

# Energy Master Planning for Resilient Public Communities—Best Practices from North American Universities

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## ABSTRACT

*Until recently, most planners of public communities (military garrisons, universities, and so on) addressed energy systems for new facilities on an individual facility basis without consideration of community-wide goals relevant to energy sources, renewables, storage, or future energy generation needs. Because building retrofits of public buildings typically do not address energy needs beyond the minimum code requirements, it can be difficult if not impossible to achieve community-level targets on a building-by-building basis. Planning on the basis of cost and general reliability may also fail to deliver community-level resilience. For example, many building code requirements focus on hardening to specific threats, but in a multibuilding community only a few of these buildings may be mission critical. Over the past two decades, the frequency and duration of regional power outages from weather, man-made events, and aging infrastructure have increased. Major disruptions of electric and thermal energy have degraded critical mission capabilities and caused significant economic impacts. This paper describes how community level quantitative and qualitative resilience analysis and metrics have been incorporated into community planning best practices. It is based on research performed under the International Energy Agency's "Energy in Buildings and Communities Program Annex 73," focusing on the development of guidelines and tools that support the planning of net zero energy resilient public communities as well as research performed under Environmental Security Technology Certification Program (ESTCP) project EW18-D1-5281, "Technologies Integration to Achieve Resilient, Low-Energy Military Installations."*

*This paper summarizes the energy master plans of three North American education facilities: the University of Texas at Austin, the University of California, Davis, and University of British Columbia. Each plan has been developed and adapted for implementation, where some are partially implemented. This paper will review each plan along with specific attainment targets (i.e., performance goals) and key infrastructure, and operational constraints used to develop these plans and provide technical, economic, and business concepts used in their development.*

## INTRODUCTION

### Campus Growth and Challenges

Fast-growing campuses in North America continue to add new buildings and to expand existing campus footprints to accommodate a physical infrastructure that will support the needs of growing academic, research, administrative, and residential functions. Designing and deploying the heating, cooling, and power supply systems that meet the needs of campuses to support campus growth requires careful planning, often years ahead of the construction.

The challenge lies in providing energy infrastructure that is economically viable, reliable, and efficient, and that also reduces the carbon footprint. In recent years, campuses have been formulating climate and energy objectives with a long-term vision of becoming carbon neutral. Another critical requirement in system design, operations, and maintenance, instituted as a response to frequently occurring natural disasters, is energy resiliency. Military installations also consider energy security as a critical requirement to enable mission continuity.

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Faced with the need to meet these multiple requirements, campus utility departments have recognized the importance of formulating energy master plans, which requires them to explore and evaluate alternatives against multiple requirements to ensure that they meet current and future campus energy needs and outline pathways to meet carbon reduction objectives.

## District Energy

In the United States, district energy systems are typically located in dense urban central business districts of cities, i.e., on university or college campuses, hospital or research campuses, military bases, industrial complexes, and airports. Steam, hot water, or chilled water runs through dedicated underground piping networks to heat or cool buildings in a given area. Many district cooling systems incorporate thermal storage to further expand peak capacity and shave the peaks from electricity demand.

By aggregating the thermal requirements of many different buildings, district energy systems enjoy economies of scale and deploy industrial grade equipment designed to use multiple fuels and technologies that would otherwise simply not be economically or technically feasible for individual buildings. Such technologies include, for example, combined heat and power (CHP), industrial waste heat recovery, and renewable energy such as biomass and geothermal heating and cooling. Properly designed and maintained district energy systems can reduce energy costs and greenhouse gas (GHG) emissions while freeing up valuable space in buildings by centralizing production equipment and optimizing the use of fuels, power, and staffing resources.

## Microgrids and Resilience

A microgrid is a collection of interconnected loads, generation assets, and advanced control equipment installed across a defined geographic area that is capable of disconnecting from the utility and operating independently. Campus microgrids are increasingly being deployed or expanded to meet resiliency objectives. Microgrid systems with CHP have proven to be resilient in extreme weather events such as Hurricane Harvey. For example, at the University of Texas (UT) Medical Branch in Galveston, TX, a 20.473 MMBtu/h (6 MW) combustion turbine operated in island mode while the site's two utility feeders were out of service due to excessive flooding. Campuses increasingly factor in the need to provide power for electrical as well as thermal energy uses such as running chillers in the event of outages.

## The Role of Energy Master Plans

Campus energy master plans provide campuses with a way to plan and transition energy sources for the longer term, while implementing strategies to optimize current energy use. They offer a customized action plan to meet growth, reliability, and resiliency objectives by adding appropriate central

plant capacity while recommending necessary building-level energy retrofits.

This paper presents three case studies that provide a diverse set of energy supply and demand objectives and drivers that focus on energy resiliency and also address energy efficiency and carbon footprint reduction. They also highlight a variety of technical solutions and tools used to assist stakeholders involved in the decision making for the evaluation of alternatives using energy master plans.

## RELEVANT NATIONAL AND STATE ENERGY FRAMEWORKS

### United States

In the absence of a mandatory federal GHG target to address climate change, states and regions are implementing their own climate change policies. These include the development of regional GHG reduction programs, the creation of state and local climate action and adaptation plans, an increased focus on energy savings from energy efficiency, and mandates to increase renewable energy generation, often in the form of a renewable portfolio standard, some of which include support for the increased use of CHP. As of late 2013, 20 states plus the District of Columbia had some form of a GHG emission (GHGE) reduction target in place.

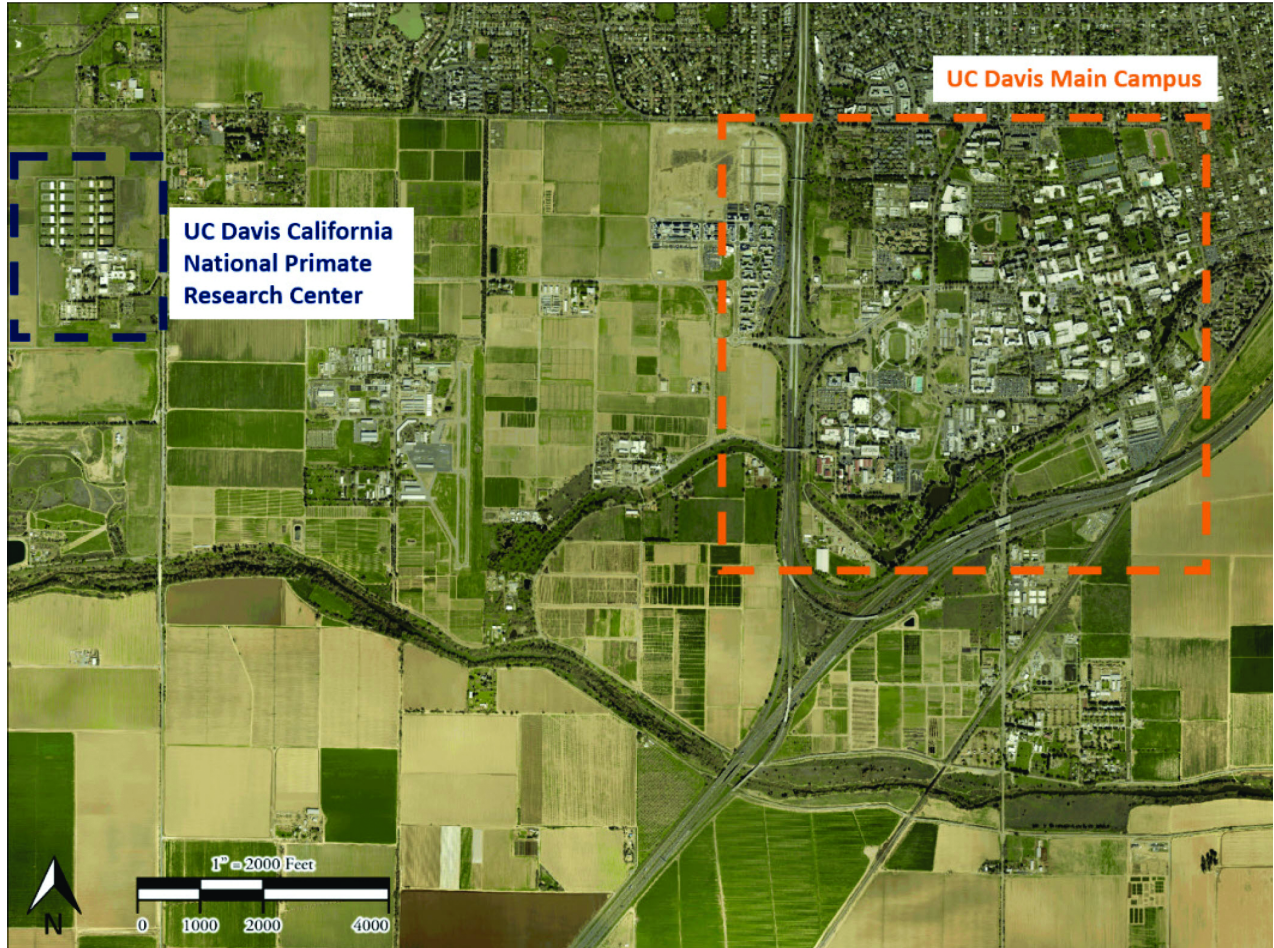
The Regional Greenhouse Gas Initiative (RGGI) is a cooperative effort by nine Northeast and Mid-Atlantic states to develop a multistate cap-and-trade program covering GHGEs. The program is aimed at reducing carbon dioxide (CO<sub>2</sub>) emissions from power plants, but participating states may consider expanding the program to other kinds of sources in the future.

California has committed to reducing its global warming emissions to 1990 levels by 2020 through the California Global Warming Solutions Act of 2006 (Assembly Bill 32) via an enforceable statewide cap on GHGEs, which began in 2013.

### Canada: Carbon Tax Act and Carbon Neutral Government Program Requirements

The province of British Columbia's broad-based carbon tax, enacted in 2008, puts a price on GHGEs to provide incentives for sustainable choices with fewer emissions. The 2018 carbon tax of \$35 per tonne of CO<sub>2</sub>-equivalent emissions will increase by \$5 per tonne annually to \$50 per tonne in 2021.

The Carbon Neutral Public Sector bill was also introduced in 2008, and required all public institutions to become carbon neutral by first reducing GHGEs and meeting provincial carbon reduction targets, and second, by paying carbon offsets on the remaining GHGEs (Government of British Columbia 2019).



**Figure 1** Location of the UC Davis California National Primate Research Center.

## MODERNIZING DISTRICT HEATING AND LEVERAGING RENEWABLE SOLAR THERMAL

### University of California, Davis

The California National Primate Research Center (CNPRC) is an organized research unit of the University of California, Davis (UC Davis). Figure 1 shows the location of the CNPRC district energy system, 2 mi (3.2 km) west of the main campus.

### Aligning with University of California's Policy on Sustainable Practices Climate and Energy Objectives

The University of California's (UC's) Policy on Sustainable Practices set three system-wide goals of reducing GHGEs to 1990 levels by 2020 and achieving carbon neutrality by 2025 for all campuses, health locations, and the Lawrence Berkeley National Laboratory (UC 2018):

- Reduce GHGEs by 2014 to the historic levels of 2000
- Achieve 1990 levels by 2020

- Become climate neutral university-wide by minimizing GHGEs and using carbon offsets or other measures to mitigate remaining GHGEs

UC Davis's 2009–2010 Climate Action Plan (CAP) outlines four primary ways to reduce GHGEs to meet the UC Policy on Sustainable Practices emissions goals (UC 2010):

- Energy conservation and efficiency
- Use of renewable energy sources
- Carbon sequestration
- Purchase of credits, offsets, or allowances

### Existing Heat and Power Supply

The CNPRC campus is currently served by natural gas provided by Pacific Gas and Electric Company (PG&E) landfill gas piped from the existing UC Davis landfill, and high voltage electricity provided by Western Area Power Administration (WAPA). Steam and chilled water are generated on site at the CNPRC combined heating and cooling plant (CHCP) to serve nine buildings on campus. Other small and/

or temporary buildings on the CNPRC campus are served by standalone heating and cooling systems.

### Energy Master Plan Drivers and Objectives

The aging district heating and cooling systems were significant drivers for the project. In addition to reducing GHGs and improving energy efficiency, increasing the reliability and improving equipment redundancy were significant goals of the project.

UC Davis explored options to reduce energy consumption and GHGs by completing a district energy master plan for the CNPRC. The energy master plan evaluated several alternatives with a life-cycle cost analysis using the following guidelines:

- Evaluate options to lower current operating expenses for the CNPRC district heating and cooling systems, including alternatives that would reduce labor expenses by eliminating the 24/7 boiler watch.
- Improve the heating and cooling systems reliability and redundancy.
- Reduce the carbon footprint of the CNPRC campus.
- Increase efficiencies of the CNPRC heating and cooling systems.
- Investigate how the findings of the resulting energy master planning report could be applied to the main UC Davis campus.
- Explore demand-side load reduction measures to further reduce the energy consumption and GHGs from the CNPRC campus.

### Evaluating Alternatives in the Energy Master Plan

Innovative solutions proposed to replace the aging steam infrastructure and absorption chiller plant included electrification and a transition to 100% renewable energy. The CNPRC district lends itself to diverse energy supplies, including biogas from a nearby landfill and biodigester and solar

thermal hot-water generation for heating. A conversion from steam-to-hot-water distribution was studied to reduce thermal losses and maintenance costs and explore alternative heat sources such as solar thermal, geexchange, air-side heat recovery using heat pumps, and air-source heat pumps.

Several technical options were evaluated, including the following:

- Maintaining the existing boilers and adding new electric chillers
- Installing new boilers and new electric chillers
- Installing heat recovery chillers and thermal energy storage
- Installing a combined cooling, heat, and power system
- Installing geexchange

### Supply-Side Thermal Energy Recommendations

The energy master plan resulted in the following recommendations:

- Solar thermal heating system to supply 17% of the CNPRC heating load with the option to expand in the future by tying in more panels
- Supplemental gas-fired hot-water boilers with a new heating hot-water (HHW) distribution system to supply 83% of the heating load
- Additional electric chillers to provide cooling
- Thermal energy storage for 2000 gallons (7580 liters) of hot water
- Future electrification through geexchange to further reduce energy costs and GHGs

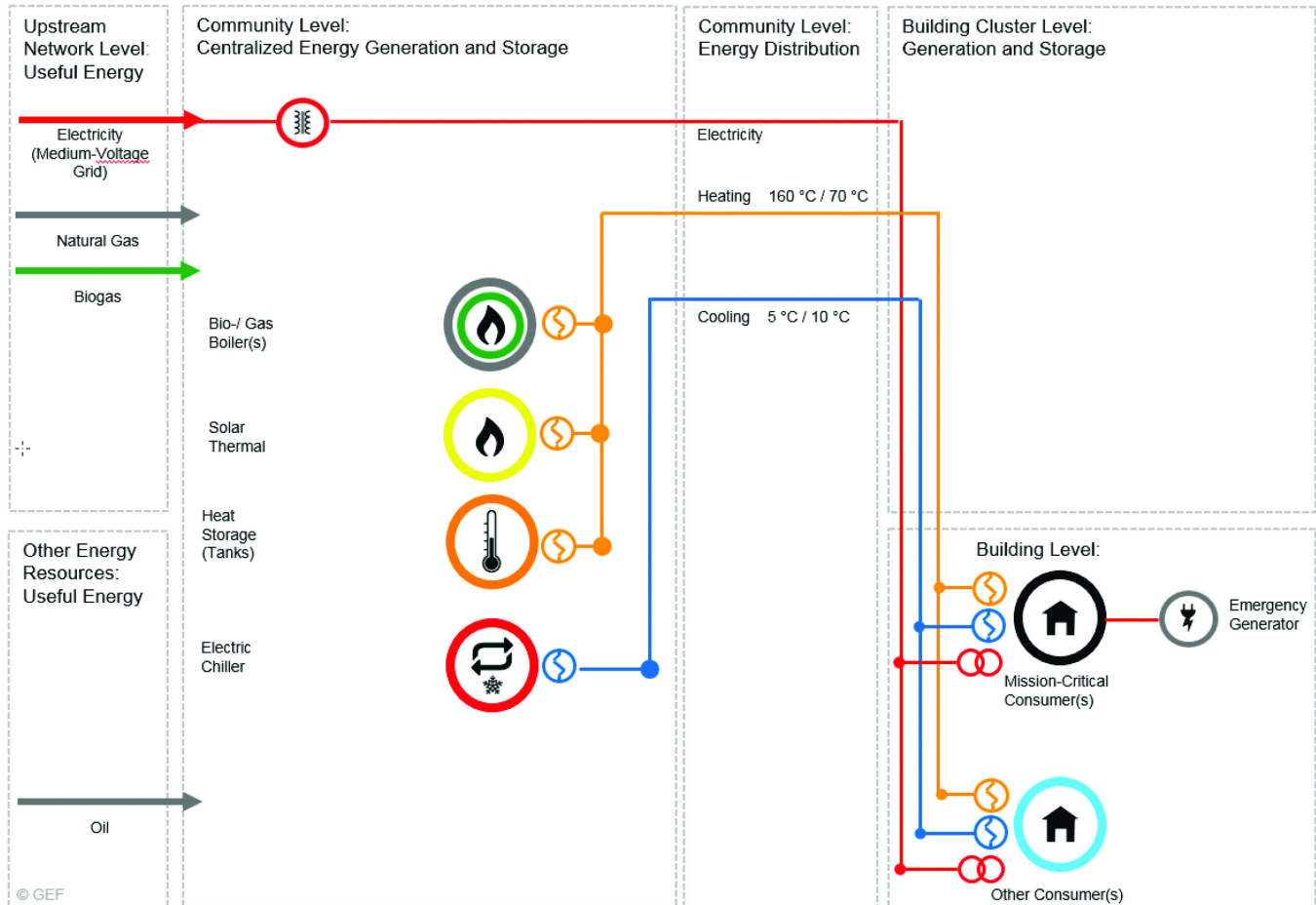
Table 1 shows the changes proposed to existing thermal energy systems at the CNPRC.

Figure 2 shows a schematic of the proposed district energy systems at UC Davis CNPRC. See Figure 3 for a legend of the symbols used in the schematics shown in Figures 2, 5, and 6.

**Table 1. Proposed Changes to Existing Thermal Energy Systems at the CNPRC**

Thermal Energy	Existing System	Recommended System
District Heating	<ul style="list-style-type: none"> <li>• 7,000 lb/h (2.05 MW) boiler—Natural gas and landfill gas</li> <li>• 10,000 lb/h (2.94 MW) boiler—Natural gas</li> <li>• Backup fuel oil system</li> </ul>	<ul style="list-style-type: none"> <li>• 300 hot-water solar thermal panels (17% of annual demand)</li> <li>• Four new supplemental hot-water boilers—Natural gas (3 MMBtu/h [1 MW] each)</li> <li>• “California Special” steam boilers that will not require 24/7 boiler watch will be installed at buildings with process steam loads</li> </ul>
District Cooling	<ul style="list-style-type: none"> <li>• 390-ton (1.4 MW) single-effect absorption chiller</li> <li>• 170-ton (0.6 MW) water-cooled chiller</li> <li>• 130-ton (0.5 MW) water-cooled chiller</li> <li>• 26-ton (0.1 MW) air-cooled chiller</li> <li>• 500-ton (1.8 MW) water-cooled chiller</li> </ul>	<ul style="list-style-type: none"> <li>• Two 500-ton (1.8 MW) electric chillers</li> <li>• Four 250-ton (0.9 MW) cooling tower cells (to serve chillers and provide redundancy)</li> </ul>





**Figure 2** Schematic of the proposed district energy system at UC Davis CNPRC.

### Demand-Side Recommendations

In keeping with the objective of energy conservation and efficiency, the following building-side recommendations were also made:

- Reduce the air change rates for the animal spaces to 12 to save nearly 20% of the campus' annual energy consumption and carbon emissions while maintaining a healthy environment for the animals.
- Perform a lighting study to create an accurate baseline for future lighting reduction studies.

The CNPRC Heating and Cooling Improvement Project will replace the old heating and cooling equipment with new energy-efficient systems housed in a new modular building with a solar thermal panel field to offset operating cost and to lower emissions. The project will provide additional capacity for future capital projects within the CNPRC district. The energy and utility master planning phase of the project has been completed. The campus is seeking funding approval for the design phase. Preliminary plans for development were approved in 2018 and await approval for budget for design.

### Resiliency

The proposed heating system has a diverse heating supply. In the event solar thermal panels cannot provide sufficient heat, hot-water boilers can supplement the heating load. The hot-water boilers can be fueled by two sources: biogas from a nearby landfill/biodigester facility or natural gas from a PG&E pipeline. It has not yet been decided whether the existing fuel oil system will be maintained for backup. Approximately 17% of the heating load is provided by solar thermal panels. Potentially all of the remaining heat load can be met with biogas from a nearby facility. In the event the biogas production is insufficient or intermittent, the facility will rely on natural gas.

### Decision Process and Stakeholders

A steam system assessment and energy master planning report were produced for the UC Davis CNPRC using current data and pricing to explore options to reduce energy consumption and GHGs. A life-cycle cost analysis was performed that included the capital cost, annual electricity cost, annual natural gas cost, annual operating expenses, annual water costs, and annual carbon costs. After analysis it was recommended

		Energy Carriers (represented by colours)							
		Renewable		Fossil		Other <sup>3</sup>	Elec- tricity	Heat	TCP
		Fluct. <sup>1</sup>	Const. <sup>2</sup>	$\sigma_{CO_2}$ high	$\sigma_{CO_2}$ low				
Useful Energy and Generation Type (represented by symbols)	C(CHP)								
	CHP								
	Heat								
	Electricity								
Upstream Energy Input									
		Fluctuating Ambient Energy	Geothermal, Biomethane, Biomass, etc.	Hard Coal, Lignite	Natural Gas, Fuel Oil	(Industrial) Waste Heat	Electricity	Cooling / Heating	
		<sup>1</sup> Sun, Wind, Water, Rivers, Sewage <sup>2</sup> Geothermal Power, Biomass <sup>3</sup> Energetically Exploitable Waste, Waste Heat							

Figure 3 Legend for symbols used in the schematics shown in Figures 2, 5, and 6.

that UC Davis should continue with the solar thermal option. The central heating and cooling plant and distribution system will be executed using the design/bid/build methodology. The solar thermal system will be executed as a separate project using the design-build approach.

To decide on viable solutions, a thorough technical and economic analysis were required. It was important to identify and understand noneconomic advantages of certain solutions. The option with the lowest net present cost was not selected because it did not align as well with other project goals. Stakeholders included staff from UC Davis, CNPRC, campus sustainability, and central plant personnel as well as from design and construction management for enabling project execution.

### Technical Highlight and Tools

Selecting the number of solar thermal panels and thermal energy storage size was a challenge. Too few panels will result in less natural gas offset; too many panels will result in excess heat production in the summer. The project settled on 300 panels, which provides approximately 17% of the total annual heat demand and achieves a potentially significant California Solar Initiative rebate.

The energy master plan used Trane Air Conditioning Economics (TRACE™) design-and-analysis software to optimize the design of a building's heating, ventilating, and air-conditioning system based on energy utilization and life-cycle cost (Trane 2019). Typically, the building types modeled or such facilities include classrooms, offices, research laboratories, and animal-care spaces. A total of 8760 hours of building load data were used to generate composite peaks; a diversity factor between 0.7 and 0.8 was used for district energy.

### Financing

The project has yet to be financed as it has not yet entered the design phase. The project will be funded by the campus and is expected to earn rebates through the California Solar Initiative rebate program to help offset project costs.

### SUPPORTING A FAST TRACK MISSION-CRITICAL CAMPUS HEALTHCARE EXPANSION: A NEW MEDICAL DISTRICT AT THE UNIVERSITY OF TEXAS AT AUSTIN

The Dell Medical School at the University of Texas at Austin (UT Austin) is a new Medical District at its southwest-ern edge in downtown Austin (Figure 4). The four-stage proj-



**Figure 4** Location of the Dell Medical School District at UT Austin.

ect, to be completed over the period of 2016 to 2020, will include three new buildings and site infrastructure for the first new medical school at a major institution of higher education in 50 years. A 267,000 gross ft<sup>2</sup> (24,831 gross m<sup>2</sup>) research building will provide research office, conference, vivarium space, and imaging suites. The 242,600 gross ft<sup>2</sup> (22,561.801 gross m<sup>2</sup>) medical office building will house outpatient clinics, a surgery center, and a café. The 83,000 gross ft<sup>2</sup> (7719 gross m<sup>2</sup>) education and administration building will include teaching spaces, a gross anatomy lab, and faculty and staff office spaces. The expansion will provide supporting district energy systems to provide heating, cooling, and electricity to the Medical District.

### Climate and Energy Objectives

In the absence of state and university-wide goals, UT Austin has not committed to a carbon neutrality deadline; however, the leadership is very committed to reducing carbon emissions. In April 2012, the Natural Resources Conservation Plan outlined several energy and water objectives for Campus Planning and Facilities Management at the University of Texas Austin regarding reliable and efficient-energy systems,

demand-side energy efficiency, alternative generation, and water conservation (Russell 2015).

### Supply Reliability and Efficiency

UT Austin had set forth several reliability and efficiency objectives including:

- Maintaining utility system performance at or above current level of reliability, annual average plant efficiency of 88%, average electrical generation performance of about 8500 Btu/kWh (8,967 kJ/kWh), and chilling station performance at approximately 0.70 kW/ton (0.058 EER [energy-efficiency rating]).
- Meet new campus demand with existing equipment and systems, thereby avoiding additional major capital investment to the extent possible.

### Demand-Side Energy Efficiency, Alternative Generation and Water Conservation

The following targets were set for August 31, 2020:

- Reduce energy consumption at the building level by an average of 20% per square foot per degree-day, using 2009 as the base year.
- Generate 5% of all energy consumed on the main campus from renewable sources including solar, wind, waste management, biomass, wood burning, small hydro and other carbon neutral sources.
- Reduce domestic water use by 20% with at least 40% of total water use coming from reuse/reclaimed sources.

### Energy Master Plan Drivers and Objectives

The planning effort was initiated to provide heating, cooling, and electricity to the Medical District expansion.

The plan, which was designed and developed in three months to support the fast track mission-critical expansion of the Medical District, included both the new 943,449 ft<sup>2</sup> (84,910 m<sup>2</sup>) from Phase 1 and the build out of 1.3 million ft<sup>2</sup> (120,900 m<sup>2</sup>) for Phase 2. The utility master plan investigated the following:

- New chilling station design criteria:
  - What capacity and efficiency are required to prevent negative impact to campus?
  - Need to continue philosophy of chilled-water loops and redundant service
  - Must be expandable to address subsequent phases of the Medical District
- It was important to also consider new space, in addition to Phases 1 and 2, to be added to the main campus (not in the Medical District), which included the construction of a graduate school of business and an energy engineering resource building. Including these two buildings added a total of 801,201 gross ft<sup>2</sup> (72,108 gross m<sup>2</sup>) to the chilled-water system. In total, Phase 1 added 1,744,650 gross ft<sup>2</sup> (157,019 gross m<sup>2</sup>) to the chilled-water system.
- Avoid power plant expansion.
- Avoid conflict between peak steam and peak power.

### Chilled-Water, Electricity, and Heat Supply Recommendations

The electricity needs of the Medical District could be provided from the existing 457,227 MMBtu/h (134 MW) CHP plant. Thermal energy would be supplied as follows:

- A new Chiller Station No. 7 (CS7), with 15,000 tons (53 MW) of chilled-water capacity for the Medical District using six 2500-ton (8.8 MW) chillers and a 5°F (-15°C) approach cooling tower. The plant can expand to 20,000 tons (70 MW) as needed.
- A 5.5-million-gallon (20,845,000-liter) thermal energy storage tank to provide more than 17 MMBtu/h (5 MW) load shifting capacity.
- A new hot-water system for heating hot water for the Medical District with a heat pump chiller and watertube

boilers to provide 53,000 MBH (15.5 MW) of HHW capacity. The system will make 40,000 MBH (11.7 MW) of HHW available from Hot Water Plant No. 1 via steam-to-hot-water exchangers as backup.

Figure 5 shows a schematic of the district energy system for the UT Austin Medical District.

### Resiliency

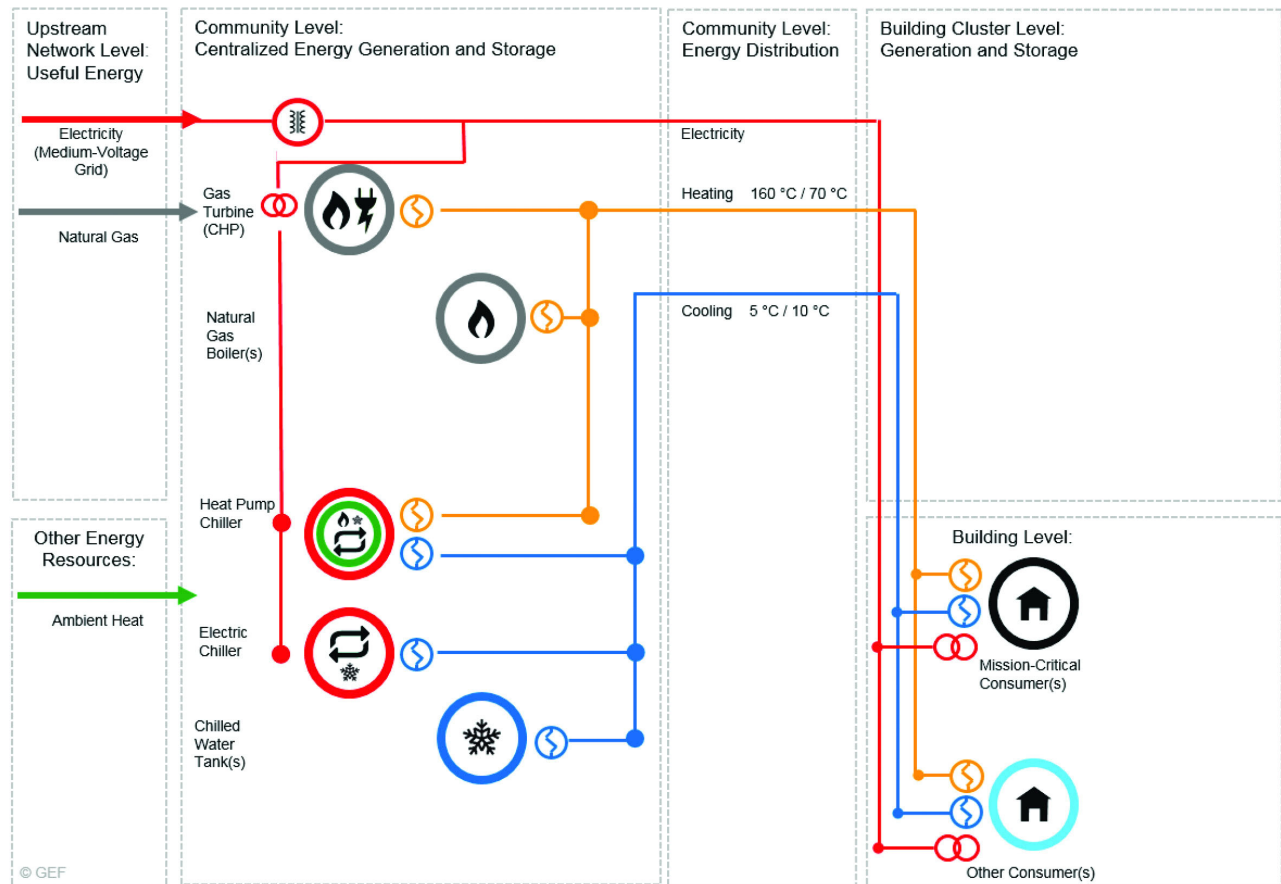
UT Austin, including the Medical District, has 100% on-site generation capacity, including N+1 redundancy for prime movers under 99% of all load conditions. This provides flexibility to serve critical research customers and the Medical District. UT Austin also has a redundant electric interconnection to the Austin Energy grid to provide 2N+2 system redundancy for nearly all system load conditions. The 5.5-million-gallon (20,845,000-liter) thermal energy storage tank provides flexible chilled-water capacity that can be deployed to cover both planned and unplanned equipment outages. Triple redundancy is provided for the hot-water loop to the district. One source is the 600-ton (2.1 MW) heat pump chiller. The second source is two hot-water boilers needed when the heat pump chiller cannot operate due to low loads, and the third source is a steam-to-hot-water plant served by the main campus CHP system. The plant is designed to add two more heat pump chillers, an additional hot-water boiler, and another steam-to-hot-water plant can be added as needed when the Medical District grows.

To ensure water supply resiliency, four independent water sources are piped to the chilling station that are each deployed on an economic basis. They include recovered water from campus air-handling unit coil condensate, reclaimed water from the city of Austin, domestic water from the city of Austin, and domestic water from the university-owned system. The domestic water from the city and university provide additional redundancy but are used only as backups to the other sources. Operations and maintenance (O&M) considerations such as bridge crane and monorails, commonality of components, and catwalks were included for resiliency.

### Decision Process and Stakeholders

A design-build project delivery method was used to expedite and allow budget flexibility through an open-book approach for the Medical District Phase 1 project and 2.2 million ft<sup>2</sup> (198,000 m<sup>2</sup>) for Phases 2 and 3 plus 1 million ft<sup>2</sup> (90,000 m<sup>2</sup>) for the main campus. The annual consumption, peak energy requirements, and water needs were estimated by analyzing the building type and actual metered energy use per gross square foot for existing campus buildings. The plant's total capacity and rate impact were determined from this analysis. The crucial parameter for the go-ahead was proving the central plant concept rates for





**Figure 5** Schematic of the proposed district energy system for the UT Austin Medical District.

**Table 2. 30-Year Net Present Value Savings Comparisons of Standalone versus District Energy**

	New Area gross ft <sup>2</sup> (gross m <sup>2</sup> )	District Cooling	Decentralized Air-Cooled	Decentralized Water-Cooled
UT Research	280,000 (25,200)	\$4,986,942	\$4,980,756	\$5,397,709
Main Office Building	235,500 (21,195)	\$4,192,374	\$4,189,172	\$4,539,859
Parking Garage	0	\$0	\$0	\$0
Hospital	515,000 (46,350)	\$9,172,410	\$9,161,033	\$9,927,929
School of Medicine	191,700 (17)	\$3,414,274	\$3,410,039	\$3,695,503
Total	1,222,200 (109,998)	\$21,768,000	\$21,741,000	\$23,561,000
Net Present Value (NPV) (30 Years)		\$40,259,000	\$55,770,000	\$51,764,000

chilled water and hot water were less expensive than stand-alone equipment in the respective buildings. The 30-year net present value savings was about \$12 million over 30 years (Table 2).

Stakeholders involved in the project include UT Austin, Seton Healthcare, Central Texas Healthcare, Flintco, and Burns & McDonnell.

### Technical Highlight and Tools

The new higher peak electricity demand, in particular the peak summer cooling energy required, was projected to strain the existing power generation assets beyond their best efficiency point. Instead of building more capacity, the university installed a second thermal energy storage tank to displace

10,000 tons (35 MW) of chilled-water-producing equipment during the peak hours of the day, approximately 1,706,100 tons (6 MW).

Another significant energy-efficiency measure was the selection of a heat pump chiller residing within CS7 that will simultaneously provide HHW and chilled water to the new district. The choice to introduce a hot-water system to the primarily steam-heated campus was driven by extensive life-cycle cost analysis of multiple options. Ultimately, extension of the steam tunnel system and installation of expensive steam-generating equipment was deemed to be cost-prohibitive compared to the direct-buried heating water system that was selected. The heat pump chiller saves \$287,000 per year in gas savings and 17 million gallons (64.4 million liters) per year in water savings.

The TERMIS simulation software tool's chilled-water and steam model was used to size and plan the distribution system (TERMIS 2012).

## Financing

Financing was not an issue because the respective electrical, steam, and chilled-water rates from the utility operation provides the revenue stream pay for the debt. The university has extremely good financing rates, so it was just necessary to show that they could not afford the standalone systems in the buildings.

## TRANSFORMATION AND TECHNICAL INNOVATION, UNIVERSITY OF BRITISH COLUMBIA

The University of British Columbia (UBC) in Vancouver, Canada is a global center for research and teaching, consistently ranked among the 40 best universities in the world. The Academic District Energy System (ADES) provides reliable, cost-effective, and increasingly sustainable utilities to multiple facilities including 400 core academic, research, and animal care buildings; 12,000 housing beds; an Olympic size swimming pool and other athletic facilities; a 330-bed hospital; and the world's largest cyclotron.

## Climate and Energy Objectives as Drivers

In 2010, the UBC Climate Action Plan (CAP) was implemented to establish significant but achievable GHGE reduction targets. UBC set the following GHGE reduction targets from a 2007 baseline, which were twice as aggressive as those set by the British Columbia provincial government:

- 33% reduction by 2015
- 67% reduction by 2020
- 100% reduction by 2050

The aging ADES steam infrastructure with \$190 million in deferred maintenance along with the seismic risk for the powerhouse supplying steam to heat academic buildings drove the conversion from the existing steam system to the new hot-water system. In addition, the GHGE reduction targets in

UBC's CAP and carbon taxes in British Columbia were also drivers for the steam-to-hot-water conversion. The construction of the Bioenergy Research and Demonstration Facility (BRDF) provided renewable energy sources that could be used to generate hot water. Locally, close to 1 million dry tonnes of waste wood is produced, with almost half of that amount not being used.

The energy plan established three main projects that would help UBC achieve these goals:

- Converting its aging ADES from steam to hot water to change how efficiently the campus is heated.
- Building the BRDF to provide renewable heat and power.
- Optimizing academic building performance and reducing energy consumption through the Building Tune-Up Program.

## Bioenergy Research and Demonstration Facility (BRDF) as a Resource

At the BRDF, gasification turns waste wood into synthetic gas, replacing natural gas used to produce 20,400 lb/h (6 MWt) of steam that is subsequently converted to hot water for campus space heating.

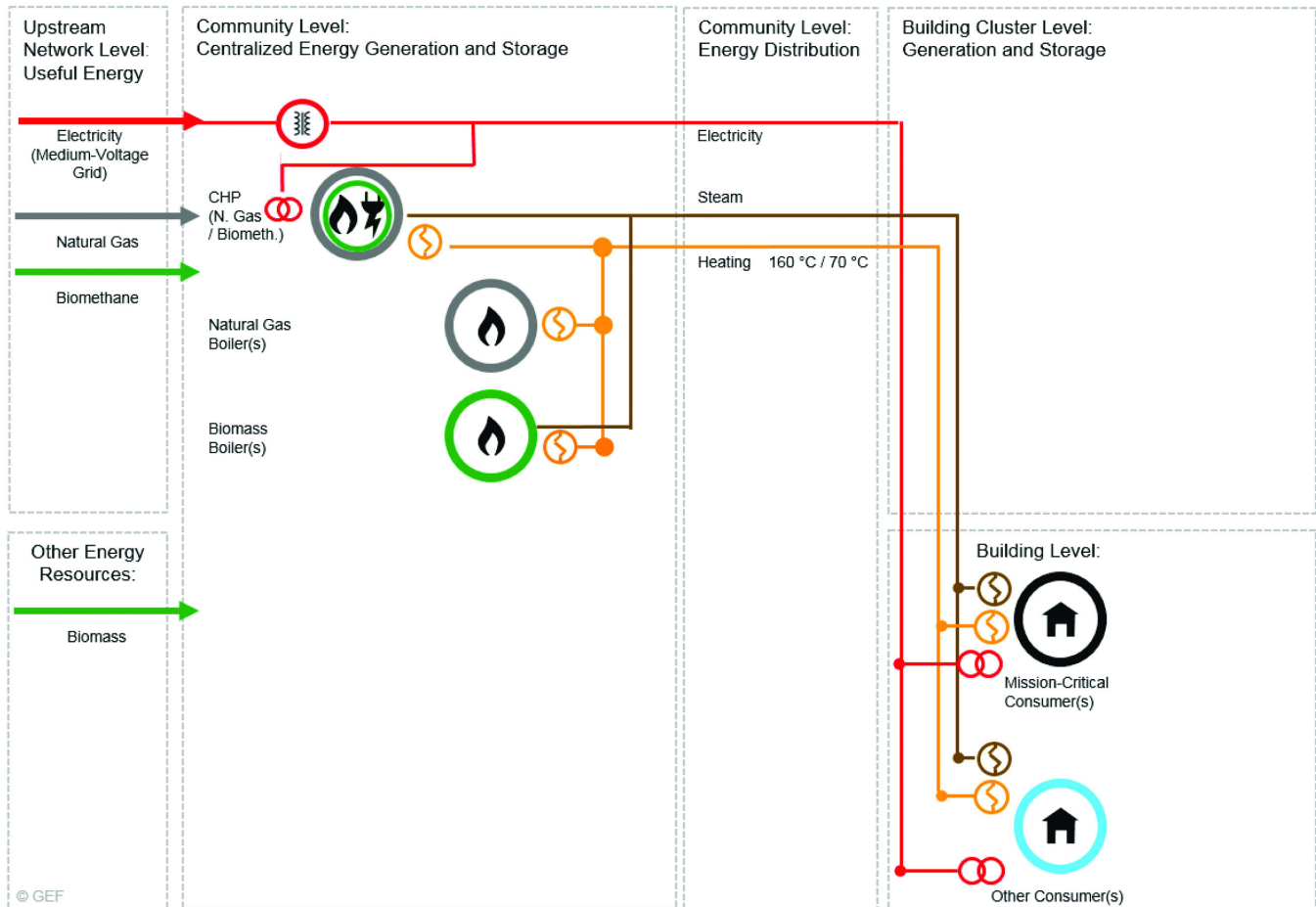
The cogeneration process uses a combination of natural gas and biomethane to fuel a General Electric (GE) Jenbacher engine. The engine produces 6,824 MMBtu/h (2 MWe) of electricity, which is fed into the campus grid. Heat recovered from the engine exhaust gas is also used to generate 4700 lb/h (1.4 MWt) via steam-to-hot-water heat exchangers. A further 3.4 MMBtu/h (1 MWt) of heat is recovered from the engine coolant and lube oil systems and supplies the ADES via a glycol-to-hot-water heat exchanger.

The facility produces 8.4 MW of thermal energy (25,100 lb/h of steam and 3.4 MMBtu/h of hot water), which accounts for 25% to 32% of the total campus heating and hot-water needs each year. In the summer, it provides 100% of campus energy needs. It also provides 7 MMBtu/h (2 MW) of electrical energy, the equivalent of 5% of the total campus electricity requirements each year. A Leadership in Energy and Environmental Design® (LEED®) Gold facility, it serves as a "living lab" for academic research and teaching while providing an operational need for the campus (Figure 6).

## Steam-to-Hot-Water Conversion

In 2010, UBC's powerhouse had a peak steam load of 250,00 lb/h (120 MWt). The powerhouse, which produces more than 55,115 tons (50,000 tonnes) of CO<sub>2</sub> annually, was identified as the primary source of campus GHGEs. It was clear that this facility presented an opportunity for the installation of a cleaner, greener campus heating system in the construction the new hot-water ADES and in leveraging the renewable resource from the BRDF.

From 2011 to 2015, UBC's aging gas-fired steam district energy system was replaced, piece-by-piece, by a state-of-the-



**Figure 6** Schematic of Bioenergy Research and Development Facility.

art, medium-temperature hot-water system. The \$88 million ADES Steam to Hot Water Conversion Project:

- replaced 0.9 miles (14 km) of 90-year-old steam piping with new insulated piping,
- converted 115 buildings to the highly efficient hot-water district energy system through 105 energy transfer stations, and addressed process and legacy steam requirements in 26 buildings, and
- built a 154-MMBtu/hr (45 MWt) natural-gas-fired Campus Energy Center (CEC) able to meet all campus energy needs.

At project completion, the new system was providing space heating and domestic hot water for 115 buildings totaling more than 9 million ft<sup>2</sup> (800,000 m<sup>2</sup>) of floor space. The project improves energy efficiency by more than 24% and was instrumental in enabling UBC to achieve its 2015 GHGES reduction target.

In 2017, the aging steam ADES was decommissioned and replaced with an efficient, medium-temperature hot-water system energized by a renewable biomass boiler, waste heat recovery from a biomethane-fueled cogeneration engine, and

high-efficiency natural-gas-fired hot-water boilers for peaking. UBC shut the doors of its steam plant, replacing the system's primary energy source with the new 155 MMBtu/h (45 MWt) Campus Energy Center that, together with the distribution, improves energy efficiency by greater than 24%. Figure 7 shows a schematic of the ADES after steam-to-hot-water conversion.

## Resiliency

The number one seismic risk on the UBC Vancouver campus was the steam powerhouse. Its decommissioning in 2017 eliminated a significant risk to UBC's infrastructure system. The steam powerhouse was replaced by the combination of the Campus Energy Center in the fall of 2015 and the BRDF in the fall of 2012, both of which were designed for post-disaster.

Many of UBC's systems have N+1 redundancy (i.e., backup) features, which offer resiliency. For example, during recent windstorms in January 2018, one transmission line was kicked out twice during a 10-day period due to felled trees. UBC campus did not experience an outage due to a fully redundant second transmission line.

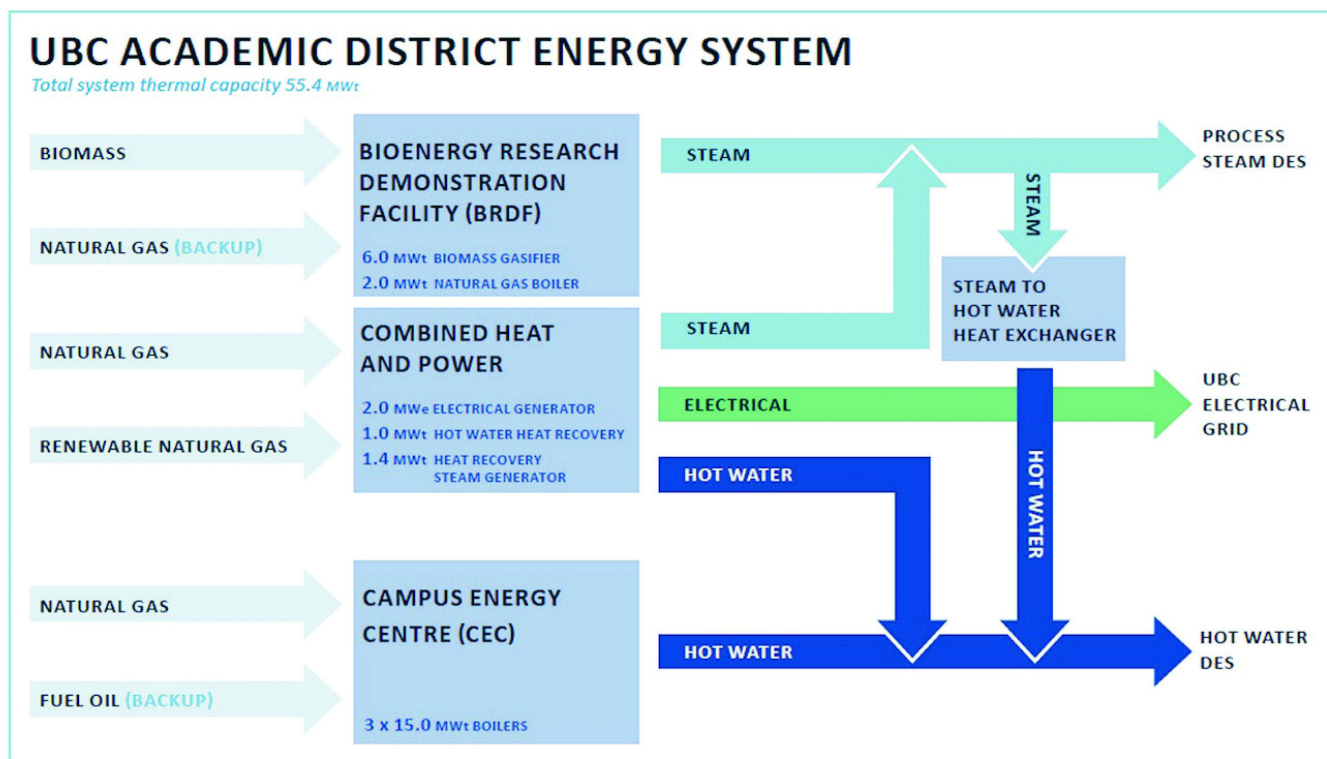


Figure 7 Schematic of the ADES after steam-to-hot-water conversion.

### Diversification of Fuel Sources

In the past, UBC was 100% reliant on utility providers for electricity and natural gas, but today, thanks to cogeneration and the use of biomass, nearly a third of the campus' energy can be provided through other means. UBC's ADES has multiple fuel options including natural gas, fuel oil, renewable natural gas, and biomass. UBC's biomass and cogeneration facility produces steam that can be used in the (soon to be fully shut down) process steam legacy grid, or that can be fully converted to hot water for the campus hot-water system.

### Decision Process and Stakeholders

The project required local community acceptance of the facility, which entailed multiple public engagement events before construction as well as a community and emissions committee during the first year of operations. Emissions, noise, aesthetics, and truck traffic were areas of concern that were addressed. Since the facility is located adjacent to a residential neighborhood, 24-hour air emission monitoring stations were installed to monitor air quality.

UBC's Energy and Water Services, Project Services, Building Operations, Risk Management Services, Infrastructure Development, Campus Planning, Finance, Treasury, Legal Services, and Human Resources were involved in the project. In addition, FVB Energy, Dialog, KWL, Fortis BC, CES, CELCO, AME Group, AES, Siemens, Lockerbie & Hole, All Pro Services Ltd., LEDCOR, Tissling, Trotter &

Morton, Division 15 Mechanical Ltd., Total Build, and Five Start were involved in the project. Over 3000 people were employed from the previously mentioned organizations throughout the project. Nexterra Energy Corp. and GE Power and Water were involved in the BRDF project.

### Technical Highlight and Tools

A major challenge was the transition period between using steam and hot water. To solve this, a Temporary Energy Center was developed to provide additional capacity over the two years during which the CEC was being built. This enabled 85 building conversions to be completed before the CEC was put into service.

In the post-design phase, the implementation of the TERMIS district energy optimization software has given UBC the ability to see the whole ADES system, plant, distribution, and energy transfer center in real-time, and to produce what-if scenarios, expansion planning, and pressure and temperature optimization.

### Financing

In 2011, the Board of Governors (BOG) approved the \$88 million (Canadian dollars) project in principle. A step-by-step approach with main funding approval contingent upon the pilot or Phase 1 performance evaluation and verification was deployed. In 2012, Phases 2 and 3 were approved. Stop No-Go or off ramp options were available up to Phase 4, the construc-



tion funding approval for the CEC. In 2013, Phase 4 was approved. Later in 2013, full funding of Phases 5 through 10 were approved.

The project's business case justifies the capital expenditure of \$88 million through commodity (e.g., natural gas, water), carbon, staff, and maintenance savings, as well as the capital avoidance of the powerhouse. The BRDF was justified through natural gas and carbon savings alone.

## CONCLUSIONS

Institutions of higher education are requiring that campus growth be undertaken in conjunction with objectives of reliability, efficiency, and carbon reduction on campus when evaluating options for expanding or managing existing district energy infrastructure. In the case of UBC, the economic impact of a carbon tax played a role in reducing natural gas use and in moving to fuel diversity by adding bioenergy.

Modernization of the aging steam system while transitioning to biomass project helped reduce GHGEs, achieved the targets in UBC's CAP, added resiliency and diversified UBC's fuel mix, and reduced operational and maintenance costs. The steam-to-hot-water conversion project demonstrates an innovative approach to infrastructure management and leverages cyclical maintenance investment to achieve multiple sustainability objectives. The project has eliminated \$190 million in deferred maintenance costs, reduced operating costs, improved safety and resiliency, and dramatically reduced energy and water consumption.

UC Davis, through its advanced energy master plan, which evaluated multiple pathways for serving the thermal load for the CNPRC, is in a position to use solar thermal resources to help meet state-wide and university-wide energy goals, when funding is approved. Major success factors include having a well-rounded project team that encompasses major stakeholders as well as having a framework with which to evaluate proposed alternative options. The framework deployed on this project consisted of an economic evaluation of the life-cycle cost, an evaluation of whether the option would align with campus initiatives, and whether the solution would provide sufficient reliability and redundancy to a center where the inability to meet demand is not acceptable.

The CNPRC will be used to demonstrate the feasibility, cost-effectiveness, and challenges faced in implementing energy efficiency and environmentally friendly projects throughout the campus.

At UT Austin, the energy master plan was developed in parallel with the fast-track expansion of the Medical District. The energy master plan process was able to leverage the existing

CHP as the building block to increase resiliency and to avoid adding peak demand by investing in thermal energy storage. The heat pump chiller saves \$287,000 per year in gas savings and 17 million gallons (64.4 million liters) per year in water savings, and reduces the campus carbon footprint (by ~44,092 tons [ $\sim 40,000$  tonnes]  $\text{CO}_2\text{e}$ ). Resiliency is key for the Medical District, and the microgrid at UT Austin has 100% on-site generation capacity, including N+1 redundancy for prime movers under 99% of all load conditions. This provides the flexibility to serve critical research customers and the Medical District. UT Austin also has a redundant electric interconnection to the Austin Energy grid to provide 2N+2 system redundancy for nearly all system load conditions.

The campuses have integrated resilience into energy master planning initiatives as soon as possible, instead of waiting for the inevitable crisis or natural disaster to spur the administration to action.

Combined with efficient and sustainable energy and water strategies, resilience efforts can reduce operational and maintenance costs in addition to reducing (or avoiding entirely) the costs of responding to a catastrophic event. Insurance premiums may be significantly lowered as well.

Energy master plans play a critical role in helping planners evaluate energy alternatives against their objectives, and to leverage district energy and microgrids to enable the consideration of a diverse set of technical solutions. While the climate zones, drivers, and objectives varied across the three campuses, energy master planning was a key to providing alternatives and pathways that resulted in desired outcomes.

## REFERENCES

- Government of British Columbia. 2019. Climate action legislation. <https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/legislation#cng-reg>.
- TERMIS. 2012. TERMIS simulation modes—Historical and real-time simulations. <http://7t.dk/products/termis/Product-Information/termis-simulation-modes.aspx>.
- Trane. 2019. TRACE™ 700. <https://www.trane.com/commercial/north-america/us/en/products-systems/design-and-analysis-tools/analysis-tools/trace-700.html>.
- UC. 2018. Policy on sustainable practices. Oakland, CA: University of California, Office of the President, <https://policy.ucop.edu/doc/3100155/SustainablePractices>.
- UC Davis. 2010. UC Davis 2009–2010 climate action plan. Davis, CA: University of California, Davis. [https://sustainability.ucdavis.edu/local\\_resources/docs/climate\\_action\\_plan.pdf](https://sustainability.ucdavis.edu/local_resources/docs/climate_action_plan.pdf).