



U.S. DEPARTMENT OF
ENERGY

Energy Efficiency and Energy Security Benefits of District Energy

Report to Congress
July 2019

United States Department of Energy
Washington, DC 20585

Message from the Secretary

The following report, *Energy Efficiency and Energy Security Benefits of District Energy*, discusses the energy efficiency benefits of district energy, an overview of how district energy increases energy security, the current status of the district energy market, challenges to district energy implementation, and future research and development opportunities.

This report is being provided to the following Members of Congress:

The Honorable Richard Shelby

Chairman, Senate Committee on Appropriations

The Honorable Patrick Leahy

Vice Chairman, Senate Committee on Appropriations

The Honorable Nita Lowey

Chairwoman, House Committee on Appropriations

The Honorable Kay Granger

Ranking Member, House Committee on Appropriations

The Honorable Lamar Alexander

Chairman, Subcommittee on Energy and Water Development

Senate Committee on Appropriations

The Honorable Dianne Feinstein

Ranking Member, Subcommittee on Energy and Water Development

Senate Committee on Appropriations

The Honorable Marcy Kaptur

Chairwoman, Subcommittee on Energy and Water Development

House Committee on Appropriations

The Honorable Mike Simpson

Ranking Member, Subcommittee on Energy and Water Development

House Committee on Appropriations

If you have any questions or need additional information, please contact me or Ms. Bridget Forcier, Associate Director for External Coordination, Office of the Chief Financial Officer, at 202-586-0176.

Sincerely,

Rick Perry



Energy Efficiency and Energy Security Benefits of District Energy

Table of Contents

Executive Summary	5
Glossary	7
I. Congressional Request	9
II. Overview	9
III. Energy Efficiency Benefits from District Energy	10
IV. Energy Security Gains from District Energy	17
V. Existing District Energy Market Status	23
VI. Challenges to District Energy Implementation	34
VII. Opportunities for Improvement in Energy Efficiency And Security	40
VIII. Future Research Opportunities	49

Executive Summary

Congress directed the U.S. Department of Energy (DOE) “to collaborate with industry to submit a report ... that assesses the potential energy efficiency and energy security gains to be realized with district energy systems.”¹ This report discusses the energy efficiency benefits of district energy, an overview of how district energy increases energy security, the current status of the district energy market, challenges to district energy implementation, and future research and development opportunities.

In a district energy system, a central plant or plants produce steam, hot water, or chilled water, which is then pumped through a network of insulated pipes to provide space heating, cooling, or hot water for nearby buildings. District energy systems serve a variety of end-use markets including downtowns (central business districts), college and university campuses, hospitals and healthcare campuses, airports, military bases, industrial complexes, and others.

Much of the energy efficiency advantages of district energy are a result of combining many diverse load profiles, which allows the central energy plant equipment to operate at high load factors with resulting higher levels of efficiency. Aggregation also provides the economies of scale that allows district energy systems to employ high efficiency technologies, such as combined heat and power (CHP), and industrial-grade equipment such as condensing economizers that would typically otherwise not be economically or technically feasible for individual buildings.

The energy security and resilience benefits of district energy infrastructure are often used to support mission-critical operations in places like hospitals, university research centers, military bases, and specialty industries like food processing and pharmaceuticals. With the integration of CHP and microgrid technologies, district energy systems can provide high levels of energy reliability providing power, heat and cooling services without interruption, even during unexpected grid outages due to extreme weather events. The ability for district energy systems to use local fuel sources and the flexibility of systems to use multiple types of fuel also contributes to the energy security of communities served by district energy. Local operational control ensures that investment decisions are being made close to the point of impact.

According to a recent estimate from the U.S. Energy Information Administration, there are more than 660 district energy systems operating in the U.S. with installations in every state, and the number of buildings and amount of floor space served by district energy is steadily increasing.² While there are challenges related to economics, engineering, and education that can pose barriers to potential projects, there are also wide-ranging opportunities for greater

¹ S. Rep. No. 115-132, at 69 (2017). Available at <https://www.congress.gov/bill/115th-congress/senate-bill/1609>.

² U.S. Energy Information Administration (EIA). 2018. *U.S. District Energy Market Characterization*. Report by ICF and IDEA prepared for the U.S. Energy Information Administration. Available at <https://www.eia.gov/analysis/studies/buildings/districtservices/pdf/districtservices.pdf>

use of district energy. Research into potential efficiency improvements, system optimization techniques, and integration of advanced technologies has the potential to help accelerate deployment of district energy.

Glossary

Several key terms related to district energy are defined below.

Combined Heat and Power (CHP): CHP, also known as cogeneration, is the concurrent production of electricity or mechanical power and useful thermal energy (heating or cooling) from a single source of energy.³

Deep Water Cooling: Also known as lake source cooling, uses cold water from a deep lake or ocean current through heat exchangers to provide chilled water for district cooling systems or for cooling buildings directly. Because heat flows naturally from the warmer chilled water return loops to the colder ocean or lake water, no energy is required beyond that needed to move the water through the distribution pipes and heat exchangers. This method eliminates conventional cooling equipment at the building or district cooling system and its associated energy use.⁴

District Energy (or District Heating and Cooling): District energy systems include a central plant or plants that produce or recover steam, hot water or chilled water for distribution to connected customer buildings through an underground insulated piping network to provide space heating, air conditioning, domestic hot water and other uses. Customers avoid the capital costs, ongoing maintenance and operation costs of on-site equipment, and benefit from economies of scale.

Distributed Energy: Distributed energy is the generation of electricity or thermal energy at or near the point of use. Distributed energy is a broad term that encompasses production of energy from a variety of technology types such as gas turbines, boilers, reciprocating engines, fuel cells, microturbines, solar photovoltaic systems, etc.

Energy Security: For the purpose of this report, energy security is discussed broadly, with a focus on allowing energy infrastructure and critical facilities to maintain operations during unexpected outages, and improving the ability to recover from disaster events when they occur. This includes the concepts of both “energy security” and “grid resilience,” which are commonly discussed together. Formal definitions for these terms are not universally accepted. Where infrastructure is concerned, security activities are generally focused on preventing a disruption from occurring, and resilience activities are generally focused on ensuring the infrastructure can rebound quickly to restore services to the communities that rely upon them.⁵

³ U.S. Department of Energy (DOE). n.d. *Combined Heat and Power Basics*. Available at <https://www.energy.gov/eere/amo/combined-heat-and-power-basics>

⁴ Cornell University Facilities and Campus Services. 2005. *Lake Source Cooling*. Available at <https://energyandsustainability.fs.cornell.edu/util/cooling/production/lsc/default.cfm>

⁵ Vugrin, E., A. Castillo, and C. Silva-Monroy. 2017. Resilience Metrics for the Electric Power System: A Performance-Based Approach. Sandia National Laboratories. <http://prod.sandia.gov/techlib/access-control.cgi/2017/171493.pdf>

Geothermal Energy: Hot water or steam extracted from geothermal reservoirs in the earth's crust can be used as a heat source for district heating systems.

Geothermal Heat Pumps: Also known as ground source heat pumps, geothermal heat pumps transfer heat from the ground or ground water directly into buildings or district heating systems.

Microgrid: A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.⁶

Primary Energy: Energy in the form that it is first accounted for in a statistical energy balance, before any transformation to secondary or tertiary forms of energy. For example, coal is primary energy, used to generate electricity, and electricity is secondary energy used at a site. Overall energy and emissions impacts of district energy are best defined in terms of primary energy. See primary energy production and primary energy consumption.⁷

Thermal Storage: Storage of heat or cold for later heating or cooling. Examples include using solar thermal energy to heat water during the day for hot water use at night; the storage of seasonal summer heat for winter use; nighttime production and storage of chilled water or ice during off-peak power periods for air conditioning during higher cost, daytime periods; and others. Thermal storage typically shifts production from high cost, high demand periods to lower cost periods. Stored thermal energy can reduce or avoid peak demand charges, reduce strain on the grid and help balance energy loads, including converting low or no cost renewable electricity into useful thermal energy for later uses, instead of storing energy as electricity in batteries.

Waste Heat Recovery: Waste heat or thermal energy from industrial processes or other sources that would normally be ejected into the environment can be recovered and used as a heat source in district heating systems. Use of waste heat reduces system fuel consumption, lowers emissions and increases efficiency.

⁶ Lawrence Berkeley National Laboratory (LBNL), U.S. DOE. n.d. *Microgrid Definitions*. Available at <https://building-microgrid.lbl.gov/microgrid-definitions>

⁷ U.S. Energy Information Administration (EIA). n.d. Glossary. Available at <https://www.eia.gov/tools/glossary/index.php>

I. Congressional Request

This report responds to language set forth in the Fiscal Year 2018 Senate Appropriations Committee Report, wherein it is stated:

“The Committee further directs the Secretary to collaborate with industry to submit a report to the Committees on Appropriations of both Houses of Congress no later than 90 days after enactment that assesses the potential energy efficiency and energy security gains to be realized with district energy systems.”⁸

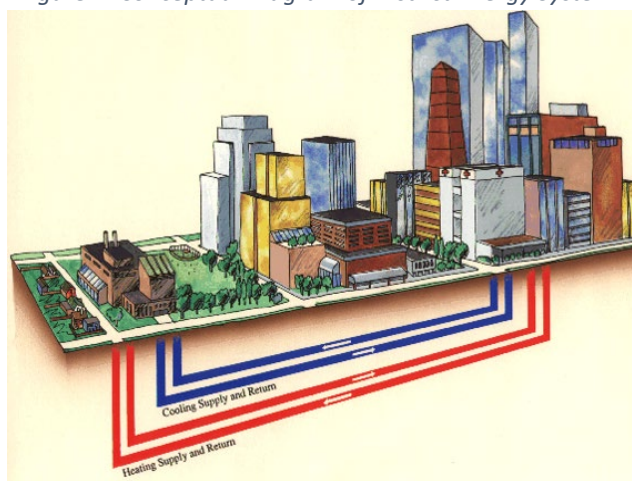
DOE prepared this report in collaboration with Lawrence Berkeley National Lab, ICF, Entropy Research LLC, and the International District Energy Association (IDEA), a non-profit trade organization representing more than 2,200 members from the district energy industry.⁹

II. Overview

In a district energy system, a central plant or plants produce steam, hot water, or chilled water, which is then pumped through a network of insulated pipes to provide space heating, cooling, or hot water for nearby connected customer buildings.¹⁰ District energy systems serve a variety of end-use markets including downtowns (central business districts), college and university campuses, hospitals and healthcare campuses, airports, military bases, industrial complexes, and others.

This report was prepared by collecting and reviewing existing literature and collaborating with experts in district energy, CHP, and microgrids. It includes data and detailed case studies that demonstrate the extent and benefits of current deployment of district energy systems. The next section of this report, Section III, discusses the energy efficiency benefits of district energy, while Section IV provides an overview of how district energy increases energy security. Section V describes the current

Figure 1. Conceptual Diagram of District Energy System



status of the district energy market, including information about where existing systems are installed, recent growth and trends impacting district energy in the U.S., and opportunities for

⁸ S. Rep. No. 115-132, at 69 (2017). Available at <https://www.congress.gov/bill/115th-congress/senate-bill/1609>.

⁹ For more information about IDEA and to access additional case studies, see <https://www.districtenergy.org/resources/resources/case-studies>.

¹⁰ EIA, 2018, p. 7.

growth in the U.S. Section VI introduces the challenges to district energy implementation and Section VII discusses the opportunities for future efficiency gains and greater energy reliability and security in district energy systems. The final section summarizes areas for research and development.

III. Energy Efficiency Benefits from District Energy

This section describes the characteristics of district energy that enable energy savings, including the ability to combine loads and create economies of scale that allow the use of highly-efficient technologies such as CHP.

How District Energy Systems Save Energy

Buildings connected to a district energy system benefit from delivery of high efficiency heating and cooling services, fuel and technology flexibility brought on by economies of scale, and additional productive space in the buildings themselves opened up by elimination of individual boilers, chillers, and cooling towers. Many of the energy efficiency advantages of district energy are a result of aggregating the diverse heating and cooling loads of multiple nearby buildings into a more steady and predictable combined load. A central energy plant that serves the aggregated heating or cooling demand of many buildings is generally more efficient than on-site heating and cooling systems that have to ramp up and down to meet the daily and hourly needs of individual buildings.

The district energy distribution system itself also serves as a type of energy storage, with steam, hot water or chilled water circulating in the system, effectively smoothing the load for the central plant. Combining a number of diverse load profiles allows the central energy plant equipment to operate at high load factors with resulting higher levels of efficiency. Serving a more stable, predictable combined load not only promotes higher load factors, but also reduces the need for excess peak heating or cooling capacity. The design for stand-alone chiller plants at individual buildings typically calls for installation of between 30% and 100% more cooling capacity than what is required from a district cooling provider.¹¹ Aggregating the energy requirements of dozens or even hundreds of different buildings also provides the economies of scale that allows district energy systems to employ high efficiency technologies and industrial-grade equipment such as condensing economizers that would typically not be economically or technically feasible for individual buildings.

Use of Advanced Technology and Local Fuel Sources

Modern district energy systems combine district heating and cooling with elements such as combined heat and power (CHP), thermal storage, geothermal heat pumps, deep lake cooling

¹¹ International District Energy Association (IDEA). August 5, 2005. IDEA Report: The District Energy Industry. Available at http://lincoln.ne.gov/city/mayor/arena/assets/idea_district_energy.pdf

or local microgrids to provide a more resilient, flexible and efficient energy system. CHP can deliver electricity and thermal energy services at overall efficiencies of 65% to 80%, an improvement over the national average of 45% for these services when separately provided by central station power generation and on-site boilers.¹² Aggregating the thermal and electricity loads of multiple buildings and users leads to an economy of scale that enables the use of larger, more efficient combustion turbine and engine generators in CHP systems, and brings the efficiency benefits of CHP to energy users that may not have had sufficient heating or cooling loads to implement this technology on their own. Economies of scale also enable the use of advanced technologies that would not be feasible for individual buildings. As an example, **Cornell University** gets chilled water to air condition the campus from the cold, deep water of nearby Lake Cayuga.¹³ When the lake source cooling system was completed in 2000, it led to a savings of 25,000 MWh per year in electricity use, representing an overall 10% reduction in campus electricity usage. The \$58 million investment by Cornell in a lake source cooling system cut electricity consumption for air conditioning by 85%.¹⁴

Economies of Scale Allow Cornell University to Invest in Efficient Technologies

- Location: Ithaca, New York
- Sector: College/University
- Energy Supplied: Steam, chilled water, electricity

Cornell's district energy system serves 80 buildings totaling over 4.5 million square feet of air conditioned space. It delivers approximately 20,000 tons of cooling capacity at peak demand, circulating about 33,000 gallons per minute. It uses a renewable lake source cooling system, which has reduced Cornell's reliance on fossil fuels and typically saves 25,000 MWh of electricity annually. This represents about an 85% reduction in energy use for campus cooling.^{13, 14}



Photo Credit: Cornell University

Economies of scale and the use of thermal storage enable district energy systems to be an effective means for integrating local fuel resources and renewables into heating and cooling

¹² U.S. Department of Energy (DOE); U.S. Environmental Protection Agency (EPA). 2012. *Combined Heat and Power: A Clean Energy Solution*. Available at <https://www.energy.gov/eere/amo/downloads/chp-clean-energy-solution-august-2012>

¹³ Cornell University, Facilities and Campus Services. n.d. Cooling Home. Available at <https://energyandsustainability.fs.cornell.edu/util/cooling/default.cfm>

¹⁴ Cornell University. May 10, 2017. "Lake Source Cooling: Innovation, energy efficiency, and environmental sustainability." Available at <https://medium.com/cornell-university/lake-source-cooling-d307913dfc47>

services. Many district heating systems in the U.S. have or are transitioning to local fuels including systems fueled by waste wood in downtown St. Paul, oat hull by-products at the University of Iowa, landfill gas at the University of California Los Angeles, and tire-derived fuel from shredded automotive tires at the University of Missouri – Columbia.^{15,16,17,18} Aggregating heating and cooling loads also allows district energy systems to incorporate technologies and fuels not generally feasible for individual buildings. In another example, **Ball State University** converted its coal-fired steam heating system and centrifugal chillers to an integrated heating/cooling district energy system using ground source heat pumps. The geothermal system now takes advantage of simultaneous heating and cooling loads on campus and achieves lower maintenance and overall energy costs.¹⁹ Opportunities also exist for incorporating waste heat from local industrial plants and other large energy users as a heat supply to the district system.

Ball State University Integrates Geothermal into District Energy System

- Location: Muncie, Indiana
- Sector: College/University
- Energy Supplied: Hot water, chilled water

Ball State University completed the final integration of a ground-sourced geothermal heat pump into their district energy system in 2018. This project demonstrated the feasibility of large-scale geothermal heat pumps and is the largest system of its kind in the US, according to the DOE. The project cut carbon emissions by 85,000 tons and improved energy efficiency which saves \$2 million a year in energy costs.¹⁹



Photo credit: IDEA

¹⁵ District Energy St. Paul. n.d. Tell Your Sustainability Story. Available at

<https://www.districtenergy.com/customer-resources/sustainability/your-story/>

¹⁶ University of Iowa Facilities Management. n.d. UI Energy Production and Distribution. Available at

<https://www.facilities.uiowa.edu/uem/district-energy/>

¹⁷ UCLA Facilities Management. n.d. Utility Distribution. Available at

<https://www.facilities.ucla.edu/services/utility-distribution>

¹⁸ U.S. Department of Energy (DOE). October 2017. Project Profile: University of Missouri. Available at

http://www.midwestchptap.org/profiles/ProjectProfiles/University_of_Missouri_Columbia.pdf

¹⁹ Ball State University Magazine. January 9, 2017. "Colossal Geothermal Project Harnesses the Earth to Heat, Cool Campus." Available at <https://magazine.bsu.edu/2017/01/09/ball-state-geothermal-project/>

Economic Benefits of Efficiency

The efficiency savings from district energy systems can be a driver for local economic growth. Heating, cooling and electricity services can be provided to building owners and tenants at lower cost rates due to the efficiency and economies of scale that district energy systems bring. This is reflected through savings on water, chemicals, insurance and fuel needed for individual building systems, making them more affordable to customers than other options. For instance, a geothermal district energy system in the rural area of **Chena, Alaska**, reduced the cost of producing power from \$0.30 per kWh to \$0.05 per kWh. Those savings led to new development at sites served by the system including increased greenhouse production and facility expansion at the Chena Hot Springs resort, which created jobs and increased local tourism.^{20,21} Similarly, the district energy system at **Ball State University** saves \$2 million a year in energy costs.²²

For building developers and owners, district energy reduces the capital cost of developing an office building by cutting the boiler and chiller plant cost from the project, frees up valuable space within the building for productive service, and increases overall architectural design flexibility.²³ Thermal energy supplied directly in usable form (heating or cooling) enables simpler building systems and operations, and greater building energy efficiency.²⁴ For existing buildings, owners avoid annual ownership, operation and maintenance costs of boilers, furnaces, chillers and cooling towers, and typically realize lower lifecycle costs. Additionally, there is often a premium value for space in densely populated areas that can be reclaimed for other productive uses by displacing mechanical equipment, flues and cooling towers. In particular, rooftop and penthouse space can be shifted from a cost center for large mechanical systems to a profit center for third parties (i.e., communications towers, restaurants, leasable footprints).²⁵ Building tenants can experience enhanced comfort and convenience through lower noise and vibration levels, and better space utilization.²⁶ Finally, fuel flexibility, re-circulating energy dollars in the local economy through the use of local energy resources, and

²⁰ U.S. Department of Energy (DOE). March 19, 2015. "EERE Success Story—Geothermal Technology Breakthrough in Alaska: Harvesting Heat below Boiling Temperatures". Available at <https://www.energy.gov/eere/success-stories/articles/eere-success-story-geothermal-technology-breakthrough-alaska>

²¹ Chena Power Company. 2007. Geothermal Power Plant Final Project Report. Prepared for the Alaska Energy Authority. Available at <http://www.akenergyauthority.org/Content/Programs/AEEE/Geothermal/Documents/PDF/FinRepChenaGeoPlant09.pdf>

²² Ball State University Magazine, 2017.

²³ Tredinnick, S. June 7, 2013. "Why Is District Energy Not More Prevalent in the U.S.?" HPAC Engineering. Available at <https://www.hpac.com/heating/why-district-energy-not-more-prevalent-us>

²⁴ State of Minnesota, Department of Administration. December 1, 2017. "Saint Paul's District Energy System". Available at <https://mn.gov/admin/government/sustainability/blog/?id=36-319427>

²⁵ Northwest CHP Technical Assistance Partnership, U.S. Department of Energy (DOE). n.d. District Energy: Economic Factors. Available at <http://northwestchptap.org/AboutCleanEnergy/DistrictEnergy/EconomicFactors.aspx>

²⁶ EIA, 2018, p. 22.

local job creation creates a market advantage for district energy systems, and establishes them as important assets for community energy planning and economic development.²⁷

Alaska's First Geothermal Power Plant Lowers Electricity Costs

- Location: Chena, AK
- Sector: Municipal
- Energy Supplied: Steam, hot water, electricity

In July 2006, the State of Alaska began operations at its first geothermal power plant in Chena Hot Springs, AK. Using two 200 kW organic rankine cycle units, the power plant provides electricity and thermal energy to the surrounding area, including the Chena Hot Springs Resort and its adjacent greenhouse. The system displaced 224,000 gallons of diesel that was previously used to provide power, along with providing 95% reliability and a \$0.25/kWh reduction in electricity costs.²¹

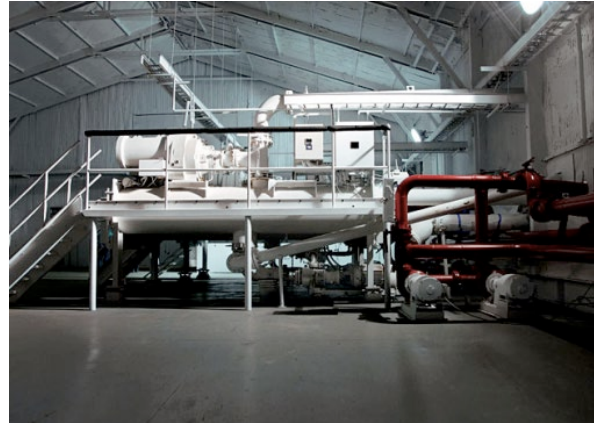


Photo credit: Chena Power

Reduced Local Impacts from Efficiency

District energy systems can reduce the impact of energy use at both the national and local level. By reducing fossil fuel use through increased efficiency, use of CHP and transitioning to alternative or waste resources, district energy can lead to reductions in indoor and outdoor air pollution and associated local health impacts.²⁸ The use of local fuels, such as landfill gas, waste wood, and agricultural waste, avoids environmental impacts that would otherwise occur, such as landfill methane emissions or overcrowding of landfills.²⁹ Furthermore, the economies of scale inherent with district energy enable the use of larger, more efficient, and often less emitting equipment, and allow the use of more effective pollution control technologies. Greater efficiency and the use of alternative fuels also leads to fewer emissions.³⁰

²⁷ District Energy St. Paul. n.d. Biomass. Available at <https://www.districtenergy.com/customer-resources/how-it-works/biomass/>

²⁸ Solbak, V. June 27, 2016. *District Energy and Co-generation for Public Buildings in Alberta*. Government of Alberta Ministry of Infrastructure. Available at http://www.infrastructure.alberta.ca/Content/docType486/Production/District_Energy_and_Cogen_for_Alberta_final.pdf

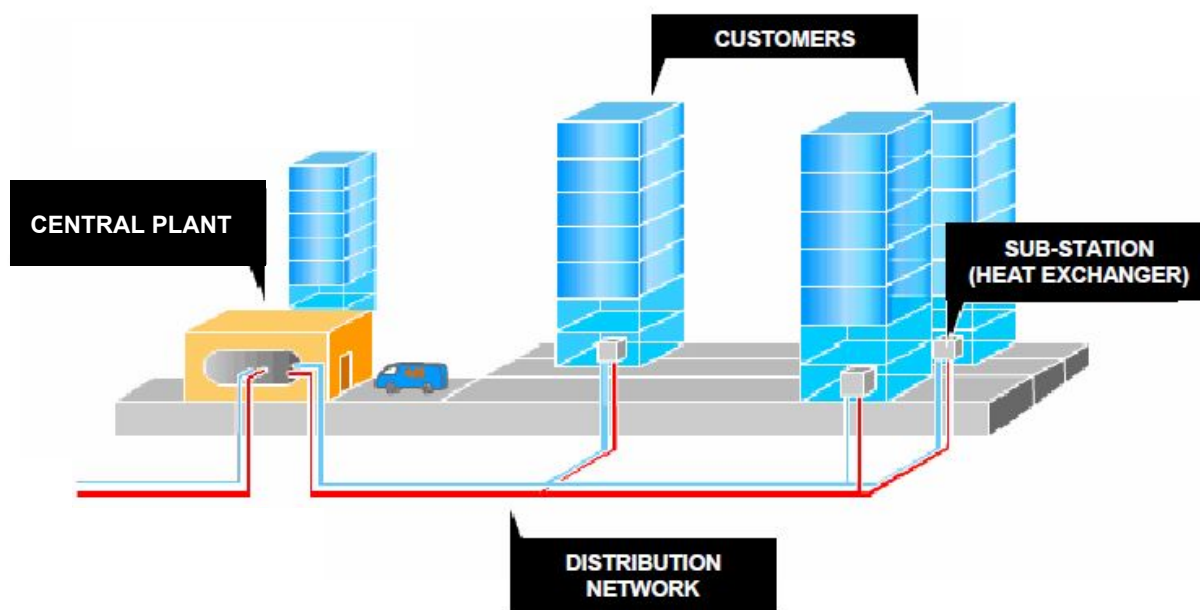
²⁹ Landfill Methane Outreach Program (LMOP), U.S. EPA. n.d. Benefits of Landfill Gas Energy Projects. Available at <https://www.epa.gov/lmop/benefits-landfill-gas-energy-projects>

³⁰ EIA, 2018, p. 26.

Current Efficiency of Existing District Energy Systems

The efficiency of district energy systems is a combination of the heating and cooling equipment efficiencies at the central plant, the efficiency of the distribution system, and efficiency of the heat exchangers located at customer buildings (shown in Figure 2). The central plant efficiency can be viewed as one measure, and the distribution efficiency, or system line losses, as another separate measure. District energy systems typically reduce primary energy demand for heating and cooling by 50 percent by using low-grade energy sources, co-generating heat and electricity, and utilizing thermal storage, which helps to smooth the demand. Integrating cooling into the district energy system can generate an additional 50% reduction in electricity use in hot climates, while also leading to lower consumption of fresh water in comparison with conventional cooling systems.³¹

Figure 2. Schematic of Example District Energy System Components



Central Plant Equipment Efficiency

For heating equipment, the efficiency of the boiler at the central plant is the main determinant of system efficiency. The average size of boilers employed in U.S. district energy facilities varies from 50,000 to 150,000 pounds of steam per hour and efficiency is estimated to typically be in

³¹ C40 Cities Climate Leadership Group (C40); United Nations Environment Programme (UNEP). 2016. *Good Practice Guide: District Energy*. Available at <http://kms.energyefficiencycentre.org/publication-report/good-practice-guide-district-energy>

the range of 80 to 85 percent depending on fuel type.³² Whatever fuel is used, boiler operation is most efficient when boilers operate at or near full-load, which is one of the primary benefits of the district heating. Table 1 summarizes estimated average boiler efficiencies based on fuel type.³³ Other factors impacting boiler efficiency include the age, type, and condition of the equipment.

Table 1. Estimated average efficiencies of heating equipment by fuel type

Heating	Boiler Efficiency
Natural Gas	82%
Oil	85%
Coal	86%
Biomass	75%

For cooling equipment, the efficiency of the chiller at the central plant is the main determinant of system efficiency. Electrically driven centrifugal chillers are the most common technology in use and the average size ranges from one hundred to several thousand tons of cooling capacity. The amount of electricity consumed to produce chilled water is estimated to be 0.6 – 1.0 kWh per ton of cooling capacity, with chillers being the most efficient when operating at near full-load. Table 2 summarizes estimated efficiencies for cooling equipment technologies.³⁴

Table 2. Estimated average efficiencies for cooling equipment technologies

Cooling	Efficiency
Electric	0.7 kWh/ton
Steam Drive	10 lbs of steam (11,000 Btu) per ton-hr of cooling
Absorption	0.7 COP for single effect; 1.1 COP for double effect

Distribution System Efficiency

The efficiency of distributing heating and cooling services to the customer is determined by heat losses, or heat gains in the case of cooling, in the distribution pipelines. The level of heat loss in the system depends on thermal insulation of pipes, pipe size, temperature of the thermal fluid (i.e., steam or hot water), outdoor ambient temperatures, and the linear heat density of the distribution system (i.e., the heat delivered per year per unit of length of the distribution network) which is a measure of the user density of the system. Steam systems

³² U.S. Energy Information Administration (EIA). 2007. *Final Report: District Energy Services Commercial Data Analysis for EIA's National Energy Modeling System*. Prepared by Energy and Environmental Analysis, Inc. and International District Energy Association.

³³ EIA, 2018, p. 43.

³⁴ Ibid, p. 44.

generally deliver 91% to 94% of their energy to the customers, and hot water and chilled water loops generally deliver 97% to 98% of their energy directly to the user.³⁵

IV. Energy Security Gains from District Energy

For the purpose of this report, energy security is discussed broadly, with a focus on the ability for district energy systems to (1) allow energy infrastructure and critical facilities to maintain operations during unexpected outages, and (2) improve the ability to recover from disaster events when they occur. This includes the concepts of both “energy security” and “energy resilience,” which are commonly discussed together. However, formal definitions for these terms are not universally accepted. Where infrastructure is concerned, security activities are generally focused on preventing a disruption from occurring, and resilience activities are generally focused on ensuring the infrastructure can rebound quickly to restore services to the communities that rely upon them.³⁶

This section describes the characteristics of district energy that enable it to increase energy security and resilience, including the ability for district energy to use local fuel sources, use multiple fuel sources, store energy, reduce exposure to outages with CHP and microgrids, protect critical infrastructure, and support restart of the surrounding grid in extended outage situations.

How District Energy Increases Energy Security and Energy Resilience

The energy security and resilience benefits of district energy infrastructure are widely recognized, and district energy systems are often used to support mission-critical operations in places like hospitals, university research centers, military bases, and specialty industries like food processing and pharmaceuticals. Key military bases like **Fort Bragg, Andrews Air Force Base, Twentynine Palms Marine Corps Base, and Fort Worth** rely on district energy infrastructure for secure energy services. With the integration of CHP and microgrid technologies, district energy systems can provide “six nines” in energy reliability (99.9999% availability) to provide power, heat and cooling services without interruption, even during unexpected grid outages due to extreme weather events.³⁷

District energy is able to provide this level of service because the use of industrial-grade production equipment and controls with N+1 production capacity³⁸ is inherent in the system’s design and operation. Systems are professionally operated and maintained and subject to

³⁵ EIA, 2018, p. 43-44.

³⁶ Adapted from Vugrin, et al. 2017.

³⁷ Morrissett, G. August 15, 2017. “Working and Future Microgrid Application: MCAGCC 29 Palms.” Energy Exchange, U.S. DOE. Available at https://www.2018energyexchange.com/2017archive/wp-content/uploads/T11S2_Morrissette.pdf

³⁸ N+1 redundancy is a form of resilience that ensures system availability in the event of component failure. Components (N) have at least one independent backup component (+1).

continuous testing, monitoring and frequent retro-commissioning. Industry best practices include continuous operational monitoring, advanced load forecasting and advanced controls to optimize operations in parallel with the regional electricity grid. As demonstrated at **University of Texas Austin**, the campus district energy/CHP/microgrid provides 100% of the electricity, heat and cooling for the campus since 1929 and over the past 35 years had only 4 hours of unscheduled interruption for reliability of 99.9998%.³⁹

Use of Local Fuel Sources and Fuel Flexibility

The ability for district energy systems to use local fuel sources, and the flexibility of systems to use multiple types of fuel contributes to the energy security of communities served by district energy. In addition to natural gas, district energy systems can be configured to use local fuels like wood waste from tree trimmings (**St. Paul, MN and Burlington, VT**); tire derived fuel (**University of Missouri**); nearby landfill gas (**University of New Hampshire**); and manufacturing waste streams (**University of Iowa**). Local operational control ensures that investment decisions are being made close to the point of impact. Investing in local energy infrastructure also keeps energy dollars recirculating in the local economy, often producing a “multiplier effect” on local jobs and tax revenues.⁴⁰

Fuel flexibility in district energy is another key attribute to increasing energy security in the future. Systems with multiple fuel options are not solely dependent on a single resource stream or imported fuel supply, which creates purchasing options and the ability to adjust as prices fluctuate. For example, the dual fuel CHP system at the **James H. Quillen Medical Center** uses biogas from a nearby landfill and can use natural gas if biogas is unavailable.⁴¹ This can strengthen local economies and improve energy security in the near-term, while also providing a platform for communities to plan for a future with infrastructure that can accommodate a variety of energy solutions. Emerging technologies like heat pumps, fuel cells or biofuels are more easily and rapidly retrofitted into central plants, without the need to install equipment in each building.

³⁹ IDEA and DOE, 2012.

⁴⁰ NH Wood Energy Council. October 20, 2016. “Report documents economic benefit of New Hampshire wood heating.” Biomass Magazine. Available at <http://biomassmagazine.com/articles/13824/report-documents-economic-benefit-of-new-hampshire-wood-heating>

⁴¹ U.S. Department of Energy (DOE). August 2015. Project Profile: James H. Quillen VA Medical Center. Available at http://www.southeastchptap.org/Data/Sites/4/documents/profiles/james_quillen_medical_center-chp_project-profile.pdf

Dual-Fuel System Powers Tennessee VA Medical Center Campus

- Location: Mountain Home, TN
- Sector: Healthcare
- Energy Supplied: Space heating, space cooling, electricity

The Mountain Home VA Healthcare system installed a dual-fuel CHP system at the James H. Quillen Medical Center in 2001 to provide electricity, heating, and cooling to the medical campus. This system uses biogas from the nearby Iris Glen Landfill and can also run on natural gas if the biogas is unavailable. The district energy system reduced energy consumption for the campus by 20%, resulting in annual savings over \$250,000.⁴¹



Photo credit: US Department of Veterans Affairs

As supply costs shift due to broader economic impacts or seasonal weather effects, a district energy facility can likewise adjust fuel choices to mitigate inflation or curtailment of supply. As customers seek alternative fuel solutions, converting a central plant from natural gas to biofuel may be much less capital intensive than converting hundreds of individual boilers in each customer building. As demonstrated by **District Energy St. Paul**, the scale of operations creates a robust market for local fuel resources like waste wood and other farm residues.⁴²

⁴² District Energy St. Paul. March 2018. *Connected for Good: 2017 Annual Report*. Available at <http://www.districtenergy.com/wp-content/uploads/2018/03/2017-Annual-Report.pdf>

Fuel Flexibility Provides Cost Savings and Resilience to Downtown St. Paul

- Location: St. Paul, MN
- Sector: Downtown Utility
- Energy Supplied: Hot water, chilled water, electricity

District Energy St. Paul operates the largest wood-fired CHP plant serving a district energy system in the Nation. It produces 65 MW of thermal energy and 25 MW of electricity for the local utility. In 2011, the system integrated the Midwest's largest thermal solar installation, which peaks over 1.2 MW and provides hot water and space heating to the Saint Paul RiverCentre and other customers. Fuel flexibility helps avoid market volatility and manage availability constraints. Biomass used in the plant is locally sourced from waste wood including, residual from manufacturing, construction waste, tree trimmings, and other sources, providing energy security and supporting the local economy.¹⁵



Photo credit: IDEA

Ability to Store Thermal Energy

The ability to store thermal energy contributes to the resilience of buildings connected to the district energy system and can support reliability of the overall electric grid. For example, large ice-storage thermal systems in **downtown Chicago and Houston** utilize low-cost, night-time electricity from nuclear generation to produce millions of pounds of ice storage in large tanks overnight.⁴³ The stored ice is melted the next day to provide chilled water district cooling service for air conditioning to over 110 large buildings in Chicago, displacing electricity demand when costs are peaking, and avoiding strain on the regional grid which may otherwise be susceptible to brown-outs.

Reduced Exposure to Outages with CHP and Microgrids

The aggregation of thermal loads from multiple buildings improves the economic viability of integrating CHP and incorporating microgrid functionality, which enhances energy resiliency. By introducing the capability to keep operating when the electric grid goes down, CHP and electric microgrids can help attract tenants seeking enhanced business continuity during outages, especially in high-rise office and residential towers served by elevators, which also improves the value of the properties served.

Hudson Yards in New York City, one of the most expensive private real estate developments in U.S. history, is an example of innovative and resilient energy design and planning that

⁴³ Enwave Energy Corporation. n.d. Locations. Available at <http://enwave.com/locations/>

incorporates a district energy microgrid with a 13.2 MW CHP system. A mini-grid of pipes and cables deliver primary heat, cooling and on-site power, offering utility service redundancy and greater efficiencies, which helps decrease energy costs and improve tenant comfort and convenience. Developers of the project at Hudson Yards describe the role of the district energy and CHP systems in achieving cost-effectiveness, resilience, and efficiency priorities: “We’ve created a network throughout these rail yards that transfers hot water and chilled water from the central plants to the buildings...[A]nd that allows us to share the efficiencies of this larger cogeneration plant.”⁴⁴

Systems such as the one at Hudson Yards are designed to meet day-to-day energy needs, in parallel with the local electricity grid. However, when the local grid is impaired or under strain, CHP microgrids can be designed to “island” and separate from the grid to supply the buildings in the district energy network. In many cases, resilient and reliable heating and cooling is equally important as electricity, especially when the end user is a data center, research laboratory or military facility.

The U.S. military has recognized the importance of resiliency and its connection to energy security objectives and uses district energy to improve operations. For example, the **Marine Corps Air Ground Combat Center Base at Twenty-Nine Palms, CA** is supported by an on-site district energy/CHP microgrid with 16.4 MW in CHP capacity and an 8.7 MW on-site solar PV system.⁴⁵ This key military microgrid optimizes efficient energy production and usage, saving taxpayer dollars and enabling continuous base operations even during events of grid interruption. Similarly, **Fort Bragg**, in North Carolina, one of the world’s largest military bases, has a district energy/CHP plant that enables the base to generate its power on-site and operate as a secure and independent power island as needed.⁴⁶

⁴⁴ Stabile, T. January 25, 2018. “Hudson Yards Emerges on West Manhattan Skyline”. ENR New York. Available at <https://www.enr.com/articles/43831-hudson-yards-emerges-on-west-manhattan-skyline>

⁴⁵ Morrisett, 2017.

⁴⁶ NC Clean Energy Technology Center. n.d. “Combined Heat and Power Plant at Fort Bragg Wins 2012 EPA CHP Award.” Available at <https://nccleantech.ncsu.edu/us-army-fort-bragg-wins-2012-epa-energy-star-chp-award/>

U.S. Army Enhances Mission Critical Operations with District Energy Microgrid

- Location: Fort Bragg, North Carolina
- Sector: Military
- Energy Supplied: Steam, chilled water, electricity

The district energy CHP microgrid system at Fort Bragg uses sophisticated controls and multiple sources of power to provide the high level of resiliency demanded by military operations. This series of controls and the software that helps manage the system allows energy to be delivered to buildings at optimal times and help maintain continuous power for mission critical operations. Overall, the microgrid provides annual cost savings of about \$1 million.⁴⁶



Photo credit: IDEA

Reduced exposure to outages helps avoid the resulting economic impacts that ripple through the economy, which can be significant. Whether the facility is a hospital that must serve its patients, or a manufacturing plant that cannot afford several days of downtime, major grid outages can be extremely costly for a business or organization. The economic research firm Moody's Analytics estimates Hurricanes Harvey and Irma combined will cost the U.S. \$20-30 billion in economic output, and Hurricane Maria could cost an additional \$40 billion in lost economic output due to impassable roads and remote locations losing power. Other studies have provided estimates for the economic impacts of grid outages from all sources at anywhere between \$20 billion and \$209 billion annually.⁴⁷

Protect Critical Infrastructure and Serve Communities during Outages

Government officials, policy makers, and disaster preparedness planners have become increasingly aware of the need to protect critical infrastructure facilities and to better prepare for energy emergencies. "Critical infrastructure" means systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.⁴⁸ These facilities deliver essential services and functions during natural disasters, emergency events, or grid outages, and district energy systems combined with CHP and microgrids can be configured to allow operations to continue uninterrupted at these sites.

⁴⁷ Campbell, R. August 28, 2012. *Weather-Related Power Outages and Electric System Resiliency*. Congressional Research Service (CRS). Available at <https://fas.org/sgp/crs/misc/R42696.pdf>

⁴⁸ 42 U.S. Code § 5195c

During Super Storm Sandy, when 8.1 million households in 21 states were without grid power, the district energy/CHP microgrids at **Princeton University**, **New York University** and **Co-Op City** in the Bronx maintained continuous power, provided heating and cooling services to their respective campuses, preserved critical research, and helped support displaced community members.⁴⁹ Buildings that were kept operational by CHP provided a place for meals, showers, and cell phone charging to families during the storm's aftermath. For example, Co-Op City's CHP plant kept the lights on for its more than 60,000 residents during and after Hurricane Sandy, while also providing needed power to the grid to assist Con Edison in re-starting nearby power stations.

V. Existing District Energy Market Status

In the United States, district energy systems are typically located on university or college campuses; on hospital or research campuses; military bases and airports; and in areas of dense building settings, often in the central business districts of larger municipalities. Most major U.S. cities have a downtown district heating or cooling system including New York, Boston, Philadelphia, San Francisco, Denver, Minneapolis, and dozens more. In some cases, the buildings connected to a district energy system are commonly owned, such as in a university campus or hospital setting. In others, the buildings have separate owners, such as in a central business district or segment of a municipality, and are interconnected individually to the distribution piping network. The number of buildings served by a district energy system can range from as few as 3 or 4 in the early stages of new system development to hundreds of buildings.

A district energy system has three major components: (1) a thermal energy generating plant, (2) a distribution system (piping), and (3) building interconnections (e.g., meters, valves, pumps).⁵⁰ Thermal energy is typically in the form of steam, hot water, and chilled water delivered at temperatures and pressures suitable for use by the heating and cooling systems of nearby, interconnected buildings. District energy systems can also provide electricity through the use of CHP or other technologies.

For heating, most district energy systems in the U.S. use steam to warm buildings and produce hot water. District hot water can also be used to deliver thermal services, which may bring greater efficiencies through lower distribution losses and has the ability to incorporate advanced energy options such as solar thermal and waste heat recovery from industrial processes and data centers. For cooling, most systems in the U.S. use chilled water distributed through closed loop networks that provide cooling services to buildings.⁵¹ However, cooling

⁴⁹ Oak Ridge National Laboratory (ORNL). 2013. *Combined Heat and Power: Enabling Resilient Energy Infrastructure for Critical Facilities*. Prepared by ICF. Available at https://www.energy.gov/sites/prod/files/2013/11/f4/chp_critical_facilities.pdf

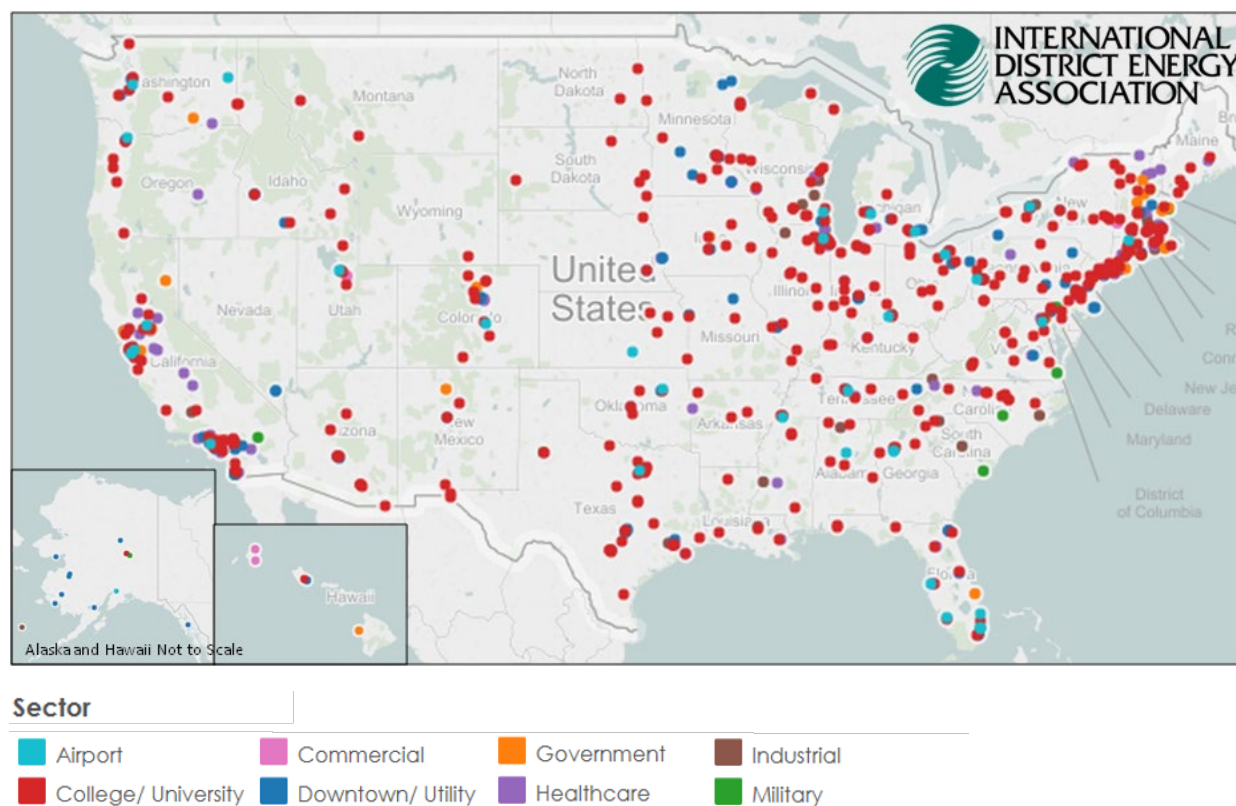
⁵⁰ Tredinnick, 2013.

⁵¹ EIA, 2018, p. 1.

can also be provided with steam, supplied through a district heating network and used to drive steam-turbine chillers or absorption chillers. For electricity, many campus systems operate as a microgrid, supplying power to a set of buildings from one or more electricity generation sources.

According to a recent estimate, there were more than 660 district energy systems operating in the U.S. in 2012, with installations in every state, providing heating to an estimated 5.5 billion square feet of floor space and cooling to 1.9 billion square feet of floor space.⁵² While there are no known district energy systems operating in Puerto Rico or other U.S. territories, there is significant policy activity related to developing microgrids and distributed generation to deliver more reliable and secure energy services. The majority of floor space served by district energy is located in commercial and institutional buildings across the country. Figure 3 shows the location of district energy systems throughout the U.S., categorized by the type of buildings served by the system.

Figure 3. Existing district energy systems in the United States



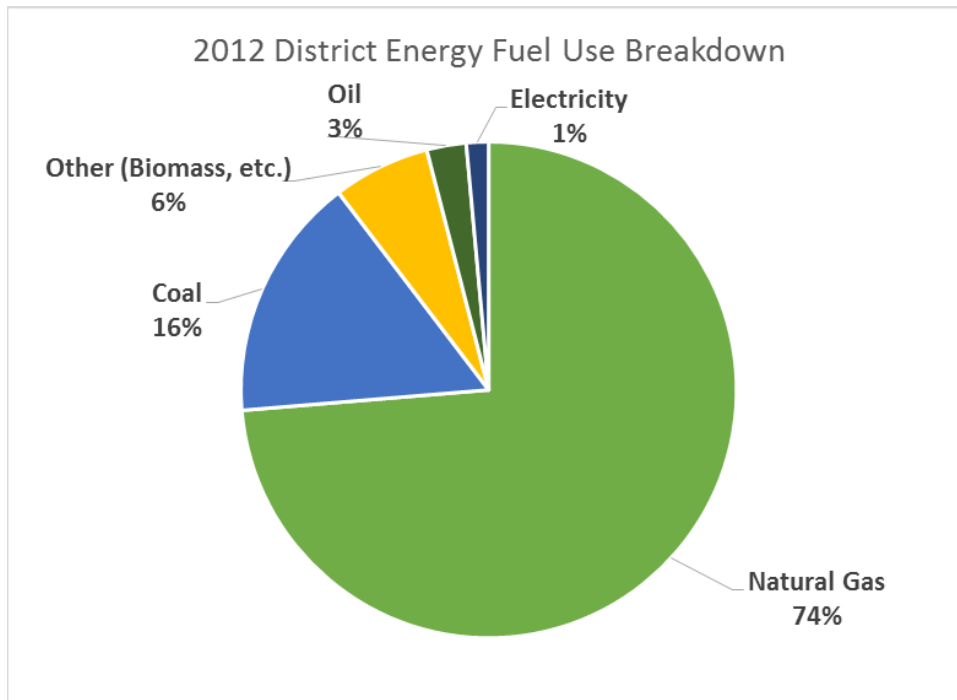
Source: International District Energy Association

These systems are characterized by a wide variety of technologies, fuels, energy services, ownership patterns, and operating responsibilities. Most systems are fossil fuel-based, with nearly three fourths fueled by natural gas (see Figure 4). However a number of other fuels can

⁵² Ibid.

be used in district energy systems including biogas, biomass, coal, fuel oil, electricity, geothermal, landfill gas, municipal solid waste, purchased steam, recovered heat, renewable cooling (lake or seawater), solar thermal, and wood waste from tree trimmings.⁵³ The 2012 fuel mix shown in Figure 4 is the latest year for which data is available and demonstrates the predominant use of natural gas, which is an abundant and affordable domestic energy source, and a significant use of biomass, which is a local energy resource that is often transformed from a waste stream to a productive fuel. The most commonly used biomass fuel is wood waste from wood products manufacturing facilities or forest residues.

Figure 4. Fuel Use in District Energy Systems in 2012



Source: U.S. Energy Information Administration

Recent Growth in the District Energy Market

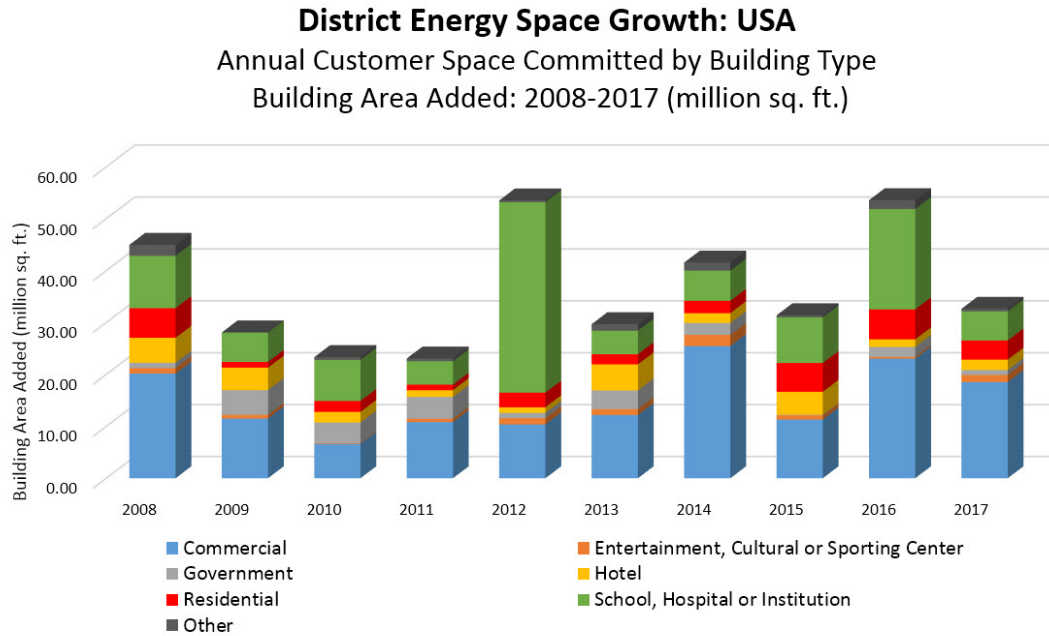
The market for district energy experienced growth over the last decade. Trends at all levels of community planning positively impacted the development of district energy networks and contributed to the expansion of end-use sectors that could be served by district energy systems. Major trends include continuing campus growth, increasing city sustainability initiatives, advancing of state renewable energy standards, and greater interest in increasing the resilience of our Nation's critical infrastructure. Figure 5 shows the breakdown of growth over the last ten years in building square footage served by district energy systems categorized by year of installation and building type.

Figure 6 shows growth in the number of buildings connected or committed to be served by district energy systems over the same period. 2012 and 2016 were peak years in terms of

⁵³ Ibid., p. 2

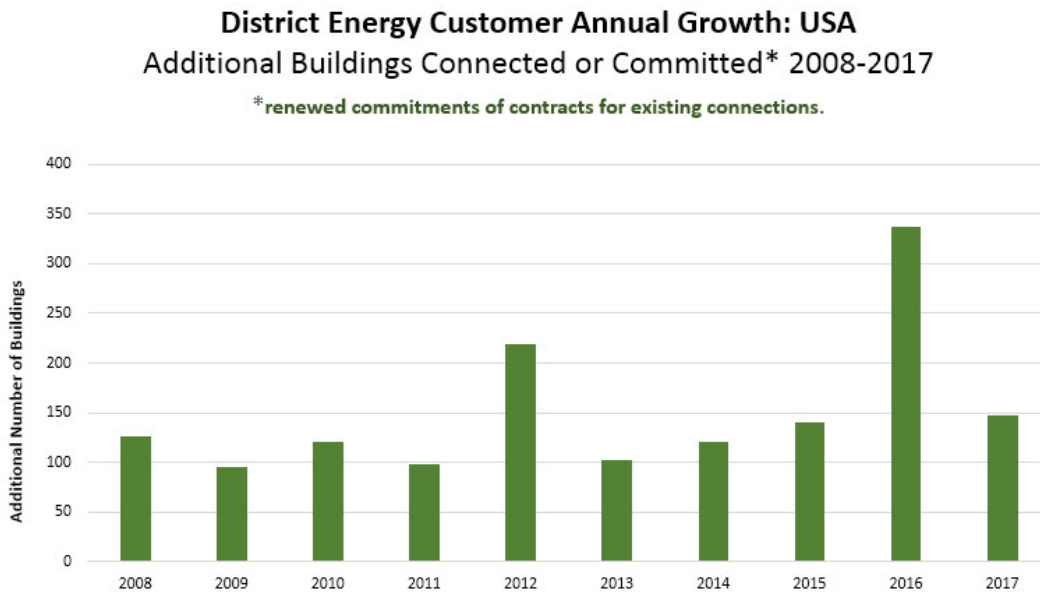
district energy growth, with the largest increases in commercial buildings and institutional buildings such as schools, universities and hospitals. Figure 7 shows the amount of cumulative growth in floor space that is served by district energy.

Figure 5. Increases in Annual Building Space (million square feet) served by district energy from 2008 – 2017



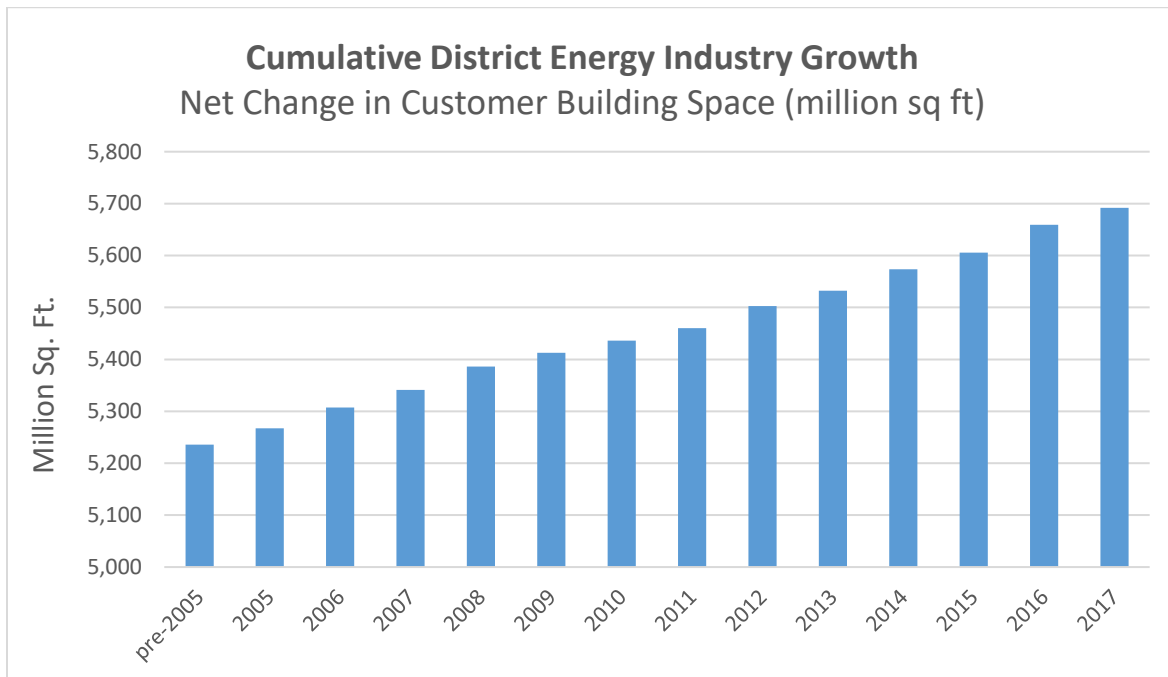
Source: International District Energy Association, May 2018

Figure 6. Number of buildings connected or committed to district energy systems from 2008 - 2017



Source: International District Energy Association, May 2018

Figure 7. Cumulative Growth in District Energy Served Floor space



Trends Impacting District Energy Expansion

Campus Growth

Campuses are expanding and adding on-site energy resources, such as CHP, and expanding district energy systems to support their growth and help reduce emissions, enhance energy security and resiliency, support mission-critical research, and achieve campus sustainability goals. This includes colleges and universities, healthcare campuses, and sites like airports and data centers, which have experienced increased investment and expansion in recent years. For example, **University of Texas at Austin**, one of the largest public universities in the U.S., has added 5 million square feet of building space over the past 15 years and has grown from 9 million square feet of building space to 17 million square feet since 1977.⁵⁴ The university's highly-efficient district energy and CHP plant has doubled the amount of power it produces to keep up with this campus growth, yet the plant uses the same amount of fuel today as it did in 1977.⁵⁵

⁵⁴ International District Energy Association (IDEA); U.S. Department of Energy (DOE). 2012. Project Profile: University of Texas at Austin, 137-MW CHP & District Energy System. Available at <https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=f0a1cfbb-7226-ee06-bfe4-0e06f39905b0>

⁵⁵ Ibid.

District Energy and CHP Help University of Texas Austin Keep Up with Campus Growth

- Location: Austin, TX
- Sector: College/University
- Energy Supplied: Steam, hot water, chilled water, electricity

As one of the largest public universities in the country, the University of Texas at Austin requires a reliable electricity and thermal energy supply for the research and student activities that take place in the 160 buildings and 17 million square feet of campus. The CHP district energy system provides the campus with highly efficient energy production, meeting those reliability needs while also allowing the campus to achieve carbon-neutral campus growth.⁵⁴



Photo Credit: The University of Texas at Austin

Increased Community Planning Initiatives

Many U.S. cities are undergoing a revitalization in their downtown districts which is leading to more urbanization and planning for sustainable growth. Cities and communities are pursuing net zero goals and exploring district energy and microgrids as part of their energy strategies. For example, the **City of Boston's** Climate Ready initiative identifies the development of district energy systems and microgrids as one of eleven strategies for increasing energy reliability and resilience in the city.⁵⁶ Additionally, the Boston Planning & Development Agency (BPDA) conducted a study in 2016, which identified 42 potential sites for district energy microgrids, with the potential to achieve more than \$1 billion in savings through lower energy costs and community benefits through emissions reductions.⁵⁷ As a result, the city is conducting feasibility assessments, cost-benefit studies, and piloting district energy microgrid projects.

Advancement of State Clean Energy Standards

Clean energy portfolio standards -- such as renewable portfolio standards (RPS), energy efficiency resource standards (EERS), and alternative energy portfolio standards -- set goals for clean energy deployment and promote the use of distributed energy technologies. As of July 2017, thirty (30) U.S. states have developed an EERS and 29 have a RPS.^{58,59} EERS and RPS goals

⁵⁶ City of Boston; Green Ribbon Commission. 2016. *Climate Ready Boston*. Available at https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf

⁵⁷ Boston Redevelopment Authority. 2016. *Boston Community Energy Study: Exploring the Potential for Local Energy Generation, District Energy, and Microgrids*. Available at <https://building-microgrid.lbl.gov/sites/default/files/2016-Boston-Community-Energy-Study.pdf>

⁵⁸ Durkay, J. August 1, 2017. "State renewable portfolio standards and goals." National Conference of State Legislatures. Available at <http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx>;

⁵⁹ U.S. Energy Information Agency (EIA). August 3, 2017. "Many states have adopted policies to encourage energy efficiency." Available at <https://www.eia.gov/todayinenergy/detail.php?id=32332>

typically set a percentage of energy to be supplied by energy efficiency or renewable energy, respectively, by a certain year. Some states include CHP in their portfolio standards due to its high efficiency or use of renewable fuels. Together, CHP and district energy can help provide a path to compliance for entities affected by these standards and, in some cases, benefit from payments for credits generated. Many existing district energy sites in the U.S. currently use renewable and/or local sources of primary energy to provide heating and cooling, while also enabling the integration of other renewable technologies, such as solar photovoltaics (PV) that provide additional electric generation.

Increasing The Resilience of Our Nation's Critical Infrastructure

“Critical infrastructure” means systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.⁶⁰ These facilities deliver essential services and functions during natural disasters, emergency events, or grid outages. District energy systems with CHP can be configured to allow operations to continue uninterrupted at critical infrastructure sites.

As an example, the Thermal Energy Corporation (TECO) that provides district energy services to the **Texas Medical Center in Houston** uses district energy and a 48 MW CHP system to produce chilled water and steam, which is piped underground to more than 19 million square feet of customer buildings at 18 institutions on the campus.⁶¹ In August 2017, when Hurricane Harvey caused massive flooding and damage in the Houston area, TECO’s natural gas-fueled CHP district energy system sustained a variety of energy services, including electricity, air conditioning, refrigeration, and heating, throughout the storm.⁶² Although several major storms during the 2017 hurricane season left millions without power, large mission-critical healthcare campuses like the Texas Medical Center and others were able to remain operational due to on-site CHP and district energy.

⁶⁰ 42 U.S. Code § 5195c

⁶¹ Thermal Energy Corporation (TECO). n.d. *About TECO*. Available at <http://tecothermalenergy.com/about-teco/>

⁶² U.S. Department of Energy (DOE). September 8, 2017. “CHP Installation Keeps Hospital Running During Hurricane Harvey.” Available at <https://www.energy.gov/eere/amo/articles/chp-installation-keeps-hospital-running-during-hurricane-harvey>

TECO Converts to CHP for Enhanced Resilience and Reduced Energy Use

- Location: Houston, Texas
- Sector: Healthcare
- Energy Supplied: Steam, chilled water, electricity

Thermal Energy Company (TECO) has been serving the thermal energy needs (heating, cooling, domestic hot water, etc.) of the Texas Medical Center, the largest medical center campus in the world, since 1968. In order to meet the high resiliency requirements of their customers, a 48 MW CHP system was added to the system in 2010. In 2017, TECO maintained continuous operations throughout the severe weather and record flooding from Hurricane Harvey and its aftermath.⁶¹



Photo credit: IDEA

District energy networks configured with CHP, or district cooling systems, can also be optimized to deliver services needed to balance and support stability of the electric grid, especially during peak times of day or days when load is high due to extreme temperatures. For example, the district energy system anchored by CHP at **Princeton University** enables the campus to significantly reduce its electric demand and manage its peak load contribution, which lowers the campus' electricity costs and alleviates stress on the grid at times when it is most constrained.⁶³ Under normal operating conditions, during the hotter summer months, the Princeton campus has a peak electric demand of approximately 27 MW.⁶⁴ By efficiently operating their CHP system, utilizing thermal storage, optimizing on-site solar generation and managing energy loads, the Princeton microgrid has reduced campus demand on the grid to under 1 MW during peak conditions.⁶⁵ This reduces strain on the regional electricity distribution grid, cuts emissions from peaking units, and avoids causes for brown-outs or black-

⁶³ Environmental and Energy Study Institute (EESI). September 2011. Fact Sheet: What is District Energy? Available at https://www.eesi.org/files/district_energy_factsheet_092311.pdf

⁶⁴ Borer, E. 2013. Energy Efficiency Infrastructure for More Resilient Local Economics: Princeton University Campus Microgrid. Available at www.princeton.edu/~jvickers/Borer_microgrid.pdf

⁶⁵ Davis, P. July 31, 2017. "Can a district energy system help to keep your electricity rates low? It does at Princeton University!" International District Energy Association (IDEA). Available at <https://www.districtenergy.org/blogs/paige-davis/2017/07/31/can-a-district-energy-system-help-to-keep-your-electricity-rates-low-it-does-at-princeton-university>

outs, thus strengthening the local economy.⁶⁶ The Princeton University microgrid is a model for campuses, military bases, industry and large clusters of buildings.

Princeton University Integrates Solar, CHP, and Thermal Storage to Increase Campus Resilience

- Location: Princeton, New Jersey
- Sector: College/University
- Energy Supplied: Steam, chilled water, electricity

Princeton University operates an innovative CHP-based microgrid that serves approximately 150 buildings. It includes a 15 MW CHP system, 4.5 MW of on-campus PV, 20,000 tons of chilled water capacity, a large chilled water thermal storage tank, and a sophisticated controls optimization program. Integrating and optimizing these technologies helps save over \$2 million per year in operating expenses, reduces emissions and supports mission-critical research housed on campus.^{63,66}



Photo credit: IDEA

International District Energy Markets

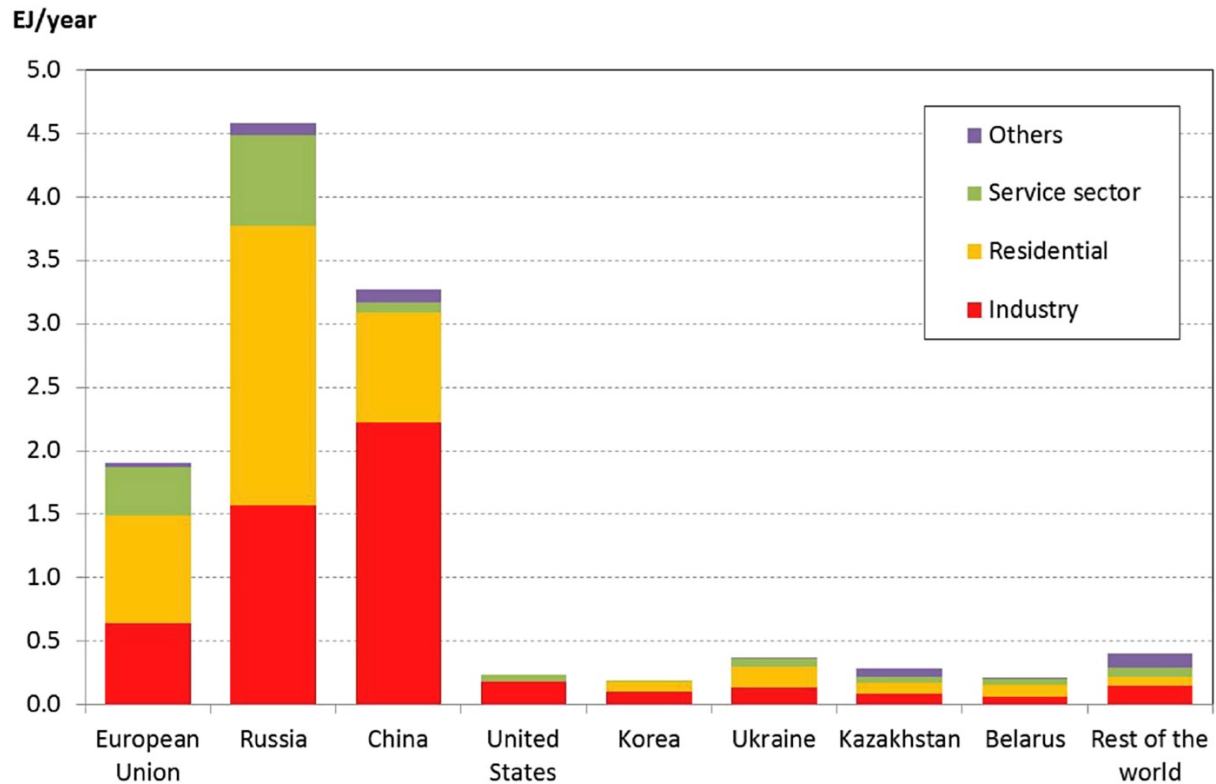
District energy networks in some countries meet a larger portion of the demand for heating and cooling than in the U.S., driven by a variety of factors, such as climate, history, infrastructure development, and population density. While the first commercial district heating systems were established in the U.S., according to the International Renewable Energy Agency (IRENA), countries such as Denmark, Poland, Germany, and China, use district energy to meet more of their overall share of heating demand than the United States.⁶⁷ Figure 8 shows an estimate of heat delivered by district energy systems worldwide in 2014.

⁶⁶ Wachtman, E. February 2015. Princeton Energy Plant Operations Best Practices. IDEA Conference, Denver. Available at

<https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=dd1412ab-2642-dd0b-ab0a-35717188f069&forceDialog=0>

⁶⁷ International Renewable Energy Agency (IRENA). 2017. *Renewable Energy in District Heating and Cooling: A Sector Roadmap for Remap*. Available at <http://www.irena.org/publications/2017/Mar/Renewable-energy-in-district-heating-and-cooling>

Figure 8. Heat deliveries in various regions and countries during 2014



Source: Werner 2017

The first European systems were introduced in Germany in the 1920s and the planned economies of the Soviet Union and China introduced district heating in the 1930s and 1950s, respectively. In former Soviet states and across northern Europe, the use of district energy is now widespread and much of the existing building stock, including residential, is connected to district heating networks. After World War II, district energy was an integral component of reconstruction efforts and European planners focused on hot water distribution systems for district heating, which helped reduce their dependence on imported fuels, and controlled air quality and reduced pollution in planned communities. Today, major cities such as Moscow, St. Petersburg, Beijing, Kiev, Seoul, Warsaw, Berlin, Hamburg, Helsinki, Stockholm, Copenhagen, Paris, Prague, Sofia, Bucharest, Vienna, and Milan have district heating systems. The total number of district heating systems worldwide is estimated to be 80,000 systems, with about 6,000 systems in Europe.⁶⁸

District heating has not been as widely applied in the United States as in Europe due to differences in infrastructure development and institutional issues. Europe, constrained by geographic limits, is comprised largely of dense urban areas closely surrounded by power plant and industrial development, which naturally support the application of district energy. However, central station power plants and manufacturing areas in the U.S. are generally

⁶⁸ Frederiksen, S.; S. Werner. 2013. District Heating and Cooling. London, UK: Majestic Books.

located at significant distances from urban centers. In addition, most U.S. buildings are conceived, designed and constructed by individual developers who rarely consider the energy characteristics of surrounding buildings. U.S. codes and design protocols have traditionally addressed energy use at a single building, rather than on a community scale, and private utilities in the U.S. reinforce this approach through their focused marketing of electric or natural gas service. This trend is beginning to change in the U.S. with the growing recognition by industry, through standards like LEED Version 4, that aggregating the energy needs of multiple buildings more holistically facilitates deployment of more efficient and resilient systems.⁶⁹

Early district cooling systems were established in Hartford, Connecticut in 1962, Hamburg, Germany in 1967, and the La Defense district outside Paris in 1967. Major district cooling systems are now found in cities such as Singapore, Tokyo, Stockholm, Paris, Dubai, Chicago, Toronto, Helsinki, Barcelona, Vienna and Berlin. The United States is among the countries with the most district cooling capacity, driven primarily by the development of downtown district systems providing chilled water. Since 1990, over 40 new downtown district cooling systems have been developed in U.S. cities. The use of district cooling in hot climates is growing fast, and the United Arab Emirates uses district cooling to meet more than a fifth of its cooling load. This can be attributed to that country's desert climate and an emphasis on smart building solutions, focus on energy efficiency planning, and unified building codes. The Dubai Supreme Energy Council and Dubai Electricity and Water Authority have announced plans to double the capacity of district cooling networks in Dubai by 2030.⁷⁰

Economies of scale and increased efficiency have made district energy an affordable option for heating and cooling urban areas in cities around the world. While most existing systems rely on fossil fuels such as coal and natural gas, some have already shifted toward the use of renewable fuels. Renewable fuels provide over 40% of district heating sources in Denmark and Switzerland, primarily through the use of waste heat and biofuels, with more limited roles for geothermal and solar thermal.⁷¹ Furthermore, several countries with high deployment of wind and solar power – such as China, Denmark and Germany – have begun using district heat systems to utilize excess renewable electricity during periods of oversupply, which reduces the need for curtailment.⁷² Surplus power is used to heat water, either with heat pumps or directly

⁶⁹ LEED v4 is the latest version of Leadership in Energy Environment Design standard which addresses thermal, visual, and acoustic comfort as well as indoor quality.

⁷⁰ Dubai Electricity & Water Authority. June 18, 2017. "Supreme Council of Energy reviews projects, initiatives, and strategic programmes to improve energy efficiency in Dubai." Available at <https://www.dewa.gov.ae/en/about-dewa/news-and-media/press-and-news/latest-news/2017/06/supreme-council-of-energy-reviews-projects-initiatives-and-strategic-programmes>

⁷¹ Ibid.

⁷² United Nations Environment Programme. 2015. *District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy*. Available at <http://districtenergyinitiative.org//report/DistrictEnergyReportBook.pdf>

using resistance heaters to store hot water for later use. A region in China with significant installed wind capacity and considerable heating needs is experimenting with wind-to-heat, using 50 MW of electric boilers, to reduce curtailment of wind power and avoid harmful emissions. In the United States, there is potential to expand the use of renewable energy in district energy networks with policy changes and targeted investment.⁷³

There is growing interest in eco-industrial parks in Europe, China and countries in Asia and Africa. Under such arrangements, businesses cooperate with each other and with local communities to reduce waste and pollution, to efficiently share resources including materials, water and district energy, and to help achieve sustainable development. Also known as industrial symbiosis, eco-industrial parks incorporate collaborative strategies such as by-product synergy (the waste from one entity is used as the raw material for another), wastewater cascading, shared logistics, and district energy. One of the earliest examples of this approach is located in Kalundborg, Denmark where an eco-industrial network links a 1,500 MW coal-fired power plant with the community and a number of private companies. Surplus heat from the power plant is used to heat 3,500 local homes in addition to a nearby fish farm, whose sludge is then sold as a fertilizer. Steam from the power plant is sold to a pharmaceutical and enzyme manufacturer and to an adjacent refinery. Additionally, a by-product from the power plant's sulfur dioxide scrubber, gypsum, is sold to a wallboard manufacturer in the park.⁷⁴

VI. Challenges to District Energy Implementation

Despite the benefits offered by district energy systems, there are still many challenges associated with their development. These challenges can occur at any stage of the project lifecycle, but most will hinder progression early in the process, resulting in dormancy or even cancellation of an installation. Many of these challenges may hinder potential projects before they even begin. While not every prospective district energy system will face each of these barriers, the challenges listed below are the most common issues that arise during project development. The challenges can be considered under three categories: economics, technical, and education.

⁷³ According to IRENA's 2017 study aimed at accelerating the use of renewable energy in district energy, the share of renewables in district heating could rise to 36% by 2030. Natural water and solar cooling could contribute 14% and 22% of total district cooling demand, respectively (p.5).

⁷⁴ National Academy of Engineering (NAE). 1997. *The Industrial Green Game: Implications for Environmental Design and Management*. Washington, D.C.: National Academy Press. Pp. 117–123.

Economics

Access to Capital

District energy projects may falter and never move beyond the initial conceptual stage, due to lack of early stage funding support and perceived risk/return assessment. Without access to the capital needed to begin a new project, facilities may choose to ignore district energy as a viable option and instead pursue smaller, individual building systems to meet their energy or cost reduction needs. Furthermore, with higher initial costs and potentially extended payback periods, many facilities may lack the incentive to proceed with district energy deployment following the initial feasibility study. Private funding sources often need to generate rates of return that exceed early stage returns from an infrastructure level investment. Even for well-scaled opportunities, the private sector often faces limitations on their investment approaches due to target rates of return, risk analysis, and competing opportunities for capital. Access to adequate early stage capital or risk financing is especially important for municipal or public sector district energy projects to advance beyond feasibility studies into the design and pre-construction phase.

Availability of Local Financing

Cities and towns often lack the available funds to carry a district energy project through the development process. Some localities have addressed this challenge by offering financing options, such as low-cost loans or bonds. For example, **St. Paul, Minnesota**, issued long-term revenue bonds to develop its heating and cooling networks and the city avoided having to guarantee debt repayments. Initial customers of the district energy system signed long-term contracts, which served as a form of collateral. Project financing has a high due-diligence cost and is best suited to mature markets or in combination with district energy customer connection guarantees. A city's issuance of bonds can be an important factor for decisions by Federal, state and private investors, who look to municipal support as a key indicator of city priority and capacity for fostering district energy.

Electricity Sales and Regulatory Restrictions

Even if a developer or municipality has the capital to move forward with a district energy system, many states and other localities have regulations in place that do not allow the sale of electricity to multiple customers by non-utility entities. Even though the district energy system can competitively provide thermal energy to multiple buildings, any electricity generated by the system may not be able to be sold directly to customers, and can only be sold under a power purchase agreement at marginal rates to the incumbent utility. More transparent rate design, reformed regulatory conditions and more electricity market access could improve the economics of a potential district energy/CHP project and stimulate more industry growth. Not only would the district energy/CHP system produce two forms of useful energy from one fuel, but would also have two revenue streams (heat and electricity) to support the investment.

Energy Cost Savings Margin

Many areas of the United States have low energy costs relative to other expenses that businesses incur. As the margin of cost savings declines relative to existing energy consumption, facilities are less inclined to pursue energy efficiency options, including district energy. These investments may be deemed unnecessary, as lower energy prices can lengthen payback periods and reduce the amount of long-term savings for customers served by a district energy system.

Technical*Changing Electric Grid*

As the U.S. electric grid continues to see increased penetration of renewables and distributed generation, stakeholders are unsure of the long-term role that current technologies and fuels will play. The trend of increased distributed energy generation, like solar PV, may impact the utility business model and change investment approaches for electricity distribution and transmission system assets. While some segments of the electricity industry support more electrification, there is a need for continued assessment and consideration of thermal energy for heating and cooling of buildings. In certain regions of the country, there may be growing market risk for thermal energy supply as a competitive offer, especially as electrification is pursued vigorously. But in market settings like central business districts, campuses, military bases, mixed-use development communities with appropriate levels of energy density, mission-critical energy needs, and end-user proximity to district energy/CHP resources, the balancing advantages of district thermal energy are likely to continue to be competitive. As the push toward electrification continues, consideration of the value of efficient thermal energy will need to evolve and be evaluated against multiple metrics including resiliency, energy efficiency, carbon intensity, reliability, convenience, level of comfort, aesthetics, price volatility, and life cycle operational risks.

Difficulty of Retrofitting District Piping

Although the downtown areas of cities and college campuses are ideal candidates for district energy, there is typically already infrastructure like roads, sidewalks, and building foundations in place that may be decades old. With so much existing infrastructure in place at these locations, it can be disruptive and expensive to install new underground piping for a district energy system. In addition, the repair of the system can be costly given the location of the pipes under streets, buildings or other impediments. Moreover, if the incumbent district energy company already serves a significant portion of customer buildings in the urban market, there may be limited market potential for incremental revenue from which to fund a capital investment or renewal project.

Need for Advanced Controls

Although district energy systems have been around for over a hundred years, there is significant room for improvement of their operation using advanced control systems. Research and development could help design systems that optimize the flow of thermal energy to

customers as well as integrate the operation of district energy and thermal storage to the electric grid. District energy can change a customer's electric demand curve and integrate control systems that can enable district energy systems to react to grid needs and provide additional economic value to customer sites.

Education

Building Owner Awareness

Many building owners, facility managers, municipal planning departments, and policymakers are not aware of the advantages of district energy. Awareness of the potential for district energy is often absent given that it is largely underground infrastructure and lacks the visibility of alternative energy technologies like wind and solar. Cities and towns typically lack the internal capacity and expertise necessary to explore the potential for district energy, CHP, and microgrids as part of their urban infrastructure development and transportation planning efforts. Opportunities to integrate smart, efficient, sustainable and resilient energy solutions are often missed in the planning stages due to the lack of critical expertise and information.

Moreover, developing a district energy system involves technical, engineering, permitting, legal, financial and regulatory matters and can be a complex undertaking, requiring a dedicated project champion who will persistently pursue the respective milestones in the development lifecycle.

Policymaker Awareness

In the US, there currently are no Federal policies that directly support deployment of district energy systems, however there are examples at the state and local levels. States including California, Connecticut, Idaho, Louisiana, Maryland, Vermont and Washington have enacted specific policies and regulations to broadly encourage more deployment of district energy systems, thermal energy systems, and CHP. Examples of these policies are summarized in Table 3.

Table 3. Example state district energy policies

State	Year	Policy
California	2007	<i>Waste Heat and Carbon Emissions Reduction Act</i> , which establishes state programs to support and facilitate both customer- and utility-owned CHP systems. ⁷⁵
Connecticut	2018	<i>Public Act No. 18-180</i> , which requires the consideration of creating a portfolio standard for thermal energy in the next integrated resource plan. ⁷⁶

⁷⁵ California State Legislature. October 14, 2007. Energy: Waste Heat and Carbon Emissions Reduction Act. AB-1613. Available at http://leginfo.ca.gov/faces/billNavClient.xhtml?bill_id=200720080AB1613

⁷⁶ Connecticut General Assembly. June 14, 2018. An act requiring the consideration of creating a portfolio standard for thermal energy in the next integrated resources plan. Public Act No. 18-180. Available at https://custom.statenet.com/public/resources.cgi?id=ID:bill:CT2018000H5348&ciq=ncsl29e&client_md=f272386a25a9fbf889b780d169f0d80f&mode=current_text

Idaho	2010	<i>Senate Bill No. 1354</i> , which relates to the development of thermal energy systems by school districts. ⁷⁷
Louisiana	2012	<i>House Resolution 167</i> , which sets guidelines for equipping critical government facilities with CHP if expected energy savings exceed expected costs. ⁷⁸
Maryland	2013	<i>Thermal Energy - Task Force and Regulations</i> , which creates the Thermal Energy Task Force to analyze and recommend changes to incorporate thermal energy into the renewable portfolio standard. ⁷⁹
Vermont	2018	<i>No. 102. An act relating to thermal efficiency monies and biomass-led district heat</i> , which authorizes funds for thermal energy and process fuel efficiency to district heat if it meets certain requirements. ⁸⁰
Washington	2015	<i>An act relating to promoting thermal energy efficiency</i> , which requires consideration of CHP in new critical governmental facilities, incorporates reports on CHP in integrated resource plans, and streamlines the permitting process for CHP. ⁸¹

In addition, several states allow district energy systems that use CHP to contribute to a renewable portfolio standard or alternative portfolio standard, which set goals for clean energy deployment and promote the use of distributed energy technologies.⁸² For example, the Massachusetts Green Communities Act of 2008 created a policy platform for an Alternative Energy Portfolio Standard that rewards thermal energy recovered from CHP as qualifying for a Tier II credit. The policy has enabled implementation of district energy CHP projects at several

⁷⁷ Legislature of the State of Idaho. 2010. An act relating to development of thermal energy systems by school districts. SB 1354. Available at <https://legislature.idaho.gov/wp-content/uploads/sessioninfo/2010/legislation/S1354.pdf>

⁷⁸ Louisiana House of Representatives. June 1, 2016. A resolution to urge and request the Dept. of Natural Resources, with the Public Service Commission, to adopt rules and regulations to ensure high levels of energy security in critical government facilities through implementation of on-site combined heat and power systems. HR 167. Available at <https://legiscan.com/LA/text/HR167/2012>

⁷⁹ Maryland General Assembly. May 2, 2013. An Act concerning Thermal Energy – Task Force and Regulations. SB 797. Available at <https://legiscan.com/MD/text/SB797/id/843170>

⁸⁰ Vermont General Assembly. April 17, 2018. An act relating to thermal efficiency monies and biomass-led district heat. HB 616. Available at https://custom.statenet.com/public/resources.cgi?id=ID:bill:VT2017000H616&ciq=ncsl29e&client_md=b945fd8f14f5285945bcb84ef88f1281&mode=current_text

⁸¹ Washington State Legislature. October 9, 2015. An Act Relating to promoting thermal energy efficiency. HB 1095. Available at https://custom.statenet.com/public/resources.cgi?id=ID:bill:WA2015000H1095&ciq=ncsl29&client_md=665af3b575e6c7c56c45c99decaf92fe&mode=current_text

⁸² For more information on states with portfolio standards that specifically include CHP (e.g., fossil-fueled CHP, waste heat to power, or where renewable fuels for CHP such as biomass, biogas, and landfill gas are eligible), see EPA's CHP Policies and Incentives Database: <https://www.epa.gov/chp/dchpp-chp-policies-and-incentives-database>

state institutions including University of Massachusetts Amherst, UMASS Medical Center, and Tufts University.^{83,84,85}

Local governments can play diverse roles in advancing district energy systems as planners and regulators, facilitators of finance, and as providers of infrastructure and services.⁸⁶ Several municipalities in Massachusetts have implemented plans and policies that foster development of district energy. The City of Cambridge's Low Carbon Energy Supply Strategy identifies energy solutions by zoning densities and specifically identifies district energy as a preferred technology to increase efficiency, enhance resiliency and reduce emissions.⁸⁷ The City of Boston's Planning and Development Agency Board implemented a Smart Utilities Policy that includes guidelines for private developers to incorporate smart utility technologies into new developments, including district energy microgrids.⁸⁸

No Established Business Plans For Multi-User Microgrids

Although microgrids are an established application of distributed generation, they often involve a single user, such as a hospital or university. For district energy systems designed to provide thermal energy and electricity to several different customers, as in a downtown loop, industry standards and best practices for developing multi-user agreements are needed. This includes business plans and regulatory guidance that addresses the ability to sell electricity, and resources to help conduct outreach and engagement with real estate developers, property managers, and local government agencies in developing microgrids that can realize new revenue streams.

Cross-cutting

Infrastructure/Customer Sequencing

Solid technical planning and engineering practices are essential to the successful deployment of a district energy system. Of equal importance are economic and financial structures to underpin a sustainable business model with appropriate governance models. When a developer or municipality must attract adequate anchor customers and then capture and retain a viable customer base, the business model or plan must have transparent and competitive rate

⁸³ UMASS Amherst, Facilities & Campus Services. n.d. Physical Plant. Available at <https://www.umass.edu/physicalplant/utilities-0>

⁸⁴ Cohen, M.; B. Goodchild. 2011. "Jet engine will drive expanded campus power plant." UMass Medical School Communications. Available at https://www.umassmed.edu/news/articles/2011/jet_engine_drives_campus/

⁸⁵ Tufts University, Operations Division. n.d. Central Energy Plant (CEP). Available at <https://operations.tufts.edu/construction/central-energy-plant-cep/>

⁸⁶ United Nations Environment Programme (UNEP). 2015. District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy. Available at <http://districtenergyinitiative.org//report/DistrictEnergyReportBook.pdf>

⁸⁷ City of Cambridge. April 2018. *Low Carbon Energy Supply Strategy*. Available at http://www.cambridgema.gov/~media/Files/CDD/Climate/NetZero/LCESS/lcessexecutivesummary_webversion.pdf?la=en

⁸⁸ Boston Planning & Development Agency (BPDA). June 14, 2018. Boston Smart Utilities Project. Available at <http://www.bostonplans.org/planning/planning-initiatives/boston-smart-utilities-project>

structures and adequate capital and cash flow to fund the enterprise and attract sufficient financing to support system growth. Additionally, a potential district energy system will have to determine infrastructure buildout and system sizing based on estimations and projections of customer needs, without a guarantee of those sales.

VII. Opportunities for Improvement in Energy Efficiency And Security

Opportunities for Future Energy Efficiency Gains

District energy networks can maximize efficiency in a variety of ways, using new or emerging technologies such as steam to hot water conversions, introducing renewable fuels or waste heat recovery, and improved operations and maintenance. The potential for future efficiency gains may come from replacement or retrofit of existing equipment with newer, more advanced equipment that is more efficient, such as higher efficiency burners and condensing economizers for boilers and the use of variable speed drives, advanced controls, and magnetic bearing compressors for chillers. Reductions in distribution system losses can also be made as system operators continue to replace steam traps, insulate pipes, replace condensate lines, and make other enhancements to reduce losses.⁸⁹

Low Temperature District Energy System Conversions

One of the technical opportunities for greater efficiency in district heating networks is converting systems from steam to hot water or from high temperature water to lower temperature water systems. Steam based district heating networks are increasingly regarded as older technology with respect to distribution line losses and maintenance costs. Many current district heating systems operate at temperatures of 212°F or above and have pre-insulated pipes, use traditional heating plants as well as some industrial waste heat where available, and rely on metering and monitoring to optimize heat delivery. One goal for future district energy systems is to transition to lower temperature networks, which operate around 140°F, integrate two-way district heating and cooling, and use sophisticated energy management systems to optimize supply, distribution, and consumption.⁹⁰

The benefits of low temperature district heating include lower distribution losses, higher production efficiencies and availability to utilize surplus heat supplies such as heat rejected from data centers. With low temperature district heating, more of the available waste heat from CHP systems can be recovered and utilized, resulting in higher CHP thermal efficiencies. Low temperature systems can use plastic piping, which can be more cost effective than

⁸⁹ Ibid, p. 40 – 44.

⁹⁰ C40, 2016, p. 6.

conventional district heating metal based pipes. The use of low temperature heat allows the integration of additional heat sources such as solar thermal collectors, deep geothermal wells, and low temperature waste heat.⁹¹ The use of locally available, renewable, or waste heat energy sources promotes price stability, and the high overall system performance achieved by using low temperature district energy leads to reduced resource consumption and lower costs for energy services. For example, **Amazon's Headquarters campus** in downtown Seattle relies on a district energy system to heat its office space by capturing low temperature waste heat from a nearby data center and recycling it through underground hot water pipes, which replaces the need for Amazon to purchase close to 4 million kWh each year.⁹²

Energy Sharing with Amazon's District Energy System

- Location: Seattle, Washington
- Sector: Corporate Campus
- Energy Supplied: Hot water

The 60,000 square foot data center at the Westin Building Exchange in downtown Seattle, which houses equipment serving more than 250 telecom and Internet companies, generates enough waste heat from cooling its servers to provide the space heating for Amazon. The central plant for the district energy system is located in Amazon's Doppler Tower. As Amazon expands, the company plans to use district energy at future campuses. District energy was included in the 2017 request for proposal for Amazon's second corporate headquarters (HQ2).⁹²

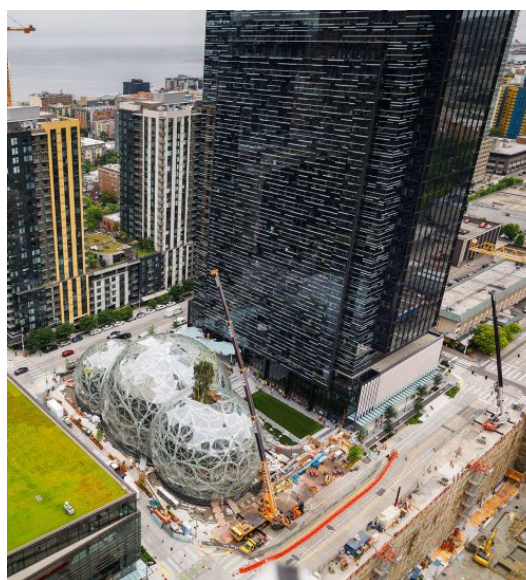


Photo credit: JORDAN STEAD / Amazon

Thermal Energy Storage

Another key way that district energy systems can maximize efficiency is through thermal energy storage. Thermal energy storage enables heating or cooling demand to be shifted by hours, days or even months, thereby smoothing the demand profile and enabling thermal services to be supplied in the most cost-effective and affordable way. Excess energy production from intermittent renewables can be stored and used later during peak thermal demand periods.

⁹¹ Schmidt, D. et al. 2017. *Low Temperature District Heating for Future Energy Systems*. Amsterdam, NL: Science Direct. Energy Procedia, Elsevier. 116. Available at <https://www.sciencedirect.com/science/article/pii/S1876610217322592>

⁹² Roberts, D. November 22, 2017. "Amazon's Seattle campus is using a data center next door as a furnace. It's pretty neat." Vox. Available at <https://www.vox.com/energy-and-environment/2017/11/22/16684102/amazon-data-center-district-heating>

Thermal storage leads to increased flexibility of system operations and flexible infrastructure leads to district energy networks that are able to expand over time and utilize different energy sources.⁹³

Equipment Technology Improvements

Since district energy technology has been around for over 100 years, there are a large number of older systems in operation. System renewal, or the upgrading of boilers, chillers and cooling towers with the newest and most highly efficient equipment can bring significant efficiency gains to an already highly efficient fleet of district energy systems. Including equipment such as flue gas heat recovery systems and variable speed drives is another way to cut both fuel and water usage. In addition, as heating and cooling technologies continue to advance, there are opportunities to increase the efficiency of the industrial sized equipment that serve district energy systems. These increases can be generated through research and development efforts by equipment suppliers, or they can be the result of needing to comply with stricter efficiency codes and standards.

Incorporating Efficient CHP Systems and Community-Based Microgrids

Not every district energy system currently uses CHP; however, combining district energy with a CHP system can be a unique opportunity to increase energy efficiency, providing both thermal and electrical power to meet the energy needs of multiple buildings. A 2016 study of technical potential for additional CHP at existing district heating plants identified 10.6 GW of CHP generating capacity as technically feasible at 64 existing district energy loops across the Nation.⁹⁴ Incorporating CHP and generating electricity on-site also facilitates the configuration of microgrids, which further enable greater efficiency through optimized operations and management of building energy loads.

Advanced Metering, Monitoring and System Optimization

Even the most efficiently designed energy systems will not achieve high energy performance standards if they are not operated correctly. Energy metering and monitoring equipment is needed to operate the system efficiently and in recent years there has been a significant increase in the capabilities and availability of advanced metering and monitoring technology. This technology advance allows for optimization of district energy systems in ways that were not envisioned even in the recent past. It is necessary to have an energy management system that continuously monitors customer loads and responds dynamically by adjusting output at the central plant or of multiple distributed energy resources. As more district systems upgrade to advanced management systems, the efficiency of district energy services will continue to rise.

⁹³ UNEP, 2015.

⁹⁴ U.S. Department of Energy (DOE). 2016. *Combined Heat and Power (CHP) Technical Potential in the United States*. Prepared by ICF. Available at <https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%2031-2016%20Final.pdf>

Distribution System Improvements

Converting high temperature district heating systems to low temperature hot water systems can result in significant gains in distribution system efficiency. Low temperature hot water systems experience significantly less heat loss from the distribution piping due to a lower temperature difference between the hot water and the surrounding environment. As noted earlier, low temperature hot water systems also enable heat recovery from lower temperature heat sources such as solar thermal and data centers. Potential efficiency improvements can also be realized with pipe restoration through re-insulation of piping and incorporation of insulating condensate receivers. In certain campus settings, the distribution network enables installation of lower-cost plastic piping to reclaim water from HVAC air handler and coil drip pans, returning this water to the central plant for reuse. Through its district energy system and other alternative water uses, the **University of Texas at Austin** recovered over 100 million gallons in 2016 to displace consumption from the municipal water utility.⁹⁵

Trends Impacting Potential for Energy Security Gains

Weather related disruptions, aging electric infrastructure, fuel supply volatility, and other trends contribute to a greater need for secure, reliable, and resilient energy infrastructure and the potential for district energy to meet those needs.

Increased Outages and Severe Weather Events

Communities across the country were impacted by 16 separate billion-dollar weather-related disaster events in 2017, leading to an increased need to protect against the risks of power outages.⁹⁶ This is coupled with national trends that indicate more prevalent electricity system outages (Figure 9), which are most often caused by weather-related events, as shown in Figure 10.⁹⁷

⁹⁵ The University of Texas at Austin Utilities and Energy Management. n.d. Water Conservation Efforts. Available at <https://utilities.utexas.edu/efficiency/water-conservation-efforts>

⁹⁶ Smith, A. January 8, 2018. "2017 U.S. billion-dollar weather and climate disasters: a historic year in context". National Oceanic and Atmospheric Administration. Available at <https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year>

⁹⁷ U.S. Department of Energy (DOE), Office of Cybersecurity, Energy Security, and Emergency Response. n.d. *Electric Disturbance Events (Form OE-417)*. Available at <https://www.energy.gov/ceser/activities/energy-security/monitoring-reporting-analysis/electric-disturbance-events-oe-417>

Figure 9. Number of US Electric System Disturbance Events from 2000 to 2018

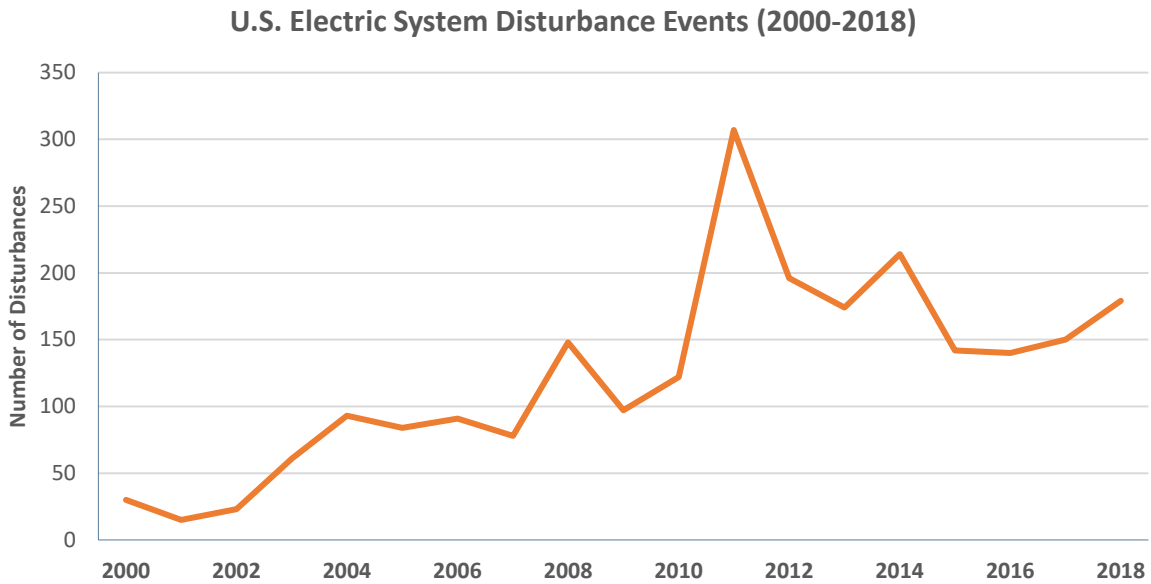
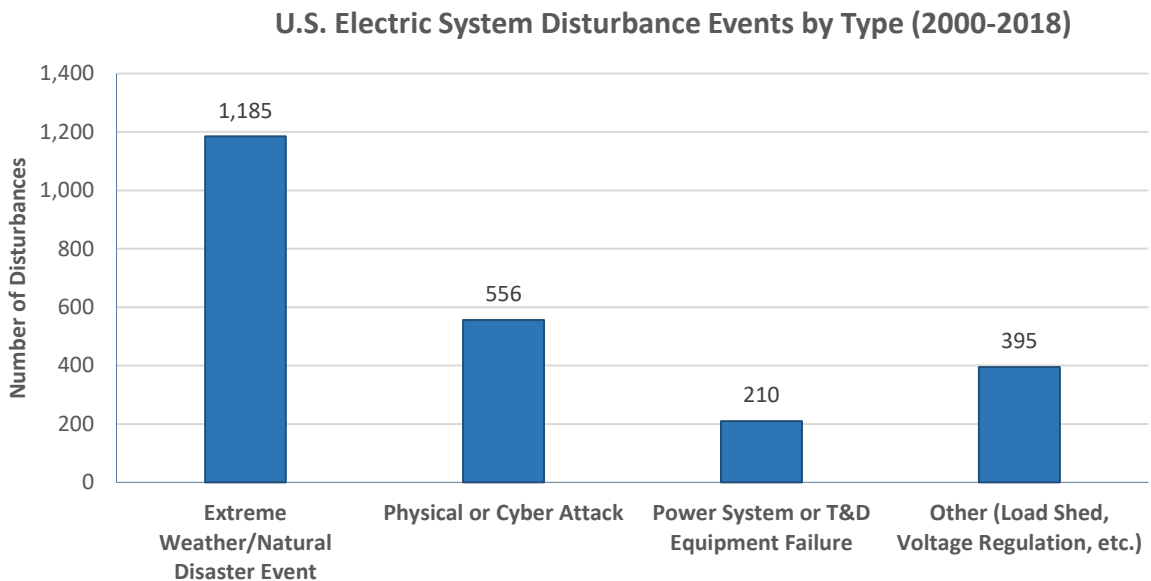


Figure 10. Type of US Electric System Disturbance Event from 2000 to 2018



Source: U.S. DOE, Form OE-417

Aging Energy Infrastructure

When central energy infrastructure fails, the impacts affect the entire economy and illustrate the need for updated, secure, and resilient infrastructure. For example, the power outage at Atlanta's airport in 2017 had national economic impact, stranding travelers in darkness for nearly 11 hours and causing major delays in air traffic nationwide. As a result, the Georgia

Public Utilities Commission is exploring the installation of a CHP microgrid at the airport's central utility plant.⁹⁸

Growth of Renewable Generation and Distributed Energy Resources

The growing penetration of renewable generation as a source of power presents new challenges to the operation of regional power grids. From 2009 to 2018, the percentage of electricity in the U.S. generated by renewables (including hydro) grew from 11% to 18%.⁹⁹ District energy systems can bring stability and balance to local or regional electric grids by shifting thermal energy generation to non-peak times, therefore helping to address volatility caused by the variability of wind and solar generation.¹⁰⁰ An example of this type of load shift is generating chilled water for a district energy system at night so that less electricity needs to be used during summer days at peak times. District energy also provides an opportunity to convert lower cost or negative-price renewable electricity into thermal energy to provide useful heat or cooling immediately or in diurnal or seasonal storage.

Reform of Utility Business Models

Several states have opened regulatory dockets to support electricity grid modernization and explore reforms to utility business models that enable greater penetration of renewables and distributed energy resources (DERs). As part of these efforts, there is growing recognition that energy security and resiliency require the electric utility to manage a transition from large, remote central station generation to resources located closer to the customer, and traditional utility regulatory models must evolve to enable greater deployment of DERs and microgrids. The large overlap between district energy systems and microgrids provides an opportunity for electric utilities to include district energy into their operational plans for how to integrate more DERs on the grid. Many utilities are also evaluating ownership models for CHP systems that generate both electricity and thermal energy to serve their customers' needs.

Increased Urbanization

Large metropolitan areas of the U.S. are growing faster than the rest of the country. In the half-century from 1960 to 2010, the urban population as a percentage of the total population has increased from just under 70% to almost 81%.¹⁰¹ Urban planning is becoming increasingly important to enable large populations to live in close quarters while maintaining reliable access

⁹⁸ Wood, E. December 21, 2017. "Regulators Want to Know If Georgia Power Considered a Microgrid for the Atlanta Airport." Microgrid Knowledge. Available at <https://microgridknowledge.com/microgrid-atlanta-airport/>

⁹⁹ Bloomberg New Energy Finance and The Business Council for Sustainable Energy. 2019 Sustainable Energy in America Factbook. Page 18. Available at <https://www.bcse.org/factbook/>

¹⁰⁰ The electricity grid is an instantaneous system where electricity generation must match electricity consumption, whereas the thermal energy in district energy systems can be generated in advance and stored in the water or steam that is inside the system piping. This allows for generation resources supporting district energy systems to be operated in a flexible fashion where they provide grid support when needed and traditional district energy support at all other times.

¹⁰¹ U.S. Census Bureau. 2012. *United States Summary: 2010. Population and Housing Unit Counts*. Available at <https://www.census.gov/prod/cen2010/cph-2-1.pdf>

to energy services. District energy is a key infrastructure consideration for expanding cities and allows for growth to be maintained in a sustainable manner.

Development and Implementation of Energy Resilience Plans

Historically, states and some cities have developed energy plans that assess energy needs, examine policy options, and develop strategies for meeting future needs. More recently, state and local governments are creating resilience plans, or incorporating resilience objectives into master energy plans, focused on addressing the role of energy in recovering from a disaster. Within the past 4 years, 16 U.S. cities have created resilience plans as part of the 100 Resilient Cities Initiative.¹⁰² For example, the **City of Pittsburgh** has championed a strategic plan to enhance energy resiliency and reliability and is re-branding itself as an innovation hub.¹⁰³ The competitive advantage of the Pittsburgh region is no longer its rivers and raw materials but its high-skilled workers, world-class research institutions, and technology-intense advanced manufacturing. The city is making strides in creating the energy infrastructure needed to support innovation and a new NRG District Energy Center in Pittsburgh's Uptown District will serve UPMC Mercy Hospital as an anchor customer, as well as future tenants on the 28-acre site.¹⁰⁴

Increased Need for Cooling

Growth in data centers and the use of personal electronic devices, appliances and office equipment in buildings that generate heat as a by-product, creates more demand for cooling, which can be met with district energy systems. Additional factors driving cooling demand include changes in building design from using heavy materials, such as stone or brick, to materials with less thermal mass such as wood or composites, and rising incomes and higher standards of living, which also lead to increased use of air conditioning.

Increased Demand for Distributed Energy at Mission Critical Facilities

The US DOE Federal Energy Management Program (FEMP) has increased its resources available to the Federal sector to support mission critical facilities and bases to be able to remain operational during extended grid outages caused by extreme weather events and other natural or man-made disasters.¹⁰⁵ In addition, Federal agencies, such as U.S. Army, have increased demand for distributed resources for making facility and community infrastructure more resilient.¹⁰⁶ Under Army Directive 2017-07, the Army must prioritize energy and water security and resilience, including providing a minimum of 14 days of power to sustain mission critical

¹⁰² 100 Resilient Cities. Available at <https://www.100resilientcities.org/>

¹⁰³ City of Pittsburgh. 2017. ONE PGH: Pittsburgh's Resilience Strategy. Available at http://pittsburghpa.gov/onepgh/documents/pgh_resilience_strategy.pdf

¹⁰⁴ NRG. n.d. NRG Energy Center Pittsburgh. Available at <http://thermal.nrg.com/projects/pittsburgh/>

¹⁰⁵ U.S. Federal Energy Management Program. Available at <https://www.energy.gov/eere/femp/energy-and-water-resilience-and-security>

¹⁰⁶ U.S. Army Corps of Engineers. n.d. Building Resilience. Available at <https://www.usace.army.mil/Missions/Sustainability/Building-Resilience/>

facilities in the case of a grid outage.¹⁰⁷ Distributed resources, local fuels, and resilient microgrids are all key elements to developing effective energy assurance strategies. The Air Force's 2017 – 2030 energy plan sets a goal of increasing the use of energy resiliency technologies and partnerships for critical infrastructure to improve energy security, and to incorporate these technologies, such as cybersecure microgrids, for critical infrastructure by 2020.¹⁰⁸ District heating and cooling systems, anchored by fuel flexible CHP and incorporating distributed renewable resources like at the **Portsmouth Naval Shipyard**, are becoming the mainstay of many mission critical resilience plans depending on the nature of the critical functions and threats.¹⁰⁹

U.S. Navy Increases Reliability for Operations at Portsmouth Shipyard

- Location: Kittery, ME
- Sector: Military
- Energy Supplied: Steam, electricity

To provide increased reliability for its operations, the U.S. Army Corps of Engineers and the U.S. Navy installed a microgrid at the Portsmouth Naval Shipyard. The microgrid provides islanding capabilities to the shipyard, eliminating downtime during a disruption on the grid. The project included several upgrades to the shipyard's system, including a new 10.4 MW CHP plant, new boilers, and a battery storage system. These improvements have led to annual energy cost savings of \$6.2 million.¹⁰⁹



Photo credit: US Navy

Next Generation Technologies for Energy Efficiency and Security

The deployment of state-of-the-art technologies described above can improve the efficiency and security of energy systems currently in use. Research and development (R&D) has the potential to improve the technical performance and lower the cost of district energy technologies, as well as provide technological advances that can lead to greater levels of resiliency and flexibility for an increasingly cyber-connected grid that is powered by an evolving mix of primary energy sources. For example, as the market share of intermittent renewable energy sources increases in many parts of the country, there is a growing need for smart control technologies to ensure the stability of the electric grid. Local district energy/CHP

¹⁰⁷ U.S. Army. "Army Energy Resilience." October 11, 2017. Available at <https://www.army.mil/standto/2017-10-11>

¹⁰⁸ U.S. Air Force. Energy Flight Plan 2017 – 2036. Available at <https://www.fbo.gov/utills/view?id=db5b0675d1c8542c583c67ffa92d89a1>

¹⁰⁹ Ameresco. 2017. *Case Study: Portsmouth Naval Shipyard, ME*. Available at <https://www.ameresco.com/wp-content/uploads/2017/07/portsmouth-naval-shipyard-me.pdf>

facilities can provide voltage support, quick start and black start, and balancing capacity along with other ancillary services to the regional and local power grid.

Technology advances can enable the next generation of district energy systems to exceed current state-of-the-art performance and can enable new capabilities and functionality, such as more efficient grid integration. For example, advances in materials¹¹⁰ can enable greater electrical and thermal performance, and advances in power electronics can enable a smart-grid. R&D opportunities include:¹¹¹

- Develop and refine interoperable grid and district energy control system architectures to enhance integration and operational flexibility
- Develop software and visualization tools that use new data from transmission and distribution system devices for enhanced, real-time operations and control
- Research material innovations and develop district energy piping distribution component designs for higher performance, reliability, and resilience
- Embed intelligence, communication, and control capabilities into distributed energy resources and systems such as microgrids to support integrated operations
- Improve thermal energy storage capabilities and systems designs that lower costs while increasing capacity and performance, and facilitating integration
- Develop high-fidelity planning models, tools, and simulators and a common framework for modeling, including databases
- Design innovative technologies and resilient and adaptive control systems to improve physical- and cyber-security of district energy operations

While district energy can provide efficiency and security advantages to our existing energy infrastructure, modern district energy systems will increasingly need to interface with a changing supply and generation mix, as well as an energy system that is changing with new digital communications and control technologies. R&D can improve not only the technical and cost performance of discrete district energy components and sub-systems, but will be required to optimally integrate district energy systems into modern energy delivery and utilization systems.

¹¹⁰ See, for example, Technology Assessments associated with Chapter 6 of the *2015 Quadrennial Technology Review*, including: ‘[6B Advanced Materials Manufacturing](#),’ ‘[6G Direct Thermal Energy Conversion Materials, Devices, and Systems](#),’ “and ‘[6M Waste Heat Recovery Systems](#)’ available at <https://www.energy.gov/quadrennial-technology-review-2015-omnibus#chap6ta>

¹¹¹ See, for example, Chapter 3 of the *2015 Quadrennial Technology Review*, “Enabling Modernization of the Electric Power System;” available at <https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter3.pdf>

VIII. Future Research Opportunities

Further research and development areas of focus could include researching the ability of CHP and district energy to provide balancing and stability services to the electric grid to support integration of intermittent energy resources. This could defer capital investment for traditional utility resources and reduce the frequency of brownouts or load congestion in energy dense settings. Research into developing operational optimization models, and identifying areas for additional efficiency improvements in district energy systems and components could improve the performance of existing district energy systems, therefore saving businesses money and enabling them to invest in their core business. Research into enabling technologies, energy master planning, and quantifying non-energy benefits of district energy use could better inform how district energy operators manage load curtailment and system deployment during weather-related interruptions or conditions of grid strain. Several private organizations, academia, and the U.S DOE's national labs are at the forefront of developing solutions to modernize U.S. energy infrastructure. As an example, the National Renewable Energy Laboratory's (NREL) Energy System Integration Facility (ESIF) is developing tools that test district-level energy planning.¹¹² NREL's advanced analytical platform, called URBANopt, allows users to investigate energy efficiency and renewable energy at the district scale and identify strategies for optimizing building and energy system performance within one geographically cohesive area within a city (e.g., a city block or district).¹¹³

By integrating and optimizing a range of technologies, district energy systems are well-positioned to contribute to maintaining the efficiency, reliability, resilience, and affordability of the nation's energy infrastructure.

¹¹² See: <https://www.nrel.gov/esif/>

¹¹³ National Renewable Energy Laboratory (NREL), U.S. DOE. n.d. *URBANopt Advanced Analytics Platform*. Available at <https://www.nrel.gov/buildings/urbanopt.html>

References

- Ameresco. 2017. *Case Study: Portsmouth Naval Shipyard, ME*. Available at <https://www.ameresco.com/wp-content/uploads/2017/07/portsmouth-naval-shipyard-me.pdf>
- Ball State University Magazine. January 9, 2017. "Colossal Geothermal Project Harnesses the Earth to Heat, Cool Campus." Available at <https://magazine.bsu.edu/2017/01/09/ball-state-geothermal-project/>
- Boston Planning & Development Agency (BPDA). June 14, 2018. Boston Smart Utilities Project. Available at <http://www.bostonplans.org/planning/planning-initiatives/boston-smart-utilities-project>
- Boston Redevelopment Authority. 2016. Boston Community Energy Study: Exploring the Potential for Local Energy Generation, District Energy, and Microgrids. Available at <https://building-microgrid.lbl.gov/sites/default/files/2016-Boston-Community-Energy-Study.pdf>
- Borer, E. 2013. Energy Efficiency Infrastructure for More Resilient Local Economics: Princeton University Campus Microgrid. Available at www.princeton.edu/~jvickers/Borer_microgrid.pdf
- Bloomberg New Energy Finance and The Business Council for Sustainable Energy. 2019 Sustainable Energy in America Factbook. Available at <https://www.bcse.org/factbook/>
- C40 Cities Climate Leadership Group (C40); United Nations Environment Programme (UNEP). 2016. Good Practice Guide: District Energy. Available at <http://kms.energyefficiencycentre.org/publication-report/good-practice-guide-district-energy>
- California State Legislature. October 14, 2007. Energy: Waste Heat and Carbon Emissions Reduction Act. AB-1613. Available at http://leginfo.ca.gov/faces/billNavClient.xhtml?bill_id=200720080AB1613
- Campbell, R. August 28, 2012. Weather-Related Power Outages and Electric System Resiliency. Congressional Research Service (CRS). Available at <https://fas.org/sgp/crs/misc/R42696.pdf>
- Chena Power Company. 2007. Geothermal Power Plant Final Project Report. Prepared for the Alaska Energy Authority. Available at <http://www.akenergyauthority.org/Content/Programs/AEEE/Geothermal/Documents/PDF/FinRepChenaGeoPlant09.pdf>
- City of Boston; Green Ribbon Commission. 2016. Climate Ready Boston. Available at https://www.boston.gov/sites/default/files/20161207_climate_ready_boston_digital2.pdf
- City of Cambridge. April 2018. *Low Carbon Energy Supply Strategy*. Available at http://www.cambridgema.gov/~media/Files/CDD/Climate/NetZero/LCESS/lcessexecutivesummary_webversion.pdf?la=en
- City of Pittsburgh. 2017. *ONE PGH: Pittsburgh's Resilience Strategy*. Available at http://pittsburghpa.gov/onepgh/documents/pgh_resilience_strategy.pdf

- Cohen, M.; B. Goodchild. 2011. "Jet engine will drive expanded campus power plant." UMass Medical School Communications. Available at https://www.umassmed.edu/news/articles/2011/jet_engine_drives_campus/
- Connecticut General Assembly. June 14, 2018. An act requiring the consideration of creating a portfolio standard for thermal energy in the next integrated resources plan. Public Act No. 18-180. Available at https://custom.statenet.com/public/resources.cgi?id=ID:bill:CT2018000H5348&ciq=ncsl29e&client_md=f272386a25a9fbf889b780d169f0d80f&mode=current_text
- Cornell University. May 10, 2017. "Lake Source Cooling: Innovation, energy efficiency, and environmental sustainability." Available at <https://medium.com/cornell-university/lake-source-cooling-d307913dfc47>
- Cornell University, Facilities and Campus Services. 2005. Lake Source Cooling. Available at <https://energyandsustainability.fs.cornell.edu/util/cooling/production/lsc/default.cfm>
- Cornell University, Facilities and Campus Services. n.d. Cooling Home. Available at <https://energyandsustainability.fs.cornell.edu/util/cooling/default.cfm>
- Davis, P. July 31, 2017. "Can a district energy system help to keep your electricity rates low? It does at Princeton University!" International District Energy Association (IDEA). Available at <https://www.districtenergy.org/blogs/paige-davis/2017/07/31/can-a-district-energy-system-help-to-keep-your-electricity-rates-low-it-does-at-princeton-university>
- District Energy St. Paul. March 2018. *Connected for Good: 2017 Annual Report*. Available at <http://www.districtenergy.com/wp-content/uploads/2018/03/2017-Annual-Report.pdf>
- District Energy St. Paul. n.d. Biomass. Available at <https://www.districtenergy.com/customer-resources/how-it-works/biomass/>
- District Energy St. Paul. n.d. Tell Your Sustainability Story. Available at <https://www.districtenergy.com/customer-resources/sustainability/your-story/>
- Dubai Electricity & Water Authority. June 18, 2017. "Supreme Council of Energy reviews projects, initiatives, and strategic programmes to improve energy efficiency in Dubai". Available at <https://www.dewa.gov.ae/en/about-dewa/news-and-media/press-and-news/latest-news/2017/06/supreme-council-of-energy-reviews-projects-initiatives-and-strategic-programmes>
- Durkay, J. August 1, 2017. "State renewable portfolio standards and goals". National Conference of State Legislatures. Available at <http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx>
- Environmental and Energy Study Institute (EESI). September 2011. Fact Sheet: What is District Energy? Available at https://www.eesi.org/files/district_energy_factsheet_092311.pdf
- Enwave Energy Corporation. n.d. Locations. Available at <http://enwave.com/locations/>
- Frederiksen, S.; S. Werner. 2013. District Heating and Cooling. London, UK: Majestic Books.

- International District Energy Association (IDEA). August 5, 2005. IDEA Report: The District Energy Industry. Available at http://lincoln.ne.gov/city/mayor/arena/assets/idea_district_energy.pdf
- International District Energy Association (IDEA); U.S. Department of Energy (DOE). 2012. Project Profile: University of Texas at Austin, 137-MW CHP & District Energy System. Available at http://www.southwestchptap.org/data/sites/1/documents/profiles/University_of_Texas-Project_Profile.pdf
- International Renewable Energy Agency (IRENA). 2017. Renewable Energy in District Heating and Cooling: A Sector Roadmap for Remap. Available at <http://www.irena.org/publications/2017/Mar/Renewable-energy-in-district-heating-and-cooling>
- Landfill Methane Outreach Program (LMOP), U.S. EPA. n.d. Benefits of Landfill Gas Energy Projects. Available at <https://www.epa.gov/lmop/benefits-landfill-gas-energy-projects>
- Lawrence Berkeley National Laboratory (LBNL), U.S. DOE. n.d. Microgrid Definitions. Available at <https://building-microgrid.lbl.gov/microgrid-definitions>
- Legislature of the State of Idaho. 2010. An act relating to development of thermal energy systems by school districts. SB 1354. Available at <https://legislature.idaho.gov/wp-content/uploads/sessioninfo/2010/legislation/S1354.pdf>
- Louisiana House of Representatives. June 1, 2016. A resolution to urge and request the Dept. of Natural Resources, with the Public Service Commission, to adopt rules and regulations to ensure high levels of energy security in critical government facilities through implementation of on-site combined heat and power systems. HR 167. Available at <https://legiscan.com/LA/text/HR167/2012>
- Maryland General Assembly. May 2, 2013. An Act concerning Thermal Energy – Task Force and Regulations. SB 797. Available at <https://legiscan.com/MD/text/SB797/id/843170>
- Morrissett, G. August 15, 2017. “Working and Future Microgrid Application: MCAGCC 29 Palms.” Energy Exchange, U.S. DOE. Available at https://www.2018energyexchange.com/2017archive/wp-content/uploads/T11S2_Morrissette.pdf
- National Academy of Engineering (NAE). 1997. The Industrial Green Game: Implications for Environmental Design and Management. Washington, D.C.: National Academy Press. Pp. 117–123.
- National Renewable Energy Laboratory (NREL), U.S. DOE. n.d. URBANopt Advanced Analytics Platform. Available at <https://www.nrel.gov/buildings/urbanopt.html>
- NC Clean Energy Technology Center. n.d. “Combined Heat and Power Plant at Fort Bragg Wins 2012 EPA CHP Award.” Available at <https://nccleantech.ncsu.edu/us-army-fort-bragg-wins-2012-epa-energy-star-chp-award/>
- NH Wood Energy Council. October 20, 2016. “Report documents economic benefit of New Hampshire wood heating.” Biomass Magazine. Available at

- <http://biomassmagazine.com/articles/13824/report-documents-economic-benefit-of-new-hampshire-wood-heating>
- Northwest CHP Technical Assistance Partnership, U.S. Department of Energy (DOE). n.d. District Energy: Economic Factors. Available at <http://northwestchptap.org/AboutCleanEnergy/DistrictEnergy/EconomicFactors.aspx>
- NRG. n.d. NRG Energy Center Pittsburgh. Available at <http://thermal.nrg.com/projects/pittsburgh/>
- Oak Ridge National Laboratory (ORNL). 2013. Combined Heat and Power: Enabling Resilient Energy Infrastructure for Critical Facilities. Prepared by ICF. Available at https://www.energy.gov/sites/prod/files/2013/11/f4/chp_critical_facilities.pdf
- Roberts, D. November 22, 2017. "Amazon's Seattle campus is using a data center next door as a furnace. It's pretty neat." Vox. Available at <https://www.vox.com/energy-and-environment/2017/11/22/16684102/amazon-data-center-district-heating>
- Schmidt, D.; et al. 2017. Low Temperature District Heating for Future Energy Systems. Amsterdam, NL: Energy Procedia, Elsevier. 116. Pp. 26-38. Available at <https://www.sciencedirect.com/science/article/pii/S1876610217322592>
- Smith, A. January 8, 2018. "2017 U.S. billion-dollar weather and climate disasters: a historic year in context". National Oceanic and Atmospheric Administration. Available at <https://www.climate.gov/news-features/blogs/beyond-data/2017-us-billion-dollar-weather-and-climate-disasters-historic-year>
- Solbak, V. June 27, 2016. *District Energy and Co-generation for Public Buildings in Alberta*. Government of Alberta Ministry of Infrastructure. Available at http://www.infrastructure.alberta.ca/Content/docType486/Production/District_Energy_and_Cogen_for_Alberta_final.pdf
- Stabile, T. January 25, 2018. "Hudson Yards Emerges on West Manhattan Skyline". ENR New York. Available at <https://www.enr.com/articles/43831-hudson-yards-emerges-on-west-manhattan-skyline>
- State of Minnesota, Department of Administration. December 1, 2017. "Saint Paul's District Energy System". Available at <https://mn.gov/admin/government/sustainability/blog/?id=36-319427>
- The University of Texas at Austin Utilities and Energy Management. n.d. Water Conservation Efforts. Available at <https://utilities.utexas.edu/efficiency/water-conservation-efforts>
- Thermal Energy Corporation (TECO). n.d. About TECO. Available at <http://tecothermalenergy.com/about-teco/>
- Tredinnick, S. June 7, 2013. "Why Is District Energy Not More Prevalent in the U.S.?" HPAC Engineering. Available <http://www.hpac.com/heating/why-district-energy-not-more-prevalent-us>
- Tufts University, Operations Division. n.d. Central Energy Plant (CEP). Available at <https://operations.tufts.edu/construction/central-energy-plant-cep/>

- UCLA Facilities Management. n.d. Utility Distribution. Available at <https://www.facilities.ucla.edu/services/utility-distribution>
- UK Department for Business, Energy & Industrial Strategy. September 15, 2017. "Heat networks". Available at <https://www.gov.uk/guidance/heat-networks-overview>
- UMASS Amherst, Facilities & Campus Services. n.d. Physical Plant. Available at <https://www.umass.edu/physicalplant/utilities-0>
- United Nations (UN). July 10, 2014. "World's population increasingly urban with more than half living in urban areas." Available at <http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html>
- United Nations Environment Programme (UNEP). 2015. District Energy in Cities: Unlocking the Potential of Energy Efficiency and Renewable Energy. Available at <http://districtenergyinitiative.org//report/DistrictEnergyReportBook.pdf>
- University of Iowa Facilities Management. n.d. UI Energy Production and Distribution. Available at <https://www.facilities.uiowa.edu/uem/district-energy/>
- U.S. Air Force. Energy Flight Plan 2017 – 2036. Available at <https://www.fbo.gov/utls/view?id=db5b0675d1c8542c583c67ffa92d89a1>
- U.S. Army Corps of Engineers. n.d. Building Resilience. Available at <https://www.usace.army.mil/Missions/Sustainability/Building-Resilience/>
- U.S. Army. "Army Energy Resilience." October 11, 2017. Available at <https://www.army.mil/standto/2017-10-11>
- U.S. Census Bureau. 2012. United States Summary: 2010. Population and Housing Unit Counts. Available at <https://www.census.gov/prod/cen2010/cph-2-1.pdf>.
- U.S. Congress. 2001. Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism (USA PATRIOT ACT) Act of 2001. H.R. 3162, Section 1016(e). Available at <https://www.congress.gov/bill/107th-congress/house-bill/3162>
- U.S. Congress. 2017. Energy and Water Development Appropriations Bill, 2018. S. Rep. No. 115-132. Available at <https://www.congress.gov/bill/115th-congress/senate-bill/1609>
- U.S. Department of Energy (DOE). March 19, 2015. "EERE Success Story—Geothermal Technology Breakthrough in Alaska: Harvesting Heat below Boiling Temperatures." Available at <https://www.energy.gov/eere/success-stories/articles/eere-success-story-geothermal-technology-breakthrough-alaska>
- U.S. Department of Energy (DOE). August 2015. Project Profile: James H. Quillen VA Medical Center. Available at http://www.southeastchptap.org/Data/Sites/4/documents/profiles/james_quillen_medical_center-chp_project_-profile.pdf

U

- U.S. Department of Energy (DOE). 2015. Quadrennial Technology Review. An Assessment of Energy Technologies and Research Opportunities. Available at <https://www.energy.gov/quadrennial-technology-review-2015>
- U.S. Department of Energy (DOE). 2016. Combined Heat and Power (CHP) Technical Potential in the United States. Prepared by ICF. Available at <https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf>
- U.S. Department of Energy (DOE). September 8, 2017. "CHP Installation Keeps Hospital Running During Hurricane Harvey." Available at <https://www.energy.gov/eere/amo/articles/chp-installation-keeps-hospital-running-during-hurricane-harvey>
- U.S. Department of Energy (DOE). October 2017. Project Profile: University of Missouri. Available at http://www.midwestchptap.org/profiles/ProjectProfiles/University_of_Missouri_Columbia.pdf
- U.S. Department of Energy (DOE). n.d. Combined Heat and Power Basics. Available at <https://www.energy.gov/eere/amo/combined-heat-and-power-basics>
- U.S. Department of Energy (DOE), Office of Electricity Delivery and Energy Reliability. n.d. Electric Disturbance Events (Form OE-417). Available at <https://www.energy.gov/ceser/activities/energy-security/monitoring-reporting-analysis/electric-disturbance-events-oe-417>
- U.S. Department of Energy (DOE); U.S. Environmental Protection Agency (EPA). 2012. Combined Heat and Power: A Clean Energy Solution. Available at <https://www.energy.gov/eere/amo/downloads/chp-clean-energy-solution-august-2012>
- U.S. Energy Information Administration (EIA). 2007. Final Report: District Energy Services Commercial Data Analysis for EIA's National Energy Modeling System. Prepared by Energy and Environmental Analysis, Inc. and International District Energy Association.
- U.S. Energy Information Agency (EIA). August 3, 2017. "Many states have adopted policies to encourage energy efficiency". Available at <https://www.eia.gov/todayinenergy/detail.php?id=32332>
- U.S. Energy Information Administration (EIA). 2018. U.S. District Energy Market Characterization. Report by ICF and IDEA prepared for the U.S. Energy Information Administration. Available at <https://www.eia.gov/analysis/studies/buildings/districtservices/pdf/districtservices.pdf>
- U.S. Energy Information Administration (EIA). n.d. Glossary. Available at <https://www.eia.gov/tools/glossary/index.php>
- Vermont General Assembly. April 17, 2018. An act relating to thermal efficiency monies and biomass-led district heat. HB 616. Available at https://custom.statenet.com/public/resources.cgi?id=ID:bill:VT2017000H616&ciq=ncsl29e&client_md=b945fd8f14f5285945bcb84ef88f1281&mode=current_text
- Vugrin, E., A. Castillo, and C. Silva-Monroy. 2017. Resilience Metrics for the Electric Power System: A Performance-Based Approach. Sandia National Laboratories. <http://prod.sandia.gov/techlib/access-control.cgi/2017/171493.pdf>

- Wachtman, E. February 2015. Princeton Energy Plant Operations Best Practices. IDEA Conference, Denver. Available at <https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=dd1412ab-2642-dd0b-ab0a-35717188f069&forceDialog=0>
- Washington State Legislature. October 9, 2015. An Act Relating to promoting thermal energy efficiency. HB 1095. Available at https://custom.statenet.com/public/resources.cgi?id=ID:bill:WA2015000H1095&ciq=ncsl29&client_md=665af3b575e6c7c56c45c99decaf92fe&mode=current_text
- Wood, E. December 21, 2017. “Regulators Want to Know If Georgia Power Considered a Microgrid for the Atlanta Airport.” Microgrid Knowledge. Available at <https://microgridknowledge.com/microgrid-atlanta-airport/>