WORKSHOP 2

Pathways to Decarbonization

Study of Campus Decarbonization

May 1, 2024

Agenda

00 Welcome and Introductions
01 Context and Workshop Goals
02 Technologies Overview
03 Decarbonization Alternatives
04 Analysis Results
05 Path Forward / Next Steps

01

Context and Workshop Goals

Planning Process

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Planning Process

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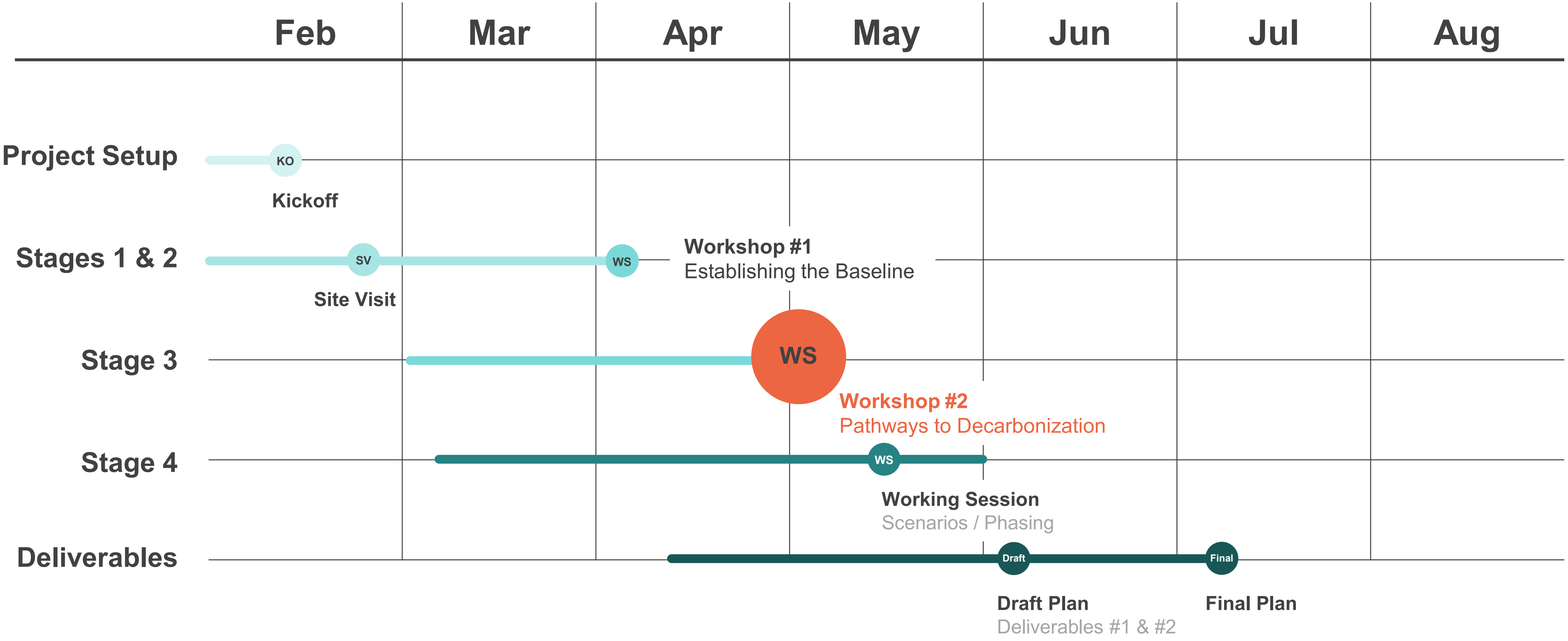
Project Schedule



#1 – Decarbonization Plan
#2 – Cost-Benefit Analysis
#3 – Climate Justice / Equity Analysis
#4 – Next Steps: Climate Action Planning
#5 – Next Steps: Collaborative Involvement

Workshop Goals

1 Review Applicable Decarbonization Technologies

2 Understand Considerations around Application at Campus

3 Communicate Methodology and Results of Alternative Analysis

4 Gain Consensus on Alternatives to Progress

02

Technologies Overview

Previous Technology Review

	Technical Maturity	Extreme Cost (CAPEX + OPEX)	Scale of Capacity	Ability to Reduce GHG	Market Readiness	Scale of Disruption or Enabling Work	Adj. Weighted Total
Weight >> 1 (worst) to 5 (best)	**5**	**5**	**5**	**4**	**3**	**2**	
Transition to Hot Water Systems							
Electric Boilers	5	1	5	5	5	1	**3.8**
Water to Water Heat Pumps	5	3	4	5	5	5	**4.4**
Air Source Heat Pumps (ASHP)	5	3	4	5	5	4	**4.3**
Geothermal Heat Pumps	5	2	4	5	5	3	**4.0**
Solar Thermal Heat Pumps	5	2	1	3	5	3	**3.0**
Expanded Thermal Energy Storage (Day/Seasonal)	5	3	5	4	5	5	**4.4**
Seasonal Thermal Energy Storage	5	1	4	4	5	3	**3.6**
Decentralized/Hybrid							
Local WSHP (tied to Condenser Loop)	5	4	4	5	5	3	**4.4**
Local Electric (ASHP/GSHP)	5	3	3	5	5	2	**3.9**
Steam System							
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**
Steam Heat Pumps	3	3	2	2	3	5	**2.8**
Deep Geothermal	2	1	5	5	2	1	**2.8**
Carbon Capture	2	2	2	3	2	3	**2.3**
Steam Thermal Energy Storage	3	3	3	3	3	4	**3.1**
Concentrated Solar	2	2	2	5	3	1	**2.5**
Small Modular Reactors (Nuclear)	1	1	3	5	2	3	**2.4**

Technologies to Cover

1. Hot Water Plant

a) Water to Water Heat Pumps (WWHP)
b) Air Source Heat Pumps (ASHP)
c) Ground Source Heat Pumps (GSHP)
d) Thermal Energy Storage (Day/Seasonal)

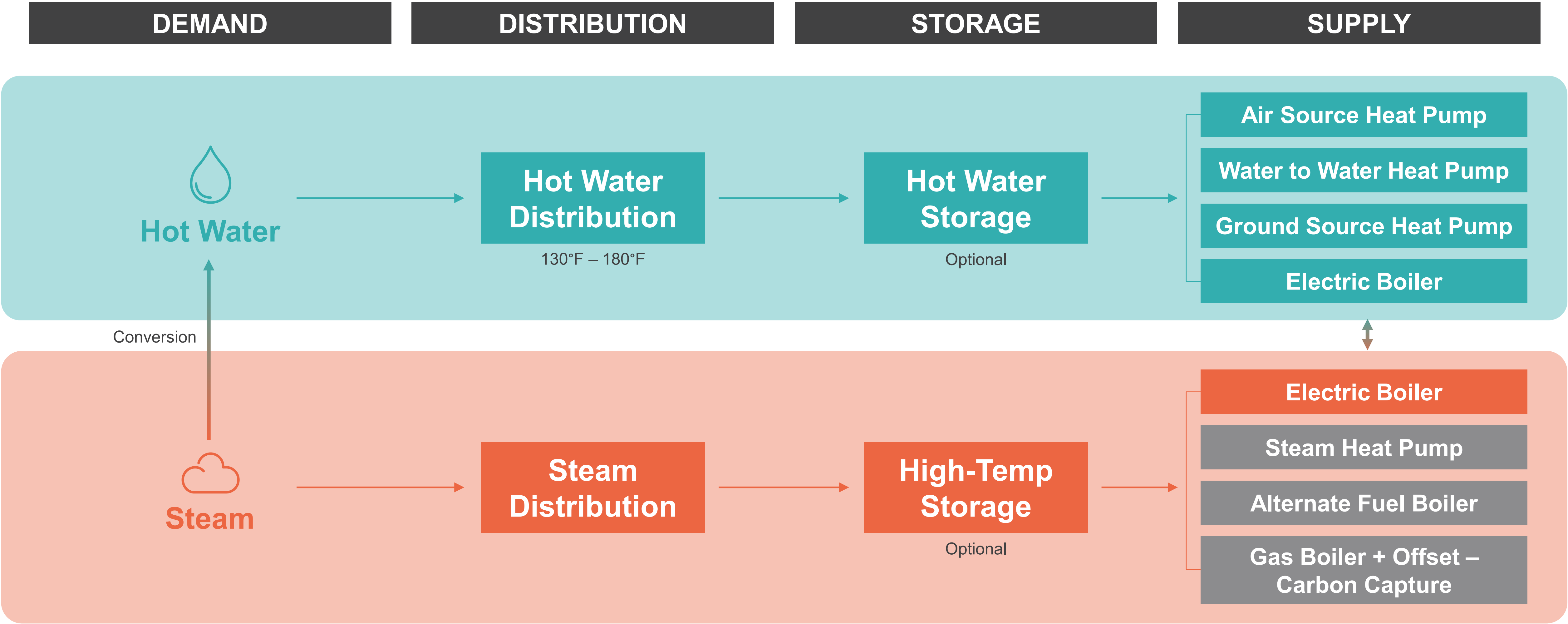
2. Steam Plant

a) Electric Boilers
b) Alternative Fuels - H_2 Storage & Distribution
c) Alternative Fuels - Biofuel
d) Other (Steam HP, Steam TES, Carbon Capture)

3. Building Level Solutions

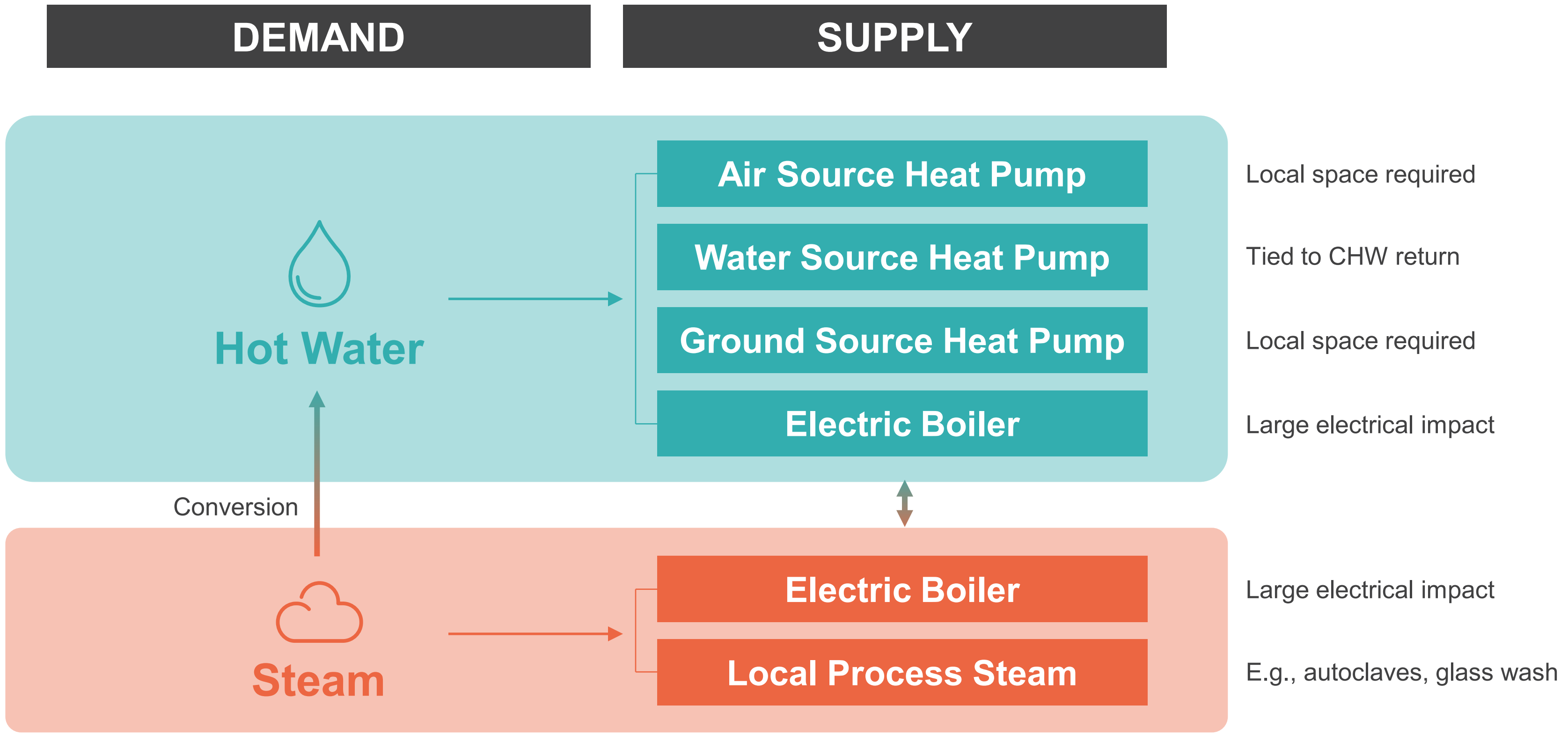
a) Heat Exhangers
b) WSHP (tied to Condenser Loop)
c) Electric (ASHP/GSHP)
d) Process steam decentralization

Technologies – Centralized

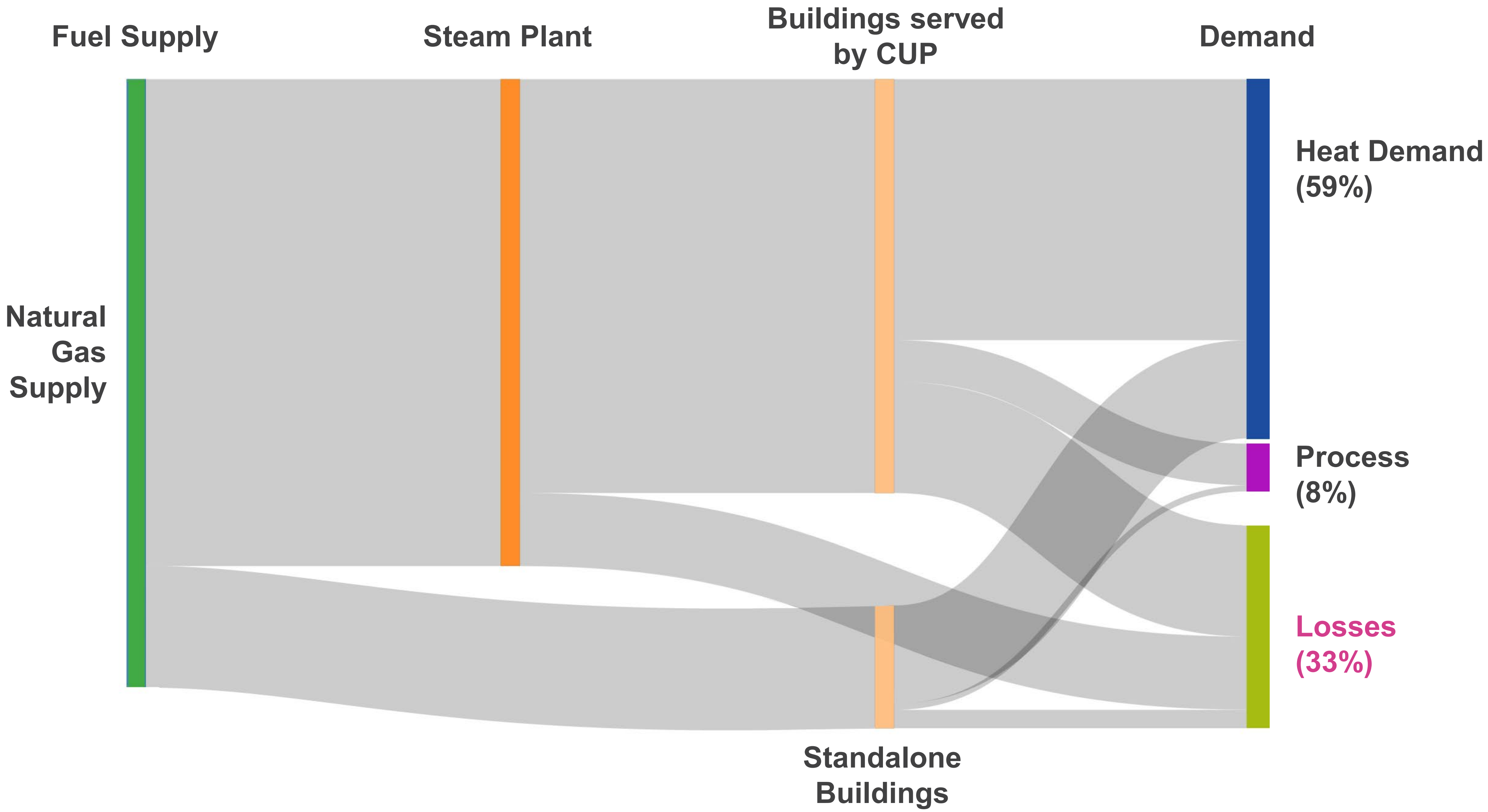


Gray = Not yet deployable at this scale

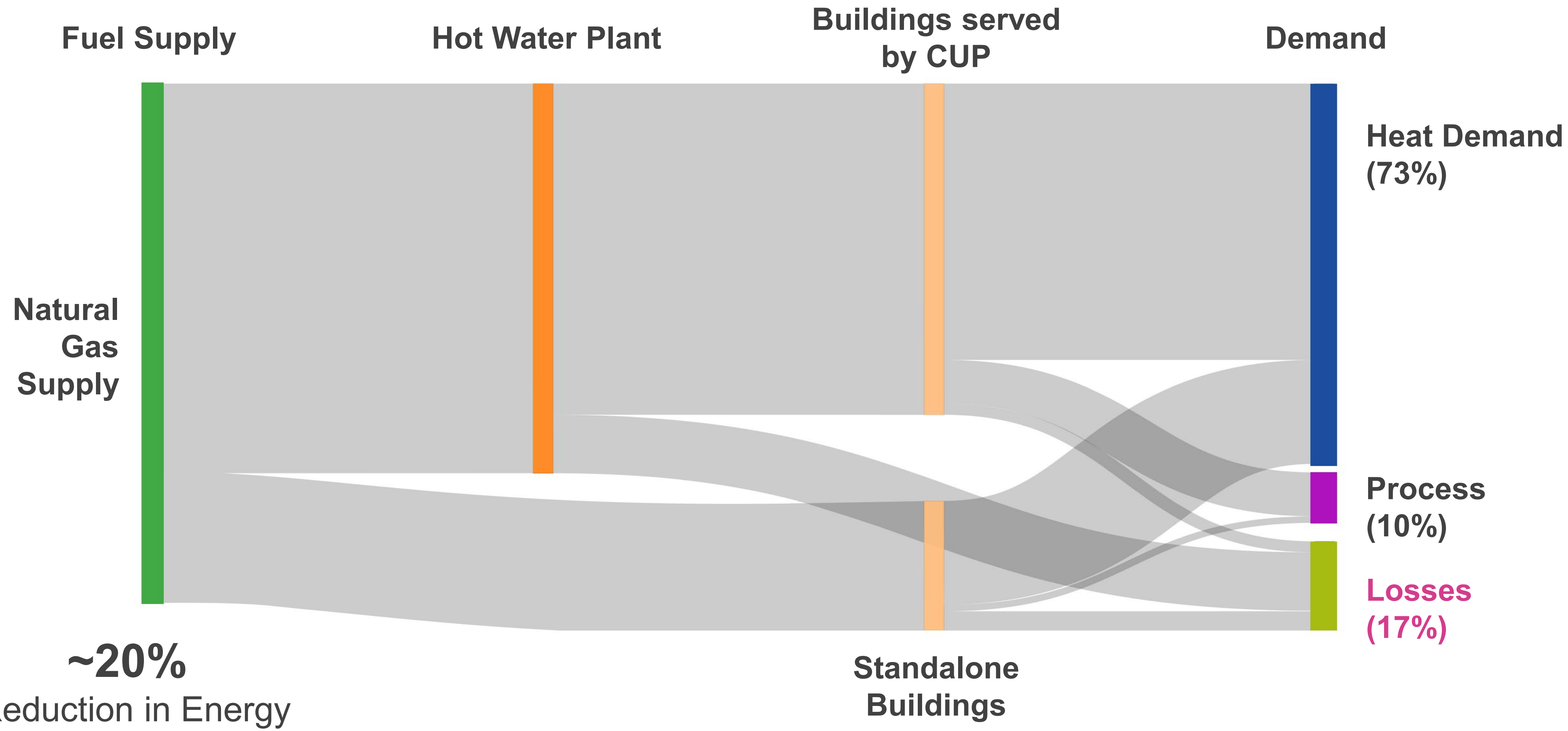
Technologies – Decentralized



Technologies – Business As Usual

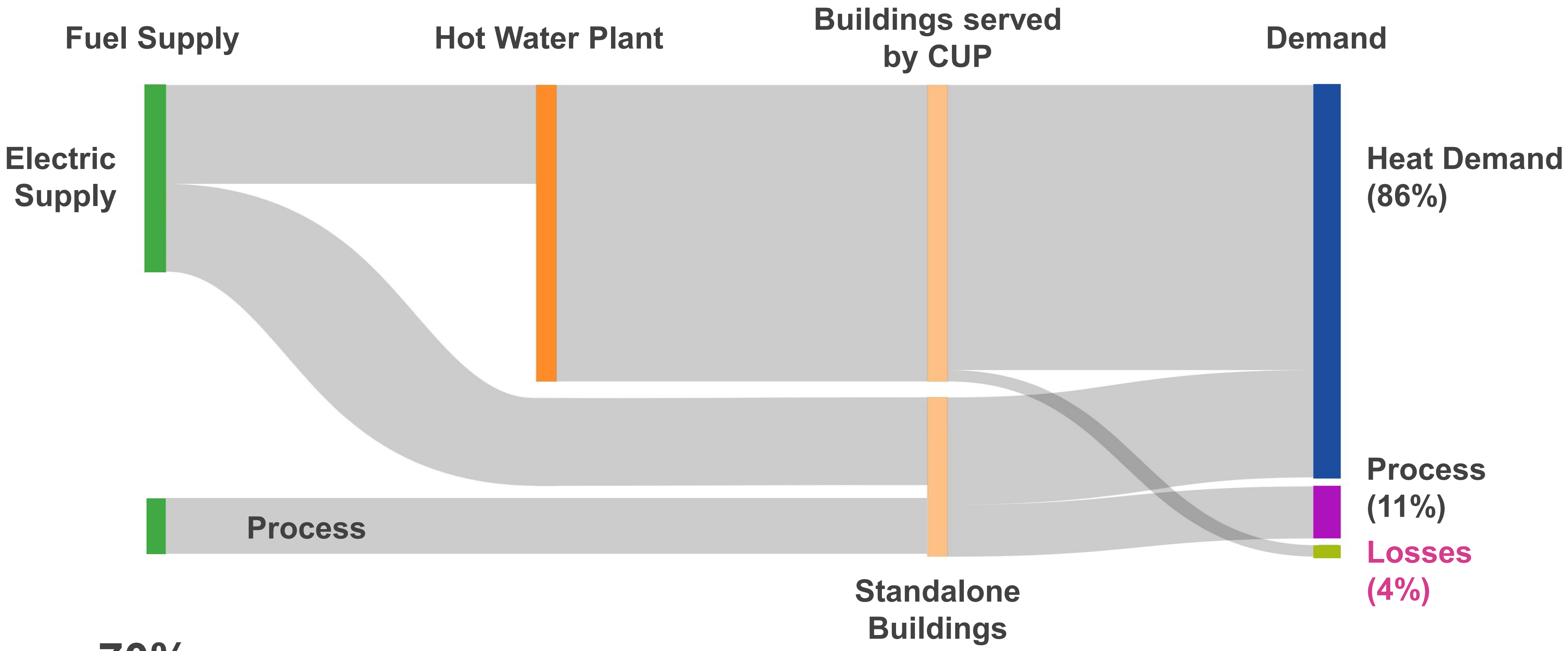


Technologies – Steam to Hot Water Conversion



~20%
Reduction in Energy

Technologies – Boiler to Heat Pump Conversion



~70%
Reduction in Energy

Water to Water Heat Pump

Summary

WWHPs (also called heat recovery chillers and water source heat pumps) produce chilled water and heating hot water simultaneously to maximize whole system efficiency.

Key Considerations

- Applicable only for simultaneous loads
- Efficiencies ranging from 5 - 11 COP depending upon hot water supply temperature (lower is better)
- Requires advanced controls to adjust operations based on demand fluctuations and outdoor conditions

Metric	
Technical Maturity and Market Readiness	Available
Cost	\$2,000 – \$2,500/ton
Space	Indoor, Medium Req.
Applicable Capacity	400 – 2,000 tons
Supply Temperature	120°F – 180°F+

Heat recovery chillers at Stanford

Air Source Heat Pump

Summary

ASHPs extract heat from ambient air and transfer it to the water through a refrigerant cycle. This also works in reverse to provide cooling as-needed.

Key Considerations

- Space availability and noise considerations
- Efficiency varies substantially by climate (better if warmer)
- New distribution piping and advanced controls
- Shorter equipment lifespan (exposed)

Metric	
Technical Maturity and Market Readiness	Available
Cost	$2,000 – $3,500/ton
Space	Outdoor, High Req.
Applicable Capacity	1,500-3,000 tons
Supply Temperature	115°F – 150°F+

ASHP Module

Ground Source Heat Pump

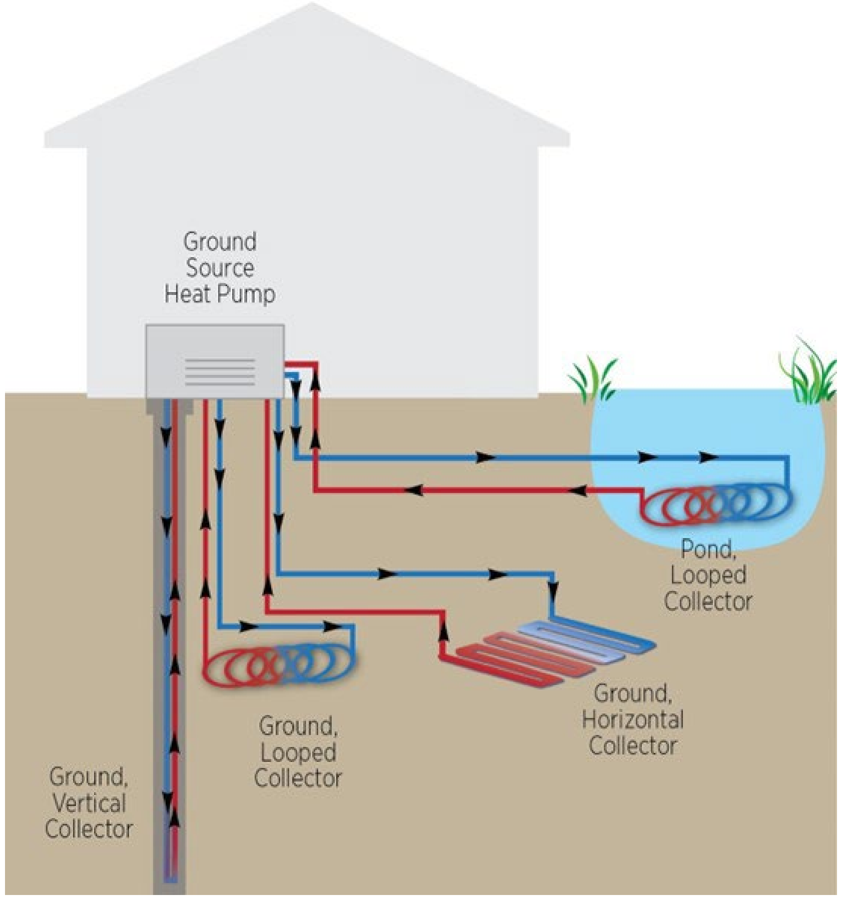
Summary

GSHPs are a combination of a water-to-water heat pump and a geo-field to temper the water loop temperature. They are generally more efficient than ASHP as ground temperatures in winter are higher than air temperatures.

Key Considerations

- Thermal conductivity and heat transfer capacity
- High upfront costs due to ground loop or borings but higher operating efficiencies
- Horizontal, vertical, and pond/lake configurations

Metric	
Technical Maturity and Market Readiness	Available
Cost	$10,000 – $15,000/ton
Space	Indoor, Medium Req.
Applicable Capacity	400 – 1,500 tons
Supply Temperature	115 - 150°F



GHSP Connection Types

HOT WATER PLANT

Thermal Energy Storage

Summary

Expanding thermal energy, which may include storing thermal energy during one seasonal condition and discharging the stored energy in the other seasonal condition, depending on the load demand.

Key Considerations

- Integration with other technology alternatives
- Space availability to expand TES
- Size and deployment to increase efficiency and/or reduce installed capacity

Metric	
Technical Maturity and Market Readiness	Available
Cost	\$10 – \$15/gal
Space	Indoor or Outdoor, High Req.
Applicable Capacity	1 – 2 Mgal
Supply Temperature	< 200°F

Thermal Energy Storage Tank

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STEAM PLANT

Electric Boiler

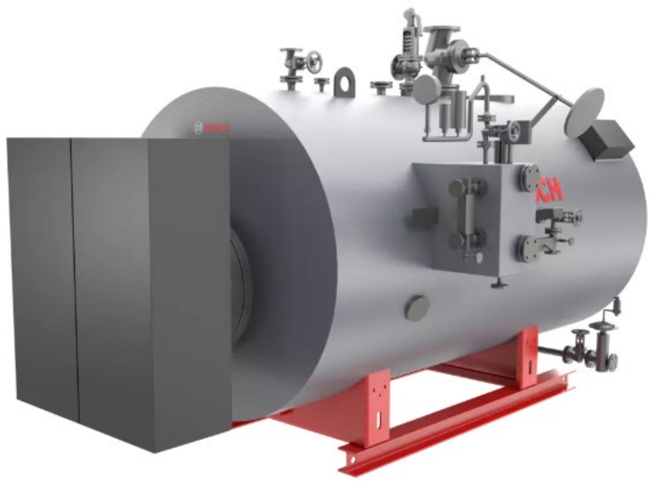
Summary

An electric boiler can directly replace a fossil fuel equivalent to produce hot water or steam.

Key Considerations

- Can be large significant electrical infrastructure improvements
- Small spatial impact when replacing traditional boilers
- Typically, high utility costs
- Electrode types are available at higher voltages, i.e. 4160 V+

Metric	
Technical Maturity and Market Readiness	Available
Cost	$9,000 – $14,000/ton
Space	Indoor or Outdoor, Medium Req.
Applicable Capacity	5 – 50,000 kBtu/h
Supply Pressure	< 250 PSI steam



Electric Boiler Unit

Alternative Fuels – Biofuel (Living Lab Opportunity)

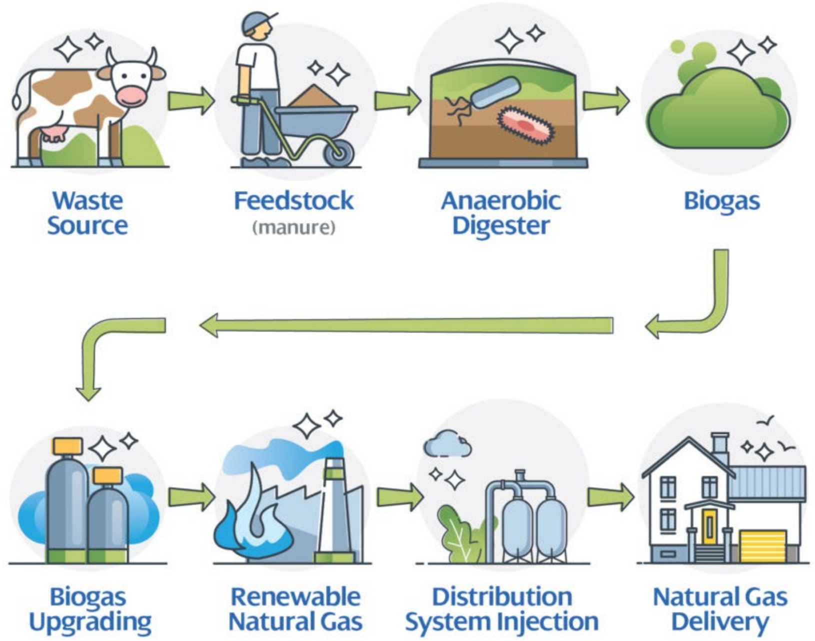
Summary

Biofuels, such as biomethane, are fuels produced from biomass materials. They may serve as fossil fuel 'offsets' in existing systems without impacting on-campus operations.

Key Considerations

- 2023 UC Sustainable Practices Policy Goal: By 2025, at least 20% of natural gas will be biomethane
- UCOP-supplied biomethane contract as a transition fuel to replace fossil gas through 2039
- Likely an 'accounting' solution without direct replacement of natural gas; on-site fuels require storage and deliveries
- Living Lab Opportunity - Produce own biofuel from campus waste streams

Metric	
Technical Maturity and Market Readiness	Available
Cost (of fuel)	\$17 – \$26/MMBtu
Space	N/A
Applicable Capacity	N/A
Supply Pressure	< 250 PSI steam



Biogas Generation Process

STEAM PLANT

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Alternative Fuels – H_2 Storage & Distribution

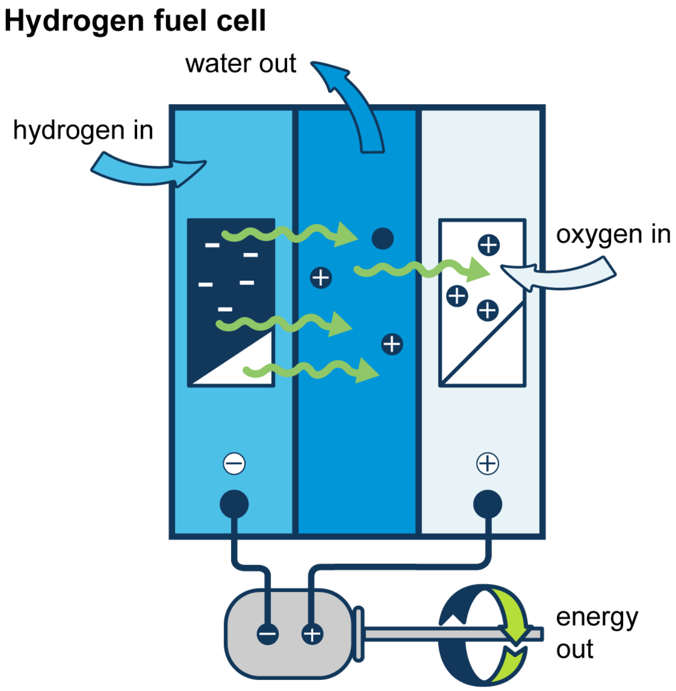
Summary

Replacing natural gas use with hydrogen which only produces water when consumed in a fuel cell. If generated by renewable energy, 'green' hydrogen is considered zero carbon.

Key Considerations

- Likely maintain the use of steam but require system conversion
- Difficult to source and challenging to import for direct use
- High operational costs (takes 7x more energy for unit heat than HP)
- Require infrastructure for storage (10x gas) and deliveries

Metric	
Technical Maturity and Market Readiness	Available
Cost (of fuel)	\$52 – \$70/MMBtu
Space	Outside, High Req.
Applicable Capacity	N/A
Supply Pressure	< 250 PSI steam



Hydrogen Fuel Cell Process

STEAM PLANT

Other – Steam Heat Pump

Summary

Steam heat pumps capture low-temperature waste heat from industrial processes, increase the temperature of that heat and use it to generate steam at the same temperature, pressure, and quality of existing boilers.

Key Considerations

- Requires high base load of steam (currently much larger than UCR's base load) to be cost effective
- Not currently available or viable at this scale
- Will require significant electrical upgrades

Metric	
Technical Maturity and Market Readiness	No commercial application
Cost	$58,000 – $63,000/ton
Space	Indoor or Outdoor, High Req.
Applicable Capacity	25 – 50,000 kBtu/h
Supply Pressure	~85 PSI steam

Steam Heat Pump

Other – Steam Thermal Energy Storage

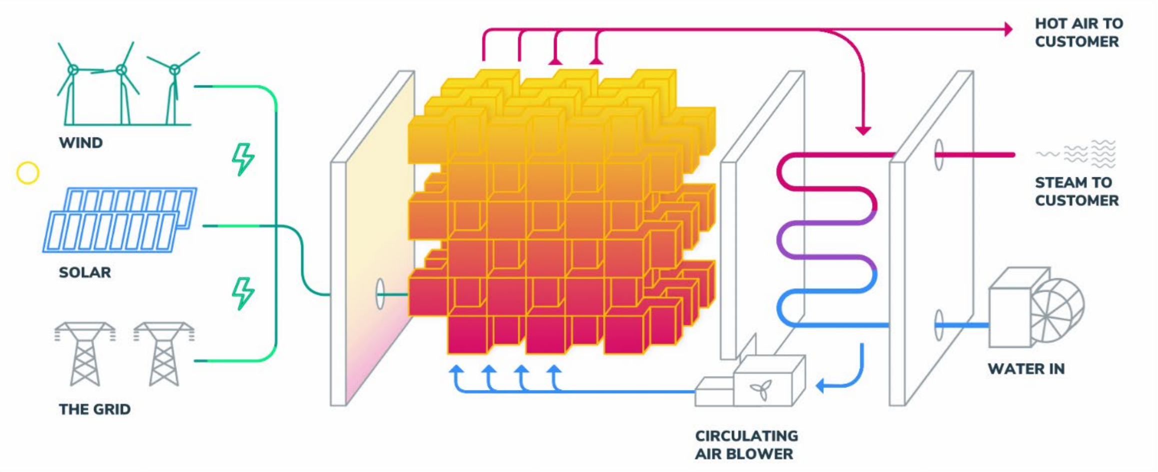
Summary

Grid connected or clean sourced power is used to heat up rock or crushed rock over a period of time to store heat (at very high temperatures) and discharge when needed.

Key Considerations

- Large space requirements to match scale needed
- Additional power and space for auxiliary fans and equipment
- Only justifiable if need high temperature (steam)

Metric	
Technical Maturity and Market Readiness	Piloted not Commercial
Cost	$8,000 – $13,000/ton
Space	Indoor or Outdoor, High Req.
Applicable Capacity	500,000 MMBtu
Supply Pressure	~80 PSI steam



Hot Storage Concept (Direct Electricity)

Other – Carbon Capture

Summary

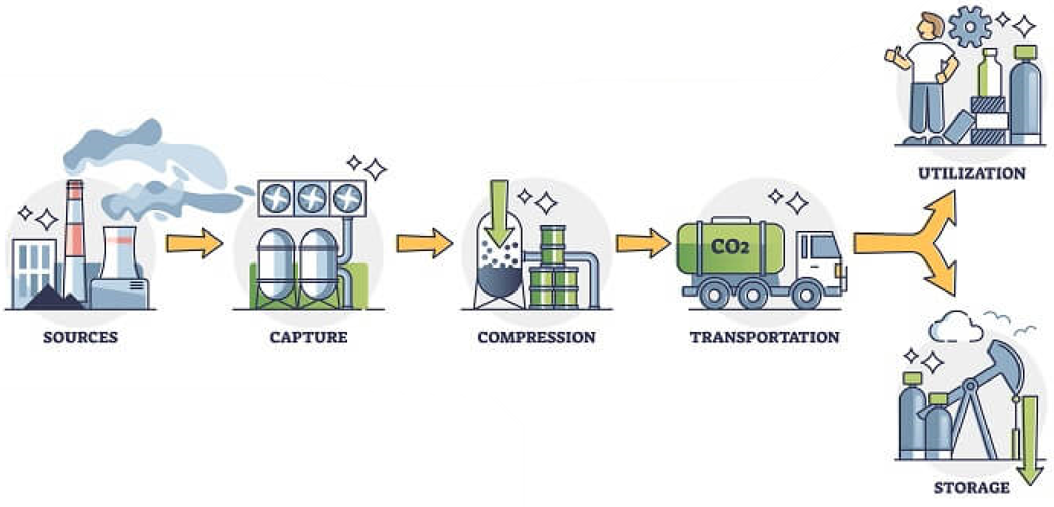
Absorb and store a portion of the carbon from point-sources or directly from the air to offset carbon emissions.

Key Considerations

- New and developing technology
- In addition to local combustion / fuel cell
- Cannot demonstrate >70% capture rate – can't meet goals
- Requires trucking for export and material delivery
- Reliance on unpredictable CO_2 market sales to be economically viable

Metric	
Technical Maturity and Market Readiness	Developing
Cost	\$15 – \$120/tCO_2e*
Space	Outside, High Req.
Applicable Capacity	N/A
Supply Temperature	N/A

*Costing sourced from the Congressional Budget Office, Nonpartisan Analysis for the U.S. Congress: Carbon Capture and Storage in the United States.



Carbon Capture Process

STEAM PLANT

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Heat Exchangers

Summary

Heat exchangers move heat from one medium to another without blending them to regulate and moderate internal temperature of a building.

Key Considerations

- Required for steam to hot water conversion
- Additional internal space allocation required

Large Capacity Heat Exchanger

Metric	
Technical Maturity and Market Readiness	Available
Cost	$3,000 – $5,000/ton
Space	Indoor, Low to Medium Req.
Applicable Capacity	Building Load
Supply Temperature	Any

Local Water Source Heat Pump

BUILDING LEVEL SOLUTIONS

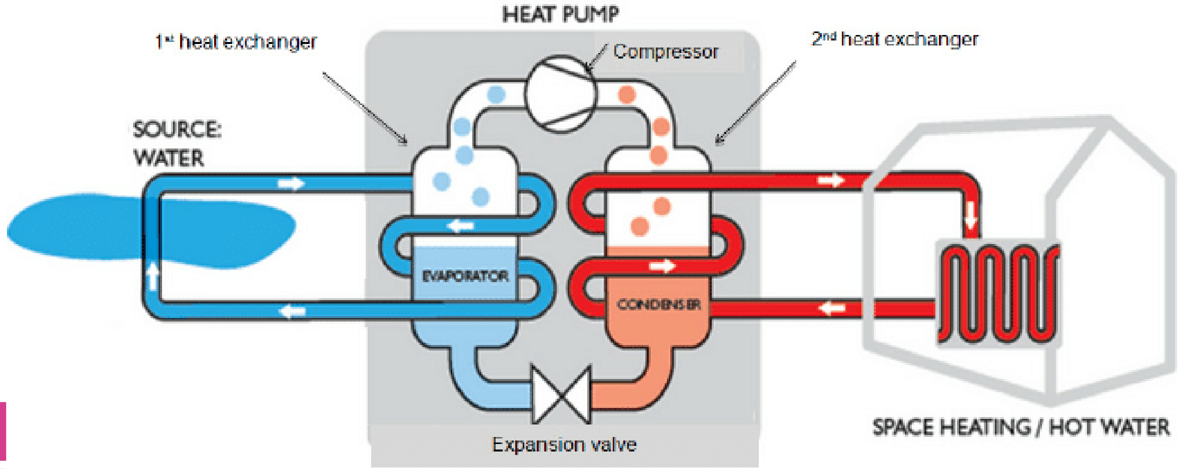
Summary

Building level heat pump technology that operates by rejecting heat or absorbing heat to and from a water loop.

Key Considerations

- Already utilized for some new buildings on campus
- Needs adequate indoor space
- Needs water-source; can connect into the chilled water return (and reduce plant cooling load)
- Can require local electrical infrastructure upgrades

Metric	
Technical Maturity and Market Readiness	Available
Cost	$3,500 – $5,000/ton
Space	Indoor, Medium Req.
Applicable Capacity	400 – 2,000 tons
Supply Temperature	110°F – 150°F



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Local ASHP

Summary

Replacing existing building level heating and cooling equipment with electric air source heat pumps.

Key Considerations

- The local climate maximizes ASHP heating efficiency
- Requires adequate available outdoor space (typically not roofs due to structural load)
- Smaller split-systems may be applicable for small buildings
- Can require local electrical infrastructure upgrades

Metric	
Technical Maturity and Market Readiness	Available
Cost	$2,500 - $5,000/ton
Space	Outdoor, Medium Req.
Applicable Capacity	20 – 60 tons
Supply Temperature	115°F – 130 °F

ASHP (top), Split System (Bottom)

BUILDING LEVEL SOLUTIONS

Process Steam Decentralization

Summary

Utilizing electric-based sterilization and cooking equipment to eliminate local gas usage.

Key Considerations

- Already used on campus in new buildings
- Can require local electrical infrastructure upgrades
- Reduced maintenance requirements
- Facilitates a steam to hot water conversion

Metric	
Technical Maturity and Market Readiness	Available
Cost (per autoclave)	$10,000 – $300,000+
Space	Outdoor, Medium Req.
Applicable Capacity	20 – 60 tons
Supply Temperature	N/A

Electric Autoclave at UCR

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Technology Summary Matrix

Technologies Considered	Technical Maturity and Market Readiness	Equipment Cost	Fuel Procurement Cost	Space	Capacity	Supply Temperature/ Supply Pressure
Water Source Heat Pumps	Available	$2-$2.5k/ton	N/A	Indoor, Medium	400-2,000 tons	120°F – 180°F+
Air Source Heat Pumps	Available	$2-$2.5k/ton	N/A	Outdoor, High	400-3,000 tons	115°F – 150°F+
Ground Source Heat Pumps	Available	$10-$15k/ton	N/A	Indoor, Medium	400-1,500 tons	115°F – 150°F+
Thermal Energy Storage	Available	$10-15/Gal	N/A	Ind./Out., High	1-2 Mgal	< 200°F
Electric Boilers	Available	$9-14k/ton	N/A	Ind./Out., Medium	5-50k kBtuh	< 250 PSI steam
Alternative Fuels – Biofuel	Available	N/A	$17-$26/MMBtu	N/A	N/A	< 250 PSI steam
Alternative Fuels - H2	Available	N/A	$52-$70/MMBtu	Outdoor, High	N/A	< 250 PSI steam
Steam Heat Pumps	Developing	$58-$63k/ton	N/A	Ind./Out., High	25-50k kBtuh	85 PSI
Steam Thermal Energy Storage	Developing	$8-13k/ton	N/A	Ind./Out., High	500,000 MMBtu	80 PSI
Carbon Capture and Storage	Developing	N/A	$15-$120/tCO_2e	Outdoor, High	N/A	N/A
Building Heat Exchangers	Available	$3-5k/ton	N/A	Indoor, Low/Med.	Building Load	Any
Local WSHP	Available	$3.5-$5k/ton	N/A	Indoor, Medium	400-2,000 tons	110°F – 150°F+
Local ASHP	Available	$2.5-$5k/ton	N/A	Outdoor, Medium	20-60 tons	115°F – 130°F+
Process Steam Decentralization	Available	$10-$300k	N/A	Outdoor, Medium	20-60 tons	N/A

02

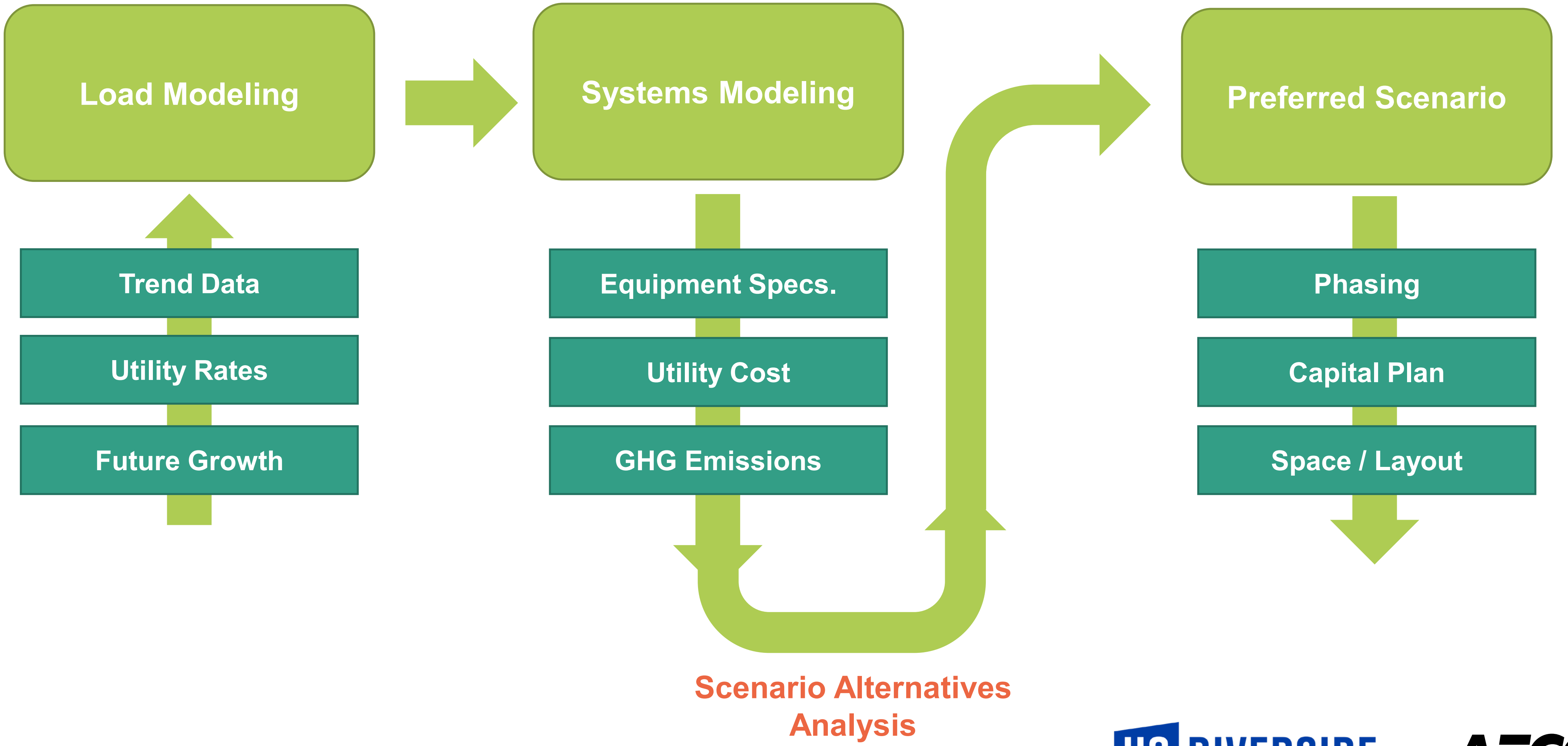
Decarbonization Alternatives

Decarbonization Alternatives Evaluation

Process of Alternative Evaluation

1. Design Parameters / Considerations
2. Alternatives Development
3. Alternative Performance Summary

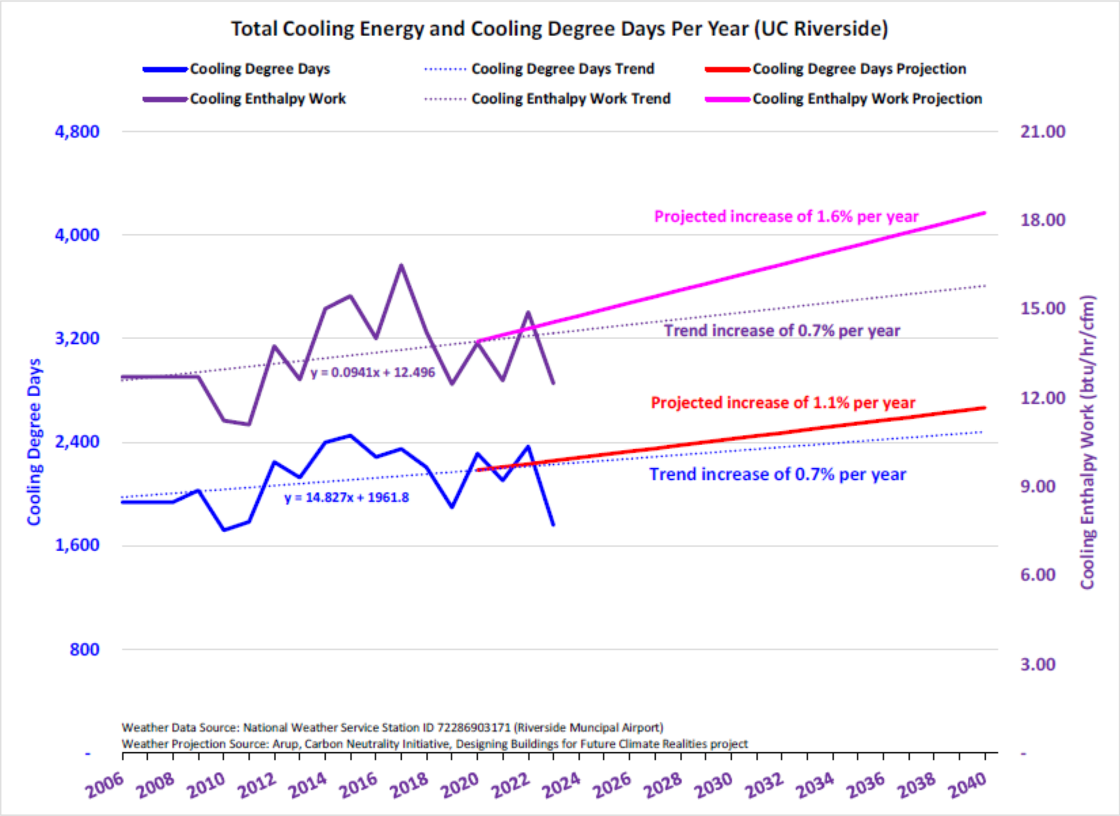
Modeling Process

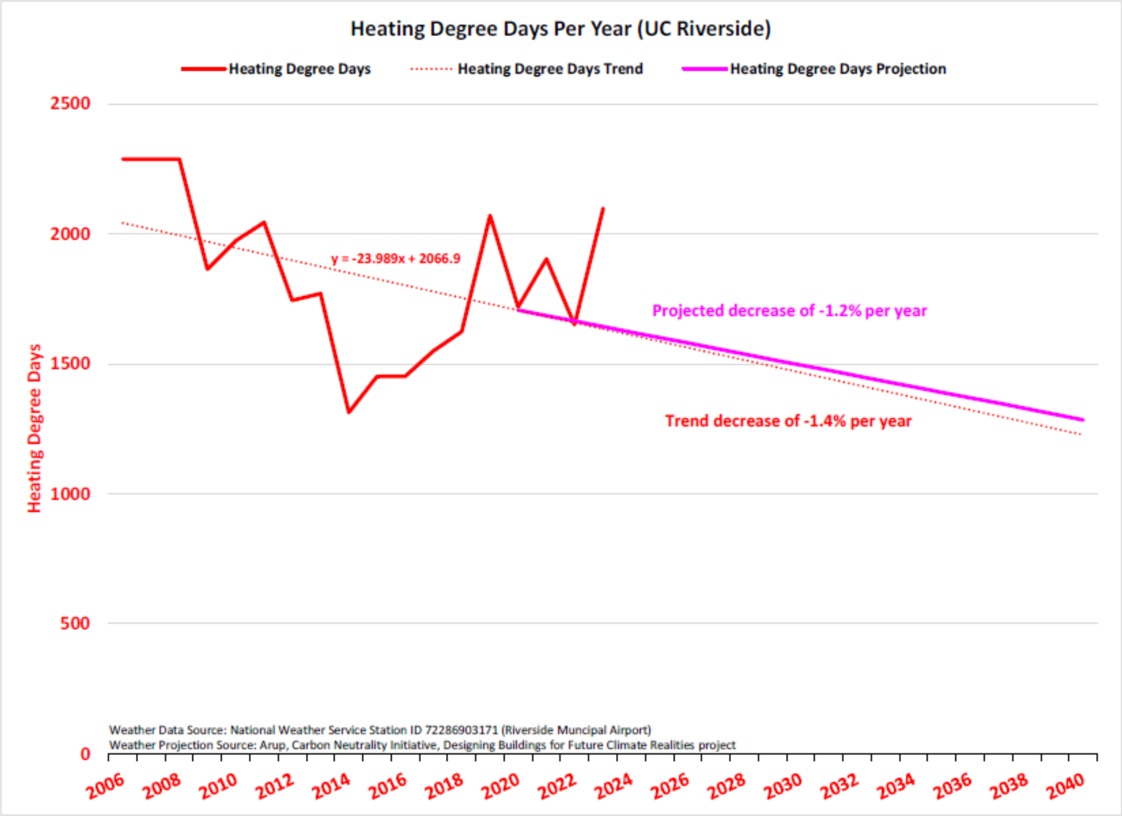


Design Parameters: Demand Changes

Projected weather characteristic changes due to climate change:

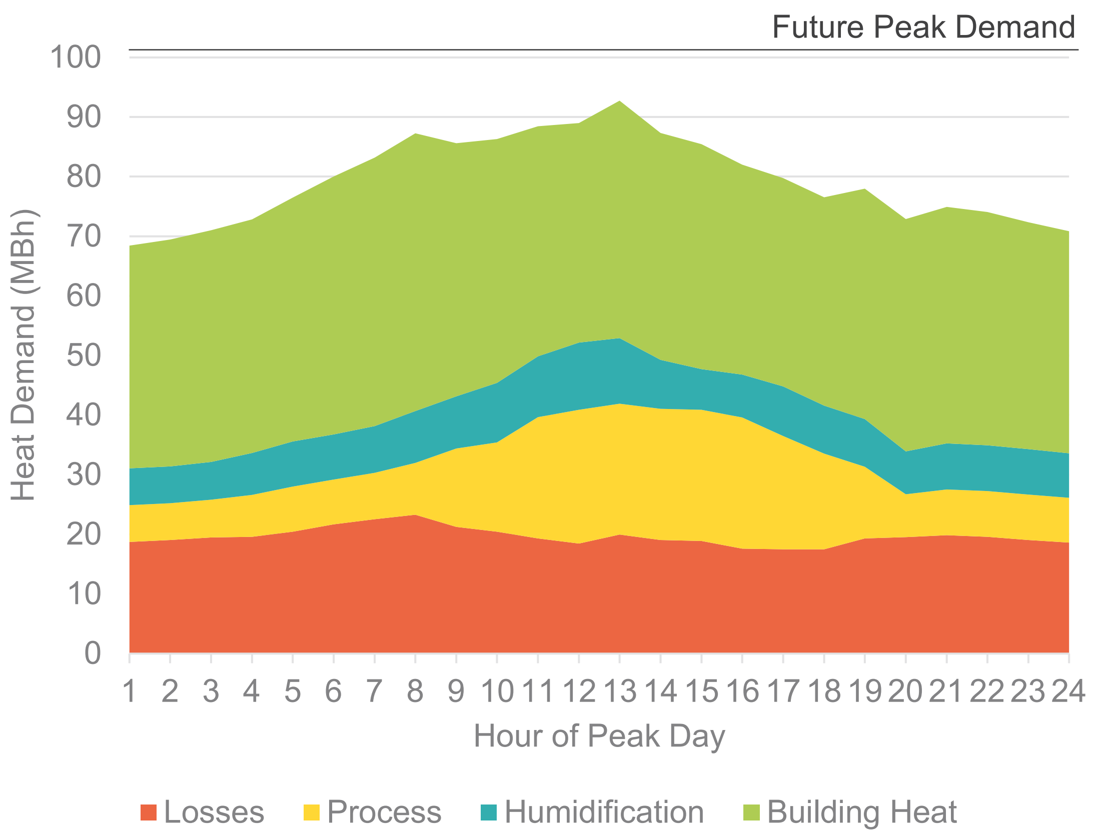
- Annual **heating** load **decreasing** by **1.2% per year**
- Annual **cooling** load **increasing** by **~1.6% per year**

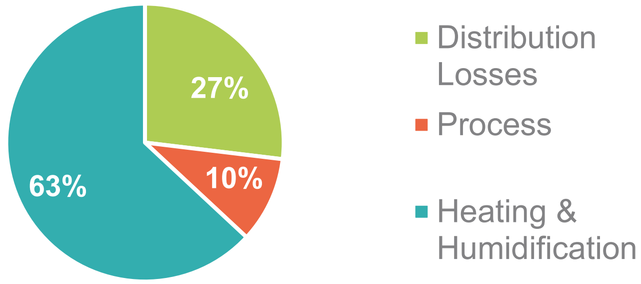




Design Parameters: Heating Demand Profile

- Additional meter data analysis and modeling has refined the estimates of building heating demand
- Estimates on process loads, humidification, and measurements of steam make-up water to complete allocation
- Heating peak demand growth from new buildings by **~10%** and annual consumption down by **~1.4%** per year due to weather projections (not including opportunities for conservation)
- Refines the modeled demand for the basis for alternatives comparison





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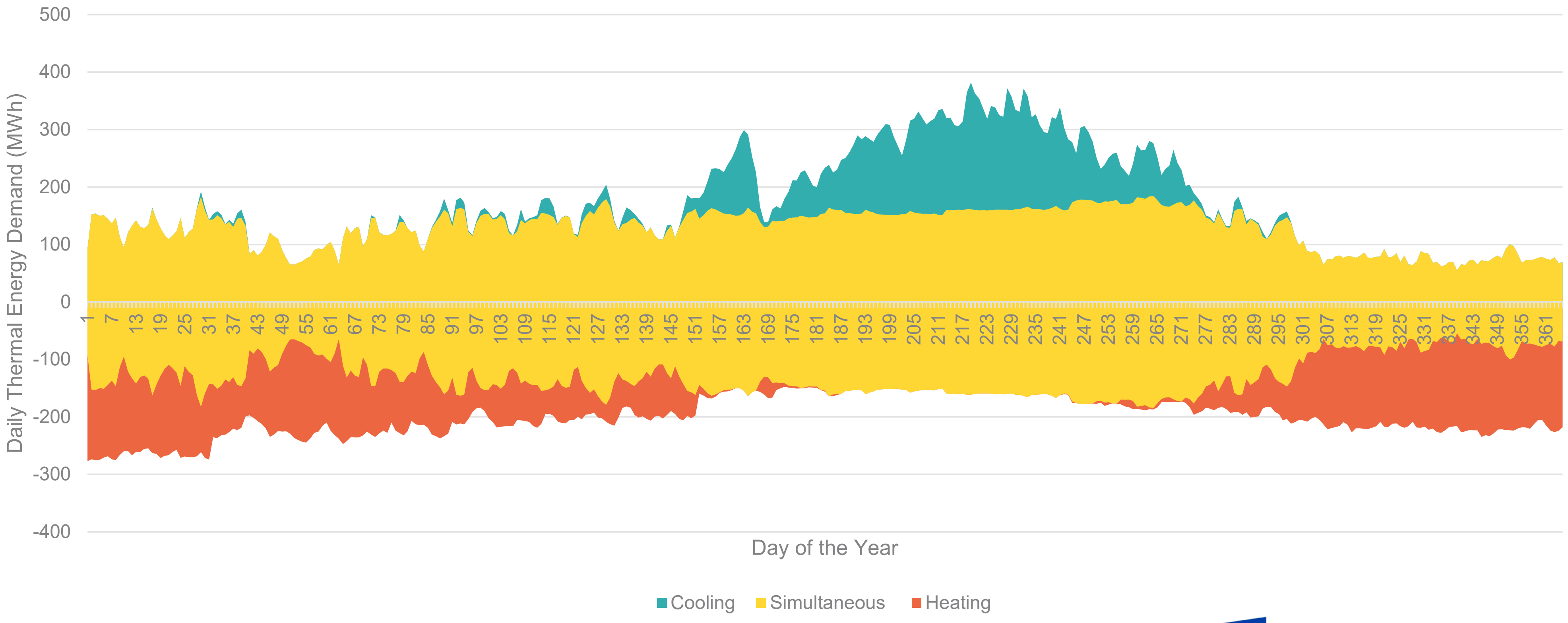
Design Parameters: Daily Thermal Balance

Under existing conditions, **>65%** of UCR heating and cooling demand is **simultaneous.**
These are ideal conditions for heat recovery chillers.



Design Parameters: ASHP Performance

The climate in Riverside allows an ASHP operate at the upper end of its design efficiency.

- Under the worst weather conditions expected at UCR, the coefficient of performance (COP) is ~2.5, **2.5x more efficient than an electric boiler**.

2021 ASHRAE Handbook - Foundamentals (IP)

RIVERSIDE, CA, USA (WMO: 722869)

Lat:33.952N Long:117.439W Elev:804 StdP: 14.27 Time zone:-8.00 (NAP) Period:98-19 WBAN:03171 Climate zone:3B

Annual Heating, Humidification, and Ventilation Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		WSF
			99.6%			99%			0.4%		1%				
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
12	36.6	38.9	1.1	6.0	61.7	6.6	8.0	64.5	26.6	62.4	23.4	63.1	2.6	60	0.398

HEATING PERFORMANCE DATA

Load	Capacity (MBH)	Input kW	Heating COP	Load Flow (GPM)	Load Leaving °F	ΔP (ft H2O)	Ambient °F
100%	3666	435.3	2.470	332.4	130.0	2.610	42.00
75%	2749	296.4	2.720	332.4	130.0	2.610	48.00
50%	1833	182.0	2.950	332.4	130.0	2.610	54.00
25%	916.5	84.88	3.160	332.4	130.0	2.610	60.00

Design Parameters: GSHP Performance

A geo-field is often used in an electrified system to improve annual heating supply efficiency because:

a) In the US, ground temperature is typically warmer than the air during heating season

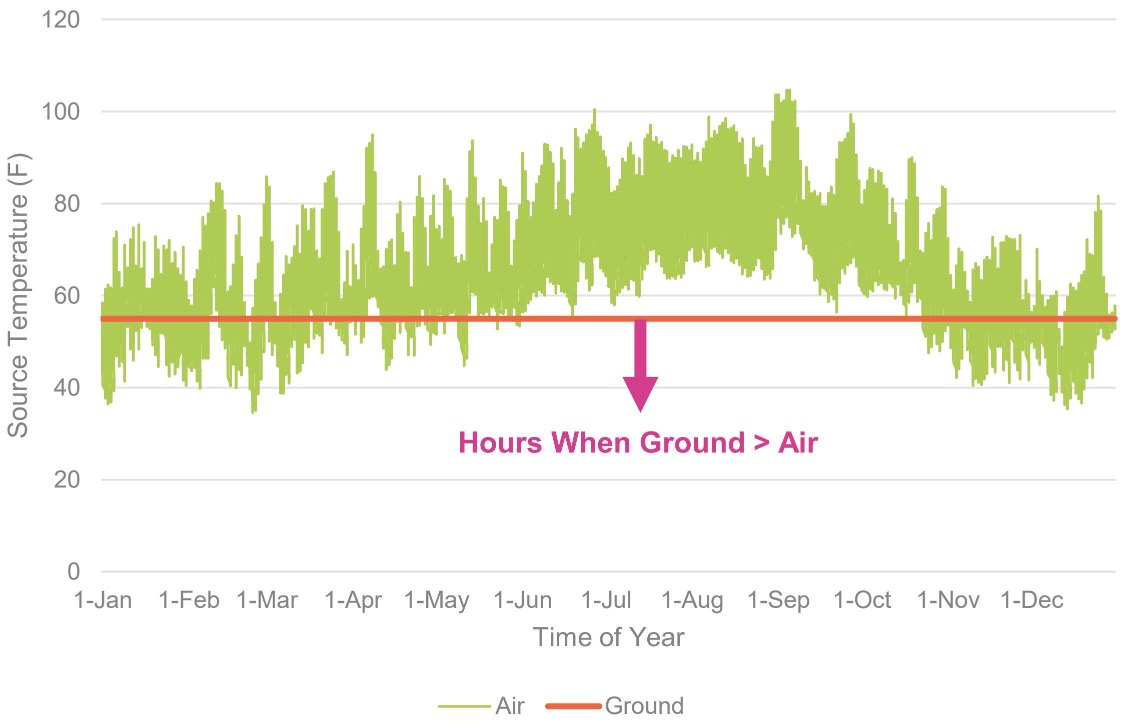
b) The ground can provide thermal storage to allow heat pumps to run in optimal conditions for longer.

Geo-fields (and associated water to water heat pumps) are typically around 3 times the cost of an ASHP per unit of capacity but can feasible due to lower operational costs over time.

However, at UCR, **these advantages are nullified** by:

a) The climate: <30% of the heating load occurs when the ground temperature is greater the outside air

b) Existing TES tanks: UCR already has very large chilled water storage tanks that may be repurposed for heat storage



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Alternatives Development

Decarbonization Alternative

Building Heating Requirements

The grade of existing heat demand (steam, hot water temperature)

Distribution Medium & Temperature

The type of distribution (hot water or steam) and the temperature or pressure of supply

Type & Configuration of Generation Equipment

The use of heat pumps, boilers, or other systems to generate heat either locally or centrally

Use of Thermal Energy Storage

Size and deployment of thermal storage to increase efficiency and/or reduce installed capacity

Space Availability

How much land or roof area is available and where

Capital & Operational Cost

Upfront (including infrastructure upgrades) and operational costs including utility and maintenance costs (considering complexity of systems)

Emissions Impact

Impact on the Scope 1 emissions and when that can be realized

Phasing & Disruption of Implementation

The ability to have a flexible, phased implementation which can impact scale and configuration of network

Equity & Environmental Justice

Ability to Leverage as Living Laboratory

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Alternative Summary

Alternative	Heating Systems	Cooling System
1. Business as Usual (Steam)	• Existing steam gas boilers serving future demand	• Existing cooling systems (chillers and TES serving demand)
2A. Hot Water – Heat Pump (Centralized)	• Replace steam plant • WSHP (simultaneous) • Air source heat pumps	• HRCs (simultaneous) • Existing and new SAT plant chillers • ASHP (backup)
2B. Hot Water – Heat Pump with TES	• Upgrade Steam Plant • HRCs (simultaneous) • Air source heat pumps • Use of TES 1 for Heat Storage	• HRCs (simultaneous) • Existing and new SAT plant chillers • ASHP (backup) • Loss of TES 1
2C. Hot Water – Heat Pump (Neighborhoods)	• Neighborhood Heat Plants • ASHP or WSHP (tied to CHW)	• Existing cooling systems

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Alternative Summary

Alternative	Heating Systems	Cooling System
3A. Steam (Today) – Electric Boilers	• Replace natural gas boilers with steam electric boilers	• Existing cooling systems (chillers and TES serving demand)
3B. Steam (Today) – Alternative Fuels (RNG)	• Existing steam gas boilers serving future demand • Fuel cost tied to RNG rate	• Existing cooling systems
3C. Steam (Future) – Heat Pumps	• Replace steam boilers with steam heat pumps (COP ~1.6) • Leverage new TES to optimize operational time	• Existing cooling systems
3D. Steam (Future) – Alternative Fuels (H_2)		• Existing cooling systems
4. Decentralized Heat Pumps for Connected Buildings	• Local AHSP or WSHP at Each Building	• Existing cooling systems

Alternative 1 – Business as Usual (Steam)

Description

- Existing steam and chilled water systems

Pros and Cons

Pros:
- Investment limited to keeping plant operating

Cons:
- Does not meet carbon reduction goals
- Significant water use and energy losses
- Lack of flexibility for future technology improvements

Performance Metrics

GHG Emissions Reduction	
Scope 1 Emissions	22,000 mtCO_2e per year
	0% reduction
Scope 2 Emissions	5,400 mtCO_2e per year
Life Cycle Cost	
Utility Costs	$6.9M total per year
Capital Costs	$0 per year
Resource Use	
Peak Electrical Demand	5,100 kW
Water Usage	51 MGal per year
Ease of Implementation	
Availability Limitations	Low
Spatial Requirements	Low
Scale of Disruption	Low

Alternative 2: Steam to Hot Water Conversion

Description

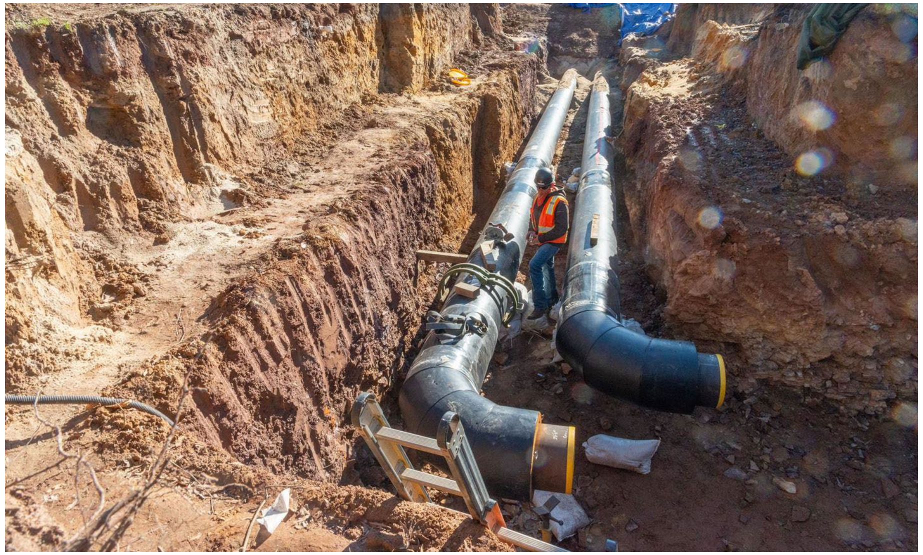
To facilitate the adoption of efficient, available zero-carbon equipment, the heating supply temperature must reduce, requiring divestment from steam systems.

If maintaining a centralized system, this **requires conversion from steam to hot water distribution** system. This is typically the single largest capital cost of heating decarbonization but also yields large energy savings.

- >20% reduction in overall heat demand (from reduction campus distribution losses)
- Added pumping requirement

Within the buildings where steam is currently used, it needs to be replaced:

- Steam coil and pipes to hot water coils and pipes
- Process steam to local electrical equipment
- Replace humidification systems where needed



Steam to hot water conversion at Princeton

Alternative 2: Steam to Hot Water Conversion

Piping Replacement

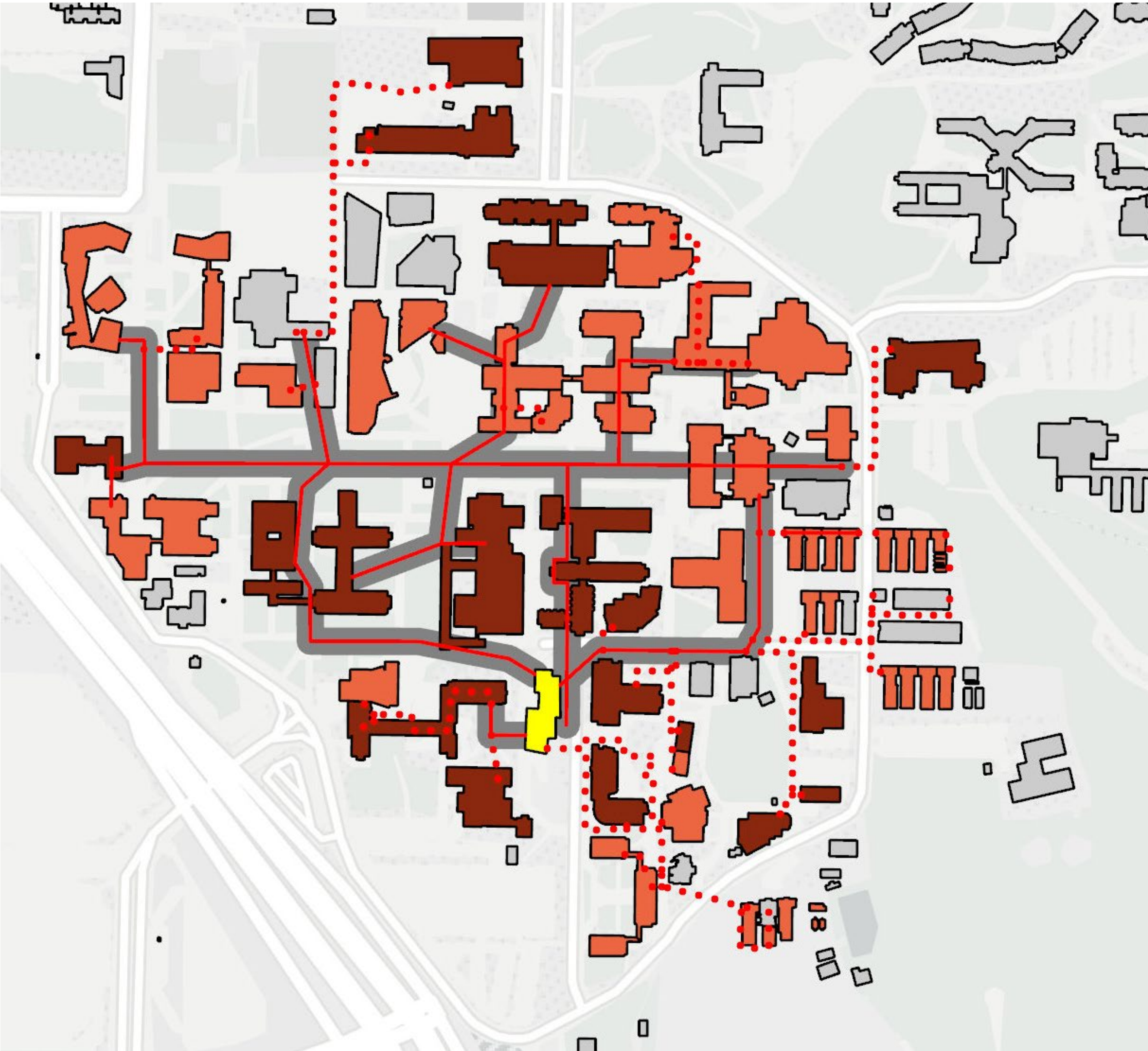
Piping Diameter	Length Installed
3-inch	8,600 LF
6-inch	19,370 LF
9-inch	3,600 LF
12-inch	3,000 LF
24-inch	1,280 LF
Total	**35,850 LF**

↓

8,700 LF (25%) of trenching required

Total: $30,000,000 – $35,000,000

All cost estimates are provisional and subject to change



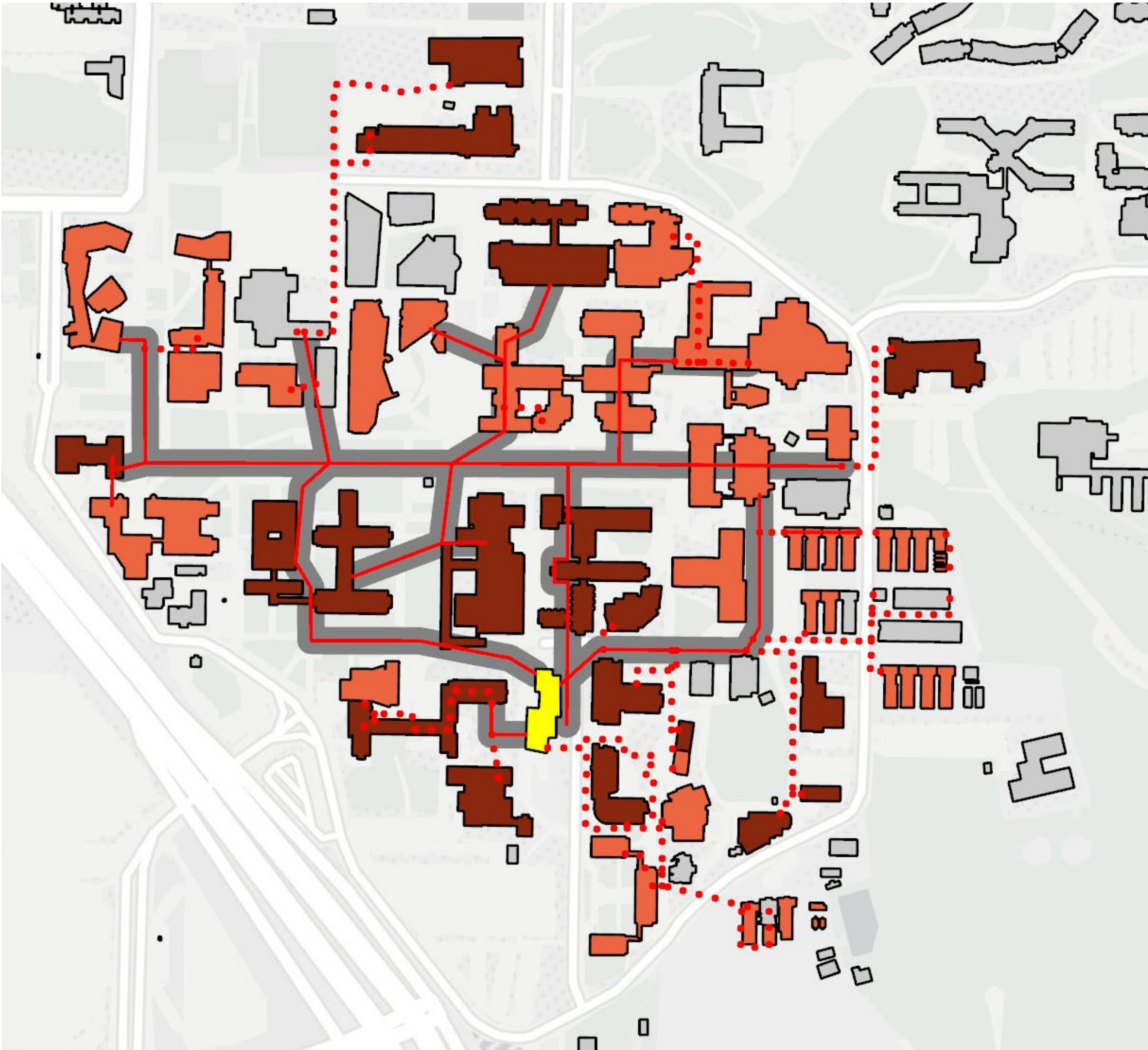
Alternative 2: Steam to Hot Water Conversion

Building System Upgrades

Required Upgrade	No. of Bldgs.
Full Steam Conversion	11 Buildings
Additional HHW Capacity	24 Buildings
New Heat Exchanger	61 Buildings
Process Conversion	12 Buildings (160 Units)

HVAC: $20,000,000 – $30,000,000
Process: $15,000,000 – $25,000,000*
*including estimated ~$6,000,000 - $8,000,000 for 9 building service upgrades

All cost estimates are provisional and subject to change



Alternative 2A: Hot Water – Heat Pump (Centralized)

Description

- **Replace steam plant with WWHPs and ASHP**
- ASHP yard adjacent to the existing Steam Plant
- Remove existing Steam Plant chillers and cooling towers

Pros and Cons

- Fully electric allowing decarbonization goals to be met
- Very efficient systems
- Maintain centralized heating hub

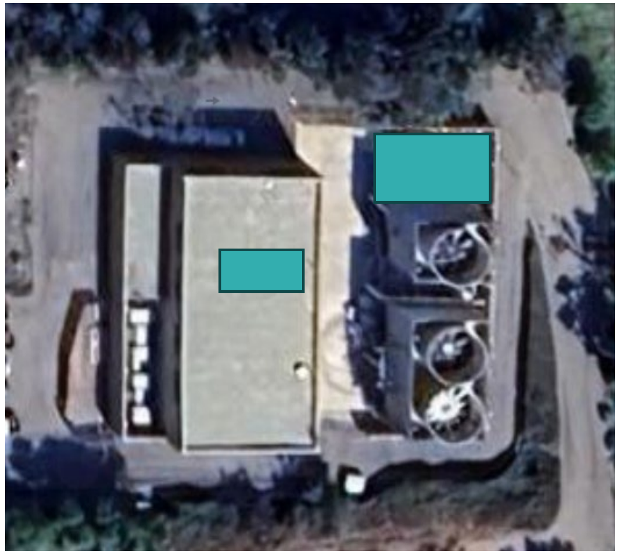
- Hot water solution requires new distribution infrastructure
- Complicated, and disruptive to enable (hot water infrastructure)

Alternative 2A: Hot Water – Heat Pump (Centralized)

- 25 kSF can fit > 100 ASHP modules (>30 MBh)
- Remove cooling towers at steam plant (ASHP provides capacity)
- Install SAT plant cooling to facilitate transition

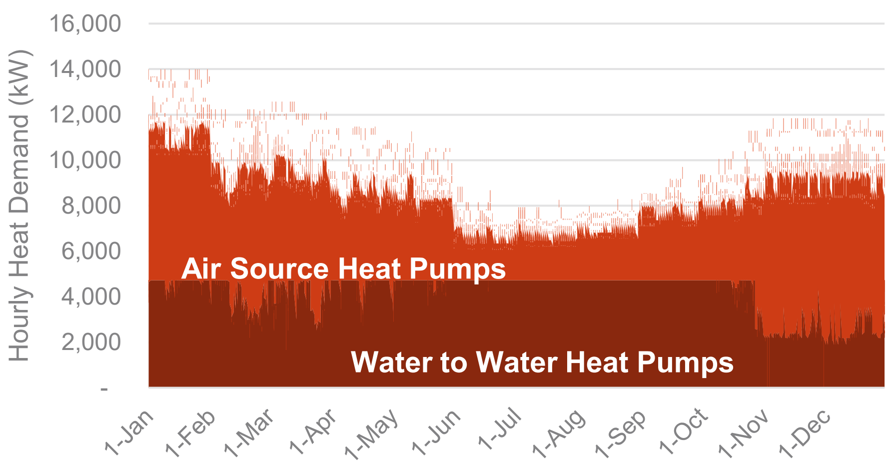
Replace Old Chillers with new HRCs (up to 5)

ASHP Location



New chiller, cooling tower and pumps

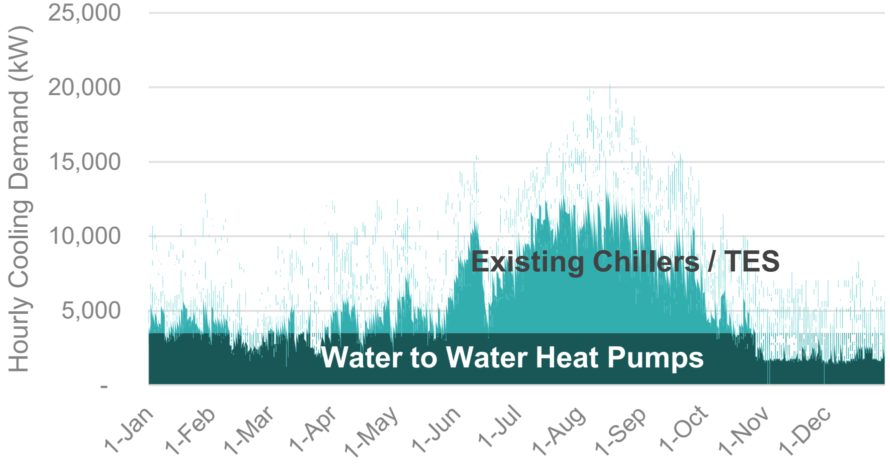
Alternative 2A: Hot Water – Heat Pump (Centralized)



Contribution of Equipment

WWHP 51%

ASHP 49%



WWHP 47%

Chillers 53%

GHG Emissions Reduction	
Scope 1 Emissions	0 $mtCO_2e$ per year
	100 % reduction
Scope 2 Emissions	10,500 $mtCO_2e$ per year
Life Cycle Cost	
Utility Costs	$3.5M total per year
Capital Costs	$87.3M
Energy Procurement	$0 per year
Resource Use	
Peak Electrical Demand	6,200 kW
Water Usage	22 MGal per year
Ease of Implementation	
Availability Limitations	Low
Spatial Requirements	Low
Scale of Disruption	Medium

Alternative 2B. Hot Water – Heat Pump with TES

Description

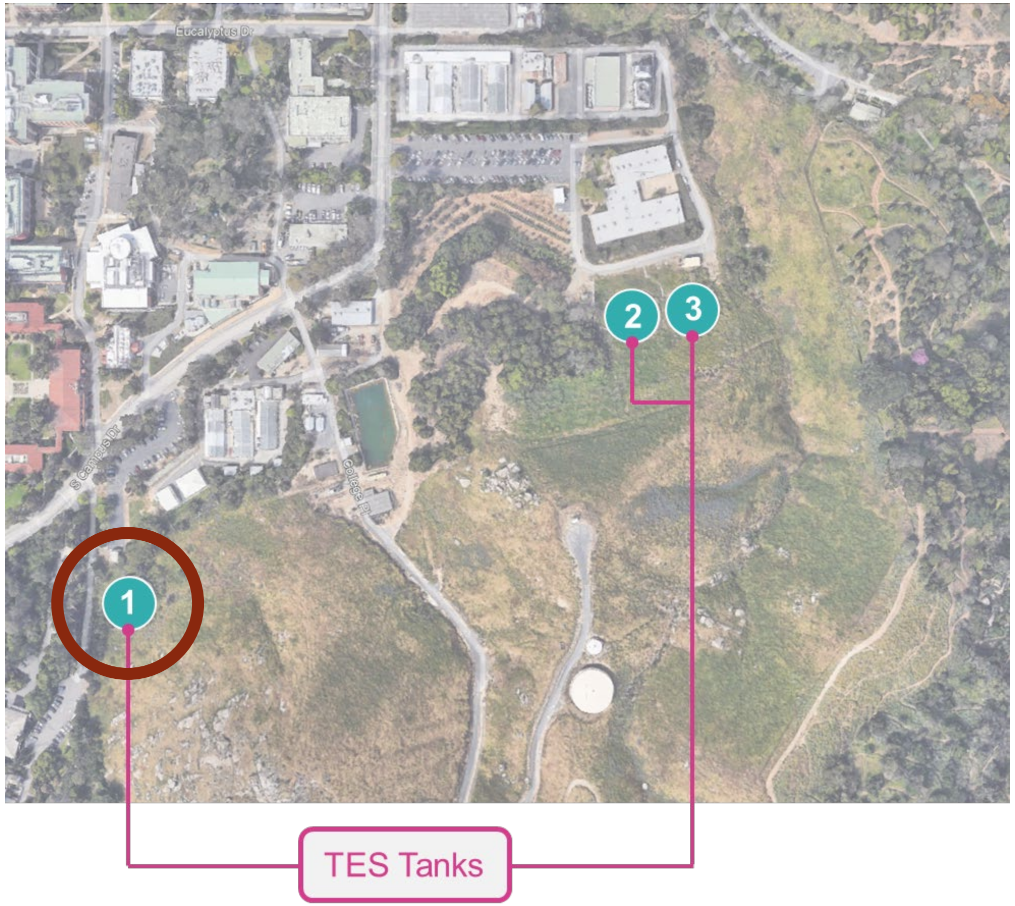
- **Same as Alt 2A**
- Repurposing TES Tank 1 for use for Hot Water
- Can be optimized for day to multi-week storage

Pros and Cons

- Greatly enhances the water-to-water heat pump run hours and feasible capacity
- Subsequent reduction in operational cost (more efficient operation)
- Increased heating supply redundancy
- (Potentially) reduced plant equipment capacity required

- Additional complexity in controls
- Reduced deployable cooling TES capacity

Alternative 2B. Hot Water – Heat Pump with TES



Equipment	Identifier	Capacity	Availability
TES Tanks	**TES-1**	**2,200,000 gal**	**24,000 Ton-hrs**
	TES-2	2,700,000 gal	24,000 Ton-hrs
	TES-3	2,000,000 gal	18,000 Ton-hrs

- **Re-pipe TES 1 for hot water storage** to maximize WWHP run times
- 7 – 10 MWh (25,000 – 35,000 MBh) heat storage capacity in a single tank

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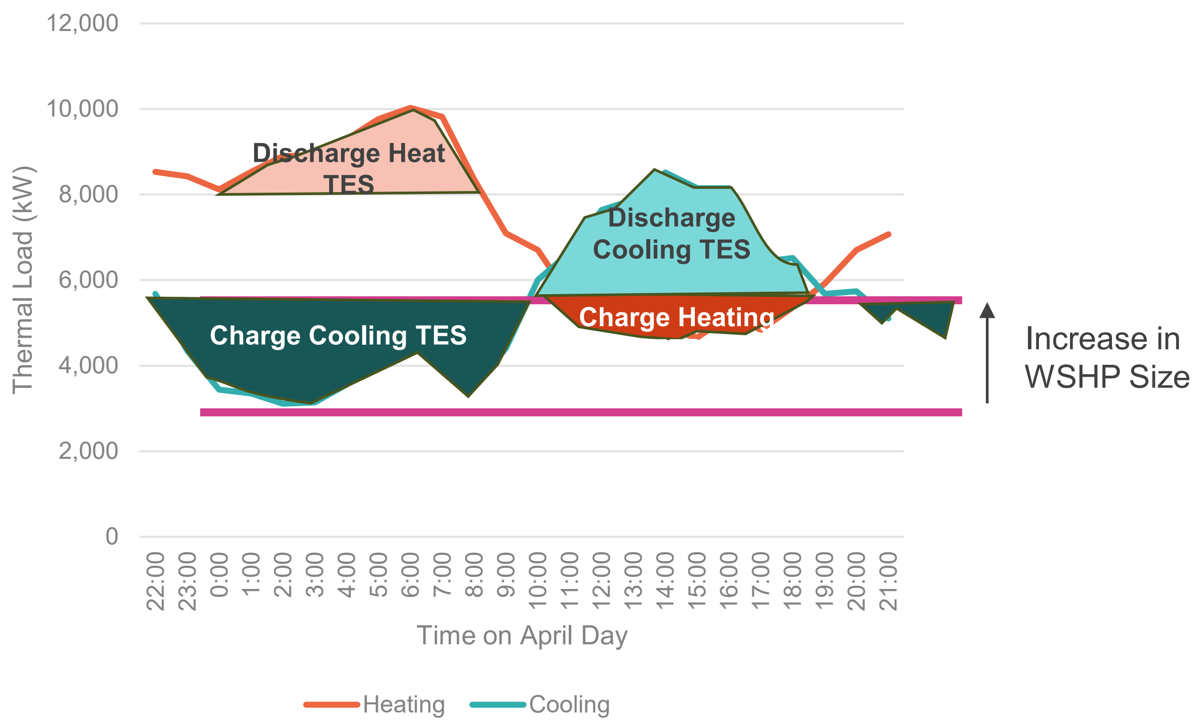
Alternative 2B. Hot Water – Heat Pump with TES

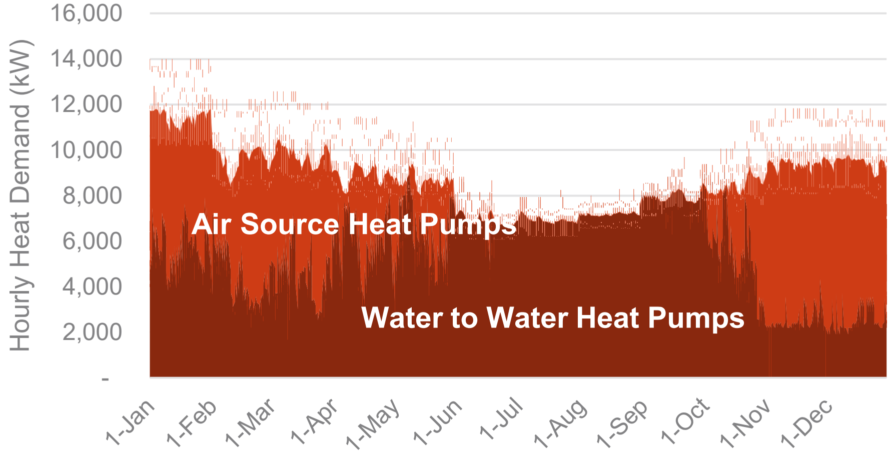
Operational Alternatives

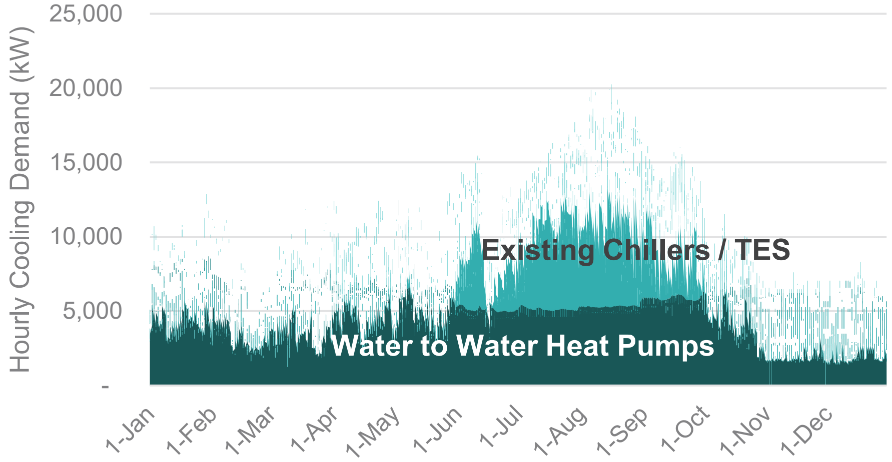
1. CHW Storage - Run the WWHP and charge chilled water TES when there is heating load
2. HHW Storage - Run WWHP in the same way but use one tank as waste heat storage
3. CHW and HHW storage - Run all equipment at the same time, use as needed to balance loads

Overall – Increased WWHP Run Times



Alternative 2B. Hot Water – Heat Pump with TES





Contribution of Equipment

WWHP 74%

ASHP 26%

WWHP 68%

Chillers 32%

GHG Emissions Reduction	
Scope 1 Emissions	0 $mtCO_2e$ per year
	100% reduction
Scope 2 Emissions	9,100 $mtCO_2e$ per year
Life Cycle Cost	
Utility Costs	$3.0M total per year
Capital Costs	$92.0M
Resource Use	
Peak Electrical Demand	5,500 kW
Water Usage	9 MGal per year
Ease of Implementation	
Availability Limitations	Low
Spatial Requirements	Medium
Scale of Disruption	Medium

Alternative 2C – Heat Pump Neighborhoods (Hot Water)

Description

- **Splitting into smaller District Plants**
- Leveraging ASHP at each location for heating-only
- Certain locations could use WSHP tied to CHW system

Pros and Cons

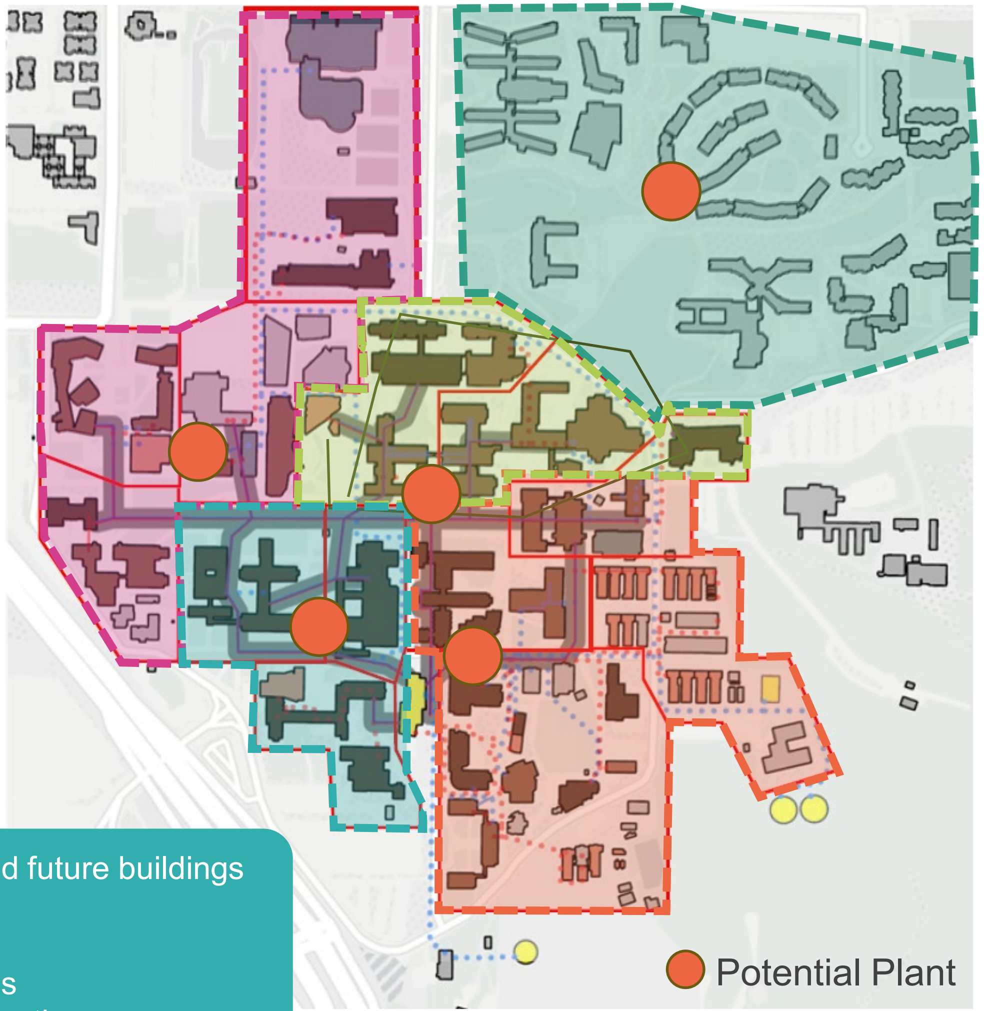
- Easier phasing
- Enhanced redundancy
- Theoretically could be used for transitioning existing gas-housing

- Increased land use requirement
- Reduced system efficiency (no WWHP)

Alternative 2C – Heat Pump Neighborhoods (Hot Water)

Heating Districts

- Identify buildings on the same existing network to minimize disruption
- Can interconnect for additional redundancy
- Phased implementation over time to align with funding
- Can encapsulate stand-alone buildings where feasible
- Require new electrical infrastructure



- Proximity to current and future buildings
- Stacking & Colocation
- Visual considerations
- Acoustic considerations
- Environmental considerations
- Safe access

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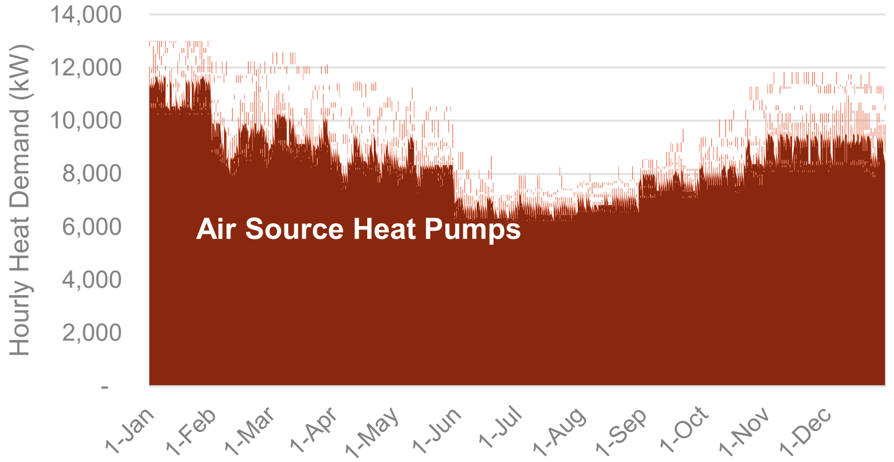
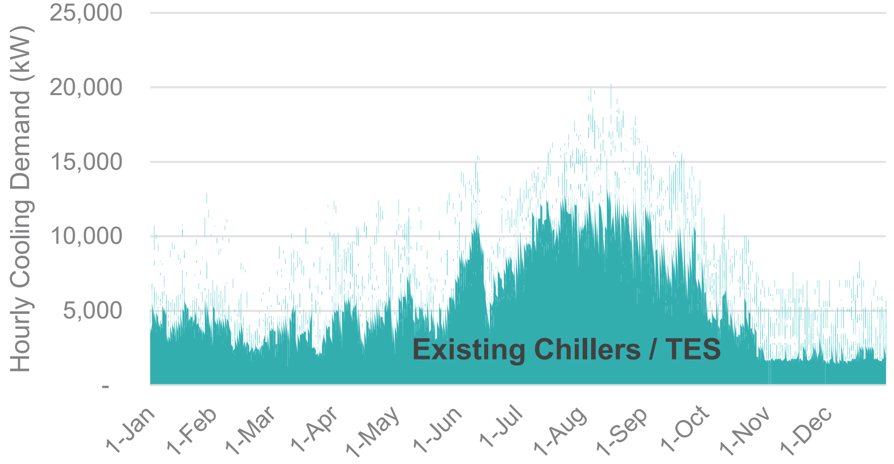
Alternative 2C – Heat Pump Neighborhoods (Hot Water)





Contribution of Equipment

WWHP 0%

ASHP 100%

WWHP 0%

Chillers 100%

GHG Emissions Reduction	
Scope 1 Emissions	0 $mtCO_2e$ per year
	100% reduction
Scope 2 Emissions	14,000 $mtCO_2e$ per year
Life Cycle Cost	
Utility Costs	$4.5M per year
Capital Costs	$85.7M
Resource Use	
Peak Electrical Demand	8,500 kW
Water Usage	42 MGal per year
Ease of Implementation	
Availability Limitations	Low
Spatial Requirements	Medium
Scale of Disruption	High

Alternative 3A – Steam Electric Boilers

Description

- **Replace natural gas boilers with electric boilers**
- Utilize existing cooling TES

Pros and Cons

- Minimal disruption to campus
- Replace ‘in-place’ in the steam plant

- New campus electrical service required (more than any other option)
- High ongoing operational cost

Performance Metrics

GHG Emissions Reduction	
Scope 1 Emissions	0 $mtCO_2e$ per year
	100% reduction
Scope 2 Emissions	40,500 $mtCO_2e$ per year
Life Cycle Cost	
Utility Costs	$11.6M per year
Capital Costs	$40.1M
Resource Use	
Peak Electrical Demand	18,500 kW
Water Usage	51 MGal per year
Ease of Implementation	
Availability Limitations	Low
Spatial Requirements	Low
Scale of Disruption	Low

Alternative 3B – RNG

Description

- Maintain natural gas boilers
- Procure renewable natural gas or biomethane to offset local gas emissions
- In short term, can leverage favorable UC contract

Pros and Cons

- No impact to existing operations

- High operational cost
- No local air quality benefits

Performance Metrics

GHG Emissions Reduction	
Scope 1 Emissions	0 $mtCO_2e$ per year
	100% reduction
Scope 2 Emissions	0 $mtCO_2e$ per year
Life Cycle Cost	
Utility Costs	$1.5M per year
Capital Costs	$0.4M
Energy Procurement (Market)	$7.0M per year
Energy Procurement (UC)	$1.7M per year
Resource Use	
Peak Electrical Demand	n/a
Water Usage	51 MGal per year
Ease of Implementation	
Availability Limitations	High
Spatial Requirements	Low
Scale of Disruption	Low

Alternative 3C – Heat Pumps

Description

- **Replace natural gas boilers with electric heat pumps**
- Higher efficiency steam electrification option

Pros and Cons

Pros

- Emerging technology that will likely be deployable at this scale in the future
- Less operational cost than electric boilers
- Maintain steam systems

Cons

- Not currently available at this scale
- High capital and operational costs at the moment

Performance Metrics

GHG Emissions Reduction	
Scope 1 Emissions	0 mtCO_2e per year
	100% reduction
Scope 2 Emissions	27,400 mtCO_2e per year
Life Cycle Cost	
Utility Costs	$7.9M per year
Capital Costs	$34.3M
Resource Use	
Peak Electrical Demand	12,100 kW
Water Usage	51 MGal per year
Ease of Implementation	
Availability Limitations	High
Spatial Requirements	High
Scale of Disruption	High

Alternative 3D – Hydrogen

Description

- Replace natural gas boilers with hydrogen fuel cells
- Purchase H2 and store on site

Pros and Cons

- Potential low carbon fuel that could meet carbon goals (if green H2)

- No certainly on supply
- Tied to a lot of deliveries, and requirement for large onsite storage
- Likely require full steam plant replacement (fuel cells)
- Unlikely to get below 3x the cost of natural gas
- Safety concerns

Performance Metrics

GHG Emissions Reduction	
Scope 1 Emissions	0 $mtCO_2e$ per year
	100% reduction
Scope 2 Emissions	40,500 $mtCO_2e$ per year
Life Cycle Cost	
Utility Costs	$1.5M per year
Capital Costs	$26.0M
Energy Procurement Costs	$21.7M per year
Resource Use	
Peak Electrical Demand	n/a
Water Usage Savings	51 MGal per year
Ease of Implementation	
Availability Limitations	High
Spatial Requirements	High
Scale of Disruption	High

Alternative 4 – Decentralized Heat Pumps

Description

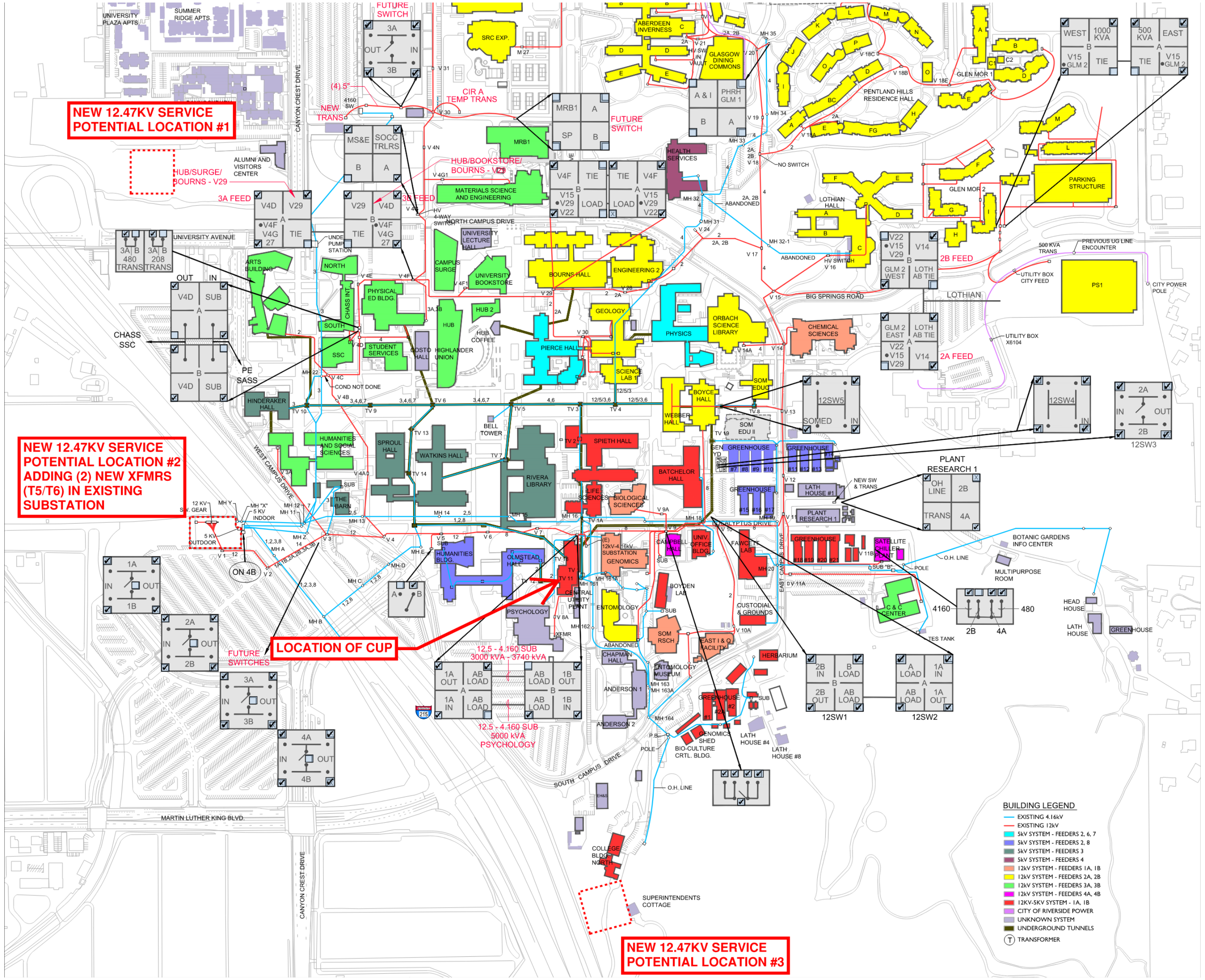
- **Locating heating equipment at each building**
- Decommissioning existing heat central plant
- Leverage either ASHP, WSHP, or small split-systems to meet demand

Pros and Cons

- Easier phasing
- Theoretically could be used for transitioning existing gas-housing

- Space constraints
- Expensive electrical upgrades
- Lose economies and efficiencies of scale

Electrical Distribution Upgrades



- Most centralized and decentralized electrification options require new campus 12.47kV service due to added load.
- Identified 3 potential locations through discussions with RPU – each with advantages and drawbacks.
- Centralized CUP upgrades: New distribution at CUP to supply ASHP/WSHP or electric boilers.
- Decentralized building upgrades: New transformers and main switchboards, plus interior distribution.

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Alternative 4B – Decentralized Heat Pumps

Description

HVAC System Replacement

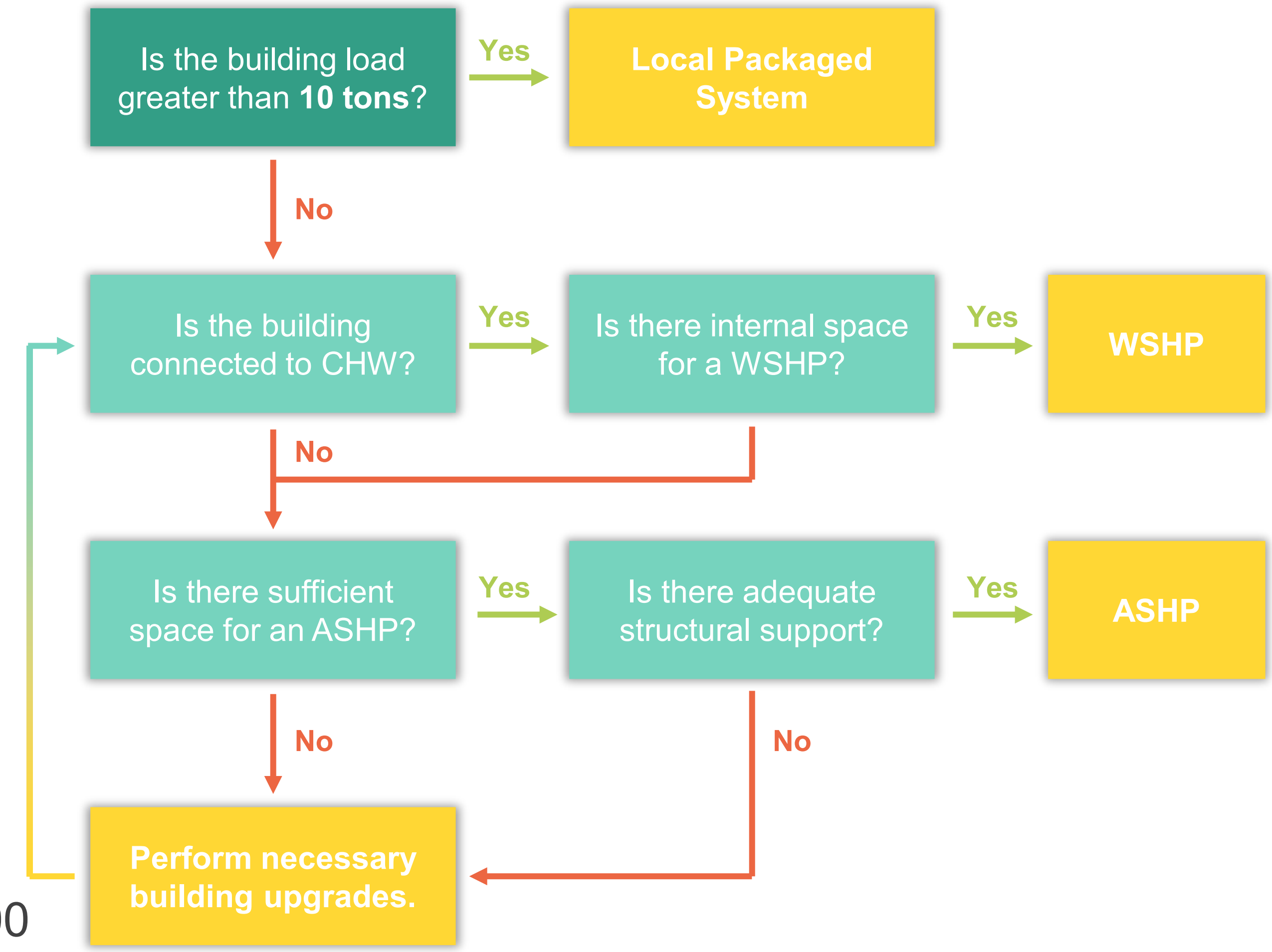
System Type	Buildings	Served Load
ASHP	42	2,000
WSHP	25	1,800
Split-System	Remaining	<300

Total: $50,000,000 – $75,000,000

Building Electrical Service Upgrades

21 Transformers would require replacement

HVAC Systems: $50,000,000 - $100,000,000
Transformers / Switchgear: $10,000,000 - $20,000,000
Total: $60,000,000 – $95,000,000*
*not including required site circuitry balancing up to additional $100,000,000



Alternatives - KPI Summary

Alternative	Electricity Savings [MWh/yr]	Natural Gas Savings [therms/yr]	Water Use (Mgal/year)	GHGe Emission Reduction [MTCO2e/yr]	1st year Utility Cost Savings [$ M/yr]	CapEx [2023 $M]*	30-year Total Cost of Ownership ($10M)*	NPV($M)*
1. Business as Usual (Steam)	n/a	n/a	51	n/a	n/a	n/a	33.2	n/a
2A. Hot Water – Heat Pump (Centralized)	-15,300	4,200,000	22	16,600	3.5	87.4	25.7	(1.5)
2B. Hot Water – Heat Pump with Optimized TES	-11,000	4,200,000	9	18,100	4.0	92.0	24.1	4.5
2C. Hot Water – Heat Pump (Neighborhoods)	-25,300	4,200,000	42	13,200	2.5	85.7	30.4	(24.7)

*Cost of process equipment replacement not included in CAPEX

All cost estimates are provisional and subject to change

All cost estimates are provisional and subject to change

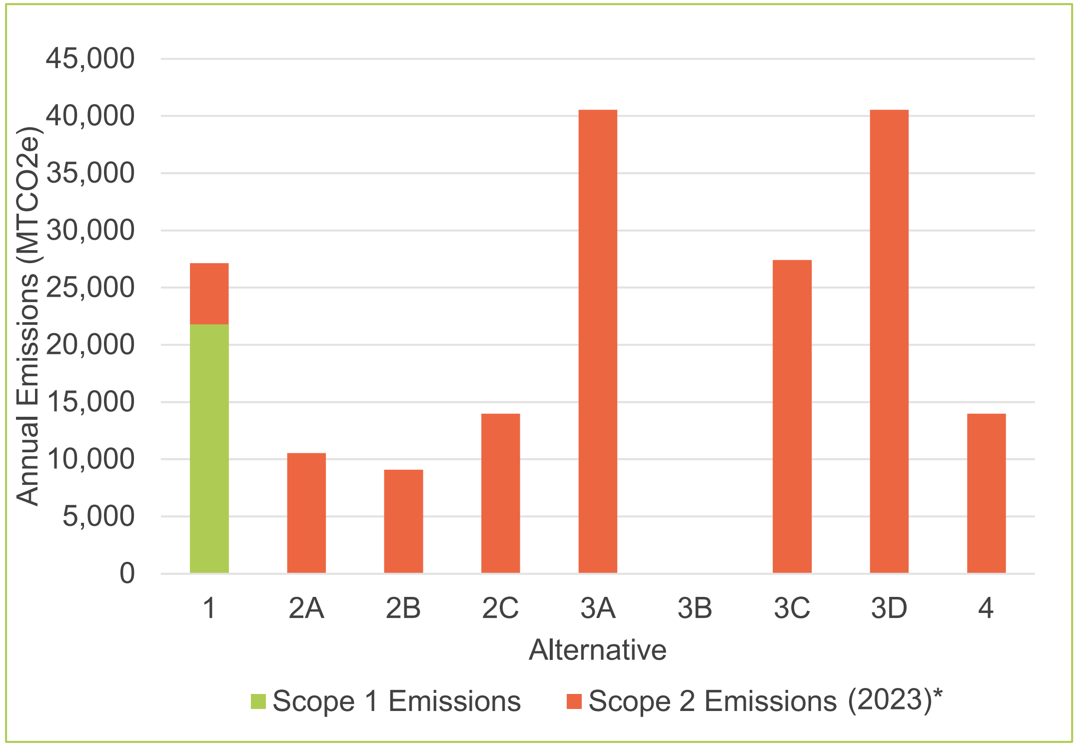
Alternatives - KPI Summary

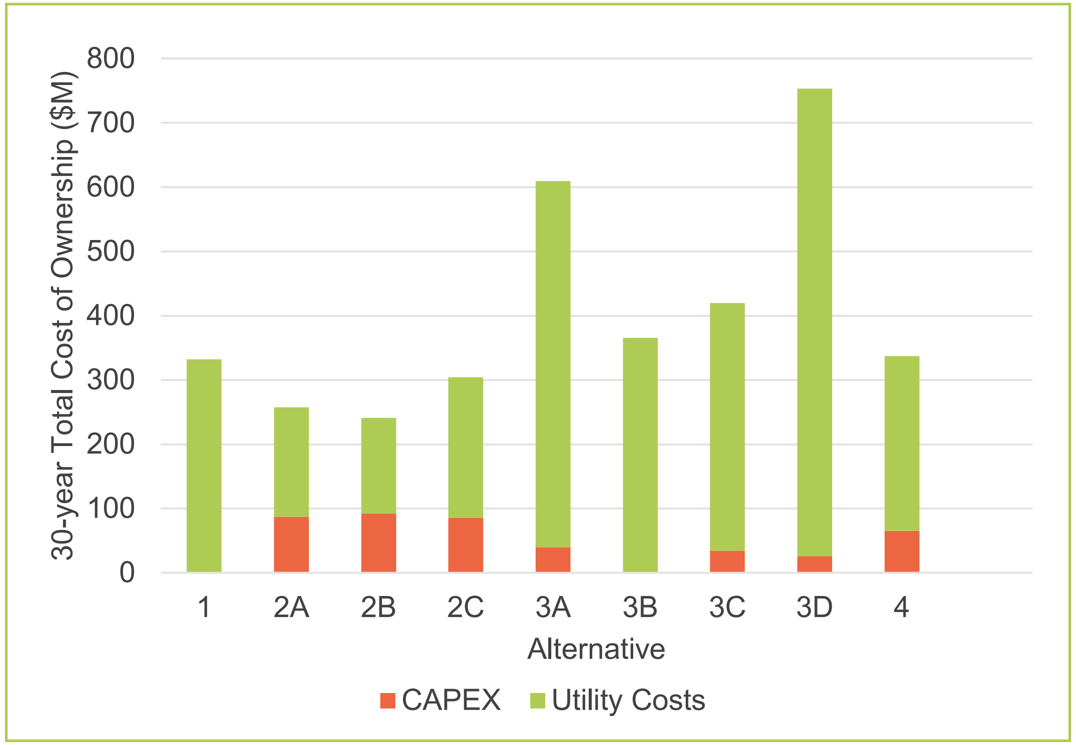
Alternative	Electricity Savings [MWh/yr]	Natural Gas Savings [therms/yr]	Water Use (Mgal/year)	GHGe Emission Reduction [MTCO2e/yr]	1st year Utility Cost Savings [$M/yr]	CapEx [2023 $M]*	30-year Total Cost of Ownership [$10M]*	NPV [$M]*
3A. Steam (Today) – Electric Boilers	(102,700)	4,200,000	51	(13,500)	(4.9)	40.1	61.0	(158.3)
3B. Steam (Today) – Alternative Fuels (RNG)	15,600	4,200,000	51	27,200	(1.6)	0.4	36.6	(197.5)
3C. Steam (Future) – Heat Pumps	(64,500)	4,200,000	51	-300	(1.0)	34.3	42.0	(58.6)
3D. Steam (Future) – Alternative Fuels (H_2)	15,600	4,200,000	51	-13,500	(16.2)	26.0	75.4	(256.7)
4. Decentralized Heat Pumps for Connected Buildings	(25,300)	4,200,000	42	13,200	1.4	65.5	33.7	(31.7)

*Cost of process equipment replacement not included in CAPEX

All cost estimates are provisional and subject to change

Alternative Comparison Summary





2023 Emissions Equivalent

30-year Total Cost of Ownership

1 – BAU
2A – Centralized Hot Water Heat Pump
2B – Hot Water Heat Pump w/Optimized TES
2C – Hot Water Heat Pump Neighborhoods
3A – Steam Electric Boilers
3B – Renewable Natural Gas
3C – Steam Heat Pumps
3D – Hydrogen
4 – Decentralized Heat Pumps

*Electricity emissions will trend to zero over time

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Summary

The preliminary alternatives analysis suggests the following:

- The cost of transitioning to **centralized electric-based heating system may be economically viable** in addition to decarbonizing the campus
  - The TOC of alternatives 2A-2C are lower than maintaining existing operations or procuring RNG.
  - The operational costs reduce greatly **due to favorable climate and long periods of simultaneous load**
  - The capital cost, while high, is **mitigated somewhat by the existing utility corridors** and relatively few buildings (11) that require a full internal retrofit
- The technologies that may allow decarbonized central steam generation (electric boilers today, or heat pumps, hydrogen, or carbon capture) are **all economically unfavorable** due to a combination of high utility and fuel costs and large infrastructure investment required.
- **Decentralized** heating systems may be easier to phase and implement, but **do not perform as well as centralized systems** over time due to high initial investment and less efficient operations.
- The next phase of the assessment will **focus in on the phasing considerations** to identify key challenges and opportunities in the development of an implementation plan.

05

Path Forward / Next Steps

Path Forward – Technical Analysis

- Finalize Alternative Analysis (Incorporating Feedback)

- Phasing Plan - Considering Timeframe of Implementation
  - Enabling Strategies,
  - Building Groupings,
  - End of Life Replacements, etc.
  - Pilot Project Location

- Share Report Table of Contents – Also First Chapters?

Alternative Matrix

Scenario Developments	Scenario Description	GHG Emissions Reduction	Life Cycle Cost	Resource Use	Resilience	Implementation	EJ & Equity	Collaborative Learning	Total
		Goal Areas Weight >> 1 (worst) to 8 (best)							
Scenario 1	Business as Usual (Steam)	–	–	–	Will be populated through Next Steps				–
Scenario 2A	Hot Water – Heat Pump (Centralized)	6	7	5					18
Scenario 2B	Hot Water – Heat Pump with Optimized TES	7	8	6					21
Scenario 2C	Hot Water – Heat Pump (Neighborhoods)	5	6	4					15
Scenario 3A	Steam (Today) – Electric Boilers	1	3	1					5
Scenario 3B	Steam (Today) – Alternative Fuels (RNG)	8	2	8					18
Scenario 3C	Steam (Future) – Heat Pumps	3	4	2					9
Scenario 3D	Steam (Future) – Alternative Fuels (H_2)	2	1	7					10
Scenario 4A	Heat Pumps for Non-Connected Buildings	–	–	–					–
Scenario 4B	Decentralized Heat Pumps for Connected Buildings	5	5	3					13

Upcoming Dates

Working Session – Phasing & Implementation

- Targeting Week of May 13

Target Draft Reports – by June 7

- Deliverables #1-5

Target Final Reports – July 12

Submission to UC Task Force – By July 31, 2024

LCCA Assumptions

Discount and Escalation Rates	
Discount Rate	4.3%
Escalation Rate – Electricity	3.0%
Escalation Rate – Natural	3.0%
Escalation Rate – Hydrogen	0%
Escalation Rate – Biomethane	2.0%

Resource Costs	
Electricity (2023)	$0.12/kWh
Natural Gas (2023)	$1.3/therm
Renewable Natural Gas	$4.12-4.89/MMBtu
Hydrogen	$6-8/kg