Decarbonization and Electrification Predesign Report

University of California, Santa Cruz

UCSC Project 11026

Affiliated Engineers Inc.

10/12/23

Final Report

I. Executive Summary

The Campus Decarbonization and Electrification Project Team has investigated and laid the groundwork to implement a suitable replacement for campus fossil fuel energy delivery systems and those systems and equipment that consume fossil fuels. This project targets a 95% reduction in fossil fuels from the 2019 reference year. UCSC's goal exceeds the UC system goal of a 90% reduction in the use of fossil fuels. Relative to the University's greenhouse gas inventory, this plan focuses on Scope 1 emissions which includes those emissions occurring as a direct result of university operations, including campus fleet vehicles. Scope 2 emissions, attributed to emissions associated with the generation of purchased electricity, are carbon free procurements provided by the University of California, Office of the President and are therefore already decarbonized.

The replacement of fossil fuel systems across the residential campus, Westside Research Park, and the Coastal Science Campus is addressed by breaking the work into (12) phases (Figure 1), grouped by campus region. Each phase recognizes existing infrastructure and the limitations of geography. Immediate opportunities exist in Porter and Rachel Carson Colleges while aging infrastructure in Stevenson, Cowell, Crown, and Merrill Colleges make them ideal secondary opportunities. As a prerequisite to transitioning away from fossil fuels, additional power from PG&E will be required. Elimination of fossil fuels from Science Hill requires the most work from PG&E to achieve due to the power needed. The total investment, in 2023 dollars, is expected to be approximately $700 million to replace the fossil fuel energy systems on campus. At a rapid pace, replacement is shown on a schedule to achieve 95% emission reductions by 2030 although options for 2035, 2040, and 2045 are presented as well.

Replacement of systems relies on proven, commercially available technologies without precluding incorporation of developing technologies as they become commercially available and viable. Replacement technologies include heat recovery, heat pumps, packaged electric equipment, battery electric vehicles, hydrogen fuel cell vehicles, and other smaller strategies as detailed in this report.

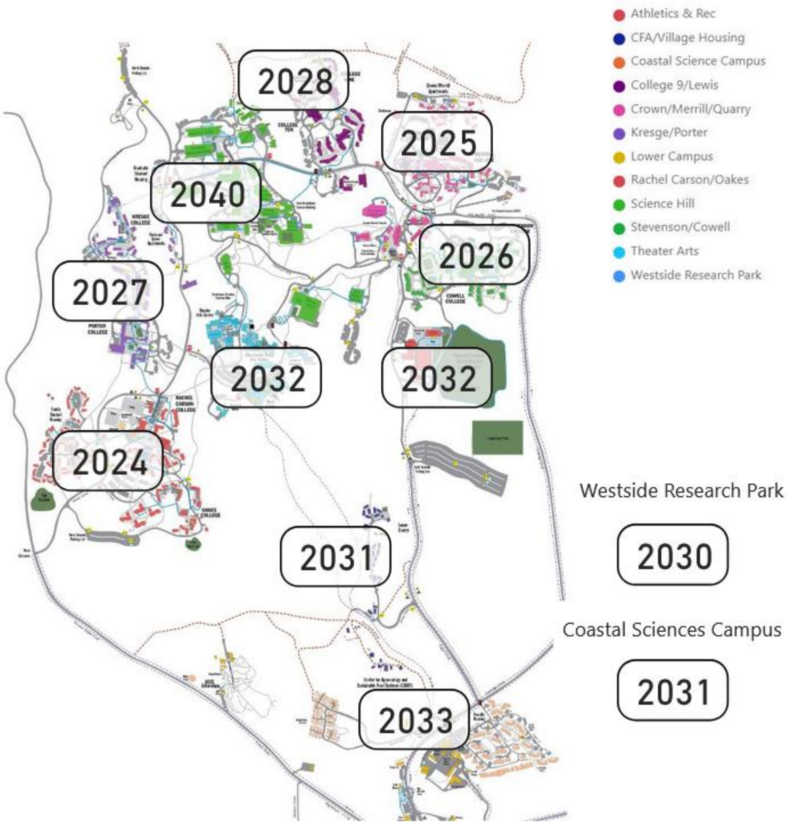

Figure 1– Recommended phasing to decarbonize by 2030

Prepared by Affiliated Engineers Inc. under the direction of
the University of California, Santa Cruz

UCSC Project 11026
Campus Decarbonization and Electronification

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II. Glossary

AEI. Affiliated Engineers, Inc.

AFDC. Alternative Fuel Data Center

ASHP. Air Source Heat Pump

BAU. Business As Usual

BESS. Battery Energy Storage System

BEV. Battery Electric Vehicle

BMS. Building Management Systems

CAISO. California Independent System Operator

CALeVIP: California Electric Vehicle Infrastructure Project cost data funded by the California Energy Commission (CEC) and implemented by the Center of Sustainable Energy (CSE)

CAPEX. Capital Expenditure

CCA. California Carbon Allowance

CES. Climate & Energy Strategy, UCSC 2017 Report

CHES. Colleges, Housing and Educational Services

CPP. Clean Power Program

CSC. Coastal Science Campus

CTE. Center for Transportation and the Environment

Cogen. UCSC's power plant that cogenerates electricity & heat from the combustion of natural gas

DC Fast chargers. Direct Current Fast chargers for battery electric vehicles

Demand Load. Maximum running load as determined by peak energy demand recorded in 2019

Decarbonization. Reduction or elimination of greenhouse gas emissions associated with an activity. Decarbonization may include electrification powered through renewable energy, switching to clean and renewable fuels or other strategies.

DER. Distributed Energy Resource

DEIJ. Diversity, Equity, Inclusion & Justice

D&E. Decarbonization and Electrification

DRVE. Dashboard for Rapid Vehicle Electrification

DHW. Domestic Hot Water

EIA. Energy Information Administration

EPA. Environmental Protection Agency

EV. Electric Vehicle

EVI-Pro Tool. The Battery Electric Vehicle Infrastructure Projection Tool

Electrification. Electrification refers to conversion of an activity or technology from directly utilizing a fuel energy source to utilizing electricity. In the context of this project, electrification refers to specifically conversion of fossil fuel systems to electric alternatives intended to be powered by clean and renewable electricity.

FFF. Fossil Fuel Free. In the context of this report, Fossil Fuel Free is defined by the University of California Office of the President as a 90% reduction in the use of fossil fuels as determined in a reference year

FTE. Full Time Equivalent

GHG. Greenhouse Gas

GWP. Global Warming Potential

HPWH. Heat Pump Water Heater

ICE. Internal Combustion Engine

IPCC. Intergovernmental Panel on Climate Change

JT&E. Just Transition & Equity

Living Lab. An integrative culture that uses the physical and operational assets of the university as part of research and coursework.

LRDP. Long Range Development Plan

MTCDE. Metric Tons of Carbon Dioxide Equivalent

MV. Medium Voltage**:** Voltages between 1 kV and 35 kV

MVA. Megavolt-amps, a measure of peak electrical demand or capacity

MW. Megawatt, a measure of peak electrical demand or capacity

NPC. Net Present Cost, represented in 2023 US dollars

NPV. Net Present Value, represented in 2023 US dollars

OPEX. Operational Expenditure

PG&E. Pacific Gas & Electric

PPDO. Physical Planning, Development, and Operations Department of UC Santa Cruz

PSPS. Public Service Power Shutoff

POCSC. People of Color Sustainability Collective

PSZ-HP. Packaged Single Zone – Heat Pump

SCC. The social cost of carbon is an estimate, in dollars, of the economic damages that results from the impact of each additional ton of greenhouse gas emissions.

Scope 1. Direct GHG emissions from sources owned or controlled by UCSC (combustion of natural gas on campus, combustion of gasoline, renewable diesel in Fleet vehicles, etc.)

Scope 2. Indirect emissions from purchased electricity. UCSC receives 100% clean, renewable electricity from UCOP's Clean Power Program.

Scope 3. All remaining indirect GHG emissions not included under Scope 2.

Transmission Service. Electrical power delivery at voltages of 69 kV and above

UCOP. University of California, Office of the President

UCSC. University of California, Santa Cruz

VMT. Vehicle Miles Traveled

WRP. Westside Research Park

ZEV. Zero Emission Vehicle

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1 Introduction

The utilization of natural gas and other fossil fuels create greenhouse gas emissions throughout the extraction, refining, transmission, and combustion processes. In California, the creation of electricity is significantly cleaner than in other states (in the regional PG&E utility grid, electricity is produced by 93% emission free sources (2021)). In addition, the University of California system procures renewable power through its Clean Power Program including its largest renewable commitment to date (2023) of 85 MW of a 3500 MW wind power project. Creating a plan to decarbonize the campus by addressing its consumption of natural gas is an essential first step in safeguarding the climate, mitigating potential campus and community concerns, and identifying opportunities for power resilience and diversification of utility cost fluctuations.

In 2013, former UC President Janet Napolitano committed the UC System to achieve net zero greenhouse gas emissions at all campuses by the year 2025 through the Carbon Neutrality Initiative and under the guidance of the newly formed UC Global Climate Leadership Council. In fall 2022, UC President Michael Drake convened the Pathways to a Fossil Free UC Task Force under the UC Global Climate Leadership Council guidance once again to challenge the UC campuses to develop a timeline and plan to significantly reduce fossil fuels in their energy systems setting forth a target for a 90% reduction in fossil fuel use.

In pursuit of UC Santa Cruz's and the broader UC system goals, UCSC's Chancellor Cindy Larive created a diverse Decarbonization & Electrification Task Force and charged them with researching the feasibility of reducing UCSC's Scope 1 & 2 carbon emissions, ideally to zero, by 2030 or as soon as possible. This effort also recognizes the recent UC Academic Senate's Climate Crisis Task Force memorial calling for "investments in UC's infrastructures that will reduce on-campus fossil fuel combustion by at least 60% of current levels by 2030 and 95% of current levels by 2035". The proposed undertaking is expected to take at least seven years with funding spread out over multiple phases. The energy delivery systems on campus will be designed to accommodate decarbonization of campus utilities, electrification of building fossil fuel uses and fleet decarbonization.

The Campus Decarbonization and Electrification Project team embarked on a 3-step process to achieve the goals of this project. The three steps, each lasting approximately two months, included:

1. Reviewing the campus energy delivery infrastructure
2. Evaluating pathways to a fossil fuel free campus
3. Selecting and developing a recommended path to a fossil fuel free campus

This report is structured to start with the 3rd step, the recommended path to a fossil fuel free campus, followed by the supporting evaluation of alternatives and concluding with the summary review of the campus energy delivery infrastructure as it stands in 2023.

2 Recommended path to a fossil fuel free campus

2.1 Overview of approach

The conceptual plan will allow UCSC to start decarbonizing immediately focusing on the ten colleges followed by the remaining regions of campus, Westside Research Park and the Coastal Science Campus. There is flexibility with which ten colleges are electrified first. Small or remote buildings can be electrified utilizing existing technologies and leveraging recent innovations aimed at the retrofit market such as single phase heat pumps. Larger buildings benefit from sharing utilities regionally. A regional 'Decarbonization Station' allows for multiple buildings to quickly be converted to electric systems with heating, domestic hot water, electric vehicle charging, and power needs to be provided under a single project in each phase. A single Decarbonization Station is able to serve two colleges and colleges have been paired for the purposes of implementation. The college pairs are:

1. Crown/Merrill
2. Stevenson/Cowell
3. College Nine/John R. Lewis
4. Kresge/Porter
5. Rachel Carson/Oakes

The remaining regions for the purposes of phased implementation are:

6. Science Hill
7. Athletics and Recreation
8. Theater Arts
9. CFA and Village Housing
10. Lower Campus
11. Westside Research Park
12. Coastal Science Campus

The Decarbonization Station approach minimizes the retrofit work required at each building and consequently reduces disruption to campus. By consolidating equipment regionally, maintenance can be reduced, and training can be streamlined by locating new technologies in a dozen key locations rather than spread across more than 60 buildings. The recommended decarbonization strategy for research facilities at Science Hill, the Coastal Science Campus, and Westside Research Park have specific adaptations to meet the density of energy required in those locations as well as the resiliency required to maintain critical research operations.

The campus fleet contributes less than 5% of Scope 1 campus emissions. Partial decarbonization of the campus fleet is required to achieve the University's goal of a 95% reduction. Electrification of the campus's light duty vehicles, including sedans, SUVs and small trucks is recommended as cost competitive battery electric alternatives to internal combustion engine light duty vehicles exist on the market and are increasingly popular. Non-fossil fuel medium duty vehicles, including work trucks and sanitation vehicles, are primarily available in limited, made to order quantities at great expense. Decarbonization of medium duty vehicles is recommended to be deferred until more non-fossil fuel options and models are available, or a bulk purchasing agreement can be organized through UCOP. Decarbonization of the campus bus and shuttle fleet is being studied by non-profit consultants, the Center for Transportation and the Environment and this report defers its recommendation to the results of their study which is expected later this year (2023). Electric Vehicle charging infrastructure will be required to support growth electrification of the fleet.

2.2 Fossil fuel free target date

Implementation of the first series of priority decarbonization projects is expected to take at least seven years (Figure 2), provided the necessary funding and additional staffing is readily available and PG&E is able to provide sufficient power to meet the needs of an electrified campus. Chancellor Larive has charged this project with identifying specific actions to reduce UC Santa Cruz's Scope 1 and Scope 2 carbon emissions by 2030, ideally to zero. Alternative timelines have been studied for comparison. Extended timelines include consideration of:

1. Timing of new infrastructure with end-of-life replacements of existing equipment
2. Realizing the full financial value of the cogeneration plant expected to be fully amortized in 2045
3. Incorporation of developing technologies

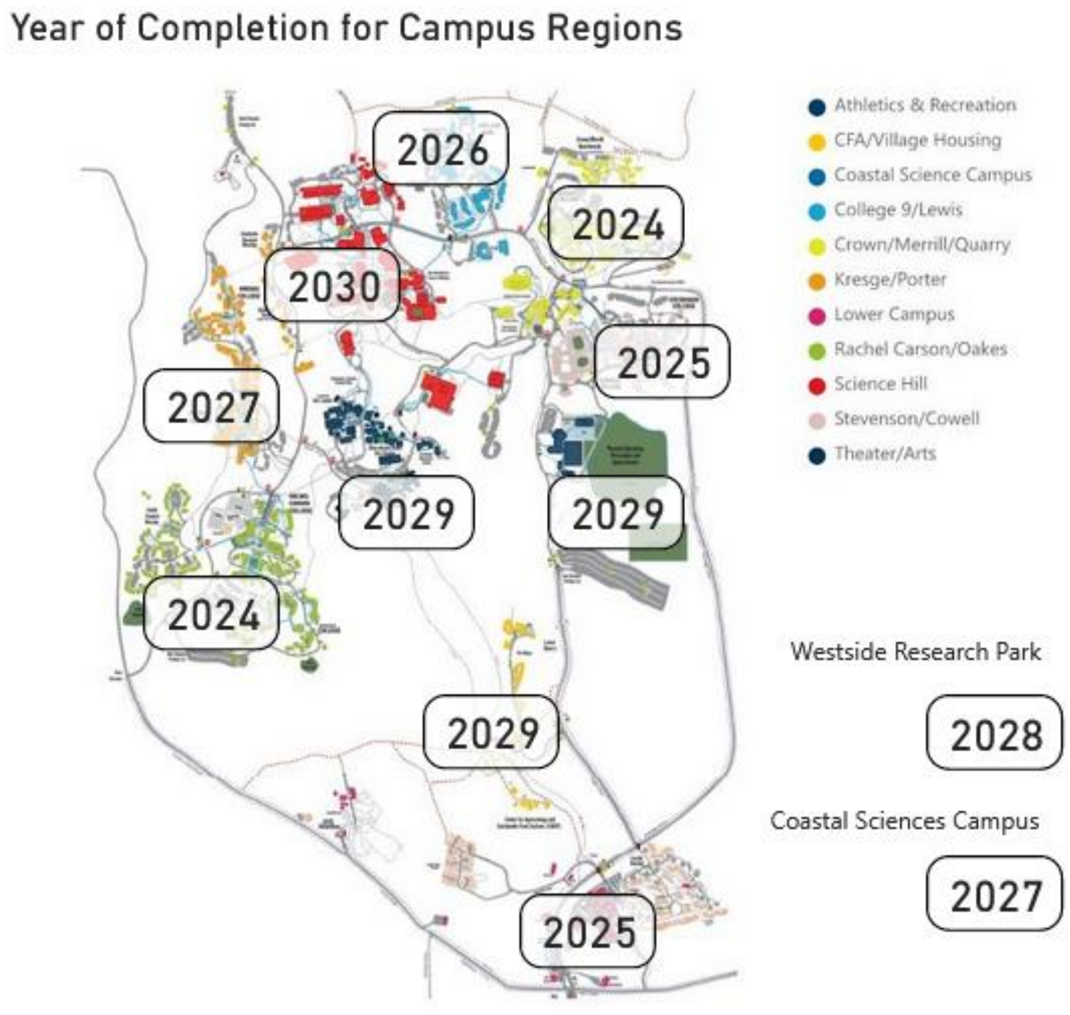


Figure 2 – 2030 Fossil fuel free target

Four scenarios for implementation are presented including completion dates for 2030, 2035, 2040 and 2045. Feasibility is dependent in part on how much and when funding is available as well as when PG&E can provide a new dedicated circuit to serve campus, however all the scenarios presented assume PG&E is able to do so prior to decommissioning the fossil-fuel based cogeneration system from continuous operation. PG&E has been engaged and is studying options to provide additional power to campus to meet the 2030 timeline. Technology exists that would allow the campus to successfully decarbonize by 2030. Determining the feasibility of considering the 2030 pathway should include evaluating myriad factors such as the utility's timeline to increase electrical capacity to the campus, campus resources and personnel capacity, internal and external funding mechanisms, and construction project timelines in relation to academic schedules. Consideration of existing biogas allocations through 2045 is included.

2030 scenario: A 2030 timeline requires conversion of at least two regions to be implemented each year, finishing with Science Hill. A biomethane allocation is assumed to be utilized from 2025 to 2030 to reduce the impact of interim gas combustion and then after 2030 the remaining biomethane allocation attributed to UCSC can be relinquished back to UCOP for use at another campus.

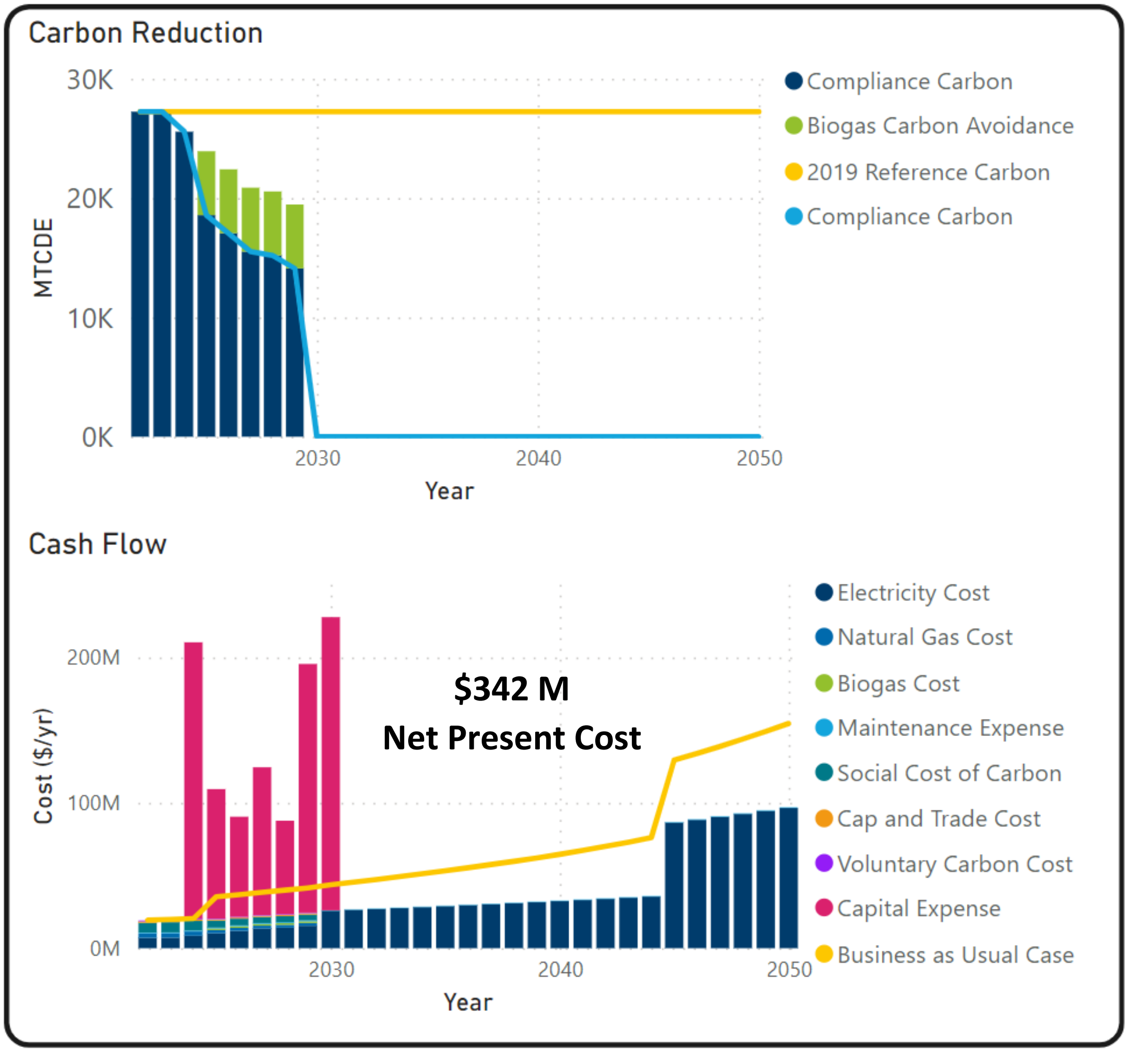
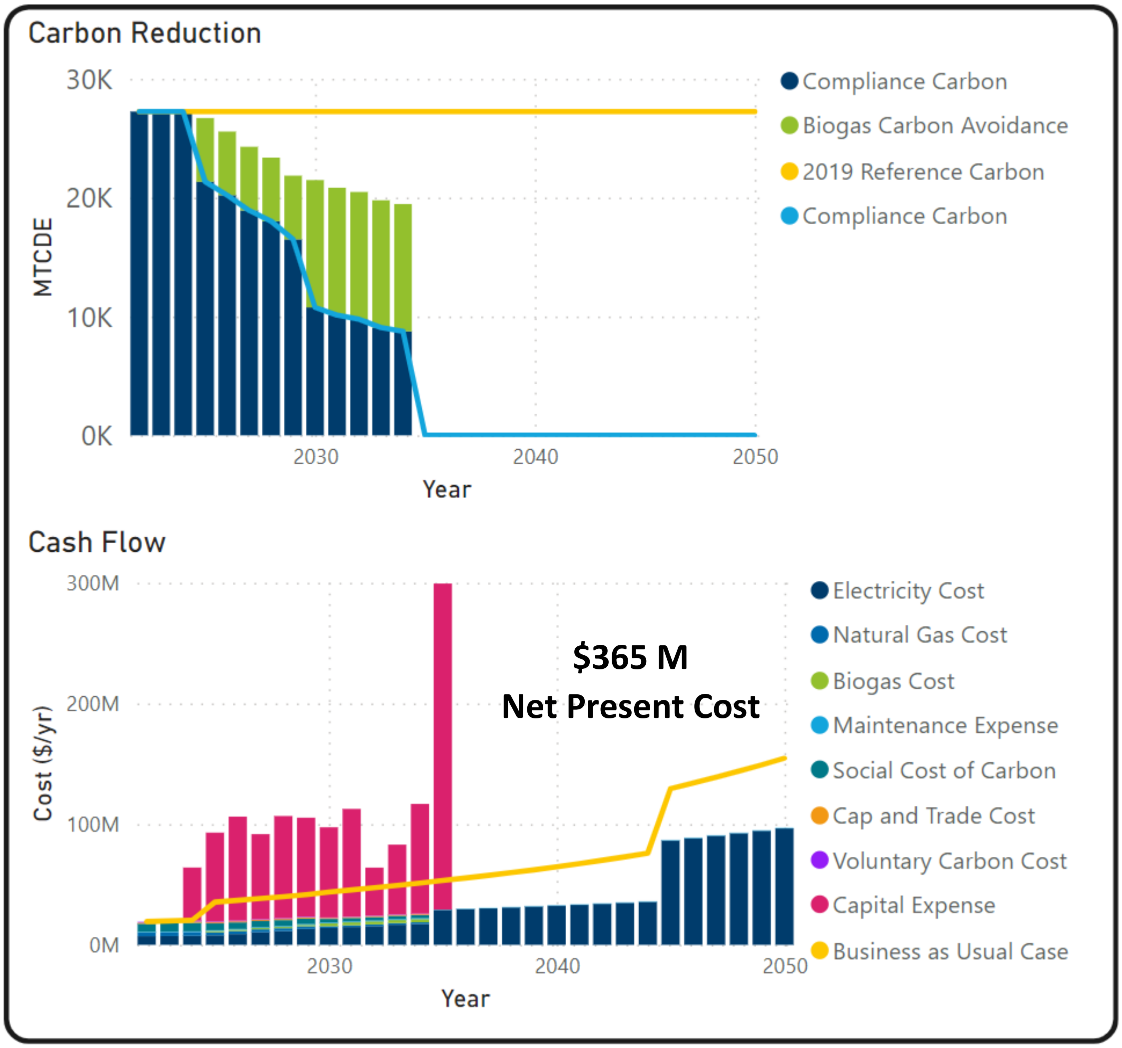


Figure 3 – 2030 Fossil fuel free target

2035 scenario: A target date of 2035 allows larger regions to be implemented sequentially with smaller regions implemented simultaneously. This scenario utilizes the full biomethane allocation from 2025 to 2035 and brings UCSC within its Cap and Trade allowances by 2030 and remains within the allowance after that date. This scenario shows annual savings in operational costs starting in 2025. Decommissioning of the cogeneration system in 2035 increases utility costs because electricity is more expensive than natural gas. It also decreases maintenance costs because the cogeneration plant no longer needs to be serviced.


Carbon Reduction

Cash Flow

$365 M
Net Present Cost

Figure 4 – 2035 Fossil fuel free target

2040 scenario: The 2040 scenario follows a trajectory similar to the 2035 scenario, attempting to keep UCSC within its Cap and Trade allowance until 2035 when the planned biomethane allocation begins to diminish. Annual cost savings are realized while the biomethane allocation is utilized up to 2035. This scenario might represent a delay in available power from PG&E requiring Science Hill to be deferred until 2040. Under a 2040 scenario, consideration of mechanisms to reduce interim carbon emissions are recommended such as expanding the current biomethane contract, utilizing an alternative biogas mixture or implementing carbon capture technologies on campus.

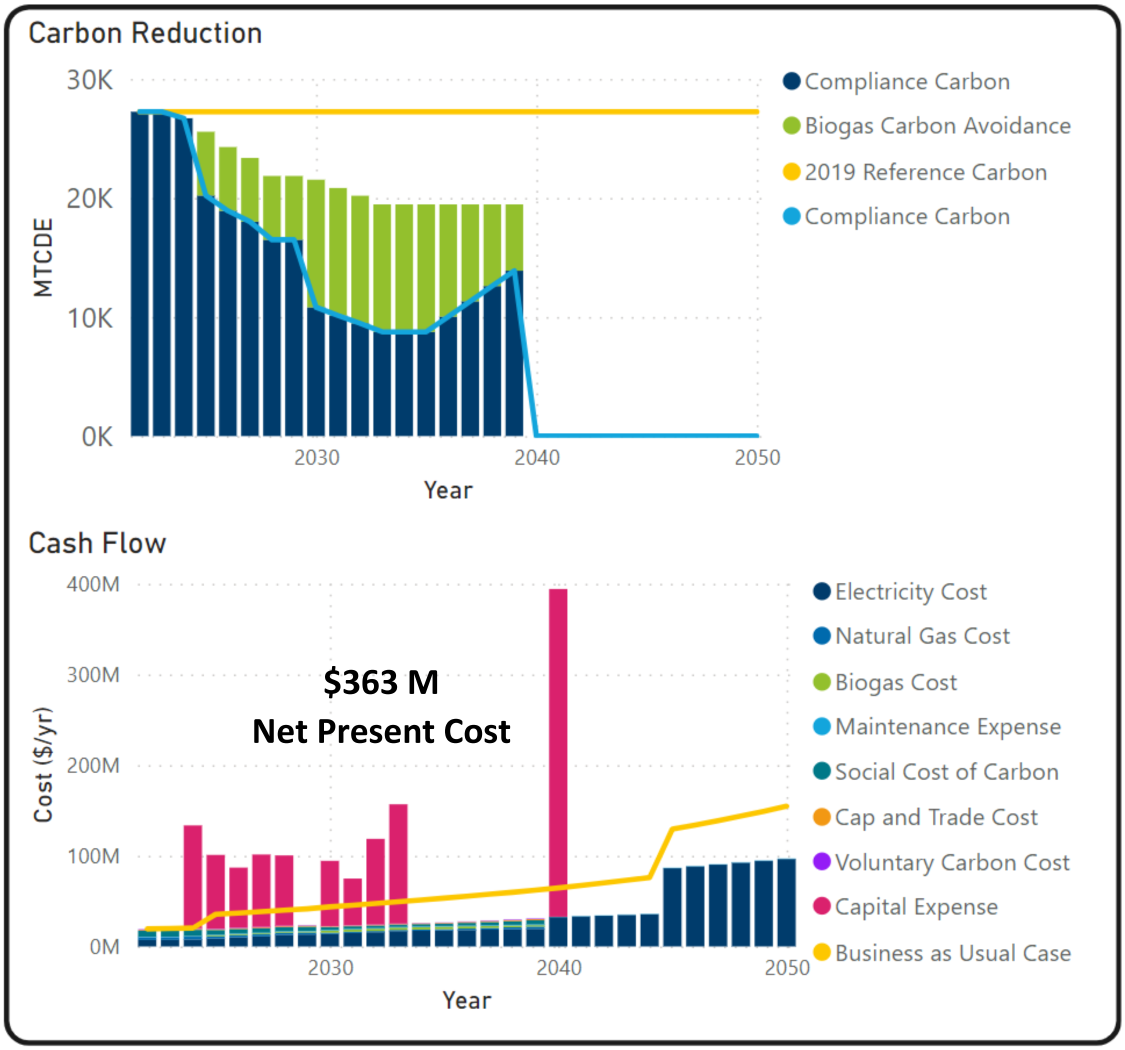


Figure 5 – 2040 Fossil fuel free target

2045 scenario: The longest scenario presented defers decarbonizing Science Hill until 2045. This scenario represents an option where the financial benefits of the cogeneration plant are maintained until the plant has been fully amortized in 2045. Notably this option sees a slight increase in annual operation costs from 2040 to 2045 due to the rising costs of carbon. Consideration of mechanisms to reduce interim carbon emissions are the most beneficial in this scenario. The 2045 scenario provides the most time for green hydrogen development and commercialization to occur. Under this scenario, the cogeneration plant might be retrofitted to green hydrogen, if commercially available, in lieu of natural gas in 2045 to eliminate its remaining emissions while the rest of the campus is electrified. PG&E is currently engaged in a pilot clean hydrogen program (Hydrogen to Infinity) in Lodi, California which may help validate commercially viability of future retrofits.

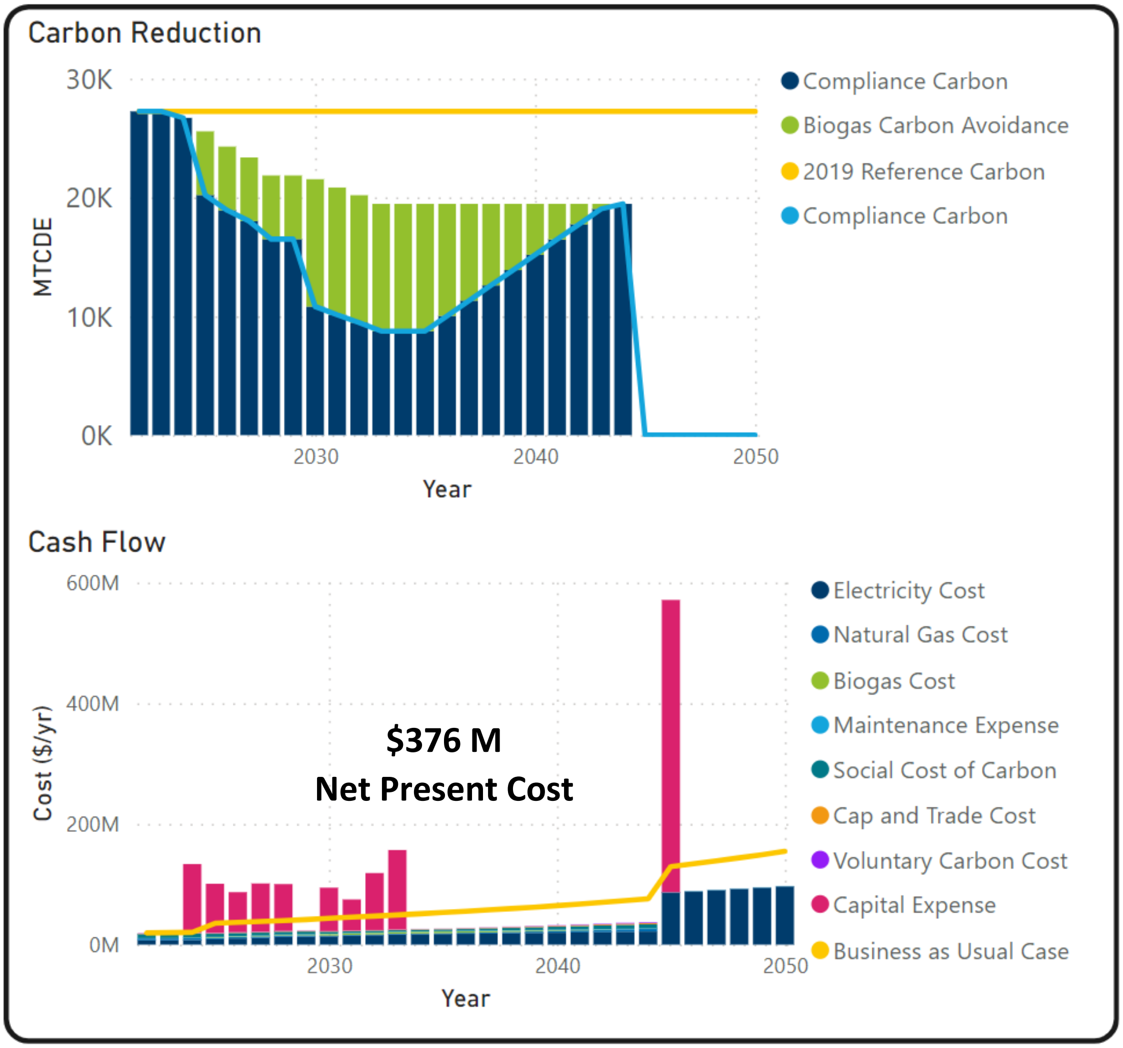


Figure 6 – 2045 Fossil fuel free target

The 2030 scenario provides the quickest carbon reduction, however this approach would require management of multiple large projects simultaneously and would require more funding and increased staffing sooner. The 2035 scenario aligns with the UC Academic Senate's Climate Crisis Task Force target date while providing additional time to secure funding and coordinate additional power from PG&E. The 2035 scenario allows for larger projects to occur sequentially with steady and consistent progress towards the fossil fuel reduction goal.

The 2040 and 2045 scenarios are viable, however these scenarios create an environmental, regulatory and financial burden after 2035 when campus emissions would exceed the Cap and Trade allowances. Under these prolonged scenarios, consideration of mitigating projects such as carbon capture, sequestration, and beneficial reuse is recommended. The cogeneration plant is being paid for until 2045, and each solution that decarbonizes Science Hill earlier than 2045 would involve the cost of paying for a cogeneration plant that is no longer active.

The overall net present cost comparison between each option is summarized in Figure 7.

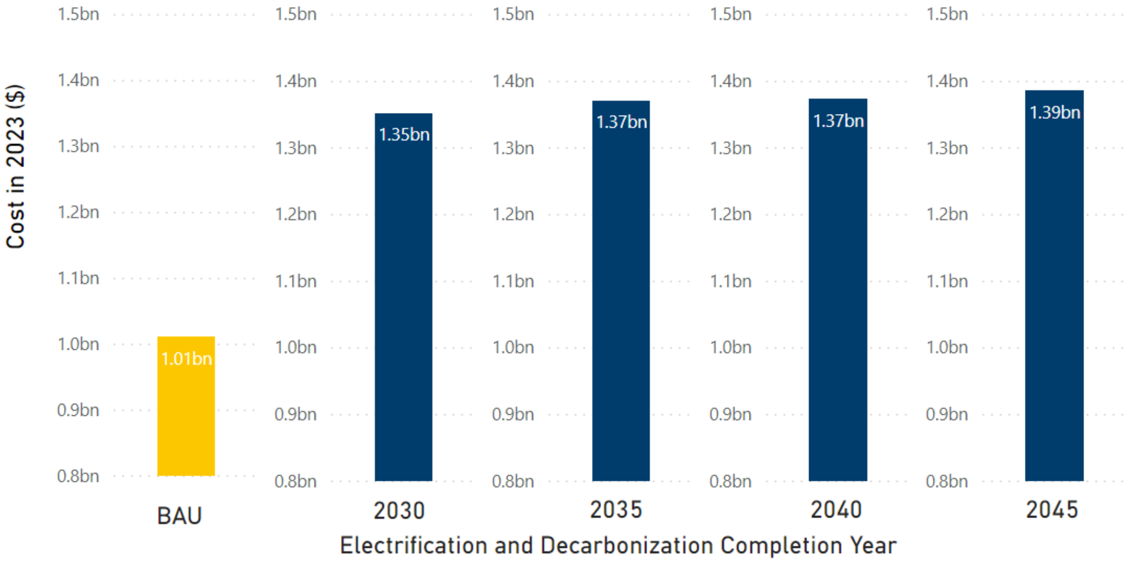


Figure 7 - Net Present Cost Comparison of Electrification and Decarbonization Targets

2.3 Phasing

A make-ready, electrical infrastructure project is recommended to occur first and as soon as possible. “Make-ready” projects are intended to be preparatory projects intended to minimize the disruption of subsequent construction work. This infrastructure project would create a new 21 kV and 12.47 kV distribution on the campus, as recommended in the LRDP 2020-2040 MV Electrical Master Plan. This new medium voltage (MV) distribution would provide greater redundancy in the campus electrical infrastructure but more critically, expand capacity on campus for electrification of existing fossil fuel systems and allow for growth as identified in the Long Range Development Plan. This MV distribution would allow PG&E to expand available power to the existing Slug Substation on campus and provide a second new substation on the west side of campus. Once complete, the MV distribution with PG&E upgrades allow for the connected regions to be decarbonized and electrified in any order, understanding the considerations noted above.

The first two to three regions (depending on the regions selected) can be implemented using the power currently allocated to campus from PG&E, if the work to be done on the 21 kV MV distribution from the Slug Station is not complete. Augmentation of the existing service from PG&E (up to 15 MW) will be required to complete phasing of the remaining regions. Science Hill cannot be one of these first regions, because Science Hill presents too large of a load for phasing and will require a secondary PG&E service to the Main Campus in order to complete phasing.

Science Hill cannot fully decarbonize until an additional dedicated 21 kV circuit from PG&E is brought to campus to expand available power. Science Hill may start decarbonizing through implementation of heat recovery chillers as replacements for existing cooling only chillers; however the cogeneration gas turbine and gas boilers must stay operational until additional power from PG&E is available. Once PG&E power is available and Science Hill is electrified, the cogeneration plant may transition from near continuous operation to operating only during PG&E outages as an alternative source of power or for limited peak shaving opportunities utilizing a clean combustion fuel. Retrofits or upgrades to the cogeneration plant would be required depending on future use cases and clean combustion fuels. Section 4.1 of this report details the proposed electrical infrastructure work required to support campus electrification.

Three key milestones for the campus electrification are summarized below:

1. Two colleges pairs may electrify utilizing the existing campus electrical infrastructure (up to 10 MVA of power available)
2. PG&E augments current 21kV circuit to campus expanding available power (up to 15 MVA power available) and new 21 kV distribution system on campus allows remaining regions to electrify except Science Hill
3. PG&E provides a new 21 kV, dedicated circuit to the west side of campus and connects to campus 21 kV distribution (up to 35 MVA of power available). Science Hill can fully electrify

Regions that are not connected to the main campus medium voltage system can begin to decarbonize as funds allow and projects can get implemented. These regions include Lower Campus, Westside Research Park and Coastal Science Campus.

As of early 2023, Porter requires the replacement of large boilers and presents an immediate opportunity to begin. The Student Housing West development provides another opportunity for an immediate catalyst project to replace fossil fuel systems in both Rachel Carson and Oakes colleges. Crown, Merrill, Stevenson and Cowell are good secondary candidates due to the age and the condition of existing infrastructure.

The timing of the remaining regions is flexible and can be implemented when funding is available and if major projects or renewals in that region create an opportunity to reduce costs. In the proposed phasing, Theater Arts as well as Athletics and Recreation are deferred due to the specialty gas equipment. Refer to section 3.1.4 of this report for additional discussion on specialty gas equipment. College 9 and John R. Lewis are also deferred as they have relatively new infrastructure and equipment relative to the other college pairs. Kresge College has recently been electrified and would require only a few buildings to connect to Porter's Decarbonization Station.

2.4 Immediate opportunities

Immediate opportunities to replace fossil fuel systems are ongoing as existing fossil fuel equipment reaches the end of its useful life. The recommended approach for small (less than 25,000 sf) and low-rise (less than three stories) buildings is to seek stand-alone electric alternatives to gas systems and equipment as they fail or reach the end of their useful life. The recommended approach for larger buildings is to replace fossil fuel heating systems with technologies that are compatible with a future connection to a Decarbonization Station once they are constructed. Over time, smaller systems can be connected to larger systems to increase efficiency and reduce maintenance associated with distributed equipment (Figure 8). This process has begun to be used for evaluation of current projects for decarbonization and a policy is in development for evaluation of future projects.

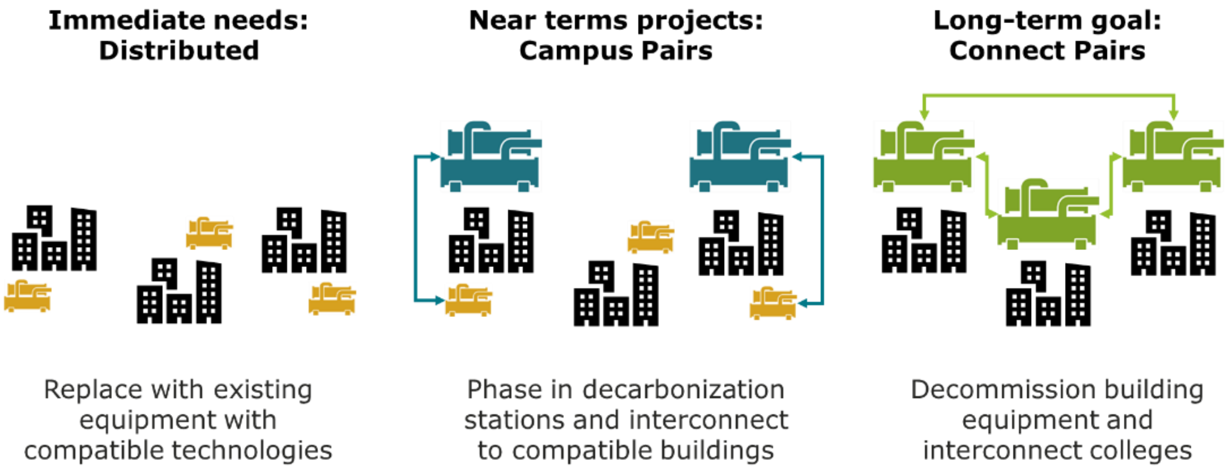


Figure 8 – Growth of non-fossil fuel systems over time

The recommendation for buildings without hot water or hot water boilers is to seek replacement of their heating systems with electrified heating systems upon failure of their fossil fuel systems or once those systems reach the end of their useful life. These systems may be replaced with commercially available air to air heat pumps or variable refrigerant systems. They may also consider a future connection to a Decarbonization Station if hydronic heating systems are utilized and is deemed cost-effective at the time of replacement.

There are several options for large buildings with boilers requiring immediate replacement. Where a Decarbonization Station exists nearby, that building can be immediately connected to the Decarbonization Station. If a Decarbonization Station does not exist in the region of campus, an alternate hot water generation technology will be required. This technology could be electric, such as a local water to air heat pump or a gas boiler can be utilized to reduce costs. The design associated with either technology will need to meet the design criteria to connect to a future Decarbonization Station including:

1. Design for low temperature hot water (typically 140°F)
2. Allow space for a heat exchanger to connect to district piping
3. Be located as to minimize disruption and piping needed to connect to district piping

Where the building requires higher heating temperatures than an air source heat pump can feasibly produce, space shall be reserved for additional water-to-water heat pump within the building. These design criteria allow for building level heating hot water equipment such as boilers to be readily connected to a future Decarbonization Station with minimal disruption and low costs. Where the interim heating hot water technology is expected to be in place for an extended period of time (more than seven years for example), consideration should be given to higher efficiency interim technologies such as water-to-air heat pumps or condensing boilers. Where connection to a future Decarbonization Station is expected within a few years, replacement with a conventional boiler, designed for low temperatures, is a cost-effective solution. An example decision tree to guide near term equipment replacements is shown below (Figure 9).

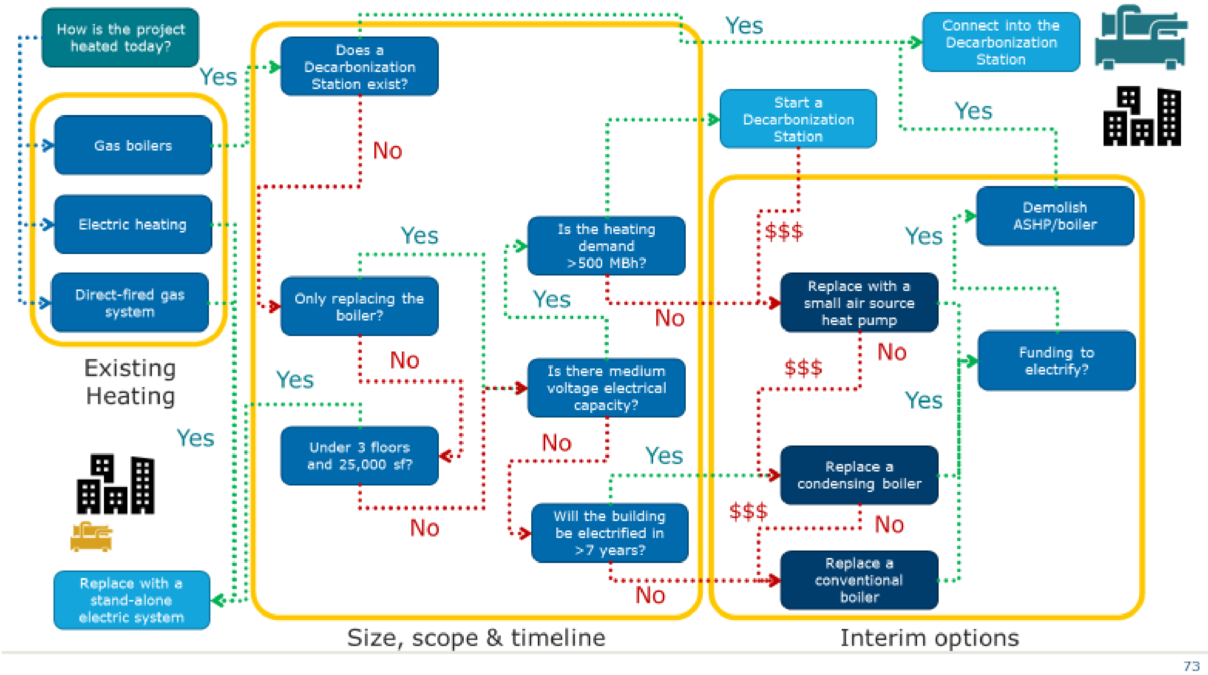


Figure 9 – Sample decision tree for immediate replacements of fossil fuel systems

The following language has been developed as guidance for near-term equipment replacements.

> Installation of new gas heating systems is prohibited under the Campus Physical Design Framework except under case-by-case approvals. Where gas and fossil fuel heating systems require replacement or expansion, non-fossil fuel systems shall be provided in their place. An engineering evaluation shall be conducted to determine the replacement heating system. The evaluation shall include the following steps:
>
> 1. Calculate the heating load requiring replacement or expansion. Utilize existing metered data where possible to validate heating demands of existing spaces.
> 2. Where hydronic equipment is utilized, conduct a temperature reset study to determine the lowest water temperatures required to heat the space or system. Temperature reset study shall gradually decrease the air and water temperatures until space temperature set-points are no longer met. The lowest water temperature meeting the space temperature set-points shall be utilized for the design of the new system.

3. New hot water systems shall be designed, specified, and selected to operate with hot water supply temperatures of 140°F or lower. Systems may be operated at higher temperatures where selected equipment allows.
4. Select an electric alternative to replace the existing gas heating systems to serve as the basis of design. Electric systems shall utilize heat pumps as the primary source for space heating.
5. Strategies to reduce heating loads are encouraged. These include heat recovery, passive solar heating and active solar heating.
6. Assess electrical capacity at the building against what is required to support electric heating. Electrical upgrades may be required. Where an electric heating system increases the building service size – further evaluation is required.
7. Confirm outdoor equipment is designed, specified, and selected to operate at the temperature conditions necessary for service. Refer to campus design temperatures.
8. Where water-source heat pumps are utilized, confirm sufficient heat is rejected to condenser loops on design days to support heat pump heating. Where the district condenser loop is utilized, further evaluation is required.

Electric Resistance Heating

Refer to Building Energy Efficiency Standards - Title 24, Part 6 (2022 California Energy Code), Section 140 regarding limitations on electric resistance heating. Electric-resistance heating is prohibitive as a primary source of comfort heating. Electric resistance heating is allowed to supplement heat pump heating systems where the heating capacity of the heat pump is more than 75% of the design heating load.

Refrigerants

Low global warming potential (GWP) refrigerants shall be selected where feasible. Selected equipment shall comply with California Air Resources Board and US EPA regulations including the SNAP and AIM Acts. By January 1, 2024 refrigerants with GWP above 700 shall not be installed in the new equipment. Allowable refrigerants for comfort cooling and heating applications include:

1. R-32
2. R-123
3. R-1233zd(E)
4. R-1234yf
5. R-744 (carbon dioxide)
6. Blends
    a. R-513A
    b. R-454B

Building Automation & Controls

New heating systems shall be configured and provided with demand response controls to allow for reduced output and disabling of the heating remotely upon receiving signal from the Building Management Systems (BMS).

Future Replacement

Where the building connects to the district heating loop, provide a plate and frame heat exchanger designed for a 2°F approach and maximum of 10 psi water pressure drop. The building side of the heat exchanger shall be designed for 140°F supply temperature and 105°F return temperature. The district side of the heat exchanger shall be designed for 142°F supply temperature and 107°F return temperatures. The heat exchanger may be operated at higher temperatures.

Where the building does not connect to a district heating loop, document reserved space for the location of a future plate and frame heat exchanger to connect the system to a district loop.

Electric Alternatives to Gas Heating Systems

1. Single zone and direct fired gas systems
    a. Packaged rooftop heat pump
    b. Split system heat pump
    c. Packaged terminal air heat pumps
2. Multi zone hydronic systems
    a. Water to air heat pumps (confirm refrigerants with installation date) Manufacturers include:
        i) Aermec NR Series
        ii) Multistack AR Series
        iii) TSI Fossil X Series
3. Systems connected to district heating hot water
    a. Single zone water to air heat pumps
    b. Water to water heat pumps

2.5 Implementation cost

Estimates of probable cost were developed for the replacement of fossil fuel energy delivery systems, supporting electrification infrastructure, and decarbonization of fleet vehicles. Below is a summary of costs, by region and project (Table 1). Phases are in the recommended implementation order however the sequence can be adjusted as long as the 21 kV distribution make-ready phase is first and sufficient power is available from PG&E for the next phase. The Microgrid Expansion on the main campus is intended to replace the gas cogeneration turbine with new on-site power generation. Please note that electrification of fleet should occur concurrently with other phases and should not necessarily be last though the cost is represented as last in Table 1. Refer to section 4.1.4 for further discussion regarding on-site power and technologies considered as part of the Microgrid Expansion including energy storage. The exact mix of technologies for the Microgrid Expansion will be subject for future Microgrid planning efforts. The cost in this study includes photovoltaics at the West Remote parking lot and optional standby engine generators in each decarbonization station. The Microgrid Expansion is specific to the Residential Campus. Microgrid projects are underway at WRP and being investigated at the CSC.

Table 1 Summary implementation costs by phase

D&E Phases	Estimate of Probable Cost
21 kV distribution	39,300,000
Porter/Kresge	59,610,000
Rachel Carson/Oakes	61,950,000
Crown/Merrill	68,380,000
Stevenson/Cowell	52,570,000
College 9/John R. Lewis	54,640,000
Westside Research Park	45,260,000
Athletics and Recreation	47,010,000
Theater Arts	52,820,000
CFA/Village Housing	14,210,000
Lower Campus	22,260,000
Coastal Science Campus	16,260,000
Science Hill	83,840,000
Microgrid Expansion	42,990,000
Fleet Procurement	25,000,000
Grand Total	**686,100,000**

Estimated costs in Table 1 are shown in 2023 dollars. Where costs are displayed for future years, the costs are escalated based on a cost escalation rate of 6%. This escalation rate for construction costs is based upon the average escalation for the past five years (2018 through 2022) in the California Construction Cost Index as reported by the Real Estate Division of the California Department of General Service. Total implementation costs are shown as a net present cost in 2023 dollars based upon a discount rate of 4.25% as agreed upon with the Campus Controller in the project Financial Workshop. Project costs are estimated utilizing cost factors on top of the estimated construction costs. Cost factors include:

4. 6.5% UCSC project management fees
5. 11% design fees
6. 5% owner's design contingency
7. 2.5% commissioning costs
8. 10% general conditions
9. 7.5% phasing and staging premium

A 20% labor and material shortage premium is applied to costs based on experience with decarbonization work in northern California to account for the use of in-demand skilled labor for this type of work and ongoing supply chain challenges facing the construction industry.

Savings associated with the Interest Reduction Act or other federal, state, and utility rebates were not included in this analysis.

A summary of the estimates of probable cost may be reviewed in Appendix A.

An example of capital expenses associated with a path to decarbonization that is complete in 2030 is shown below (Figure 10). Costs for future years are escalated at a rate of 6% per year.

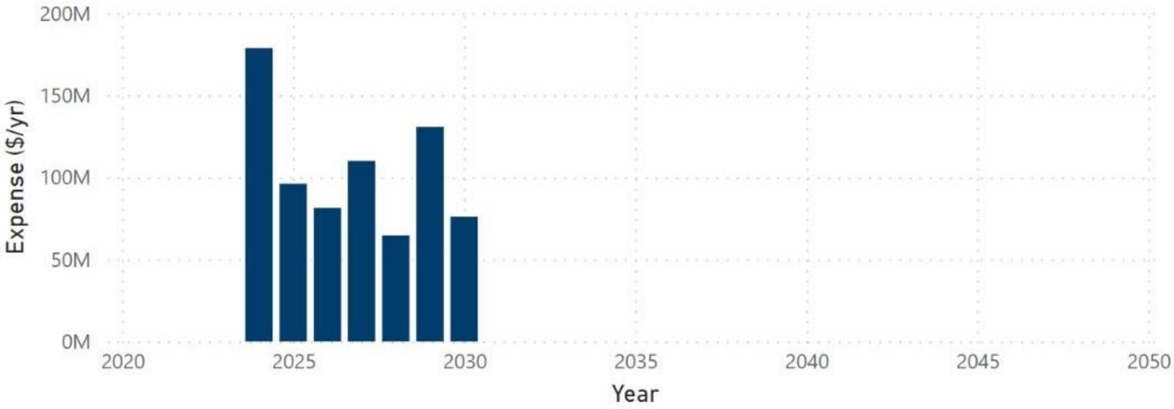


Figure 10 – Capital expenses (electrification complete by 2030)

Capital expenditures include the implementation costs required to achieve the targeted fossil fuel reductions. Note that a portion of the proposed costs are expected to be incurred to support the LRDP growth and fund deferred maintenance and normal equipment replacements.

2.6 Operational cost

Operational costs are estimated for each scenario. Annual operational costs include:

- Electricity costs
- Natural gas costs
- Biomethane purchases
- Routine maintenance costs
- Cap and Trade regulatory costs
- Investments in lieu of offsets, replacing prior commitments to voluntary carbon offsets

Water cost savings are expected but not accounted for in this analysis. Training and development costs are split between capital costs (single time training sessions) and maintenance costs (ongoing technical development).

Operational costs are calculated for the proposed decarbonization pathways and for a 2019 reference business as usual case. The reference business as usual case assumes existing gas equipment is maintained while new growth is electrified. Under the reference business as usual case, voluntary carbon credits are redirected to fund decarbonization efforts in accordance with new (2023) UC Sustainable Practices Policy. Deferred and planned maintenance savings are not included in this analysis.

Decarbonization and electrification leads to savings in avoided carbon (credits/social costs) and maintenance costs but increases in utility costs. UC Santa Cruz has the highest electric costs in the UC system based on UCOP reporting. Average electric costs are 25% higher than the next highest costs at another UC campus. LRDP growth is included under all scenarios starting in 2045 (Figure 11).

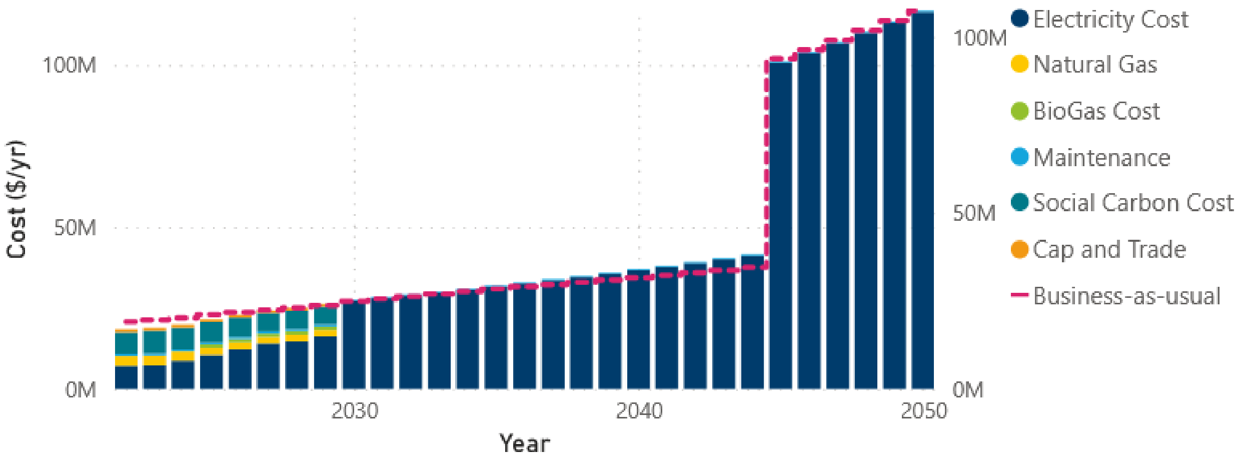


Figure 11 – All operational costs (electrification complete by 2030)

Annual maintenance costs have been estimated by technology based on $/unit capacity benchmarks as reported in the US Energy Information Administration – Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case report prepared for the US EIA by Guidehouse. There is a significant reduction in maintenance costs associated with decommissioning the cogeneration turbine, which for the purposes of this report coincides with the electrification of the systems serving Science Hill (Figure 12). A reference business as usual cost value is also shown for each year as represented by a stepped line. These values represent the cost of maintenance if no decarbonization and electrification projects are undertaken.

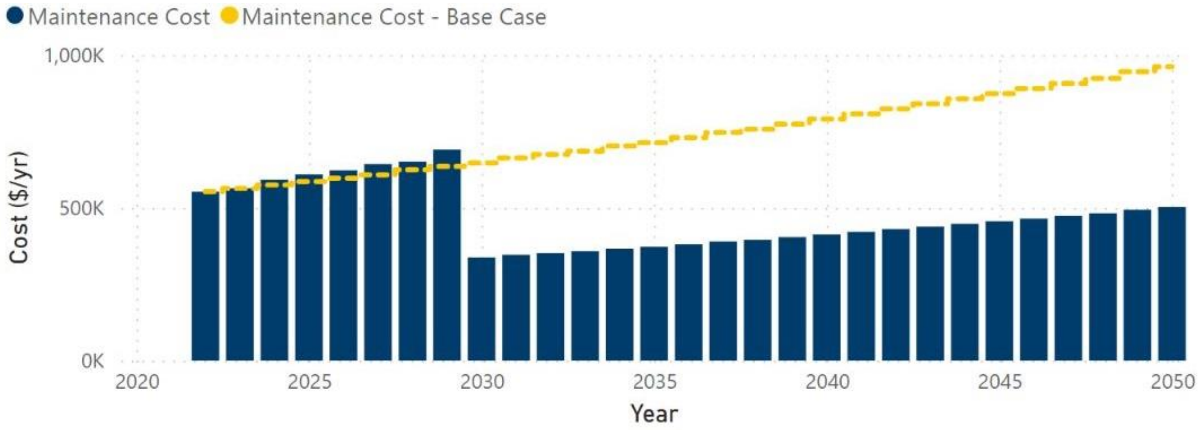


Figure 12 – Maintenance costs (electrification complete by 2030)

The utility costs for this same scenario are higher than the “Base Case” because electric energy costs are higher than natural gas energy. There will be a substantive increase in 2030 (the year that Science Hill is electrified, and cogeneration turbine is decommissioned in this scenario) and a large increase in 2045 (the year that the LRDP is completed, nearly doubling the total square footage of the buildings on campus) (Figure 13).

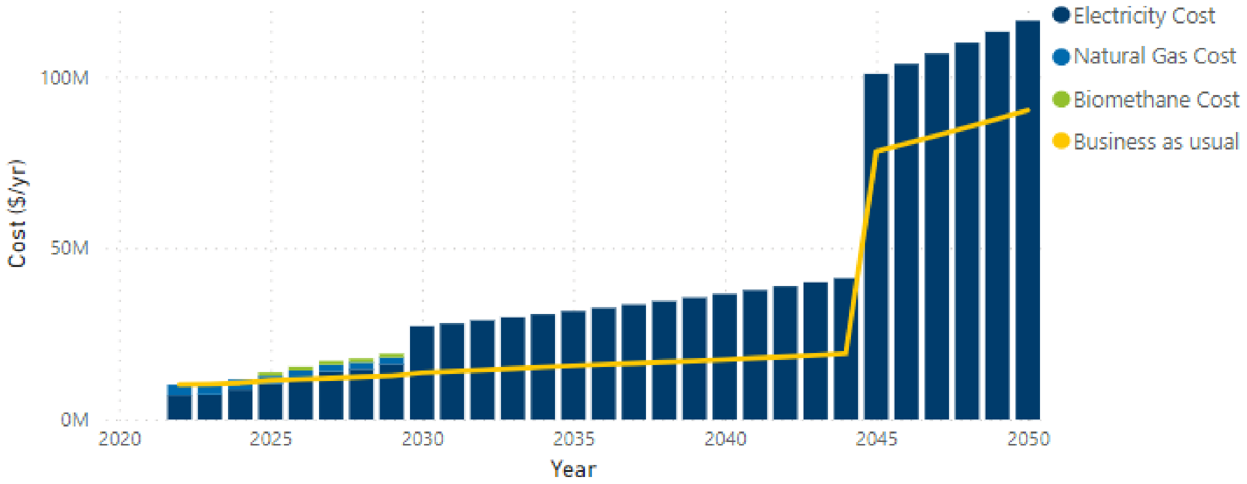


Figure 13 – Utility costs (electrification complete by 2030)

All operational costs are escalated independently based on UCOP or 3rd party projections with the exception of biomethane costs which are fixed as part of a UCOP agreement.

2.7 Just transition and equity in climate action

The University of California, Santa Cruz is committed to promoting and protecting an environment that values and supports every person in an atmosphere of civility, honesty, cooperation, professionalism, and fairness. In February 2023, the UCSC D&E Task Force began applying a Just Transition and Equity (JT&E) lens to recommendations resulting from its technical study findings. As a result, the D&E Task Force has called for the formation of a JT&E Subcommittee to conduct a Diversity, Equity, Inclusion and Justice (DEIJ) analysis. The JT&E Subcommittee plans to launch in Summer 2023 and is expected to deliver an initial internal evaluation in December 2023.

This effort will help inform whether the UCSC campus should consider an additional review and partnership with an external consulting firm on this topic as part of its ongoing D&E planning efforts. In this process, the Subcommittee will identify the impacts and opportunities of the Task Force's recommendations for all campus community stakeholders, and also note potential inequitable impacts and make recommendations to mitigate harm.

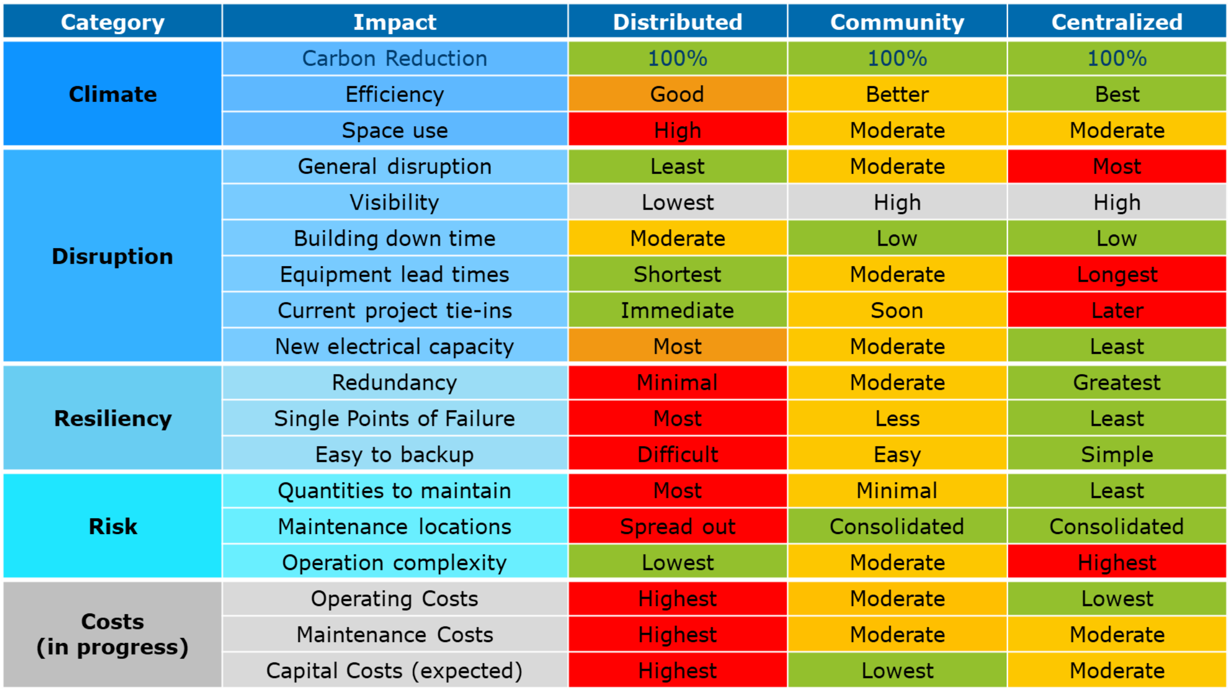
The JT&E Subcommittee will be co-chaired by the Sustainability Office's Sustainability & Equity Special Projects Manager. Membership will reflect the campus' diverse stakeholders, including staff, students, and faculty across multiple disciplines. Other partners include the Division of Student Affairs & Success, College 9 & John R. Lewis College, and the People of Color Sustainability Collective (PoCSC).

The subcommittee will conduct analysis through inclusive and community-centered approaches, which can include survey instruments to key community members, engagement with the local Santa Cruz community, academic research, and town halls to gain input and feedback. In addition, the JT&E Subcommittee will take into account the interconnections between its work and the broader community needs and concerns, such as housing, supply chain standards, and equitable sourcing practices.

3 Building fossil fuel use

3.1 Summary of building decarbonization approach

Heating is the largest single source of greenhouse gas emissions in buildings on campus (section 6.1.4). Heating may be electrified utilizing multiple technologies and approaches. Heat pumps were identified as the primary electric heating technology due to their high efficiency and proven track record (section 3.1.2). Heating approaches vary from small distributed systems to regional or community scale systems up to large centralized systems. A community approach was identified as the best fit (Figure 14) for most buildings on UC Santa Cruz's upper campus utilizing a decision matrix. The community systems are organized by college pairs and regions (section 2.1). Smaller buildings throughout campus are recommended (section 3.1.1) utilize distributed systems



Category	Impact	Distributed	Community	Centralized
Climate	Carbon Reduction	100%	100%	100%
	Efficiency	Good	Better	Best
	Space use	High	Moderate	Moderate
Disruption	General disruption	Least	Moderate	Most
	Visibility	Lowest	High	High
	Building down time	Moderate	Low	Low
	Equipment lead times	Shortest	Moderate	Longest
	Current project tie-ins	Immediate	Soon	Later
	New electrical capacity	Most	Moderate	Least
Resiliency	Redundancy	Minimal	Moderate	Greatest
	Single Points of Failure	Most	Less	Least
	Easy to backup	Difficult	Easy	Simple
Risk	Quantities to maintain	Most	Minimal	Least
	Maintenance locations	Spread out	Consolidated	Consolidated
	Operation complexity	Lowest	Moderate	Highest
Costs (in progress)	Operating Costs	Highest	Moderate	Lowest
	Maintenance Costs	Highest	Moderate	Moderate
	Capital Costs (expected)	Highest	Lowest	Moderate

Figure 14 – Heating electrification decision matrix

3.1.1 Approach by building scale heating and hot water

Small buildings lend themselves toward distributed, building-level replacements for gas heating equipment. Building-level replacements are most efficiently implemented as part of building renovations and equipment replacements. The small-scale electric heating equipment required to support these small buildings is commercially available and widely utilized. These equipment options are Split Systems, Variable Refrigeration Systems, and Packaged Single Zone Heat Pumps (Figure 15, from left to right respectively).

Figure 15 – Distributed scale heating equipment

Medium-sized academic and administrative buildings are well suited for a community heating approach within the college pairs (or equivalently sized region on campus). Most of the medium sized buildings on campus have boiler systems serving them, and therefore have existing piping infrastructure routed through them. The effort of this project presents the opportunity to combine these similar systems together. The equipment best suited for this scale and application is an array of air source heat pumps, in 2 pipe or 4 pipe configurations (Figure 16).

Figure 16 – Nodal scale heating equipment

When the mechanical costs of the nodal heating approach utilizing Decarbonization Stations are compared to a distributed approach, where each building has an independent system, the cost to install completely new electrified systems would nearly be twice the cost of the Decarbonization Stations (Figure 18). Distributed air source heat pumps at each building, compared to Decarbonization Stations, would cost another $15 million dollars in addition to adding more maintenance, reducing redundancy and losing the opportunity to leverage thermal energy storage.

Figure 17 – Central scale heating equipment

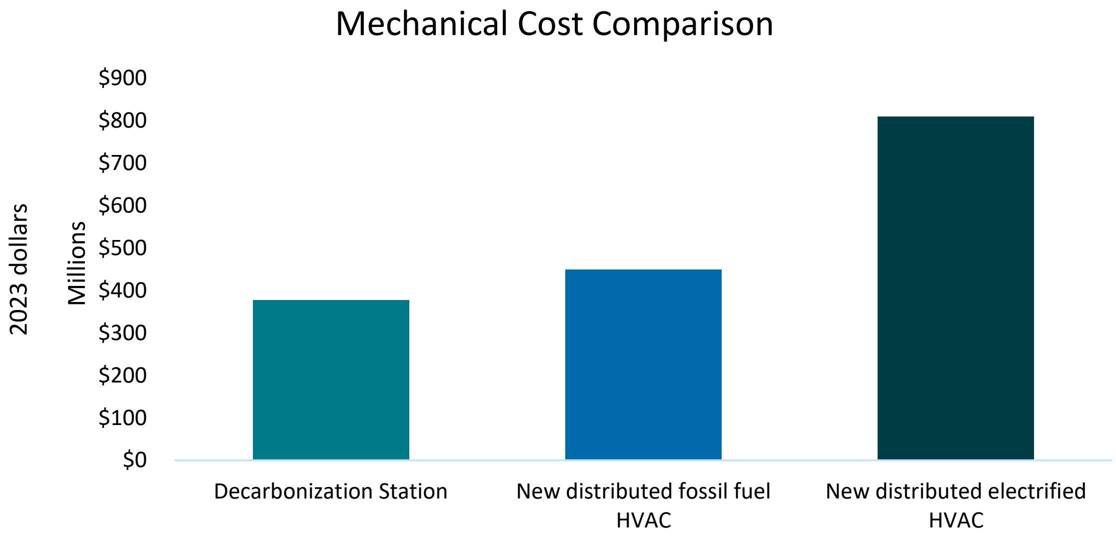


Figure 18 – Cost comparison or distributed systems versus Decarbonization Stations

Large-sized academic and research buildings are located mostly on Science Hill but also apply to the Westside Research Park and the Coastal Science Campus. They currently have year-round heating and cooling needs. These buildings will employ several different technologies in order to recover the most energy during days of normal operation and to reduce energy costs during days of peak operation. The technologies employed will be a combination of heat recovery chillers, air source heat pumps, and electric boilers (, from left to right respectively)

A distributed approach is recommended for the Coastal Science Campus. While the Coastal Science Campus includes critical research facilities, the size and smaller cooling needs relative to the buildings in Science Hill and the Westside Research Park lead to a better fit with distributed systems.

3.1.2 Screening of heating technologies

The natural resources on the UC Santa Cruz campus accentuate the environmental benefits of utilizing existing land developments over new developments. New developments bear a greater financial and environmental burden relative to peer universities. Limitations on new land development restrict the opportunity for large scale photovoltaics (greater than 1 MW) and wind or ground source heating solutions. It places a greater emphasis on compact technologies and utilizing existing developments, such as air and water heat pump technologies. The karst geology throughout campus further limits the opportunity for ground source heating and cooling technologies due to reduced performance and increased costs associated with applying these systems in areas with karst exposure. This constraint places a greater emphasis on compact technologies.

Various heating technologies were screened with stakeholders at workshops during the D&E project. Refer to Section 4.1.4 for additional discussion of power generation technologies.

Heating technologies considered included:

1. Electric resistance heating
    a. Electric boilers
    b. Direct electric resistance heaters
2. Clean fuel combustion heating
    a. Hydrogen
3. Heat pump technologies
    a. Water to water heat pumps
    b. Water to air heat pumps
    c. Air to water heat pumps
    d. Air to air heat pumps
    e. Variable refrigerant flow systems

Electric resistance heating is currently limited under the Building Energy Efficiency Standards - Title 24 to 25% of the system capacity. Hydrogen was considered a potential clean source of fuel; however, it is not commercially cost competitive to generate using clean power on-site.

Due to the limitations of clean fuel combustion and electric resistance heating, heat pumps were selected as the primary heating technology to be deployed on campus. Also, heat pump technology is more mature and commercially available than other technologies. A combination of heat pump technologies is employed depending on the needs of each building. Electric resistance heating is used in limited areas with large heating demands to supplement heat pumps.

3.1.3 Electrification of food service

UC Santa Cruz has several food service locations spread across its campus. The five college dining halls include:

1. College Nine and John R. Lewis College Dining Hall.

2. Cowell/Stevenson Dining Hall.

3. Porter/Kresge Dining Hall.

4. Crown/Merrill Dining Hall.

5. Rachel Carson/Oakes Dining Hall. This dining hall will also serve the planned Student Housing West, a 3000-bed student residence nearby, when constructed.

Figure 19 – Existing kitchen equipment

By transitioning to electric kitchens where electrical capacity exists, the university can capitalize on the benefits listed below. This approach aligns with the goal of promoting sustainability and modernizing the campus infrastructure. Electric kitchens offer several benefits comparative to those that use natural gas. These include:

- **Safety:** Electric kitchens are generally considered safer than gas kitchens. With electric appliances, there is no open flame or gas leak risk, reducing the chances of accidents, fires, or explosions.
- **Environmentally friendly:** Electric kitchens produce zero direct emissions at the point of use. By using electricity generated from UCOP's clean, renewable sources, electric kitchens can significantly reduce carbon footprints and contribute to a cleaner environment.
- **Indoor air quality:** Gas burners emit combustion byproducts, including nitrogen dioxide, carbon monoxide, benzene, and particulate matter, which can degrade indoor air quality. Electric kitchens eliminate these emissions, resulting in healthier indoor environments for occupants.
- **Improved comfort:** Compared to conventional gas ranges, electric induction cooking transfer more heat directly to the pan and food and less to the surround environment. The efficient transfer of heat results in lower space temperatures in electric kitchens resulting in a more comfortable environment that requires less mechanical cooling and less energy consumed.
- **Ease of use and maintenance:** Electric appliances are generally easier to use and maintain. They often feature digital controls, precise temperature settings, and automated functions, making cooking tasks more convenient. Electric appliances also tend to have fewer parts and simpler maintenance requirements compared to gas appliances.
- **Cost savings:** Electric appliances tend to have longer lifespans and require less frequent repairs, which can lead to reduced maintenance costs over time. Also, all-electric commercial kitchens waste less heat. Induction cooktops deliver heat just to the cookware, not to the surrounding space like gas burners do. This reduces the kitchen operating temperatures which reduces space conditioning costs.

To further promote the benefits of electric kitchens, it is highly recommended to organize training sessions and tours with chefs who specialize in working with electric appliances. These experienced professionals can showcase the advantages of electric cooking, demonstrate innovative techniques, and share expertise on maximizing the efficiency and capabilities of electric kitchen equipment.

3.1.4 Electrification of process equipment

To achieve the goal of electrification and campus decarbonization, several electric alternatives for the various process equipment commonly found in different campus settings are recommended:

- Steam humidification: Steam humidification systems can be transitioned to electric alternatives. Electric humidifiers, such as resistive steam humidifiers, use electricity to generate steam, providing effective humidity control without relying on fossil fuels. Fossil fuel based steam humidification is not present on campus.

Figure 20 – Resistive steam humidifiers & Autoclaves

- Steam sterilization: Steam sterilization processes, used in limited applications on Science Hill, can be electrified by utilizing electric steam generators or autoclaves. These electric alternatives produce steam using electricity instead of burning fossil fuels. Autoclaves on campus have already been electrified.
- Direct research: Various research equipment like Bunsen burners in many applications can be replaced with electric hot plates rather than relying on fossil fuels, providing a safer and more sustainable option.

Figure 21 – Electric Bunsen burner & electric cage washers

- Animal care cage wash and sanitation: Electric alternatives are commonly implemented for cage wash and sanitation processes in animal care facilities. Electric-powered cage washers equipped with efficient water heating systems can provide effective cleaning and sanitation without the need for fossil fuels.

- Pool heating at Athletics and Recreation center: Natural gas boilers are used for pool heating. However, electric heat pumps and/or active solar hot water heating can be utilized as an alternative. Electric heat pumps extract heat from the surrounding air or ground, efficiently heating the pool water without burning fossil fuels. Solar water heating systems are available however in review of previous engineering evaluations on campus the project team determined they are not cost-competitive relative to heat pumps.
- Kilns and crucibles at the foundry: Kilns used in pottery and ceramics can be electrified. Electric kilns offer precise temperature control and can achieve similar results to traditional fuel-fired kilns. Electric melting furnaces or crucibles can be used instead of traditional fuel-powered alternatives. Electric crucibles offer controlled heating for melting metals and other materials, reducing the reliance on fossil fuels.

Figure 22 – Existing kilns and crucibles at the foundry

Our calculations have taken into account the additional electrical demand required to electrify these specific pieces of equipment. With the exception of pool heating, the energy consumption associated with these fossil fuel-dependent processes is relatively small compared to space heating and domestic hot water systems. However, it is possible to independently electrify these processes when the equipment is due for replacement. This approach will minimize service disruptions to the existing infrastructure and operations.

3.2 Upper Campus

3.2.1 Decarbonization Station

Through consolidation of heating equipment within each college pair, the decarbonization and electrification effort can minimize costly electrical upgrades at each building. It will also consolidate the campus' 400+ boilers and water heaters with eight Decarbonization Stations (Figure 23) across campus and provide additional redundancy to allow for maintenance of the systems without disruptions to the buildings. From a heating perspective, the college pair combinations make it such that Decarbonization Stations are each similarly sized. The Decarbonization Stations can be configured to provide seasonal cooling in lieu of heating only or can be arranged to provide simultaneous heating and cooling in colleges where high energy intensive activities or equipment are utilized. The Decarbonization Stations also provide a convenient location to co-locate new medium voltage electrical equipment and distributed energy resources such as energy storage or standby power technologies. Co-locating new power infrastructure adjacent to a large consumer of power in the electric heat pumps provides for efficient infrastructure and saves overall electrical costs. Centralizing equipment also allows for thermal energy storage to be cost-effectively employed and reduce utility costs as well as limit the stress on the electrical system. The equipment can be located in stand-alone yards, on rooftops of new buildings or integrated into parking garages.

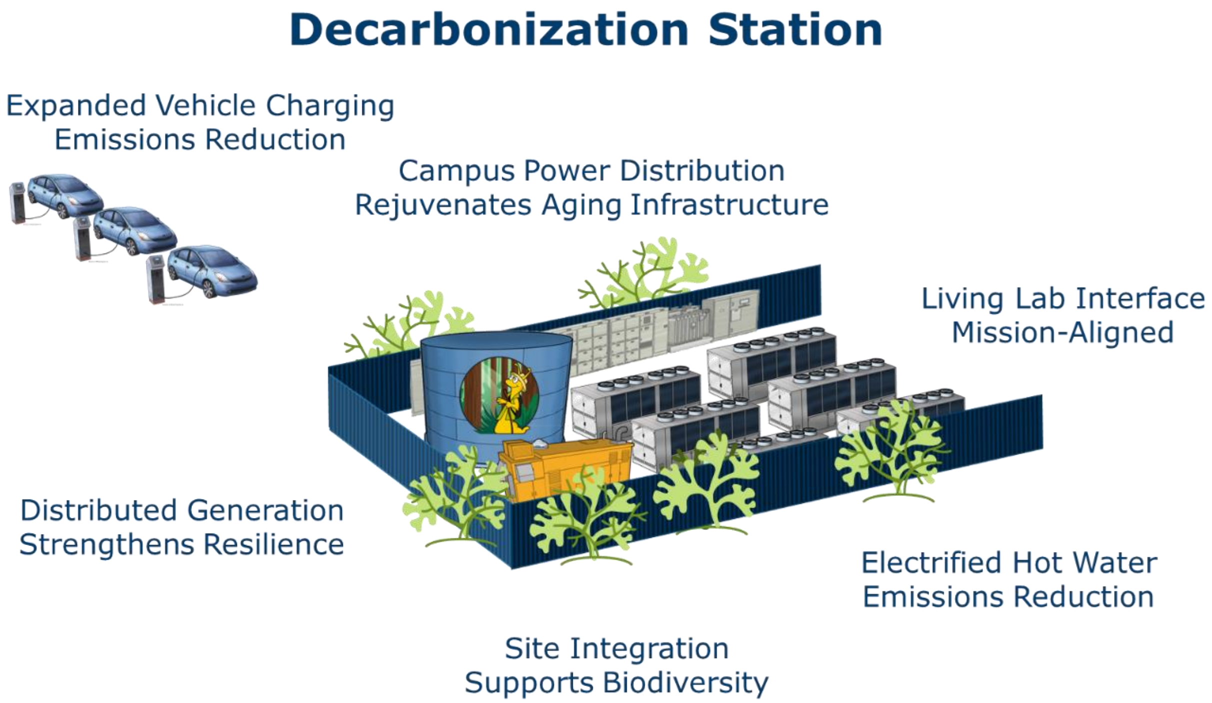


Figure 23 – Decarbonization Station concept

3.2.3 Infrastructure siting

While there are many technical, logistical, and constructability criteria for the siting of the Decarbonization Station, there are several critical additional criteria. The ultimate sites of the Decarbonization Stations will need to consider proximity to current and future buildings, visual, acoustic, environmental, and safe access, considerations (Table 2).

Table 2 - Summary criteria for siting of Decarbonization Stations

Proximity to current and future buildings	• Consider upcoming construction projects for colocation with stations to optimize economics, environmental site review, operational disruptions, and visual impacts. • Stations are to be collocated with new 21kV:12kV substations
Stacking & colocation	• Maintain access to ambient air and sufficient airflow clearances. On-grade or rooftops preferred. Below grade acceptable with sufficient area wells. • Strive to minimize footprint through stacking of equipment where feasible. Thermal storage tanks may be stacked below equipment.
Visual Considerations	• Stations shall avoid disrupting views of meadows and the bay. • Screening and landscaping shall be considered, and stations shall be adapted to the character of each site in which they are located.
Acoustic Considerations	• Stations should not be located near windows • A minimum clearance of 35’ should be provided from the heat pumps to the nearest building to mitigate noise to levels of 65 dB or lower. • Heat pump fans shall be designed and selected to minimize noise. • Acoustic performance shall be evaluated by an acoustic engineer.
Environmental Considerations	• Sites should avoid protected or potential habitat areas • Preference should be given for utilizing land that has previously been developed or collocating the Decarbonization Station with another development.
Safe Access	• Equipment requires level ground • Approximately 15,000-20,000 SF of site area for sufficient access and clearances. • Road access for mechanical and electrical trade work trucks is required. • Equipment shall be located within secure enclosures designed for outdoor installations.

One potential configuration of the Decarbonization Station is shown below (Figure 24). The station requires an area of approximately 105’ by 130’ if collocated with future electrical substations. Decarbonization Stations without substations can be considerably smaller. Appendix D includes a full-sized pre-design drawing.

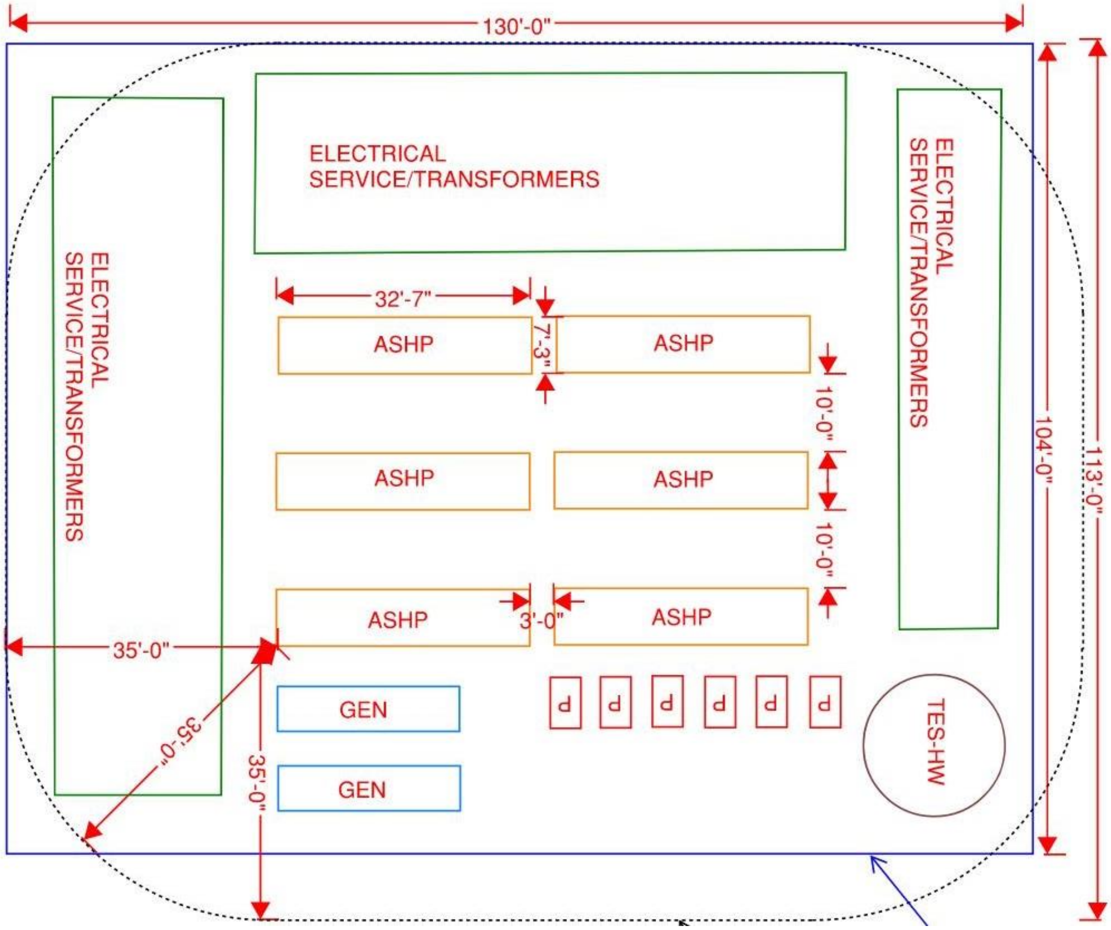


Figure 24 – Decarbonization Station space requirements

Proximity to current and future buildings

Over the coming decades, UCSC’s Long Range Development Plan (LDRP) outlines the plan for significant growth in enrollment and facilities. New construction has been carefully considered for suitability for the proposed use, required or desirable adjacencies, and accessibility by various travel modes. Efficient Decarbonization Station sites are located in proximity to current buildings and future development sites. Integrating Decarbonization Stations with upcoming construction and renovation projects will optimize economics, environmental site review, operational disruptions, and visual impacts.

Heat pumps require access to ambient air but can be easily integrated into rooftops, parking lots, or other open air situations. Parking garages are excellent opportunities for co-location. The electrical gear and thermal storage is best located at grade and can be integrated into back of house electrical rooms or yards. The storage tank can be integrated into site work and provides vertical surfaces for potential branding or murals.

Visual Considerations

The UCSC campus is recognized as one of the most stunning and unique in the country. Sited on a former ranch, the campus includes wide open meadows and thick forests. It is cut north to south with deep ravines with intermittent streams.

On the campus-wide scale, development has generally focused within the tree line, with only a limited amount of development in the meadow areas. In particular, the Science Hill zone, with the tallest and most complex buildings, is located within the forest areas dominated by tall redwoods. Only smaller Arts facilities, residential colleges, or sports facilities have been located within the meadows on the lower half of the site. In these cases, the smaller buildings have been sited to complement sloping sites.

Similarly, surface parking has been nestled within depressions or within tree lines. The only parking structure on site is within the heavily treed central campus.

While the Decarbonization Stations are small compared to most structures on campus, they will need to be located throughout the campus. Care should be taken to site them as inconspicuously as possible. Ideally the stations will blend into their immediate environment, with the treatments of each individual station being adapted to the character of each site.

Acoustic Considerations

Although some station locations may be in isolated locations, many will need to be in proximity to other buildings, in basements, or on rooftops. Generally, locating a station directly adjoining or near a regularly utilized building should be avoided. In particular, residence halls, classrooms, research labs, and student social spaces are examples of uses that could be negatively impacted by acoustic issues.

Wherever possible, the stations should be far enough from any of these use types for station equipment operations to be imperceptible. Ideal locations would be in proximity to other infrastructure uses or unoccupied building spaces. They may abut walkways, plazas or other social spaces. Attention to the locations for the stations and how their sites and perimeters are screened, can be used to minimize acoustic impacts on campus life.

Environmental Considerations

The Long Range Development Plan has identified lands that are suitable for future development based on an understanding of local and regional ecology as well as the ways that the campus environment is used for a variety of research endeavors. The plan identifies areas that support sensitive vegetation/habitats that in some cases support threatened or endangered species. These areas are excluded from future development. Other areas are excluded based on their steep topography or karst geologies.

Sites considered suitable for long term campus growth are based on a strategy of infill development, where additional development is added to or is adjacent to already developed areas, thus minimizing environmental impacts, and also enhancing ease of access by the campus community.

Similarly, sites suitable for Decarbonization Stations will be in already developed or disturbed areas, or those where future development is planned.

Safe Access

Safety and access to the equipment is a key consideration in site selection. Sites must have adequate access for work vehicles and trucks for the replacement and expansion of equipment over time. Care should be taken that sufficient access is provided around the equipment for safe maintenance including regulated clearances around electrical equipment. Finally, the surrounding site must be protected and maintained. Landscaping should be maintained to avoid overgrowth and a level site is preferred to minimize earthwork costs.

3.2.4 Living Laboratory Opportunities

Opportunities exist for showcasing the Decarbonization Stations as a living laboratory opportunity for students. The area can be used as an outreach space to educate our campus community about our fossil fuel free journey and electrification technologies through art and signage (Figure 25). The stations will be a utility/infrastructure element in an academic, residential, or open space/landscape environment on the campus.

Figure 25 – Alamo Interpretive Panels, Page

3.2.5 Hot water distribution

The Decarbonization Stations are proposed to be connected to buildings through a new piping distribution system. The piping from the air source heat pumps will be connected at the Decarbonization Station in such a way that additional air source heat pumps can be added in the future. Piping will be installed in a concrete trench with either two or four pipes (Figure 26), depending on the selected configuration of the air source heat pumps. The trench will have a removable lid and will be constructed with concrete walls (as opposed to burying the pipes directly into the ground). The piping will be insulated. The concrete trench provides the piping with protection against karst collapse and will be designed for seismic, expansion and deflection requirements. The piping trench will be sloped to low points and will include leak detection to alert facilities staff regarding failures. The proposed trench design will provide easy access for inspection, maintenance and repairs and protect the pipes inside. The trench may include or be collocated next to other utilities for ease of construction and maintenance.

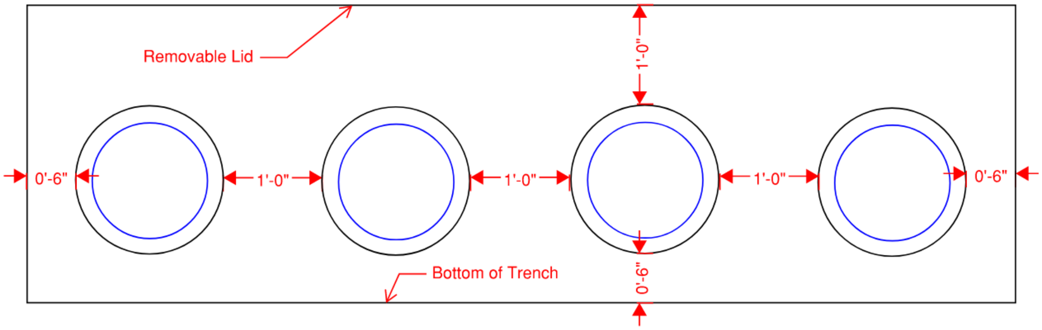


Figure 26 – Piping distribution – trench clearances

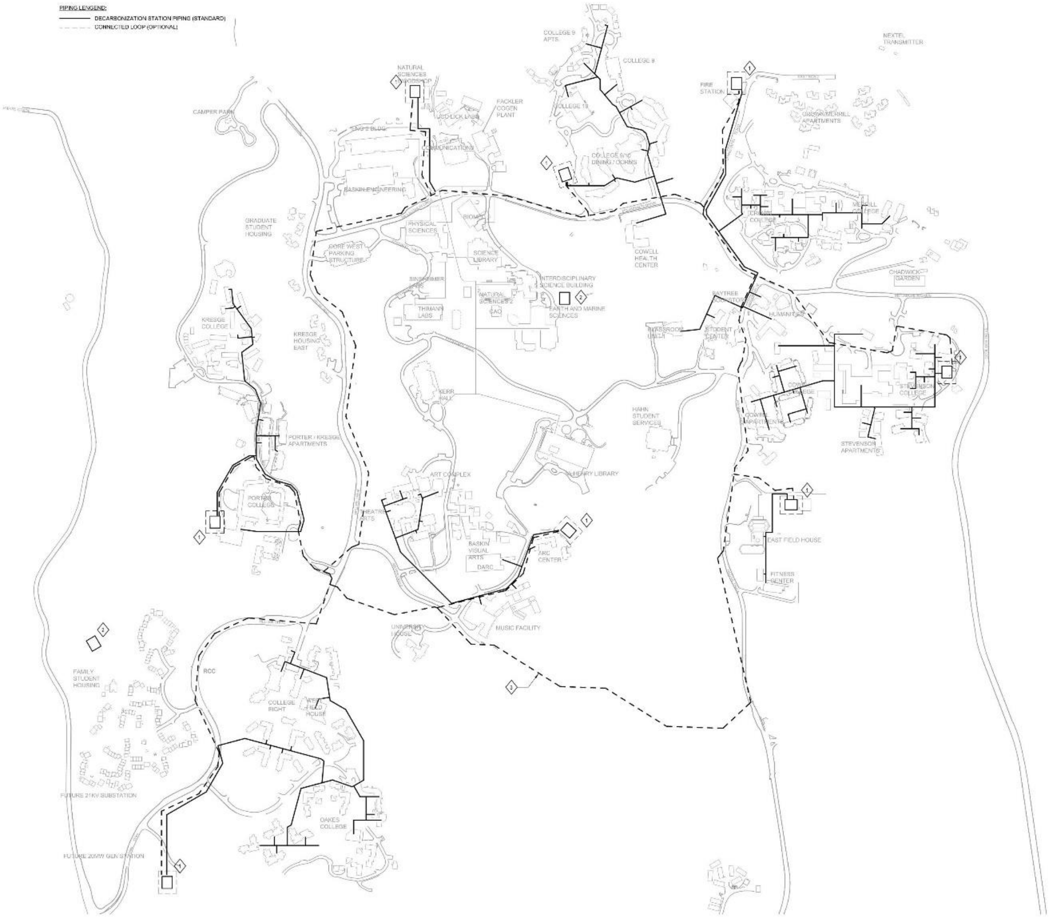


Figure 27 – Piping distribution – Upper Campus

The planned piping distribution (Figure 27) connects the campus pairs (shown as solid black) as well as an option to connect both the Decarbonization Stations together and the Science Hill system is shown in a black dashed line. Trenched piping is proposed to follow existing electrical infrastructure where feasible. The southeast leg of the optional "connected" (dashed piping) follows a planned expansion of Meyer drive in the Long Range Development Plan.

Plastic PERT or PP-RCT piping (Table 3) is recommended for lower cost and is suitable for the distribution temperatures and pressures when selected with the appropriate wall thickness. Piping distribution will be designed to meet allowable pressure ratings of the selected materials. Heat exchangers will be used at each building to separate the community distribution piping from building piping. Decoupled building piping may be designed for and operated at higher temperatures and pressures. Piping materials were selected with guidance from campus engineering and operations staff during a review workshop.

Table 3 - Piping materials

Pipe	Material	Pros	Cons	Rating	Available Sizes
Thermacor: FERRO-THERM; Perma-Pipe: Xtru-Therm; Rovanco Steel System	Pre-Insulated: Steel & Polyurethane	Welded Joints, Insulated	Cost: $$$, Expansion Loops / Joints, Corrosion	++ Pressure, Max 250°F	½"-42"
Pex-A	Cross-linked Polyethylene	No Expansion Loops, Cost: $, Spool Delivery/Flexible, Corrosion Resistant	Mechanical Joints, Spool Lengths, Availability, ID to match IPS	(DR6): 210 psig @180°F (DR7.4): 170 psig @180°F	Spool: 14" & under (14" spool = 320' max.) Sticks: 16" – 24"
PP-R	Polypropylene	Corrosion Resistant	Expansion Loops / Joints ++	(SDR 11) 62 PSIG @ 180 F	1"-18"
PP-RCT	Random Copolymer Polypropylene	Corrosion Resistant	Expansion Loops / Joints	(SDR 11) 100 PSIG @ 176 F	1"-24"
Thermacor: FERRO-THERM; Perma-Pipe: Xtru-Therm; Rovanco Steel System	Pre-Insulated: Steel & Polyurethane	Welded Joints, Insulated, Pressure Rating	Cost: $$$, Expansion Loops / Joints	++ Pressure, Max 250°F	½"-42"
DI	Ductile Iron- Cement Lined	Pipe Size vs Steel, Cost: $, Pressure Rating	Not welded, Corrosion	150-350 psig	4"-64"
HDPE	High Density Polyethylene	Corrosion Resistant, Welded, Flexible	Pipe Size vs Steel, ID to match IPS	(DR11): 200 psig (DR13.5): 160 psig	(DR11): 4"-30" (DR13.5): 4"-42"
PVC	Polyvinyl Chloride	Corrosion Resistant, Cost: $	Not as Durable	210 PSIG @ 73F 130 PSIG @ 100 F 50 PSIG @ 140 F	½"-24"

3.2.6 Building Conversions

Most buildings at Science Hill are already served by chilled water and heating hot water. While the technologies producing this water will change, the distribution will remain intact. The only conversions for buildings at Science Hill are related to process equipment (steam production, lab equipment).

Buildings outside of Science Hill with existing natural gas boilers will have their boilers removed and will be connected to the piping originating from new Decarbonization Stations. A plate and frame heat exchanger is planned to be installed in each connected building to decouple the building hot water loop from the utility piping.

Buildings not having existing boilers will have their gas systems removed and replaced with appropriately sized split systems or packaged rooftop systems. The process for determining what new electric system will replace the existing system will depend on both the size of the building in question and available roof/surrounding space.

3.3 Science Hill

Large, high energy intensive buildings, such as those that make up Science Hill, benefit from a centralized approach (Figure 28).

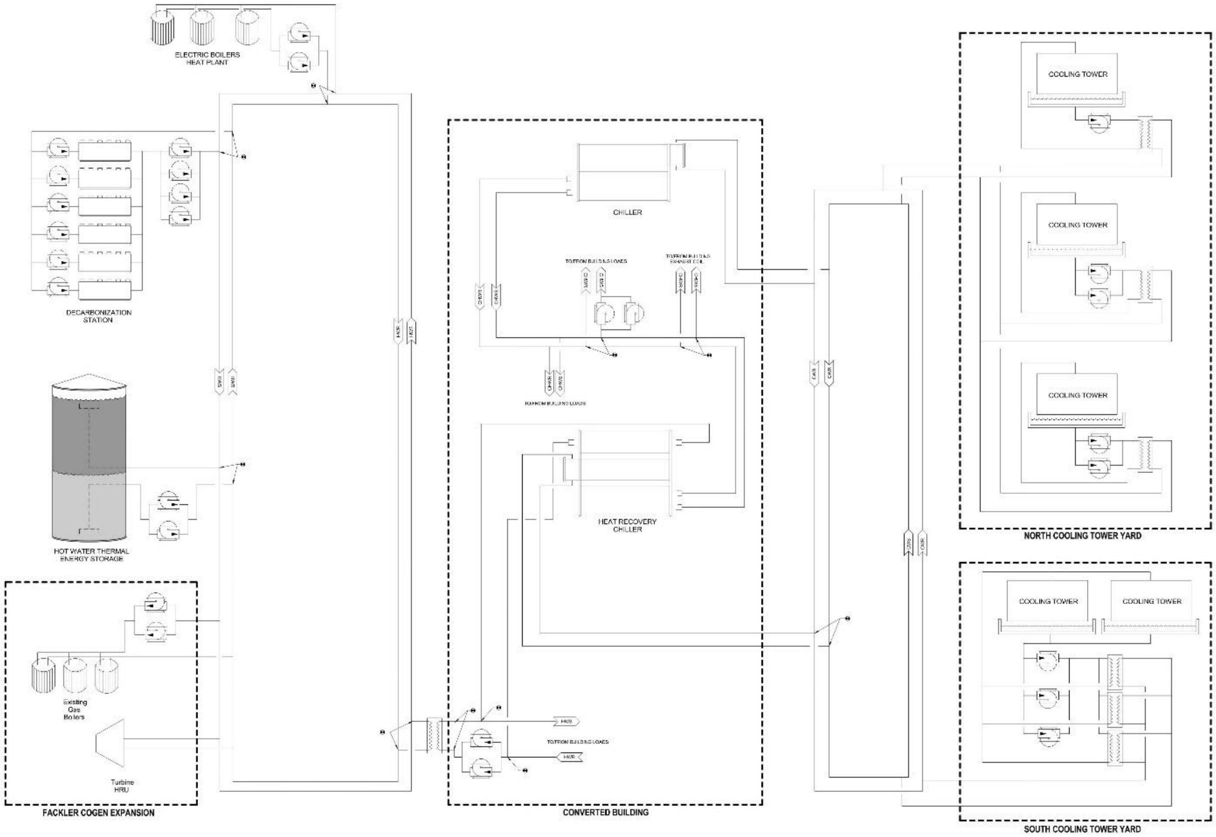


Figure 28 – Centralized scale, heating, and cooling technologies for Science Hill

Due to the high-intensity research on Science Hill, a combination of strategies is required to electrify the heating systems without causing significant disruptions. Heat recovery chillers can replace existing cooling-only chillers and efficiently provide cooling and heating simultaneously without the need for water-consuming cooling towers required by conventional chillers. Additionally, heat generated from people and equipment can be captured at the exhaust systems. Once recovered heat has been maximized, additional heating can be supported by an outdoor Decarbonization Station, and small electric boilers utilized only for the coldest days on campus.

3.3.1 Buildings without boilers

There are some buildings on Science Hill that are not connected to the existing hot or chilled water distribution. These buildings are small in size and are served by small independent gas heating systems. These gas systems will be replaced with electric packaged units.

3.4 Lower Campus

The lower campus consists of the Arboretum, the Center for Argoecology, Physical Plant facilities, transportation facilities, administration space, residential buildings for student and faculty housing and support buildings. Most of these spaces are served using independent packaged gas rooftop units or split furnaces. These systems consume a lot of fossil fuels and are less energy efficient.

Split and packaged heat pumps offer efficient and versatile alternatives in both light commercial and residential construction. They offer numerous advantages over traditional furnaces and packaged gas rooftop units. They are highly energy-efficient, utilizing advanced technology such as variable-speed compressors and smart controls to optimize performance. Heat pumps also have the ability to reverse their operation, providing both heating and cooling from the same system. This versatility eliminates the need for separate heating and cooling equipment, resulting in cost and space savings, and simplified maintenance.

Split heat pumps consist of two main components: an outdoor unit, typically placed on the rooftop or ground, and an indoor unit installed inside the building. This configuration allows for greater flexibility in system design, as the indoor units can be distributed throughout the building to accommodate individual zones or areas.

Packaged heat pumps, on the other hand, combine all the components into a single, compact unit. These units are commonly installed on rooftops or on a concrete pad adjacent to the building. These are particularly suitable for smaller buildings where space constraints may limit the installation of multiple indoor units or where a rooftop installation is preferred. Packaged heat pumps are an excellent choice for residential applications where simplicity, convenience, and energy efficiency are priorities.

Non-residential buildings have the option to utilize conventional split or packaged heat pumps, as well as variable refrigerant systems. These systems are readily available in the market and offer competitive pricing, making them a cost-effective choice for meeting the heating and cooling needs.

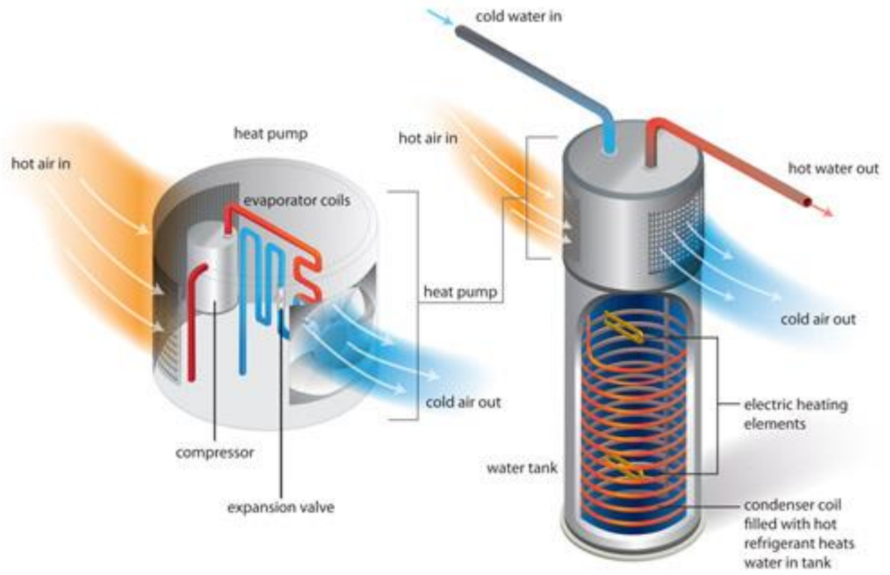


Figure 29 – Heat pump water heater

When considering retrofit options for heating and domestic water, using 120V heat pump water heaters (HPWHs), such as the Rheem Performance Platinum 50 Gallon Hybrid Electric Water Heater or an equivalent system is recommended. These units typically require a dedicated electrical circuit to accommodate their power demands. The existing electrical infrastructure can support the additional load of the HPWH without overloading the circuit. These units are generally designed to fit in compact spaces, making them suitable for retrofit applications. Additional ducting or venting may be required based on manufacturer's requirements and the installation clearances. They can be installed in various locations, such as utility rooms, basements, or even closets, depending on the available space and accessibility for maintenance.

One advantage of 120V HPWHs is their energy efficiency. They utilize heat pump technology to extract heat from the surrounding air and transfer it to the water, resulting in significant energy savings compared to conventional electric water heaters. Additionally, they often come with features such as smart controls, energy-saving modes, and advanced diagnostics, enhancing their usability and performance.

3.5 Westside Research Park

3.5.1 Fossil fuel free heating and research

Westside Research Park (WRP) has its own cooling towers, chillers, and boilers. These systems distribute chilled water and heating hot water throughout the buildings. WRP provides sufficient space both inside and outside its facilities for equipment replacement and potential expansion, as seen in the loading dock/corp yard area and the chiller/pump room (Figure 30).

Figure 30 – Loading dock/ pump room

The existing cooling tower (Figure 31) and chillers at the WRP will continue to be utilized. The electrification plan involves the introduction of a new air source heat pump plant and the incorporation of heat recovery chillers. The proposed location for the air source heat pump plant is on the east side of the building, where available space will allow for the additional equipment to be housed in the loading dock/corp yard area. The heat recovery chillers will be connected in parallel with the existing chillers. There are existing taps in the main pipe headers intended for additional chillers to be installed, allowing for easy integration of this new equipment.

Figure 31 – Existing cooling tower and chillers

This comprehensive approach allows the Westside Research Park to optimize its existing infrastructure while transitioning to more efficient and sustainable heating and cooling systems. By introducing the air source heat pump plant, WRP can take advantage of ambient air temperature to extract heat, thereby improving energy efficiency. Furthermore, the incorporation of heat recovery chillers (Figure 32) enables the utilization of waste heat generated during the cooling process, further enhancing overall energy performance. No significant electrical upgrades are necessary.

Figure 32 – Heat recovery chiller

The strategic placement of equipment and the availability of both indoor and outdoor spaces for installation ensure a seamless integration of the new systems. This approach minimizes disruptions to WRP's operations during the implementation phase.

3.6 Coastal Science Campus

3.6.1 Fossil fuel free heating and research

The Coastal Science Campus buildings, located in close proximity to the coast, rely on boilers and independent systems for heating and cooling. In considering any decarbonization solution for this campus, it is crucial to account for the coastal air conditions and the need for seawater temperature control for the marine mammal complex. While the area offers ample space outside for equipment installation (Figure 33), the coastal location poses challenges due to the moisture and salt content in the air.

Figure 33 – Exterior space at coastal science campus

To address these challenges, implementing independent water source heat pumps for the Coastal Sciences Campus with an N+1 redundancy is recommended. These heat pumps would vary in size and quantity for each area of the campus. By utilizing water source heat pumps instead of air source heat pumps, the risks associated with the salt content in the coastal air can be mitigated. Air source heat pumps in coastal regions tend to deteriorate faster and require more maintenance compared to their water source counterparts.

Water source heat pumps are split units, the indoor unit (serving the HVAC system) is afforded protection from corrosion while the outdoor units will require several corrosion protection measures to ensure the longevity and efficiency of the equipment. Here are several corrosion protection measures that can be implemented:

1. Stainless Steel (SS) or Aluminum (AL) Construction: Stainless steel or aluminum components, such as coils, are corrosion resistant to salt-laden air.
2. Avoiding Dissimilar Metals: It is crucial to avoid using dissimilar metals in close proximity, particularly on coils. Mixing different metals can lead to galvanic corrosion, where an electric current is generated between the metals, accelerating corrosion.
3. Protective Coatings: Applying protective coatings to exposed surfaces can provide an additional layer of defense against corrosion. Coatings such as epoxy, polyurethane, or specialized marine-grade coatings can help prevent direct contact between the equipment and corrosive elements. Routine inspection of the protective coatings and periodic reapplication of the coatings is recommended.

4. Reduced Fin Per Inch (FPI): Reducing the number of fins per inch on heat exchanger coils can decrease the surface area for salt deposits to accumulate, reducing the potential for corrosion.
5. Regular Cleaning and Maintenance: Routine cleaning removes salt deposits and other corrosive agents, preventing them from accumulating and causing damage over time.

Despite the implementation of these corrosion protection measures, in the event that the outdoor units sustain damage, the cost of replacing them remains relatively affordable as compared to replacing the entire unit.

3.6.2 Resiliency

Considering the sensitivity of the equipment and resources in this area, there is a contingency plan to retain some natural gas boilers (Figure 34**Error! Reference source not found.**) serving animal care and critical research areas for emergency situations. The combination of independent water source heat pumps and a backup natural gas system allows for a reliable and flexible approach to meet the heating and cooling needs of the Coastal Sciences Campus.

This solution not only takes into account the specific requirements of the campus' location but also aims to decarbonize the operations by reducing reliance on natural gas. By transitioning to water source heat pumps for day-to-day operations, the Coastal Sciences Campus can achieve greater energy efficiency, reduce maintenance costs associated with coastal conditions, and contribute to the overall sustainability goals of the campus.

Figure 34 – Existing natural gas boilers

4 Electrification infrastructure

4.1 Upper Campus

Affiliated Engineers addresses UCSC's electrical distribution in four sections: Upper Campus, Lower Campus, Coastal Sciences Campus, and Westside Research Park. Upper Campus electrical distribution is defined as the sixty-six transformers fed by four 12.47 kV feeder circuits (A1, A2, B1, and B2) providing power to the colleges via the Merrill Substation. The Merrill Substation maintains two 21 kV: 12.47 kV Y-Y, 8.625 MVA transformers, T52 and T53. The Merrill Substation transformers are fed from underground feeder cables routed from the Slug Substation on Lower Campus. At the Slug Substation, PG&E provides up to 10 MW of electric capacity via a single 21 kV circuit originating at the Paul Sweet Substation off-campus. Appendix C contains the one-line diagram for UCSC's Existing Medium Voltage Electrical Distribution System.

4.1.1 Update to campus electrical plan

This section addresses the decarbonization effort to decommission the Fackler Cogeneration Plant on Upper Campus and the implications for capacity, resilience, and reliability for doing so. Approximately 4 MW of electrical supply power is produced by the operation of the cogeneration plant. Together with PG&E, both energy sources are used to meet the Upper Campus electrical demand. The overall campus energy demand shows which energy source is used to provide power to the Upper Campus for calendar year 2019 (Figure 35). The peak energy demand for Upper Campus occurred on October 22, 2019 and at 7.631 MW. This represents the baseline peak energy demand referenced throughout the remainder of this evaluation.

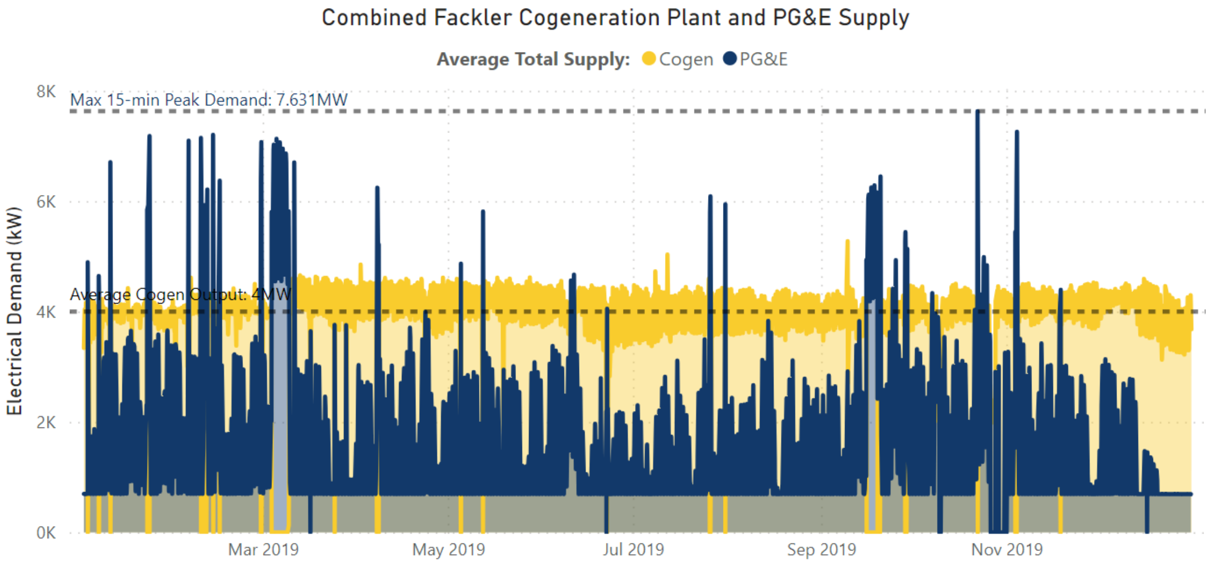


Figure 35 – Overall campus energy supply and demand

Methods of electrifying heat demand, process, and equipment loads are discussed in Section 3.1, and the impact of those pathways are discussed here. A baseline evaluation of the demand load by building type was performed using UCSC's EnergyCAP program and ION Metering Network. Using the peak metered data from calendar years 2018-2019, Affiliated Engineers determined the mean watts/square foot of each building as categorized by its primary function. The approach taken to identify the mean watts/square foot of each building with recorded metered data can be found in the appendix. The mean values for each building type were then determined from this data (Table 4). These values were used to estimate the peak energy demand for buildings with no recorded metered data as well as projected new development buildings from the LRDP. Note that these values are expected to rise from added electrical demand due to electrified thermal loads normally met with cogeneration.

Table 4 – Summary of mean watts per square foot

Building Type	Mean Watts per Square Foot
Academic	2.23
Administrative	2.63
Data Center	8.80
Facilities & Support Services	4.60
Food Service	7.85
Low Rise Residential	1.00
Multi-Family	0.58
Recreation	4.60
Research	4.91
Site Lighting	0.40

Appendix E provides the data for the calculated demand loads on the sixty-six campus transformers and the impact of pursuing both the distributed and community approach for electrification. It is important to note that the implementation of the community approach would require the installation of new, dedicated transformers to supply power to the ASHP's in the Decarbonization Stations and alleviate the majority impact of electrification on existing campus transformers. The installation of an electric boiler plant at Science Hill is also captured in the community approach and would require a newly installed and dedicated transformer.

Projections for pursuing the distributed approach would result in the overloading of fourteen campus transformers whereas the community approach would result in the overload of four campus transformers. The use of Decarbonization Stations accounts for the future increase in space heating and cooling as trends for more extreme high and low temperatures result from global climate change. This recommended method provides increased resilience for thermal demands as UCSC continues to grow from new development as identified in the LRDP and cogeneration is phased down to decommissioning.

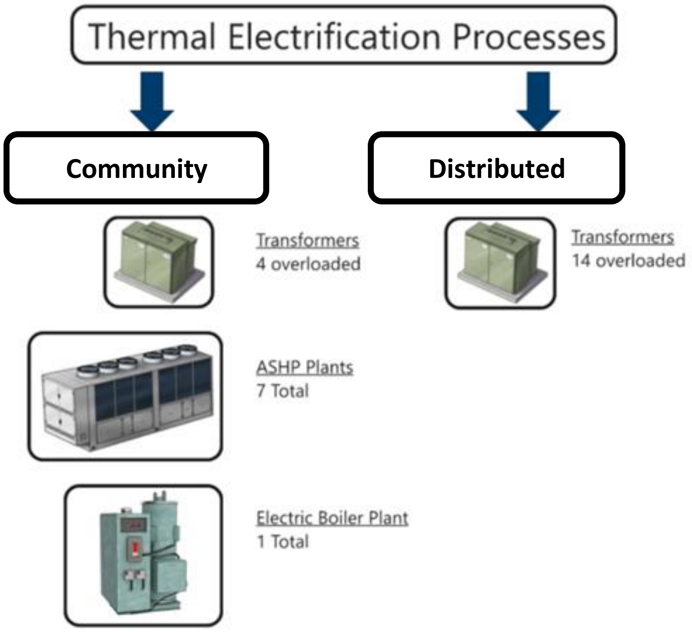


Figure 36 – Summary of electrification process outcomes for Upper Campus

4.1.2 PG&E Service Expansion

4.1.2.1 Augmentation of existing 21 kV circuits at the Slug Substation

Prior to phasing college electrifications and new construction outlined in the LRDP, the Upper Campus electric capacity must be addressed. The installation of new equipment to electrify thermal loads and new development will raise electric demand on campus. The Fackler Cogeneration Plant has 4.6 MW of rated output and generally provides 4 MW of power to the Upper Campus while in operation. The PG&E service at the Slug Substation is capable of providing up to 10 MW of electric power. This means that with a 2019 peak demand of 7.631 MW at an average of 0.9 power factor, the Upper Campus has approximately 2.3 MW of additional electrical capacity to serve the Upper Campus energy demands. Affiliated Engineers has participated in three meetings with UCSC and PG&E to discuss reinforcement of the 21 kV circuit to the Slug Substation for up to 5 MW of additional capacity. The current PG&E demand and the required system augmentation threshold line based on the decarbonization by 2030 scenario is illustrated below (Figure 37). Having up to 15 MW of available capacity for the existing service would increase campus power resiliency in the event that the Fackler Cogeneration Plant is out of service for scheduled maintenance or any unplanned outage.

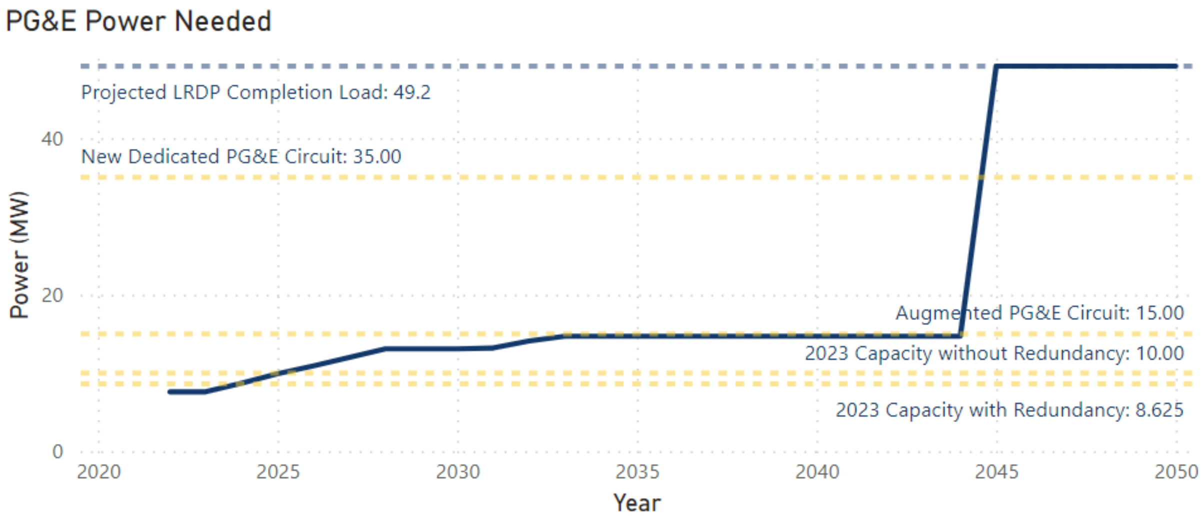


Figure 37 – PG&E total campus power required

4.1.2.2 Evaluation of new 21 kV circuit at the west side of campus

The decommissioning of the Fackler Cogeneration Plant poses an inherent risk to the ability of UCSC to meet campus energy demand. Preliminary engineering studies are being performed by PG&E to support a separate 21 kV service to the Upper Campus in the vicinity of the West Remote Parking Lot where a new substation (Banana) will be provided. The intent is that the second 21 kV PG&E service will be separate from and interconnected with the Merrill Substation to improve resiliency and allow for future flexibility. Interlocks required by PG&E's Greenbook to prevent paralleling both sources together will be provided. The Banana Substation will help to provide a 21 kV backbone along the perimeter of the Main Campus as shown on the campus map in Appendix C Along the 21 kV service perimeter, medium voltage switches will be used to tap off three substations similar to Merrill Substation and assume load from the existing feeder circuits supplying the campus transformers. The electrical schematic in Appendix C shows the medium voltage electrical configuration for connecting the new Banana Substation to the existing Merrill Substation.

The additional service from PG&E at the Banana Substation will be able to supply the Upper Campus with an additional 20 MW of power for a total of 35 MW after circuit reinforcement at the Slug Substation circuit. This increased capacity will allow UCSC to strategically progress through the electrification of colleges while simultaneously furthering new construction plans as a part of the LRDP. Science Hill represents the largest conversion of thermal loads into electrical demand and is recommended as the last step before shutting down the Fackler Cogeneration Plant.

4.1.2.3 Evaluation of transmission level services from PG&E

Campus peak energy demand at the completion of the LRDP (Figure 37) is projected to exceed 35 MW. This meets the threshold requirements by PG&E to consider transmission level services to meet UCSC's planned growth. PG&E is studying routing of a new transmission line to Santa Cruz. A new transmission line (greater than 60 kV) is expected to require a longer period for permitting, approvals and implementation compared to a new 21 kV distribution circuit. It is recommended that regular discussions and negotiations are prioritized with PG&E until full utility infrastructure needs are met.

4.1.3 Reliability of electrical infrastructure

4.1.3.1 Redundancy for the dead-end radial transformers and associated loads

Maintaining safe and reliable power delivery to UCSC's Upper Campus requires an evaluation of redundant components in the electrical distribution. See Appendix C for the electrical configuration of UCSC's Medium Voltage System. There are sixty-six transformers being fed from four 12.47 kV feeder circuits. Of the sixty-six campus transformers, fifty-one are fed from two circuits and the remaining fifteen receive power from a single circuit. Incorporating redundant power supplies to each of these campus transformers improves reliability for these dead-end radial loads. Reconfiguring these dead-end radial transformers with two feeder circuits while decentralizing the electrical configuration of UCSC's medium voltage system for increased overall system reliability is recommended.

4.1.3.2 Redundancy for the Merrill Substation transformers

Redundancy also exists at the Merrill Substation for the stepdown transformers T52 and T53. Each of these 8.625 MVA rated transformers provides enough capacity to serve the 2019 peak energy demand of 7.631 MW. At a power factor of 0.9, there is less than 1 MW of capacity that exists with full redundancy. The operation of both Merrill Substation transformers creates four single points of failure for UCSC to meet campus energy demand at T52, T53, MF1, or MF2. Based on current infrastructure, a second substation between Science Hill and Colleges 9/John R. Lewis with at least one equivalent size transformer would suffice to maintain redundancy of the existing distribution system while energy demand exceeds the capacity of a single Merrill Substation transformer and remains below PG&E's existing capacity constraint of 10 MW. Two new transformers would provide redundancy and allow for future growth. This would not require coordination with PG&E to implement but would require the strategic implementation of a new medium voltage switch between the Slug Substation and the Merrill Substation for MF1 and MF2 to tap off and be routed to the new substation.

4.1.3.3 Redundancy of energy sources

Redundant energy sources provide the highest system reliability. Failure of PG&E power supply will require that the alternate source be able to sustain critical loads on campus. The Fackler Cogeneration Plant provides base loading of about 4 MW to campus. Upon decommissioning cogeneration heating water to meet thermal loads on Science Hill, the function of the Fackler Cogeneration Plant may operate to provide power to the campus in the event of a mid-to-long term loss of PG&E power. The Cogeneration Plant will require retrofit to operate in a standby configuration. Ongoing projects continue to increase reliability of the Cogeneration Plant during outages.

The second 21 kV service to the Banana Substation will be fed from a separate transformer at PG&E Paul Sweet Substation, providing an increase in system reliability for any outages that may occur at the Paul Sweet Substation. This additional layer of reliability would provide electrical capacity and flexibility for reconfiguring the Upper Campus medium voltage system for any maintenance requirements, unplanned outages, or public safety shutdowns.

PG&E operates under the California Independent System Operator (CAISO) which ensures that supply assets can meet projected load demands for the state of California. Rotating block outages are a method of energy conservation that CAISO can implement to PG&E's service territories for increased reliability when energy demand is expected to be higher than available supply. PG&E also implements Public Safety Power Shutoffs when severe weather poses an inherent risk to the environment (such as high winds during wildfire season). There are no defined timeframes for the longevity of these types of outages. UCSC is susceptible to these shutdowns and the implementation of a second service to the Upper Campus may assist in diversifying the regions that may be required to rotate through an outage or be shut off due to these circumstances.

4.1.3.4 Risk of reliability due to aging infrastructure

The evaluation of UCSC's electrical infrastructure shines light on the on-going programs and plans for replacing UCSC's four 12.47 kV feeder circuits and associated medium voltage switches. Safety and reliability are essential to ensuring that the expansion of UCSC's electrical distribution does not interrupt the power supply to buildings. It is recommended that the feeder cables and associated conduit be replaced using industry standard and code compliant methods and sizing. Due to aging infrastructure, any consideration to reuse existing conduit or duct bank infrastructure should be done with caution to not compromise integrity of system upgrades.

Plans to install new 21 kV to 12.47 kV substations strategically located on the campus will provide new feeder circuits to associated college pairs and increase the reliability of UCSC's electrical distribution system by supplying power to campus transformers from more than one new feeder circuit.

Multiple new circuits from new substations to replace the majority of circuits A1, A2, B1 and B2 will require the installation and replacement of medium voltage switches on the Upper Campus. There are forty switches in UCSC's medium voltage system installed as early as 1985 that need replacement. New switches should be standardized for existing and new medium voltage infrastructure to support the completion of the new 21 kV backbone and newly installed substations.

4.1.4 Evaluation of distributed energy resources

Space is reserved in the Decarbonization Station layouts to accommodate distributed energy resources. Distributed energy resources are on-site sources of power to campus. On-site sources of power serve three key functions in relation to the decarbonization and electrification effort.

1. DERs increase available power to electrify campus faster while PG&E brings power to campus
2. DERs provide resiliency as a standby power resource during an outage
3. DERs can reduce costs through efficient generation or reducing peak demands

4.1.4.1 Screening of power generation technologies

In a series of workshops with key stakeholders from the University, alternative on-site power generation systems were considered and screened for applicability to UCSC's campus. Selected technologies were screened based on three key factors

1. Site constraints

Site space on campus is limited due to environmental protections and space reserved for future development of academic buildings. Large scale wind and large-scale solar development are limited by these site constraints. Photovoltaic solar is already implemented in strategic locations such as the East Remote Parking lot and multiple additional locations have been identified in UCSC's 2017 Climate Energy Strategy. It is recommended that additional PV solar and accompanying battery systems be pursued across campus.

2. Regulatory permitting, environmental impact

Both modular nuclear power and coastal hydropower were discussed at the ideation workshop. Both of these technologies face major regulatory and local political hurdles. Although modular nuclear plants are currently in permitting processes around the country, these projects are requiring 10 years or more to develop, permit, and manage community concerns over safety and waste disposal. Coastal hydropower is still a new and developing technology but poses potential environmental impacts to the marine ecosystems. Additional industry research and development is required before adoption at the university scale.

3. Developmental technologies

Two technologies were considered for on-site power generation that are still in development stages. Small scale wind technologies exist but have limited commercial viability beyond demonstration projects. Ongoing monitoring of the technology's development is recommended for future consideration.

Green hydrogen fueled power production is a developing market worth ongoing monitoring. Currently, on-site production of green hydrogen in large quantities, beyond the needs of limited fleet vehicles, is not cost-competitive due to the amounts of renewable power generation required for production and the efficiency of the process. Commercial green hydrogen production facilities are currently in development in California and may be able to serve future systems as these facilities become operational and enter the marketplace.

Technologies considered for further evaluation

Electric energy storage technologies can be implemented in scalable configurations and are mature technologies from a regulatory and technology development perspective. Considered storage technologies include thermal energy storage, battery energy storage systems and flywheels. Energy storage technologies only store energy and are well suited to power systems for short durations. Flywheels provide the shortest duration of power often lasting minutes rather than hours. Thermal and battery energy storage systems are suitable to supply power for several hours but are less cost-effective for multiple day outages.

Small scale solar electric photovoltaic systems are encouraged including those recommended by the 2017 CES. The Microgrid Expansion phase includes cost estimates for the planned solar at the West Remote Parking. Colocated photovoltaic systems may be considered to expand solar power on campus. Agrivoltaics, are the colocation of photovoltaic panels in agricultural areas to protect shade tolerant crops. The lower campus may be a viable candidate for this type of system.

Fuel-based systems allow for critical power needs to be met during multi-day outages where comparative energy storage systems would be prohibitively large. Limited use of new fossil fuels systems are considered where they:

1. Are operated in a way to reduce overall greenhouse gas emissions
2. Increase resilience and reliability of the campus power system
3. Are cost-effective relative to alternative solutions

4.1.4.2 Evaluation of DERs to serve peak demands

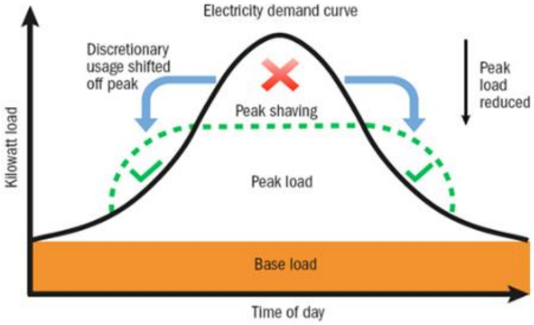


Figure 38 – Peak shaving versus base loading illustrations

New buildings, in conjunction with electrification measures, will drive increased peak demands from the 2019 peak demand of 7.631 MW. Managing and reducing this peak demand allows for more of campus to be electrified while PG&E is working in parallel to provide more power to campus.

The Decarbonization and Electrification project evaluated multiple methods for reducing peak demand to maximize electrification implementation speed, maintain reliability, and increase resiliency. The approach can be split up by discussing the focus on peak shaving and base loading with both sources (Figure 38).

Non-fossil fuel energy resources were prioritized for evaluation. Among storage technologies, thermal energy storage was identified by this project as a low cost way to reduce peak power demand. Thermal energy storage (TES) is able to be implemented within the Decarbonization Stations to reduce peak heating which is expected to occur in the early morning in the winter (Figure 39). Heat is stored by charging a hot water tank during period of low heating demand and ideally when clean photovoltaic energy is plentiful. That heat is discharged from the tank during peak periods in the morning. Based on hourly analysis of heating demands, thermal storage applied across each college pair is expected to reduce peak power needs by approximately 1.5 MW. For perspective, 1.5 MW is equivalent to the power needed to electrify one of the college pairs. 30,000 gallons of thermal energy storage is incorporated into the layout for the Decarbonization Stations in each college pair.

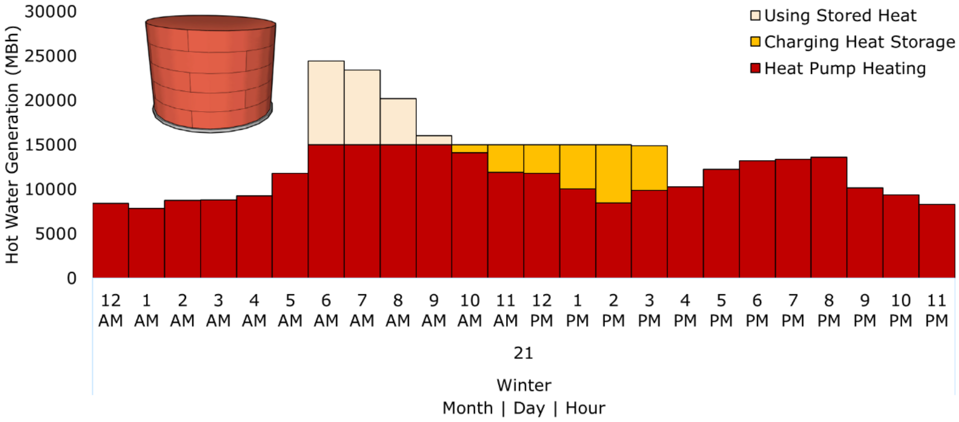


Figure 39 – Thermal energy storage

Electrochemical battery energy storage systems (BESS) are an alternative technology to thermal energy storage. BESS systems are more flexible than thermal storage systems and can be utilized to serve other uses of power beyond heating. The most common types of BESS currently on the market are large scale lithium ion battery systems due to their compact size and low cost compared to other BESS technologies. Alternative BESS systems which use more common minerals such as iron-air and zinc-air systems are becoming increasing cost-effective and should be considered with larger footprints. BESS systems are excellent are reducing demands for periods between 2 and 8 hours and can supplement thermal energy systems for greater demand reductions.

Flywheel systems are mechanical energy storage systems that can provide power for short durations. Flywheel systems are used conventionally as part of uninterruptible power systems (UPS) to provide power for a short duration to cover the gap in time between when power is lost and a standby engine generator is started to provide additional power. Conventional flywheels operated between 15 seconds and 15 minutes at a time in this capacity. Advanced, special application flywheels can be designed as part of a flywheel energy storage system (FESS) to provide power for longer durations up to between 30 minutes and 4 hours.

Additional space in each Decarbonization Station is provided for additional DERs beyond the thermal energy storage system. A BESS or FESS system may be considered for this space as a carbon free resource to supplement the TES. Due to the additional investment necessary for these systems, they are included in the Microgrid Expansion phase later in the project.

If on-site power is determined to be required for a greater duration (more than 8 hours) or greater intensity (in terms of MW depending on the duration) than the energy storage systems can provide, a fuel-based system designed to operate in a limited capacity can be installed as an alternative. Clean, renewable fuels are currently limited in availability in 2023 (see green hydrogen discussion in section 4.1.4.1) and these systems would be expected to use fossil fuels until green hydrogen or alternative clean fuels are more commercially available.

4.1.4.3 Evaluation of peak shaving with natural gas generation

The evaluation of peak shaving generator DERs was evaluated for potential to reduce peak demands and reduce utility costs. This option is considered as a contingency option should PG&E be unable to provide sufficient power in the short term to meet campus needs. If PG&E is able to provide power to align with UCSC’s electrification timeline, energy storage systems are recommended instead of new natural gas DERs. While these plants are intended to utilize natural gas in the interim, green hydrogen or biofuel may be utilized as it becomes commercially available. Natural gas plants are intended to be “on call” and ready to supply power to support peak power demands to reduce stress on PG&E’s system. This system can be owned and operated by UCSC. The existing campus gas turbine could be retrofit for this use or new generation engines or turbines could be purchased. Below is a list of pros and cons for operating plants in this way.

Pros (as compared to fuel cell alternative):

1. Provide peak shaving of power demand
2. Lower initial capital investment costs
3. Lower fossil fuel consumption
    a. Only consumed during peak demand times on an intermittent basis
4. Lower operating costs
    a. Only consumed during peak demand times on an intermittent basis
5. Reliable for rapid startup
6. Advancing technology allows operation with lower grade methane and/or hydrogen applications

Cons (as compared to fuel cell alternative):

1. Plants would combust fossil fuel and emit greenhouse gases
    - Greenhouse gas emissions would be less than current cogeneration plant
2. Inefficient operation due to intermittent nature of usage
    - Combustion plant generates electricity with less efficiency than fuel cell

4.1.4.4 Evaluation of base loading with natural gas fuel cells

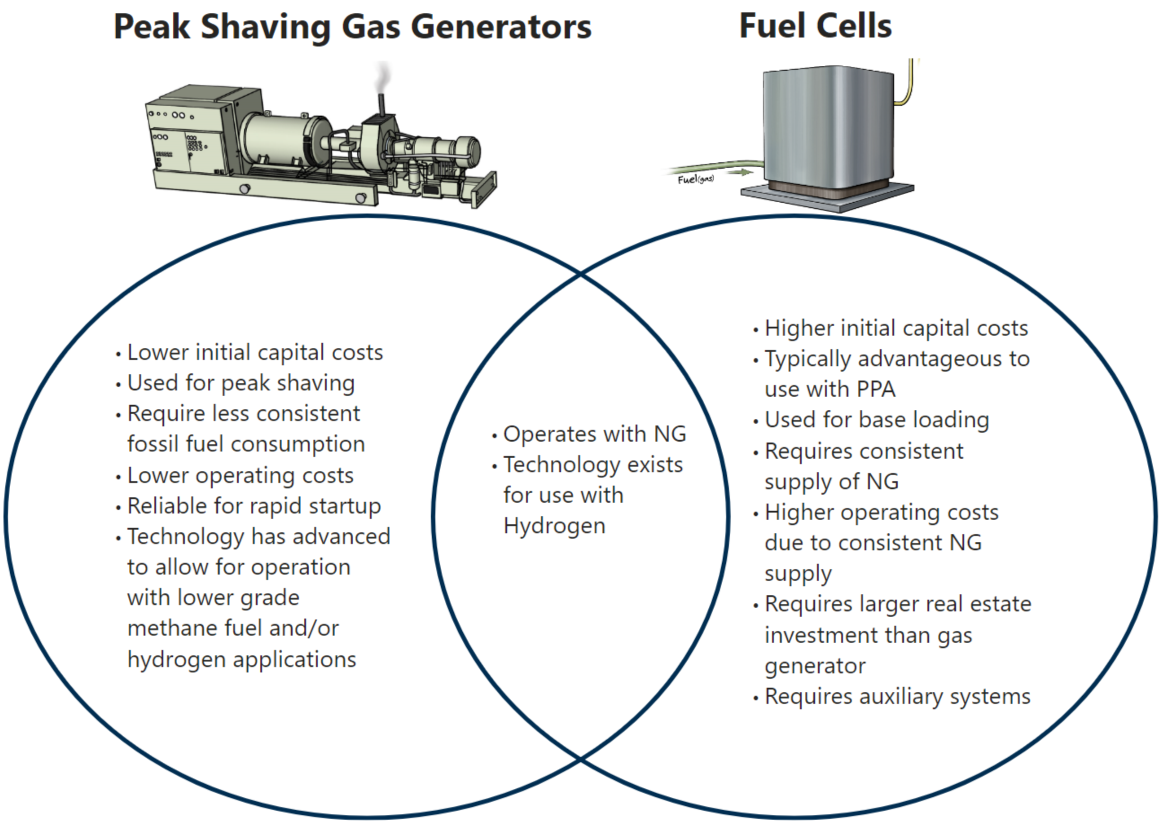
The assessment of base loading over peak shaving is to gauge the impact of continuously running natural gas fuel cells and evaluate the cost savings during peak times. Fuel cells, unlike natural gas generators, are a relatively new technology that provides the opportunity for immediate use of green hydrogen if it were available. In alignment with UCSC’s decarbonization initiatives, the consideration for fuel cells with natural gas supply now and hydrogen supply in the future would make long-term investments more reasonable. Below is a list of pros and cons for operating natural gas fuel cells this way.

Pros (as compared to peak shaving plant alternative):

1. Used for continuous base loading
    a. Refer to illustration (Figure 37)
2. Comparatively efficient operation
3. Reliable source of power
4. Low emission level when using natural gas
5. Typically, advantageous to use with Power Purchase Agreement financing model
6. Advancing technology allows operation with hydrogen supply

Cons (as compared to peak shaving plant alternative):

1. Requires consistent supply of natural gas for base loading
    a. More fossil fuel consumption and associated greenhouse gas emissions
2. Higher initial capital costs
3. Higher operating costs due to consistent natural gas supply
4. Larger footprint
5. More auxiliary systems



- Lower initial capital costs
- Used for peak shaving
- Require less consistent fossil fuel consumption
- Lower operating costs
- Reliable for rapid startup
- Technology has advanced to allow for operation with lower grade methane fuel and/or hydrogen applications

- Operates with NG
- Technology exists for use with Hydrogen

- Higher initial capital costs
- Typically advantageous to use with PPA
- Used for base loading
- Requires consistent supply of NG
- Higher operating costs due to consistent NG supply
- Requires larger real estate investment than gas generator
- Requires auxiliary systems

Figure 40 – Resilient power generation technology comparison

4.1.5 Conclusion for future DERs on Upper Campus

Energy storage systems are recommended for implementation by the Decarbonization and Electrification project under the premise that PG&E is able to provide timely power to campus. If PG&E is delayed in providing additional power to campus, a pivot to natural gas engines can be considered to continue to electrify systems and realize incremental reductions in overall greenhouse gas emissions. Fuel cells are not recommended at this time based on the quantity of biomethane available to UCSC however should be re-evaluated if a local provider of green hydrogen becomes available within the next 7 years. A comparison between natural gas engines and fuel cells is summarized in Figure 40. Both technologies may be retrofit for green hydrogen if available in the future.

4.2 Lower Campus

Lower Campus electrical infrastructure is composed of PG&E owned transformers and serves primarily light commercial and residential buildings. In comparison to the Upper Campus, the systems are smaller, and the overall campus electrical demand is small. Electrification measures discussed in Section 3.3 for heating, hot water generation, and domestic hot water equipment may be implemented for replacing existing systems as a proactive measure or upon failure.

In addition to mechanical and piping measures, natural gas cooking equipment may be considered for replacement in existing applications and should be implemented within all new construction and renovation plans. Branch circuits may need to be installed to accommodate new 240V cooking equipment.

The conversion of natural gas to electrical cooking will increase the building energy demand. This constitutes an evaluation for additional branch circuits, service panels, electrical service mains, and conductors. Each building being considered for improvement should undergo a load study for at least thirty days. This monitored period shall be followed by an electrical evaluation to determine available capacity and subsequent feasibility for the appropriate electrification measures. Coordination studies should be executed with PG&E to avoid exceeding rated limits of PG&E owned equipment.

4.3 Westside Research Park

A tour of the Westside Research Park was performed during Affiliated Engineers' site visit. The facility was under previous ownership by Texas Instruments and now serves as a research facility. Both figures below show the on-site, outdoor electrical equipment and enclosed PG&E switchgear. The robust electrical distribution system is provided by PG&E through a 3000A double-ended switchboard. Electrical capacity exists for the number of unoccupied spaces in the building and backup generation is provided to compensate for a loss of power.

Figure 41 – Westside Research Park

Figure 42 – Enclosed PG&E service at Westside Research Park

UCSC is currently exploring the potential for a microgrid to operate at the Westside Research Park. While this work is outside the scope of this report, the recommendations for the site, in addition to the electrification methods in Section 3.4, is to utilize high efficiency lighting, occupancy controls, and daylight harvesting using photocell controls to increase building efficiency and energy management. The implementation of the microgrid using solar PV and BESS meets the initiatives of UCSC's decarbonization goals.

4.4 Coastal Science Campus

The Coastal Science Campus is geographically unique, with multiple buildings located within hundreds of feet from the coastline. On-site research and animal care are the primary operations for the Coastal Science Campus. If a loss of PG&E power occurs, animal life safety becomes a critical concern and redundant systems are in place to maintain animal, employee, and student safety.

Electrical infrastructure consists of multiple PG&E owned transformers, three UCSC owned transformers, one emergency diesel generator, and three natural gas generators. Visual inspection of outdoor electrical equipment immediately revealed signs of corrosion and degradation (Figure 43). Sea salt spray is a unique challenge that requires attention for critical equipment supplying power to this campus. The following are recommendations for equipment replacement that will improve longevity, reliability, and resiliency of systems:

- NEMA 4X stainless steel electrical enclosures
- Stainless steel connectors and fasteners
- Corrosion-resistant protective coatings (baked enamel, epoxy powder coat, polyvinyl chloride [PVC] coating)
- Galvanization
- Avoid dissimilar metals and maximize nonmetallic components to minimize galvanic corrosion

Figure 43 – Examples of environmental corrosion at Coastal Science Campus

It is recommended that the existing natural gas boilers be maintained as backup emergency heating systems. Using existing boiler equipment for emergency operation prevents newly electrified equipment from increasing the required generator size and reduces associated costs.

Electrification of thermal loads discussed in Section 3.6 will result in increased load on existing transformers and installed electrical equipment. This constitutes an evaluation for additional branch circuits, service panels, electrical service mains, and conductors. Prior to electrification, each building should undergo a load study for at least thirty days. This analysis along with an electrical evaluation will determine available capacity and appropriate electrification measures. Coordination studies should be executed with PG&E before exceeding rated limits of PG&E owned equipment.

5 Fleet fossil fuel use

5.1 Recommendation on the campus fleet

It is recommended that the electrification of light duty fleet vehicles continues. Light duty vehicles are readily available in a variety of models and configurations and in many cases are more cost-effective than their fossil fuel counterparts. Light duty hydrogen vehicles are available but in much more limited models and configurations compared to their battery electric counterparts.

Medium duty vehicles on campus, include delivery vehicles, work trucks and refuse vehicles on campus. Hydrogen and battery electric medium duty vehicles currently have limited availability outside of custom and made-to-order vehicles. Evaluation of the replacement of medium duty vehicles should be conducted on a case by case basis with considerations for vehicle availability, charging infrastructure, and cost. Where medium duty electric vehicles are available for competitive prices, they should be considered alongside internal combustion engine counterparts considering the Social Cost of Carbon.

Vehicles referred to as heavy duty by this study refer exclusively to large campus shuttles and buses. Vehicles classified as heavy duty, are addressed by non-profit consultants, the Center for Transportation and the Environment and this report defers its recommendation to their results of their study which is expected later this year (2023).

Three procurement timelines for decarbonization of the campus fleet including:

1. Business as usual (BAU) – this scenario assumes electrification only where required by state mandates
2. 2045 Target – this scenario includes immediate electrification of light duty vehicles and deferred electrification for medium duty vehicles
3. 2030 Target – this scenario includes immediate electrification of both light and medium duty vehicles

The business as usual scenario results in the lowest net present costs at a total modeled cost of $63 million through 2050 (Figure 44). The business as usual scenario includes the lowest procurement costs but the highest carbon and operational costs. Notably, the highest net present cost scenario, the 2030 Target, only incurs an additional $1.5 million net present costs through 2050 as compared to the BAU scenario. The 2045 Target is the recommended scenario with a net present cost between the BAU and 2030 Target. The 2045 Target is recommended due to operational impacts related to medium duty vehicles as their availability is currently limited. The limited competitive and availability among medium duty vehicles will result in significant compromises in vehicle options that would need to be made to electrify early. These options are particularly critical to medium duty work vehicles as they may limit the functional performance of those vehicles.

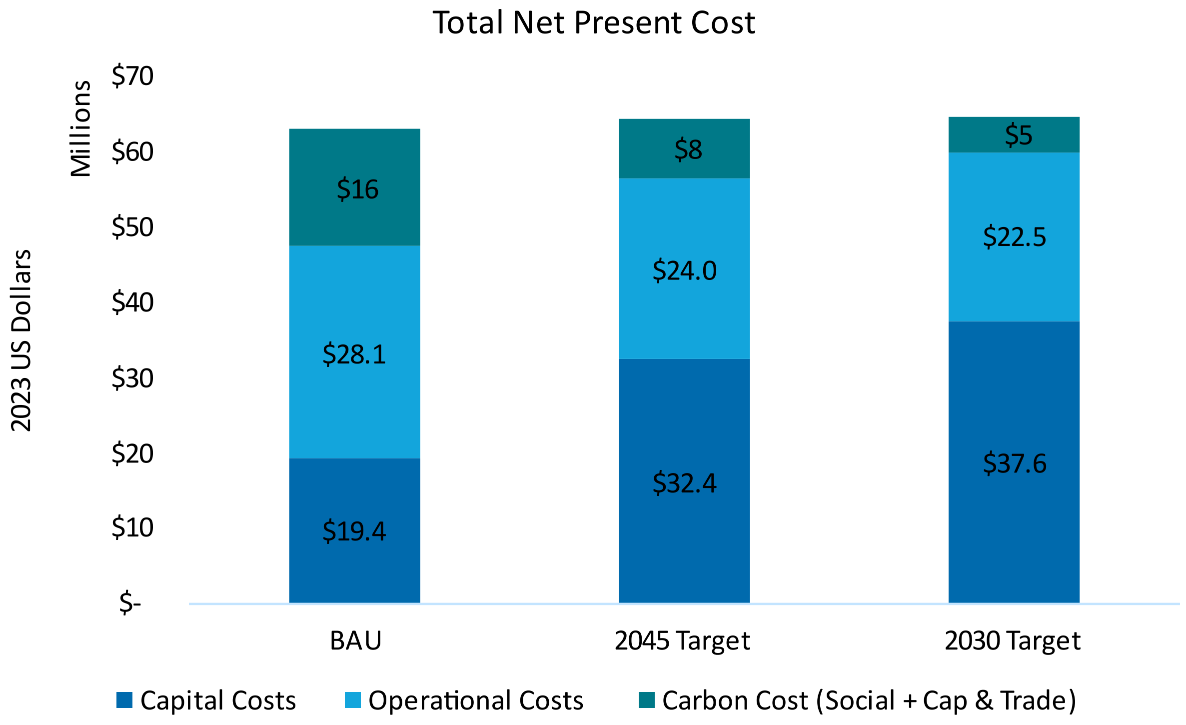


Figure 44- Total fleet net present cost comparison by scenario

Capital net present costs includes construction of a network of charging stations around campus available to fleet vehicles.

5.2 Relevant trends in fleet electrification

The state of California has implemented significant mandates to support fleet electrification. Executive Order N-79-20, mandates that by 2035, all light-duty vehicles sold in the state must be zero-emission vehicles. By 2045, the requirement extends to all vehicles. These mandates serve as crucial steps in the transition towards a cleaner and more sustainable transportation sector in California.

In addition to the state mandates for fleet electrification, regionally EV Reach Codes have begun to be adopted by local municipalities, with updated versions released in October 2022. These codes aim to further accelerate the adoption of electric vehicles in the region and can provide a policy guideline for consideration. These codes, where adopted, mandate that all new multifamily parking facilities must have EV charging infrastructure, covering 100% of the parking spaces. For new office parking, 50% of the spaces must be equipped with EV charging. Furthermore, 20% of other new parking areas are required to have EV charging capabilities. To encourage the transition of existing infrastructure, the codes also mandate that 10% of the existing parking spaces be retrofitted with EV charging facilities. The EV Reach Codes play a crucial role in facilitating the accessibility and availability of EV charging infrastructure, contributing to the wider adoption of electric vehicles in the region.

UC’s Sustainable Practices Policy states that starting on July 1, 2023, a minimum of 50% of all vehicle acquisitions, including both leased and purchased vehicles, will consist of zero-emission vehicles, plug-in hybrid vehicles, or dedicated clean transportation fueled vehicles. With the exception of public safety vehicles that have specific performance needs, all sedan and minivan acquisitions will be either zero-emission or plug-in hybrid vehicles. In cases where zero-emission vehicles are not yet available, irrespective of vehicle size, the priority will be given to the utilization of clean transportation fuels and other low-emission fuels.

5.3 Consideration of battery electric versus hydrogen fuels

The two fuel sources under consideration for the main fleet are battery (electric) and hydrogen electric fuel cell. There are multiple types of hydrogen fuel, represented by colors. What is referred to as "Green" hydrogen would be required for this decarbonization project. "Green" hydrogen produced by 100% renewable energy. Similar to green hydrogen availability for power generation, green hydrogen is limited for fleet use. Projects to create more "Green" hydrogen production are in development, although as of 2022, Green Hydrogen remains less than 5% of the global supply of hydrogen fuel. The CTE report is anticipated to address availability of green hydrogen in their recommendation for heavy duty vehicles.

5.4 Light and medium duty vehicles

Full electrification of the campus vehicle fleet by 2030 would require replacement of newer vehicles well before the end of their useful life and is estimated to require $38 million (in 2023$) between now and 2030. Additional savings may be captured through early resale of vehicles. The majority of the fleet conversion cost is associated with ‘medium duty’ work and delivery trucks which are not currently mass-produced today and are primarily available as made-to-order vehicles at a significantly increased cost. Delaying the full electrification of only these medium duty vehicles until 2045 is projected to significantly reduce the cost of fleet electrification by allowing time for these vehicles to drop in price and become commercially available. Medium duty vehicles account for less than 2% of campus emissions and may be deferred to start in 2030 while the campus still achieves a 95% emissions reduction sooner.

5.4.1 Fleet electrification capital and operational costs

The UCSC fleet's vehicle price calculation methodology relied on the utilization of DRVE model, the Dashboard for Rapid Vehicle Electrification tool, courtesy of Atlas Public Policy. DRVE is a Microsoft Excel-based model that utilizes the fleet inventory to compare electrification scenarios. The electrification model compares procurement and operational costs of internal combustion engine vehicles and comparable electric vehicle alternatives. Procurement costs are based upon Kelly Bluebook MSRP values and were adjusted to reflect trim levels and procurement costs typical of UCSC fleet vehicles. Operational costs are based upon UCSC rates and maintenance, and insurance costs are based upon database costs source collected by Atlas Public Policy.

Battery electric vehicle procurement costs are higher on average than comparable fossil fuel vehicles (Figure 45) although light duty vehicles are competitive. Notably medium duty delivery and work trucks are several times more expensive than their fossil fuel equivalents based on 2023 Kelly Bluebook pricing.

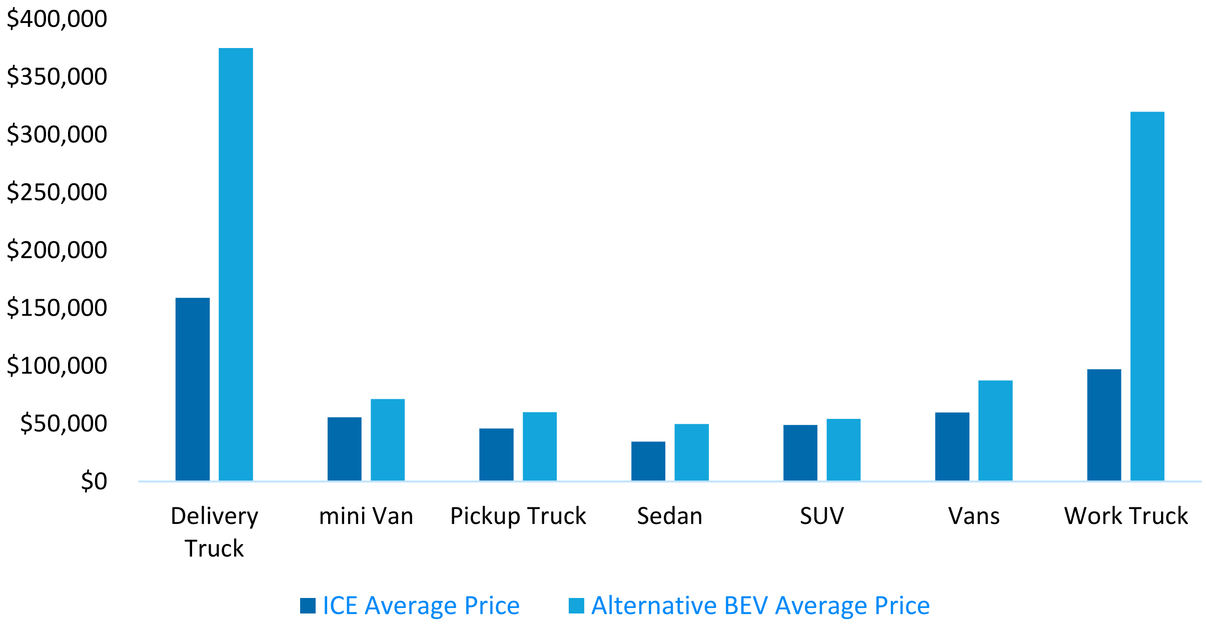


Figure 45 – 2023 vehicle purchase cost by vehicle type

The operational costs of a vehicle are influenced by the Vehicle Miles Traveled (VMT). An average VMT of 5,000 miles per year was calculated based on a combination of telematics, mileage, fuel and carbon data. Higher vehicle utilization with greater annual VMT, results in more favorable net present costs for electrification scenarios compared to the BAU case. Ongoing efforts to consolidate fleet vehicles is recommended to maintain and increase fleet utilization where possible.

5.4.2 Charging infrastructure

5.4.2.1 Charging Stations types and locations

Recognizing the growing popularity and importance of electric vehicles, it is recommended for UCSC to develop a network of charging stations across the campus, dedicated to fleet electric vehicles.

Fleet electric vehicle charging infrastructure is included in the cost to electrify each region of campus. Modeled costs include seven charging stations in each campus pair region as described below:

- Four Level 2 chargers, delivering a power output of 8.3kW. These chargers offer efficient and reliable charging options for EV owners with light-duty vehicles.
- Two high capacity Level 2 chargers with a power output of 19.2 kW installed for medium-duty vehicles, with higher power demands.
- One DC Fast charger. This DC Fast charger is based upon an output of 48 kW, enabling rapid charging for light and medium duty EVs as well as slow charging for heavy duty vehicles ensuring the availability charging for all fleet vehicles types within close proximity.

In total, 120 Level 2 chargers and 24 DC Fast chargers are proposed as a start to support light and medium duty vehicle charging. This charging infrastructure will support the diverse needs of the electric vehicles at UCSC, providing reliable and efficient charging options for vehicles of varying power requirements.

5.4.2.2 Electric vehicle charging profiles and demand

In order to model the impact of vehicle charging on UCSC electrical infrastructure, prototypical charging profiles were utilized. These profiles were sourced from the Battery Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite software developed by the Department of Energy Alternative Fuel Data Center (DOE AFDC). This modeling takes into account UCSC's light, medium, and heavy-duty power requirements.

Both weekdays and weekends profiles were used for electric power demand modeling however the weekday profile is the most critical as it aligns with other peak demands of power on campus. Profiles were selected for Level 2 and DC fast chargers at work places. The AFDC profiles were compared to metered charging data from UC Davis to validate reasonableness of the data set. The overall profile and peak periods are reasonably aligned between the modeled profile and metered data from UC Davis. Notably, the data reveals that on weekdays, the charging loads reach their peak around 10:00 a.m. (Figure 46 and Figure 47).

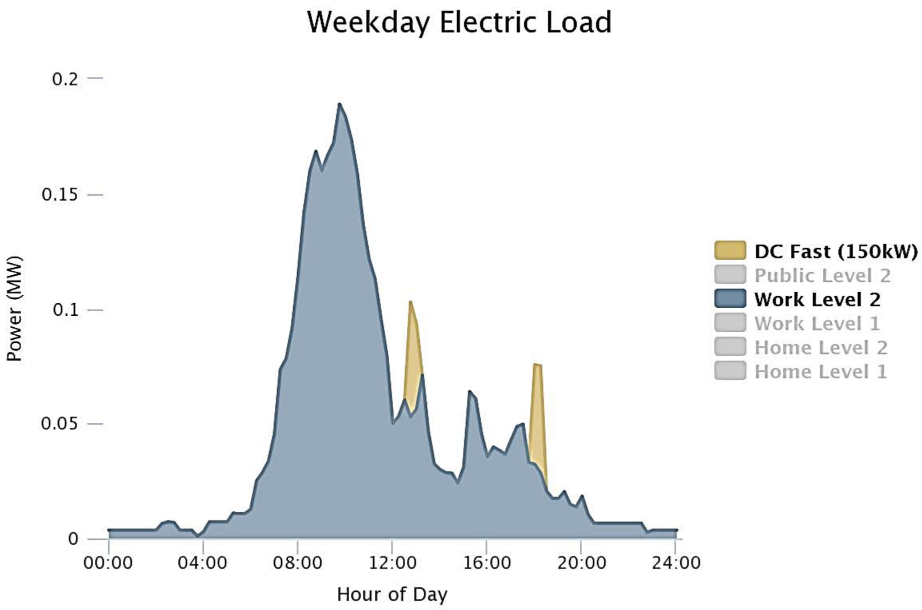


Figure 46 – Weekday daily charging electric load profile

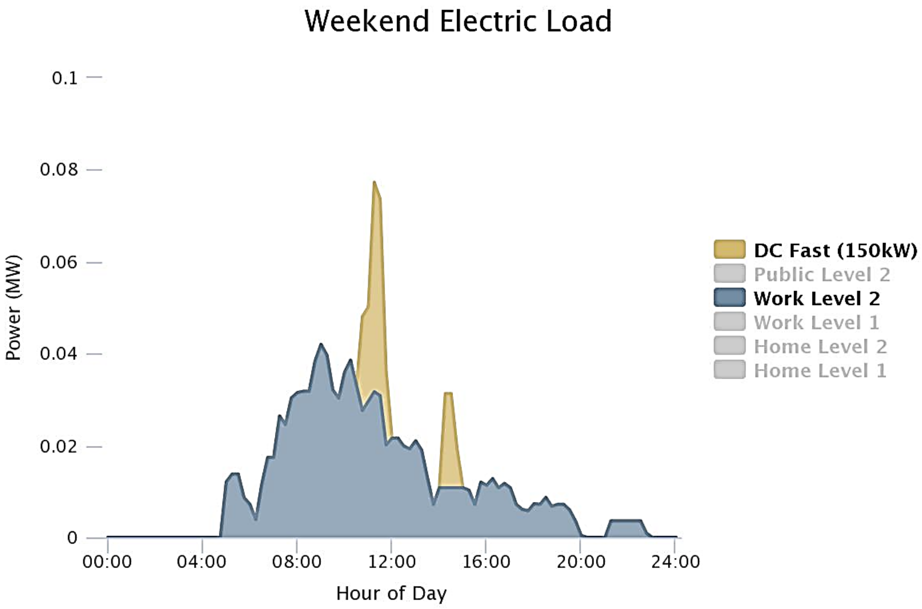


Figure 47 – Weekend daily charging electric load profile

Adjusted for concurrent charging across campus (Figure 48), a total peak demand of 1.5 MW was projected if the fleet were to be fully electrified by 2030.

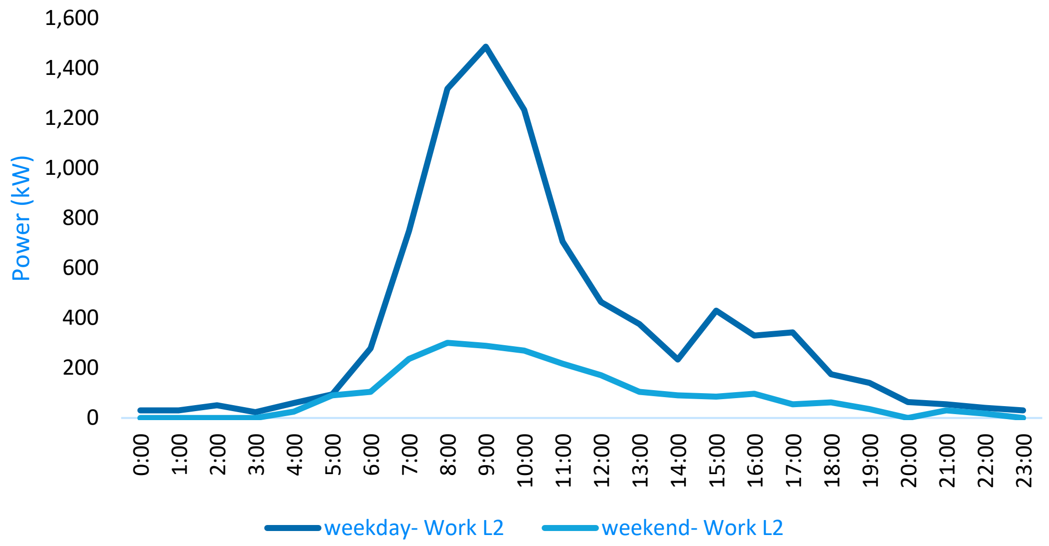


Figure 48 – UCSC total daily vehicle charging profile

5.4.2.3 Charging infrastructure cost

The infrastructure costs for vehicle charging stations was based on reported costs by the California Electric Vehicle Infrastructure Project (CALeVIP) and validated by recent project experience. The estimated cost of implementing BEV charging stations at UCSC includes $15,000 for Level 2 chargers for the light duty fleet, $25,000 for Level 2 chargers for the medium duty fleet, and $150,000 for DC fast chargers. These costs were determined by considering the unique requirements and capacity demands of each charging station category, such as the number of vehicles to be serviced, charging speed, and infrastructure enhancements. Overall, the total cost for Level 2 chargers amounts to $2.25 million, while fast chargers will require a total investment of $3.6 million. Supporting power for these chargers is included under the 21 kV distribution and supporting electrical cost estimates for electrification of each region of campus.

6 Assessment of the campus energy infrastructure

6.1 Summary of previous work

The recommendations in this report (section 2) and the evaluation of alternatives (sections 3, 4, and 5) are built upon previous work. The foundational previous studies are discussed in this section including identifying where this report deviates or builds upon past recommendations. In addition, an assessment of the current energy delivery systems as of 2023 was performed to begin the Decarbonization and Electrification Pre-Design effort and the key findings from that assessment which informed these recommendations are documented here as well.

6.1.1 LRDP

The UCSC 2021 Long Range Development Plan was prepared through a highly collaborative process and one that included extensive engagement with campus constituents as well as members of the city's leadership and community members. It was prepared starting in 2017 and completed in 2021. The LRDP's purpose is to project the physical needs of the campus as it continues to grow.

The LRDP projected an overall campus population (students, faculty, and staff) expansion from just over 21,000 in 2018-2019 to 33,000 in 2041. It was estimated that in order to accommodate this increase in enrollment and associated space for academic and support uses, as well as student residential life and employee housing, the campus building space would increase from 3,753,000 to 9,382,000 assignable square feet.

This growth in campus space would span all use types, but would be an approximate even split between academic/teaching/research an housing, on a square foot basis.

The strategy for accommodating this growth was twofold:

Infill academic and research uses in and at the periphery of the existing academic core, thus minimizing the expansion of this core area and optimizing ease of access by the entire campus community especially by walking, cycling, and shuttle.

Expand student housing by infilling new housing units within or adjacent to existing colleges, and by adding two new pairs of colleges immediately to the southwest of Rachel Carson and Oakes Colleges and to the northeast of Crown and Merrill Colleges.

As the plan notes:

The timespan of the 2021 LRDP is a critical period of action to address climate change and advance UCSC's ambitious greenhouse gas emissions reduction goals. The LRDP provides an opportunity for the campus to develop a robust long-term strategy to decarbonize.

At the time of LRDP preparation, sources of energy for UCSC were primarily the campus's cogeneration plant and purchased electricity, with the cogeneration plant representing the majority of UCSC's carbon impact.

The LRDP identified two primary strategies to reach carbon neutrality: alternative energy sources and energy efficiency. At the time of LRDP preparation, the UC system's Sustainable Practices Policy encouraged alternative energy sources such as solar and biogas. The policy has moved to all-electric buildings for new construction and began requiring electric vehicle purchases.

6.1.2 Campus electrical plan

A Medium Voltage Electrical Master Plan was developed by Stantec Consulting Services for UCSC's Long Range Development Plan from 2020-2040. Affiliated Engineers was provided with the report as a reference for foundational knowledge of the existing and future electrical infrastructure development on the Upper Campus. The report scope was limited to the Main Residential Campus.

Affiliated Engineers performed its own evaluation of the objectives outlined in the MV Electrical Master Plan. It included evaluations of the Westside Research Park, Lower Campus and Coastal Sciences Campus. Key objectives outlined in the MV Electrical Master Plan included:

- Enhanced reliability of service throughout the campus
- Provide additional electrical capacity to support the growth targets described in the 2021 LRDP
- Complete the electrical infrastructure improvement projects started as a result of the previous electrical Master Plan
- Identify and implement additional sustainable, renewable energy and energy storage
- Develop a Standby Generation System Plan campus wide providing standby and emergency power to facilities and support infrastructure
- Provide a second PG&E 21 kV Service Entrance Substation to the campus site on the west side of the campus that is independent of the existing 21 kV service at the east side of the campus
- Address the reliability and continuity of electrical service to the Emergency Response Systems radio transmitter complex on the hill at the end of Chinquapin Road (project underway as of 2023)
- Address new concepts for providing Alternative Electrical System source power and power quality enhancements

The MV Electrical Master Plan remains in alignment with Affiliated Engineers on the topics of increasing electrical capacity, increasing redundancy of power to campus loads, and the investment in alternative distributed energy resources. The MV Electrical Master Plan also provided key phasing action items to accomplish its objectives shown below.

- Merrill Substation Inner Loop Configuration
- Tenant Multi-Function Remote Antenna Site
- New 21 kV Distribution System
- Three Phases of Implementing a Central Standby Generation Facility
- Connecting New West and Northside Buildings to New 21 kV System
- Connecting New Eastside Buildings to 12 kV System

Affiliated Engineers’ assessment of the phased action items above includes the discussions for upgrading the existing 21 kV service from PG&E at the Slug Substation and installation of a secondary service at the west side of Main Campus. These recommendations support increased system reliability with redundant feeder sources from PG&E as well as increased system capacity to meet the LRDP growth of an additional 6.2 million assignable square feet. Transmission level services have been discussed with PG&E as a result of Affiliated Engineers’ energy demand projections above 35 MW as a result of new development from the LRDP.

Affiliated Engineers, Inc. recommendations in this plan which differ from the MV Electrical Master Plan include the implementation of three substations like the Merrill Substation to provide smaller loops serving colleges and smaller microgrids in lieu of a Central Standby Generation Facility.

The MV Electrical Master Plan was completed prior to the finalization of the 2021 LRDP and introduced the Main Campus medium voltage distribution system work and future planning methods. These recommendations were considered and realigned with the recommendations provided in this report by Affiliated Engineers.

6.1.3 CES Report

The Climate and Energy Strategy report published in 2017, laid the foundations for the work today. The 18-month process developed a plan to target carbon neutrality by 2025 for Scope 1 and Scope 2 emissions and address the impacts of the Cap and Trade regulation.

The CES plan recommended the development of renewable energy and energy efficiency projects to achieve on campus emission reductions. The CES plan, based on the guidance from UCOP at the time, relied on carbon offsets to achieve neutrality. The current decarbonization and fossil fuel free efforts seek to minimize the use of offsets and offsetting mechanisms whenever feasible.

More than 100 energy efficiency projects were recommended by CES and many have been implemented over the past 5 years and more are planned. The Decarbonization and Electrification project supports continued implementation of the CES efficiency projects. Continued investment in energy efficiency reduces the electrical demand across campus which allows for UCSC to decarbonize more of the campus in the interim period in which PG&E works to provide more power to campus.

The renewable energy recommendations from the CES also contribute towards faster decarbonization by reducing electrical demand during peak periods and serving as power generation assets during outages. A diverse on-campus microgrid provides cleaner and more reliability energy. The CES included planning for a West Remote Parking photovoltaic array which has been incorporated into cost estimates for the Rachel Carson/Oakes decarbonization work.

6.1.4 Greenhouse gas inventory

Prior work on developing and maintaining a greenhouse gas inventory for the campus has been essential to the Decarbonization and Electrification effort. Work from the CES was built upon to understand the distribution of Scope 1 emissions on campus. Past inventories were paired with energy metering from EnergyCAP to provide a breakout of emissions by region of campus and by end use. Fossil fuel end-uses included heating and power, building-side equipment, the chemical inventory, types of vehicles. A Sankey diagram (Figure 49) has been developed to show the relative distribution of emissions by region and use. This information served as the basis of planning for this project and was key when developing phasing and understanding infrastructure impacts.

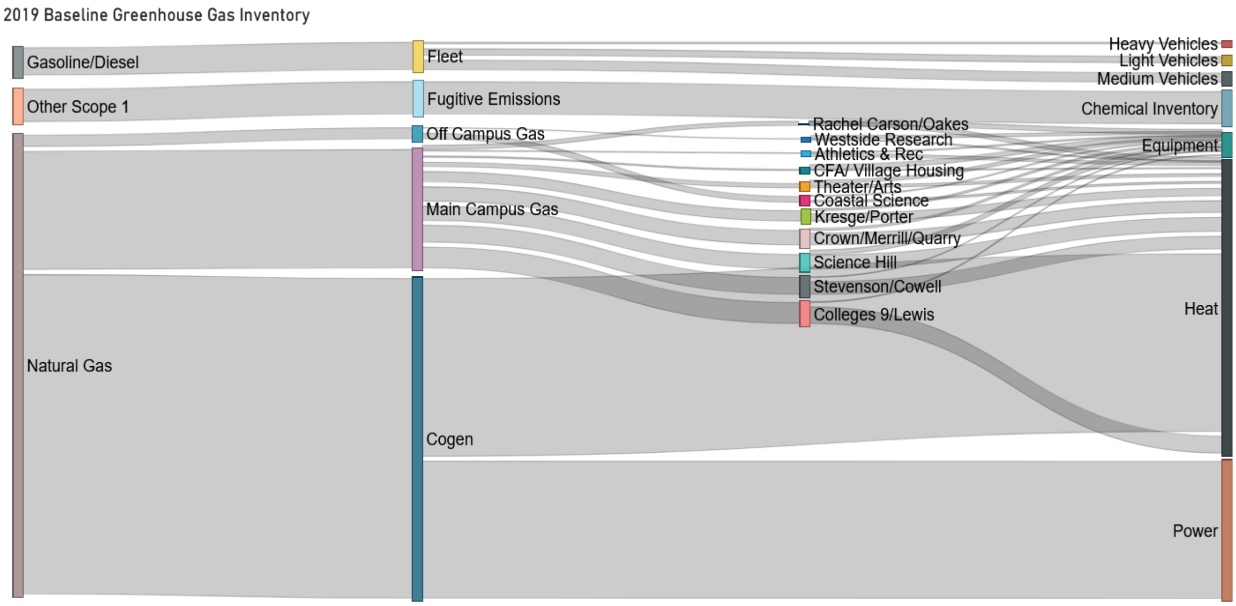


Figure 49 – Sankey diagram breakout of the 2019 greenhouse gas inventory

6.2 Stakeholder workshops and engagement

The project team has hosted eight workshops with campus stakeholders including representatives from Physical Planning, Development, and Operations; Transportation and Parking Services; Colleges, House and Educational Services; Real Estate and Contract Services; Risk & Safety Services; Baskin School of Engineering; and the Climate Coalition. The workshops covered topics dedicated to understanding the infrastructure needs as well as ideate and screen potential technology pathways to decarbonization. Woody biomass and nuclear options were discussed with stakeholders, and these were eliminated from consideration due to expected community resistance and technical limitations. Expansion of cooling to non-research buildings is under evaluation in respect to increasing temperatures.

A summary of key stakeholder workshops and outcomes is included below.

1. Visioning – 12/16
    a. Reviewed UC system goals
    b. 95% fossil fuel reduction target
    c. Review of past efforts/plans
    d. Conservation is important but taking longer to achieve than initially planned
2. Ideation – 12/16
    a. Reviewed common decarbonization technologies
    b. Nuclear eliminated due to community sentiment
    c. Large wind turbines not feasible due to campus siting
    d. Ground water related technologies not desirable due to environmental impacts
    e. Heat recovery is a common technology among decarbonization projects
    f. Solar thermal and vertical axis wind of interest
    g. Colocation of photovoltaics to be considered
    h. Equitable procurement of PV is critical
3. Campus Reference Case – 12/16

   a. Reviewed existing 'business-as-usual' costs and carbon neutrality efforts
   b. Carbon neutrality was previous plan, reaffirmed new goal is to be 95% fossil fuel free
   c. Expansion of cooling outside of laboratories is not currently planned for, impact to be studied
   d. Cost model to include cap & trade, investments in lieu of offsets, social cost of carbon
   e. No baseline plan for vehicle electrification, new vehicles required to be hybrid

4. Resiliency – 12/20
   a. Reviewed and discussed campus needs during outages
   b. Remaining 5% of fossil fuels may be resilient power
   c. Santa Cruz at end of power distribution and gas pipelines
   d. 3-days of water storage is on campus, but pumps lack resilient power
   e. Cogen turbine is newest in UC system, long amortization schedule
   f. Science Hill can be powered by Cogen during outages, but flexibility exists to serve other buildings
5. Transportation – 12/20
   a. Reviewed make-up of existing fleet and current commuting patterns
   b. CTE engaged to study shuttle decarbonization
   c. Interest in fuel cell electric buses to share infrastructure with City of Santa Cruz
   d. Uncertainty in availability of medium duty vehicles, discussed fleet challenges
   e. Vehicles across a wide variety of departments, most associated with facilities
   f. Light duty vehicles in fleet are cost-competitive to electrify today, medium duty vehicles available at a premium
   g. Evacuation services not needed, some fleet vehicles need to remain operational during outages, commuting charging does not need to be supported during an outage
6. Existing Infrastructure – 1/11
   a. Reviewed current design standards & impacts on electrification
   b. Opportunity for heat recovery identified in Science Hill
   c. Large quantity of aging boilers on campus, prioritize aging infrastructure
   d. Dining halls were originally all-electric
   e. Coastal Science Campus dehumidifiers and foundry are difficult to decarbonize but impact is small, may be among 5% not to decarbonize.
   f. Aging medium voltage feeders on campus have been failing and their capacity may need to be de-rated due to age
7. Campus Growth – 1/13
   a. Reviewed LRDP planning
   b. Intent is to move parking to perimeter of Science Hill, reduce surface parking and consolidate in parking structures
   c. Potential decarbonization infrastructure sites reviewed, may be located adjacent to existing and future development to support growth
   d. 30% of LRDP growth is likely in near term, remaining growth may occur later
   e. Cooling likely needed in the future for new buildings and major renovations

8. Near Term Opportunities - 1/31
    a. Reviewed approach to decarbonization project implementation
    b. Discussed pre-design studies to validate scope of electrification work
    c. Reviewed current projects and steps to electrify fossil fuel uses
9. Financial workshop - 2/15
    a. Reviewed key inputs to cost model
    b. Discussed potential phasing, modularity in approach
    c. 4.25% discount rate to be applied as cost of capital
    d. Construction costs rising faster than inflation
    e. Cap & trade costs to be based on UCOP projections
    f. Voluntary carbon offset purchases no longer required, new policy moves previous expenditures to reinvestment in decarbonization starting in 2025
    g. Social cost of carbon to be based on UCOP equity weighted value and escalation
    h. Cost factors to be broken out including phasing, general conditions, etc. Cost factors to be coordinated with PPDO
10. Siting Considerations – 2/21
    a. Reviewed siting consideration for decarbonization equipment
    b. New heating equipment primarily on grade, rooftop options may be considered where practical
    c. Residential equipment does not necessarily need screening, may be located on adjacent grade
    d. Smaller sites can use a combination of full and partial screening
    e. Cost competitive mesh screening can be utilized, integrate vegetation where possible
    f. PG&E substation identified as a model for larger projects

6.3 Review of energy delivery systems

6.3.1 Buildings fossil fuel uses

The existing cogeneration turbine accounts for approximately 60% of the campus greenhouse gas emissions. Providing a decarbonized source of heating for Science Hill and adjacent buildings and upgrading the campus electrical infrastructure will allow the turbine to be turned off during normal operation and greatly reduce emissions. De-energizing the turbine during normal operation is expected to over-utilize the PG&E service to campus which will decrease the reliability of service. Adding a new medium voltage feed to campus, as proposed in the existing utility plans, will increase reliability, and allow for de-energizing the cogeneration turbine. The Decarbonization and Electrification Pre-Design project addresses the sizing impacts to this new service in Section 4. The cogeneration turbine is proposed for conversion to a simple cycle, standby turbine to serve as an alternate source of power to a PG&E failure. Conversion to clean combustion fuels will be considered when available.

Many of the gas boilers serving the colleges outside of Science Hill are approaching their service life and due for replacement. Residential apartments are often served by arrays of water heaters, which leads to a relatively simple replacement with new systems.

Figure 50 – Existing gas boilers and water heaters

Some boilers are still in good condition and regions with newer equipment can be phased towards the end of project work. This has a twofold advantage of replacing aging equipment with the correct electrified equipment, while also getting the advantage of using the newer equipment for longer (paying for its first cost over a longer period) before replacement.

Figure 51 – Gas boilers (good condition)

6.3.2 Electrical infrastructure

6.3.2.1 Primary source of power

The Main Campus is served by local utility provider PG&E from the off-campus Paul Sweet Substation via nominal 21 kV feeder circuits FDR 2102 and FDR 2105. The two overhead feeder circuits provide up to 10 MW of power from PG&E and are fed underground from a pole-mounted interrupter switch outside of the Slug Substation to the service entry where PG&E takes meter measurements. The Slug Substation is adjacent to Coolidge Drive on the Main (Lower) Campus. UCSC takes control and operation of the service from PG&E at the Slug Substation and routes the 21 kV service up Coolidge Drive via 2 sets of 3#250kcmil, 1/C, copper, underground feeders MF1 and MF2.

The two underground feeder circuits provide power to the stepdown transformers, T52 and T53, at the Merrill Substation northeast of Alan Chadwick Garden. T52 and T53 are oil filled, air cooled transformers rated for 8.625 MVA and stepdown voltage from 21 kV to 12.47 kV to provide power to Switchboard M. Switchboard M derives the four feeder circuits A1, A2, B1, and B2 composed of 2 sets of 3#250kcmil, 1/C, copper feeders each. There are sixty-six operating campus transformers fed by the four feeder circuits that supply power to the buildings in each of the colleges. The classifications of campus transformers vary and can be seen below (Table 5).

Classification	Quantity
Air Cooled	3
Forced Air, Air Cooled	17
Oil Cooled	39
Forced Air, Oil Cooled	5
Turned Over for Construction	2
TOTAL	66

Table 5- UCSC Campus transformer classifications

6.3.2.2 Alternative Sources of Power

As of 2023, UCSC has 2.35 MW of installed solar PV between the McHenry Library Rooftop and East Remote Parking Lot. Solar PV is a clean energy alternative that does not require fossil fuels and will not be affected by UCSC's target goal of 95% reduction in greenhouse gas emissions.

6.4 Fleet composition

6.4.1 Fleet share

The 2023 fleet at UCSC comprises a total of 426 vehicles. The fleet composition can be categorized into different vehicle types and duty types. The majority of vehicles fall under the light-duty category, which includes sedans, SUVs, mini-vans, and vans, accounting for 246 units. The second largest group consists of medium-duty vehicles such as delivery, pickup, refuse, and other work trucks, totaling 152 vehicles. Additionally, there are 28 heavy-duty vehicles including shuttles and buses.

To visually represent the fleet composition, the following pie charts are included (See Figure 52). The first chart illustrates the fleet share by fuel type, indicating that only 5% of the total vehicles in the fleet are electric and the majority of the fleet still relies on conventional fuel sources such as gasoline or renewable diesel. The second chart presents the fleet share by duty type, showcasing the proportion of vehicles used for light-duty, medium-duty, and heavy-duty purposes. Lastly, the third chart shows the fleet share by vehicle type.

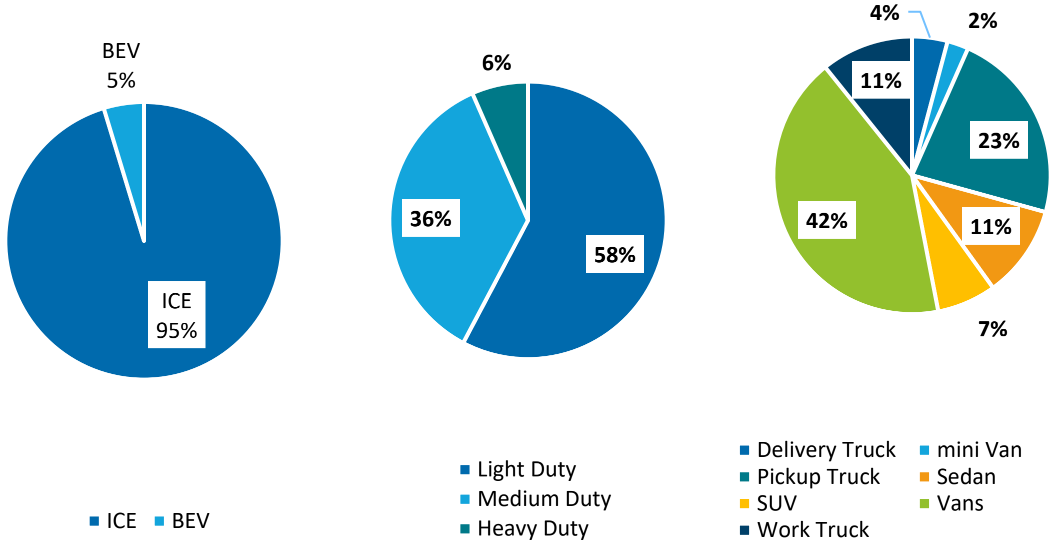


Figure 52 – UCSC Fleet share

6.4.2 Fleet distribution

In terms of fleet age, the UCSC fleet exhibits a diverse range of vehicle ages (Figure 53).

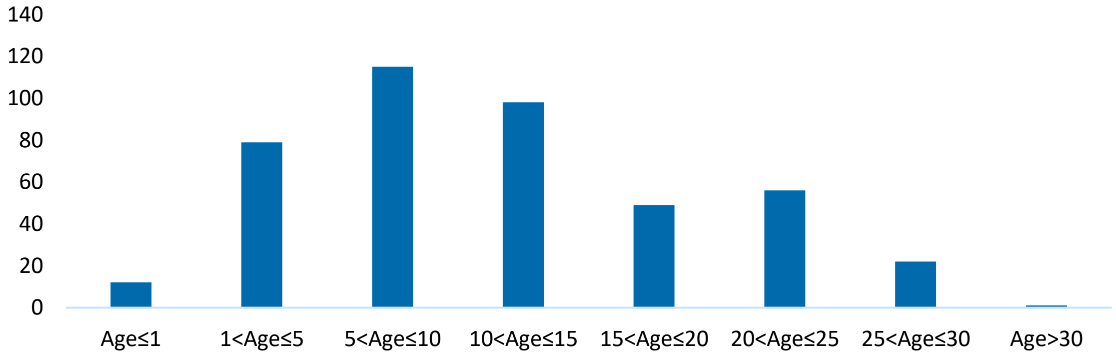


Figure 53 – UCSC Fleet age distribution

Analyzing the age distribution of the fleet provides crucial insights for fleet management, especially considering the potential replacement of ICE vehicles with BEVs. It aids in identifying the necessity for potential vehicle replacements, assessing maintenance requirements, and strategically allocating future budgets.