U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Combined Heat and Power Technology Fact Sheet Series

Microgrids Overview

A microgrid is a group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the larger utility grid to operate in either grid-connected or island mode. Microgrids are in the early stages of implementation, with approximately 458 microgrids currently in operation and over 225 planned microgrids expected to come online between 2021 and 2023—nearly a 50% increase.[1] Combined Heat and Power (CHP) can play a central role in microgrid development and widescale adoption by providing reliability and resilience, and ensuring continuous operation for host facilities—including buildings, campuses, and communities—in the event of grid outages.

Figure 1. Montgomery County Public Safety Headquarters microgrid. A microgrid serves the Montgomery County Public Safety Headquarters in Maryland with 865 kW CHP, integrated with 2 MW of solar. Find more information at *https://chptap.lbl.gov/profile/135/MoCoPublicSafetyHQ-Project_Profile.pdf*

Photo credit: Montgomery County, Maryland

Applications

Microgrids are designed to improve electricity resilience by enabling facilities to continue operating in the event of a utility grid outage. Microgrids can be characterized as operating either *conditionally* or *continuously* when grid-connected. Conditional microgrids supply power based on the availability of renewable resources or economic market signals such as demand response or real-time pricing. They can supply continuous power during a grid outage through the use of energy storage or backup/standby generators, but conditional microgrids do not consistently supply power to connected loads during normal operation.

As highlighted in **Figure 2**, a microgrid's size can vary considerably, depending on its service area: (1) a single customer/facility (single-customer microgrid), (2) a group of facilities within a distribution feeder circuit (partial-feeder microgrid), (3) an entire distribution feeder circuit (full-feeder microgrid), or (4) an entire substation circuit with multiple feeders (full-substation microgrid). This fact sheet focuses on microgrids that consist of multiple technologies and/or multiple customers/facilities.

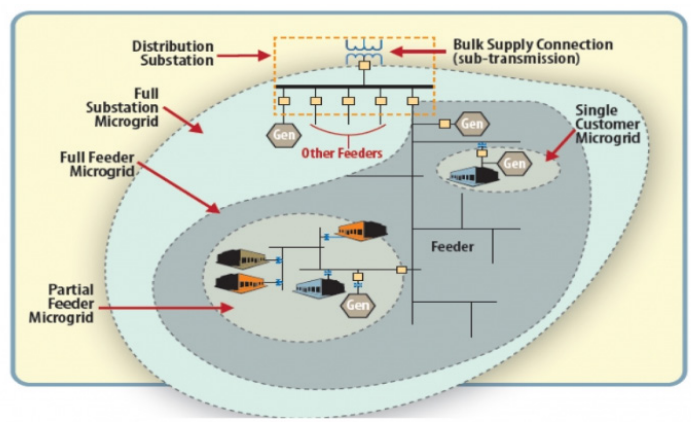

Figure 2. Possible microgrid configurations.

Photo credit: U.S. Department of Energy Office of Electricity

1 DOE Microgrid Installation Database, https://doe.icfwebservices.com/microgrid, February 2021. Database includes only microgrids with multiple technologies and/or multiple buildings, serving operational functions beyond emergency/standby power.

Continuous microgrids that supply consistent power to the connected loads—such as those with CHP—tend to be larger than conditional microgrids. With 24/7 operation, continuous microgrids may provide more efficiency, emissions, and grid support benefits than microgrids that operate conditionally.

Continuous microgrids are most often deployed in institutional campus settings, such as military facilities, government buildings, hospitals, and universities, where all buildings are owned and operated by a single entity. Microgrids with CHP are most commonly deployed in college/university campuses, commercial buildings, cities/communities, hospitals, military facilities, and multi-family buildings. CHP systems operate reliably and continuously during multi-day power outages, making them ideal when energy resilience is of utmost importance. Applications for microgrids that operate continuously are shown in **Figure 3**.

Much of the recent interest in microgrids has been for community microgrids that provide energy resilience for multiple critical loads in cities and municipalities (e.g., police stations, emergency responders, hospitals, gas stations, and supermarkets).

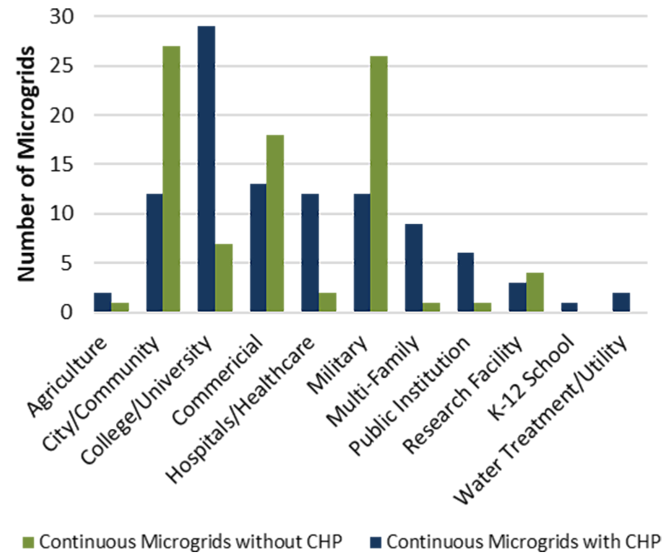

Figure 3. Number of continuous microgrids, existing and planned, by application.
Graphics credit: ICF, DOE Microgrid Database, February 2021

Community microgrids involve multiple stakeholders, which often presents challenges related to microgrid asset ownership and participant contract terms and conditions, resulting in a number of different business models. In one approach, a third-party developer provides "microgrids as a service." In this business model, the developer assumes responsibility for engineering, financing, installing, operating, and maintaining the microgrid through long-term power purchase agreement contracts.

Another approach involves utilities offering microgrids as a rate-based service. For example, some utilities are exploring utility-owned microgrids with CHP for large customers. In this scenario, the utility benefits by selling both electricity and thermal energy (e.g., steam) to the customers, with an efficient and cost-effective source of electricity for the grid. The customer benefits by securing a resilient local source of power.

Technology Description

Microgrids can use any combination of DER technologies. According to the DOE Microgrid Database, CHP has the most operational capacity of any DER technology for existing U.S. microgrids, but non-CHP natural gas generation and solar photovoltaics (PV) have the most capacity in planned microgrids (i.e., announced projects expected to come online within the next three to four years).[2]

Figure 4 shows the operational and planned capacity for continuous microgrids in the United States as of February 2021, based on known microgrids and upcoming installations incorporating multiple technologies and/or serving multiple buildings. The majority of CHP microgrids do not incorporate other DER technologies, but for those that do, solar PV is the most common and contributes the most non-CHP capacity. CHP is most often used to supply baseload power and thermal energy for continuous microgrids, while other DERs provide supplemental power. For conditional microgrids, non-CHP natural gas, solar PV, and storage technologies are most often deployed.

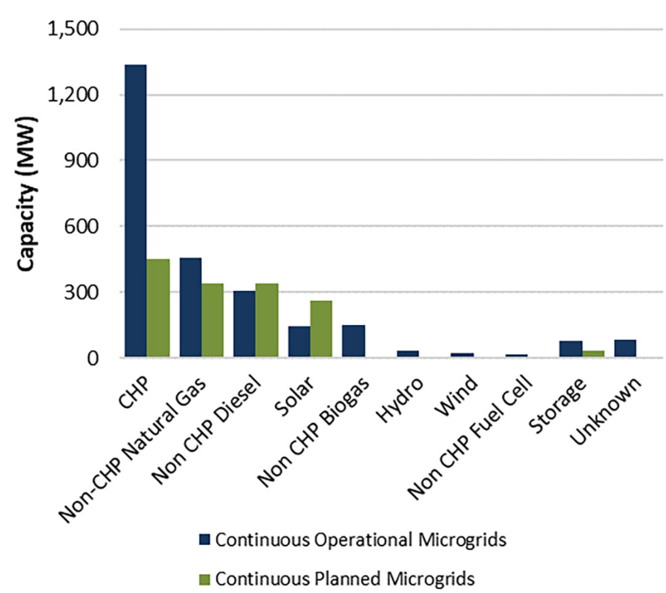

Figure 4. Capacity of DER technologies used in existing and planned continuous microgrids.
Graphics credit: ICF, DOE Microgrid Database, February 2021

2 Information on planned microgrids maintained by ICF for DOE Microgrid Installation Database. February 2021.

Drivers

End users choose to install microgrids because of a combination of site-specific factors or implementation drivers. There are six primary implementation drivers for microgrids:

- **Clean power:** Achieve emission reductions through efficient and/or zero-carbon microgrid technologies.
- **Economics:** Reduce electricity, heating, cooling, and other costs through various mechanisms, such as self-generation (avoided utility costs), shared operation and maintenance, and lower fuel prices.
- **Reliability and resilience:** Ensure power delivery during grid outages and other major disruptive events (especially important for critical infrastructure facilities).
- **Remote grid:** Provide power to remote locations that cannot rely on the power grid, such as an island community or community distant from the electricity grid.
- **Renewables integration:** Incorporate renewable technologies into the power generation mix while using other technologies, e.g., CHP, to offset the associated intermittency.
- **Research and development:** Investigate new technologies, microgrid configurations, and financing arrangements.

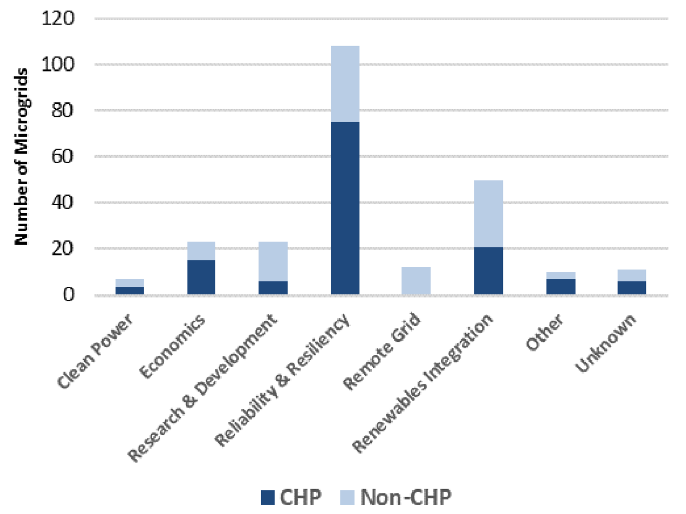

Figure 5. Primary implementation drivers for continuous CHP and non-CHP microgrids (both existing and planned).
Graphics credit: ICF internal research, February 2021

Hybrid CHP Systems

A new category of microgrid installations is emerging in the form of hybrid CHP systems, which incorporate a combination of CHP and other DERs in a single installation. The defining characteristic of hybrid CHP systems is coordination between developers of different DER technologies (i.e., CHP, PV, and/ or energy storage) to engineer and optimize combined systems. When configured as a microgrid, a hybrid CHP system can provide maximum resilience with minimal fossil fuel emissions. In a typical hybrid configuration with CHP, solar PV, and energy storage, CHP would be used for baseload power and heat, while PV and storage are used opportunistically to maximize renewable output and participate in utility markets for grid services (see **Figure 6**).

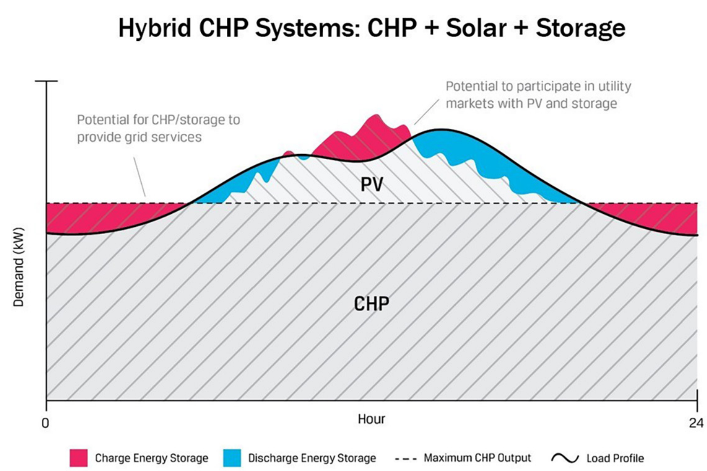

Figure 6. Hybrid CHP operation with CHP, solar PV, and energy storage. Graphics credit: ICF

In operational microgrids with multiple technologies, DERs are typically installed piecemeal over time. For example, a building or campus may already have a CHP system installed, and later, management decides to install rooftop PV, additional backup generators, and energy storage in a microgrid configuration. However, this approach can lead to inefficiencies in the design, sizing, and installation of the system and its components. The original CHP system may become larger than is needed when the additional DERs are incorporated, resulting in lower operational efficiencies and more emissions than a hybrid design. When hybrid systems are installed strategically for specific use cases, the components can be designed to work together, with optimal sizing and maximum efficiency.

Hybrid CHP systems can consist of any combination of CHP and other DER technologies, although solar PV and energy storage have been most commonly connected with CHP in multi-technology microgrids (along with backup diesel generators). As more hybrid CHP systems are installed, certain technology combinations, such as CHP+PV or CHP+PV+storage, could lend themselves to standardized equipment options in the U.S. Department of Energy's (DOE's) packaged CHP eCatalog.[3]

3 U.S. Department of Energy (DOE) packaged CHP eCatalog https://chp.ecatalog.lbl.gov/

A challenge associated with hybrid CHP is establishing teams of DER developers and financiers that can deliver multi-technology solutions to customers. The product is complex, and simplified power purchase agreements with no capital investment will likely be needed to attract end users. As developers and financiers gain experience with hybrid CHP systems, offerings can become more standardized, reducing these challenges.

Benefits of CHP Microgrids: Reliability, Resilience, and Power Quality

CHP microgrids provide a variety of reliability, resilience, and power quality benefits to customers located both within and outside the microgrid. Microgrid customers can benefit from immediate continuation of service in the event of a utility system outage.

Additionally, by avoiding dependence on utility power, microgrids can benefit other utility customers by reducing demands on local grid infrastructure, decreasing the likelihood of utility system equipment failure and removing load from the grid as it recovers from an outage. **Table 1** captures the range of reliability, resilience, and power quality benefits CHP microgrids can provide.[4,5]

Table 1. Benefits of Microgrids that Incorporate CHP

Reliability	• CHP systems are located closer to loads than central generators, reducing the likelihood of distribution outages. • Fast-ramping capabilities allow quick responses to changes in grid-supplied power, providing flexibility to serve dynamic loads. • CHP systems reduce stress on the local distribution grid, extending the life of grid components and reducing the risk of an outage caused by individual distribution equipment failure.
Resilience	• CHP systems operate near-continuously and can provide firm backup generation during outages. • Island-capable systems can maintain heat and power service to loads within the microgrid network during outages, as well as fulfill load-shedding requests during high-demand periods.
Power Quality	• CHP microgrids serving large, power-quality-sensitive commercial and industrial customers, such as data centers and high-tech manufacturing, can provide high-quality power without service interruptions or voltage dips. • By locating generation closer to loads, CHP and district energy systems prevent voltage fluctuation and other power quality issues that often arise on the utility distribution system.

CHP plays an important role in many microgrids as a resilient baseload DER anchor. Natural gas pipelines are rarely affected by extreme weather events, and thus gas-fired CHP can be a reliable source of both electricity and thermal energy for host facilities. CHP can be configured with black start capability and the ability to continue operation during utility outages. Other DERs such as PV may require a reference voltage/frequency, which the utility grid normally provides; CHP can be the source of this reference voltage/frequency during utility outages. Based on the cost of power outages and the historical frequency of local outages, microgrid planners can estimate the value that resilient microgrids will provide and incorporate these savings into financial pro formas. Overall, the impact that mitigated outage costs will have on a microgrid project depends on the customer class and sector, frequency and duration of outages, and relative cost of microgrid equipment and installation.

DOE Microgrid Installation Database

Along with CHP installations, the U.S. Department of Energy's CHP Deployment Program tracks microgrid installations across the United States. Information on operational microgrids, including location, capacity, and technologies deployed, can be found online in the DOE Microgrid Installation Database: https://doe.icfwebservices.com/.

4 Chittum and Relf, Valuing Distributed Energy Resources: Combined Heat and Power and the Modern Grid. ACEEE White Paper. April 2018. Available at https://aceee.org/white-paper/valuing-der

5 Tim Banach, Bob Chester, Gavin Dillingham. CHP: Enabling Resilient Energy Infrastructure. DOE EERE Webinar. April 3, 2013. Available at https://www.energy.gov/sites/prod/files/2013/11/f4/chp_enabling_resilient_energy_infrastructure.pdf

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