a group of interconnected loads and DERs capable of operating in island mode or interconnected with the utility (PG&E).

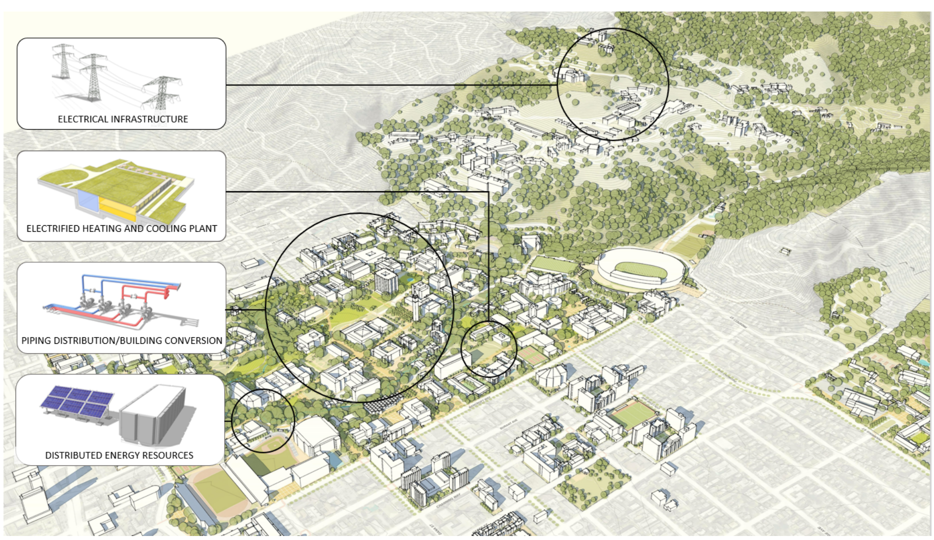


Figure 1.1.1 Campus Clean Energy Plan Overview: Overview of associated scope across campus

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 approximately 50% of the campus over to the new EHCP with a focus on academic buildings with significant steam consumption. 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 Electrified Heating and Cooling Plant, the campus will see an estimated 70% reduction in scope 1 carbon emissions from fossil fuel combustion.

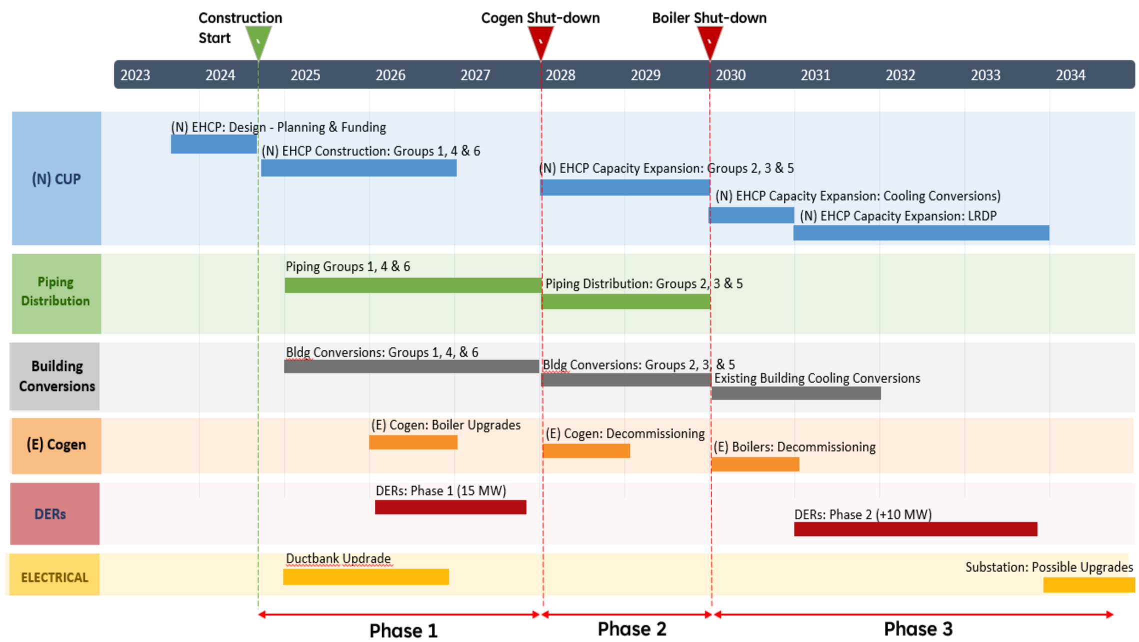


Figure 1.1.2a Clean Energy Plan Schedule

Figure 1.1.2b Clean Energy Plan Carbon Reduction

The project is generally split into the component parts defined in more detail below;

- Electrified Heating and Cooling Plant
- Piping Distribution
- Building Conversions
- Distributed Energy Resources
- Electrical infrastructure and microgrid

Electrified Heating and Cooling Plant:

The Electric Heating and Cooling Plant will be the new central hub for the generation and distribution of thermal utilities to serve the campus. 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 the North Field. 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.

8M Gallons of 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 North field site with a replacement recreation field while the plant itself will serve as a living lab, providing educational benefits.

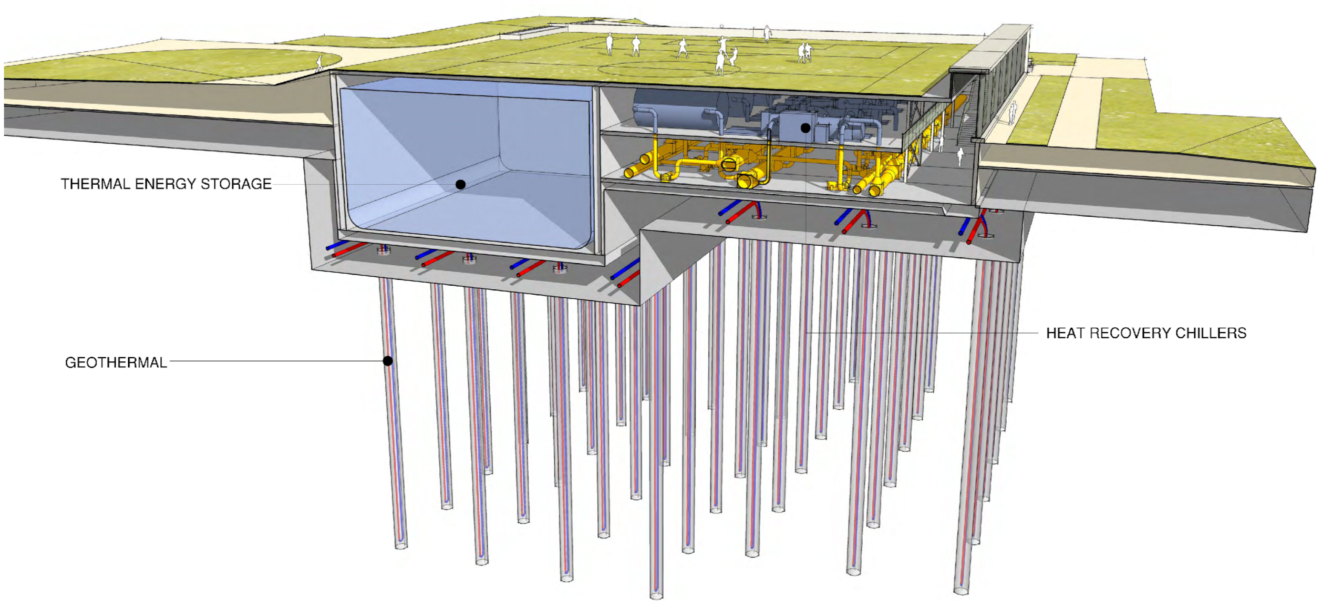


Figure 1.1.3 Electrified Heating and Cooling Plant overview

Piping Distribution & Building Conversions:

The campus distribution and building conversions scope is divided into Groups of buildings that consider;

- Mix of academic / non-academic buildings
- Buildings with existing steam cooling
- Proximity to Electric Heating & Cooling Plant
- Alignment with existing steam infrastructure mains

Figure 1.1.4 Distribution and Building Conversions Grouping

Groups 1, 4 and 6 collectively represent 75% of the campus steam load with Groups 4 and 6 within regions of the steam system that 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 with Groups 2, 3 and 5 following.

The piping distribution will comprise underground chilled water (CHW) and heating hot water (HHW) pipes emanating from the EHCP and connecting to buildings identified in each group. Once complete, the distribution piping will form a loop to provide additional resiliency. Piping materials will be further evaluated during the design phase. Trenching and piping distribution routes will be coordinated with site accessibility improvements where feasible.

Building conversions scope will align with the phasing of the piping distribution and will comprise:

- 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

Distributed Energy Resources and Campus Electrical Upgrades:

Campus electrical distribution upgrades are required to support the new Electrified Heating and Cooling Plant, Distributed Energy Resources and future projected growth of the campus as part of the Long Range Development plan (LRDP).

Distributed Energy Resources (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;

- 7.5 MW of fuel cell installed in the vicinity of the existing cogeneration plant
- 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) at Strawberry Canyon

Electrical infrastructure upgrades will be phased to align with the projected electrical load growth and installation of Distributed Energy Resources. Upgrade of the existing utility service capacity serving the campus (Hill Substation) is not anticipated to be required during the major phases of work connecting the existing 90 campus buildings and those in planning and construction to the clean energy system but is likely required to support the future campus growth (LRDP). Supplemental on-site clean power generation (DERs) will also be required to support the LRDP.

1.2 ELECTRIFIED HEATING AND COOLING PLANT

a. <u>Findings</u>

The North Field has been selected as a location for an Electrified Heating and Cooling Plant (EHCP) with heat recovery chillers. Concepts include locating thermal energy storage below grade with mechanical equipment rooms at grade and a recreation field or venue location at the rooftop level.

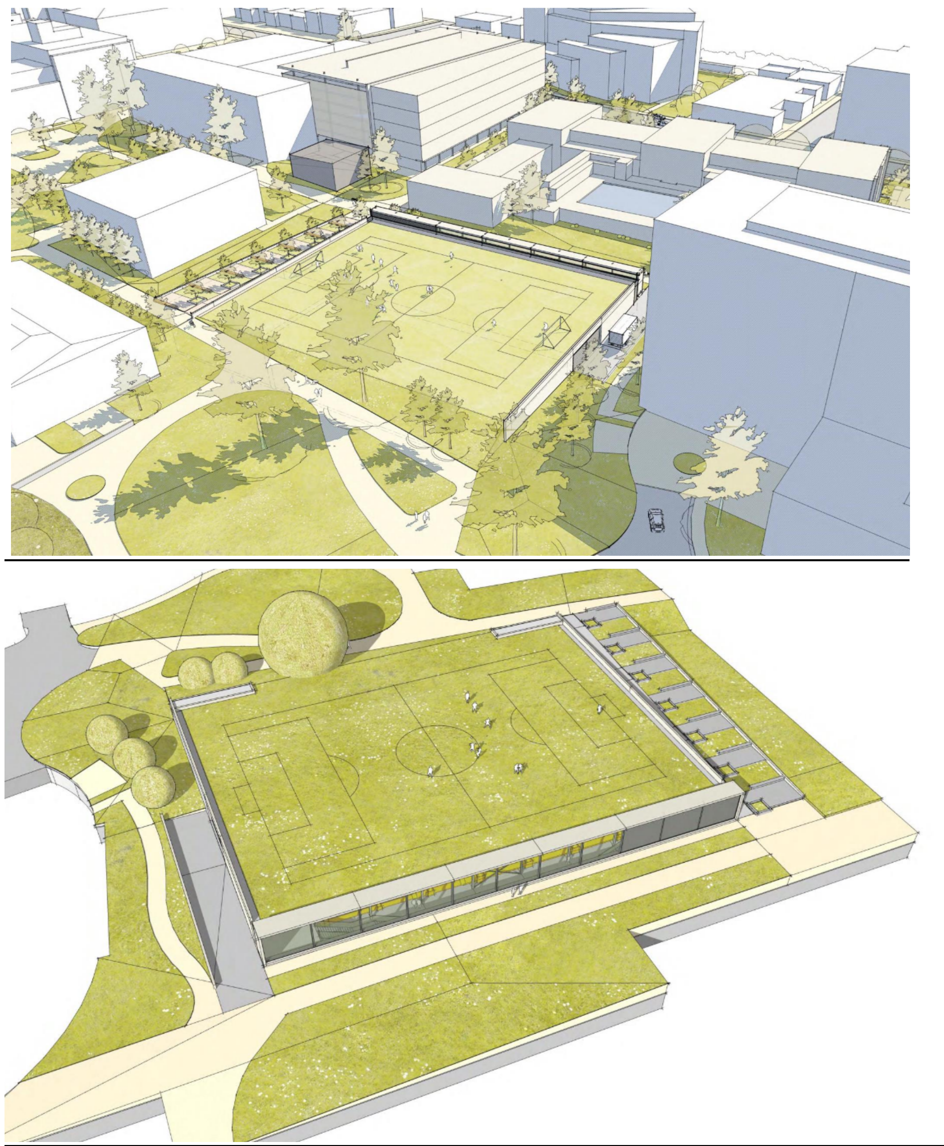


Figure 1.2.1a – North Field EHCP Campus Context

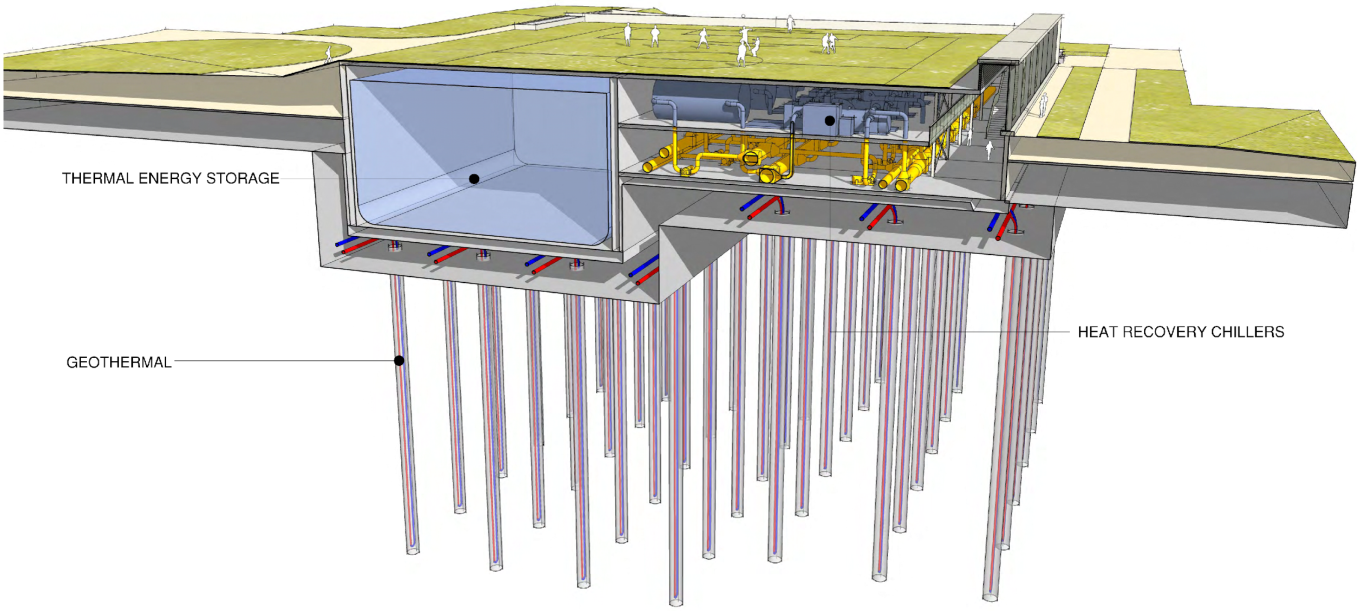


Figure 1.2.1b – Concept Rendering of Electrified Heating and Cooling Plant (EHCP) at North Field

b. <u>Background</u>

Thermal utilities on campus are centralized steam and distributed (building by building) chilled water. Campus buildings currently receive all heating from the cogeneration plant, a central location from which all steam is generated and distributed. This cogeneration process is fueled by natural gas and is responsible for the majority of UC Berkeley's scope 1 carbon emissions.

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 the following equipment;

- Absorption chillers (served with campus steam) and cooling towers
- Water-cooled chillers and cooling towers
- Air cooled chillers
- Packaged DX rooftop units

As the campus moves toward decarbonization, waste heat from the cooling process should be captured back at the Electrified Heating and Cooling Plant (EHCP) using heat recovery chillers where it can be reused for campus heating. This requires buildings to be connected to the EHCP via new campus chilled water infrastructure.

c. 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.

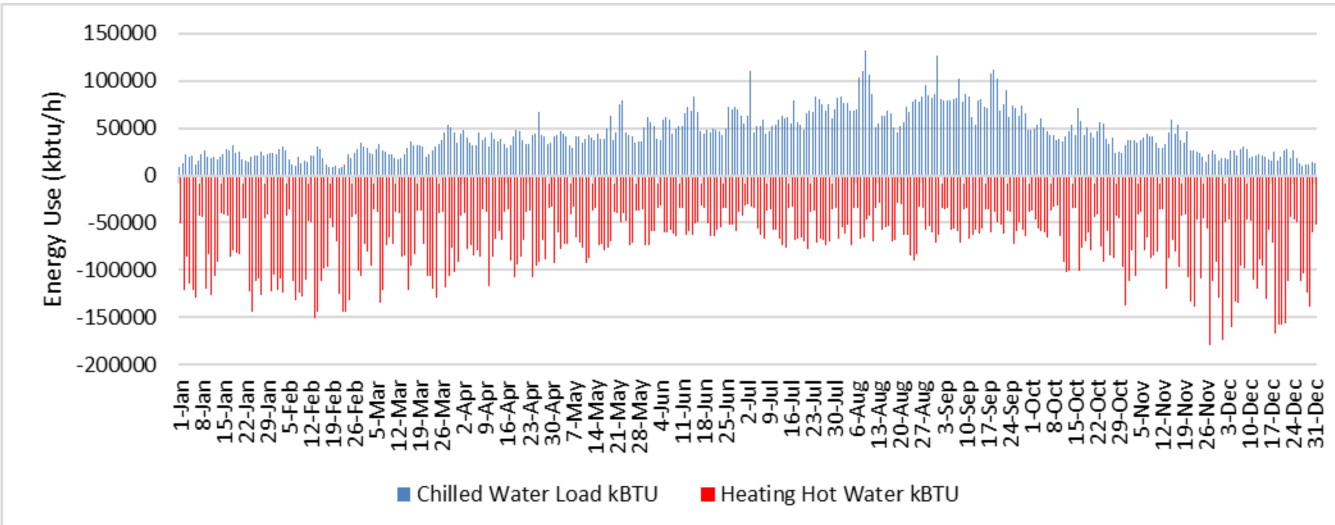


Figure 1.2.2 – Current Day Campus Thermal Utility Load Profile

Many buildings on campus do not currently have chilled water cooling. UC 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 UC Berkeley's Long Range Development Plan (LRDP) to include future additions and renovations on campus.

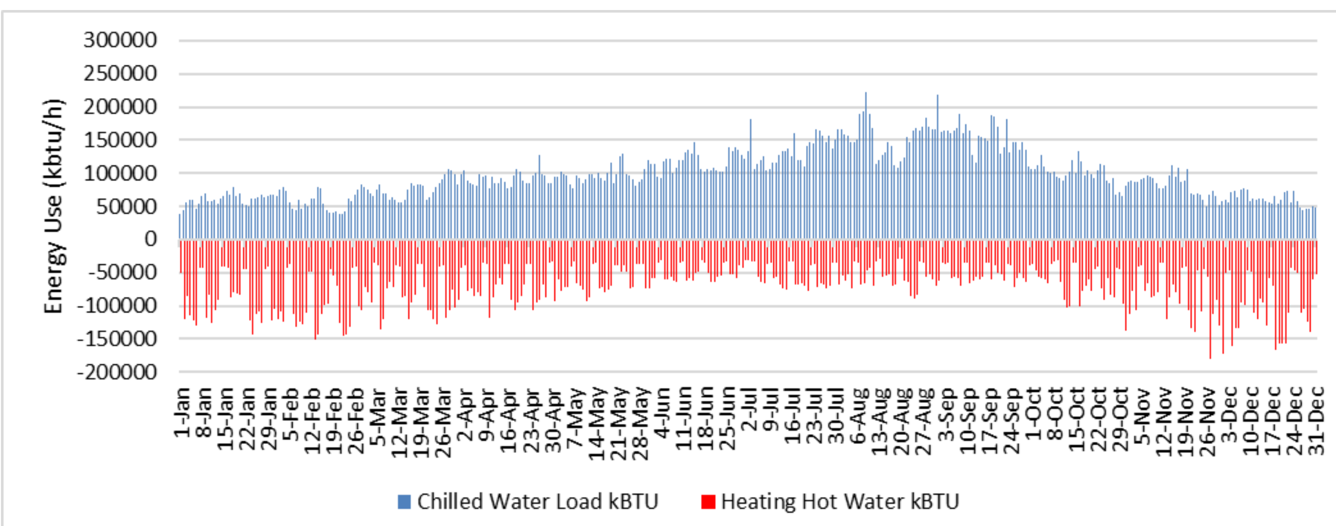


Figure 1.2.3 – Projected Future Campus Thermal Utility Load Profile

Existing Utilities – Steam:

The future load profile serves as a target for the new Electrified Heating and Cooling Plant (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 located in the southwest quadrant of campus. The HRSG provides a constant base of 70,000 pounds per hour and the boilers supplement based on demand. For periods of time through the summer the campus steam demand is less than the base provided by the HRSG. Excess steam is required to be vented to the atmosphere during these times to allow the cogeneration system to continue operation producing electricity.

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 Electric Heating and Cooling plant. 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 can be decommissioned.

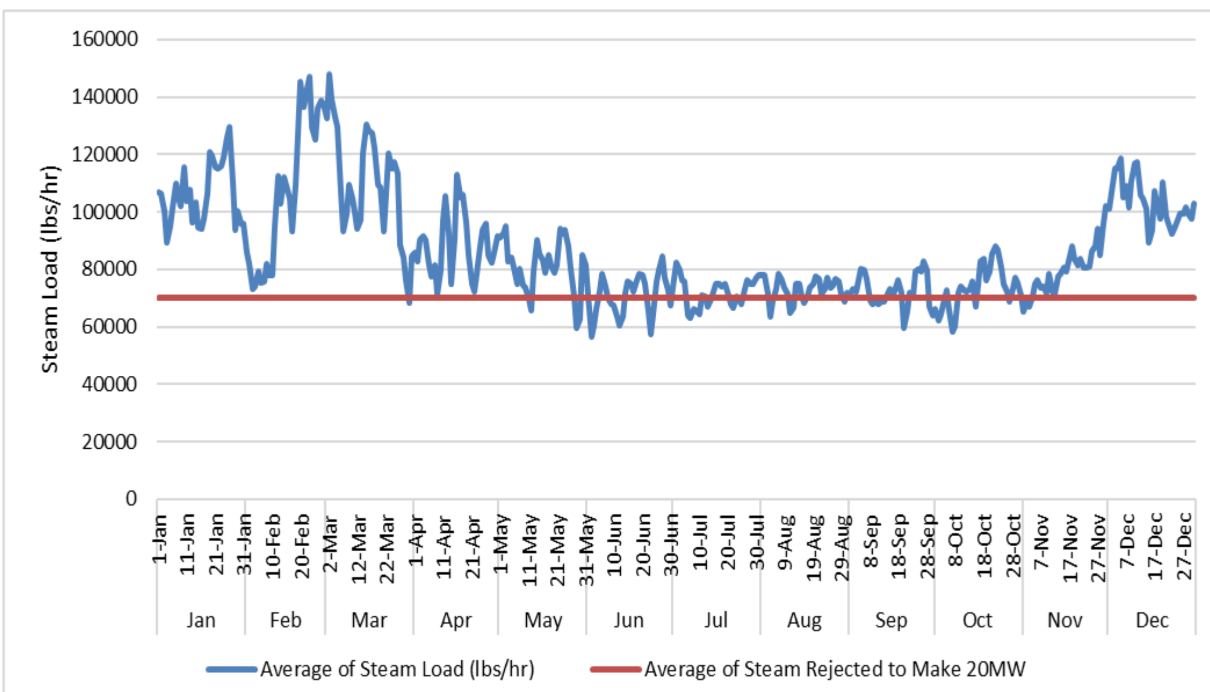


Figure 1.2.4 – Current Campus Steam Use

Existing Utilities – Chilled Water:

The UCB campus currently has approximately 53 water-cooled chillers distributed around campus, with capacities ranging from 25-1,400 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, AEI recommends incorporating existing distributed equipment from the following buildings which have / will have sizeable chiller plant installations (>500 Tons) with remaining useful life;

1. Satardja Dai
2. Stanley Hall
3. Koshland Hall
4. Li Ka Shing
5. Valley Life Sciences
6. Heathcock (proposed)
7. Gateway Hall (proposed)

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. 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 – Electrified Heating and Cooling Plant:

Different technologies were evaluated to efficiently generate and distribute heating hot and chilled water throughout campus. Heating generation by means of fossil fuels was not considered as part of this evaluation. The load profile used in each evaluation is shown in Figure 1.2.3 – Projected Future Campus Thermal Utility Load Profile.

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. A concept schematic is shown in Figure 1.2.5 – EHCP Thermal Utility Schematic.

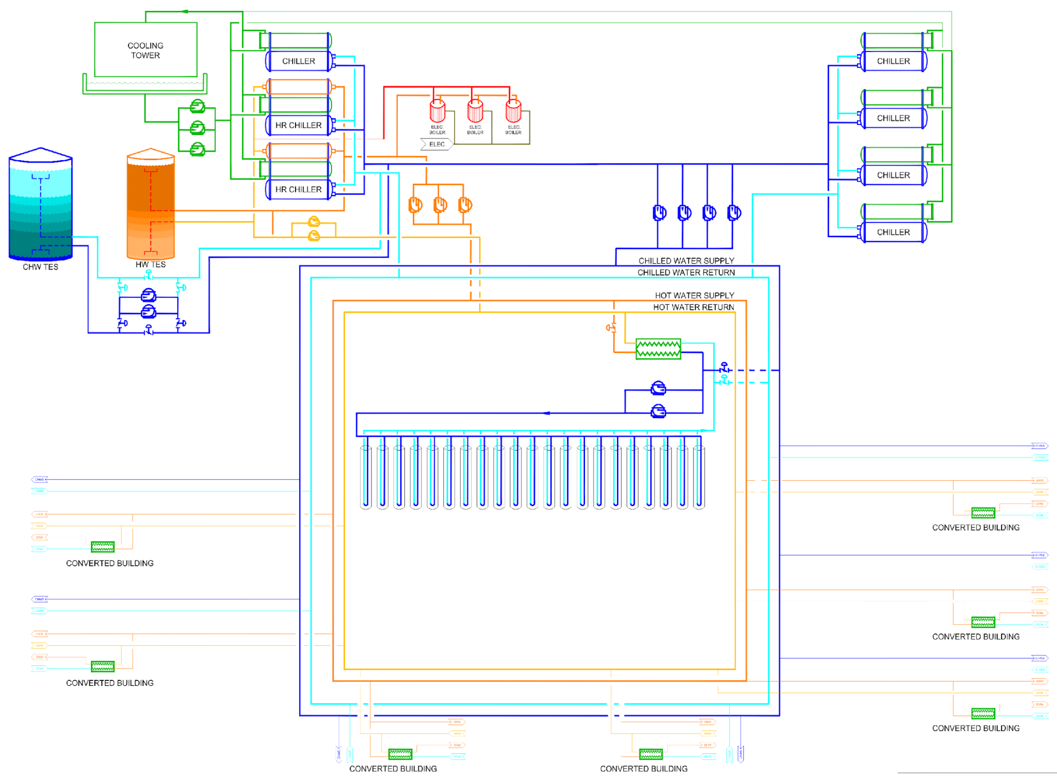


Figure 1.2.5 – Electrified Heating and Cooling Plant Thermal Utility Schematic

Because heat pumps generate heating and cooling simultaneously, proper equipment operation depends on a correct ratio of load to always exist. Incorporating thermal energy storage (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 1.2.6 - Typical Winter Week of Thermal Utility Dispatch shows how heat pumps used in conjunction with TES operate to meet the heating and cooling loads without the need for a supplemental boiler.

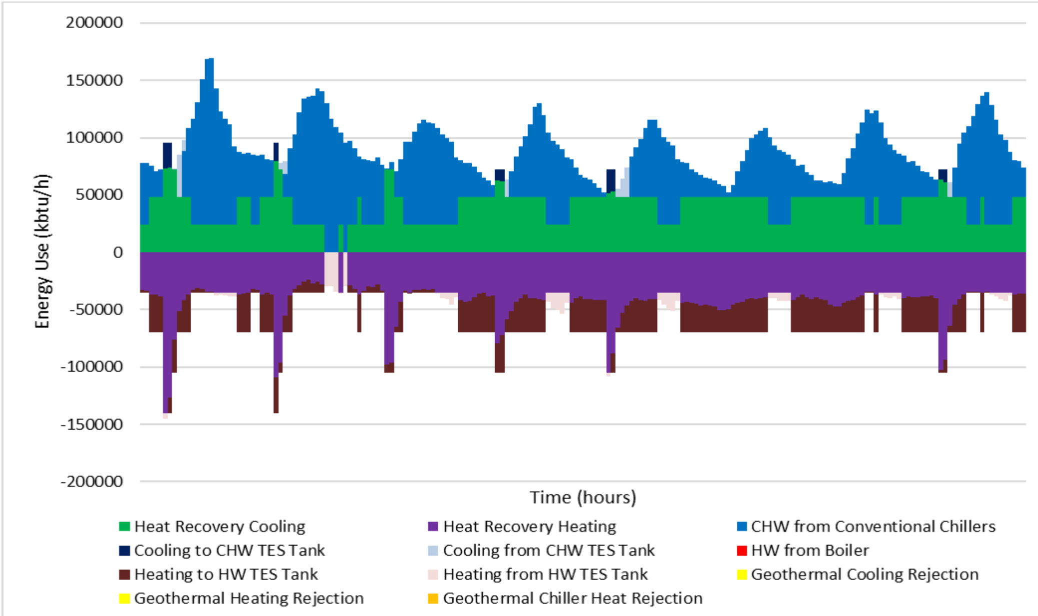


Figure 1.2.6 – Typical Winter Week of Thermal Utility Dispatch

In the summer, due to a reduced heating demand, a different operational strategy can be implemented to reduce energy cost. Figure 1.2.7 – Typical Summer Week of Thermal Utility Dispatch 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.

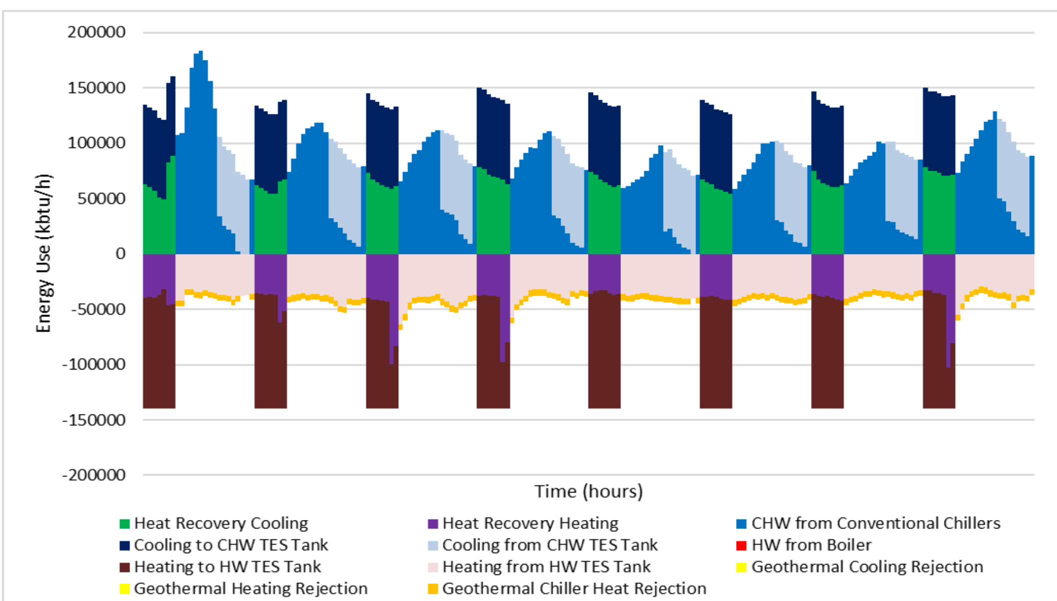


Figure 1.2.7 – Typical Summer Week of Thermal Utility Dispatch

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. To preserve space on top of the EHCP for a recreational field, central cooling towers serving the EHCP will be located at an adjacent or other site.

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 near University House on campus and determined that the underground thermal properties are well suited for implementing a geothermal system on campus. A thermal response test at the test site indicated an average thermal conductivity on 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, we assessed the available capacity and determined that the proposed geothermal system will contribute to approximately 5% 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.

1.3 BUILDING CONVERSIONS

a. Findings

There are approximately 90 buildings on campus that are heated by steam provided by the existing cogeneration facility. When the cogeneration facility is de-commissioned, the new Electric Heating and Cooling Plant (EHCP) will be the source of heat for all these buildings. The cooling systems in approximately 60 of these buildings will connect to the EHCP and provide a significant portion of the heating energy through heat recovery. These fundamental changes require specific changes within the existing building stock to adapt to the new approach:

- Remove the steam to hot water heat exchangers and replace with water-to-water heat exchangers.
- In steam-heated buildings remove the steam piping and radiators and replace with hot water piping and water-based heating elements.
- Remove most of the existing distributed chilled water cooling systems inside the buildings, and connect to the new campus chilled water infrastructure.
- Replace existing rooftop packaged DX cooling systems with chilled water air handling units and connect to the new campus chilled water infrastructure.
- Add local electric steam systems to serve autoclaves and glasswashers in science buildings.

For the purpose of cost estimating, the scope of work for the building conversions has been split into the following distinct packages.

1) Basic Conversions:
    a. Basement Heating Hot Water
    b. Rooftop Heating Hot Water
    c. Steam Heating to Hot Water Heating
    d. Steam / Heating Hot Water mix
    e. Basement Chilled Water
    f. Rooftop Chilled water

2) Specialty Conversions:
    a. Process Steam
    b. Process Cooling
    c. Packaged DX AHUs
    d. Swimming Pools

Buildings that do not currently have cooling will not have cooling added as part of the building conversions scope. However, chilled water laterals will be provided to each building to facilitate easy cooling additions in the future and the central plant and associated chilled water infrastructure will be capable of supporting cooling additions to all connected buildings on the campus.

b. Background

Decarbonization of the campus requires the elimination of fossil fuel consumption which necessitates shut-down and decommissioning of the cogeneration plant that currently provides steam for heating, hot water, process steam loads and some cooling (absorption cooling) across the campus. New and emerging heat pump and heat recovery technologies that replace steam as a heat mover operate at a lower temperature (140°F to 165°F). This shift will require weaning all the buildings on the central campus off steam for building and potable water heating, and in the science buildings, sterilization in autoclaves. In a significant paradigm shift, most of the heat needed will come from the buildings themselves, via the cooling systems that today are throwing the heat away via the cooling towers during the day. It is estimated that more than 80% of the campus heating energy (at full build out) can be recovered as waste heat from the campus cooling systems, the remaining auxiliary heat will be sourced from geothermal, exhaust source heat recovery (new labs buildings) and electric boilers at the EHCP.

Most of the buildings on the conversion list are on the core campus or immediately across the street from the core campus where the University in the past has negotiated the routing of steam and condensate piping across public streets; the assumption has been that new connections in the existing locations across city streets can be made as part of this project. There are other University buildings that are further from the core campus that were never served by the cogeneration facility, and for this effort have been excluded from the scope of this project. Due to the distances involved from the proposed location of the EHCP for many of these off-campus buildings, the economics and challenges will favor other, more localized decarbonization approaches.

Figure 1.3.1 - Giannini Hall Steam Radiators

Figure 1.3.2 - Stanley Hall Cooling Towers (1872 tons total): existing cooling towers in Phase 1 that will continue to be used to serve the campus

c. Analysis

To analyze the changes needed to the existing building stock, AEI's engineers toured the Mechanical, Electrical and Piping (MEP) systems of 72 buildings. Utilizing the as-built documentation for all buildings and the information gathered during the field surveys, AEI assessed the changes required in each building to adapt them to receive Heating Hot Water and Chilled Water from the EHCP.

A cost model was developed based on this assessment, and each building was packaged based on similar needs. For example, buildings with existing heating hot water systems which would have new water-to-water heat exchangers placed in lieu of the existing steam-to-hot water heat exchangers were placed in one package and a cost model was built for this package. While in another cost package, we placed buildings heated by steam radiators which would need to have the existing steam and condensate piping within the building replaced with new heating hot water piping, which would be a more invasive and costly conversion. Below is a list of the packages that were needed for all the buildings in scope.

Basic Conversions:

HHW Packages (Roof and Basement): Remove Campus Steam/Building HHW Heat Exchangers add Campus Hot Water/Building HHW Heat Exchangers, reuse the bulk of the building HHW system. Additionally, DHW and IHW systems will be served by individual Campus HHW/DHW (IHW) Heat Exchangers (60 buildings)

CHW Packages (Roof and Basement): Remove existing building chillers, add Campus CHW/Building CHW Heat Exchangers, reuse the bulk of the building CHW system. (34 buildings)

Steam Packages: Remove existing building steam heating system, add Campus HHW/Building CHW Heat Exchangers, new HHW piping system, and new HHW heating coils, HHW baseboards heaters, etc. (23 buildings)

Specialty Conversions:

Process Steam: Replace Plant Steam for autoclaves, glasswashers, etc. with centralized electric steam boilers for buildings with 4 or more autoclaves, and local electric steam generators at each autoclave for buildings with less than 4 autoclaves. (10 buildings)

Process Cooling: Replace process cooling systems with a Campus CHW/Process Cooling HX and controls connecting to the existing process cooling piping loop in the building. (8 buildings)

DX Cooling AHUs: Remove air cooled DX AHU's and replace with AHU's with cooling coils, add all supporting CHW piping, pumps and Campus CHW/Building CHW HX if needed. (10 buildings)

Pool Heating: The HAAS Pavilion and Hearst Gym pool Steam/Pool water HX's will be removed and replaced with Campus HHW/Pool Water HX's. These need to be stainless steel due to the chlorine in the pools.

Numerous buildings fit into several categories, a large laboratory building like Li Ka Shing needs its heating hot water system converted, as well as its chilled water system and its process steam system which is needed for autoclaves and other sterilizing needs. All the categories were summed for all buildings by zones on the campus to arrive at the building conversion costs for each zone.

With cost models created for each building conversion types, and the types of conversions needed in each building, we attributed cost to each of the campus conversion sectors establish by the EHCP and distribution teams.

d. Temperature

The maximum HHW temperature available from the Electrified Heating and Cooling Plant (EHCP) will be 170°F, and on the building side of the HX's 165°F is expected. There are a number of buildings operating at temperatures higher than 165°F today. AEI's experience in other conversion projects is that for the most part this is a minor issue in the mild climate of California, but some heating elements might need to be changed or supplemented in these buildings.

UC 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 bulk of the buildings successfully handled the lower HHW supply temperature without cold complaints from the occupants. There were two building that needed 170°F (Birge Hall, and Physics South), and Barker Hall was found to need 180 F heating hot water supply temperature water to avoid cold complaints.

These are good results that mitigate concerns about the existing building stock's ability to operate at the temperatures that will be supplied by the new central plant. In AEI's experience the three buildings that did not successfully operate at 160°F will require additional examination, but we have found these can be attributed to control issues, balancing issues, or at the most undersized coils in a few zones of the building rather than a systemic building issue.

The return water temperatures of both CHW and HHW are keys to the performance of the EHCP. In many of the buildings during our site survey we observed that the "delta-T" (the temperature difference between the supply & return temperatures) needed improvement. This will require ongoing focus as the design progresses, historically changing 3-way valve, constant volume systems into 2-way valve variable volume systems, and otherwise eliminated by-pass of the thermal coils of water from the supply side to the return side is the effort that creates the greatest improvements for the least cost.

Creating design standards for new buildings being built on campus so they are compatible with the EHCP is in progress at this time.

1.4 MECHANICAL DISTRIBUTION

a. Findings

AEI developed a new thermal distribution system that would distribute heating hot water and chilled water to buildings on campus from the new Electrified Heating and Cooling Plant (EHCP). Through field surveys and consideration of existing utilities, a large, looped network comprised of smaller sub-loops for resiliency and operational efficiency was developed to distribute thermal utilities. There are a total of 6 groups of buildings that will be connected to the new chilled water and heating hot water distribution networks with groups 1, 4A, 4B, and 6 recommended as the first group of distribution and building conversion for implementation. These groups were selected first for highest thermal loading (57%% of total chilled water and 51% hot water loads) of the new EHCP and to connect to existing chiller assets on campus. This also aligns with the campus steam system deferred maintenance prioritization of the North Campus Loop and Lower West Campus Loop to avoid significant repair costs.

There are also segments of main distribution piping that do not necessarily have to be installed if looping is not a critical feature desired at the time. Though pipe material is another option to evaluate, the analysis has been limited to plastic pipe for chilled water and steel pipe for heating hot water at this time.

b. Background

UC Berkeley currently operates a steam distribution system that services most buildings on campus. Steam is generated at the cogeneration facility and distributed through an increasingly deteriorating piping network. The UCB steam system is a looped system in which distribution "laterals" are connected to distribution "mains" that can flow in two directions. A main will be defined as the larger piping that connects thermal utilities from the new EHCP to the campus. A lateral will be defined as the piping that connects the main to a building or to a smaller subset of buildings in the new system.

The new chilled water and heating hot water systems each require a supply pipe and a return pipe to the EHCP for a total of four pipes within any given trench. Though a looped system is not necessary to provide thermal utilities to a building, a looped system is recommended as it provides several key benefits:

- Reduced service interruptions caused by sudden pipe breaks and outages
- Reduced pumping power due to reduced fluid velocity and consequent reduced head loss
- Increased maintenance flexibility

AEI analyzed potential locations for pipe routing by conducting field walks, evaluating existing features on campus that are advantages or challenges for pipe installation, and reviewing utility maps. Figure 1.4.2 shows existing utilities congestion in campus roads and sidewalks and surface hardscape/landscape features that are difficult to restore to original conditions without significant work.

Figure 1.4.2 – Image of Congested Existing UG Utilities (left) & Image of Surface Hardscape/Landscape Features (right)

c. <u>Analysis</u>

Pipe material, looping configurations, and building groupings were the focus of the distribution analysis. AEI evaluated two options for pipe materials and insulation:

- Option 1 (removed from study) – represents an alternate thermal utility network
- Chilled Water: PVC C900 with no insulation
- Heating Hot Water: Polyethylene of Raised Temperature with Powder Insulation
- Option 2 (Base Case) – represents a typical thermal utility network
    - Chilled Water: PVC C900 with no insulation
    - Heating Hot Water: Standard Schedule Steel with Pre-insulation

After reviewing the pressure gradient of the campus in further detail, Option 1 was removed from consideration until a detailed study could be performed to confirm that polyethylene of raised temperature can meet the pressure/temperature related performance requirements for the campus.

Grouping for the distribution systems follows the same grouping strategy for building conversion that is defined by the desired thermal loading of the new EHCP plant. The table below identifies the building groupings and peak cooling water and heating loads for each building.

Building Name	Group	Peak Cooling Load (CHW TONS)	Peak Heating Load (MBH)
CAMPBELL	1	231	1729
DONNER LAB	1	375	2809
STANLEY	1	812	6087
BIRGE	1	251	1884
BOWLES	1	113	2211
LEWIS	1	182	1363
GILMAN	1	68	1325
GREEK THEATER	1	18	357
Physics North and South	1	395	2961
GIAUQUE LAB	1	69	520
STERN	1	116	696
LATIMER	1	488	3659
PIMENTEL	1	22	436
TAN	1	310	2322
HILDEBRAND	1	342	2563
DATA CENTER	1	2000	0
PIEDMON2232	2	10	197
Kevin Chou Hall	2	113	2198
PIEDMON2224	2	11	214
PIEDMON2240	2	12	237
LAW	2	427	8326
CHEIT	2	49	964
HAAS STU BLD	2	147	2871
PIEDMON2234	2	6	126
PIEDMON2222	2	6	120
COLLEGE2251	2	22	436
STADIUM	2	0	0
SIMPSONSAHPC	2	215	4190
MINOR ADDITN	2	148	1110
MINOR	2	123	924
FAC CLUB	2	55	1064
I HOUSE	2	247	1482
SIMON	2	56	1085
MORRISON	2	109	814
HERTZ	2	46	905
HARGROVE LIB	2	45	872
SENIOR	2	5	88
Anthropology and Art Practice Building	2	181	3534
FAC CLUB W	2	28	554
WURSTER	2	593	4449
CALVIN LAB	2	88	663
ESHLEMAN	3	102	1986
ART GALLERY	3	6	121
SPROUL	3	171	3328
ALUMNI HOUSE	3	24	460
HAAS PAVIL	3	397	1905
REC SPRT FAC	3	313	1504
HEARST GYM	3	207	994
ARCH AND ENG	3	8	155
ANTHONY	3	3	60
UCB ART MUSE	3	158	3084
Social Sciences Building	3	297	5796
CHAVEZ	3	160	3120
KING UNION	3	158	3087
ZELLERBACH	3	236	4594
STARR LIB	4B	101	1976
SUTARDJA DAI	4A	413	3094
NORTH GATE	4B	36	706
SODA	4B	292	2192
MCLAUGHLIN	4B	76	1482
BLUM HALL	4B	37	714
DAVIS	4A	367	2756
CORY	4A	549	4121
HAVILAND	4B	78	1531
HEARST MIN	4A	377	2829
HESSE	4B	110	827
O'BRIEN	4A	110	826
MCCONE	4B	190	3708
ETCHEVERRY	4B	473	3546
BECHTEL CNTR	4A	74	1439

Life Sciences ADDITION (WEILL)	5	538	4036
DURANT	5	34	656
CALIFORNIA	5	87	1690
DWINELLE	5	470	9158
GARDNERSTACK	5	291	5683
DOE ANNEX	5	204	3972
MOFFITT	5	201	3917
DOE LIBRARY	5	256	4995
MOSES	5	63	1225
VALLEY LSB	5	1122	8418
DWINELLE AN	5	13	255
SOUTH	5	47	912
STEPHENS	5	90	1762
WHEELER	5	215	4183
WARREN	6	106	2071
WELLMAN	6	117	878
NW AN FACIL	6	141	1057
MULFORD	6	249	1868
GIANNINI	6	106	2061
HILGARD	6	205	1541
MORGAN	6	151	1133
OXFORD NRLAB	6	18	133
UNIV HOUSE	6	24	145
LI KA SHING	6	589	4414
OXFORD IN GH	6	11	86
OXFORD INSCT	6	9	69
OXFORD RES	6	177	1325
GPB TEACH	6	70	526
BARKER	6	230	1722
KOSHLAND	6	410	3074

There are limited segments of pipe dedicated to looping for resiliency and operational efficiency. Figure 1.4.3 represents the groupings identified in the full build-out of the campus, inclusive of all the segments needed for full looping:

Figure 1.4.3 -Grouping Identification Map

The proposed initial grouping for ability to connect to existing assets and maximize thermal loading for the new central plant is defined as groups 1, 4A, 4B, and 6 without full looping as shown in Figure 1.4.4 below.

Figure 1.4.4 – Groups 1, 4A, 4B, & 6 with no Alternates

A recycled water distribution network (Figure 1.4.5) proposed as part of the UC Berkeley Resilient Water Plan has overlapping corridors with the proposed chilled water and heating hot water piping. Some corridors were adjusted to increase the quantity of overlapping trench to take advantage of shared costs in trenching, surface restoration, and general conditions. The current layout plans for distribution to be provided in all overlapping trenches with lateral connections to future buildings, buildings with significant planned MEP renovations per the LRDP, the EHCP for cooling tower make-up, and large landscaped areas that require irrigation water.

UCB will connect to a proposed recycled water connection from EBMUD at the south end of campus to reduce the burden of collecting and producing recycled water on campus.

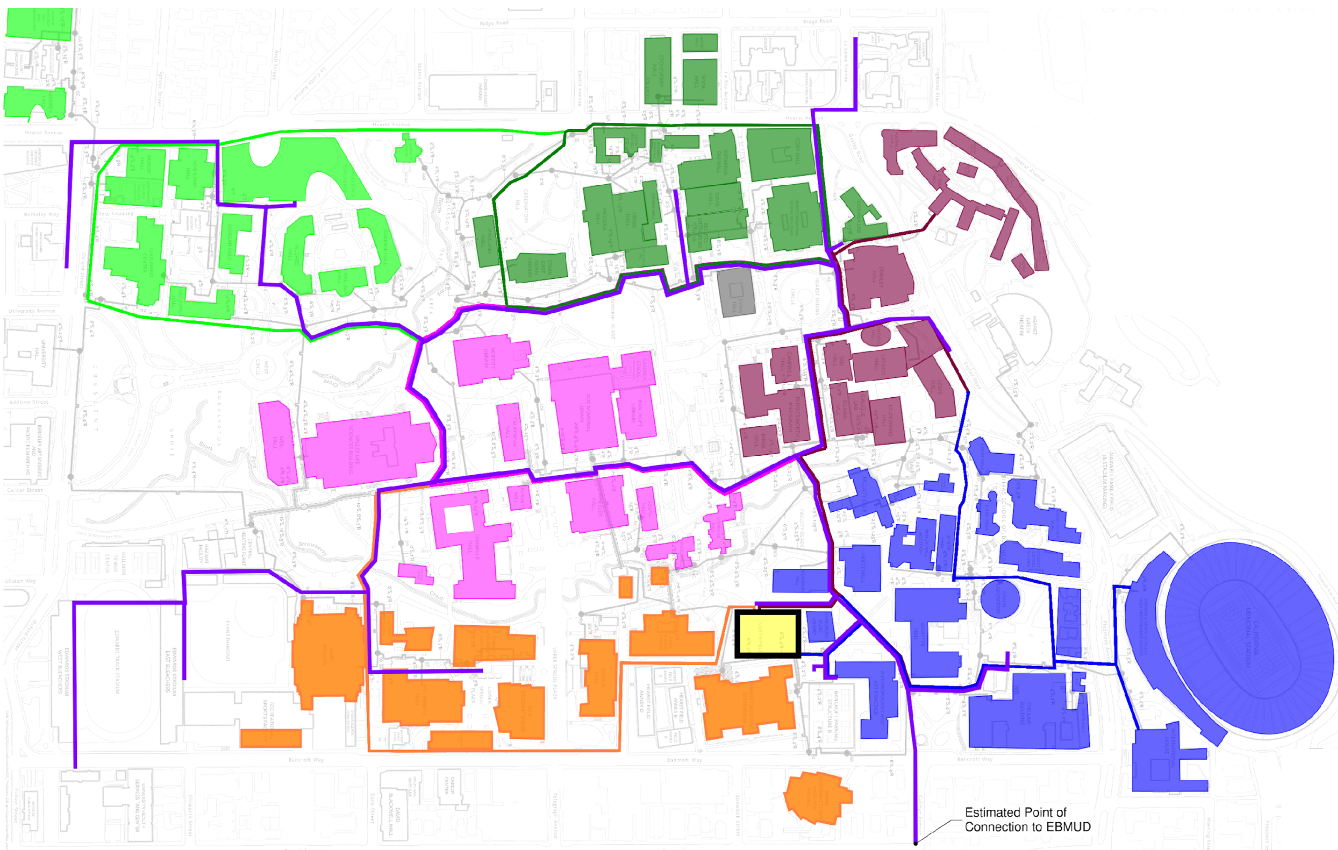


Figure 1.4.5 – Recycled Water Distribution Map

1.5 ELECTRICAL DISTRIBUTION

a. Findings

UC Berkeley maintains a robust medium voltage campus electrical distribution system. This infrastructure will require enhancements to meet the campus decarbonization goals. In planning for UCB campus growth over the next two decades as well as the electrification of thermal utilities and the impact of electric vehicles (EVs), data centers, etc., AEI has analyzed the existing electrical distribution system and has identified its limiting components. Existing feeders from Hill Substation limit the capacity of the campus distribution system to 48 MVA[1] while retaining 2N redundancy. AEI has proposed utilizing existing 5" conduits in duct banks to install additional conductors to and from Hill Substation, which would increase the capacity to 55 MVA .

With these additional conductors from the Hill Substation and utilizing the forced-air ratings of the existing service Hill Substation transformers (62.5 MVA) for the infrequent occurrence when the campus is powered from a single transformer, the UCB campus capacity limitation of the existing distribution system would be increased to 55 MVA while retaining 2N redundancy. This increased capacity will postpone the need to upgrade the electrical utility service at Hill Substation. Future campus loads in excess of 55 MVA would require Hill Substation and other equipment upgrades/additions. AEI recommends initiating design a minimum of 5 years before loads are planned to exceed 55 MVA. UCB should allow sufficient time to design, procure, and install all equipment, feeders, and devices required for an upgrade to Hill Substation.

b. Background

Growth on the UC Berkeley campus is constrained, not only by the geographic boundaries, but also by the capacity of the Hill Substation and the medium voltage campus distribution system.

Critical to determining whether a substation upgrade is required is an understanding of the existing load and growth of this load over time. AEI's analysis has established a projected peak demand of 58.1 MVA by grouping and summing future building electrification loads and long-range development plan loads while considering non-coincident loads.

[1] MVA is used in this document when referencing equipment capacities and loads. Transformer bank ratings are given in MVA, and bus/conductor capacities can be calculated without requiring a power factor. Power factor will vary for loads.

	Description	Additional Load	Total Campus Load	Comments
1	Existing Load	-	36.6 MVA	Sum of non-coincident metered loads as provided by UC Berkeley. Approximately 12 million square feet. Group 0
2	Electrified Heating and Cooling Plant Groups 1, 4, 6	6.1 MVA	42.7 MVA	Net addition. Includes offsets for : Reduction of building level cooling Addition of building level steam production (humification and sterilization)
3	Electrified Heating and Cooling Plant Groups 2, 3, 5	5.4 MVA	48.1 MVA	Net addition. Includes offsets for : Reduction of building level cooling Addition of building level steam production (humification and sterilization)
4	Buildout of LRDP through 2030 (Group 7)	5.6 MVA	53.7 MVA	Approximately 1.4 million GSF
5	Buildout of LRDP through 2040 (Group 8)	4.5 MVA	58.1 MVA	Approximately 2.5 million GSF

Figure 1.5.1 – Load Data

c. Analysis

In order to get an accurate representation of the load on Hill Substation as well as the new EHCP at the end of the existing building electrification projects and the long range development plan, the following values were assumed for electrical and mechanical utility demand per gross square foot as a function of space type (see unit definitions at end of section).

Building Type	VA/SF	CHW SF/TON	HHW BTUH/SF
Academic/Admin	2.00	650	30
Athletic	3.00	600	8
Field/Parking	0.15	0	0
Laboratory	4.00	375	20
Residential	1.50	750	8

*Clark Kerr Campus is not included in the scope of this report

Figure 1.5.2 – Projected Loads for Master Plan Buildings

Through studying the existing distribution system and available capacities throughout the existing equipment and feeders, AEI identified the existing from the Hill Substation to be the limiting system components.

An evaluation revealed how utilizing existing spare conduits in duct banks could increase the capacity. The modeled results showed that the additional sets of conductors increased the capacity of each feeder from 48 MVA to 55 MVA. This would effectively increase the capacity of the entire existing campus distribution system to approximately 55 MVA while retaining 2N redundancy.

AEI recommends providing these additional conductors to increase the campus-wide electrical system capacity, as it provides the system with the required capacity upgrade for the foreseeable future while retaining 2N redundancy to the existing system, and greatly reduces cost when compared to upgrading the Hill Substation in the near-term. What must be noted with this recommendation is the assumption that the EV charging loads will be both non-coincident for the fleet charging, as well as fed from a separate PG&E service for significant parking structure EV charging projects. UC Berkeley must consider the planning of future EV charging carefully, as it will greatly impact the need to upgrade Hill Substation.

The currently under construction IS8/SS8 switchgear downstream of the Hill Substation are being installed to accommodate the loads of the future EHCP. To provide 2N redundancy to SS8 while postponing the installation of the new IS8 duct bank from Hill Substation, AEI has proposed an interconnect duct bank solution from an existing SS6.

Over the next 25+ years, the campus loads are expected to increase per Groups for building electrification, as well as the LRDP expanded projects. More likely than not, there will be a point in the next 15 years where campus infrastructure upgrades will be required (see Figure 1.5.7). AEI recommends initiating design a minimum of 5-7 years before the LRDP loads are planned to exceed 55 MVA, currently projected in the 2037-2038 timeframe.

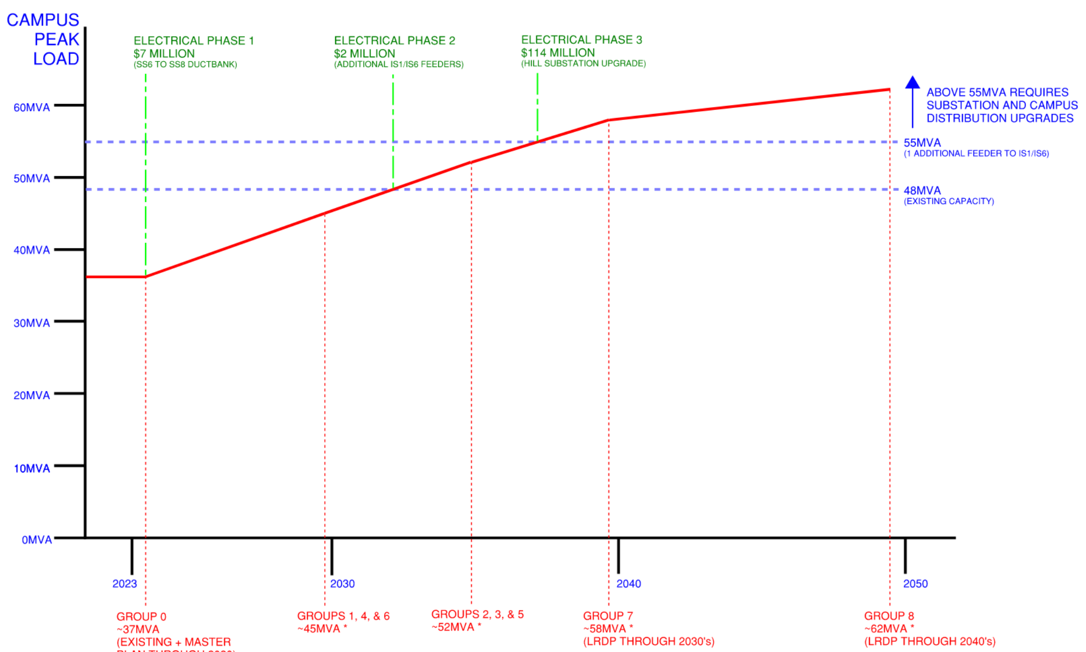


Figure 1.5.7 – Campus Capacity Load Graph

d. Distributed Energy Resources (DERs) - Electrical Infrastructure

Refer to section "1.6 DERs" for scope on Distributed Energy Resource (DER) equipment. Proposed DER systems on campus include Fuel Cells, Batteries, and Photovoltaic (PV) systems. The proposed DER equipment locations have been investigated for availability, feasibility, visibility, safety, cost, and ease of integration into the existing distribution system.

e. SCADA & Microgrid Systems

To incorporate multiple DERs into a campus distribution system while connected to utility power as well as in an island mode scenario, a SCADA system and microgrid system are envisioned to be installed alongside the Campus DERs. The SCADA system will remotely control switchgear breakers and other protection devices across campus. The microgrid system will monitor both the DERs and the campus electrical distribution system and provide intelligent monitoring and controls (through the SCADA system) based on campus usage and available DER resources.

Available power from DERs can vary with a number of factors: time of day and time of year, weather (forecasted as well as current cloud cover), battery capacity while peak shaving, heating loads during colder seasons, etc. The complexity of the quantity of variables on a campus electrical distribution system with multiple DERs is further increased when preparing to operate in island mode (when the campus is disconnected from Utility power and the DERs are providing power to the whole campus). To assure a system operates smoothly at all times, a microgrid system's programming considers all incoming, historical, and forecasted data while providing automated control and streamlined monitoring to all systems on campus.

AEI proposes the SCADA and microgrid system headend equipment locations be in a control room located within the EHCP. From this location, there would be wired (fiber) connections to each of the distribution switchgear on campus. The fiber would then connect to the ethernet switch provided at each switchgear, and the switchgear relays connected to each ethernet switch would be programmed into the microgrid system (two fiber wires to each switchgear location is recommended for redundancy purposes). This would allow for monitoring and control and the main and feeder breakers at all medium-voltage switchgear across campus. This level of monitoring and control across campus is paramount for programming the microgrid sequence of operations during an island mode scenario.

While providing SCADA controllability at the MV distribution switchgear level would ensure successful operability of the campus grid in island mode, it will not provide the granular control required to keep all critical buildings online during a utility power outage. In order to provide this level of control, SCADA controllability would need to be added to selected existing vault and pad mounted 3-way selector switches across campus. Each equipment location has two vacuum switches that select incoming Line 1 or Line 2. With both switches open, the downstream building is disconnected. The existing S&C switches are not currently equipped with SCADA controllable switches. Selected buildings fed from distribution loops that contain both critical and non-critical loads would have their vacuum switches replaced with SCADA ready switches, and then connect to the SCADA and microgrid systems to allow load shedding at the building level. This level of controllability is costly, however, with our initial pricing estimates showing an initial cost of 10x over the switchgear breaker only controls. Because of this, AEI is including switchgear breaker only controllability in the SCADA system cost estimate.

To further reduce the campus loads during a switch to island mode, building level BMS systems can be programmed to ramp down mechanical equipment across campus to reduce the load seen at each switchgear. The BMS systems are not required to be tied into the Microgrid system, but automation of BMS systems during a power outage can assist the microgrid operation and should be considered.

1.6 DISTRIBUTED ENERGY RESOURCES (DER)

a. Findings

The objectives framing the evaluation of a clean energy microgrid and distributed energy resources are;

- Be cost competitive
- Be feasible to fund and construct, and connect to UC Berkeley's grid
- Provide clean, low-carbon energy
- Provide resilient power for up to 5 days of utility outage
- Provide an opportunity to be phased and grow overtime
- Attract potential partners and external funding opportunities

An extensive list of existing, new and emerging on-site power generation technologies was considered with preliminary filtering based on site constraints, commercial development and / or availability. The following list of technologies were carried forward for detailed evaluation and further optimization.

- Solid Oxide Fuel cells (SOFC)
- Photovoltaics (PV)
- Battery Energy Storage System (BESS)
- Gas turbine (bio-fuel or hydrogen capable)
- Pumped hydro storage (PHS)

An optimization tool used to analyze the above technologies has been developed. The tool evaluates many combinations of the above technologies at different capacities against the following variables;

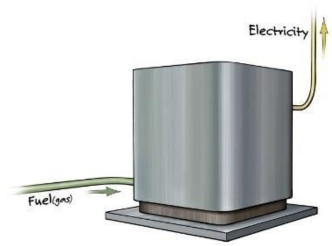
- Campus critical load (15 – 30 MW range)
- Outage Duration (12 – 120 hrs)
- Weather Conditions (Clear / Overcast)

Results from the analysis that comply with the defined criteria are filtered based on capital expenditure ($) and simple payback (years) to determine the optimal set of solutions for the campus.

Using the optimization tool and evaluating other qualitative benefits, the team 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 RECs (Renewable Energy Certificates) 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.

Battery Energy Storage

Solar Photovoltaics



Solid Oxide Fuel Cells

Figure 1.6.1 – Recommended mix of Distributed Energy Resources (DERs)

Suitable sites have been identified and evaluated for the mix of technologies with the fuel cells located at and around the existing cogeneration site which will be decommissioned. Solar PV opportunities exist across Hill Campus and on existing main campus building roofs and car-ports.

Fuel cells will initially be supplied with natural gas with carbon emissions offset by biomethane procured by the University with the longer-term goal of transitioning to green hydrogen or replacing the fuel cells at the developed sites with future energy storage technologies that have a higher energy density and are more cost effective than current technologies.

b. Background

The aim of this project's distributed energy resource analysis was to find the most cost-effective means of allowing the main campus to ride through up to 5 days of power outage by utilizing local, onsite, clean energy systems. A 5-day outage was considered to be required to support a scheduled Public Safety Power Shutdowns (PSPS) requested by Pacific Gas & Electric, for the purposes of reducing large-scale grid failures and fire risks associated with high power demands. The potential PSPS events evaluated considered various amounts of preparation time ranging from no warning to several hours to multiple days. PSPS events were considered to be potentially coincident with wildfire events resulting in heavily polluted ambient conditions which could reduce the output of photovoltaic systems. Other critical load events considered in the analysis include unscheduled power outages due to electrical equipment failure and /or loss of power due to a seismic event.

Multiple on-site power generation systems were considered including:

- Modular nuclear
- Wave and run-of-the river hydro
- Geothermal power (including deep earth)
- Fuel Cells
- Photovoltaics
- Wind Turbines
- Electrochemical Batteries
- Thermal storage

Modular nuclear was screened out of the project due to limited states of commercial development and long expected permitted timelines for the use of nuclear fuel coupled with anticipated local resistance.

Wave and run-of-the-river hydropower are not immediately available on the main campus site or near the campus electrical infrastructure.

Deep earth heat (geothermal) power was considered although technologies to access this source are still in development and are currently economically prohibitive in this area based on available resource estimates from the National Renewable Energy Laboratory (NREL). This technology is different to geothermal heat exchange system proposed as part of the EHCP design.

Large-scale wind turbines were screened out of the project due to the space requirements and siting challenges associated with UC Berkeley's urban campus. Large-scale wind requires turbines over 1 MW in size would be required to achieve economies of scale comparable to photovoltaics.

Hydrogen is considered as a fuel source for fuel cells but was screened out for immediate use due to the lack of commercially available clean, green hydrogen sources and the high cost of on-site green hydrogen production powered using grid energy. Technologies capable of transition to future commercially available green hydrogen sources are noted as beneficial in providing flexibility to future market conditions.

c. Analysis

Technologies considered for detailed analysis were all readily, commercially available with a history of successful and proven implementations. Photovoltaics, a simple cycle turbine, reciprocating engines and fuel cells are all viable generation technologies available for consideration. Turbines, engines and fuel cells are all capable of operating, with some adjustments, on multiple fuel sources both fossil fuel based and clean. Turbines and engines rely on combustion and continue to have local NOx emissions due to the need for combustion air. Fuel cells are able to operate with minimal SOx and NOx local emissions as compared to combustion alternatives.

Distributed energy resources were considered to be clean if:

1. The resource does not use fossil fuels OR
2. The resource does not use fossil fuel *combustion,* and the remaining carbon emissions from the fossil fuel use is within UC Berkeley's transitional biomethane REC allocation, and a transition to renewable alternative is considered once UC biomethane procurement contracts expire (2039).

Sources – available	**Generation - feasible**	**Power Storage**
Gas (Biogas RECs)	Photovoltaics	Battery (electrochemical)
Solar	Simple Cycle Gas Turbine	Pumped Hydro Reservoir
~~Wind~~	Fuel Cell	~~Hydrogen~~
	Engine Generator	
Sources – developing	**Generation – site constraints**	**Power Storage – developing**
Hydrogen	Wind Turbine	Compressed air
Deep earth heat	Hydro Turbine	
	Wave Turbine	
Sources – not available at site	Solar Thermal Power	
Wave		
Hydro	**Generation – immature**	
	DEGS (deep boring)	

Figure 1.6.2 – Preliminary screening of technologies considered.

This report recognizes that elimination of fossil fuels altogether is preferred, and non-combustion fossil fuel use paired with transitional biomethane offsets is less desirable. Hydrogen-flexible, methane solid oxide fuel cells are considered a cost-savings measure within the limits of UC Berkeley's biomethane offset allocation. Intended implementation of fuel cells allows for quick conversion to a 100% green hydrogen fuel source once it is commercially available to the campus and continues to use natural gas methane as an interim fuel. The fuel cells are able to accommodate hydrogen-methane blends and the cells may be cost-effectively switched out for 100% hydrogen-capable cells every 5 to 7 years. The fuel cells oxidize methane and emit carbon dioxide locally. However, fuel cell electrical conversion efficiency is more than twice that of combustion alternatives, resulting in significantly reduced local CO2 emissions and a substantial reduction in sulfur oxide and nitrogen oxide emissions compared to the equivalent combustion of methane in a gas turbine or engine.

Photovoltaic systems, fuel cells and lithium-ion battery systems are recognized to have substantial embodied carbon footprints including the use of minerals extracted from the earth. Preference is encouraged for photovoltaic and electrochemical systems that are sourced from ethical providers. Most photovoltaic systems are recognized to be carbon-positive (i.e. operational carbon savings offset embodied carbon) within 5 years by the US Energy Information Administration. Consideration of alternative photovoltaic and battery options such as iron-air batteries are encouraged where cost-competitive and space efficient.

Many combinations of different technologies and sizes were evaluated as part of a screening and optimization tool developed specifically for the project. The tool filters the mix of technologies that are able to supply up to 5 days of power to campus during an outage while contributing to reducing energy costs during normal operation. The optimization tool demonstrates that on-site renewable energy generation coupled with energy storage solutions alone would not be financially viable to support the anticipated campus critical load and required duration. However, a mix of renewable energy generation, energy storage and a base load generator (fuel cell or combustion engine) would be financially viable (payback within life-time of the system). The base load generator would need to run on natural gas (offset by biomethane RECs within the University's UC allotment) for the near-term with the flexibility to transition to an alternative fuel source (green hydrogen) in the future.

Critical loads were identified as either life-safety or for business continuity (or for both). Buildings that have life-safety loads are generally supported by local emergency generators. The table below outlines assumptions for critical load assessment and load shedding capabilities for different building / use types.

Building Type	Critical Load?	Life Safety/ Egress Only	Heating Required	Heating Relaxed	Cooling Required	Cooling Relaxed	Notes
Laboratory	✓	×	✓	×	✓	×	Business as usual
Residences	✓	×	✓	✓	×	✓	Relaxed thermal conditions – cooling optional
Academics	×	✓	×	-	×	-	Load shed to life safety only as needed
Administration	×	✓	×	-	×	-	Load shed to life safety only as needed
Athletics	×	✓	×	-	×	-	Load shed to life safety only as needed
EHCP	✓	×	✓	✓	✓	✓	Only powered enough to satisfy critical thermal loads

Based on the above assumptions, the campus critical load is estimated to currently be around 15 MW (peak) and anticipated to grow to up to 25 MW (peak) upon full realization of the long-range development plan (LRDP). In order to ride through an extended PG&E outage, a mix of distributed energy resources are recommended to take advantage of the unique benefits of various resources.

A combination of 7.5 MW of fuel cells, 12-15 MW of solar and 45 MWh of battery energy storage with grid forming inverters can cost-effectively replace the current resiliency needs for the campus and form a microgrid during extended outages and Public Safety Power Shutdowns. The 12-15MW of solar includes the hill and main campus. An additional 5-15 MW of fuel cells, 5 MW of solar, and 170 MWH of BESS can be added to continue to meet resiliency needs as the campus density grows under the Long Range Development Plan. This mix of distributed energy resources can be procured through a power-purchase agreement at an energy purchase cost competitive to PG&E. A power purchase agreement will minimize capital outlay with the third parties owning and operating the system on behalf of the campus.

The tool was developed to analyze in more depth the preferred configuration of fuel cells, solar photovoltaics and battery energy storage. A snapshot of the tool dashboard with various modeled scenarios is indicated below (Figures 1.6.3a,b,c,d).

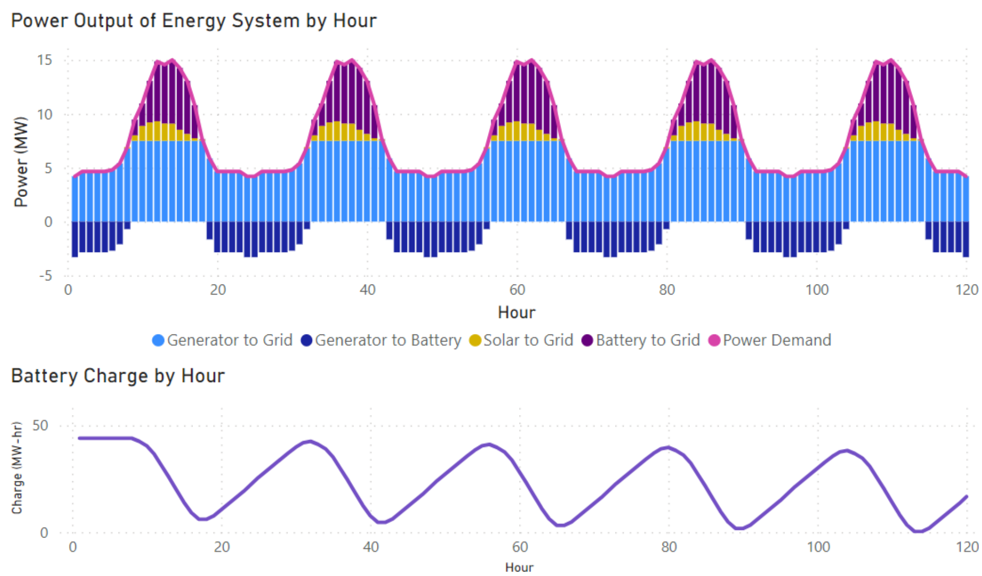


Figure 1.6.3a – Fuel Cell / PV / Battery optimization tool (winter cloudy day)

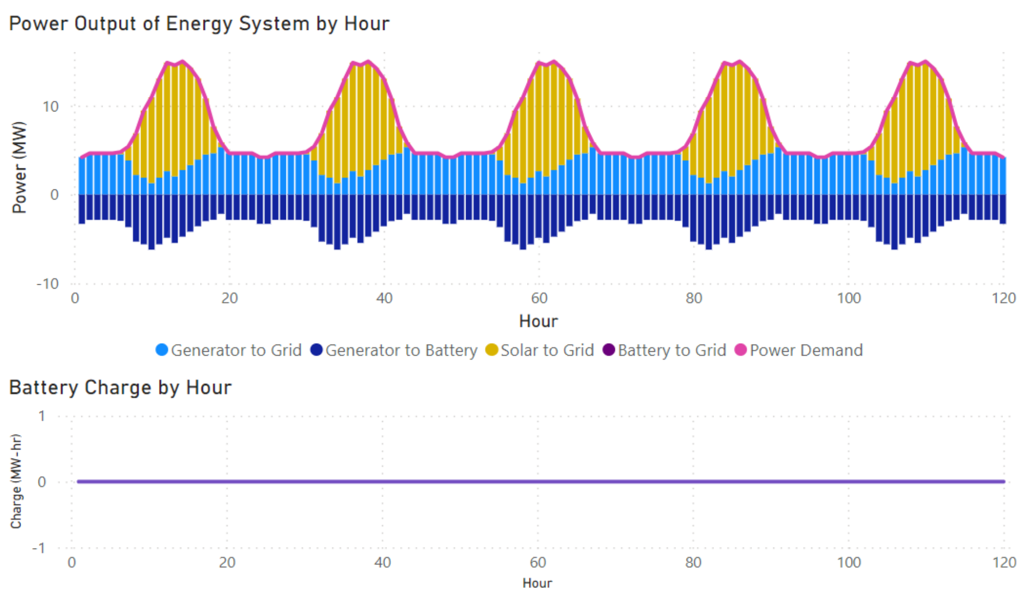


Figure 1.6.3b – Fuel Cell / PV / Battery optimization tool (summer clear day)

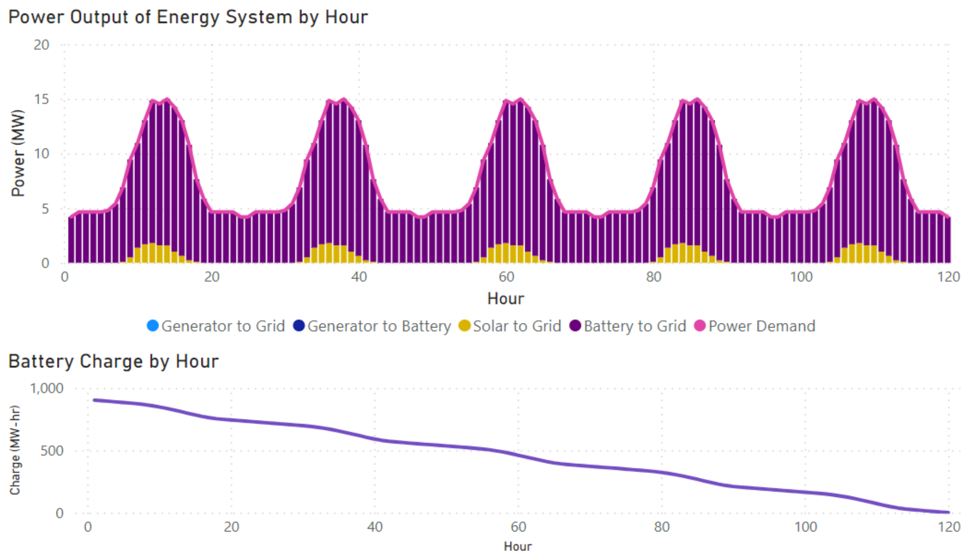


Figure 1.6.3c – Fuel Cell / PV / Battery optimization tool (no fuel cell)

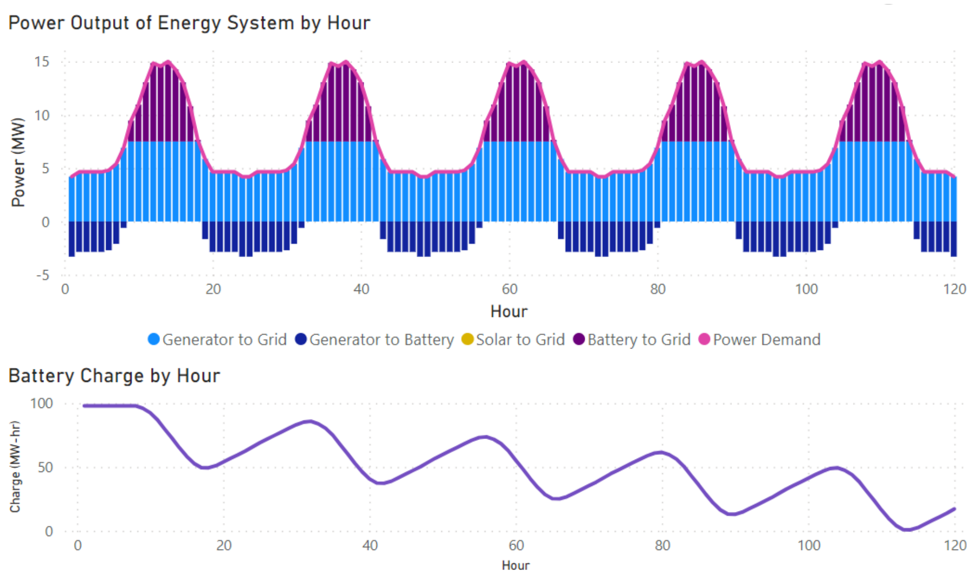


Figure 1.6.3c – Fuel Cell / PV / Battery optimization tool (no solar)

Maximize Photovoltaics

Approximately 12-15 MW of photovoltaics has been identified as low impact on the hill campus (refer to Figure 1.6.4 below) through Berkeley's solar studies. Space for another 2-3 MW of solar has been identified on existing rooftops and parking garages across main campus.

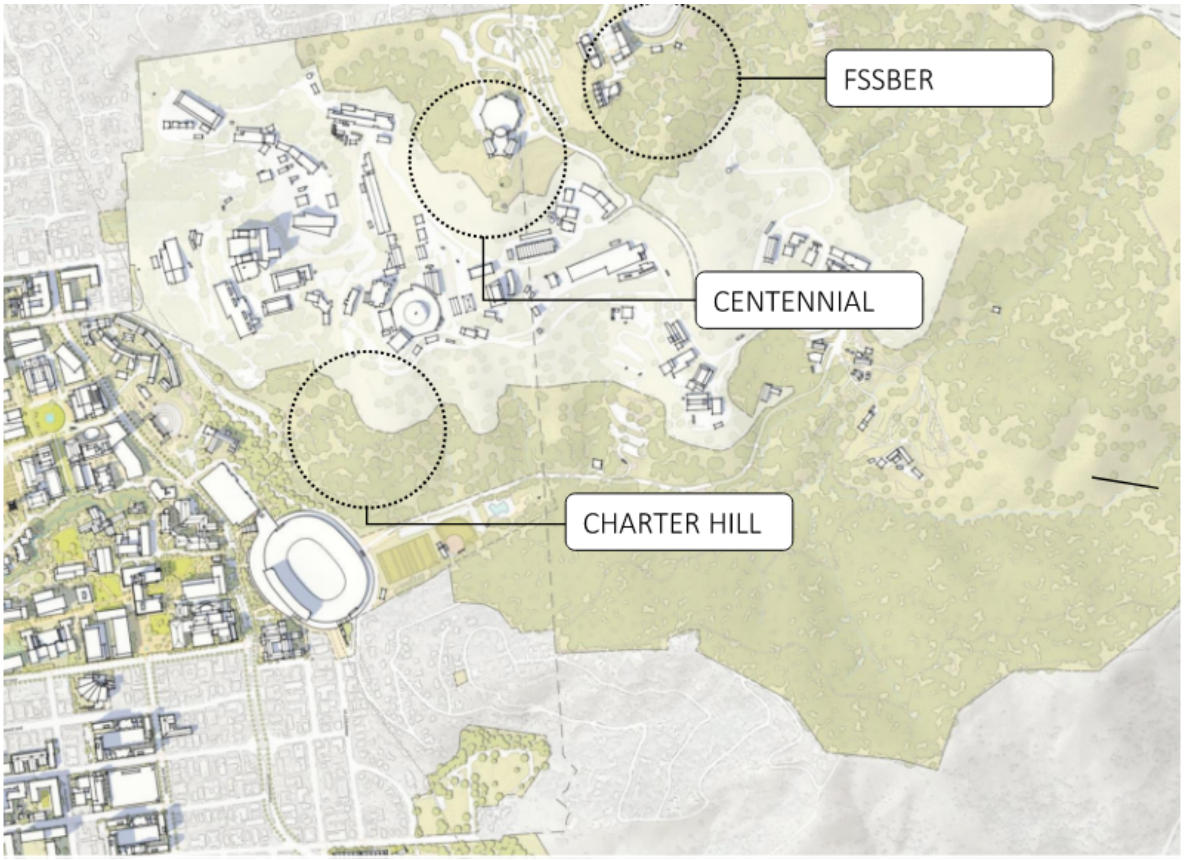


Figure 1.6.4 – Hill campus potential solar sites

Maximizing the available on-campus solar is recommended as it provides a year-round source of renewable energy while providing a resilient source of power during a sustained grid outage. Photovoltaics alone are not enough to provide multi-day power cost-effectively and require supplement power during the evenings. Additionally, for the purpose of critical load analysis, we have assumed an extended power outage could occur during unfavorable conditions for solar production either during cloudy conditions or a more extreme wildfire event resulting in significant smoke cover. This is a conservative approach that reduces the contribution of solar PV to the critical load during an outage and increases the required contribution from the fuel cells and / or batteries.

The inclusion of on-site photovoltaics (coupled with battery energy storage) provides additional resiliency against loss of both utility power and natural gas service outage to the campus as might be experienced during a significant seismic event. On a clear summer day, 12 MW of solar PV coupled with 45MWh of battery energy storage could provide between 65-80% of the Phase 1 critical loads for the campus in the event that both utility power and natural gas service is interrupted.

Fuel Cells

Fuel cells are a cost-effective way to meet evening energy demands and baseload energy needs during the day. The fuel cells would be paired with grid-forming inverters and battery energy storage to meet intermittent power spikes and maintain stable operation. 7.5 MW of fuel cells would cover the current needs for critical loads and can grow up to 10 or 15 MW to meet the needs of the campus over time as green hydrogen becomes available. Currently a 7.5 MW fuel cell plant can run on fossil gas offset by Berkeley's biomethane allocation and would be estimated to consume 360,000 MMBtu/yr of the campus's initial 450,000 MMBtu/yr biomethane allocation. Both photovoltaics and fuel cells can be provided through power purchase agreements at rates competitive to PG&E prices to avoid capital expenditures. Replacing fuel cells with energy storage for 5 days at this time increases the microgrid costs by over $1 billion with no payback based on current battery technologies. In the future battery technology and costs can improve making them more viable.

Site constraints, acoustical concerns and proximity to existing high-pressure gas infrastructure weighed into the evaluation of the sites and favored the area around the existing cogen building and adjacent areas. The site planned for the fuel cells will be designed to accommodate alternative energy storage technologies once they become more commercially viable at this scale. The image below is a rendering indicating the preferred location for the fuel cells across from the cogen building.

Figure 1.6.6 – Fuel Cell (7.5MW)

Energy Storage Systems:

An on-site energy storage system is required to buffer the generation and demand. Battery energy storage and a pumped hydro scheme were both considered.

Battery Energy Storage:

A 45 MWh battery storage solution was determined to be required in conjunction with 12MW of PV and 7.5 MW of fuel cells. The team evaluated several sites on campus to locate the batteries and reviewed requirements for separation from buildings and public right of ways with the campus fire marshal. In conclusion, it was determined that the preferred locations for a battery array of this size would be sites close to existing electrical infrastructure including the existing cogen plant and at Switch Station 6 on campus. Additional locations will need to be identified.

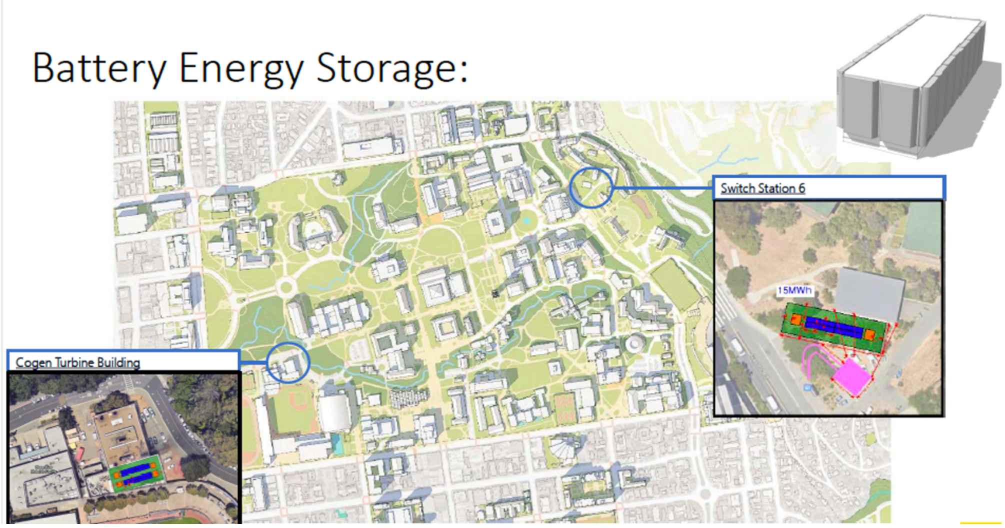


Figure 1.6.7 – Potential battery locations

Pumped Hydro Storage:

Pumped hydropower storage (PHS) is a long-term and low-carbon energy storage solution. Berkeley's unique geography unlocks the potential for a small-scale closed-loop pumped hydropower alternative to electrochemical batteries using rare earth metals. Water is pumped up to an upper storage tank during times when power is clean and plentiful and then run through a hydropower turbine on the way to a lower reservoir when additional power is needed during outages or to reduce dependence on the utility during peak hours of operation. The cost-optimal PHS solution maximizes vertical distance between the reservoirs while minimizing the horizontal distance. The vertical distance increases the potential energy of the system and therefore the storage capacity without increasing the reservoir sizes. As the horizontal distance increases, the distribution costs and friction in the system increase without adding any energy to the system. Recommended locations for a potential PHS project are indicated below with an upper reservoir located near the Space Sciences Laboratory and the lower reservoir located around at the Strawberry Canyon Corporation Yard. Preferred reservoir locations were selected to maximize vertical separation and minimize horizontal separation while utilizing already developed sites to minimize environmental disruption. Maximizing the feasible sites with upper and lower storage volumes of 20M Gallons provides up to 15 MWh with a turbine output of approximately 3.5 MW for a duration of 4.75 hrs. A hydropower turbine would be located at the lower reservoir site.

The pumped hydro scheme would need to be supplemented with battery energy storage to meet the critical load requirements of the campus during Phase 1. The life-expectancy of a pumped hydro scheme is expected to exceed 60 years whereas lithium-ion batteries would need to be replaced every 7-10 years.

Figure 1.6.8 – Pumped Hydro system concept

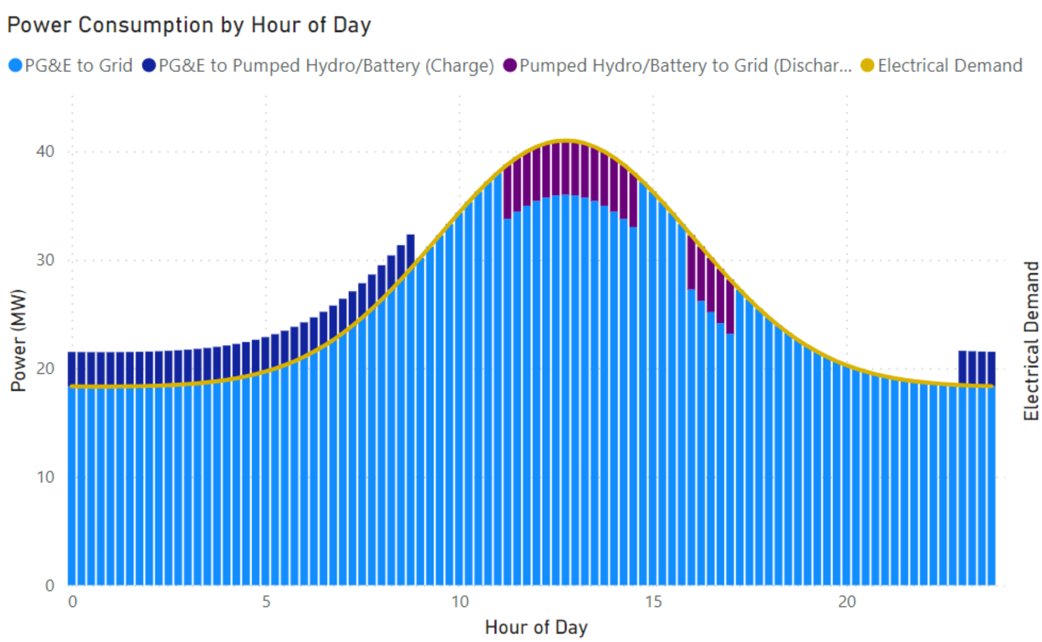


Figure 1.6.9 – Pumped Hydro evaluation tool (grid analysis)

Combined Heat & Power Plant modification (standby only):

A short-term option would be to repurpose the existing cogeneration plant to run as a simple cycle turbine (power generation only) during a power outage. As soon as building heating, process and cooling (absorption chiller) loads are transitioned off the steam system, the cogeneration plant will need to be shut-down for continuous operation. The gas turbine could then be modified and used as a backup power resource only. Under this scheme the gas turbine would run intermittently as required for routine operation (once every month) and during a scheduled power outage or an extended unscheduled power outage. This extends the useful life of the existing asset however, this it does not align with a number of goals of the project including capital investment to convert, operation and maintenance costs associated with staffing and maintaining the gas turbine engine, and gaps in critical load needs as it requires significant start-up time for unscheduled outages.

1.7 ENERGY AND CARBON ANALYSIS

a. Findings

A model was developed to analyze and determine the timeline for the phased implementation of the Clean Energy Campus plan to support the transition off natural gas and meet the campus building energy decarbonization goals. This model integrated the analysis performed for the Electrified Heating and Cooling Plant (EHCP), building conversions, mechanical distribution, electrical distribution, and distributed energy resources (DERs). Included in the analysis were the following life cycle costs;

- Campus utility costs (electricity, natural /bio gas and water)
- Operation and Maintenance (O&M) costs
- Carbon emissions costs (regulatory, UC, and social costs)
- Capital Expenditure costs (including deferred maintenance and avoided costs)

With each of these analyses the results were compared against the Business-as-Usual 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 results documented herein are representative of the phasing strategy outlined in this report and as highlighted below;

- Phase 1 (2025-2028): Groups 1, 4 and 6
- Phase 2 (2028-2032): Groups 2, 3 and 5
- Phase 3 (2030-2040): Long Range Development Plan (LRDP)

Additional clarifications related to the clean energy plan results presented herein;

- All results assume Distributed Energy Resources (DER's) including solar PV, batteries and fuel cells are installed and operated by others as part of a Power Purchase Agreement (PPA). Capital Expenditure pertaining to DERs is limited to land development and infrastructure cost upgrades.
- DERs are implemented to coincide with the decommissioning of the cogeneration plant at the end of 2027.
- Cost of carbon includes regulatory cost of carbon only, social cost of carbon and / or UC voluntary cost of carbon are not included in the model results herein.
- Addition of cooling to existing buildings currently without is deferred to 2032 through 2040.

The total cost of ownership over a 25-year (2025-2050) 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 Business-as-Usual case (excluding social cost of carbon). The figure overpage 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 the social cost of carbon increases the cost of the Business As Usual case to $3.27 Billion.

Figure 1.7.1a Phase 1 buildings, Groups 1, 4 and 6 highlighted

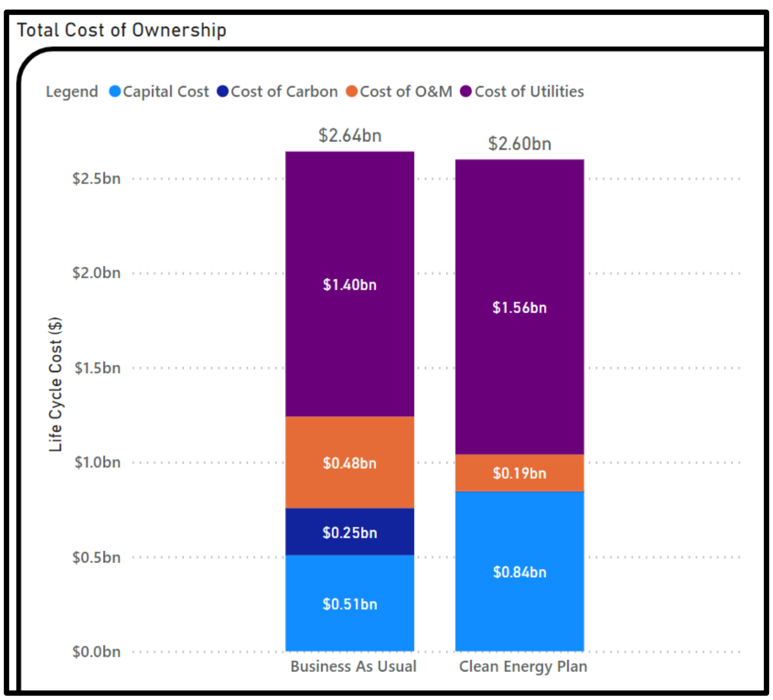


Figure 1.7.1b Total Cost of Ownership (regulatory carbon cost only) over 25 years

b. <u>Background</u>

AEI developed a robust model to help guide the project team to make informed decisions on project implementation to support the campus building energy decarbonization goals. The model accounts for carbon, energy, and costs. The AEI team collaborated with Energy Strategies, with input from the UC Berkeley team, to establish input parameters for the analysis. This includes parameters such as inflation and escalation assumptions, cost of carbon allowances and offsets, purchased electricity and natural gas costs and emission factors. The results of this carbon, energy and costs analysis were shared with UC Berkeley's financial advisor, Ernst & Young, and used to inform their funding and financial models.

c. Analysis

The analysis was broken into separate models for carbon, energy and cost. With each of the models, phase implementation was incorporated and influenced the results. The following will detail the analysis for:

- Energy Consumption and Energy Source
- Utility Cost
- Carbon Emissions and Costs
- Operation and Maintenance Costs
- Capital Expenditure (CAPEX)

First, annual site electrical consumption and site steam consumption were calculated based on when the Electrified Heating and Cooling Plant (ECHP) would be brought online and buildings would be converted. The graph shows site steam consumption remaining constant until 2028, when the first phase of implementation would be complete and a significant portion of the campus load would be removed from the steam system. The site electrical consumption graph indicates a reduction in existing building electrical loads as distributed electrical cooling systems are decommissioned and cooling transitions to the EHCP. Meanwhile, the EHCP electricity load grows as buildings are converted from steam to electrified heating with heating and cooling thermal energy generated centrally at the EHCP. As demonstrated in the graph, the site steam consumption drops considerably after the conversion of Phase 1 buildings (groups 1, 4 and 6). The annual electricity consumption of the (ECHP) is calculated based on the assumptions of the new equipment (equipment efficiency factored in) – heat recovery chillers, water-cooled chillers, and thermal energy storage.

To accompany the energy consumption calculation, the sources of the energy were analyzed. The graph overpage shows from present day until 2028 that the source of electricity for the campus is largely from Cogen and the natural gas consumption is largely by Cogen. From 2028 onward, when it is assumed Cogen will be taken off line, the electricity sources are a combination of fuel cells, solar PV and grid imported. The site natural gas consumption decreases significantly once Cogen is decommissioned and from 2031 onward the natural gas consumption by the fuel cells (7.5 MW) is below the University's transitional biomethane allotment.

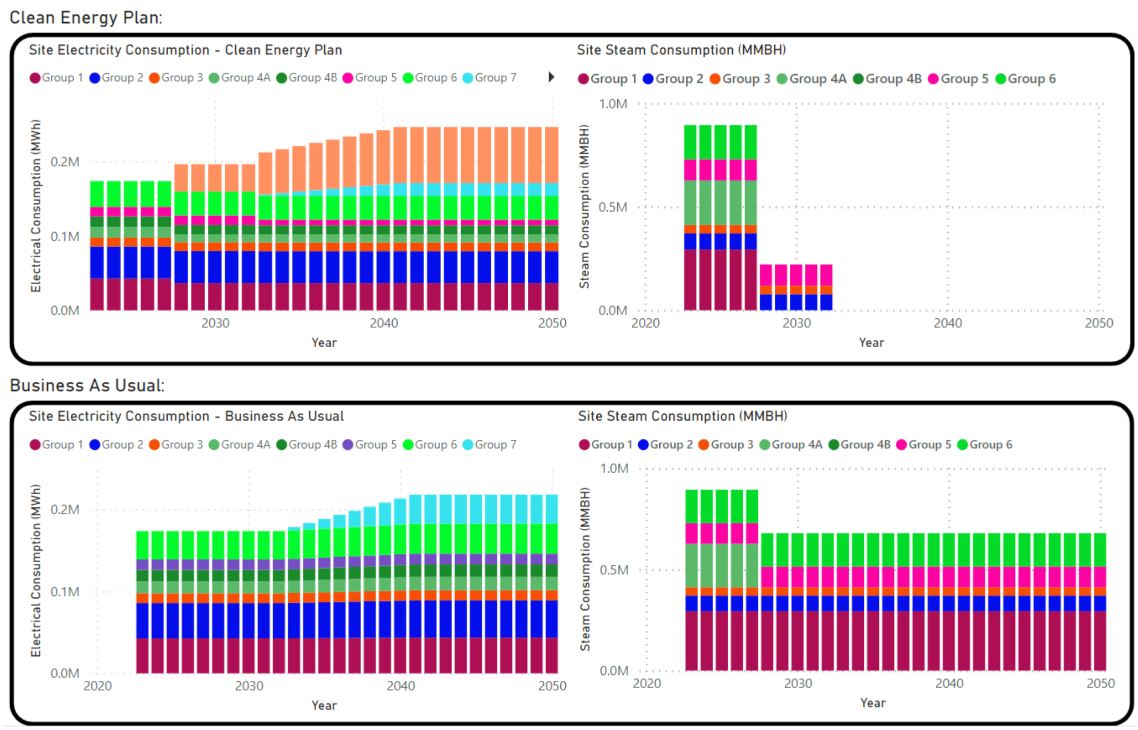


Figure 1.7.2 Annual Energy Consumption by Group

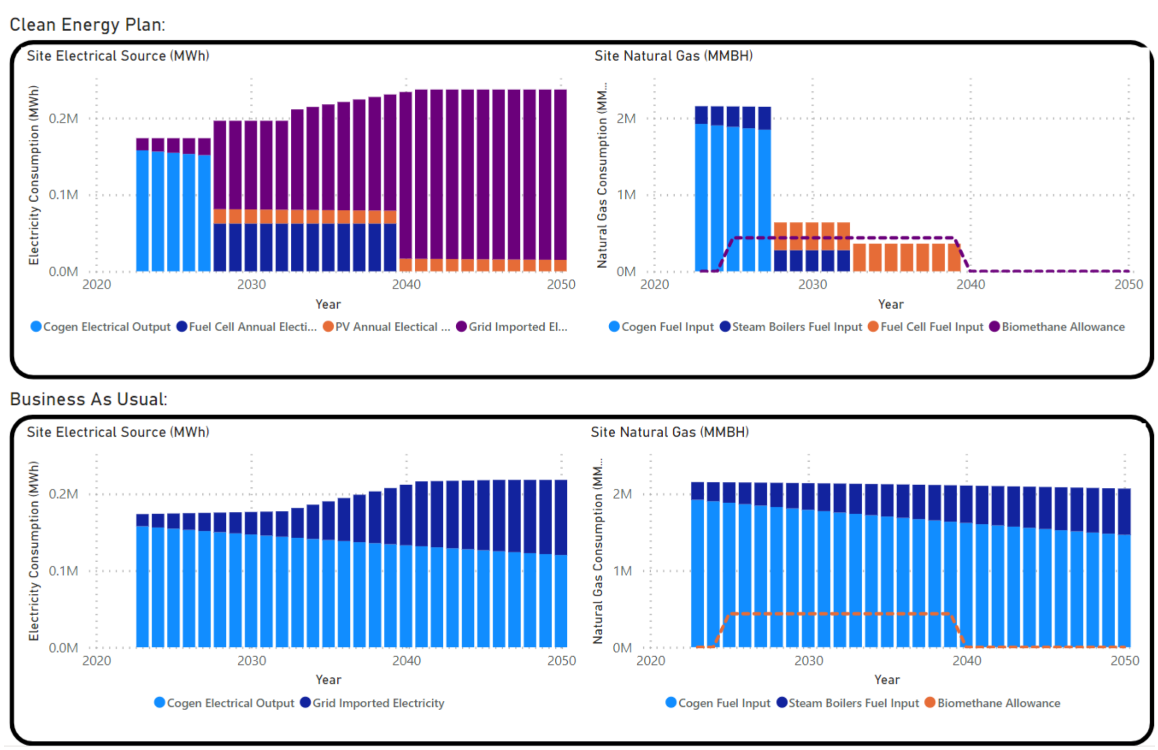
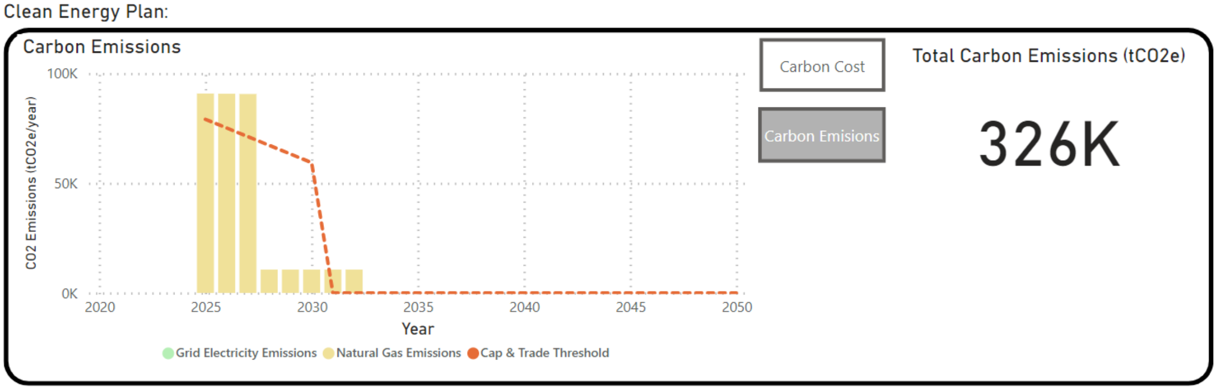


Figure 1.7.3 Annual Energy Source

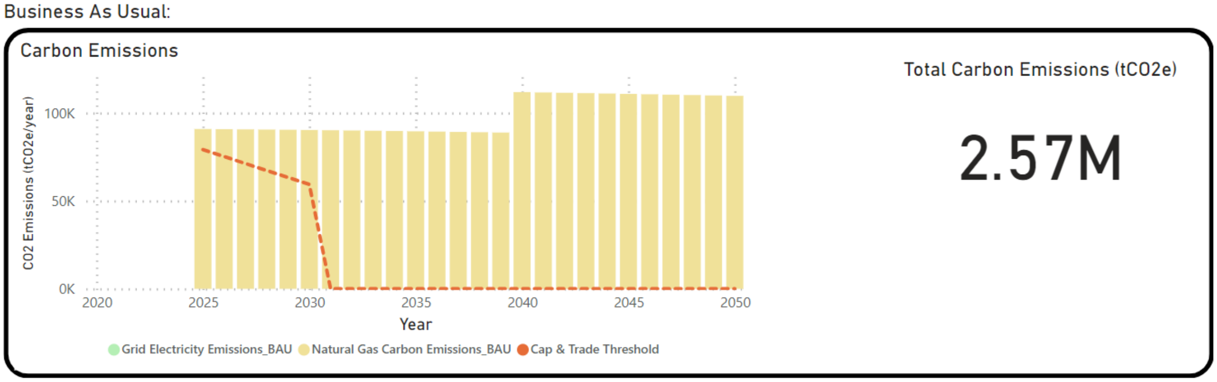
After the annual energy consumption and the sources from which the energy is coming from where calculated, annual utility costs were analyzed. The life cycle utility costs for the clean energy plan as modeled resulted in $1,559M compared to $1,405M for Business-As-Usual. Utility costs used for the model 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.

A crucial part of the total analysis was determining when the campus would be able to achieve its carbon 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 carbon reduction by 2030 after phases 1 and 2 of the project were implemented. The graph below indicates the projected carbon emissions for the main campus for the clean energy plan and business as usual case. A significant reduction in carbon emissions is realized just through implementation of Phase 1 conversions (Groups 1, 4 and 6) and the subsequent decommissioning of the cogen plant coupled with the University's purchase of renewable energy and transitional biomethane RECs.

Clean Energy Plan:



Business As Usual:



The cost of carbon associated with the emissions defined above is comprised of:

- California Cap & Trade Program offsets and allowances,
- UC System carbon offsets cost equivalent per UC policy,
- UC System Social Cost of Carbon.

The graphs below overpage that should the campus remain Business-as-Usual, the campus would incur $250M total life cycle cost of carbon, compared to only $4M for the new Clean Energy Plan. This is for regulatory and UC carbon costs only. Including the social cost of carbon, these numbers increase significantly for the Business as Usual case, to 1.16M.

The next cost analysis performed was for operation and maintenance (O&M) costs. The O&M costs for the clean energy plan include some Cogen and steam repair costs while the Cogen system is still fully operational and while some buildings are still on steam after Cogen is decommissioned. Historic data and trends received from UC Berkeley facilities group was used to project steam system repair costs. After 2032, once the steam system is fully decommissioned, the O&M costs for the clean energy plant are only facilities maintenance and operator labor. The Business-as-Usual case requires annual costs every year devoted to steam repair and plant costs both within the buildings and underground throughout the campus. The total O&M costs for the clean energy plan resulted in $194M compared to $483M for Business-As-Usual, demonstrating the high ongoing maintenance and repair costs associated with the aging steam infrastructure.

Lastly, the capital expenditure (CAPEX) for the new Clean Energy Plan was analyzed based on when the phases of implementation would occur and the total CAPEX is comprised of costs for:

- Electrified Heating and Cooling Plant (EHCP)
- Piping Distribution
- Building Conversions
- Steam Boiler Upgrades
- Equipment and Coge Decommissioning
- Electrical Upgrades
- Distributed Energy Resources

The Business-as-Usual case, while continuing to use existing infrastructure, will require CAPEX to keep the system functional. These costs include:

- Steam system replacement,
- Cogen replacement,
- steam boiler replacement,
- existing cooling equipment replacement (deferred maintenance),
- new building heating and cooling equipment and existing building cooling additions.

The total estimated CAPEX costs for the clean energy plan resulted in $843M compared to $528M for Business-As-Usual.

All the presented analysis was combined into a Total Cost of Ownership model over the 25 years analyzed. This resulted in a cost of $2.6 Billion for the new Clean Energy Plan compared to the cost of $2.64 Billion for the Business-as-Usual case. This graph can be referenced at the start of this section.

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