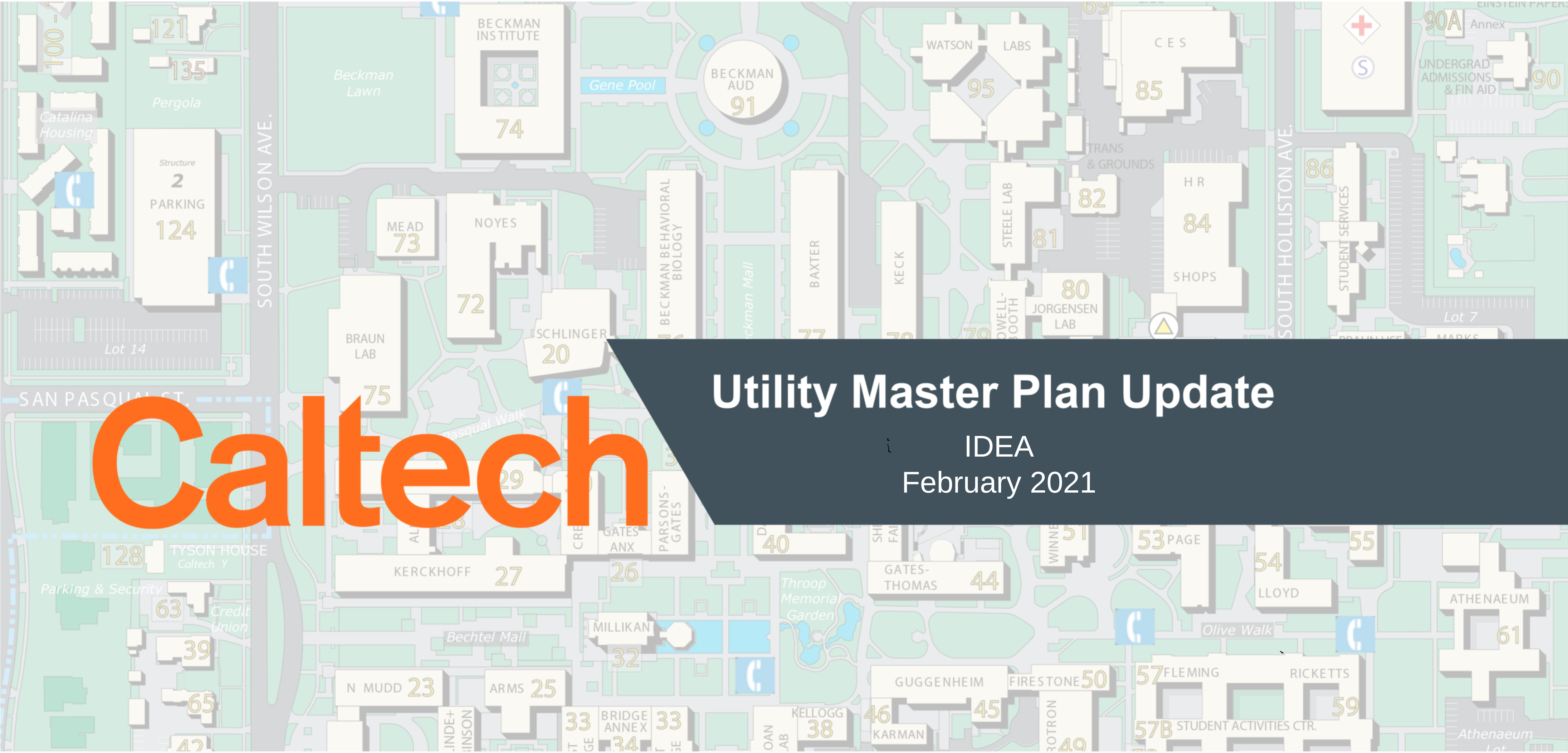
CampusEnergy2021

BRIDGE TO THE FUTURE

Feb. 16-18 | CONNECTING VIRTUALLY

WORKSHOPS | Thermal Distribution: March 2 | Microgrid: March 16



Caltech

Utility Master Plan Update

IDEA

February 2021

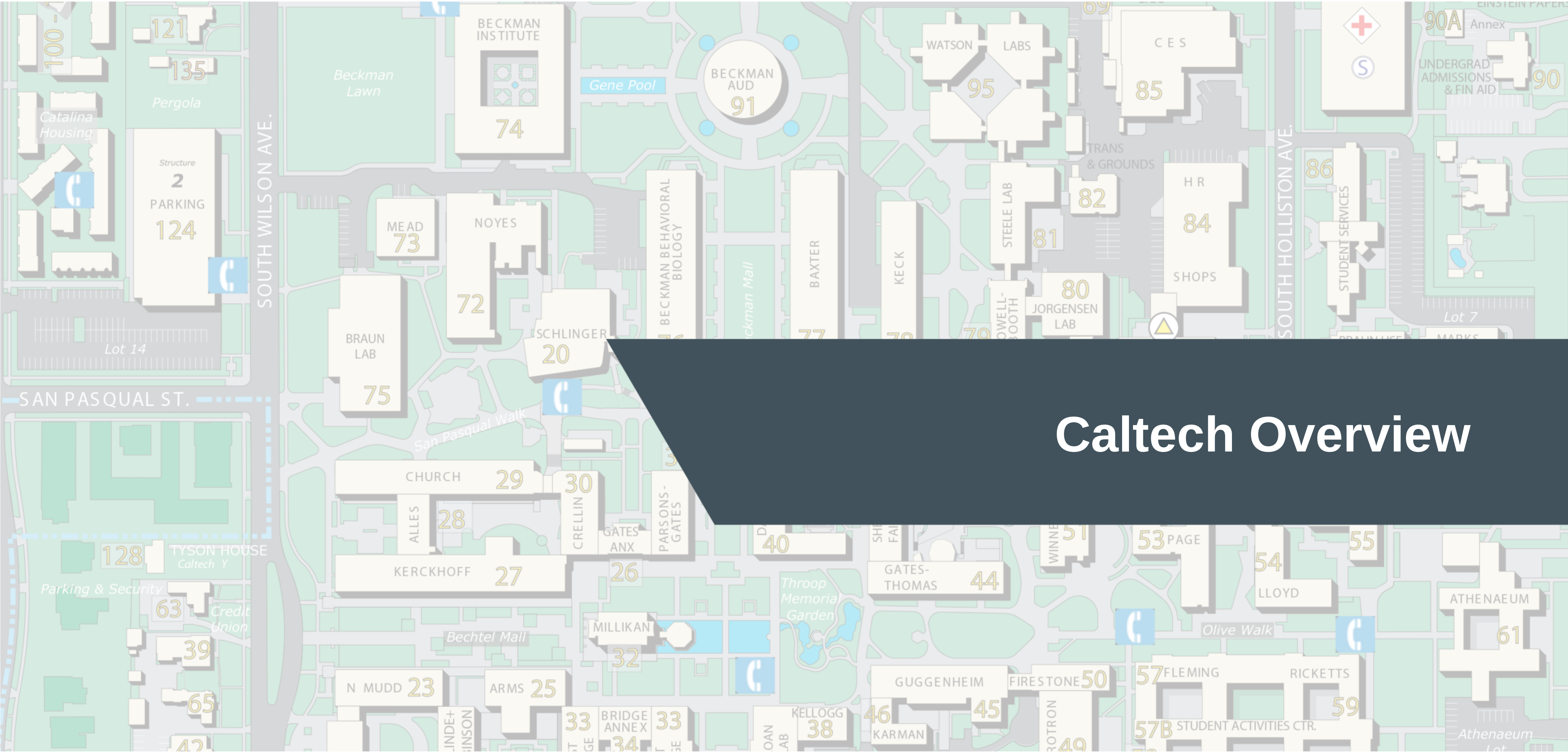
Affiliated Engineers

Q&A Will Not Be Answered Live

Please submit questions in the Q&A box.
The presenters will respond to questions off-line.

Agenda

- Caltech Overview
- Energy planning
  - History of cogeneration system
  - Energy Resource Plan
- Utility Master Plan
  - Chilled water system modeling
  - Chilled water system improvements
- CHW System Improvements



Caltech Overview

Sustainability At A Glance – Key Performance Indicators

Fiscal Year 2019 At A Glance — Key Performance Indicators

Energy While achieving the lowest demand since FY08, Caltech has enhanced supply and price reliability through smart energy management and purchasing strategies.	↓ **5%** total electricity demand since peak in FY16, lowest demand since FY08	**100%** electricity produced on-site, marking three consecutive years as net exporter	↓ **3%** energy intensity by area since FY17 peak but 7% increase since FY11	**$11.2M** in annual energy costs, flat since FY17 and a 22% decrease since FY11	**$17M** in cumulative energy cost reductions compared to FY11 baseline
Water Water consumption fell slightly in FY19 due to conservation measures at the utility plants and irrigation savings that resulted from turf removal and an unusually rainy winter.	↑ **12%** water consumption since FY17 but a 44% decrease since FY06 peak	↓ **30%** irrigation water use from FY18 mostly due to significantly wetter year in FY19	↓ **12%** water use per square foot from FY14 peak but constant since FY11	**$1.3M** in annual water costs, down 15% from FY18 but up 20% from FY11	↑ **10%** In campus costs per gallon since FY11 but down 13% from FY18
Materials Waste generation fell again in FY19, as we've begun to establish a new baseline after the closure of the Recycling Center. Recycling markets continue to be unreliable.	**27%** campus non-hazardous waste diversion rate, down from 37% in FY17	↓ **35%** municipal solid waste per capita, down to .24 tons from .41 in FY14	↓ **22%** hazardous waste diversion since FY17, down to 55%	**$771K** In total campus waste costs, up 15% from FY14	↓ **95%** drop in net recycling revenue compared to FY17 due to commodity prices
Built Environment Caltech continues to transition towards more sustainable land use practices. 2019 saw progress in lawn care electrification, drought resistant vegetation, and sustainable buildings.	**2** buildings pursuing LEED certification in 2020	**176K** square feet of LEED building space to be added by 2021	**16%** of campus now covered with low-water vegetation, up from 4% in 2012	**8,000** square feet of turf removed from campus in 2019	**14%** Of campus building square footage is now LEED certified, up from 6% in 2011
Transportation 2019 saw a mixed bag of indicators for progress. While drive alone rates and campus AVR are trending in the wrong direction, new programs should bring progress in commuting trends in 2020.	**1.60** campus occupants per vehicle, down from 1.63 in 2018	↑ **2%** campus drive alone rate, up to 44%	**8.7 miles** average commute distance, up from 8.0 in 2018	**72%** staff drive alone rate, highest since record keeping began in 2005	**145/10** carpools and vanpools at the end of 2019, respectively
Emissions Caltech's emissions were flat from last year, continuing a trend in place since 2012. Despite emissions intensity improvements, we will not meet our 2020 Climate Action Plan goal.	↓ **1%** regulated greenhouse gas emissions since 2016	↓ **22%** total greenhouse gas emissions since 2008	↓ **3%** emissions intensity per capita from 2017 but flat since 2015	**1.12** pounds of CO2e per research dollar, down 2% since 2018	**14.1** MTCO2e per person, down 6% since 2014 but flat since 2015

Energy Map

N. Wilson Parking Structure
380 KW

S. Wilson Parking Structure
440 KW

S. Wilson Parking Fuel Cell
1 MW

Linde + Robinson Laboratory
5 KW

Linde + Robinson Laboratory Fuel Cell
200 KW

Cahill Center
27 KW

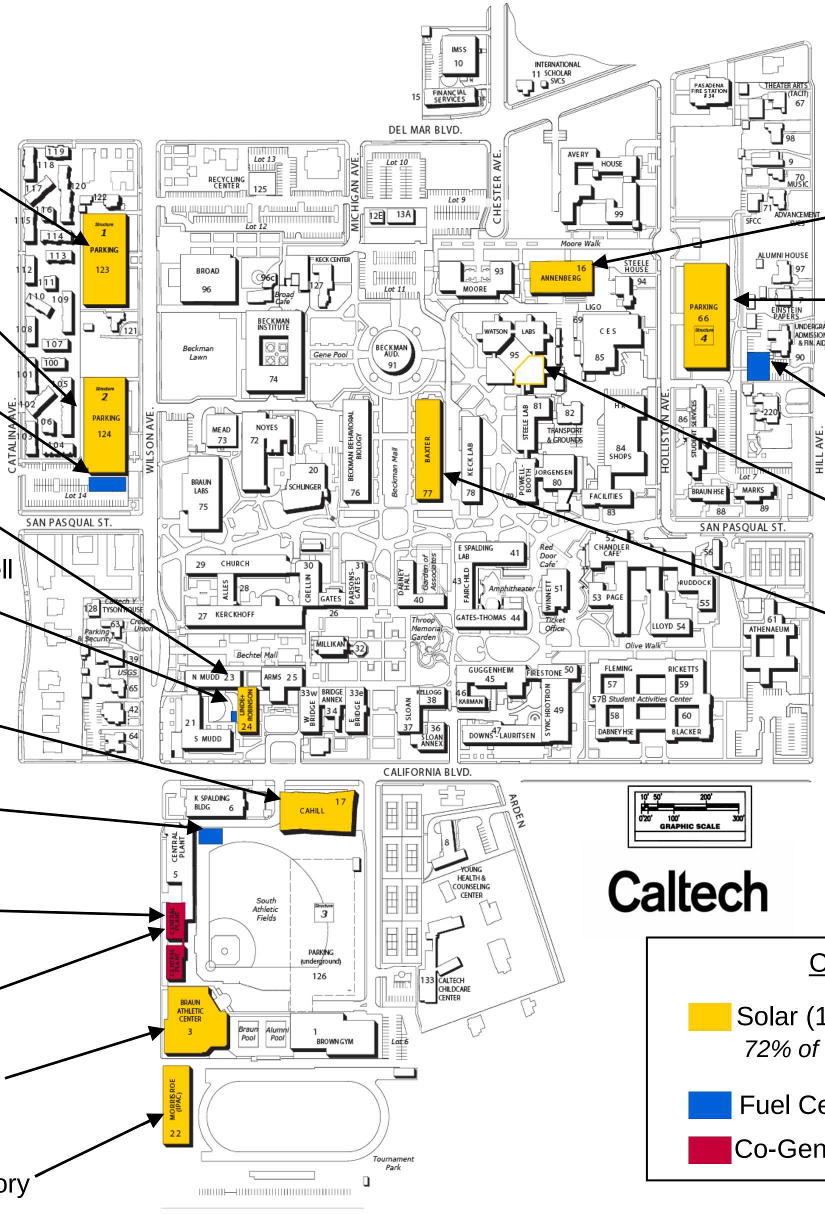
Central Plant Fuel Cell
1 MW

Central Plant Gas Turbine
10 MW

Central Plant Steam Turbine
2.5 MW

Braun Gym
94 KW

IPAC Laboratory
40KW



Annenberg Center
64 KW

Holliston Parking Structure
200 KW

Satellite Plant Fuel Cell
1 MW

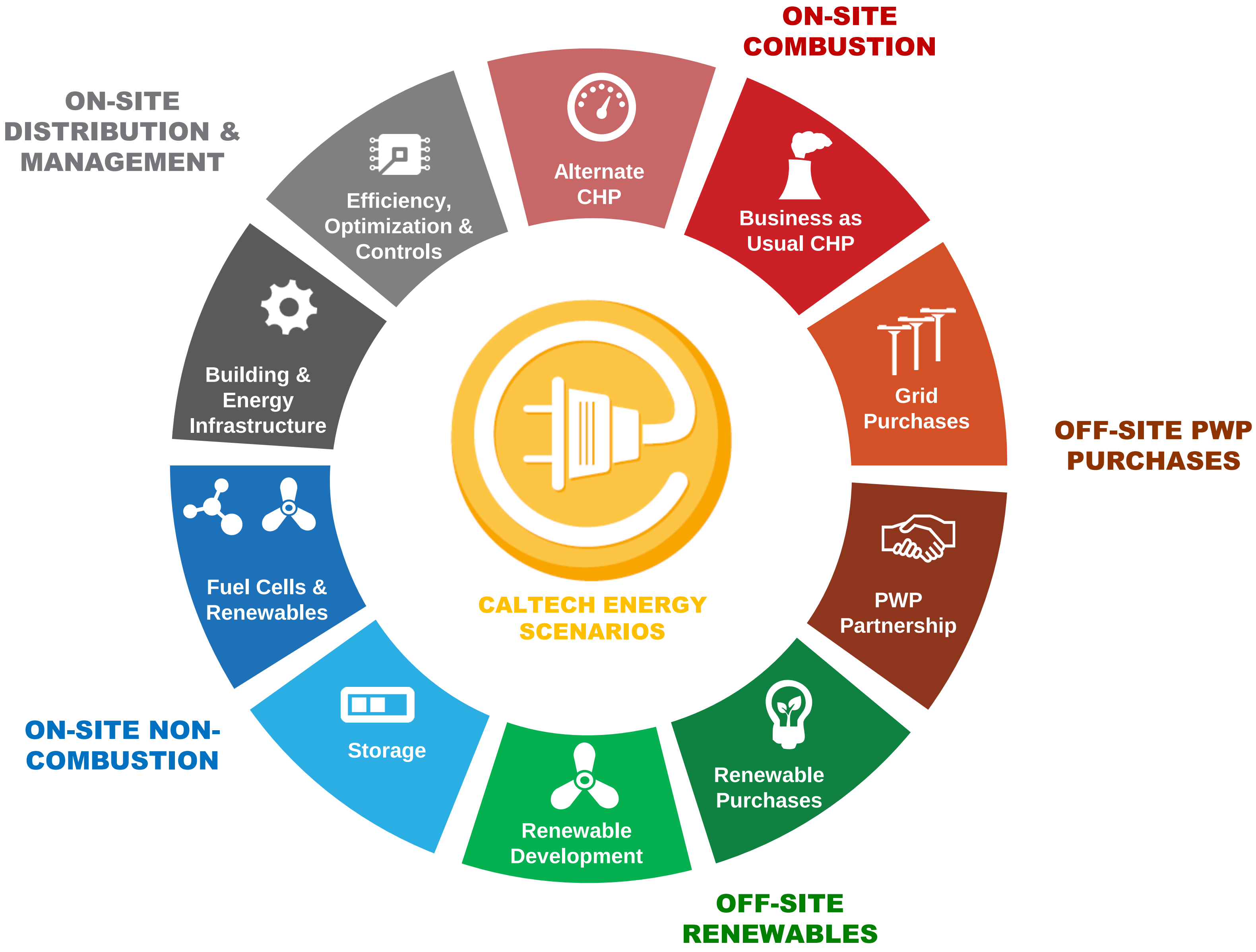
Watson Laboratory
Student Solar Initiative

Baxter Hall
131 KW

On-Site Generation

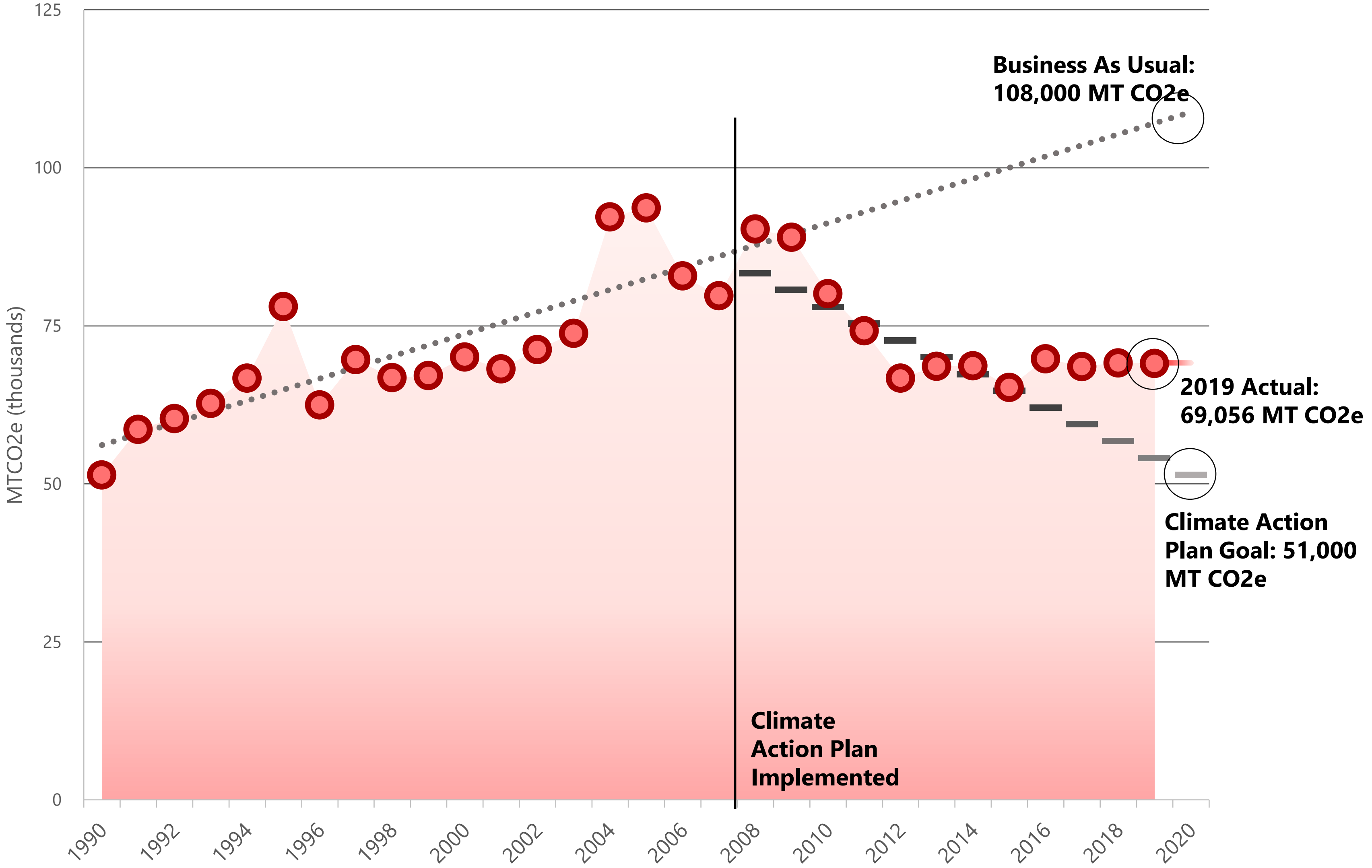
- Solar (1.3 MW)
  72% of campus space eligible for solar used
- Fuel Cells (~3.23 MW)
- Co-Generation (12.5 MW)

Initial Energy Scenario Categories



Campus Carbon Emissions Progress

Emissions flat since 2016, not on target to meet 2020 goal



Utility Master Plan
Chilled Water System

Goals of Caltech UMP

- Identify ways Caltech can continue to meet campus energy requirements in an economical manner while remaining sensitive to environmental concerns, reducing risks, and addressing reliability and adaptability.

- Minimize Total Cost of Ownership including capital expenditure, operation and maintenance, and utility costs.

Goals of Caltech UMP

- Enable adaptability and reliable capacity to meet campus growth, while improving controllability.

- Reduce environmental impact, emissions, and campus risk to regulatory changes.

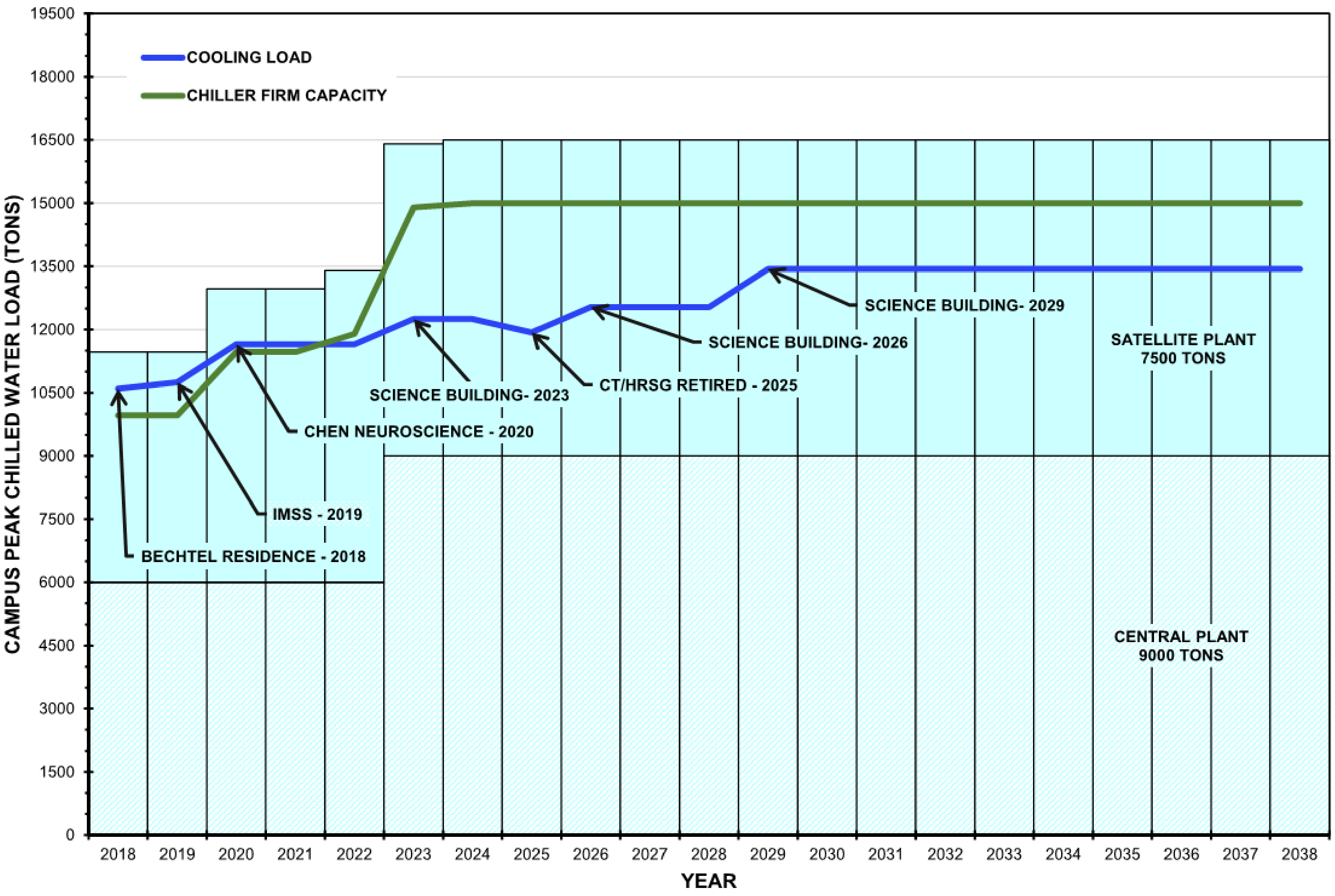
CALTECH ENERGY SCENARIOS

Utility Master Plan

- AEI hired to provide outside confirmation of Caltech Energy Resources Plan

- Deeper dive into utility systems
  - Existing Conditions
  - Establish/Verify Business as Usual
  - Investigate Combined Heat and Power Usage
  - Bring perspective of campuses across country to Caltech

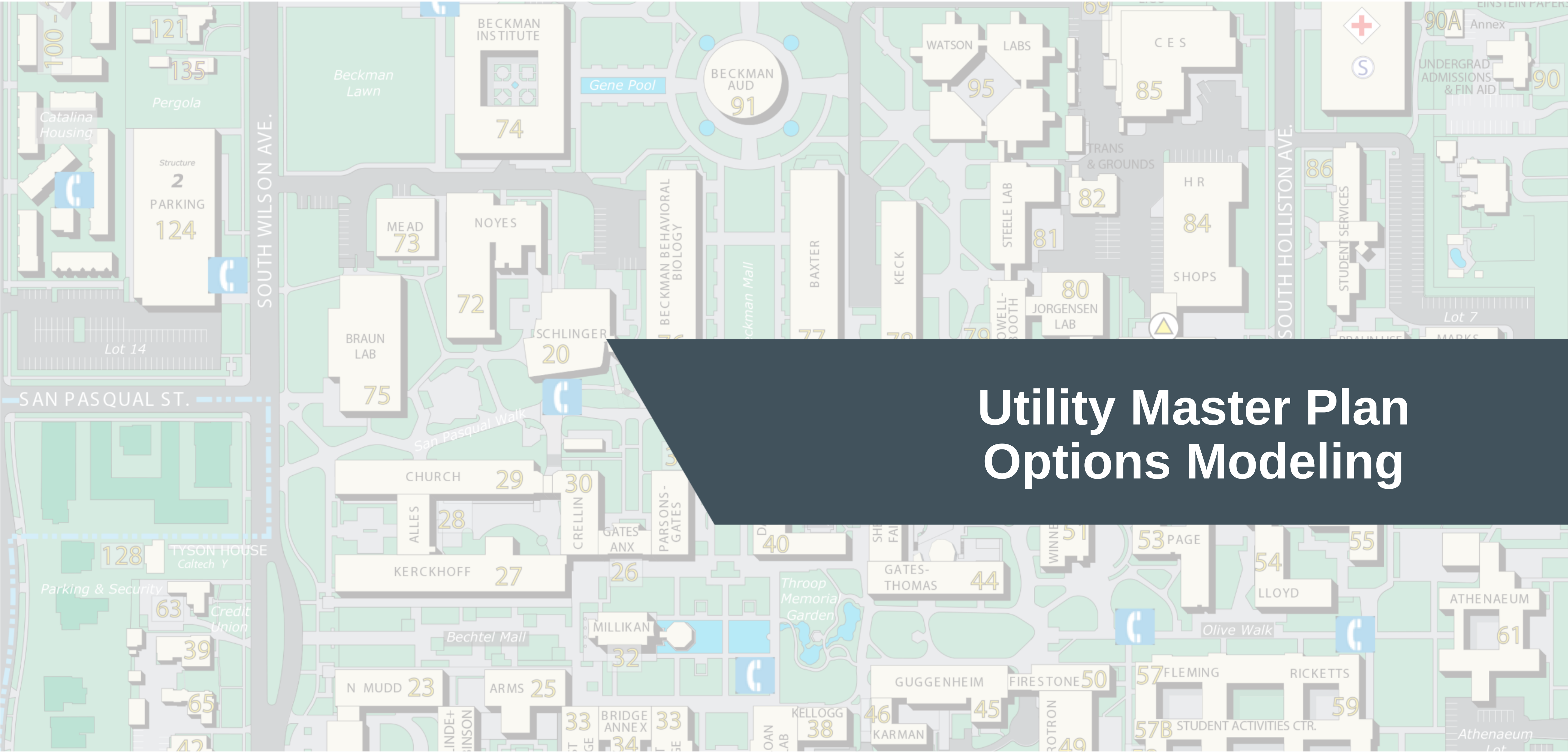
Cooling Capacity vs Future Loads



Utility Master Plan – Chilled Water Improvements

- Inefficient Chilled Water System
- Issues with space in central and satellite plants
- Mismatch in design/sizing between pumps, towers, and chillers
- Develop A3 Analysis for
  Chilled Water System Improvements

Efficiency, Optimization & Controls



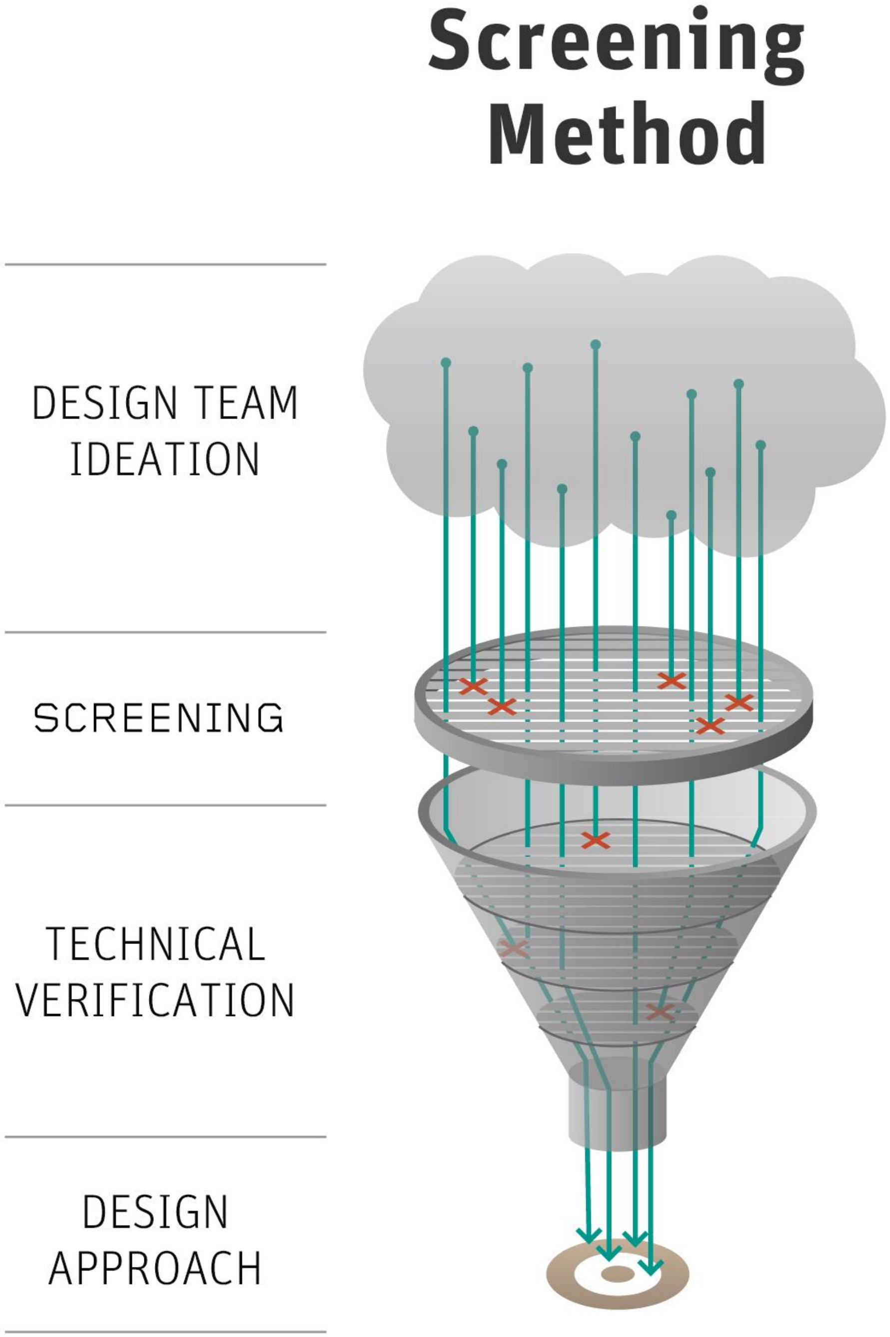
Utility Master Plan Options Modeling

Options

- Options investigated to provide heating, cooling and electric power to campus

- System reliability, environmental impacts, sustainability, regulations, and budget requirements included in analysis

- Options screened with Caltech facilities and services staff
  - Viable, significant in scale, and contribute meaningfully to Caltech's energy, environmental and operational goals



A3 Analysis

A3 No	Title	Revison	Champion	Date Started	Rev Date	Collaborators	Approved By	Approve Date	Status
COO1	Satellite Chiller Plant Improvements	3	AEI	10/1/2017	4/6/2018	Caltech			Development Collaborative review Q Implementation

Caltech

Section 1 - Background

Caltech currently uses constant speed chillers and packaged cooling towers with a 7°F or 11°F approach. Given the electrical demand of the existing chilled water system, variable speed chillers, cooling towers with lower approach, and improved chiller dispatch was considered as an alternate means of producing chilled water. This analysis considers replacing chilled and condenser water pumps, improving the chiller plant dispatch, replacing Chiller 4 in 2019 instead of 2020, and replacing the central plant cooling towers in 2020 instead of 2023.

The Campus Cooling Load versus Capacity chart indicates the addition of the Chen Neuroscience Research Building results in a campus peak cooling load 185 tons greater than chilled water firm capacity. The Satellite Plant Chiller 4 and the Central Plant Cooling Towers are at the end of typical equipment life expectancy. Replacing Chiller 4 with a 1,500-ton chiller, or replacing the Central Plant Cooling Towers with larger towers would result in firm capacity.

Section 2 – Problem Statement/Current State

Considerations of this A3 should include: campus firm capacity, first cost, maintenance, repair & replacement costs, fuel costs, total cost of ownership, and maintainability.

BAU: Addition of variable speed 1,500-ton electric-centrifugal 5kV Carrier chiller, pumps, and cooling tower at Satellite Plant.
EFF: Replace chilled and tower water pumps and improving chiller dispatch, starting in 2020.
CH-4: Replace Satellite Plant Chiller 4 with a variable speed 1,500-ton chiller in 2019, increasing capacity from 1,065 to 1,500 tons.
CP CT: Replace Central Plant Cooling Towers with 2,250 ton towers in 2020, increasing capacity from 6,000 to 9,000 tons.

Section 3: Goal

The goal is to provide sufficient chilled water capacity to meet growing campus loads, replace equipment at the end of useful life, improve efficiency of campus chilled water system operation, and increase Central Plant chilled water generation capacity by replacing cooling towers to match existing chiller capacity.

Section 4 – Analysis

TOTAL COST OF OWNERSHIP
Central and Satellite Plants

Option	Capital Cost ($)	Present Value: Capital Expenditures ($)	Present Value: Non-fuel Maintenance, Repair, Replace ($)	Present Value: Carbon Costs ($)	Present Value: Fuel Costs Costs ($)	Total Cost of Ownership (no Carbon Costs) ($)	Total Cost of Ownership (w/ Carbon Costs) ($)
BAU	$ 4,840,000	$ 35,868,132	$ 27,615,551	$ 2,574,903	$ 89,601,211	$ 153,084,894	$ 155,659,798
EFF	$ 1,750,000	$ 37,991,113	$ 28,646,617	$ 2,194,781	$ 76,373,764	$ 143,011,493	$ 145,206,275
CH4	$ 2,799,000	$ 39,055,811	$ 29,282,075	$ 2,483,015	$ 88,992,793	$ 157,330,680	$ 159,813,695
CP CT	$ 7,408,000	$ 36,815,789	$ 28,469,782	$ 2,564,133	$ 89,226,414	$ 154,511,985	$ 157,076,118

NOTES:
1. Capital expenditures include costs to replace existing chillers, towers, and pumps at end of useful life. Useful life based on industry standards: packaged chiller - 23 years; packaged cooling tower - 15 years; pumps - 25 years
2. Central Plant Cooling Towers 1-4 replaced in year 2023, Satellite Plant Chiller 4 replaced in year 2020
3. TCO calculated for Central and Satellite chilled water plants over 20 year period (2018 to 2038)
4. Discount Rate = 5.0%; Escalation Rate = 2.5%
5. Electricity Cost = $0.1441/kWh
6. Carbon Cost = $16/MT
7. Non-fuel maintenance, repair, and replacement based on 3.5% of total asset value

COOLING TOWER DESIGN CONDITIONS

Plant	Cooling Tower	Wet Bulb (°F)	EWT (°F)	LWT (°F)	Capacity (tons)
Central Plant	CT-1	74	95	85	1,300
	CT-2	74	95	85	1,300
	CT-3	74	95	85	1,300
	CT-4	74	95	85	1,300
Satellite Plant	CT-1	74	91	81	1,500
	CT-2	74	91	81	1,500
	CT-3	74	95	85	1,500
	CT-4	74	95	85	1,500
	New CT-5	76	91	81	1,500

NOTES:
1. Satellite Plant Towers CT-1 and CT-2 are operated at 70% capacity at night to reduce noise. The resulting reduction in tower capacity is not modeled in this analysis.

Section 4 – Analysis cont.

Existing and new chillers are modeled using manufacturer's data for compressor energy given the hourly chilled water load and entering condenser water temperature. Cooling tower leaving water temperatures are modeled using the tower design conditions listed in the Cooling Tower Design Conditions table and adusted for hourly wet bulb temperatures.

Chiller operation is modeled to represent current operation of the chilled water plants. Chillers are dispatched in the following order:

New 1,500-ton chiller with 5°F cooling tower (Satellite Plant)
Existing 1,500-ton chillers with 7°F cooling tower
Existing 1,500-ton chillers with 7°F cooling tower
Any of six remaining 1,500-ton chillers with 11°F cooling tower

BAU: Chiller 5 is installed in 2019 with a 1,500-ton cooling tower, one new VFD chilled water pump, and one new VFD tower water pump. Chiller dispatch is modeled based on current operation. Satellite Plant Chiller 4 is installed in 2020 with one new VFD chilled water pump and one new VFD tower water pump. Central plant cooling towers 1 through 4 are replaced in 2023 with 2,250-ton towers.

EFF: Efficiency improvements include replacing chilled and tower water pumps with variable speed pumps and a revised dispatch strategy for chilled water plants to reduce energy consumption. Revised dispatch strategy is modeled by selecting the number of chillers operating to keep chillers operating between 50 and 80% loaded.

CH-4: Satellite Plant Chiller 4 is replaced a year early in 2019 with a 1,500-ton VSD chiller, increasing firm capacity by 435 tons. One new VFD chilled water pump, and one new VFD tower water pump are installed with chiller 4. Chiller dispatch is modeled based on current operation.

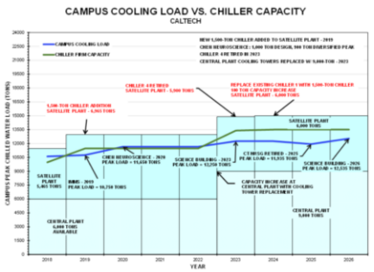
CP CT: Central plant cooling towers 1 through 4 are replaced in 2020 with 2,250-ton towers, increasing firm capacity by 3,000 tons. Chiller dispatch is modeled based on current operation.

Annual operating fuel savings associated with replacing Chiller 4 with a 1,500-ton variable speed chiller, without changes to dispatch strategy, pumping, or cooling towers, is on the order of $40,000. The Campus Cooling Load versus Chiller Capacity chart indicates Campus Firm capacity can be provided without replacing chiller 4 if the Central Plant Cooling Towers are replaced with larger towers. Discussions with Caltech indicated a firm capacity shortage of 185 tons, until the Central Plant cooling towers are replaced, is an acceptable condition.

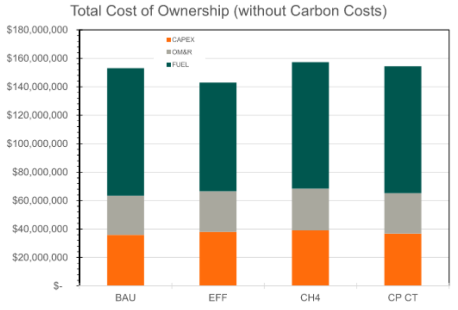
SIMPLE AMORTIZATION
Central and Satellite Plants

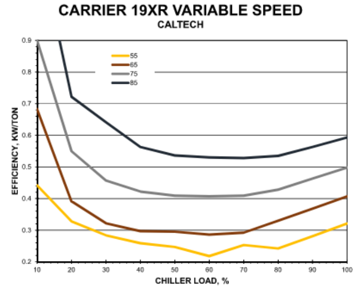
Option	Capital Cost ($)	Annual Savings ($)	Simple Amortization (years)
BAU	$ 4,840,000	---	---
EFF	$ 1,750,000	$ 1,240,000	1.4
CH4	$ 2,799,000	$ 40,000	70.0
CP CT	$ 7,408,000	$ 132,427	55.9

NOTES:
1. CP CT installs cooling towers in 2020 versus 2023.
2. Savings associated with cooling tower installation improve with implementation of dispatch model, variable speed pumps, and installation of variable speed chillers.



NOTES:
1. Chiller 4 retirement in 2023 was selected for representation purpose. Chiller can remain in operation as long as chiller is servicable.





Section 5 - Recommendation

The Satellite Plant pumps should be replaced in 2019 with the addition of Chiller 5, and the Central Plant pumps should be replaced in 2020. A project to develop and implement a chiller plant dispatch model should be scheduled immediately. Efficiency improvements have a simple payback less than 2 years.

It is not recommended to replace Satellite Plant Chiller 4. Firm capacity will be availabe when the Central Plant cooling towers are replaced. Firm capacity will only be 185 tons less than campus load, with additional load of Chen Neurosciences Research Building, until Central Plant cooling towers are replaced.

Based on the age of the Central Plant cooling towers, a project to replace the towers should be scheduled within the next 5 years.

Bundling the efficiency improvements and the Central Plant Cooling Tower replacement results in increased tower savings and a combined simple payback of 7.2 years.

Chilled Water System Analysis

- A detailed energy and economic model of the chilled water system and options was developed.

- The model includes probable estimates of construction costs (CAPEX), non-fuel operations, maintenance, and repair costs (OM&R), utility rates, emission rates, and economic analysis

- Chilled water demand based on three years of hourly measured data

Chilled Water System Analysis

- Existing and new chillers are modeled using manufacturer’s data for compressor energy given the hourly chilled water load and entering condenser water temperature.

- Cooking tower leaving water temperatures are modeled using the tower design conditions and hourly wet bulb temperatures.

Chilled Water System Analysis

- Chiller operation is modeled to represent current operation of the chilled water plants.

New 1,500-ton chiller with 5°F approach cooling tower
Existing 1,500-ton chillers with 7°F approach cooling tower
Existing 1,500-ton chillers with 7°F approach cooling tower
Any of six remaining 1,500-ton chillers with 11°F approach cooling tower

Chilled Water System Recommendations

- Replace Satellite pumps in 2019 with addition of Chiller 5

- Implement a chiller plant dispatch model immediately

- Replace Central Plant towers within next 5 years.
  - Central Plant pumps replaced with cooling tower project.

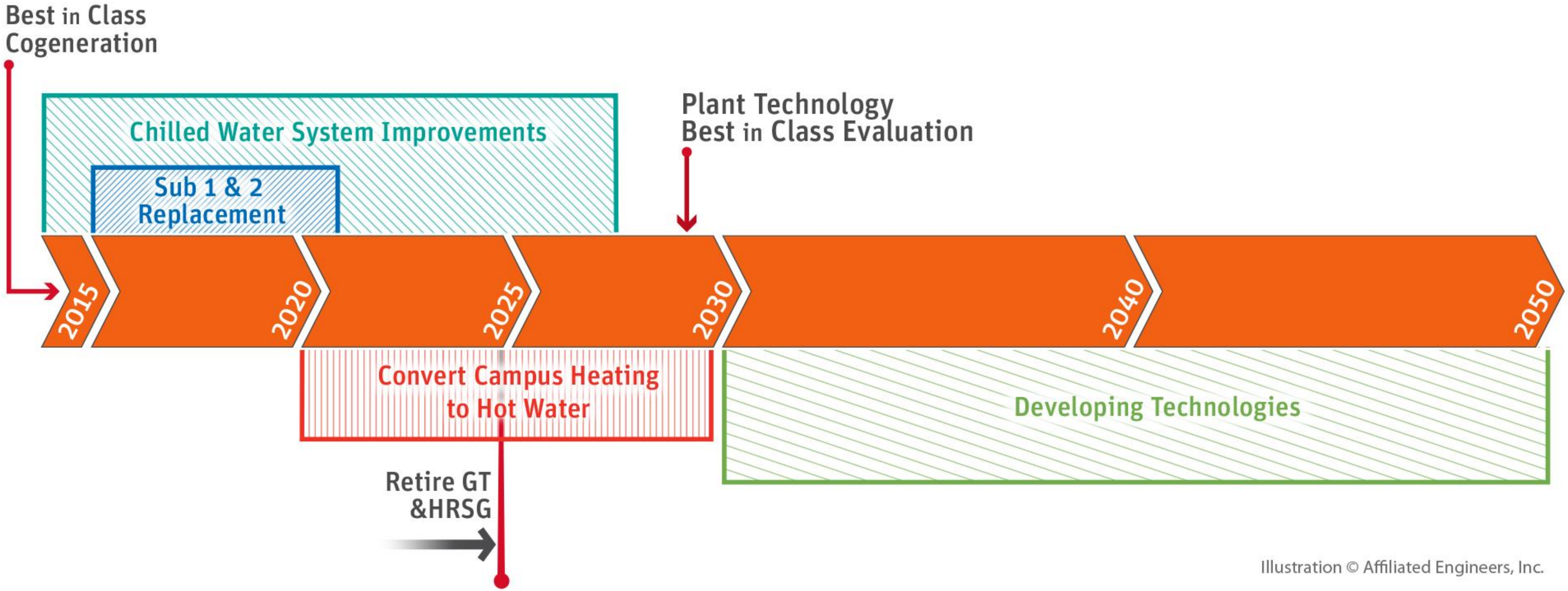
- Replace constant speed chillers with VSD chillers as chillers reach end of useful life.

Path Forward

Chilled Water System Efficiency Improvements

- Upgrade control strategy
- All variable speed plants
  - Chillers
  - Towers
  - Pumps
- Properly sized pumps
- Comparing to BAU-ERP shows the benefits of improving the chilled water system efficiency over the 20-year study period.
  - $16,400,000 savings
  - 71,400 $MTCO_2e$ reduced

Implementation Plan



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