Resilient Microgrids for Rhode Island Critical Services

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Stakeholders and subject-matter experts consulted during this study did not review the final report before its publication. Their acknowledgment does not indicate endorsement or agreement with the report’s content or conclusions.

ACKNOWLEDGEMENTS

The consultant team comprised a number of contributors from three organizations who made this project possible. The consultant team leader, overall project manager and lead author Chris Lotspeich of Celtic Energy Inc. assumes responsibility for all errors and omissions.

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Numerous stakeholders and subject matter experts were interviewed or otherwise consulted for this report. The authors are grateful for their time, consideration, information and insights. Most of those interviewed did not review the final report before its publication. Their acknowledgment does not indicate endorsement or agreement with the report’s content or conclusions.

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EXECUTIVE SUMMARY

INTRODUCTION

The United States faces a critical national vulnerability: over-reliance on an Electric Power System (EPS) or "grid" that serves us very well under normal conditions but is vulnerable to prolonged disruptions from a range of natural and man-made hazards, despite the historical best practices of regulated utilities. Long duration outages lasting more than one week—and potentially months—are rare, but outage frequency and duration are increasing and the risks of severe disruptions are growing. Worst case plausible scenarios could devastate the economy and harm or kill Americans in numbers not seen since the Civil War. National planning and action to reduce these risks is thus far insufficient to the scale of the problem, and evidently national preparedness for this type of emergency is lacking. A large burden of preparedness falls on state and local shoulders.

The good news is that solutions are available to reduce these risks and provide other benefits as well. Distributed Energy Resources (DERs) such as combined heat and power, solar energy, wind power, energy storage and energy efficiency can deliver energy services at lower cost, risk and pollution than can the grid alone. Growing deployment of these solutions is increasingly economical due to technological innovation and state-level energy policies. Microgrids can integrate DERs with controls and switchgear to enable both grid-connected and grid-independent operations to energize society's critical infrastructure when the power is out, and provide other benefits that help maximize DERs' value during normal "blue sky" operations. State level policies and programs can accelerate deployment of these technologies by addressing barriers in the marketplace and the current legal and regulatory environment.

Several states have undertaken research and funding efforts to support microgrid development, including California, Connecticut, Maryland, Massachusetts, New Jersey and New York. Rhode Island is considering development of a similar program. This report is the deliverable for a consulting contract with the Rhode Island Office of Energy Resources (OER), as requested in solicitation #754979 *Resilient Microgrids for Critical Services*. In the wake of multi-day power outages due to severe weather events in recent years, OER sought consultant support for design of a program intended to enhance the energy assurance of critical infrastructure through deployment of distributed energy resources and other means. This effort draws from lessons learned in other states with similar programs. This report describes technologies, procurement strategies, and polices that can contribute to microgrid development.

Intro section 1.1 Critical facilities are dependent on vulnerable critical infrastructure: Our modern society and economy rely on interdependent "systems of systems" of critical infrastructure. The EPS is arguably the most fundamental of these, in that so many other critical systems rely upon it to sustain functionality. The traditional EPS model of fewer large units of centralized generation capacity connected to remote customers is inherently more vulnerable to disruption than an emerging, more distributed model of many small units of distributed generation located at or close to customers. The centralized model is subject to the loss of larger blocks of generation capacity with fewer points of failure. The distributed model reduces reliance on wires, line losses, and the risk of transmission and distribution disruptions.

Microgrids reflect the epitome of the distributed EPS model. Although microgrids can greatly increase the probability that power will be available during outages, in most cases the EPS provides more reliable service on a day-to-day basis. A grid-connected microgrid benefits from EPS reliability to back up its own onsite DERs, which often are not as reliable as the grid. Yet a microgrid can have a good probability of being operational during any given EPS disruption. Critical facility microgrids are generally less susceptible to severe weather disruptions than is the EPS, if only due to reduced reliance on vulnerable transmission and distribution networks.

Microgrids comprising small numbers of critical facilities could not much reduce the numbers of customer power service interruptions, but they could significantly reduce suffering and improve public health and safety for large numbers of people by maintaining critical services and safe havens during prolonged outages. Microgrids and their DERs can contribute to achieving multiple goals including:

- Least cost procurement of electricity service delivery and EPS operation (*e.g.*, by shedding load, contributing power, or helping defer transmission and distribution system upgrades)
- Reduced facility operating costs
- Enhanced public health and safety
- Protection of vulnerable populations
- Community economic development and resiliency
- Increased deployment of cleaner energy resources
- Energy-related emissions reductions
- Climate change risk mitigation (*e.g.*, via greenhouse gas emissions reduction)
- Climate change risk adaptation (*e.g.*, via critical facility mission assurance)

Intro section 1.3 Risks to the Rhode Island EPS: Hazards that pose risks of long duration power outages (defined here as lasting longer than 3 days) are listed below. Appendix A describes these hazards in more detail, and suggests potential policy responses. Hazards listed in **bold font** are "High-Impact, Low-Frequency (HILF) Events" or "Black Sky Hazards" that can cause very long duration outages (defined here as lasting longer than one week, and potentially for weeks to months). Some Black Sky events can have regional or national effects with potentially catastrophic impacts, such as electromagnetic hazards caused by solar flares or the electromagnetic pulse (EMP) created by a high-altitude nuclear explosion.

<u>Natural hazards</u>

- Weather – Wind: Tree fall, blown debris, **severe storms**
- Weather – Wind: Storm surge, seawater inundation
- Weather – Precipitation: Rain, freshwater inundation
- Weather – Precipitation: Snow, **ice**
- Weather – High heat, drought, wildfires

- Geologic/Seismic – Earthquake, **tsunami,** volcano
- **Space weather – Solar flare / coronal mass ejection (CME) / geomagnetic disturbance (GMD)**
- Pandemic

Manmade hazards

- Aging infrastructure, equipment failure
- Human error, accidents
- **Physical attack**
- **Cyberattack**
- **Intentional Electromagnetic Interference (IEMI) attack**
- **Nuclear weapons – Electromagnetic Pulse (EMP) attack**
- Nuclear weapons – **War,** terrorism, dirty bombs

National Grid is the electricity distribution company (EDC) serving ~99% of RI customers. The RI Energy Assurance Plan (RIEAP) states: "National Grid's system contains a considerable amount of redundancy and system protection to minimize the impact of events to its customers…. National Grid's electric system is reported to be designed to withstand the loss of any single high voltage element (*e.g.*, transmission lines, transformers or power plants) without any impact to customers, which is compliant with NERC standards."[1] National Grid also is the state's only natural gas Local Distribution Company (LDC) and maintains redundant pipeline and storage capacity for system reliability and resilience, including for RI's power generation which is almost entirely dependent on natural gas supply.[2]

Despite best practices, any EDC is vulnerable to hazards that can cause prolonged outages. Severe weather events and other natural and man-made disasters pose challenges that are almost impossible for grid operators to overcome.

PART A: RHODE ISLAND CRITICAL INFRASTRUCTURE

Section A1 What is a critical facility?: Critical facilities can be categorized by ownership as being either public sector or private sector. Typically, the public sector is responsible for public health and safety, although companies can play key roles. Companies provide vital services to the community that can be particularly valuable during prolonged power outages. Most state microgrid programs consider the following facility types to be mission critical:

- Continuity of government functions: Municipal centers, public works
- Public safety: First responders, emergency operations centers, emergency shelters
- Health: Hospitals, clinics, pharmacies, dialysis centers
- Potable water supply, wastewater treatment facilities and networks

[1] RIEAP, p.9-8.
[2] RIEAP, p. ES-7.

- Residential facilities where vulnerable populations can shelter in place: multifamily housing, nursing homes, corrections facilities
- Fuel and energy supply: Gas stations, delivery terminals, storage facilities
- Communications and information technology: Cell phone towers, radio masts, internet servers, data centers
- Transportation: Train and bus stations, airports, maintenance facilities
- Food supplies: Supermarkets
- Access to funds: Banks, ATMs

The Rhode Island Emergency Management Agency (RIEMA) has developed a comprehensive Rhode Island Critical Infrastructure Program Plan (RICIPP) based on the USDHS criteria and classifications. RIEMA modeled its definition of critical infrastructure and Key Resources (CIKR) on the Patriot Act terminology:[3]

> "Critical infrastructure includes those assets, systems, networks, and functions—physical or virtual—so vital to Rhode Island that their incapacitation or destruction would have a debilitating impact on security, economic security, public health or safety, or any combination of those matters."

RIEMA added two sectors (Emergency Services and Information Technology) to the four designated by NIAC, for a total of six Life Line Sectors out of the sixteen CIKR sectors; see Figure A-2.[4]

Figure A-2: Rhode Island Critical Infrastructure and Key Resource sectors

Life-Line Sectors	Remaining Sectors
• Communications	• Agriculture & Food
• Emergency Services	• Banking & Finance
• Energy	• Chemical & Hazardous Materials Ind.
• Information Technology	• Commercial Facilities
• Transportation Systems	• Critical Manufacturing
• Water & Waste Water Systems	• Dams
	• Defense Industrial Base
	• Government Facilities
	• Health Care & Public Health
	• Nuclear Reactors, Materials & Waste

Image courtesy John McCoy, RIEMA.

RIEMA has convened a multi-stakeholder process to develop Sector-Specific Plans (SSPs) to identify CIKR facilities and interdependencies, assess hazards and prioritize protection initiatives. Each sector has a designated Sector Lead Agency (SLA). A database of critical facilities is under development, including stakeholder working group input from each of the 16 sectors to help identify critical facilities.

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[3] John McCoy, RIEMA, personal communications, Feb. 2nd, 2016.
[4] John McCoy, RIEMA, personal communications, Mar. 2nd, 2017.

Many of these facilities are represented in the Rhode Island Geographic Information System (RIGIS) software. The RIGIS critical facility database can be used to inform microgrid planning, for example by depicting flood zone locations, or determining the type and location of proximal critical facilities that might be considered for inclusion in a microgrid.

Section A2: Critical facility prioritization: Two approaches to microgrid program implementation have differing implications for how OER might apply prioritization criteria: A "Bottom Up" approach that solicits funding applications from eligible projects (*e.g.*, via RFP), and a "Top Down" approach where the OER team identifies critical facilities for targeted outreach. The approaches are not mutually exclusive and can be implemented in a parallel and complementarily manner. Both approaches evaluate and rank applicant projects according to qualitative and quantitative attributes, and fund projects with the best cost/benefit ratio or highest score. Prioritization information sources include:

RIEMA information. Life Line sector facilities are prioritized over other sectors; within each sector SSPs and SLAs are designating priority facilities. CIAT scores indicate criticality of surveyed facilities.

Policy recommendation: OER could require facilities that apply for microgrid program funding to complete a RIEMA CIAT survey. The survey's energy-related questions could be expanded to collect additional energy assurance information such as annual energy use and cost; critical loads including mission-critical energy-using systems and HVAC systems type; BUG characteristics (*e.g.*, size or fuel type, or presence of additional onsite distributed energy resources (*e.g.*, solar photovoltaics or combined heat and power systems). Microgrid funding applications could also collect this type of information.

Cost-Benefit Analysis (CBA). CBA calculations provide Key Performance Indicators (KPIs), such as $/kW of DER capacity, which could inform microgrid project evaluation. (See Part C for further discussion.)

Indirect, non-traditional or "macroeconomic" factors. Microgrids and DERs convey numerous "bigger picture" costs and benefits that typically are not reflected within standard microeconomic project financial analysis, can be hard to quantify, and often are not readily monetized. Docket 4600's Total Resource Cost Test organizes benefit/cost aspects according to where the effects accrue: Power System Level, Customer Level and Societal Level. These "beyond the customer meter" factors include, but are not limited to:

- Costs savings and reductions for grid operators and ratepayers
    - Dispatching microgrid generation provides peak load reduction or local voltage support, resulting in avoided or deferred grid capacity additions or operations and maintenance costs in transmission, distribution and substation assets
    - Reduction in system "line losses"
    - Reduction in electricity prices due to reduced demand
- Avoided costs of outages for critical facilities, local businesses, communities and insurers
- Avoided costs of emissions for cleaner DERs

  - Criteria pollutant reductions
  - Social cost of carbon
  - Improved local air quality
- Public health and safety benefits
  - fewer deaths and injuries during disruptions or due to emissions
- Safe shelter for vulnerable populations / demographics
  - Low to moderate income
  - Children and elderly
  - Disabled, medically dependent
  - Domestic violence shelter
  - Transitional housing, corrections
- Geographic preferences
  - Dispersion across state
  - Location in HUD or USDA funding-eligible area
  - Avoidance of flood zones)
- Economic development benefits
  - Local job creation
  - Technological innovation
  - Attraction of industries with power reliability and energy services
- Contribution to meeting State goals
  - Deployment of renewable energy in State facilities
- National security benefits
  - Reduced oil dependence
  - Increased cybersecurity

There are two primary options for quantifying these types of factors for the purposes of an OER microgrid program, "Economic Valuation" and "Point Scoring" (see Section C1 for further discussion):

- *Economic Valuation method*. Macroeconomic factors could be assigned monetary value using reference criteria such as are contained in Docket 4600's Total Resource Cost Test, or the NY Prize CBA tool. This approach provides more objective, precise (if not accurate) information that can be integrated with "microeconomic" analysis using a dollar value common denominator. Valuation of program goals in dollar terms can be complex and more subjective, such as the added value when a microgrid serves a low to moderate income demographic. Developing this detailed analysis is more resource-intensive for both the program and its participants. If this approach is taken, OER should provide a detailed template and guidance for applicants to apply the appropriate conversion factors to their project, and/or support applicant CBA with funding or technical assistance teams.
- *Point Scoring method*. A streamlined scoring process with abstracted values representing macroeconomic factors and program preferences could simplify evaluation of funding applications. This approach provides information that is more subjective and less accurate, precise and detailed than the Economic Valuation method, and cannot be integrated with "microeconomic" analysis in monetary terms but rather is used in

parallel. This abstracted analysis is less resource-intensive for both the program and its participants. If this approach is taken, the OER team could score funding applications based on information provided in the applications.

Policy recommendation: OER should use the Point Scoring method to simplify the process and conserve program and project resources. This authors suggest a scoring template in Table C-1, which OER can modify as desired.

Public Track and Unique Asset Track options. The basic structure of all the state microgrid programs to date (*e.g.*, CA, CT, MA, NJ, NY) has been to make available funding and other support to eligible applicants via a competitive solicitation. OER could consider a complementary approach to provide more targeted support to unique assets and critical facilities that the Governor can call upon during emergencies.

Policy recommendation: OER could have a two-track approach to identifying and prioritizing critical facilities in a microgrid program: a bottom-up "Public Track" and a top-down "Unique Asset" track.

The "Public Track" approach would be similar in structure to other state microgrid funding programs. Most of the recommendations of this report are intended to inform creation of this type of program. OER could issue an RFP solicitation for municipalities and other critical facility owners to apply for microgrid funding support. This "bottom-up" approach would allow any project that meets the RFP-specified criteria to respond. Applications would be scored based on criteria including a cost/benefit analysis, and a scoring factors that reflect OER program objectives.

A complementary "Unique Asset Track" would take a "top-down" approach: OER would convene an Interagency Working Group (IWG) that includes RIEMA and other agencies as appropriate. The IWG would identify highly critical facilities that provide or enable unique assets and services during a declared emergency. These Unique Assets (UAs) could include, but are not limited to:

- State Emergency Operations Center
- National Guard specialized ground units and armories (*e.g.*, mobile generators, fuel tankers, engineers with heavy equipment, communications, water purification, mobile hospitals, etc.)
- National Guard and other state-owned rotary- and fixed-wing aviation assets
- State agency specialized first responder teams (*e.g.*, collapse rescue, canine, search and rescue, hazardous materials and radiological incident emergency response, Explosive Ordinance Disposal, marine rescue and spill response, etc.)
- State-owned or quasi-public transportation UAs (*e.g.*, airports)

The IWG would reach out to Unique Assets (UAs) and offer funding or other assistance to encourage microgrid development. Track implementation options include:

A. UAs could be solicited to participate in the Public Track application process, and could receive a preferential scoring factor.
B. The UA Track could be conducted as a separate parallel effort to the Public Track, with discrete dedicated funds and outreach.

UAs would be asked to assess their energy assurance strategies, capabilities and facility dependency. If a UA is highly dependent on its base facility, that location could be prioritized for microgrid assistance. If a UA is not facility-dependent due to its ability to relocate personnel and equipment to another location and sustain mission-critical operations, the UA should verify its energy assurance strategy and capability to sustain operations beyond 72 hours at alternate locations. For example, if a specialized team's base facility loses power, and the team can move to an alternate location or staging area, what is that alternate location's grid-independent energy assurance?

Policy recommendation: OER could prioritize energy assurance for private sector facilities that enable service restoration for the EPS, natural gas and other critical infrastructure networks.

CI interdependencies: The EPS depends on the natural gas system, and *vice versa*. RI is almost entirely dependent on natural gas supply for electricity generation, with ~97% of in-state generation capacity fueled by natural gas.[5] Power production comprises ~58% of RI natural gas consumption, with industry using ~8% and other retail customers ~34%.[6] "Natural gas-fired generators in Rhode Island do not receive firm gas transmission. Similar circumstances are anticipated in nearby states. Consequently, a disruption in the supply of natural gas would affect electric supply."[7] It is important to note that gas supply capacity and redundancy provide significant resilience; the non-firm gas supply contracts of the power stations render them more vulnerable to curtailment.[8]

Policy recommendation: OER could consider requiring natural gas fueled microgrids to secure firm supply contracts.

National Grid is the only Local Distribution Company (LDC) for natural gas delivery in the state; it does not produce any gas. There are no natural gas wells in RI. Pipelines provide ~93% of the state's supply[9], and RI is effectively at the "end of the line". Two primary pipelines coming through New York state, each with two offshoot lateral lines, supply ~72% of the state's natural gas and also deliver the ~20% of gas coming from Canada [10]: Algonquin Gas Transmission (AGT) provides ~60% of pipeline capacity and Tennessee Gas Pipeline (TGP) provides ~40%.[11]

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[5] RIEAP, p. ES-7.
[6] RIEAP, p. ES-9.
[7] RIEAP, p. 9-10.
[8] For further discussion see RIEAP pp. 9-13 & 9-14.
[9] RIEAP, p. ES-10.
[10] RIEAP, p. ES-10. The same source states on p. ES-12 that AGT and TGP provide 77% of the state's natural gas.
[11] RIEAP p. 3-5.

Pipelines are more resilient against severe weather events than are the overhead EPS transmission and distribution (T&D) networks, which are more exposed to wind, precipitation and inundation hazards. In the event of a cyberattack the pipelines can be operated in manual mode.[12] A major failure that halts supply on either AGT or TGP could take 16–18 months to repair.[13] AGT and TGP rely on compressor stations to maintain supply, which require electricity to operate. Pipeline and lateral redundancy enable the LDC to endure the loss of two compressor stations before it curtails peak day deliveries.[14]

Liquid natural gas (LNG) imports provide ~7% of the state's supply.[15] LNG storage provides a vital buffer and swing supply capacity to help meet short-term demand peaks that exceed pipeline supply capacity. The LDC maintains LNG storage sufficient for ~13 days of peak discharge output.[16]

Liquid fuels: Liquid petroleum fuels—particularly gasoline, diesel fuel and building heating oils—provide critical energy services. Supply disruptions ripple through other critical infrastructure and services, and hinder other community and economic functions. Rhode Island's liquid fuel supply chain is vulnerable to disruptions, particularly storm surge. The concentration of 5 of the state's 6 terminals and 90% of the storage capacity along the Providence waterfront increases geographic risk.[17] OER's microgrid program could address a major vulnerability by installing DERs well above storm surge levels to enable grid-independent terminal operations. As of 2014, none of the terminals had on-site BUGs capable of supporting operations.

Policy recommendation: OER could prioritize petroleum marine terminals and storage facilities for microgrid support, *e.g.*, by preferential scoring and/or including them in a Unique Asset Track.

Downstream of the terminals, petroleum delivery relies on tanker trucks, so the distribution network can function if the terminals are operating and the roads are passable. Storage capacity provides a time buffer if the terminals cannot operate but storage facilities are operable and roads are open. "Rhode Island's petroleum wholesalers report that average inventory levels [are] sufficient to meet the State's needs for approximately two (2) to three (3) weeks."[18]

Gas stations are the vital interface between the gasoline and diesel supply chain and the public. Retail service stations utilize electricity to operate pumps for fueling vehicles. It is uncommon for service stations to have a backup generator. "Consequently, a prolonged electric outage would effectively close all retail service stations and preclude vehicles from being re-fueled…. Rhode Island is not prepared to respond to such impacts."[19] This situation presents an

[12] RIEAP p. 4-21.
[13] RIEAP p. 9-11.
[14] RIEAP, p. 9-12.
[15] RIEAP p. ES-10.
[16] RIEAP p. 9-13.
[17] RIEAP p. 9-15.
[18] RIEAP, pp. 9-15 and 9-17.
[19] RIEAP p. 9-17.

opportunity for OER to enhance service station energy assurance with sector-specific dedicated microgrid support.

Policy recommendation: OER could prioritize service stations for microgrid support, *e.g.*, by preferential scoring and/or including them in a Unique Asset Track focused exclusively on gas stations.

PART B: MICROGRIDS TECHNOLOGIES AND APPLICATIONS

Section B1 – Definition: There are numerous definitions of "microgrid." The U.S. Department of Energy (DOE) Microgrid Exchange Group definition is perhaps the most widely referenced: "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."

Definitions of microgrid types, configurations and ownership models are discussed in more detail in Section B3 and B7. For the purposes of this Part of the report, we reference the microgrid typology suggested by the New Jersey Board of Public Utilities (NJBPU)[20], with minor modifications:

Microgrid type	DERs	Facilities	Meters	Facility owners
Level 1 single facility	1–2+	1	1	1
Level 2 campus	1–2+	2+	1–2+	1
Level 3 multi-user community	1–2+	2+	2+	2+

Section B2 - General purpose: Microgrids serve many purposes and provide multiple services and benefits, including:

- Energy assurance for critical facility mission assurance, continuity of operations and resilience.
- Reduced outage costs.
- Facility owner cost reduction and/or revenue generation.
- Grid operator cost reductions and lower customer electricity costs.
- Increased deployment of renewable resources and improved environmental quality.
- Avoided grid losses and improved DER utilization.
- Greater local control over energy resources.

Applications: Level 1 single-facility microgrids include all critical facility types and are typically used primarily for energy assurance and secondarily to maximize DER benefits during "blue sky" normal operation. Level 2 campus microgrids most commonly include military bases, higher education campuses, health care complexes, high-density residential developments,

[20] NJBPU, *Microgrid Report*, 2016, p.17.

industrial parks, and remote or island communities, as well as corporate campuses and prisons. Utility cost benefits and energy assurance are primary objectives. _Level 3 multi-user community microgrids are very rare although several projects are under development. Applications include provision of electric service at the community scale when connection to a larger "macrogrid" is too costly or otherwise prohibitive (*e.g.*, remote communities or islands); and energy services management at the local scale.

The Minnesota microgrid report described microgrid applications by organizing critical facilities into three asset categories, defined by the critical mission: crisis response and management; public health and safety; and basic needs and services. See Figure B-2.

Figure B-2: Microgrid Applications by Critical Facility Asset Categories[21]

Asset Category	Examples	Priorities and Microgrid Factors
Crisis Response and Management	■ Utility and transportation crew dispatch, supply, and staging centers ■ Government command and control centers ■ Telecom infrastructure	■ Critical to facilitate repair and recovery, minimizing the damage from a crisis and avoiding cascading effects on interdependent systems. ■ Microgrids can be more effective when crisis management facilities are clustered together, allowing asset sharing and load diversity.
Public Health and Safety	■ Hospitals and other health care facilities ■ Police and fire departments ■ Public water systems	■ Vital to support first response, medical care, and law and order. ■ Many such facilities already have backup power systems that can be upgraded with microgrid technologies to increase their effectiveness.
Basic Needs and Services	■ Storm shelters and temporary housing ■ Grocery stores ■ Fuel infrastructure, including gas stations ■ Public transportation and transit systems	■ Vital products and services to support basic needs of residents, and provide shelter and vital mobility for displaced and at-risk populations. ■ Load-management systems and protocols can help conserve fuel and extend effectiveness of basic backup power supplies.

Figure 1-2: Energy Assurance Priorities and Microgrid Applications

Section B3 Types: This section describes microgrid types with examples, including:

- Remote microgrids: Islands, remote communities and commercial installations (e.g., mines).
- Level 1 microgrids: Single- or multiple-DER, Single facility, single owner, BTM installations.
- Level 2 campus microgrids: Single- or multiple-DER, multiple facility, single owner

[21] Microgrid Institute, *Minnesota Microgrids: Barriers, Opportunities, and Pathways Toward Energy Assurance*, 2013, p. 17.

installations.
- Utility owned/operated microgrid.
- Utility distribution microgrids—Hybrid ownership model.
- Virtual microgrids.
- Level 3 Multi-user community microgrid.

Section B4 Overview of Microgrid Technologies: This section describes the following topics in detail, with references for further discussion.

Demand Side – Critical Loads: Critical facilities (CFs) support critical missions, which requires that the facility have energy supply for its critical loads (CLs) to enable personnel to remain in the CF and operate essential equipment. This is the primary purpose of a CF microgrid. The mission determines what loads are critical. Most CFs have a common set of "core loads" that enable occupants to remain indoors in safety and comfort, *e.g.*, life safety systems, lighting, HVAC, potable water supply, and wastewater removal. Requirements for maintaining safe indoors temperatures under the extremes of four-season conditions should be considered, and can be met using both passive and active measures.

Further considerations include load shedding and isolation, DER sizing, energy efficiency. Load characteristics inform DER selection and microgrid design. Some specialized equipment such as sensitive electronics have low fault tolerance and require high power quality. DERs must be capable of following the CF load as it changes up or down in island mode, including spikes of inrush current on device start-up. Microgrids that include multiple CFs should consider the complementary aspects of each facility's energy requirements and load profile that can inform economic DER selection and operation. DERs for facility load reduction include solar thermal and heat pump technologies.

Supply Side – Distributed Generation: DG can be categorized according to whether or not the device has rotating equipment (*i.e.*, shaft power), the device's ability to operate in grid-independent mode, and by operating modes: emergency, base load and intermittent generation. Common DG types are depicted in Figure B-3.

Figure B-3: DG Technologies[22]

	DG Technology	Typical Module Size
Nonrenewable	Combined cycle gas turbine	35–400 MW
	Internal combustion engines	5 kW–10 MW
	Combustion turbine	1–250 MW
	Micro-Turbines	35 kW–1 MW
	Fuel cells	1 kW–5 MW
	Stirling engine	2-10kW
	Reciprocating engine	5 kW–50 MW
Renewable	Small hydro	25 kW –10 MW
	Wind turbine	200 W–5 MW
	Solar electric	20 W–100 kW
	Solar thermal	1–80 MW
	Biomass	100 kW–20 MW
	Geothermal	5 kW–100 MW
	Ocean energy	100 kW–1 MW

Section B4.2 DG technologies in microgrid applications: This section includes both selections from other reports and the authors' comments on some of the advantages, limitations and potential strategies regarding common DG technologies in microgrid applications. Examples include:

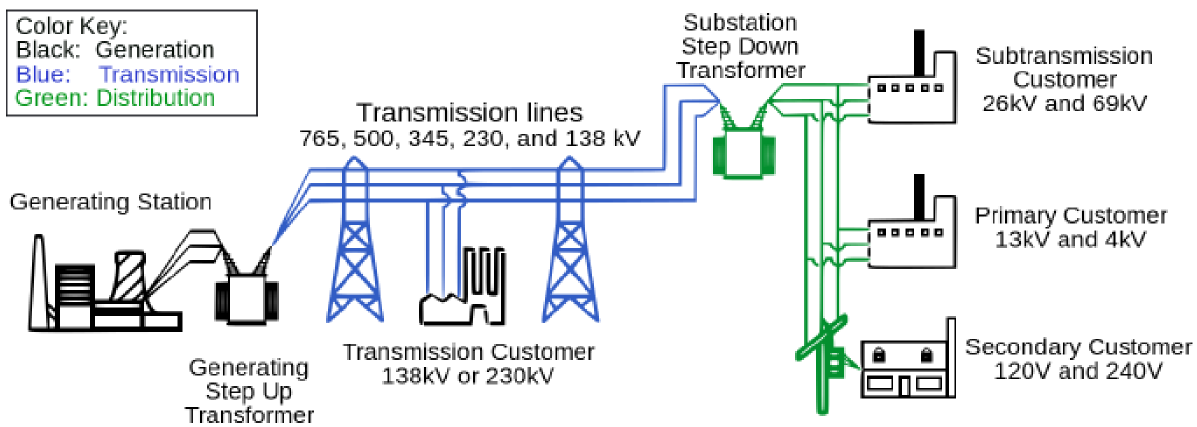
- Standby Backup Generators
- Base Load Constant Duty Assets: Combined Heat & Power
- CHP Prime Movers: Steam Turbines
- CHP Prime Movers: Natural Gas Turbines
- CHP Prime Movers: Microturbines
- Solar Photovoltaic Power
- Energy Storage
- Wind Power
- Hydropower

B4.3 - Microgrid interconnection, controls, and operational considerations: This section discusses microgrid's core technical and operational considerations, driving factors in microgrid design and configuration of its relationship with the larger grid to which it is connected. Put colloquially: this is the hard part of microgrid design and operation, and controls are the special sauce that enables safe and economical operation.

[22] NYSERDA 2014, p. 10.

Electricity distribution infrastructure in grids and microgrids: Figure B-6 depicts the major components of the "macrogrid". The EPS is defined as the medium- to lower-voltage (at or below 69 kV) distribution portion of the network, depicted in green.

Figure B-6: Electric Grid Systems Components[23]



The EDC owns and manages this segment connecting higher-voltage transmission with low-voltage customers; the EPS stops at the customer meter. EPS infrastructure is akin to that contained within (some) microgrids, albeit on a smaller scale and often at lower voltages. Both the EDC and microgrid owners have similar tasks and objectives for electric power generation and distribution in a safe and reliable manner, with comparable tools and equivalent concerns about system resilience in the face of faults, accidents, and insults such as severe weather.

Above-ground or overhead EPS and microgrid distribution infrastructure hardening techniques and technologies are similar. Hardening the entire EPS would be very expensive, and localized equipment damage could still cause widespread outages. Microgrids are a cost-effective approach to enhancing EPS and community resiliency without extensive and expensive EPS hardening; plus microgrids can provide a host of benefits that buried wires cannot.

This section B4.3 discusses important technical issues in some detail with extensive references to, and excerpts from, other sources.

- *Meters*. Meters play a number of technical and economic roles in microgrid development and operation.
- *Point of common coupling (PCC) of a microgrid to the EPS*. This is the electrical interface between the macrogrid and a microgrid.
- *Interconnection standards such as IEEE 1547*. This vital standard addresses a range of technical requirements and considerations for microgrid operation and interconnection with the EPS. IEEE is revising this standard to include microgrids, expected by 2018.
- *Synchronization of microgrid and EPS*. This is an essential set of issues for microgrids to

[23] NJBPU 2016, p. 45.

safely disconnect from, and reconnect to, the EPS. We describe three strategies: active synchronization, sync check, and open transition (the last being generally the simplest and safest).

- *Voltage control and power control*. This is a primary challenge in microgrid operation.
- We reference a NYSERDA report for discussion of metering and monitoring locations and key parameters for safe operation; strategies for supplying critical loads; and black start considerations including cold-load pickup and inrush current.
- *Inertia*. This is an important stabilizing factor in the grid that poses challenges for microgrids.
- *EPS circuit types and implications for microgrid interconnection*. We reference a NYSERDA report for excellent detailed discussion of microgrid operation where connected to (rural) radial, (suburban) loop, and (urban) spot and grid networks.
- *Controls*. We discuss microgrid controls systems types and functionalities, with consideration of centralized *vs*. decentralized strategies, primary-secondary-tertiary levels of control, microgrid energy management, and complexity and interoperability issues.

Section B5 discusses microgrids' technical and economic performance characteristics.

Section B6 outlines microgrid benefits and value streams. Microgrid benefits (and costs) accrue to different parties: some to the owner, some to the utility, some to society. Not all benefits can be monetized. Different microgrid procurement "business models" provide varied opportunities to monetize potential mixes of value streams. Where and how microgrids provide value depends upon the specific assets and aspects of a microgrid. Distributed generation (DG) is a "prime mover" of value; controls enable islanding, optimal economic dispatch of generation, demand response (DR) and ancillary services revenue; energy storage (ES) provides greater frequency regulation capabilities. These components contribute to the microgrid value chain. Value streams that are available to the microgrid/DER owner could be included in cost/benefit analysis (CBA). Benefits are categorized as both directly and indirectly monetizable; safety and security; public and environmental health benefits; and additional community benefits.

Section B7 highlights microgrid ownership, procurement and financing strategies and business models. Different owner types have different options. Facility-owned or utility-customer-owned options include direct purchase; Rhode Island Infrastructure Bank (RIIB) Commercial Property Assessed Clean Energy (C-PACE) financing; Energy Savings Performance Contracts (ESPCs). Third-party ownership models include Power Purchase Agreements (PPAs) and Energy Services Agreements (ESAs); note that some third party ownership models could challenge the EDC's monopoly franchise and/or require PUC regulatory oversight. Potential options that (probably) require enabling legislation or other precedent approval include community ownership, Energy Improvement Districts (EIDs) or similar structures, and utility full- or hybrid-ownership models.

Section B8 outlines market barriers to microgrid development. These are categorized in terms of real or perceived risks that are legal, administrative, organizational, technical and economic.

Section B9 provides a brief overview of microgrid market status, which can be considered both in terms of the market maturity of microgrid components, and microgrid development. Legal and regulatory barriers and high cost pose formidable barriers to rapid adoption. State policies and programs have a strong influence on the marketplace, and grant-funded programs have had varied success yet account for a large share of recent installments. There is much buzz about microgrid growth, but the sheer scale of marginal investment are small. Slow growth, large potential, and significant impacts of policy levers will shape the marketplace.

Section B10 references case studies and DER data that provide microgrid cost information. Section B11 discusses alternatives to microgrids, including critical mission assurance strategies that are not necessarily tied to a dedicated facility; and trade-offs in cost and complexity between creating multiple Level 1 single-facility microgrids rather than connecting them to form one Level 2 campus microgrid microgrid, as well as between enhanced standby generation *vs*. installing constant-duty DERs.

PART C: COST/BENEFIT ANALYSIS OF CRITICAL INFRASTRUCTURE MICROGRIDS

Section C1 describes a cost-benefit analysis (CBA) framework. An OER microgrid program needs a standardized CBA framework to help compare projects on an equivalent basis and allocate finite resources, and this report is tasked with recommending a methodology.

Each microgrid will have project-specific features that shape the CBA, including ownership structure, procurement strategy and investment vehicle(s), sources of supplemental funding, operating modes, and other considerations. The CBA framework should utilize standard "microeconomic" financial methods and metrics used in energy and facility capital investment projects, to help align the program with the marketplace. In addition, OER wants to consider "macroeconomic" costs and benefits that extend beyond the project to affect the grid, society, the economy and the environment. The authors describe below two primary options for a programmatic approach to quantifying macroeconomic factors: "Economic Valuation" and "Point Scoring" methods.

Economic Valuation method: Macroeconomic factors are assigned monetary value using reference criteria such as are contained in Docket 4600's Total Resource Cost Test, or the NY Prize CBA tool.[24] This approach provides more objective, precise (if not accurate) information that can be integrated with "microeconomic" analysis using a dollar value common denominator. Valuation of program goals in dollar terms can be complex and more subjective, *e.g.*, the added value when a microgrid serves a low to moderate income demographic. Developing this detailed analysis is more resource-intensive for both the program and its participants.

Policy recommendation: If OER prefers to use the Economic Evaluation method, the program should use the NY Prize CBA template, and where applicable modify the conversion factors to use Docket 4600 or other state-specific approaches. OER should provide applicants with a detailed CBA template and instructions, as well as feasibility analysis funding and/or technical support sufficient to the task.

[24] See "NY Prize Community Microgrid Benefit-Cost Analysis Information" section and links at: https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize/Resources-for-applicants

Point Scoring method. A streamlined scoring process with abstracted values representing macroeconomic factors and program preferences could simplify evaluation of funding applications. This approach provides information that is more subjective and less accurate, precise and detailed than the Economic Valuation method, and cannot be integrated with "microeconomic" analysis in monetary terms but rather is used in parallel. This abstracted analysis is less resource-intensive for the program and its participants. If this approach is taken, OER could score funding applications based on information provided in the applications. The authors provide an example of a scoring system in Table C-1, which OER can modify as desired.

Policy recommendation: An OER microgrid program could develop a tool similar to (but more refined than) the author's spreadsheet-based CBAM tool, complemented by the Point Scoring method to simplify the process and conserve program and project resources.

Section C2 describes the author's Cost-Benefit Analysis Model (CBAM) tool, which was based on the CBA tool developed for the NY Prize microgrid program.[25] The CBAM tool is attached to this report for OER use only. This tool is not for public use, and is provided to OER to serve as a conceptual template for development of a comparable but more complex and refined tool; development of such a finished tool is beyond the scope of this report. The CBAM tool provides information that can be used to develop a microgrid project *pro forma* as part of a funding application, similar to that employed by the CT DEEP microgrid funding program Round 3 RFP,[26] which the authors recommend as an OER program application template. See Section E for case study applications of the CBAM to pilot project candidate facilities.

Section C2.3 describes how the CBAM tool can be used to assess grant award amounts according to different funding strategies, including "Eligible Equipment," "Capital Contribution" and "Credit Enhancement" approaches described below.

Eligible Equipment. OER could award grants based on eligible equipment. This categorical equipment-based approach has the advantages of being consistent and equitable in application, and the potential disadvantage that the grant amount might not be sufficient to ensure project gets financed and built. The CT microgrid program Rounds 1 and 2 funded only electrical infrastructure such as circuits/wires, transformers, switchgear, point of common coupling, controls, etc. but did not fund generation; Round 3 of the program allows funding of generation and energy storage. Funding microgrid electrical architecture but not generation is reasonable, because the former does not directly produce cost savings or revenue while the latter can reduce costs and is eligible for a variety of distributed generation policy and economic incentives.

[25] See "NY Prize Community Microgrid Benefit-Cost Analysis Information" section and links at: https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize/Resources-for-applicants

[26] http://www.dpuc.state.ct.us/DEEPEnergy.nsf/c6c6d525f7cdd1168525797d0047c5bf/69dc4ebaa1ebe96285257ed70064d53c?OpenDocument

Capital Contribution. OER could contribute capital to a microgrid project sufficient to enable it to be financed by an applicant-designated procurement model or investment vehicle (*e.g.*, 25 year term ESA, 20 year C-PACE assessment, or 15 year ESPC). This approach has the potential advantage of conserving program funds in cases where a modest contribution could spur project financing and leverage private investment, perhaps at lower program expenditure than an equipment-based approach. It has the disadvantages of inconsistency and potential inequity in application among various candidate projects, as well as project- and owner-specific financial criteria such as acceptable and available simple payback (SPB) periods. Award criteria parameters could improve consistency and equity, such as a funding cap of "X" dollars per kW of microgrid generation. (The CT program cap is $7,000/kW and $3 million per project.) Apparently, no other state has taken this contribution approach. The text provides an example.

Credit Enhancement. OER could use program funds to buy down the interest rate on a third-party financing to enable a microgrid project to get a loan on acceptable terms. This approach has the potential advantage of conserving program funds and leveraging private investment. It has the disadvantage of potential inconsistency and inequity due to case-by-case, microgrid project- and owner-specific financial criteria and ability to get a loan. Institutions such as the CT Green Bank offer this type of approach to support energy and microgrid projects.

<ins>Policy recommendation</ins>: OER should use the Eligible Equipment method to simplify program administration and foster consistency and equity in funding awards. Eligible equipment grants should exclude generation, but include energy storage and electrical infrastructure. Reference the CT microgrid program electrical equipment list,[27] but make eligible facility internal rewiring to enable critical load circuit modifications and load shedding. OER should consider also providing applicants with the option to request Capital Contribution and Credit Enhancement awards also, which would be evaluated on an equivalent basis with Eligible Equipment applications (*e.g.*, dollars per project or $/kW of DER capacity). This would provide an incentive to applicants to leverage non-program funds such as private investment, because smaller grant requests would be assessed more favorably.

PART D: MICROGRID PROGRAM AND POLICY RECOMMENDATIONS

Section D1 provides an overview of other states' microgrid programs in CA, CT, MA, NJ and NY. CA, CT and MA programs are broadly similar in structure, with CA funding a smaller number of microgrid projects (7) than CT (11) and MA (21), mostly Level 1 single facility or Level 2 campus microgrids. Each state issued solicitations for grant funding applications for microgrid projects. NJ provided funding for DERs at scores of municipal critical facilities, and its Energy Resilience Bank has a program to fund Level 1 microgrids at wastewater treatment facilities and hospitals.

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[27] See list in CT DEEP *Final Round 3 Application Instructions*, Part E-1, pp. 9–10, accessed at: http://www.dpuc.state.ct.us/DEEPEnergy.nsf/c6c6d525f7cdd1168525797d0047c5bf/69dc4ebaa1ebe96285257ed70064d53c?OpenDocument

Some states are working on the bigger picture barriers and opportunities surrounding Level 3 multi-user community microgrids. Both the NJ Town Center DER project and the NY Prize program are working to develop pathways to Level 3 multi-user community microgrids. CA is developing a microgrids roadmap. The MA Clean Energy Center (MA CEC) and Boston Redevelopment Authority (BRA) have conducted research and tool development aimed at fostering Level 3 microgrids. Research and policy deliberations underway in Maryland[28] (in particular) and Minnesota[29] (less so) are also grappling with these issues. But only in NY and to a lesser degree MD (and arguably in CA) is this effort occurring in the context of a comprehensive rethinking of traditional utility regulation. See D2.2 for further discussion.

<u>Policy recommendation</u>: Many of the more complex successful microgrids were built in phases, such as the University of California - San Diego campus microgrid.[30] OER should take the same approach and develop microgrid programs and policies in phases.

The first phase is the primary focus of this report: a program aimed at helping public agencies and others conduct feasibility assessments of the potential for Level 1 single facility and Level 2 campus critical facility microgrids, with a competitive solicitation to identify and fund promising projects. OER should model this microgrid program on a hybrid of the CT and MA programs: follow the CT DEEP program structure, plus elements of the MA DOER CCERI program (particularly up-front feasibility assessment support and allowance of Level 1 single-facility microgrids). Complement the solicitation with a top-down effort to focus energy assurance support on uniquely critical assets, including liquid fuels terminals and gas stations. This program can be conducted in successive iterations with public feedback and other quality assurance in between funding "rounds" to facilitate programmatic learning and continuous improvements.

The second phase would evaluate the pros and cons of potential pathways to development of Level 3 multi-user community microgrids. This exploration should only occur in the context of a comprehensive review of energy policy and utility regulation akin to the NY REV process, and although microgrids can be one driver of this discussion, they should not be the primary motive. The RI energy policy community is undertaking numerous innovative and forward-thinking policy deliberations and implementation efforts, many of which share common elements and vision. But in the authors' humble opinion, a comprehensive framework and forum is lacking (although it might be emerging). Community-scale microgrid development could spur that discussion, but should not precede it. See section D2.2 for further discussion.

[28] See *Maryland Resiliency Through Microgrids Task Force Report* at: http://energy.maryland.gov/documents/MarylandResiliencyThroughMicrogridsTaskForceReport_000.pdf
[29] See *Minnesota Microgrids: Barriers, Opportunities, and Pathways Toward Energy Assuranc*e at: http://mn.gov/commerce-stat/pdfs/microgrid.pdf
[30] https://building-microgrid.lbl.gov/ucsd

Section D2.1 suggests principles to inform policy goals of program design. The 2015 *Rhode Island Thermal Working Group Report* developed an excellent set of ten principles that are broadly applicable to other energy programs, including microgrids.[31] The following principles of program design are drawn from lessons learned by administrators of similar microgrid programs in other states, as well as other energy programs and general programmatic management best practices. They are somewhat repetitive of the Thermal Working Group principles in places.

- Design the program carefully with a multi-stakeholder team before roll out.
- Employ an integrative design approach with the participation of key stakeholders from inception through implementation.
- Take an all-hazards approach.
- Seek alignment with existing objectives: emergency plans, GHG goals, energy programs, etc. Build on past accomplishments, current programs and efforts underway.
- Prioritize public and community benefits, with a focus on support for local and state public agencies.
- Prioritize protection of vulnerable populations: LMI, medically dependent, elderly, prisoners, etc.
- Deploy program funds cost-effectively by leveraging market forces, private investment and existing programs.
- Educate the marketplace with proactive outreach, template documentation and program transparency.
- Make the program as user-friendly as possible, yet detailed enough to foster successful project design.
- Enable microgrid host/owner an optimum degree of choice and foster market flexibility and creativity in microgrid development.

Section D2.2 addresses the biggest policy decision: What (if any) changes to regulatory regime and role of EDC and/or third party market actors in MG development does OER want to pursue? *The biggest questions relate to potential reshaping of the EDC business model by allowing it to do things it does not or cannot currently do, and/or by allowing non-utility entities to do things that are currently exclusively EDC functions or to compete directly with EDCs for service provision.*

The authors recommend that significant modifications to the regulatory regime should not be undertaken for microgrid program development alone, in isolation from more comprehensive consideration. State-supported microgrids are a means to an end— energy assurance for critical infrastructure mission assurance—and they can support multiple policy objectives simultaneously, but microgrids are not an end in themselves. Minor modifications that require regulatory approval, such as novel tariffs or other case-specific issues of rate design to support Level 1 or Level 2 microgrid development, probably do not constitute much of a challenge to the

[31] See 2015 *Rhode Island Thermal Working Group Report*, pp. 13–14, at: http://www.energy.ri.gov/documents/Efficiency/Rhode_Island_Thermal_Working_Group_Report.pdf

current regulatory regime. In contrast, policies intended to foster development of Level 3 multi-user community microgrids would involve more significant changes to the regulatory regime and the EDC business model that touch on nearly every aspect of energy policy and EPS planning and operations, of which microgrids are but one aspect.

If Rhode Island wishes to revisit and re-imagine fundamental aspects of the EPS and the role of the EDC, the authors recommend that effort should be allowed the time and resources to develop a comprehensive, thoughtful, multi-stakeholder consultative process. A single-issue foray into tinkering with fundamental issues risks undesired unintended consequences. However important or time-sensitive is the need to improve energy assurance and socioeconomic resilience, those imperatives should not push microgrids into being the primary driver of fundamental change to the current regulatory regime.

Many Level 2 and Level 3 microgrids are built in phases; this approach can be applied to microgrid program design as well. An initial phase of strategy development and program definition with an integrative design approach can establish both short- and long-term objectives and measures. Successive iterations of program development can be undertaken with intervals enabling stakeholder feedback, analysis of lessons learned and implementation of program improvements. Each phase's structure and investments should provide a flexible basis for future development, with an eye towards technological developments and marketplace trends. A program comprising largely administrative measures can be initiated while longer-term, multi-stakeholder discussions and processes are pursued with regards to legislative and regulatory elements.

OER could consider convening a working group with representatives from the PUC, EDC and other stakeholders to assess what microgrid-related actions by the EDC, customers, and/or third party non-utility microgrid developers are allowable and desirable under the current legal and regulatory regime. This working group could then consider what changes (if any) to the current regulatory environment would be desired to foster development of multi-user Level 3 community microgrids.

This section lists microgrid program design options in roughly ascending order of the degree and complexity of change required of the current regulatory environment. It describes factors that hinder development of Level 3 multi-user community microgrids such as actual or perceived regulatory and legal constraints.

Section 2.3 provides recommendations for administrative program measures and actions that OER could undertake under current conditions, including:

Provide program funding to assist with MG development at program & project level. Funding types and sources, program administrative costs, and funding strategies are discussed. As the level of program funding is uncertain, to help conserve resources the following funding priorities are suggested for the Eligible Equipment approach, ranked most to least important:

- Eligible equipment - Electrical infrastructure but not generation or storage (*e.g.*, point of common coupling, wires, controls, switchgear, transformers, communications, protective relays and transfer trips, etc.).
- Feasibility analysis.
- Eligible equipment - Energy storage systems.
- Eligible equipment - Generation and energy storage equipment.

Capital Contribution and Credit Enhancement strategies could complement the Eligible Equipment approach, and could foster applicant use of private investment. See section C2.3 for further discussion.

Develop multi-stakeholder inter-organizational program administration team. Program design and implementation should include a core team comprising representatives from OER, RIEMA, RIGIS, RIIB, PUC/DPUC and National Grid. Critical facility owner/operator and microgrid developer stakeholders could be considered the primary "target market" of the microgrid program, and could provide input to program design but don't necessarily need to be regular participants in program design. See section 2.3 for a list of suggested stakeholders. OER should consider developing a list of pre-approved contractors, categorized by microgrid-related service offering.

Provide EDC with direct role in program and in MG project planning and development, and require microgrids to coordinate with the EDC on design and operations. Microgrid projects need to coordinate with the EDC for safe management of grid operations, and must be designed to meet interconnection requirements. Key microgrid project and program considerations about respective roles and responsibilities must be clarified with the EDC. OER could consider requiring microgrid project developers to work with the EDC by making an interconnection application a prerequisite for funding applications, or including the EDC in feasibility assessments. A microgrid program could impose a significant burden on EDC staff time, for example by a spurring a surge in energy usage data and interconnection information requests. Preplanning, streamlining and standardizing anticipated microgrid-related processes could reduce costs and uncertainty for both developers and the EDC; see section 2.3 for a list of suggested plans and program options and further details.

Define microgrid and critical facility for program participation and project eligibility to utilize program-related enabling rules and exceptions. One benefit of a programmatic definition is that clearly-defined microgrid project conditions could create a unique space in which special conditions, new rules or exemptions, and experimental administrative/legislative/regulatory measures can apply. This definitional "safe space" could be restricted to those projects that receive program support, or extend to all projects that meet the definition. This approach could reduce programmatic risk by limiting unintended consequences from program-specific measures, and reduce political risk by fostering stakeholder buy-in. See section 2.3 for discussion of issues that would be useful to define or clarify in program eligibility, and recommended actions.

Develop and deploy a robust education program. For most RI energy marketplace participants and facility owners, microgrid design and operational configurations are relatively new concepts and involve unfamiliar combinations of both existing and newer technologies and business models. A microgrid support program itself will be new to all involved, and can be thought of as being somewhat "ahead of the marketplace." Program elements should include a website with posted FAQs, public presentations and "meet and greet" meetings to match projects with goods and services providers.

Use project planning guides, and a detailed RFP / application that defines technical and economic requirements. This should include project planning guides and reference material, RFP-type funding application forms, and business model templates.

Consider a two-tier process to provide high-level screen of feasibility analysis. This could benefit potential microgrid developers and critical facility owners by enabling them to develop a pre-screening process involving high-level estimates and a minimum of effort, so that OER can let projects know whether they "made the cut" to proceed to a higher level of feasibility analysis. If OER provides robust up-front feasibility analysis support, this separate step might not be necessary.

Provide funding support for feasibility analysis. If sufficient program funding is available, OER should provide up-front funding, and ideally contracted technical support teams, to assist project developers with feasibility analysis. Such funding increases program size and cost but is likely to provide better results. RIGIS can provide mapping information conducive to microgrid development, such as locations of proximal critical facilities.

Prioritize energy efficiency and clean energy. Load reduction via energy efficiency is generally cheaper and cleaner than onsite generation. Projects should be required to conduct detailed energy audits and invest in load reduction before sizing and installing onsite generation. OER should favor renewable and clean(er) energy sources such as PV, wind and CHP for microgrid projects, to align with other policy goals. OER should consider the program and project role of existing and new fossil-fueled generators. See section 2.3 for discussion of program features.

Employ rolling application deadlines and/or allow several months for feasibility analysis and application development, especially for municipalities. The program could provide sufficiently long RFP development periods or rolling deadlines (perhaps with a backstop period of 12–24 months) to facilitate participation by public sector organizations with often-prolonged processes for decision making, procurement and energy/facility capital improvement project development. Planning and scheduling should also consider the time it will take for administrative processes, and alignment with DER program deadlines such as REG program open access periods.

Employ design and construction schedules with ample time and administrative flexibility. It is important to provide sufficient time and flexibility with awardee project development schedules to allow for protracted municipal procurement processes, marketplace learning, and common design and construction schedule slippage. Microgrid project novelty and complexity are drivers of project delay. In both CT and MA only a minority of funding recipients remain on schedule and most are not yet operating as of early 2017, even many months after funding awards. The microgrid program team should be as flexible and reasonable as possible; should expect delays; and should be willing to grant extensions of six months of more.

Application review, selection process & criteria. A competitive solicitation RFP should establish criteria for selection including prerequisites such as minimum performance requirements, and request information about project technical and financial characteristics. OER and its program team would evaluate applications involve a scoring process. The recommended approach is a streamlined Point Scoring system to reflect non-traditional "macroeconomic" factors. Significant feasibility analysis support should be provided if a detailed Economic Evaluation approach is taken. See section C1 for further discussion.

Provide streamlined or preferential administrative and permitting processes. Administrative and permitting documentation and processing times for common islandable-DER-related technologies could be standardized and streamlined in cases as a part of program design. Priority could also be given to microgrid projects for certain administrative processes such as siting and permitting, *e.g.*, by enabling applicant projects to move to the head of the queue. Microgrid planning guides could facilitate project development. Modifications to permitting processes must be undertaken with care, to allow that critical public interests (*e.g.*, environment, land use, justice) that are vetted in a permitting process must remain a priority. Examples could include interconnection applications, REG program installation configurations for grid-independent operation, and DER (*e.g.*, battery energy storage systems) siting and permitting prioritization.

Consider award disbursements based on milestones. Provide initial disbursements of award funds with further disbursements tied to project milestones, *e.g.*, 1/3 of an award could be provided upon award with 2/3 provided upon project completion. Up-front funding disbursements of a portion of the funding upon award will help municipalities and their contractors with project development. Final disbursements should come only after thorough commissioning and islanding testing of a microgrid installation.

Commissioning must be complete to receive full funding. Commissioning (Cx) of microgrid installations is vital and should include full-load functionality testing of all major microgrid systems at every stage of operation: from grid-parallel, through disconnection or islanding from the EPS, grid-independent island mode, and reconnection to the EPS.

Require performance evaluation and data monitoring and collection annually or in real time for contract term. Funded or designated microgrids should be required to meet specified performance metrics, and to provide annual reporting or real-time data access.[32] A minimum requirement would be compliance with IEEE 1547.4.

[32] For further discussion with examples see CEG/RPP, *What States Should Do*, June 2015, p.24.

Section 2.4 provides recommendations for legislative measures and actions that could support microgrid development, including:

Expand DG / DER program support. Rhode Island has a number of programs and incentives that support DG and DER development. These could be enhanced to facilitate microgrid development, and in cases could apply only to islandable DERs in a microgrid configuration. See section 2.4 for further discussion of relevant programs and recommended actions, including a feed-in tariff for islandable DERs; RECs or other production-based revenue for CHP power and/or thermal output; expanded net metering; Virtual Net Metering (VNM) for an expanded set of eligible generation, beneficial accounts and multiple customer classes; and expanded community aggregation options.

Include microgrids in RES or as a stand-alone mandate, with incentives.

Enable approved microgrids to distribute power across public ROW and utility easements. Legislation that explicitly allows critical facility microgrid developers to distributed power across a public right of way or a utility easement would address a significant barrier to development of Level 2 campus-type microgrids. As with other proposed exceptions to the current regulatory context, it could make sense to limit this ability to projects that meet a narrow definition of a designated municipal or public purpose microgrid. The Mass CEC helped fund a study by Harvard Law School of the issue that concluded that there was no statutory barrier to municipalities distributing power across a ROW.[33] OER should undertake a similar review of RI law.

Create enabling structures to facilitate economical and legal and low-risk project development behind the meter (BTM). The state could consider legislation enabling special purpose entities or modifications to existing programs to create or expand financing and procurement options for microgrid development by public agencies in particular. Potential approaches include Energy Improvement Districts or similar structures, and expanding RIIB C-PACE program scope for defined microgrids.

Section 2.5 provides recommendations for regulatory measures and potential PUC actions that could support microgrid development. Please note the authors' cautionary comments in section 2.2 regarding making potential fundamental changes to the regulatory regime for the primary motive of microgrid policy. See this section for discussion of aspects of marketplace regulatory structure to consider in enabling Level 3 microgrids, and of current and recent PUC actions and dockets that relate to microgrid development.

Inducing changes in EDC behavior can be accomplished via mandates and/or incentives such as performance-based regulations. Requirements can convey greater certainty of achieving desired outcomes, yet risk high costs, unintended consequences and stakeholder (*e.g.*, EDC) alienation. Effective incentives can help align commercial interests and investment with public policy

[33] http://environment.law.harvard.edu/wp-content/uploads/2015/08/masschusetts-microgrids_overcoming-legal-obstacles.pdf

objectives and promote least-cost achievement of desired results. A detailed exploration of the issues, risks and trade-offs around mandate or incentive design for the EDC in Rhode Island is beyond the scope of this report. Potential regulatory measures include:

Require, incent or enable the EDC to provide information on potential locations for microgrid development of greatest value to the EPS. The PUC could require or incent the EDC to provide information about the costs and benefits to the EPS at the distribution and potentially transmission levels, to inform microgrid planning. This information could be made available solely to the OER microgrid team to inform evaluations of funding applications. Alternately or additionally, this information could be made available to the marketplace in at least a generalized level of detail, either upon request at a project-specific level or in the form of publicly-identified areas that would benefit the most from microgrids, akin to the "opportunity zones" identified by NYSERDA for the NY Prize competition.

Require, incent or enable the EDC to create custom tariffs for cost recovery and/or rate risk reduction in microgrid locations, and/or for microgrids to monetize sources of value that they provide to the EPS and EDC. A detailed exploration of the issues, risks and trade-offs of these aspects of market re-design in Rhode Island is beyond the scope of this report. Microgrids and their DERs provide benefits to the EPS as well as impose costs and their full net value should be compensated, just as the costs they impose on the system should be recovered. It would be important that the services sold in each direction are identified, evaluated and priced in a consistent, fair and transparent way.

Custom tariffs that are customer- or project-specific enable the EDC to recover costs from those customers who will most directly benefit from a microgrid. This is arguably more equitable than, and preferable to, socializing the costs across all customers statewide by adding them to the EDC's rate base. Please note that there may be some precedent for rate-basing investments in localized EDC improvements in the context of LCP and NWA. The EDC already has at least one option to apply a custom tariff for enhanced reliability, by adding a second feeder for N+1 redundancy. This capability might already enable the EDC to develop reliability enhancement custom tariffs for other types investments, possibly including investments such as hardening or other modifications to distribution infrastructure connected to—or within—a microgrid.

Another potential policy would be to allow the EDC to enter into project-specific long-term fixed-rate contracts (10–25+ years) to reduce tariff variability risk and facilitate microgrid financing.

Require, incent or enable the EDC to procure energy from resilient islandable DERs.

Require, incent or enable the EDC to use on bill financing for microgrid investments.

Require, incent or enable the EDC to own or contract for generation and/or storage, in excess of 15 MW cap. An alternative or possibly complementary approach to "animating the marketplace" could be for the state to expand the ability of the EDC to own or contract for generation and storage, giving the EDC a more direct role in Level 3 multi-user microgrid ownership and development. This approach would entail fundamental alteration of the regulatory regime and is not recommended in the absence of a NY REV-type comprehensive re-examination of the current model. See this section for further discussion and policy options and trade-offs.

Require, incent or enable the EDC to participate in utility-directed and/or hybrid microgrid models. See cautionary discussion in the previous section. In a utility-directed microgrid, the EDC owns and operates the microgrid assets, including generation and storage. In a hybrid microgrid ownership model, the EDC shares ownership of microgrid assets with a third party, *e.g.*, the EDC might own the distribution network and controls while a third party owns the generation. One strategy could be to enable differently-regulated EDC subsidiaries to play a role in microgrid project development.

Exempt microgrids from PUC regulation that are publicly-owned or below a size cap. See this section for further discussion of potential PUC requirements for designated exempt classes of microgrids.

Enable non-utility third parties to own and operate Level 3 multi-user microgrids. Enabling third parties to compete with the EDC in providing energy services and owning and operating microgrid DERs and distribution infrastructure could constitute the greatest change to the regulatory regime. A variation on this approach could involve pathways to municipalization or cooperative ownership models.

ABBREVIATIONS

ACEEE = American Council for an Energy-Efficient Economy
ACP = Alternative Compliance Payments
AGT = Algonquin Gas Transmission natural gas transmission pipeline
AHJ = Authorities Having Jurisdiction (over a regulated topic)
ASHRAE = American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ATS = Automatic transfer switch
BC = Behavior Change (for EE)
BCV = PAG's Babcock Village property in Westerly, RI
BES = Battery energy storage
BMS = Building Management System ("controls")
BTM = Behind The Meter
BUG = Back-Up Generator
C-PACE = Commercial Property Assessed Clean Energy
CA = California
CAP = Climate Action Plan
CBA = Cost-Benefit Analysis
CBAM = Cost-Benefit Analysis Model
CDBG-DR = (HUD funded) Community Development Block Grant – Disaster Relief
CEMP = (State) Comprehensive Emergency Management Plan
CES = Comprehensive Energy Strategy
CF = Critical Facility
CFB = Circulating Fluidized Bed (coal plant technology)
CHP = Combined Heat and Power or cogeneration
CI = Critical Infrastructure
CIAT = Critical Infrastructure Assessment Tool (in RI CIPP)
CIKR = Critical Infrastructure and Key Resources (in RI CIPP)
CIP = Critical Infrastructure Protection
CIPP = Critical Infrastructure Protection Plan
CL = Critical Load
CME = Coronal Mass Ejection or solar flare
CNG = Compressed Natural Gas (for vehicles)
COO = Continuity Of Operations
COOP = COO Plan
COTS = Commercial Off The Shelf equipment
CSF = NIST's Cybersecurity Framework
C_x = Commissioning
D/B = Design / Build
D/B/B = Design / Bid / Build
DBOOM = Design, Build, Own, Operate, Maintain
DBT = Design Basis Threat
DER = Distributed Energy Resource
DER-CAM = LBNL's Distributed Energy Resources Customer Adoption Model software

DG = Distributed Generation
DHS = U.S. Department of Homeland Security
DHW = Domestic hot water for residential use
DoD or DOD = U.S.. Department of Defense
DOE = U.S. Department of Energy
DR = Demand Response (curtailable loads)
E1 = EMP very short duration pulse that can damage electronic equipment
E3 = EMP short duration pulse that can cause GMD and GIC
EDC = Electricity Distribution Company (*i.e.*, non-vertically integrated utility)
EE = Energy Efficiency (load reduction)
EIA = U.S. Energy Information Administration
EISC = Electric Infrastructure Security Council
EMA = (State or local) Emergency Management Agency
EMP = Electromagnetic pulse
EOC = Emergency Operations Center
EOP = (State) Emergency Operations Plan
EPC = Engineering, Procurement, Construction
EPFAT = Emergency Power Facility Assessment Tool (of FEMA and U.S. Army Corps of Engineers)
EPRI = Electric Power Research Institute
EPS = Electric Power System (*i.e.*, the "Grid" or "Macrogrid")
ES = Energy Storage
ESA = Energy Services Agreement
ESCO = Energy Services Company
ESPC = Energy Savings Performance Contract
EUI = Energy Use Intensity (kBtu/SF)
EV = Electric Vehicle
FC = Fuel cell
FEMA = Federal Emergency Management Agency
FERC = Federal Energy Regulatory Commission
FITC = Federal Investment Tax Credit
FTE = Full Time Equivalent employee(s) in labor hours
Genset = Generator set (*e.g.*, emergency or backup power, typically fossil fueled)
GHG = Greenhouse Gases (CO_2 & equivalent, as per CAP)
GIC = Geomagnetically-induced currents due to an EMP or CME
GIS = Geographic Information System software
GMD = Geomagnetic disturbance due to an EMP or CME
HHW = Heating hot water for hydronic system space heating
HILF = High-Impact, Low-Frequency (events that disrupt critical infrastructure)
HOMER = NREL's Hybrid Optimization of Multiple Energy Resources modeling software
HP = Horsepower
HUD = U.S. Department of Housing and Urban Development
HVAC = Heating, Ventilation and Air-Conditioning systems
HX = Heat exchanger
ICS-CERT = USDHS's Industrial Control Systems Cyber Emergency Response Team

IED = Improvised Explosive Device
IEMI = Intentional Electromagnetic Interference
ISO-NE = Independent Systems Operator-New England
IWG = Interagency Working Group
kBtu-hr = Kilo-(one thousand) Btu (British Thermal Units) per hour of thermal energy
kW or KW = Kilowatts or one thousand Watts
kWh or KWh = Kilowatt-hours of energy production or consumption
LBNL = USDOE’s Lawrence Berkeley National Laboratory
LCOE = Levelized Cost of Energy
LDC = Local Distribution Company for natural gas
LMI = Low to Moderate Income demographic
LNG = Liquid Natural Gas
MA = Massachusetts
MACRS = Modified Accelerated Cost Recovery System accelerated depreciation schedule
MBH = Thousand Btu’s per hour of energy output
MCO = Mission Critical Operations
MD = Maryland
MED = Major Event Day
MFH = Multifamily housing
MG = Microgrid
MMBtu or MBTU = Million British Thermal Units of heat energy content of fuel
MN = Minnesota
MT = Mass Transit
NEC = National Electrical Code
NERC = North American Electric Reliability Corporation
NFPA = National Fire Protection Association
NG = Natural Gas
NIAC = National Infrastructure Advisory Council
NIPP = National Infrastructure Protection Plan
NIST = National Institute for Standards and Technology
NJ = New Jersey
NM = Net metering
NPV = Net Present Value
NRC = Nuclear Regulatory Commission
NREL = USDOE’s National Renewable Energy Laboratory
NY = New York
OA = Outside air
O&M = Operation and Maintenance
OER = Rhode Island Office of Energy Resources
OXP = POAH’s Oxford Place property in Providence, RI
PAG = Property Advisory Group-Cathedral Development Group
PEM = Proton Exchange Membrane
POAH = Preservation Of Affordable Housing
PPA = Power Purchase Agreement
PV = Photovoltaic solar power

RCx = Retro-commissioning
RE = Renewable Energy
REC = Renewable Energy Credit (*e.g.*, 1 MWh of "green" energy attribute)
REG = RI's Renewable Energy Growth program
RES = RI's Renewable Energy Standard
RF = Radio Frequency
RGGI = Regional Greenhouse Gas Initiative
RI = Rhode Island
RICIPP = RIEMA's Critical Infrastructure Program Plan
RIEAP = Rhode Island Energy Assurance Plan
RIEMA = Rhode Island Emergency Management Agency
RIGIS = Rhode Island Geographic Information System
RIHMP = Rhode Island Hazard Mitigation Plan
RIIB = Rhode Island Infrastructure Bank
RIOER = Rhode Island Office of Energy Resources
ROW = Right Of Way or easement
RTO = Regional Transmission Operators
SAIDI = System Average Interruption Duration Index
SAIFI = System Average Interruption Frequency Index
SBC = Systems Benefit Charges
SCADA = Supervisory, Control and Data Acquisition software
SF = Square foot or square feet
SIP = Shelter In Place
SIRI = Systems Integration Rhode Island planning process
SLA = Sector Lead Agency (in RI CIPP)
SLR = Sea Level Rise
SOO = Sequence Of Operations
SOW = Scope Of Work
SP = Sustainability Plan
SSP = Sector-Specific Plans (in RI CIPP)
ST = Solar thermal
T&D = Transmission and distribution electrical infrastructure
TELF = Tax Exempt Lease Financing
TELP = Tax Exempt Lease Purchase
TGP = Tennessee Gas Pipeline natural gas transmission pipeline
UA = Unique Asset
USDHS = U.S. Department of Homeland Security
USDOE = U.S. Department of Energy
USGCRP = U.S. Global Change Research Program
V = Volt
V2B = (Electric) Vehicle to Building relationship/connection
V2G = (Electric) Vehicle to Grid (electric or natural gas distribution system) relationship/connection
VFD = Variable Frequency Drive electric motor controller (see also VSD)
VNM = Virtual Net Metering

VSD = Variable Speed Drive Electric Motor Controller (see also VFD)
WT = Wind turbine

GLOSSARY

Ancillary Services: The Independent System Operator-New England administers competitive markets for services that are required to support the power system. The two most important are reserves and regulation. The reserves market pays resources (*e.g.*, generators) to be available to provide fast ramping power in the event of a unit or line trip. The regulation market pays resources to keep load and generation in constant balance by quickly adjusting their output/consumption in response to constantly changing load conditions (*e.g.*, a large load may decrease its consumption at a time when the system experiences low voltage, thereby restoring adequate voltage on the line).

ANSI-c84-1*:* American National Standard for Electric Power Systems and equipment, 2011 edition.

Anti-islanding: Safety protocols intended to ensure that distributed energy resources can't feed power onto utility distribution lines during a system outage. IEEE 1547 includes anti-islanding standards to protect the safety of utility line workers. (*See also "islanding.")*

Applicant: The entity that applies for a State microgrid program grant, *e.g.*, in response to an RFP or similar solicitation.

Backfeed: Flow of electricity in the opposite direction from usual flow.

Balancing: Active efforts to match energy supply and demand to maintain stable system operations -- pertinent for large-scale and small-scale grids. Microgrids can help transmission operators keep large grids balanced, and microgrids internally perform balancing services to operate in island mode.

Black start capability: A black start is the process of restoring a power generating system to operation without relying on the external electric power transmission network.

Building Energy Management Systems: A software control application that enables facility managers to configure, monitor, and automate HVAC, lighting, and programmable building devices.

Bulk energy (as in, bulk energy suppliers or bulk energy system): Bulk energy refers to power bought or sold on the wholesale energy market, defined below.

Capacity market: A market administered by the New York Independent System Operator designed to pay for sufficient resources (including traditional electric generators, but also demand response resources) to ensure that projected loads can be met on a long-term basis. This market matches buyers and sellers of capacity using the clearing price methodology.

Combined heat and power (CHP) (a.k.a., ”cogeneration”): Energy systems that supply both electricity and thermal energy from the same fuel source, thereby increasing energy efficiency. CHP systems could power microgrids at hospitals, institutional and corporate campuses, and some industrial sites.

Commercially Proven Technology*:* Technology, equipment or systems readily available on the commercial market. Does not include experimental or R&D technology.

Critical Facility: FEMA definition: “A structure or other improvement that, because of its function, size, service area, or uniqueness, has the potential to cause serious bodily harm, extensive property damage, or disruption of vital socioeconomic activities if it is destroyed or damaged or if its functionality is impaired. Critical facilities include health and safety facilities, utilities, government facilities and hazardous materials facilities. For the purposes of a local regulation, a community may also use the International Codes’ definition for Category III and IV buildings.” RIEMA definition: “Critical infrastructure includes those assets, systems, networks, and functions—physical or virtual—so vital to Rhode Island that their incapacitation or destruction would have a debilitating impact on security, economic security, public health or safety, or any combination of those matters.”

Demand Response: The New York Independent System Operator supports a number of programs designed to pay customers to undertake voluntary reductions of their load

Demand response (DR): Energy loads capable of being voluntarily reduced or curtailed under certain conditions in a given location based on price and reliability signals. If efficiency is the first step in designing a microgrid, then DR is the second.

Deployment costs: Deployment costs are a component of overall system costs. Deployment costs refer specifically to costs incurred in order to field the software or hardware components in the target system.

Distributed Energy Resource (DER): Smaller-scale power generation or storage. It is also known as Distributed Resources or Distributed Generation. End-use energy efficiency could also be considered a form of DER, particularly if the load reduction is dispatchable as in a demand response program.

Distributed Generation (DG): A generally small (up to roughly 50 MW) electric production facility that is dedicated to the support of nearby associated load. DG is the central asset in any microgrid.

EDC: Electric Distribution Company. An EDC manages the distribution (but not necessarily generation) between wholesale high voltage transmission to low-voltage end use. In Rhode Island, National Grid is the EDC serving almost the entire state, and generally does not own generation capacity with limited exception.

Electric Power System: All electrical wires, equipment, and other facilities owned or provided by the EDC or MEU that are normally operated at voltages below 69 kV to provide distribution service to customers.

Energy Improvement District (EID): A vehicle used by local and state governments to promote planning, development, and funding activities supporting energy infrastructure improvements in a defined geographic area or community. Community leaders could consider microgrids as part of Energy Improvement District planning.

Energy management system (EMS): Software and hardware for balancing energy supply (including storage) and demand to maintain stable operations. Smart grid EMS software established the IT framework for operating microgrids.

Energy service company (ESCO): A non-utility entity that provides retail, commercial, or industrial energy services. A microgrid service provider could be considered a type of ESCO, combined with a type of IPP.

EPA Tier (Diesels): EPA standard for off-road diesel exhaust emissions:

- **Tier 1** Emissions standard for engines manufactured between 1994 and 2001
- **Tier 2** Emissions standards for engines manufactured between 2001 and 2006
- **Tier 3** Emissions standards for engines manufactured between 2006 and 2008
- **Tier 4** Emissions standards for engine manufactured between 2008 and present.

EPC: Engineer, Procure, Construct. Normally is a single entity that has overall responsibilities for all of these activities related to a project.

Generation Controller: A hardware platform or software application that manages power generation components.

Generator: A device for producing electricity, and potentially useful byproduct thermal energy.

Hierarchical control scheme: A control scheme that distributes control authority and control actions vertically across layers. Usually a top layer, called master control, orchestrates the overall system control. Mid-tier layers coordinate groups and report back to the master control layer. The lowest layers control remote nodes in the system.

IEEE-1547: Institute of Electrical and Electronics Engineers, Standard for Interconnecting Distributed Resources with electric power systems. Incorporates by reference, IEEE-1547.4 – IEEE Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems.

IEEE-C62.41: Institute of Electrical and Electronics Engineers, Recommended Practices for Surge Voltages in Low Voltage AC Power Circuits.

IEEE-C62.45: Institute of Electrical and Electronics Engineers, Surge Testing for Equipment Connected to Low Voltage Power Circuits.

Interconnection Facilities: Include all facilities and equipment between the microgrid and the Point of Interconnection, including any modification, additions, or upgrades that are necessary to physically and electrically interconnect the microgrid to the EDC's Distribution System.

IPP: Independent power producers are non-utility companies that generate and sell energy to one or more customers. Most IPPs sell their output in wholesale markets, whereas microgrids serve retail customers directly.

Island Peak Load: Maximum operating electrical load of the microgrid when not connected to the utility grid. This load may be less than the normal facility demand, if some loads are intentionally removed from the distribution system for the duration of time when the microgrid is in island mode.

Island Mode or Intentional Islanding: Occurs when the microgrid has been isolated from the Electric Power System by planned operation of the disconnecting means consistent with its interconnection agreement. The microgrid DER(s) as a result is serving segregated load(s) on its microgrid's side of the Point of Interconnection.

Islanding: Intentional islanding is the act of physically separating a defined group of electric circuits from a utility system, and operating those circuits independently. Islanding capabilities are fundamental to the function of a microgrid. (*See also "anti-islanding."*)

Loop distribution system: A loop system, as the name implies, loops through the service area and returns to the original point. The loop usually ties into an alternate power source. By placing switches in strategic locations, the utility can supply power to the customer from either direction. See, by contrast, network and radial distribution systems.

MEU: Municipal Electric Utility.

Microgrid: 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 and that connects and disconnects from such grid to enable it to operate in both grid-connected or Island Mode.

Microgrid Controller: A hardware platform or software application that manages devices and operations in a Microgrid system.

Microgrid System Architecture: The end-to-end structural design and partitioning of a complete microgrid system. Defines the structure of hardware and software components, data, and interfaces.

MUSH: Military installations, universities, schools, and hospitals. Many of the first commercial microgrids are being installed for customers in MUSH applications.

New Load: Electrical load within one or more critical facilities that is presently supplied only with power purchased from the EDC with no emergency generator source, i.e. that portion of the facility load that does not receive power from an existing emergency generator during an emergency.

Net Metering: Net metering is a method of measuring the energy consumed by a customer and the surplus energy produced by a generator.

Network distribution system: Network systems are the most complicated distribution systems, as compared to loop or radial distribution systems. They can be thought of as interlocking loop systems. A given customer can be supplied from two, three, four, or more different power supplies. This system will provide the highest power reliability, and is more common in high load density or urban areas. See, by contrast, radial and loop distribution systems.

N+1: in power generation, ability for a generating plant to maintain normal operation after the failure of a single generator.

Net-zero: The condition in which a building or campus is capable of generating energy equal to its aggregate annual consumption. Some net-zero energy buildings can be upgraded to function as islandable microgrids.

One-Line Diagram: A diagram which shows, by means of single lines and graphic symbols, the course of an electric circuit or system of circuits and the component devices or parts used therein (as defined in IEEE 100 The Authoritative Dictionary of IEEE Standards Terms).

PACE Finance: Property Assessed Clean Energy Financing. This mechanism allows financing of energy efficiency upgrades or renewable energy installations for eligible buildings. In Rhode Island the Rhode Island Infrastructure Bank administers the Commercial PACE or C-PACE program. An eligible property owner can arrange financing for energy improvements, which is attached to the property via an assessment that is senior to mortgage (akin to a sewer lien). The loans are repaid over the assigned term (typically 15 or 20 years) via an annual assessment on their property tax bill. Host municipal governments process financing payments, then forward the funds on to the lender.

Parallel Mode: A Generating Facility that is electrically interconnected to a bus common with the EDC's or MEU's electric distribution system, and which operates in parallel either on a momentary or continuous basis.

Peak load support: Refers to the ability of generation assets to provide power during hours when energy demand is at its highest across a system. A microgrid may provide peak load support to the macrogrid, *e.g.*, by exporting power onto the macrogrid when the macrogrid is facing its highest demand period.

Photovoltaics (PV): Solar electric energy cells in any of numerous forms and configurations. Rapid advances in PV technology create opportunities for remote and cost-effective green microgrids.

Plug-in electric vehicle (PEV): Transportation vehicle with an onboard electricity storage system and the ability to charge from an outside power source. Campuses with charging stations for fleet PEVs (and employee cars) will integrate V2G as storage and balancing assets in microgrid systems.

Point of Interconnection: The point at which the microgrid's local electric power system connects to the Electric Power System, such as the electric power revenue meter or premises service transformer. Also referred to as the point of common coupling.

Power Factor: Ratio of real power (kW) to apparent power (kVA).

Power quality: The quality of electrical power may be described as a set of parameters, such as the continuity of the power service, or variations in voltage magnitude, under which electrical devices taking power off the system can function properly.

Pre-paid Power Purchase Agreement (PPA) model: A power purchase agreement is a type of financing where a third party owns and maintains the DER system, and the end user agrees to pay for that power over a given term (often 15-20 years). Sometimes, a PPA provider will offer the end user the option to pre-purchase all the energy the user is likely to require upfront in exchange for a particularly low rate.

Prime mover: Machine that converts thermal energy into mechanical motion used to drive a generator (engine).

Pro-Forma: Financial statement intended to show anticipated future financial performance of the project.

Radial distribution system: This distribution system connects multiple users to a single source of power. The distribution system runs from the power source and terminates at the end users, meaning any power failure on that line would cut off power supply to those customers. This system is widely used in sparsely populated areas. See, by contrast, network and loop distribution systems.

REC: Renewable Energy Credit. One REC equals one megawatt/hour of energy produced by a renewable source.

Smart city: A community that plans and develops infrastructure, buildings, and operations to intentionally optimize efficiency, economics, and quality of life. Some smart city plans call for microgrids as part of special development districts with enhanced infrastructure services.

Smart grid: A energy system characterized by two-way communications and distributed sensors, automation, and supervisory control systems. Smart grid systems allow utilities to dispatch microgrids for grid balancing and ancillary services.

Spinning Reserve: That portion of the operating generator capacity held in reserve to accommodate momentary short duration surges in demand that occur as a result of motors starting and similar transients. Also, reserve to sustain short term overload for sufficient time to allow the load management system to respond, or additional generation to be brought on line.

Spot Network: A spot network is a small network typically with a nominal voltage of 480Y/277 volts in which the secondaries of two or more distribution transformers are connected to a common network bus through Network Protectors usually in a single location (see Interconnection Guidelines).

Switching infrastructure: The components in the electrical design that control and implement connect/disconnect/routing functions.

System integration: Part of the overall system design process, referring to the testing and validating of the interoperability of the various software and hardware components that compose the system.

Transactive energy: A market system in which retail energy consumption and supply decisions are driven by competitive market pricing, through a combination of long-term contracts and spot- and forward-market bids and tenders. Microgrids and their component nodes could be managed as part of a transactive energy system.

Transfer trip: A transfer trip is a protection system that sends a trip command to remote circuit breakers when an electrical fault is detected, thereby helping isolate and clear the fault.

Transmission and Distribution (T&D) investment deferral: Electric transmission and distribution systems require periodic upgrades in order to meet increasing demand. T&D investment deferral refers to the benefit microgrids may provide to the utility by reducing the load that the utility must serve in a given area, thereby potentially allowing the utility to make less short-term investment in upgrading its distribution system in that area.

Urban secondary network system: A secondary network system refers to the low-voltage circuits supplied by the network units (the network transformer and its associated network protector).

Urban spot network: A secondary network distribution system that consists of two or more network units at a single site. The secondary network-side terminals of these network units are connected together with bus or cable. The resulting interconnection structure is commonly referred to as the paralleling bus or collector bus. In spot networks, the paralleling bus does not have low-voltage ties to adjacent or nearby networks. Such spot networks are sometimes called isolated spot networks to emphasize that there are no secondary voltage connections to network units at other sites.

Utility tie point, or, point of common coupling: The point at which the interconnection between the electric utility and the customer interface occurs.

V2G: Vehicle-to-grid technology, integrating PEVs together for dispatchable electricity storage for grid support and ancillary services. EVs will provide storage capacity for microgrids through V2G technology.

Virtual Net Metering: Virtual net metering allows the production from a renewable energy resource to be allocated to multiple public sector metered accounts.

Virtual power plant (VPP): Aggregated power generating capacity that's provided by multiple, real DG facilities operating in different locations. Some microgrid DG systems could run in VPP clusters.

Wholesale energy market: A market for the sale of large quantities of electricity (1 MW or greater), which is provided from high-voltage transmission lines. This market is operated by the Independent System Operator-New England, and provides power to registered market participants, which include investor-owned utilities.

BIBLIOGRAPHY

The following works cited and recommended are listed in (modified) modified American Psychological Association (APA) format. The authors' modifications include putting abbreviated publication titles in [brackets] before the APA format title, to align with footnote citations in the body of the report. APA style is most commonly used to cite sources within the social sciences. All website and URL references were accessible as listed in March 2017.

Advancing and Maximizing the Value of Energy Storage Technology: A California Roadmap. (2014). Retrieved from http://www.caiso.com/informed/Pages/CleanGrid/EnergyStorageRoadmap.aspx.

Massachusetts Energy Storage Initiative Study: Alevo Analytics, Daymark Energy Advisors, Customized Energy Solutions, Strategen, Sustainable Energy Advantage. (2016). *State of Charge: Massachusetts Energy Storage Initiative Study*. Retrieved from http://www.mass.gov/eea/docs/doer/state-of-charge-report.pdf

Casazza, Jack, and Frank Delea. *Understanding Electric Power Systems: An Overview of the Technology and the Marketplace*. Hoboken, NJ: John Wiley & Sons, 2003. Print.

Center for Energy, Marine Transportation and Public Policy at Columbia University. (2010). *Microgrids: An Assessment of the Value, Opportunities and Barriers to Deployment in New York State* (Report 10-35). New York City.

Community Microgrid Initiative: Innovation for a Clean Energy Future. (2015). Clean Coalition.

Emmett Environmental Law & Policy Clinic, Harvard Law School. (2014). *Massachusetts Microgrids: Overcoming Legal Obstacles.* Cambridge.

Governor Cuomo Announces $815 Million for Next Phase of Long Island Recovery from Superstorm Sandy. (2013, October 24). Retrieved from http://www.governor.ny.gov.

Grimley, M., & Farrell, J. (2016). *Mighty Microgrids.* Institute for Local Self-Reliance, Energy Democracy Initiative.

Hotchkiss, E., Metzger, I., Salasovich, J., & Schwabe, P. *Alternative Energy Generation Opportunities in Critical Infrastructure.* (2013). Retrieved from http://www.nrel.gov/publications.

IEEE-PES Task Force on Microgrid Control. "*Trends in Microgrid Control*." IEEE Transactions on Smart Grid (2014): 1905-919. Web. 30 May 2017.

International District Energy Association & OBG. (2015). *Community Microgrids: A Guide for Mayors and City Leaders Seeking Clean, Reliable and Locally Controlled Energy.* Microgrid Knowledge. Energy Efficiency Markets, LLC.

International District Energy Association, Schneider Electric, & Microgrid Knowledge. (2014). *Think Microgrid: A Discussion Guide for Policymakers, Regulators and End Users.* Energy Efficiency Markets, LLC.

International District Energy Association & Solar Turbines. (2014). *The Energy Efficient Microgrid: What Combined Heat & Power and District Energy Bring to the Microgrid Revolution.* Microgrid Knowledge. Energy Efficiency Markets, LLC.

KEMA, Inc. (2014). *Microgrids – Benefits, Models, Barriers and Suggested Policy Initiatives for the Commonwealth of Massachusetts.* Burlington.

Koppel, Ted. *Lights Out*. New York: Crown Publishing, 2015. Print.

[MD 2014] Maryland Resiliency Through Microgrids Task Force. *Maryland Resiliency Through Microgrids Task Force Report*. Retrieved from http://energy.maryland.gov.

McCafferty, S. (2014, January 14). *Doing it right: Top 6 things to consider when developing microgrids.* Retrieved from http://www.smartgridnews.com.

Microgrid Institute for the Minnesota Department of Commerce. (2013). *Minnesota Microgrids: Barriers, Opportunities, and Pathways Toward Energy Assurance.*

Microgrids for Resiliency – US Initiatives. (2015).

Mirzazad, Saharnaz. *Solar Energy & Resilient Communities.*

National Grid. (2015). *National Grid Proposed REV Demonstration Project Filing*.

New Jersey Transit Corporation. *Request for Proposal No. 15-031: Design, Engineering, Construction Assistance and Other Technical Services for the NJ Transitgrid Project*. Retrieved from http://www.njtransit.com.

[NYSERDA 2010] New York State Energy Research and Development Authority (NYSERDA), *et al*. (2010). *Microgrids: An Assessment of the Value, Opportunities and Barriers to Deployment in New York State* (Report 10-35). Albany.

[NYSERDA 2014] New York State Energy Research and Development Authority (NYSERDA), New York State Department of Public Service, & New York State Division of Homeland Security and Emergency Services. (2014). *Microgrids for Critical Facility Resiliency in New York State* (Report 14-36). Albany.

Resilient Power Project / Clean Energy Group: Mullendore, S. (2015). *Energy Storage and Electricity Markets: The value of storage to the power system and the importance of electricity markets in energy storage economics*. Retrieved from http://www.cleanegroup.org/ceg-resources/resource/energy-storage-and-electricity-markets-the-value-of-storage-to-the-power-system-and-the-importance-of-electricity-markets-in-energy-storage-economics/
Resilient Power Project / Clean Energy Group: Mullendore, S., Sanders, R., Milford, L.. *et al*. (2015). *Resilience for Free: How Solar + Storage Could Protect Multifamily Affordable Housing from Power Outages at Little or No Net Cost*. Retrieved from http://www.cleanegroup.org/ceg-resources/resource/resilience-for-free/

Resilient Power Project / Clean Energy Group: Mullendore, S., Sanders, R., Milford, L. (2015). *Solar+Storage 101: An Introductory Guide to Resilient Power Systems*. Retrieved at http://www.cleanegroup.org/ceg-resources/resource/solar-storage-101-an-introductory-guide-to-resilient-solar-power-systems/

Resilient Power Project / Clean Energy Group: Sanders, R., & Milford, L. *et al*. (2015). *What Cities Should do: A Guide to Resilient Power Planning*. Retrieved from http://www.cleanegroup.org/ceg-resources/resource/what-cities-should-do-a-guide-to-resilient-power-planning/

Resilient Power Project / Clean Energy Group: Olinsky-Paul, T. (2015). *What States Should Do: A Guide to Resilient Power Programs and Policy.* Retrieved from Resilient Power website: http://www.resilient-power.org. Accessed at: http://www.cleanegroup.org/ceg-resources/resource/what-states-should-do-a-guide-to-resilient-power-programs-and-policy/

Schmidt, Stephan. (2014). *Solar Energy Resilience & Planning.*

Smart DG Hub: Emergency Power. (2015). Retrieved from Sustainable CUNY website.

Stockton, Dr. Paul, ed. *E-PRO Handbook*. N.p.: The Electric Infrastructure Security Council, 2014. Print.

Ulbig, Andreas, Theodor S. Borsche, and Goran Andersson. "*Impact of Low Rotational Inertia on Power System Stability and Operation.*" (2014): n. pag. Web.

Wood, E. (2015, July 9). *NY Prize Stage 1 Awards: Who, Why and What's it Mean for Community Microgrids.* Retrieved from http://microgridknowledge.com.

Zamora, Ramon, and Anurag K. Rivastava. "*Energy Management and Control Algorithms for Integration of Energy Storage Within Microgrid*." EIII (2014): 1805-810. Web.