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User Objectives and Design Approaches for Microgrids: Options for Delivering Reliability and Resilience, Clean Energy, Energy Savings, and Other Priorities

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Abbreviations

ADC: Aligned Data Centers

ANGB: Air National Guard Base

APS: Arizona Public Service

CEC: California Energy Commission

CHP: combined heat and power

DER: distributed energy resource

DER-CAM: Distributed Energy Resources Customer Adoption Model

DoD: U.S. Department of Defense

DOE: U.S. Department of Energy

ERA: Energy Resilience Assessment

IEEE: Institute of Electrical and Electronics Engineers

KEA: Kodiak Electric Association

kW: kilowatt (capacity)

kWh: kilowatt-hour (energy)

LBNL: Lawrence Berkeley National Laboratory

LMI: low to moderate income

MSWG: Microgrids State Working Group

MW: megawatt (capacity)

MWh: megawatt-hour (energy)

NARUC: National Association of Regulatory Utility Commissioners

NASEO: National Association of State Energy Officials

NJ BPU: New Jersey Board of Utilities

NREL: National Renewable Energy Laboratory

NWA: non-wires alternative

OE: Office of Electricity

PACE: property assessed clean energy

PCC: point of common coupling

PIT: Pittsburgh International Airport

PV: photovoltaics

REC: renewable energy credit

ROW: right-of-way

SDG&E: San Diego Gas & Electric

SEPA: Smart Electric Power Alliance

VoLL: value of lost load

Contents

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 aimed 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.

Based on member input, the MSWG developed two companion briefing papers to answer key questions about microgrids: (1) User Objectives and Design Approaches for Microgrids: Options for Delivering Reliability and Resilience, Clean Energy, Energy Savings, and Other Priorities and (2) Private Sector, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids. Read together, these resources provide readers with an understanding of both why and how customers—whether an investor-owned, cooperative, or municipal utility; federal, state, or local government entity; individual or group of residential, commercial, and/or industrial customers; or other organization—select, design, and pay for microgrid projects.

Microgrids are both a compelling and challenging investment for potential customers seeking solutions to energy supply issues. DOE's Microgrid Exchange Group offers a helpful definition: "[A microgrid is] a group of interconnected loads and distributed energy resources 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 grid to enable it to operate in both grid-connected or island-mode." As a highly customized solution requiring significant study and expertise, customers need to fully analyze the design and operation of a microgrid prior to development.

A microgrid involves four distinct components:

1. **Load(s):** The consumer(s) of electricity. Load can be designated as critical, high-priority, or low-priority. Critical load is uninterruptible, meaning that any disruption of electric service, regardless of duration, is highly costly or may impact human life and safety.
2. **Distributed energy resources (DERs):** The supply of electricity. DERs are generation, storage, and load control (i.e., energy efficiency or demand response) technologies located at the distribution system. DERs can be powered by a range of fuels including diesel, natural gas, and solar power.
3. **Controls:** The management system of the microgrid. A microgrid controller performs multiple functions, including: (a) identifying when and how to connect and disconnect from the grid; (b) maintaining real and reactive power balance when the microgrid is disconnected and operating in islanded mode, and (c) dispatching DERs to support load.
4. **Interconnection/point of common coupling (PCC):** The point at which the microgrid connects to the distribution network. It is at this point that the microgrid controller connects and disconnects to the larger grid.

Customers choose to install microgrids based on a wide range of motivations, which often include increasing reliability and resilience, decreasing electricity costs, expanding access to clean energy, and/or providing power to remote communities (e.g., when extending the existing transmission/distribution grid is infeasible or too costly). Customer motivations are not mutually exclusive; in fact, customers often have multiple motivations for installing a microgrid, such as increasing renewable generation while improving reliability and resilience. This paper cites numerous examples of operational microgrids across the country that represent one or more of these objectives.

After the end user comes to an understanding of why a microgrid or other energy investment may be needed, there are four general steps to arrive at an operational microgrid:

1. Feasibility study;
2. Engineering, design, and business planning;
3. Construction; and
4. Operation.

While construction can occur very quickly, even in a matter of days, steps 1 and 2 require substantial time and data, as these stages entail the majority of a customer's decisions about the microgrid's design. Designating critical loads, generation source(s), interconnection to the larger grid, and control systems are key elements of these initial phases. Decisions around each element are heavily dependent on the characteristics of the customer, local distribution system, and area in which the potential microgrid is to be located, as well as the customer's overarching objectives and motivations for procuring a microgrid. This paper explores each of these motivations and discusses how each one impacts the design of a microgrid, offering multiple case studies of how each objective has translated into currently operational microgrid projects. Across all of these objectives, questions influencing key decision points include:

1. Designating critical loads and energy efficiency investment options, classifying loads across four tiers of prioritization and accounting for opportunities to reduce energy needs through pre-microgrid efficiency measures;

2. Considering a microgrid that connects to multiple facilities and/or across multiple meters and public rights-of-way, recognizing that multi-facility microgrids add complexity but may deliver additional benefits;

3. Selecting generation and storage resources, accounting for policies incentivizing renewable generation, combined heat and power, and biofuels; reliability of liquid/gaseous fuel delivery and availability of fuel storage; availability of wind and solar resources; and environmental considerations;

4. Considering cost drivers, including retail electricity rate structures, energy export prices, non-wires alternatives, and access to competitive energy services markets;

5. Selecting software, inverters, communication, and control systems, considering the impacts of systems on the microgrid's capabilities and overall costs; and

6. Exploring interconnection options and considering where and how to interconnect to the distribution grid in order to minimize added costs.

Using Lawrence Berkeley National Laboratory's Distributed Energy Resources Customer Adoption Model (DER-CAM), the paper next details how various customer objectives results in different design and operational choices. DER-CAM demonstrates that different objectives result in varying combinations of generation and storage resources and operational decisions for an optimal microgrid solution. To illustrate differences in design choices, the DER-CAM model shows that a hypothetical Florida hospital that is focused on reliability and resilience might focus on procuring a solar+storage microgrid with a combined cold storage and flow battery if it needs to be able to operate islanded for three weeks following a hurricane. In another example, the DER-CAM model offers a far more complex configuration for a California warehouse seeking to achieve electricity bill savings: a combination of solar PV, solar thermal, cold storage, controllable central heating capacity, and controllable central cooling capacity to offsets 60 percent of annual electricity purchases. DER-CAM also demonstrates how different objectives influence operational choices and electricity dispatch decisions. For example, a hypothetical Maryland school hosting a microgrid primarily to integrate clean energy resources will pursue a different dispatch strategy for its generation and storage resources than a California warehouse interested in using a microgrid to lower peak demand charges. In all cases modeled, customers continue to partially rely on the local distribution utility under normal conditions, but make use of on-site renewable generation, storage, controllable load, and other investment options to achieve distinct objectives and deliver savings and/or revenue from on-site generation and, where allowed, electricity exports.

The optimal solutions modeled above demonstrate the feasibility of customer-sited microgrids to achieve customer objectives—currently with payback periods of between 16 and 20 years. The length of payback period generally depends on four main factors: (1) current on-site energy consumption and spending, (2) level of energy generation from the microgrid, (3) capital cost of the microgrid, and (4) funding and/or financing arrangements. Customers installing microgrids are diverse and there is significant variation in financial arrangements, ownership and operational structures, and interaction between the microgrid and the local distribution utility, where a utility is present. Readers are encouraged to consult the companion paper, Private Sector, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids, for a more in-depth discussion of funding and financing approaches to microgrids.

Finally, this paper discusses the role of State Energy Offices and Public Utility Commissions in furthering the development of microgrids to satisfy customer and system needs, emphasizing the important role of these entities as conveners to facilitate productive collaboration among diverse stakeholders. Many of the regulatory and policy barriers to microgrid development are complex and have no one-size-fits-all solution. Uncertainty over the regulatory treatment of microgrids, risk of added costs and delays from interconnection queues, lack of valuation methodologies for the full range of benefits provided by microgrids, challenges associated with stakeholder communication and collaboration all present barriers to microgrids. Addressing these barriers will require cooperation not only between State Energy Offices and Public Utility Commissions, but also from regulated utilities, municipalities, microgrid adopters, and other stakeholders. Initial actions State Energy Offices and Public Utility Commissions could consider taking to navigate these obstacles include:

1. **Clarifying the regulatory treatment of microgrids** by developing state-specific definitions reflective of jurisdictional characteristics, needs, and challenges. Multi-customer microgrids are particularly hindered by regulatory uncertainty. Ensuring consistent regulatory treatment of microgrids will remove uncertainty and enable fair consideration of microgrids alongside other energy investments.
2. **Encourage the provision of transparent and current interconnection information** to facilitate timely, cost-effective interconnection for microgrid customers. Several states use pre-application reports to offer information to prospective applicants. States may consider other strategies to help streamline interconnection processes.
3. **Continue to discuss and advance methodologies to value the full range of benefits that microgrids can offer**, particularly regarding energy resilience. Many Public Utility Commissions and State Energy Offices are already considering definitions and valuation methodologies for resilience that more fully account for the impacts of interruptions in energy service, particularly those driven by high-impact, low-frequency events. These efforts are generally outcome-based and not specific to any type of energy resource, which supports a more robust cost-benefit analysis process that will reflect more of the benefits provided by microgrids and other resilience investment options.
4. **Facilitate productive engagement between microgrid adopters and community/stakeholder groups** to identify opportunities for microgrids to provide greater energy, socioeconomic, and/or environmental benefits to both connected customers and the surrounding community. Customers and states have supported numerous examples of microgrids providing a higher level of benefits when multiple parties are involved in development.

The MSWG does not seek to offer prescriptive recommendations State Energy Offices and Public Utility Commissions. Many of the regulatory and policy barriers to microgrid development are complex and have no one-size-fits-all solution. Rather, this paper seeks to (1) illuminate microgrid adopter needs and challenges so that State Energy Offices and Public Utility Commissions can acquire a more complete understanding of barriers to microgrid adoption and (2) highlight successful approaches to problem-solving that can be considered for replication or modification in other jurisdictions. The MSWG will continue to develop additional resources to support these efforts and enable State Energy Offices and Public Utility Commissions to more effectively speed the deployment of microgrids throughout the states, including through sharing challenges faced and lessons learned as states pursue various strategies to address barriers to development.

I. Introduction

The U.S. economy is highly dependent on affordable, reliable electricity, with increasing priority placed on low- or zero-emissions fuels. Several new trends have emerged. Threats to electric service have increased, with electric infrastructure being damaged from more frequent and intense severe weather events, cyber and physical attacks, and other events.[1] Numerous states and utilities are prioritizing the integration of high levels of renewable resources. And communities that lack reliable electricity, whether because of being in remote locations dependent on infrastructure prone to single points of failure, areas prone to frequent and/or severe natural disasters or extreme weather, or other factors, are experiencing substantial costs as a result. In response, state policymakers, state regulators, customers, and other stakeholders have considered various investment options to achieve their state policy goals, balancing considerations for cost, reliability and resilience, and environmental performance. Microgrids are often among these options.

Microgrids can provide reliable, resilient, affordable, clean, and efficient power to public and private customers. Microgrids can complement policy goals around enhancing reliability and resilience, integrating renewable resources, shaping demand to align with supply, and powering remote communities. Customers must decide what their objectives are early in the process of considering a microgrid, identify their jurisdiction's policy and regulatory issues, and design the project in alignment with those priorities and considerations.

In 2019, the National Association of Regulatory Utility Commissioners (NARUC) and the National Association of State Energy Officials (NASEO) jointly established a Microgrids State Working Group (MSWG) with support from the U.S. Department of Energy (DOE) Office of Electricity (OE). The MSWG's objectives were to bring together NARUC and NASEO members to explore the capabilities, costs, and benefits of microgrids; discuss barriers to microgrid development; and develop strategies states can utilize to plan, finance, and deploy microgrids to improve resilience. As NARUC and NASEO convened meetings and activities for the MSWG, members indicated a need for a common definition of a microgrid and its components, terminology for the types of microgrids, and additional information on how the ultimate objectives of the microgrid end user(s) impact design and configuration choices. Microgrids can be a key element of state policy and regulatory planning and decision-making for distribution system, energy resilience, and climate change mitigation and adaptation planning, but understanding the needs of and challenges faced by microgrid adopters is critical to unlocking this potential.

To that end, this white paper examines and summarizes relevant research and analysis from experts at DOE, National Laboratories, electric utilities, microgrid developers, and other relevant entities. While written intentionally for State Energy Offices and Public Utility Commissions, and their staffs to improve understanding of design considerations for microgrids, it can also serve as a resource for customers considering resilience investments, microgrid developers and installers, and other stakeholders.

1 Kate Anderson, National Renewable Energy Laboratory, "Resilient Renewable Energy Microgrids," October 2017, https://www.nrel.gov/docs/fy18osti/70033.pdf

II. Definitions

For this paper, as well as during the microgrid design phase, it is important to use a common set of terms when referring to a microgrid and its components. Potential microgrid customers should enter the microgrid design process with a clear understanding of these terms and their relevance to the customer's needs and objectives. State Energy Offices and Public Utility Commissions, and state legislatures can all play constructive roles in clarifying the regulatory treatment of microgrids through developing state-specific definitions reflective of jurisdictional needs.

As a starting point, DOE's Microgrid Exchange Group developed a broadly accepted definition in 2012:

"[A ***microgrid*** *is] a group of interconnected loads and distributed energy resources 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 grid to enable it to operate in both grid-connected or island-mode."*[2]

This definition involves four distinct components:

1. **Load(s): the consumer(s) of electricity.** Load can be designated as critical, high-priority, or low-priority. Critical load is uninterruptible, meaning that any disruption of electric service, regardless of duration, is highly costly or may impact human life and safety.
2. **Distributed energy resources (DERs): the supply of electricity.** DERs are generation, storage, and load control (i.e., energy efficiency or demand response) technologies located at the distribution system. DERs can be powered by a range of fuels including diesel, natural gas, and solar power.[3]
3. **Controls: the management system of the microgrid.** A microgrid controller performs multiple functions, including: (a) identifying when and how to connect and disconnect from the grid; (b) maintaining real and reactive power balance when the microgrid is disconnected and operating in islanded mode, and (c) dispatching DERs to support load.[4]
4. **Interconnection/point of common coupling (PCC): the point at which the microgrid connects to the distribution network.** It is at this point that the microgrid controller connects and disconnects to the distribution grid.

While DOE's definition is useful, it does not include discussion of how many customers or facilities might be connected to a microgrid, an important consideration during an initial evaluation of a proposed microgrid. The New Jersey Board of Utilities (NJ BPU) has developed a classification system for microgrids according to number of customers (*Figure 1 and Figure 2*):[5, 6]

1. **Level 1 or single customer:** a single DER serving one customer through one meter. Example: a data center using an on-site microgrid to provide backup power.
2. **Level 2 or single customer/campus setting (partial feeder microgrid):** a single DER or multiple DERs serving multiple facilities, controlled by one meter at the PCC. Example: a microgrid sited on a college campus connected to multiple buildings.

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2 Dan Ton and Merrill Smith, U.S. Department of Energy, "The U.S. Department of Energy's Microgrid Initiative," 2012, https://www.energy.gov/sites/prod/files/2016/06/f32/The%20US%20Department%20of%20Energy%27s%20Microgrid%20Initiative.pdf

3 Consortium for Electric Reliability Technology Solutions, Lawrence Berkeley National Laboratory, "Distributed Energy Resource Microgrids," https://certs.lbl.gov/research-areas/distributed-energy-resource-0

4 National Renewable Energy Laboratory, "Microgrid Controls," https://www.nrel.gov/grid/microgrid-controls.html

5 State of New Jersey Board of Public Utilities, "Microgrid," https://www.state.nj.us/bpu/about/divisions/opp/microgrid.html

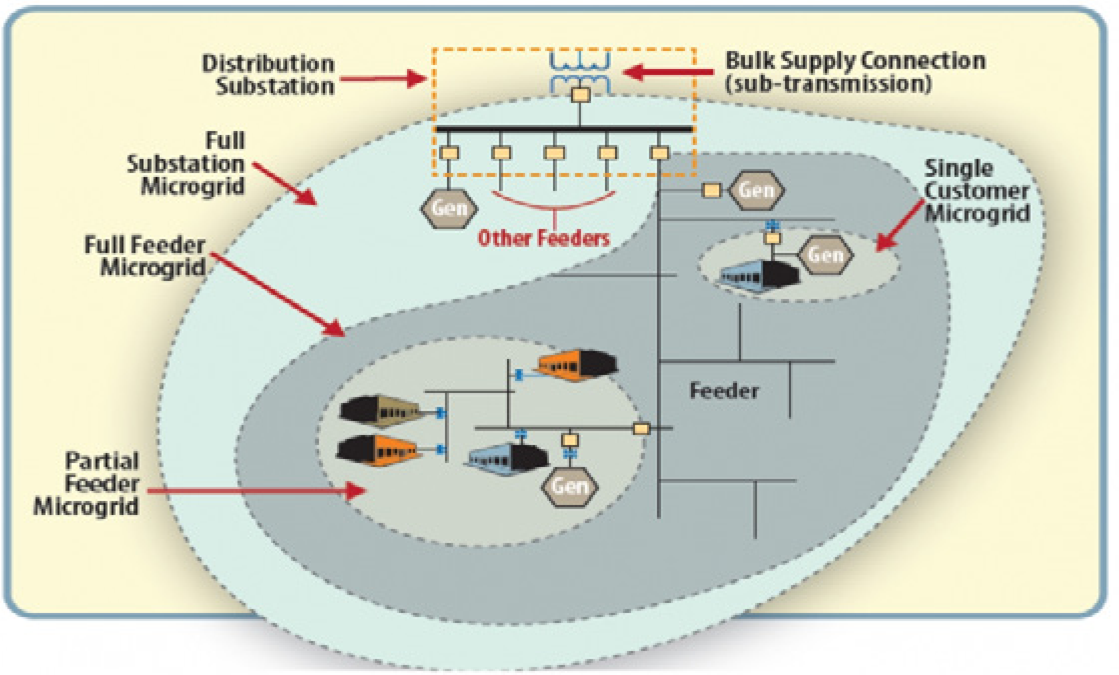
6 Office of Electricity, U.S. Department of Energy, "The Role of Microgrids in Helping to Advance the Nation's Energy System," https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/role-microgrids-helping

3. **Level 3 or multiple customers (advanced or full feeder microgrid):** a single DER or multiple DERs serving multiple facilities/customers on multiple meters. The DER(s) may be located on a different site from the facilities/customers. While the advanced microgrid has one PCC, the individual facilities/customers within the advanced microgrid may have their own individual connections to the distribution grid. Example: a community microgrid connecting multiple buildings with individual meters.

Figure 1: NJ BPU Microgrid Classification

Microgrid Type	DERs	Facilities	Meters	PCC
Level 1	1	1	1	1
Level 2	1+	1+	1	1
Level 3	1+	2+	2+	1

Figure 2: Types of Microgrids



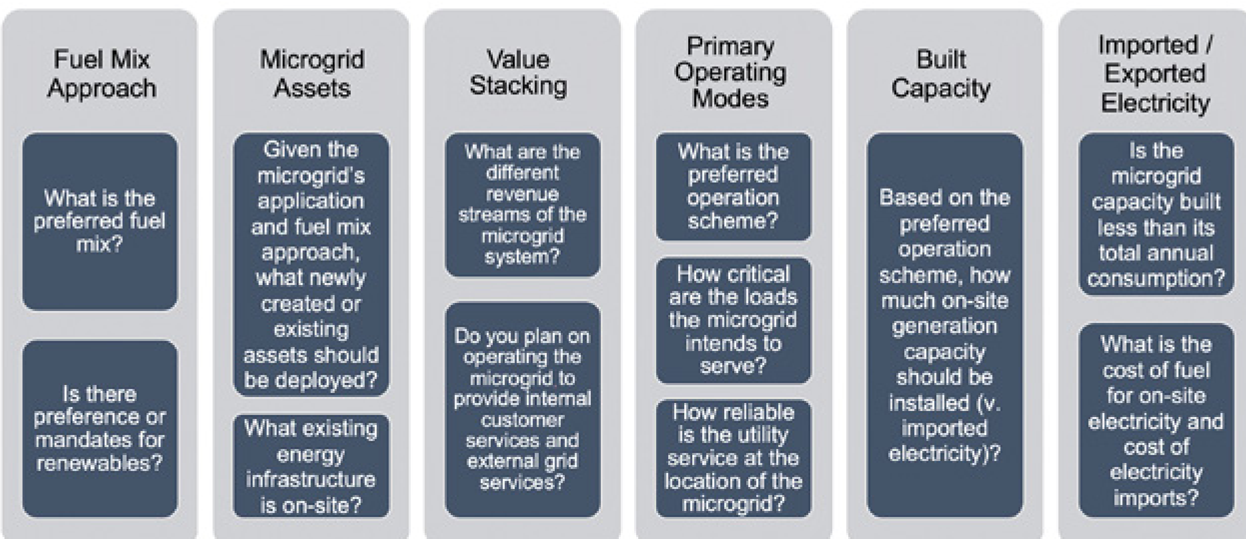
III. Microgrid Decision Points and Design Process

After the end user comes to an understanding of why a microgrid or other energy investment may be needed (see discussion of objectives in Section IV), there are four general steps to arrive at an operational microgrid: (1) feasibility study; (2) engineering, design, and business planning; (3) construction; and (4) operation.[7,8] While construction can occur very quickly, even in a matter of days, steps 1 and 2 require substantial time and data, as these stages entail the majority of a customer's decisions about the microgrid's design.

A feasibility study determines whether and how a microgrid will interact with the proposed facility or facilities and the electric distribution system. The feasibility study will consider options for each of the four distinct components of microgrids and should evaluate potential revenue streams available to the microgrid, such as peak shaving, net metering, demand response participation, and ancillary services.[9] Typically, the cost and time investment required for a feasibility study increases with the complexity of the microgrid. Using NJ BPU's classification system, a Level 1 microgrid would see a relatively brief and inexpensive feasibility study, while a Level 3 microgrid would require significantly more expertise and time. However, regardless of the number of DERs, facilities, and meters involved, an interconnection study can add complexity, cost, and time to a feasibility study. Once a feasibility study is complete, the technical design of the microgrid commences, based on recommendations from the feasibility study. These feasibility and design costs can make up a significant portion of total microgrid costs.[10]

This section discusses the specifics of the design process—how the microgrid customer makes decisions about the four components (load, DERs, controls, and interconnection) and operating modes of a microgrid prior to the construction phase. A microgrid customer will have to consider a number of questions related to each

Figure 3: Preliminary Microgrid Design Considerations



7 Sam Cramer, National Association of State Energy Officials, "Private Sector, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids," December 2020

8 At the end of the life of a microgrid, the project will need to be decommissioned and individual components disposed of according to all applicable regulations. Generators may be able to be resold or recycled. Land dedicated to solar PV or other generation sources typically must be returned to the state it was in prior to the project. While not typically part of the design process, customers should be aware of the estimated operating lifetime of a microgrid and assess the costs of decommissioning and disposal or management.

9 John Vernacchia, Eaton, "Understanding Microgrid & Energy Storage Feasibility Studies," Presentation to Microgrid 2017 Conference, https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=cc2543de-8404-9f4f-f3ce-3fb057d186ad&forceDialog=0

10 Julieta Giraldez et al., National Renewable Energy Laboratory, "Phase I Microgrid Cost Study: Data Collection and Analysis of Microgrid Costs in the United States," October 2018, https://www.nrel.gov/docs/fy19osti/67821.pdf

component, such as: how to designate critical and other categories of load; the optimal amount of distributed generation; whether to make any energy efficiency investments; which types and quantities of DERs to include; what kind of controller to install; and where to interconnect. Engaging stakeholders such as the distribution utility, State Energy Offices and Public Utility Commissions, consumer advocate, community groups, and neighboring electricity customers is also a critical part of the design process. Successful engagement can maximize the social benefits of a microgrid, particularly with regards to increased reliability and resilience, discussed further in section IV.A. Questions influencing key decision points are shown graphically in *Figure 3*[11] and discussed in more detail in subsequent sections III.A–III.F.

A. Designating Critical Loads and Energy Efficiency Investment Options

The first step in assessing the feasibility of a microgrid is identifying critical load needs of the connected facility or facilities. Sandia National Laboratories offers a four-tiered system for classifying load.[12] These terms were initially developed for U.S. Department of Defense (DoD) facilities, but can easily be extended to cover other microgrid customers:

1. **Tier 1:** noninterruptible critical load that must be powered at all times.
2. **Tier 2:** interruptible priority load that should ideally be powered at all times, but can be temporarily interrupted during a disruptive event. (During islanded operations, Tier 2 load may be served as necessary and feasible by the microgrid during islanded operations.)
3. **Tier 3:** nonessential load that will not be powered during islanded microgrid operations.
4. **Tier 4:** loads that are too small to justify the cost of automation and connection to the microgrid, and therefore would not be connected (e.g., streetlights, which would remain connected to the main distribution grid).

Microgrid customers will need to decide how to categorize their facility's or facilities' load across these tiers. Separating Tier 1 (critical) and Tier 2 (noncritical) load may be difficult based on existing electrical infrastructure and interconnections.[13] If the microgrid will be connected to facilities that have yet to be built, load designation decisions should be made early in the construction process so that electrical infrastructure within the facility can ensure support for critical load.

Additionally, a microgrid customer can assess energy efficiency investment options prior to or concurrently with load classification. Efficiency investments can shift demand from system or customer peak to times of lower system or customer demand, offering the potential for cost savings, depending on electric retail rate structure and design. Optimal efficiency investments can both reshape and lower a customer's overall demand, translating into two key impacts to the microgrid consideration process: (a) reducing the required peak generation capacity of a microgrid, thus enabling higher-priority loads to be served during grid outages and (b) impacting the types of DERs that may be suitable for the microgrid.

B. Considerations for Multifacility Microgrids

Another decision point in microgrid design is arriving at the optimal number of facilities that should be connected to the microgrid given critical load and DERs—choosing between a Level 1, 2, or 3 microgrid, as defined by the NJ BPU. A common barrier to Level 3/multifacility microgrids is the ability to operate across

11 Smart Electric Power Alliance, 2020

12 Jason Edwin Stamp, Sandia National Laboratories, "Microgrid Modeling to Support the Design Process," July 1, 2012, https://www.osti.gov/servlets/purl/1140385

13 New York State Energy Research and Development Authority, New York State Department of Public Service, and New York State Division of Homeland Security and Emergency Services, "Microgrids for Critical Facility Resiliency in New York State," December 2014, https://www.nyserda.ny.gov/-/media/Microgrids-Report-Summary.pdf

rights-of-way (ROWs). In most jurisdictions, only regulated public utilities are allowed to distribute electricity to multiple customers across a public ROW, that is, across a street, or "to or for the public."[14] A microgrid seeking to connect facilities across a ROW, or even to supply multiple customers, is generally prohibited from doing so unless it receives permission to operate as a public utility, receives a regulatory waiver to operate across a ROW, or compensates the distribution utility for use of distribution infrastructure. Operating as a public utility is prohibitively burdensome, costly, and complex, and is not a sensible proposition for a microgrid customer or group of customers seeking solely to install backup power on their property or properties.[15, 16] Waivers are rare, although a few examples exist, such as the Burrstone Energy Center microgrid in Utica, New York, which sought to power a hospital, nursing home, and nearby college. In planning the microgrid, Cogen Power Technologies obtained a waiver from the New York Public Service Commission to cross a public ROW to connect to the college. Although the process was "time-consuming and expensive," according to an interview with Cogen Power Technologies staff, the request was ultimately successful and the microgrid was able to serve the college across the ROW.[17] Some states, such as Connecticut, have explicitly allowed municipal microgrid electric distribution lines to cross ROWs, but this exception is not extended to private customers.[18] Resolving cross-ROW issues is complex and uncertain, presenting a substantial barrier to Level 3 microgrid development. California, the District of Columbia, Maine, and New York have taken recent legislative and/or regulatory actions to clarify the regulatory treatment of multicustomer microgrids. Creating a distinct microgrid operator entity, separate from a public utility, is one among several options states are considering as part of regulatory frameworks to address barriers to microgrid development.[19]

C. Selecting Generation and Storage Resources

Microgrids can make use of a wide variety of DERs. As part of the load designation process, the customer will need to understand how much generation is needed, when it is needed, and what (if any) level of intermittency is acceptable. A microgrid serving Tier 1 load, for example, cannot rely solely on intermittent generation resources. Based on these needs and other factors, the customer can select a single DER or a combination of DERs to power the microgrid.

Possible DERs for a microgrid include fuel oil, diesel, natural gas, combined heat and power (CHP), biofuels, solar photovoltaics (PV), wind, and fuel cells, and may be combined with energy storage technologies.[20] Every option has benefits and drawbacks. Selecting the optimal mix of generation and storage resources requires accurate information about load and a complete understanding of available incentives for various resources. Factors that will influence DER selection are discussed below. The following section (III.D) briefly discusses other cost considerations impacting DER selection.

a. *Policies incentivizing customer-sited low- or zero-emission generation, energy storage, and energy*

14 Jacob Geffs, "Statutory Definitions of Public Utilities and Carriers," 12 Notre Dame L. Rev. 246, 1937, http://scholarship.law.nd.edu/ndlr/vol12/iss3/3

15 District of Columbia Department of Energy and Environment, "Deploying Clean Energy Microgrids in the Nation's Capital," Attachment B: Preliminary List of Barriers to Realizing the Full Potential of Microgrids in the District of Columbia, 2015, https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/Attachment%20B%20-%20Microgrid%20Barriers%20by%20Category.pdf

16 Howard Shafferman, Ballard Spahr LLP, "Microgrids: Regulatory Opportunities and Issues," November 10, 2014, https://www.ballardspahr.com/-/media/files/events/eventmaterials/2014-11-10_microgrids_regulatory_opportunities_and_issues.pdf?la=en&hash=9080F5FAF720CDEE071A5DDDD0962312

17 Institute of Sustainable Energy, Boston University, "Multi-User Microgrids: Obstacles to Development and Recommendations for Advancement," November 2018, https://www.necec.org/files/necec/pdfs/Multi-User%20Microgrids:%20Obstacles%20to%20Development%20and%20Recommendations%20for%20Advancement.pdf

18 Matt Grimley, Institute for Local Self-Reliance, "Report: Mighty Microgrids," March 3, 2016, https://ilsr.org/report-mighty-microgrids/

19 Paul de Martini et al., Smart Electric Power Alliance and Pacific Energy Institute, "How to Design Multi-User Microgrid Tariffs," August 2020, https://pacificenergyinstitute.org/wp-content/uploads/2020/08/SEPA-PEI-How-to-Design-Multi-User-Microgrid-Tariffs.pdf. See p. 20.

20 See note 10.

efficiency, such as tax credits, net metering, clean energy targets, property assessed clean energy (PACE) financing, and renewable portfolio standards and credits

Strong policies to encourage and finance renewable generation, including solar, wind, geothermal, and fuel cells, as well as energy efficiency, might make investments in these resources financially preferable to fossil fuels, depending on load characteristics and customer preferences. Whether or not specific incentives for energy storage exist, storage may become an attractive investment alongside renewable generation for microgrids to mitigate some of the localized distribution reliability challenges posed by high penetrations of DERs.[21, 22]

Energy storage can be paired with wind and solar generation to better match generation and load. The customer's needs will affect whether to procure storage, which type(s) of storage to procure, and an optimal charge and discharge strategy for installed storage. With most forms of energy storage capable of discharging power for up to four hours, and able to adjust discharge output to follow load, storage can charge on wind and/or solar power and discharge to serve load in the microgrid when needed, up to the technical limitations of the energy storage equipment. For example, consider a microgrid with Tier 1 load requiring uninterrupted, 24-hour power. If a customer selected distributed solar generation, meeting these needs would require multiple batteries and an oversized solar PV array to enable all batteries to obtain a sufficient charge while the sun is out. Depending on the predicted length of an outage, such a system is likely to be expensive compared with other options and may even be technically infeasible without some level of firm, dispatchable generation (e.g., CHP, biofuels, natural gas generation, diesel generation) instead of or in addition to solar PV and energy storage. On the other hand, a microgrid serving Tier 2 and/or Tier 3 load may find intermittent renewable generation, perhaps combined with energy storage, a more preferable option than CHP or other fossil-fueled generation.

b. *Policies incentivizing distributed CHP and biofuels*

Incentives for CHP and biofuels may make such systems attractive options for potential microgrid customers. Often, policies aimed at encouraging renewable generation and energy storage also cover CHP and biofuels, such as PACE financing. Other policies include payments for energy exports from CHP systems, discounted natural gas rates for customers using CHP, inclusion in state portfolio standards, and others. The U.S. Environmental Protection Agency hosts a database of state and federal CHP incentives and definitions of various policies, and the North Carolina Clean Energy Technology Center's Database of State Incentives for Renewables & Efficiency provides a database of state and federal incentives for biomass.[23]

c. *Reliability of liquid or gaseous fuel delivery to the DER(s), and cost of delivery*

Microgrid customers may be able to rely on a pipeline or other method of delivering fuel to the DER, rather than storing fuel on site. However, customers should consider the reliability, including the potential for interruptibility,[24] and costs of delivery before choosing to incorporate a DER requiring liquid or gaseous fuel

21 Kaitlyn Bunker et al., Rocky Mountain Institute, "Renewable Microgrids: Profiles from Islands and Remote Communities Across the Globe," November 2015, https://rmi.org/wp-content/uploads/2017/04/Islands_Microgrid_Profiles_Islands_Global_Remote_Communities_CaseStudy_2015.pdf.

22 Herman Trabish, Utility Dive, "How Utilities Can Mitigate Grid Impacts of High Solar Penetrations," October 16, 2014, https://www.utilitydive.com/news/how-utilities-can-mitigate-grid-impacts-of-high-solar-penetrations/320407/

23 See U.S. Environmental Protection Agency, "dCHPP (CHP Policies and Incentives Database)," https://www.epa.gov/chp/dchpp-chp-policies-and-incentives-database; U.S. Environmental Protection Agency, "Glossary—dCHPP," https://www.epa.gov/sites/production/files/2015-07/documents/glossary_-_dchpp_chp_policies_and_incentives_database.pdf; and North Carolina Clean Energy Technology Center, "Database of State Incentives for Renewables & Efficiency," https://www.dsireusa.org/

24 Interruptible contracts for fuel delivery are common procurement mechanisms for natural gas-fueled electricity generators. Generators purchase supply and delivery of natural gas, either of which may be firm or nonfirm ("interruptible"). Interruptible contracts for natural gas delivery can be curtailed if demand from firm customers exceeds available supply; interruptible customers may also outbid each other during times of scarcity for natural gas delivery. See U.S. Energy Information Administration, "Today in Energy: Natural Gas Power Plants Purchase Fuel Using Different Types of Contracts," February 27, 2018, https://www.eia.gov/todayinenergy/detail.php?id=35112

into a microgrid. Customers may choose to invest in a combination of fuel delivery and backup on-site fuel storage for when delivery is unavailable.

d. Availability of land for liquid or gaseous fuel storage, and cost of storage

Locations with limited fuel storage capacity may wish to rely on delivered fuels or a resource that does not require a fuel source to run, such as wind, solar, or energy storage. Facilities in dense urban areas or in locations prone to flooding or natural disasters may find the costs of fuel storage to be prohibitively expensive.

e. *Availability of wind and solar resources*

Customers that wish to rely on renewable resources will need ample wind and/or solar to power those DERs. The National Renewable Energy Laboratory (NREL) offers tools to aid in decision-making: the National Solar Radiation Database Physical Solar Model provides solar resource data,[25] and the Wind Integration National Dataset Toolkit does the same for wind availability.[26]

f. Environmental and air quality considerations within and outside of the microgrid

Users of the facilities within the microgrid may have preferences for noncombusting resources.[27] For example, a hospital serving patients with respiratory illnesses may shy away from diesel generators, as burning diesel has detrimental air quality impacts and can exacerbate respiratory problems.

Additionally, many states have permitting processes and rules governing the installment, periodic testing, and operation of combusting generators, typically overseen by the state environmental or air quality regulator. The Retail Compliance Center hosts a database of state permitting options for emergency generators.[28] Some states may relax emergency generator rules during emergencies; for example, California has regulations around the use of backup generators, but the California Air Resources Board has determined that public safety power shutoffs[29] constitute emergency events in which backup generators may be used, temporarily superseding such regulations.[30]

D. Cost Considerations

The payback period for microgrid costs will look significantly different depending on the types of DERs installed, how the microgrid is configured, and load profiles within the microgrid. Site-specific characteristics of distributed generation make generalized comparisons difficult;[31] however, renewable generation sources typically require a larger upfront capital investment but minimal long-term operating and maintenance costs while the reverse is more likely to be the case for fossil generators.[32] Payback periods for microgrid capital costs are highly project-specific and depend on the microgrid funding and/or financing mechanism(s),[33]

25 National Renewable Energy Laboratory, "NSRDB: National Solar Radiation Database," https://nsrdb.nrel.gov/about/u-s-data.html

26 National Renewable Energy Laboratory, "Wind Integration National Dataset Toolkit," https://www.nrel.gov/grid/wind-toolkit.html

27 Combusting resources such as natural gas, wood, or kerosene release gases and particles including carbon monoxide, nitrogen dioxide, fine particulate matter, and formaldehyde, which can cause irritation and serious health problems if inhaled regularly over long periods of time. See California Air Resources Board, "Combustion Pollutants & Indoor Air Quality," https://ww2.arb.ca.gov/resources/documents/combustion-pollutants-indoor-air-quality

28 Retail Compliance Center, "Emergency Generator Permitting Matrix," January 1, 2020, https://www.rila.org/retail-compliance-center/emergency-generator-permitting-matrix

29 During a public safety power shutoff, a distribution utility turns off power during weather conditions that pose a high risk of wildfires. See Pacific Gas & Electric, "Learn about Public Safety Power Shutoff (PSPS) Events," https://www.pge.com/en_US/residential/outages/public-safety-power-shuttoff/learn-about-psps.page

30 California Air Resources Board, "California Air Resources Board Regulations Allow for the Use of Back-up Generators during a Public Safety Power Shutoff," https://ww2.arb.ca.gov/sites/default/files/2019-10/portable_generator_FS_0.pdf

31 Kennedy Maize, POWER Magazine, "The Economic Thicket of Generating Cost Comparisons," April 1, 2019, https://www.powermag.com/the-economic-thicket-of-generating-cost-comparisons/

32 Richard Korthauer, Schneider Electric, "Portable Generators vs. Standby Generators vs. Solar: What's Best?" October 18, 2019, https://blog.se.com/residential/2019/10/18/portable-generators-vs-pad-mount-generators-vs-solar-whats-best/

33 See note 7.

state and federal financial incentives, market access and participation, and other factors. While multiple value streams can be available to a microgrid, depending on the state and/or market in which the microgrid is located, resources must be explicitly configured to participate in those markets.

Retail rate structures for the local electric utility and the presence (or lack) of net metering will also influence microgrid costs and design, as well as the potential selection of renewable DERs. High rates for retail electric service and high demand charges (also referred to as capacity charges[34]) can push a customer to consider on-site investments to lower volumetric charges and/or peak demand payments. Depending on the presence and structure of demand charges or time varying rates, microgrids can be a pragmatic choice for peak shaving. Microgrids configured to export power to the distribution grid can take advantage of net metering rates in which the customer receives a credit equal to the full retail rate for each kilowatt-hour (kWh) of power exported back to the grid. However, as installed net metering system capacity or energy production is reaching predetermined thresholds or at the request of distribution utilities, many states have already completed or have started to transition to net metering successor tariffs, that is, less-than-retail rates for exported electricity.[35]

A case study of the Bridgeport, Connecticut, City Hall Complex Microgrid offers an illustration of revenue streams from a microgrid. The microgrid consists of 795 kilowatts (kW) of natural gas generator sets and 250 kW of diesel generation. The Connecticut Department of Energy and Environmental Protection, the State Energy Office, provided a $2.975 million grant toward the microgrid's capital costs, with the City of Bridgeport covering the remaining $5.3 million. The project was built and is owned and operated by a third party, with an operating agreement designating the share of microgrid revenues to be passed onto the city. Monetized benefits include:

- City savings of $61,000 in reduced electric chilling costs
- Class III renewable energy credit (REC) revenues in excess of $100,000
- Use of virtual net metering credits (with approval from the Connecticut Public Utilities Regulatory Authority) amounting to a $379,680 credit against production costs
- Over the 20-year term of the project, $2 million in avoided capacity charges compared to business as usual
- Nominal profits from sale of hot water from city hall to a connected, privately owned building
- Future participation in ISO-New England markets for demand reduction, ancillary services, and other services, pending the creation of those markets

Microgrids may also be considered as non-wires alternatives (NWAs) in a utility's resource portfolio. *Figure 4*[36] provides a demonstration of how microgrids and DERs can meet varying distribution utility needs traditionally satisfied by large capital investments. For example, if demand in a particular neighborhood or region on the distribution grid is forecasted to increase to a degree that necessitates a feeder or substation upgrade, a microgrid either owned or procured by the utility could be a more cost-effective way to meet those needs than a capital-intensive infrastructure improvement.[37] Importantly, the distribution utility is the entity that will need to assess needs and opportunities for NWAs. The utility may choose to either bid out certain aspects of the microgrid or build, maintain, and operate the microgrid itself, depending on electricity competition and retail choice laws.

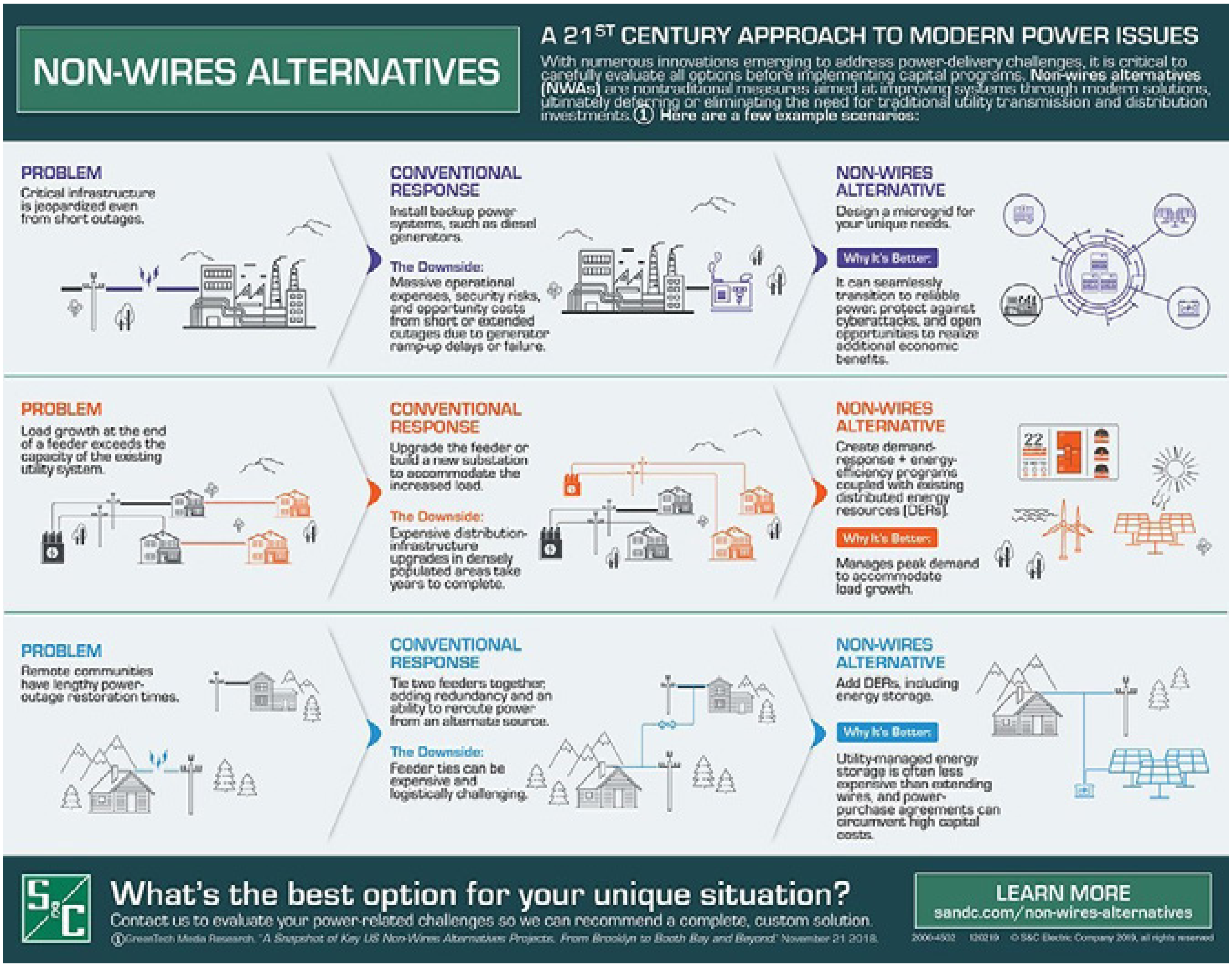
34 Electric Choice, "What Are Capacity Charges?" https://www.electricchoice.com/blog/what-are-capacity-charges/

35 Tom Stanton, National Regulatory Research Institute, "Review of State Net Energy Metering and Successor Rate Designs," July 24, 2019, https://pubs.naruc.org/pub/A107102C-92E5-776D-4114-9148841DE66B

36 Schneider Electric, "Non-Wires Alternatives: A 21st-Century Approach to Today's Power Challenges," https://www.sandc.com/en/solutions/non-wires-alternatives/

37 Cara Goman, ABB, Microgrid Knowledge, "Integrating Renewable Energy into Microgrids: Opportunities, Challenges and Strategies," August 4, 2016, https://microgridknowledge.com/integrating-renewable-energy-into-microgrids/.

Figure 4: Non-Wires Alternatives



Market access and the availability of revenue from competitive markets for particular services[38] can also influence a microgrid's anticipated payback period and how the microgrid is designed. Depending on the size of these markets, a microgrid could be designed to include smart building controls, energy efficiency technologies, and/or advanced inverters capable of delivering services and benefits beyond the microgrid. In recent years, the Federal Energy Regulatory Commission has taken steps toward improving DER access to organized markets with Orders 841 and 2222. Both orders are still being implemented by state public utility commissions and market operators but could facilitate the availability of additional value streams for microgrids.[39]

38 While several independent system operators facilitate organized, competitive wholesale markets for services such as demand response and ancillary services, even states that do not participate in these markets may pursue distribution markets for such services. See Jeremy Klingel and Stuart McCafferty, Black & Veatch, "The Business of Electricity: Will Distribution Markets Dominate?" September 10, 2019, https://www.bv.com/perspectives/business-electricity-will-distribution-markets-dominate

39 See Federal Energy Regulatory Commission, "FERC Approves First Compliance Filings on Landmark Storage Rule," October 17, 2019, https://www.ferc.gov/news-events/news/ferc-approves-first-compliance-filings-landmark-storage-rule; and Federal Energy Regulatory Commission, "FERC Opens Wholesale Markets to Distributed Resources: Landmark Action Breaks Down Barriers to Emerging Technologies, Boosts Competition," September 17, 2020, https://www.ferc.gov/news-events/news/ferc-opens-wholesale-markets-distributed-resources-landmark-action-breaks-down

E. Software, Inverters, Communication, and Controls

Microgrid controls enable continuous stability in normal and abnormal conditions, maintaining power availability throughout the system.[40] Controller costs generally account for between 4 and 11 percent of total microgrid costs, according to a 2019 NREL analysis.[41] Before selecting and configuring a controller, the microgrid customer should assess how often they expect to operate the microgrid in normal grid-connected, islanded, and outage or black start mode.

Advanced inverters and controls can enable automation, interoperability, and communication of a microgrid and its components. Two recently revised standards from the Institute of Electrical and Electronics Engineers (IEEE), a leading developer of industry standards, impact microgrid configuration. IEEE Standard 1547-2018: Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces[42] leverages advances in inverter technologies to specify safe, reliable, and cost-effective interconnection, interoperability, and communication requirements for DERs, enhancing the ability of DERs to provide bulk power system reliability and grid services (e.g., voltage/power control, reactive power, power quality, ride-through of abnormal system conditions) in ways similar to centralized generation resources.[43] Transitioning from grid-connected to islanded mode, microgrid dispatch, and other requirements are enabled through IEEE Standard 2030.7-2017: Specification of Microgrid Controllers.[44] Controllers conforming to IEEE and other industry standards can also enable automatic load shedding (automatically disconnecting part of electrical load within a building when power supply is interrupted).[45] These capabilities are highly dependent on not just advanced inverter and control systems but also advanced communications systems enabling the bidirectional flow of information between the DERs and the distribution system.[46]

Controls are a key feature to enable renewable microgrids. As a 2020 ABB report describes, a microgrid operating with 80 percent solar PV generation could experience massive fluctuations in capacity in very short time periods because of shifting cloud cover. Suddenly losing 40 to 50 percent of generation would be crippling for a utility. For a microgrid, however, a controller, when combined with a diverse mix of DERs and critical load, would be able to call on other DERs to continue to supply critical load, shed noncritical load, and otherwise respond to disruptions to maintain critical functions.[47]

F. Interconnection

Another consideration within a feasibility study is the microgrid's interconnection to the distribution system. Any DER seeking to connect to the distribution system must apply for interconnection and provide data on how the microgrid will affect local feeders and the distribution system to the electric distribution utility. The utility then reviews the application and signs an interconnection agreement with the customer. Interconnection agreements are administered by Public Utility Commissions.[48] Because of the large number of DERs seeking to

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40 See note 38.

41 See note 10.

42 NREL operates an educational website on IEEE 1547-2018, available at https://www.nrel.gov/grid/ieee-standard-1547/

43 Jason Allnutt, Institute of Electrical and Electronics Engineers, "IEEE 1547 and P2800 – DER Interconnection Standards: IEEE Conformity Assessment Program (ICAP)," Presentation to NARUC Winter Policy Summit, February 10, 2019, https://pubs.naruc.org/pub/A56B7605-94BF-097C-41C7-F0CAB7435874

44 David Narang and Michael Ingram, National Renewable Energy Laboratory, "Highlights of IEEE Standard 1547-2018," Presentation to PJM Technical Workshop on DER Integration with IEEE, July 30–31, 2019, https://www.pjm.com/-/media/committees-groups/task-forces/derrttf/20190730-workshop/20190730-item-08-introduction-of-ieee-1547-2018-std.ashx

45 Ward Bower et al., Sandia National Laboratories, "The Advanced Microgrid: Integration and Interoperability," March 2014, https://www.energy.gov/sites/prod/files/2014/12/f19/AdvancedMicrogrid_Integration-Interoperability_March2014.pdf

46 Kelsey Horowitz et al., National Renewable Energy Lab, "An Overview of Distributed Energy Resource (DER) Interconnection: Current Practices and Emerging Solutions," April 2019, https://www.nrel.gov/docs/fy19osti/72102.pdf

47 See note 38.

48 National Association of Regulatory Utility Commissioners, "An Introduction to Interconnection Policy in the United States," https://pubs.naruc.org/pub.cfm?id=5375FAA8-2354-D714-51DB-01C5769A4007

come online, distribution-level interconnection queues can be lengthy, and additional studies may be required, adding cost and time to an application.[49] Utilities are responsible for overseeing interconnection and do so with varying levels of public transparency. Argonne National Laboratory illustrates the importance of sound interconnection policy:

> *"When microgrids are deployed and interconnected to the distribution grids, they will have an impact on the operation of the distribution grid. The challenge is to design this interconnection in such a way that it enhances the reliability and security of the distribution grid and the loads embedded in the microgrid, while providing economic benefits to all stakeholders, including the microgrid owner and operator and the distribution system operator."*[50]

While interconnection can add to the time frame of a project, assessing the present state of the local distribution system and its ability to meet future demands can also illuminate business cases for microgrids from the distribution utility's perspective. However, the lack of uniform public transparency practices and data quality among interconnection regimes is a hindrance to including distribution system data in the microgrid feasibility study and design process.

To counter this hindrance, a growing number of states (12, as of November 2018) offer interconnection pre-application reports. Prospective interconnection applicants can request that a utility provide technical information about a specific point of interconnection prior to formal application. Pre-application reports offer low-cost (but limited) information about distribution grid conditions and can inform applicants of technical limitations that might threaten a project early in the process, rather than after lengthy and costly studies are completed. Reports can also aid applicants in selecting points of interconnection with low costs and little to no detrimental grid impacts. An NREL analysis found that the introduction of pre-application reports by utilities in Massachusetts corresponded with a 24 percent increase in approval rates for interconnection applications for projects of at least 500 kW, suggesting that reports may help increase application approval rates and improve the interconnection process.[51]

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49 An NREL analysis found the median timeline for the full solar PV interconnection process to be 53 days, with timelines increasing with project size and complexity. See K. Ardani et al., National Renewable Energy Laboratory, "A State-Level Comparison of Processes and Timelines for Distributed Photovoltaic Interconnection in the United States," January 2015, https://www.nrel.gov/docs/fy15osti/63556.pdf

50 Ning Kang et al., Argonne National Laboratory, "Interconnection, Integration, and Interactive Impact Analysis of Microgrids and Distribution Systems," January 2017, https://publications.anl.gov/anlpubs/2017/03/134097.pdf

51 Zachary Peterson and Eric Lockhart, National Renewable Energy Laboratory, "Evaluating the Role of Pre-Application Reports in Improving Distributed Generation Interconnection Processes," November 2018, https://www.nrel.gov/docs/fy19osti/71765.pdf

IV. Exploring Microgrid Objectives

Any decision to invest in a microgrid is driven by the customer's needs. Business cases for microgrids have generally developed around four overarching objectives: increased reliability and resilience, bill savings, clean energy integration, and supplying power to remote communities.[52] Below, each objective is discussed in detail. Two case studies of operating microgrids are offered for each of the four use cases. The case studies illustrate customer motivations and demonstrate that the four use cases are not mutually exclusive; in fact, customers often have multiple motivations for installing a microgrid, such as increasing renewable generation while improving reliability and resilience.

A. Increased Reliability and Resilience

A frequent driver of microgrid installation is the customer's wish to improve reliability and resilience, regardless of whether the area is connected to an existing distribution network. Most outages occur in the distribution system.[53] Distribution wires are exposed to multiple hazards, both routine and infrequent. Thunderstorms, high winds, or other severe weather events can cause poles or wires to fall. Squirrels and other animals damage distribution infrastructure. And equipment that enables the distribution system (e.g., substations, transformers) may fail, leading to local outages.[54]

Assessing the Value of Reliability and Resilience

Outages result in costs to the customer in terms of lost activity, spoiled goods, damaged equipment, and interruptions to electricity-dependent services; and broader societal costs associated with repairing damaged infrastructure, rebuilding impacted communities, and foregone economic activity, as well as having detrimental impacts on human health and safety. Extreme weather causes the majority of long-term outages today, with damage from animals, mostly squirrels, causing most short-term outages (*Figure 5* [55]). The National Oceanic and Atmospheric Administration tracks the frequency and magnitude of extreme weather and climate events. In the first six months of 2020, the United States had already seen 10 weather and climate disaster events causing more than $1 billion in damage each as well as 80 cumulative deaths. In 2017, the United States experienced 16 climate and weather disaster events causing over $1 billion in damages, including the severe hurricanes Harvey (impacting mainly Texas and Louisiana), Irma (Florida), and Maria (Puerto Rico). Cumulatively, these events caused 362 deaths and $350 billion in damages.[56]

Ideally, the cost of an outage should be measured by capturing the value of lost load (VoLL): costs faced by consumers who lose electricity for a period of time. In practice, accurately assessing VoLL for all impacted customer types is challenging, and the use of VoLL as a metric to assess utility investments and performance has been limited. Utilities have conducted customer surveys to assess VoLL, but because of the costs of administering (and readministering) surveys and limits to a customer's ability to impartially state their own willingness to pay to avoid an outage of a duration they may not have ever experienced, pinpointing VoLL is difficult.[57] In practice,

52 Based on NARUC and NASEO research and interaction with members of the MSWG and general market research

53 Joseph Eto and Kristina Hamachi LaCommare, Lawrence Berkeley National Laboratory, "Tracking the Reliability of the U.S. Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions," October 2008, https://emp.lbl.gov/sites/all/files/lbnl-1092e.pdf

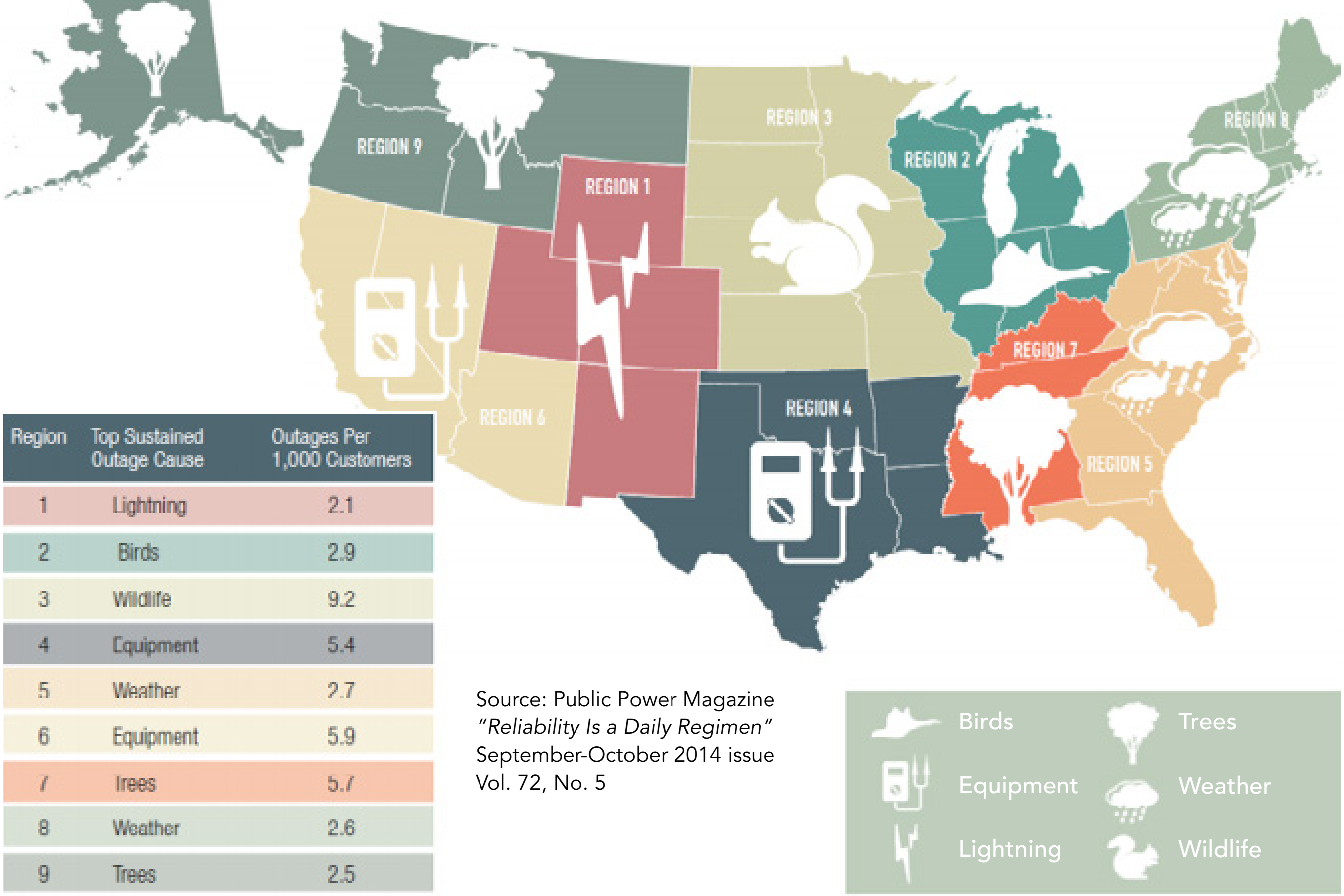
54 Alex Hofmann, American Public Power Association, "Defending Against Outages: Squirrel Tracker," July 26, 2017, https://www.publicpower.org/blog/defending-against-outages-squirrel-tracker

55 Electric Power Research Institute, "Metrics for Micro Grid: Reliability and Power Quality," 2016, http://integratedgrid.com/wp-content/uploads/2017/01/4-Key-Microgrid-Reliability-PQ-metrics.pdf

56 Alison Silverstein, Rob Gramlich, and Michael Goggin, "A Customer-Focused Framework for Electric System Resilience," May 2018, https://gridprogress.files.wordpress.com/2018/05/customer-focused-resilience-final-050118.pdf; National Centers for Environmental Information, National Oceanic and Atmospheric Administation, "Billion-Dollar Weather and Climate Disasters: Overview," https://www.ncdc.noaa.gov/billions/. Because of Hurricanes Harvey, Irma, and Maria, 2017 was a year of notably high weather-related damages.

57 Anubhav Ratha, Emil Iggland, and Göran Andersson, IEEE, "Value of Lost Load: How Much Is Supply Security Worth?" 2013 IEEE Power & Energy Society General Meeting, July 2013, https://ieeexplore.ieee.org/document/6672826

Figure 5: Regional Causes of Power Outages



Region	Top Sustained Outage Cause	Outages Per 1,000 Customers
1	Lightning	2.1
2	Birds	2.9
3	Wildlife	9.2
4	Equipment	5.4
5	Weather	2.7
6	Equipment	5.9
7	Trees	5.7
8	Weather	2.6
9	Trees	2.5

Source: Public Power Magazine
"Reliability Is a Daily Regimen"
September-October 2014 issue
Vol. 72, No. 5

utilities measure and report reliability metrics, but a true methodology to capture the value of resilience remains elusive and is the subject of numerous active inquiries among state public utility commissions.[58]

The distribution system is generally reliable to a degree of 4–5 nines in urban areas and 2–3 in rural, that is, 99.99–99.999 percent reliable in urban areas and 99–99.9 percent in rural. Four nines translates to 52 minutes and 36 seconds of downtime per year; five nines means just 5 minutes and 15 seconds of downtime per year.[59] However, these numbers are based on existing reliability metrics including System Average Interruption Frequency Index, System Average Interruption Duration Index, and Customer Average Interruption Duration Index. These metrics intentionally exclude major events, used by utilities to distinguish between planning for and responding to routine interruptions versus nonroutine or extraordinary interruptions, which are growing increasingly frequent and severe.[60] According to U.S. Energy Information Administration data, customers have experienced approximately two hours of electric service interruptions for each of the years between 2013 and 2018, excluding major events. During that time frame, major events caused between 1.5 and 6 hours of additional interruption.[61] Even excluding major events, distribution reliability is not improving; in fact, outage duration because of routine interruptions increased by 12 minutes between 2013 and 2018. Given this slight decline in grid performance and the increasing severity and frequency of major events driven by both natural/

58 Wilson Rickerson, Jonathan Gillis, and Marisa Buckley, Converge Strategies, "The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices," Report for the National Association of Regulatory Utility Commissioners, April 2019, https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198

59 See note 57.

60 See note 54.

61 U.S. Energy Information Administration, "Today in Energy: U.S. Customers Experienced an Average of Nearly Six Hours of Power Interruptions in 2018," June 1, 2020, https://www.eia.gov/todayinenergy/detail.php?id=43915

climate and man-made physical and cyber threats, more customers are considering microgrids to maintain energy services during these growing interruptions.

Reliability and resilience are distinct terms related to interruptions in energy service. The Federal Energy Regulatory Commission (FERC) defines reliability as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the amount desired, measured by the frequency, duration, and magnitude of outages.[62] System Average Interruption Frequency Index, System Average Interruption Duration Index, and Customer Average Interruption Duration Index metrics are broadly collected by utilities and reported to regulators to measure reliability performance.[63] Regulators, policymakers, and utilities have not yet developed a broadly accepted definition of and relevant performance metrics for resilience, but there is general agreement that resilience encompasses high-impact, low-frequency events leading to outages impacting large areas over long durations.[64] While reliability measures performance during an event, resilience extends before, during, and after an event by integrating robustness, resourcefulness, rapid recovery, and adaptability.[65] A customer may choose to install a microgrid to improve both reliability and resilience—both decreasing the likelihood of an interruption to electricity service and, when an outage does occur, decreasing its duration and impact, accelerating recovery to pre-event service levels, and learning from the event to improve performance during subsequent events. Additionally, because outages may only occur for a few minutes or hours each year, a microgrid can be configured to provide both (1) power in islanded mode during "black sky" events that interrupt electricity generation and/or distribution and (2) "blue sky" services under normal operating conditions, delivering additional value (and revenue) streams to the customer and the grid. Smart Electric Power Alliance (SEPA), a nonprofit organization that facilitates the electric power industry's smart transition to a clean and modern energy future, provides a breakdown of the multiple value propositions of grid-connected and islanded microgrids (*Figure 6*[66]).

Figure 6: Types of Multiuser Microgrid Blue-Sky and Island Services

	Customer Service	Grid Service
Blue-Sky Service	• Community Solar Programs • Decarbonization	• Wholesale Energy Market Participation / PURPA PPA • Wholesale Ancillary Services • Distribution NWA
Island Service	• Resilience Services • Islanded Energy Services	• System Resilience Services • Microgrid Forming Services

62 Federal Energy Regulatory Commission, "Reliability Primer," April 2020, https://www.ferc.gov/sites/default/files/2020-04/reliability-primer_1.pdf

63 John Kueck et al., Oak Ridge National Laboratory, "Measurement Practices for Reliability and Power Quality: A Toolkit of Reliability Measurement Practices," June 2004, https://info.ornl.gov/sites/publications/Files/Pub57467.pdf

64 Kiera Zitelman, "Resilience and Distributed Energy Resources," Presentation to Sandia National Laboratories, Designing Resilient Communities Stakeholder Advisory Group, January 23, 2019

65 Benjamin Preston et al., Argonne, Brookhaven, Los Alamos, Oak Ridge, Pacific Northwest, and Sandia National Laboratories, "Resilience of the U.S. Electricity System: A Multi-Hazard Perspective," Prepared for U.S. Department of Energy, Office of Energy Policy and Systems Analysis, August 2016, https://www.energy.gov/sites/prod/files/2017/01/f34/Resilience%20of%20the%20U.S.%20Electricity%20System%20A%20Multi-Hazard%20Perspective.pdf

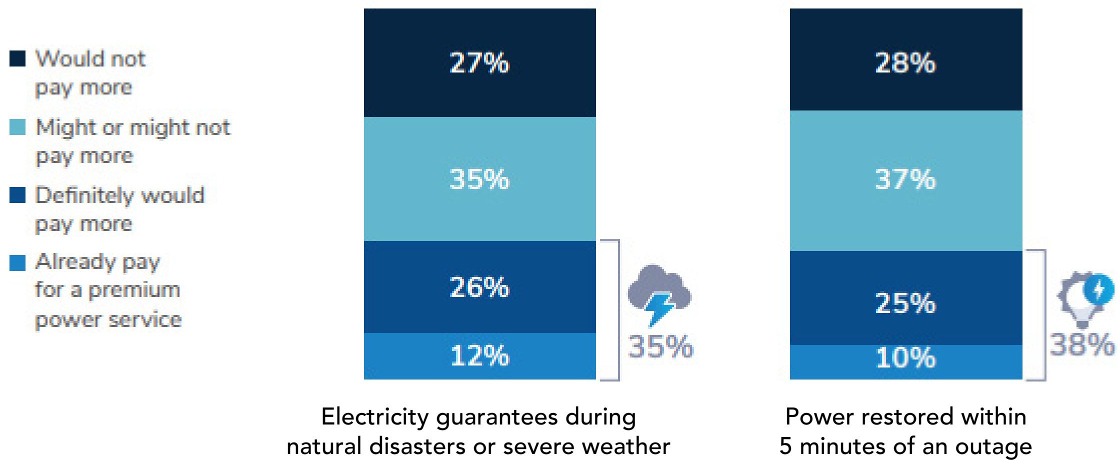
66 See note 19.

Potential Microgrid Contributions

For some customers, particularly those reliant on electricity for mission-critical functions, even a brief and temporary interruption may be unacceptable. These customers may find microgrids to be a pragmatic investment to enable increased reliability in support of their core mission. Customers in areas that experience frequent storms and other severe weather events will be even likelier to consider microgrid investments. For example, North Carolina customers experienced nearly 30 hours of power interruption in 2018, due largely to Hurricanes Florence and Michael.[67] According to an S&C Electric-commissioned report, "Overall, outage duration has remained relatively stagnant, which implies utility efforts to improve the grid have not been drastic enough to move the needle on reliability and change the perspective of even their most critical customers."[68]

Commercial and industrial customers in particular are concerned about power reliability, noting that a power outage, regardless of duration, can lead to production stoppage, loss of business, facility shutdowns, loss of inventory, equipment restarts, delivery or service delays, worker downtime, extra work time, and other financial costs.[69] A 2018 S&C survey found that 70 percent of companies are concerned about power reliability, with 60 percent actively seeking ways to improve reliability beyond their utility provider (*Figure 7*).[70, 71]

Figure 7: Paying More for Resilience and Restoration



Data centers are the likeliest type of business to look beyond their utility to improve reliability, related to the fact that they experienced average power outage costs of nearly $750,000 per year.[72] A data center industry report noted an increasing trend toward "distributed resilience," involving physical and IT resilience via investments in microgrids, automated software controls, and other software to "automate" resilience.[73] Data centers "represent large static loads on the grid, which because of the information they store, require higher levels of reliability and power quality than most other large users of electricity."[74]

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67 See note 62.

68 S&C Electric and Frost & Sullivan, "2020 State of Commercial & Industrial Power Reliability Report," May 2020, https://microgridknowledge.com/wp-content/uploads/2020/05/Technical-Paper-100-T125.pdf

69 Id.

70 S&C Electric and Frost & Sullivan, "2018 State of Commercial & Industrial Power Reliability Report," https://microgridknowledge.com/white-paper/commercial-industrial-power-reliability/

71 See note 696.

72 Peter Asmus, Navigant Research, "Data Centers and Advanced Microgrids: Meeting Resiliency, Efficiency, and Sustainability Goals Through Smart and Cleaner Power Infrastructure," 2017, https://guidehouseinsights.com/-/media/project/navigant-research/reportfiles/schneiderelectricnavigantresearchdatacentersandadvancedmicrogridswhitepaper102017pdf.pdf

73 451 Group, "Next Generation Resiliency," https://451research.com/next-generation-resiliency

74 Arizona Public Service, "APS Provides Top-Tier Reliability and Value for Data Centers," 2018, https://www.aps.com/-/media/APS/APSCOM-PDFs/Business/Economic-Development/Why-Arizona-and-APS/DataCenterFactSheet_2018.ashx?la=en

Airports are another potential growth market for reliable, resilient microgrids. After outages at other airports, the Pittsburgh International Airport (PIT) built a microgrid consisting of five natural gas-fired generators and 7,800 solar panels, capable of producing 23 megawatts (MW) of energy to meet PIT's peak load of 14 MW. As of July 2020, construction was underway, and the microgrid is expected to be operational by summer 2021. The PIT project will be the first microgrid to completely power an airport during blue sky conditions.[75]

Military facilities are also fertile ground for microgrids to enhance resilience and reliability. Each branch of the DoD has its own energy resilience and reliability goals. In the past, energy reliability has often translated to standalone diesel generators connected to individual buildings within a base or larger network, sized to up to double peak building load as a contingency during routine, short-term outages.[76] As DoD threat analyses have indicated the need to prepare for energy assurance during longer-term outages caused by severe weather and determined adversaries, military energy strategies have evolved to require backup power for anywhere from 7 to 14 days, or even longer depending on base characteristics.[77]

R&R Case Study #1: APS/ADC Microgrid

Aligned Data Centers (ADC) built its second data center in a former manufacturing facility in Phoenix, AZ. The data center requires over 60 MW of power. ADC needed higher reliability than the local utility, Arizona Public Service (APS), could provide. Concurrently, APS was considering options to improve system reliability during extreme heat events. Summer temperatures in Phoenix routinely climb over 100 degrees, increasing demand as customers power up air conditioning and increasing the likelihood of distribution system failure due to high heat. APS and ADC shared the upfront cost of a microgrid powered by 63 MW of diesel generators, with APS having the option to use excess power from the microgrid (beyond ADC's needs) to provide power to the grid should a component fail. To enable this option, APS built a 69-kV bidirectional substation adjacent to the data center.

Sources: https://www.azcentral.com/story/money/business/energy/2016/03/14/aligned-data-center-phoenix-have-aps-microgrid/81491012/

https://mse238blog.stanford.edu/2017/08/rsty/data-centers-as-microgrids/

https://www.utilitydive.com/news/case-study-aps-invests-in-microgrid-as-phoenix-metropolitan-area-grows/503687/

In response to these needs, the Office of the Secretary of Defense commissioned the Energy Resilience Assessment (ERA) tool,[78] enabling comparisons of the costs and comparisons of various energy resilience investment options. Importantly, the ERA allows DoD facilities to compare the costs of traditional standalone diesel generators with various combinations of DERs into microgrids.[79] The ERA is being used across the DoD and is slated to support resilience planning at other federal agencies in the future.

Finally, community "resilience hubs" are another key growth area for microgrids. Focusing on maintaining the provision of critical services such as public safety, communications, food and medicine distribution, and health care during a broader grid outage, municipal governments have looked at establishing microgrids to power one or multiple public buildings (e.g., hospitals, police stations, schools). While an outage may persist for hours or even days, a microgrid-powered resilience hub would be able to maintain basic public services, decreasing the impacts and costs of an outage. Operating a microgrid during normal conditions can deliver

75 Chris Teale, Utility Dive, "Construction Begins on Pittsburgh International Airport Microgrid," July 24, 2020, https://www.utilitydive.com/news/construction-begins-on-pittsburgh-international-airport-microgrid/582207/

76 See note 73.

77 CNA Military Advisory Board, "National Security and Assured U.S. Electrical Power," November 2015, https://www.cna.org/cna_files/pdf/national-security-assured-electrical-power.pdf

78 Madelaine Millar, Lincoln Laboratory, Massachusetts Institute of Technology, "New Software Helps Users Build Resilient, Cost-Effective Energy Architectures," July 2, 2019, https://www.ll.mit.edu/news/new-software-helps-users-build-resilient-cost-effective-energy-architectures

79 Wilson Rickerson, Jonathan Gillis, and Marisa Buckley, Converge Strategies, "The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices," Report for the National Association of Regulatory Utility Commissioners, April 2019, https://pubs.naruc.org/pub/531AD059-9CC0-BAF6-127B-99BCB5F02198

substantial cost savings to facilities. A California Kaiser Permanente medical center saw its energy costs decrease by one-third after installing a 250 kW/1 MWh solar plus storage microgrid, supported in part by the California Energy Commission. The microgrid can decrease the facility's peak load by close to 25 percent and can island the center's life safety emergency branch. Pushed by public safety power shutoffs, Kaiser Permanente is considering additional microgrids at other facilities throughout California.[80] Hospitals are typically required by state and National Fire Protection Association codes and standards to maintain a backup power supply—historically, generally a diesel generator—that can continue to power lifesaving services and critical functions during an outage.[81] Frequently testing and exercising backup power systems is key to preparing to continue to deliver energy services during an emergency. Procuring a microgrid that can function alongside the distribution grid under blue sky conditions provides this regular exercise, positioning health facilities to be reliable and resilient through outages while enjoying bill savings under normal conditions.[82]

As another example, Commonwealth Edison's Bronzeville microgrid in Chicago, Illinois, uses solar PV, battery energy storage, and backup fuels to power the city's public safety headquarters, a medical facility, and just over 1,000 residential, commercial, and industrial customers within the microgrid boundaries.[83] Commonwealth Edison plans to connect the Bronzeville microgrid to an existing microgrid at the nearby Illinois Institute of Technology to further enhance community resilience in the future.[84] To plan the Bronzeville project, Commonwealth Edison based its decision-making on three factors: power delivery infrastructure, critical infrastructure, and input from external stakeholders including state and local emergency management agencies.[85] The Urban Sustainability Directors Network recommends that resilient microgrid planners engage

R&R Case Study #2: Otis Air National Guard Base

Otis Air National Guard Base (ANGB) is part of the Joint Base Cape Cod, located in Barnstable County, MA. To enable ANGB's mission of providing worldwide precision intelligence and command and control, the base invested in a microgrid involving a 1.5 MW wind turbine, 1.6 MW diesel generator, 1.6 MW/1.2 megawatt-hours (MWh) lead acid battery, and Raytheon controller. The microgrid can island from the grid to power the base during an outage, but also participates in electricity markets during grid-connected mode, earning revenue from ISO New England's frequency regulation, and demand response markets. Otis ANGB's microgrid set a number of "firsts" for military energy assurance:

- First time a microgrid integrated enough wind and battery capacity to meet 100 percent of electricity needs at a military base or defense facility;
- First time a U.S. military facility connected to an ISO; and
- First microgrid to leverage battery storage to form a base-wide microgrid completely independent from any utility grid or external power provider.

Sources: https://www.safie.hq.af.mil/News/Article-Display/Article/1629645/otis-microgrid-ribbon-cutting-marks-a-new-era-in-energy-resiliency-and-grid-sec/

https://cleantechnica.com/2018/09/10/otis-microgrid-cape-cod-military-base-to-run-fully-on-renewable-energy/

80 Kavya Balaraman, "COVID-19 Propels Microgrids in Healthcare Sector, but Regulatory, Awareness Hurdles Remain," June 29, 2020, https://www.utilitydive.com/news/covid-19-microgrids-healthcare-sector/580492/

81 Adam Dutka, Microgrid Knowledge, "How Hospital Microgrids Can Solve Energy Challenges," May 18, 2020, https://microgridknowledge.com/hospital-microgrids-powersecure/

82 Tammy Worth, Health Dive, "What Happens When the Lights Go Out?" October 27, 2014, https://www.healthcaredive.com/news/what-happens-when-the-lights-go-out/325423/

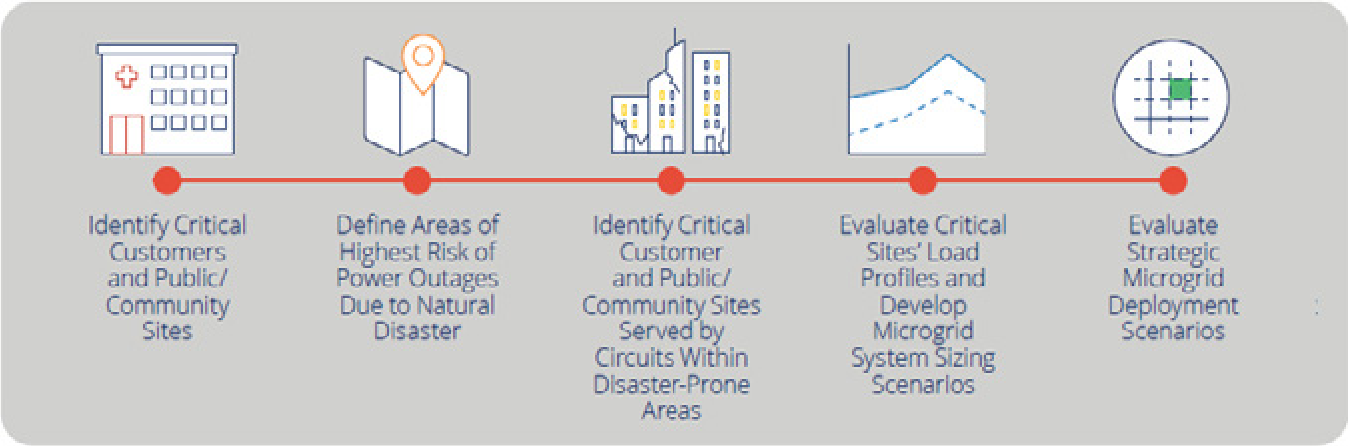
83 Illinois Commerce Commission, "ICC Approves Bronzeville Community Microgrid, Nation's Most Advanced," February 28, 2018, https://www.icc.illinois.gov/downloads/public/ComEd%20Bronzeville%20Microgrid%20Project%20Press%20Release.pdf

84 Commonwealth Edison, "ComEd Bronzeville Community Microgrid Demonstrates Ability to Keep Power Flowing in Event of an Emergency," April 17, 2019, https://www.comed.com/News/Pages/NewsReleases/2019_04_17.aspx

85 Aleksi Paaso, Commonwealth Edison, "Utility Microgrid Procurement," Presentation to NARUC-NASEO Microgrids State Working Group, August 19, 2020, https://pubs.naruc.org/pub/8843D122-155D-0A36-3165-CF32492AED65

with community members and stakeholder groups to (1) assess community support for a microgrid; (2) pinpoint buildings that are already used frequently and trusted by the community; (3) size the microgrid appropriately to meet community needs during extreme events; (4) consider hybrid combinations of renewable generation, energy storage, and firm diesel or natural gas generation; and (5) plan to offer a wide range of community services in the microgrid.[86] Similarly, SEPA employs a five-step approach to planning community microgrids for resilience,[87] shown in *Figure 8*.

Figure 8: SEPA Approach for Planning Microgrids for Community Resilience against Natural Disasters



Source: Smart Electric Power Alliance, 2020

While siting and planning community microgrids, planners should assess the likelihood and impact of various threats to electricity delivery and act to mitigate those threats. A project led by Sandia National Laboratories to improve community resilience in New Orleans, Louisiana, used historical hurricane data to map floods and their impacts on electricity infrastructure and public services. The project team used this analysis to identify existing buildings—both private buildings like gas stations, grocery stores, and pharmacies, and public facilities—that could be powered by microgrids during a hurricane-induced outage. The process prioritized locations in areas that were unlikely to see flooding to maintain public accessibility during an emergency.[88]

B. Bill Savings

Some microgrid customers are driven primarily by a desire to lower their energy costs. Areas with high volumetric rates, time-varying rates, and/or high demand charges may push customers to consider investing in microgrids.[89] Lawrence Berkeley National Laboratory (LBNL) research found that demand charge savings from distributed solar PV depend on the design features of the demand charge in question. Demand charge design may vary by seasonal differentiation, frequency of billing demand measurement and ratchets, averaging interval, timing of billing demand measurement, peak period window definition, and tiering.[90] For example, demand charges based on a designated daytime peak period aligning with maximum solar production, such

86 Kristin Baja, Urban Sustainability Directors Network, "Resilience Hubs: Shifting Power to Communities and Increasing Community Capacity," 2018, https://www.usdn.org/uploads/cms/documents/usdn_resiliencehubs_2018.pdf

87 Smart Electric Power Alliance, "The Microgrid Playbook: Community Resilience for Natural Disasters," 2020, https://sepapower.org/resource/the-microgrid-playbook-community-resilience-for-natural-disasters/

88 Kristen Meub, Sandia National Laboratories, "How Microgrids Could Boost Resilience in New Orleans," May 24, 2018, https://www.sandia.gov/news/publications/labnews/articles/2018/25-05/microgrids.html

89 See note 1.

90 See Naïm Darghouth, Galen Barbose, and Andrew Mills, Lawrence Berkeley National Laboratory, "Implications of Rate Design for the Customer Economics of Behind-the-Meter Storage," August 2019, https://eta-publications.lbl.gov/sites/default/files/darghouth_rate_design_storage_final.pdf; and Aman Chitkara et al., Rocky Mountain Institute, "A Review of Alternative Rate Designs: Industry Experience with Time-Based and Demand Charge Rates for Mass-Market Customers," May 2016, https://rmi.org/wp-content/uploads/2017/04/A-Review-of-Alternative-Rate-Designs-2016.pdf for discussion on demand charge design and impacts on customer behavior.

Bill Savings Case Study #1: Mission Produce Microgrid

Mission Produce is one of the world's largest avocado sellers, operating packing facilities and refrigerated ripening centers in multiple countries. Mission installed a 1 MW rooftop solar PV array at its packing facility in Oxnard, California, later deciding to incorporate the array into a solar + storage microgrid, citing bill savings as its primary motivation. Oxnard is a frequent demand response area where customers are strongly incentivized to reduce or shift usage off peak periods, with workers sometimes sent home because of lack of power during demand response events. Mission decided to install 0.5 MW/2 MWh of flow batteries at a cost of $1 million. The microgrid is partially financed through California's Self-Generation Incentive Program, which provides $0.40 per watt-hour for up to 40 percent of total project cost. The project's biggest value stream is demand charge savings, followed by energy arbitrage.

Sources: https://ww2.energy.ca.gov/2018publications/CEC-500-2018-022/CEC-500-2018-022.pdf
https://www.pv-magazine.com/2015/09/21/unienergy-powerit-partner-on-energy-solution-for-californias-mission-produce_100021184/
https://www.sce.com/sites/default/files/inline-files/135650_DR%20Programs%20Fact%20Sheet%200520%20FINAL%20WCAG.pdf

as mid-afternoon, will result in increased savings from a solar PV system.[91] Whether the magnitude of these savings is enough to justify the upfront costs of a microgrid installation inclusive of solar PV depends on many factors. Demand charge savings are unlikely to offset the entire capital cost of a microgrid, but can be one among multiple financial motivations for microgrid adoption.

In addition to demand charge savings, microgrids operating under blue sky conditions can deliver savings to customers in the form of electric bill reductions for excess generation exported to the grid in territories in which some form of net energy metering is in effect. Several state and territory energy offices have supported microgrids for affordable housing developments to deliver these benefits to low to moderate income (LMI) customers. As an example, New Partners Community Solar Corporation installed a 62 kW rooftop solar array on the Maycroft Apartments building, an affordable housing provider in Washington, DC. The solar array qualifies as a Community Renewable Energy Facility that passes on savings directly to residents, reducing average monthly electric bills for 100 LMI households by approximately $40.[92] Maycroft Apartments also includes 46 kW/56 kWh of energy storage connected to the solar array that can island to power the building during an outage for up to three days. Pepco, Jubilee Housing, the Clean Energy Group, and the DC Department of Energy and Environment also supported the project.[93] New York City has a similar project funded in part by the

Bill Savings Case Study #2: Medford, Massachusetts, Microgrid

Similar to Mission Produce, the City of Medford, Massachusetts, leveraged an existing 235-kilowatt (kW) solar PV array into a microgrid by adding 100 kW/255 kWh of energy storage. The city's primary motivation was to reduce demand charges by utilizing the microgrid to lower monthly peak load. Massachusetts has particularly high demand charges, sometimes accounting for up to 70 percent of a commercial customer's electricity bill. The microgrid will also deliver revenue to the city by participating in demand response programs.

Sources: https://microgridknowledge.com/microgrid-demand-charges-medford/

http://www.medfordma.org/2019/03/27/solect-energy-awarded-competitive-rfp-contract-with-the-city-of-medford-for-a-microgrid-energy-management-system/

91 Naïm Darghouth et al., Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory, "Exploring Demand Charge Savings from Residential Solar," January 2017, https://emp.lbl.gov/sites/default/files/solar_res_dc_briefing_final.pdf

92 Clean Energy Group, "Maycroft Apartments," https://www.cleanegroup.org/ceg-projects/resilient-power-project/featured-installations/maycroft-apartments/

93 Solar Builder Mag, "2019 Solar Builder Editor's Choice Projects of the Year," November 12, 2019, https://solarbuildermag.com/featured/editors-choice-awards-2019/

New York State Energy Research & Development Authority: the Marcus Garvey microgrid, consisting of 480 kW solar PV, 400 kW fuel cell, and 300 kW battery installed across 21 low-rise affordable apartment buildings.[94]

C. Integrating Clean Energy

Microgrids can facilitate the integration of renewable energy generation and energy storage. Municipal facilities may find this motivation particularly relevant, as it enables governments to showcase renewable microgrids and encourage their adoption by other customers, similar to how rooftop solar PV adoption frequently occurs in "clusters" as potential adopters decide to procure their own systems after observing new systems being installed by their neighbors.[95]

Integrating Renewables Case Study #1: Blue Lake Rancheria Microgrid

The Blue Lake Rancheria microgrid, operated by Pacific Gas & Electric, provides power to a Red Cross evacuation center and a six-building campus in a Native American community in Humboldt County, California. The microgrid includes 420 kW of solar PV, 500 kW/950 kWh of battery storage, a 1 MW diesel generator, and 300 kW of controllable load. The California Energy Commission (CEC) supported Blue Lake Rancheria through the Electric Program Investment Charge program, a ratepayer-funded program to support new, emerging, and pre-commercialized clean energy technologies benefitting California ratepayers. In 2018, according to a CEC case study, the microgrid delivered approximately $200,000 of energy savings and 175 avoided tons of carbon dioxide emissions to the community compared to pre-installation. Blue Lake Rancheria is connected to Pacific Gas & Electric's distribution grid and automatically islands during an outage and reconnects afterward. The microgrid has successfully islanded and provided power to the community during outages induced by an October 2017 wildfire and multiple public safety power shutoffs.

Sources: https://ww2.energy.ca.gov/2019publications/CEC-500-2019-011/CEC-500-2019-011.pdf
https://microgridknowledge.com/blue-lake-rancheria-microgrid-outages/, https://www.cpuc.ca.gov/energyrdd/
https://new.siemens.com/global/en/company/stories/infrastructure/2020/blue-lake-rancheria-energy-resilience.html

Solar PV is projected to be the leading DER choice for microgrids over the next five years, according to GTM Research.[96] Steep declines in cost and improvements in performance of solar, wind, and battery resources (*Figure 9, Figure 10*[97]) have vastly improved their competitiveness compared to more traditional distributed diesel, propane, natural gas, and oil generation. The use of renewable DERs unlocks a range of benefits for microgrid customers, including minimal fuel and operating costs, reduced emissions, on-site fuel, and reduced peak demand.[98]

94 Elisa Wood, Microgrid Knowledge, "Marcus Garvey Microgrid Begins Operating As a First for NYC Affordable Housing," June 9, 2017, https://microgridknowledge.com/marcus-garvey-microgrid/

95 Marcello Graziano and Kenneth Gillingham, "Spatial Patterns of Solar Photovoltaic System Adoption: The Influence of Neighbors and the Built Environment," *Journal of Economic Geography* Vol. 15 Issue 4, July 2015, https://academic.oup.com/joeg/article/15/4/815/2412599

96 GTM Research, "Integrating High Levels of Renewables into Microgrids: Opportunities, Challenges and Strategies," ABB, February 2016, http://www.sustainablepowersystems.com/wp-content/uploads/2016/03/GTM-Whitepaper-Integrating-High-Levels-of-Renewables-into-Microgrids.pdf

97 Bloomberg New Energy Finance, "Battery Power's Latest Plunge in Costs Threatens Coal, Gas," March 26, 2019, https://about.bnef.com/blog/battery-powers-latest-plunge-costs-threatens-coal-gas/; Lazard, "Levelized Cost of Energy and Levelized Cost of Storage 2019," November 7, 2019, https://www.lazard.com/perspective/lcoe2019

98 See note 38.

Figure 9: Storage Cost Profiles

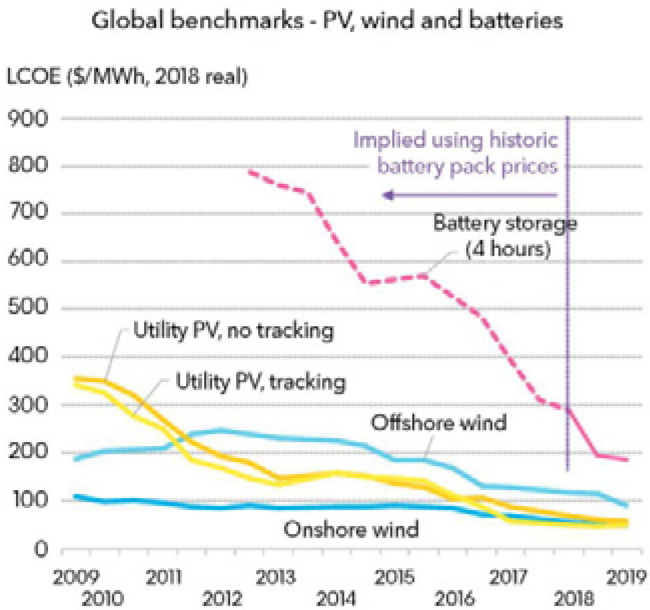
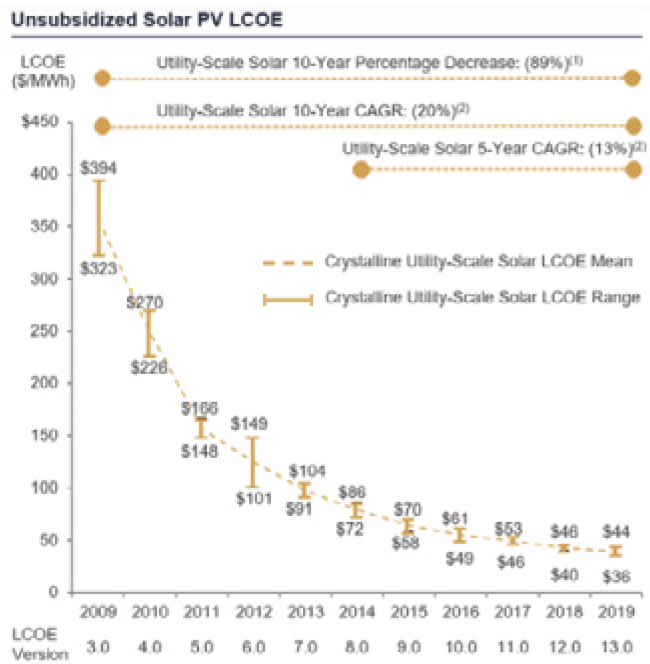


Figure 10: Solar Cost Profile



In areas with high penetrations of renewable generation, whether in front of or behind the meter, microgrids can provide ancillary services to improve reliability and aid the integration of more renewables, turning inverter-based resources from liabilities into contributors to grid reliability. Regions in Europe, for example, have experienced grid inertia[99] issues associated with high renewable penetration as wind, solar PV, and battery storage reduce the quantity of inertia available, although new "grid-forming" inverters compliant with IEEE 1547-2018 and other updated industry standards can counter the lack of inertia by actively reducing the

Integrating Renewables Case Study #2: Borrego Springs Microgrid

Borrego Springs is a small community in California, served by San Diego Gas & Electric (SDG&E). The community experiences frequent outages because of its remote location at the end of a single 30-mile, 69-kV transmission line prone to high winds, storms, and extreme heat. To improve reliability and integrate renewable energy, SDG&E built a microgrid to serve the 2,500 residential and 300 commercial and industrial customers in Borrego Springs. SDG&E utilized existing solar resources in the community, including a 26 MW commercial system and 3 MW of customer-owned rooftop solar, as well as other distributed generation and batteries. As one of the first renewable microgrids in California, SDG&E used Borrego Springs to demonstrate integration of 100 percent renewable energy with an advanced controller. SDG&E and project partners evaluated multiple controllers and selected the Spirae Wave controller to successfully island Borrego Springs during a disruption to the transmission line and integrate the distributed solar and storage resources in the community. The microgrid can be controlled both locally and from the remote SDG&E Distribution Control Center.

Sources: https://ww2.energy.ca.gov/2019publications/CEC-500-2019-013/CEC-500-2019-013.pdf
http://www.sdgenews.com/article/borrego-springs-claim-energy-fame-microgrid-enhances-reliability
https://www.nrel.gov/docs/fy19osti/74477.pdf

99 Grid inertia is the tendency of large rotating generators to remain rotating. During the failure of a power plant, inertia from other grid-connected resources can provide a temporary bridge for mechanical power plant control systems to detect and respond to the failure without a broader interruption. See National Renewable Energy Laboratory, "Inertia and the Power Grid: A Guide without the Spin," May 28, 2020, https://www.nrel.gov/news/program/2020/inertia-and-the-power-grid-a-guide-without-the-spin.html.

amount of inertia needed to maintain system reliability during a disturbance.[100] Microgrids can instantaneously react to fluctuations in supply and demand on the distribution system, offering frequency regulation to stabilize the grid in the face of intermittent renewable generation.[101] Recent research has pointed to the ability of modern, advanced inverters to enable an entirely inverter-based microgrid, such as one consisting entirely of renewable generation, to operate reliably and produce an adequate level of inertia despite the lack of spinning generators.

D. Powering Remote Communities

Remote communities face higher costs and technical challenges to provide reliable electricity. Island or rural communities are often dependent on the delivery of liquid fuels, mainly oil, for heating and electricity needs. Aside from the greenhouse gas and local air quality impacts of burning oil, oil prices are highly volatile and expose the community to financial risk. Additionally, delivery of fuel—typically by pipeline, truck, barge, or rail—adds cost and risk.[102] Small-scale electricity systems tend to be more expensive and complicated to maintain.[103] For these reasons, remote communities routinely pay a steep premium for electricity. Customers in Hawaii and Alaska pay the highest and second highest average retail rates for electricity in the United States: 28.72 cents/kWh and 20.22 cents/kWh, respectively, compared to a national average of 10.54 cents/kWh.[104]Customers in remote communities are more likely to fall into low- and moderate-income categories, meaning that they spend a greater percentage of their income on energy services.

Alaska is a particularly compelling example of the need to develop other solutions to resilience beyond imported oil. Alaska has the second-highest average annual energy cost in the country, at $2,883 per year.[105] Transmission and distribution lines are costly to construct and maintain in Alaska, and the vast distance between population centers—even in the more populated southern coastal region—adds expense. With low population density and high energy demand, Alaska is a fertile growth market for microgrids, particularly renewable microgrids.

Island Case Study #1: Kodiak, Alaska, Microgrid

Kodiak Island, the second-largest island in the United States, is a small fishing community of around 15,000 residents, concentrated in the town of Kodiak. The Kodiak Electric Association (KEA) cooperative utility serves the island. Interconnecting to a grid off the coast of Kodiak Island was infeasible, leading KEA to rely mainly on diesel fuel and hydropower to supply the community. After a 2007 commitment to generate 95 percent of power from renewable sources by 2020, KEA invested in 9 MW of wind turbines, 3 MW of lead-acid batteries, and 2 MW of flywheel storage resources to integrate larger amounts of renewable generation into the island's existing microgrid. Multiple types of storage enable reliable operation at high levels of variable renewable generation. Shifting reliance to wind, storage, and hydropower from diesel has reduced KEA customer rates by 3.6 percent since 2000, a collective savings of $4 million annually. With more reliable and cheaper electricity, KEA customers can now switch from oil heating to electric heat pumps for additional savings.

Sources:
https://rmi.org/wp-content/uploads/2017/04/Islands_Microgrid_Profiles_Islands_Global_Remote_Communities_CaseStudy_2015.pdf
https://www.hitachiabb-powergrids.com/references/grid-edge-solutions/kodiak-island

100 Paul Denholm et al., National Renewable Energy Laboratory, "Inertia and the Power Grid: A Guide Without the Spin," May 2020, https://www.nrel.gov/docs/fy20osti/73856.pdf.

101 See note 38.

102 See note 96.

103 See note 21.

104 U.S. Energy Information Administration, "State Electricity Profiles," November 2, 2020, https://www.eia.gov/electricity/state/

105 Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy, "Low-Income Energy Affordability Data (LEAD) Tool," https://www.energy.gov/eere/slsc/maps/lead-tool

The state is already first in the United States in terms of installed microgrid capacity, with 122 microgrids operational as of July 2019, according to Navigant.[106] NREL estimates as many as 200 microgrids in Alaska, with most reliant on imported diesel. These communities paid up to 10 times the national average for energy and experienced frequent disruptions lasting days to months prior to microgrid construction.[107] While diesel remains an expensive source of generation for Alaskans and is not without risk of interruption, the proliferation of microgrids across the state has still managed to deliver improved outcomes and lower costs. The Alaska Energy Authority, the state energy office, has recognized the benefits of microgrids for Alaskan communities by supporting microgrid projects in Kipnuk, Shungnak, Kokhanok, and Chefornak.[108]

Island Case Study #2: Moku o Lo'e Microgrid

Coconut Island is home to the Hawaii Institute of Marine Biology, a University of Hawaii research facility. While the island is connected to the larger Oahu island grid via an undersea cable, frequent service interruptions were highly disruptive to the facility's critical research activities, such as life support equipment for marine organisms under study. Peak demand for the island was 500 kW. Prior to the microgrid, the island had an existing 200 kW rooftop solar PV installation and two emergency backup diesel generators totaling 440 kW. The facility installed energy storage, building controls, small-scale wind turbines, and an advanced control system to form an island microgrid capable of meeting peak demand at greater reliability than the undersea cable, enabling the institute to carry out its core functions more effectively.

Sources: https://energy.ehawaii.gov/epd/public/energy-project-details.html?rid=139-2080c3932b3bbd09
http://naseo.org/Data/Sites/1/rocheleau_180402-naseo.pdf
https://www.utas.edu.au/__data/assets/pdf_file/0009/778617/IPS-Connect-2015-Richard-Rocheleau.pdf

106 Gwen Holdmann and Peter Asmus, Alaska Center for Energy and Power and Navigant Research, "Microgrid Innovation in the Circumpolar Arctic: Lessons for Developing World Markets," 2019, https://microgridknowledge.com/wp-content/uploads/2020/05/navigant-research-u-of-alaska-microgrids-circumpolar-arctic-wp.pdf

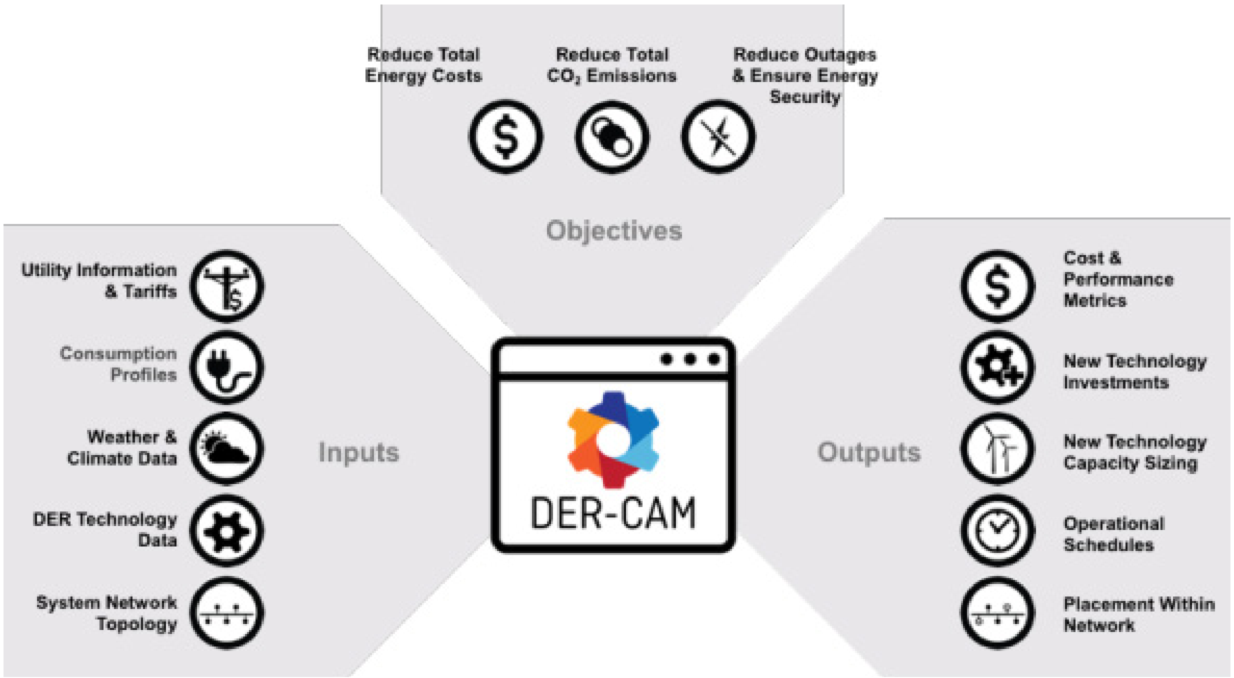
107 Grid Modernization Laboratory Consortium, U.S. Department of Energy, "Alaska Microgrid Partnership," https://gmlc.doe.gov/projects/1.3.21

108 See Alaska Energy Data Gateway, "Alaska Microgrid Partnership Overview," https://akenergygateway.alaska.edu/alaska_microgrid_communities/ and National Governors Association, "Alaska's Renewable Energy Microgrids," November 5, 2019, https://www.nga.org/uncategorized/alaskas-renewable-energy-microgrids/

V. Modeling Microgrid Objectives

To model how these various factors affect microgrid design and configuration choices, NARUC used the Distributed Energy Resources Customer Adoption Model (DER-CAM) model, developed by LBNL. DER-CAM is a decision support tool to find optimal investments for DERs in individual buildings and microgrids (*Figure 11*[109]).

Figure 11: DER-CAM Objectives, Inputs, and Outputs



National Laboratories, companies, and other organizations offer many subscription- or fee-based models and free, publicly available tools. In the interest of enabling NARUC and NASEO members to understand and use a model themselves, NARUC prioritized models that were free and available to the public. NARUC deemed DER-CAM to be the appropriate model for this paper through conversations with staff at various National Laboratories offering various DER modeling tools and research on the capabilities of each tool. The substantial specialization involved in microgrid design eliminated some of the models from consideration, and the presence of diverse sources of distributed generation as potential solutions in DER-CAM positioned it as the most appropriate tool for this publication compared to models specific to renewable generation.[110] Further, DER-CAM's inclusion of sample load and site data and utility tariffs facilitated a comparison of results for different types of customers.

DER-CAM operates with a seven-part workflow consisting of definitions of various conditions and parameters, running a base case, defining DER investment options, and running alternative investment cases to arrive at an optimal solution (*Figure 12*[111]):

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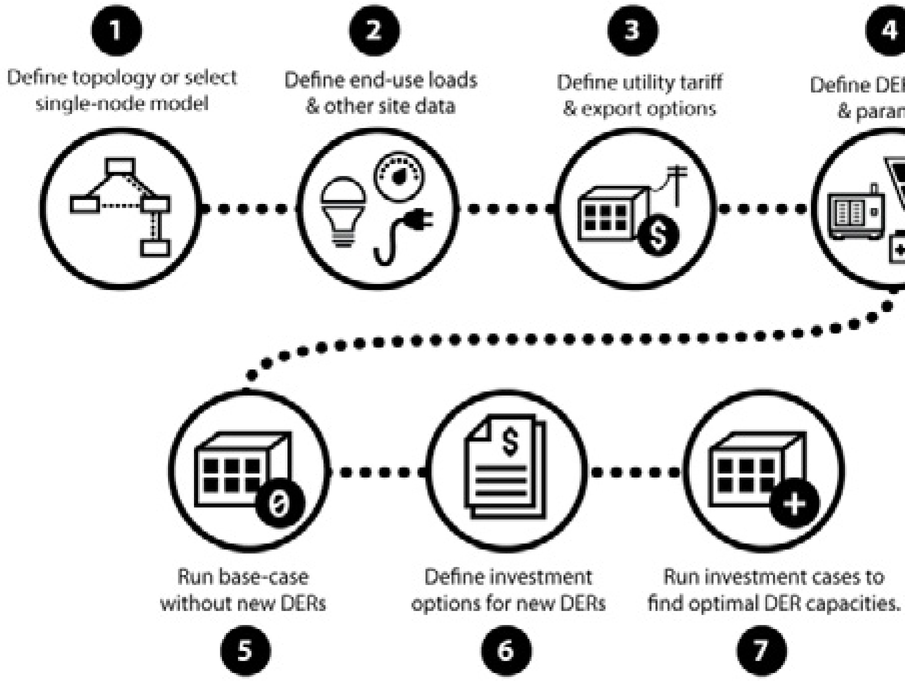
109 Lawrence Berkeley National Laboratory, "The Distributed Energy Resources Customer Adoption Model (DER-CAM)," https://gridintegration.lbl.gov/der-cam

110 The National Renewable Energy Laboratory's Renewable Energy Integration & Optimization tool is primarily meant to evaluate the economic viability of on-site, grid-connected solar PV, wind, and battery storage. See https://reopt.nrel.gov/tool. The Electric Power Research Institute's Distributed Energy Resources Value Estimation Tool, funded in part by the California Energy Commission, models the value of energy storage, DERs, and microgrids based on their technical merits and constraints. See https://www.der-vet.com/.

111 See note 109.

Figure 12: DER-CAM Workflow



NARUC used DER-CAM to model the four microgrid objectives discussed above. NARUC utilized DER-CAM's databases of building types, solar resources, and utility information, selecting an appropriate location and building type for each objective. For each DER-CAM run, NARUC enabled the considerations of all types of DER technologies included in the model except for electricity discharge from electric vehicles,[112] as well as at least five discrete backup generators with capacities appropriate to serve the building's load.

A. Increased Reliability and Resilience

To model this objective, NARUC selected a hospital constructed post-1980 in Miami, Florida. South Florida has experienced some of the most destructive hurricanes to hit the United States, including Andrew (1992), Charley (2004), Wilma (2005), Irma (2017), and Michael (2018).[113] In 2017, customers at Florida Power & Light, the state's largest utility serving approximately 10 million customers, experienced a collective 19 billion minutes of outages due to named storms.[114] Customers in the region are thus likelier than regions not experiencing extreme weather-driven outages to consider investments in reliability and resilience. NARUC specified three weekdays of outages occurring during the month of August.

Using the DER-CAM model, the optimal solution is a solar + storage microgrid consisting of 3 kW solar thermal and 166 kWh of combined cold storage and a flow battery costing approximately $56,000 in upfront capital expenditures.[115] Additionally, the optimal system invests in 357 kW of controllable central heating capacity and 107 kW of controllable central cooling capacity (*Figure 13*). The system is expected to deliver aggregate savings in excess of capital costs in approximately 18 years (*Figure 14*).

112 While discharge from EV batteries is technically feasible, it is not commercially feasible in most jurisdictions and often conflicts with vehicle warranties.

113 Matthew Lavietes, Reuters, "Florida's Most Deadly and Destructive Hurricanes," 2020, https://jp.reuters.com/article/instant-article/idUSKCN1VJ2CB

114 Florida Public Service Commission, "Review of Florida's Investor-Owned Electric Utilities: 2017 Service Reliability Reports," December 2018, http://www.psc.state.fl.us/Files/PDF/Utilities/Electricgas/DistributionReliabilityReports/2017/Review%20of%20Florida%E2%80%99s%20Investor-Owned%20Electric%20Utilities%E2%80%99%20Service%20Reliability%20in%202017.pdf

115 Interconnection costs are not included in DER-CAM capital cost estimates, due to difficulty reliably estimating interconnection study timelines and associated costs.

Figure 13: Florida Hospital DER Capital Costs and Capacities

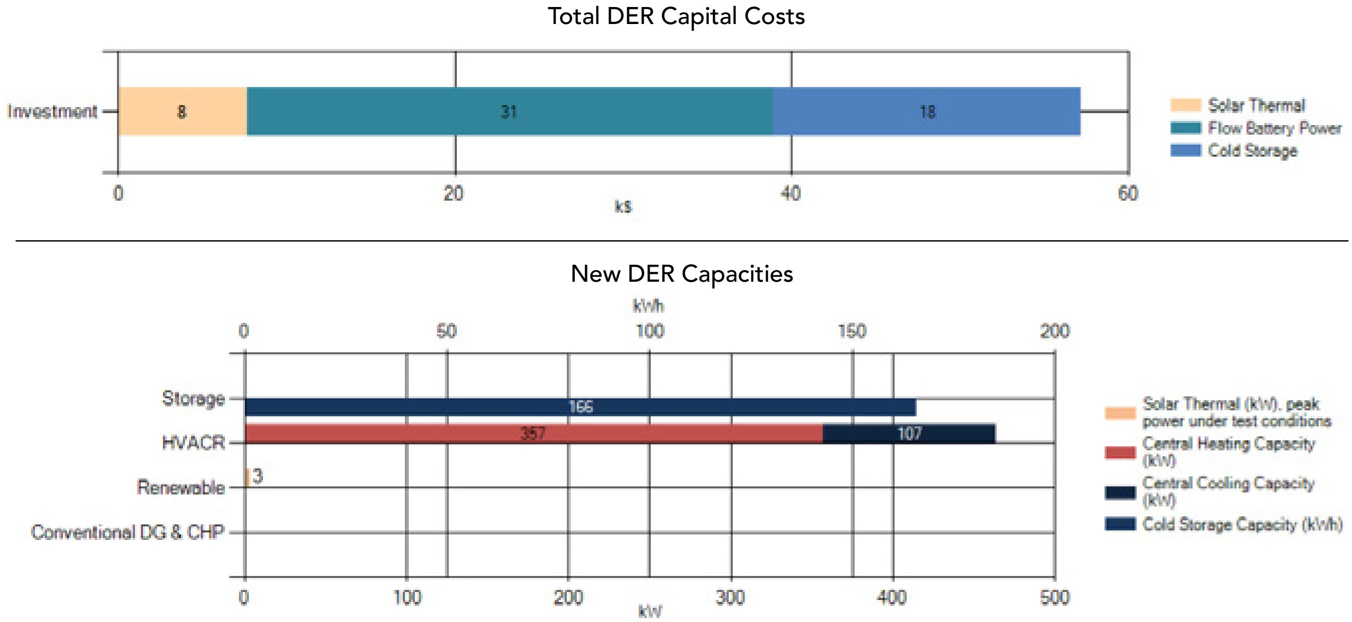
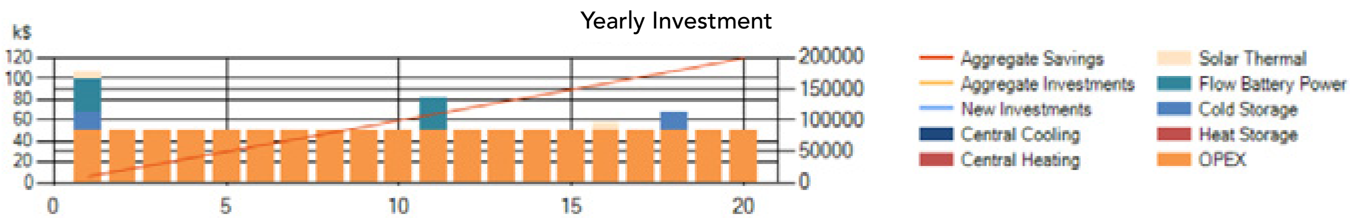


Figure 14: Florida Hospital Yearly Savings and Investments



The following cooling and heating dispatch charts (*Figure 15*, *Figure 16*) show the microgrid's operation over 24 hours during an emergency.

Figure 15: Florida Hospital Cooling Dispatch During Emergency Day

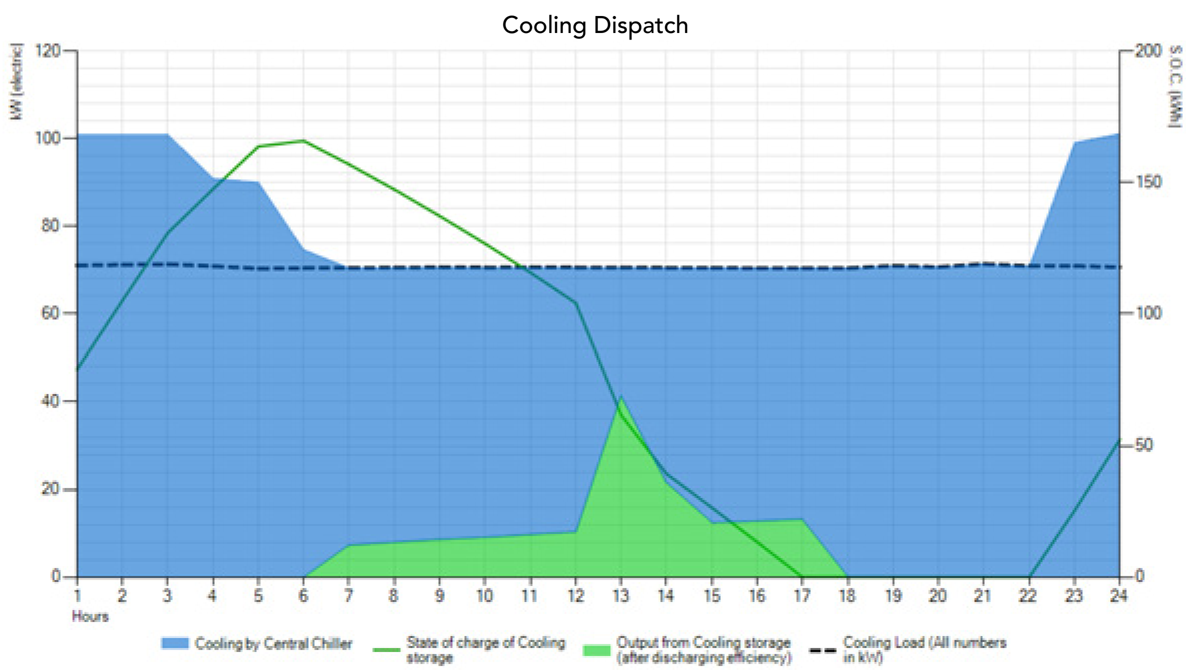
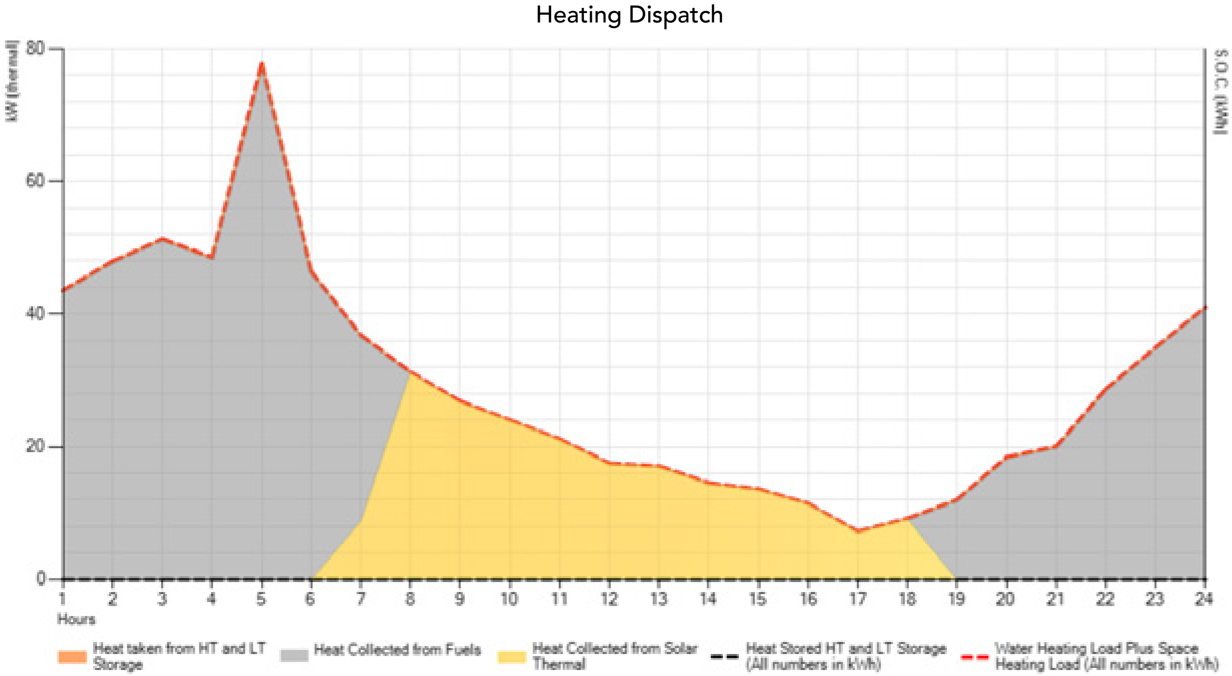


Figure 16: Florida Hospital Heating Dispatch During Emergency Day

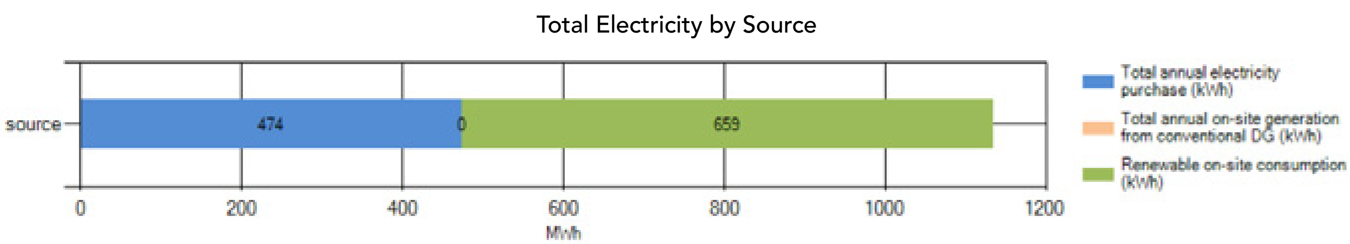


B. Bill Savings

To model a microgrid investment to achieve bill savings, NARUC selected a warehouse constructed post-1980 in San Francisco, California. Californian commercial electricity customers experience some of the highest demand charges in the country,[116] representing up to one-third of an average commercial customer's bill.[117] These customers are likelier to consider on-site generation to decrease their peak demand and lower their electric bills.

The DER-CAM model models the optimal solution as consisting of an upfront $1.12 million investment in 314 kW of solar PV, 3 kW of solar thermal, 6.3 MWh of cold storage, 975 kW of controllable central heating capacity, and 259 kW of controllable central cooling capacity. This system offsets 60 percent of annual electricity purchases (*Figure 17, Figure 18*). Aggregate savings in excess of initial capital expenditures is estimated to occur within 20 years (*Figure 19*).

Figure 17: California Warehouse Electricity Procurement

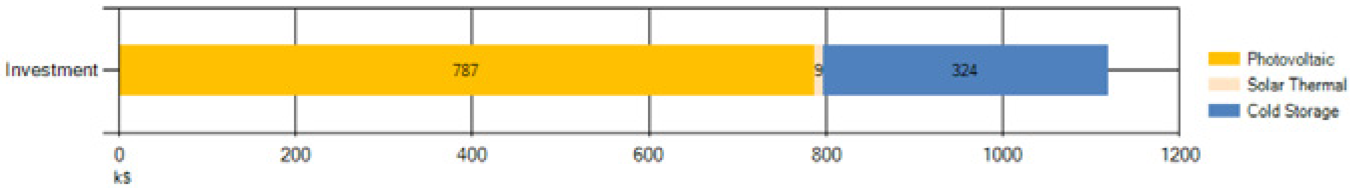


116 Joyce McLaren, National Renewable Energy Laboratory, "A Survey of U.S. Demand Charges," Presentation to Clean Energy Group, September 19, 2017, https://www.nrel.gov/solar/assets/pdfs/2017-us-demand-charges-webinar.pdf

117 Tom Arnold, "The Free Lunch Algorithm," Facilities Engineering Journal, 2013, http://www.calmac.com/stuff/contentmgr/files/0/bdc94cfab118e59a93b60c018d28ea64/pdf/the_free_lunch_algorithm.pdf

Figure 18: California Warehouse DER Capital Costs and Capacities

Total DER Capital Costs



New DER Capacities

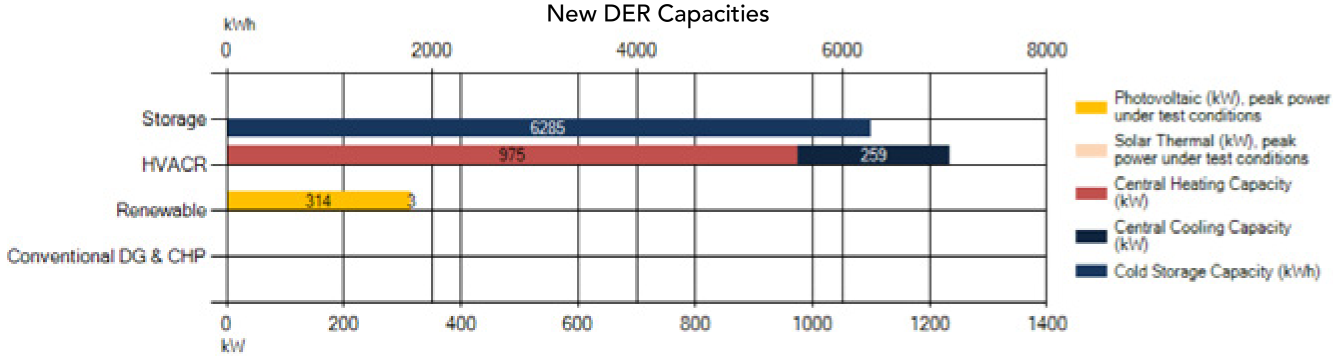
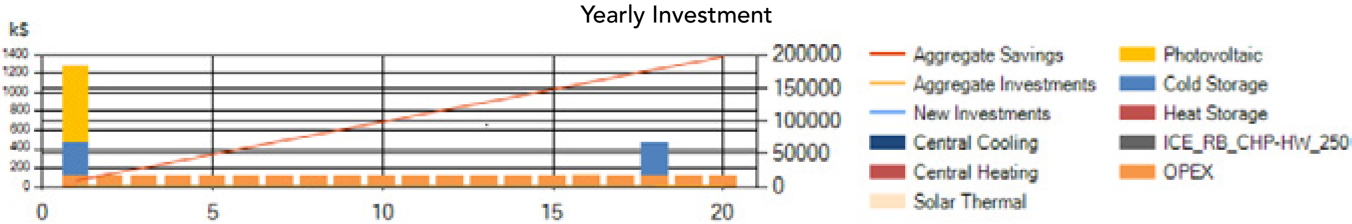


Figure 19: California Warehouse Yearly Savings and Investments

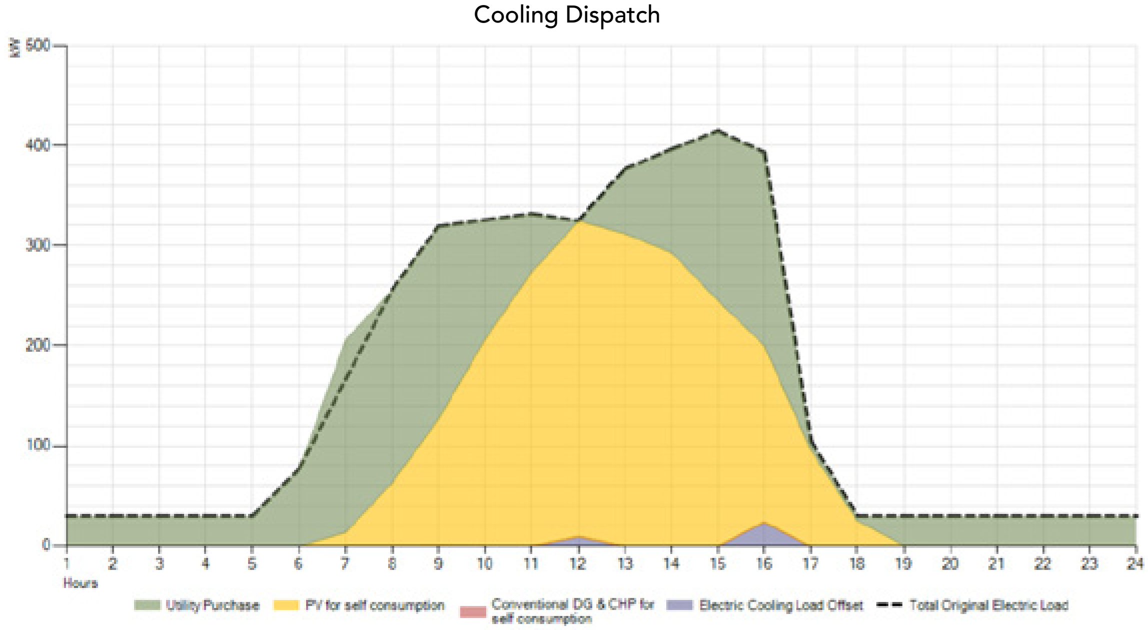
Yearly Investment



The following figure shows electricity dispatch during a peak day in September (*Figure 20*). On-site PV begins generating throughout the morning, reaching 100 percent of electric load at 12 p.m. and subsequently declining.

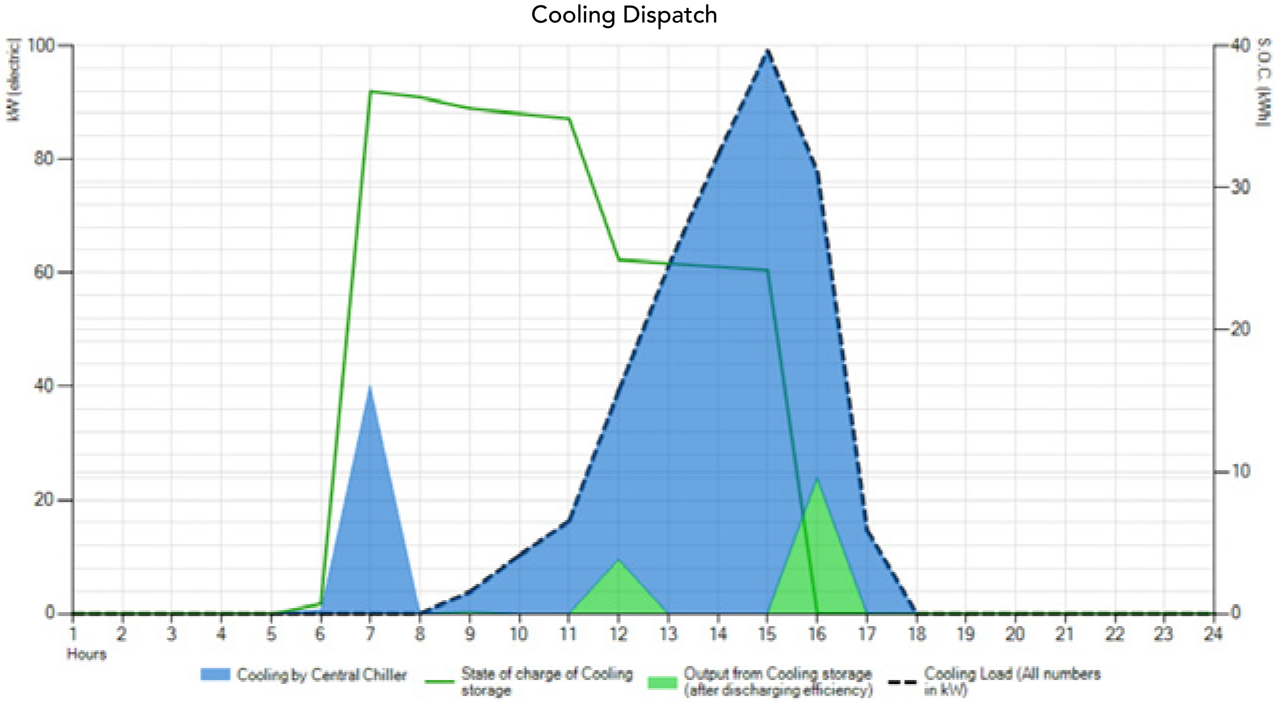
Figure 20: California Warehouse Electricity Dispatch, September Peak Day

Cooling Dispatch



The next figure shows cooling dispatch on the same peak day in September (*Figure 21*). Cooling storage charges in the early morning and begins discharging at 11 a.m., accounting for approximately one-fifth of cooling load in the late afternoon.

Figure 21: California Warehouse Cooling Dispatch, September Peak Day



C. Integrating Clean Energy

To model renewable energy integration, NARUC selected a primary school in Baltimore, Maryland, constructed post-1980. Maryland has strong incentives for customer-sited clean energy[118] and aggressive state clean energy goals, leading to significant development of in-state solar, wind, and biomass resources.[119] This environment facilitates municipal interest in renewable generation.

DER-CAM offers an optimal microgrid that almost entirely replaces annual electricity purchases with on-site renewable generation. The solution consists of 798 kW of solar PV, 23 kW of solar thermal, a 1.7 MWh flow battery, 5.5 MWh of cold storage, 2 MW of controllable central heating capacity, and 402 kW of controllable central cooling capacity. Total upfront capital costs reach $3.17 million, with annual operating expenditures averaging $27,000 (*Figure 22, Figure 23*). The microgrid can also export power to the distribution utility, achieving $6,000 in annual revenue for the school and delivering enough savings to offset capital costs by year 18 (*Figure 24*).

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118 State Policy Opportunity Tracker, Center for the New Energy Economy, "State Profile: Maryland," https://spotforcleanenergy.org/state/maryland/

119 U.S. Energy Information Administration, "Maryland: State Profile and Energy Estimates," October 15, 2020, https://www.eia.gov/state/analysis.php?sid=MD

Figure 22: Maryland School Electricity Procurement

Total Electricity by Source

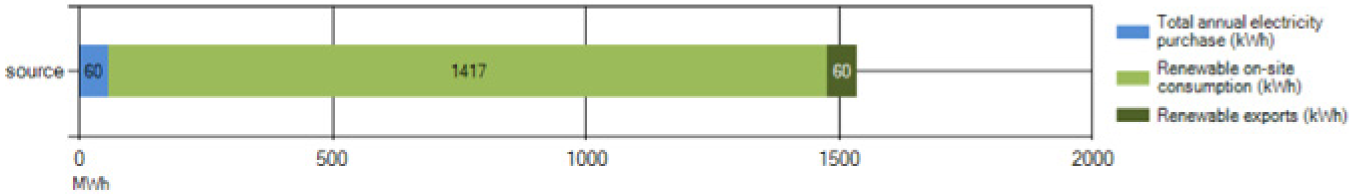
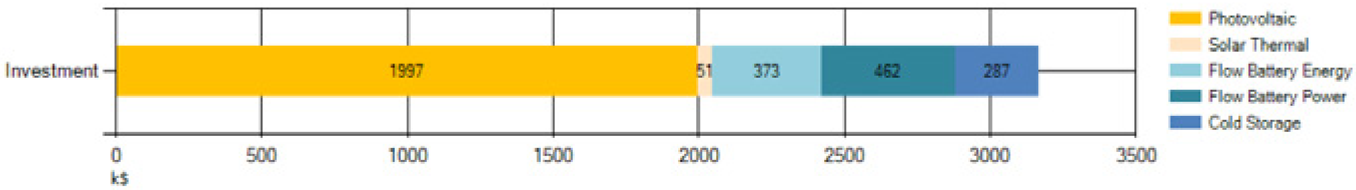


Figure 23: Maryland School DER Capital Costs and Capacities

Total DER Captal Costs



New DER Capacities

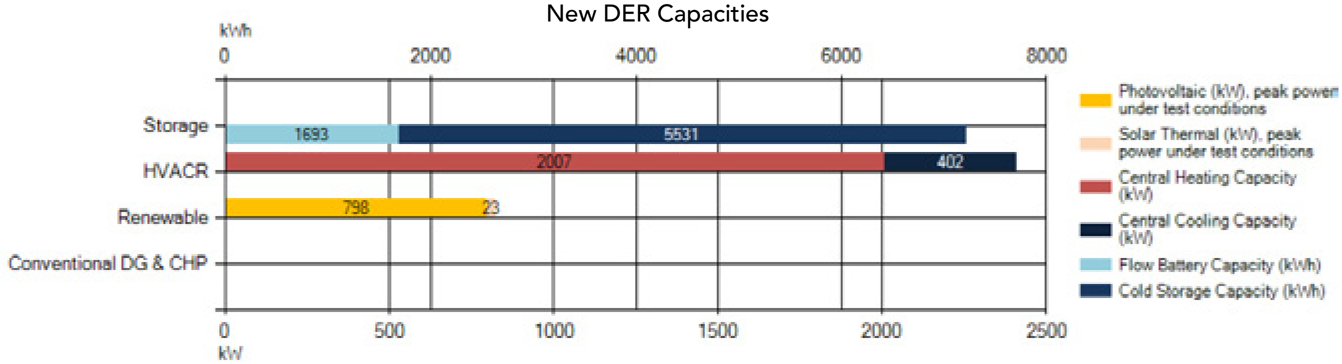
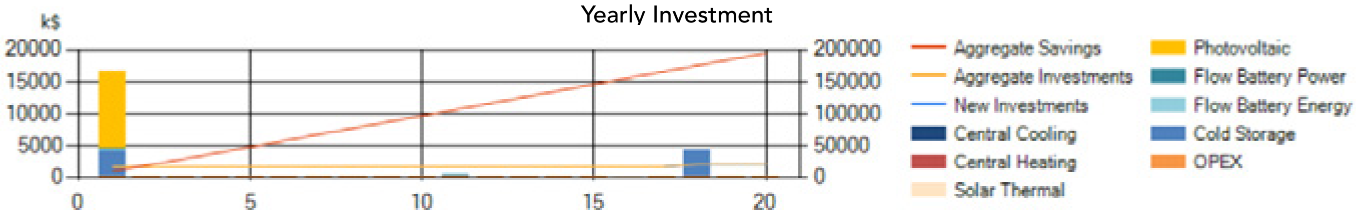


Figure 24: Maryland School Yearly Savings and Investments

Yearly Investment



The following figures show electricity dispatch during two weekdays in cold (February, *Figure 25*) and warm (September, *Figure 26*) months in which school is in session. Solar PV and the flow battery provide the majority of building load in both cases.

Figure 25: Maryland School Electricity Dispatch, February Weekday

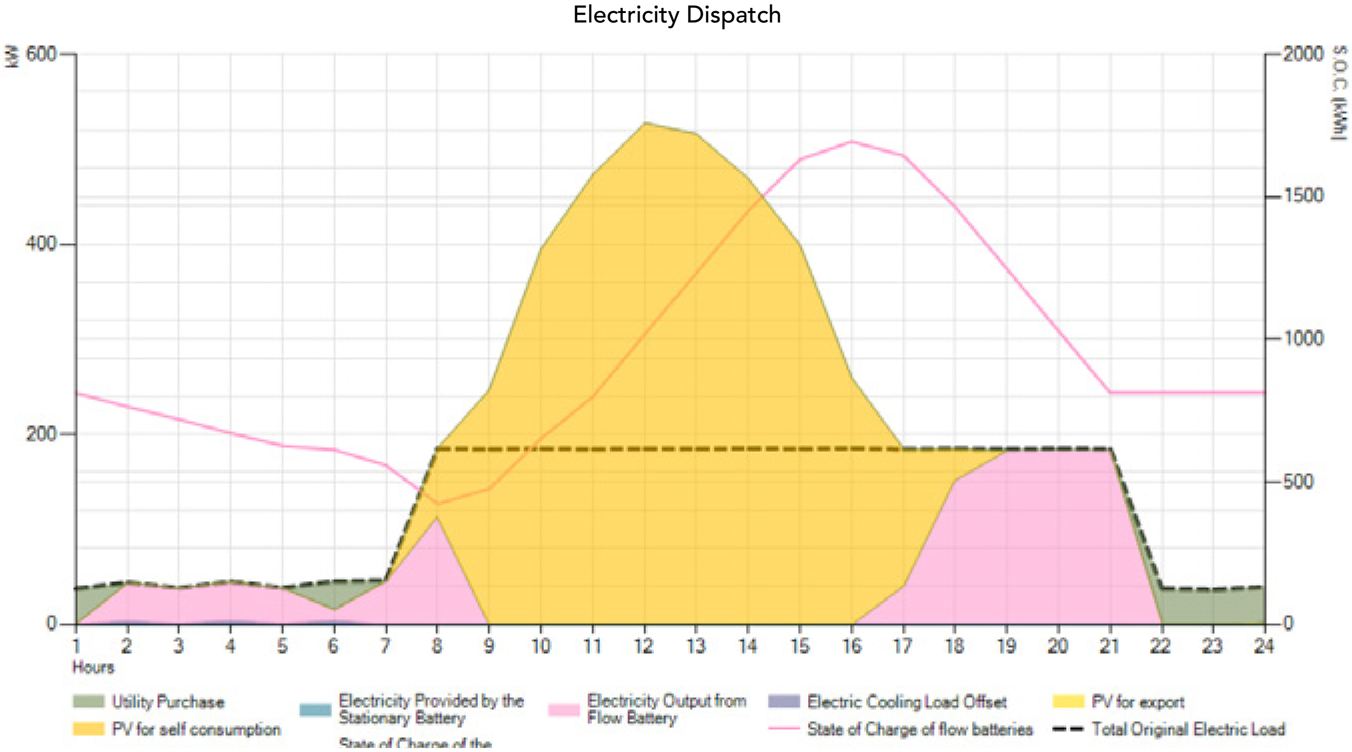
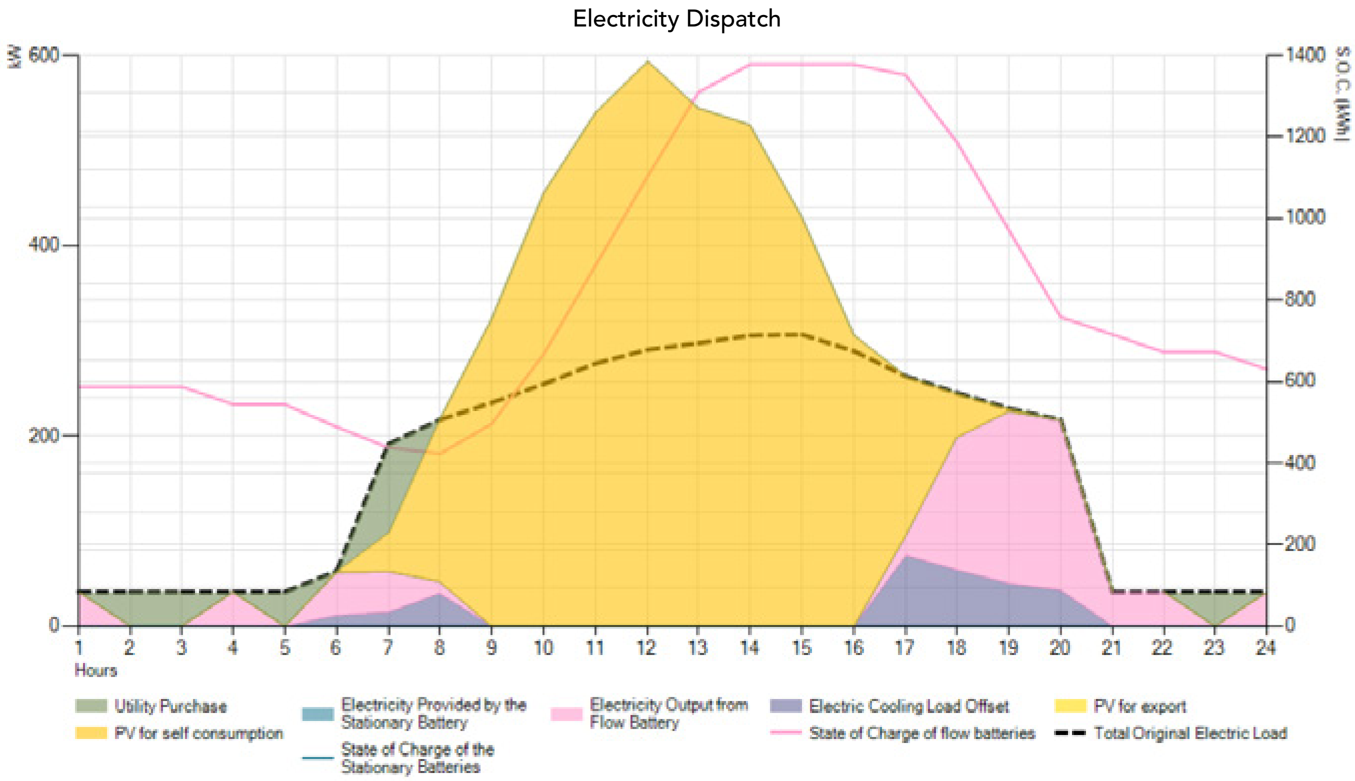


Figure 26: Maryland School Electricity Dispatch, September Weekday



D. Powering Remote Communities

To model the fourth objective, NARUC selected a mid-rise apartment building in Anchorage, Alaska. DER-CAM's built-in databases only include major cities, limiting the ability of the model to create an optimal solution for a remote customer. However, given the rural nature of Alaska and Anchorage's relatively small population compared to other cities available in the model, Anchorage was deemed to be the best available solution for this objective.

According to the DER-CAM model, the optimal solution consists of 80 kW solar PV, 5 kW solar thermal, 322 kW of controllable central heating, and 140 kW of controllable central cooling, totaling $290,000 in capital expenditures. The system offsets annual electricity purchases by 106 MWh per year (*Figure 27, Figure 28*) and achieves savings equivalent to capital costs by year 17 (*Figure 29*).

Figure 27: Alaska Apartment Building Electricity Procurement

Total Electricity by Source

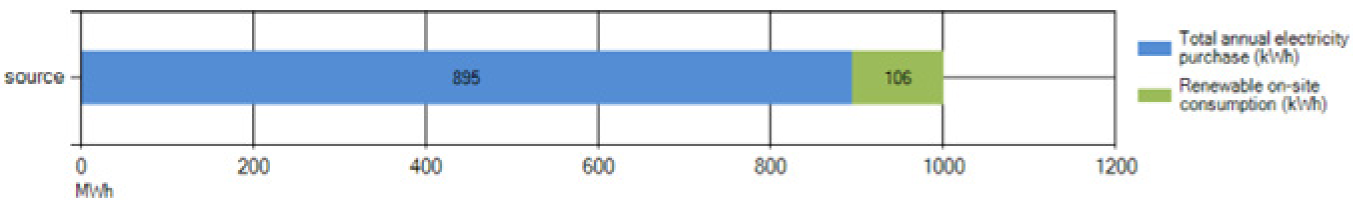
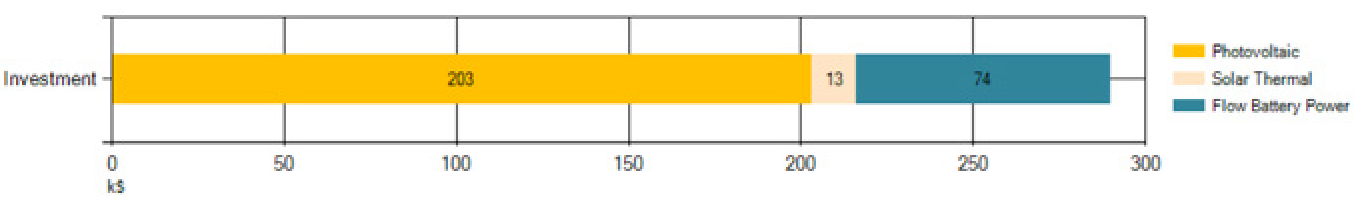


Figure 28: Alaska Apartment Building DER Capital Costs and Capacities

Total DER Captal Costs



New DER Capacities

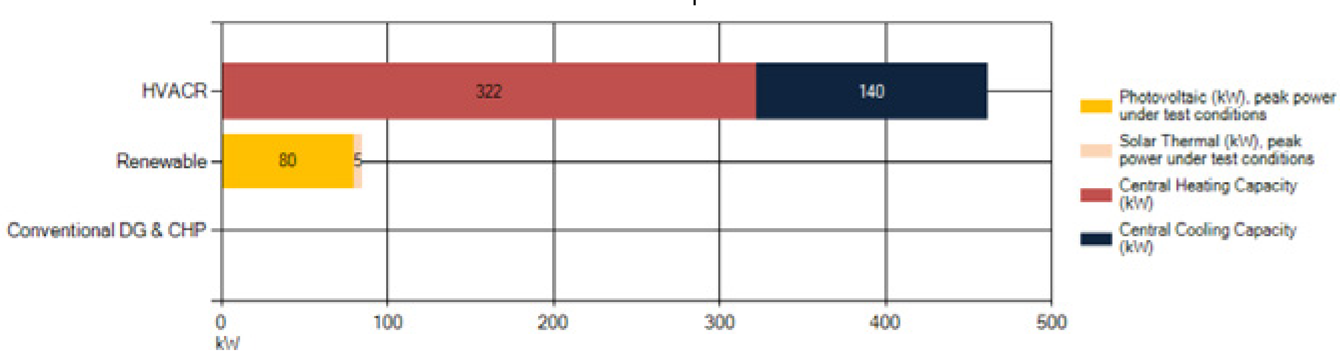
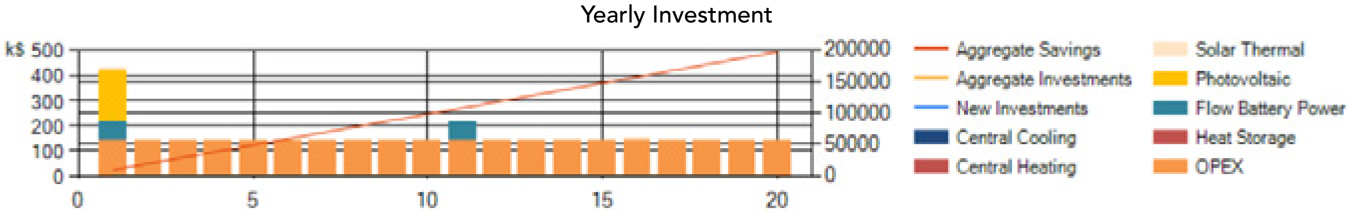


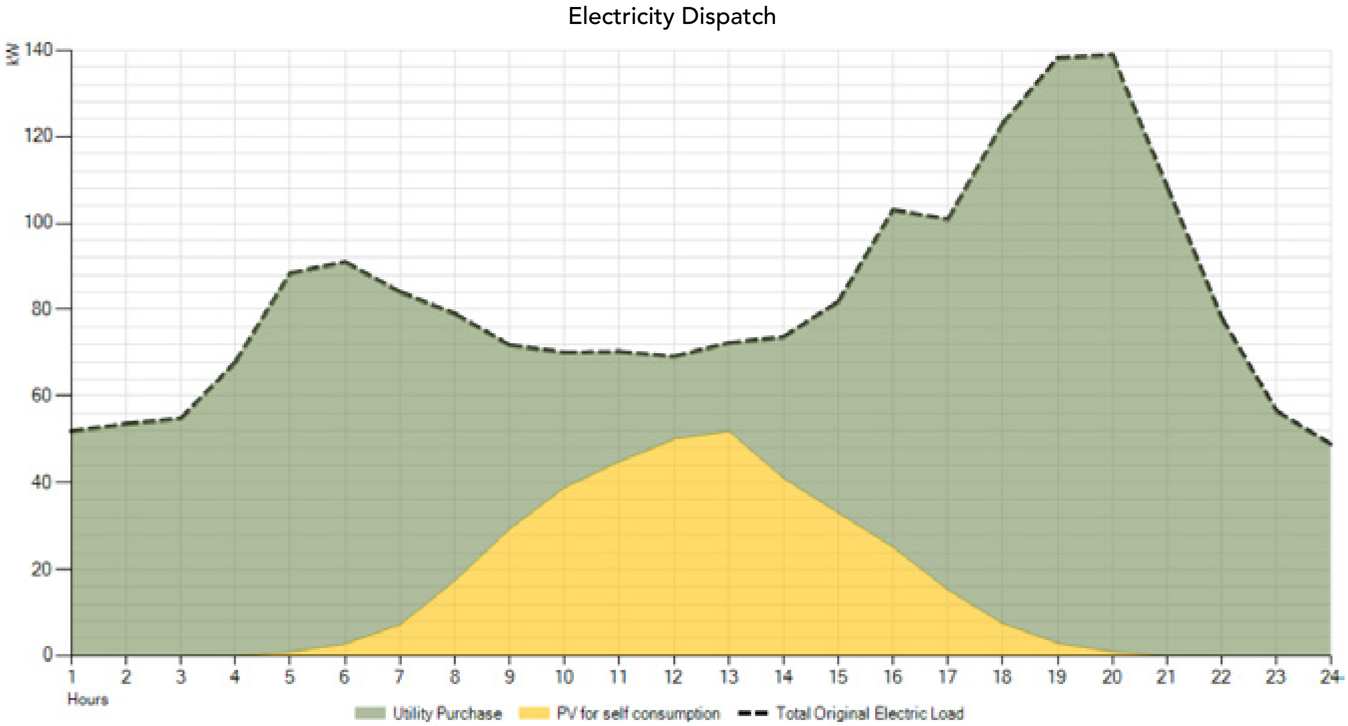
Figure 29: Alaska Apartment Building Yearly Savings and Investments

Yearly Investment



During a typical weekday in May, on-site solar PV generation peaks at just over two-thirds of building load (*Figure 30*).

Figure 30: Alaska Apartment Building Electricity Dispatch, May Weekday



E. Discussion

The optimal solutions modeled above demonstrate the feasibility of customer-sited microgrids to achieve customer objectives with payback periods of between 16 and 20 years. In all cases, customers continue to partially rely on the local distribution utility under normal conditions, but make use of on-site renewable generation, storage, controllable load, and other investment options to achieve diverse objectives and deliver savings and/or revenue from on-site generation and, where allowed, electricity exports. Pronounced cost declines for solar PV and energy storage, as well as financial incentives for renewable generation and storage, are major factors that contribute to the inclusion of solar and storage in many of the optimal solutions offered by DER-CAM.

Estimating payback periods for microgrid projects is highly dependent on individual project characteristics, and as a generalized model, DER-CAM's estimates discussed above fail to capture the many factors that influence payback. The length of payback period generally depends on four main factors: (1) current on-site energy consumption and spending, (2) level of energy generation from the microgrid, (3) capital cost of the microgrid, and (4) funding and/or financing arrangements.[120] While DER-CAM uses data from utilities and other sources to model some of these factors, the model does not capture the availability of private- and public-sector funding and financing options that many microgrid projects take advantage of to lower initial capital costs.[121] Additionally, many microgrid projects leverage revenue streams from competitive markets for clean energy, energy, capacity, and ancillary services, which DER-CAM also does not include. Incorporating these sources of revenue into the planning process will likely shorten the length of the payback period.

120 Centrica Business Solutions, "What Is the Average Payback Period of a Solar PV Installation?" https://www.centricabusinesssolutions.com/us/blogpost/what-average-payback-period-solar-pv-installation

121 See note 7.

Motivations for pursuing microgrids are varied and highly dependent on each customer's power needs, local resources, existing electric distribution network, and other factors. Customers installing microgrids are diverse, and there is significant variation in financial arrangements, ownership and operational structures, and interaction between the microgrid and the local distribution utility, where a utility is present.

Payback periods for microgrids differ depending on DER types, capabilities, and configurations as well as the microgrid's level of access to competitive markets for energy, capacity, and ancillary services. There is significant variation in market access in different states and independent system operator/distribution utility service territories. As discussed above, renewable microgrids that meet state requirements can receive revenue from state RECs sold in competitive markets in states with renewable portfolio standards.

Not all microgrid benefits are currently monetized universally. Mainly, the lack of a valuation methodology for resilience, particularly for community resilience, can make cost-benefit analysis for a microgrid more difficult. While RECs and carbon trading programs offer payments for reduced carbon dioxide emissions, microgrids located in states that do not participate in such programs will not be paid for their pollution reduction benefits. And while providing power to island, rural, or other remote communities delivers clear societal benefits in terms of improved quality of life and lower energy costs for residents of those communities, advances in social welfare may not translate into increased revenues for microgrid owners and operators.

Uncertainty around interconnection studies and costs is a significant barrier to microgrid development. Pre-reports are an important step toward improved transparency and reduced costs associated with interconnection. However, interconnection is still a highly unpredictable part of the microgrid feasibility and design process given that interconnection decisions sit entirely within the electric distribution utility and cannot be influenced by the microgrid customer or developer, aside from providing all requested data and paying for any interconnection study costs. Microgrids are subject to the utility's timeline, which can add delays to the project.

VI. Conclusion

Microgrids, while highly specialized, can be applied to a wide range of customers and scenarios to deliver reliable, resilient, clean, and affordable electricity. This paper seeks to communicate to state regulators and state and territory energy offices who install microgrids, why they do so, and how their motivations impact microgrid design and operation. Increased demand for reliability and resilience, cheap solar PV, and falling energy storage costs are poised to drive microgrid development in the near future. Microgrids can leverage existing customer-sited DERs to decrease the need for additional generation. Understanding these trends is key to addressing policy and regulatory barriers to microgrids and enabling the deployment of microgrids to achieve reliability, resilience, affordability, and renewable integration goals.

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