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Clean Energy Microgrids:

Considerations for State Energy Offices and Public Utility Commissions to Increase Resilience, Reduce Emissions, and Improve Affordability

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Executive Summary

In fall 2019, the National Association of Regulatory Utility Commissioners (NARUC) and the National Association of State Energy Officials (NASEO) initiated a joint Microgrids State Working Group (MSWG), funded by the U.S. Department of Energy (DOE) Office of Electricity (OE). The MSWG aims to bring together NARUC and NASEO members to explore the capabilities, costs, and benefits of microgrids; discuss barriers to microgrid development; and develop strategies to plan, finance, and deploy microgrids to improve resilience.

This report, *Clean Energy Microgrids: Considerations for State Energy Offices and Public Utility Commissions to Increase Resilience, Reduce Emissions, and Improve Affordability*, focuses specifically on how clean energy microgrids can achieve both resilience and clean energy benefits. The paper provides an overview of the challenges faced by clean energy microgrids, outlines benefits that clean energy microgrids can provide, and details economic and cost considerations for the development of clean energy microgrid projects. Outlined in the paper are the necessary technological components of a clean energy microgrid, including generation, storage, energy efficiency measures, and smart controls. Current technologies are highlighted, along with potential configurations of clean technologies that are approaching cost competitiveness with commercially available options. The paper concludes with both policy and regulatory considerations for State Energy Offices and Public Utility Commissions to enhance the development and deployment of clean energy microgrids. Although it touches on the clean energy microgrids' role in integrating distributed energy resources (DERs) into the larger grid, this is not the focus of this paper.

Introduction and Context

Microgrids[a] can provide reliable, resilient, affordable, and efficient electric power to critical infrastructure, disadvantaged communities, higher learning institutions, and other electricity consumers. Clean energy and resilience goals initiated through recent state and federal policy and regulatory decisions present many opportunities to advance microgrid development; however, competing cost- benefit considerations and other challenges must be mitigated to scale microgrid deployment and to realize their full value. Over the past several years, State Energy Offices and Public Utility Commissions have explored and learned from various microgrid applications, but information, research, investment, policy, and regulatory gaps remain. To address these issues and enable microgrids to deliver benefits to the public, NARUC and NASEO formed the Microgrids State Working Group (MSWG) to share public- and private-sector best practices to advance beneficial microgrid development and take advantage of technical expertise from the U.S. Department of Energy (DOE).

While microgrids are primarily pursued as an energy resilience solution, states are also concerned with decreasing greenhouse gas emissions from the electricity sector. Clean energy microgrids can provide both benefits simultaneously and even decrease overall emissions when replacing diesel or natural gas back-up supply or large-scale fossil fuel generation. A 2020 study by the California Air Resources Board found that during an October 2019 Public Safety Power Shutoff (PSPS), 166.4 tons of nitrous oxides (NOx) and 19.4 tons of particulate matter were emitted from back-up generators. Nine tons of particulate matter is equal to the emissions of almost 30,000 heavy duty diesel trucks driving in California over the course of a single month.[1]

For the purposes of this paper, clean energy is defined as energy that is derived from zero-emissions resources. This includes sources such as renewable energy (solar, wind, water, geothermal, biomethane, biodiesel, renewable natural gas, and biomass) as well as nuclear energy. While nuclear energy traditionally has not been a generation source for microgrids, new small modular reactors (SMRs) have the potential to provide carbon-free energy to microgrids in the future. Storage is often paired with a clean energy resource in a microgrid and will also be discussed in the paper. One of the most prevalent technologies used for microgrids is combined heat and power (CHP). CHP is the simultaneous production of electricity and useable heat energy from a single fuel source. A CHP system captures heat produced as a byproduct of electricity generation that would otherwise be wasted or generates electricity from waste heat from high-heat intensive processes. CHP is a very efficient technology and can operate at about 75 percent efficiency, compared to 50 percent when electricity and heat are generated separately.[2] CHP systems can either use fossil fuels or renewable energy. For the purposes of this report, it is not considered a renewable energy source, but several microgrids in the United States do combine CHP with a renewable source.

Microgrids are becoming more prevalent across the United States. The U.S. Department of Energy's (DOE) Combined Heat and Power and Microgrid Installation Database provides a listing of microgrid installations throughout the country. According to the database, 687 microgrid sites with a capacity of 4,357 MW have been installed across the United States as of December 31, 2022. Most installations are located in Texas (257 sites), followed by California (91) and New York (68). However, New York leads the states for capacity installed (662.5 MW), with Texas second (645.6 MW) and California third (442.5MW).[3] As mentioned previously, CHP is currently the most prevalent technology powering microgrids, with a total of 2,399 MW accounting for more than 50 percent of all microgrids. Non-CHP combustion represents about 30 percent of the total installation. Solar, wind, and hydro combined make up less than 10 percent of currently installed microgrid technology. Across the United States, 136 MW of storage has been installed as part of a microgrid (**Figure 1**).

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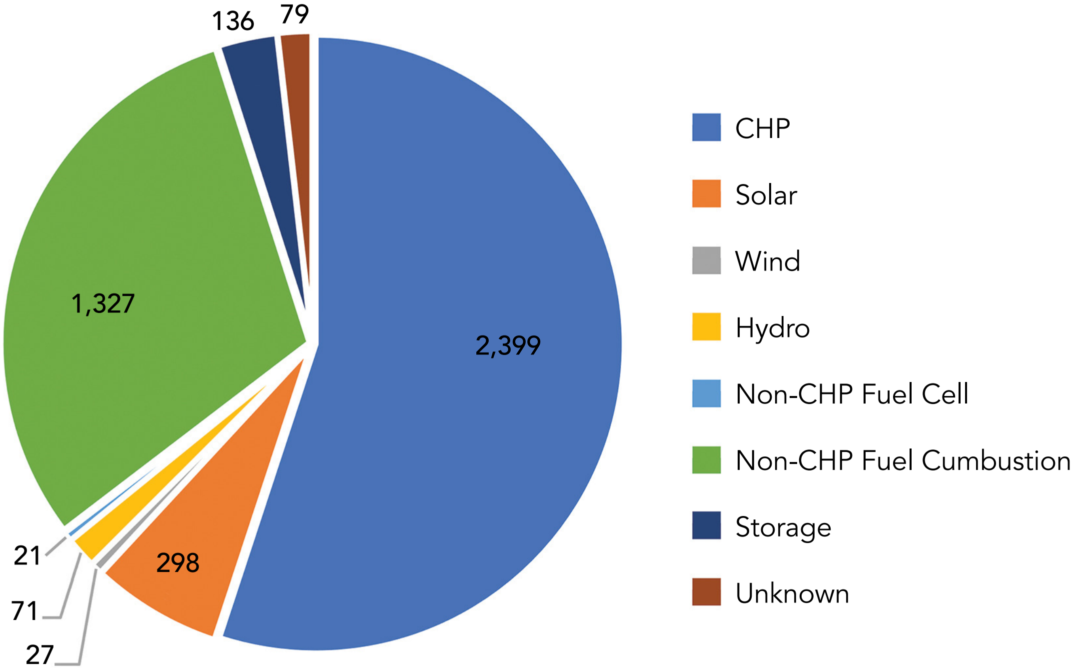
[a] The U.S. Department of Energy microgrid definition: "A microgrid is a local energy grid with control capability, which means it can disconnect from the traditional grid and operate autonomously," How Microgrids Work | Department of Energy.

Figure 1: Total Installed Microgrid Capacity in the United States in MW as of December 2022[4]



Totals may include duplicate sites (microgrids with more than one technology)

In 2020, diesel and natural gas were the primary fuel sources of microgrids (CHP or otherwise), representing 40 percent of installed capacity each. Therefore, fossil fuels make up about 80 percent of microgrid generation sources, which is higher than the 60 percent of fossil fuels powering the U.S. electricity sector.[5] However, analysts predict that by 2025 wind, solar, hydropower, and energy storage will represent 35 percent of annual installed microgrid capacity.[6] This can be attributed to, for example, an increase in federal and state policies encouraging clean energy development, private sector investment in projects that provide a resilience value, lower costs, and increased funding streams.

As microgrids provide an excellent resilience benefit, states will have to examine how both resilience and achieving state decarbonization and emissions reduction goals can be achieved concurrently with microgrids, while also considering potential requirements at certain critical facilities to have back-up diesel generation and/or onsite fuel supply available in an emergency.

Benefits of Clean Energy Microgrids

Clean energy microgrids provide a multitude of benefits and services that encompass both the energy and non-energy sectors including decarbonization, increased resilience, cost savings, and grid efficiency. These benefits are discussed in detail in the section below.

Decarbonization

In recognition of the critical need to reduce greenhouse gas emissions, decarbonization goals have been developed on the national, state, local, utility, and corporate levels. Bringing more renewable generation online is a key component of meeting these goals: already, 30 states and two territories have Renewable Portfolio Standards (RPS) or Clean Energy Standards (CES) in place,[7] which usually require utilities to generate a certain percentage of their electricity from renewable sources. Utilities also have voluntary goals to reduce greenhouse gas emissions. According to the Smart Electric Power Alliance's Utility-Carbon Reduction Tracker, more than 100 utilities have 100 percent renewable goals in place, both voluntary and state required.[8] Additionally, the Biden Administration announced federal goals of 100 percent carbon-free electricity by 2035 and other clean energy goals, such as the 50 percent reduction from 2005 levels of greenhouse gas emissions by 2030.[9]

While the majority of microgrids currently are powered by fossil fuels such as diesel and natural gas, over the next five years, a surge in microgrid development is anticipated, with capacity doubling, particularly from solar generation.[10] Lower costs of storage and expanded incentives for renewable generation is anticipated to help spur this growth.[11] Many clean energy microgrids are currently paired with fossil CHP, natural gas or diesel generators; however, clean energy microgrids paired with battery storage might eliminate the need for fossil fuel back-up and reduce concerns about the variableness of renewables. Long duration battery storage will also allow for a more complete transition away from other fossil fuel back-up resources. In addition, clean energy microgrids eliminate the need for complex inter-state fuel deliveries and reduce concerns over delayed fuel shipments in an energy emergency.[12]

The risk of fuel scarcity is particularly high for communities in remote and rural areas where diesel generators are relied on for back-up power.[13] A 2022 study funded by the International Centre for Integrated Mountain Development and the Institute for Advanced Sustainability Studies compared the emissions of on-site diesel generators and a solar PV-based microgrid supported by battery storage. The study determined that the diesel generator had high air pollutant emissions which could be 100 percent mitigated by a solar PV-based microgrid. The average carbon dioxide emission factor, determined by a review of 13 diesel generators, was almost 2,600 g/L. As a result of switching to the solar PV-based microgrid, more than 375,000 liters of diesel were not needed, which led to a reduction of more than 975,000 kg of carbon dioxide annually.[14] This reduction in emissions aligns with the goals of island locations such as Puerto Rico, where the isolated nature of many communities leads them to rely on diesel generators, with clean energy microgrids under consideration as a partial replacement. Puerto Rico's Act-133-2016 stipulates that the "goal of microgrids is to reduce energy consumption based on fossil fuels through local renewable energy generation."[15] Renewable microgrid capacity in Puerto Rico is expected to grow from nearly 8 MW in 2021 to more than 140 MW by 2030.[16] This demonstrates the important role clean energy microgrids have in displacing fossil fuel generation on the island and in other remote areas. In the coming years, investment in these projects will be spurred by federal funding such as the Investment Infrastructure and Jobs Act (IIJA), which includes funding specifically for microgrids in remote and rural areas.

Box 1: U.S. Army Climate Strategy

The U.S. Army released its new Climate Strategy plan in February 2022, with a goal of providing 100 percent of Army installation electricity needs from carbon-free sources by 2030. One of the ways the U.S. Army will meet this goal is by installing a microgrid at all their locations (base, station, yard, etc.). Microgrids will increase army resilience and help decrease emissions. Currently, the army purchases more than $740 million of electricity from the main grid every year and releases 4.1 million metric tons of harmful emissions into the atmosphere. These include carbon dioxide, methane, nitrous oxide, and other greenhouse gases.

Resilience

Clean energy microgrids serve key roles in providing resilient and reliable service. The National Renewable Energy Laboratory (NREL) considers the main resilience benefits of microgrids to be providing energy security and survivability.[17] When there is a disruption or blackout, microgrids can island themselves from the main electric grid and continue providing power. During blue sky conditions, microgrids stay connected to the grid. Having a secure and steady source of back-up power is crucial, particularly at critical infrastructure locations such as wastewater treatment plants, emergency shelters, and hospitals. These entities often rely on diesel generators as back-up power sources and in many states are required to have sufficient fuel on hand for a certain period, as well as test these systems regularly. However, absent state maintenance requirements, diesel back-up generators are used less frequently, so it is not always clear if they have been well maintained or will be able to function in a no-notice emergency situation.[18] The controller operating a microgrid allows it to connect and disconnect seamlessly. There are also opportunities for remote monitoring and testing of microgrids.[19] Additionally, microgrids can power a building longer than the fuel supply required for diesel back-up generation; this is especially crucial for situations when additional fuel is unavailable or cannot be delivered due to unsafe conditions.

Microgrids in island mode can allow critical facilities to continue to provide valuable services even when there are outages on the main grid. This resiliency is especially important in remote areas or other isolated communities. Microgrids have been widely installed in Alaska, where many communities are located far from centralized energy generation. These locations are at risk from power disruptions and the potential cascading impacts. For example, prolonged power outages can lead to backed up sewage and impacts to fresh water supply. The interdependencies between the critical sectors are particularly evident during a blackout or other electricity disruption. Microgrids as part of larger resilience hubs can be an opportunity to address a multitude of these concerns at one central location.

The resilience benefits of clean energy microgrids are particularly valuable in disadvantaged communities who may not have consistent access to clean, reliable electricity. These communities may face energy insecurities and be more susceptible to power disruptions or outages and the resulting harmful effects. They may also experience slower recovery timelines.[20] The California Public Utilities Commission has a Resiliency and Microgrids Working Group, developed under state law, to address, among other issues, the opportunities microgrids may offer to disadvantaged communities. The Commission authorized the state's largest three investor-owned utilities to implement a Microgrid Incentive Program that includes up to $200 million in grant funding to increase resilience in vulnerable communities, partially by investing in clean energy microgrids.[21] Another example of how microgrids can support energy reliability in underserved areas comes from the Kentucky Regional Microgrids for Resilience study, which was prepared for the Kentucky Office of Energy Policy. The study looked at thousands of potential locations for resilient, community microgrids and identified 12 locations that would have the greatest benefit, partially through an assessment of population density and underserved communities.[22] The planned Knox County Community renewable energy microgrid (supported by a standby generator and battery storage system) would serve an emergency operations center, gas station, hospital, and nursing home in Barbourville, where the median household income is $13,297 and close to 40 percent of the population lives under the poverty line.[23] When developing these projects, it is important to involve local communities with equity goals that are well defined and quantifiable.[24]

Box 2: Microgrids in Alaska

DOE's Grid Modernization Laboratory Consortium leads an Alaska Microgrid Partnership, which looks to cut back on the need for diesel fuel in remote areas, cut electricity costs, and facilitate deployment of renewable energy and hybrid microgrids in isolated parts of the state.[25] Many of these projects will be supported by battery storage. These projects are critical in Alaska as many communities are completely isolated with no main road system or access to population centers.[26] Without the microgrids, it would be next to impossible to maintain the critical facilities necessary for day-to-day life such as water and sewer systems.

Grid Services and Transmission Alternatives

Clean energy microgrids offer significant opportunities to provide grid services. In many instances, grid-connected microgrids can deliver additional grid resilience through various services, such as voltage regulation and demand response, thus making the resilience benefits bidirectional. When a microgrid is installed together with a renewable energy system, microgrids also can provide local balancing of generation and load, making the overall system more efficient.[27] Although studies have found that to displace 1 kWh of fossil fuel generation, more than 10 kWh of renewable generation is needed, this is in large part due to variableness of renewable energy and the fact that renewable generation is often constructed far from the distribution site, leading to line losses as electricity travels across long distances.[28] Microgrids provide local generation and thus eliminate this power loss, as well as alleviate grid congestion. This minimizes the need for expensive, high-capacity transmission lines. As microgrids can be deployed quickly versus the long-term planning horizon for new transmission lines, they can accelerate decarbonization efforts as a result.

Non-Energy Benefits

There are significant non-energy benefits to clean energy microgrids, including improved air quality, health, and safety; additional value streams; and cost savings (which will be explored further in the next subsection). In terms of air quality, renewable energy generation provides net-carbon emissions reductions and mitigates the release of other air emissions such as sulfur oxides, whereas burning fossil fuels releases GHGs and toxins like sulfur oxides (SOx) and nitrogen oxides (NOx). Exposure to SOx and NOx is harmful to the respiratory system and can lead to adverse health effects.[29] By investing in clean energy microgrids, communities can reduce their fossil fuel generation while also lowering the risk of potential harmful public health impacts and reducing air pollution. The Oregon Department of Energy's 2020 Biennial Energy Report features a review of resilient microgrids and specifically highlights the ability of renewable energy microgrids to "avoid…constituent air pollutants by displacing fossil generation."[30] In California, Tesla was fined for violating air quality standards. The local air quality board has tasked the company with reducing local air pollution by constructing a renewable energy microgrid. The community microgrid project will use 160 kW of solar and battery storage.[31]

A significant additional economic benefit is the value of avoiding electricity system disruptions and the costs associated with these outages. The benefit (or avoided cost) is known as the value of lost load (VoLL) – a monetary indicator representing the costs of an electrical outage. Clean energy microgrids help avoid blackouts or service interruptions and quantifying these benefits might spur investment and encourage microgrid development. However, measuring the complete cost of a blackout is challenging. There are multiple layers including, most importantly, lives lost, which is difficult to quantify. There are several approaches to looking at the value of lost load including blackout studies, willingness to pay/avoid, and direct costs.[32] In California, Taylor Farms, a fresh food producer, is working to install a microgrid made up of fuel cells, solar power, and a battery that is able to island from the main grid and continue providing power, reducing the possibility of food spoilage or other disruptions to their critical service.[33]

Additional benefits of clean energy microgrids are overall economic and workforce benefits. For example, a recent study by Guidehouse looked at the renewable energy economic benefits of microgrids and determined that, by 2030, renewable energy microgrids will contribute more than $72 billion to the GDP by 2030.[34] This will also lead to the creation of half a million jobs in the same time frame, most of which will be concentrated in the biomass and energy storage sectors, according to the per megawatt installed capacity.[35]

Policy, Cost, and Affordability Considerations

While costs for renewable energy sources and storage technologies are continuing to decrease,[36] one of the key hurdles for the deployment of clean energy microgrids that rely on renewable energy generation and a zero-emissions storage solution continue to be higher costs compared to fossil fuel generation. A recent paper by the Idaho National Lab estimates that to achieve carbon neutrality with only solar generation and electricity, the price for energy would need to increase by 80 percent.[37] While renewable energy prices and costs of battery storage are predicted to continue to fall (energy storage may be reduced by as much as 67 percent by 2030[38]), for the more immediate deployment to be economically feasible, grid-connected clean energy microgrids will need to tap into additional revenue streams valuing their resilience and environmental benefits.

However, as noted previously, methods for quantification and renumeration of resilience and environmental benefits are in the early stages, making financing clean energy microgrids a challenge. It is usually cheaper to provide resilience benefits with fossil fuel generation rather than with variable clean energy resources such as wind and solar. This is especially true when it comes to critical facilities that need reliable energy for an extended period of time when the grid is unavailable. Energy storage in the form of batteries can provide some resilience benefits; however, the current costs for storage and the duration of available energy remain a challenge, especially for remote microgrids, which do not have the larger electric grid to fall back on in the event of low wind and solar output.

Grid-connected clean energy microgrids provide multiple other cost-saving opportunities, including demand response, peak shaving, and ancillary services.[39] During high demand periods, microgrids continue to provide services to the electric grid, which reduces the risk of a possible power outage due to Public Safety Power Shutoffs or other events. Power outages can not only lead to lives lost, but also incur significant costs when equipment goes down for extended periods of time. In addition, microgrids can island themselves when the main grid is down, which keeps the power on at critical facilities providing additional saved costs. Microgrids can provide savings when connected to the grid during operation[40] by allowing owners to sell electricity back to the grid. Microgrids can purchase electricity from the utility, or the electricity can be self-generated. This was a notable exception in the Hawaii Microgrid Services Tariff, which provided lower than retail rate credits that can allow for electricity to be sold to the grid. Renewable energy is not as susceptible to price fluctuations or the high costs experienced by natural gas and diesel generators.[41] Overall, microgrids provide ongoing control and management of energy resources to their adopters year-round due to their ability to connect or disconnect from the grid and provide needed services at either time. Conventional natural gas or diesel generators are only needed during certain events or times of the year, which means that the recoup of their capital and fuel costs can be significantly limited, prolonging their payback periods. Microgrids also allow for flexibility in energy consumption depending on time of use, price and demand charges.[42] Avoided energy costs lead to more free capital for communities to invest in other policy priorities.

NASEO and NARUC's paper, Private, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids,[43] has further information on the cost components of microgrids, potential revenue streams, public-private partnership opportunities for microgrids, and the role of public funding and state programs for microgrid development and deployment.

Current Clean Energy Microgrid Technologies

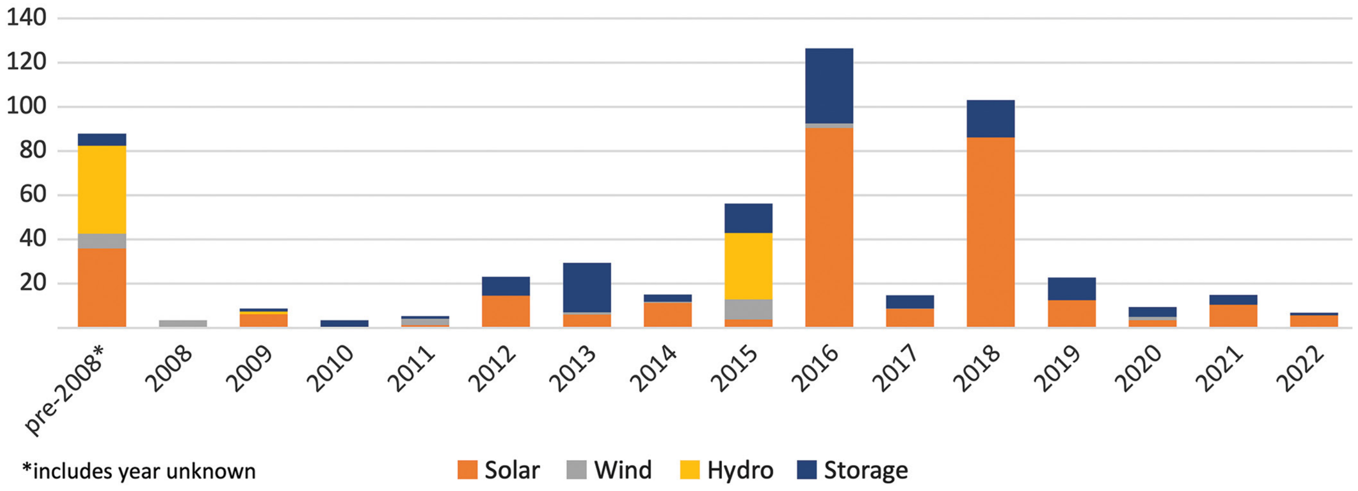
The following section examines current clean energy sources for microgrids and outlines several relevant case studies. It also provides an overview of potential new clean energy resources and other elements of microgrids that could enable a higher percentage of renewable energy integration. It is important to note that clean energy microgrids often combine two or more energy sources (for example, renewable energy with a diesel back-up generator). This allows the microgrids to continue to provide a reliable service when there are challenges with variable renewable energy sources.

Variable Clean Energy Generation

According to DOE's microgrid database, as of December 2022, solar is the leading renewable energy generation source for microgrids with 298 MW deployed, followed by hydro (71 MW) and wind (27 MW).[44]

Hydropower was the dominant renewable energy power source for microgrids before 2009, when solar and wind began to be deployed more significantly in microgrids in the United States, with a peak deployment in 2016 (Figure 2). In 2016, just over 100 MW of solar generation were installed in U.S. microgrids, while annual installation of wind peaked in 2015 with 9 MW. Several factors contributed to the significant increase in solar in 2016, including a concern that the Investment Tax Credit would not be extended beyond that year and the falling costs of solar.[45] There are several companies working to advance deployment of wind powered microgrids, but many of those projects will also be incorporating solar and storage.

Figure 2: Microgrid Renewable Energy Deployment Between 2008 and 2022[46]



Costs for renewable energy resources such as solar and wind have decreased significantly in recent decades. For example, the percent change in total installed costs for solar PV from 2010 to 2022 was 81 percent.[47] Falling costs, along with federal and state incentives, and corporate demand for renewable power, have led to the rise of renewable energy, including microgrids powered by wind and solar. Analysts estimate that by 2030, the national cumulative microgrid capacity will total more than 32,000 MW, with a large percentage powered by solar, wind, and hydro generation.[48]

Wind, solar, or hydro, paired with a back-up generator and/or storage, is often the main generation source for microgrids, but clean energy microgrids may combine different generation sources, including multiple renewable sources (such as wind paired with solar) or fossil-fuel generation. While diesel and natural gas are the most common fossil-fuel based generation, natural gas generators do have lower emissions of carbon dioxide, sulfur, and nitrogen oxides compared to diesel.

Compared to solar, microgrids that incorporate wind generation are relatively rare due to sizing and infrastructure concerns. There are also limitations to rooftop wind installations due to specific needs around siting and building structure.[49] Most microgrids that do have wind as a generation source include it in combination with other resources such as solar, but in areas where wind is the dominant renewable resource and land for solar installations might be limited, microgrids could be predominantly powered by wind generation. Additionally, innovative wind turbine design might provide new opportunities. A Texas company has developed a 36-kW wind-powered microgrid that combines solar generation with a wind turbine design that is installed on a building's rooftop. The vertical-axis turbine array generates power, which together with the power from solar panels is fed through an integrated energy management system and is then used to power the building.[50]

Box 3: Community Solar and Microgrid

A new microgrid installation in the District of Columbia innovatively leverages community solar. In addition to providing electricity to Gallaudet University, the microgrid will also serve DC's community solar program. A community solar program provides the opportunity for residents and businesses that cannot install their own PV installation with access to a solar installation off-site through a subscription model. The microgrid's electricity generation, which will be comprised of 2.5 MW of solar panels, a 1.2 MW/2.4 MWh energy storage system, and a 4.5 MW CHP system, will be tracked through the utility and then allocated to the community solar program through sensors and monitoring systems.[51]

The variable nature of solar and wind continues to remain a challenge for microgrids – especially ones that are dependent on stable electricity flows, such as remote, non-grid-connected microgrids. A stable backup/baseload sources must be included in non-grid connected microgrids to mitigate against blackouts, brownouts, and voltage and frequency drops. Grid-connected microgrids can potentially offset any reduced generation from their solar and wind resources with generation from the grid. However, should the microgrid need to be islanded due to the larger power grid experiencing a disruption leading to outages, microgrids cannot rely on solar and wind resources alone. While hydropower is not as variable as solar and wind, it is geographically limited and increasing drought conditions have impacted the availability of the resource. According to the Energy Information Administration (EIA), hydropower generation in the Pacific Northwest was 14percent below the 10-year average in 2021 and, in California alone, the generation fell 48 percent below the 10-year average.[52]

Firm Clean Energy Generation and Renewable Fuels

Currently, microgrids relying on renewable energy are often paired with a diesel generator or natural gas as a fuel source to ensure reliability. For example, during Winter Storm Uri, more than 100 grocery stores in Texas were able to continue to operate due to their gas-powered microgrid, not only saving costs by preventing food spoilage but also ensuring food security for the communities served.[53] While natural gas has lowered sulfur and nitrous oxide (NOx) emissions more than diesel, it still emits greenhouse gases during combustion and potentially from pipelines or storage facilities through leaks. However, natural gas provides firm generation, which is critical during grid outages for customers requiring a continuous power supply. To decrease emissions while still providing resilience benefits, several microgrids use biofuels, such as biogas or biodiesel. Biogas is captured as methane from landfills, livestock/agricultural sources, wastewater treatment plants, or other organic waste products, and then purified to renewable gas, which can be injected in natural gas pipelines[54] (**Table 1**). Depending on the source of the renewable gas, biogas can be carbon negative. The carbon intensity ranges from -300 g CO_2e/MJ to 50 g CO2e/MJ on average (using a lifecycle approach), which is significantly lower than diesel with about 80 g CO2e/MJ and conventional natural gas with about 70 g CO2e/MJ.[55] Renewable natural gas can be utilized as a transition source of generation when looking to decarbonize a microgrid project or cut back on diesel or conventional natural gas use. Some microgrids in Texas demonstrate the resilience of microgrids using renewable gas. A 60 MW microgrid project was recently announced in San Jose using renewable natural gas that will provide decarbonized resilience for a data center.[56]

Table 1: Feedstock for Renewable Natural Gas Production[57]

Feedstock for RNG		Description
Anaerobic Digestion	**Animal manure**	Manure produced by livestock, including dairy cows, beef cattle, swine, sheep, goats, poultry, and horses.
	Food waste	Commercial, industrial and institutional food waste, including from food processors, grocery stores, cafeterias, and restaurants.
	Landfill gas (LFG)	The anaerobic digestion of organic waste in landfills produces a mix of gases, including methane (40-60%).
	Water resource recovery facilities (WRRF)	Wastewater consists of waste liquids and solids from household, commercial, and industrial water use; in the processing of wastewater, a sludge is produced, which serves as the feedstock for RNG.
Thermal Gasification	**Agricultural residue**	The material left in the field, orchard, vineyard, or other agricultural setting after a crop has been harvested. Inclusive of unusable portion of crop, stalks, stems, leaves, branches, and seed pods.
	Energy crops	Inclusive of perennial grasses, trees, and annual crops that can be grown to supply large volumes of uniform and consistent feedstocks for energy production.
	Forestry and forest product residue	Biomass generated from logging, forest and fire management activities, and milling. Inclusive of logging residues, forest thinnings, and mill residues. Also, materials from public forestlands, but not specially designated forests (e.g., roadless areas, national parks, wilderness areas).
	Municipal solid waste (MSW)	Refers to the non-biogenic fraction of waste that would be landfilled after diversion of other waste products (e.g., food waste or other organics), including construction and demolition debris, plastics, etc.

However, renewable natural gas also faces challenges, most notably that it has historically been significantly more expensive than conventional natural gas. In 2019, the average natural gas spot price was $2.57 per million Btu (MMBTU) compared to between $7 and $20 per MMBTU for renewable gas.[58] In addition to the high costs, there is not enough availability to completely replace natural gas. A report by University of California, Davis, found that renewable natural gas could only replace about 4.1 percent of California's gas demand.[59] Still, renewable natural gas is an opportunity to displace some fossil generation, particularly in instances where the back-up generator would be running infrequently and could make an impact on health and decarbonization efforts. If renewable natural gas production, for instance, was dedicated to supply microgrids, it is sufficient to fully decarbonize 700,000 MW of resiliency microgrids. Where renewable natural gas is used is important to determining net benefits and displacing diesel back up is a high impact application due to local air quality benefits. Although renewable natural gas does emit less carbon dioxide compared to conventional natural gas or diesel, it is not always carbon-free depending on the source. There are occasions where renewable natural gas can be carbon negative, such as when the methane is from organic sources.

Storage Technologies

To ensure that microgrids solely reliant on clean energy can also provide resilience benefits in the event of a grid outage, microgrids are often paired with a storage technology that can store generated electricity (charge) and be used as a power source in situations where clean energy is not available (discharge). Microgrids paired with storage systems reduce peak demand and improve reliability. Generally, five storage options are currently available to microgrids – batteries, flow batteries (also known as regenerative fuel cells), hydrogen, kinetic energy storage, and pumped storage hydropower (**Table 2**). Currently, the most common storage installation is lithium-ion batteries.

This section examines lithium-ion batteries and some other potential storage technologies in clean energy microgrids. Flow batteries (or regenerative fuel cells) and hydrogen are discussed in the next section.

Table 2: Overview of Current Storage Technologies[60]

Options	Advantages	Disadvantages
Batteries (including lead acid, sodium-sulfur, lithium ion, and nickel-cadmium)	• Long history of research • Successful implementation across microgrids • Displaces fossil-related emissions	• Waste disposal • Limited number of charge-discharge cycles • Critical mineral components • Limited lifespan • Market challenges • Overheating concerns
"Flow batteries" or "regenerative fuel cells" (including zinc-bromine, polysulphide bromide, vanadium redox)	• Decoupling of power and energy storage • Ability to support continuous operation at maximum load and complete discharge without risk of damage • Lifespan of over 20 years[61]	• Relatively early state of deployment • Market challenges
Hydrogen from hydrolysis	• Can be clean, depending on the source • Very abundant in its natural state • Potential lifespan of around 30 years[62]	• Relatively low end-to-end efficiency • Challenge to store hydrogen, as it must be stored under high pressure or injected into natural gas pipelines • Limited deployment • Currently, often a byproduct of fossil fuel production
Kinetic energy storage (flywheels)	• Fast response • High charge-discharge cycle • High efficiency • Lifespan of over 20 years[63]	• Limited discharge time • High standing losses
Pumped Storage Hydropower	• Cost-effective • Supports grid reliability • Provides back-up support to wind and solar generation • Tested technology • Clean and flexible	• There can be issues with reduced efficiency • Drought • Limited geographic availability

The sizing of the energy storage system for clean energy microgrids is of crucial importance for operational and economic considerations. If a storage system is sized too small, it might not be able to deliver energy to critical loads during a power outage when the microgrid is islanded, decreasing resilience benefits. For clean energy microgrids, it is especially important to estimate how long a microgrid might have to operate in place of the larger grid — days, weeks, or months, as this will affect the type and size (power and energy) of both installed generation, and more importantly, of installed storage.[64] If, however, the installed energy storage system is too large, the microgrid might become uneconomical and cost-prohibitive as the storage system will not charge or discharge enough to recover its cost. Overall, the costs of lithium-ion batteries have been decreasing substantially[65] and will continue to become more cost effective as the cost drops. Storage is also a key component for resilience, enabling the microgrid to operate during variable periods of solar and wind, and providing cost benefits by charging during times when wind and solar are abundant and prices are low or even negative and by discharging during peak demand when energy prices rise. This can avoid more expensive front-of-the-meter energy consumption.

Batteries

The most prevalent storage technology paired with renewable energy in microgrids is batteries. These include lead-acid, lithium-ion, redox flow, and other batteries. Prices for batteries have fallen dramatically over the past decades; however, constraints on lithium and other minerals used in battery manufacturing might affect prices going forward.

Box 4: Supporting Grid Resilience with Batteries

Several clean energy microgrids have relied on batteries to supply energy during a grid outage. Duke Energy's McAlpine microgrid test site in Charlotte, North Carolina, includes a 50-kW solar installation and a 500 W lithium-ion battery. The clean energy microgrid serves a fire station and was able to continue operation during thunderstorms and Hurricane Hermine in 2016. A test run showed that the clean energy microgrid was able to sustain energy for up to 26 hours.[66] A redox flow battery was used in a solar plus storage microgrid project in San Diego County. DOE outlines the ability of redox flow batteries to get to full power in sub seconds, to sit idle without minimizing capacity, and to discharge power for up to 12 hours at a time.[67] The battery can store 8 MW hours of energy and power thousands of homes with zero emissions.[68]

Aside from the resilience benefits of supporting variable renewable energy resources, batteries can also provide system support to microgrids through peak shifting and frequency regulation.[69] For example, battery systems can determine the most appropriate time of day to charge and discharge the battery depending on availability of the needed resource such as sunlight or wind power and customer or system peak demand. Similarly, the battery can charge and discharge depending on various frequencies. Frequency regulation is of particular concern to renewable energy microgrids supplied by an intermittent energy source, so the battery can provide stability, especially when connected to an inverter utilizing frequency watt control.[70] This is valuable when a microgrid is going between grid-connected and islanded mode, as the frequency will need to be adjusted to that of the main electric grid.[71]

Many of these battery systems will be tested at the National Renewable Energy Laboratory's Flatirons Campus, which has set up a "Fort Renewables" to mimic a military base design and test renewable energy plus battery microgrids in collaboration with the U.S. Department of Defense. The projects at "Fort Renewables" will be tested against various scenarios to determine the most appropriate and resilient battery design.[72] Overall, batteries are seen as a better alternative to diesel generators for the Department of Defense because the diesel generators currently in use are outdated, which increases the risk of potential leaks or mechanical challenges. These generators are also unable to provide support during outages beyond a few days and there are concerns with getting fuel delivered and increased emissions.[73]

Concerns with batteries remain – the significant cost, the limited charge density for redox batteries, the use of critical materials produced mainly outside of the United States, and the environmental impact for lead acid batteries are all challenges large-scale battery deployment face.

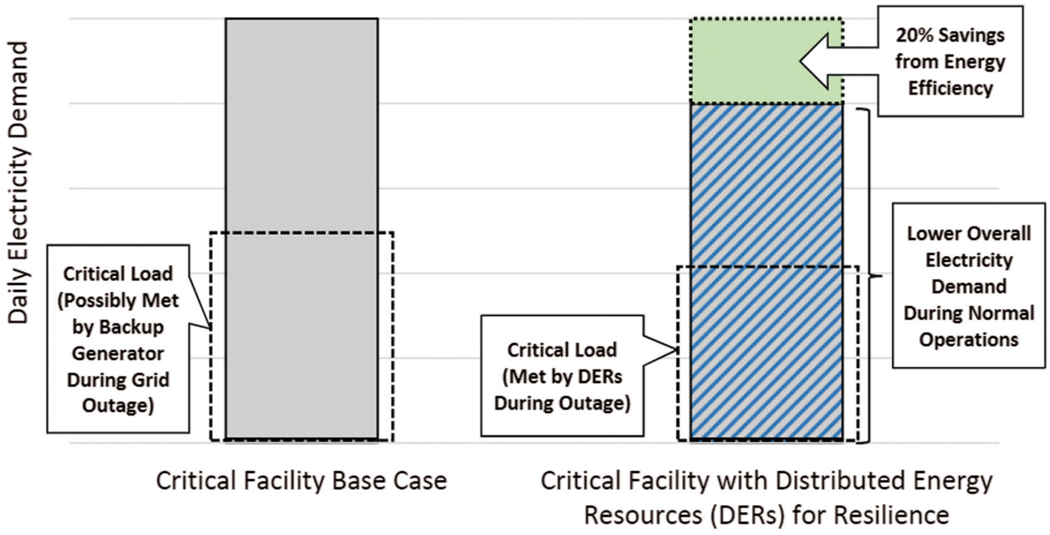
Kinetic Energy Storage (Flywheels)

Depending on the geography, microgrids might be able to take advantage of other storage options in place or in addition to batteries. Kinetic energy storage, or flywheels, allow for injecting or absorbing large amounts of energy almost instantly.[74] There is no friction loss when using a flywheel, no environmental impact, and minimal wind resistance.[75] Kodiak Island in Alaska, the second largest island in the United States, is powered by a microgrid comprised of 28 MW of hydropower and wind. Hydropower comprises about 76 percent of the electricity generation and a wind farm of six 1.5 MW wind turbines provides an additional 23 percent.[76] The microgrid is not connected to the larger power grid and is the only source of electricity for about 15,000 island residents and the island's port operation, which includes several large fish processing plants and transport cranes. In addition to the renewable energy generation sources, the microgrid includes a 3 MW battery energy storage system and two flywheel energy-storage devices. These flywheel devices were installed when the port of Kodiak Island wanted to install additional cranes while not increasing its reliance on diesel generators. Diesel generators require costly and complex fuel delivery, especially in Alaska, and produce harmful emissions. The operation of the large cranes requires a large surge of electricity, which is a significant burden on the microgrid. To enable the operation of the crane, it was connected to a 2 MW flywheel system. The system is charged when the crane lowers a cargo container, and the electricity is discharged when the crane is lifting a container. In addition to electricity stored, the flywheel system is also used to smooth out fluctuations in electricity generated by variable wind resources. The system enabled Kodiak Island's microgrid to save costs on diesel barged in for its generators and to decrease its emissions while expanding its port operations.[77]

Energy Efficiency and Load Management

In addition to generating clean electricity from a variety of sources, right sizing clean energy microgrids through energy efficiency measures and efficient load management will achieve additional emissions reductions and cost savings. There will also be an increase in resilience by reducing the need to generate and store electricity while operating the microgrid in island-mode or grid-connected mode (**Figure 3**).

Figure 3: Distributed Energy Resources for Resilience: Before and After Energy Efficiency and DER Investments[78]



A central controller in a microgrid monitors the system, coordinates distributed energy resources, balances loads, and disconnects or reconnects the microgrid to the larger grid. Smart controls and advanced inverters can provide targeted load management in an emergency, reducing energy needs by diverting energy to only critical loads within a building. Several innovative approaches to load management and microgrid controls are currently being implemented. The California Energy Commission (CEC) awarded funding for the first renewable energy microgrid at a hospital in the state. The microgrid includes solar panels and batteries, which led to a significant reduction in the run-time of diesel generators, decreasing emissions and costs. Notably, the project developed a novel microgrid controller, which optimizes both technical and financial performance. According to the CEC, the microgrid controller "can island the hospital's life safety emergency power branch, including emergency lighting and exit signs, and provide power services during emergencies. During non-emergency periods, the controller enabled the microgrid to achieve performance goals such as reducing utility energy consumption, site peak load, and utility costs with the capability to participate in demand response and electrical islanding."[79]

The Maryland Energy Administration funded a project to support the development of a clean energy microgrid with innovative controls in an affordable housing community in Fairmount Heights. The project will include six single-family homes available to first-time homebuyers that earn 80 percent or less of the area's median income.[80] The homes connected to the microgrid will be required to meet several energy efficiency standards, including DOE's Zero Ready Energy standards and the Passive House Institute's certification[81] that requires several key criteria to be met including a maximum annual heating and cooling energy use rate.[82] The BlockEnergy Smart Platform combines solar panels, energy storage and a smart distributed control system into one networked microgrid that can island from the grid in case of a power outage. The utility-owned infrastructure combines up to 50 homes at a time in a mesh network, with the possibility to link multiple neighborhoods.[83]

In California, EcoBlock is a new CEC-funded project that aims to couple energy efficiency with a renewable energy microgrid. The construction of a block-level solar-powered microgrid is planned for spring 2023 and will include energy retrofits, water efficiency upgrades, and electrification of appliances and building equipment to improve community resilience in Oakland. The project is designed to be equitably developed in collaboration with the community.[84]

Potential New Clean Energy Generation and Storage Sources for Microgrids

In addition to the clean energy sources discussed above, new and emerging clean energy resources are potential options for microgrids to generate electricity with reduced or no emissions. A few of these technologies that could be used for clean energy microgrids are discussed below, although there may be other supportive technologies that will be developed in the near future.

Nuclear Microreactors and Small Modular Reactors (SMRs)[b]

Nuclear microreactors are smaller, simplified versions of conventional nuclear reactors. Their size ranges from 1-20 MW (sometimes under 50 megawatts electric (MWe)) and they are defined by three main features:[85]

1. All components are assembled in a factory and shipped to the installation location. This eliminates the need for construction on-site.
2. Due to their small size, microreactors are easily transportable by truck, ship, airplane, or rail.
3. Microreactors do not require specialized skills to be operated due to their simple and responsive design and include safety features that prevent overheating or a nuclear meltdown.

Microreactors are likely to be deployed in the near term with some experts estimating that microreactors will be ready for deployment either for remote or grid-connected pilot projects in the next 3 to 4 years,[86] and others seeing a slightly longer timeframe — until 2030 for pilot projects and commercial development between 2030 and 2040.[87] In April 2022, the U.S. Department of Defense announced that Idaho National Laboratory will build the first electricity-generating nuclear microreactor in the United States. This pilot will let the Department of Defense determine, at a later date, if the technology will be used in other operations.[88]

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[b] For more information on nuclear energy, see NARUC's publication, Nuclear Energy as a Keystone Clean Energy Resource.

Challenges for implementation remain. For example, many current microreactor designs envision the use of high-assay, low-enriched uranium (HALEU) fuel, which is not yet commercially available in the United States.[89] This is complicated by the fact that Russia is one of the major suppliers of HALEU. There is a facility under development in Ohio from Centrus Energy that is the first to be licensed in the United States. for HALEU production.[90] In 2021, the IIJA provided funding to DOE to support further deployment of nuclear energy. DOE intends to use the funding, in part, to establish a HALEU Availability Program to further its commercial deployment in the U.S.[91]

Slightly larger than microreactors are Small Modular Reactors (SMR). SMRs are small nuclear reactors that have about one third of the generating capacity of conventional nuclear power plants,[92] or about 50-300 MWe.[93] In the United States, light water-cooled SMRs are under licensing review by the Nuclear Regulatory Commission, with a deployment target of the late 2020s or early 2030s.[94] SMRs not only generate electricity but are also capable of producing heat and other byproducts such as clean hydrogen.[95] As SMRs have smaller generation capacity and a faster ramp up time, they would also be ideally suited to be right sized for certain types of larger microgrids and used to balance the variableness of renewable generation. In addition, the long-lasting fuel design makes SMRs an appealing clean energy alternative to diesel generators.[96] However, there are currently no microgrids powered by SMRs in the United States, as reactor technology is still being developed.

When microreactors and SMRs are ready for commercialization and become available for integration with renewable energy microgrids, several challenges might hinder full-scale adoption, including costs, fuel needs (see previous above), siting and safety considerations, regulatory hurdles, and long-term storage needs for nuclear waste. While their small size makes them suitable for microgrids, it also presents the units with a greater security and proliferation risk as a target of fuel theft, especially for those designs using HALEU. New safety regulations geared toward microreactors and SMRs also might be necessary and could further delay deployment. Additionally, a May 2022 study outlined that SMRs could produce more voluminous and chemically reactive waste than existing Light Water Reactors (LWRs).[97] This will require additional considerations regarding the long-term storage of waste products.

Another challenge is the potential cost of microreactors and SMRs. Estimates currently range from between $0.14/kWh and $0.41/kWh for the first two-unit 5 MWe microreactor, with costs expected to fall to $0.09/kWh–$0.33/kWh as numbers of deployed microreactors increase to around 50.[98] However, the microgrid's location and benefits might outweigh potential costs for using a microreactor or SMR as power source. A microgrid in Alaska, which currently depends on diesel fuel that is brought in by airplane, for example, could be one of the sites that would benefit from a microreactor or SMR despite the cost. The cost of fuel is already comparable and electricity costs for small rural communities in Alaska were around $0.35–$0.60/kWh in 2020.[99] A microreactor or SMR would also help remote communities mitigate against fuel supply challenges, and energy security risks stemming from a reliance on fuel being brought in by plane, ship, or pipeline, which increases energy security risks. Additionally, SMRs or microreactors could replace diesel generators in rural microgrids and be paired with wind or solar generation, potentially reducing both costs and emissions.

Low-Carbon Hydrogen and Fuel Cells

Low-carbon hydrogen is low- or zero-carbon hydrogen, made by using clean energy (renewable or nuclear electricity) to split water into oxygen and hydrogen through electrolyzation.[c] Low-carbon hydrogen could be a valuable option to reduce carbon emissions from microgrids through two paths – power to hydrogen or hydrogen to power. For the power to hydrogen concept, an electrolyzer is used to create hydrogen as described previously. The second option, hydrogen to power, uses a fuel cell powered by hydrogen to create

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[c] For more information on hydrogen, see NASEO's publication, Hydrogen: Critical Decarbonation Element for the Grid, Manufacturing, and Transportation.

electricity for the microgrid. A fuel cell uses hydrogen and oxygen to produce electricity, generating water and heat as byproducts.[100]

A microgrid installed in Sonoma, California, uses the power to hydrogen concept to successfully run nearly emissions free. The Stone Edge Farm microgrid includes a PV installation, batteries, and an electrolyzer. When the batteries are fully charged, and the PV panels are still generating electricity, the electrolyzer is used to produce hydrogen. The produced hydrogen is stored and used on-site by a fuel-cell or by hydrogen-powered vehicles.[101] The microgrid remained operational during a 2017 wildfire that caused the farm to be evacuated. However, due to safety concerns, the hydrogen production was turned off during the 10-day evacuation period, as hydrogen is highly flammable.[102] The highly combustible nature of hydrogen is one of its disadvantages, especially when it is considered for microgrids that might be located in wildfire-prone areas. Additionally, the cost of hydrogen prevents it from being competitive with cheaper fuels in most places in the United States. DOE's Energy Earthshot Initiative, launched in June 2021, aims to reduce the cost of clean hydrogen by 80 percent to $1 per 1 kilogram within a single decade. This would enable clean hydrogen to compete with more carbon-intensive fuels.[103]

Advantages of low-carbon hydrogen, especially for use in microgrids, include the small footprint of electrolyzers and fuel cells. Both electrolyzers and fuel cells are highly modular and can be appropriately sized for different loads. Fuel cells are usually stackable, which means they can be scaled to any size appropriate for the intended application. Electrolyzers also come in a variety of sizes – some are small, appliance sized, whereas others can be large-scale generation facilities.[104] Additionally, as the Stone Edge Farm microgrid showcases, renewable hydrogen can be used to store electricity produced by renewable energy and then used when PV panels or wind turbines are not producing electricity. Renewable hydrogen is therefore an additional storage component for microgrids, augmenting batteries as described above. This also means that they have the potential to provide the same services as batteries, such as load shifting and peak shaving.

Montgomery County, Maryland, recently opened the Brookville Smart Energy Depot, powered by a microgrid made of solar panels, onsite battery storage, and backup generation both to charge the county's electric buses and, down the line, to produce renewable hydrogen fuel for fuel cell-powered vehicles.[105] In the future, the county envisions replacing the use of compressed natural gas for buses that service more rural routes and which will need to have a longer range than electric buses. Microgrids that use renewable energy to produce hydrogen or charge electric vehicles can not only reduce emissions in the transportation sector, but also increase resilience in the event of electrical outages. This is especially important in regions where evacuations of large populations might become necessary (i.e., hurricane zones).

New Battery Technologies

As mentioned above, conventional batteries, such as lithium-ion batteries, have challenges that might affect their ability to provide energy to microgrids when the microgrid is islanded and when power needs to be provided over a long period. Additionally, batteries rely on critical materials and rare earth elements, which struggle with supply chain concerns and national security implications. An alternative storage technology under development is iron-air batteries. These batteries would store energy for long durations using iron, an abundant and inexpensive resource. Progress on deploying iron-air batteries has been hampered by concerns about low efficiency and limited life spans.[106] However, in 2021, Minnesota cooperative Great River Energy announced a 1 MW pilot project with a new form of iron-air battery, designed to provide long-duration storage at less than $20/kWh, far below the current costs of lithium-ion batteries of $137/kWh in 2020. The project is anticipated to come online in 2023. Georgia Power has also announced a project using the technology, pending regulatory approval. Whereas both projects are on a larger scale, the iron-air technology could be applicable to microgrids as well, since the system is modular and can be scaled up or down in size.[107] Pairing wind and solar generation with a small iron-air battery may offer a clean energy microgrid at a lower cost and with a longer duration of energy storage, providing resilience benefits without emissions during islanding.

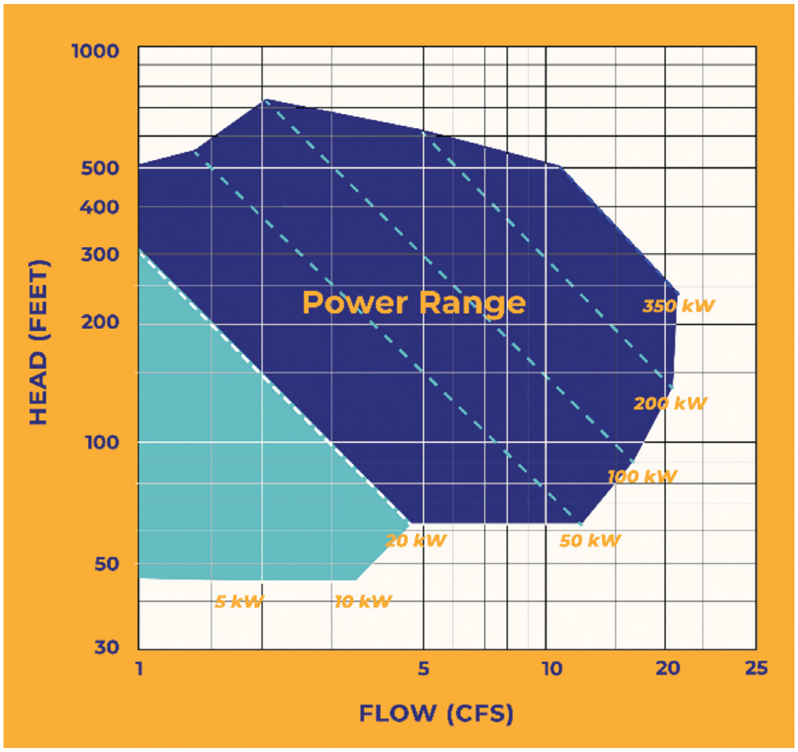
Other potential opportunities are zinc-air batteries that are already being deployed and magnesium air batteries, which are also under development.

Micro-Hydroelectric Systems

As mentioned previously, hydropower is the oldest form of renewable energy and provides almost one-third of U.S. utility-scale renewable energy generation. However, hydropower is not always geologically feasible on a microgrid scale. A potential opportunity to harness hydropower for microgrids could be the use of pressure reducing valves (PRVs). PRVs are commonplace in the U.S. water system and are used to reduce water pressure caused by elevation change. Water pushes against a spring or air or a combination of the two and thus dissipates energy, which reduces pressure downstream.[108] PRVs can be replaced with systems that harness the energy that the PRV releases. The Skagit Public Utility District (PUD) in Washington installed such a micro-hydroelectric system in 2021 to generate electricity from the excess water pressure in its water systems.[109] The system can produce more than 90,000 kWh of electricity annually.[110] The Hillsboro Stadium in Oregon is another example of the use of the system.[111] A Colorado State Energy Office report from 2016 estimated "that there is conservatively 20 to 25 MW of hydropower potential in replacing PRVs[112] systems. Detailed case studies of two water districts in Colorado found a range of 139,880 kWh to 375,000 kWh that could be produced annually.

The company that installed the systems at the Skagit PUD and the Hillsboro Stadium estimates power ranges, depending on the flow and drop of the water, of between 5 kW and 350 kW (**Figure 4**).

Figure 4: Estimated Power Ranges of Converting Pressure into Electricity[113]



Water utilities and districts and other entities like the stadium in Hillsboro could benefit from installing micro-hydroelectric systems, such as enhanced PRVs, to reduce costs on-site, reduce reliance on grid electricity and enhance resilience. By adding batteries or other forms of storage, these micro-hydroelectric systems also could provide clean electricity to small microgrids – enabling resilience while decreasing emissions.

Geothermal Electricity Generation

Geothermal has only recently been considered for clean energy microgrids. Geothermal energy uses hot water from reservoirs below the earth's surface to generate electricity to be used for heating and cooling. The hot water is brought to the surface through deep wells. In the United States, geothermal energy generates about 16 billion kWh or 0.4 percent of utility-scale electricity generation in seven states, mainly in the West.[114] An example of a microgrid using geothermal power energy is at the Chena Hot Springs Resort in Alaska. To reduce reliance on a diesel generator, the resort worked with United Technologies Incorporated to install an Organic Rankine Cycle (ORC) system, which enables use of the relatively low geothermal temperature prevalent in Chena Hot Springs. When the 400-kW facility was installed in 2006, the resort reduced its energy costs significantly and decreased reliance on fuel purchases.[115] In the first 26 months of operations, fuel savings amounted to $650,873, despite a 116 percent increase in load due to additional installations, such as a greenhouse. Operation and maintenance and debt load for the project are about $73,500 per year.[116]

Geothermal is an inherently clean energy source - geothermal fields emit about 17 percent of CO2 produced by a natural gas plant on a per-MWh basis.[117] Geothermal has a long-life span and because of its predictability, it is considered a baseload resource in contrast to more variable wind and solar generation.[118] However, geothermal resources also are locationally dependent and are often located far from load centers.[119] Additionally, costs to develop geothermal resources are high, particularly with the need for exploratory drilling. Reducing some of the risk associated with drilling could lead to lowered costs. Despite its challenges, new types of geothermal energy systems could become an option for clean energy microgrids.

Geothermal Heat Pumps

Geothermal heat pumps (GHPs), also known as ground source heat pumps, transfer heat that was stored underground into buildings during cold temperatures and back out during hot temperatures.[120] For example, the Massachusetts nonprofit Home Energy Efficiency Team (HEET) has developed a GeoMicro District concept, which uses geothermal energy to heat and cool buildings. The system could operate as an islanded microgrid or be interconnected to form a larger network. An application from the utility Eversource to develop a pilot project was approved by the Massachusetts Department of Public Utilities and the project began with the design phase in 2022.[121] In Idaho, Blaine County applied for a Federal Emergency Management Agency (FEMA) Building Resilient Infrastructure & Communities (BRIC) grant to support a feasibility study for a microgrid combining solar, wind, and geothermal heat pumps to power several critical facilities, such as a medical center, a jail, a waste water treatment plant, and an emergency operations facility.[122]

Considerations for State Energy Offices and Public Utility Commissions

State Energy Offices and public utility commissions have multiple policy and regulatory options to support the development and deployment of clean energy microgrids that enhance resiliency for the electricity grid and benefit customers. Potential options for State Energy Offices and Public Utility Commissions to support the development and deployment of clean energy microgrids are outlined in the next section. Appropriate policy and regulatory opportunities will vary by state.

Microgrid Tariffs Specifically for Clean Energy Microgrids

In 2021, the California Public Utilities Commission created a microgrid tariff for its investor-owned utilities, a development spurred by state law SB 1339, which required regulatory changes to support microgrid development.[123] The Commission ruled that only net energy metering (NEM) eligible resources are eligible to receive the microgrid tariff – for microgrids using NEM-eligible and non-NEM eligible resources only the NEM-eligible portion will be able to apply for the microgrid tariff. This includes storage resources allowed under NEM. The ruling is geared to incentivize clean energy microgrids and constrain the use of fossil fuel back-up generation. However, through a Working Group, California is still addressing questions such as whether energy exports from a microgrid that were generated by non-renewable resources should be compensated and if so, what level of compensation would be prudent.[124]

Developing a microgrid tariff that specifically incentivizes clean energy microgrids is a regulatory approach, which can strengthen the value stack for such microgrids beyond providing immediate resilience benefits for microgrid customers. Such a tariff would have to address cost-shifting to non-participating customers, the value of resilience benefits, and the value of clean energy to the grid if net-metering compensation is not available. To develop a microgrid tariff, public utility commissions could order the creation of a working group to study and advance the implementation of a microgrid tariff, similar to the approach both California and Hawaii took when they implemented a microgrid tariff in 2021. Working groups that bring together relevant stakeholders such as utilities, DER developers, marginalized communities, other state agencies, and customers allow public utility commissions to consider a variety of viewpoints in creating a microgrid tariff. A first step for a regulatory framework could also include the development of a roadmap or report based on the working group meetings.

In developing microgrid tariffs or other financial incentives, energy justice considerations are crucial. Marginalized communities are most often disproportionately affected by poor air quality, and microgrids relying on fossil fuel-based generators would only further exacerbate the problem. The California microgrid tariff rule also includes a requirement for the utilities to develop a $200 million microgrid incentive program. The program will fund clean energy microgrids for vulnerable communities that are facing power outages as well as pilot new technologies and regulatory approaches.[125] It is important that such a fund takes the need of communities into account and allows them to decide what the right approach for enhancing resilience and air quality is in their community. Additional options to incentivize the development of clean energy microgrids in disadvantaged communities could be specific financial grants (see section below for IIJA-related funding for microgrids) or a carve-out in RPS or CES (see below).

Adoption of Relevant Technical Standards

In 2020, NARUC adopted a resolution recommending that public utility commissions adopt and implement the IEEE Standard 1547-2018 for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interface.[126] This voluntary standard requires distributed energy resources to be able to provide grid supportive functionalities relating to voltage, frequency, communications, and controls.[127] Public utility commissions are the state agencies with authority to adopt this standard. As of September 2022, only Minnesota, Maryland, and Hawaii had adopted the standard, with 13 states and the

District of Columbia having initiated an inquiry or an open docket.[128] In expansion of previous iterations of IEEE-1547, IEEE-1547-2018 addresses microgrids by giving "special exemptions to DERs in intentional islands from the ride-through performance and trip requirements and allows them to disconnect from the grid and form an island as long as certain power balance criteria are met."[129] In addition to adopting IEEE-1547, public utility commissions might want to consider standards and considerations of when microgrids can island from the larger electric grid to provide clarity to the utilities and operators of the larger grid and microgrid developers.[130] While important for all kinds of microgrids, this might become especially important for grid-connected clean energy microgrids, which derive some market value from supplying the larger grid with clean energy. Clean energy microgrids connected to smart inverters also can provide grid support functions such as voltage regulation, frequency support, and ride-through capabilities.

Expanding Renewable Portfolio Standards

As clean energy technologies are evolving, states have begun to include additional resources by expanding RPS into CES. CES typically include zero emissions resources that are not considered renewable energy, such as nuclear energy. To strengthen opportunities for new clean energy generation well suited for microgrids such as small modular nuclear reactors or microreactors, more states could consider expanding their RPS into a CES. Additionally, states could consider if their definitions of renewable or clean energy needs to be updated in light of new clean energy technologies. Other considerations could include specific carve-outs for clean energy microgrids to fulfill RPS requirements or requirements for clean energy microgrids to be located in energy justice communities. While RPS would only apply to utility-owned microgrids, states could also consider expanding their Renewable Energy Certificates (RECs). Grid-connected microgrids that pair renewable energy with fossil fuel backup systems could earn RECs when they export renewable energy to the grid, and continue to operate fossil fuel generation during any absence of solar and wind.[131] This could alleviate reliability concerns of microgrid customers considering variable renewable energy sources for a microgrid, particularly without a battery system, and allow for a gradual emission reduction until further energy storage or non-variable clean energy generation sources are installed. RPS could also be extended to gas utilities and require them to add an increasing percentage of renewable natural gas to their sales. In turn, recipients of government incentives for renewable natural gas would need to be required to purchase renewable natural gas.

Incentives and Financial Grant Support of Clean Energy Microgrids

To support new and innovative clean energy technologies, states could provide grant funding to overcome market risk aversion or decrease initial deployment costs until the costs decline. The IIJA passed in November 2021 opens additional microgrid funding, which states, tribes, and developers could access. In a review of the IIJA provisions, Think Microgrid estimates that the legislation includes more than $41 billion for grant programs, studies, and working groups relevant to microgrids.[132] A few provisions in IIJA of note are sections 40101, 40103, 40106, 40107, and the highway infrastructure program.

Section 40101 provides $5 billion over five years, 50 percent of which will be provided to states via a formula program established by DOE to increase the resilience of and harden the electricity grid. Eligible activities include the use or construction of battery-storage. While microgrids are generally eligible to receive funding, grant funding cannot be used to construct electricity generation. Section 40103 includes financial assistance to remote and rural areas, including for the development of microgrids, and section 40106 establishes a $2.5 billion revolving loan fund for transmission facilities, including connecting isolated microgrids to an existing transmission, transportation, or telecommunication infra-structure corridor located in Alaska, Hawaii, or a territory of the United States. Section 40107 authorizes $3 billion to the Smart Grid Investment Matching Grant Program and expands the program to include grid flexibility and energy storage, and technologies that can mitigate impacts of extreme weather or natural disasters on grid resilience. Finally, the highway infrastructure program stipulates that the new Joint Office between DOE and the Department of Transportation

(DOT) provide technical assistance to support zero emissions charging and refueling infrastructure, including microgrids, and establish and promote a program to support remote renewable energy generation, storage, and grid integration, including microgrids, in transportation rights-of-way.[133] As State Energy Offices and State Departments of Transportation begin to plan for implementation of EV infrastructure funding, considering the development of clean energy microgrids for charging stations would ensure that emissions are not shifted from the transportation sector to the electricity sector.

There are several incentives available that will further spur economic growth of renewable energy microgrids including tax credits and renewable energy credits (RECs). Although there is no federal incentive supporting microgrid deployment, some states have started to develop incentive programs. The California Public Utilities Commission (CPUC) authorized its three largest investor-owned utilities to propose implementation details for formulating a Microgrid Incentive Program (MIP) in 2021 to fund clean energy microgrids.[134] A decision must then be issued by CPUC by early 2023 to officially adopt the implementation plans for the program. There has also been legislation passed by the Colorado State Legislature that led to the development of a microgrids for community resilience grant program.[135] While the Colorado legislation does not include requirements concerning clean energy, the eligible cooperative electric association or municipally owned utility applying for the grant may see further benefits in prioritizing clean energy microgrids in their rural service areas. The program also plans to prioritize proposed projects that have a higher reliance on non-fossil-fuel-based generation.[136] The Public Service Commission of Wisconsin Office of Energy Innovation announced more than $900,000 in grant awards to study Critical Infrastructure Microgrids in the state.[d] Several of the selected awardees are looking specifically at clean energy microgrids. For example, the Bayfield County Highway and Forestry Microgrid study will look at developing a clean energy microgrid for the highway garage buildings which provide critical community services such as snow plowing. On a larger scale, the Appleton Airport microgrid will incorporate rooftop and ground-mounted solar PV, lithium-ion batteries, a CHP system, geothermal, an electrolyzer, and green hydrogen delivery. It will also be supported by generators that will utilize renewable fuels and natural gas.[137] State programs have allowed for innovative project ideas to be deployed and reinforce the role clean energy microgrids can play in community resilience.

Engaging with National Laboratories for Technical Assistance and Modeling Expertise

DOE and its national laboratories are researching topics related to microgrids including new renewable energy technologies, which might be applicable to microgrids; methods to value benefits such as resilience and emissions reductions; tools and planning options for microgrid developers; and policy and regulatory approaches to incentivize renewable energy development including renewable energy microgrids. One example is Idaho National Laboratory's (INL) Net-Zero Carbon Microgrids project, which intends to provide research and tools to increase the use of renewable energy and zero-carbon generation in microgrids. Supported by DOE, INL will provide policy and program support for policy makers, standards-making bodies, and regulators. This will include a planning and decision tool for microgrid planning and design intended to optimize renewable energy and minimize greenhouse gas emissions as well as integrating economic and financial considerations. By including greenhouse gas emissions considerations in the tool, INL hopes to help policymakers and regulators to understand the impact of tariffs and incentives on net-zero carbon microgrids.[138] Tools such as these and technical assistance can provide State Energy Offices and public utilities commissions with additional expertise and allow them to plan for incentives to support clean energy microgrids.

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[d] An interactive map of the projects is available here: [Critical Infrastructure Microgrid and Community Resilience Center Pilot Grant Program (wi.gov).]

Developing Clean Energy Technologies Database and Technology Pathways

New and emerging technologies like nuclear microreactors, innovative battery technologies, clean hydrogen and micro-hydroelectric systems could increase clean energy microgrids' ability to deliver resilience and emissions benefits. However, it can be difficult to understand the costs and benefits of emerging technologies, their viability, and their specific application to microgrids. A clean energy technologies database for generation, storage, and energy efficiency measures for microgrid applications could provide a useful tool Including emissions data, resilience benefits, costs, and technological maturity as well as information on successful pilot microgrid projects using the technology, would provide a robust data set for grant program development, policy setting, and regulatory considerations. Information on which specific technologies could be especially beneficial in certain contexts – for example the high cost of microreactors might only make them economically feasible in remote communities with high energy costs. Potentially developed and hosted by national labs or DOE, this type of easily accessible information would allow communities and developers interested in developing a microgrid to understand if a specific technology is suitable in their context.

In addition to a technology database, State Energy Offices could consider analysis of technological transition pathways for microgrids. For example, fuel cells are often operated with natural gas. Although natural gas still produces greenhouse gas emissions, its use decreases particulate matter and reduces greenhouse gas emissions compared to diesel generators. These technological investments made today will have ramifications for decades to come. As part of the technologies database and pathways analysis, technologies that achieve or help facilitate near-term emissions reduction, vis-à-vis a diesel back up power source, for example, could be considered through an emissions step-down approach. This would include pathways for technologies that currently use fossil fuels, for example fuel cells, that could transition to use of low or zero-emissions resources such as clean hydrogen. National lab resources such as DER-CAM and HOMER could provide modeling support for such studies.

Additionally, State Energy Offices and public utility commissions could benefit from additional data on microgrid deployment and the opportunity to replace diesel back-up generation. While the above referenced DOE database provides some insights into the status of microgrids across the country, a more comprehensive overview and a more extensive determination of all potentially classifiable projects (especially ones that mix clean energy with fossil generation) could be helpful for states. Additional information that could be valuable would be the level of microgrid (building, campus, or community) – often the choice of technology is influenced by the level a microgrid serves. Further, it would be informative to subdivide existing diesel generation in states by:

1. existing standby diesel generators that were retrofit into the microgrid
2. new standby diesel generators
3. existing life-safety diesel generators (which are required by law or regulation) and are unlikely to be replaced.

Conclusion

Microgrids are often considered as a tool to enhance resilience. However, as states are increasingly interested in decreasing greenhouse gas emissions, clean energy microgrids can provide an opportunity to achieve both goals simultaneously. Although challenges such as costs and technological limitations remain, State Energy Offices and public utility commissions have several pathways to support the deployment of clean energy microgrids, such as tariffs, incentives, grants, and the expansion of RPS and CES.

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