# Zero Energy University Campuses: A 2018 Progress Update on Reaching Campus Energy Goals

## Preprint

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**ABSTRACT**

Many universities have aggressive energy-reduction and climate action plans. To reach these goals, leading universities have developed a suite of common energy-efficiency and renewable generation strategies. In this paper, we present a common set of approaches across the following areas: zero energy campus definitions and planning, best practices for including energy targets in new construction procurement contracts and design guidelines, implementing pilot new construction zero energy projects, aggressively implementing best-in-class laboratory energy-efficiency strategies, planning for and optimizing on-site and off-site renewable energy projects, and high-performance district energy systems. Best practices are compiled from various experiences, including programs funded by the U.S. Department of Energy, Energy Efficiency and Renewable Energy program. The summary of these best practices is to reduce campus energy use and then meet the remaining campus energy needs with renewable energy. The five-step process to developing and implementing campus energy-reduction plans is described: 1) determine baseline energy consumption, 2) analyze technology options, 3) develop a plan and set priorities, 4) implement the plan, and 5) evaluate progress. The process follows a logical hierarchy of actions to evaluate options by energy sector and set specific targets. It encompasses all energy systems on campus, recognizing that campus-wide measures have increased potential for reducing energy use. Common strategies are explained along with examples and results.

## Background

### University Campus Goals

The higher education sector spends more than $6 billion on annual energy costs and totals an area of about 5 billion square feet of floor space (Better Buildings 2018). Universities are among the leaders in the United States in setting goals such as zero energy or carbon neutrality. The primary origin of significant U.S. university leadership on campus emissions reductions was the American College & University Presidents' Climate Commitment (ACUPCC). The ACUPCC was launched in 2007, and 336 institutions had joined the initiative by September 15, 2007 (Second Nature 2017). As of early 2018, more than 650 institutions have signed up, with representation from all 50 states.

Several university systems have pledged climate goals for their entire university system. For example, the University of California (UC) has pledged to become carbon neutral by 2025 (buildings and vehicle fleet), becoming the first major university system to commit to this goal (University of California 2013). Further, several university campus energy and sustainability ratings have emerged, such as the Sierra Club's Cool Schools (Sierra Club 2017). One of the most rigorous sustainability ratings is the Association for the Advancement of Sustainability in Higher Education Sustainability Tracking, Assessment & Rating System (STARS). STARS is a self-reporting system that provides a bronze, silver, gold, or platinum sustainability rating. By

June 2018, more than 900 institutions had registered to use STARS, but only four campuses have achieved the STARS platinum rating: University of California, Irvine (UCI); Stanford University; Colorado State University; and the University of New Hampshire (AASHE 2018). As the largest energy users at universities are buildings and infrastructure, with labs and food service as the highest energy using sectors, this paper focuses on the energy use of buildings and infrastructure (Better Buildings 2018).

### Zero Energy Buildings and Campuses

Zero energy buildings (ZEBs) represent the state of the art for energy performance at the individual building level. Many new buildings can be designed to be ZEB, or at least zero energy ready, by minimizing energy use and making them solar ready by "designing and constructing the building in a way that facilitates and optimizes the installation of a rooftop solar photovoltaic (PV) system at some point after the building has been constructed" (NREL 2017). In addition, universities have led the ZEB movement through their showcase zero energy projects. Early ZEB projects include the Oberlin College Adam Joseph Lewis Center (Pless, Torcellini, and Petersen 2006) and the first Living Building Challenge certified project, the Living Learning Center at Tyson Research Center at Washington University in St. Louis (Tyson Research Center 2010). In 2018, across all of US Higher Education, there are currently over 60 individual zero energy buildings that have been verified or are actively seeking zero energy verification (NBI 2018).

The concept of zero energy can go beyond individual buildings to an entire campus or community. In 2009, Carlisle, VanGeet, and Pless (2009) adapted the ZEB building definitions to develop definitions for zero energy communities. The U.S. Department of Energy (DOE) (Peterson, Torcellini, and Grant 2015) has since formalized source energy-based definitions for zero energy campuses, portfolios, and communities. The DOE campus definition, for example, "allows for the building sites on a campus to be aggregated so that the combined on-site renewable energy could offset the combined building energy from the buildings on the campus." Recently, the State of California adopted the DOE ZEB common definition approach for state-owned buildings, with further guidance provided for extending the ZEB campus definition to a state portfolio (Burgoyne 2017).

Approaching zero energy at larger scales also offers several potential advantages. For more information, see "From Zero Energy Buildings to Zero Energy Districts" (Polly et al. 2016).

## Process to Develop and Implement Campus Energy-Reduction Plans

The National Renewable Energy Laboratory (NREL) has developed a five-step process to develop and implement campus energy-reduction plans. The process follows a logical hierarchy of actions to evaluate options by energy sector and set specific targets. It encompasses every energy system on campus, recognizing that campus-wide measures have increased potential for reducing energy use. The steps are: 1) determine baseline energy consumption, 2) analyze technology options, 3) develop a plan and set priorities, 4) implement the plan, and 5) evaluate progress (NREL 2018).

## 1. Determine Baseline Energy Consumption

To evaluate strategies and track progress, it is important to establish a baseline energy consumption and other baseline metrics for the university campus, including annual energy use intensity benchmarking of individual buildings. To determine baseline energy consumption, a baseline year must be chosen. The baseline could represent the current year or could be tied to a previous year if necessary to align with the time frame of goals or other factors driving improvement. Once a baseline year is chosen, all energy use for that year must be estimated. Energy use and other associated metrics can be categorized by:

- **Scope 1**: Direct combustion of fuels on campus. Common fuels include natural gas, diesel fuel, fuel oil, propane, and biomass such as wood chips.
- **Scope 2**: Indirect impact from purchased electricity. The source energy associated with electricity consumption can be obtained by multiplying total campus electricity imported from the grid by the average site-to-source multiplier for electricity included in Table 1 of the DOE *Common Definition for Zero Energy Buildings* document (Peterson et al. 2015). Note this is also required if using DOE zero energy campus definition. For more precise estimates, universities could contact their local utility to obtain emissions factors or use the U.S. Environmental Protection Agency's eGRID database for regional emissions factors (eGRID 2018).
- **Scope 3**: Other indirect off-site impacts, such as transportation. The DOE definition for a zero energy campus does not include transportation. Some other definitions of zero energy or zero carbon campuses do include transportation impacts from commuters and business travel.

## 2. Analyze Technology Options

An effective campus energy-reduction plan follows a portfolio approach and addresses each energy sector on campus. This requires a combination of targeted improvements to buildings and infrastructure as well as improvements in operation and education for building operators and occupants. Strategies that impact human behavior and energy policies can save money, energy, and carbon emissions on campuses with minimal cost investment. Some examples include energy conservation programs, flexible work schedules, and space planning and management.

Efficiency improvements in buildings, especially those made in conjunction with other planned upgrades and remodels, can be some of the most cost-effective strategies for meeting energy and emissions goals on university campuses. A variety of resources exist for assessing potential energy-efficiency savings in existing buildings and for designing new high-performance buildings on campus, such as the 50% Savings and Zero Energy Advanced Energy Design Guides (Bonnema et al. 2012). Building energy simulation can also be used by university engineering staff and researchers or hired consultants to assess specific opportunities within existing campus buildings based on buildings' detailed energy system characteristics, such as: enclosure insulation levels and airtightness; heating, ventilating, and air-conditioning (HVAC) equipment types, efficiency levels, and distribution systems; lighting systems and controls; service and domestic hot water systems and efficiencies; and electric equipment and miscellaneous electric loads.

There are additional efficiency opportunities for buildings connected to district or campus energy systems, and there are advantages to approaching efficiency upgrades and building load control and flexibility at a campus scale. To support this scale of analysis, NREL is developing the URBANopt advanced analytics platform for high-performance buildings and energy systems within one geographically cohesive area, such as a district or university campus (Polly et al. 2016). The URBANopt platform is being developed to investigate detailed energy trade-offs between building locations and geometry, building energy-efficiency features, building and district energy storage strategies and technologies, aggregated grid services such as dynamic and responsive loads, district energy system locations, and district energy system performance characteristics to identify best approaches for reaching campus energy goals.

Many energy generation options are available in addition to grid-provided electricity and imported fuels. Renewable energy options such as solar, wind, and biomass can provide additional cost-effective energy sources and help progress toward campus energy and emissions-reduction goals. For a campus to claim emissions reductions from renewable energy generation, they must own the Renewable Energy Certificates (NREL 2015). The competitiveness of on-site renewable energy compared to standard electricity purchasing from a utility depends on many factors, such as installed cost, incentives, renewable resources at the site, available area, utility rate structures and interconnection rules, and the time the energy is needed versus the time the renewable energy is available. NREL has developed a techno-economic decision-support model called REopt™ that is used to optimize energy systems for buildings, campuses, communities, and microgrids (REopt 2018). REopt recommends optimal mixes of renewable energy, conventional generation, and energy storage technologies to meet cost-savings and energy performance goals. NREL has developed the free REopt Lite Web tool to evaluate the economic viability and system size of grid-connected PV and battery storage at a site, identify battery dispatch strategies to minimize energy costs, and estimate how long a system can sustain critical loads during a grid outage.

Solar PV has achieved dramatic cost reductions during the last decade: the installed cost of commercial PV (200+ kW) reduced 65% between 2010 and 2017, and the installed cost of utility-scale PV reduced 77% during the same period. Solar PV works on surfaces that receive sufficient solar exposure, and it is the most common on-campus renewable energy source installed at universities to date (Solar Resource Guide 2017). Butte College, California, was the nation's first college campus to become zero annual energy in 2011 by installing 4.5 MW of PV. Butte College has added several new buildings since 2011, but the PV system still supplies 75% of the energy needs of the growing campus (Butte College 2010). Hampshire College in Amherst MA has also recently reached 100% renewable with an on-site PV system and a certified zero energy new building (Hampshire College 2017). An important lesson for other campuses is that if energy use increases, renewable energy generation must also increase if zero energy is to be maintained. By 2017, about 400 universities and colleges have adopted solar, with about 650 MW of installed capacity (Elgqvist and Vangeet 2017).

As a starting point to analyze solar PV, universities and others can use NREL's PVWatts tool (PVWatts.nrel.gov) to estimate the electricity production of a grid-connected roof- or ground-mounted PV system based on several simple inputs. More detailed solar analysis can be conducted using NREL's System Advisor Model (SAM.nrel.gov), which can be used to make performance predictions and cost-of-energy estimates for grid-connected renewable energy projects based on specified system design parameters. Energy production should be monitored post installation for the life of the PV system and compared to estimates, and repairs should be made as needed. Finally, NREL offers a variety of resources to universities seeking to go solar, with the aim to increase the deployment of mid-scale solar PV systems, engage stakeholders to develop deployment solutions, and empower decision makers (NREL 2018b).

Combined heat and power (CHP) systems can reduce source energy use because they recover heat that is typically wasted in the generation of electric power and deliver that energy in a useful form. CHP can have positive economics if the waste heat is used. CHP can also provide resiliency in the form of electricity (and heat) in the event of a grid outage if the CHP and electric infrastructure are designed to island from the grid. Many universities have CHP systems that use natural gas as a fuel. If a university has a zero carbon goal and CHP, the fuel must be zero carbon, such as biomethane, biodiesel, or hydrogen generated from zero carbon energy sources. Middlebury College, Vermont, installed a biomass gasification CHP system in 2009 that provides all heating, cooling, and 3,000–5,000 MWh of electricity per year (15%–20% of annual electricity consumption). The college has also installed 1.1 MW of PV. The CHP and PV systems are a key element for Middlebury College in reaching carbon neutrality (Middlebury 2016). As the electric grid becomes cleaner, the emissions savings from CHP and on-site renewable energy are reduced compared to grid electricity, depending on the CHP fuel source. In addition, to transition from off-site carbon neutral strategies to zero energy campus strategies, the College is investigating additional on-site and local renewable projects.

**A Focus on Laboratory Building Energy Use**

Many university campuses are focusing on their laboratory spaces when developing an energy plan. A typical laboratory is three to four times more energy intensive than an average commercial building, and laboratories can account for up to 70% of a campus's energy footprint (Better Buildings 2018). When the University of California Irvine (UCI) set a goal of becoming carbon neutral by 2025, they discovered that lab buildings were approximately 20% of the campus building area but consumed 65% of the energy on the UCI campus. UCI began the Smart Labs Initiative with the following key elements:

- Fundamental platform of dynamic, digital control systems
- Variable-air volume and demand-based ventilation
- Low power density, demand-based lighting
- Exhaust fan discharge velocity optimization based in dispersion study
- Pressure drop optimization to minimize fan energy
- Fume hood flow optimization
- Commissioning with automated cross-platform fault detection (UCI 2018).

UCI was able to reduce the energy use of 10 lab buildings by an average of 60% by implementing Smart Labs strategies. The UCI Smart Labs savings were for lab buildings that already exceeded California's energy code by an average of 20%. The investment costs were substantial but resulted in a payback period of 6–8 years and addressed deferred maintenance in the buildings. Similarly, the newest laboratories at the University of Colorado have integrated high efficiency heat recovery coils with indirect evaporative cooling for summer outside air precooling and winter exhaust air preheating – allowing for significant downsizing of their boilers and chillers and energy savings (CU 2016).

The DOE Better Buildings Alliance higher education group consists of 30 colleges and universities representing more than 300 million square feet of space that are sharing best practices and engaging with technical experts to advance their energy-savings goals (Better Buildings 2018). DOE has initiated the Better Buildings Smart Lab Accelerator (BBSLA 2018) based largely on the UCI Smart Labs. DOE Better Buildings Accelerators are designed to demonstrate specific innovative policies and approaches that will accelerate investment in energy efficiency upon successful demonstration. Each accelerator is a targeted, short-term, partner-focused activity designed to address persistent barriers that stand in the way of increased efficiency. There are currently 13 different accelerators.

The BBSLA works with partners that commit to reducing energy use in labs by at least 20% during the next 10 years. Accelerator partners work together to develop standardized approaches to overcoming common barriers to energy efficiency in laboratories. DOE helps partners document model strategies that include operational changes, technological upgrades, and strategic energy management approaches. Eight universities and AASHE are currently BBSLA partners, as are several federal agencies. It is estimated that if all laboratory buildings in the country improved their energy efficiency by 20%, annual energy and cost savings could reach approximately 40 trillion BTUs and $1 billion (Shehabi et al. 2017).

While university labs are historically large energy users, there are a few leading university laboratory projects that are proving that with best in class lab energy efficiency strategies integrated with on-site rooftop and parking canopy PV systems, zero energy labs are possible. The Venter Institute on UC San Diego's campus was an early example of a biology laboratory reaching zero energy (Venter 2018). Massachusetts's Bristol Community College's newest academic teaching laboratory is also targeting zero energy, utilizing ground source heat pumps, advanced demand-based lab air control, and rooftop and parking canopy PV systems to reach zero energy on site (BCC 2017).

## 3. Develop a Plan and Set Priorities

University campuses should carefully consider where to set energy-reduction targets because they are long-term goals against which progress will be measured for many years. Campus-wide targets are usually expressed in terms of percentage reduction in energy consumption by a certain year. In preparing energy-reduction plans, there is usually a desire for specific goals and a need to stay within financial constraints. Because of this, a hybrid approach that combines goals and financial constraints is typical.

By evaluating energy-reduction measures as a group, universities can combine measures that yield a higher return (i.e., a high cost-benefit ratio) with measures yielding a lower return. This portfolio approach allows large-impact measures that might have marginal financial performance to be worked in with smaller measures that have very high financial return. This approach also allows the bundling of measures for approval or financing, which could in turn lead to reduced transaction costs. In other words, one can obtain an acceptable cost-benefit ratio for the entire group of energy projects, some of which would not be included if the same cost criteria were individually applied to each project.

NREL previously identified and presented initial design principles, economic drivers, and master planning principles for zero energy districts (Polly et al. 2016). The design principles are generally applicable to university campuses; therefore, we present them again in Table 1 with some adaptations and new supporting discussion to emphasize challenges and opportunities for university campuses. We see these principles as strategies and concepts that should be considered for all campuses; however, we recognize that not all campuses may be able to successfully implement these principles because of project-specific constraints and challenges.

**Design Principles.** Table 1 outlines four core design principles for new ZEBs and updating campuses to reach their energy goals: maximize building efficiency, maximize solar potential, maximize renewable thermal energy, and maximize load control. Detailed descriptions of the design principles can be found in Polly et al. (2016). Ultimately, these principles are interrelated and must be maximized together using analysis approaches and tools that account for trade-offs among principles. For example, increasing building enclosure efficiency can affect the feasibility of certain district thermal systems. To arrive at a final solution, an iterative design process can be used to consider all systems and their interactions as well as associated costs and value streams.

**Table 1. Zero energy campus design principles (adapted from Polly et al. 2016)**

| Design Principle | Design Sub-Principle presented in general order |
|---|---|
| Maximize Building Efficiency in New Construction and Major Renovation | Orientation: Maximize natural daylighting, passive solar design. |
| | Enclosure: Employ efficiencies currently being implemented in the ZEB industry (e.g., DOE Zero Energy Ready Program; Zero Energy Advanced Energy Design Guides). |
| | Miscellaneous Electric Loads: Carefully select best-in-class products, develop robust control strategies, and verify with ongoing monitoring to minimize miscellaneous electric loads (Lobato et al. 2011). |
| | Lighting: Use 100% light-emitting diode, with controls for occupancy and daylighting variability. |
| | HVAC: Employ district-connected systems that maximize thermal energy recovery opportunities from low-grade heat sources across the district (e.g., ambient temperature district loops with building-scale heat pumps). |
| Maximize Solar Potential | Arrange buildings in districts to prevent building-to-building shading (e.g., shorter buildings oriented south, ideally). |
| | Orient buildings and roof slopes for maximum solar access. |
| | Minimize other buildings systems that require roof space (e.g., target 75% plus solar thermal/PV coverage of total roof area). |
| | Reserve all parking lots and garages to be shaded parking with PV. |
| | Improve potential for off-grid resiliency and maximize rooftop solar access. |
| Maximize Renewable Thermal Energy | Evaluate potential for renewable thermal energy systems and waste heat recovery (e.g., ground-source district heat pump systems, industrial waste heat recovery, and wastewater heat recovery). |
| Maximize Load Control | Establish controls for building and district system energy demands to accommodate the variable renewable energy supplies (e.g., PV and wind) and support the district's interaction with the electric grid. |

**Include Energy and Sustainability Strategies in Planning and Design Guidelines**

As the key priorities and strategies for reaching a campus's energy goals become clear, these strategies should become integrated with a campus's design and construction guidelines and master planning efforts. For example, requiring an energy recovery effectiveness for lab outside air systems higher than 80%, or including demand-based control of laboratory air supply and exhaust in the Facility Design guidelines can ensure these leading energy efficiency practices are implemented in all new projects. A specific example is at Colorado College, in Colorado Springs, which has integrated their sustainability, energy management, and integrated design strategies throughout their Facility Design Guidelines, Purchasing Guidelines, and Maintenance Guidelines. Based on their building baseline and energy use intensity (EUI) benchmarking efforts, combined with strategies to integrate EUI goals within individual new project requirements (Scheib et al. 2014), Colorado College developed "Facility Life Cycle Design Guidelines for Sustainability" that include aggressive zero energy ready project requirements. As Colorado College has previously achieved zero energy buildings and strives to maintain that level for all new building designs, all new or major renovations are to follow their design guidelines, as summarized in Table 2 (Colorado College 2018).

**Table 2. Colorado College Design Guidelines Minimum Construction Performance Targets**

| Performance Goal | Goal Quantification |
|---|---|
| Total Energy Use | 20 kBtu/ft$^2$/yr or less |
| Water Use – Building | 2.4 Gal/Building ft$^2$/yr or less |
| Water Use – Irrigation | 14 Gal/Turf ft$^2$/yr or less |
| Total Building Power Factor | Not less than 0.95 lagging at the utility meter |
| Indoor Air Quality | 700 PPM $CO_2$ or less during occupied hours |
| Artificial Lighting | 0.30 W/ft$^2$ or less |
| Lighting Levels | 35 Foot-candles in classrooms |

Another recent example of universities including their building benchmarking energy use data within their design guidelines and capital construction procurement process is at the University of Chicago. For a recently completed 390,000 ft$^2$, 800 bed campus residence hall project, the University of Chicago capital construction team integrated an energy performance-based procurement approach that included setting up a competitive procurement process and amending their RFP language to include a maximum energy performance requirement of 55 kBtu/ft$^2$/year. For a follow-on 100,000 ft$^2$ speaking forum facility using this same model at the University of Chicago, the RFP included a more aggressive energy use target. This project established a three-tiered energy requirement, with a maximum EUI requirement of 45 kBtu/ft$^2$/year, a "highly-desirable" requirement of 35 kBtu/ft$^2$/year, and a "if-possible" goal of zero energy. In this framework, the teams could self-select their own energy efficiency level based on what that they felt would fit within the project budget as part of a competitive design-build team selection process (McMillan et al. 2016).

## 4. Implement the Plan and Evaluate Progress

Successful implementation of an energy plan involves flexibility and long-term support from university leadership and stakeholders. Plans typically involve measuring and reporting progress toward a specific target and interim targets. Several universities have made progress toward their campus-wide energy and emissions-reduction goals, with leading examples described as follows:

- A combination of energy-efficiency programs, renewable energy procurement, energy-efficient building standards, and other measures have set the University of California (UC) system on a trajectory toward their zero carbon goal by 2025. UC's 2017 emissions are 3% less than its emissions in 2000, even with the addition of more than 36 million square feet of new space and campus enrollment growth of more than 66,000 students (University of California 2017). UC established a Wholesale Power Program (WPP) to improve the campus's abilities to manage their energy supplies and reduce the cost of carbon-free electricity. UC became a registered electric service provider (ESP), which allows it to procure electricity and provide it to campuses that have direct access rights authorized by the California Public Utilities Commission. Direct access service allows retail electric service customers to purchase electricity from an ESP instead of from a regulated electric utility. Their electricity is delivered through the utility's distribution system. Three UC medical centers and seven UC campuses and have direct access rights. Approximately 25%–30% of UC-purchased electricity is now served by the WPP. Participating campuses have decreased their carbon emissions while paying less than they did under past programs because UC contracted for renewable energy under the WPP from two solar projects in Fresno County totaling 80 MW. These agreements combined are the largest solar purchase by any university in the country. The solar projects are now supplying about 14% of UC total annual purchased electricity (University of California 2017).
- As part of the UC system's efforts to reduce its system-wide carbon footprint, each UC campus has installed on-site PV generation. System-wide, the campuses are home to more than 36 MW of solar power systems that produce more than 52 million kWh of renewable electricity annually. UC Davis's West Village Student Housing zero energy project is a leading example of attempting to reach 100% renewables with on-site PV, heat pumps, and energy efficiency in new construction (UC Davis 2015).
- Arizona State University has developed significant amount of on-site and off-site solar, with 24.1 MW on-site and 28.8 MW off-site as of June 30, 2017 (ASU 2017). They also recently completed their Student Pavilion, their first new zero energy building on campus, with additional zero energy projects planned (ASU 2018).
- The University of Hawaii Maui College is expected to complete the installation of 2.8 MW of PV and 13.2 MWh of battery distributed energy storage in 2019. When the PV plus storage is complete, it will provide 100% of the campus energy needs (UH 2018).
- Cornell's newest campus on New York City's Roosevelt Island, Cornell Tech, was designed with best in class energy efficiency, a shared geothermal district system, and on-site PV canopies that provide shading for multiple buildings. The primary 160,000 $ft^2$ classroom building, The Bloomberg Center, is targeting zero energy, and their on-site housing apartment building will be the U.S.'s largest Passive House project (Cornell Tech 2017).
- Multiple universities are adopting zero energy building concepts for their new construction projects on their campuses. These individual building examples are key elements of a campus wide zero energy effort, as they represent notable early efforts to adopt leading energy efficiency and on-site PV strategies which can set the standard for

future new construction and renovations on their campuses. A few notable examples not previously discussed include:

- North Shore Community College Health and Student Services Building. This 58,000 $ft^2$ office and classroom building, completed in 2011, was Massachusetts first owned zero energy building (NSCC 2011).
- UMass-Amherst Crotty Hall. This 16,800 $ft^2$ economics zero energy office building was completed in 2017. "James Boyce, an economics professor at UMass, said that he hopes Crotty Hall will pave the way for new net-zero buildings on campus in the future" (UMass 2017).
- Georgia Tech Kendeda Building for Innovative Sustainable Design. A 37,000 $ft^2$ classroom and environmental education building at Georgia Tech is seeking to become the first zero energy Living Building Challenge in the Southeast (Kendeda 2017).
- The University of Colorado-Boulder Indoor Practice Facility: In 2016, CU completed a 106,000 $ft^2$ indoor practice facility with 850 kW rooftop PV system, resulting in CU's first on-site zero energy facility (CU 2017).

- Multiple US Higher Education campuses are leading the US in implementing next generation district thermal energy systems. Next generation district thermal energy systems move from district thermal energy systems of 4-pipe hot water or steam and chilled water thermal districts to 2-pipe heat recovery loops that operate between ambient air and average ground temperatures. Variations of this concept include central heat pump loops that recovery waste heating/cooling and distribute with 4-pipe hot water/chilled water systems (UNEP 2018). Examples of notable next generation university campus district thermal energy systems include:
  - Stanford Energy Systems Innovation. In 2015, Stanford removed their existing CHP central plant and added a district electric heat pump heat recovery central plant with thermal energy storage, 5 MW of on-site PV, and 68 MW of off-site PV. This system has been a key to reaching over 50% campus wide renewable electricity. (Stagner 2016).
  - Ball State Campus Geothermal. To replace existing coal fired boilers, Ball State drilled approximately 3,600 ground source heat pump wells to provide heat pumps in 47 buildings with district shared, ground exchange loops. This would result in the largest district geothermal system in the US, saving $2,000,000 in annual energy savings across 5.5 million $ft^2$ of campus facilities (Ball St 2012).
  - Colorado Mesa University District Geothermal. Colorado Mesa University has connected many of their new buildings on campus to a shared ground source heat pump loop across seven shared well fields, maximizing thermal energy recovery across all their connected buildings. Nine separate buildings across 696,000 $ft^2$ of campus facilities are connected to the shared heat pump loop, providing 89% of the energy needed to heat and cool connected buildings while saving the University as much as $459,497/year (Colorado Mesa 2018).
  - Missouri Science and Technology Campus Geothermal System. A campus wide ground source heat pump system was installed in 2014 to provide a shared heating and cooling system for about 2/3's of the general and educational spaces on the campus over 17 buildings containing 1.2 million square feet of space. In 2017, Missouri S&T saw a reduction of 57% in energy use from their campus scale

ground source heat pumps system, which consists of 789 wells that are 400-440 feet deep. Those wells supply three regional plants, each with 500-ton capacity, plus a dedicated geothermal system for a remote building (Missouri S&T 2014).

**Conclusions**

Many universities have achieved or have plans to achieve significant energy reductions. A few have even reached on-site zero energy. To reach these goals, leading universities have developed a suite of common energy-efficiency and renewable generation strategies. In this paper, we presented a common set of approaches including best practices for including energy targets in new construction procurement contracts and design guidelines, aggressively implementing best-in-class laboratory energy-efficiency strategies that are proving to save over 60% in the largest energy user in higher education, planning for and optimizing on-site and off-site renewable projects, striving for zero energy for all new construction, especially to set a standard for future new construction on their campuses, and high-performance district energy systems. The summary of these best practices becomes a process to reduce campus energy use and then meet the remaining campus energy needs with renewable energy. We presented the five-step process to developing and implementing campus energy-reduction plans: 1) determine baseline energy consumption, 2) analyze technology options, 3) develop a plan and set priorities, 4) implement the plan, and 5) evaluate progress. We presented some examples of energy-reduction results from leading universities.

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