AECOM

UCR CAMPUS

DECARBONIZATION STUDY

October 2024

UC RIVERSIDE

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Disclaimer

This document comprises Deliverables 1+2 of the state-funded decarbonization study conducted for the University of California Riverside in support of the University of California Policy on Sustainable Practices (2024).

The scope of analysis, findings, and recommendations of this study are aligned with the State-Funded Carbonization Study Scoping Guidance (February 1, 2024) from the Pathways to a Fossil Free University of California Task Force. It is intended as a resource for fulfillment of University of California decarbonization goals; acknowledged that implementation of the strategies identified is contingent on contextual factors beyond the scope of this study.

Acknowledgements

The University of California Office of the President, University of California, Riverside, and AECOM would like to thank the following participants for their engagement in the development of this Campus Decarbonization Study:

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Acronyms and Abbreviations

ASHP	air source heat pumps
BAU	business-as-usual
CapEx	capital expenses
CARB	California Air Resources Board
CBECS	Commercial Building Energy Consumption Survey
CHASS	College of Humanities, Arts and Social Sciences
COP	coefficient of performance
CUP	Central Utility Plant
CY	calendar year
EIA	United States Energy Information Administration
EPA	United States Environmental Protection Agency
EUI	energy use intensity
°F	degrees Fahrenheit
GHG	greenhouse gas
GSHP	ground source heat pump
HUB	Highlander Union Building
HVAC	heating, ventilation, and air conditioning
HX	heat exchanger
I-215	Interstate 215
IEA	International Energy Agency
IRS	Internal Revenue Service
ISC3	Inland Southern California Climate Collaborative
kBtu	thousand British thermal units
kBtu/h	thousand British thermal units per hour
KPI	key performance indicator
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LAO	Legislative Analyst's Office
LCC	life cycle cost
LRDP	Long Range Development Plan
Mgal/yr	million gallons per year
MMBtu	million British thermal units
MSF	million square feet
$MTCO_2e$	metric tons carbon dioxide equivalent
$MTCO_2e$/yr	metric tons carbon dioxide equivalent per year
MVA	million volt-ampere
MWh	megawatt hours
MWh/yr	megawatt hours per year
$M/yr	million dollars per year
NASA	National Aeronautics and Space Administration
NPV	net present value
PSI	pounds per square inch
RNG	renewable natural gas
RPU	Riverside Public Utilities
SAT	Satellite Plant
SCC	social cost of carbon
SoCalGas	Southern California Gas Company
TCO	total cost of ownership
TES	thermal energy storage
UC	University of California
UCOP	University of California Office of the President
UCR	University of California, Riverside
UTLF	Undergraduate Teaching and Learning Facility
WSHP	water source heat pump
WWHP	water-to-water heat pump

Executive Summary

Overview

In response to the climate action goals outlined in University of California (UC) Sustainable Practices Policy, state-funded studies were commissioned for each UC campus to inform campus-specific decarbonization strategies, emission targets, and climate action plans. The purpose of this study of campus decarbonization is to identify pathways for University of California, Riverside (UCR) to transition away from on-campus fossil fuel use while responding to regional drivers and aligning with the UC goals and existing UCR plans, including the UC Framework for Environmental and Climate Justice.

This study identified eight potential pathways for UCR to achieve at least a 90 percent reduction of energy-related Scope 1 emissions by the UC target date of 2045. Energy and financial cost modeling was conducted, and it was determined that, under the conditions laid out in the study, a centralized electrified heating system enabled by steam-to-hot-water conversion, may be the best solution for UCR.

Methodology

This study was informed by an existing conditions and performance assessment, future conditions modeling, technology review, systems modeling, and subsequent scenario pathway comparison. The process was supported by a stakeholder engagement process, anchored by the core advisory team, consisting of representatives from the Academic Senate; Facilities Services; Office of Sustainability, Planning, Budget, and Administration; and Planning, Design, and Construction.

Existing and future conditions assessments provided the baseline, or business-as-usual (BAU), representing how UCR's energy system may continue to operate without new investment into decarbonization. The technology review assessed a wide range of existing and emerging low- and zero-carbon heating technologies for their feasibility for deployment at UCR. Five feasibility factors were used as scoring criteria to narrow the options down for consideration in scenario development.

Five decarbonization scenarios — the application of decarbonization strategies, singly or in combination, as informed by the technology review — which include a total of eight alternative pathways, were developed for comparison. The scenarios represented the range of technically feasible interventions that may be required for the building systems, distribution network upgrades, plant equipment, and primary utility supply, and how these may best fit together as comprehensive solutions for campus decarbonization. The alternative scenarios were evaluated, compared, and subsequently narrowed down to one featured concept. The BAU scenario, which does not meet the emissions reduction target, was modeled as a point of comparison.

The results of the comparison are summarized in the performance scorecard shown on Figure ES-1. Quantitative metrics are provided for the GHG emissions reductions, life cycle cost, and resource use evaluation criteria. The resilience, implementation, environmental justice and collaborative learning criteria were rated qualitatively and represented as either a low, medium, or high in terms of favorability, on this figure.

The analysis suggests that while all alternatives may technically be able to meet the decarbonization goals by 2045, the centralized electrified hot water scenario (Scenario 1) performs best when considering the collective performance against all criteria. Scenario 4.1 represents the purchase of biomethane offsets and represents no change in onsite operations. Although it is currently projected to have the lowest associated costs of the decarbonization pathways, long-term financial risk on account of limited resource availability is inherent to Scenario 4.1. For this reason, it was not selected as the featured decarbonization pathway; instead, it could be considered as an interim solution for short-term emission reductions.

Featured Scenario

A potential pathway for UCR to achieve decarbonization goals is through implementing **Scenario 1.2: Electric Central Hot Water Plant, with additional thermal energy storage (TES)**. This scenario involves electrification of the existing central steam plant with a combination of water-to-water and air source heat pumps, expansion of the existing Satellite Plant cooling capacity, and a transition of all served buildings, processes, and distribution infrastructure (where needed) from steam to low-temperature hot water. This would likely require a new electrical service to serve higher demand, along with localized electrical infrastructure upgrades to facilitate the electrification of the central plant and process loads (research or kitchen) currently served by steam or natural gas.

This scenario takes advantage of UCR's consistently high simultaneous heating and cooling demand to optimize plant operational efficiency, which is further enhanced by the addition of a new hot-water TES tank. When combined with a reduction in distribution losses of greater than 75 percent in the transition from steam to hot water, this strategy could reduce thermal utility costs by approximately 50 percent ($4.5 million per year) compared to the existing system. By maintaining the newest steam boilers as backup, and with the installation of the TES and a new electrical service, this strategy also enhances campus resilience.

The buildings currently not connected to the steam plant could be transitioned to a local electrified alternative when the existing gas-fired boilers reach the end of their useful life and require additional maintenance to operate effectively. This approach can minimize the investment premium and potential distribution.

This strategy may impact almost every building over the next 15 to 20 years. It is likely to be complex and costly to undertake such a large infrastructure transformation, and as such, a well-considered phasing timeline is essential. This study developed one example implementation schedule that considers planning design and equipment procurement timeframes, minimizes campus disruptions, spreads out capital investment, provides early living lab and research opportunities, that could meet the campus' 2045 carbon reduction goal.

With legacy steam infrastructure primed for renewal, UCR has an opportunity to begin its decarbonization transition and emerge as a more sustainable and resilient university.

Scenario		BAU	1.1	1.2	2	3.1	3.2	4.1	4.2	5
GHG Emissions Reductions[1] Scopes 1 and 2, *Percentage*		○ 0	● 100	● 100	● 100	● 100	● 100	● 100	● 100	● 100
Lifecycle Cost[2] 30-Year TCO, *Millions USD*		● 754	● 968	● 1006	◑ 1072	◑ 1099	○ 1364	● 955	○ 1289	◑ 1086
Resource Savings	Energy, *1,000 MMBtu*	○ 0	● 349	● 356	● 297	◑ 95	● 209	● 398	● 398	● 230
Resource Savings	Water, *Mgal*	○ 0	● 29	● 42	◑ 9	○ 0	○ 0	○ 0	○ 0	◑ 9
Qualitative	Resilience and Reliability	○	◑	●	●	◑	◑	◑	○	◑
Qualitative	Ease of Implementation	●	○	○	○	◑	○	●	○	○
Qualitative	Environmental Justice	○	●	●	●	●	●	◑	◑	●
Qualitative	Collaborative Learning	○	◑	◑	◑	○	●	○	●	◑

Scenario

BAU	Existing Steam & CHW Distribution (Business-as-Usual)
1.1	Electric Central Hot Water Plant (without TES)
1.2	Electric Central Hot Water Plant (with TES)
2	Electric Distributed Hot Water Plants
3.1	Electrified Steam Systems (Steam Boilers)
3.2—Future	Electrified Steam Systems (Steam Heat Pumps)
4.1	Alternative Fuels (Biomethane)
4.2—Future	Alternative Fuels (Hydrogen)
5	Decentralized Electrification

Rating in terms of favorability

- ○ Low
- ◑ Medium
- ● High

[1] Percent reduction of Scopes 1 and 2 emissions from the 2019 baseline by 2045 (excluding non-building energy)

[2] 30-year total cost of ownership (TCO) which includes capital investment, replacement costs, and utility costs, but excludes social cost of carbon

Figure ES-1: Scenario Performance Scorecard

Figure ES-2 summarizes an example schedule to implement the featured scenario. Districts are areas of the campus grouped and sequenced based on the above-discussed criteria. Implementing the scenario on this schedule would allow UCR to meet the emissions reduction requirements by 2045. With additional funding this could potentially be accelerated. If additional near-term funding is available, UCR would look to pilot a localized heat pump plant.

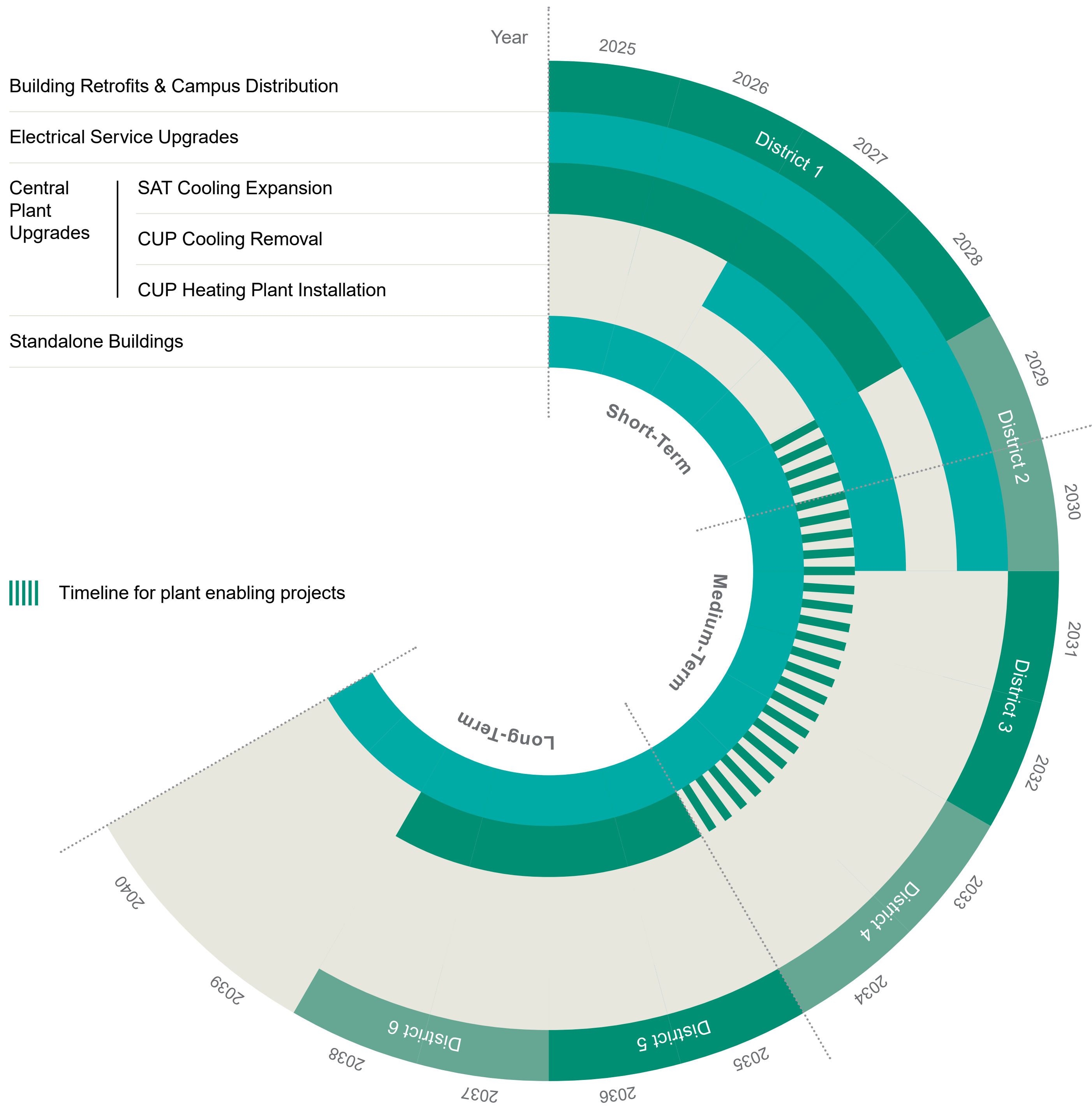


Figure ES-2: Implementation Timeline Summary

The featured scenario has a total estimated capital cost of between $350 and $400 million (in 2024 dollars). When investment is phased in alignment with the example implementation timeline, the total year of expenditure costs would rise to approximately $600 million considering a 6% per year escalation in capital costs.

The 30-year total cost of ownership of the featured scenario is approximately $300 million greater than the BAU case (2024 dollars). Implementing the featured scenario rather than the BAU case, the avoided Social Cost of Carbon would be approximately $70 million over 30 years.

These estimates are reflective of a 15-year implementation period starting in 2025. Delay in the timeline of project implementation would increase the total cost of implementation as well as significantly reduce the potential environmental benefit of realizing short-term emissions reductions. **Figure ES-3** shows this investment allocated by year, aligned with scheduled project implementation.

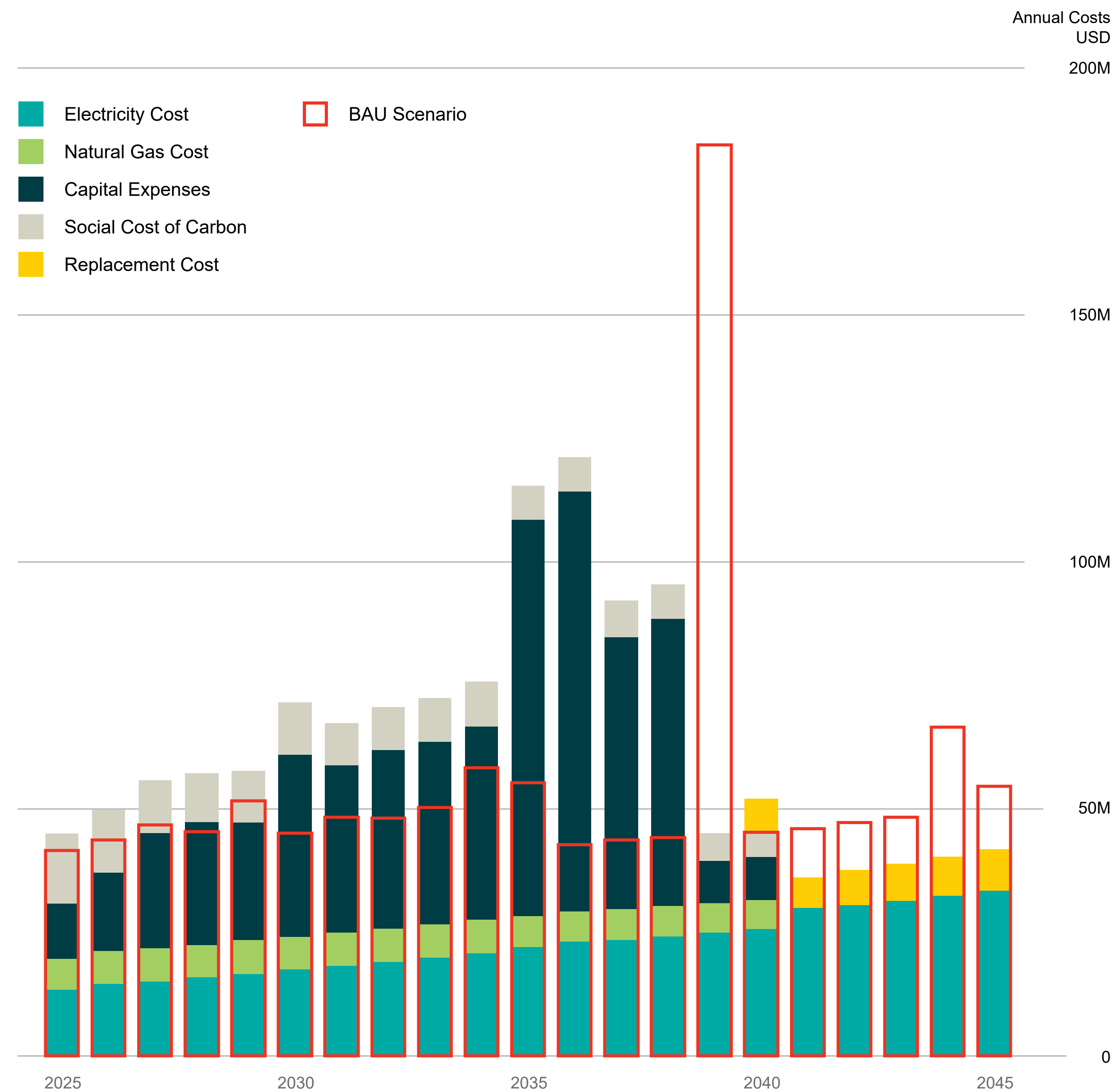


Figure ES-3: Capital Investment per Year for Featured Scenario

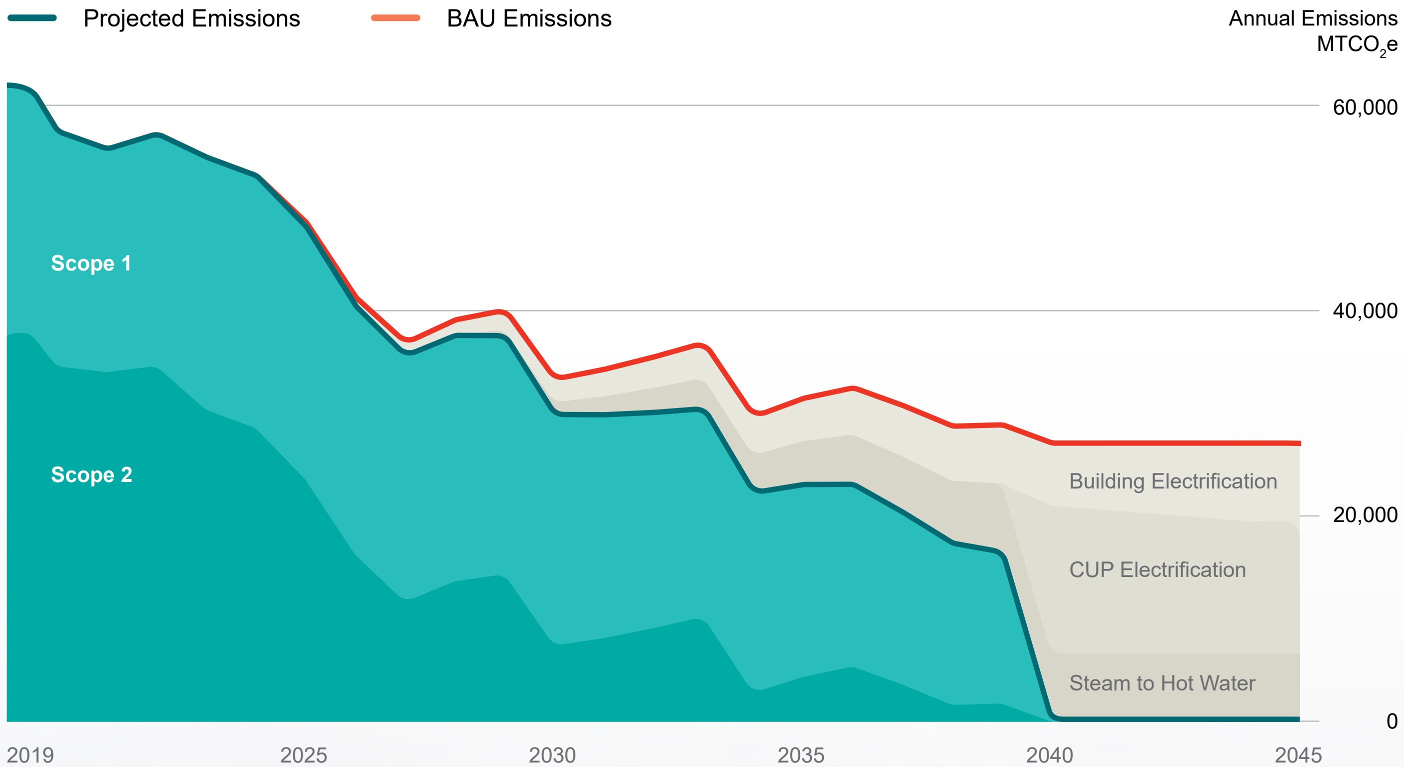


Figure ES-4: Decarbonization Glidepath for Featured Scenario

Figure ES-4 shows the GHG emissions pathway associated with the featured scenario and illustrates a timeline to eliminate campus natural gas emissions, which accounted for 90 percent of UCR's Scope 1 emissions in 2019. The remaining 10 percent of Scope 1 emissions include other stationary combustion emissions, mobile emissions, and refrigerants emissions that are not analyzed in this study. If Riverside Public Utilities were to achieve its 2040 clean electricity target, this alone would reduce total annual campus emissions (i.e., Scope 1 and Scope 2) by more than 50 percent; but Scope 1 emissions are projected to increase as the campus grows. Building and infrastructure steam-to-hot-water conversion could potentially reduce Scope 1 emissions by up to 15 percent through reduced system losses and enable a switch from centralized gas-fired steam to electric heat pumps in 2040 to eliminate central plant emissions. Converting the remaining stand-alone gas building to electric could close the remaining gap and achieve the UC emissions reduction goals.

Realizing a Decarbonized Campus

This campus decarbonization study has combined technical and financial analysis with stakeholder engagement to evaluate, compare, and identify a featured pathway to Scope 1 emissions reductions of more than 90 percent at UCR before 2045. This strategy is considered to be well-suited to the UCR campus for the following reasons:

Highly Efficient Solution

UCR has heating and cooling load characteristics (tied to the climate and campus use) that allow extensive use of efficient water to water heat pumps. This can be further enhanced using existing TES systems to maximize electrified plant efficiency.

Minimized Disruption

Although still a complex logistical challenge, only 11 buildings require a full steam retrofit, and more than 70 percent of the existing steam pipe is in accessible utility corridors.

No Major Existing Anchor Steam Use or Generation

UCR does not have an existing hospital nor does its electrical or thermal systems utilize cogeneration. These are both typically complex challenges to decarbonize due to their large demand for steam or natural gas.

Aging Campus Infrastructure

The existing campus steam distribution infrastructure is nearing or at the end of its design life, and will likely require significant investment in the near future. This may present an opportunity for replacement with infrastructure that facilitates decarbonization.

Project Economics

UCR has a low electricity rate by UC standards, and the analysis conducted in this study suggests that an electrified system, when fully realized, may have a lower total annual utility cost than maintaining the use of the existing system.

Collectively, these synergies create a case for the featured scenario implementation when considered over the anticipated 50-year life cycle of campus energy systems. With a phasing example that maintains flexibility for future changes in timing and scheduling, and allows for enhancements in technologies and campus growth, this decarbonation study provides an example investment pathway that could achieve UC's decarbonization goals by 2045.

UCR has an opportunity to begin its decarbonization transition on a technically sound and sustainable pathway in alignment with UC goals.

1. Introduction

The University of California, Riverside (UCR) is widely recognized as one of the most ethnically diverse and innovative research universities in the nation. Through groundbreaking programs, research initiatives, and community partnerships, UCR remains committed to leading the charge in fostering a more sustainable future for generations to come.

In alignment with the latest University of California (UC) climate action goals (2023), UCR commissioned this study of campus decarbonization, the objective of which is to identify pathways to transition away from on-campus fossil fuel use, eliminating associated greenhouse gas (GHG) emissions, by 2045.

1.1 Background

UCR comprises nearly 1,108 acres in the city of Riverside. Bisected by the Interstate 215 (I-215) and State Route 60 freeways, nearly half of the total area is devoted to agricultural teaching and research fields. East Campus, occupying approximately 604 acres, comprises the core cluster of academic buildings and campus services. UCR hosts more than 26,000 students, and future enrollment goal of 35,000 students by 2035, a 35 percent increase over the next decade.

Utility service for a network of key buildings in East Campus is provided by the campus-owned and -operated Central Utility Plant (CUP), which operates via combustion of natural gas. In any given year, 80 percent of Scope 1 GHG emissions from UCR are attributable to this utility plant.

1.1.1 Decarbonization Goals for UC

In 2024, UC updated its *Sustainable Practices Policy*[1] and adopted new, stronger climate actions goals. The new goals[2] serve to accelerate the transition away from fossil fuel use at all UC campuses and academic health centers by committing to:

- Prioritizing reductions of direct (i.e., Scope 1) GHG emissions at all UC locations;
- Limiting the use of carbon offsets;
- Incorporating transportation and waste-related emissions in UC's reduction targets;
- Tailoring decarbonization plans to the specific circumstances of UC locations;
- Reflecting the values of anti-racism, diversity, equity, and inclusion in UC climate actions; and
- Aligning the UC's climate action plans with the net-zero carbon pollution goals set by the state of California.

Additionally, the UC *Framework for Incorporating Environmental and Climate Justice into Climate Action*[3] requires each campus to consider how decarbonization actions impact disadvantaged communities, both on and off campus. The framework (discussed in more detail in Section 1.5) includes environmental and climate justice principles, evaluation questions, best practices, and guidance on equity metrics.

1.1.2 Regional Drivers and Regulatory Context

UC campus decarbonization and climate actions plans are to be aligned with applicable state, county, and city policies, notably including:

- Achieving carbon neutrality by reducing anthropogenic GHG emissions to 85 percent below 1990 levels by 2045 (Scoping Plan Update, California Assembly Bill 32, 2022);
- Requiring 100 percent of electric retail sales to end-use customers to be generated from renewable and zero-carbon resources by 2045 (California Senate Bill 100, 2018);
- Following Energy Code that sets building energy efficiency requirements for new and existing buildings (California Building Code-Title 24, Part 6, most recent year available);
- Promoting sustainable construction practices, including energy, through CALGreen (California Building Code-Title 24, Part 11, most recent year available);
- Reducing GHG emissions 80 percent below 1990 levels by 2050 (Riverside County Climate Action Plan, 2019); and
- Implementing measures to achieve carbon neutrality by 2040 (Envision Riverside 2025 Strategic Plan, 2020).

Photo Credit: University of California, Riverside.

1 University of California. 2024. Sustainable Practices Policy: All Campuses, Health Locations, and the Lawrence Berkeley National Laboratory. April 10. Available online at: https://policy.ucop.edu/doc/3100155/SustainablePractices.
2 University of California. 2023. UC's New Climate Action Goals: Frequently Asked Questions. UC Capital Programs, Energy and Sustainability. July 20. Available online at: https://www.universityofcalifornia.edu/sites/default/files/2023-07/uc-new-climate-action-goals-faq-final.pdf.
3 University of California. 2022. UC's A Framework for Incorporating Environmental & Climate Justice into Climate Action. April 21. Available online at: https://www.ucop.edu/leading-on-climate/_files/uc-framework-for-ejcj-in-climate-action_final-4.21.22.pdf.


Photo Credit: University of California, Riverside.

1.1.3 Alignment with Existing UC Riverside Plans

This study was conducted considering the following existing UCR strategic plans, as listed below.

UCR Strategic Plan (2023)[4]
This plan establishes the following Pillars of Our Mission:

- Distinctive, transformative research and scholarship;
- A rigorous, engaging, and empowering learning environment;
- A welcoming, inclusive, and collaborative community;
- Advancement of the public good; and
- Sustainability for climate action and environmental justice.

UCR Long Range Development Plan (2021)[5]
This plan defines guiding planning principles, including:

- Recognizing that stewardship is both an environmental and fiscal imperative;
- Creating value by leveraging existing campus buildings and infrastructure; and
- Reducing demand for energy and pursuing carbon-neutral energy sources.

1.1.4 Previous Studies

This study considered previously conducted energy assessments at UCR, notably including:

- Phase 2 Tier II Energy Assessment (2023);
- Tier II Energy Assessment for Bio Sciences, Boyce Hall, Chemical Sciences, Science Labs, Genomic, Chung Hall, and Webber Buildings (2022); and
- Southern California Gas Company (SoCalGas) Project Feasibility Study UCR Central Plant (2019).

1.2 Purpose

In direct response to the 2024 update to the UC Sustainable Practices Policy and newly adopted climate action goals, state-funded studies were commissioned for each UC campus to inform campus-specific decarbonization strategies, emission targets, and climate action planning.

Study outputs are presented across five deliverables, described below:

- Deliverable 1 – Strategy to Achieve 90 Percent Reduction in Scope 1 Emissions by 2045
- Deliverable 2 – Total and Operation Cost Analysis
- Deliverable 3 – Climate Justice and Equity
- Deliverable 4 – Climate Action Planning Considerations
- Deliverable 5 – Collaborative Involvement for Climate Action and Sustainability

This document comprises Deliverables 1 and 2.

Primary goal of this study:

Develop strategies (i.e., technical solutions) to achieve at least a 90 percent reduction in Scope 1 emissions by no later than calendar year (CY) 2045 relative to a 2019 baseline year.

1.3 Scope

This study comprises identification and analysis of direct actions to address the Scope 1 emissions of UCR, a majority of which are attributable to operations of the CUP.

Assumptions

- The maturity, commercial availability, and efficacy of decarbonization technologies are rapidly evolving.
- Analysis was conducted with the best-available present-day understanding of considered technologies. This analysis excludes speculation of the performance or availability of future technologies.
- Alignment with existing campus planning and guidance documents and policies was observed.
- Alignment with applicable existing federal, state, regional, and local policies and plans was observed.
- No specific decarbonization technology was excluded or exclusively considered in this study.
- All assumptions provided by the UC Office of the President (April 24, 2024) were observed.

Exclusions

- Analysis of building-level energy conservation measures (i.e., energy efficiency measures) was excluded from this study. However, a rate of energy efficiency improvement was considered in the development of campus loads for future projections.
- Analysis of campus vehicle fleet transitions (i.e., associated Scope 1 emissions and power demand from zero-emission alternatives) were excluded from this study.
- Analysis of energy procurement (i.e., Scope 2 GHG emissions and onsite renewable power generation feasibility and expansion) was excluded from this study.
- Analysis of Scope 3 GHG emissions was excluded from this study.
- Analysis of fugitive emissions (i.e., unintended release of pollutant gases, such as natural gas leaks or industrial leaks) was excluded from this study.


Photo Credit: University of California, Riverside.

4 University of California, Riverside. 2024. UC Riverside Strategic Plan. UCR 2030. Available online at: https://strategicplan.ucr.edu/.
5 University of California, Riverside. 2021. UC Riverside Long Range Development Plan. November. Available online at: https://lrdp.ucr.edu/.

1.4 Methodology

This study of campus decarbonization was conducted via a four-stage collaborative energy planning process, as depicted in **Figure 1-1**.

1.4.1 Where Are You Today?

Developing strategies for achieving decarbonization goals begins with a comprehensive understanding of the baseline energy use and GHG emission profiles of the campus. This analysis is conducted via methodical data collection and review, onsite facility and equipment inspections, and stakeholder engagement and is summarized in Sections 2.1 through 2.3 of this study.

1.4.2 Where Are You Headed?

After establishing a baseline profile of the campus, the next step is to develop a clear vision of future energy service requirements relative to climate action and GHG emission reduction goals. This includes developing models of future energy use, considering future enrollment, cost escalation, changing regional and local climate, and specific physical development projects, among other topics. This analysis includes collaboration with existing system operators, campus planners, and the utility service provider, among others.

1.4.3 Where Are Your Opportunities?

A comprehensive analysis of decarbonization technologies is conducted. Equity, operability, spatial compatibility, technical maturity, and financial viability, among other factors, are fully considered. This includes complete reimagining of the Central and Satellite Utility Plants with different decarbonization technologies, as presented in Section 3 of this study.

1.4.4 How Could You Get There?

The final phase explores implementation scenarios of decarbonization technologies, including phasing and funding strategies. Engineering concepts are refined and presented with enablement criteria and limitations identified. Of these, a recommended decarbonization pathway is recognized. Implementation scenarios are presented in Section 4 of this study, with additional detail available in the appendices.

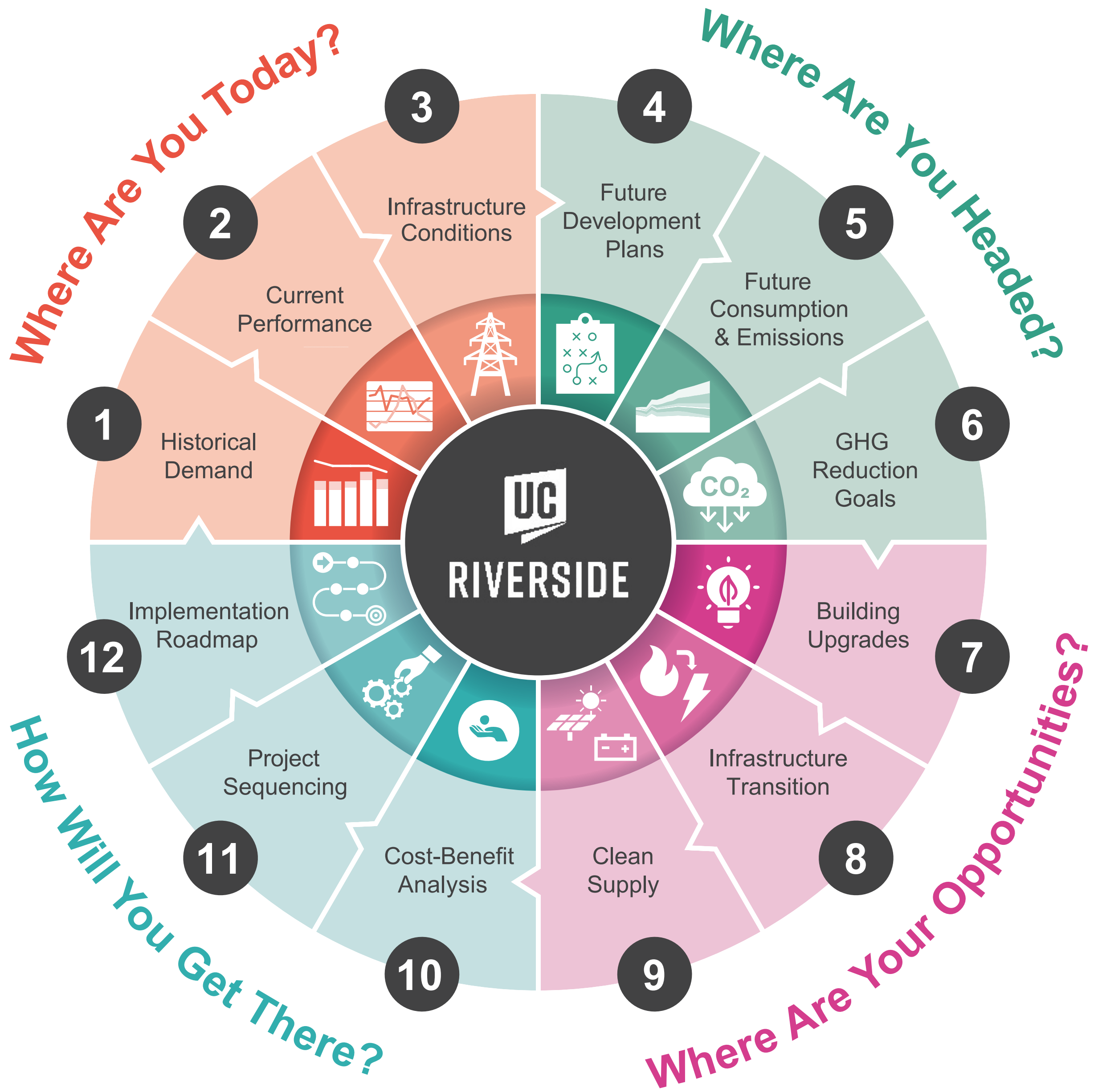


Figure 1-1: Planning Methodology

1.5 Environmental and Climate Justice

The implementation of equitable climate solutions at UCR would require an interdisciplinary, multi-stakeholder, and multi-sectoral approach. This report, which focuses on the feasibility of infrastructure scenarios on campus is one of several actions, which should be read in tandem with Deliverables 3, 4, and 5, all of which would need to be considered to achieve this goal.

1.5.1 Procedural Justice and Community Power

Stakeholder engagement and the involvement of community members most impacted by climate change is and should be an important part of the continued development and implementation of this study and related climate action planning. Engagement conducted for Deliverables 1, 2, 3, 4, and 5 during the course of this study constitute "Inform," "Consult," "Involve," and "Collaborate" per the International Association for Public Participation Spectrum of Public Participation.[6]

Specifically for this study, the core advisory team includes representatives from the Academic Senate, Facilities Services, Office of Sustainability, Planning, Budget and Administration, Planning, and Design and Construction. The core advisory team provided suggestions on external events, as well as organizations and stakeholders to involve in the process. Students, faculty, and staff were engaged during three technical workshops, as well as in person and through virtual events, including the following:

- Workshops: Establishing the Baseline, Pathways to Decarbonization, Phasing
- Campus Events: Inland Southern California Climate Collaborative (ISC3) Culture and Climate Action Fair, UCR Sustainability Showcase and Flea Market, UCR Academic Sustainability Retreat, UCR Student Leader Dinner and Discussion
- Virtual Meetings: UCR Academic Senate Sustainability Committee Meetings, ISC3 General Members Meeting

Notably, Deliverable 4 outlines a comprehensive framework for equitable climate action planning on campus and offers greater opportunities for engagement with frontline and marginalized communities.

1.5.2 Restorative and Distributive Justice

The principles of restorative and distributive justice refer to the consideration of benefits and burdens that result from climate solutions and the commitment to protect those who are most impacted by climate change and the transition away from fossil fuels. Section 4 of this study outlines Environmental Justice and Equity metrics that have been integrated into the technical analysis of infrastructure scenarios.

Deliverable 3 evaluates economic and Workforce Equity based on potential transition related job impacts. Deliverable 4 provides suggested equity metrics for climate action planning.

6 International Association for Public Participation. 2018. IAP2's Spectrum of Public Participation. Available online at: https://www.iap2.org/page/pillars

2. Campus Performance and Infrastructure

Successful decarbonization cannot be achieved without a detailed understanding of campus energy infrastructure and historical usage trends. This section presents an analysis of existing district and building energy systems, which serve as a baseline against which to evaluate decarbonization scenarios.

2.1 Campus Buildings Overview

UC Citrus Experiment Station, the predecessor to UCR, was founded in 1907 to spearhead research in biological pest control and the use of growth regulators. The first undergraduate institution at the site was established as the College of Letters and Science in 1954, later becoming the College of Humanities, Arts and Social Sciences (CHASS). The institution grew to become a general campus of the UC System in 1959. Early traces of original infrastructure can be dated back to as early as the start of the 1900s; most of the campus and its utility spines emerged around the mid-1900s, approximately 70 years ago.

Campus facilities are recorded as far back as 1916; these include South Anderson Hall (P5357) and The Barn (P5358). Over time, UCR has made major renovations on antiquated structures and has built new facilities. Recent examples of recently built buildings include the School of Medicine Education Building 2 and Student Health and Counseling Center, and future buildings, such as North District Phase 2 Student Housing, Undergraduate Teaching and Learning Facility, and OASIS Park, which will all support the campus' research along with academic and student growth. UCR has grown to encompass various types of buildings, predominantly learning spaces, research facilities, accommodations, various greenhouses, and storage spaces.

UCR has changed in many ways through its history, and the campus has shifted its functionalities to match the academic evolution since the early 1900s, resulting in variations in the ways electricity and natural gas are used. For the purposes of this study, 2019 is considered the baseline for comparison and performance tracking per the 2024 UC Sustainable Practices Policy until the full decarbonization goal year.

2.2 Existing Performance

It is important to understand UCR's baseline energy performance, which sets a "starting point" for Scope 1 emissions; and how the campus uses its electricity and natural gas resources.

2.2.1 Energy Consumption

UCR purchased 97,980 million British thermal units (MMBtu) (979,800 therms) of natural gas from SoCalGas and 366,867 MMBtu (3,668,670 therms) from Shell Energy North America (Shell Energy), for a total of 464,847 MMBtu (4,648,470 therms) of natural gas used on campus in 2019. In the same year, UCR purchased 391,046 MMBtu (114,609 megawatt-hours) of electricity from Riverside Public Utilities.

2.2.2 Carbon Emissions

The 2019 campus electricity consumption was equivalent to 44,640 MTCO2e of Scope 2 emissions. Natural gas emissions on campus accounted for 90% (24,670 MTCO2e) of UCR's total Scope 1 emissions in 2019 (27,547 MTCO2e). Thus, the focus of the study is to decarbonize all natural gas sources. The remaining 10% of Scope 1 emissions include vehicle fleet emissions (6%), refrigerant leakages (4%), and other stationary diesel combustion emissions (0.5%) but are not analyzed in this study for further actions at this time.[7] A focus on decarbonization of all campus natural gas use positions UCR to reach the 90% reduction of Scope 1 emissions target.

Major contributors to natural gas emissions include the boilers at the Central Utility Plant (CUP), boilers and kitchen ovens at Aberdeen-Inverness and Lothian Residence Halls, boilers at Pentland Hills Residence Hall, and other unidentified and unmetered combustion sources used for comfort heating and cooking appliances on campus.[8]

Figure 2-1 organizes the natural gas and electricity consumption values and associated costs and emissions related to each resource use. Figure 2-2 translates Figure 2-1 into a proportional breakdown of the amount of electricity versus natural gas that is consumed on campus and shows how natural gas is primarily used.

2.2.3 Energy Costs

The price of electricity has increased at an average rate of 3.5 percent per year since 2019, but natural gas price trends have been more volatile during the same term.

Natural Gas	Electricity	Total Energy
Utility Consumption 464,847 MMBtu (4,648,470 therms)	Utility Consumption 391,046 MMBtu (114,609 MWh)	Utility Consumption 855,893 MMBtu
Utility Costs $3 Mil	Utility Costs $12 Mil	Utility Costs $15 Mil
Natural Gas Emissions 24,670 MTCO2e	Electricity Emissions 44,640 MTCO2e	Utility Emissions 69,310 MTCO2e

Notes:
MMBtu = million British thermal units; MTCO2e = metric tons carbon dioxide equivalent; MWh = megawatt-hours

Figure 2-1: Baseline (2019) Utility Consumption and Emissions

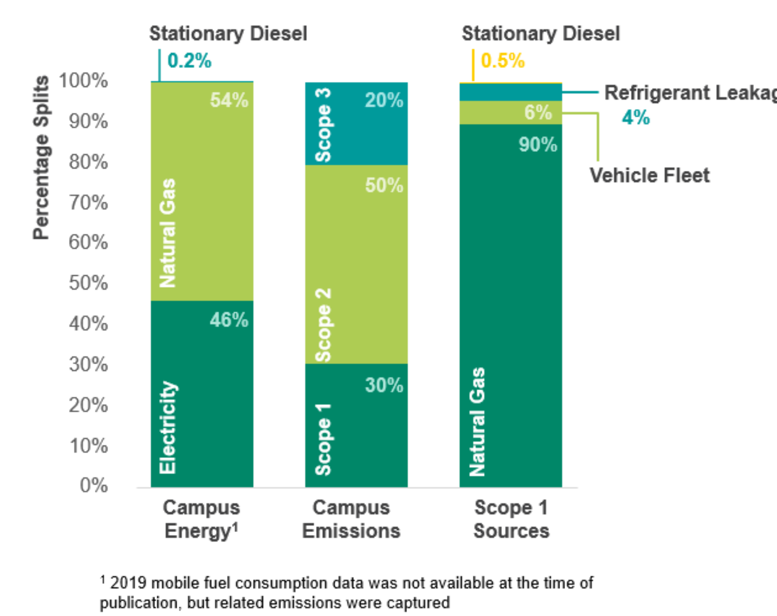


Figure 2-2: Resource Use Breakdown

7 University of California, Riverside. 2023. UCR's Climate Change Working Group database.
8 United States Environmental Protection Agency, 2020. Cal e-GGRY. GHG Annual CY 2019 Summary Report for University of California, Riverside. March 26.

2.3 Infrastructure Systems

To support UCR's operations and infrastructure, Riverside Public Utilities (RPU) and SoCalGas deliver electricity, water, and natural gas utilities to the campus. In addition to direct utility building connections, the CUP and Satellite Plant (SAT) play a large role in producing chilled water, steam, compressed air, and vacuum air to serve campus needs. Additionally, three thermal energy storage (TES) tanks are used to store and manage excess chilled water generated during off-peak hours, when electricity demand and rates are lower, for later use during peak demand periods.

Approximately 90 percent (24,670 $MTCO_2e$) of Scope 1 emissions is from natural gas use related to steam generation and building heating and processes. Gas is primarily used by boilers at the CUP, boilers at Aberdeen-Inverness Residence Hall, Lothian Residence Hall, and Pentland Hills Residence Hall; and by cooking activities at the Highlander Union Building (HUB), Aberdeen-Inverness Residence Hall, and Lothian Residence Hall. CUP boilers make up 76 percent of natural gas use. UCR has additional unidentified or unmetered combustion sources related to comfort heating and cooking appliances that also contribute to Scope 1 emissions.[9]

Section 2.3 summarizes the conditions and configurations of the electrical, natural gas, steam, chilled water, and centralized utility plants on the campus. The section also covers findings from onsite assessments and discussions with key stakeholders.

2.3.1 Electrical

RPU supplies the campus with 12.47-kilovolt (kV) service to UCR's main tie-in connection point at the main switchgear through two 27 million volt-ampere (MVA) transformers (for a total design capacity of 54 MVA). The entire campus,except for North District developments, are supported by the primary supply feeders and switchgear located between the borders of West Campus and East (or Main) Campus, along I-215. North District housing is served by a feeder from RPU's Hunter Substation.

From the main switchgear, some of the 12.47 kV electricity service is stepped down to 4.16 kV for distribution throughout the campus. Some uses on campus directly receive 12.47 kV electricity, such as the housing areas north and northeast of East Campus. Both systems traverse the campus through underground duct banks and tunnel vaults that consolidate much of the campus' utility networks. The 4.16 kV system can now be back-fed from the 12.47 kV service; these two systems were previously separate services.

Distribution circuits from the switchgear are arranged in an A/B configuration to provide redundant supply to buildings. Circuit 1 A/B primarily supplies buildings in the south and southeast of East Campus and the CUP. Circuit 2 A/B serves buildings in the northeast of East Campus. Circuit 3 A/B supplies buildings in the northwest, and Circuit 4 A/B provides power to the solar field, central East Campus, and the SAT. Figure 2-3 is an overview of power flow from supply sources to end users, and Figure 2-4 is a conceptual infrastructure layout.

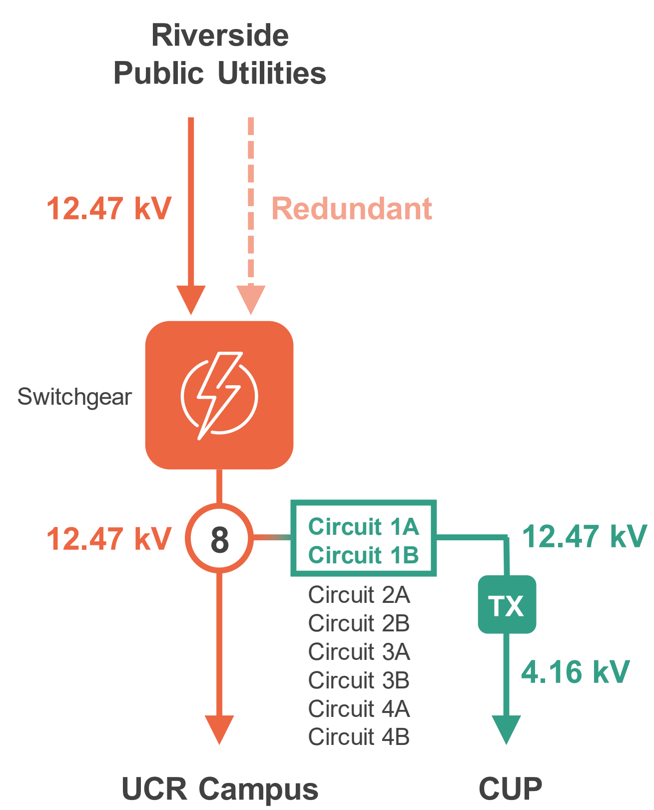


Figure 2-3: Electricity Supply Diagram

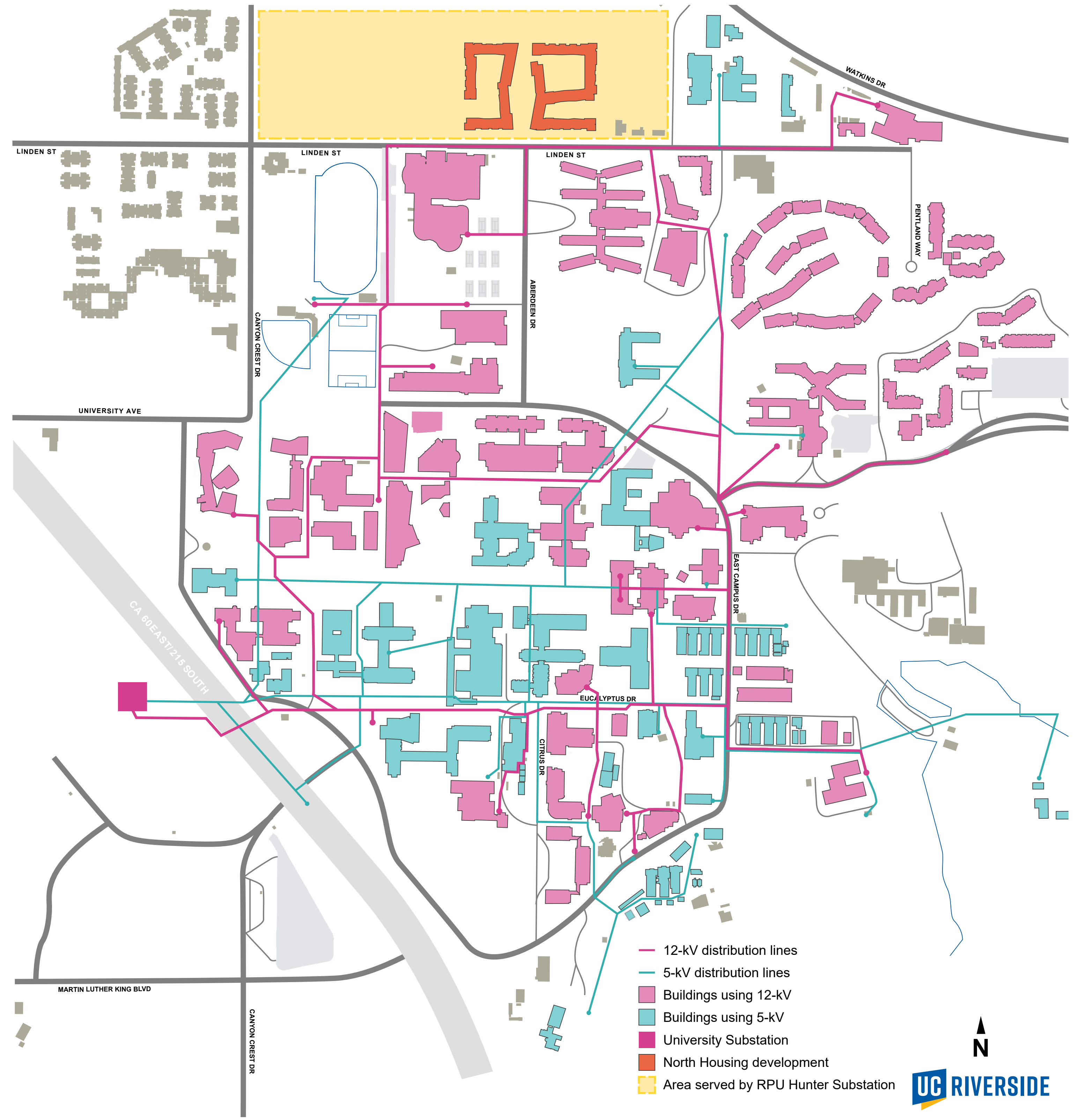


Figure 2-4: Electrical Infrastructure Layout

9 United States Environmental Protection Agency, 2020. Cal e-GGRY.GHG Annual CY 2019 Summary Report for University of California, Riverside. March 26.

A 2020 load study report[10] showed that minimal capacity remains on the 12.47 kV service. At the time of the study, the maximum metered daily coincident demand was shown to be approximately 32 MVA; the average campus demand was about 22 MVA. Each RPU transformer at the switchgear is rated for 27 MVA, meaning that a single transformer is not able to support the campus' maximum electrical demand but can support an average load. According to facility representatives at UCR, the ideal scenario would be to have each circuit loaded at no more than 50 percent of its individual capacity; however, this allocation is not possible with the current loading on the system.

In discussions between UCR and RPU, multiple options were identified for increasing campus supply capacity with a new 12.47 kV feeder, including adding transformers at University Substation (current main switchgear) or connecting to new feeders to the east of campus. One of these options could be required in the coming years to facilitate any growth on campus without compromising supply integrity, and to foster power resilience.

UCR receives most of its electricity supply from RPU; however, the campus owns rooftop and carport solar photovoltaic systems distributed throughout the campus, such as at Parking Lot 30 and School of Medicine Education Building 2. Combined, the renewable systems have a total capacity of approximately 8,300 kW that produced about 11.4 MWh of electricity in 2023. UCR plans to continue installations of solar photovoltaic systems, which would further help increase power resilience.

2.3.2 Natural Gas

Natural gas is supplied to the East/Main Campus area through a main service line; housing areas are served by a separate gas service (not from the main). The 100-pound-per-square-inch (PSI) natural gas main starts at the CUP and is then distributed underground through tunnels with local meters or regulators at select facilities that use natural gas. Other standalone buildings outside the East/Main Campus area that use gas have direct connections with the utility provider and receive low-pressure gas. About 20 buildings are connected to the main service line from the CUP, and fewer than 10 buildings in the East/Main Campus receive gas directly from the provider. Figure 2-5 provides an overview of the

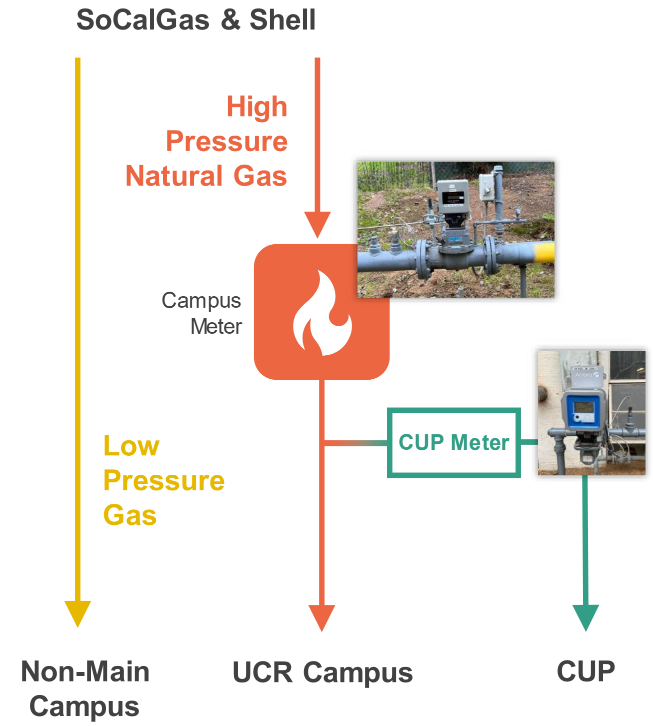


Figure 2-5: Natural Gas Supply Diagram

natural gas supply sources and supply pathways until end uses; Figure 2-6 is a conceptual infrastructure layout of the gas system.

Natural gas infrastructure is owned by SoCalGas, and natural gas is purchased from both SoCalGas (21 percent) and Shell (79 percent). Starting in summer 2024, UCR will purchase natural gas through the University of California Office of the President (UCOP) instead of Shell, and SoCalGas will remain as the commodity distributor. Primary uses of natural gas at UCR include gas-fired boilers at the CUP for steam production; direct building uses for laboratories or similar setups; and decentralized heating and process loads, especially for housing types that include domestic hot water heating and other processes like cooking in kitchens.

Referring to the energy consumption in Section 2.2, 464,847 MMBtu of natural gas is consumed on site. 349,527 MMBtu (76 percent of total gas) is consumed by the CUP. Housing is metered to use 19,934 MMBtu (4 percent) of gas, and the remaining 91,386 MMBtu (20 percent) is for process (e.g., labs) and other unspecified uses. The GHG Annual CY 2019 Summary Report presents a reporting discrepancy between the total gas purchases and breakdown of gas uses. The report notes that 4,000 MMBtu was unaccounted for and could represent gas leaks or unmetered uses.

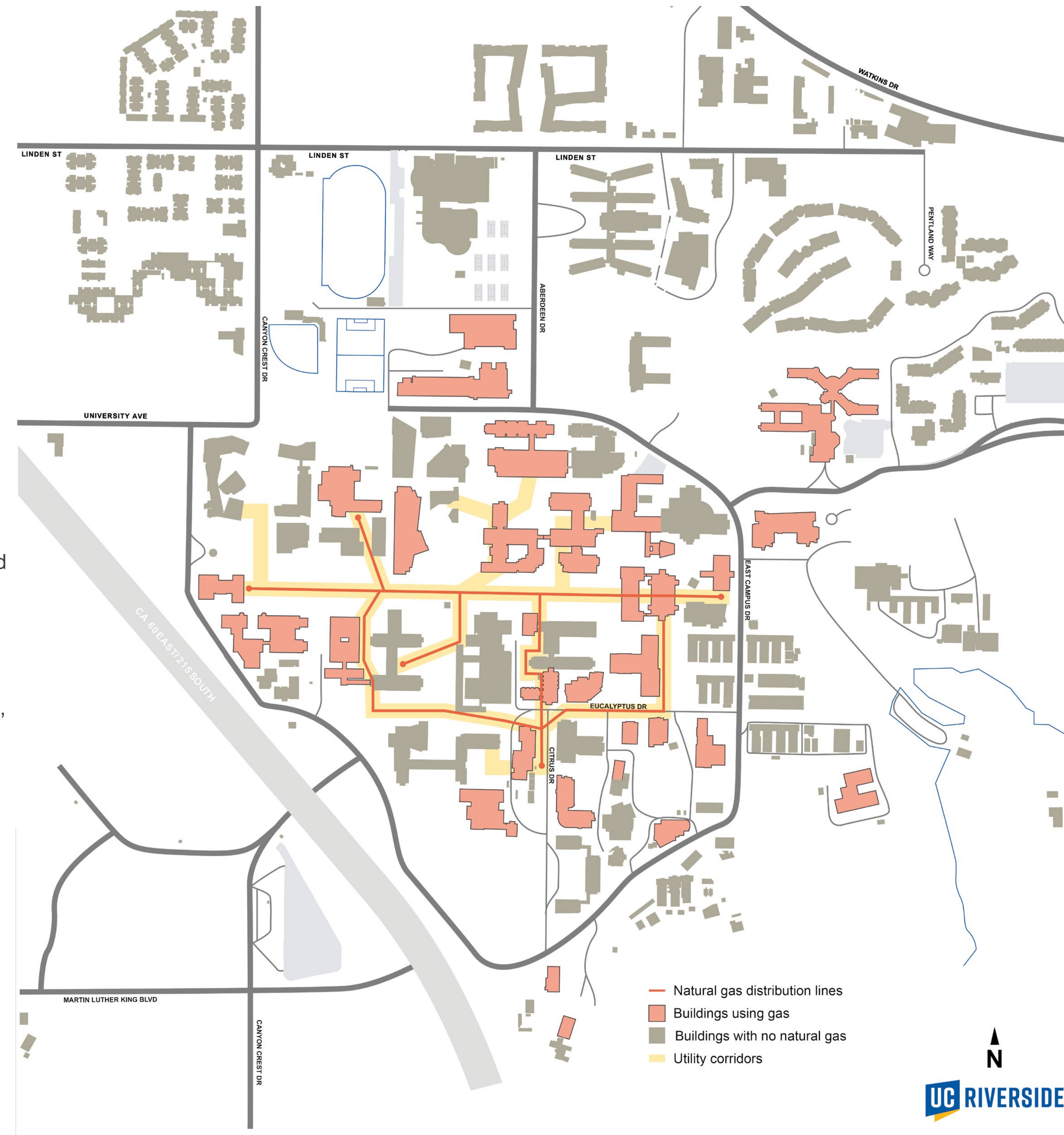


Figure 2-6: Natural Gas Infrastructure Map

10 Salas O'Brien. 2020. Power System Analysis – Final. Report Prepared for UC Riverside. December

2.3.3 Steam

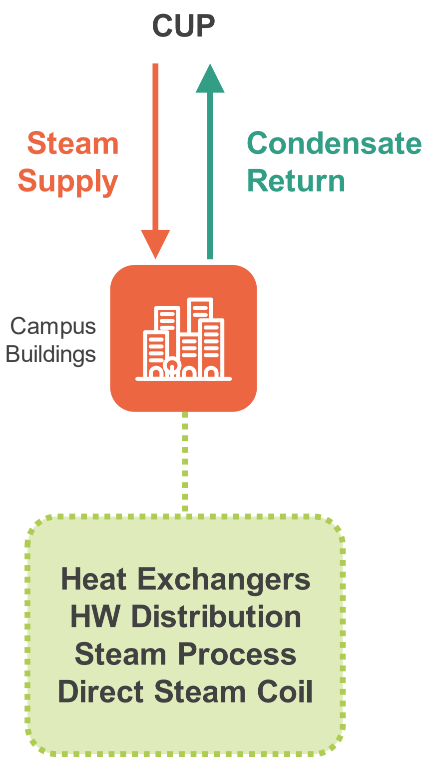


Figure 2-7: Steam Supply Diagram

The campus' thermal heating infrastructure is predominantly on a steam network. Steam is produced at the CUP and is distributed through piping in the undergrounded utility tunnels at a minimum of 85 PSI. Condensate from the steam distribution system is collected from buildings and pumped back to the CUP for re-introduction into the system, and roughly 80 percent of steam is recovered as condensate back at the plant. The existing capacity of the steam system is sufficient to meet the campus' existing peak heating demand. Steam distribution pipes are as old as 1950s and beyond their design life, but with continued maintenance and repairs, they are generally in adequate condition and are insulated (with some additions needed).

Approximately 50 buildings on campus (~13 percent of all buildings)—excluding greenhouses—are connected to the CUP and receiving steam. Some of UCR's many greenhouses and greenhouse-type buildings use the CUP's steam for heating and others are all-electric. Buildings receiving steam account for more than 75 percent of the total gas use on campus.

Figure 2-7 and Figure 2-8 provide a simple overview of the steam distribution system and photographs of the system, and Figure 2-9 presents a conceptual map of the campus steam distribution system.

Based on available trend data, it is estimated that 70 percent is useful heat for space heating, hot water and humidification; 10 percent is for process steam; and 20 percent results from losses.

Figure 2-8: Photographs of the Central Utility Plant

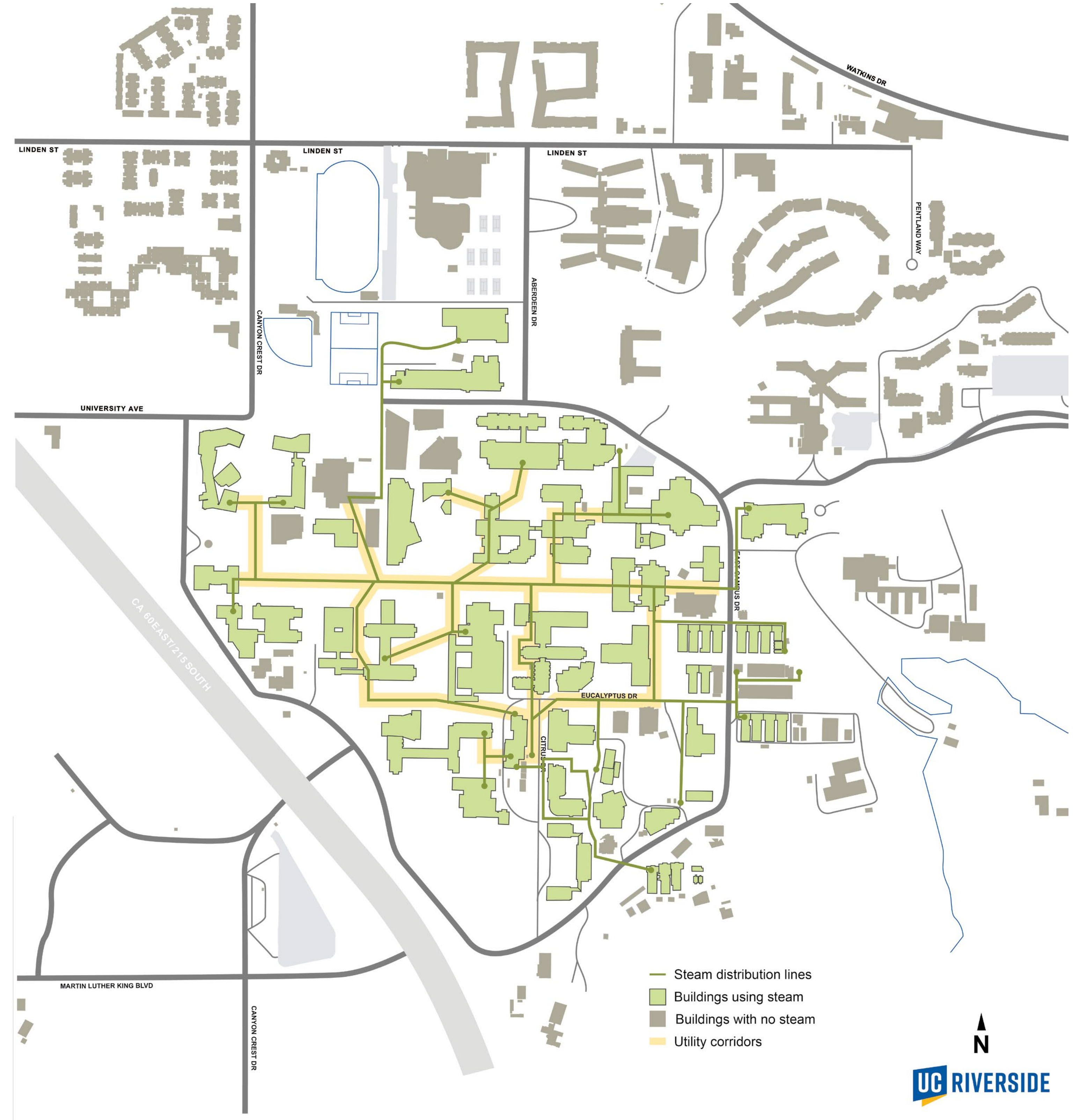


Figure 2-9: Steam Infrastructure Map

2.3.4 Chilled Water

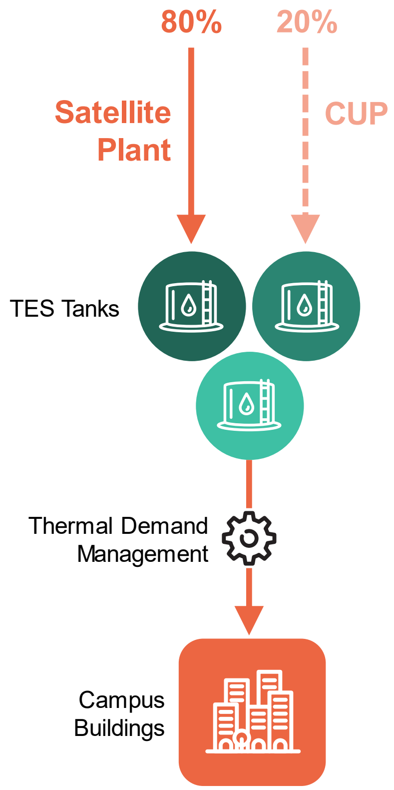


Figure 2-10: Chilled Water Supply Diagram

Chilled water is distributed around the campus from the CUP and SAT through direct buried lines or tunnels to meet the cooling demands of connected buildings. The SAT serves about 80 percent of the campus' cooling needs using the CUP as supplemental supply, and excess cooling gets stored in the three TES tanks for thermal demand management. Chilled water distribution pumps vary in speed based on a single differential pressure transmitter near Bourns Hall. UCR is in the process of implementing more transmitters to enable more efficient operations of the pumps. **Figure 2-10** and **Figure 2-11** provide a simple overview of the chilled water distribution system and photographs of the system, and **Figure 2-12** presents a conceptual map of the campus chilled water distribution system.

Capacities at the CUP and SAT adequately serve the campus' cooling demand. However, operational limitations exist at the CUP, including lack of isolation values or control valves, and capacity losses due to the series configuration of chillers. The electric chillers are required to be connected in series to reach a supply temperature of 38 degrees Fahrenheit (°F), making the system inefficient.

Currently, about 45 buildings in the East/Main Campus area are connected to the chilled water distribution loop. Standalone buildings not receiving central chilled water rely predominantly on direct expansion units for space cooling. Student Success Center was the first building on campus to pilot the use of air source heat pumps (ASHPs), following the School of Medicine Education Building 2.

The chilled water network is the most expansive thermal network, compared to those for natural gas and steam, extending as far north to the Student Recreation Center and as far south to the southern most TES tank.

Figure 2-11: Chilled Water Piping in Tunnels

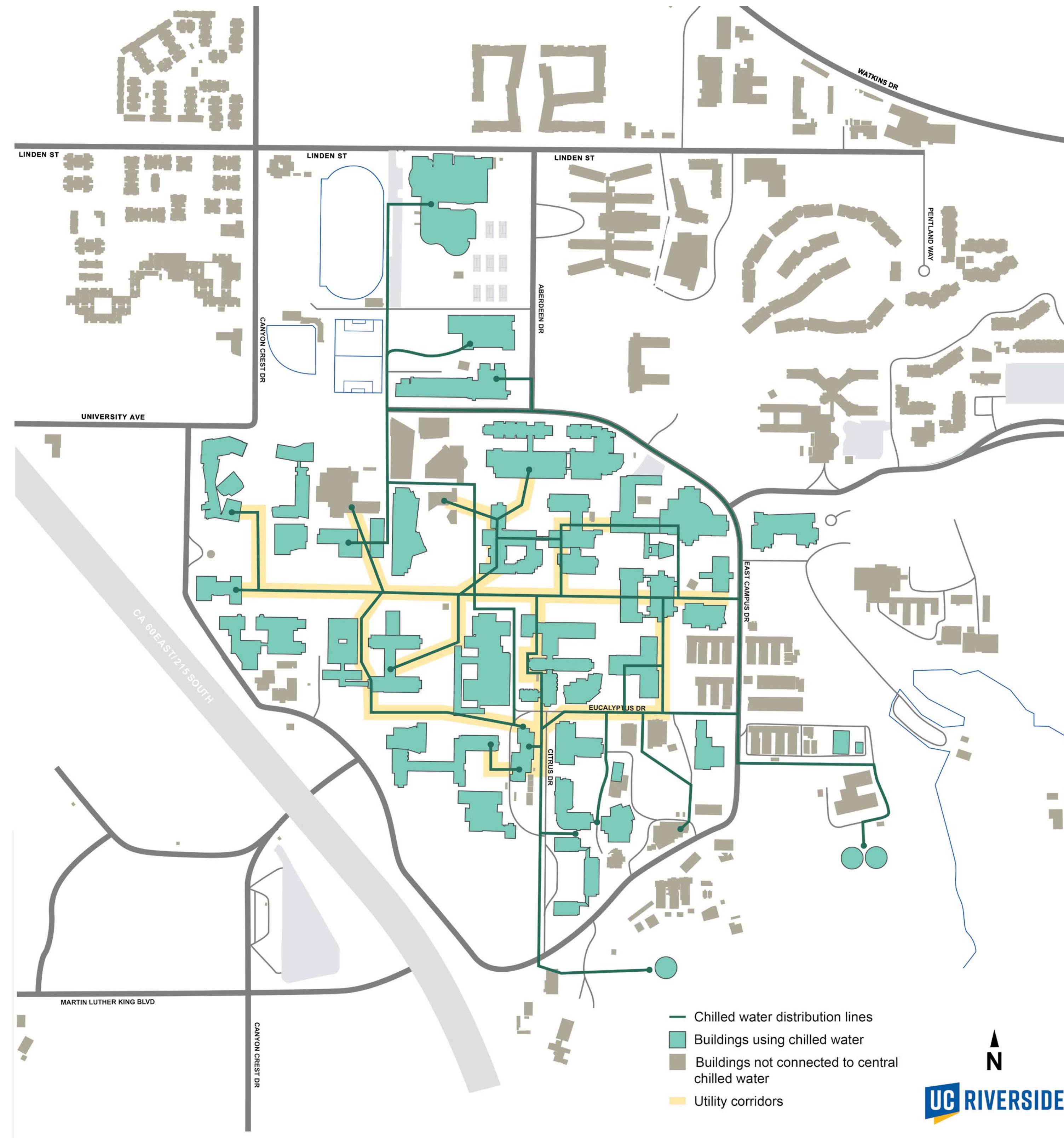


Figure 2-12: Chilled Water Distribution Map

2.3.5 Central Utility Plant and Satellite Plant

The CUP produces chilled water, steam (with a condensate water return loop), compressed air, and vacuum air to serve campus needs. The SAT, approximately a quarter of a mile east of the CUP, provides most of the campus' chilled water needs. Three chilled water TES tanks with a total capacity of 7.6 million gallons are positioned south and southeast of East Campus. They serve to store and manage excess chilled water generated during off-peak hours, when electricity demand and rates are lower, for later use during peak demand periods.

The CUP and SAT have water-cooled chillers and cooling towers for chilled water production, and only the CUP has gas-fired boilers to support heating demands. Schematics of the layout of heating and cooling equipment at the CUP and SAT are provided in **Figure 2-13** and **Figure 2-14**. Overviews and descriptions of steam and chilled water distribution steam are provided in the following sections.

As seen in **Figure 2-13**, the CUP contains five water-cooled chillers, five cooling towers, four gas-fired boilers, and associated chilled and hot water distribution pumps. They have a total capacity of 6,255 tons. Three chillers are older than 25 years, and the 18-year-old chiller is at end of its design life. Chiller #2 the newest unit, is less than 10 years old. All five cooling towers were installed in 2000 making them 24 years old.

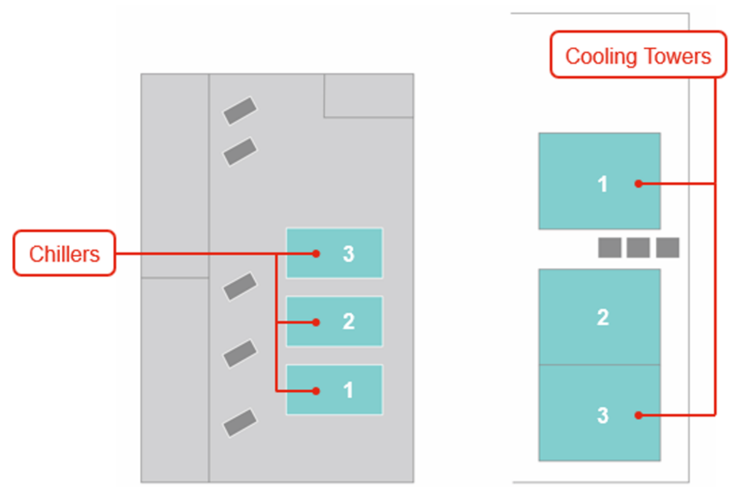


Figure 2-14: Satellite Plant Equipment Layout

On the heating side at the CUP, boilers #2 through #5 have a total heating capacity of 150,000 pounds per hour. The gas-fired boilers at the CUP may not be in any better condition than the cooling assets. Most of the boilers are nearing or exceeding 60 years old and were only modified to fit low-nitrogen-oxide burners in the mid-1980s (when they were 20 years old).

The chilled water and steam supply seem historically reliable, with little to no disruptions in distribution; however, the CUP infrastructure is at fatal risk of abrupt failures, given the age of equipment, planned growth from the Long Range Development Plan (LRDP), and increased global average surface temperature. In short, a heavier lift is to be expected from the cooling units in the future, and the campus currently relies on the existing, aging boilers to output all its heating energy.

As shown on **Figure 2-14**, the SAT has three water-cooled chillers and three cooling towers; these occupy a significantly smaller footprint than the CUP. The TES tanks are situated toward the southern end of the campus, two tanks are near the SAT, and the third (TES #3) cannot be operated independently in the summer during high cooling demand periods.

All three chillers have a cooling capacity of 2,000 tons and are 21 years old; the cooling towers are the same age as the chillers. Given that the average useful lifespan for such equipment is 25 years, the SAT's assets could also be included in a replacement timeline.

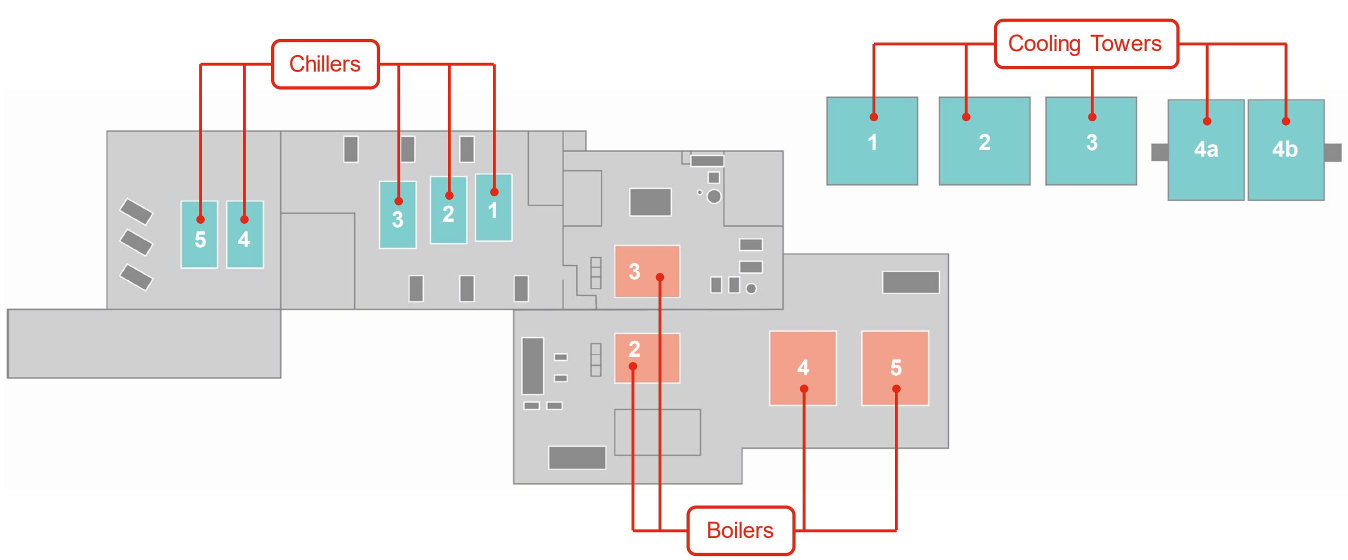


Figure 2-13: CUP Equipment Layout

Thermal Demand

Figure 2-15 illustrates the trend profiles for heating and cooling on the campus, showing the amounts and timing of use.

Heating and cooling peaks and troughs are driven by space conditioning needs; heating peaks during the winter months and cooling during the summer. The slight taper of heating use in December could be related to reduced student activity during semester transitions.

It is estimated that heating demand peaked around January 4, 2023, with a peak load estimated at 6,600 MMBtu. It is estimated that cooling demand peaked around August 17, 2023, with a peak load of 5,760 tons.

Controls

CUP and SAT operations and domestic water equipment are on Trane control systems. In contrast, building systems are controlled by various control platforms (e.g., Johnson Control, Alerton, Siemens, and Automated Logic) and across five different interfaces—ranging from more than 20 years to recent—but these are being consolidated. UCR has the controls infrastructure in place to measure trends, but the trend points are not established to collect data. In addition, across individual buildings, programmed control strategies are not consistent or optimally setup for specific building types. This makes it challenging to program standardized protocols, and increases the likelihood of future difficulties in acquiring replacement parts for the controls systems, maintenance, updates, etc. Building controls can be retro commissioned, optimized, and programmed for efficiency in building use and operation. Communication between the buildings can also be improved.

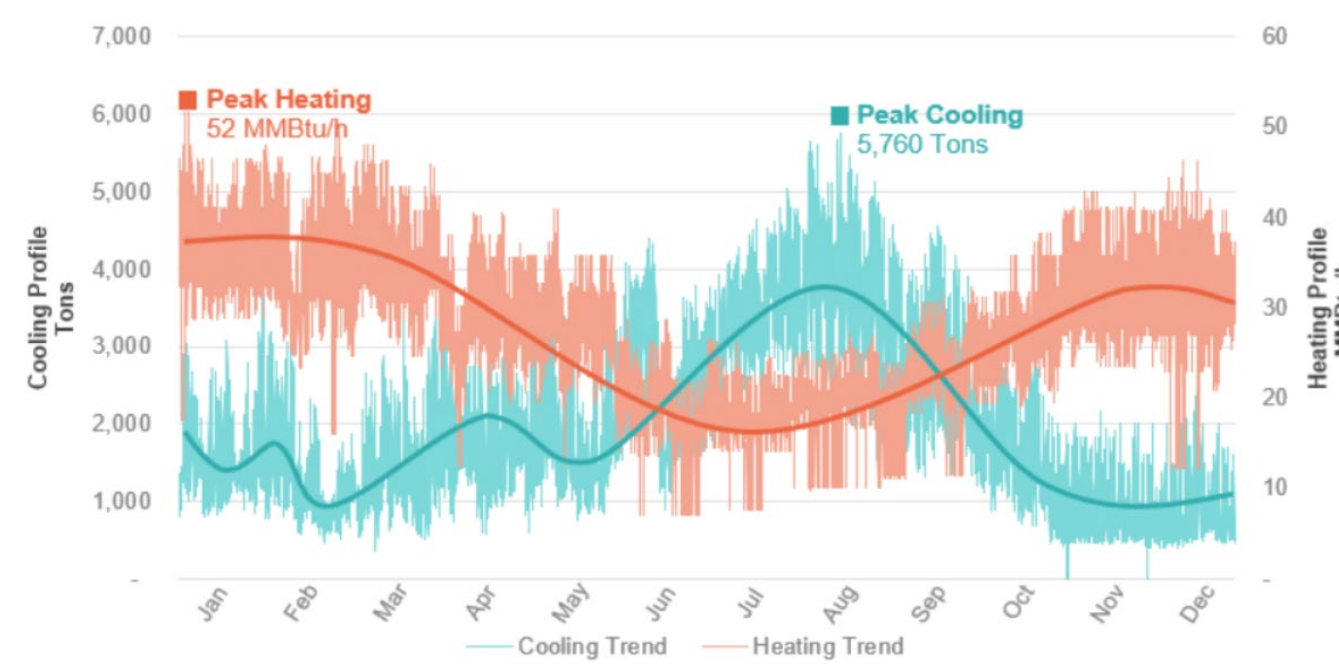


Figure 2-15: Existing Thermal Demand Profile (Monthly)

3. Decarbonization Strategies

This section presents analysis of technologies for replacement of the existing campus district and building energy systems, enabling decarbonization.

The technologies assessed fall under three main categories:

- **Centralized Hot Water Plant** – technologies suitable for a central plant that generate hot water; requires steam-to-hot-water infrastructure conversion
- **Centralized Steam Plant** – technologies suitable for a central plant that produce steam
- **Building Level Solutions** – technologies suitable at building scale

3.1 Technology Review and Considerations

The following feasibility factors were used to conduct a preliminary evaluation of technologies and eliminate those likely to be unfeasible for application at UCR in the timeline of this study. These factors include:

- **Technical Maturity and Market Readiness** – availability and reliability of technology; defined by NASA's Technology Readiness Levels[11]
- **Cost** – includes capital and operating expenses, including fuel purchase
- **Scale of Capacity** – considers whether the technology can deliver heat at a scale applicable for UCR
- **Scale of Disruption** – considers space requirements, scale, and duration of impact during implementation and operation
- **Ability to Reduce GHG** – includes Scope 1 and Scope 2 emissions; none were considered that could not contribute to the 90 percent Scope 1 reduction target

Technologies considered here are commercially at the time of this publication; this analysis excludes speculation of the performance or availability of future technologies. Through application of these evaluation factors, a list of 14 potentially applicable technologies was developed. These technologies are described on the following pages.

A holistic approach to decarbonization involves energy conservation and efficiency, fuel switching, and clean energy supply and storage. The campus should continue its investment in conservation measures to reduce its energy demand to both reduce operational costs and loads, allowing new equipment to be optimally sized. As conservation projects will continue to be implemented in the future (such as through the Carbon Insets Program[12]), the potential impact of energy efficiency (via sensitivity analysis) on project feasibility are considered in the strategic analysis.

3.2 Centralized Systems

Figure 3-1 presents two main decarbonization options for the CUP and their associated technologies. The first strategy focuses on the conversion from steam-to-hot-water heating systems across the campus. Reduction in temperature allows the use of more efficient technologies such as heat pumps and TES (illustrated as the blue decision flow). Individual buildings using steam for heating would have to replace existing heating coils and tertiary (building-level) pumps if the centralized system is converted to hot water. For process steam uses inside buildings, steam process equipment should be exchanged for local electric equivalents.

The second strategy is maintaining steam delivery and distribution across campus by using different steam supply technologies, with the option of pairing supply with high-temperature storage solutions (illustrated as the orange decision flow).

3.2.1 Conversion to Hot Water Systems

To facilitate the adoption of efficient and market-ready electric heating equipment, building heating supply temperatures on campus should be reduced to within the range of 110°F–180°F, with lower temperatures facilitating more efficient operations.

To maintain a centralized heating system operating at these temperatures the thermal network would be required to transition from a steam distribution system to a hot water distribution, network, impacting buildings and infrastructure campus wide.

Compared to the existing steam distribution system which has losses of between 15% and 25% on a given day, a hot water network typically experiences between 2% and 4%, a reduction of over 75%. Further savings are realized using heat pumps which move heat rather than generate heat and thus require a lot less energy than traditional heating systems. Heat pump conversions may be the most economical, most technically feasible, and most actionable zero-emission solution available at present. The following page summarizes the available heat pump technologies and TES.

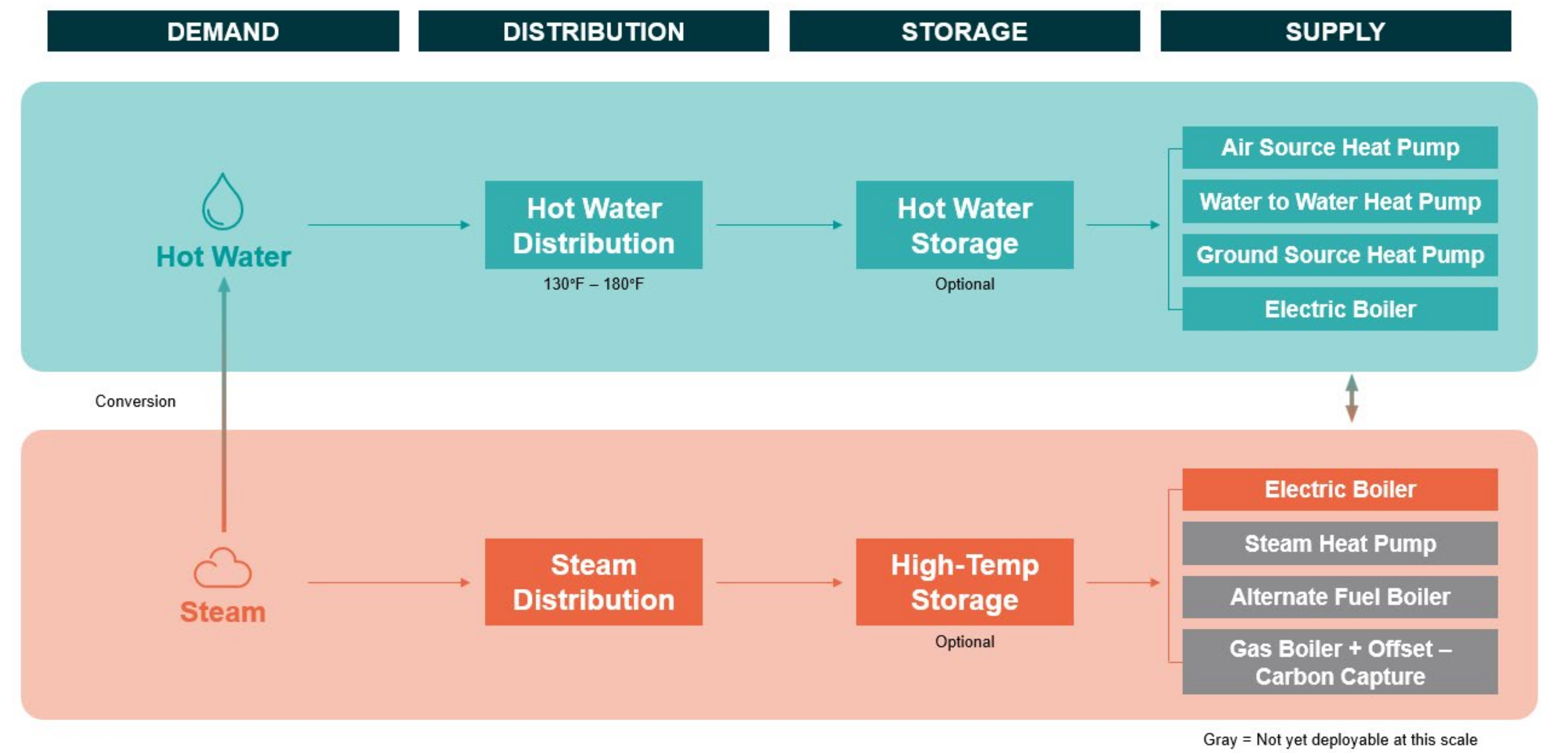


Figure 3-1: Summary of Centralized System Decarbonization Technologies

11 National Aeronautics and Space Administration. 2024. NASA's Technology Readiness Levels. Available online at: https://esto.nasa.gov/trl/.
12 The Carbon Insets program is another way to move the campus toward carbon neutrality by identifying and implementing energy saving projects that reduce greenhouse gas. In coordination with Riverside Public Utilities (RPU), UCR conducts an energy audit and evaluates energy savings projects. Some projects currently underway include updating building airflow and exhaust, insulation of steam pipes, and chilled water valves, which will help reduce close to 1100 metric tons of greenhouse gas.

Water-to-Water Heat Pumps

Water-to-water heat pumps (WWHPs), also known as heat recovery chillers and water source heat pumps (WSHP), produce chilled water and heating hot water simultaneously to maximize whole-system efficiency. These heat pumps are only applicable for simultaneous loads and have Coefficients of Performance (COPs) ranging from 5 to 11, depending on the hot water supply temperature needed. (Note that the lower the hot water supply temperature, the higher the COP.) These pumps require advanced controls to adjust operations based on demand fluctuations and outdoor conditions.

Figure 3-2: Example of WWHP Units[13]

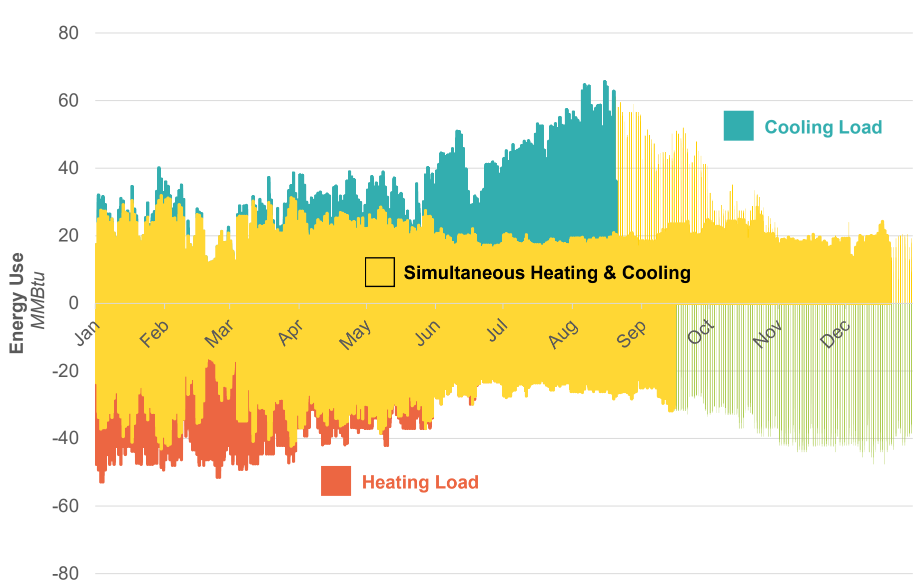


Figure 3-3: Heating, Cooling, and Simultaneous Loads

Water-to-Water heat pumps can supply heating and cooling simultaneously more than 70 percent of the time.

WWHPs allow a central plant to operate extremely efficiently when there is simultaneous heating and cooling demand. Assessment of the existing UCR hourly demand data (**Figure 3-3**) suggests that this occurs more than 70 percent of the time due to the rare combination of climate conditions and facility demand characteristics. This greatly enhances the feasibility of WWHPs at UCR to the extent that it would likely be the technology at the core of any centralized system.

Air Source Heat Pumps

ASHPs extract heat from ambient air and transfer it to the water through a refrigerant cycle. This process also works in reverse to provide cooling as needed. Efficiencies of ASHPs vary substantially depending on the surrounding climate. However, efficiency improves when the climate is warmer. The climate in Riverside allows an ASHP to operate at the upper end of its design efficiency. Under the worst weather conditions expected at UCR, the COP of an ASHP is approximately 2.5, which means the ASHP is 2.5 times more efficient than an electric boiler that would serve the same purpose. ASHPs at the CUP could primarily operate as heating sources and serve as backup cooling to the chillers at the SAT. Some ASHPs are already in place on campus at School of Medicine Education Building 2.

Considerations for ASHPs include space availability, noise considerations, new distribution piping, and advanced controls. Because ASHPs must be installed outside, where they are exposed, they have shorter equipment lifespans (15-20 years) than other heat pump equipment. **Figure 3-4** is an example of a modular ASHP.

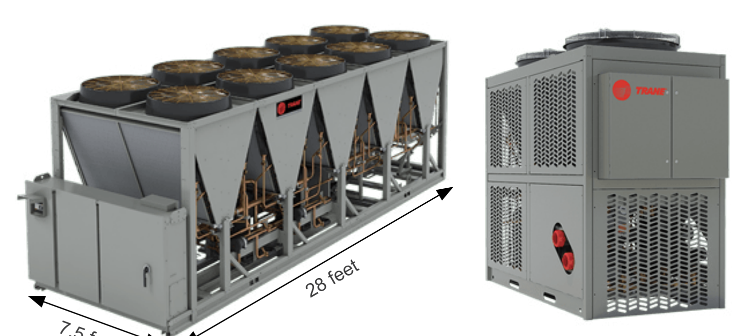


Figure 3-4: Example of Modular ASHP Units[14]

Thermal Energy Storage

TES technologies collect, store, and discharge heating and cooling energy for later reuse, which can help optimize energy costs, increase energy savings, and improve performance of heat pumps. UCR currently has three TES tanks that are part of the CUP and SAT chilled water loop and are charged during off-peak hours (**Figure 3-5**).

Figure 3-5: One of UCR's Three TES Tanks

Expanding the capacity of TES may be considered. The expansion of the hot water storage tank could enable increased simultaneous heating and cooling loads, thus improving heating and cooling efficiencies. With UCR having a higher cooling load than heating load, extracted heat can be redirected into the hot water TES. The use of heating storage may also allow reduced installed capacity of heat pumps at the CUP.

UCR's landscape terrain would have to be carefully considered when deciding appropriate locations for additional TES tanks. This may include any land use designations and permissible uses from the LRDP. Implementation costs are likely to be directly proportional to the level of effort to modify the terrain, such as blasting of rock, which was required for the previous TES tank install. Expansion of TES would require adequate space availability.

13 Stanford University. 2024. Sustainable Stanford: Stanford Energy System Innovations. Central Energy Facility. Available online at: https://sesi.stanford.edu/energy-systems/central-energy-facility.
14 Trane. 2023. What Is an Air-to-Water Heat Pump? Available online at: https://www.trane.com/commercial/north-america/us/en/products-systems/heat-pumps/air-to-water-heat-pumps.html.

3.2.2 Maintaining a Steam System

The technologies assessed under this category include current and future deployment potential. These technologies can be implemented while maintaining the existing steam infrastructure on campus but are far less efficient than hot water systems.

Electric Boilers

Conventional fossil fuel-fired boilers can be replaced with electric boilers (**Figure 3-6**) to eliminate onsite combustion emissions and maintain the production of steam. If an electric boiler were used to produce steam, it would have the least impact on downstream buildings and could be installed in the current location of the existing gas boilers, due to similar scale. However, installing electric boilers entails high utility costs and requires significant electrical infrastructure improvements to meet increased demand.

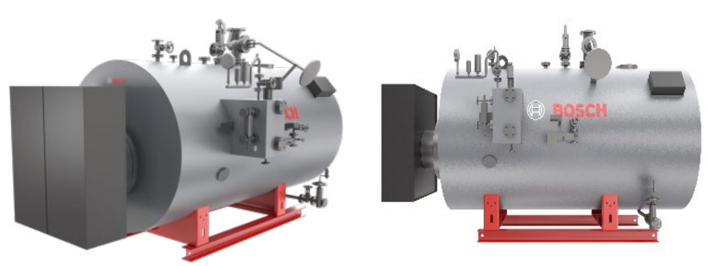


Figure 3-6: Example of Electric Steam Boilers[15]

Alternative Fuels

Alternative fuels, including hydrogen and biofuel, may serve as fossil fuel "offsets" in existing systems without impacting on-campus operations. Onsite fuels require storage and deliveries to campus, whereas natural gas is distributed through an extensive pipeline network.

Biofuels, such as biomethane, are fuels produced from biomass materials. The goal set in the 2024 UC Sustainable Practices Policy is that at least 20 percent of natural gas purchases will be reallocated to procure biomethane by 2025. Thus, a UCOP-supplied biomethane contract is in place to help transition away from fossil fuel gas through 2039. UCOP plans to sell allocated biogas for cash infusions to distribute across the UC campuses to be used towards campus decarbonization. UCR may choose to retain some cash infusions to purchase offsets in the event UCR exceeds their cap-and-trade emissions allowance. If the sale of the contract is not successful, the existing contract could still help supplement a decarbonization solution by showing that Scope 1 emissions may be reduced by purchasing less natural gas, rather than directly replacing natural gas uses at the campus.

There may be a Living Laboratory opportunity in the assessment of campus waste streams (e.g. citrus or dining waste) for biogas generation. However, the amount of natural gas that could be replaced as a result of this process is likely to be so small as to be negligible as decarbonization strategy.

The availability, commodity cost, and risk of future escalation of biofuel should be monitored during UCR's decarbonization transition. It is likely that a combination of market demand and limited supply could significantly increase the cost of biomethane in the future, posing a significant financial risk to an offset strategy for the campus in the mid- to long-term.[16]

Hydrogen fuel produces only water when consumed in a fuel cell. If generated by renewable energy, "green" hydrogen is considered zero carbon. If natural gas is replaced with hydrogen fuel, the use of steam heating across the campus could likely be maintained, but this would require system conversion and operational costs could be high. For each unit of heat produced, a fuel cell requires about seven times more energy input than is needed for operation of a heat pump. Additionally, infrastructure would be required for storage (ten times more storage for hydrogen than for natural gas), and deliveries of hydrogen would need to be established. Hydrogen fuel can be difficult to source and challenging to import for direct use.

Further analysis is needed to determine whether reliance on hydrogen fuel is technically feasible and economical, and how this compares to the importance of focusing on replacing gas-consuming infrastructure to decarbonize Scope 1 emissions.

Exploring the feasibility of biofuel production at UCR could present a Living Laboratory opportunity, however its contribution to campus decarbonization would likely be negligible

Steam Heat Pumps

Steam heat pumps capture low-temperature waste heat from industrial processes and increase the temperature of that heat and use it to generate steam at the same temperature, pressure, and quality of existing boilers. However, steam heat pumps require a high baseload of steam use, currently much larger than UCR's baseload, to be cost effective. The technology could require significant electrical upgrades.

Steam heat pumps are not currently available or viable at this scale, but their use is becoming more prevalent in the industrial sector, leveraging the abundance of waste heat. It is expected that they will require as much space as the boilers that they would replace. Although these heat pumps do not necessitate combusting fuels, this technology results in a COP higher than 1 and continues to become more commercially viable.

The technology exists for larger applications and continues to advance and diversify as it matures. The industry trends of steam heat pumps should be monitored as the years go on and if UCR is committed to retaining steam infrastructure for the future.

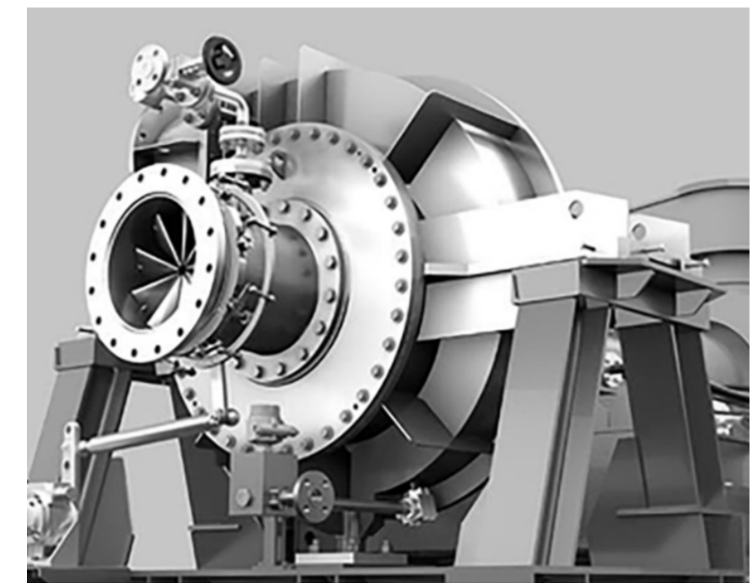


Figure 3-7: Example of Steam Heat Pump

Steam Thermal Energy Storage

Steam TES consists of grid-connected or clean-sourced power used to heat up rock or crushed rock over a period of time, allowing heat to be stored (at very high temperatures) and discharged when needed. Steam TES is not commercially available—though some manufacturers are outputting this technology—and is more applicable for high-temperature steam needs. This technology requires a large space to match the heating scale needed for UCR, along with additional power for auxiliary fans and equipment. It may be possible to apply steam TES in conjunction with steam heat pumps or electric boilers to mitigate demand costs (similar to non-steam TES systems), operating the mitigation control strategy while maintaining steam use and transitioning to an electrified system.

15 Bosch. 2024. Electrical Steam Boiler ESLB Available online at: https://www.bosch-industrial.com/global/en/ocs/commercial-industrial/electric-steam-boiler-elsb-19175285-p/.
16 California Energy Commission. 2018. Deep Decarbonization in a High Renewable Future Available online at: https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf.

3.3 Standalone Building Systems

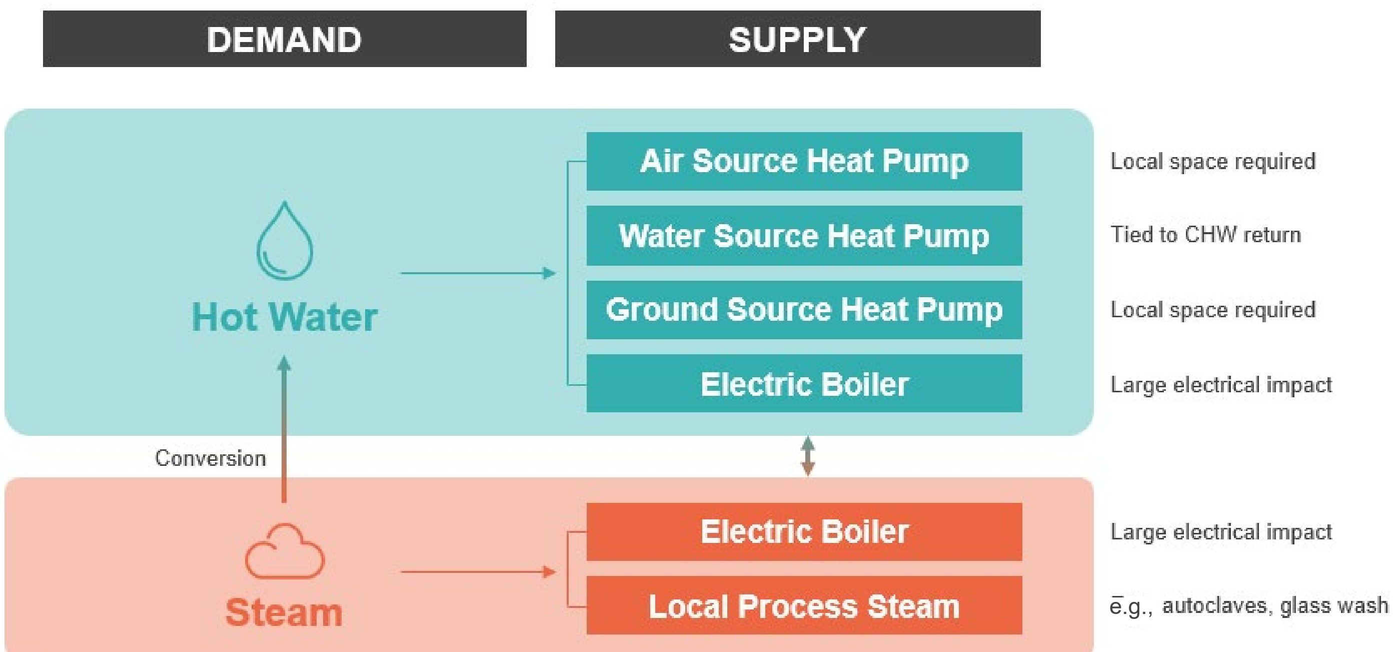


Figure 3-8: Summary of Standalone Building System Decarbonization Technologies

Figure 3-8 presents the technology options applicable for the provision of hot water or steam at a stand-alone building level. Technologies associated with decarbonization at the standalone building level include heat exchangers (HXs), local WWHPs, local ASHPs, and process steam decentralization. Each disconnected building should be assessed for space availability to integrate new heating, ventilation, and air conditioning (HVAC) technology; the same technology may not apply to all decentralized buildings due to spatial constraints.

Heat Exchangers

HXs move heat from one medium to another, without blending them, to regulate and moderate internal temperature of a building. HXs are required for the conversion of steam to hot water and need additional internal space allocation in buildings. Buildings using steam directly may not have adequate space for HXs.

Local Water to Water Heat Pumps

Building WWHPs extract heat energy from water to provide heating and hot water for facilities. WWHPs are either in a closed-loop system or an open-loop system. Local WWHPs are already used for some new buildings on campus. Implementing or converting to local WWHPs requires adequate indoor space; connection to a water source, such as the existing chilled water return loop (which can reduce the SAT's cooling load); and potentially local electrical infrastructure upgrades.

Local WWHPs may be most useful at those disconnected buildings with water sources nearby; otherwise, local ASHPs may be a better technology. WWHPs also offer a higher COP year-round than ASHPs, with a more stable heat source, but have higher implementation costs related to creating geo-fields. Heat sources would need to be identified for use of WWHPs. The returned chilled water loop acts as a free source of heat, pulling the waste heat from the return loop for WWHPs. Another application to be considered is using this technology for neighborhoods: if a building has waste heat, another building could benefit from using that heat. If noise pollution is of concern, WWHPs are generally quieter than ASHPs, passively rejecting heat that passes through a water source via compressors; ASHPs, by contrast, actively reject heat with additional fans.

Local Air Source Heat Pumps

Existing building-level heating and cooling equipment can be replaced with electric ASHPs. ASHPs extract heat from outside air to provide heating for a facility and remove heat from the inside to cool the facility. Like other heat pump systems, they are efficient because heat is transferred rather than generated. The efficiency of ASHP heating can be maximized based on the local climate, and ASHPs are much more efficient than electric resistance systems. ASHPs require adequate available outdoor space (they are typically not installed on roofs due to structural load requirements) and may require local hot water buffer tanks and electrical infrastructure upgrades in certain cases. In this study, it was assumed that 5 square feet of would be required for every ton of ASHP installed. Thus, the space required ranges from 10 square feet to 2000 square feet depending on the facility. Smaller split systems may be applicable for small buildings or buildings with more modest heating demands.

Process Steam and Gas Electrification

Process steam and gas electrification includes using electric-based sterilization, humidification, and cooking equipment to eliminate local steam and gas use. Autoclaves in laboratory-type settings are observed to be the primary process steam users, with lesser direct natural gas use for equipment such as Bunsen burners.

Electric autoclaves (or electric steam generators) (Figure 3-9) for sterilization are available as substitutes for steam autoclaves, but are costly; therefore, it is recommended that the existing steam autoclaves be replaced with electric versions once they require additional maintenance to maintain effective use. New buildings on campus already use process steam decentralization and facilitate a steam-to-hot-water conversion. Although process steam decentralization can require local electrical infrastructure upgrades, it reduces maintenance requirements.

Resistive steam humidifiers (Figure 3-10) offer an electric alternative to fossil-fuel–based steam humidification. Electrical resistance is used to generate steam, using high electrical resistance to heat water until the boiling point, when it produces steam. These humidifiers provide precise humidity control with advanced control systems; clean steam, free from contaminants and minerals; and higher efficiency in converting electrical energy into steam.

Similar to electric autoclaves available for purchase, flameless electric Bunsen burners (Figure 3-11) or hot plates are used in settings where open flames pose a safety hazard, and a microbe-free environment is necessary. In an increasing number of cases, electric Bunsen burners are preferred over gas burners because they combine the efficiency of a gas burner with the safety and control of an electric heater.

Some cooking areas at UCR, such as those at The Barn, North District Phase 1, and Pentland Hills Residence Hall (Figure 3-12), are all electric. New kitchens to be constructed, such as the one for North District Phasing 2, are planned to be electric as well. For the remaining gas cooking uses at places like the HUB and Lothian Residential Hall, alternatives to the existing equipment should be adopted, where feasible.

Figure 3-9: Example of an Electric Autoclave[17]

Figure 3-10: Example of a Resistive Steam Humidifier[18]

Figure 3-11: Example of an Electric Bunsen Burner[19]

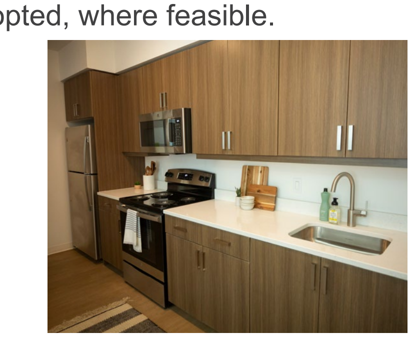


Figure 3-12: Kitchen Space at North District Phase 1[20]

17 SteelcoBelimed. 2024. MST-V 600 Series. Available online at: https://www.belimed.com/en-us/products/sterilizers/mst-v.
18 Carel. 2024. Resistive steam humidifier. Available online at: https://www.carel.com/resistive-steam-humidifier.
19 Cole-Parmer. 2024. Cole-Parmer® BB-200 Series Electric Bunsen Burners. Available online at: https://www.coleparmer.com/p/cole-parmer-bb-200-series-electric-bunsen-burners/66782.
20 Photo from UCR.

3.4 Technology Summary

Table 3–1 compares the shortlisted technological solutions at UCR, considering the aforementioned evaluation factors: technical maturity and market readiness, cost, potential space requirements, level of disruption, and applicable capacity. Refer to Appendix B for a detailed table that includes specific costs broken down by capital cost and fuel cost, along with applicable supply temperatures that dictate what building and distribution upgrades may be needed.

All technologies were considered sufficiently feasible to be included in a campus decarbonization strategy. The only technology included that is not currently deployable on the campus is the use of steam heat pumps and associated storage. These are included in the analysis of potential decarbonization pathways because they are considered close enough to commercial deployment (within the next 15 years) and present a more efficient alternative to centralized electric boilers for steam generation.

Table 3–1 Technology Summary Matrix

Rating in terms of Favorability
= High
= Medium
= Low
= Not applicable

	Maturity & Readiness	Cost	Space Requirements	Scale of Disruption	Scale of Capacity
WWHPs	High	Medium	Medium	Medium	High
ASHPs	High	Medium	Low	Medium	High
TES	High	Medium	Low	High	High
Electric Boilers	High	Low	Medium	High	High
Biomethane	High	Medium	Not applicable	High	High
Hydrogen	Medium	Low	Low	Medium	Medium
Steam Heat Pumps	Low	Low	Low	Low	Low
Steam TES	Low	Low	Low	High	Low
Heat Exchangers	High	High	High	High	High
Local WWHP	High	High	Medium	Medium	High
Local ASHP	High	Medium	Medium	High	High
Process Steam	High	Medium	Medium	Medium	High

Notes:
ASHP = air source heat pump
TES = thermal energy storage
WWHP = water-to-water heat pump

3.4.1 Technologies Considered but Not Included

After the qualitative technology analysis was undertaken, the following options were found not to have sufficient feasibility and/or scale to be continued for consideration:

- **Electric Boilers for Hot Water Generation** – As recently as five years ago, the default technology option for electric heating was electric resistance. However, with recent developments in efficiency and reliability of heat pump technology, a heat pump is now a superior option, having lower operational cost, lower emissions, and reduced load on electrical infrastructure. With UCR's climate, utility rates, and electrical infrastructure constraints, electric resistance boilers were therefore not considered for heating hot water.
- **Ground Source Heat Pumps (GSHPs)** – GSHPs use a combination of a WWHP and a geo-field to temper the water loop temperature. Geo-fields are used in an electrified heating system because they typically operate more efficiently than air-source equivalents (because ground temperatures are typically warmer than air temperatures during the heating seasons), they provide thermal storage to allow heat pumps to run in optimal conditions for longer, and the equipment can last longer. However, GSHPs can have high upfront costs associated with borings and loop installation, which can be more than three times higher than ASHP. At UCR, many of the advantages of GSHPs are also nullified by the mild/warm local climate (in less than 30 percent of heating hours is the ground temperature warmer than the air) and existing TES tanks, which allow improved heat pump performance. The primary reason for the omission of GSHPs, however, is the spatial requirement. Using the available areas near the existing plant, only approximately 10 percent of the load could be met with GSHP. This is insufficient to realize the main benefits of a GSHP system. However, developments in boring methods are continuing to increase the capacity of geo-loops and thus GSHP could still play a part of the technical solution in the future.
- **Deep Geothermal Energy** – This technology involves circulating water deep below the earth surface to take advantage of its natural heat. Although this technology is being investigated for its feasibility for campus steam generation in colder climates, it was not included for UCR due to the high cost, high disruption, land area requirements, lack of application at this (small) scale, and limited operational benefit compared to other technology options.
- **Seasonal TES** – Seasonal TES stores heat or cold for months either above or below ground for use when demand is higher. Additional thermal storage at this scale was ruled out due to a marginal cost-to-benefit ratio, given UCR's demand profile, the high investment costs, and extreme spatial requirements. The existing cooling capacity could be deployed for longer periods if needed.
- **Carbon Capture** – Carbon capture technologies absorb carbon from point-sources or directly from the air to offset carbon emissions from other activities. The captured carbon can then be either used on site, compressed and transported to be used in other applications, or injected into deep geological formations. These technologies are usually large scale, and there is still ongoing development for small-scale applications. Carbon capture requires trucking for export (e.g., carbon dioxide) and material delivery (e.g., hydrogen) and relies on unpredictable carbon dioxide market sales to be economically viable. Carbon capture systems would have to be paired with local combustion activities or a fuel cell for the scale UCR needs. Based on preliminary literature research and analysis, current carbon capture systems cannot guarantee more than a 70 percent capture rate; therefore, UCR would not be able to meet its decarbonization goals with this type of system. Although the existing steam boilers continue to be operated, there may be a Living Laboratory opportunity for UCR students to further explore carbon capture's potential impact campus-wide via a pilot project and if this type of technology could offer backup capabilities for base-load power in the event RPU's service is interrupted.
- **Solar Thermal Hot Water** – This technology leverages solar thermal collectors to capture heat from the sun and mitigate hot water demand. This was not considered, because there would be large space requirements for any significant contribution to carbon reduction. However, Glen Mor currently utilizes this technology, such that it may be viable at more housing areas and there may be opportunities for a small-scale application as part of a Living Laboratory.
- **Concentrated Solar Energy** – This technology uses mirrors to focus light to heat high-temperature fluid, creating steam. This was not considered, mainly due to the technology's large-scale requirements and high cost.
- **Small Modular (Nuclear) Reactors** – This technology generates local nuclear power and heat through a small-scale (as low as 20-megawatt) nuclear reactor. In addition to the perceived and real environmental and safety concerns, and the long and risky procurement and development period, this technology was ruled out due to its large capital and operational costs.

The scope of the campus decarbonization study did not include evaluating energy conservation and efficiency. Continued investment in conservation measures should ideally be implemented before any heating supply technologies to ensure that new equipment is being sized appropriately for the reduced load, thereby reducing operating costs, and to ensure that the more efficient demand profile is fully considered, thereby reducing capital costs. Onsite findings indicate a large potential to economically reduce heating demand by more than 30 percent in some buildings, in addition to continued implementation of other energy saving measures. Implementing measures identified via energy audit is recommended.

4. Decarbonization Scenarios

The decarbonization scenarios in this section present alternative pathways to achieve a 90 percent reduction of campus Scope 1 emissions by 2045. Each scenario comprises select, integrated decarbonization strategies for UCR.

Each scenario integrates a range of technical considerations, including building systems, distributed network upgrades required, existing CUP equipment and limitations, utility supply opportunities and constraints, and how these best fit together as comprehensive solutions to campus decarbonization. The scenarios have been developed considering the following:

- **Building Heating Requirements** – grade of existing heat demand (e.g., steam or hot water temperature)
- **Distribution Medium and Temperature** – type of distribution (e.g., hot water or steam) and the temperature or pressure of supply
- **Type and Configuration of Generation Equipment** – use of heat pumps, boilers, or other systems to generate heat either locally or centrally
- **Use of TES** – Size and deployment of thermal storage to increase efficiency and/or reduce installed capacity

Photo Credit: University of California, Riverside.

4.1 Scenario Description

In total, five major decarbonization scenarios are explored in this section in addition to the BAU scenario. Some scenarios include variant configurations, which comprise strategy alternatives or aspects contingent on technological advancement. Each of these scenarios are briefly described below:

- **Business-as-Usual** – This scenario assumes that no interventions would be needed to reduce GHG emissions, and that operations on campus could continue as usual, with the existing steam and chilled water supply being sufficient to meet future demand.
- **Scenario 1: Electric Central Hot Water Plant** – This scenario involves electrification of the existing CUP, enabled by building and distribution transitions from steam to low temperature hot water. This scenario has two variants:

  Scenario 1.1 – Components include a heat pump central plant with no use of a TES system.

  Scenario 1.2 – Components include a heat pump central plant with a centralized hot water TES system.

- **Scenario 2: Electric Distributed Hot Water Plants** – This scenario involves localizing heating networks with interconnected district heat pump plants. It requires a transition of building and distribution infrastructure from steam to hot water.
- **Scenario 3: Electrified Steam Systems** – This scenario is intended to minimize disruption to campus buildings and infrastructure by converting natural gas steam generation to electric steam generation. Two variants were assessed:

  Scenario 3.1 – Actions involve replacing gas-fired steam boilers with electric steam boilers.

  Scenario 3.2 (Future Consideration) – Actions involve reassessing the feasibility of steam heat pump technology in the future as the technology matures and becomes more applicable for commercial uses, then replacing the gas-fired steam boilers with electric steam heat pumps.

- **Scenario 4: Alternative Fuels**– This scenario uses alternative fuel options to generate steam at the CUP. It has advantages similar to those of Scenario 3, in that it minimizes disruption to campus operations and quickly meets decarbonization goals. This scenario has two variants to consider:

  Scenario 4.1 – Actions involve maintaining the existing gas-fired boilers but offsetting emissions from natural gas consumption through the boilers with biomethane procurement under the UCOP contract.

  Scenario 4.2 (Future Consideration) – Actions involve planning for and implementing a transition from natural gas steam generation to hydrogen fuel steam generation in the future if methods to source and store hydrogen and transportation logistics become more feasible for UCR.

- **Scenario 5: Decentralized Electrification** – This alternative involves installing building-level electric heating systems. It would require building upgrades to replace steam with hot water and decommissioning of the existing steam infrastructure and potentially electrical breaker and panel upgrades.

In Scenarios 1, 2, 3, and 5, localized electrified building systems and equipment are assumed for all buildings not connected to the CUP.

4.2 Scenario Analysis

To determine the best decarbonization pathway for UCR, comprehensive analysis of each scenario was conducted. This analysis leveraged evaluation criteria, developed with UCR, to assess the impact of scenario implementation on campus goals.

4.2.1 Evaluation Criteria

Each of the scenarios was evaluated using criteria aligned with the study's goals. These evaluation criteria were either quantitative or qualitative, depending on the applicable performance indicator. The criteria definitions for assessment are summarized in **Figure 4-1**, and additional details on the metrics and methodology behind the calculations is presented in Appendix F.

4.2.2 Scenario Modeling Methodology

For the quantitative metrics that support the evaluation criteria, detailed systems modeling was undertaken, which consisted of three phases:

- **Data Collection and Conditioning** – accessing, reviewing, and filling the gaps in existing building characteristics and operational trend data
- **Demand Projections** – modeling future demand growth to serve as a reference for equipment-sizing life cycle analysis of emissions and cost performance
- **Systems and Scenario Modeling** – evaluating the impact and performance of each combination of technologies with the goal of refining scenario configurations and determining the best decarbonization pathway

GHG Emissions Reduction
GHG emissions reduction is the decline in Scope 1 (direct) and Scope 2 (indirect) GHG emissions associated with heating, cooling, and electricity of campus operations.

Life Cycle Cost
A life cycle cost is the total cost of ownership over the life of an asset.

Annual and Peak Resource Use
Annual resource use refers to the total amount of utility resources (e.g., natural gas, electricity, water) consumed over the course of a year, and peak resource use refers to the greatest amount of resources consumed during the year.

Resilience and Reliability
Resilience is the ability to quickly recover from disruptions caused by natural disasters, technical failures, or human-made incidents. Reliability is the ability of utility infrastructure to consistently deliver resources to end-users without interruptions.

Ease of Implementation
Ease of Implementation relates to the degree of simplicity, practicality, and effort to phase and integrate any given scenario into the UCR campus over time.

Environmental Justice
Environmental justice is considered to acknowledge and appraise disproportionate and adverse human health and environmental effects on campus and in the surrounding communities.

Collaborative Learning
Collaborative learning criteria touches on the education value implementing a scenario can have on the UCR campus for faculty, students, and community.

Figure 4-1: Evaluation Criteria Descriptions

Data Collection and Conditioning

To establish a strong foundation for strategy analysis, it was necessary to create an hourly demand profile for heating and cooling demands for the CUP. Available meter trend data on boilers, chillers, TES tanks, and water use were supplemented with data analysis and modeling to develop a 2023 hourly load model. Estimates were made on process loads, humidification, and distribution losses, where needed, to isolate space heating and hot water demand characteristics.

Demand Projections

The campus decarbonization study should consider how heating and cooling demands may transform over time as UCR applies decisions to decarbonize systems and infrastructure while supporting its own developmental growth in the future. Future energy demands were projected using the following methodology:

- The LRDP provided guidance on the physical development of the campus including projections for each space type based on the proposed projects with anticipated construction completion by end of 2026 and growth/development assumptions through 2035. Modeled projections assumed a linear interpolation from 2027 to 2035 and no growth after 2035 through 2045. Future LRDPs should be taken into consideration in the future to refine projections.
- The 2024 UC Sustainable Practices Policy sets whole-building energy performance targets that are expressed as a percentage of total annual electricity and thermal targets, as developed for the UC Building 1999 Energy Benchmarks by Campus. For any planned development, these whole-building energy performance compliance targets were applied and accounted to determine future energy consumption.
- Future thermal demands are also driven by projected changes in weather characteristics due to climate change. Climate change is impacting the amount of time that heating and cooling systems should operate, with systems running longer to provide more degrees of heating or cooling.[21]

Systems and Scenario Modeling

The modeling performed to determine the existing and projected thermal load profiles was then used to evaluate a BAU scenario and scenario alternatives as recommended paths forward toward decarbonization. The alternatives were evaluated based on different equipment specifications, as well as utility costs and GHG emissions inputs.

The following factors were considered in the scenario modeling:

- Size and configuration of equipment and associated capital expenses (CapEx) and operational expenses;
- Efficiencies of equipment and resultant impacts on energy use, utility costs, emissions, and the social cost of carbon (SCC)[22];
- Infrastructure limitations (e.g., availability capacities on electrical transformers); and
- Space availability (i.e., available land or roof area and locations of availability).

For a comprehensive list of scenario projection modeling assumptions and details about the scenario modeling methodology, see Appendix E.

The next section consolidates the scenario modeling results and illustrates how each scenario alternative performs when evaluated using the evaluation criteria.

21 Joseph C Stagner, an energy consultant, documented a Fossil Fuel-Free Pathway Plan (FFFPP) for the UC system in February 2024 that analyzed long-term weather trends and potential impacts to campus heating and cooling loads.
22 UC Santa Cruz. 2023. Social Cost of Carbon. May 30. Available online at: https://sustainability.ucsc.edu/news-events/news/s-cost-carbon-2023.

4.3 Scenario Performance Summary

In addition to the BAU scenario, eight alternative scenarios were explored that enable 90 percent reduction in Scope 1 emissions. The alternative scenarios were evaluated and compared to identify those which perform best. The BAU (which does not meet the emissions reduction target) is modeled as a point of comparison for the eight other scenarios that meet the decarbonization goal.

Business-As-Usual

The BAU scenario represents a continued use of the existing steam, chilled water, and stand-alone gas systems, without outside interventions to address old equipment that requires additional maintenance to maintain effective use and infrastructure replacement. All other scenarios are compared to the BAU as a reference baseline, and maintaining a BAU pathway does not achieve decarbonization goals.

Performance Summary

- BAU has the least required capital investment and, overall, the lowest total direct cost (including utility cost) over the next 30 years. However, when considering the SCC, the total cost is comparable to some scenarios.
- Although this option limits investments to those required to keep the existing system operating, it does not help UCR meet their carbon reduction goals. Moreover, it involves significant water use and energy losses, and does not stand to benefit significantly from future technology improvements.

Scenario 1: Electric Central Hot Water Plant

The main strategies deployed in this scenario are the following:

- In Scenario 1.1, steam building systems would be replaced with low-temperature hot water systems (necessitating heating coil, pipe, pumps, and HX replacements).
- In Scenario 1.1, a phased replacement of steam distribution with hot water piping would be required to allow for a lower supply temperature.
- In Scenario 1.1, the cooling capacity at the SAT would be expanded to enable replacement of chillers and cooling towers at the CUP with WWHPs and ASHPs. A maximum of two existing steam boilers can be maintained for additional reliability while allowing space for new hot water distribution pumps.
- In Scenario 1.2, a hot water TES tank would be added, allowing increased WWHP capacity and greater plant efficiency and redundancy.

Performance Summary

- The use of WWHPs (configured in Scenario 1.1 as three, and Scenario 1.2 as five, 500-ton units) for the significant simultaneous load provides the greatest benefit to this scenario, drastically increasing supply efficiency (exceeding a COP of 5). The transition to a hot-water distribution system reduced losses by more than 75 percent. This scenario has the lowest utility operational costs once fully deployed.
- This scenario allows for more efficient operations and the ability to use hot-water–compatible equipment, as opposed to limiting options for carbon-free steam equipment. However, this scenario involves disruption to the campus and potentially complicated implementation when transitioning from steam to hot water, replacing piping across the campus.
- The costs of upgrades are greater in buildings that are currently using steam or hot water higher than 140°F to meet its requirements due to required heating coil replacements. The electrification of equipment would necessitate an upgrade of the existing electrical distribution systems and some building transformers, contributing to costs.

Scenario 2: Electric Distributed Hot Water Plants

The main strategies deployed in this scenario are the following:

- Clusters of buildings would be defined into “districts” that could be served by district hot water plants.

Photo Credit: University of California, Riverside.

- Appropriate locations would be determined for district hot water plants, ranging in capacity from 400 to 800 tons, to serve respective districts.
- ASHPs would be leveraged at each district hot water plant for heating only. Certain locations of district hot water plants may potentially use WWHPs connected to the chilled water distribution loop.
- Building-level steam infrastructure would be converted to hot water in the same way as Scenario 1.

Performance Summary

- This scenario performance is similar to Scenario 1 with a few key differences.
- With a smaller load being served at each plant and a greater proportion of the load being met by ASHP rather than WWHP, system efficiency would be less than Scenario 1.
- This option can completely divest from the use of existing steam plant, opening that space for other uses. However, it would likely require more space overall, spread across the campus.
- This alternative would likely have more flexibility in phasing and allow for an earlier switch to electric heating and may be applicable to housing buildings not currently served by the CUP.
- Interconnecting district hot water plants could enhance supply redundancy.

Scenario 3: Electrified Steam Systems

The main strategies deployed in this scenario are the following:

- In Scenario 3.1, natural gas boilers at the CUP would be replaced with electric boilers of equivalent capacity (up to 100,000 MBh).
- In Scenario 3.2, natural gas boilers at the CUP would be replaced with emerging steam heat pump technology.
- The existing TES tanks would be used.
- The primary electrical service lines supporting the CUP and electrical distribution system would be upgraded.

Performance Summary

- These alternatives minimize disruption at the building level because it would not be necessary to alter the existing steam distribution network.
- These strategies, particularly Scenario 3.1, would require more extensive upgrades to electrical systems than are needed under other scenarios, and would therefore result in significantly higher electrical system upgrade costs.
- These systems are significantly less efficient than heat pumps and, as such, operational costs would be higher than other scenarios.
- Steam heat pumps provide greater efficiency than electric boilers, reducing utility cost. However, this comes at the cost of a higher space requirement.

Scenario 4: Alternative Fuels

The main strategies deployed in this scenario are the following:

- In Scenario 4.1, the favorable UCOP contract for biomethane procurement would be leveraged in the short term.
- In Scenario 4.1, the existing natural gas boilers would be maintained at the CUP.
- In Scenario 4.2, natural gas boilers at the CUP would be replaced with a hydrogen equivalent.

Performance Summary

- Scenario 4.1 is unique in not requiring any new or invasive construction and/or equipment installation. However, it does not reduce the campus demand and dependency on natural gas nor reduce on-campus natural gas combustion.
- Scenario 4.1 allows the goal to be met faster than any other alternative, but at a high operational cost premium. Biomethane costs may increase overtime as demand increases due to decarbonization mandates or strives that focus on eliminating the use of natural gas.
- The biomethane purchase option can be used with any other scenario to also realize faster decarbonization.
- Scenario 4.2 becomes infeasible if a reliable and cost-effective supply of hydrogen cannot be maintained and would likely require a full steam plant replacement and additional space for storage and deliveries.
- Scenario 4.2 is unlikely to get below three times the cost of natural gas, and safety should be considered during implementation.
- Scenario 4.2, despite using a zero-emission hydrogen fuel cell, introduces new transportation-related air pollution from delivery of hydrogen to campus.

Scenario 5: Decentralized Electrification

The main strategies deployed in this scenario are the following:

- Existing gas equipment at standalone or unconnected buildings would be replaced with electric equivalents as they reach end of design life.
- ASHPs would be installed in most buildings. The existing CUP would be decommissioned.
- WWHPs could be used to connect to the centralized chilled water loop. However, consideration must be given to ensure that the chilled water return temperature is adequate for successful operation where there is a connection already in place.

Performance Summary

- This scenario is the most flexible in terms of phasing, with the potential to align most building upgrades with deferred maintenance and end of life replacement projects, thereby reducing cost premiums.
- New systems and supporting electrical upgrades would require more space both inside and outside of each building, raising risks for unforeseen cost and challenging implementation.
- Decentralized heat pumps lose economies and efficiencies of scale relative to centralized options.
- Decentralized electrification is the default approach adopted for all buildings not currently connected to the CUP.

4.3.1 Scenario Comparison and Results

The results of each scenario alternative are summarized in a performance scorecard, as shown in Table 4–1. Quantitative metrics are provided for the GHG emissions reductions, life cycle cost, and resource use evaluation criteria. The remaining criteria are rated qualitatively; a scenario could either have a low, medium, or high level of impact on an evaluation criterion where high is always considered the most favorable. A detailed comparison table of all scenarios, with a few additional metrics under each of these criteria, is presented in Appendix G.

Table 4–1 Scenario Performance Scorecard

Rating in terms of favorability
- (green) = High
- (yellow) = Medium
- (red) = Low

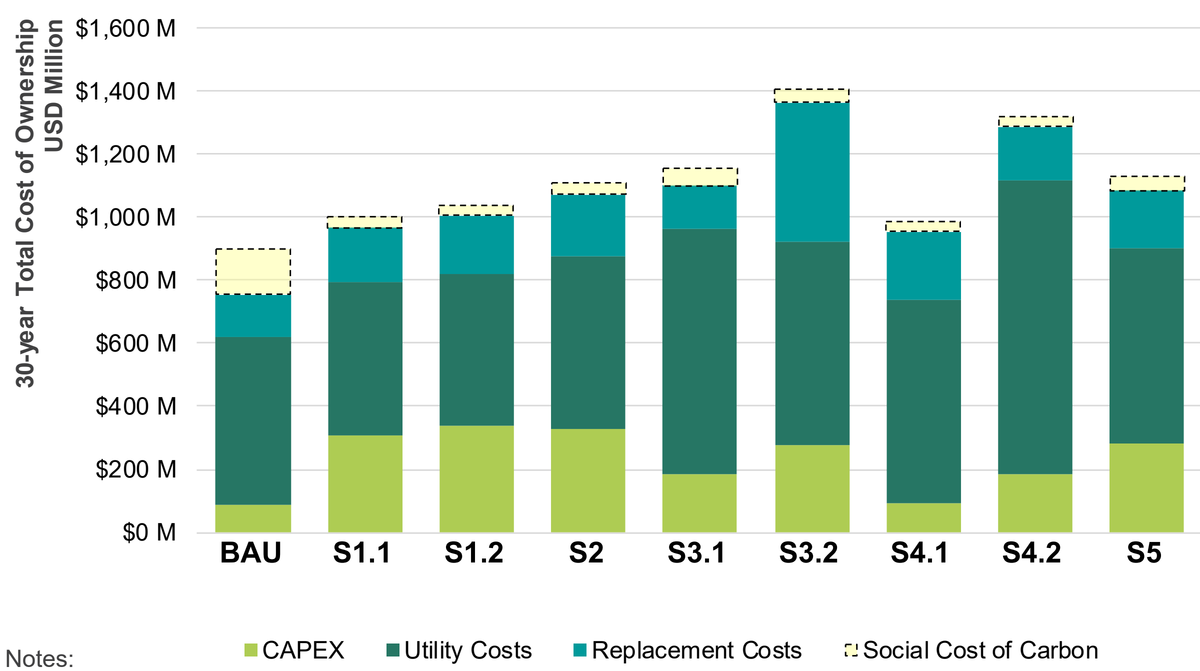
	GHG Emissions Reductions[1]		Life Cycle Cost[2]		Resource Savings Per Year				Resilience and Reliability	Ease of Implementation	Environmental Justice	Collaborative Learning
	Scope 1 & 2 Percent		30-Year TCO Million USD		Energy 1,000 MMBtu		Water Mgal		Qualitative			
Business-as-Usual Existing Steam & CHW Distribution	0%	Low	$754 M	High	0	Low	0	Low	Low	High	Low	Low
Scenario 1.1 Electric Central Hot Water Plant (no TES)	100%	High	$968 M	High	349	High	29	High	Medium	Low	High	Medium
Scenario 1.2 Electric Central Hot Water Plant (with TES)	100%	High	$1006 M	High	356	High	42	High	High	Low	High	Medium
Scenario 2 Electric Distributed Hot Water Plants	100%	High	$1072 M	Medium	297	High	9	Medium	High	Low	High	Medium
Scenario 3.1 Electrified Steam Systems (Steam Boilers)	100%	High	$1099 M	Low	95	Medium	0	Low	Medium	Medium	High	Low
Scenario 3.2 – Future Electrified Steam Systems (Steam Heat Pumps)	100%	High	$1364M	Low	209	Medium	0	Low	Medium	Low	High	High
Scenario 4.1 Alternative Fuels (Biomethane)	100%	High	$955 M	High	398	Low	0	Low	Medium	High	Medium	Low
Scenario 4.2 – Future Alternative Fuels (Hydrogen)	100%	High	$1289 M	Low	398	Low	0	Low	Low	Low	Medium	High
Scenario 5 Decentralized Electrification	100%	High	$1086 M	Medium	230	High	9	Medium	Medium	Low	High	Medium

Notes:
[1] Percent reduction of Scopes 1 and 2 emissions from the 2019 baseline by 2045 (excluding non-building energy)
[2] 30-year total cost of ownership (TCO) which includes capital investment, replacement costs, and utility costs, but excludes social cost of carbon

The analysis suggests that all alternatives could technically be able to meet the decarbonization goals by 2045. Of the scenarios that involve on-site intervention, centralized electric pump-based heating was found to have the overall lowest total cost of ownership (TCO). Each of the related alternatives would achieve the decarbonization goals, reduce utility cost by around 50 percent due to a reduction in losses and increased efficiencies, relatively inexpensive electricity, and mitigate high capital costs by using the existing utility corridors.

In contrast, alternatives associated with decarbonized central steam generation heating systems are economically unfavorable primarily due to the high utility and fuel costs. Building-level heating systems tend to not perform as well as centralized systems over time due to less efficient operations and complexity in implementation.

Figure 4-2 shows the 30-year TCO for each scenario, illustrating the financial level of investment required over 30 years after implementation for each scenario, including the BAU scenario. This includes capital investment, utility costs, required replacement costs, and the SCC for all scenarios. Additional details and assumptions for TCOs for each alternative are provided in Appendix F.



Notes:
S = Scenario

Figure 4-2: 30-year TCO of Scenarios

The sequencing of upgrades is relatively flexible with the noted exception of electrical service upgrades. Consideration should be given to refining upgrades to align with required deferred maintenance investment into the existing buildings, which could potentially reduce the collective campus disruption and the total cost premium of certain upgrades.

The evaluation suggests that Scenario 1, Electric Central Hot Water Plant, represents the best option for UCR to achieve 90 percent Scope 1 emissions reduction. The optional enhancement offered by an additional TES presents an opportunity to increase plant efficiency and improve heat supply reliability compared to the existing system. It results in the greatest energy and water use savings and provides the opportunity for campus research with new technologies and controls.

The steam alternatives (Scenarios 3 and 4) allow continued use of steam; however, the losses, high utility and fuel costs, and large infrastructure investment required make these options cost prohibitive. Hydrogen use would similarly require a sizeable infrastructure investment and comes with risks associated with technology maturity, safety, and long-term commodity cost uncertainty.

Scenario 4.1 is the least disruptive (requiring no on-site intervention) but carries more risk. The renewable natural gas (RNG) rate could be subject to change in the medium- to long-term and, with demand expected to increase, it could likely rise. A RNG rate increase of less than 50% would lead to a 30-year TCO higher than Scenario 1. There is also a regulatory risk that because it's essentially an 'offset' and does not reduce local emissions, it may not be compliant in the long-term. If earlier GHG reductions are desired, RNG procurement can be used in the featured scenario to mitigate emissions during the transition period to an electric heating system.

Scenario 5 is likely more flexible in its implementation timing because buildings can be decarbonized one by one on a schedule that works best for UCR. However, this alternative does not benefit from the greater efficiency of simultaneous heating and cooling that can be provided under Scenarios 1.1 and 1.2, and a decentralized system would likely be a lot more costly to maintain than a central plant.

Considering the collective performance against all criteria, Scenario 1.2 with neighborhood phasing is the recommended pathway. This recommendation is for implementation today and is still recommended based upon known information if the project cannot start for the next 10 years or more. However, it is important to understand under what conditions the other alternatives may become more viable. These include:

- Scenario 3.2, steam heat pumps, could potentially become viable if the technology can scale down to smaller units and the average COP increases from 1.6 to above 3. Currently, the space required, lack of units in the required capacity, and lower efficiency than hot water ASHPs and WSHPs make this technology infeasible.
- If a local, incentivized source of hydrogen is developed, allowing for a piped connection, it may be part of a longer-term solution. However, given the cost of the commodity, its value will likely be more as a replacement for gas for heating fuel backup.

The following section describes Scenario 1 in more detail.

4.4 Featured Scenario

The featured scenario for UCR to achieve decarbonization goals—while reducing water use, generating the most utility cost savings with the most readily available technology, and being the most profitable of the mature and market ready technologies—is **Scenario 1: Electric Central Hot Water Plant**.

A full-system decarbonization is realistic and, when considering the SCC, life-cycle-cost-effective. This is due to UCR having: lower than average electrical rates; a mild winter conditions, allowing ASHPs to operate efficiently; a high, consistent simultaneous load (allowing high efficiency heating through heat recovery chillers); and large existing TES capacity to further optimize operations. At UCR, the required steam to hot water conversion, while complex, is feasible because: relatively few buildings have steam distributed throughout the building; existing utility corridors can be used for new piping; all steam loads can be electrified; and there are no known uninterruptible steam load requirements (unlike a hospital setting).

The following subsections focus on proving more detail of this solution and the procedural strategies that may be required to implement Scenario 1 at UCR, including replacing steam building systems with low-temperature hot water systems, phasing replacements of steam distribution infrastructure with hot water piping, expanding cooling capacity at the SAT to replace chillers and cooling towers at the CUP with WWHPs and ASHPs, expanding electrical service capacity, and more.

4.4.1 Project Descriptions

The following sections detail the projects required at the building-level and in utility plants to transition from the use of natural gas to electricity.

Building-Level Interventions

The required building intervention in Scenario 1 takes a different path based on if it's connected to the CUP or is a standalone building generating its own heating hot water and hot water. **Figure 4-3** provides guidance on what building modifications may be necessary to remove steam uses from a connected building.

- **Connected Buildings with Heating Hot Water** – If a connected building is using centralized steam to create heating hot water through an HX for space heating purposes, the steam HX would have to be replaced with one that supports the new low-temperature (140°F) hot water distribution loop. It should not be necessary to update heating coils and building piping if building already operates at 140F supply temperature or less. In addition, buffer tanks should be included to account for the lag between demand and hot water production along with new hot water heat pumps. **Optional**: If buildings choose to connect to the new condenser water return loop as a heating source, HXs would not be required, and losses affiliated with using HXs would be avoided.

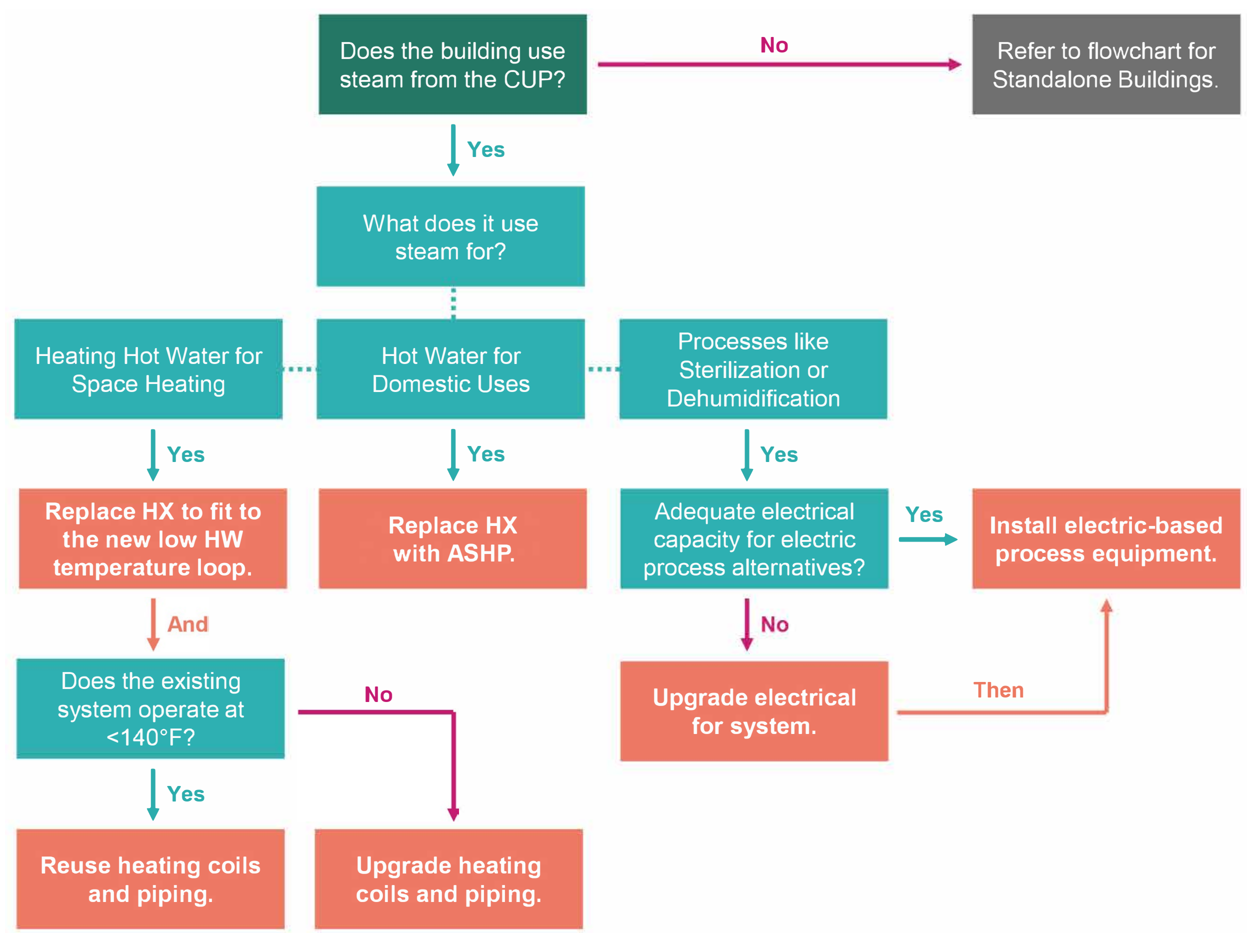


Figure 4-3: Building Upgrade Decision Flowchart for Connected Buildings

- **Connected Buildings with Domestic Hot Water** – If a connected building is using centralized steam to create domestic how water, the HX should be replaced with a standalone electric heat pump to provide sufficient hot water temperature for domestic uses. It may also require new HHW piping and pumps where they do not currently exist. As with HHW, local buffer tanks maybe required to balance the supply with the demand. DHW has different requirements for people consumption and cannot be sourced from the centralized closed system. For example, materials need to be lead-free and meet different more stringent requirements. Note that no connected buildings using domestic hot water supplied at a temperature more than 140°F were observed during onsite assessments. If any connected building requires domestic hot water greater than 140°F, likely for large kitchen uses, heating coils and piping may have to be considered for upgrades.
- **Connected Buildings with Process Steam** – If a connected building is using centralized steam directly for process loads, such as sterilization or humidification, the building would at minimum need to update heating coils and piping and evaluate whether adequate electrical capacity is available to replace steam-generating process equipment with electric alternatives. If buildings do not have an adequate electrical capacity, the building transformer would have to be upgraded before installing electric alternatives.

For buildings that are not connected to the CUP for hot water heating—but which still use natural gas directly for hot water heating, cooking, or laboratory uses—all gas equipment such as boilers, appliances, and Bunsen burners should be replaced with electric-based alternatives. Appropriate replacements for boilers can be determined by following the process in **Figure 4-4**. In addition, local sites should be test fitted and validated considering equipment dimensions, equipment sensitivity, noise, impacts to existing sites or future development of sites and test for equipment feasibility.

Plant and Heating Distribution Upgrades

The transition from a steam to a low-temperature hot-water heating network requires significant changes in the horizontal infrastructure, at the CUP and a few modifications at the SAT. Those changes are as follows:

- An additional 2,000-ton chiller and cooling tower should be added at the SAT to free up space in the CUP. There is already allocated space where this chiller and cooling tower can be installed. With the existing TES tanks and chillers and the new chiller, the SAT can meet peak cooling demand without contribution from the CUP. **Figure 4-5** shows the location of this proposed addition.
- The five water-cooled chillers, five cooling towers, and four natural gas boilers should be removed at the CUP and replaced with five heat recovery chillers, or WWHPs, inside the CUP and 18 banks of modular ASHPs outside (approximately 3,750 tons in total). This would expand the previous footprint of the CUP by approximately 15,000 to 25,000 square feet. It is recommended but optional to retain two gas boilers to provide heating supply redundancy. This would likely come at the additional cost of stand-by gas utility rates. A new hot water TES could be installed adjacent to TES tank 1 and connected to the CUP, requiring approximately 2,500 to 7,500 square feet of space. This transition is represented in the diagram in **Figure 4-6**. It is assumed that the new equipment installs do not impact structural or building code requirements as they are limited to equipment retrofit. However, this should be reassessed as the project moves forward.
- The steam distribution infrastructure piping should be replaced throughout campus. This would use existing, underground utility corridors where possible

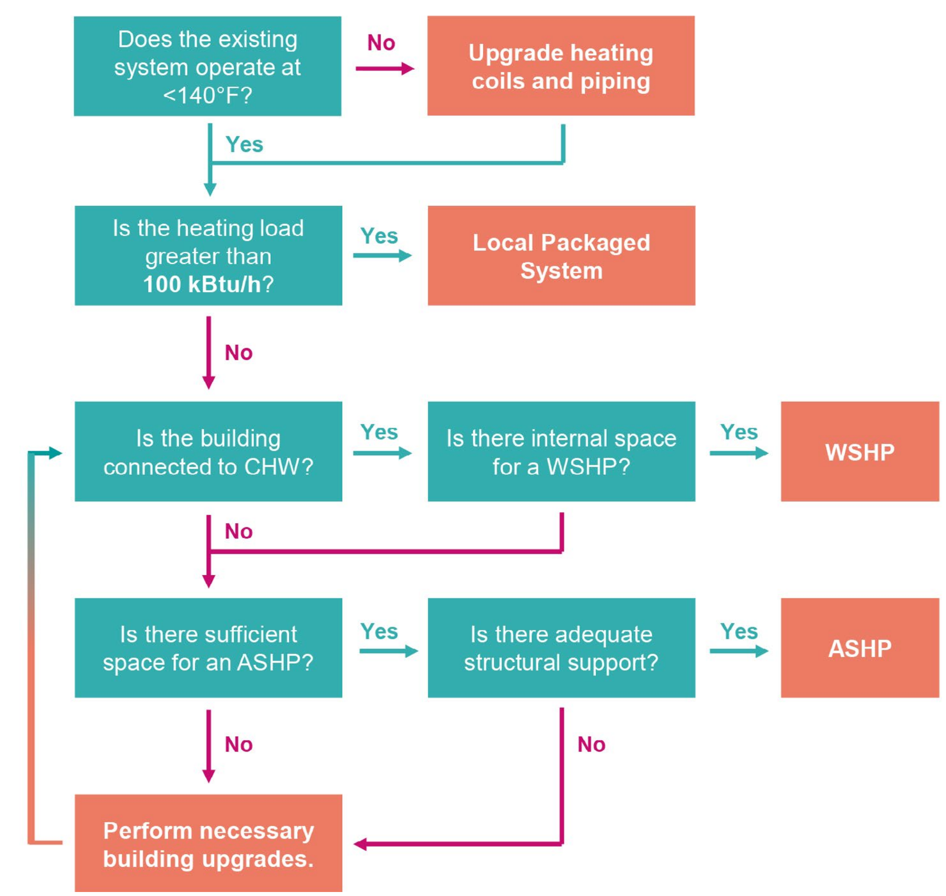


Figure 4-4: Building Upgrade Decision Flowchart for Standalone Buildings

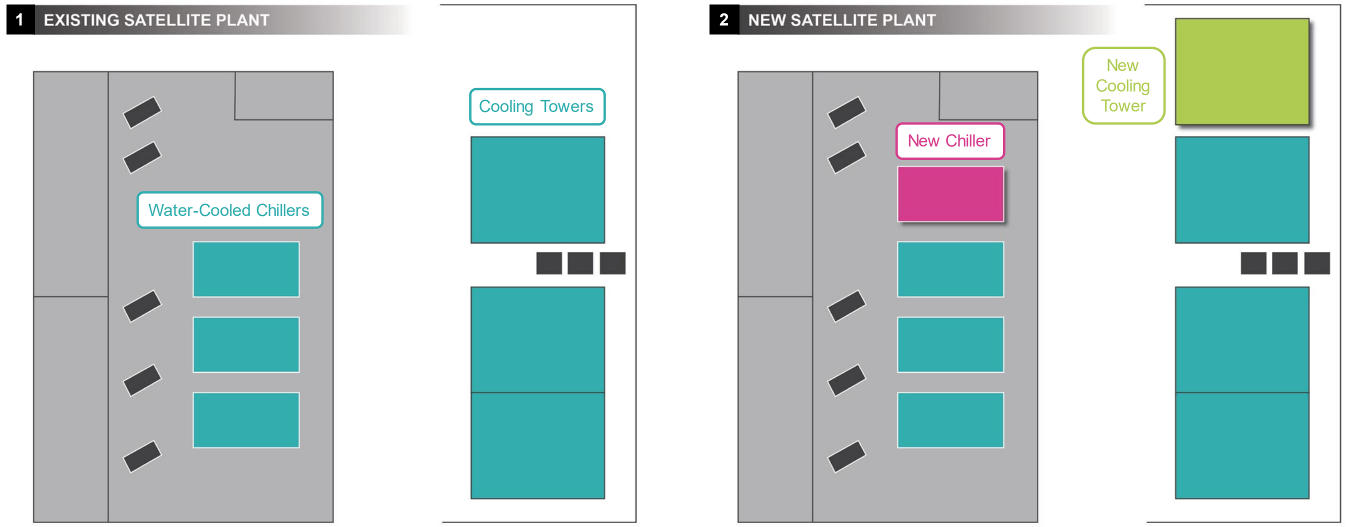


Figure 4-5: Satellite Plant Upgrades of the Featured Scenario

Figure 4-6: CUP Upgrades of the Featured Scenario

and by direct-burying new piping following the paths of the existing steam pipes. If using the corridors, steam piping would have to be removed prior to installation of any new hot water pipes due to spatial constraints in the tunnels. Removal of existing steam infrastructure could disrupt activities at the connected buildings necessitating local temporary boilers.

- A looped configuration of the new heating hot water infrastructure is recommended to provide supply redundancy and added resilience to the distribution loop, rather than following the existing radial layout.
- In addition to the projects described above for campus decarbonization, certain electrical upgrades are required in the BAU scenario to facilitate planned campus growth. An additional transformer bank should be implemented at the existing University Substation to increase service capacity. A new feeder would connect the substation to the CUP to facilitate its electrification. An alternative new service option for increased resilience is to install a new substation in partnership with RPU which would connect to a separate and redundant supply feeder to the northeast of campus.

Table 4–2 Capital Cost Summary of Featured Scenario

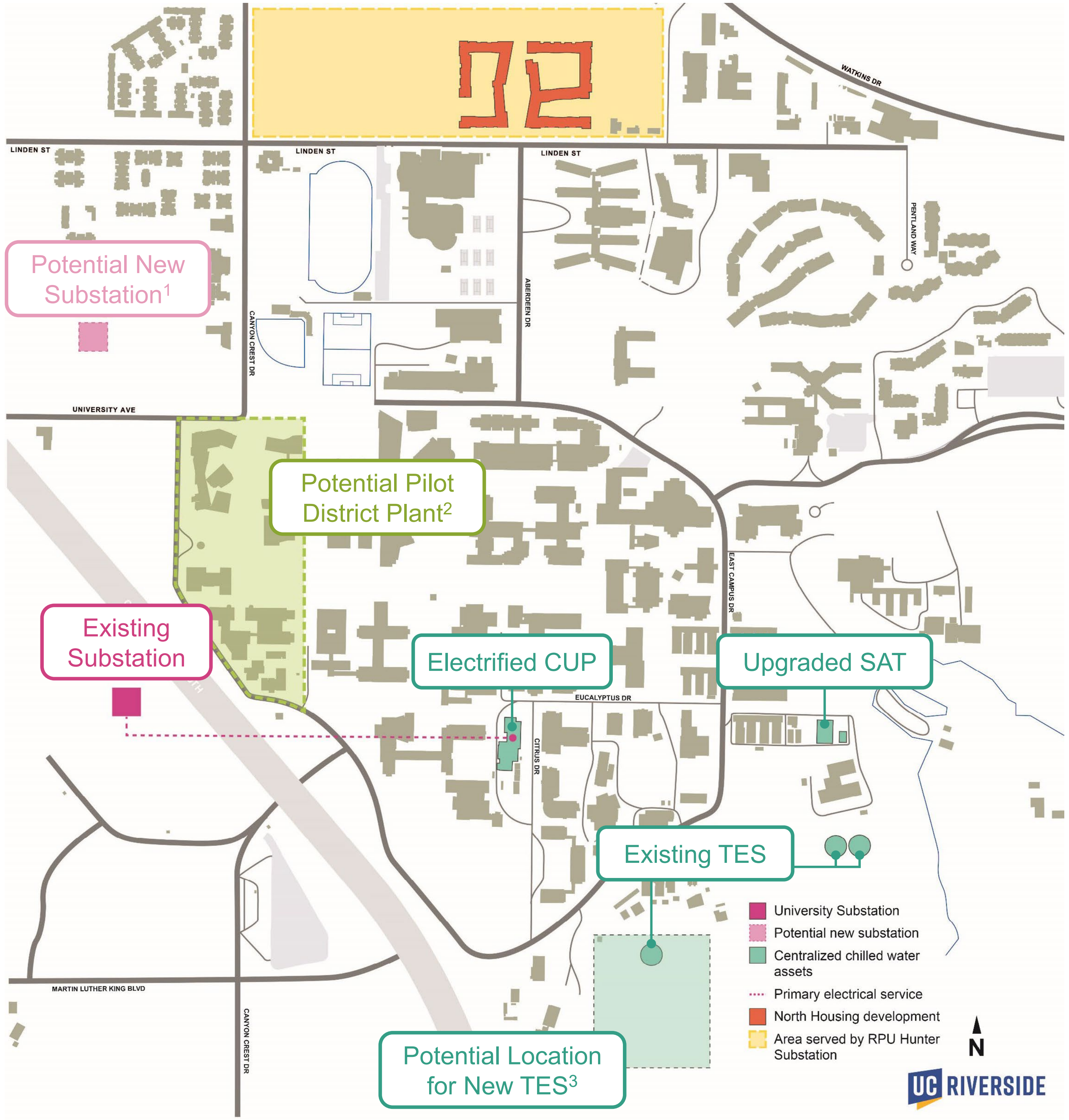
Infrastructure Component	Cost [$ million]	Included Items
Campus Electrical Service	30–35	• New RPU service • 12.47 kV switchgear • Campus distribution feeders
Central Plant Equipment	70–80	• Water to water heat pumps • Air source heat pumps • Thermal energy storage • Pumps and auxiliary
Central Plant Electrical	10–20	• New 12.47kV connection • Transformers & switchboard • Control upgrades
Thermal Distribution	60–70	• Hot water distribution piping • TES piping and associated work
Non-Connected Building Equipment	50–55	• Non-connected facilities heat pumps and split systems
Building Upgrades	130–140	• Heat exchangers • Hot water piping • Coil replacements • Building modifications • Building level controls upgrades • Process electrification equipment • Building transformers and main switchboard replacement
Total	**350–400**	

The capital costs estimated for this prefered scenario are summarized in **Table 4-1**. The largest area of investment is associated with the upgrades required to the buildings to facilitate the transition away from steam and high temperature hot water. A proportion of the capital investment for the thermal energy storage and heat pumps may be eligible for Inflation Reduction Act funds, which can reduce total costs. **Figure 4-7** shows a map of the key infrastructure associated with this scenario.

4.4.2 Flexibility and Enhancements

Additional variations can be integrated into the fundamentals of the featured scenario when planning to execute the scenario. The following variations can be considered for inclusion:

- **Additional Electrical Substation** – Electrical demand on the campus will increase. All North District Developments are fed from Hunter Substation to help alleviate capacity required from University Substation. However, even with Hunter Substation supporting future North District developments, a single transformer at University Substation can no longer sustain the campus' peak demand and must share the load with the second transformer, negating the original intention of having built redundancy at the substation. The plan (and thus cost) included within the featured scenario and BAU scenario is to increase capacity at the University Substation; however, another substation besides Hunter Station supporting North District development would not only offer additional electrical capacity to support growing electrification but would also restore power supply redundancy.
- **Thermal Energy Storage** – Including this component to the featured scenario is optional and could be removed if capital cost savings are prioritized. However, an additional TES tank for hot water increases the efficiencies and deployable capacity of the heat recovery chillers and, overall, the new plant operations as well as providing a



Notes:
[1] Proposed locations are not final and subject to change, further environmental assessments may be required.
[2] Potential Pilot District Plant footprint is estimated at approximately 40' x 40'. Subject to change.

Figure 4-7: Featured Scenario Key Infrastructure Map

potential temporary source of hot water should any generation issue occur thus increasing plant reliability due to redundancy, and resiliency for the case of electric grid outages.

- **Independent District Plants** – Instead of pursuing a large, centralized utility plant to serve the majority of the campus, as proposed in the featured scenario, multiple, smaller-scaled district plants could be deployed to support clusters of buildings. The footprint required to accommodate district plants varies and may range from 1,500 to 5,000 square feet containing rows of ASHPs and pumps. Scenario 2, which resembles this type of enhancement, was rejected as the featured scenario due to the increased land requirements and reduced system efficiencies it would entail. Additionally, the new locations of the LRDP projects to occur by 2026 that are not in areas currently served by the CUP (e.g., School of Business, North District Phase 2 Undergraduate Teaching and Learning Facility, Undergraduate Teaching and Learning Facility, and OASIS Park) may warrant the implementation of a local district plant (or plants).
- **Mini-Districts in North Housing** – It is not necessary to use smaller district plants for housing clusters in North Housing to decarbonize natural gas use in these areas (because standalone replacements are available). For this reason, and because of potential phasing and disruption complexities, such mini-districts were not included in the scope of the featured scenario. However, mini-districts could still be considered, using them to potentially connect the North Housing complex into the campus' future hot-water distribution loop.
- **Phased Plant Transition** – Given that extensive changes may need to take place at the CUP, and that modifications need to yield the least disruption to campus activities, the transition of the plant itself can be phased in portions of the campus. An example of a phased approach could be demonstrated by starting with a "Phase 1 Pilot" (refer to Section 4.4.3 for phasing details).

4.4.3 Phasing

It is neither economically nor logistically viable to conduct all upgrades of the featured scenario within a single year. Phasing upgrades in terms of short-, medium-, and long-term action items would allow the campus to start the necessary work without causing undue disruption and costs. Short and medium-term projects can also lay the foundation for long-term projects to assuage logistical concerns and ease the transition.

Phasing Considerations

The phasing considerations include the following factors, which are discussed in further detail in the sections below. These factors can help to identify key challenges and opportunities in the development of an implementation approach.

- **Scale of Allowable Disruption** – This refers to measurable disruption or downtime on a building or multiple buildings in a section of the campus. Examples include temporary building discontinuity, partial campus shutdown, disrupted utility supplies, construction activities impacting commutable hardscapes.
- **Capital Costs and Available Funding** – This refers to the availability and timing of investment over next 20 years, and strategies to implement more cost-efficiently. Examples include aligning with deferred maintenance, or capital renewal plans.
- **Rate of Decarbonization** – This refers to how quickly the campus can realize decarbonized operations considering reasonable interim targets.
- **Other Variables**:
  - **Resilience** – Identifying where there are opportunities to enhance resilience and where are additional investments necessary to mitigate risk
  - **Enabling Projects** – The order of necessary infrastructure investments for implementation and how it impacts scheduling and timeline
  - **Siting Considerations** – Available land, impacted development areas, technology-specific infrastructure, environmental factors, and other considerations as it relates to the LRDP and feasibility
  - **Pilot Programs and Living Laboratory Opportunities** – Considering best location/technology/research value combinations to define potential pilot areas

Scale of Allowable Disruption

For each of the scenarios, some level of disruption would likely be experienced in buildings or in certain public areas as the projects are implemented. Because large upgrades can take more than a year to design, coordinate, and staff, it is important to have a clear plan and set a core team to be tasked with carrying out the upgrades.
Some key considerations to observe during downtime planning:

- Buildings are currently retrofitted with zero allowable downtime (upgraded while in use).
- Scheduling of gas boiler replacements (with heat pumps) should be aligned with existing boiler end of life.
- The CUP has planned outages for two weeks per year.
- Infrastructure in utility corridors cannot be replaced in parallel with upgrades and should be entirely removed to add new hot water infrastructure due to spatial constraints in the tunnels.

In the short term, easier replacements can be done with minimal impact to buildings, and more involved upgrades can be scheduled during periods of vacancy or minimal impact. Examples of short-term upgrades include:

- Converting steam HXs to hot water HXs or use temporary gas boilers at connected buildings.
- Installing ASHPs or WWHPs configured in a district plant to serve a select cluster of buildings.
- Replacing thermal and electrical distribution infrastructure.

Medium-term projects would tackle upgrades that are more complicated; this would allow time for coordination and scheduling with the building users while taking opportunities when presented. Examples of medium-term upgrades include:

- Performing local building upgrades as opportunities allow.

Long-term projects focus on projects that either rely on short- and medium-term projects or require a great deal of planning and preparation to mitigate campus impact. An example of long-term upgrades include:

- Conversion of the CUP heating from steam to hot water.

Capital Costs and Funding Availability

The availability and timing of capital funding to implement any decarbonization plan has yet to be determined. Accordingly, any phasing approach should allow for flexibility in project spend and timing. These include:

- New and replacement boilers, steam piping, ASHPs, WWHPs, and steam HPs.
- Local electrical service upgrades for process electrification.
- Provisional decentralized building capital costs (i.e., standalone buildings).
- Avoided costs associated with BAU scenario; and
- Site-wide electrical upgrades required across all scenario alternatives.

The estimated TCO costs exclude the following:

- Cost of electrified process equipment replacements.
- Operations and maintenance costs.
- Temporary equipment costs.

Rate of Decarbonization

The rate of decarbonization refers to how quickly the campus can realize emissions reduction from its energy operations. The suggested phasing timeline, presented in the following section, is intended to reflect a realistic, achievable pathway, considering the goals to minimize disruption; reflect project implementation, construction, and procurement timelines; and invest modestly over time while still realizing immediate emissions reductions. Phasing could be accelerated if sufficient capital is identified and the upcoming UCOP contract can be leveraged for biomethane purchase.

Implementation Timeline

There are several phasing alternatives for implementing the featured scenario. As the CUP undergoes the transition from steam to hot water, local district plants would likely be required to facilitate phasing. The proposed phasing timeline example could be treated as a viable initial vision, acknowledging that it would need to be flexible to accommodate add-ons outlined in Section 4.4.2 (Flexibility and Enhancements) and inevitable variations in funding, planning, design, and implementation timeframes. The following example timeline is structured into recommended short-term (or enabling) projects, with an implementation timeline from zero to five years; medium-term projects to begin in five to 10 years; and long-term projects to begin in more than 10 years.

This phased implementation example shows six districts (as depicted in **Figure 4-8**) transitioning from steam to hot water over a 15-year period.

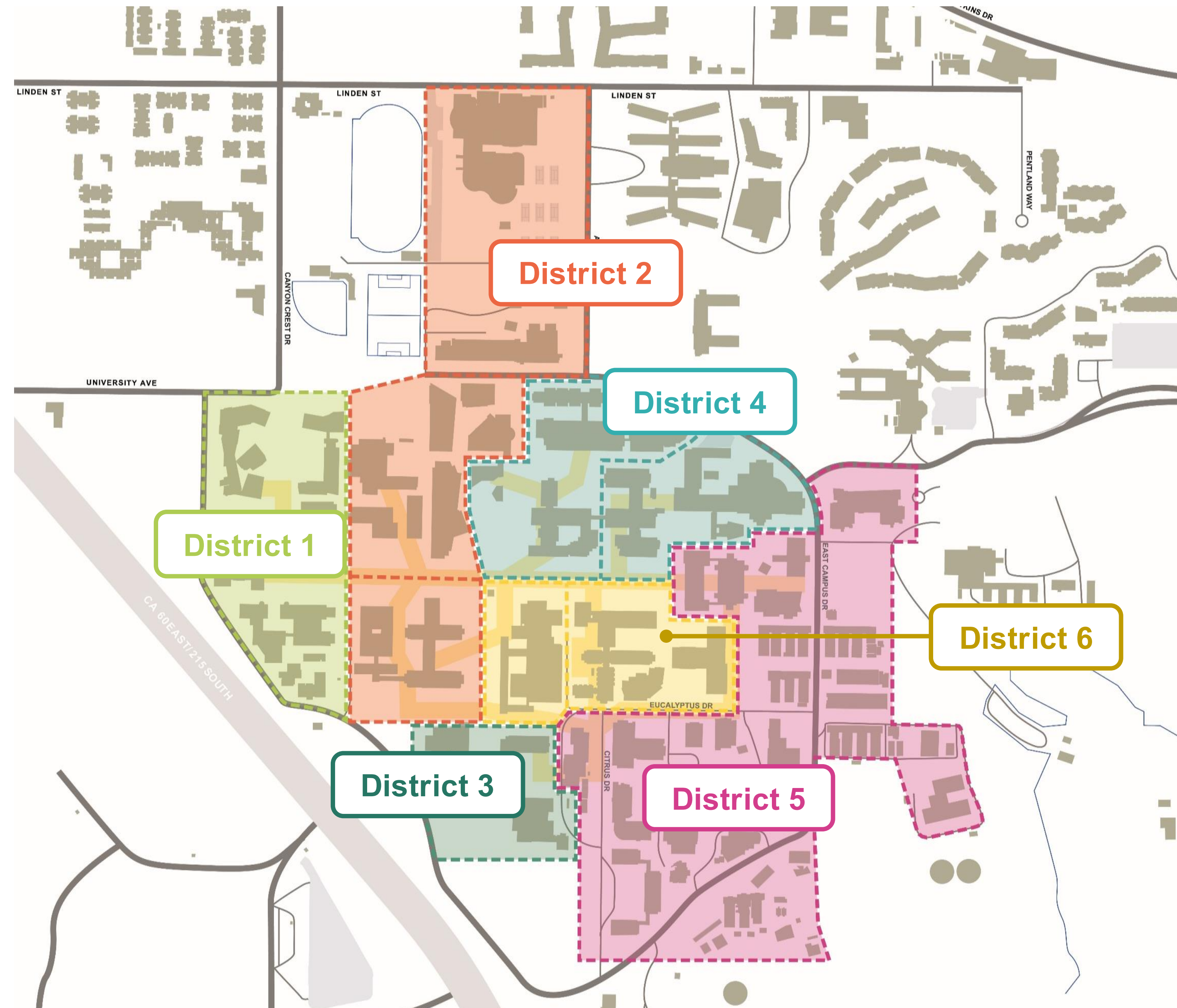


Figure 4-8: Potential Scenario Phasing Example

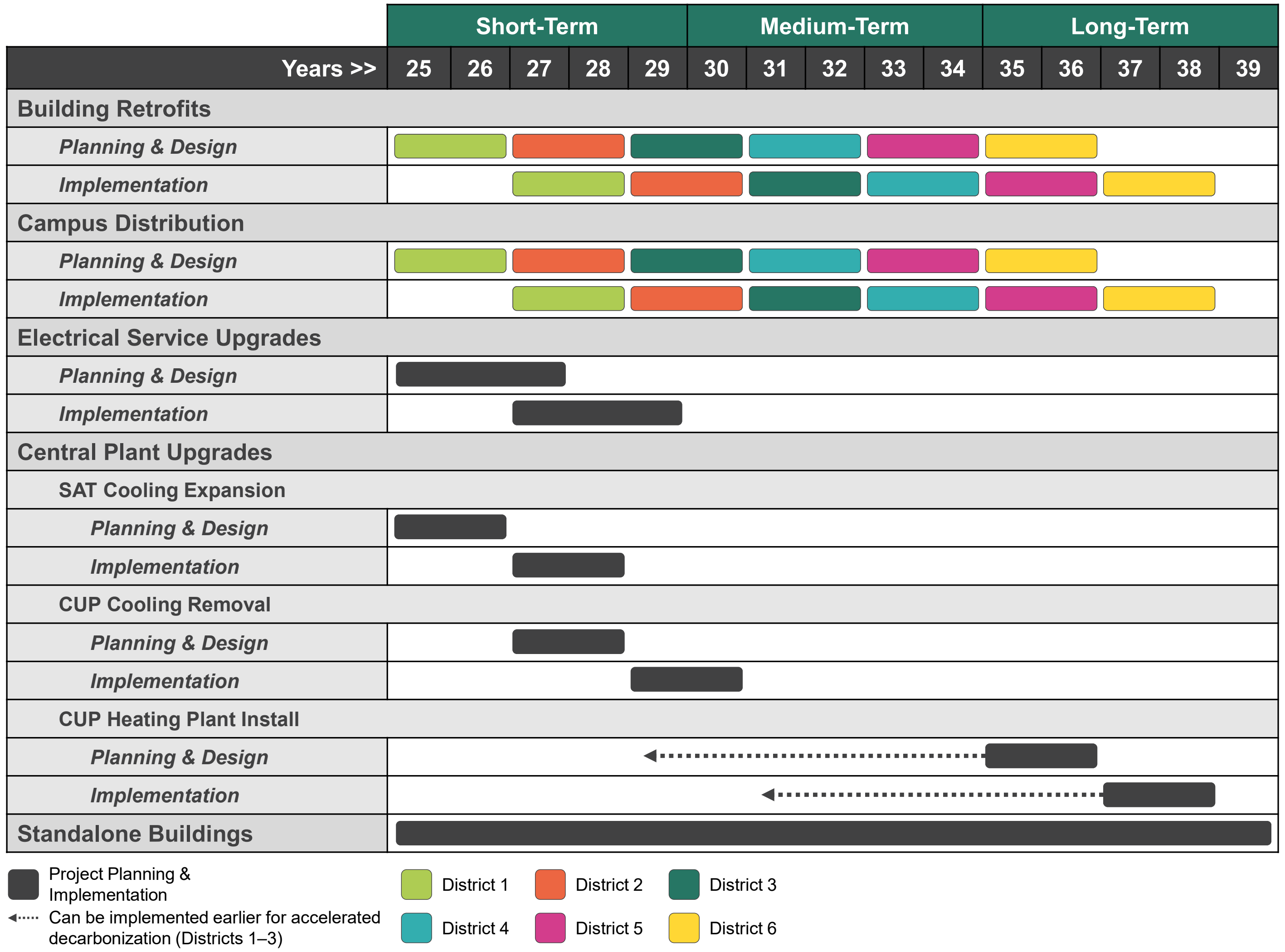


Figure 4-9: Implementation Timeline the Featured Scenario

Figure 4-9 summarizes a an example implementation timeline for this featured scenario.

The phasing timeline includes a District 1 Pilot (or a Living Laboratory opportunity) and subsequent Districts 2 through 6. The District 1 Pilot is an opportunity to evaluate using a district heat pump plant to build confidence in the installation, operation and maintenance of this system before ultimately converting the CUP.

This selected District 1 Pilot encapsulates five buildings on the western side of Main Campus: Arts Building, CHASS, Student Success Center, Hinderaker Hall, and Humanities and Social Sciences—but any group of buildings could be within the boundary of a Phase 1 Pilot, and the phasing strategies would still apply. The Student Success Center falls within the District 1 boundary but is newly constructed and all-electric, not requiring major modifications. Throughout the phasing periods, standalone buildings (that are to remain standalone after the transition) should upgrade existing gas-using equipment to electric options.

When deciding where to place district plants, it is recommended that consideration be given to the area requirements for the plant, available land within UCR's ownership, strategic pipe lengths and tunnel infrastructure from plant to end user, and proximity to large consumer(s) to minimize distribution losses.

The electrical service upgrades should be considered the first focus of project implementation. This is due to two main factors:

1. The lead time of electrical equipment, especially large transformers and switchgear can be up to four years, necessitating early project definition and equipment procurement.
2. Campus electrical load could increase with the building projects currently planned and constructed and thus a service increase is required to facilitate this growth without compromising supply reliability. The District 1 Pilot may also add new load to the system and this upgrade should be completed in advance of the district plant coming online.

The phasing of the key steps for featured pathway implementation are listed below.

Short-Term Projects (2025 – 2030)

- Continue to assess buildings for energy conservation opportunities, prioritizing those that reduce thermal demand in buildings that are impacted by the first phase of steam-to-hot-water conversion.
- Update the campus design guidelines to require new building heating systems to operate at <140°F. This enables higher efficiency operations and provides flexibility for future supply options.
- Upgrade campus electrical service capacity and campus feeders.
- Develop building upgrade plan for early phases (e.g., District 1, 2 and 3).
- Complete District 1 building upgrades (e.g., upgrading steam HXs, heating coils, and building piping).
- Install local ASHPs with dedicated hot water piping for District 1.
- Add cooling capacity (e.g., chiller and cooling tower) at the SAT and decommission chillers and cooling towers at the CUP.

Medium-Term Projects (2030 – 2035)

- Continue building upgrades and implement district plants for Districts 2, 3 and 4.
- Prepare the CUP to install heat recovery chillers, pumps, and ASHPs including electrical panel upgrades.
- Optional schedule enhancement: District 3 (and later District 5) implementation would be adjacent to the CUP presenting an opportunity for connection. With installation of ASHPs and pumps (but not WWHPs) the CUP could serve buildings connected to date with hot water.

Long-Term Projects (2035+)

- Continue building upgrades and implement district plants for Districts 4, 5, and 6.
- Install WWHPs, ASHPs, pumps, and auxiliary equipment at the CUP.
- Commission the converted CUP to enable full campus low temperature water and chilled water supply.

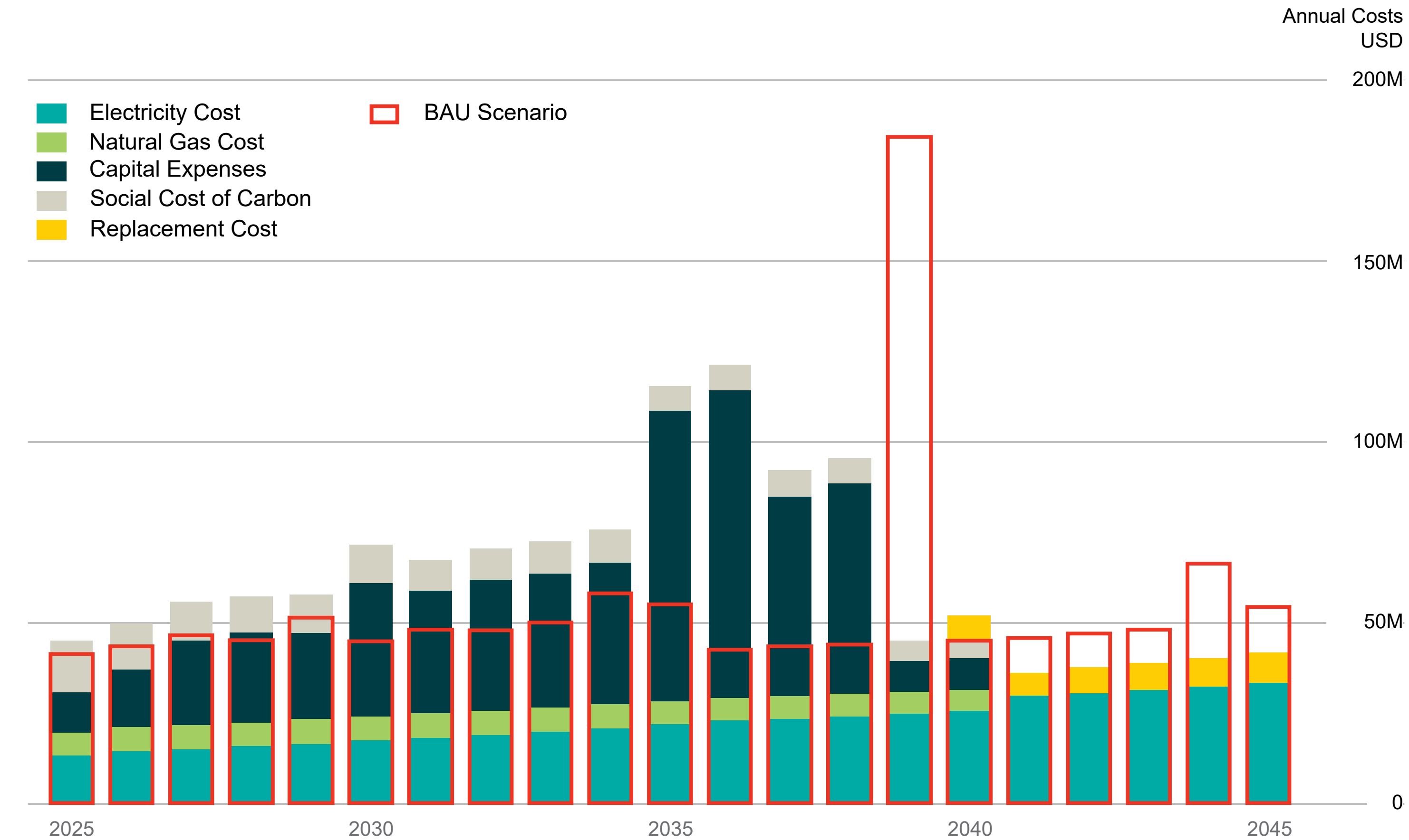


Figure 4-10: Capital Investment per Year for Featured Scenario

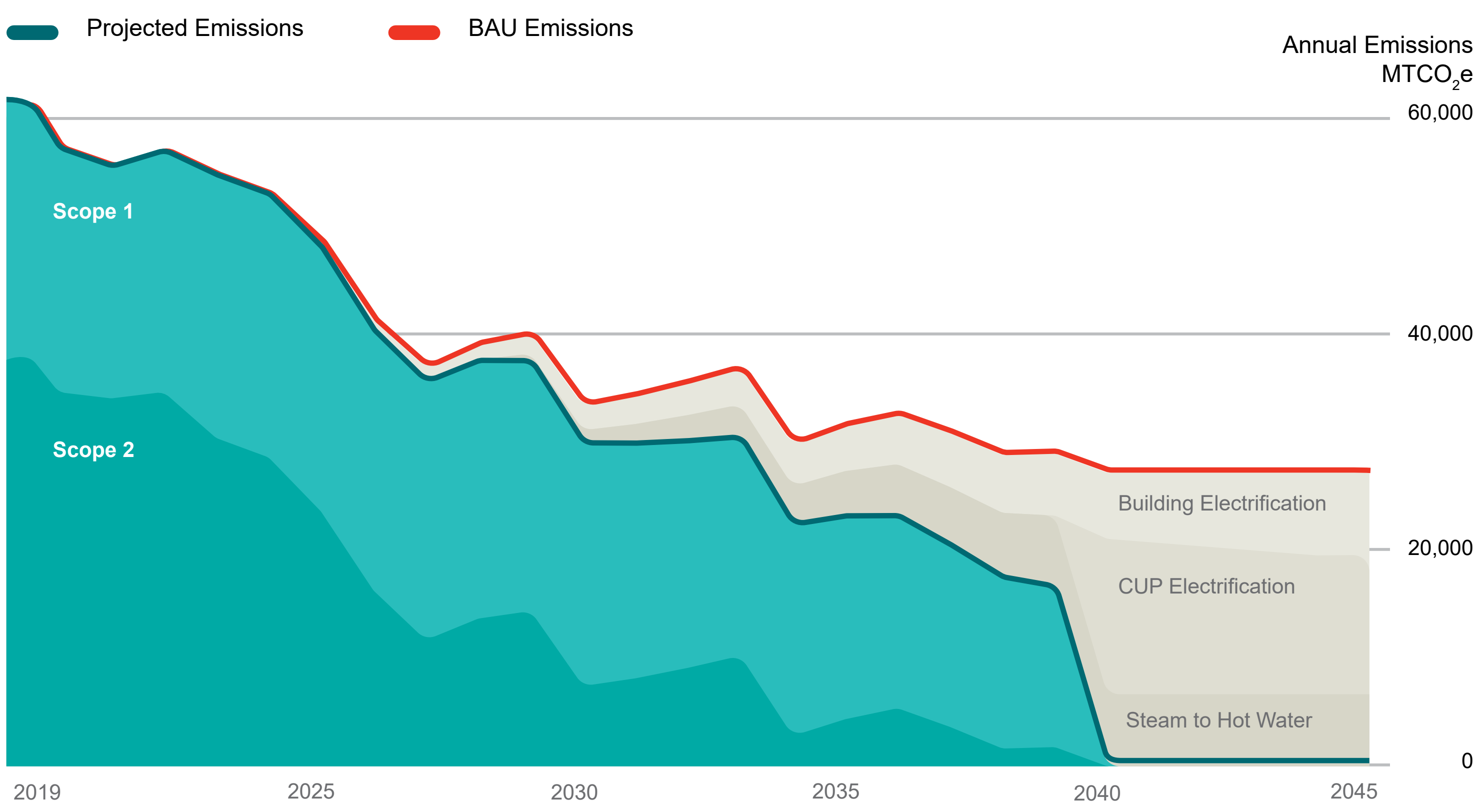


Figure 4-11: Decarbonization Glidepath for Featured Scenario

The featured scenario has a total estimated capital cost of between $350 million and $400 million (in 2024 dollars). When investment is phased in alignment with the example implementation timeline, the total year of expenditure costs would rise to approximately $600 million considering a 6% per year escalation in costs.

The 30-year total cost of ownership of the featured scenario is approximately $300 million greater than the BAU case (2024 dollars). Following the featured pathway rather than the BAU case, the avoided Social Cost of Carbon would be approximately $70 million over 30 years.

Delay in the timeline of project implementation would increase the total cost of implementation as well a significantly reduce the potential environmental benefit of realizing short-term emissions reductions. Figure 4-10 shows this investment allocated by year, aligned with scheduled project implementation.

Figure 4-11 depicts the GHG emissions pathway associated with the featured scenario implementation timeline. If RPU achieves its 2040 clean electricity target, this alone would reduce total annual campus emissions (i.e., Scope 1 and Scope 2) by more than 50 percent; but Scope 1 emissions are projected to increase from 2019 to 2045 as the campus grows.

Building and distribution conversion from steam to hot water systems could eliminate steam losses which are estimated at approximately 10-15 percent of Scope 1emissions. The District 1 Pilot and early stand-along building electrification could also facilitate GHG emissions reductions before 2030. The majority of the Scope 1 savings are not realized until the full central plant electrification is complete. Between 2025 and 2045, building electrification of non-connected buildings would continue at a consistent rate, reducing Scope 1 emissions in proportion to the amount electrified.

With this implementation schedule and RPU's clean energy commitment, building-tied Scope 1 and Scope 2 emissions should meet the 2045 decarbonization goals.. This timeline could be accelerated with the purchase of clean power and or biomethane. This would allow for more rapid emissions reductions but would come at the expense of additional utility costs.

4.5 Future Studies and Considerations

This study of campus decarbonization presents multiple scenarios and one example pathway for meeting the campus' emission reduction goals based on current conditions. Further studies and stakeholder engagement should be undertaken to better inform campus decarbonization decisions as the decarbonization assessment process continues.

Notably, this study only comprises strategies related to the campus building thermal energy supply systems. Future studies could consider implementation of additional energy efficiency measures, on-site distributed energy resources (such as energy storage and solar) and microgrids, transition of campus vehicle fleets (associated with up to 10% of campus Scope 1 emissions), and refinement of understanding of community and equity impacts. These strategies may be implemented alongside the thermal system decarbonization pathway to help accelerate total campus emissions reduction and enhance operational resilience.

Pursuing Living Laboratory opportunities, such as the District 1 Pilot plant covered in this study, may help the campus further explore various decarbonization strategies and refine a potential implementation pathway.

UCR is committed to developing a more sustainable and resilient campus that will allow the university to meet its decarbonization goals. This study provides context and guidance that can aid the UCR stakeholders in further refining a vision and subsequent plan for campus decarbonization.

4.6 Vision Forward

UCR is committed to developing a more sustainable and resilient campus that will allow the university to meet its decarbonization goals. This study steers UCR toward a sustainable future with a strong framework for implementation. The study presents a recommended approach to mitigate Scope 1 emissions of existing and planned growth at the university and sets forth an integrated strategy that has been developed through a strategic energy master planning process. This strategy:

- Reduces the environmental impact;
- Reduces operational costs; and
- Enhances the resilience of UCR operations.

These decarbonization goals and study pathway can only be accomplished through a deliberate and collaborative effort that will involve everyone at the university. Progress toward achieving decarbonization goals should be shared with all relevant stakeholder groups as identified in this process. Stakeholders should jointly determine the frequency of updates and the media by which they are communicated. The initial understanding should be refined by stakeholders to more clearly demarcate how each group contributes to the successful implementation of the roadmap to decarbonization.

Photo Credit: University of California, Riverside.

Appendices

Appendix A – Energy Rates and Schedules

Table A-1 presents the Riverside Public Utilities (RPU) electricity schedules for 2022, 2023, and 2024. Forecasted electricity schedules are publicly available through RPU and are also summarized in Table A-1 for years beyond 2024 through 2028. Table A-2 offers natural gas schedules from SoCalGas for the years 2022 through 2024.

Table A-1 was used to develop hourly utility costs based on modeled data for scenarios. Time of use, holiday off peak hours, and weekend off peak hours were considered in the calculation of electricity costs. Table A-2 was used in the baseline condition for comparison against scenarios.

Table A-1: Electricity Schedules

Year	Flat Charge	Demand Charge (per kW)			Network Access Charge	High Voltage Network Access Charge	Energy Charge (per kWh)		
	> 750 kW	On-Peak	Mid-Peak	Off-Peak	Per max billed kW	Per max billed kW	On-Peak	Mid-Peak	Off-Peak
2022	$5,300	$7.27	$3.64	$1.82	$-	$1.16	$0.11	$0.09	$0.08
2023	$5,300	$7.38	$3.69	$1.85	$-	$1.71	$0.12	$0.09	$0.08
2024	$2,650	$7.66	$3.83	$1.92	$3.87	$2.24	$0.12	$0.10	$0.08
2025	$2,650	$7.97	$3.98	$2.00	$4.85	$3.22	$0.12	$0.10	$0.09
2026	$2,650	$8.29	$4.14	$2.08	$5.83	$4.20	$0.13	$0.11	$0.09
2027	$2,650	$8.41	$4.20	$2.11	$6.81	$5.18	$0.13	$0.11	$0.09
2028	$2,650	$8.58	$4.28	$2.15	$7.77	$6.14	$0.13	$0.11	$0.09

Notes:
kW = kilowatt; kWh = kilowatt-hour

Table A-2: Natural Gas Schedules

Year	Transportation Charges (per therm)				CARB Fee Credit	Cap-and-Trade Cost Exemption
	Tier 1	Tier 2	Tier 3	Tier 4	Per therm	Per therm
2022	$0.40	$0.29	$0.22	$0.17	$0.00577	$0.06014
2023	$0.43	$0.31	$0.23	$0.18	$0.00300	$0.05506
2024	$0.53	$0.41	$0.34	$0.29	$0.00231	$0.17484

Note:
CARB = California Air Resources Board

Appendix B – Technology Assessment Summary

As shown in Table B-1, each key performance indicator (KPI) was assigned a "weighted importance" factor, with 1 being the factor of lowest importance to University of California, Riverside (UCR) and 5 being the highest. Based on the understandings of UCR's decarbonization goals, infrastructure limiting factors, funding constraints, willingness to experiment, etc., the weighted importance factor defines how important each KPI is for UCR's considerations. At the time of this study's publication, technical maturity, extreme cost, and scale of capacity are the most important KPIs to consider for UCR's needs. The importance of the KPIs may change as the campus' needs fluctuate. The "adjusted (adj.) weighted total" considers the technology's performance under each KPI and the weighted importance of the KPI; this is the metric used to compare the performance of technologies.

Table B-1: Weighted Importance Factors of Key Performance Indicators

	Technical Maturity	Extreme Cost	Scale of Capacity	Ability to Reduce GHG	Market Readiness	Scale of Disruption or Enabling Work	Adj. Weighted Total
Weighted Importance >> 1 (low) to 5 (high)	**5**	**5**	**5**	**4**	**3**	**2**	
Hot Water Plant							
Water to Water Heat Pumps (WWHP)	5	3	4	5	5	5	**4.4**
Thermal Energy Storage (Day/Seasonal)	5	3	5	4	5	5	**4.4**
Air Source Heat Pumps (ASHP)	5	3	4	5	5	4	**4.3**
Ground Source Heat Pumps (GSHP)	5	2	4	5	5	3	**4.0**
Electric Boilers	5	1	5	5	5	1	**3.8**
Seasonal Thermal Energy Storage	5	1	4	4	5	3	**3.6**
Solar Thermal Heat Pumps	5	2	1	3	5	3	**3.0**
Steam Plant							
Electric Boilers	5	2	5	5	5	1	**4.0**
Alternative Fuels - H2 Storage & Distribution	3	3	3	3	4	3	**3.1**
Alternative Fuels - Biofuel	4	3	2	2	5	3	**3.1**
Other - Steam Thermal Energy Storage	3	3	3	3	3	4	**3.1**
Other - Steam Heat Pumps	3	3	2	2	3	5	**2.8**
Other - Carbon Capture	2	2	2	3	2	3	**2.3**
Deep Geothermal	2	1	5	5	2	1	**2.8**
Concentrated Solar	2	2	2	5	3	1	**2.5**
Small Modular Reactors (Nuclear)	1	1	3	5	2	3	**2.4**
Building Level Solutions							
Heat Exchangers	5	4	5	5	5	4	**4.7**
Local WSHP (tied to Condenser Loop)	5	4	4	5	5	3	**4.4**
Process Steam Decentralization	5	3	5	5	5	3	**4.4**
Local Electric (ASHP/GSHP)	5	3	3	5	5	2	**3.9**

Table B-2 contains the rubric for each KPI scoring applied to each technology, and Table B-3 provides the scoring criteria for NASA's Technology Readiness Levels.

Table B-2: Technology KPIs Scoring Rubric

Level	Technology Readiness	Level	Market Readiness
1	Basic principles observed and reported	1	Basic market need observed
2	Technology concept and/or application formulated	2	Market needs for a specific target market articulated
3	Analytical and experimental critical function and/or characteristic proof of concept	3	Market needs validated through preliminary demonstration
4	Component and/or breadboard validation in laboratory environment	4	Product attributes and features established
5	Component and/or breadboard validation in relevant environment	5	Other product dimensions of price, place, promotion established
6	System/subsystem model or prototype demonstration in a relevant environment	6	Product concept tested in intended market. Market size verified
7	System prototype demonstration in an operational environment	7	Product acceptance demonstrated in market trial
8	Actual system completed and qualified through test and demonstration	8	Produce feature validated in test market

Table B-3: NASA's Technology Readiness Levels

KPIs	1 Base	2 Low	3 Medium	4 Medium-High	5 High
Technology Readiness	NASA Technology Readiness Ranking of 1	NASA Technology Readiness Ranking of 2-3	NASA Technology Readiness Ranking of 4-5	NASA Technology Readiness Ranking of 6-7	NASA Technology Readiness Ranking of 8-9
Market Readiness	NASA Market Readiness Ranking of 1	NASA Market Readiness Ranking of 2-3	NASA Market Readiness Ranking of 4-5	NASA Market Readiness Ranking of 6-7	NASA Market Readiness Ranking of 8-9
Cost	Greater than 2x Conventional Cost	1.5-2x Conventional Cost	Up to 1.5x Conventional Cost	Up to 1x Conventional Cost	Conventional Cost
Scale of Disruption	Strategy not implemented	Requires substantial revisions to existing design concepts	Can be integrated into existing designs with moderate revisions	Can be integrated into existing designs with some revisions	Very easily integrated into existing designs
Scale of Capacity	Strategy not implemented	Limited applicability across campus	Applicability to some parts of campus	Applicability to half of campus	Wide applicability across campus
Ability to Reduce GHG	BAU (Baseline)	50%	75%	90%	100%

Table B-4 presents the decarbonization technologies considered in terms of the following evaluation factors: technological maturity and market readiness, equipment cost, associated fuel cost, space requirement, subject equipment capacity, and subject supply temperatures.

Table B-4: Summary of Shortlisted Technological Solutions

Technologies Considered	Maturity and Readiness	Equipment Cost	Fuel Cost	Space	Capacity	Supply Temperature
WWHPs (WSHPs)	Available	$2 to $2.5k/ton	Not Applicable	Indoor, Medium	400 to 2,000 tons	120°F to 180°F+
ASHPs	Available	$2 to $2.5k/ton	Not Applicable	Outdoor, High	200 to 400 tons (per bank)	115°F to 140°F+
TES	Available	$10 to 15/Gal	Not Applicable	Ind./Out., High	1 to 2 Mgal	< 200°F
Electric Boilers	Available	$9 to 14k/ton	Not Applicable	Ind./Out., Med.	5,000 to 50,000 kBtu/h	< 250 PSI steam
Biomethane	Available	Not Applicable	$17 to $26/MMBtu	Not Applicable	Not Applicable	< 250 PSI steam
Hydrogen	Available	Not Applicable	$52 to $70/MMBtu	Outdoor, High	Not Applicable	< 250 PSI steam
Steam Heat Pumps	Developing	$58 to $63k/ton	Not Applicable	Ind./Out., High	25,000 to 50,000 kBtu/h	85 PSI
Steam TES	Developing	$8 to 13k/ton	Not Applicable	Ind./Out., High	500,000 MMBtu	80 PSI
Heat Exchangers	Available	$3 to 5k/ton	Not Applicable	Indoor, Low/Med.	Building Load	Any
Local WSHP	Available	$3.5 to $5k/ton	Not Applicable	Indoor, Medium	400 to 2,000 tons	110°F to 150°F+
Local ASHP	Available	$2.5 to $5k/ton	Not Applicable	Outdoor, Medium	20 to 60 tons	115°F to 130°F+
Process Steam Decentralization	Available	$10 to $300k/autoclave	Not Applicable	Outdoor, Medium	20 to 60 tons	Not Applicable

Notes:
ASHP = air source heat pumps; °F = degrees Fahrenheit; Ind. = Indoor; k = thousand (e.g., $2.5 = $2,500); kBtu/h = thousand British thermal units per hour; Med.= Medium; Mgal = million gallons; MMBtu = million British thermal units; Out. = Outdoor; PSI = pounds per square inch; TES = thermal energy storage; WSHP = water source heat pump; WWHP = water-to-water heat pump

Appendix C – Long Range Development Plan Projects

Table C-1: Long Range Development Plan Projects

Building	Completion Year	Single Use	Estimated GFA
Multidisciplinary Research Building 1	2019	Research	201,100
Plant Research 1	2021	Research	28,200
Student Success Center	2021	Learning	80,000
Student Health and Counseling Center	2023	Healthcare	42,300
School of Medicine Education Building 2	2023	Learning	95,500
School of Business	2024	Learning	63,400
North District Phase 1 – Housing	2021	Housing	539,988
North District Phase 2 – Housing	2025	Housing	436,000
Opportunities for Advancement, Social Inclusion and Sustainability Park	2026	Research	45,000
Undergraduate Teaching and Learning Facility	2026	Learning	101,000
CDI	No Details	Learning	70,000
Advancement Center (ARENA) Ph 1	No Details	Research	No Details
Residence Hall	No Details	Housing	No Details
UCR Agricultural Research, Education and Neighborhood Advancement Center (ARENA) Ph 2	No Details	Research	No Details
Undergraduate Teaching and Learning Facility 2	No Details	Learning	No Details
Undergraduate Teaching Greenhouses	No Details	Learning	No Details
Multispecialty Ambulatory Clinic	No Details	Healthcare	No Details

Notes:
ARENA = Agricultural Research, Education and Neighborhood Advancement Center; GFA = gross floor area (square feet); UCR = University of California, Riverside
Source: https://lrdp.ucr.edu/sites/default/files/2021-11/2021lrdp-final_0.pdf

Appendix D – Life Cycle Cost Assessment Assumptions

General Assumptions

- Electricity costs associated with decentralized systems for buildings (Scenario 4) connected to the CUP are assumed to be 15 percent more than electricity costs associated with steam-to-hot-water conversion with neighborhood heat pumps (Scenario 2C).
- Indirect and soft costs validated by AECOM cost estimating team and discussion with UCR facilities team.
- Additional 20% added to building level retrofit costs based on UCR's previous experience of unforeseen project costs
- The cost estimation factors used in the life cycle cost analyses of this study were developed in alignment with guidance from the Pathways to a Fossil Free UC Task Force and UC Riverside project team members, as applicable. Life cycle cost estimates presented in this study are reflective of the values identified in this appendix.

Table D-1: Indirect Costs

Indirect Costs (Multiplier of 73 Percent)	
Design and Construction Contingency	30%
General Contractor General Requirement and Conditions	10%
Insurance and Bonding	2.5%
General Contractor Home Office Overhead and Profit	7.5%
Phasing Allowance/Temporary Work	10%

Table D-2: Soft Costs

Soft Costs (30 Percent)	
Project Management	
Construction Administrative Services	5%
Professional Fees	
Design and Engineering	8%
Owner-Furnished-Contractor Installed Design and Procurement	1%
Surveys, Tests, and Inspections	1%
Third-Party Commissioning	1%
Fees and Assessments	
Permits and Inspection	1%
Entitlements and Planning Fees	1.5%
Utility Connection Fees	0.5%
Community Workforce Agreement	1%
Project Design Contingency	5%
Other	5%

Table D-3: Discount and Escalation Rates

Rate	
Discount Rate	4.25%
Escalation Rate – Electricity Year 1	6.6%
Escalation Rate – Electricity Year 2	6.3%
Escalation Rate – Electricity Year 3+	4.3%
Escalation Rate – Electricity Year 3+ (Alternative 1.B Phased only)	3%
Escalation Rate – Natural Gas	3.0%
Escalation Rate – Hydrogen	0%
Escalation Rate – Biomethane	2.0%
Escalation Rate – Social Cost of Carbon	1.5%
Escalation Rate - CapEx	6%

Table D-4: Resource Costs

Resource	Cost
Electricity (2023)	$0.12/kWh
Natural Gas (2023)	$1.3/therm
Renewable Natural Gas	$21-24/MMBtu
Hydrogen	$6-8/kg
Social Cost of Carbon (2020)	$246/MTCO2e[23]

Notes:
kWh = kilowatt-hour; MMBtu = million British thermal units; MTCO2e = metric tons carbon dioxide equivalent

Table D-5: Equipment Replacement Assumptions

Equipment	Replacement Timeline	Cost
ASHP	Every 15 years	Same as capital cost (low)
WSHP	Every 25 years	Same as capital cost (low)
Boiler	Every 20 years	Same as capital cost (low)
Steam heat pumps	Every 15 years	Same as capital cost (low)
Existing steam pipes	Every 5 years for the next 35 years	Same as estimated capital cost for hot water pipes

Notes:
ASHP = air source heat pumps; WSHP = water source heat pump

23 UC Social Cost of Carbon also available at https://sustainability.ucsc.edu/initiatives/social-cost-carbon

Appendix E – Modeling Processes and Assumptions

For the qualitative metrics that support the evaluation criteria, detailed systems modeling was undertaken. It consisted of three phases:

- Data collection and conditioning – accessing, reviewing, and filling the gaps in existing building characteristics and operational trend data
- Demand projections – modeling future demand growth to serve as a reference for equipment sizing life cycle analysis of emissions and cost performance
- Systems and scenario modeling – evaluating the impact and performance of each combination of technologies with the goal of refining scenario configurations and determining the best decarbonization pathway

Demand Projections

Projection of Future Demand

Determination of future peaks is critical for understanding how the campus could grow and what is required to accommodate that growth. The Long Range Development Plan (LRDP) was used as a guiding post for projecting the future growth and demand of the campus; however, AECOM recognizes through stakeholder engagement that the actual growth may be less. University of California (UC) Benchmarks and Commercial Building Energy Consumption Survey (CBECS) space type energy-use intensities, combined with the floor area of campus buildings, allowed for calculation of energy use through 2045.

Energy loads are modeled from the baseline year through 2045 by incorporating general building characteristics, estimated projects outlined in the LRDP, University of California, Riverside (UCR) whole building energy performance benchmarks outlined in the UC Sustainable Practices Policy[24], and assumed future loads to understand future peak load.

- Once the projection model estimates what the campus may need in terms of energy requirements to meet future loads, scenarios are developed to demonstrate how UCR can meet future energy requirements while attaining greenhouse gas (GHG) reduction goals.
- Future growth, utility rates, and trend data were gathered from UCR to be used as inputs for modelling the load and validating the model against real data.

Campus Space Growth

The LRDP provides guidance for the physical development of the campus, including types of development and land uses, facilities expanded, and new program initiatives. The LRDP projects space needs based on enrollment growth and operational funding. Figure E-1 lists the different space types across campus and illustrates how much assignable area is allocated in 2018, how much growth area is expected by the end of 2026, and how much growth is projected through 2035. The LRDP is considered a guide rather than a plan; realized development is likely to differ, but it was considered an appropriate source for this analysis to consider the high end of potential load growth. The LRDP allocates approximately 3.2 million square feet (MSF) for new growth by 2035; of that, nearly 2 MSF is programmed by 2026. LRDP projects considered in the projection analysis are provided in Appendix C.

UC Benchmarks

The 2023 UC Sustainable Practices Policy sets whole-building energy performance targets that are expressed as a percentage of total annual electricity and thermal targets, as developed for the UC Building 1999 Energy Benchmarks by Campus. For any planned development, these whole-building energy performance compliance targets were applied and accounted to determine future energy consumption.

Weather Projections

Future thermal demands of the campus (i.e., heating and cooling demands) are driven by the load changes forecast in the LRDP, along with projected weather characteristic changes due to climate change. Climate change is impacting the amount of time that heating and cooling systems should operate, with systems running longer to provide more degrees of heating or cooling.[25]

Figure E-3 summarizes the projection modeling methodology.

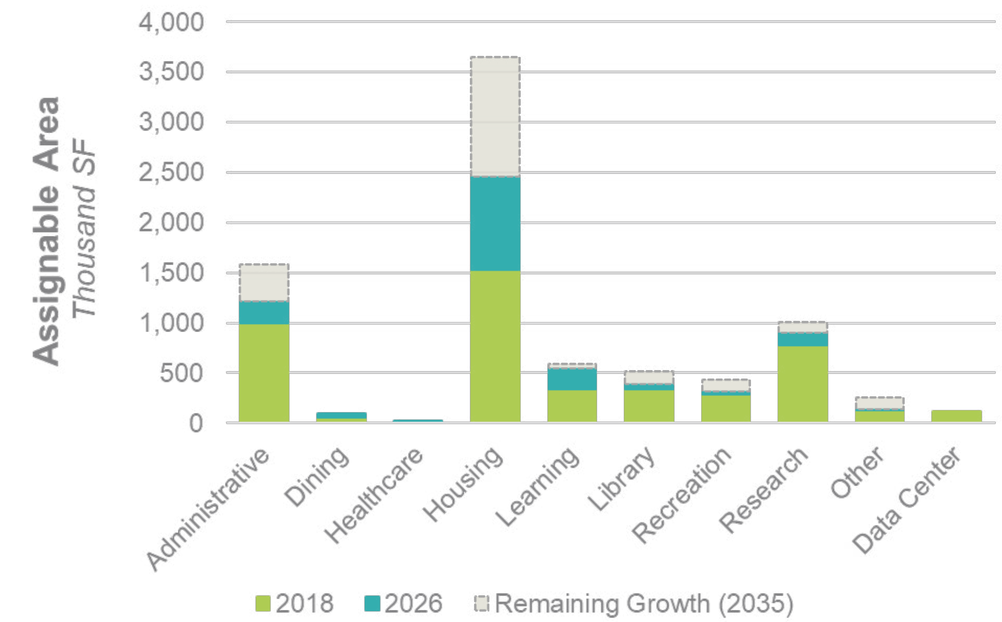


Figure E-1: Assignable Area for LRDP Projects

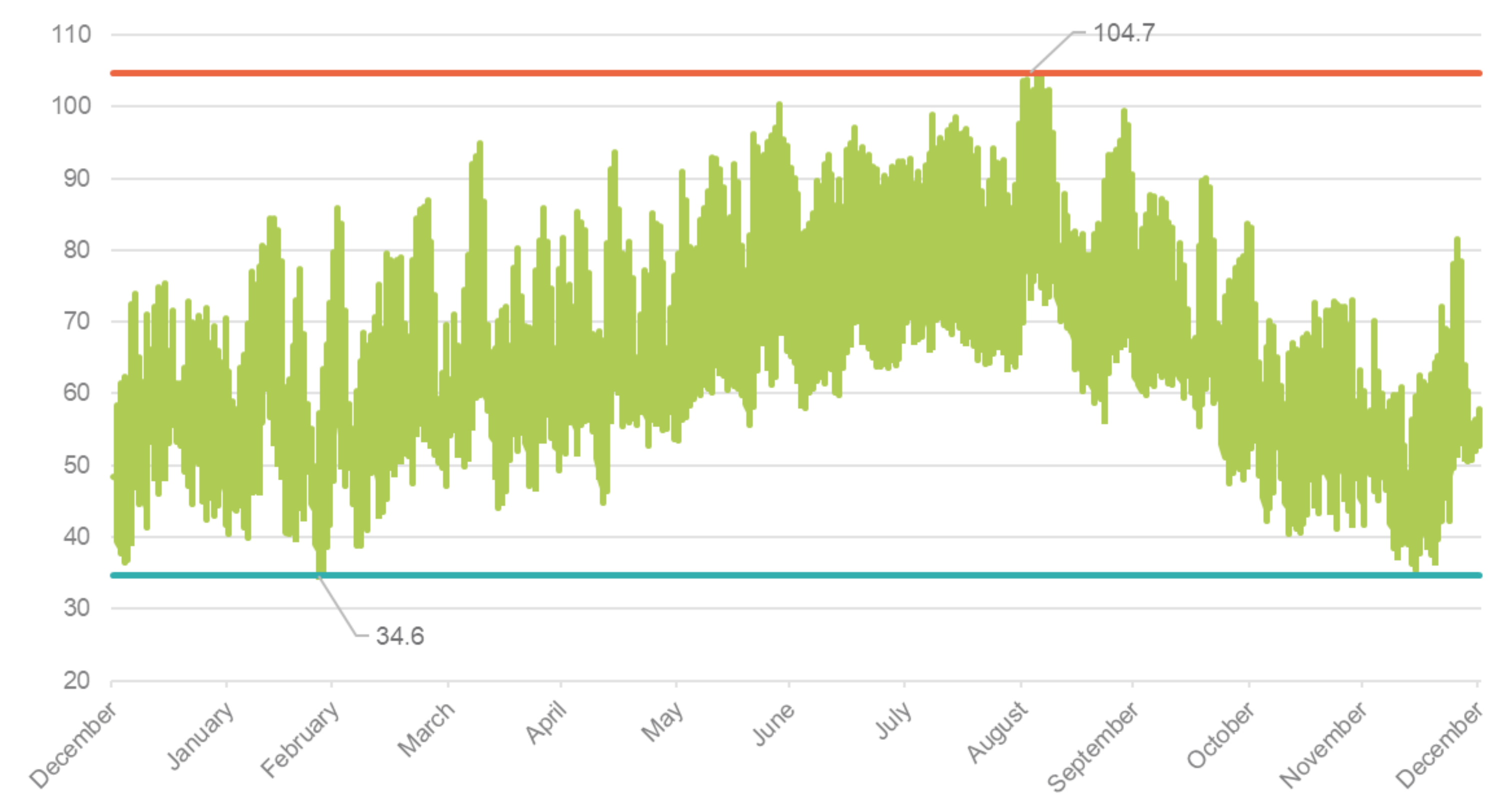


Figure E-2: Hourly Weather Profile for Riverside in 2022

24 University of California. 2024. Sustainable Practices Policy: All Campuses, Health Locations, and the Lawrence Berkeley National Laboratory. April 10. Available online at: https://policy.ucop.edu/doc/3100155/SustainablePractices.
25 Joseph C Stagner, an energy consultant, documented a Fossil Fuel-Free Pathway Plan (FFFPP) for the UC system in February 2024 that analyzed long-term weather trends and potential impacts to campus heating and cooling loads.

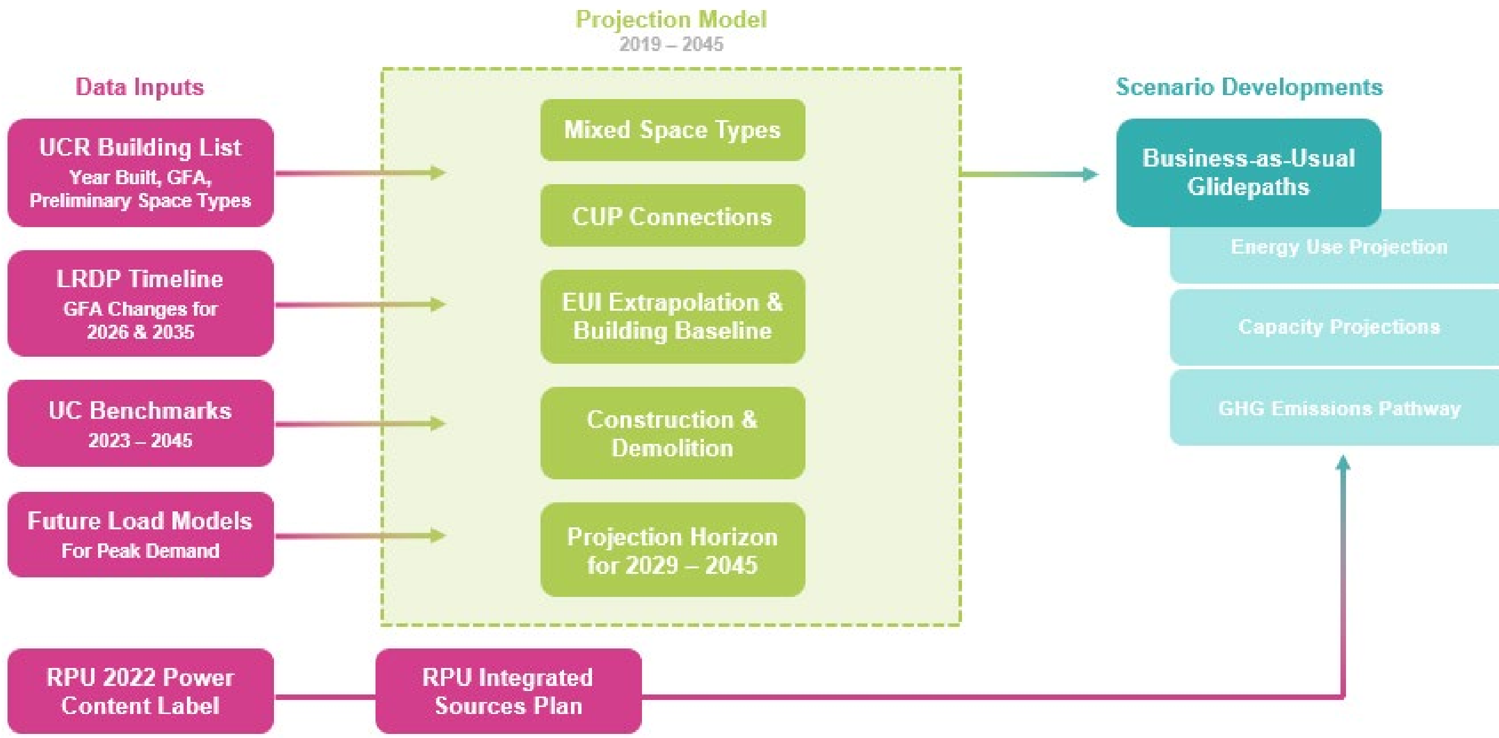


Figure E-3: Projection Methodology Flowchart

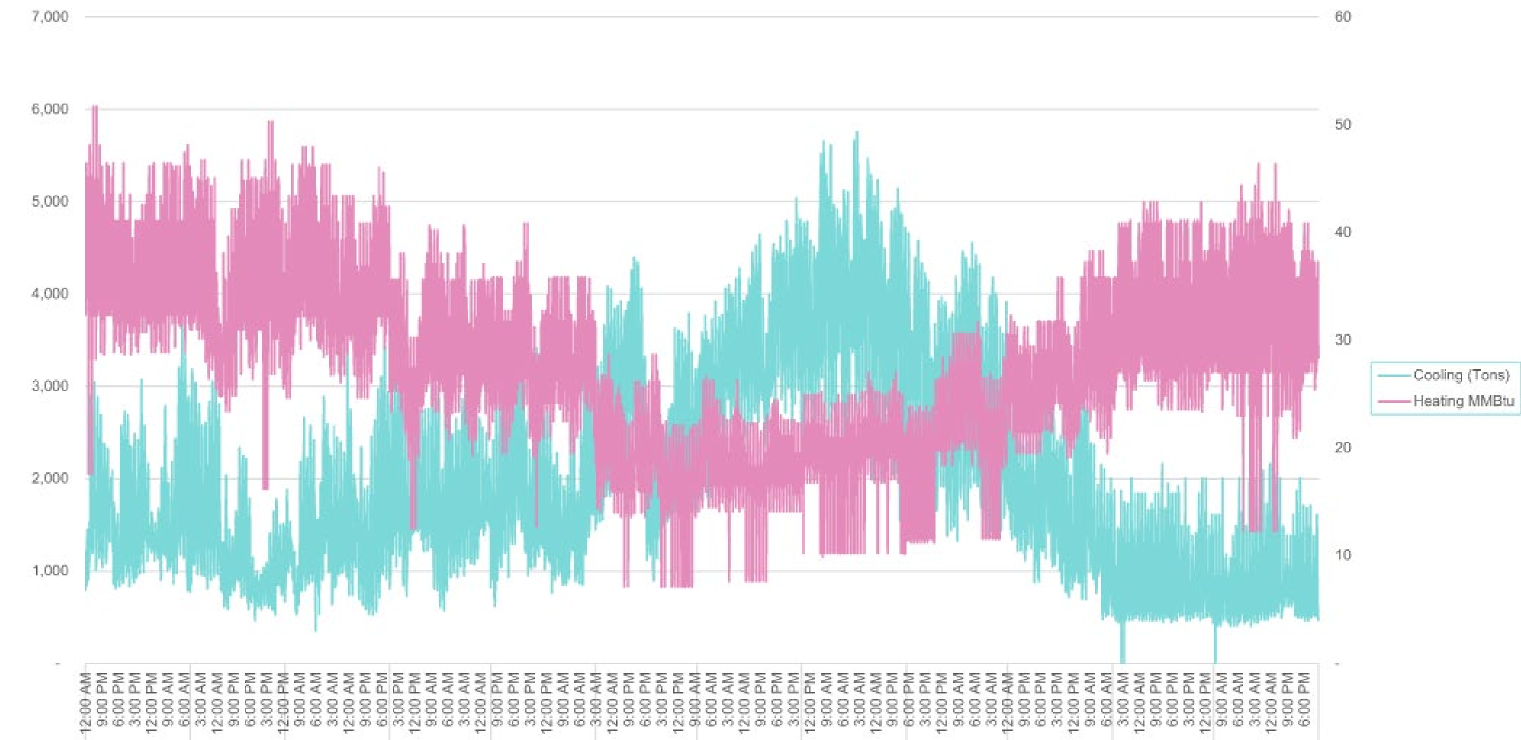


Figure E-4: Hourly Demand Profile for Heating and Cooling

Baseline CUP Load Modeling

- Heating
  - Data for four buildings (Olmstead, Rivera, Sproul, and the Science Library) was available with nearly comprehensive hourly data for 2018.
  - A weather model was developed based on the loads of these four buildings and the weather profile for 2018. This model removed process loads by cutting out load based on the peak for the month.
  - The profile created was then upscaled to the campus level using a factor based on the floor area of the buildings vs. the floor area of the campus.
  - Using the created model, it was applied to the 2022 weather profile for Riverside to model the 2022 campus load.
  - In the model, Olmstead was weighted more heavily than the others as its profile had less baseload and resulted in a more realistic usage profile.
  - This was validated against daily data.
- Cooling
  - Similar to heating, a weather model was made based on Olmstead, Rivera, Sproul, and the Science Library. The methodology for generating the load was the same as heating except all buildings were weighted
  - The resulting profile was validated against thermal energy storage data.

Systems and Scenario Modeling

The modeled load was then used to evaluate scenarios based on different equipment specifications, as well as utility cost and GHG emissions inputs.

Factors considered in the scenario modeling include:

- Size and configuration of equipment and associated capital and operational costs;
- Efficiency of equipment and resultant impact on energy use, utility costs, and emissions;
- Infrastructure limitations (e.g. electrical transformers); and
- The quantity and location of available land or roof area.

From those generated scenarios, a featured scenario was identified based on its economic and physical characteristics.

Universal Scenario Assumptions

The following components were considered in the analysis in the same way across each of the scenarios.

- Campus Demand Growth
  - For UCR, the technical review determined that the annual heating load is projected to decrease by 1.2 percent per year, and the annual cooling load is projected to increase by 1.6 percent per year. Excerpts of the heating and cooling trends and projections from the report and weather profile are represented in Figure E-1 and Figure E-2.
  - Peak heating demand is projected to increase by 13 percent in 2035 compared to peak heating demand in 2022; peak cooling demand is projected to have a 41 percent increase for 2035.

- 20 percent improvement in heating equipment COPs is assumed, while cooling is assumed to have no improvement due to already having very high efficiency near limits.
- 41 percent increase in campus floor area is assumed based on the LRDP.

- Approach to non-Central Utility Plant (CUP) connected buildings (both heating, electrical, and process equipment):
  - It is assumed that all non-connected building heating, hot water, and process systems would be replaced with an electrified alternative.

- Electrification
  - The average efficiency of existing boilers is assumed to be 95 percent efficient, such that 100 thousand British thermal units (kBtu) of natural gas consumed provides 95 kBtu of useful heat.
  - Air source heat pump efficiency was assumed to have an average coefficient of performance (COP) of 3, based on the warm climate of the UC Riverside environs such that a heat pump must use 30 kBtu (8.8 kilowatt-hours) to produce 90 kBtu of useful heat.
  - This provides an improvement ratio of 3.16, calculated by dividing the heat pump COP by the boiler COP, which was used to determine the increase in electricity that would result from converting from gas to electric equipment; gas use was divided by the improvement factor to get the electricity increase.

- Requirement for a new electrical service to serve the campus:
  - Due to existing campus capacity limitation, a new service (consisting of two new transformers in University substation) are assumed to be required under each scenario.
  - Assessment of fleet electrification was not in scope but was assumed to be consistent across all scenarios and would contribute to the need for new electrical service.
  - It is assumed that new 12.47-kilovolt (kV) service, switchgear, and duct banks will be required to accommodate new development that would adhere to the 2023 UC Sustainable Practices Policy. The new transformers and 12.47 kV service are assumed to be situated in the existing substation yard. A new substation is not included in the cost estimate but may be recommended for enhanced campus resilience.

- Emissions
  - Riverside Public Utilities' (RPU's) portfolio emissions will reach to zero by 2040[26]. Linear interpolation between known values is used to create a year-by-year projection of electricity emissions factors.
  - The 2022 electricity emissions were determined from RPU's Power Content Label.
  - For Scope 1 emissions, 0.05291 $MTCO_2e$/MMBtu[27] is used based on data from the EPA.

- Steam to Hot Water Conversion
  - Heat exchangers are assumed to produce 33 British thermal units per hour per square foot.
  - Building hot water piping is estimated based on the building footprint and could vary significantly due to the location of mechanical rooms relative to the steam system building entrance.
  - Estimated coil replacement is based on the number of air handling units identified from the previous Tier II Energy Assessments.

- The approach to process and auxiliary steam and natural gas electrification.
- Concerning utility rates and escalation, all life cycle cost assessments and sensitivity analyses used consistent assumptions, which can be found in Appendix A.
- Energy conservation and demand reducing projects.
- Heat recovery chiller COPs from Development of District Energy System Electrification options
  - Example COP calculation – 1.28 kilowatts (4,356 Btu) input for 12,764 Btu Cooling output and 17,120 Btu at 145F output = COP 6.9 ((17,120 + 12,764)/4,356)

26 City of Riverside Public Utilities. 2024. 2023 Riverside Public Utilities Integrated Resource Plan. January 31. Available online at: https://riversideca.gov/utilities/sites/riversideca.gov.utilities/files/pdf/2023%20Riverside%20Public%20Utilties%20Integrated%20Resource%20Plan_Final.pdf.

27 United States Environmental Protection Agency. EPA Center for Corporate Climate Leadership. Emission Factors for Greenhouse Gas Inventories. June 5. Available online at: https://www.epa.gov/system/files/documents/2024-02/ghg-emission-factors-hub-2024.pdf.

Appendix F – Evaluation Metrics

Greenhouse Gas Emissions Reduction

Definition

Greenhouse gas (GHG) emissions reduction is the decline in Scope 1 (direct) and Scope 2 (indirect) GHG emissions associated with heating, cooling, and electricity of campus operations.

Metrics and Assessment Methodology

The annual fuel use of each scenario (covering electricity, natural gas, biomethane, and hydrogen) was quantified and then multiplied by their respective emissions intensities to estimate annual emissions.

Electricity (Scope 2) – Electricity emissions are the only factor that was time-dependent in this assessment, reflecting the forecasts of more clean energy contribution in generation. Two different emissions profiles were used to help quantify the value of adopting the University of California Clean Power Program (100 percent clean energy) compared to continued use of Riverside Public Utilities (RPU) power. Emission factors of RPU were estimated following trends of RPU's 2023 Integrated Resources Plan which forecasted total portfolio emissions through 2030 and a linear interpolation between 2030 and 2040, when RPU is targeting 100 percent clean energy.

Fuels (Scope 1) – Emissions factors for natural gas, biomethane, and hydrogen are sourced from the Energy Information Administration.[28] Natural gas was the primary fuel used by the campus, and its emissions factor was applied to the projected gas use of the campus for each year to estimate the overall emissions. For Scenario 4 – Alternative Fuel Central Steam Plant, an emissions factor of zero was used to represent biomethane's renewability. Hydrogen, if paired with carbon capture, was also assumed to have an emissions factor of zero. Without carbon capture, the International Energy Agency reports about 12 to 13 kilograms of carbon dioxide equivalent per kilogram of hydrogen gas on average as of 2021.[29]

Life Cycle Cost

Definition

Life cycle cost (LCC) assessment is a method for estimating the total cost of a project over its lifetime or period of assessment. The assessment considers costs associated with the project, including initial costs, future costs, and any residual value (where applicable). Projected utility costs consider the prices of electricity, natural gas, and the social cost of carbon (SCC)[30] to change over time inflated by defined escalation rates.

Capital Cost refers to the capital expenses associated with technology transitions.

Utility Cost refers to costs associated with purchasing resources from utilities for the campus, considering commodity and demand charges.

Replacement Cost refers to renewal costs for equipment with an anticipated asset life less than the study period.

Avoided Cost is the cost of replacement in the baseline case. This is compared against the replacement cost to determine what the savings or additional cost would be when looking at replacements for equipment.

Operations and Maintenance Cost account for additional labor or materials required with a strategy compared to the current level of effort to maintain the existing Central Steam Plant (e.g., decentralized heating systems require more labor hours to adequately maintain them).

Energy Procurement Costs are costs associated with procuring cleaner energy (e.g., electricity and natural gas) resources per year driven by University of California Office of the President (UCOP) assumptions.

Social Cost of Carbon estimates in dollars the economic damages related to emitting one additional metric ton of carbon dioxide into the atmosphere. This metric quantifies economic implications of the effects of climate change and is derived by UCOP assumptions.

Metrics and Assessment Methodology

In addition to reporting capital, utility, replacement, energy procurement, operations and maintenance costs, and the SCC, the following metrics were evaluated and presented for each scenario for LCC comparison.

Total Cost of Ownership estimates the direct and indirect costs associated with the purchase, operation, and maintenance of an asset over 30 years. This is used to compare scenarios on an even playing field to determine which scenario would cost the least.

Net Present Value evaluates the profitability of an investment or project and considers the time value of money. This is similar to total cost of ownership, which is used to compare the overall costs of each scenario and determine the best value scenario.

Utility Cost Metrics incorporated time of use costing schedules.

Capital Costs were marked up with an applied multiplier of 1.73 for indirect construction costs and an additional multiplier of 1.30 for project soft costs. Labor costs were also included in capital costs.

Detailed LCC assessment assumptions are included in Appendix A

Annual and Peak Resource Use

Definition

"Annual resource use" refers to the total amount of utility resources (e.g., natural gas, electricity, or water) consumed over the course of a year; "peak resource use" refers to the greatest amount of resources consumed during the year. Annual resource use aids in understanding overall energy needs. Peak resource use, particularly peak energy use, is crucial for understanding the maximum demand placed on energy systems to ensure systems are adequately sized and operating at maximum efficiencies. Water resource use, although not a direct impact on Scope 1 emissions reduction, is important to track to be conscious of overall sustainability impacts and to identify irregularities with energy systems using water.

Metrics and Assessment Methodology

Total annual consumption of electricity, documented in kilowatt-hours; and natural gas, documented in thousand British thermal units, were quantified to be converted into equivalent Scope 1 and Scope 2 emissions and project electricity and natural gas use for future years, based on future energy-use intensities and space type growth.

Peak electricity demand, reported in kilowatts, was estimated for future years to determine the cost of the electrical distribution upgrades for the campus. The peak data were sourced from the 2022 and 2023 15-minute data shared by University of California, Riverside (UCR).

Annual water use was used to illustrate the benefits of using different technologies. By reducing water use, UCR can reduce water costs and improve drought resilience.

Resilience and Reliability

Definition

Each scenario considered the benefits of resilience and reliability. Resilience is the ability to quickly recover from disruptions caused by natural disasters, technical

28 United States Energy Information Administration. 2023. Carbon Dioxide Emissions Coefficients. September 7. Available online at: https://www.eia.gov/environment/emissions/co2_vol_mass.php.
29 International Energy Agency. 2023. Towards hydrogen definitions based on their emissions intensity. Available online at: https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity/executive-summary.
30 UC Santa Cruz. 2023. Social Cost of Carbon. May 30. Available online at: https://sustainability.ucsc.edu/news-events/news/s-cost-carbon-2023.html#:~:text=The%20UC%20is%20utilizing%20the,with%20a%201.5%25%20escalation%20rate.

failures, or human-made incidents. Reliability is the ability of utility infrastructure to consistently deliver resources to end users without interruptions.

Metrics and Assessment Methodology

Some of the metrics, like equipment redundancy, supply redundancy and diversity, and islandability, are quantifiable; the remainder can be qualitatively tracked.

Equipment Redundancy refers to extra equipment in the system that is available for backup when there is a local equipment failure or maintenance requirement reflected. Equipment redundancy is reported by the minimum number of components required to handle the system's full load under normal conditions (N) and the additional components that act as a backup (+1, +2, +3, etc.), which can take over the load if any of the primary components fail.

Supply Redundancy and Diversity refers to supply pathways available, quantified by the number of alternative supply routes.

Hardness refers to the ability to withstand local hazards or cyberattacks without disruption. This is qualitatively related to exposed infrastructure.

Islandability refers to the system's ability to be operational without direct off-campus connection, measured by the amount of onsite storage and generation.

Serviceability refers to the availability of the local workforce and/or vendor support to adequately commission and maintain the system. This is qualitatively observed.

Recovery refers to the system's ability to be controlled and automated for rapid recovery. This is qualitatively observed.

Ease of Implementation

Definition

Ease of implementation relates to the degree of simplicity, practicality, and effort necessary to phase and integrate any given scenario into the UCR campus over time. These criteria consider the potential impacts on individual buildings and on the overall campus, along with the extent of necessary disruption on campus activities.

Metrics and Assessment Methodology

Spatial Requirements refers to the total square footage and campus value of land required to implement a scenario.

Disruption refers to the recorded length of time that projects of a scenario impact, inhibit, or halt campus operations. This is measured in the preferred units of time (e.g., days, weeks, or months); and in scale of operations compromised, in terms of number of buildings, percent loads, or other.

Speed refers to the recorded length of time to complete projects or phases in a scenario, measured in the preferred units of time (e.g., days, weeks, or months).

Equipment Procurement refers to the availability and lead time for equipment to be acquired and installed, measured in the preferred units of time (e.g., days, weeks, or months).

Environmental Justice and Equity

Definition

Environmental Justice and Equity refers to the fair distribution of environmental benefits and burdens of implemented scenarios across the UCR campus and adjacent neighborhoods and communities.

Metrics and Assessment Methodology

Public Health refers to the benefits and impacts associated with air and water quality that result from technology and infrastructure changes. This is measured either by using air and water quality metrics or by qualitatively observing the effects.

Workforce Equity refers to job opportunities and risks for low-wage workers associated with a technology or infrastructure transition. This is qualitatively documented.

Supply Chain Equity refers to opportunities and risks related to fair labor practices associated with infrastructure transition. This is qualitatively documented.

Community Support and Stewardship refers to support for community members for types of infrastructure, or opportunities for co-design or Living Laboratories, through platforms such as listening sessions, surveys, or previous efforts that UCR has deployed for community engagement.

Construction Impacts refers to potential disruptions related to constructing new infrastructure, such as noise, traffic, and length of construction time. This is qualitatively reported.

Community Impacts refers to potential disruptions related to operating and maintaining new infrastructure, such as noise, traffic, or trucks. This is qualitatively reported.

Collaborative Learning

Definition

Collaborative learning criteria touches on the educational value that implementing a scenario on the UCR campus can have for faculty, students, and community.

Metrics and Assessment Methodology

The following metrics are to be evaluated qualitatively and could be used to compare the scenarios against each other.

Accessibility for Research and Education refers to the ability to leverage an energy project to provide additional educational and/or research value.

Value of Research and Educational Opportunity refers to the quality of research or education that could be enabled by the system.

Community Accessibility refers to opportunities for access and education of wider community.

Knowledge Sharing refers to opportunities for new research and innovation that can be shared with other institutions and industries.

Appendix G – Scenario Comparison and Results

The results of each scenario alternative are summarized in Table G-1.

Table G-1: Comparison of Scenarios

Alternative	Electricity Savings [MWh/yr]	Natural Gas Savings [therms/yr]	Water Use (Mgal/yr)	GHG Emission Reduction [MTCO2e/yr]	1st year Utility Cost Savings [$ M/yr]	CapEx [2024 $M]*	30-year TCO ($10M)*	30-year TCO including SCC ($10M)*	30-year NPV ($M)*
BAU (Steam)	n/a	n/a	51	n/a	n/a	86.9	75.4	90.2	(220.7)
1.1 Hot Water – Heat Pump (Centralized)	(23,700)	4,300,000	22	17,300	2.6	307.8	96.8	100.2	(300.7)
1.2 Hot Water – Heat Pump with TES	(21,800)	4,300,000	9	17,700	2.8	339.6	100.6	104.0	(339.0)
2 Hot Water – Heat Pump (Neighborhoods)	(39,100)	4,300,000	42	13,800	0.5	326.3	107.2	111.0	(405.0)
3.1 Steam (Today) – Electric Boilers	(98,100)	4,300,000	51	500	(7.3)	183.3	109.9	115.4	(432.4)
3.2 Steam (Future) – Heat Pumps	(64,800)	4,300,000	51	8,000	(2.9)	275.7	136.4	140.9	(696.8)
4.1 Steam (Future) – Alternative Fuels (RNG)	(9,300)	4,300,000	51	20,500	(5.8)	90.0	95.5	98.5	(288.0)
4.2 Steam (Future) – Alternative Fuels (H2)	(9,300)	4,300,000	51	20,500	(25.4)	186.4	128.9	131.9	(621.7)
5 Decentralized Heat Pumps for Connected Buildings	(58,700)	4,300,000	42	9,400	(2.1)	280.1	108.6	112.9	(418.5)

Notes:
BAU = business-as-usual; CapEx = capital expenses; GHG = greenhouse gas; H2= hydrogen; $ M/yr = million dollars per year; Mgal/yr = million gallons per year; MTCO2e/yr = metric tons carbon dioxide equivalent per year; MWh/yr = megawatt hours per year; n/a = not applicable; NPV = net present value; RNG = renewable natural gas; TCO = total cost of ownership; TES = thermal energy storage

Table G-2: Infrastructure Space Requirement Summary

Equipment/Infrastructure	Applicable Scenario	Area Required (SF)		Location Note
		Low	High	
Standalone ASHP (Non-CUP connected buildings)	All	10	2,000	Installed outside on ground or roof if available
Additional Central Plant Exterior Space	1.1, 1.2	15,000	25,000	Will require removal of existing tanks and cooling towers
Temporary District Plant (Up to 15 years)	1.1, 1.2	0	1,500	May be located in existing tunnels or require some above ground space.
TES	1.2	2,500	7,500	Tank footprint ~2,500, but offset may be required
District Plant (Permanent)	2	1,500	5,000	Permanent structure. See Figure G-1

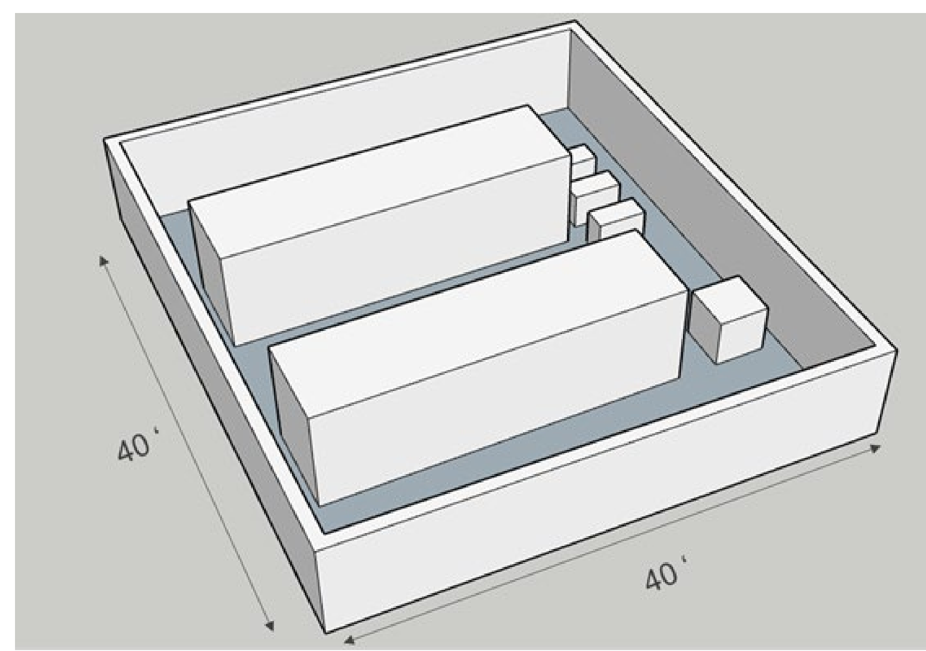


Figure G-1: Example Layout of a District Plant with ASHP and Pumps (Applicable to Scenario 2)

Appendix H – Scenario Cost Calculations

Please see attached cost workbook - Master Costing Workbook_Final.xlsx