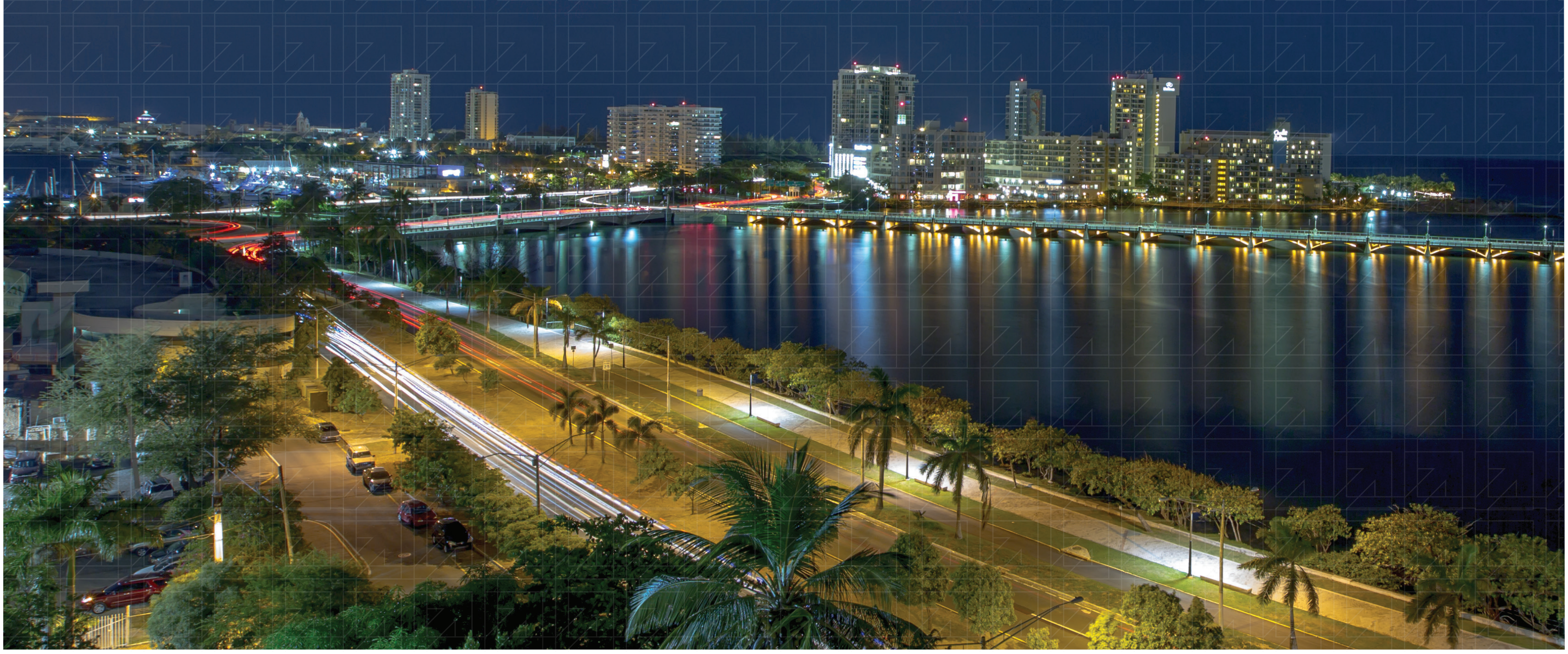
GRID MODERNIZATION PLAN FOR PUERTO RICO



Prepared for:
Central Office for Recovery, Reconstruction and Resiliency

GOVERNMENT OF PUERTO RICO

COR3
CENTRAL OFFICE OF RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

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EXECUTIVE SUMMARY

In September 2017, Puerto Rico was hit by Hurricanes Irma and Maria, two of the strongest Atlantic storms in recent decades. Trailing Irma by just 2 weeks, Hurricane Maria struck Puerto Rico as an upper-level Category 4 storm with sustained winds in excess of 150 mph and rainfall exceeding 24 inches. Maria devastated the island, which was still in emergency response mode following Irma. The combined impact of the two hurricanes led to a complete failure of Puerto Rico's electric power grid, decimating transmission and distribution (T&D) lines across the island, flooding substations, generation, and distribution facilities, resulting in the longest duration power outage in US history.

Before the September 2017 hurricanes, Puerto Rico's electric power system had numerous characteristics that made it highly vulnerable:

- Maintaining the electric system reliability, stability, and resilience of an island power system is more difficult compared to places like the US mainland. A lack of interconnection with neighboring utilities and power systems makes it necessary to carry additional amounts of reserve capacity, as there is no ability to rely on neighboring systems for electrical system stability. This is true for mainland Puerto Rico and the smaller islands of Vieques and Culebra. In addition, outages and other events cascade across the system much more rapidly and with greater consequence on island power systems, even on islands as large as Puerto Rico.
- Puerto Rico's location and geography creates challenges as it is mountainous and has relatively high electricity demand for an island of its size. Building and maintaining a robust T&D system is made more difficult by the mountains, year-round tropical growth, and the close proximity of buildings and streets in the urban areas, such as San Juan.
- The island's thermal generators are substantially older than the industry average, with low efficiency and high fuel and operating costs. The aging generators have low availability with some unable to operate, which contributes to an unreliable electric power system.
- Only a small portion (<2%) of the generating fleet uses distributed or renewable energy technology. A significant amount of wind and solar generation, and their delivery systems, were heavily damaged during the storm and unavailable.
- A significant portion of the transmission system, particularly south-to-north, was constructed over mountain ranges with substandard clearance to the ground and vegetation. Major lines were built on lattice towers, some of which were unable to withstand Category 4 sustained winds (150 mph). Major load centers (San Juan, northeast) and a significant portion of generation (southwest) are geographically separate, thus reliably serving load in the highly populated San Juan area requires availability of that transmission. The geography of the island makes those lines susceptible to repeated damage in future hurricane events.
- Much of the distribution system was similarly built in small, crowded corridors, with lower than industry standard clearance to vegetation, buildings, and the ground. Two-thirds of the distribution system consists of 4 kV circuits, which conform to standards that are 50 years old—and which proved unable to withstand Category 4 and 5 winds and associated flooding.

- The system lacked adequate control, monitoring, communications, information systems, and backup generation technology, limiting the ability to monitor outage and restoration activity to isolate damaged circuits and take corrective action to ensure load could be served at critical facilities such as hospitals.

Given these pre-hurricane physical characteristics, Puerto Rico's power system was unable to withstand Hurricanes Irma and Maria and the system sustained crippling and permanent damage. After the storm, several organizations from the US mainland supported Puerto Rico Electric Power Authority (PREPA) in the response and recovery efforts in Puerto Rico. This included utilities from New York which formed the New York State Contingent (NYSC), utilities representing the American Public Power Association (APPA) and Edison Electric Institute (EEI), and others that worked on recovery efforts from September 2017 through approximately April 2018 in close coordination with the Federal Emergency Management Agency (FEMA), US Army Corps of Engineers, trade organizations, federal agencies, and the Government of Puerto Rico.

Figure 1. Broken Distribution Poles After the Storm

Source: Public Broadcasting Service by Patty Gorena Morales and Michael Rios

A substantial repair and rebuild is still required to fully bring electric generation and delivery systems across the island to proposed codes and standards. To restore a Puerto Rico power system that achieves industry standard reliability and resilience requires action that goes well beyond the repair and rebuild of existing and damaged facilities.

Figure 2. PREPA Rebuild Aerial Operation

Source: Puerto Rico Electric Power Authority

To support all facets of the intermediate and long-term recovery efforts in Puerto Rico, Governor Rosselló established the Puerto Rico Central Office of Recovery, Reconstruction, and Resiliency (COR3). Among many other tasks, COR3 has been charged with developing this Electric Grid Modernization (GridMod) Plan to provide the vision, transformation approach, and cost estimate input for the permanent reconstruction of a more reliable, resilient, and decentralized Puerto Rico energy system.

The GridMod Plan is developed as a strategy and roadmap to guide Puerto Rico in working with FEMA to fund repair and reconstruction activities in the energy sector, and to initiate FEMA program funding support activities. As necessary, other funding sources will also be considered. The GridMod Plan is aligned with PREPA's Integrated Resource Plan (IRP), particularly with respect to generation investments, and includes additional identified investments to harden the transmission and distribution system. As the IRP is revised and finalized, GridMod Plan implementation will be revised to reflect the IRP ultimately approved by the Puerto Rico Energy Bureau (PREB). Similarly, the GridMod Plan implementation will be adjusted as needed to reflect evolving legislative and regulatory initiatives arising from the Puerto Rico Energy Public Policy, Act 17-2019.

COR3 managed a collaborative process (referred to as the Working Group activities) to assess what is needed to rebuild the Puerto Rico power system and to achieve industry standard levels of reliability and resilience. Within the Working Group, COR3 engaged key stakeholders, including PREPA, the New York Power Authority (NYPA), the US Department of Energy (DOE) and National Labs, and the Homeland Security Operational Analysis Center (HSOAC). The Working Group reviewed hurricane damage sustained to generation, transmission, and distribution systems; reviewed lessons learned, and recommendations identified in post-hurricane reports such as the Governor's Recovery Plan,[1] the Build

[1] *Transformation and Innovation in the Wake of Devastation: An Economic and Disaster Recovery Plan for Puerto Rico.*

Back Better,[2] and the NYPA[3] and FEMA[4] After Action Reports; evaluated the overall system configuration technology used on the island; and determined what is needed to achieve the strategic objectives identified in the Governor's Recovery Plan.

Based on these findings, the Working Group developed initiatives and associated cost estimates using the following principles:

- The plan uses industry accepted codes and standards to guide construction of new and rebuilt facilities to comply with engineering best practices and current design and construction guidelines.
- The plan embraces grid infrastructure, such as monopole transmission towers and concrete distribution poles that are designed to withstand hurricane-force winds and recommends replacement of grid infrastructure severely damaged by the hurricanes such as 4 kV distribution circuits and certain lattice transmission towers.
- The plan considers the unique geography of Puerto Rico and recommends transformation to a more decentralized power grid using distributed renewables, storage, thermal generation resources, islandable grids, and microgrids to improve local area reliability.[5] This transformation is critically important to prevent widespread grid failure during catastrophic events.
- The plan recognizes the need for information technology investments and cybersecurity efforts to ensure that grid operators have redundant and diverse communications, automated functionality, and monitoring and operational controls to operate the distributed grid reliably and securely.
- The plan recommends the repair and replacement of existing thermal resources with new combined cycle and simple cycle technology, in order to maintain reliability as Puerto Rico transitions toward 100 percent renewable energy by 2050. It also recommends the implementation of a more distributed generation fleet, including renewable and energy storage resources, and flexible peaking and microturbines to support islandable grids and microgrids.
- The plan recognizes that the successful transformation of Puerto Rico's electricity system will require large-scale changes to a variety of complementary areas that enable the operation of a more modern, resilient, and flexible power grid. These focus areas can be categorized as "People, Process, Organization, and Performance" elements, changes to which will be critical to running a transformed utility operation.

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[2] *Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico.*

[3] *The New York State Utility Contingent Emergency Response to Hurricane Maria After Action Report.*

[4] *2017 Hurricane Season FEMA After-Action Report.*

[5] Islandable grids and microgrids differ in context in this document. Islandable grids refer to the composite grids (eight islandable grids) of the entire power system designed to separate under stress conditions allowing each system to survive. Microgrids refer to single entities within the system or within an individual islandable grid.

- Commitment to new ways of working will be imperative as the utility fundamentally changes through the implementation of large-scale capital programs, new regulatory frameworks, and policy mandates. These changes, coupled with existing human capital challenges at PREPA associated with attrition, knowledge gaps, and the significant loss of experienced personnel, will require significant organizational change. Operational and organizational change projects in these areas must be managed as a cohesive program and integrated with the capital program deployment schedule defined through the GridMod Plan.

In general, these initiatives and cost estimates[6] were developed with the recognition that damaged facilities must be rebuilt to proposed industry standards, and that a reconstruction requires the reconfiguration and expansion of the power system to a more decentralized operating model.

Summary of Results

The Working Group estimates a total of approximately $21 billion of investments is needed to rebuild the Puerto Rico power system to industry standard levels, as shown in Table 1. The largest spend requirements are focused on the direct rebuild of transmission, substation, and distribution systems to harden the power grid and improve its ability to withstand hurricane conditions. Total expenditures in those categories are $12.2 billion, or 60% of the total. The tables and charts that follow provide an aggregated summary of spend levels based on the Working Group's assessment. More detailed descriptions of key drivers underlying the spend requirements and how these requirements should be prioritized and implemented are outlined in Section 4 through Section 6.

Table 1. Summary of Cost Estimates by Category

Category	*Cost Estimates ($M)*
Transmission & Substations[7]	$ 6,498
Distribution	$ 5,703
Generation & Fuel	$ 3,868
Technology	$ 1,835
DER & Microgrids	$ 1,755
Security	$ 290
System Operations	$ 215
Emergency Preparedness	$ 112
Operational Efficiencies	$ 21
Regulatory & Policy	$ 12
TOTAL	***$ 20,309***

In the Transmission & Substations category, projected expenditures focus primarily on increasing reliability and resilience and hardening the power system to protect against upper Category 4 hurricane conditions. For example, two of the largest investment initiatives include $1.7 billion to harden 350 miles of the 230 kV transmission grid, and $1.3 billion to reinforce or relocate existing high and medium

[6] Most of the investments are capital investments with limited Operations & Maintenance (O&M) programs/initiatives.

[7] Includes all substations rated at transmission and distribution voltages.

voltage substations and substation digitization over the longer term. Proposed transmission investments align with the 2019 IRP and are required for all resource scenarios and strategies evaluated in the IRP.

Transmission investments include about $0.5 billion for new or upgraded transmission lines and substations needed to create eight islandable grids that can operate independently in the event of major damage to power generation or delivery facilities.

In the Distribution category, the cost estimates are similarly focused on hardening the system to withstand hurricane conditions. For example, two of the largest initiatives include $3.4 billion in distribution pole strengthening to withstand high winds, and approximately $1 billion for submersible flood-proof distribution system equipment upgrades. Similar to transmission, all proposed distribution investments are common to and are required for each resource scenario and strategy outlined in the IRP.

In the Generation & Fuel category, primary near-term investment is directed at improving the reliability of existing units, improving operational flexibility to enable the generation system to react more quickly, and better supporting integration of a decentralized energy system. For example, $0.14 billion is directed at improving the reliability of existing thermal generation and converting key facilities to liquefied natural gas. An additional $0.5 billion is directed at replacing existing peaking generation units, many of which are in need of repair.

The generation and fuel capital expenditures listed in Table 1 represent only projects and spending categories that the Working Group believes are potentially fundable by FEMA to improve reliability and to mitigate future hazards[8]. Fully transforming the Puerto Rico power sector, and achieving industry standard levels of reliability and resilience, will require additional capital expenditures for generation and fuel. The estimated total of federally and privately funded capital expenditures for generation and fuel is $9.2 billion for the 2019-2028 period. That estimate includes 2,580 MW of new solar and 1,120 MW of battery storage resources identified in PREPA's June 7, 2019 IRP submission, to comply with expanded Renewable Portfolio Standard (RPS) requirements under Act 17-2019. We anticipate the additional resources will be privately funded and contracted by PREPA or developed by Puerto Rico consumers and businesses.

In the Technology category, $0.7 billion is directed at establishing the control infrastructure. An additional $0.7 billion is directed at installing advanced metering infrastructure (AMI), which will enable grid operators to restore power more quickly following major storms and facilitate expansion and integration of rooftop solar technology.

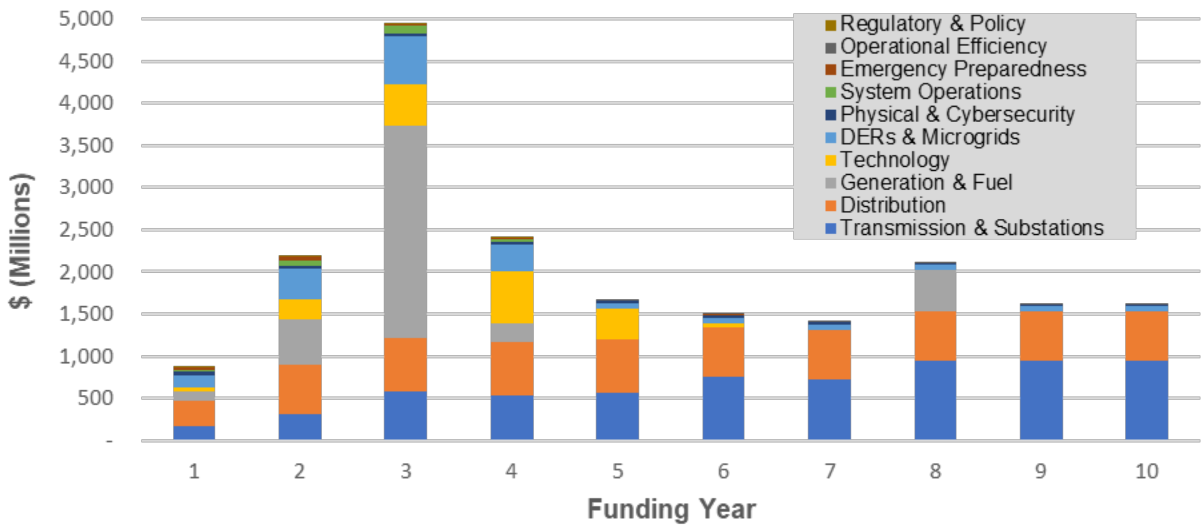
In the DER & Microgrids category, investment is required to implement a more decentralized and flexible grid and to ensure load can be served at critical infrastructure facilities. $1.2 billion of projected expenditures in this area are directed at microgrid implementation. That amount is in addition to

[8] The estimate includes targeted capital expenditures for improving the reliability of existing generating resources, costs for the peaker replacement program, costs for battery storage identified in the IRP, and costs for LNG fuel infrastructure.

expenditures listed in other categories needed to upgrade transmission and to install flexible generation to implement the islandable grid concept recommended in PREPA's IRP.

Annual expenditure patterns are illustrated in Figure 3 and Table 2. The cumulative expenditure patterns are illustrated in Figure 4 and Table 3. As shown, $6.6 billion of projected expenditures are needed in first 3 years, and over $12 billion are needed in the first 5 years.

Figure 3. Annual Cost Estimates by Category



Source: GridMod Plan Funding Analysis

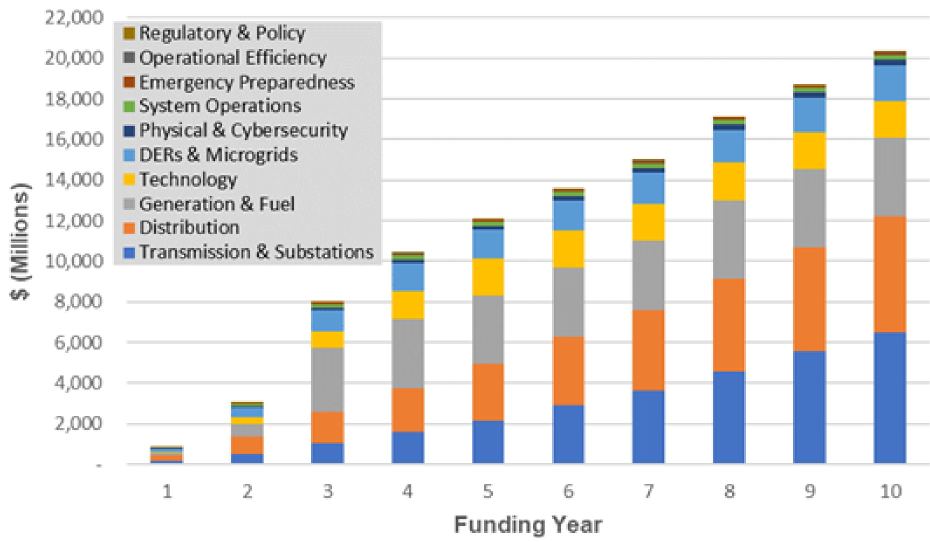
Table 2. Annual Cost Estimates by Category

Category	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
Transmission & Substations	$ 168	$ 318	$ 590	$ 530	$ 572	$ 752	$ 727	$ 947	$ 947	$ 947	$ 6,498
Distribution	$ 302	$ 583	$ 633	$ 633	$ 633	$ 584	$ 584	$ 584	$ 584	$ 584	$ 5,703
Generation & Fuel[9]	$ 112	$ 531	$ 2,504	$ 234	$ -	$ -	$ -	$ 486	$ -	$ -	$ 3,868
Technology	$ 56	$ 244	$ 496	$ 612	$ 365	$ 62	$ -	$ -	$ -	$ -	$ 1,835
DER & Microgrids	$ 136	$ 360	$ 572	$ 313	$ 58	$ 62	$ 63	$ 64	$ 63	$ 64	$ 1,755
Security	$ 40	$ 32	$ 38	$ 31	$ 29	$ 30	$ 24	$ 22	$ 22	$ 22	$ 290
System Operations	$ 23	$ 65	$ 92	$ 35	$ -	$ -	$ -	$ -	$ -	$ -	$ 215
Emergency Preparedness	$ 25	$ 42	$ 10	$ 10	$ 10	$ 10	$ 5	$ -	$ -	$ -	$ 112
Operational Efficiencies	$ 1	$ 4	$ 8	$ 3	$ 1	$ 1	$ 1	$ 1	$ 1	$ 1	$ 21
Regulatory & Policy	$ 3	$ 4	$ 3	$ 2	$ -	$ -	$ -	$ -	$ -	$ -	$ 12
Total	***$ 865***	***$ 2,182***	***$ 4,945***	***$ 2,404***	***$ 1,668***	***$ 1,501***	***$ 1,405***	***$ 2,105***	***$ 1,617***	***$ 1,618***	***$ 20,309***

Source: GridMod Plan Funding Analysis

[9] The Working Group notes that the trajectory of implementation for solar and storage capacity and corresponding cost projections proposed in the current version of the IRP may prove challenging. However, the Working Group used the current IRP values in this report.

Figure 4. Cumulative Cost Estimates by Category



Source: GridMod Plan Funding Analysis

Table 3. Cumulative Cost Estimates by Category

Category	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*
Transmission & Substations	$ 168	$ 486	$ 1,076	$ 1,606	$ 2,178	$ 2,930	$ 3,657	$ 4,604	$ 5,551	$ 6,498
Distribution	$ 302	$ 884	$ 1,517	$ 2,150	$ 2,782	$ 3,367	$ 3,951	$ 4,535	$ 5,119	$ 5,703
Generation & Fuel	$ 112	$ 643	$ 3,147	$ 3,382	$ 3,382	$ 3,382	$ 3,382	$ 3,868	$ 3,868	$ 3,868
Technology	$ 56	$ 300	$ 796	$ 1,408	$ 1,773	$ 1,835	$ 1,835	$ 1,835	$ 1,835	$ 1,835
DERs & Microgrids	$ 136	$ 496	$ 1,068	$ 1,381	$ 1,439	$ 1,501	$ 1,564	$ 1,628	$ 1,691	$ 1,755
Security	$ 40	$ 71	$ 109	$ 141	$ 170	$ 200	$ 224	$ 247	$ 268	$ 290
System Operations	$ 23	$ 88	$ 180	$ 215	$ 215	$ 215	$ 215	$ 215	$ 215	$ 215
Emergency Preparedness	$ 25	$ 67	$ 77	$ 87	$ 97	$ 107	$ 112	$ 112	$ 112	$ 112
Operational Efficiencies	$ 1	$ 5	$ 12	$ 15	$ 16	$ 17	$ 18	$ 19	$ 20	$ 21
Regulatory & Policy	$ 3	$ 7	$ 10	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12	$ 12
Total	***$ 865***	***$ 3,047***	***$ 7,992***	***$ 10,396***	***$ 12,064***	***$ 13,565***	***$ 14,969***	***$ 17,074***	***$ 18,691***	***$ 20,309***

Source: GridMod Plan Funding Analysis

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INTRODUCTION

CENTRAL OFFICE OF RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

1. INTRODUCTION

Purpose

The purpose of this document is to provide the vision, transformation approach, and cost estimate input for the permanent reconstruction of the Puerto Rico energy system. A key intent of the document is to present the proposed programs and investment plan to transform the current power system to a more reliable, resilient, and decentralized electric power system. The document also provides guidance to the Federal Emergency Management Agency (FEMA) for the evaluation of program funding support. This initiative is led by the Puerto Rico Central Office of Recovery, Reconstruction, and Resiliency (COR3) in partnership with Puerto Rico Electric Power Authority (PREPA). COR3 was created as a division within the Puerto Rico Public Private Partnerships Authority (P3A) to achieve the objectives illustrated in Figure 1-1.

Figure 1-1. COR3 Objectives

Consistent with this mandate, COR3 has contracted Navigant Consulting, Inc., n/k/a Guidehouse Inc. (Navigant) to provide technical advisory, program management, and federal funding formulation services to analyze, define and deliver the new energy system for Puerto Rico, in coordination with PREPA, the Puerto Rico Fiscal Agency and Financial Advisory Authority (AAFAF), and relevant advisors. Additional advisors to COR3 and PREPA have participated in the development of this Grid Modernization (GridMod) Plan, including DCMC Partners, Ankura, Filsinger Energy Partners, and ICF. The plan also included collaboration with and insights from additional entities, including the New York Power Authority (NYPA) and the Homeland Security Operational Analysis Center (HSOAC). Staff from Financial Oversight and Management Board (FOMB)[10] for Puerto Rico have also been consulted in development of the plan. Collectively, these entities are referred to as the Working Group. Staff from the US Department of Energy (DOE), through its National Labs, also participated in working group sessions and provided technical advice and insights but did not take a position on specific project or spending initiatives.

[10] The Financial Oversight and Management Board for Puerto Rico was created under the Puerto Rico Oversight, Management and Economic Stability Act (PROMESA) of 2016. The Board consists of seven members appointed by the President of the US and one ex officio member designated by the Governor of Puerto Rico.

Approach

On October 24-25, 2018, COR3 convened the Energy System Modernization (ESM) Summit at the Puerto Rico Convention Center in San Juan. The purpose of the ESM Summit was to bring stakeholders together so that a wide range of entities and individuals could align as "One Team," learn from one another, and continue to consolidate efforts to rebuild and transform the Puerto Rico energy sector and power system. An important component of this alignment was the formation of the Working Group (and subgroups by major funding category) tasked with developing and completing this GridMod Plan.

At the ESM Summit, the COR3 team indicated that the Working Group would take advantage of work already completed and lessons learned to build the GridMod Plan. COR3 also presented some strawman suggestions for starting points for each Working Group category.

Through discussions at the Summit, it was also recognized that:

- Several potential transformation and reliability-enhancing projects had already been identified and did not require further study, while other projects required additional analysis.
- The initial prioritization of low hanging fruit type projects would be a key initial step in the planning process.
- There are several complex, high priority projects, such as transmission expansion/rerouting or microgrid formation, that require collaborative decision-making as those projects play a large role in defining and shaping the path forward across many areas.

In follow-up communications with Puerto Rico stakeholders, COR3 confirmed and received additional information about privatization and transformation initiatives that were moving along parallel paths in Puerto Rico. The initiatives required additional cooperation, collaboration, and information sharing ahead of the development of the GridMod Plan.

Given the urgency of these initiatives, the process for this document was broken into two stages:

- Stage 1: COR3 developed a more detailed and thorough Initial/Strawman GridMod Plan for modernization projects and initiatives over the next 10 years, including characterizing likely decisions on complex projects. In completing the Strawman Strategy, COR3 engaged available stakeholders and worked with PREPA, Filsinger Energy Partners, Ankura, Siemens, and others.
- Stage 2: COR3 convened the Working Group to further review and refine the GridMod Plan and complete more detailed analyses as needed.

The Working Group relied on numerous sources to assess the current state of T&D assets to develop a 10-year implementation plan. Two key sources included the Build Back Better report and the Governor's Recovery Plan. Each of these reports were prepared based on input from extensive working groups, government laboratories, industry experts, and PREPA staff.

Other key sources and inputs to the Working Groups' analysis included:

- Damage assessment reports from the Build Back Better report
- PREPA damage assessment reports (also reported by NYPA)
- COR3 field inspections
- Ongoing damage assessment reports
- Extensive interviews with PREPA and expertise provided by the Working Group
- FEMA design and planning guidelines
- Codes and standards developed on behalf of COR3 and PREPA
- Project Worksheets (PWs) prepared as of the date of this report
- DOE technical studies
- After Action Reports prepared by the New York State Contingent and FEMA

At the ESM Summit, COR3 requested that interested Working Group stakeholders and participants sign-up for participation in one or more of the 10 GridMod Plan categories based on their experience and expertise. Those categories and their primary areas of focus are outlined in Table 1-1.

Table 1-1. Working Groups Categories

Working Group Category	*Focus Areas*
Transmission & Substations	Hardening and reinforcement, renewables integration, rerouting, environmental factors, vegetation management, flood-mitigation, digitization
Distribution	Hardening, radial feeds, automation, vegetation management
Generation & Fuel	Generator retirement and upgrades, renewable energy integration, fuel supply and storage, battery storage
DERs & Microgrids	Islandable grid design, distributed energy resources (DER), energy efficiency (EE), demand response (DR), microgrids, smart grids, communication upgrades, diagnostics
Technology	Grid automation, metering systems (AMI), smart street lighting, and customer systems (CIS)
Security	Physical and cybersecurity systems, etc.
System Operations	Control center enhancements, facility hardening, revised operating procedures, centralized, decentralized, and islandable operations
Operational Efficiencies	Improvements to operations and maintenance practices to improve the organization's operational efficiency and emergency preparedness to catastrophes
Emergency Preparedness	Storm restoration response and advanced planning, mutual assistance planning, supply and logistics planning, depot hardening and staging, inventory and asset management, emergency operation center planning, training and exercises
Regulatory & Policy	Regulatory and policy framework and initiatives to enable development and implementation of recommended investments and activities for each category

The subgroups within the Working Group collaborated through in-person work sessions, conference calls, and email/document exchanges. The Working Group has provided valuable insight and expertise in development of the final GridMod Plan, and COR3 is grateful for each individual's participation.

Organization

This plan is structured to provide:

- Background information on Puerto Rico's energy system before and after Hurricanes Irma and Maria (Section 2)
- An overview of the energy system's transformation strategy and Courses of Action to achieve the vision outlined in the Governor's Recovery Plan (Section 3)
- A description of the current and future state for each of the Working Group categories identified above as well as a detailed implementation plan to achieve the recommended future state (Section 4 through Section 6)
- A summary of next steps required to implement the GridMod Plan (Section 7)

ENERGY SYSTEM OVERVIEW

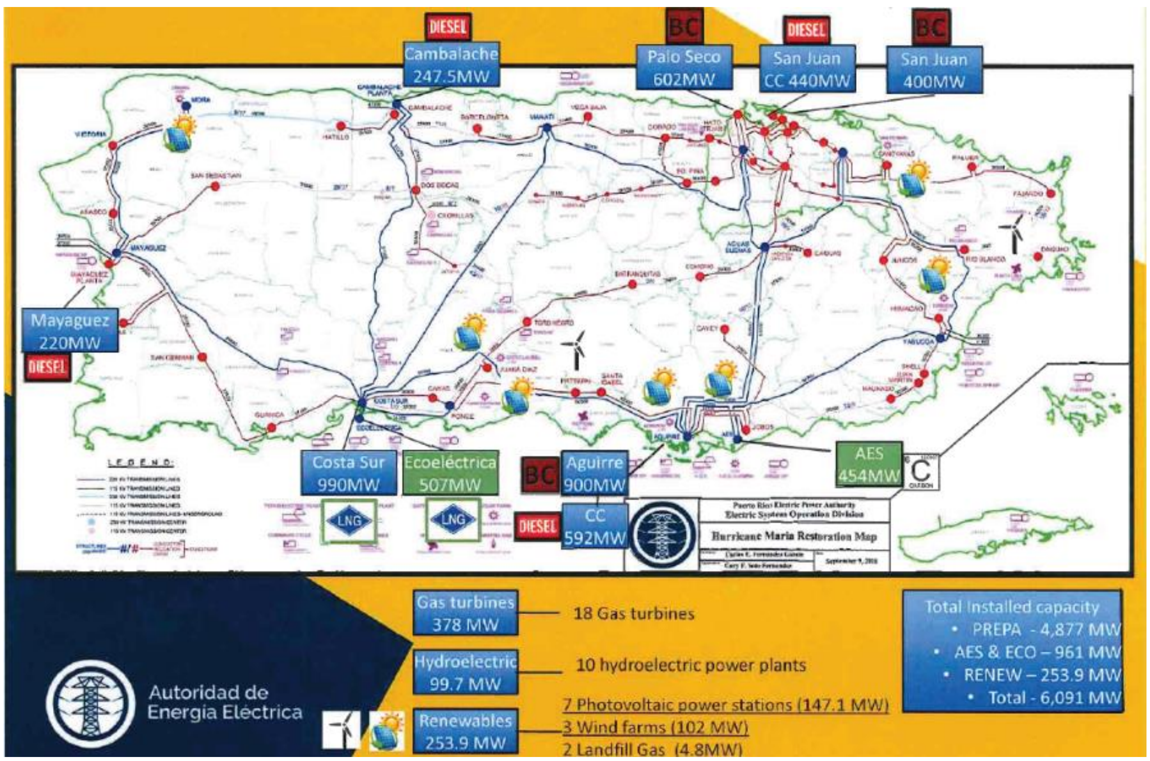
CENTRAL OFFICE OF RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

2. ENERGY SYSTEM OVERVIEW

PREPA is a vertically integrated utility that supplies power to 1.4 million customers in Puerto Rico and the smaller islands of Vieques and Culebra. The power system includes ten fossil fuel and ten hydroelectric generation sites, owned and operated by PREPA, as well as privately owned generation facilities consisting of two cogeneration plants, two windfarms, and seven solar farms. The system also has 34 MW of currently operational hydroelectric generation capacity. Total generating capacity, both installed and available, is 4,877 and 4,324 MW respectively.[11] The electric grid includes 2,585 miles of transmission lines, 31,485 miles of distribution lines across the service territory, and 334 substations[12]. The power delivery and generation system include 559 power transformers and over 2,000 circuit breakers, of which over 700 are Oil Circuit Breakers (OCB'S) that need to be replaced due to condition and failure potential. PREPA generates approximately two-thirds of its electricity and purchases the remaining from third parties. A map of the existing installed generation capacity managed by PREPA is included in Figure 2-1.

Figure 2-1. Puerto Rico Generation Installed Capacity



Source: Puerto Rico Electric Power Authority

Electricity sales in Puerto Rico declined by 18% since the 2008 recession and from net migration. Starting in 2007 until 2017, Puerto Rico's real gross national product shrank by approximately 17% and the population declined by over 15%. For Fiscal Year 2018, total energy sales declined 22% from 2017, reflecting the disruption in the transmission and distribution (T&D) networks due to the hurricanes as well as customer billing delays.

[11] PREPA 2019 IRP.

[12] Substation count refers to the number of high side voltage transmission and sub-transmission substation sites.

The power system supports the entire Commonwealth of Puerto Rico, a geographic area approximately 110 miles east to west and 35 miles north-to-south. The island includes central mountain ranges extending the length of the island from east to west with peaks as high as 4,390 feet. Coastal lowlands formed by the erosion of the central mountains extend inwards on the north coast for 8-12 miles and 3-8 miles in the south. The northern coastal lowlands are humid while those on the south side of the island are semi-arid.

Puerto Rico's geography, climate, and dispersion of its electric power customers across the Commonwealth, as illustrated in Figure 2-1, present many challenges in operating and maintaining the power system. These challenges are a key reason why the Working Group is recommending a substantial reconstruction effort, aimed at both repairing and hardening damaged facilities, but also transforming the power system to a more decentralized and flexible grid.

The electric power system consists of generation, transmission, distribution, communication, and control center facilities and is operated as a single integrated system. PREPA's T&D systems, a majority of which are above ground, were particularly vulnerable to the high winds, torrential rains, and erosion-related landslides associated with the hurricanes. Significant winds can exceed structural ratings and stormwater runoff from the mountains can cause serious flooding issues that result in long duration repairs to the power grid infrastructure.

Figure 2-2. Monacillo Control Center

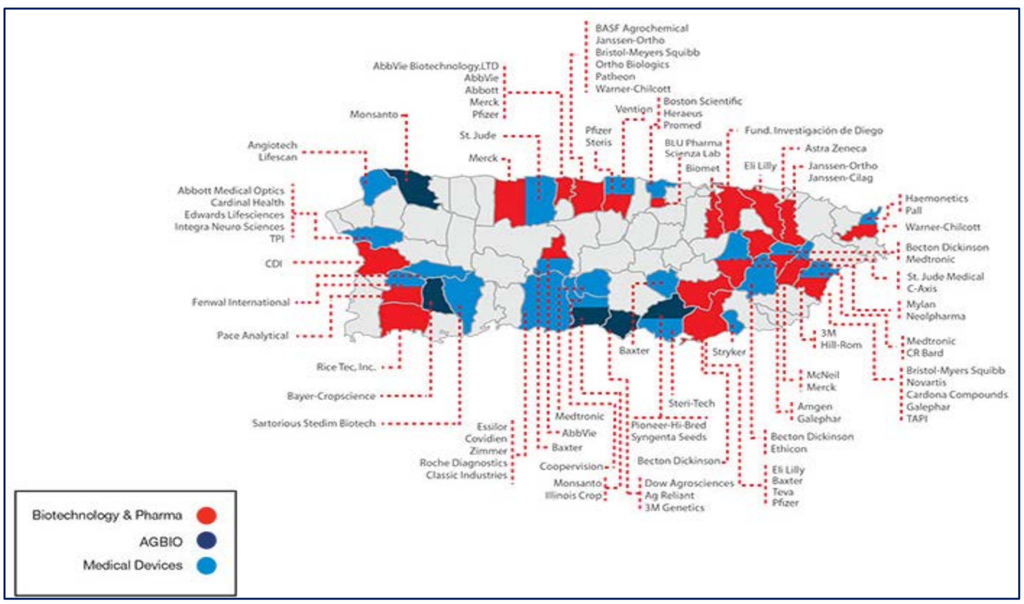
Source: Puerto Rico Electric Power Authority

The generation and flow of electricity within the system is maintained and controlled by primary and backup dispatch control centers. The primary dispatch center is located at Monacillo, approximately 7 miles south of San Juan. Energy management and supervisory control and data acquisition (SCADA) systems are used to remotely control power flow on the island, including large generating units and various substations. The backup control center in Ponce is intended to be online continuously to assume control of the power system if the primary control center becomes inoperable.

The interconnected transmission network includes supply circuits rated at 230 kV, 115 kV, and 38 kV, which transmit electrical power from generation plants to the distribution substations, where it is then delivered to customers via lower voltage distribution lines. The transmission system consists of 2,585 circuit miles of lines: 413 circuit miles of 230 kV lines, 700 circuit miles of 115 kV lines, and 1,472 circuit miles of 38 kV lines. Included in these totals are approximately 37 miles of underground 115 kV cable, 63 miles of underground 38 kV cable, and 55 miles of 38 kV submarine cable.

PREPA-owned generation is primarily located along the northern and southern coasts. The southern coast has two of the largest and most critical generating facilities—Aguirre and Costa Sur. Electric power generation facilities are interconnected via high voltage overhead transmission lines and connect to the north through mountainous terrain. Due to the physical location of these electrical connections, they are subjected to hurricane-force winds and are most likely to fail, as was experienced during Hurricane Maria. When these major pathways are rendered unusable, the bulk of the electric generation in the south cannot be moved to the north side of the island, where the highest level of electric demand exists.

Figure 2-3. Puerto Rico Manufacturing Facility Locations



Source: Build Back Better

This presents a challenge because the largest portion of the island's electric energy demand is concentrated in the northeast, in and around the city of San Juan. The high energy demand density is due to the highly concentrated population and the presence of commercial areas, a sea port, the island's main port, and manufacturing plants. Manufacturing in Puerto Rico, one of the largest contributors to the island's economy, is primarily pharmaceuticals and medical devices, with many major plants located in the northeast part of the island, as illustrated in Figure 2-3. These facilities account for approximately 65% of the system's energy demand.

Natural Disaster Impacts

Hurricane Irma struck Puerto Rico's northern coastline over September 6 and September 7, 2017 as a Category 5 storm, knocking out power to more than 1 million residents and critical infrastructure. That weekend, PREPA restored service for approximately 70% of the affected customers, with others expecting to wait months for power to be restored.

Two weeks later, on September 20, 2017, Hurricane Maria made its way up the Caribbean as a Category 4 hurricane, bringing winds of 150-plus mph and dumping 25 inches of rain on Puerto Rico. Hurricane Maria followed a northwesterly track as it reached Puerto Rico, with the southeast corner of the island being the first and one of the hardest hit areas, shown in Figure 2-4.

Figure 2-4. Hurricane Maria Trajectory and Flooding

Source: KatRisk LLC

The storm ultimately impacted most of the island with a combination of high winds and flooding. Other severely impacted areas included the northern coast, as the rotation of the hurricane caused a coastal surge to meet major rain runoff from the mountains, leading to sustained flooding.

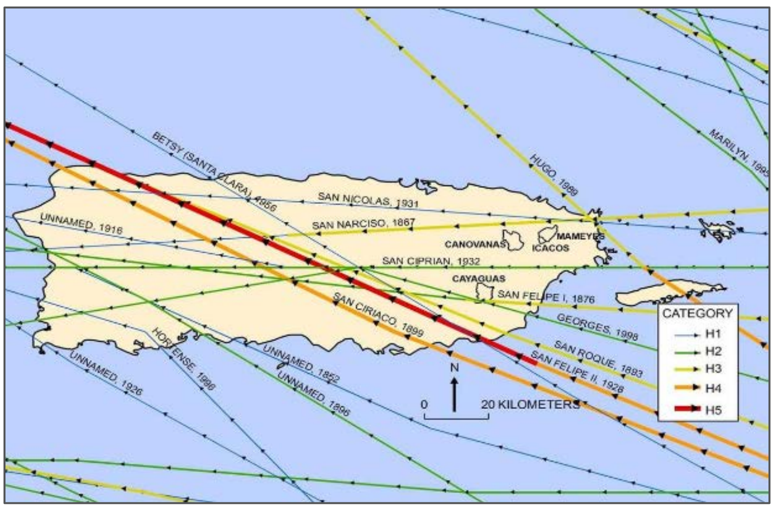
Transmission lines in the center of the island were severely impacted, as high winds were funneled through changes in terrain and damaged large transmission lattice towers. Historical storm tracks illustrated in Figure 2-6 suggest similar impacts can be expected in the future.

Hurricane Maria devastated the island, which was still in emergency response mode following Irma. The combined impacts of the two hurricanes led to a complete failure of Puerto Rico's power grid, with outages lasting over several months. Because of the extended and unprecedented damage, a significant portion of the generation, transmission, and distribution system should be rebuilt, including high voltage transmission lines that may survive lower category hurricanes.

Figure 2-5. Transmission Structure Knocked Down by Hurricane Maria

Source: Institute of Electrical and Electronics Engineers

Figure 2-6. Puerto Rico Historical Hurricane Storm Tracks



Source: US Geological Survey

Response and Recovery

The hurricanes decimated T&D lines across the island and caused widespread wind and flooding damage to substations, generation, and distribution facilities. In response, several organizations from the US mainland supported PREPA in the response and recovery efforts in Puerto Rico after Hurricane Irma and Maria's impact. This included organizations from New York who formed the New York State Contingent (NYSC) and numerous other utilities that worked on recovery efforts from September 2017 through approximately April 2018 in close coordination with trade organizations, federal agencies, and the Government of Puerto Rico.

A Unified Command Group was created to coordinate restoration efforts from the extensive team involved in the restoration.

Utilities and organizations that participated in the recovery effort include:

- Federal Emergency Management Agency (FEMA)
- US Department of Energy
- US Army Corps of Engineers
- New York Power Authority (NYPA)
- New York State Department of Homeland Security and Emergency Services (NYS DHSES)
- Puerto Rico Emergency Management Agency (PREMA)
- Puerto Rico Electric Power Authority (PREPA)
- American Public Power Association (APPA)
- Edison Electric Institute (EEI)
- AVANGRID (NYSEG, RG&E)
- Central Hudson Gas and Electric Corporation
- Consolidated Edison, Inc.

Seven regional Incident Management Teams (IMT) consisting of mainland electric utilities were assigned to specific areas of the island, working via the Unified Command Group to expedite restoration efforts Figure 2-7 outlines areas of responsibility for each IMT.

Ultimately, damage from the hurricanes resulted in the longest duration power outage in US history. Power was eventually restored to virtually all customers in Puerto Rico in August 2018, 11 months after Hurricanes Irma and Maria. However, a substantial repair and rebuild is still needed to fully bring electric generation and delivery systems across the island to current Codes and Standards.

Figure 2-7. Utility Restoration Teams[13]

Source: US Geological Survey

[13] Referred to in the testimony of Carlos D. Torres before the US House Energy and Commerce Committee, April 2018.

Energy System Transformation

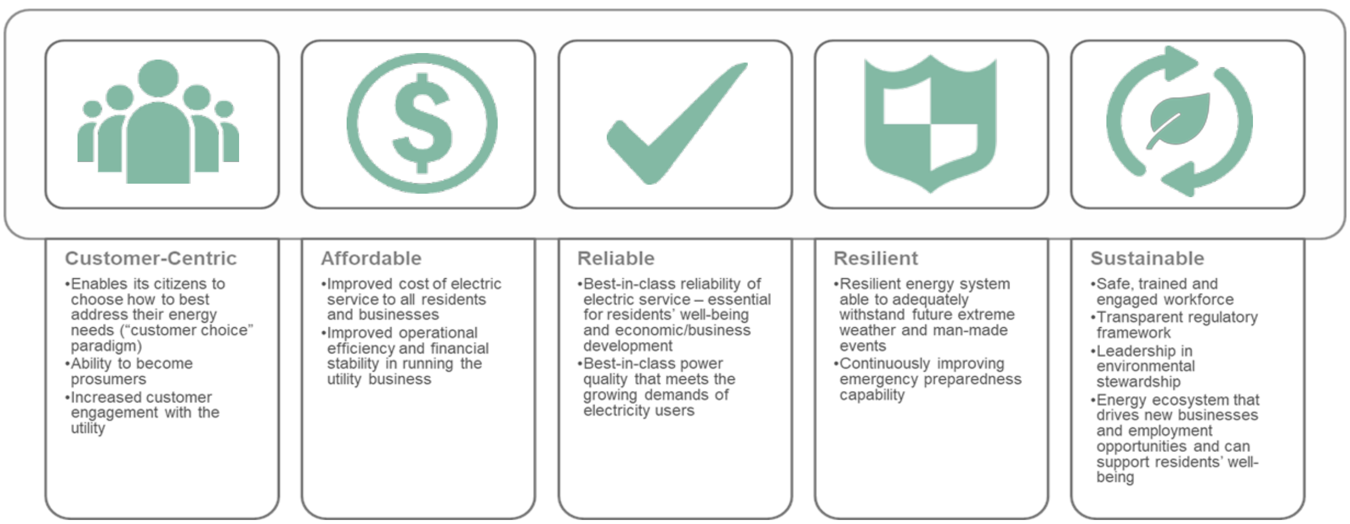
The Governor called this a “transformative moment in the history of Puerto Rico.” The devastation to the electric power system presents an unprecedented opportunity to rebuild and transform the system to one that is hardened, smarter, more efficient, cleaner, and less dependent on fossil fuel imports. The new system will be designed and constructed using current power system codes and standards with modern grid technologies. The recommendations in this plan are formed through stakeholder experience with power system hardening from hurricanes encountered on the US mainland over the last decade.

The vision in the Governor’s Recovery Plan is summarized in the following statement and the five imperatives for modernizing Puerto Rico’s energy system are included in Figure 2-8.

Governor’s Vision: “Transform the energy system to ensure customer-centric, affordable, resilient, reliable, and scalable electricity that incorporates more renewables, microgrids, and distributed energy resources (DER); can drive new businesses and employment opportunities; and can support residents’ well-being.”

This future electric power system in Puerto Rico will rely on increased renewable energy resources, such as wind and solar, incorporate new distributed energy resource technologies such as energy storage and microgrids, and enable energy to become more affordable and sustainable to improve the way of life for the citizens of Puerto Rico.

Figure 2-8. Strategic Imperatives



Source: ESM Summit

Key principles for the Grid Modernization Plan include:

- Modernize the thermal generation portfolio to reduce fuel costs and improve operational flexibility
- Decentralize generation and move to cleaner, more sustainable energy sources in support of Puerto Rico's renewable energy goals
- Optimize the generation fleet via retirements of inefficient or environmentally noncompliant units, invest in base facility repairs and reliability projects, develop an inventory of spare parts and harden generation stations for high wind and flooding conditions
- Upgrade current generation stations to use liquefied natural gas (LNG) and expand import and storage capacity to improve availability and deliverability of LNG, a more diverse and lower cost fuel source
- Use proven emerging technologies such as energy storage, microgrids, and energy efficiency to provide greater system flexibility and resiliency throughout the island
- Repair and harden the T&D infrastructure to current industry codes and standards and design to withstand extreme Category 4 storms (150 mph+ sustained winds)
- Reinforce substations through a defense-in-depth approach to withstand winds, floods, and mudslides; implement microgrids and use undergrounding for critical infrastructure (e.g., hospitals, police and fire stations, emergency shelters, critical communications infrastructure i.e. cellphone towers, water treatment plants, airports, sea ports, commercial centers, and industrial centers)
- Upgrade system voltages where necessary to address capacity and performance issues, and improve system flexibility and resiliency (e.g., 4 kV to 13 kV for distribution, 38 kV to 115 kV for transmission)
- Improve the cybersecurity posture of the operational control networks to ensure reliable delivery of power
- Implement defense-in-depth physical security protections at control centers, and generation sites to meet industry physical security protections
- Use modern technologies and automation to lower the number of outages, reduce recovery times, lower operation costs, and enable integration of sustainable energy resources
- Follow recommendations from the Hurricane Maria After Action Report to develop an industry best practices approach to emergency preparedness, response and mutual assistance for PREPA

TRANSFORMATION STRATEGY

GOVERNMENT OF PUERTO RICO

COR3 CENTRAL OFFICE OF RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

3. TRANSFORMATION STRATEGY

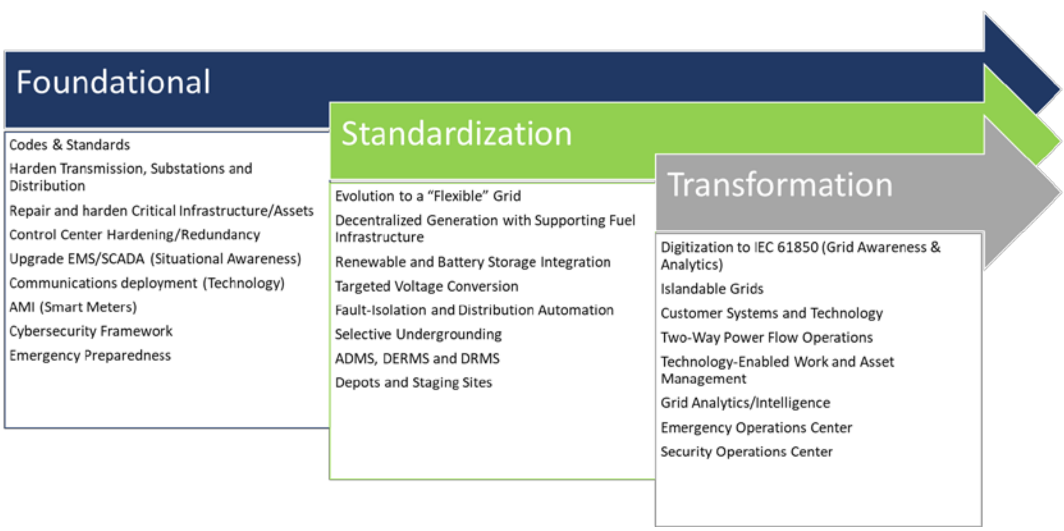
Rebuilding and transforming the Puerto Rico energy system is a complex undertaking. Substantial resources are currently directed toward this effort, led by COR3 in partnership with PREPA, and supported by a multitude of stakeholders and subject matter experts local to and external to the island. The transformation effort recognizes that there are near-term investments and projects that can address current reliability and power quality risks, bringing immediate benefit to the people and businesses of Puerto Rico. These projects are currently being identified and prioritized in parallel with the development of this GridMod Plan.

In this plan, the Working Group has addressed system transformation needs across three stages:

- Short-term priorities (1-3 year)
- Mid-term (3-7 years) and
- Long-term rebuild initiatives (7-10+ years)

These stages in the plan are sufficiently detailed to ensure the new transformed energy system can be effectively commissioned, operated, and maintained during the reconstruction program. This includes the strategic consideration of a concession agreement for future operation of transmission, distribution, and generation assets and services, as illustrated in the timeline diagram in Figure 3-1.

Figure 3-1. Energy Recovery Phases



To capitalize on near-term transformation opportunities, PREPA has been developing and initiating procurement for resources and technologies that can be implemented to enhance reliability and resiliency in high risk areas of its system. COR3 is coordinating with PREPA to review and prioritize all procurement activities and ensure a cooperative, transparent and compliant procurement process for all permanent project contract work in the future. These activities have been coordinated within the Working Group and the initiatives in this document.

Puerto Rico's Governor and leaders from different sectors have identified the need for comprehensive change across multiple areas to deliver the power grid of the future for Puerto Rico. This is outlined in ICSE report, *Public Collaborative for Puerto Rico's Energy Transformation* (October 2018), as areas of change opportunity:

- The Promotion of a Vision for Self-Sufficiency and Credibility
- An Independent Regulator with Enforcement Powers
- A Modern Regulatory Framework and Integrated Resource Plan
- The Involvement of Cooperatives and Municipalities in the Transition

Identifying programs of work and successfully driving change in each of these opportunity areas will serve to deliver a more *resilient*, a more *reliable*, a more *sustainable*, a more *affordable*, and a more *customer-centric* power grid, all of which are key attributes of the future state electric grid defined in this plan.

At the center of the transformation reflected in the GridMod Plan is the fundamental shift in the way electricity will be generated and distributed, and the evolution of the traditional relationship among stakeholders across the electrical system. It is also clear that these opportunities for change extend into core focus areas that establish the framework within which work is conducted, commonly referred to as "**People, Process, Organization, and Performance**."

- People: Building the workforce of the future that is aligned to new utility operating requirements; "right-sizing" the utility, while focusing on training, succession and advancement
- Process: Designing and implementing repeatable business processes for key utility activities; building a business process culture, exemplified by continuous improvement
- Organization: Building an operating model that is aligned to the Vision, Mission and Objectives of the utility; considering roles, span of control, and governance in the organizational design
- Performance: Defining metrics, measuring and reporting utility performance in relation to targets; building the performance discipline that informs evaluation, compensation, and advancement

Designing and successfully driving change in these areas will be central to achieving the broader electricity system transformation across all planning horizons envisioned in this document. The following shown in Table 3-1 are examples of key elements within these focus areas.

Table 3-1. Organizational Change Components for Puerto Rico

Focus Area	*Descriptions*	*Definition*
People	Capabilities	Skills required to operate and maintain the system of the future
	Staff Levels	Right-sizing utility operations given new strategies and operating requirements
	Resource Optimization	Identifying the right mix of employees and contractors to ensure optimal delivery
	Training & Succession	Consistently improving the workforce to achieve higher levels of productivity
	Recruitment & Succession	Identifying and retaining the best resources; building the next generation leadership
Process	Efficiency	Delivering services "right first time" with minimal waste
	Quality	Delivering highest quality results; consistently striving to improve operations

Focus Area	Descriptions	Definition
	Innovation	Methods of identifying and applying new techniques to best deliver work
	Continuous Improvement	Designing practices that support a culture of continuous learning and improvement
Organization	Operating Model	Translating the strategic vision into design principles around the organization
	Span of Control	Hierarchies and reporting relationships to achieve optimal effectiveness
	Roles & Job Design	The design of key roles aligned to process and operating requirements
	Governance & Decision-making	Policies and protocols that specify authorities and accountabilities
Performance	Business Goals & Metrics	Clear goals, targets and metrics identified in key performance areas
	Rewards & Compensation	Standard performance management systems and protocols applied to employees
	Reporting	Consistent reporting across multiple metrics to provide insight into performance

Adopting and integrating projects in these key areas into spend plans will be imperative for long-term success of the transformation program. In addition, incorporating change management tools and techniques into the long-term program will be critical. The discipline of Change Management has increased in prominence across the utility sector over the last several years as utilities aim to transform strategic plans and business models, implement and utilize new forms of technology, and address succession and talent management challenges. Common components of broader change management (including a change management charter and plan, stakeholder engagement and communication, and change "readiness" assessment) will be a central element of GridMod Plan management.

Energy Sector Office Execution Approach

PREPA and COR3 have formed the Energy Sector Office (ESO) to jointly govern the energy system transformation in Puerto Rico. The two organizations formalized the ESO through a Partnership Agreement, outlining roles, responsibilities, and facilitating unity of effort in planning, stakeholder engagement, and ultimately execution of the GridMod Plan. Within the ESO, a program management office (PMO) has been established with industry experts from Navigant Consulting, other advisors, and local partners to lead planning, project definition, funding formulation, and program management and administration. PREPA and COR3 are continually working together to improve the governance model to get energy projects obligated and implemented.

An initial priority for the PMO has been leveraging the knowledge of world-class technical experts to help inform a truly innovative path forward to achieve the objectives of delivering a more customer-centric, affordable, resilient, and sustainable energy system. As described herein, the PMO has led a stakeholder process to engage industry experts from the Department of Energy, Large Public Power Companies and others over the last five months to deliver on this plan. In addition to defining investments required for a more modern, resilient and sustainable energy grid, this plan includes the technology strategy and execution plan for grid modernization. This includes recommendations for foundational digital technologies and systems, planning for new energy control systems, substation and distribution automation, field area and wide area network communications, cybersecurity, data analytics, and related applications and IT/OT systems infrastructure.

Another key priority for the PMO has been working directly with FEMA to coordinate and execute energy infrastructure and facilities damage inspections, repair/replacement statement of work and cost estimating, environmental and historic preservation compliance and permitting analysis, and hazard mitigation and resiliency conceptualization as required by the Stafford Act 428 legislation and Bipartisan

Budget Act of 2018 (BBA). The PMO is also developing new design and construction codes and standards for the reconstruction of the energy delivery system, ensuring conformance with current industry codes and best practices, including technically feasible and cost-effective resiliency measures. Furthermore, the PMO has the primary responsibility for the implementation, tracking, control and reporting[14] for the 27 Energy COAs related to the electrical grid reconstruction and overall energy system transformation.

Finally, the PMO will define and execute the energy recovery program communications plan, with a focus on creating a voice of the customer and clear regulatory alignment for the GridMod Plan. The stakeholder analysis is underway, with plans for an island-wide roadshow to share the plan and develop the necessary business and community support. The communication plan will then extend into Washington, DC with the objective of developing the necessary support for this plan and securing the funding required to transform the energy system for the businesses and people of Puerto Rico.

Potential Funding Sources

This GridMod Plan adds granularity to the Governor's vision and sets the foundation for turning the Governor's vision into action, resulting in a modernized, standardized, resilient, and expandable energy system in Puerto Rico that is customer-centric and affordable. Accordingly, this plan was developed without regard to one particular funding source. Multiple funding sources will be fully explored for elements of the GridMod Plan based on the various procedural, eligibility, and funding availability requirements of each source. In Table 3-2 is a listing of some of the key sources of funding that will be fully explored to support the execution and implementation (note – this list is not exhaustive).

Table 3-2. Funding Source Categorization

Funding Source	*Description*
US DHS, FEMA Public Assistance **(10% cost share for permanent work projects under Presidential Disaster Number 4339)**	Funding to restore damaged or destroyed infrastructure to its pre-disaster design, function and capacity based on applicable codes and standards. Additional funding is available for cost-effective measures that reduce future damages from similar event types. (406 mitigation) Per Section 20601 of the 2018 Bipartisan Budget Act, FEMA may provide additional assistance to restore critical services to an industry standard without regard to pre-disaster condition.
US DHS FEMA Hazard Mitigation Grant Program **(25% cost share for projects)**	HMGP provides funds to state, tribal and local governments and private non-profit organizations after a disaster declaration to reduce risk to life and public or private property through cost-effective mitigation measures. The key purpose of this state-administered grant program is to enact mitigation measures that reduce the risk of loss of life and property from natural hazards.
US HUD Community Development Block Grant, Disaster Recovery (CDBG–DR) **(Cost share – N/A)**	The special appropriation provides funds to the most impacted and distressed areas for disaster relief, long-term recovery, restoration of infrastructure, housing, and economic revitalization. Funding may be used to match other federal resources.
US Department of Energy	Technical and other assistance for energy efficiency and conservation, strategic energy planning, renewable energy, disaster resiliency and recovery.

[14] Not all energy sector COAs are assigned to PREPA; the PMO will coordinate with other agencies as necessary for implementation, tracking, control and reporting of these COAs.

Funding Source	*Description*
US Economic Development Administration, Disaster Recovery	Facilitate the timely and effective delivery of federal economic development assistance to support long-term community economic recovery planning and project implementation, redevelopment and resiliency.
US Department of Agriculture, Rural Development	Loans, loan guarantees, and limited grant assistance to address high energy costs, renewable energy and conservation, distributed generation, and other purposes.
Government of Puerto Rico	Disaster relief and other potential supplemental appropriations through the Puerto Rico legislative process.
PREPA	PREPA operating and appropriated funding will be fully explored and evaluated for availability to match, augment, and directly fund projects and other outlays necessary for recovery, reconstruction, and resiliency.
Potential Private Sector Investments	As available by the private sector for new generation projects and concession of transmission and distribution.
Non-Governmental Organization Engagement and Donations	Technical assistance, resources, donations, and funding from private non-profit and nongovernmental organizations will be fully explored, evaluated, and considered.
Federal Department and Agency Annual Appropriations	In the future year annual federal appropriations, funding opportunities for grants, technical assistance, and other resources will be fully explored, evaluated, and considered.
Supplemental Appropriations in Future Fiscal Years	Shortfalls and unmet needs for the execution of the GridMod Plan will be evaluated for potential requests for future year supplemental appropriations by the US Congress.

Source: DCMC Partners

Example System-Wide Project Formulation Approach
US DHS FEMA Public Assistance Funding

In addition to the traditional authorities within the Public Assistance Program of providing funding for the repair or replacement of damaged facilities based on applicable codes and standards, and cost-effective mitigation measures to reduce future losses, the special provision listed below applies to energy sector projects in Puerto Rico following Hurricanes Irma and Maria:

Section 20601 of the 2018 Bipartisan Budget Act (BBA) (P.L. 115-123) allows FEMA to provide assistance, pursuant to Section 428 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 US C. 5121 et seq.), for critical services as defined in Section 406 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act for the duration of the recovery for incidents DR–4336–PR, DR–4339–PR, DR–4340-USVI, and DR–4335–USVI to—

(1) replace or restore the function of a *facility or system* to industry standards without regard to the pre-disaster condition of the facility or system; and

(2) replace or restore components of the *facility or system* not damaged by the disaster where necessary to fully effectuate the replacement or restoration of disaster-damaged components to restore the function of the facility or system to industry standards.

Through a system-wide and overall solutions-based evaluation of the planned recovery, reconstruction, and resiliency

Puerto Rico has created a unified effort among a broad spectrum of stakeholders to move forward in disaster recovery through assistance to and investments in individuals, families, housing, communities, infrastructure, economic recovery efforts, and the environment. The funding sources listed above for the recovery, reconstruction, and resiliency measures of the energy system will directly support the Governor's recovery vision and assist in fulfilling the energy sector Courses of Action described in the Governor's Recovery Plan. All components within the energy system will be evaluated as one entire system for technical compatibility and potential funding allowances. It is critical for technical reviews and funding justifications to be substantiated through a systemwide evaluation of the plans and designs for recovery, reconstruction, and resiliency based on industry standards and best practices.

As Puerto Rico looks to the future, it sees the recovery effort as an opportunity not just to rebuild what was damaged, but also to transform Puerto Rico's energy system by implementing solutions that:

- Are cost-effective and forward-looking;
- Are resilient and built in accordance with industry codes, specifications, and standards;
- Harness innovative thinking and best practices from around the world; and
- Contribute to greater economic development, revitalization, and growth of Puerto Rico (in alignment with broader Government efforts to achieve fiscal and economic stability).

Puerto Rico will move forward in its economic and disaster recovery, including the energy system transformation, by investing in infrastructure, people, and the environment. Federal funds from FEMA and other government entities will help in achieving this vision. To fully deliver on all the economic, infrastructure, and societal goals identified by the Government and highlighted in this plan, private sector creativity and resources will also need to be harnessed.

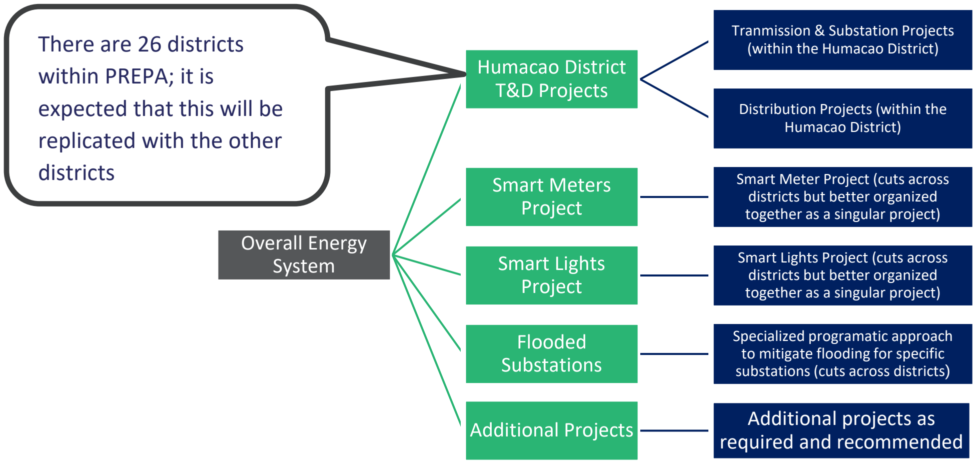
FEMA funds or other federal disaster recovery grant funding will be available to partially finance the restoration of PREPA's energy system.

Project Funding Formulation

To organize the execution of the energy projects consistent with established FEMA procedures, the entire group of energy sector projects could be grouped into a singular Project Worksheet (PW). Subgroups or individual (standalone) projects can be organized as Project Sites (shaded in green below). A conceptual grouping[15] is illustrated in Figure 3-2. The approach to organize the execution of the energy projects will be vetted with FEMA to make the project funding and formulation process efficient. COR3 intends to work closely with FEMA to ensure the PW specifications are structured to best meet FEMA's requirements, and to facilitate timely submission, review and funding of the eligible projects described in this GridMod Plan.

[15] Team is continuously working with FEMA to optimize groupings of projects in project development process.

Figure 3-2. Project Funding Formulation and Execution Approach



Energy Courses of Action

In August 2018, Governor Rosselló's office published a comprehensive island recovery plan titled "Transformation and Innovation in the Wake of Devastation: An Economic and Disaster Recovery Plan for Puerto Rico" (also known as the Governor's Recovery Plan). The Governor's Recovery Plan, with analytic inputs from the Homeland Security Operational Analysis Center (HSOAC)[16], includes twenty-seven (27) recommended Courses of Action (COAs) for the energy recovery effort and is in response to the Bipartisan Budget Act of 2018 (Public Law 115-123). The Governor's Recovery Plan states that implementing a new vision for the energy sector is an opportunity to literally power the future of Puerto Rico. Specifically, the plan states that recovery efforts should focus first on customers but also emphasize establishing a financially viable, reliable, resilient, and sustainable energy system that powers the economic engine of Puerto Rico.

Since May 1, 2019, COR3 has restructured the 27 Energy Sector COAs into 10 (categorized at GridMod Plan COAs) that created alignment between the Governor's Recovery Plan and the GridMod Plan.

Relationship to the Transformation Categories

To organize the GridMod Plan, initiatives/programs are grouped into the 10 major transformation categories Appendix B summarizes how these transformation categories map to each of the energy sector COAs (as applicable). For example, the action to align grid standards with industry best practices and ensure timely compliance and enforcement and to utilize USDA RUS standards for grid reconstruction (ENR COA-001) is mapped to all the transformation categories (indicated by a green check mark). The table further explains the context of the relationship on an ENR COA to the transformation categories. In some cases (e. g., ENR COA-026), the mapping is non-existent; the transformation categories do not address the implementation planning specific to ENR COA-026 in this plan. In addition, unless indicated, the ENR COAs are assigned to PREPA.

The Working Group recommends further review of the mapping between the energy sector COAs and the transformation categories during the GridMod Plan implementation phase. This mapping will be used to reconfigure the energy sector COAs and align them with the transformation categories for a more efficient action plan reporting process.

[16] HSOAC is a federally funded research and development center operated by the RAND Corporation under contract with the Department of Homeland Security (DHS).

ENERGY SYSTEM INFRASTRUCTURE TRANSFORMATION

GOVERNMENT OF PUERTO RICO

CENTRAL OFFICE OF
RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric
Power Authority

4. ENERGY SYSTEM INFRASTRUCTURE TRANSFORMATION

4.1 Transmission & Substations

Sections 4.1 and 4.2 describe the current and proposed future state of the power delivery system for transmission, substation, and distribution assets. The sections detail the Working Group's approach to identifying assets that were damaged in the hurricanes or that do not meet current design standards, with recommended courses of action that should be taken to achieve reliability and resiliency objectives for the island. Proposed enhancements and an implementation plan are documented for the short-term (2019 through 2022) and over the mid- and long-term (2023 through 2028). The power delivery system repairs and upgrades proposed by the Working Group consider recommendations from prior agency reports.

The 10-year transformation plan for transmission, substation, and distribution assets is based on the assumption that existing assets that were repaired following Hurricane Maria would be upgraded to current design standards, which for most assets is upper Category 4 sustained winds (150 mph).[17] Critical assets that may have survived the storm, but nonetheless are damaged, obsolete, or substandard with regards to performance or reliability also are targeted for replacement. Proposed investments align with the 2019 Integrated Resource Plan (IRP) and are required for all resource scenarios and strategies evaluated in the IRP. However, the GridMod Plan includes investments to further harden transmission lines and substations beyond those outlined in the IRP, particularly for the 230 kV system, where the GridMod Plan assumes most lines require reinforcement to withstand upper Category 4 winds.[18]

Not all T&D assets will be replaced. Less critical assets—those that are relatively new, in good condition, or those that have been rebuilt to current standards—are excluded from the proposed list of replacement assets. For example, some lines and substations located in areas (e.g., valleys) where hurricane-force winds are tempered or shielded by terrain are assigned a lower priority and excluded. The Working Group adopted a structured and manageable selection process for asset replacement, based on a realistic plan and schedule that can be implemented in a safe and reliable manner, consistent with the Governor's Recovery Plan objectives.

The identification of transmission and substations (T&S) assets for replacement is based on criticality and known conditions. The inspection reports that were completed shortly after Maria (and used to support cost estimates in the Build Back Better report) provided condition assessments for many substations and transmission lines, including specific equipment components such as substation switchgear panels and transmission towers. These reports were followed by recommendations for asset repairs and upgrades that the Working Group relied upon to support findings outlined in the following sections. Additional repair and asset condition data was provided by PREPA. The Working Group recognizes that engineering studies are necessary to refine the asset selection and costs presented in

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[17] *Energy Resilience Solutions for the Puerto Rico Grid",* Recommendation No. 5, p. 18.

[18] The IRP assumes three 230 kV lines are upgraded.

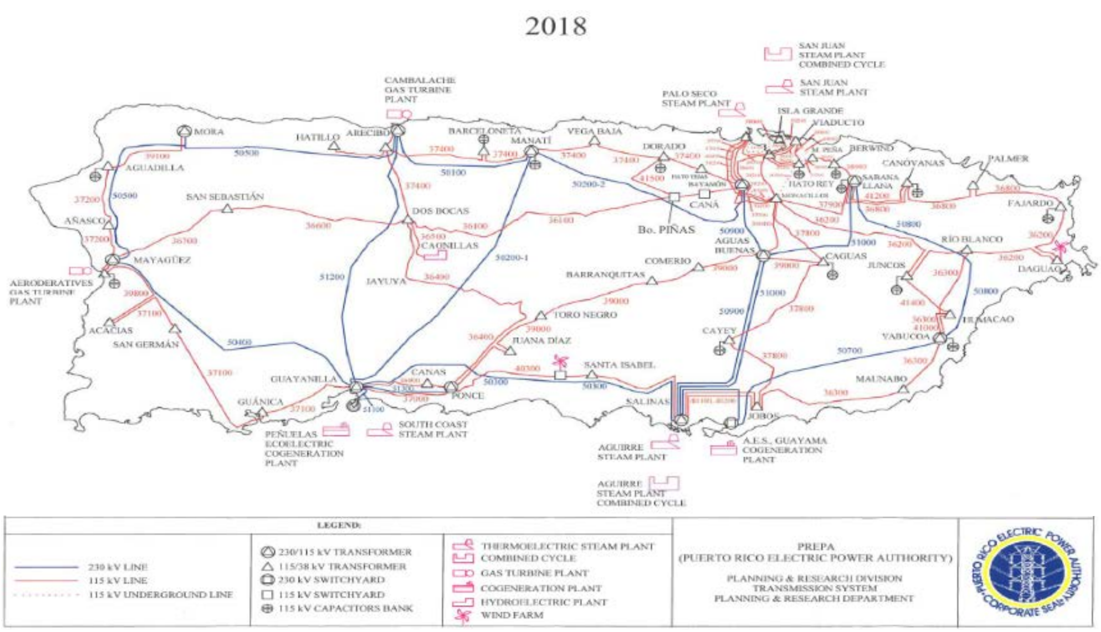
this plan. Accordingly, following the issuance of this report, the Working Group expects to refine the list of assets and costs as detailed damage assessments, statements of work, and cost estimates are completed.

Costs presented herein are at the budgetary level, and these will be refined as more detailed damage assessments are prepared and engineering studies of specific assets are finalized. Asset replacement costs were developed based on current unit costs provided by PREPA and the Working Group team, further adjusted based on known conditions and asset type. Unit costs for lines and substations were developed at the component level, where possible; for example, individual breakers or switchgear at substations. Otherwise, costs were prepared on a per mile basis for some transmission lines or representative costs for substations by voltage class and capacity. Other costs were derived and obtained from the IRP and incorporated into this plan. Costs for distribution system upgrades are further allocated at the district level.

Current State

The transmission system consists of 2,585 circuit miles of lines: 413 circuit miles of 230 kV lines, 700 circuit miles of 115 kV lines, and 1,472 circuit miles of 38 kV lines. Included in these totals are approximately 37 miles of underground 115 kV cable, 63 miles of underground 38 kV cable, and 55 miles of 38 kV submarine cable, most of which are shown in Figure 4-1.

Figure 4-1. High Voltage Transmission Diagram



Source: Puerto Rico Electric Power Authority

Many of PREPA's transmission lines damaged during the storms were constructed decades ago, located in difficult to access rights-of-way with many line sections spanning ridgelines and mountain tops. Lengthy spans are not uncommon. The geography of the island can make transmission line construction difficult. PREPA indicated that only 15% of its transmission lines were built to withstand a mid-Category 4 storm with the remaining 85% are built to lesser standards.

Table 4-1 presents damage assessment reports prepared in the Build Back Better report for 230 kV and 115 kV transmission lines. The distribution damage assessment included 38 kV lines as many are located roadside and are built to construction standards similar to lower voltage lines. Table 4-2 presents damage assessment data by region and type of transmission structure prepared by PREPA**.**

Table 4-1. Transmission Line Damage Information

kV	Line Segment	Structures (Towers/Poles)	Damages (Conductors/Insulators)
230	17	106	220
115	84	530	453
Totals	***101***	***636***	***673***

Source: Table 3-1 from Build Back Better

Table 4-2. Transmission Poles Damage Information

Region	Broken Poles Wood	Broken Poles Steel	Broken Poles Concrete	Leaning Poles Wood	Leaning Poles Steel	Leaning Poles Concrete
Arecibo	217	83	34	55	38	12
Bayamón	151		29	18	3	9
Caguas	173	7	211	30	1	10
Carolina	146	1	186	6		30
Mayagüez	258	14	13	33	7	
Ponce	597	5	38	63	16	19
San Juan	152	1	40	10		8
Total	***1,694***	***111***	***551***	***215***	***65***	***88***

Source: Puerto Rico Electric Power Authority

Most substations experienced some level of damage from Hurricane Maria. Several experienced extensive damage and some substations located in flood-prone areas will need to be relocated or raised. NYPA's inspection reports for individual substations provided damage assessments at the major component level based on visual inspections; testing of equipment for internal damage or loss of functionality was not part of the inspections. Figure 4-2 displays one example of a severely flooded substation.

The reports indicate several substations were critically damaged or remain inaccessible due to mudslides and inundation, with extensive damage to switchgear, protection, and control systems caused by flooding. This level of damage is often visible only by onsite inspection. Several substation control houses suffered water intrusion from stormwater or wind-driven rain. The field inspectors reported that many substations affected by flooding became inoperable due to the presence of contaminants and physical damage. Table 4-3 presents the substations and/or substation control rooms that were flooded during the hurricane. The 18 substations in the following table are identified as high risk.

Figure 4-2. Dorado Substation Flooding

Source: NYPA Substation Assessment Report

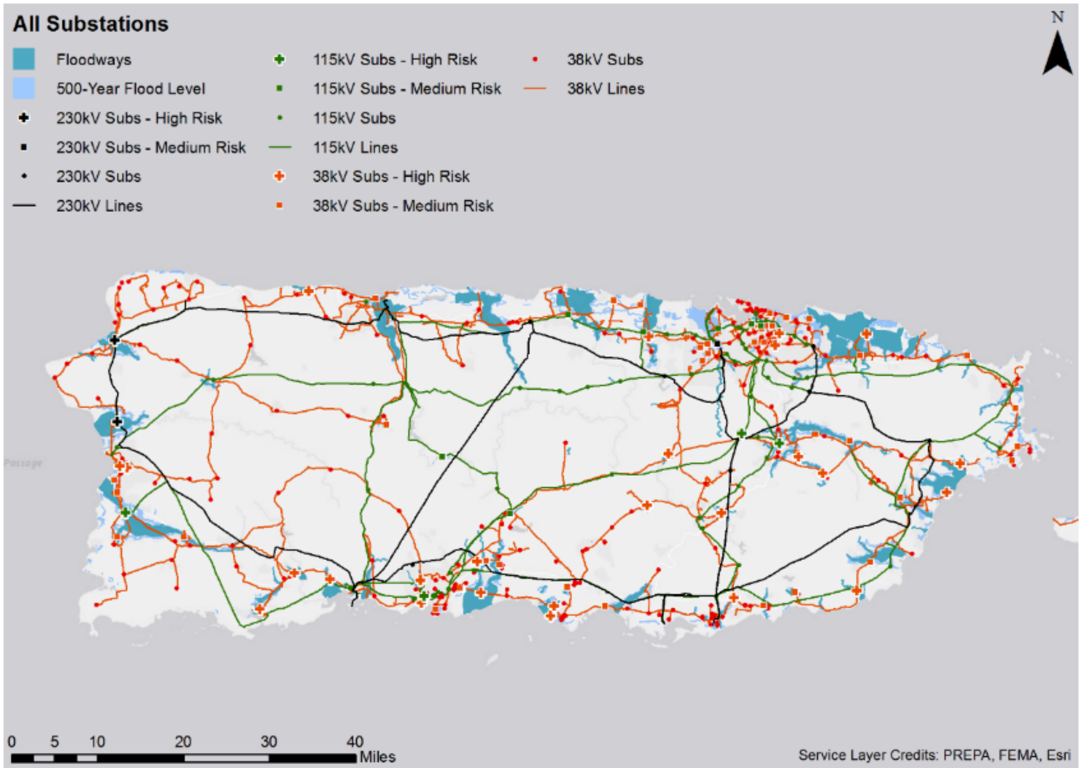
Table 4-3. PREPA Flooded Substations Information

Station	Notes	In Floodplain Area?
Acacias		Yes
a. 6801	Substation Flooded – Relay Building Not Flooded	
b. TC 6802	Substation Flooded – Relay Building Not Flooded	
Arecibo Pueblo 8002	Substation Flooded and Relay Building Flooded	Yes
Bayview 1802	Both Substation and Relay Building Flooded	Yes
Cambalache TC 8004	Both Substation and Relay Building Flooded	Yes
Caparra 1911 & 1924	Both Substation and Relay Building Flooded	No
Cataño 1801	Relay Building Flooded	No
Charco Hondo 8008	Both Substation and Relay Building Flooded	No
Dorado TC 9203	Both Substation and Relay Building Flooded	Yes
Fonalledas	Both Substation and Relay Building Flooded	Yes
a. 1401		
b. 1421		
La Virgencita 9404	Both Substation and Relay Building Flooded	Yes
Pámpanos 5005	Both Substation and Relay Building Flooded	Yes
Punta Lima	Both Substation and Relay Building Flooded	Yes
Río Grande 2302	Relay Building Flooded	No
Río Grande Estates 2306	Relay Building Flooded	No
San José substation 8104	Both Substation and Relay Building Flooded	Yes
Tallaboa 5402	Both Substation and Relay Building Flooded	No
Tapia 1102	Both Substation and Relay Building Flooded	No
Victoria	Both Substation and Relay Building Flooded	Yes
a. TC 7001		
b. 7008		

Source: Hurricane Maria Damage Verification Report: PREPA Substations - Executive Summary, NYPA, October 2017.

Figure 4-3 illustrates flood zones on the island and the location of substations within these zones. The map also shows the locations of substations, each of which has been assigned a level of risk.

Figure 4-3. Flood Risk Areas



Source: Hurricane Maria Damage Verification Report: PREPA Substations - Executive Summary, NYPA, October 2017.

Table 4-4 presents damage assessment reports from the Build Back Better report. While repairs were made to these substations to enable their return to normal operation, equipment remains at risk with many legacy equipment components obsolete or below current design or material standards.

Table 4-4. NYPA Substation Inspection Information

Region	*Number of Stations*	*Good Condition*	*Some Exposure*	*Minor Damage*	*Major Damage*	*Old Station*
Arecibo	41		11	26	3	
Bayamón	60	6	7	28	18	
Caguas	51	6	4	27	11	
Carolina	31		1	3	23	
Mayagüez	54		21	21	10	
Ponce	32			7	24	
San Juan	60		12	8	40	
Vieques	5			1	2	1
Total	***334***	***12***	***56***	***121***	***131***	***1***

Source: Table 3-4 from Build Back Better

Many PREPA substations that experienced minor damage are equipped with legacy protection systems that do not meet current design standards, such as decades old oil circuit breakers, which collectively have a high failure probability, and electromechanical relays. There also are many 38 kV substations serving 4.16 kV and other low voltage distributions lines that should be converted to operate at 13.2 kV. Distribution voltage conversions are discussed in greater detail in Section 4.2.

Future State

The planned future state of the transmission system and substations is structured to prioritize spending on power delivery assets over the mid- and long-term; defined as 2024 through 2028, respectively. For the short-term, emphasis is placed on hardening and upgrading assets serving critical loads and immediate needs that can be designed and constructed within the next few years.

Over the mid- and long-term, new and upgraded transmission lines are needed to reliably interconnect new or upgraded generation assets, which could include over 2,000 MW of solar generation and internal combustion units at eight or more regional locations, as outlined in the IRP. Further, the transmission investments proposed for the future state are required for all resource scenarios and strategies evaluated in the IRP.[19] However, the GridMod Plan includes investments to further harden distribution lines and substations beyond those outlined in the IRP, which focused most heavily on upgrades required for islandable grids and critical loads.

The Working Group expects that the transmission plans will be refined as conditions change (e.g., higher than expected amounts of installed renewable generation) and opportunities for spending efficiencies are identified. All upgrades are based on meeting industry codes and standards that are being prepared with PREPA.[20] This includes designing all new or rebuilt 38 kV lines and substations to 46 kV basic insulation levels (BIL) to align with industry standards on the mainland.[21] In alignment with ENR COA-001, these include incorporating USDA RUS standards into PREPA codes and standards, where applicable.

Figure 4-4 highlights the eight proposed islandable grid areas in Puerto Rico to interconnect new or upgraded generation assets.

These grid areas should have the following features and capabilities:

- The T&D system is configured into eight islandable grids to support resiliency and facilitate the integration of renewable and distributed energy resources
    - These islandable grids would be operated independently in the event of grid failure and supported by sufficient distributed generation resources to serve critical loads
    - Prevents systemwide blackouts if key transmission lines fail

[19] The Working Group's analysis for transmission assumes that owners of large renewable resources will be required to pay for any additional investments to interconnection their projects to PREPA's transmission or primary distribution system.

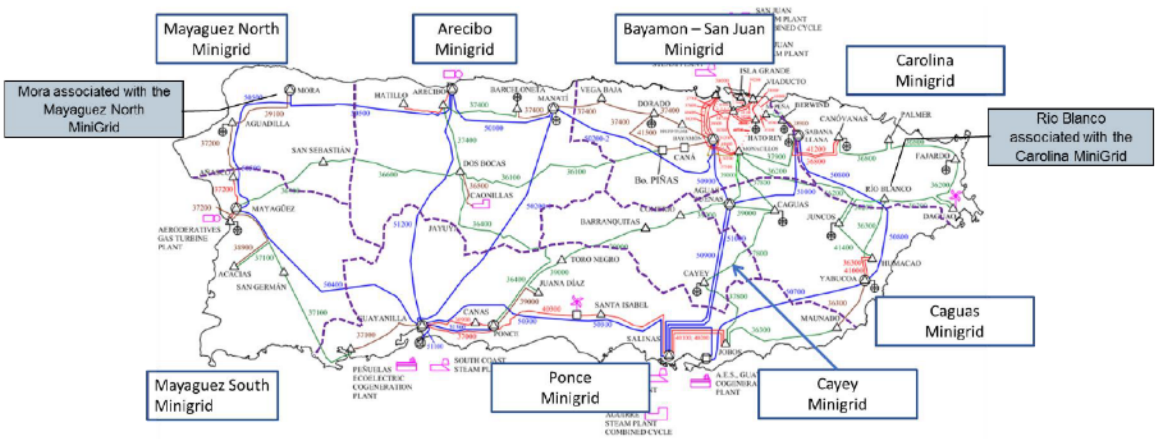
[20] COR3 recognizes that various codes and standards are under development at the time of issuance of this report. The recommendations, plans and costs presented in this report may be adjusted as new or revised standards are prepared.

[21] Although new 38 kV facilities will be insulated at 46 kV, they will continue to operate at 38 kV.

- Improves ability to respond to and recover from catastrophic events
- Adoption of electrical protection systems that automatically adjusts relay settings when operating in "Island Mode"

Within each islandable grid, small-scale microgrids will support critical load infrastructure such as hospitals, police stations, and communications. This provides an additional layer of resiliency and hardening for key operation centers.

Figure 4-4. Proposed Islandable Grid Regions



Source: Puerto Rico Electric Power Authority

Although many existing transmission and substation assets do not meet the upper Category 4 wind standards established to guide the rebuild effort, the Working Group recognizes that it is not possible or practicable to rebuild the entire delivery system, nor is it necessary for the following reasons:

- Many lines are shielded from high winds or located in areas where winds are tempered due to terrain.
- The IRP envisions a power delivery system that is resilient and capable of withstanding the loss of major lines via an islanding mode of operation.

However, the islanding concept will require new or upgraded 115 kV and 38 kV transmission lines within each of the eight regions to achieve this vision, with attendant costs for power generation and delivery infrastructure, communications, and controls. Each of these areas are addressed in this and other sections of the plan.

Longer-term priority projects include:

- Focus on hardening 230 kV and 115 kV lines after the 230 kV North-South lines and other critical short-term 115 kV and 38 kV projects have been completed
- Focus on other critical substations after those located in flood-prone areas have been repaired or relocated
- Rebuild 38 kV transmission to a 115 kV design standard for future voltage conversion

Future transmission projects are expected to incorporate new design and equipment standards that meet the upper Category 4 storm criteria, but at lower cost. Some lines may be constructed along new rights-of-way along highways where new or expanded roads can accommodate new transmission lines. These new lines will be constructed using streamlined design that improves aesthetics while maximizing the use of limited corridors; for example, use of monopole steel design for transmission and circular poles where concrete is used.

COA HIGHLIGHT

ENR COA-007: Improve Grid Assets' Resilience to High Windspeeds

The longer-term transmission plan also will provide for integration of new generation facilities while meeting island-based contingency criteria for bulk power operations. New or upgraded lines may be required to ensure voltage and generation stability for the recommended IRP. These upgrades include targeting 38 kV transmission to operate at 115 kV where rights-of-way can accommodate the additional clearances required for higher operating voltages. The COR3 long-term plan converts about 10% of existing 38 kV to 115 kV. Because many existing 38 kV lines also have distribution underbuilds, these projects will include separation of distribution lines on their own structures.

For the short-term, most substation repairs and relocations will follow current design standards. Over the long-term, COR3 proposes to introduce new design standards based on the IEC 61850 communications protocol standard. This includes increased use of digital equipment and Intelligent Electronic Devices (IEDs) such as digital relays. While recently revised codes and standards incorporate substation automation (e.g., transformer monitoring), COR3 expects enhanced automation and controls will be introduced to improve situational awareness and reliability. COR3 recommends pilot applications at two to three substations to confirm functionality and operational effectiveness. Pending successful trials, the design standard for substations will be updated for new or upgraded substations. The new design standards may include Non-Conventional Instrument Transformers, Process Bus applications, and elimination of copper cabling, which collectively, can reduce the substation footprint by up to 30% while reducing cost and enhancing safety.

Implementation Roadmap

The primary objective of reinforcing transmission assets is to improve their ability to withstand hurricane-force winds. Like substations, the proposed design for the transmission network is best summarized in the Governor's Recovery Plan ENR COA-007.

Given its geography and the general trajectory of hurricanes in the Caribbean, the southern portion of the island is more susceptible and more vulnerable to major hurricanes. This puts key northern load centers at risk, as generation located in the south is needed to serve load in the north given the current Puerto Rico power system. Thus, the short-term reconstruction focus is on transmission lines that deliver output from generating plants located in the south to the northern section of the island. The two 230 kV transmission north-south lines, which sustained considerable damage during the storm, are targeted for hardening and upgrade.

The transmission system rebuild is based on a design standard capable of withstanding upper Category 4 storms. Sufficient design margins are included to ensure high survivability for Category 5 events in areas where damage is most likely to occur.

Existing 115 kV poles that are otherwise designed for Category 4 conditions and that are located in areas susceptible to leaning or uprooting during high winds are targeted for reinforcement. Those that are damaged and unable to meet the Category 4 standard are replaced while others in areas prone to mudslides or leaning receive concrete grout injections around the base embedment to strengthen and stabilize foundations. New transmission should be designed and built with monopole steel poles, high strength insulators, and vertical construction. Notably, monopole construction fared better than lattice towers during the storm, as highlighted in Figure 4-5.

Figure 4-5. Monopole vs. Lattice Tower Design

Source: New York Power Authority and Con Edison Damage Assessments

The 115 kV system will be reinforced or upgraded within each region to enable islandable operation. The 115 kV system will be configured as the backbone delivery system for eight islandable grids, capable of independently delivering output from generators to critical loads within each island area. Upgrades are required at several substations to provide requisite isolation from the fully integrated network to one where each grid is capable of operating as an independent network. Additional circuit breakers and control schemes also are required to isolate and serve critical loads while operating in islanding mode. Hundreds of individual projects have been identified to accommodate standalone operation for each of the eight regions, which will improve both the condition and resiliency of the grid. The 115 kV upgrades required for islandable grids is common to all resource scenarios and strategies outlined in the 2019 IRP.

Transmission Near-Term Upgrades

Several near-term transmission upgrades have been identified as high priority projects. The projects target the hardest hit areas such as the Humacao District and other areas that experienced considerable damage, along with supply to high priority loads such as medical facilities and major airports. While most of the short-term projects focus on transmission lines and ties to generating stations, they also include new or upgraded substations needed to connect to or provide additional transformation capacity to accommodate the line upgrades.

Table 4-5 lists proposed reinforcement to critical 230 kV and 115 kV lines that deliver generation output from plants in the south to load centers in the north. These lines are highly susceptible to wind-related damage and many structures were damaged during the storm. The reinforcement project will be implemented in two stages. The first stage focuses mostly on 115 kV lines and substations in the eastern and northern sections of the island. The second stage reinforces 230 kV lines from Aguirre to the north, many of which are located on ridgelines and difficult to access slope-side locations.

Table 4-5. North-to-South Transmission Reinforcements

Project Name: North-to-South Transmission Backbone	
Description	Stage 1: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Jobos TC Gas Insulated Substations 115 kV and 46 kV Switchyards - Cayey TC Gas Insulated Substations 115 kV and 46 kV Switchyards - Caguas TC Gas Insulated Substations 115 kV and 46 kV Switchyards b) Reconstruction/Hardening of Transmission Lines - Line 37800 Monacillo TC - Buen Pastor Sect. - Line 37800 Buen Pastor Sect. - Caguas TC - Line 37800 Caguas TC - Cayey TC - Line 37800 Cayey TC - Jobos TC Stage 2: a) Reconstruction/Hardening of Transmission Lines - Line 50900 Aguirre S.P. - Aguas Buenas TC GIS - Line 51000 Aguirre S.P. - Aguas Buenas TC GIS - Line 50900 Aguas Buenas TC GIS - Bayamón TC - Line 51000 Aguas Buenas TC GIS - Sabana Llana TC
Justification	Critical transmission facilities for system security and reliability; makes the whole system more resilient; high interconnectivity between reliable and dependable generating units with major load centers, providing resiliency and reliability after system contingencies, major system disturbances or natural atmospheric climate events that cause grid’s fragmentation and local islanding conditions; reconstruction and hardening of deteriorated transmission infrastructure increases system operational safety margins by potentially reducing the number of system contingencies, faults, outages, and grid's transient disturbances.

Source: ESO Project Development

The Humacao District suffered considerable damage due to Hurricane Maria. Its transmission system was especially hard hit, with damage to lines that still exists today. Proposed upgrades include new underground 38 kV lines and substations, the reinforcement of 115 kV facilities, and new or reconfigured lines to accommodate islanding operation and connection to area generating resources. New or entirely rebuilt substations should be constructed to a GIS design standard. Table 4-6 presents a three-stage plan for upgrading transmission assets in the Humacao District.

Table 4-6. Humacao District Transmission Projects

Project Name: Humacao District – Transmission System Projects	
Description	The Humacao District Transmission System Projects are divided and grouped in stages. Stage 1: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Humacao Pueblo 46 kV Sect. GIS - Rio Blanco 115 kV and 46 kV Switchyards GIS b) New Underground Lines and Circuits - Underground 46 kV Line Humacao Ind. Zone Sect. GIS - Humacao Pueblo Sect. c) Reconstruction/Hardening of Transmission Lines - Line 36200 Rio Blanco TC - Daguao TC - Line 12500 Humacao TC - Humacao Pueblo Sect. - Line 3700 Humacao TC - Yabucoa Sub. 2901 - Line 5400 Rio Blanco TC – Naguabo Stage 2: a) New Switchyard Facilities - Juan Martín 115 kV Sect. - Naguabo 46 kV Sect. GIS - Pueblito del Rio 46 kV Sect. GIS b) New Underground Lines and Circuits - Underground 115 kV Line Yabucoa TC - Sun Oil - Juan Martín Sect. c) Reconstruction/Hardening of Transmission Lines - Line 9900 Humacao Pueblo Sect. - Rio Blanco TC - Line 3000 Rio Blanco TC - Pueblito del Rio - Line 5400 Daguao TC – Naguabo Stage 3: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Verdemar 46 kV Sect. b) Reconstruction/Hardening of Transmission Lines - Line 36300 Yabucoa TC - Juan Martin Sect. - New 46 kV Line Verdemar - Naguabo Sect. GIS
Justification	Critical transmission facilities for system security and reliability; makes Humacao District more resilient; high interconnectivity with critical loads and major load centers; strategically planned and localized new underground circuits and gas insulated substations provide reliability to critical distribution substations and loads; integration with existing and future local generation provides resiliency and reliability after system contingencies, major system disturbances or natural atmospheric climate events that cause grid's fragmentation and local islanding conditions; structural integration and strategic interconnectivity with planned grid stabilizing technologies like battery energy storage systems supports power quality and grid's response to system disturbances; significantly increases reliability to remote municipalities and loads in the eastern area; reconstruction and hardening of deteriorated transmission infrastructure increases local system operational safety margins by potentially reducing the number of system contingencies, faults, outages, and grid's transient disturbances.

Source: ESO Project Development

Other regions sustained considerable damage or are prone to unreliable operation, including critical loads in San Juan, Ponce, and northwestern sections of the island. Critical 115 kV transmission lines that sustained considerable damage are still out of service. For example, to address transmission supply constraints and damage to facilities serving Luis Muñoz Marín (LMM) Airport in San Juan, new underground 38 kV transmission needs to be constructed in the near-term. This high priority plan will provide redundancy via enhanced connections to the 115 kV and 38 kV network, with more direct ties to area generating plants. Proposed upgrades for lines and substations that serve the airport are also listed, which will provide alternative supply lines capable of providing continuous supply during major disruptive events.

Table 4-7. LMM Airport Supply Upgrades

Project Name: LMM International Airport Support	
Description	Stage 1: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Villamar 46 kV Sect. Gas Insulated Substation - Martin Peña GIS Line Terminal - Berwind TC 115 kV and 46 kV Switchyards b) New Underground Lines and Circuits - New Underground 46 kV Line Martin Peña GIS - Villamar Sect. - New Underground 115 kV Line Martin Peña GIS - Berwind TC c) Reconstruction/Hardening of Transmission Lines - Line 3600 Martín Peña GIS - Lloréns Torres Sect. Stage 2: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Sabana Llana TC GIS for 115 kV, 46 kV and 13.2 kV Switchyards - Los Angeles 46 kV Sect. GIS b) New Underground Lines and Circuits - New Underground 115 kV Line Sabana Llana TC - Berwind TC - Underground 46 kV Line Berwind TC - Los Angeles Sect. c) Reconstruction/Hardening of Transmission Lines - Line 6700 Martin Peña GIS - Seboruco - Tapia Stage 3: a) New Switchyard Facilities - Vistamar 46 kV Sect. b) New Underground Lines and Circuits - Underground Line 46 kV S. Llana TC - Vistamar - Los Angeles Sect. - Underground of 46 kV Line 3600 Los Angeles Sect. - Aeropuerto Num. 2 Substation 1616 (ACB 3621C) c) Reconstruction/Hardening of Transmission Lines - Line 3600 S. Llana TC - Los Ángeles Sect. - Line 38900 Sabana Llana TC - Berwind TC - M. Peña GIS
Justification	Makes the International airport more resilient by strategically integrating existing and future transmission and sub transmission underground circuits with gas encapsulated transmission centers and generation facilities; specifically increases airport's reliability by electrically integrating the airport substations directly to the main generation facilities in the north by extending 115 kV metro zone underground loop; system designed to continuously maintain service in multiple contingencies scenarios by allowing airport to be interconnected to robust transmission and sub transmission network though different electrical paths and geographical routes; improves operational flexibility and capability to provide service to the airport facilities even in severely post-fragmented operational conditions.

Source: ESO Project Development

The transmission system in the northwestern section of the island sustained considerable damage, which highlights the need to reinforce transmission supply to critical area commercial and industrial load, and the Aguadilla Airport. Facilities serving these loads are unreliable and subject to disruptions in service. Table 4-8 presents a three-stage reinforcement plan, with hardening of substations and 38 kV lines. New underground transmission lines and hardening of existing lines are proposed in Stages 2 and 3, which will provide greater redundancy and better reliability to the area.

Table 4-8. Northwestern Area Supply Upgrades

Project Name: Northwestern Area Support (Aguadilla Airport Support Service Facilities and Aerospace Technology-Electronics Industry Corridor)	
Description	Stage 1: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Victoria TC Gas Insulated Substations 115 kV and 46 kV Switchyards - Mora TC Gas Insulated Substations 115 kV and 46 kV Switchyards - Aguadilla D.H. 46 kV Sect. b) New Underground Lines and Circuits - Underground 46 kV Line Aguadilla D. H. Sect. - Ramey Field 3(ACB 2813) - Underground 46 kV Line Moca Sect. GIS - Aguadilla D.H.Sect. - Underground 46 kV Line Victoria TC - Hosp. El Buen Samaritano - Aguadilla D.H.Sect. c) Reconstruction/Hardening of Transmission Lines - Line 2800 Victoria TC - Aguadilla D.H. Sect. Stage 2: a) New Underground Lines and Circuits - Underground 46 kV Line Moca Sect. GIS - ACB 2727 (Hewlett Packard Industry Zone) b) Reconstruction/Hardening of Transmission Lines - Line 2700 Victoria TC - Aguadilla D.H. Sect. - Line 2700 Mora TC - Aguadilla D.H. Sect. - Line 2800 Aguadilla D.H. Sect. - Ramey (ACB 2845) Stage 3: a) New Underground Lines and Circuits - Underground 46 kV Line Mora TC - ACB 2717A b) Reconstruction/Hardening of Transmission Lines - Line 6000 Aguadilla D.H. Sect. - Ramey (ACB 6015) - Line 2700 ACB 2791C - ACB 2745
Justification	Grid support for the northwestern region; essential to maintain reliability and service continuity to the very important industrial and commercial sectors in the municipality of Aguadilla, including the emergent aerospace technology industry and critical airport facilities located at the Ramey Base zone; advanced structural deterioration and serious thermal limitations of the existing electric sub transmission lines that supply Ramey Base, cause frequent outages, system faults and costly electric service interruptions to the industries and airport support service facilities, as well as to the commercial and residential customers located in and around the Ramey area in Aguadilla.

Source: ESO Project Development

As described previously, much of the damage at substations was caused by flooding and mudslides resulting from heavy rains. Accordingly, the proposed design and reinforcement of substations is best summarized in the Governor's Recovery Plan ENR COA-006.[22]

Supplementing the ENR COAs are the DOE's recommendations for substations, which provide additional insights and suggestions for designing the future grid. The following excerpt contains clear, concise recommendations that helped guide the Working Group in its development of substation reinforcement plans:[23]

> *The DOE team observed that several substations were flooded (both salt water in coastal areas affected by storm surge, and fresh water associated with rainfall induced flooding). The DOE team recommends that the newly revised FIRMs [Revised Flood Insurance Rate Maps] be studied*

[22] "*Transformation and Innovation in the Wake of Devastation*, an Economic and Disaster Recovery Plan for Puerto Rico", p. 221.

[23] *Energy Resilience Solutions for the Puerto Rico Grid*, US Department of Energy, June 2018, Section C1C.Substations, p. 21.

and that substation assets found within flood areas are re-sited to avoid these areas or raised and/or waterproofed accordingly using flood-resistant materials, and anchors as required to survive these events.[24] *In addition to avoiding these areas, recommendations are to raise substations to the 0.2% flood elevation if possible. This is particularly important for key substations that are deemed essential to the reliability of the overall T&D infrastructure or associated with key generating assets. These aforementioned substation assets need to include transformers, circuit breakers, associated switchgear, and especially control equipment including protective relays and communications gear.*

The findings and recommendations from the Governor's Recovery Plan and DOE reports are consistent with substation design and selection criteria from the Build Back Better report. Build Back Better recommends the reinforcement and storm hardening of approximately 90% of the 230 kV, 115 kV, and 38 kV substation sites. Substation replacements include upgrading relay protection equipment and SCADA systems to enable improved system control, reinforcing and hardening substation facilities through defense-in-depth flood protection, and adding security access and monitoring systems.

The Working Group recommends that equipment subjected to flooding damage should be replaced. This includes protective relays, communication electronics, battery banks and battery chargers, dry-type transformers, air-blast circuit breakers, instrument transformers, meters, motors and pumps, breaker racking mechanisms, and SCADA, among other equipment categories.

ASCE 24-14 provides guidance on the design standards that meet the minimum requirements and expected performance for the siting, design, and construction of buildings and structures in flood hazard areas. FEMA deems ASCE 24 to meet or exceed the minimum National Flood Insurance Program requirements for buildings and structures. A list of applicable structures, including commercial, residential, industrial, educational, healthcare, critical facilities, and other occupancy types, can be found in Table 1-1 of the "Highlights" summary of the design code.[25] The improvements outlined in the GridMod Plan will conform to ASCE 24-14 and ENR COA-006.

COA HIGHLIGHT

ENR COA-006: Improve Grid Assets' Resilience to Flooding

The susceptibility of many substations to flooding or water intrusion, confirmed by damage reports summarized in Table 4-3, requires some substations to be moved or reinforced. A defense-in-depth approach is recommended at suitable locations to harden substations for flood and water or mud intrusion. This approach was successfully deployed in New York and New Jersey following Hurricane Sandy and has proven to be a cost-effective alternative to raising substation equipment or relocating them to higher ground.

[24] FEMA P-348, Protecting Building Utility Systems from Flood Damage. February 29, 2017.

[25] American Society of Civil Engineers Flood Resistant Design and Construction Standard International Code 24-14 Highlights.

The defense-in-depth approach generally entails four levels of defense:

1. The first level includes a flooding barrier surrounding the site, typically along the fence. While earthen berms and concrete walls are options; another cost-effective method to construct these barriers is to use heavy-duty sand bags enclosed in metal mesh (Figure 4-6).
2. The second level includes high capacity pumps permanently installed inside the perimeter with sufficient capacity to accommodate both leakage and expected levels of rainfall.
3. The third level involves backup of critical equipment via standby generators, with control buildings equipped with protection walls and pumps.
4. The fourth level indicates that, where required, individual components such as transformer control cabinets and air vents should be raised.

Figure 4-6. Substation Flood Barrier

Source: Con Edison

For the substations targeted for reinforcement or replacement, the Working Group recommendations include designs capable of sustaining high Hurricane Category 4 design standards for both wind and flooding. However, wind studies for 38 kV substations indicate those facilities may be less susceptible to high winds, as many are near buildings, which provide partial wind shielding on one or more sides.

Enhancements for all substations should include the phased replacement of undamaged but obsolete equipment that, while marginally functional, may present higher operating risks and hinder expansion of DER. New or rebuilt substations that are highly susceptible to damage or that are located in space-constrained areas should be built to a Gas Insulated Substation design standard. Roof mounted solar will be installed on control house roofs and substations to provide battery system backup. A pilot project is underway at the Caguas Transmission Center to confirm the applicability of this technology.

Significant upgrades to control and protection schemes will also be required for islanding operations as the reconfigured grids (when operating in islanding mode) will change fault duty at each breaker location. Adjusted relay settings will be required, either automatically or via operator control to ensure safety and reliability is not compromised when operating as an island. Section 5.1 provides additional detail on the monitoring and control systems that will be needed to support an islandable mode of operation.

Substation Near-Term Upgrades

Based on the current state assessment and criticality review, several near-term substation upgrades have been identified as high priority projects. The projects are targeted to the hardest hit areas and to areas with high priority loads such as medical facilities and major airports. Table 4-9 presents a range of upgrades needed to bring distribution substations and lines in the Humacao District to current design standards. The Humacao District is located in the southeast section of the island, one of the areas that sustained the greatest damage due to being in the direct path of Hurricane Maria.

The upgrades focus on converting the legacy 8.32 kV distribution system to operate at 13.2 kV, PREPA's current voltage standard. Several new substations will need to be built to serve higher voltage lines in the district along with capacity upgrades at existing stations to serve future loads and to provide transfer capability for fault location, isolation, and service restoration (FLISR). FLISR and the distribution conversion is addressed in greater detail in Section 4.2. Two new mobile substations will be located in the district to provide capacity backup for maintenance or loss of a substation due to storms or failed equipment.

Table 4-9. Humacao District Substation Upgrades

Project Name: Humacao District - Substations	
Description	a) New Distribution Substations - 13.2 kV Substation in Las Piedras - 13.2 kV Substation in Humacao TC - 13.2 kV Substation in Naguabo - 13.2 kV Substation in Yabucoa b) Increase Capacity - Verdemar Substation - Candelero Substation - Juan Martin Substation c) Mobile Substations - 1 substation of 115/13.2/8.32/4.16 kV - 1 substation of 38/13.2/8.32/4.16 kV
Justification	Distribution system facilities necessary to upgrade and replace the existing 8.32 kV distribution substations; upgrade the 8.32 kV distribution system loads to 13.2 kV; provide the necessary substation transformation capacity for the voltage conversion process; provide sufficient capacity for load transfers between distribution feeders and substations during contingency conditions; increase the reliability of the distribution system; supply load growth and future developments.

Source: ESO Project Development

Lines and substations serving critical load centers also are targeted for near-term upgrades. Table 4-10 outlines comprehensive plans to improve both the resiliency and sources of supply to the San Juan Medical District. The plan reinforces substations and transmission lines over three stages. The first is the hardening of 115 kV and 38 kV switchyards (designed to 46 kV, but operated at 38 kV, PREPA's sub transmission voltage) along with new 38 kV underground lines to provide redundancy of supply to the area. Stages 2 and 3 further reinforce area substations with ties to the 115 kV grid. Transmission lines are reinforced and ties to area generation are created to provide a secure source of supply to the district.

Table 4-10. San Juan Medical District Upgrades

Project Name: San Juan Medical District	
Description	The San Juan Medical District Projects are divided and grouped in stages. Stage 1: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Monacillo TC GIS for 115 kV, 46 kV, and 13.2 kV Switchyards - San Juan Medical Center GIS for 46 kV and 13.2 kV Switchyards b) New Underground Lines and Circuits - Terminals of Underground 46 kV Line Hato Rey TC - Veterans Affairs Hospital - Underground 46 kV Line Monacillo TC - San Juan Medical Center Sect. - Underground 46 kV Line Hato Rey TC - San Juan Medical Center Sect. (interconnection to the new San Juan Medical Center Sect. GIS) c) Reconstruction/Hardening of Transmission Lines- Line 8900 San Juan Medical Center Sect. - Venezuela Sect. Stage 2: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Hato Rey TC GIS for 115 kV, 46 kV and 13.2 kV Switchyards b) New Switchyard Facilities - Venezuela TC GIS for 115 kV, 46 kV and 13.2 kV Switchyards c) New Underground Lines and Circuits - Underground sub transmission system and circuits for internal facilities at San Juan Medical Center (includes integration of critical loads to new loop) - Underground 46 kV Line San Juan Medical Center Sect. - Reparto Metropolitano - Underground distribution system for internal facilities at San Juan Medical Center d) Reconstruction/Hardening of Transmission Lines - Line 15500 Monacillo TC - San Juan Medical Center Sect. Stage 3: a) New Switchyard Facilities - Fonalledas 46 kV Sect. GIS b) New Underground Lines and Circuits - Underground 46 kV Line Venezuela TC - Fonalledas Sect. - San Juan Medical Center Sect c) Reconstruction/Hardening of Transmission Lines - Line 8900 Tap Américo Miranda. - Reparto Metropolitano (to reconfigure 8900 Venezuela TC - Jardines Metropolitanos - Reparto Metropolitano) - Line 8900 Monacillo TC - San Juan Medical Center Sect.
Justification	Makes San Juan Medical District more resilient; provides multiple interconnection paths with strategically located transmission centers to provide high level of reliability to critical loads under multiple contingency scenarios; integrates the medical district critical network of hospitals and medical facilities to redundant sub transmission local underground loops; integrates through different electrical and geographical routes the medical district to the metro zone 115 kV underground loop in order to provide direct interconnection with the major generation sources in the north; improves operational flexibility and capability to provide service to the medical district even in severely post-fragmented operational conditions; the planned infrastructure prepares the foundation for the evolution of advanced local and system self-healing schemes to provide enhanced levels of reliability at the district.

Source: ESO Project Development

Table 4-11 outlines a plan to reinforce substations and transmission lines to improve system reliability and voltage stability of the eastern region. Upgrades include hardening of transmission lines and 115 kV and 46 kV switchyards, new underground lines, and new switchyard facilities.

Table 4-11. Eastern Region Pharma Corridor Upgrades

Project Name: Eastern Region Pharma Corridor	
Description	Stage 1: a) Reconstruction/Hardening of Transmission Centers and Switchyard Facilities - Yabucoa TC 115 kV Switchyard GIS - Humacao TC 115 kV and 46 kV Switchyards GIS - Juncos TC 115 kV and 46 kV Switchyards GIS - Villa Betina 115 kV Sect. - Quebrada Negrito 115 kV Sect. b) New Switchyard Facilities - Humacao Industrial Zone 46 kV Sect. GIS c) New Underground Lines and Circuits - Underground 115 kV Line Yabucoa TC - Humacao TC - Underground 115 kV Line Humacao TC - Juncos TC - Underground 46 kV Line Humacao TC – New Humacao Ind. Zone Sect. GIS d) Reconstruction/Hardening of Transmission Lines - Line 36200 Juncos TC - Monacillo TC - Line 5300 Las Piedras Sect. - Juncos TC Stage 2: a) New Switchyard Facilities - Las Piedras 46 kV Sect. GIS b) New Underground Lines and Circuits - Underground 46 kV Line Juncos TC - Las Piedras Sect. c) Reconstruction/Hardening of Transmission Lines - Line 41400 Humacao TC - Juncos TC (includes relocation to Yabucoa TC) - Line 5300 Humacao TC - Las Piedras Sect. - Line 12600 Humacao TC - New Humacao Ind. Zone Sect. GIS
Justification	Supports pharmaceutical, biotechnology, and gas supply industrial facilities in Juncos, Las Piedras, and Humacao; critical transmission infrastructure for system reliability as well as for voltage stability of eastern region; strategically planned and localized new underground circuits and gas insulated substations provide reliability to critical industrial loads; strategic interconnectivity with future and existing local generation provides resiliency and reliability after system contingencies, major system disturbances or natural atmospheric climate events that cause grid's fragmentation and local islanding conditions; structural integration and strategic interconnectivity with planned grid stabilizing technologies like battery energy storage systems supports power quality and grid's response to system disturbances; reconstruction and hardening of deteriorated transmission infrastructure reduces line faults, outages, and transient disturbances that cause internal disruptions in industrial-sensitive processes due to system frequency and voltage deviations and excursions.

Source: ESO Project Development

Table C-5 in Appendix C presents high priority near-term repairs for 18 substations that incurred water damage for insurance estimation purposes—COR3 expects additional repairs and upgrades beyond those included in the estimates. These substations are classified as unreliable based on damage assessment reports completed by NYPA shortly after Hurricane Maria struck the island. Most damage occurred in the control house, switchgear, and protective devices that were flooded. Some of these substations will be relocated while others will be elevated above minimum flood plain levels per proposed codes and standards.

Cost Estimates

The most important next step in determining reconstruction costs is to verify the assessment of damage to substations and lines targeted for upgrade over the mid- and longer term. The damage assessment process is underway, and the quantities targeted for replacement or upgrade that appear in this plan will be refined as the data becomes available. Costs presented herein align with upgrades and additions outlined in the IRP but include investments to further harden the T&D system to withstand upper Category 4 winds; particularly for 230 kV lines.

The design for eight islandable grids will require additional engineering studies to confirm the location and routing of new lines and substations outlined in the IRP, and the reconfiguration of the system to tie to generating sources, reconfigured substation breakers arrangements, and new protection schemes when operating in island mode. Further, the design of new lines and substations may be altered depending on the amount and location of new conventional and renewable generation. These facilities will be described in greater detail upon completion and acceptance of a recommended resource plan from the IRP.

Most transmission and substation investments are capital projects designed to harden the power delivery system—mostly within existing right of ways (ROWs)—to withstand hurricane-force winds, built using common design standards with flexibility to allow for islanding capability to improve resiliency and to facilitate integration of renewable and DER. Appendix C presents major T&S investments.

Table 4-12. Transmission and Substations Major Investment Areas ($M)

Major Investment Areas	*Cost ($M)*
Harden 350 miles of the 230 kV transmission grid, mostly hardening along new or existing ROW	$ 1,700
Reinforce or relocate existing high and medium voltage substations, and digitization	$ 1,300
Harden about 20% of existing 115 kV lines	$ 500
Rebuild about 10% of 38 kV lines to 115 kV design standard	$ 500
New transmission to support eight islandable grids	$ 500

Source: GridMod Plan Funding Analysis

Table C-1 in Appendix C provides a detailed breakdown of cost components for 230 kV and 115 kV transmission lines that were damaged or do not meet the high Category 4 wind standard established for overhead transmission lines. A key departure from the Build Back Better report is the elimination of the assumption that 230 kV lines would be relocated roadside, with existing lines in place until cutover is made. Because of difficulties in obtaining permanent easements and congestion in areas where new lines would be relocated, the Working Group derived costs based on hardening of some structures and the replacement of lattice tower for inverted "V" construction with steel poles, as a better approach to improving transmission system reliability and resilience.

Table C-2 and Table C-3 in Appendix C provide a detailed breakdown of cost components for 230 kV, 115 kV, and 38 kV substations. These tables present supporting details and derivation of substation costs by major component with unit costs applied to estimated quantities for substandard design, equipment damage or susceptibility to flooding as outlined in prior sections. These include new or rebuilt substations to a GIS design standard in space-constrained areas or where stations are located in areas subject to high winds and flying debris.

4.2 Distribution

Current State

The distribution system was not originally designed to withstand a Category 4 hurricane. Hurricane Maria caused significant damage, with up to 75% of circuits needing repair. Underground equipment experienced water and contaminant intrusion. Distribution poles—primarily galvanized steel, concrete, and a limited population of wood—were susceptible to high winds. Concrete and wood poles experienced severe damage during Hurricane Maria while galvanized steel poles fared better.

Pre-storm, the distribution system was made up of roughly 1,200 circuits operating at voltages from 4 kV to 13 kV. There were 30,000 miles of lines, with about 28,200 miles of circuits overhead and the rest located underground. The overhead system included about 30 auto loops to provide redundant substation feeds to customer demand centers.

Distribution lines ran near transmission poles and other structures, increasing the likelihood of wind causing contact and short circuits. Long sections of line failed under a domino effect due to the limited use of dead-end breakaways on poles. There were few feeder ties and limited redundancy, or automation, to provide backup or aid in the restoration of service. Numerous substations located along distribution circuits that step-down primary voltages to lower primary or secondary voltages were also severely damaged. The distribution system, including distribution substations, are equipped with a large number of OCBs, older power transformers, metalclad switchgear, and fuses on the high side of power transformers, many of which will need to be replaced to meet current industry standards.

Future State

Puerto Rico's future distribution system will use design standards capable of withstanding high Category 4 storms, with sufficient design margins to ensure survivability for Category 5 events in areas where damage is most likely to occur. However, the vision for the distribution system of the future goes beyond design standards and entails a transformation into a modern grid capable of integrating DER. The future state for distribution is common to all resource scenarios and strategies evaluated in the IRP, including the high renewable penetration at the primary and secondary voltage levels.

The Working Group recommends leveraging proven power system technologies to better contain outages, reduce recovery times, lower operation costs, and enable more sustainable energy resources that will reduce reliance on imported fuel. Additionally, the Working Group recommends the increased use of renewable energy resources, such as wind and solar, and incorporating new distributed energy resource technologies,

Figure 4-7. Distribution Line Repairs

Source: PREPA

such as energy storage and microgrids, to enable energy to become abundant, affordable, and sustainable, and to improve the lives of the citizens of Puerto Rico.

To achieve the distribution system vision of the future, the Working Group recommends a suite of distribution hardening and modernization initiatives, summarized in Table 4-13. These technologies should be implemented on a priority basis in critical areas and in districts most vulnerable to hurricane damage (i.e., Humacao, Vieques, and Culebra). This includes upgrading lines and substation equipment to accommodate bidirectional power flows and associated protection systems needed to integrate distributed resources. Greater attention will be placed on power quality and methods and equipment to mitigate performance impacts caused by variable output from renewable resources. Over the next 10 years, the Working Group recommends successively deploying these technologies to each of Puerto Rico's districts according to level of damage and criticality. Each distribution project will consist of stages corresponding to hardening and modernization technologies. These recommendations are also summarized in Table 4-13.

The proposed investment to rebuild PREPA's distribution system is $5.7 billion over 10 years. The cost of technology, communications, and operational systems used in conjunction with many of the proposed rebuilds is presented in the System Operations section. These include fiber and mesh networks to distributed generation to enable distribution operators to monitor and, when necessary, control their output via SCADA to prevent the violation of operating or performance criteria.

Table 4-13. Summary of Distribution Technologies and Applicable Projects

Distribution Hardening and Modernization Technologies

- **Build poles to code and install guying wire and breakaway low voltage service connectors on poles in high wind areas.**
- **Selectively underground distribution feeds into critical facilities and urban centers.**
- **Upgrade conductor size and use fully insulated wire (tree wire or bundled conductor) in areas where trees are present.**
- **Replace insulators with higher insulation rating.**
- **Install automated switching devices and enhance protection and controls by converting from electromechanical relays to more modern and flexible microprocessor-controlled devices on critical line segments. At least two automated sectionalizing devices should be installed on overhead mainline sections.**
- **Selectively convert lower voltage 4, 7, and 8 kV lines to operate at 13 kV, which will improve efficiency and the ability to restore energy service during storms.**
- **Increase spacing and insulation to 25 kV or higher, where applicable.**
- **Improve real-time visibility for distribution system operators, with telemetry provided throughout the circuits enabling issues to be identified quickly and accurately.**
- **Improve remote fault isolation and service restoration capability, thereby decreasing outage duration and area of impact.**
- **Increase operational flexibility with appropriately-sized line sections for circuit switching, which will minimize outages during planned maintenance and unplanned outages.**
- **Enhance situational awareness for DER operations, including the management and control of smart DER interconnections.**

Near-Term Projects (1-3 years)	Mid- and Long-Term Projects (4-10 years)
1. Vieques and Culebra Distribution Upgrade 2. Humacao Distribution Upgrade	Roll out distribution hardening and modernization technologies to all 26 districts of Puerto Rico

To ensure the longevity of these investments, the Working Group envisions partnerships with local research and education institutions. These partnerships will place PREPA at the center of T&D innovation on the island and attract the next generation of talent who will steward the T&D system of the future. These investments are detailed under Operational Efficiencies (Section 6.1).

Implementation Roadmap

The following solutions are designed to both harden Puerto Rico's distribution system against future storms and bring the system in line with the smart grid transformation unfolding across the mainland US in the 21st century.

Pole Strengthening for Wind Damage

Distribution poles are highly vulnerable to strong winds and falling trees. To help minimize the impact of major storms, pole assets must be kept in good condition. Some wooden poles will be replaced with concrete, steel, or polymer poles in critical areas for added storm resiliency. These critical poles may include riser poles, highway crossings, waterway crossings, and poles that serve important load centers.

The Working Group recommends a pole replacement program using a stronger class of poles and stronger wire to withstand high winds associated with Category 4 and 5 storms. Third-party equipment (communication cables) installed on the pole must be considered when evaluating pole strength. Small or thin overhead wire that cannot withstand high wind forces must be reconductored with stronger, fully insulated wire to withstand Category 4 wind forces.

In general, all pole construction should adhere to the latest codes and standards for Category 4 hurricanes when possible. Intermediate poles should be installed on longer spans. The Working Group also recommends installing breakaway disconnectors that disconnect low voltage secondary wires when trees or debris strike.

Selective Undergrounding for Wind Damage

Undergrounding is a proven method for making electricity grids more storm resilient. However, it is disruptive and costly during the construction phase. The Working Group recommends selective undergrounding of the distribution lines that serve critical loads such as town centers, medical facilities, and airports, or where required per Puerto Rico law or regulations. Undergrounding projects can be timed to coincide with other major construction projects, such as roadwork and fiber optic cable installation, to ease the cost burden and the disruption caused by undergrounding.[26]

[26] Gelbien, L and Rasheed, B. For Extreme Storms, Utilities Must Go Beyond Business as Usual. Electric Light and Power, June 2014.

Breakaway Disconnect System

In a storm, fallen live wires pose a safety threat to both customers and crews. A breakaway disconnect system ensures that lines are disconnected at the pole instead of at the weatherhead. The line comes down safely deenergized, minimizing the possibility of damage to either utility equipment or the service connection. The crew can restore service quickly without running new lines or splicing, and simply by replacing the breakaway link.

Source: Thomas & Betts

Replacement of Insulators for Wind Damage

High winds and salt water contamination of traditional porcelain insulators are major drivers of power failures during a storm. These older style insulators are prevalent on the Puerto Rico power system and susceptible to flashover due to contamination, and thus are unable to hold the wire in place during a major storm. Modern polymer insulators with higher Basic Insulation Level ratings have a much lower occurrence of flashover. The vise-top designs can hold the wire in place during high winds. In addition, polymer insulators are lightweight and shatter-resistant. The Working Group recommends polymer insulators in areas prone to high winds and saltwater contamination. New cross-arms will be required to install polymer insulators. The replacement of insulators for wind damage also aligns with ENR COA-007 to improve grid assets' resilience to high windspeed.

The flooding of substations and distribution switchgear along the coastal US Northeast mainland during Hurricanes Sandy and Irene caused extensive, long-term outages. Even where underground cables were present, aboveground pad mounts and other switching devices failed because of flooding. Repair and replacement are time-consuming and costly for such major pieces of equipment. New York utilities used sealed underground cable conduits, replaced copper wire with fiber optic in its control wiring, and installed flexible connectors that can lift its relay panels 10-12 feet above the ground in the event of a major storm.[27] In addition, according to DOE, many utilities along the US Gulf Coast have elevated their substations as much as 25 feet based on predictions for Category 3 storms.

The Working Group recommends that selective undergrounding of overhead construction will be required in flood-prone areas. Fully submersible control panels and switchgears will be required in such areas. The underground equipment would include cables, conduit, underground termination, submersible transformers, underground switches, and underground terminations.

COA HIGHLIGHT

ENR COA-007: Improve Grid Assets' Resilience to High Windspeed

The Working Group also recommends replacing poles with deeper subgrade support, and selectively undergrounding in areas susceptible to wind-driven debris. Additional recommendations focus on spot

[27] Department of Energy "Hardening and Resiliency: US Energy Industry Response to Recent Hurricane Seasons", 2010.

replacement of underground distribution with overhead, and installation of engineered cable protection and conduits in likely washout areas.

Distribution Voltage Conversion

Approximately two-thirds or approximately 750 of Puerto Rico's 1,200 distribution circuits consist of 4 kV, 7 kV, and 8 kV overhead distribution lines. The back-to-back hurricanes of Maria and Irma demonstrated that many 4 kV lines could not withstand the high winds and torrential rains of a Category 4 hurricane. The 4 kV circuits sustained some of the worst damage in Puerto Rico during the recent hurricanes.

There are two options to address the deficiencies of the 4 kV overhead system: 1) selectively convert the 4 kV overhead construction to underground; or 2) selectively convert the 4 kV circuits to 13 kV overhead construction using up-to-date codes and construction standards. Converting to an underground system is extremely expensive, disruptive to the customers, and time-consuming. The Working Group believes a more cost-effective method would be to convert the 4 kV overhead system to a 13 kV overhead system using modern codes and standards that can withstand hurricane-force winds and torrential rain.

As part of the conversion process, two items should be given consideration: 1) Selective undergrounding of areas where the power supplies critical loads such as hospitals, water pumping stations, water treatment, telecommunications, cooling stations (i.e., malls, relocation centers, etc.); and 2) In locations where the existing 4 kV circuits have limited access for a bucket truck, which makes repairs difficult and time-consuming, the line should be relocated to areas accessible by an aerial bucket truck.

Converting lower voltage overhead circuits to operate at 13.2 kV requires rebuilding the circuit using new poles, cross-arms, insulators, proper storm guying, remote controlled switches, pole top transformers, and substation transformer upgrades to convert these lines to 13 kV.

In addition, the proliferation of the wide range of operating voltages made post-hurricane restoration efforts complicated and time-consuming. Adoption of a single standard voltage (13.2 kV) would make it more straightforward in the future to stock spare parts, standardize operating procedures, and coordinate repairs. This program will significantly increase resiliency and reliability for customers in Puerto Rico.

Distribution Automation for Faster Service Restoration

As the electric grid is repaired or rebuilt to the latest codes and standards, it will be prepared for future technologies. For instance, as the distribution lines are upgraded, equipment will be installed that will be leveraged for future investment.

> ***As the electric grid is repaired or rebuilt to the latest codes and standards, it will be prepared for future technologies. For instance, as the distribution lines are upgraded, equipment will be installed that will be leveraged for future investment. One such example, at specific locations, instead of installing manually operated switches will have their advance functionality disable until the distribution automation and FLISR investment takes place. In this manner we reduce the overall cost and eliminate the possibility of removing equipment that was recently installed.***

One such example, at specific locations, instead of installing manually operated switches, automated switches will be installed. Automation switches will have their advance functionality disabled until the distribution automation (DA) and FLISR investment takes place. In this manner, the overall cost is reduced and the possibility of removing equipment that was recently installed is eliminated.

The Working Group recommends replacing obsolete electromechanical relays with modern microprocessor relays for enhanced protection and control of the distribution grid. In addition, to substantially improve reliability and resiliency, the Working Group recommends supervisory (remote control and indication) reclosers equipped with fault location. In the future, FLISR capability is recommended. This will require the reconfiguration, extension, and upgrade of distribution feeders to provide feeder tie transfer capability between substations and substation busses.

FLISR has become the common standard in service reliability among mainland utilities. When a fault occurs on a distribution circuit, FLISR can reduce the number of customers who lose power by automatically isolating the trouble area and restoring power to remaining customers by routing power through adjacent circuits. In addition, this technology can help crews locate the fault more quickly, resulting in shorter outage durations. A study of five mainland utilities that conducted FLISR operations concluded that FLISR reduced the number of customers without power by up to 45% and reduced the customer minutes of interruption (CMI) by up to 51%.[28]

FLISR technologies and systems, depicted in Figure 4-8, involve automated feeder switches and reclosers, line monitors, radio communication network, Remote Terminal Units (RTUs), line extensions, distribution management systems (DMS), SCADA systems, grid analytics, models, and data processing tools. These technologies work in tandem to restore power automatically, reducing both the number of customers without power and the duration of the outages. However, FLISR communication networks require increased resilience because they must operate under conditions where the grid itself is damaged or not functioning properly. In case of extensive grid damage, upstream transmission lines will need to be restored first before FLISR is applied to restore sections of the distribution lines.

[28] Department of Energy, Smart Grid Investment Grant Program. Fault Location, Isolation and Service Restoration Technologies Reduce Service Impact and Duration. December 2014.

Figure 4-8. Electronic Reclosers, Control Units and Line Sensors Installed by Duke Energy

Source: DOE, Smart Grid Investment Grant Program. FLISR Technologies Reduce Service Impact and Duration. December 2014

In traditional distribution circuits, electricity typically flows through a single feeder to get to an end use customer. If any portion of that feeder sustains a fault, all downstream customers are affected. FLISR works by sectionalizing the distribution feeder and tying it to adjacent feeders. FLISR isolates the trouble section and allows redundant pathways for electricity to flow to customers. The Working Group proposes that most feeders of the 1,000 customers or more should have FLISR capability, i.e., two normally closed reclosers and an open tie-recloser to restore service. More than half of Puerto Rico's 1,200 distribution circuits operate at 4 kV and the remainder at 13 kV. The 4 kV circuits will have reclosers installed when they are converted to 13 kV.

Distribution Automation for DER Integration

The integration of DER into electric delivery creates challenges for grid planning and operation. Traditional one-way power delivery system is not designed for the two-way power flows resulting from DER. Renewable energy output is often intermittent and creates both operational uncertainty and power quality problems.

To mitigate these risks and ensure reliable and safe DER integration, the Working Group recommends:

- Conducting a DER hosting capacity study on select feeders to avoid system violations
- Conducting a system impact study to surface adverse effects to grid operation, safety, and reliability
- Reviewing DER facility designs and schedules to mitigate system impacts from DER
- Requiring DER projects to comply with the Institute of Electrical and Electronics Engineers (IEEE) 1547 interconnection standard which covers the performance, operation, testing, safety, and maintenance of the interconnection
- Using IEEE pre-certified inverters to fast-track DER installation

- Using load tap changers, capacitors, and voltage regulators to mitigate frequency and voltage issues
- Leveraging energy storage to mitigate the intermittency of DER output

Power Quality

The GridMod plan described in prior sections includes several upgrades to improve power quality to industrial, commercial, and residential customers throughout the island. The objective is to stabilize steady voltage voltages, reduce momentary interruptions, and proactively mitigate rapid voltage excursions. The ability to address rapid variations in voltages will become increasing important as greater amounts of intermittent resources such as behind-the-meter and directly connected solar are installed on the power delivery system. Power Quality programs that are incorporated into the short and long-term improvement plan include distribution voltage conversions, installation of additional reclosers and sectionalizing devices, sensors and controls, voltage regulating devices, new protective relaying, and enhanced vegetation management practices. Collectively, each of these strategies will improve PQ at the distribution level. For example, distribution feeder upgrades and voltage conversions will stabilize voltages via low impedance conductors and higher operating voltages. Further, proposed upgrades to distribution control and monitoring systems will enable operators to rapidly detect and address disturbances and voltage variances.

The GridMod Plan recognizes the value of power conditioning equipment to stabilize voltages and mitigate rapid variations in voltage, particularly for large solar plants. Prospectively, many new solar installations will include energy storage and power conditioning equipment as a requirement for interconnection. The large number of microgrids that are proposed also will be equipped with Power Quality Conditioners.

These devices improve power quality via their ability to:

- Deliver voltage and current at the correct level and enable equipment to function properly
- Ensure efficient and stable power transfer between the distribution system and Microgrid
- Isolate Microgrids and the distribution system disturbances and anomalies
- Provide convert DC output from solar panels to AC at stable voltages
- Cost-effective integration with solar and energy storage system

Because many industrial customers are served at the transmission level, Power Quality at the transmission level will be improved via fewer line interruptions achieved by hardening and enhanced vegetation management. Substation Automation systems, real-time monitoring and state estimation, and advanced relaying each will contribute to fewer power quality events as system operators will be able to take corrective action before these events occur.

Cost Estimates

Over the next 1-2 years, the Working Group recommends deploying distribution hardening and transformation technologies in the following critical locations.

Table 4-14. Vieques and Culebra Distribution Upgrade

	Project Name: Vieques and Culebra Distribution
Description	Upgrade and modernize Vieques and Culebra distribution system damaged by the hurricanes. Part of a long-range energy systems modernization plan for the Vieques and Culebra islands.
Justification	Energy systems availability and stabilization.

Source: ESO Project Development

Table 4-15. Humacao District Distribution System Upgrade

	Project Name: Humacao District – Distribution System Projects
Description	Upgrade the distribution system infrastructure to operate at 13.2 kV (15 kV voltage class). Reconfiguration of 13.2 kV feeders using smart grid technologies. Underground of distribution feeders up to critical loads. Hardening (upgrade of poles and conductors) to improve structural and electrical capacity resiliency. Includes the modification of construction standards.
Justification	Increase the reliability and flexibility of the distribution system; reduce the electrical losses; improve the voltage regulation along the circuits; improve the system security during fault conditions; allow multiple interconnection paths between distribution substations and feeders to provide a high level of reliability to critical loads, even during emergency conditions like hurricanes, earthquakes and system faults; reconstruction and hardening of deteriorated distribution system infrastructure to reduce faults, outages, and power quality deficiencies.

Source: ESO Project Development

Over the next 3-10 years, the Working Group recommends the rebuild and reinforcement of up to 75% of Puerto Rico's 1,200 distribution circuits. Districts and regions with the greatest storm damage and the highest customer density should be targeted first. As detailed damage assessment studies become available, complete engineering studies should be performed on all the districts in Puerto Rico. Not all distribution assets should be replaced. Less critical assets—those that are relatively new, in good condition, or that are expected to withstand future storms—are excluded from the Working Group's proposed list of replacement assets.

Many of the technologies proposed in this section, such as DA and DER integration, are relatively new for Puerto Rico. These should be piloted in the Humacao District. Lessons should be learned from these initial deployments and they should slowly be scaled up in a piecemeal fashion to the rest of Puerto Rico.

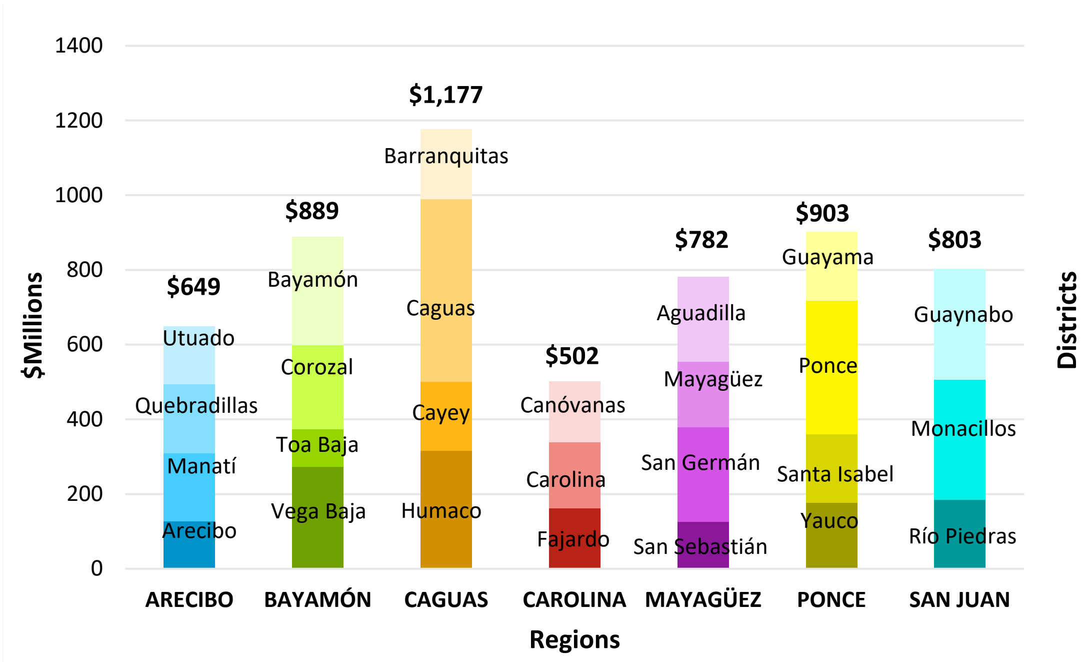
The Working Group estimated the total distribution upgrade effort to cost $5.7 billion over 10 years. A breakdown is given in Table C-4 in Appendix C. These investments are expected to unfold in each of Puerto Rico's 26 districts as separate projects.

To allocate distribution investments (cost estimates) at the district level, the Working Group used the following factors:

- Initial post-hurricane damage assessment
- The number of critical loads (hospitals, airports, sanitation facilities, etc.) and priority loads (urban centers, etc.) that need underground or redundant supply
- Customer density
- The total number of distribution poles that need to be upgraded

The resulting district-level breakdown of total distribution capital cost is provided in Figure 4-9. These costs can be further refined with a detailed district-level damage assessment and actual cost data from on-the-ground distribution work in Puerto Rico.

Figure 4-9. Allocation of Distribution Investments to Regions and Districts



Source: GridMod Plan Funding Analysis

4.3 Generation

While some units may be retired in the short term, others are expected to operate for several years. To ensure reliable operations, there will be a need to provide sufficient resources (money and people) to keep the plants operating. For the existing generation fleet, additional analysis is necessary to finalize the reliability projects that need to be completed, a timeframe for that completion, and the funding source for the projects. A review of the existing organization's capability to operate these assets must be completed as well.

Current State

The approximate total operable capability of PREPA's existing available capacity is 4,324 MW (installed capacity of 4,877) plus an additional 961 MW of Independent Power Producer (IPP) generation (EcoEléctrica and AES-PR). EcoEléctrica, L.P. in the Municipality of Peñuelas (507 MW of gas-fired capacity) and AES-PR in the Municipality of Guayama (454 MW of coal-fired capacity) are the two largest sources of generation on the island. The majority (68%) of this capacity is from oil-fired plants. However, PREPA also has 12 utility-scale renewable power purchase operating agreements (PPOAs) covering projects in operation, including, covering total solar capacity of 98.1 MW, wind capacity of 102 MW and landfill gas capacity of 4.8 MW.[29] PREPA's IRP also notes that approximately 540 MW of steam turbine capacity plus some peaking capacity is not in sufficient operational condition. This includes certain steam turbines at Costa Sur, Palo Seco, and San Juan, as well as a gas turbine at Cambalache.

Future State

To meet the future objectives of resiliency, reliability, sustainability, and affordability, the future PREPA generation fleet will require significant modifications and transformation over the next 5 to 10 years. This includes a major transition toward renewable generation, supplanted with battery storage and natural gas generation. The fuel infrastructure and generation actions required to achieve this transformation will be driven by the IRP submitted to PREB. This is a requirement for PREPA under current law and PREB rules. Accordingly, this GridMod Plan mirrors the Action Plan outlined in PREPA's IRP.

COA HIGHLIGHT

ENR COA-008: Maintain Storm-Resilient Generation Assets

On March 14, 2019, PREB issued a Resolution and Order directing PREPA to revise the February 13, 2019 IRP to cure a number of procedural issues, and to complete additional and revised analyses to make the IRP fully compliant with PREB's regulations and previous orders. PREPA submitted a revised IRP on June 7, 2019, which resulted in some changes to PREPA's IRP, particularly in areas related to near-term renewable resource expansion, the extent to which LNG-fueled thermal generation is feasible and cost-effective, and the ultimate definition and implementation of islandable grids.

[29] PREPA 2019 IRP.

Puerto Rico Energy Public Policy, Act 17-2019 puts Puerto Rico on a path toward 100% renewable energy by 2050. Implementation of this law will further change the IRP and the Action Plan. Consequently, PREB directed PREPA to expand/revise current scenarios consistent with the requirements of the Puerto Rico Energy Public Policy, Act 17-2019.

The generation plan outlined in this report and PREPA's IRP Action Plan starts the transition of Puerto Rico toward a higher Renewable Portfolio Standard (RPS) requirement and greater reliance upon renewable energy resources. Over the initial 5 years of the current plan, substantial solar and battery resources will be procured to facilitate transition to a more decentralized and distributed generation system. In parallel, investments will be made in LNG infrastructure and in new peaking and combined-cycle thermal generation. Such investments will ensure permanent and rapid improvement in reliability and resiliency of the generation fleet, make the system more storm resilient, and facilitate integration of renewable and storage resources. Generation assets will be maintained, and additional assets developed to enhance storm resiliency, which supports ENR COA-008. Over time, it is anticipated that the Puerto Rico system will continue to transition to greater proportions of renewable energy generation, to the maximum extent it is physically and economically feasible. The GridMod Plan implementation will be adjusted as needed to reflect the eventual IRP approved by PREB and the new and evolving initiatives created by the Puerto Rico Energy Public Policy, Act 17-2019.

Implementation Roadmap

During this period of transition, it is important that the existing generation assets required to serve load fulfill the primary responsibility of reliability at a cost as low as possible given the asset mix. Several existing PREPA generating units will likely be retired by 2023. This includes units at San Juan, Costa Sur, Palo Seco, and Aguirre.

Following the core principles of customer-centric, resiliency, reliability, affordability, and sustainability for the current generation fleet, the following key action items need to be completed:

1. Ensure that the existing generation assets required to serve the peak load of the PREPA customers remain reliably available during the transition period moving toward natural gas and renewable resources.
    a. This will include the evaluation, selection, and completion of projects that will repair certain damage to the plants and/or conduct current or delayed maintenance to improve/ensure reliable operations.
    b. Review current operating, maintenance, and asset management policies and procedures to ensure best practices in these areas.
    c. Ensure there are sufficiently trained employees to operate and maintain the plants during the transition.
    d. Evaluate the option to have a third-party operator take responsibility for operating and maintaining the existing units until they are retired. The advantage of this approach includes:

i. The ability to bring in plant managers with experience in turning around plants that have reliability challenges.

ii. The ability to provide additional qualified operators to support plant operations. An issue raised during plant visits is the lack of sufficiently qualified operators to support operations at all plant sites.

iii. The ability of the third-party operator to employ current PREPA staff to avoid the loss of institutional knowledge.

2. Identify the generation assets that will be converted from oil-fired to dual-fuel units to meet short-term and long-term goals of affordability and reliability.
   a. Verify primary fuel delivery is clearly identified for continuous operation and define the level of onsite storage of the secondary fuel to meet operating requirements.
   b. The current list of units to be converted to natural gas include the following:
      i. San Juan units 5 and 6
      ii. Mayagüez units
3. Evaluate the technical and economic capability of existing hydro generation assets.
   a. In the push toward greater renewable resources, the existing PREPA hydro assets can play an important role. However, to better understand the overall benefit, a comprehensive review of these assets should be conducted to better define the cost of returning them to full service and the benefit to Puerto Rico. To bring them to full service likely includes the need for dredging reservoirs and any dredging effort will need to be coordinated with the water supply sector. Once this review has been completed, a modified scenario of the IRP may need to be completed to finalize recommended future actions.

Installation of new gas-fired and solar generation assets is also required to meet the future needs of the island and to allow for cleaner and less expensive generation.

Based on the June 7, 2019 IRP filing, the following new generation assets are anticipated under the IRP 5-Year Action Plan:

- Peaker replacement (18 units) with newer, more efficient combustion turbines (CTs) or with reciprocating engines. The peaking units were critical in providing generation after Hurricane Maria and are also needed to support islandable grid formation and operation.
- Installation of a medium-sized combined cycle unit at Palo Seco.
- Installation of a medium-sized combined cycle unit at Yabucoa.
- Installation of up to 1,800 MW of utility-scale solar generation. For development of a single-point capital expenditure estimate, the Working Group used IRP ESM Scenario.

- Installation of 920 MW of battery storage. For development of a single-point capital expenditure estimate, the Working Group used the IRP ESM Scenario.
- Assume 960 MW installed customer-owned solar capacity by 2028, and 1,798 MW by 2038.

COA HIGHLIGHT

ENR COA-015: Enable Private Assets for Standby and Baseload Generation

The new generation units to be installed must meet the needs of a system with significant renewable and variable resources. This includes consideration for flexibility, ramp rates, and the ability to operate at low loads. Other key decisions will include determining the ownership of these new plants and assets.

Other key decisions will include determining the ownership of these new plants and assets. Options range from construction and ownership by PREPA to build, own, and operate by a third party, with an option for PREPA to assume ownership of the plants at a later date. The plan enables third-party (private) assets to serve as standby and baseload generation, which is aligned with ENR COA-015.

New Utility-Scale Renewables and Storage Systems

Puerto Rico had a previous RPS target of 20% renewable energy by 2035[30]. The Puerto Rico Energy Public Policy, Act 17-2019 establishes a new timeline for the implementation of renewable energy on the island: 40% by 2025; 60% by 2040; and 100% by 2050. Since the original RPS was passed, renewable energy costs have declined considerably and in Puerto Rico are priced competitively with fossil-fired generation. Accordingly, the Working Group's vision is to integrate significant cost-effective renewable energy while maintaining a reliable grid. To support the integration of renewables and the islandable grids previously discussed, the Working Group also envisions installing utility-scale battery energy storage systems throughout the island.

PREPA's current IRP Action Plan assumes solar energy will be installed because:

- Solar energy is price competitive with fossil-fired generation.
- Several of the existing wind turbines on the island were damaged during the 2017 hurricanes and further study of current technologies ability to withstand hurricane-force winds is required before planning new wind farms.
- Detailed biomass resource and supply chain studies have not been done at a level to support developing a biomass-fired plant.

[30] Act 82 Act 82 of July 19, 2010, as amended, defines specific requirements to promote energy diversification by creating an RPS (Renewable Portfolio Standard). This rule requires load serving entities to supply increasing shares of retail sales with qualified renewable and alternative sources starting at 12 percent in 2015 increasing to 15 percent in 2027 and 20 percent in 2035. PREPA has not met RPS targets to date.

As a result, the Working Group recommends focusing on solar energy development while also conducting the following studies:

- Study the feasibility of onshore and offshore wind turbines to withstand wind speeds that may be experienced in Puerto Rico.
- Conduct a biomass resource potential assessment and then create a roadmap to build an industry and workforce to support a biomass-fired powerplant.
- Scan wave and ocean thermal technologies to assess their technology readiness level.

Cost Estimates

In developing the GridMod generation roadmap and cost estimates, the Working Group coordinated with PREPA and Siemens to align the GridMod generation plan with PREPA's IRP Action Plan. Since the IRP is still under review by PREB, the GridMod Plan implementation will be adjusted to reflect the final IRP approved by PREB.

The GridMod Plan indicates a strong transformation of the Puerto Rico energy mix away from mostly oil-fueled generation toward increased renewable energy sources. For fossil generation, the plan envisions substantially higher use of LNG as a fuel source, with one to three ship-based LNG terminals and a potential land-based LNG terminal in the San Juan area. The adoption of LNG and new thermal resources is seen as part of the transition to a 100% RPS, as those units will be approaching the end of their operating lives by 2050. This will help to ensure reliability and resilience as greater amounts of renewable technology are installed during intermediate years. The Working Group agrees with those actions as necessary to improve reliability, resiliency, and economics of existing generation on the island.

The Working Group also agrees with the approach of building flexibility into the plan's implementation steps, so that greater amounts of solar and storage can be procured if costs are reasonable and if development and interconnection proceed as intended. For purposes of developing a single-point capital expenditure forecast, the Working Group used the ESM Scenario from the IRP, which represents a reasonable estimate of the amounts of those resources that will be procured pursuant to the proposed IRP Action Plan. However, the overall GridMod Plan includes adequate transmission system upgrades to accommodate a more robust solar expansion if feasible.

With the passage of the Puerto Rico Energy Public Policy, Act 17-2019, the Working Group anticipates that the final IRP approved by PREB may include a greater portion of renewable resources and potentially a lesser amount of new thermal resources than reflected in the current GridMod Plan. Upon PREB approval of the final IRP, the GridMod Plan implementation will be adjusted accordingly. It is anticipated that much of PREPA's current generation fleet will be replaced by new renewable, storage, and thermal resources, with the new thermal resources serving as a bridge toward 100% renewable energy requirements. The Working Group notes that the trajectory of implementation for solar and storage capacity and corresponding cost projections proposed in the current version of the IRP may prove challenging. However, the Working Group used the current IRP values in this report.

Table 4-16. Generation Major Investments Areas

Major Investment Areas	*Cost ($M)*
Peaker Replacement	$ 509
Generation Reliability	$ 140
Battery Energy Storage	$ 2,722

Source: GridMod Plan Funding Analysis

4.4 Fuel Infrastructure

Current State

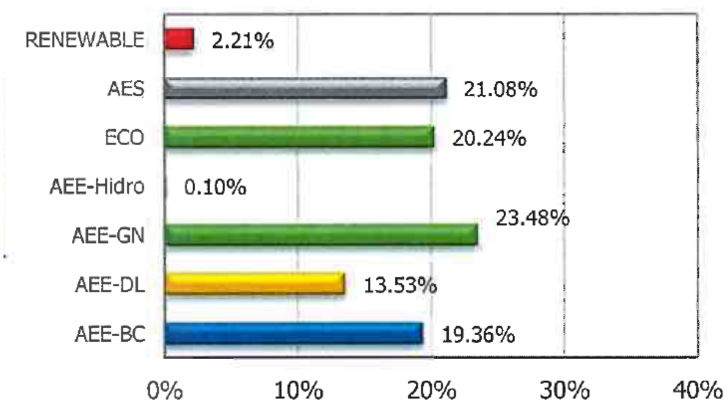
Currently, fuel supply for power generation in Puerto Rico is provided through a combination of natural gas, coal, and petroleum products (fuel oil and diesel) as displayed in Table 4-17 and Figure 4-10.

Table 4-17. Fuel Supply for Power Generation

Fuel Type	*Nameplate Capacity (MW)*	*Percentage (%)*
No 6. Fuel Oil	1532	30.2
Diesel	1664	32.8
Natural Gas	1327	26.1
Coal	454	9.0
Hydro	99	2.0

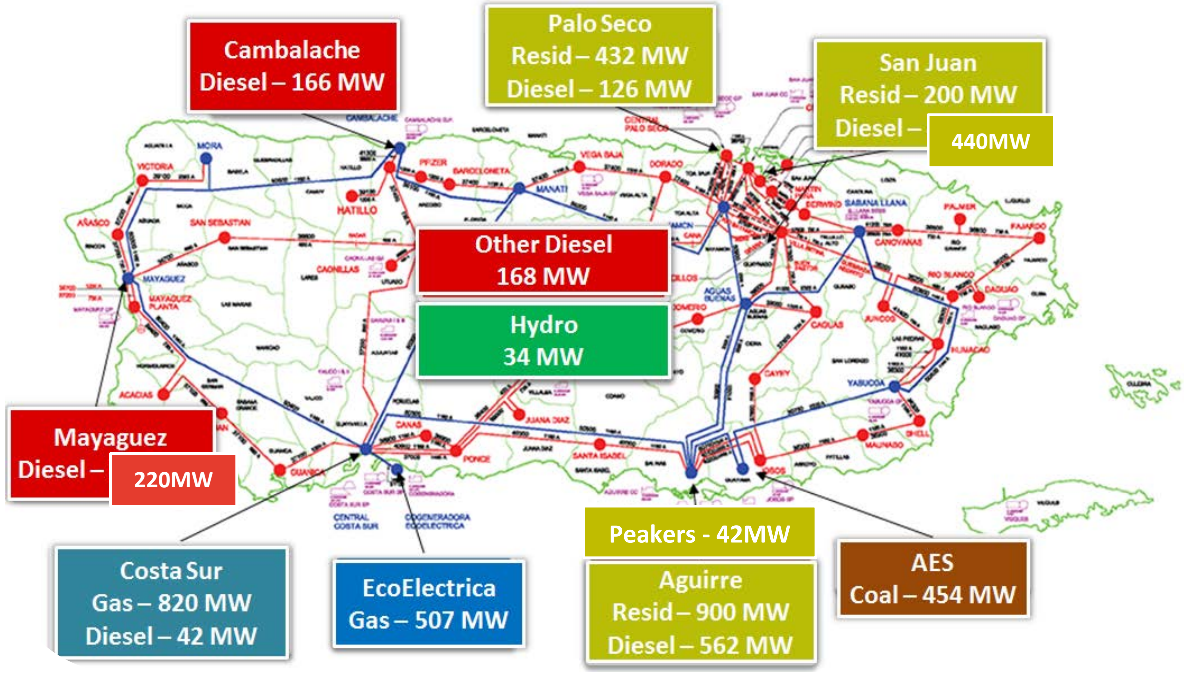
Source: Puerto Rico Power Authority

Figure 4-10. Total Production per Fuel Type Accumulated



Source: PREPA Flash Report as of December 2018

Figure 4-11. Puerto Rico Power Generation Fuel Supply



Source: Siemens (corrected by PREPA)

Natural Gas

Natural gas is used at the privately owned EcoEléctrica cogeneration facility and at the Costa Sur steam plant, which are both located at Guayanilla Bay. Natural gas is imported as LNG into the Peñuelas terminal and regasification facility on the southwestern coast. The EcoEléctrica plant is adjacent to the regasification facility and the Costa Sur plant receives gas via a short pipeline. The LNG terminal has one 160,000 m^3 storage tank and space to add a second of the same size.

Coal

The privately-owned AES facility burns Colombian bituminous coal. The coal is delivered to Puerto Rico at the Las Mareas Port, just south of the plant site, and is transported to the plant via covered conveyors.

Residual Fuel Oil

Three steam-electric power plants run on residual fuel oil: Palo Seco and San Juan in the north, and Aguirre on the south coast. Residual fuel oil is delivered to Puerto Rico by ship and is stored centrally at the former Commonwealth Oil Refinery complex on the southwest side of the island. From there it is delivered by barge to these three plants. There is also a pipeline connection to Costa Sur; however, most of the Costa Sur plant operates on natural gas delivered from the Peñuelas LNG terminal. Each of the three steam-electric plants has onsite storage for residual fuel oil. Palo Seco has capacity to store 450,000 barrels, San Juan 138,000 barrels, and Aguirre 780,000 barrels. Costa Sur has 800,000 barrels of storage that could be converted for other use.

Diesel

Diesel is used at the combined-cycle units at Aguirre and San Juan and at the combustion turbine units at Cambalache, Mayagüez, and nine other small facilities around the island. Diesel fuel is delivered to storage facilities at Yabucoa and Bayamón and from there is barged to the four larger stations (Aguirre, San Juan, Cambalache, and Mayagüez). The nine other small facilities around the island operate infrequently and receive fuel deliveries by truck when required.

Future State

This section discusses the transition to a fuel infrastructure that is more reliant on solar and natural gas. The list below provides an overview of the preliminary results from PREPA's IRP.

The IRP Action Plan proposes substantial solar and battery energy storage systems over the 2019 to 2028 period. In addition, gas use is to be expanded beyond the EcoEléctrica and Costa Sur power plants.[31]

- San Juan units 5 and 6 (440 MW) are to be converted to natural gas. To support this, PREPA negotiated with New Fortress Energy to construct and operate a medium-scale LNG import facility and undertake the conversion of the generation facilities. This contract is understood to be for a 5-year term.
- The Mayagüez power plant (220 MW) will be converted to gas by 2022. An LNG/gas supply facility will be required to facilitate this.
- A new CCGT will be constructed at Palo Seco (302 MW) close to the San Juan and Palo Seco facilities. LNG/gas supply facilities will be required to facilitate this.
- A new CCGT will be constructed at Yabucoa (302 MW) on the southeastern side of the island. LNG/gas supply facilities will be required to facilitate this.
- Seven distributed peaking plants (probably utilizing reciprocating internal combustion engines) will be installed. A number of these will be dual-fuel capable and will require natural gas supply infrastructure.

Further, the previously proposed floating LNG import terminal at the Aguirre power plant has been cancelled. The AES-PR coal-fired power plant is expected to be retired by 2027 when the current PPOA expires.

Implementation Roadmap

The most significant implication of the IRP Action Plan, regarding fuel infrastructure, is the need for additional LNG (gas) import, storage, and delivery infrastructure. Currently, LNG is imported only at Costa Sur, which supplies the EcoEléctrica power plant and the Costa Sur plant and is not connected to other power plants on the island.

[31] The draft IRP states 620 MW of battery energy storage systems through 2028 and 800 MW of batteries by 2038.

Given the scale and distributed location of the proposed gas-fired power investments, the required LNG infrastructure will need a detailed development plan and implementation strategy. The proposed gas-fired power plants and distributed peaking units are strategically located throughout Puerto Rico to ensure grid resiliency and to support islandable grid formation and operation. However, doing so complicates the cost-effective and efficient delivery of LNG.

Options could include the separate development of gas import facilities specific to each of the four locations where gas will be utilized. However, as the LNG import infrastructure costs will be a significant portion of the delivered gas cost, an individual power plant focused gas infrastructure approach may not be the optimum solution for the island of Puerto Rico.

A study to assess the most appropriate LNG (gas) import strategy for San Juan and the nearby Palo Seco power plant was conducted in 2015. This study looked at commercial, engineering (including environmental), and regulatory issues to make a recommendation as to the best overall approach for these facilities. Given the recommendations from the IRP, a similar comprehensive analysis should be undertaken for the island of Puerto Rico.

The Working Group recommends considering options for the import of LNG (natural gas) that could include (but would not be limited to) the following:

- Single onshore facility with pipeline gas distribution:
    - Import of LNG to an expanded terminal at Costa Sur with a second LNG storage tank, if required.
    - Gas would be distributed by pipeline to San Juan/Palo Seco/Bayamón, Mayagüez, and Yabucoa.
    - A truck loading/ISO container facility at Costa Sur would enable delivery of LNG to the distributed peaker plant.
    - History of strong local opposition to an earlier approved but cancelled cross-island gas pipeline suggests this approach may not be feasible.
- Single onshore facility with LNG barge distribution:
    - Import of LNG to an expanded terminal at Costa Sur with a second LNG storage tank.
    - LNG would be distributed by LNG barge or LNG ship to small-scale, land-based storage and regasification facilities located adjacent to new power plants in San Juan/Palo Seco/Bayamón, Mayagüez, and Yabucoa.
    - A truck loading/ISO container facility at Costa Sur and a north coast power plant location would enable delivery of LNG to the distributed peaker plants.
    - Small LNG storage and regasification facilities would be developed to optimize storage and ship delivery schedule to minimize cost.
    - Mobile regasification units and bullet storage units would be located at each of the distributed peaker plants.

- Two LNG hubs with distribution by either pipeline or LNG barge/LNG ship:
    - Import of LNG to the onshore terminal at Costa Sur with LNG barge/ship or pipeline distribution to Mayagüez.
    - Import of LNG to a new mid-scale nearshore LNG import terminal at San Juan/Palo Seco/Bayamón with LNG barge or pipeline distribution to Yabucoa.
    - A truck loading/ISO container facility at Costa Sur (or San Juan) would enable delivery of LNG to the distributed peaker plants.

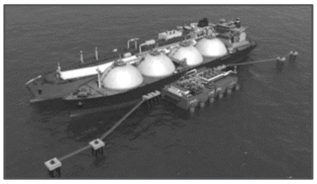
Other options could be developed from different portfolios of the following concepts. The optimum portfolio for Puerto Rico will be based on the appropriate balance of costs (capital and operating), size of the facilities required at each location, environmental and regulatory concerns, etc.

Onshore Terminal: LNG storage tanks, such as those as Costa Sur, combined with a marine jetty and regasification facilities.

Pipeline: Gas pumped at high pressure from an LNG import terminal to one or more gas-fired power stations.

Offshore Terminal: A reinforced concrete structure (Gravity Based Structure, or GBS) which hosts two LNG tanks, a regasification plant, and mooring and LNG unloading facilities. A gas pipeline would deliver gas to shore for onward transportation.

FSRU: An LNG carrier fitted with regasification equipment. Several configurations are possible with the FSRU moored to a jetty or to a buoy at a nearshore location. Depending on the configuration, visiting LNG carriers berth ship to ship or to the jetty.



LNG Barge: A modified LNG carrier is used for LNG storage. Regasification can be undertaken on a floating barge or can be skid mounted and deployed on the jetty or onshore. Like the FSRU concept, multiple configurations are possible.

Mid-Scale: A small LNG carrier, with Moss or Type-C tanks, delivers LNG to a small jetty. LNG is stored onshore in Type-C tanks. A small regasification plant is installed onshore. These projects are often modular in design and so can be scaled over time.

ISO Containers: LNG is loaded and stored on purpose built 20-foot or 40-foot containers. Delivery can be by truck or vessel.

The choice of concept for each location and the makeup of the overall LNG/gas infrastructure portfolio need to consider the impact of the LNG import price. It is likely that importing small LNG cargos (i.e., less than 140,000 m^3) will command a price premium and that the long-term impact of this may be significant. Information on major investment categories can be found in Table 4-18. Detailed costs for major investments in generation and fuel infrastructure can be found in Appendix C.

Table 4-18. Fuel Infrastructure Major Investments Areas

Major Investment Areas	*Cost ($M)*
Fuel Infrastructure	$ 497

Source: GridMod Plan Funding Analysis

4.5 Distributed Energy Resources

DER and microgrids can help reduce energy costs for customers and increase resiliency during grid outages. This section describes the Working Group's plan to enable these technologies.

Current State

Puerto Rico's current DER and microgrid experience includes:

- Very little microgrid penetration and no coordinated effort to develop more
- One grid in which issues in one region can impact the whole island
- Very few energy efficiency programs
- No DR programs
- Unmanaged installations of behind-the-meter solar PV

If more microgrids or coordinated DER had been installed prior to Maria, they could have been used to provide emergency power to critical facilities and accelerate recovery times.

Future State

The Working Group envisions a future where all critical facilities have microgrids that provide backup power. DER is an integral part of PREPA's planning and operations, and the grid can island into sections to prevent emergencies from cascading. This vision includes:

- A prioritized list of microgrid sites to develop and a coordinated effort to develop them.
- A grid made up of islandable grids that can operate independently if the interconnected grid is compromised.
- A full suite of energy efficiency programs that save 2%+ per year.
- A full suite of DR programs.
- A managed, coordinated DER program—that includes solar PV, combined heat and power (CHP), energy storage, backup generators, and EVs—adds value to the grid and brings down costs.

Implementation Roadmap

Microgrids

The Working Group envisions a future where critical loads could operate in isolation and provide much-needed services to Puerto Ricans immediately after a natural disaster. Examples of critical loads include hospitals, police and fire stations, emergency shelters, critical communications infrastructure (i.e., cellphone towers), water treatment plants, airports, sea ports, telecommunication centers, commercial centers, and industrial centers. Proposed investments in Microgrids aligns with recommendations in the 2019 IRP, including islandable grids and each resource scenario and strategy.

After Hurricanes Irma and Maria, reports such as Build Back Better, analysis within the Governor's Recovery Plan, and DOE's resiliency study for Puerto Rico all made similar recommendations to study and develop microgrids at critical infrastructure locations. The Working Group envisions the microgrids are controlled by the DER management system (DERMS) discussed in the technology and system operations sections of this plan.

The Puerto Rico Energy Bureau provided new regulatory rules on microgrid development in May 2018. These regulations open the door for individual entities to sell electrical energy to other customers with Puerto Rico's grid, fundamentally shifting away from the regulated monopoly and allowing development of microgrids. The next step is to have PREPA provide interconnection rules for microgrids, providing a complete path for entities to interconnect as a microgrid.

Several studies have looked at where microgrids should be developed and the resulting costs:

- During the Build Back Better report analysis, members of the Working Group conducted a high-level assessment of critical facilities for public safety and resiliency and recommended the development of 159 microgrids at an estimated cost of approximately $1 billion.

- Sandia National Laboratory (Sandia) conducted a detailed analysis[32] and identified 159 critical public safety and resiliency areas for microgrid development at a cost ranging from $1,165 million to $2,027 million (depending on level of load covered). The Working Group reviewed this analysis and believes it is an accurate starting point for further development activities.
- PREPA is currently conducting a feeder level analysis to identify feeders serving critical loads and determine how much the load is. PREPA has identified 104 priority feeders and 459 critical feeders that serve critical infrastructure and commercial and industrial customers.

The key next step is to develop a final list of candidate sites for microgrids, consistent with recommendations outlined in the IRP for islandable grids, discussed in further detail below. The Working Group recommends that Sandia and PREPA work together to compare their respective analyses and decide on a final list of sites to develop. Next, the Working Group recommends assessing the best approach—taking into account current policies and regulations—to develop the sites. After deciding on an approach, the Working Group recommends ramping up development over a 5-year period, starting with the most critical sites first. The budget in Table 4-19 uses Sandia's cost estimates ($1.16 billion) and assumes the microgrids are built only to serve each project's critical loads.

Islandable Grid

COR3 and PREPA are pursuing a transformation to a more decentralized power grid, utilizing distributed renewables, storage, and thermal generation resources. Accordingly, the Working Group recommends the development of both islandable grids and microgrids to improve local area reliability and allow grid operators to isolate damaged circuits and regions in the event of future hurricanes.
This transformation aligns with COA-002 in the Governor's Recovery Plan and is critically important to prevent widespread grid failure during catastrophic events, and to ensure that critical facilities such as hospitals continue to receive electric service following a hurricane. This transformation is also necessary to allow grid operators to isolate and react to normal reliability events, to reduce customer outages, and to achieve electric system reliability during normal system conditions at levels comparable to those achieved on the US mainland. Figure 4-12 shows the proposed boundaries for each islandable grid.

Figure 4-12. Recommended Islandable Grid Boundary Recommendations

Source: Siemens

[32] Analysis of Microgrid Locations Benefitting Community Resiliency for Puerto Rico, Sandia National Laboratory SAND2018-11145, September 30, 2018.

To the knowledge of the Working Group, a grid architecture like this has never been deployed. As a result, the Working Group expects the details and costs to evolve as design of the islandable grid continues.

Implementing this will require the following:

- **Design and Engineering Studies and Implementation Oversight:** Implementing this will require a team dedicated to design, engineering, and implementation. The implementation will include pilot testing, evaluation, and coordination. Since this has never been done before, the budget for these teams is a high-level estimate of $50 million that will need to be refined.
- **Generation:** The generation for each section will come from existing and future renewables, fossil-fired generation, and energy storage. The costs for these plants are accounted for and discussed further in Sections 4.3 and 4.4.
- **Transmission**: The cost to upgrade the transmission system—include new switching equipment and controls—to be able to implement the islandable grids is accounted for in Section 5.
- **Systems**: Since no system like this has been deployed, the exact control and communications systems to manage it will be complex and have to be developed as part of the implementation. The Working Group's estimates are contained in Section 5.1.

The Working Group recommends gradually deploying the grid since this type of grid architecture is the first of its kind. After a final set of designs are agreed upon, the Working Group recommends rolling out the islandable grid sections in stages. After the first section has been operating for at least 1 year, the remaining sections can be implemented.

Distributed Energy Resources

DER—such as solar PV, energy efficiency (EE), and demand response (DR)—can help customers save on their energy bills and reduce fossil fuel imports while supporting workforce development for their design and installation. PREPA already has 173 MW of behind-the-meter solar PV installed on its systems but has not recently had EE or DR programs. In addition, the Working Group anticipates customers will be adopting energy storage, EVs, and combined heat and power (CHP) in the future to bring down their energy spend and help with resiliency.

COA HIGHLIGHT

ENR COA-022

Enable and Promote Distributed Generation

In alignment with COA-022 in the Governor's Recovery Plan, the Working Group envisions a future where DER is an important part of the energy mix but does not cause grid issues. Rather, DER is installed in a way that helps the electric grid, causes minimal upgrades costs, and provides situational awareness and control via the DERMS system.

The Working Group recommends starting with the following items:

- Develop and launch EE programs
- Develop and launch DR programs
- Conduct a distributed solar integration study, including feeder hosting capacity studies, and develop a program to incent DER installations that benefit the grid.

The Working Group calls this a guided DER program.

Figure 4-13. Solar Farm

Source: Inside Climate News

EE Plan and Recommendations

The Working Group strongly recommends developing a robust portfolio of energy efficiency programs that caters to all types of customers. The goals should include:

- Raise awareness among energy consumers of energy use and the associated economic and environmental consequences
- Promote, design, and deliver programs and carry out other activities related to energy efficiency and energy conservation
- Promote the development of an energy efficiency services industry

What is important in these objectives is that they are in cohesion and can result in a successful rollout of energy efficiency. Increasing consumer awareness and building the capacity locally to deliver EE within a portfolio of well-designed and implemented programs can fully optimize the energy grid's reliance to demand-side resources. Therefore, the Working Group believes that the EE programs should consider the awareness and capacity building of an EE services industry equally as strong as having energy efficient buildings.

As part of its IRP[33] analysis, Siemens commissioned Newport Partners to develop some initial EE program ideas and costs. Newport Partners recommends launching residential and commercial AC and lighting programs. The Working Group agrees with these recommendations and recommends studying more programs after these have successfully launched such as retrocommissioning, building code enforcement, insulation, and sealing. The ramp-up and budget shown in Section 4.3 are taken directly from Newport Partner's analysis.

The Working Group recommends the following next steps to launch the EE programs:

- Develop a program charter that includes goals, governance, detailed annual budgets, and evaluation, measurement, and verification.
- Assign a team to lead the work.
- Create detailed program plans for each measure that include market awareness and industry building activities.
- Conduct solicitations for third parties to run each program.

DR Plan and Recommendations

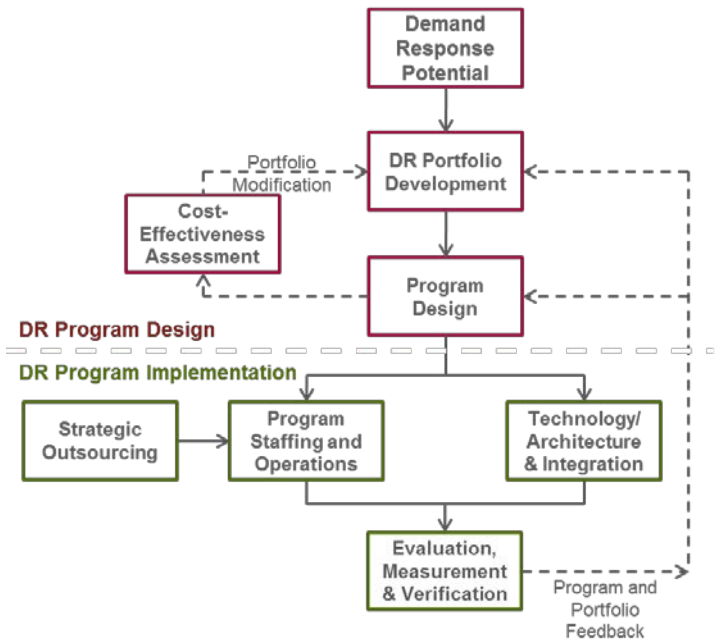
Similar to the EE plan, Newport Partners developed DR plans for the IRP. These include residential AC—specifically targeted at window AC and mini-split units, which are the most prevalent types of AC in Puerto Rico—and commercial lighting and AC programs. The Working Group reviewed the analysis in detail. While some of the key assumptions need to be vetted, the Working Group agrees with the initial approach and budgeting. In parallel with launching the DR programs, the Working Group recommends studying other types of DR programs including dispatchable backup generators, water heater controls, peak time rebates, critical peak pricing rates, and time-of-use rates. Figure 4-17 shows the Working Group's recommended next steps in developing and implementing a DR program. This can be started by hiring a small team to lead this effort and undertaking similar steps to those discussed for EE. The budget in Table 4-19 was taken from the IRP analysis. The Working Group recommends using this as a starting point but assumes it will evolve as programs are designed.

Guided DER Plan and Recommendations

PREPA already has 173 MW of behind-the-meter solar PV on its system and anticipates another 850 MW will be installed in the next 20 years, along with 71 MW of CHP. In addition, the Working Group anticipates customers will adopt energy storage in large numbers for resiliency purposes and begin to adopt EVs because of the economic benefits and reduced fuel imports. The consequences are large if this DER is unmanaged.

[33] *Forthcoming* IRP Analysis by Siemens AG.

Figure 4-14. Recommended DR Program Development Process



The integration costs to accommodate two-way flows of intermittent generation and changing voltage conditions could be huge if: (1) DER is installed in areas of the grid that cannot accommodate it, (2) DER is operated in a way that does not benefit the grid, and (3) PREPA does not have visibility or control over its output. The Working Group recommends PREPA launch a program to help to reduce this risk and guide the installation and operation of DER to benefit the grid. This concept is relatively new, so we expect the details to evolve as it is studied further. The first step is to conduct a feeder level DER integration study that includes hosting capacity studies. This will provide insight on where DER can provide benefits and where upgrade costs will be incurred for interconnection.

The next step is to design and test a program to incent customers to:

- Install DER: First solar PV but eventually energy storage, EVs, and backup generators—on feeders where it can provide benefits.
- Agree to utility control of their DER for the following:
  - **Solar PV:** Agree to limited curtailment during times of over production in which too much solar is being generated such that there is not enough load or available storage capacity.
  - **Energy storage and EVs:** Allow limited (less than 10 events per year) utility control for dispatch during peak events. This technology is not yet commercial for EVs, but the Working Group anticipates it will be in the next 10 years as costs fall and customer awareness increases.
  - **Backup generators:** Allow for utility dispatch during emergency events.
- Operate DER in a way that benefits the grid. For example, incenting customers to charge EVs when demand is low or discharge energy storage when demand is high.

After PREPA designs a program, the Working Group recommends testing it with customers and DER project developers. Based upon their feedback, PREPA should revise the program and launch a pilot. The budget estimates in Table 4-19 assume a gradual rollout with an incentive of $0.25/W provided. The Working Group expects this amount to change before launch as market data is collected.

Cost Estimates

While fully implementing this vision will take over 5 years, the Working Group recommends the following actions take place immediately to ensure the projects begin in 2019:

- Conduct feeder hosting capacity studies
- Assign responsibility to a team to develop both the EE and DR program scope, governance, and implementation plans
- Form a team to decide on a priority list of microgrid sites to develop

Table 4-19. DERs and Microgrids Major Investment Areas ($M)

Major Investment Areas	*Cost ($M)*
Microgrids	*$ 1,159*
Islandable Grid Design	*$ 50*
EE Programs	*$ 196*
DR Programs	*$ 200*
Guided DER Programs	*$ 150*

Source: GridMod Plan Funding Analysis

Table 2 and Table 3 in the Executive Summary contain the Working Group's current budget. Some of the 2019 expenditures may shift into later years depending on when the activities begin. The estimates are based upon each budget item's contribution to resiliency or transformation. Most of these items except for energy efficiency will improve resiliency or help transform Puerto Rico's grid.

ENERGY SYSTEM TECHNOLOGY TRANSFORMATION

GOVERNMENT OF PUERTO RICO

COR3
CENTRAL OFFICE OF RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

5. ENERGY SYSTEM TECHNOLOGY TRANSFORMATION

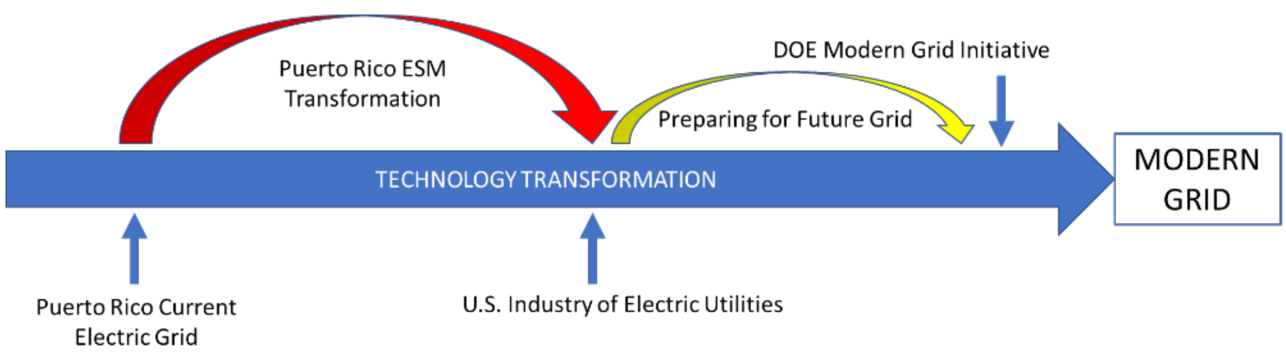
5.1 Technology

The objective of this section is to examine the current state of electrical grid technology in Puerto Rico and identify the Working Group's technology recommendations and funding estimates to address:

- Rebuilding the Puerto Rico electric grid to industry standards.
- Applying best practices to mitigate future restoration efforts while also considering the specific characteristics of Puerto Rico.

As represented in Figure 5-1, this section not only focuses on transforming the current state of technology to meet US industry standards, but also to prepare it for the grid modernization initiatives described throughout this document.

Figure 5-1. Transforming Puerto Rico Energy System



Overview

The reports, Build Back Better and Puerto Rico Energy Resilience Solutions for the PR Grid, highlight the importance of rebuilding to current codes and industry standards, hardening for greater storm resiliency, and designing for the future. Technology is a significant enabler to achieve these goals. Today, technology is the primary means by which electric utilities advance reliability, resiliency, sustainability, customer-centricity, and affordability. This is demonstrated through several major DOE efforts such as the Smart Grid Initiative Grant (SGIG) program and the Grid Modernization Initiative (GMI).

The DOE GMI continues to work from the SGIG, which established that grid technologies are helping utilities improve reliability and resiliency through mitigating outages and improving outage restoration capabilities. These utilities are also improving the overall service reliability and efficiency of their systems and driving costs down through better system planning and technology implementation.

The DOE GMI defines the "Modern Grid" as a transforming paradigm with the following attributes:

- Greater resilience to hazards
- Improved reliability for everyday operations
- Enhanced security to identify and respond to an increasing and evolving number of threats
- Additional affordability to maintain economic prosperity
- Superior flexibility to respond to the variability and uncertainty of conditions at one or more timescales, including a range of energy futures
- Increased sustainability through additional clean energy and energy efficient resources

Utilities continue to deploy embedded systems and strive to transform their organizations by implementing integrated hardware, software, and communications throughout all the industry areas, which include: transmission, distribution, generation, metering, system planning, outage management, and customer facing systems. Many technologies overlap between these industry areas and systems frequently share data and decisions based on data from one device. For Puerto Rico, the application of technology is key for aligning with industry standards and mitigating future hazards.

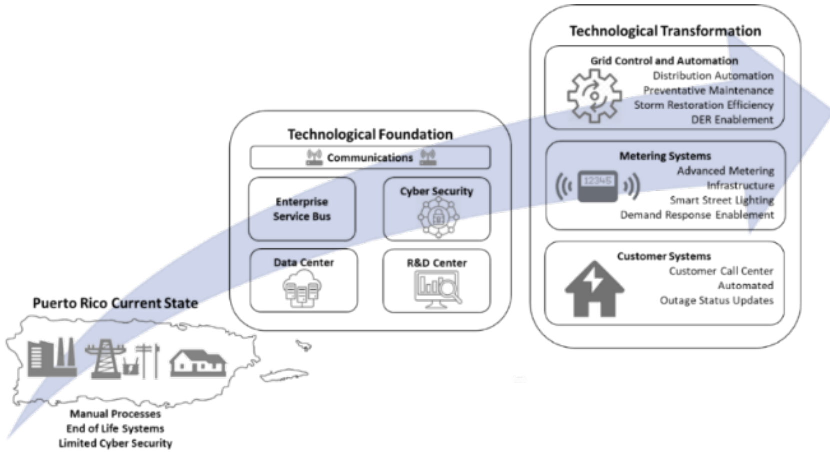
Transforming technology within the electric grid industry standards and aligns with mitigating future restoration efforts.

The three technology categories discussed in this section include:

1. Grid Control and Automation
2. Metering Systems
3. Customer Systems

These categories include the systems that utilities leverage to improve resiliency, reliability, sustainability, affordability, and customer-centricity. The current and future state of these technology categories in Puerto Rico are discussed in more detail in the sections that follow.

Figure 5-2. Puerto Rico Technology Transformation



Current State

As represented in Figure 5-1 and Figure 5-2, PREPA's state of technology is significantly behind US industry standards. Substandard technology coupled with the collapse of the communication infrastructure after Hurricane Maria caused cascading failures and significantly impacted restoration efforts. The current state of the three technology categories outlined above (i.e., Grid Control and Automation, Metering Systems, and Customer Systems) is discussed in the following sections.

Grid Control and Automation

Grid Control and Automation consists of the technology systems identified in Table 5-1. Each of the systems in the table are utilized today within the electric utility industry to manage operations, maintain reliability, and provide advanced analytics and real-time information. In Puerto Rico, some of the systems identified below are partially implemented at some level (indicated in bold) via older technology and others are simply not implemented at all (indicated in italics).

Table 5-1. Grid Control and Automation Systems

Grid Control and Automation		
Advanced Distribution Management Systems (ADMS)	*Distribution Communications*	**SCADA Communications**
Energy Management System (EMS) for eight islandable systems	**Asset Management System (AMS)**	*Enterprise System Bus (ESB)*
Geographic Information System (GIS)	*Work Management System (WMS)*	**Data Historian**
Distributed Energy Resource Management System (DERMS)	*Demand Response Management System (DRMS)*	*Damage Assessment & Emergency Response Tools*
Emerging Technologies Testing and R&D Center	*Data Analytics*	**Data Center**

It is important to note that the impact from the storms caused a significant communication system failure, which directly limited restoration capability. Specifically, the communication failure had cascading effects on most of PREPA's existing systems.

These system failures, as well as the overall status of the systems (e.g., out of date, partial system deployment, lack of integration) after Hurricane Maria caused significant challenges during the restoration, including:

- Difficulty conducting damage assessments
- Challenges identifying and prioritizing outages and asset repair
- Limited ability to organize and dispatch crews based on prioritized work schedules
- Limited information (e.g., estimated restoration times, outages) for PREPA Customer Service Representatives to provide to customers

Metering Systems

PREPA currently has 1.5 million customers. It reads and bills 1.3 million meters every month using automated meter reading (AMR). The remaining 200,000 meters were damaged after Hurricanes Irma and Maria. The damaged meters can no longer be read, and the corresponding customers cannot be billed, resulting in estimated lost revenues of $250 million per year.

Other challenges with the current state of PREPA's metering system include:

- A limited ability to implement flexible modern tariffs based upon time-of-use energy and demand rates.
- There are no meter readers in the field that have historically been able to visually identify theft and other safety issues.
- The utility and the customer must be reactive (after the outage has occurred and the customer has called into the utility) relative to outage management.
- Safety is a concern for collections as a field visit.
- Customers must wait until their monthly billing date and have no granular usage interval information to manage their own energy consumption.

Figure 5-3. Example of Damaged Meters and Electricity Theft

Damaged Meter

Stolen Meter

Source: PREPA Fiscal Plan 2017

Smart Street Lighting

There are currently no smart street lights serviced by PREPA. However, there are an estimated 500,000 street lights in Puerto Rico and about 100,000 were damaged during Hurricane Maria and require replacement.

Customer Systems

PREPA currently has a hybrid portfolio of customer systems consisting of 22 disparate applications supporting 3 core business systems: Customer Information Systems (CIS), Billing, and Customer Call Centers. This portfolio consists of legacy systems (supported and unsupported), manual process and internally custom developed systems. The interfacing between many of these systems is non-real-time and batch preventing timely information to the customer. Additionally, Customer Systems portfolio supports business functions related to the following Table 5-2.

Table 5-2. Customer Systems Portfolio Supported Business Functions

Customer Systems Functions			
Operations	Work Initiation	Customer Calls	Solution Design
Outage Planning	Service Orders	Reconciliation	

Source: COR3 Working Group

Customer Information System (CIS) and Billing

PREPA's CIS is currently not supported by the software vendor and poses potential risks that need to be addressed. Two major risks are functionality and security. CIS supports billing, and if the CIS fails, customers cannot be billed which could contribute to revenue loss. Additionally, if the system cannot perform the required business functions, the call centers for the company cannot run effectively, and meter reading, cash processing, and credit & collections are rendered inoperable.

Call Center

Currently PREPA has approximately 30 walk-in centers. These centers are outdated and consist of various custom applications. The demographics on the island are changing and the need for call centers will diminish with the advent of Self-Service Technologies.

Future State

Restoration efforts continue for the communication system today. Any future state of the Puerto Rico grid as well as technology within the grid is fundamentally dependent upon a robust communication system enabling technology as noted in the *After-Action Report Workshop with PREPA, July 2018* and the *DOE, Office of Electric Report: Current/Proposed Communications Plan for Puerto Rico, Aug 2018*.

As represented in Figure 5-1, the goal of the technology section is to drive recommendations for PREPA that provide a future state aligned with US industry standards. The future state of the three technology categories (Grid Control and Automation, Metering Systems, and Customer Systems) are identified in the following sections.

Grid Control and Automation

For Puerto Rico, the future state of the electrical grid must rely on adoption of technology. The Grid Control and Automation section focuses on software and communication systems, facilities, and tools used in support of monitoring and control of the grid. The systems identified represent best practices and are used within industry to support improving grid performance. As identified by DOE SGIG, attributes of the modern grid are enabled by smart grid technologies, tools, and techniques that can work effectively in utility applications and improve grid planning and operations. The remainder of this section identifies some examples of systems, the interaction of systems, and coupling of data and functionality between them.

Distribution Automation

DA covers a wide area of technology and methodologies applied to the distribution grid. Application of DA technologies has been a proven solution to improving utility reliability, resiliency, and restoration efficiency following major outages. One technology within DA is automation feeder switching (AFS). AFS and FLISR help automate and more effectively provide information to manage outages that occur along the distribution system, ultimately reducing outages for customers.

Automation improves the speed and accuracy of key distribution functions to deliver reliability improvements and cost savings to customers. DA is enabled by many systems, including advanced distribution managements system (ADMS). ADMS, which is the combination of DMS and outage management system (OMS), interfaces with energy management system (EMS), mobile work management system (MWMS), geographic information system (GIS), asset management system (AMS), and others. These systems rely on communication networks that provide data connectivity to remote devices for monitoring and control capability. In this section, communication networks are referred to as SCADA communications and distribution communications. SCADA communications generally refer to communication between substations and system operations, while distribution communications generally refer to communication between grid devices and the ADMS. Distribution communication is sometimes referred to as field area network.

DA technologies improve restoration times following extreme weather events, improve equipment monitoring, enable preventive maintenance, lower environmental emissions, and improve integration of DER. This section is coordinated with other technology discussions within other sections in this report (Section 5.2 – Security, Section 5.3 – System Operations, and Section 6.1 – Operational Efficiencies).

Communication Networks

Communication networks are foundational to all technology deployments within the utility. They enable flow of information and control, enabling grid operators to manage power flows and address reliability issues. Optimizing the control and performance of system operations, detailed in Section 5.3, is a key objective of utility systems. DA operation relies heavily on robust communication systems to analyze data and provide actionable information for grid operators.

The Working Group recommends the design and delivery of communication networks (SCADA and distribution) with backup infrastructure and establishing facilities such as a Data Center and Emerging Technologies R&D Center in Puerto Rico to fully support validation and verification of systems and enabling technologies. Implementing supporting infrastructure such as communication networks, Data Centers and Emerging Technologies R&D Centers aligns with ENR COA-003.

COA HIGHLIGHT

ENR COA-003: Design and Build a Supporting Infrastructure for the Electricity System, Including Communications

Systems Enabling FLISR and AFS

FLISR and AFS, when integrated with an ADMS, automate power restoration through automated fault finding and switching. AFS and FLISR work via smart switches that identify faults on the distribution system and perform switching actions instantaneously.

As shown by the SGIG Program case studies between 2013 and 2014 (Smart Grid Investment Grant Program Final Report Dec 2016), improved FLISR and AFS operations led to a significant reduction in the number of customers interrupted (CI) and CMI during outage events. Utilities that automated their FLISR operations saw a 55% reduction in CI and 53% reduction in CMI. The Working Group's recommendations for FLISR deployment are discussed in more detail in Section 4.2 - Distribution.

ADMS, which often incorporates DMS, OMS, and distribution communications, serves as a platform for controlling FLISR and AFS operations. The Working Group recommends that PREPA implement an ADMS to serve as the primary controller for FLISR and AFS operations.

Enabling More Efficient Restoration Efforts

Following major storms, technology systems in a modern grid work together to restore power to customers. Utilities often integrate SCADA, AMI with GIS, OMS, and MWMS to set up automated processes for locating and restoring customer outages. SCADA systems can also more efficiently manage restoration efforts by remotely placing and removing hot line tags on transformers and performing remote switching. In alignment with COA-019 in the Governor's Recovery Plan, the Working Group recommends that PREPA implement and integrate the aforementioned systems to best prepare themselves for an efficient and effective restoration process following major storms and outage events.

COA HIGHLIGHT

ENR COA-019: Design and Deploy Data Systems to Inform Response and Recovery Decisions

During the SGIG Program, utilities proved that utilizing and integrating these systems decrease outage times, reduce truck rolls and vehicle-miles traveled, and improve the line crew safety. For example, through an AMI deployment that was integrated to the OMS, PEPCO was able to restore power to customers 3 days sooner following both Hurricane Sandy in 2012 and another major storm in 2014. During the same storms, PEPCO's OMS integrated with AMR (non-AMI) meters proved to be ineffective, only successfully sending 1% of power failure alarms. Utilities also optimized restoration dispatch by integrating OMS with GIS and MWMS, allowing operators to pinpoint outages and improve the efficiency/safety of repair crews.

Enabling Monitoring and Preventative Maintenance

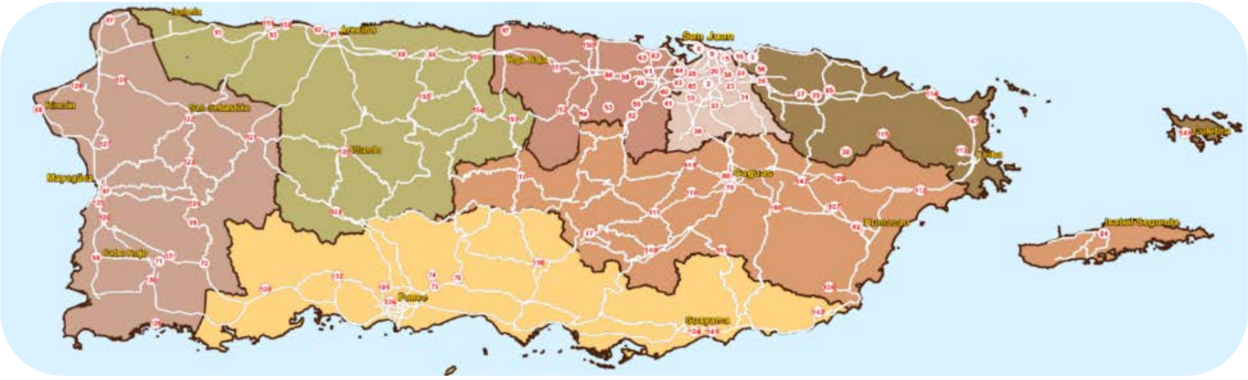
Improved equipment monitoring, and preventive maintenance requires data from sensors to identify, fix, or remove broken or faulty transformers before they fail and cause outages. Data from sensors is often collected by a Data Historian which provides time series historical data.

The Historian provides a platform for aggregated analytics and predictive maintenance to improve reliability. As an example, when using a GIS and AMS, or if operating an integrated GIS/AMS, utility planners overlay historical weather patterns on top of an asset map to predict which areas and assets are more prone to outages or shorter life cycles. Analyses like this greatly enhance a utility's grid resilience and better position the utility's response strategy and overall reliability. The Working Group recommends that PREPA implement and integrate the previously mentioned systems and strategies to improve asset management, and preventive monitoring and maintenance of the grid.

Enabling Management of Customer Load and Generation

Both demand response management systems (DRMS) and distributed energy resource management systems (DERMS) represent the key applications to manage the interaction between the utility and the customer for power generation and load adjustments. DERMS will enable the customer-owned microgrids via monitoring and interaction within the grid, providing opportunity for increased reliability and resiliency via system load and generation.

Figure 5-4. Microgrid Systems for Puerto Rico



Source: Puerto Rico Electric Power Authority

Today, utilities are beginning to use DERMS to monitor, dispatch, and integrate DER into grid operations. This type of interaction between the utility and customer resources is also key to improving resiliency for Puerto Rico. The increased use of DER will help reduce emissions, lower electricity bills for customers, and increase resilience by decreasing reliance on central power generation. The Working

Group recommends that PREPA implement and integrate DERMS and DRMS systems and strategies to improve reliability and resiliency.

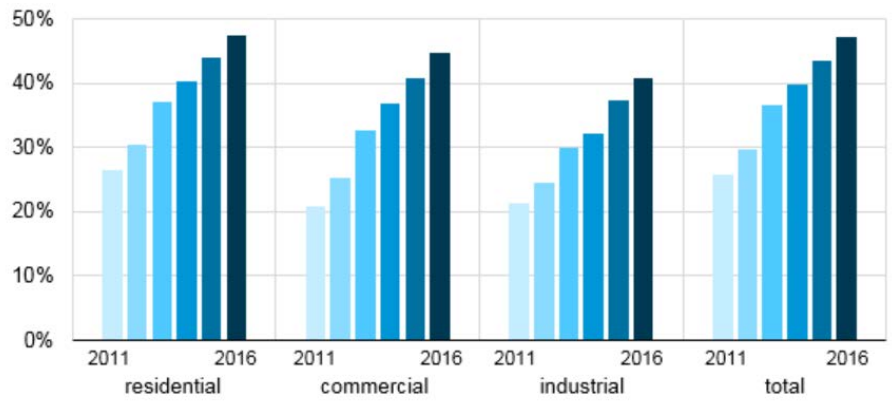
Metering Systems

For Puerto Rico to rebuild to industry standards and mitigate future restoration efforts of the electrical grid, AMI is a foundational technology essential for reliability and restoration. AMI consists of smart meters, a communications network, a head end system, and a meter data management system (MDMS). The meter data (usage, status, location) become key enablers of data for other systems within the utility back office systems providing advantages and efficiencies. The metering communications network can also support DA infrastructure and help reduce outage times if designed to accommodate bandwidth and latency requirements.

The meter today can indicate to the utility a loss of electricity (lights out) during an outage providing the utility a precise view of affected customers. This provides the utility the ability to diagnose and deploy needed resources for expedited restoration. Appropriately designed, the meter and the communication network can enable demand response (DR), interaction with DER, maintenance management, outage management, and customer service system integration. AMI is the industry standard in meter reading today, with well over 50% of US households having smart meters.

Electric meter capabilities and integration with customer systems require communication networks to be designed for different data types and latency and bandwidth requirements. These networks must be capable of delivering accurate, reliable, and voluminous streams of data in a timely manner. Current approaches to the metering and distribution communication networks include mesh architectures and LTE solutions that vary based upon geography and customer density.

Figure 5-5. Smart Electricity Meter Installation (2011-2016, % of Total Sector)



Source: Energy Information Administration

These communication networks connect the meters to headend systems, which manage data communications between smart meters and other information systems including MDMS, CIS, OMS, and DMS. The headend system transmits and receives data, sends operational commands to smart meters, and stores interval load data from the smart meters to support customer billing.

AMI provides a number of important functions including:

- Integrated service switch
- Time based rates
- Remote meter programing
- Power quality
- Home Area Network interface
- Customer Energy Dashboard/Portal to allow the utility and the customer to view their daily and hourly usage during the month

AMI also provides connectivity to smart grid devices and sensors that allow for:

- Proactive maintenance for outage avoidance/prevention
- Greater reliability and minimizing the effect/duration of an outage
- Expansion of use for any other Internet of Things (IoT)
- Enabling communications and integration of smart street lighting
- Proactive ticket generation and customer communications for outage management
- Enabling DERMS and DRMS
- Enablement of transactional energy allowing for the metrology to accommodate the net metering implications of DER

The above benefits provided by AMI display its alignment with ENR COA-011 to implement technologies that enable real-time information and grid control.

COA HIGHLIGHT

ENR COA-011

Design and Deploy Technologies to Improve Real-Time Information and Grid Control

The Working Group recommends that PREPA implement an AMI system including the deployment of meters, the supporting communication network, MDMS, and associated systems to improve outage restoration times, increase efficiencies, and provide the platform necessary to enable new tariffs and DER integration. The existing 18k PLC AMI pilot results should be evaluated for subsequent expansion and compared against a Radio Frequency (RF) Mesh communications solution for all 1.5M smart meters. In addition, when exploring final solutions, the synergy of tandem implementations of Electricity and Water combined should be explored to effectuate the sharing of new communications infrastructure.

Smart Street Lighting

PREPA has developed specifications for 65 W LED luminaires, 125 W LED luminaires, and LED photocontrols. These specifications can be used as a basis for a complete smart lighting project and the replacement of damaged lights as they include requirements for 7-pin control receptacles on luminaires that are compatible with smart lighting controls.

Smart street lighting generally consists of advanced technologies for the efficient operation, monitoring, and management of street lighting. It is made possible by a variety of technology innovations, communication networks, and control systems that are deployed with advanced metering.

Smart street lighting provides the following capabilities:

- Remote on-off control
- Dimming and scheduling
- Energy monitoring and billing
- Performance monitoring
- Color controls
- Emergency response
- GPS tracking of street lights

These capabilities result in energy savings, public safety benefits, faster and more efficient outage response times, decreased operations and maintenance (O&M) costs, increased reliability and improved asset management.

Smart street lights also provide a platform for additional smart city solutions that include: environmental monitoring, traffic monitoring, smart parking, gunshot detection, traffic lighting control, smart waste management, public messaging, and HD video surveillance. The Working Group recommends that PREPA implement a smart street light system concurrently with the AMI system to strengthen the communications canopy at optimal costs.

Customer Systems

The evolution of the smart grid, especially the dynamic rate and billing information enabled by AMI and smart meters, is transforming CIS applications. A sophisticated CIS is necessary for complex account management in which customers can also be energy providers, such as in the case of solar panel owners. The activation of automatic connect/disconnect capabilities is also made easier with a new generation of CISs directly connected to the AMI.

The changes required in CISs are not limited to smart meters. Rather, the CIS is at the heart of a much more complex customer management process than utilities have previously handled. While it interfaces with the usual finance and accounting functions that update customer accounts and generate bills, the CIS also interfaces with all the processes that customer information can affect. These include energy trading and DR for optimizing aggregated energy transfer and the regulatory and compliance requirements from which the billing process will retrieve elements.

The major difference between the current system architecture and the future is the real-time transfer of data. The data transport is controlled by the Enterprise Service Bus (ESB). The ESB is a new feature that will convert data and transfer protocols automatically. The ESB is also recommended for providing the communication between other grid systems. Fewer systems and the implementation of the ESB allows for real-time data transfer providing up to the minute information to the customer and utility employees. Information that took days to process is now available in seconds through the ESB.

Implementation Roadmap

In addition to the approaches provided previously, the Working Group has relied on similar installation cost and estimation tools from the industry in different locations throughout the mainland.

Cost Estimates

Detailed design and analysis need to be completed to optimize the architectures and systems. Table 5-3 includes the technology cost summary based upon recommendations from the Working Group.

Table 5-3. Technology Major Investment Areas ($M)

Major Investment Areas	***Cost ($M)***
Grid Control and Automation	*$820*
Metering Systems	*$900*
Customer Systems	*$115*

Source: GridMod Plan Funding Analysis

5.2 Security

Current State

In the continental US, bulk electric system (BES) industry experts and regulators are implementing the North American Electric Reliability Corporation (NERC) critical infrastructure protection (CIP) reliability standards to better protect and secure critical physical and cyber systems and assets. Over the last 11 years, in response to these CIP standards, the BES is improving and maturing its security posture. Puerto Rico, however, is not covered by these regulations and, as a result, is behind on current standards and controls and therefore is at risk.

While Puerto Rico does not fall under NERC compliance, the NERC CIP standards and recognized best practices are drawn from the National Institute of Standards and Technology (NIST), the Department of Homeland Security, DOE, and other organizations to provide a framework to improve physical and cybersecurity on the island. A best practice approach for PREPA is required, leveraging these industry approved security frameworks to harden and protect its facilities, assets, data, and resources. The focus on security becomes more critical for energy reliability, resiliency and safety as modern energy infrastructure and technologies are planned and deployed.

Future State

A strong physical security program must be developed and implemented at PREPA to safeguard personnel and prevent unauthorized access to assets, business processes, control systems, equipment, and sensitive information that may reside in the facility. The Working Group recommends implementing physical security solutions prioritized on the most critical facilities and assets. The physical security hardening will be closely coordinated with the infrastructure and facilities hardening projects discussed throughout this roadmap to minimize expenses and prevent duplicative or conflicting efforts.

As an illustration of the importance of physical security, on April 16, 2013, the Metcalf substation in Northern California was sabotaged in the early morning hours, causing tens of millions of dollars of damage. That attack served as a wake-up call that the BES's critical infrastructure was not adequately protected from potential attackers. Since then, a concerted effort has been undertaken to improve the physical security posture of its critical substations and control centers across the continental US. As an integral substation to the supply of electricity to the Bay Area and Silicon Valley, this sabotage attack encouraged the Federal Energy Regulatory Commission (FERC) to direct NERC to develop and implement NERC CIP-014 to identify critical substations and control centers and protect those critical facilities.

Although PREPA does not fall under NERC's jurisdiction, it should consider aligning to NERC standards for physical security by adopting security best practices and independently protecting its most important substations, generation, and control centers from any potential physical attack. These best practices include significantly enhancing physical security measures and developing a program dedicated to realizing a more mature security posture with risk mitigations in place and a better protected grid. This program and the associated security solutions it directs will need to evolve as the power grid and its threats and vulnerabilities change in Puerto Rico.

The future state of PREPA's physical security should include the following:

1. **Physical Security Controls and Measures:** Conduct threat and security posture assessment to identify high risk facilities such as control centers and transmission and generation facilities. Select, design and implement physical security controls based on risk posed by the facility. Implement a defense-in-depth approach utilizing the "five Ds of perimeter security" (Deter, Detect, Deny, Delay, and Defend) to protect critical systems and components at key facilities. This may include physical structures (e.g., fencing and berms) to prevent access and technical controls such as physical access control systems, lighting, remote management, and more. Further, develop and establish processes to safeguard physical security equipment.
2. **Physical Security Monitoring:** Design and implement continuous and real-time physical security monitoring that aggregates at a central security center. The monitoring systems will employ technologies such as motion detectors, closed circuit television, alarmed door contacts, infrared perimeter control, multifactor authentication, and other technologies as necessary and appropriate for each site. This will also employ the use of PREPA security personnel through onsite and remote monitoring of critical sites. Develop protocols and procedures to respond to physical security events and investigations.

3. **Personnel Security:** Develop procedures and protocols to limit physical access and confirm identity prior to provisioning such access using background investigations and personnel screening techniques and limiting access based upon the least privilege access principle, i.e., restricting access to only those with an articulable need to access certain sites.
4. **Physical Security Organization and Staffing:** Establish a mature physical security organization structure. Develop, implement, and manage physical security staffing processes and personnel development programs. Design and establish protocols for resource allocation, training, and succession planning for key physical security roles.

To implement the roadmap, PREPA and supporting stakeholders must make physical security a high priority and fully embrace it at the executive level and across the organization to create a culture of security. In addition, assessments and evaluations will need to be candidly performed, and resources will need to be made available. The Working Group recommends PREPA and supporting entities invest approximately $165 million between 2019 and 2028 to achieve the future state and to align physical security on the island with industry best practices. These recommendations are in alignment with ENR COA-005 to design and build grid hardened grid assets to support critical infrastructure.

Cybersecurity

With the increased digitization and interoperability of Incident Command System (ICS) and OT, cybersecurity is a pervasive and growing concern within the electric industry. As PREPA rebuilds and modernizes its electric system, it is presented with a unique opportunity to design control networks and associated elements with security that is built in. Ultimately, these enhancements will help protect the electric system, reduce risk, and minimize threats and vulnerabilities. PREPA should develop a comprehensive cybersecurity plan based on best practices identified in NERC CIP, NIST, C2M2, and observed electric industry cybersecurity best practices. Further, PREPA should build a best in class platform that is forward-looking and adaptive to address the rapid convergence of IT, OT, ICS, and the IoT threat environment.

The Working Group's approach will identify needs and implement plans addressing the following subject areas across the PREPA footprint.

1. **Network Infrastructure Security**
   Network infrastructure security is the heart of BES security. Accordingly, network infrastructure security is the primary focus of the NERC CIP reliability standards. Strong network infrastructure security involves:
   - Identification and classification of all critical or essential cyber assets
   - Implementation of a least privilege access program
   - Establishment of a secure network architecture

COA HIGHLIGHT

ENR COA-005

Design and build hardened grid assets to support critical infrastructure

- Remote access protections
- Physical security protections of cyber assets
- Restriction of ports and services to only those with a business need
- Continuous vulnerability management and security patching programs
- Malware prevention solutions
- Design and implementation system monitoring and alerting
- Risk-based user access controls
- Configuration management and change control programs

Collaboration between PREPA's teams is necessary to assess, design, and build the secure architecture necessary to protect against malicious users in a manner that works for PREPA given its resources and systems. As part of this, the Working Group recommends PREPA select vendors to deliver the necessary hardware, software, and tools to automate these security processes as much as possible. As a final step, the necessary policies and procedures to guide PREPA to conduct these ongoing activities would be created. These policies and procedures will be in place to help ensure the processes and tools are implemented as intended on an ongoing basis.

2. **Data Governance and Protection**
   Ensure data protection requirements are established across PREPA to identify and protect cybersecurity information pertinent to the operation of PREPA's electric infrastructure during storage, transit, and use. Develop processes and plans to either destroy or redeploy cyber assets that will no longer be used in a protected, access-restricted environment.

3. **Cloud Strategy and Security**
   The use of web-based tools and data storage on the cloud is cost-effective for a variety of businesses due to the reduced IT hardware and personnel costs. As mentioned earlier in this report, cloud computing also reduces the impact of damaged or destroyed local hardware and cyber assets. Currently, the use of the cloud is limited among the electric industry due to reduced ability for regulators to audit the security of cloud providers, a restriction not currently imposed on PREPA. The Working Group proposes to assess PREPA's use of cloud storage for protected information, services, and possible use for PREPA's business needs in accordance with information protection practices, security concerns, and resilience needs.

4. **Grid Modernization**
   Grid modernization and the digitization of the grid and grid edge will employ any combination of multiple go-to-market technology strategies (i.e., data protection, cloud, network security, supply chain, physical security) to ensure PREPA's electric system is technologically advanced, efficient, reliable, and secure. As part of an effective cybersecurity program, each technology employed by PREPA to improve performance and reduce costs must also be evaluated for the introduction of new cyber vulnerabilities and threats. Once identified, these threats must be

mitigated to prevent misuse of the technologies in a way that could harm the reliability or resilience of the Puerto Rico electric system.

5. **Supply Chain Risk Management**
   The supply chain is increasingly viewed as a source for inherent vulnerabilities of digital interconnected devices. Accordingly, the Working Group proposes to develop and apply a supply chain risk management framework and establish a detailed plan and procedures to limit the security risks to its systems posed by vendor products and services.

6. **IoT Security**
   The Working Group proposes working with network engineers and vendors to establish a trust-based system that utilizes fingerprinting technology. Additional steps include the delivery and application of a governance structure for safely and securely utilizing connected digital technologies from AMI to phasor measurement units.

7. **Virtualization Security**
   Virtualized machines and systems can lower your IT costs. However, virtualized machines must follow the same security protocols as traditional devices. This includes high watermarking the devices to ensure that all elements on the same network receive the same level of security and trust. Additionally, PREPA's personnel will need to become familiar with virtualized devices and their proper configuration.

8. **Mobile Device Management**
   Mobile devices have become ubiquitous. Their use in secured environments, however, must be tightly controlled and guided. The Working Group proposes to help PREPA to develop a mobile device management policy that includes what types of devices may be used in a secure environment, what types of mobile devices will be allowed to establish remote access, and what security protections must be installed and enabled on the mobile devices themselves.

9. **Communications Security**
   As PREPA prepares to build out its security infrastructure to its substation with dark fiber, cybersecurity efforts will work with PREPA to ensure the communications infrastructure is secure against man in the middle attacks using encryption, detection, or other methods.

10. **Incident Response and Restoration Plans**
    The Working Group shall develop and coordinate efforts with PREPA to develop incident response plans for dealing with cybersecurity attacks. This will include identification, evaluation, and escalation of events and steps to isolate the problem and preserve evidence for later forensic analysis. The appropriate cyber asset backups and restoration plans also need to be developed for use if an incident brings down a cyber asset, group of cyber assets, or an entire system.

11. **Cybersecurity Governance**
    PREPA will need to implement a comprehensive cybersecurity governance structure and program, overseen by PREPA executives and senior management, that will direct PREPA's organizational structure and guide handling of the cybersecurity program across PREPA's electric system operations. This governance program will identify desired outcomes, identify and protect cyber assets, and set forth cybersecurity priorities.

This governance program will address the following:

- Roles and responsibilities that include authorizations for cybersecurity decisions
- Cybersecurity policies
- Cybersecurity awareness and training
- Program monitoring, assessment, and metrics
- Communication structure i.e., issue reporting and program information distribution
- Adaptability – i.e., cybersecurity is a rapid evolving field with changing technologies, emerging threats, and creative adversaries

12. Cybersecurity Operations Monitoring

The cybersecurity strategy includes a Security Operations Center (SOC) within the Emergency Operations Center (EOC) facility. The SOC will house an information security team responsible for monitoring and analyzing the security posture on an ongoing basis. The function of the SOC will be to detect, analyze, and respond to cybersecurity incidents using a combination of technology solutions and a strong set of processes. These facilities are necessary to perform routine O&M informed by periodic risk assessment (ENR COA-004).

> **COA HIGHLIGHT**
>
> ***ENR COA-004***
>
> ***Perform routine operations and maintenance (O&M) informed by periodic risk assessment***

The SOC will be staffed with security analysts and engineers as well as managers who oversee security operations. SOC staff work close with organizational incident response teams to ensure security issues are addressed quickly upon discovery. The SOC will monitor and analyze activity on networks, servers, endpoints, databases, applications, websites, and other systems, looking for anomalous activity that could be indicative of a security incident or compromise. The SOC would be responsible for ensuring that potential security incidents are correctly identified, analyzed, defended, investigated, and reported.

13. Ongoing Cybersecurity Assessments and Testing

Additionally, the Working Group proposes to incorporate cyber vulnerability assessments, cybersecurity incident response tests, and evaluations of the implementation of cybersecurity principles and practices in the years following the initial implementation. For example, risk management strategies should be developed and annual evaluations of PREPA's cybersecurity program maturity should be conducted using DOE's Cybersecurity Capability Maturity Model (C2M2). In total, the Working Group recommends PREPA and supporting entities invest approximately $130 million between 2019 and 2028 to achieve the future state and to align cybersecurity on the island with best practices.

Implementation Roadmap

PREPA leadership must include physical security as a strategic initiative and fully embrace it at the executive level and across the organization to create a culture of security. In addition, assessments and evaluations will need to be regularly performed to identify and mitigate vulnerabilities as the Grid Modernization Plan is implemented.

The Working Group recommends the following initiatives. These initiatives are tried, tested, and consistent with best security practices as described by NERC, NIST, C2M2, and leading bulk power companies in the continental US.

- Develop overall physical security strategy to establish the goals and objectives of PREPA. The strategy will be used to establish the priorities and success factors of physical security for PREPA.
- Develop criteria for the identification of the PREPA critical sites and facilities. This must be determined and designed with the needs and operability of the PREPA system in mind. Criteria will be developed that identifies facilities and components essential to the reliable operation of the PREPA system.
- Implement the above criteria to identify and rate PREPA critical sites (substations, generators, and control centers) to be protected. The resulting ratings would be in a tiered list such that implementation of controls could be evaluated and prioritized to ensure the highest risk facilities are treated in an appropriate order.
- Conduct a physical security baseline program and tools assessment—this will involve a thorough assessment of PREPA's current competencies to evaluate PREPA's current physical security posture and vulnerabilities.
- Build the necessary physical security policies, procedures, and guidelines by 2022 for PREPA's administration and workforce to uphold.
- Build an overall Physical Security Program by 2022 to detail and document the tools, processes, and procedures for the daily monitoring and protection of PREPA facilities, assets, and people.
- Develop and execute individual security plans that delineate the specific tools and processes to be put in place to protect and harden critical sites (estimated to be more than 30 critical sites) between 2021 and 2024 using an encompassing defense-in-depth strategy.
- Develop and execute overall Security Plan to detail the physical security measures and processes at the estimated 300 non-critical substations between 2021 and 2028.
- Build a modern Security Operation Centers between 2021 and 2024 to centrally manage physical security coordination, alerting, and response throughout the PREPA footprint.

This approach is tried, tested, and consistent with best security practices as described by NERC, NIST, C2M2, and leading bulk power companies in the continental US. PREPA's cybersecurity vulnerabilities must be addressed. A great deal of work is to be undertaken to build a transformed and resilient grid. Resiliency must not only be thought about in terms of preparing for and recovering from the next tropical cyclone; PREPA must also be prepared to resist, defend, respond to, and recover from a cyber-attack on its electric infrastructure.

The following high-level actions need to take place in the following order to achieve this future vision for the transformed grid:

- Conduct a PREPA-wide baseline cybersecurity program and tools assessment. The Working Group will conduct a thorough assessment of PREPA's current architecture, tools, policies, processes, and staff competencies to evaluate PREPA's current cybersecurity posture and vulnerabilities (2019).
- Deliver a gap assessment detailing PREPA's cybersecurity deficiencies (2019).
- Develop and deliver a PREPA cybersecurity improvement plan from the baseline cyber assessment that will set forth a prioritized roadmap for development. This plan will include sections on PREPA's technology, policy, and procedural framework, staff, and vendors and include detailed steps to improve the cybersecurity posture of PREPA.
- Implement the cybersecurity improvement plan, which will likely include the following (2019-2028):
  - In-depth network architectural design
  - Procurement of tools/solutions
  - Installation and troubleshooting of new technologies and software
  - Training and hiring of PREPA staff
  - Delivery of documentation framework of policies, procedures, processes, and internal controls
  - Smart grid cybersecurity architecture design, planning, implementation, and controls for grid edge digital devices
- Assess, test, and evaluate PREPA cybersecurity improvements. This will include, at a minimum, programmatic reviews, cyber vulnerability assessments, penetration testing, program maturity evaluations, and incident response drills (2020-2028).

The steps listed above will bring PREPA first to industry cybersecurity bare minimums, then eventually to meet industry best practices.

Priority Projects

The prioritization of these security tasks follows a logical path to address the immediate vulnerabilities, close gaps, and build a sustained and best practice security program for PREPA over the next 10 years.

The Working Group recommends the following tasks and timelines in a prioritized order:

- Assess and identify PREPA critical facilities (Begin 2019).
- Baseline cybersecurity and physical security posture and tools assessment for high risk facilities (2019-2020).
- Design and implement protections such as OT and IT including SCADA, firewalls, remote access, etc. (Begin 2020, 10 years).
- Physical and cyber program build (NERC CIP and NIST) (Begin 2020, 5 years).
- Non-critical facilities controls baseline assessment and controls (Begin 2026, next 4 years).
- SOCs capability assessment and improvements (Begin 2020, 9 years).

Cost Estimates

This cost estimate can vary based on the number of critical substations designed and identified in the transformed grid. It is also dependent on the threats observed with the bulk electric grid and for PREPA and Puerto Rico. Using the concept of "design basis threat," the sites will be hardened corresponding to the criticality and the threats determined to implement the "5D" approach to deter, detect, deny, delay, and defend against physical intrusion.

The time required for the tasks described in this section is estimated to be about 10 years. Timing of the physical security hardening would coincide with the rollout of the design, implementation, and execution of building the new PREPA modernized grid.

The Working Group estimates $290 million in expenditures is needed to analyze, validate, and build a 21st century, physically-secure PREPA utility that can combat the current threats, vulnerabilities, and risks associated with operating a modern utility.

The Working Group anticipates $126 million in expenditures over the next 10 years to determine the cybersecurity posture of the current grid, identify gaps and priorities, and develop and implement the architectural cybersecurity design to build a 21st century, best practice cybersecurity program.

Table 5-4. Security Major Investments ($M)

Major Investment Areas	*Cost ($M)*
Physical Security Controls and Measures	$ 118
Governance and Implementation	$ 72
Physical Security Monitoring	$ 36
Assessment and Planning	$ 15
Personnel Security	$ 11
Physical Security Organization and Staffing	$ 11
Cybersecurity Organization and Staffing	$ 11
Personnel and Security	$ 10
Assessment and Testing	$ 7

Source: GridMod Plan Funding Analysis

5.3 System Operations

Current State

PREPA's primary and backup control centers are located in Monacillo and Ponce, respectively. Control center staff play a critical role in managing the operations of the grid during major storms. They are responsible for isolating faulted lines and substations, dispatching generation to minimize the number of customers affected, and restoring power as quickly as possible following a storm, assuring customer, work crew, and system safety.[34]

PREPA has an EOC or Technical Operations Center (TOC) in Monacillo and a backup support center in San Juan (Santurce). The EOC was established in 1998 and was used in response to Hurricane Maria. It is the center that directs PREPA's planning and operational decisions during an emergency event. There are also centers for each region (COR). The EOC is managed by PREPA's Electrical System Operation Division (DOSE).

PREPA also has an SOC in Monacillo that is used to monitor and analyze security incidents on more than 400 cameras. A third party is used to manage this function. However, the SOC is more than ten years old and many of the cameras need to be repaired or upgraded.

Future State

COA HIGHLIGHT

ENR COA-011

Design and deploy technologies to improve real-time information and grid control

The GridMod Plan proposes initiatives that will not only improve PREPA's ability to restore power to customers faster following major storms but will also enable PREPA to efficiently manage the operation of traditional generating plants with distributed resources, including energy storage systems capable of shifting midday solar output to align with evening peaks. Additionally, primary and backup control centers will need to be upgraded to withstand a Category 5 hurricane.

The primary and backup control center facilities will also be enhanced to support Distribution Control Center operations in addition to System Control Center operations. It will be important for PREPA to deploy and extend new communication networks to monitor and control distributed resources and to automate newly proposed intelligent devices on the distribution system. Control center facilities are necessary for improving real-time information and grid control, which support ENR COA-011.

Operating Considerations

In addition to the rebuild recommendations in the sections that follow, the following operating measures are recommended to limit damage in the future and improve the resiliency of the system:

[34] Build Back Better, p.35.

- Black start capability at generating stations and automated synchronization at select substations.
- Plan to automatically split and operate the power system on the main island of Puerto Rico as independent electrical islands should the transmission grid be severed or become unstable again in the future.

Figure 5-6. Modern Control Center

Source: Doug Murray / Florida Power and Light

Implementation Roadmap

Energy Control Center

The proposed modernization includes the installation of primary and backup control center equipment and data centers at each control center to host the IT and OT infrastructure and systems required by system operations, including EMS/SCADA, DA, monitoring, and control of DER and energy storage. The automated systems and advanced outage and DMSs for both the primary and backup control centers will improve system resilience, efficiency, and security to achieve the desired functionality described previously.

The data centers will centralize system operations IT/OT operations and equipment, as well as store, manage, and disseminate energy grid system data. The data centers' critical system operations IT/OT systems are vital to the continuity of daily operations. Consequently, the security[35] and reliability of data centers and their information is an important consideration for system operations.

[35] Security is further detailed in Section 5.2 of this report.

Key elements of a data center include:[36]

- **Facility:** The location and “white space,” or usable space, that is available for IT equipment. Providing round-the-clock access to information makes data centers some of the most energy-consuming facilities in the world. A high emphasis is placed on design to optimize white space and environmental control to keep equipment within manufacturer-specified temperature and humidity ranges.
  - **Support infrastructure:** Equipment contributing to securely sustaining the highest level of availability possible for critical control systems. Some components for supporting infrastructure include: Uninterruptible Power Supply: Battery banks, generators, and redundant power sources.
  - **Environmental Control:** Computer room ACs; HVAC systems; and exhaust systems.
  - **Physical Security Systems:** Biometrics and video surveillance systems.
- **IT equipment:** Equipment for IT operations and storage of the organization’s data. This includes servers, storage hardware, cables and racks, and a variety of information security elements, such as firewalls.
- **Operations staff:** To monitor operations and maintain IT and infrastructure equipment around the clock.

The system operations modernization strategy includes an upgraded EOC to provide central command and carry out the principles of emergency preparedness and emergency management—or disaster management functions at a strategic level during an emergency—and ensuring the continuity of operation of a company, political subdivision, or other organization. The functions of the EOC will be to collect, gather, and analyze data; make decisions that protect life and property, maintain continuity of the PREPA operations, and disseminate those decisions to all concerned agencies and individuals in the event of an emergency. The Working Group also recommends that the backup EOC in San Juan be relocated because it is currently in close proximity to the EOC in Monacillo. Separating the EOCs would reduce the likelihood that a strong natural disaster or other emergency event would damage both facilities.

Diagnostic Center

The Working Group also recommends building a Smart Grid Diagnostic Center (SGDC) in the same facility where the EOC is built. The purpose of the SGDC will be to aide system operations to use smart grid technology and analytics. The SGDC will deliver real-time actionable data to support faster and better-informed incident response by the EOC during emergencies. Additional benefits include reduced duration and number of outages, faster repairs, and more accurate time estimates for restoration.

Security Operations Center

Cyber threats remain a top national security threat. According to the 2018 *Worldwide Threat Assessment of the US Intelligence Community*, there is a growing risk of cyber-attacks on the US’s critical

[36] The website for Palo Alto Networks, Inc., “What is a data center?”.

infrastructure which includes the electric grid. The modernization strategy includes an upgraded SOC within the EOC facility as well as a backup SOC to ensure redundancy in security operations. The SOC will house a cybersecurity team responsible for monitoring and analyzing the security posture on an ongoing basis. The function of the SOC will be to detect, analyze, and respond to cybersecurity incidents using a combination of intrusion alarms, technology solutions and strong set of processes. The SOC will also have partnerships and procedures in place with local law enforcement to better detect and respond to cybersecurity incidents. Section 5.2 contains additional information on Security.

Figure 5-7. Security Operation Center

Source: Pierre Gonzales / OmniSOC

System Studies

There are several areas where systems studies are critical to applying recommended solutions from the GridMod Plan. Several of these were identified in Build Back Better and others were identified in the Working Group process.

These areas include:

- Power System studies for entire grid and islandable grids
    - Load flow contingency analysis identifying the potential critical paths and supporting load and generation matching for each island
    - Optimal Load flow, contingency, voltage and security analysis studies
    - Stability, Short Circuit, Protective relaying and coordination studies
    - Black start and islandable grid processes
    - Ensure that the existing generation assets required to meet the peak load of the PREPA customers remain reliably available during the transition period moving toward natural gas and renewable resources
    - Identify the generation assets that will be converted from oil-fired to dual-fuel units to meet short-term and long-term goals of affordability and reliability
    - Evaluate the technical and economic capability of existing hydro assets

- Investigate fuel infrastructure solutions for additional LNG import, storage, and delivery infrastructure

- Technology studies
  - Analysis of the role of communications, monitoring, control, and data historian with Islanding Grids
  - Analysis of all system stakeholder requirements that need support within Communications, including: Distribution, Substation, Protection, Metering, Security, Transmission, Generation, EMS, etc.
  - Analysis of stakeholder usage of data/monitoring from their systems in the field
  - Analysis of segregation of traffic based upon cybersecurity recommendations
  - Analysis of communication architecture to support cybersecurity recommendations
  - Outlining of DERMS requirement for microgrid support within the Grid, should be aligned with PREPA rules which are being established
  - Overlay DERMS communication requirements with AMI communication requirements (802.15.4 versus high speed options)
  - Analysis of current governance, policy, standards, guidelines, and procedures of any and all existing cybersecurity
  - Examination of future state of technology and alignment to a risk-based approach to cybersecurity providing a “GAP” analysis and path forward for requirements
  - Analysis of Rule for Microgrids with PREP

Cost Estimates

Table 5-5. System Operations Major Investments ($M)

Major Investment Areas	*Costs ($M)*
Hardened T&D Primary and Backup and Control Centers	$ 100
System Studies	$ 55
Island Controller	$ 40
Primary and Backup EOC, SOC, and Diagnostic Center(s)	$ 20

Source: GridMod Plan Funding Analysis

ENERGY SYSTEM MANAGEMENT TRANSFORMATION

GOVERNMENT OF PUERTO RICO

COR3
CENTRAL OFFICE OF
RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

6. ENERGY SYSTEM MANAGEMENT TRANSFORMATION

6.1 Operational Efficiencies

The Working Group has recommended investments in hardware and software be installed to transform Puerto Rico's electric grid with technology as an enabler. Equally important is an underlying investment in organizational capabilities and asset management practices to support and maintain these new investments. Operational efficiency initiatives, which are required to leverage new technology and maintain new investments, represent another transformation that will unfold among the workforce operating and maintaining Puerto Rico's grid of the future. A transformation of the magnitude outlined in this plan will require a significant investment in change management and capacity building at PREPA.

Current State

As previously discussed, the current T&D infrastructure at PREPA is not built to the latest codes and standards. The 10-year transformational plan will bring a vast array of new asset types, including ones that the PREPA workforce is not currently trained to operate. Operating procedures taught at PREPA's current training facility are not consistent with the new codes and standards being introduced. In addition, current asset management practices are not aligned with industry standards and do not minimize reliability risk. Modern asset management practices will need to be adopted to maximize the working life of the new assets by fully leveraging the new Enterprise Asset Management System (AMS) recommended in this document.

Utilities all over the US are experiencing an aging workforce and skill gaps. According to PREPA's 2018 financial plan, it has lost approximately 30 percent of its workforce since 2012 and is faced with a significant shortage in skilled workers, particularly in Generation, T&D, Customer Service and IT. The 2018 financial plan also notes that approximately 10% of PREPA's current workforce (~600 employees) has submitted paperwork to retire. These staffing challenges have been amplified after Hurricanes Irma and Maria. To maintain a vital and capable workforce into the future at PREPA, the Working Group recommends reaching out to local educational institutes to attract talent and forming research partnerships to stay engaged with the newest innovations in the energy industry. This will require a paradigm shift in PREPA's outlook as a modern and dynamic organization.

Future State

The Working Group recommends the following initiatives to improve PREPA's operational efficiency:

- Asset management program
- Skills training program
- Educational outreach and research partnerships

Given the current skills gaps and the pace of retirement at PREPA, the Working Group also recommends that potential talent development and retention strategies be developed to ensure positions in critical functions continue to be filled with adequate talent.

Implementation Roadmap

The following programs outlined below support ENR COA-018 to train the future energy workforce.

Asset Management Programs

PREPA currently does not have an asset management program that evaluates the maintenance and replacement requirements of the distribution, transmission and substation equipment. The Working Group recommends a comprehensive asset management program at PREPA to ensure the longevity of the investments being proposed and to streamline the O&M of those assets. This asset management program should be in line with the international industry standard (ISO-55000) and other global industry asset management forums (Global Forum for Maintenance and Asset Management, GFMAM).

COA HIGHLIGHT

ENR COA-018

Right Size and Train the Future Energy Workforce

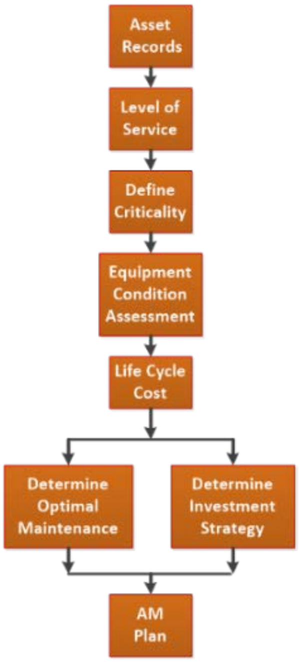
The Working Group recommends a best in class utility asset management program covering:

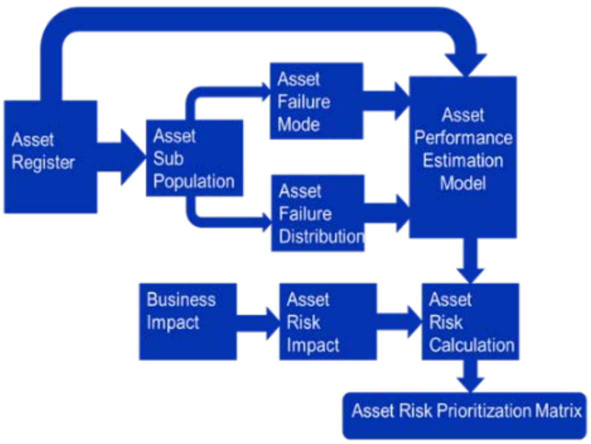
- Long-term asset management through risk and gap analysis, reliability centered maintenance, life cycle cost techniques and financial and operational metrics to improve and achieve performance measures.
- Equipment criticality, failure rates, and condition assessment.
- Failure Mode Effects Analysis for critical and high value assets.
- The most critical assets should be assessed to ensure they are operating within their design conditions.
- Manufacturer-recommended inspection programs for transmission, distribution and substation equipment.
- Preventive maintenance programs for medium and low voltage distribution poles and lines. Pole inspection is a major maintenance program for utilities.
- Vegetation management to comply with new codes and standards.
- Asset end of life management including a replacement schedule for critical assets.
- Track and report key performance indicators for asset maintenance, including:
  - A dashboard view for each substation showing the maintenance record and overdue status of each asset.

- The percentage of all assets planned for maintenance that were completed in a given period (i.e., quarterly).
- The worst-performing assets with a disproportionate effect on reliability.

- Procedures for online maintenance tools such as Infrared Radiation scanning, functional checks, oil sampling, etc.

Figure 6-1. Asset Management Planning Steps in Accordance with PASS 55/ ISO 55000.





Source: Asset Management Standards

PREPA Skill Training Facility

The Working Group recommends a Skills Training Center (STC) at PREPA. The STC would include formal classrooms training, laboratories to evaluate and test equipment, and hands-on testing facilities for distribution, substations, transmission, and meters.

Figure 6-2. Example of a Reclosers Testing Facility at CenterPoint Energy

Source: CenterPoint Energy

The following courses of study should be offered at the STC, in addition to periodic refresher classes.

Substation Field Employees Training Program

The program will include classroom training and a hands-on training yard for substation technicians. The curriculum will include new equipment installation, relays and breakers maintenance, control wiring installation, and control circuits troubleshooting.

Figure 6-3. A Station Training Yard with a Control House and Equipment

Source: CenterPoint Energy

Linemen Training Program

Newly hired linemen will go through an apprentice program consisting of a combination of on-the-job (OTJ) training and classroom training at the STC with an emphasis on hands-on practice using the training yard at the STC. It is expected that existing linemen will be trained at the STC on the new equipment that will be installed over the next 10 years. Some of the new equipment will consist of solar and wind farms, microgrid, DA, and new construction standards.

Figure 6-4. Training Yard with Facilities (T/D Overhead and Underground)

Source: CenterPoint Energy

Meter Technicians Program

Apprentices should be hired on an as needed basis to serve as AMI meter technicians. Apprentice training should include OTJ training, offsite training, home/self-study, and limited classroom training.

Figure 6-5. Example of AMI Meter Training

Source: CenterPoint Energy

Operational Technology Training Programs

Training should be offered for each of the operational technologies being implemented, including the new asset management software. Training should be required for both back office and field force as appropriate. Utilities commonly request software vendors to offer training programs as part of procurement contracts and PREPA should explore the same.

Educational Outreach and Research Partnerships

Faced with an aging workforce and scarcity of qualified young talent, many of the nation's utilities have partnered with local colleges and universities. These partnerships not only ensure a future supply of skilled workforce, but also give utilities a share in the research and innovation being produced at these institutions. One example of such partnerships is Duke Energy's investment in North Carolina community colleges which has recently reached the $30 million in investments to addressing aging workforce concerns. The investment is spread out among 49 schools to help students with industry-specific training[37]. Another example is Eversource Energy, which is partnering with the University of Connecticut to improve their storm outage prediction technology and create a more robust and powerful model. Along the same lines, the Working Group recommends PREPA forge partnerships with local colleges and universities. The program can be designed to include a skills training curriculum for young workforce entrants as well as competitive grant awards for research and innovation focused on clean energy, grid modernization and storm resiliency.

Cost Estimates

The Working Group recommends kicking off the procurement process an asset management software vendor on a priority basis. Early deployment of the software is needed because it takes time to load existing assets into the software and new assets should be loaded as they are installed. Early deployment will also leave more time for training and change management.

New training infrastructure should be set up in the near-term to ensure workforce is fully skilled to operate new grid assets as they are installed. Educational outreach and research partnerships should be pursued on an ongoing basis. It can be piloted at select institutions and then scaled up.

Table 6-1. Operational Efficiencies Major Investments ($M)

Major Investment Areas	*Cost ($M)*
7Asset Management Program	$ 5.4
Training Facility	$ 7.0
Educational Outreach and Research Partnerships	$ 9.0

Source: GridMod Plan Funding Analysis

6.2 Emergency Preparedness

Hurricanes Irma and Maria tested Puerto Rico's emergency preparedness, including the planning, response, and recovery completed by PREPA, the Government of Puerto Rico, and supporting entities such as the NYSC. This section describes the current state and targeted future state for Puerto Rico's emergency preparedness. Specific initiatives to achieve the future state include inventory and spare enhancement, best practice emergency response planning documents, formal mutual assistance agreements, and improved training.

Implementation priorities for improved planning and preparedness are proposed for the next 1-3 years, with larger investments in depots and staging facilities and spares inventory phased in over the next 5-7 years. Overall, these initiatives will focus on strengthening the resiliency of the PREPA electric grid and the preparedness of resources involved to ensure future hurricanes and other emergencies are addressed using a well-understood emergency and mutual assistance framework.

[37] https://www.elp.com/Electric-Light-Power-Newsletter/articles/2016/06/college-utility-partnerships-becoming-a-cottage-industry.html

Current State

The destruction caused by Hurricane Maria significantly undermined the most fundamental aspects of emergency preparedness, including on-island resources, logistics, supply chain management, coordination, and communication. These challenges were exasperated by the lack of an up-to-date, companywide PREPA Emergency Response Plan, signed mutual assistance agreements, and emergency preparedness training. PREPA has Emergency Operational Plans for each division and plant with a National Incident Management System-based framework and communication protocols; however, these plans were not well-understood, maintained and updated, consistently practiced, or fully utilized in the response to Hurricane Maria.

As a result, roles and responsibilities for PREPA and supporting entities were unclear, emergency and safety processes and procedures were undefined, and the Emergency Management Assistance Compact vehicle for mutual assistance (and other Memorandums of Understanding [MOU]) were not well-understood by stakeholders.

PREPA's financial challenges further complicated the emergency response and recovery because it only had approximately one-third of the T&D spares needed to restore the grid as well as limited labor, equipment, and trucks across its 23 warehouses, seven regions, and two depots in Palo Seco and Ponce.

According to information available at the time of developing this plan, PREPA had approximately $39 million in spare inventory when Maria hit the island, compared to approximately $93 million in 2003. In addition, the regions have inventory storage at facilities that are not hardened or environmentally controlled, staging sites are set up on the fly, and the depots are not consistent in their inventories. For example, the Palo Seco depot is primarily dedicated to transmission spares and the Ponce depot is primarily dedicated to distribution spares.

PREPA's decentralized approach created additional challenges in getting functioning spares to areas of need in a timely manner and contributed to broader inventory and asset management logistics issues. Finally, components of PREPA's infrastructure are custom-made and therefore require significant procurement time. In some cases, the custom equipment limited the ability of supporting entities to provide industry standard utility equipment to PREPA to expedite restoration. Taken together, these financial and logistical challenges significantly delayed power recovery on the island.

The hurricanes highlighted the need for significant attention and investment on preparedness, training, and other fundamental aspects of emergency and mutual assistance planning. Investment in these areas is especially important for events that require significant transatlantic support for logistics, supply chain, and wraparound services, such as Hurricane Maria.

Future State

To address the emergency preparedness challenges discussed above, the Working Group has defined a future state that includes the following:

- Formal and up-to-date emergency response, supply and logistics, and mutual assistance plans
- Formal, signed MOUs and agreements for mutual assistance with partnering entities
- Formal mutual aid vehicle/FEMA reimbursement structure
- Sufficient spares, equipment, and trucks to support recovery of the existing grid for 2019 and 2020 hurricane seasons and to support recovery of the future modernized grid in 2021 and beyond; this inventory should also be regularly used (and replaced) for ongoing maintenance needs and to prevent future emergencies
- Standardized off-the-shelf equipment to reduce procurement lag times and improve on-island supplies for emergencies
- New centralized depot facilities with distribution and transmission equipment that is managed in a centralized asset management system, and made available to support all seven regions, 26 districts across the island
- Organizational maturity in emergency response preparedness, including annual drills aligned to the Homeland Security Exercise and Evaluation Program, training and external stakeholder involvement in preparation and drills such as local and federal government entities, law enforcement, and supporting utilities
- A culture of emergency preparedness, response, and recovery

The Working Group recommends PREPA and supporting entities invest an estimated $112 million between 2019 and 2026 to achieve the future state described above and to align emergency preparedness on the island with best practices. Specific initiatives associated with this investment are discussed in Appendix C. This investment estimate is based on the information that was made available by the Working Group during the drafting of this plan. Additional analysis and information is needed to further refine this estimate and its various components.

Implementation Roadmap

Five major emergency preparedness initiatives have been identified to achieve the future state, including improving or developing:

1. On-island Inventory (Spares, Trucks, and Equipment)
2. Emergency Response Plan
3. Mutual Assistance Plan
4. Supply & Logistics Plan, Depots and Staging Sites
5. Training, Table Tops, and Exercises for Emergency Response, Mutual Assistance, and Supply and Logistics Plans

Each of these initiatives contribute to a more mature emergency preparedness, response, and recovery capabilities. While some of these initiatives have begun in 2019 in anticipation of the next hurricane season, they are just getting started and require more significant resources and investment.

On-island Inventory (Spares, Trucks and Equipment)

Adopting effective asset management strategies such as the targeted inventory of critical spares, trucks, and equipment is critical to improving emergency preparedness (and maintenance practices more broadly) on the island. Building, tracking, and maintaining this inventory is important to support both the existing grid and the modernized grid as it is developed over the next several years.

In total, this initiative is estimated to cost approximately $55 million between 2019 and 2024, including:

- Procuring sufficient spares, equipment, and trucks for the existing grid at an estimated cost of approximately $20 million in 2019, including $10 million for spares and $10 million for equipment and trucks.
- Procuring enough spares for the modernized grid is estimated to cost approximately $5 million in 2022 and $15 million in 2023.
- Purchasing equipment and trucks according to a life cycle procurement schedule at an estimated cost of approximately $5 million in 2022, 2023, and 2024, for a total investment of $15 million.

This is a rough estimate based on high level inventory statistics that were available at the time of drafting this plan. Additional study and analysis are needed to assess current and future inventory needs and to develop a life cycle procurement schedule for equipment and trucks. To the extent that additional information or studies are made available, the estimates in this plan will be updated.

The first step to improve emergency preparedness for the hurricane season in 2019 and 2020 is to identify, procure, and properly store adequate system spares, trucks, and equipment based on existing needs and expected failures. This initiative is especially important for spares and equipment typically requiring long lead times.

Once procured, they need to be stored at depots and key staging sites in advance of any storm. PREPA's Operations and Warehouse branch should work to actively use and replace this inventory as appropriate for both maintenance and emergency needs. The supply sources and depots and staging areas for spares, trucks, and equipment will also eventually need to be identified in the Supply and Logistics Plan and in formal emergency supply contracts.

To support inventory optimization, The Working Group recommends an assessment of PREPA's current inventory tracking process to ensure that spare and equipment inventory are properly tracked. If needed, PREPA should consider identifying and implementing an inventory tracking system that can integrate with PREPA's Enterprise AMS and automatically track inventory maximums and minimums.

This system should integrate inventories across PREPA's depots and 23 warehouses. It should also be supported by documented procedures and training for PREPA employees.

The modernized grid will also require a new inventory of spares for emergency response and recovery in 2022 and beyond. It is recommended that the modernized grid use industry standard equipment, wherever possible, to reduce procurement lag times and to be in a better position to receive supplies from mainland entities during an emergency.

MOUs, the Mutual Assistance Plan, and the Supply and Logistics Plan should be updated to reflect any new materials or spares that will be brought to the island under these agreements.
Finally, the modernized grid will require PREPA to identify, purchase, and distribute needed equipment and trucks per a life cycle plan. This life cycle plan will prioritize equipment replacement using parameters such as average asset life cycle, service level targets, design standards, maintenance requirements, and equipment criticality. Over the long-term, the life cycle plan will guide PREPA's performance reliability for these assets and identify when and where investments and replacements should occur.

Emergency Response Plan

A comprehensive, up-to-date Emergency Response Plan (ERP) is a core aspect of effective emergency planning. PREPA's Electrical System Operation Division (Grid Operations) has an Emergency Operational Plan (EOP) prepared under FEMA's CPG 101 (Developing and Maintaining Emergency Operational Plans) and each division and plant at PREPA have a similar plan available in Spanish; however, these plans were not widely utilized in response to Hurricanes Irma and Maria.

PREPA is currently making substantial changes to its existing plans, such as changes in delegation of authorities from the CEO to the operations managers to increase accountability and decision-making. In addition to these changes, the ERP should be updated in English and Spanish to incorporate best practices and reflect the lessons learned from responding to and recovering from Hurricanes Irma and Maria. It is estimated that updating the ERP will cost approximately $2 million between 2019 and 2021.

The Working Group recommends forming an Emergency Response Team in early 2019 to develop the ERP. Participants should include PREPA, local and federal government officials, and mutual assistance providers. This team will develop the vision, guidelines, and objectives for the ERP based on the existing EOP and best practices. An important aspect of defining these objectives is to identify and prioritize risks to determine which hazards and threats, such as hurricanes, merit special attention in the ERP.
PREPA and the Emergency Response Team will develop the first iteration (30% solution) of an up-to-date ERP prior to the 2019 hurricane season.

Specific elements of the ERP will include:

- A formal ICS framework in Puerto Rico that aligns with FEMA practices and a prioritized list of critical facilities to focus on in an emergency
- Alternate facilities/locations identified to take on the responsibilities of executing an ICS response in the event the San Juan or Monacillo EOC locations are not available
    - PREPA is currently working with Interamerican University (INTER) on a collaborative agreement to use INTER as an Alternative EOC in an emergency.
- Staging areas identified and agreed to with the Commonwealth or local governments
- Grid diagrams and drawings
- A comprehensive damage assessment capability that includes standard templates and a prioritization of infrastructure
- References to MOUs with mutual assistance entities
- Well-defined materials list and supply chain agreements and protocols
- Communications plan with directory and information sharing protocols
    - This includes a policy, process, and procedure for gathering PREPA personnel availability to respond in an emergency (i.e., automated call down system)
    - Includes a process or procedure to use portable, temporary communication equipment to augment the existing system communication equipment, such as portable repeater towers and equipment and communications in a briefcase (e.g., laptop, solar charger, batteries, and satellite phone) for key personnel
    - Also includes a PREPA pocket reference book for emergencies with critical contact information (phone numbers, Delegation of Authorities, ICS structure)
- Well-defined Delegation of Authority policy or memo to eliminate gaps in authority and responsibility to get work completed if the primary employee is not available
- Expedited port clearance processes for mobilization and demobilization in an emergency event and clearing protocols for support vehicles
- Restoration and business continuity plans

Once the initial ERP is drafted and approved by PREPA leadership and the appropriate stakeholders in 2019, it should be distributed to the entire PREPA workforce, local law enforcement, and supporting entities.

The 30% solution of the ERP should also be revised and matured over the next 3 years to get to a comprehensive, near 100% solution. Lessons learned after each hurricane season, as well as new information, insights, and updated priorities, should be incorporated.

ERP development should also feed into PREPA's broader Emergency Management Program, which should include the necessary resources, policies, processes, procedures, and controls to support the implementation of the ERP. A capability or workflow study may be needed to determine the capabilities and resources necessary to support the execution of the ERP.

Mutual Assistance Plan

While mutual assistance significantly improved the recovery of the electric grid after Hurricane Maria, there was also confusion and a lack of formal planning between PREPA and mutual assistance providers. Accordingly, a Mutual Assistance Plan will help define roles and responsibilities, event triggers, communication and financial reimbursement protocols, and other information to support expedited recovery in future emergency events. It is estimated that developing a Mutual Assistance Plan will cost approximately $2 million between 2019 and 2021.

To develop a Mutual Assistance Plan, a task force (Mutual Aid Team) must be created in early 2019. In alignment with COA-012, members should include PREPA, the Commonwealth of Puerto Rico, Mutual Assistance Providers, the federal government, entities from the private sector, and other stakeholders. This team will develop the vision, guidelines, and objectives for the Mutual Assistance Plan. In addition, the Mutual Aid Team will work closely with FEMA to design and implement a permanent solution for significant PREPA emergency scenarios.

COA HIGHLIGHT

ENR COA-012

Coordinate federal and state emergency response with private sector

Prior to the 2019 hurricane season, PREPA and the Mutual Aid Team will develop the first iteration (30% solution) of the Mutual Assistance Plan.

Given the short timeframe, it is expected that this version will require additional maturation. Specific elements of the Mutual Assistance Plan will include:

- Identifying the appropriate vehicle for mutual assistance participants.
- Developing formal event triggers to ensure mutual assistance providers are aligned with PREPA; document these event triggers in formal agreements and align these event triggers to the ERP.
- Defining communication protocols between PREPA and Mutual Assistance Providers.
- Identifying flyaway teams to arrive on-island prior to broader deployment to work with PREPA to identify resources needed and confirm deployment plans for mutual assistance providers.
- Defining a standard format for damage assessments that can be put into work packages for deployment teams and meet the requirements for FEMA reimbursement.

Similar to the ERP, this iteration of the Mutual Assistance Plan should be circulated, confirmed, and finalized prior to the 2019 hurricane season. The Mutual Assistance Plan should also be reviewed annually to incorporate lessons learned and updated information after each hurricane season. Mutual Assistance participants should also be confirmed annually through formal agreement extensions. Any changes to the Mutual Assistance Plan should be communicated to all impacted stakeholders and may require additional socialization and training.

Supply and Logistics Plan

Several significant and core challenges to initializing, leading, and completing restoration activities after Hurricane Maria fell into the categories of resource acquisition and management (logistics), supply chain, and governance. Accordingly, the Working Group recommends a Supply and Logistics Plan be developed to identify processes associated with pre-staging, communication, procurement, lodging, and transportation during and after an emergency event in Puerto Rico. It is estimated that this initiative to develop a Supply and Logistics Plan will cost approximately $3 million between 2019 and 2021. In addition, it is estimated that operationalizing depots and staging sites to support this plan will cost approximately $50 million between 2020 and 2025.

The Working Group recommends forming a Supply and Logistics Team in early 2019 to develop the Plan with members from PREPA, the Commonwealth, the federal government and military, and the NYSC, among others. This team will develop the vision, guidelines, and objectives for the Supply and Logistics Plan. An important task for the Supply and Logistics Team will be to define the role of federal agencies in procuring, expediting, and managing the delivery of major materials from the mainland suppliers to the island for an emergency event. The team should also review all existing PREPA materials related to supply and logistics as well as best practices from the mainland.

Develop Supply and Logistics Plan (Pre-Hurricane Season 2019)

Prior to the 2019 hurricane season, PREPA and the Supply and Logistics Team will develop the first iteration of the Supply and Logistics Plan. Given the short timeframe, it is expected that this version of the plan will be a 30% solution and will require additional maturation during and after the 2019 hurricane season.

COA HIGHLIGHT

ENR COA-009

Design and build fuel supply chain to provide reliable energy source

Specific elements of the Supply and Logistics Plan align to ENR COA-009 and will include:

- Determine Sources of Supply
    - Identify current sources of supply
    - Working with PREPA logistics and supply personnel, determine required spares and sources of supply
    - Establish supply contracts for emergencies
    - Develop barging plan
- Determine Depot and Staging Areas

- Examine and assess existing depots and staging areas agreed to with the Commonwealth and local governments; identify gaps
  - Establish formal staging agreements where appropriate with local governments
  - Develop recommendations for future staging recognizing new modernized grid, and effectiveness to aid in expedited recoveries
- Work with FEMA to determine wraparound services such as pre-staging, communications, procurement, lodging, and transportation
  - Prearrange hotels and other critical "must have" supplies (potable water), etc.
  - Prearrange meals and dining areas
  - Prearrange work sites, ICS locations, and space for Mutual Assistance crews/teams
  - Prearrange transportation (cars, trucks)
- Define processes, protocols, and partnership agreements for the TOC in Monacillo, including emergency supply agreements with food, fuel, and water suppliers near the Monacillo Complex, as well as the COE in Santurce (a support center for the TOC) and the regional operational centers (COR)
- Draft Sourcing and Transportation Plan
- Address arrival and departure, port, customs, and delivery issues

Similar to the ERP and Mutual Assistance Plan, this iteration of the Supply and Logistics Plan should be circulated, confirmed, and finalized prior to the 2019 hurricane season.

Revise and Mature Supply and Logistics Plan (2020+)

While the 30% solution of the Supply and Logistics Plan will provide a robust framework in advance of the 2019 hurricane season, it is critical that the plan continue to be revised and matured over the next 3 years to get to a comprehensive, near 100% solution. Specifically, lessons learned, new information, insights, and updated priorities should be incorporated into the Supply and Logistics Plan.
Over the long-term, the Supply and Logistics Plan should be reviewed annually, and changes should be communicated to all stakeholders.

An important component of the Supply and Logistics Plan is the development or enhancement of centralized depots and staging sites. It is estimated that five centralized depots will be operationalized between 2020 and 2025 at an estimated cost of $50 million total, or $10 million each. This assumes that each depot will cost approximately $300 per square foot for a 33,000 square foot site. This is a high-level estimate that will require additional refinement once site locations and capacity requirements are confirmed. Site costs will vary depending on whether the site currently exists and needs to be hardened or if it needs to be built on existing government-owned or privately-owned land.

For improved logistics during an emergency event, these depots should meet the following criteria:

- Structures should be environmentally controlled and hardened to properly store and protect equipment.
- Structures should be geographically optimized for efficient and effective maintenance and restoration. This includes being near transportation capabilities (e.g., ports, airports, highways), staging sites, and major restoration areas (e.g., San Juan, Aguadilla, Ponce, Culebra, Vieques, Humacao).
- Depots should have both distribution and transmission spare equipment to meet all the needs of the facilities and infrastructure that it will serve.

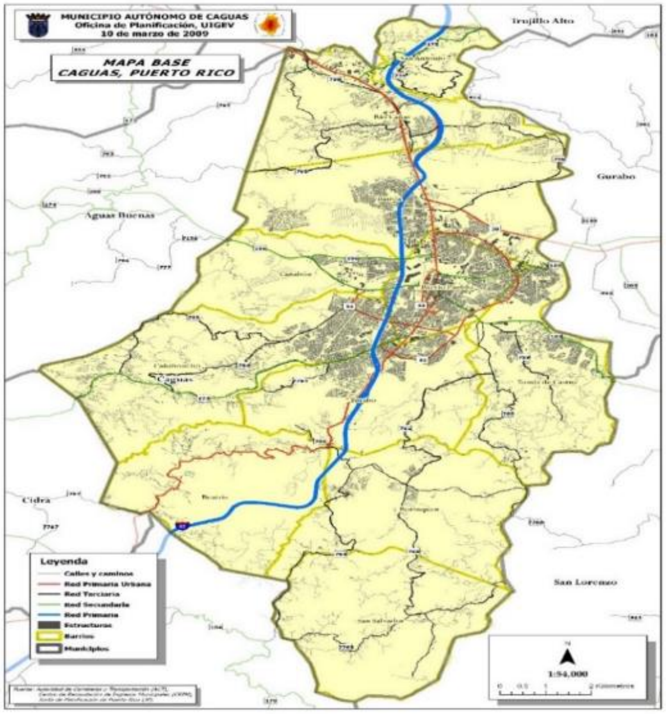
Given PREPA has two existing depots at Palo Seco and Ponce, it is recommended that, if feasible, these be used as two of the five centralized depots, although they will require additional hardening, environmental controls, and modernization. Specifically, an assessment of the Palo Seco depot (General Store #11 and Engineering Warehouse #5) should be conducted to determine if it can be appropriately hardened or if it needs to be relocated because it is in a tsunami flood area.

If relocation is determined necessary, one potential location for a new depot is the Municipality of Caguas as it is a central municipality with access to both the north and the south of the island via Highway 52.

Figure 6-6. Map of Palo Seco Plant and Depot in Flood Area

Source: PREPA, December 20, 2018.

Figure 6-7. Map of Caguas (Potential Palo Seco Depot Relocation)



Source: PREPA, December 20, 2018

In addition to the Ponce depot and Palo Seco depot (or relocated depot at Caguas), potential locations for the other three depot sites that would require new construction include:

1. Eastern Puerto Rico at Roosevelt Roads (new site on Commonwealth land with plenty of land, airstrip, and port)
2. Northwest corner between Aguadilla and Mayagüez (new site near freeway system from northwest of Ponce, and Port of Mayagüez)
3. East of San Juan such as Sabana Llana (plenty of land, near freeway system, port of San Juan, and International Airport)

Importantly, the results of the Palo Seco relocation assessment will also determine the capacity needed for this depot. If the depot is relocated to Caguas and has significant capacity, the Sabana Llana depot may not be needed. A more detailed study of existing and required depots and staging sites will need to be completed to further refine these locations and the cost estimate.

Train to, Table Top, and Exercise to the ERP, Mutual Assistance, and Supply and Logistics Plan

Training and exercising to the ERP, Mutual Assistance Plan, and Supply and Logistics Plan will be critical to Puerto Rico's preparedness for future hurricanes and other emergency events. It is through training and exercises that PREPA personnel and other stakeholders will have the knowledge, skills, and abilities needed to perform the tasks identified in the Plans.

While PREPA has provided certain emergency response training to staff at five locations (Monacillo, San Juan Power Plant, Palo Seco Power Plant, Cambalache Power Plant, and Costa Sur Power Plant) and is in the process of training other grid operations personnel, training should be expanded to cover all the plans described previously and provided to all staff at PREPA. Training and exercises should be provided on a regular cycle, including on an annual basis and when the plans are updated.

Specific tasks that should be completed prior to the 2019 hurricane season include:

- Develop a training plan with topics, dates, and the required participants.
- Execute the training plan and provide training on the updated PREPA Emergency Response, Mutual Assistance, and Supply and Logistics Plans to expanded sets of PREPA personnel.
- Develop and provide education and outreach materials related to the plans.
- Conduct an emergency response, scenario-based walk through (table top) of a Category 4 hurricane approaching, making landfall, and leaving a wake of destruction to validate the ERP, Mutual Assistance Plan, and Supply and Logistics Plan.

PREPA and supporting entities should also conduct "after action" evaluations post-hurricane(s) to learn from problems encountered. This training cycle should be repeated annually.

Cost Estimates

The major investment areas for emergency preparedness include:

- Spares, Trucks, and Equipment (Hurricane Season 2019): $20 million
- Depot and Staging Areas (Modernized Grid): $50 million
- Required Spares (Critical and long lead time) to support 5-6 weeks (Modernized Grid): $20 million
- Lifecycle Replacement of Trucks and Equipment (Modernized Grid): $15 million
- Emergency Response and Mutual Assistance Plans: $4 million
- Supply and Logistics Planning: $3 million

Table 6-2. Emergency Preparedness Major Investment Areas ($M)

Major Investment Areas	*Cost ($M)*
Spares, Trucks, and Equipment (Hurricane Season 2019)	$ 20
Depot and Staging Areas (Modernized Grid)	$ 50
Required Spares (Critical and long lead time) to support 5-6 weeks (Modernized Grid)	$ 20
Lifecycle Replacement of Trucks and Equipment (Modernized Grid)	$ 15
Emergency Response and Mutual Assistance Plans	$ 4
Supply and Logistics Planning	$ 3

Source: GridMod Plan Funding Analysis

As described throughout this section, these are high level estimates based on the information available at the time of drafting this plan. Many components of this estimate required the Working Group to make assumptions regarding the current and future state of the grid. Additional study and analysis is needed to refine this estimate.

6.3 Regulatory & Policy

The overall GridMod Plan calls for the transformation of the Puerto Rico energy system, with substantial investment in a hardened and more reliable T&D system, and with a significant shift to renewable and distributed generation resources. The transformation envisions increased reliability and resiliency with replacement of unreliable and inefficient peaking and intermediate-load fossil generation with more flexible and efficient resources, greater reliance on LNG as a fuel source, and a more dispersed, fuel-diverse generation portfolio on the island.

For the successful implementation of the GridMod Plan, it is necessary to examine and address several regulatory requirements and policy issues (such as the industry codes and standards, the IRP and RPSs), discuss potential regulatory reforms and solutions, highlight pros and cons of different options, and outline an implementation roadmap to follow. The Working Group's analysis and recommendations in this area are discussed in the following sections.

Codes and Standards

Supported by industry subject matter experts, COR3 and PREPA are working to identify commonly accepted industry codes and standards and draft additional criteria to govern the design and construction for the new energy system. This effort includes the review and updating of PREPA's current standards to align with accepted industry standards for improved reliability, resiliency, and maintainability for Puerto Rico's power grid. The Energy Sector Office is providing the required codes and standards documentation to FEMA, as required to satisfy the eligibility review of requested funding for permanent projects.

Codes and Standards Design Criteria Documents (DCDs) are under development for the following disciplines: distribution, transmission, protection and control, substations, civil/structural, and communications. The Codes and Standards Team is reviewing and updating PREPA-specific design documentation and drawings and creating new definitions and drawings where needed. The drawings are designed to provide uniformity in design and construction of electrical components, and to detail material and construction requirements that will be used in constructing new facilities. The codes and standards documents will also serve as specifications for procurement of engineering and construction firms.

Integrated Resource Plan (IRP)

PREPA has developed an IRP to guide its near, intermediate, and long-term resource development and procurement activity. Under Puerto Rico Energy Bureau (PREB) regulations and pursuant to Act 57-2014, PREPA is required to complete an IRP every 3 years.

The IRP must consider the following:

- A range of reasonable resources to meet PREPA's demand over a 20-year period
- A range of load conditions
- Evaluate both supply-side and demand-side resource options
- Include a 5-year Action Plan to guide resource procurement following IRP approval

PREPA has retained Siemens to assist with the analytic work in developing its IRP. Siemens released the preliminary drafts and analysis in late September-October 2018 and on February 13, 2019 filed its IRP for review by PREB. As the IRP results envision a substantial shift toward renewable energy resources and battery storage technology, PREPA also examined transmission and deliverability considerations related to widescale renewable and storage resource deployment.

On March 14, 2019, PREB issued a Resolution and Order which directed PREPA to revise the February 13, 2019 IRP to cure a number of procedural issues, and to complete additional and revised analyses to make the IRP fully compliant with PREP's regulations and previous orders. PREPA submitted a revised IRP on June 7, 2019, which resulted in some changes to PREPA's IRP, particularly in areas related to near-term renewable resource expansion, the extent to which LNG-fueled thermal generation is feasible and cost-effective, and the ultimate definition and implementation of islandable grids. The IRP results indicate a strong transformation of the Puerto Rico energy mix away from oil-fueled generation toward solar powered generation. For fossil generation, the IRP envisions substantially higher use of LNG as a fuel source, with one to three ship-based LNG terminals, and a potential land-based LNG terminal in the San Juan area.

The IRP details a 5-Year Action Plan, which outlines a series of steps PREPA proposes to follow to implement results from the IRP. Under current PREB rules, PREPA generation procurement activity must be consistent with the Action Plan.

The IRP Action Plan Includes the Following Steps:

- **Maximize the rate of installation of solar PV generation for the plan's first 5 years (2019 to 2023)**. PREPA plans to install up to 1,800 MW of solar PV from 2019 to 2023. RFPs will be issued for blocks of approximately 250 MW of solar PV. The actual amount installed will depend on the bid pricing received and PREPA's ability to interconnect the projects in an efficient manner.
- **Install 920 MW of battery energy storage in the first 5 years of the plan.** The amount of battery storage installed varies with the degree of solar penetration and is also influenced by regulatory policy such as the approach taken for renewable energy curtailment. Here again, the recommended action places Puerto Rico on a path toward a more diverse and decentralized energy system, with improved economics and reliability.

- **Convert San Juan 5 & 6 combined cycle (CC) to burn natural gas.** This is a transition activity to improve reliability and economics at San Juan 5 & 6, and to improve generation reliability in the San Juan area.
- **Install new gas turbines (GTs) capable of burning containerized natural gas.** The Action Plan includes replacement of existing peaking resources at various locations across the island, with new peaking resources, or with more flexible reciprocating engine technology. The peaking resources were critical in providing local area support post-Hurricane Maria and are an important supply source to support the concept of islandable grids in Puerto Rico. However, across the peaker fleet there are availability and reliability deficits, so fleet replacement is critical to achieve industry standard levels of reliability and resiliency on the island.
- **Develop a land-based LNG terminal in San Juan to supply a new CCGT and San Juan 5 & 6 CC**. This action is designed to create a more sustained and economic fuel solution for the northern part of the island, with LNG supply able to provide natural gas at Palo Seco and San Juan**.**
- **Install a CCGT at Palo Seco** to improve reliability and resiliency in the San Juan area, and to improve overall economics for PREPA ratepayers. This is a robust decision across all IRP scenarios.
- **Extend a renegotiated contract with EcoEléctrica, or alternatively, install a CCGT at Costa Sur upon EcoEléctrica contract expiration**. The IRP Action Plan envisions contract extension at EcoEléctrica at a reduced price compared to the current PPOA. The Action Plan also suggests pursuing development activities for a replacement CC at Costa Sur so PREPA is positioned to procure needed efficient generation in the event that negotiations with EcoEléctrica prove unsuccessful.
- **Develop a ship-based LNG terminal at Mayagüez.** The existing peaking resources at Mayagüez are the most efficient simple cycle plants in PREPA's fleet, so it is economic to bring ship-based LNG to fuel those resources.
- **Develop a ship-based LNG terminal at Yabucoa.** Under the Action Plan, this terminal would fuel a CCGT in the Yabucoa or Caguas area to improve reliability and resiliency in the northeast part of the island, including San Juan.
- **Install a CCGT at Yabucoa, or Mayagüez**. The IRP Action Plan includes a CCGT unit at Yabucoa including development of a ship-based LNG terminal. The plan also suggests pursuing development activities for a CC at Mayagüez as a hedge in case development or LNG procurement at locations such as Yabucoa are not successful.
- **Upgrade the transmission network to support an islandable grid.** The IRP also includes the concept of islandable grids. This concept is advanced as a way to improve overall electric reliability on the island, especially in the event another strong hurricane occurs. Both scenarios include substantial transmission system investment to support the potential implementation of islandable grids.

The Puerto Rico Energy Public Policy, Act 17-2019 puts Puerto Rico on a path toward 100% renewable energy by 2050. Implementation of this law will further change the IRP and the Action Plan.

As the IRP is the official resource plan for PREPA and for Puerto Rico, the GridMod Plan implementation will be adjusted based on the final plan approved by PREB. The regulatory issues discussed below apply as implementation concerns, regardless of the exact form of the final IRP.

Future State

The overall GridMod Plan envisions substantial investment in new renewable energy and energy storage facilities, and substantial expansion of LNG import capability. Additional Puerto Rico energy policy initiatives also envision increased private sector investment activity in the generation sector, with targeted private ownership of new renewable, storage, and fossil generation resources, and potential privatization of existing generation.

The GridMod Plan's regulatory and policy section is intended to identify key areas where policy reforms or development are likely needed to ensure that the IRP result can be implemented as effectively and efficiently as possible. Many of these areas will also be addressed during implementation of the Puerto Rico Energy Public Policy, Act 17-2019.

A key goal of this initiative is to identify areas where potential challenges are likely to be encountered in transforming the Puerto Rico electric system, and to examine policy and regulatory changes that will help to overcome or offset those challenges. Many areas of potential challenge arise due to a greater reliance on private and competitive forces in the industry.

Implementation Roadmap

Specific areas where regulatory initiatives should be examined are discussed in the following sections. Estimated costs for implementing regulatory changes are $12 million.

Transmission Interconnection Process and Studies

With a plan to develop substantial solar PV generation on the island, the issue of providing non-discriminatory interconnection and transmission access is an important policy area. In mainland US markets where substantial solar power plant development activity has occurred, the magnitude of project requests for interconnection studies and for transmission access has quickly overwhelmed host utility companies and independent system operators tasked with completing interconnection studies. This occurred because transmission access and interconnection capability are key milestones affecting successful project development, and relatively long lead times are needed to study the transmission system and make deliverability and network upgrade evaluations. This causes project developers to take out options on land for project sites, develop engineering drawings and details, and submit requests for interconnection studies. In many situations, the requests may vary and cover multiple project configurations, which require multiple transmission studies.

To ensure PREPA is not overwhelmed with interconnection study requests, causing delay and uncertainty in project development cycles, it will be beneficial to examine current regulatory policies and processes governing interconnection options to ensure the process is fair, non-discriminatory, and efficient. Under the rules, any generator with a rated capacity greater than 5 MW is considered a producer of large-scale energy, and its interconnection is assessed under a power purchase process (power purchase agreement) or other services, as applicable.

The interconnection rules for DER projects of 5 MW or less connecting to the transmission grid require that PREPA complete an interconnection assessment within 120 days of receiving a completed request. For DER projects 1 MW or less connecting to PREPA's distribution system, the interconnection rules provide faster timeframes, with projects that are 10 kW or less receiving the fastest review. The rules also outline required documentation that must be submitted by project developers and a process for working with PREPA in cases where additional documentation is needed.

Utility-scale solar projects are often greater than 5 MW in capacity, averaging 60 MW per project in the US mainland. It would be disadvantageous to PREPA ratepayers to procure large-scale solar resources through a net energy metering (NEM) program.

These interconnection rules are subject to revision with passage of the Puerto Rico Energy Public Policy, Act 17-2019. Successful implementation of generation transformation will require Puerto Rico to examine interconnection processes and to develop standardized policies and procedures for addressing the interconnection for projects developed to sell power to PREPA through power purchase agreements, feed-in tariffs, or other procurement mechanisms.

For Puerto Rico to integrate large amounts of solar generation, it will not only be important for the interconnection rules to allow fair, non-discriminatory transmission access, but also to create a rational queuing and study process so that PREPA can realistically and efficiently manage the process.

In developing the overall interconnection process, there are some considerations that should be examined and potentially adapted based on studies and approaches that have proven successful in other jurisdictions:

- Establish standard fee schedules for interconnecting projects that do not trigger network upgrades or related transmission reinforcement.
- Develop pre-application reports, available to project developers for a set fee, that provide summary interconnection and transmission information at a given location.
- Post information about preferred interconnection points, both from cost and process review timeline perspective.
- Posting line/substation capacity ratings and technical information for review and use by project developers can be beneficial in having projects sited in preferred electrical locations. Studies indicate providing this information in advance also reduces project cancellations, so it has potential to reduce interconnection study workload for PREPA and to focus resources on projects most likely to successfully interconnect.
- Provide fast-track interconnection process based on project size/favorable location. Develop a tiered screening process for projects requiring more detailed review.

- Publish equipment cost list for common interconnection investments. Publish typical interconnection cost for similarly sized/situated project.
- Develop cost-sharing allocation process for common interconnection upgrades (funded initially by first project interconnecting, but proportional cost sharing for subsequent interconnections).

Renewable Project Site Selection

Another key challenge in transforming the Puerto Rico energy system toward a more resilient, distributed energy system, focuses on siting new generation in the most beneficial locations. The Working Group expressed a goal of designing a collector system approach for interconnecting solar PV and battery projects.

Under this approach, private solar projects under development will be encouraged, and potentially incented, to locate in areas that facilitate connection to common substations so that several projects interconnect at the same place.

This approach allows for more rational T&D system planning, and for faster integration of renewable resources on the island. It will also improve the efficiency of system operations as those resources are integrated. This is another key area of regulatory policy development in terms of supporting a planning process that uses a collector system design, and in ensuring the interconnection process and potential cost allocation/tariff/incentive structure guides generation developers to follow that process.

Policy options to consider in this area include:

- What policies/incentives are needed to provide incentives for generators to interconnect at preferred locations? Adequate incentives may be developed through interconnection cost differences, or application of penalties or bonuses to encourage interconnection at preferred locations.
- To what extent can preferred scoring mechanisms in RFP processes conducted by PREPA be used to both limit the number of needed interconnection studies, and to create adequate incentives for use of preferred interconnection locations?
- Would a feed-in-tariff structure be advantageous in Puerto Rico in providing incentives to renewable projects to connect in preferred sites and in attracting desired levels of renewable energy development?
- How have other jurisdictions addressed this issue?
- How will interconnection costs be allocated to projects if PREPA builds a collection system and substations in advance of project development, or oversized relative to queued projects?

Commercial and Residential Solar Development

> **COA HIGHLIGHT**
>
> ***ENR COA-027: Establish regulations to transform the energy sector***

With substantial anticipated solar expansion on the island, it will be necessary and beneficial to have a portion of those resources use rooftop commercial and residential sites, rather than relying wholly on utility-scale solar projects developed on greenfield sites. As the island's geography has many areas with steep incline and/or robust vegetation, it appears that siting of large-scale solar may encounter some challenges, or at least higher costs. The Working Group believes it will be beneficial to explore regulatory policy options to maximize the use of rooftop solar, provided it is not cost prohibitive and provided that its development is not harmful to PREPA customers unable to participate. For example, PREPA's IRP forecasts 362 MW of customer-owned solar expansion by 2029, and 807 MW by 2038.

In many jurisdictions, rooftop solar adoption has occurred through NEM programs, particularly for residential solar expansion. NEM is attractive for residential customers, because it eases implementation of solar panels at the residential sites and is convenient for customers. The effective pricing level for solar energy production in an NEM framework is the fully embedded cost of service for each affected customer class.

This pricing level provides a subsidy to NEM customers because they are compensated at levels that reflect utility system T&D embedded costs, in addition to the generation cost. This is a positive incentive for customers able to afford residential solar systems at their home or business. However, for customers who cannot afford solar, or who reside in apartments or condominiums that do not allow them to install their own solar technology, an NEM program can create a cost-shifting that disadvantages them. As part of the transformation strategy, another area of potential regulatory action is to examine the design of an NEM, or a commercial and residential solar pricing structure that leads to economically advantageous siting of residential and rooftop solar, but that does not unfairly shift costs to lower income classes of consumers, or consumers who are unable to participate in NEM programs.

Many states and jurisdictions globally are reexamining the remuneration of solar at the grid and at the individual customer level to develop tariff schemes that more accurately pay for DER based on their locational value while balancing the cost passed on to all customers. There are numerous efforts in the US and around the world to reexamine distributed solar tariffs principally structured as net metered schemes to develop more sophisticated compensation based upon localized value.[38] Developing seamless interconnection and modern compensation schemes will be critical steps in the regulatory and policy path toward a grid designed to integrate more renewables.

[38] See for example the ongoing Value of Distributed Energy Resources" or "VDER" New York Department of Public Service, Case # 15-E-0751.

The Working Group believes multiple policy options should be explored to address the following:

- How have current net metering policies in Puerto Rico succeeded, and how have they failed?
- What is the best way to implement the NEM program outlined in the Puerto Rico Energy Public Policy, Act 17-2019?
- What policies will provide the appropriate incentives for location and sizing, and minimize cross-subsidization?
- What alternatives to NEM have been implemented or studied in the industry, and how could those translate to use in Puerto Rico?
- If FEMA funds rooftop solar, what policies on ownership need to be put in place? Would this be an opportunity to enable low income customers to participate in rooftop solar?
- Should Puerto Rico further develop its community solar options so that residents living in condominium or apartment complexes (or are otherwise unable to participate in rooftop solar programs) are better able to participate in solar energy procurement programs?

PURPA Compliance

To date, PREPA and Puerto Rico have not seen widescale project development occurring pursuant to the Public Utility Regulatory Policy Act of 1978 (PURPA). Under PURPA, renewable energy projects with a capacity of 80 MW or less may be eligible to obtain Qualifying Facility (QF) status. With QF status, a project may be entitled to sell capacity and energy produced by the project to PREPA at an avoided cost rate. With the intended expansion of renewable energy resources on the island, a number of projects could seek QF status to sell output to PREPA at avoided cost. It is in the interest of Puerto Rico to procure renewable resources through a competitive process, rather than through a PURPA compliance-based process.

PURPA compliance is implemented at the state level, with oversight from the FERC. Puerto Rico falls under the state definition under PURPA. In states where renewable projects have received avoided cost type payments, avoided cost is typically calculated based on the marginal cost of energy and capacity for the purchasing utility. In Puerto Rico, this approach could result in paying avoided cost rates that are calculated based on oil-based fuel costs, which would result in overpayment to renewable QF resources. Such an approach would be a deterrent to efficient reconstruction and transformation of the Puerto Rico power system. The Working Group believes this issue should be examined in a regulatory process and that PURPA compliance strategies should be developed, followed by appropriate regulatory filings with FERC.

Key questions to examine in the regulatory proceedings include:

- What is an appropriate avoided cost approach for Puerto Rico? FERC has accepted technology-specific avoided cost approaches that Puerto Rico may want to explore.
- What other policy options should be adopted to avoid overpaying for QF projects? Another potential PURPA compliance strategy is to use RFP processes to select the most competitive project(s), and the bid price of the winning project is determined as its avoided cost.
- What FERC filings are needed to implement preferred policy options?

Regulatory Model

Puerto Rico's overall regulatory and ratemaking structure is complicated by the current bankruptcy, privatization, and liberalization initiatives, and by the introduction of FEMA public funding of a portion of investments. Anticipated increases in microgrid development, independent power producers, and potential cooperative formation further complicate future regulatory direction.

As an area of potential regulatory reform, the current regulatory structure may require examination in order to outline how that structure will work with a transformed Puerto Rico energy system. In alignment with ENR COA-027, it may be beneficial to make modifications to the regulatory structure to more efficiently accommodate the transformation.

As part of this evaluation, the examination and adoption of key features of alternative regulatory models and regulatory changes being implemented in the US mainland may prove beneficial in Puerto Rico.

Jones Act Options

The Merchant Marine Act of 1920, also known as the Jones Act, was originally designed to create a safe network of merchant mariners within the US after World War I in reaction to the US fleet being destroyed by the German navy. The Jones Act requires all goods shipped between US ports to be transported by US vessels (and operated primarily by Americans). The act is meant to ensure the US has a merchant marine fleet that can transport goods between US ports, increase national security during war times, and support a US maritime industry. The Jones Act also outlines the maritime industry's responsibilities regarding the safety and well-being of crew. It safeguards the rights of sailors from being exploited and requires compensation for injuries due to employer negligence and outlines safety requirements.

Under the Jones Act, any vessel can enter Puerto Rico. However, for the transportation of goods between two US ports, that shipping must be carried out by a vessel that was built in the US and operated primarily by Americans. The law also restricts transportation from foreign vessels, if those vessels also have stop-off deliveries in other US mainland ports.

Some studies have indicated that shipping costs to Puerto Rico are materially higher because of the Jones Act. As the Working Group envisions substantial imports of LNG, and of capital equipment to complete the transformation effort, a waiver of the Jones Act has potential to significantly lower the cost of grid modernization in Puerto Rico. Requirements of the Jones Act were waived by the Trump Administration following Hurricane Maria, but that waiver lasted only 10 days and was not renewed or extended.

Absent legislation, a longer-term waiver requires a request from the Department of Defense that the waiver is needed for national defense, or a finding by the US Maritime Administration that there is a shortage of Jones Act-compliant vessels. In addition, the Secretary of Homeland Security must also declare the waiver to be in the interest of national defense before it is issued. Those are steep hurdles and would require substantial cooperation from the federal government. A waiver may be possible for LNG imports, as there are currently no Jones Act-compliant vessels in operation or under construction

Alternatively, the Jones Act could be revisited legislatively, and the option of waiving the act's requirements for Puerto Rico considered. Recently, the Puerto Rico House announced it would ask the US Congress for a permanent waiver. Previous legislative measures seeking to provide a permanent Jones Act waiver to Puerto Rico, introduced in the US Senate following Hurricane Maria, have not advanced toward legislation. The Working Group will monitor activities contemplating a Jones Act waiver and will also develop potential cost savings estimates for Puerto Rico, if a permanent waiver were granted.

CONCLUSION AND NEXT STEPS

CENTRAL OFFICE OF RECOVERY, RECONSTRUCTION AND RESILIENCY

Puerto Rico Electric Power Authority

7. CONCLUSION AND NEXT STEPS

In this GridMod Plan, the Working Group has detailed the repair, rebuild, and reconstruction programs and capital expenditures needed in the Puerto Rico energy sector. These reconstruction programs are needed to repair and rebuild permanent damage of the Puerto Rico power system caused by the destructive Hurricanes Irma and Maria in late 2017, and to achieve industry standard reliability and resiliency. The GridMod program outlined in this plan recognizes the unique geography and demography of Puerto Rico, and the challenges those features create in providing industry standard levels of electric reliability and resiliency.

The reconstruction strategy in the GridMod Plan embraces technologies that performed well during the hurricanes and replaces technologies that failed. The reconstruction strategy also develops a more decentralized power system in Puerto Rico, tailored to the island's geography, demographics, and population dispersion, and uses a greater degree of DER and microgrids in tandem with a rebuilt and strengthened T&D system. This rebuilt system will prove much better able to withstand and react to future hurricane events, will preserve investments already made by FEMA (and other funders), and will enable Puerto Rico to enjoy electric system reliability and resiliency at performance levels much closer to industry standards.

Importantly, the strategy reflected in this plan also recognizes the significant changes required in "People, Process, Organization, and Performance" areas that drive utility operations. Further, the amount of change that will be introduced to legacy "ways of working" and related organizational cultures will be significant and will need to be actively managed as detailed project plans for these initiatives are developed.

Next Steps

The Working Group recognizes that there are several technical areas where further study and refinement would be beneficial after publication. In those cases, COR3 will continue to collaborate with PREPA to ensure needed studies and analyses are completed. A key example of this is the PREPA IRP, which was filed with PREB in February 13, 2019 is undergoing further revision pursuant to PREB review and direction. In addition, a more detailed breakdown of and next level planning for both the T&D grid, technology and business readiness workstreams will be undertaken. This will help prioritize projects based on need and value/benefit to PREPA and the overall energy sector. Programs specified in the GridMod Plan will be used as a guide for the ESO and PREPA to execute the energy sector recovery and reconstruction program.

Under COR3's direction and oversight, the GridMod Plan will be used to develop Project Worksheets for review and potential funding by FEMA; as necessary, alternative funding sources will also be evaluated. The Working Group has provided an initial categorization of funding sources and COR3 is committed to working closely with FEMA and other stakeholders to find the best path forward to reconstruct a Puerto Rico power system capable of providing industry standard levels of reliability and resiliency to the people of Puerto Rico.

Key activities post-publication of the GridMod Plan includes:

- **Stakeholder Roadshow** – Key Puerto Rico stakeholders will be identified and engaged so they fully understand the benefits of the GridMod Plan to the island. It is imperative that Puerto Rico's influential groups/organizations link the power system modernization as the primary driver of economic development for the island. Reliable energy together with telecommunications, water, and transportation are considered lifeline systems—as identified in the Governor's Recovery Plan. The GridMod Plan is Puerto Rico's plan to "transform the energy system to ensure customer-centric, affordable, reliable, and scalable electricity that incorporates more renewables, microgrids, and DER; can drive new businesses and employment opportunities; and can support residents' well-being."
- **Emerging Technologies R&D Center** – COR3 will embark on activities to establish a center (preferably with one of the major universities in Puerto Rico) to provide an avenue to fully support validation and verification of systems and enabling technologies.
- **Detailed Capital Planning for PREPA's Energy System** – Using the GridMod Plan as a basis, COR3 will work with PREPA to solidify the next level planning, schedule, and budget for PREPA's energy system with consideration to various scenarios. These plans will drive the capital deployment and execution efficiency of the reconstruction efforts.
- **Detailed Capital Planning for PREPA's Technology and Communications Infrastructure** – Using the technology-centric programs outlined in the GridMod Plan, COR3 will work with PREPA's technology teams to detail the sequencing and integration of IT/OT systems, communications networks upgrades, and their associated cybersecurity activities.
- **Emergency Preparedness** – The 2019 storm season is fast approaching; preparedness is a foundational aspect of ensuring that ongoing investments in the reconstruction efforts to transform Puerto Rico's energy system are harmonized with organizational effectiveness in emergency planning and execution.

APPENDIX

APPENDIX A. GLOSSARY

Term	Definition
Advanced Distribution Management Systems (ADMS)	An ADMS is a grid management platform that integrate distribution operations with outage management and SCADA systems, maintaining a single as-operated model of the distribution network that is based off of the as-built model.
Automated Feeder Switching (AFS)	Process that automatically isolates and reconfigures faults along the distribution or transmission system via sensors, controls, switches and communication systems in order to limit outages.
Asset Management System (AMS)	AMS provide utilities with a means of managing infrastructure components to extend service life, reduce maintenance costs, and address potential failure points.
Cable	A conductor with insulation, or a stranded conductor with or without insulation and other coverings (single-conductor cable), or a combination of conductors insulated from one another (multiple-conductor cable).
Capacity	The maximum output of electricity that a generator can produce under ideal conditions.
Circuit	A conductor or system of conductors through which an electric current is intended to flow.
Combined Cycle (CC)	A form of power generation that captures exhaust heat often from a CT (or multiple CTs) to create additional electric power beyond that created by the simple CT and enhance the overall efficiency of the unit by producing more output for the same level of input.
Combined Cycle Gas Turbines (CCGT)	Generation technology that uses gas-fired turbines to create energy and then captures resulting heat waste to create steam, which powers steam turbines to increase energy output and efficiency.
Combustion Turbine (CT)	A form of power generation that forces air into a chamber heated through the combustion of a type of fuel (often diesel or natural gas) which causes the heated air to expand and power the circulation of a turbine that spins an electric generator to produce electricity.
Conductor	A wire or combination of wires not insulated from one another, suitable for carrying electric current.
Customer Information Systems (CIS)	The utility customer information system (CIS) market is composed of utility companies looking for commercial off-the-shelf software packages that address business-critical utility meter-to-cash (M2C) and customer service business processes. M2C functions covered include: account maintenance, order processing, product/service management, rate design, billing, credit collection, accounts receivable, statement preparation, and payment processing.
Damage Assessment & Emergency Response Tools	Centralized platform with mobile components to assess and respond to system emergencies. These system coordinate assets, people, and technology to more efficiently responds to disasters.
Data Analytics	Applications and systems drawing insights from raw information sources grounded upon improved assets, grid operations, and customer systems such as: DER, DR.
Data Center	Centralized location of computer systems and communications systems.
Disconnect Switches	Disconnect switches or circuit breakers are used to isolate equipment or to redirect current in a substation.
Distribution Communications	Communication systems providing monitoring and control of distribution assets in substation, feeders, and customers.
Distributed Energy Resources (DER)	Physical and virtual assets that are deployed across the distribution grid, typically close to load, and usually behind-the-meter, which can be used individually or in aggregate to provide value to the grid, individual customers, or both.
Distributed Energy Resource Management System (DERMS)	DERMS enables optimized control of the grid and DER (to the extent that a utility may be able to dispatch and control DER). To minimize disruptions and the presence of phantom loads, utilities need to manage the grid more proactively. Common use cases include volt/volt-ampere reactive (Volt/VAR) optimization, power quality management, and the coordination of DER dispatch (when possible) to support operational needs.
Distribution System	A system that originates at a distribution substation and includes the lines, poles, transformers, and other equipment needed to deliver electric power to the customer at the required voltages.
Distribution Management System (DMS)	A DMS is a suite of application software supporting electric distribution system operations. These may consist of real-time, simulation, and static engineering applications.
Demand Response Management Systems (DRMS)	DRMS helps utilities manage DR programs and improve program ROI. It allows utility operators to view and add to the database of loads available for DR, to call events and/or issue pricing signals, and to perform the measurement and verification after events to determine how much customers need to be compensated for reducing their load.

Term	*Definition*
Electric Circuit	Path followed by electrons from a power source (generator or battery) through an external line (including devices that use the electricity) and returning through another line to the source.
Emerging Technologies Testing and R&D Center	Validation and verification of technology and its application within the PR grid, focused upon meeting functional and integration requirements and training next generation workforce.
Energy Efficiency (EE)	Any number of technologies employed to reduce energy consumption. Examples include more efficient lighting, refrigeration, heating, etc.
Energy Management System (EMS)	An EMS interacts with generation and grid assets via SCADA to perform grid operations.
Enterprise System Bus (ESB)	An ESB is fundamentally an architecture, set of rules and principles for integrating numerous applications together over a bus-like infrastructure. An ESB provides handling of data from separate systems to independent dissimilar. Example would be meter outage data to and Outage Management System.
Fault Location, Isolation and Service Restoration (FLISR)	FLISR technologies and systems involve automated feeder switches and reclosers, line monitors, communication networks, DMS, outage management systems (OMS), supervisory control and data acquisition (SCADA) systems, grid analytics, models, and data processing tools. These technologies work in tandem to automate power restoration, reducing both the impact and length of power interruptions.
Feeder	A circuit, such as conductors in conduit or a busway run, which carries a large block of power from the service equipment to a sub-feeder panel or a branch circuit panel or to some point at which the block power is broken into smaller circuits.
Fossil Fuel	A fuel source that is derived from the decomposition of plant and animal matter under the ground. Typically, coal, oil, and natural gas fall under the definition of fossil fuels.
Generation	Refers to the amount of electricity that is produced over a specific period of time.
Geographic Information System (GIS)	GIS consisting of a database of assets location, characteristics, and interdependencies. A GIS captures, stores, manipulates, analyzes, and manage all types of geospatially referenced data.
Historian	Historian is a time series data used to collect and store status point from all grid devices, providing a platform to examine data from multiple perspectives based upon a historical view for planning, analysis, and verification of performance.
Integrated Resource Plan (IRP)	The process of projecting future energy demand, and analyzing current and future energy, transmission, and distribution resources to plan to meet such future demand at minimized cost to the system owner/operator and its stakeholder.
Meter Data Management System (MDMS)	A MDMS is a software application that accepts the input of data from utility meters, validates that data, and makes the data available for use in other applications.
Microgrids	A group of interconnected loads and DER 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.
Mobile Work Management System (MWMS)	Software tool designed to help improve efficiencies of team work. Specifically related to prioritization, documentation, and flow of work in the field.
Oil Circuit Breakers	Oil circuit breakers are used to switch circuits and equipment in and out of a system in a substation.
Outage Management System (OMS)	OMSs are software applications, often integrated with other utility applications, used to detect, diagnose, and plan assistance in the restoration of power during an outage.
Photovoltaics (PV)	Method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect.
Power Purchase Operating Agreement (PPOA)	A contract between PREPA and an energy producer (the "counterparty"). The counterparty agrees to produce electricity and to operate the resource that produces that electricity for PREPA over a specified period of time. PREPA agrees to pay for the energy produced (and associated Green Credits as applicable).
Radio Frequency Mesh (RF Mesh)	A communications network (typically used in AMI) consisting of nodes, relays and access points that are interconnected to form a “mesh topology.”
Renewable Portfolio Standard (RPS)	An energy policy which specifies the proportion of the energy mix that must come from renewable resources for an electricity provider. Typically, an RPS will require a certain age of renewables be used (on a capacity or energy basis) by a certain year in the future.
Right of Way (ROW)	The legal right, established by usage or grant, to use land for the purpose of expansion or maintenance of services such as transportation, electrical lines or gas pipelines.
SCADA Communications	Communication systems providing monitoring and control of transmission and substations assets.

Term	Definition
Substation	A high voltage electric system facility used to switch generators, equipment, and circuits or lines in and out of a system, as well as to change voltages from one level to another or current.
Transformer	Converts the generator's low voltage electricity to higher voltage levels for transmission to the load center.
Transmission System	Series of towers and wires that transmit high voltage electricity from the generation source or substation to another substation in the electric distribution system.
Supervisory Control and Data Acquisition (SCADA)	Refers to computer-based control systems used in a wide variety of industrial monitoring and process control applications used in many industrial and utility applications. SCADA systems generally include specific types of sensing, control, and computing devices connected by some form of local or wide area network communications.
Voltage	The effective potential difference between any two conductors or between a conductor and ground.

APPENDIX B. COA DESCRIPTIONS AND MAPPING

Energy Sector Courses of Action	*Transformation Categories*									
	Trans & Subs	*Dist*	*Gen & Fuel Infra*	*Grid & DERs*	*Tech*	*Sec*	*Sys Ops*	*Emer Prep*	*Policy & Regs*	*Ops Eff*
COA-001 ***Establish and Enforce Best Practices for Electricity Grid***	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	All of the transformation categories are directly or indirectly affected by the establishment and enforcement of grid standards aligned with industry best practices tailored to the unique conditions in Puerto Rico as recommended by ENR COA-001. Extensive review of codes and standards that are currently in effect will have to be completed and considerations to the upgrade of these codes and standards need to consider the reliability and resiliency requirements for the trasformed energy system.									
COA-002 ***Design, Build, and Maintain "Islandable" Portions of the Electrical Grid***	✓	✓	✓	✓	✓	✓	✓	✓		
	ENR COA-002 entails the design and creation of "islandable" or sectionalized grids that can balance generation and load to continue delivering locally generated electricity if sections of the transmission grid fail. Modifications to the transmission, substations, generation controls and corresponding technology to coordinate the control of the "islandable" grids are essential elements to consider. Once fully integrated, "islandable" grids will be a major part of PREPA's emergency preparedness plan.									
COA-003 ***Harden Supporting Infrastructure for the Electricity System, Including Communications***	✓	✓			✓	✓	✓			
	ENR COA-003 involves strengthening the electricity system by hardening supporting infrastructure, such as control centers, communication systems, and collection systems. Implementation plans within this report includes an assessment of existing communication infrastructure that supports grid monitoring and control functionality. Hardened and redundant (with diverse communications paths) control centers are key enablers for resiliency and efficient grid operations.									
COA-004 ***Perform Routine Operations and Maintenance Informed by Periodic Risk Assessment***	✓	✓	✓		✓	✓	✓			
	ENR COA-004 aims to improve O&M with ongoing risk assessments and predictive maintenance. In the operational efficiencies and technology categories discuss tools and practices that support periodic risk assessments that will inform maintenance of the electrical system.									
COA-005 ***Design and build hardened grid assets to support critical infrastructure***	✓	✓			✓	✓	✓			
	ENR COA-005 prioritizes the hardening of electricity and distribution assets. Programs/initiatives are outlined to design assets that enable rapid response time for electricity to support other critical infrastructure. Although focused on the distribution assets, the tie to the transmission and substation assets are also addressed.									
COA-006 ***Improve Grid Assets' Resilience to Flooding***	✓	✓					✓			
	ENR COA-006 prioritizes hardening the grid to flooding. As recommended by this COA, transmission, substations, and distribution programs/initiatives include (1) altering siting requirements in floodplains; (2) altering asset types to reduce vulnerability; (3) reducing exposure by moving, raising, or waterproofing assets; (4) strengthening assets against hydrostatic and hydrodynamic pressures; (5) decommissioning assets where flood risks are too costly to mitigate; and (6) expediting repairs to reduce mold and rot damage. This is particularly addressed with the substations that were severly impacted by the storms.									

<table>
<tr><th rowspan="2">Energy Sector Courses of Action</th><th colspan="10">Transformation Categories</th></tr>
<tr><th>Trans & Subs</th><th>Dist</th><th>Gen & Fuel Infra</th><th>Grid & DERs</th><th>Tech</th><th>Sec</th><th>Sys Ops</th><th>Emer Prep</th><th>Policy & Regs</th><th>Ops Eff</th></tr>
<tr><td rowspan="2">COA-007
Improve Grid Assets' Resilience to High Windspeeds</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="10">Similar to ENR COA-006, ENR COA-007 prioritizes hardening the grid to high wind speeds. As recommended by this COA, transmission, substations, and distribution programs/initiatives include (1) underground high risk lines for critical loads; (2) designing and installing poles and towers to withstand a minimum of 150 mph winds, per US standards; (3) vegetation management; (4) reducing T&D distances by moving generation closer to load centers; (5) structural analysis of the transmission system structures and distribution system poles; and (6) establishing dual-use programs to better manage third-party use of assets. The generation plan details the move to more flexible generation closer to load centers.</td></tr>
<tr><td rowspan="2">COA-008
Maintain Disaster-Resilient Generation Assets</td><td></td><td></td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="10">ENR COA-008 prepares the generation system for disaster impacts. The generation plan outlined in this plan is consistent with prioritizing the maintenance of generation assets that were resilient to hurricane damage or that were newly installed during the power restoration efforts to ensure resilience to future disasters. An assesment of the current state of generation assets and the necessary close coordination to PREPA's IRP are discussed in this plan.</td></tr>
<tr><td rowspan="2">COA-009
Design and Build Fuel Supply Chain to Provide Reliable Energy Source</td><td></td><td></td><td>✓</td><td></td><td></td><td></td><td></td><td>✓</td><td></td><td></td></tr>
<tr><td colspan="10">ENR COA-009 establishes a fuel and materials supply chain that is prepared for future disasters. The Emergency Preparedness category addressed developing a comprehensive Supply & Logistics Plan, Depots and Staging Sites.</td></tr>
<tr><td rowspan="2">COA-010
Improve the Availability of Ancillary Services for the Grid</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="10">COA-010 entails improving the availability of ancillary services by (1) upgrading generation blackstart capacity; (2) repairing or replacing damaged or high risk supervisory control and data acquisition (SCADA) systems; (3) selectively installing redundant battery systems and backup generators for charging; (4) expanding the use of renewable and DER. These are all discussed in the generation plan as well as in the microgrids and "islandable" grid integration sections of this plan. To efficiently put these into effect, the corresponding technology upgrades/installations need to be included.</td></tr>
<tr><td rowspan="2">COA-011
Design and Deploy Technologies to Improve Real-Time Information and Grid Control</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td colspan="10">ENR COA-011 recommends installing distributed energy resource management system (DERMS), advanced metering infrastructure (AMI), improving the monitoring and analytic capabilities of the EMS and the supervisory control and data acquisition (SCADA), etc. These and other technology-related initiatives are discussed throroughly in this report. With the integration of "islandable" grids, the report also discusses developing control system strategies to maintain adequate operational security margins and system stability under major events and significant system perturbations.</td></tr>
<tr><td rowspan="2">COA-012
Coordinate Federal and State Emergency Response with the Private Sector</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>✓</td><td>✓</td><td></td></tr>
<tr><td colspan="10">ENR COA-012 is not directly assigned to PREPA; this is assigned to the State Agency for Emergency Management and Disaster Management. However, this report discusses the need for improved emergency response plan. It includes the recommendation to evaluate response efforts and design new incident response</td></tr>
</table>

Energy Sector Courses of Action	Transformation Categories									
	Trans & Subs	Dist	Gen & Fuel Infra	Grid & DERs	Tech	Sec	Sys Ops	Emer Prep	Policy & Regs	Ops Eff
	plans that efficiently align resources, lines of authority, and areas of need for the power sector (capitalizing on previous work with the After Action Reports).									
COA-013 ***Pre-Position Materials and Prepare Workforce for Rapid Response***								✓		
	ENR COA-013 is not directly assigned to PREPA; it is assigned to the Department of Economic Development and Commerce. However, this report discusses the need for improved emergency response plan. This report discusses the development of Supply & Logistics Plan, Depots and Staging Sites.									
COA-014 ***Design and Build Grid Assets to Meet Current and Future Demand***	✓	✓	✓	✓	✓	✓			✓	
	ENR COA-014 recommends to design and build generation, transmission, and distribution assets to meet current and future demand projections, including right-sizing and relocation as required. This report is closely aligned to PREPA's IRP. The Technology category complements current efforts by PREPA that include updating and strengthening analytical tools, especially for dynamic system monitoring.									
COA-015 ***Enable Private Standby Generation to Provide Emergency Power***			✓	✓	✓	✓	✓	✓	✓	
	ENR COA-015 recommends the creation and enforcement of policies requiring certain private facilities, such as hospitals and communication towers, to maintain backup generation. Establish enforceable inspection and maintenance measures for compliance with requirements. The regulatory and policy category included discussions to incent consumer investment in DER that could provide emergency energy services.									
COA-016 ***Provide Backup Generation to Priority Loads***			✓	✓			✓			
	ENR COA-016 recommends the maintainance of electricity delivery to priority loads — water, communications, manufacturing, health services, schools, airports, and seaports — to ensure the sustained delivery of public services in the absence of the bulk power system. This is addressed in the microgrid integration initiatives in this report.									
COA-017 ***Provide Energy and Water to Critical Facilities That Serve as Congregate Shelters***								✓		
	ENR COA-017 creates a reliable energy source after a catastrophe. Enhances emergency response. Identification of these critical facilities and necessary investments are addressed by the Emergency Preparedness category.									
COA-018 ***Right-Size and Train the Future Energy Workforce***										✓
	ENR COA-018 is not directly assigned to PREPA; it is assigned to the Department of Economic Development and Commerce. This ENR COA requires training a workforce capable of installing, operating, and maintaining Puerto Rico's future energy system (especially in asset management, system planning, and data management) and of quickly responding to and repairing damages to the electric system. Investments within this ENR COA are related to the operational efficiencies category.									
COA-019					✓	✓				✓

Energy Sector Courses of Action	***Transformation Categories***									
	Trans & Subs	***Dist***	***Gen & Fuel Infra***	***Grid & DERs***	***Tech***	***Sec***	***Sys Ops***	***Emer Prep***	***Policy & Regs***	***Ops Eff***
Design and Deploy Data Systems to Inform Response and Improve Operations and Maintenance	ENR COA-019 requires the establishment of data systems to inform decisions during response and improve ongoing O&M. Technology systems to support inventory and asset management is included as one of the key investement items.									
COA-020 *Design and Build Capital Assets to Reduce Restoration Time and Cost*	✓	✓	✓		✓		✓	✓		
	ENR COA-020 recomended (1) investments to enhance maintenance and operations, (2) standardization of components, (3) relocation of T&D assets to improve access, (4) stockpiling of rapidly deployable grid restoration assets, (5) installation of additional assets to reduce failures, and (6) the redesign of some existing generation and substation units. This ENR COA focuses on restoration time and both asset and technology investments are necessary. These are discussed in the technology and emergency preparedness sections of this report.									
COA-021 *Establish Energy Response and Preparedness Plan*								✓		
	ENR COA-021 entails the creation and maintainance of an emergency response and preparedness plan. Reevaluate and update plans on a regular schedule. Establish and update mutual aid agreements. Streamline an incident command system. These are the areas of focus of the 2019-2020 inititives outlined in th emergency preparedness section of this report.									
COA-022 *Enable and Promote Distributed Generation*	✓	✓	✓	✓	✓	✓	✓		✓	
	ENR COA-022 recommends integrating DER and energy efficiency improvements, and maintaining service continuity to critical customers and loads. These prevent cascading failures and provides emergency power to critical needs and provides reliable power options to consumers. The move toward a decentralized and flexible generation with the integration of distributed generation is an essential transformation initiative outlined in this report.									
COA-023 *Design Best Strategies for Renewable Energy Resources*	✓	✓	✓	✓	✓	✓	✓		✓	
	ENR COA-023 Determine the appropriate strategies for all types of existing and potential renewable energy resources (e.g., wind, solar, biomass, hydro, tidal). Assess the possibility of revitalizing hydropower facilities across Puerto Rico, especially facilities with black start or “islanding” capabilities. Prioritize the development of ideal renewable energy sites.									
COA-024 *Design Best Strategies for Affordable and Stable Energy Prices*	✓	✓	✓	✓	✓		✓			✓
	ENR COA-024 requires the establishment of a system that provides affordable, reliable, and high-quality electric power to small businesses, commercial and industrial users, and the broader economy of Puerto Rico. The generation mix and the move to a more flexible/renewable sources supports this ENR COA. The corresponding T&D grid investments provide the infrastructure that provide high-quality electric power to small businesses, commercial and industrial users, and the broader economy of Puerto Rico.									

Energy Sector Courses of Action	Transformation Categories									
	Trans & Subs	Dist	Gen & Fuel Infra	Grid & DERs	Tech	Sec	Sys Ops	Emer Prep	Policy & Regs	Ops Eff
COA-025 *Build Capacity for Municipality Decision-Making of Energy Systems*	COA-025 requires increasing the capacity for municipalities to make decisions concerning energy systems. This ENR COA is not addressed in this report, but will be reflected during plan implentation as integration with legisltative initiatives evolves.									
COA-026 *Establish Energy Sector Governance Responsibilities for State-Level Agencies*										
	ENR COA-026 is not directly assigned to PREPA; it is assigned to the Office of the Governor. This ENR COA is not addressed in this report.									
COA-027 *Establish Regulations to Transform the Energy Sector*									✓	
	ENR COA-027 is not directly assigned to PREPA; it is assigned to the Department of Economic Development and Commerce. Part of the discussion within this report is to identify possible regulatory policies, guidelines and/or requirements that need to be addressed to support the GridMod Plan.									

APPENDIX C. DETAILED SYSTEM COST ESTIMATES

Table C-1. Detailed Transmission Cost Estimates (230 kV/115 kV)

Hazard Type	Hazard	Mitigation	Unit Cost ($TH)	Number	Units	Total Cost ($M)
Wind damage	Pole failure from wind loading	Replace poles for higher wind loading	$195	500	poles	$98
Pole failure from contacts	Pole failure from contacts	Tree removal & trim	$19.5		Circuit Mile	
	Wind damage cannot be mitigated	Underground transmission wires	$19,500	45	Circuit mile	$878
	Conductors Slapping	Install intermediate poles	$195	400	poles	$78
	Debris damage to conductors or equipment	Install wider spacing	$650		Linear Mile	
Insulator failure	Salt water contamination	Replace insulators with higher insulation level	$195	50	linear Mile	$10
	Insulator failure	Replace insulators with newer designs	$195	50	linear mile	$10
Flooding	Poles fail because of ground subsidence or water-driven debris	Straighten & Grout existing or Replace poles with deeper sub-subgrade or engineered foundations	$1,625	300	Circuit Miles	$488
	Poles fail because of water-driven debris	Underground transmission wires	$19,500	5	Circuit Miles	$98
Wind damage & accessibility	230 kV OH lines susceptible to failure during storms	Rebuild/strengthen lines; replace lattice towers w/ monopole design	$4,600	350	Circuit mile	$1,610
	Total					***$3,270***

Table C-2. Detailed Substation Cost Estimates (230 kV/115 kV)

Hazard Type	*Hazard*	*Mitigation*	*Unit Cost ($TH)*	*Number*	*Units*	*Total Cost ($M)*
Wind damage	Fence Failure	Install Hurricane-rated fencing	$940	18	site	$17
	Control building damage	Replace or reinforce control building	$11,489	15	site	$172
	Structure Failure	Replace with Hurricane-rated structure	$1,300	5	site	$7
	Salt water contamination	Replace insulators with higher insulation level	$650	10	site	$7
Water damage	Flooded control Equipment	Replace with newer design	$1,560	34	site	$53
	Flowing water/debris displaces subs. equipment	Relocate or elevate substation	$36,400	2	site	$73
	Rain intrusion into equipment	Install water-tight enclosures for control equipment	$520	16	site	$8
	Water intrusion into transformers, regs & breakers	Elevate equipment or equipment air vents	$104	10	site	$1
	Site Flooding	Install water barriers & engineered solutions	$5,700	16	site	$91
Command and control	Incomplete situational awareness	Install SCADA and remote video monitoring, and water alarms	$1,170	34	site	$40
	Inability to synchronize or black start	Install remote synchronization and black start schemes	$6,500	6	site	$39
Unreliable operation	Breakers fail to open or close - At/near end of life	Replace breakers	$650	80	per unit	$52
	Grounding Systems Compromised	repair/Replace grounding Systems	$130	26	site	$3
	Inadequate spill control	Install SPCC Containment	$2,600	34	system	$88
	Batteries discharge during extended outages	Install redundant batteries and backup generation	$130	12	site	$2
	Transformers at/near end of life	Replace transformers	$2,600	59	unit	$153
	No remote control on high side	Install high side switchers or breakers	$520	11	site	$6
	Total					***$812***

Table C-3. Detailed Substation Cost Estimates (38 kV)

Hazard Type	Hazard	Mitigation	Unit Cost ($TH)	Number	Units	Total Cost ($M)
Wind damage	Fence Failure	Install Hurricane-rated fencing	$130	107	site	$14
	Control building damage	Replace or reinforce control building	$5,238	80	site	$419
	Structure Failure	Replace with Hurricane-rated structure	$1,300	163	site	$212
	Salt water contamination	Replace insulators with higher insulation level	78	25	site	$2
Water damage	Flooded control Equipment	Replace with newer design	$5,238		site	
	Flowing water/debris displaces subs. equipment	Relocate or elevate substation	$5,238		site	
	Rain intrusion into equipment	Install water-tight enclosures for control equipment	$33	25	site	$1
	Water intrusion into transformers, regs & breakers	Elevate equipment or equipment air vents	$4	25	site	$-
	Site Flooding	Install water barriers & engineered solutions	$1,420	50	site	$71
Command and control	Incomplete situational awareness	Install SCADA and remote video monitoring, and water alarms	$130	100	site	$13
	Inability to synchronize or black start	Install remote synchronization and black start schemes			N/A	
Unreliable operation	Breakers fail to open or close - At/near end of life	Replace breakers	$325	96	per unit	$31
	Grounding Systems Compromised	repair/Replace grounding Systems	$65	100	site	$7
	Inadequate spill control	Install SPCC Containment	$208	176	site	$37
	Batteries discharge during extended outages	Install redundant batteries and backup generation	$65	50	site	$3
	Transformers at/near end of life	Replace transformers	$325	50	unit	$16
	No remote control on high side	Install high side switchers or breakers	$390	78	site	$30
	Total					***$856***

Table C-4. Detailed Distribution System Cost Estimates

Distribution Initiative	*Estimated Cost Comments*	*Estimated Cost ($M)*
Overhead Distribution (Includes 38 kV)		
Pole Strengthening for Wind Damage	Estimated cost includes the following mitigation actions for approximately 40,000 distribution poles and 150,000 connections on 2,000 linear miles of distribution infrastructure: (a) replacing poles for higher wind loading, (b) installing breakaway service connections, (c) installing tree wires, (d) installing intermediate poles, and (e) installing wider spacing or install tree wire; associated construction costs were estimated using NY utility comparator data (need to be refined when actual PREPA data is obtained)	$3,432
Insulator Replacement for Wind Damage	Estimated cost includes the following mitigation actions for 1,000 linear miles of distribution infrastructure: (a) replacing insulators with higher insulation level and (b) replacing insulators with newer designs; associated construction/unit costs were estimated using NY utility comparator data (need to be refined when actual PREPA data is obtained)	$208
Submersible and Flood-Proof Equipment	Estimated cost includes costs for 40,000 poles that failed because of ground subsidence, 50 linear miles of poles failing because of water-driven debris and 1,000 poles failing because of water-driven debris; associated construction/unit costs were estimated using NY utility comparator data (need to be refined when actual PREPA data is obtained)	$965
Accessibility	Estimated cost includes costs for 150 linear miles for overhead lines are not easily accessible (50 linear miles are assumed to be replaced with underground); associated construction/unit costs were estimated using NY utility comparator data (need to be refined when actual PREPA data is obtained)	$429
Distribution Automation for Faster Service Restoration	Estimated cost includes costs for 1,200 feeders to add automated switches with FDIR capability; associated construction/unit costs were estimated using NY utility comparator data (need to be refined when actual PREPA data is obtained)	$234
Distribution Automation for DER Integration	High level estimate, hosting capacity studies need to be completed to confirm DER integration mitigation costs; assumes 300 feeder sets @ $1M	$400
Underground Distribution		
Storm Surge/Flooding/Flowing water	Estimated cost includes costs for 30 linear miles for underground infrastructure to install submersible equipment, to install equipment or terminations flooding for 100 sites, replacing 10 linear miles with overhead, and installing engineered protection of cables and conduits for 10 linear miles; associated construction/unit costs were estimated using NY utility comparator data (need to be refined when actual PREPA data is obtained)	$35

Table C-5. Short-Term Substation Reliability Projects

PREPA Damage Facility	Cost Estimates	PREPA Damage Facility	Cost Estimates
Substation Num. 9404, La Virgencita	$ 2,749,883	Substation Num. 7008, Victoria TC	$ 10,677,534
Substation Num. 8008, Charco Hondo	$ 4,421,813	Substation Num. 6801 & 6802, Acacias TC	$ 3,557,933
Substation Num. 8104, San José	$ 3,164,013	Substation Num. 5402, Tallaboa	$ 2,365,404
Switching-transition Station, Punta Lima	$ 1,649,915	Substation Num. 5005, Pámpanos	$ 2,382,605
Substation Num. 9203 & 9207, Dorado TC	$ 8,362,320	Substation Num. 8002, Arecibo Pueblo	$ 5,293,361
Substation Num. 8004, Cambalache TC	$ 8,642,543	Substation Num. 1802, Bayview	$ 3,292,375
Substation 2302, Alturas de Río Grande	$ 1,617,509	Substation Num. 1801, Cataño	$ 4,377,330
Substation 2306, Río Grande Estates	$ 1,669,123	Substation Num. 1102, Tapia	$ 2,048,500
Substation Num. 1911 & 1924, Caparra	$ 6,815,380	Substation Num. 1401 & 1402, Fonalledas	$ 2,953,434
Total for 18 Damage Substations: $ 76,040,976			

Source: Scope of Work for Insurance Claim – Damage Substations

Table C-6. Detailed Distribution District Allocation Cost Estimates

	District	Region	Distribution CAPEX for District ($M)	Distribution CAPEX for Region ($M)
1	ARECIBO	ARECIBO	155	649
2	MANATÍ	ARECIBO	184	
3	QUEBRADILLAS	ARECIBO	182	
4	UTUADO	ARECIBO	127	
5	BAYAMÓN	BAYAMÓN	291	889
6	COROZAL	BAYAMÓN	225	
7	TOA BAJA	BAYAMÓN	101	
8	VEGA BAJA	BAYAMÓN	272	
9	BARRANQUITAS	CAGUAS	186	1,177
10	CAGUAS	CAGUAS	489	
11	CAYEY	CAGUAS	186	
12	HUMACAO	CAGUAS	315	
13	CANÓVANAS	CAROLINA	163	502
14	CAROLINA	CAROLINA	177	
15	FAJARDO	CAROLINA	161	
16	AGUADILLA	MAYAGÜEZ	228	782
17	MAYAGÜEZ	MAYAGÜEZ	175	
18	SAN GERMÁN	MAYAGÜEZ	253	
19	SAN SEBASTIÁN	MAYAGÜEZ	126	
20	GUAYAMA	PONCE	185	903
21	PONCE	PONCE	358	
22	SANTA ISABEL	PONCE	183	

	District	Region	Distribution CAPEX for District ($M)	Distribution CAPEX for Region ($M)
23	YAUCO	PONCE	177	
24	GUAYNABO	SAN JUAN	296	803
25	MONACILLOS	SAN JUAN	323	
26	RÍO PIEDRAS	SAN JUAN	184	

Table C-7. Detailed Generation and Fuel Infrastructure Cost Estimates

2019-2028	Estimated Cost ($M)
Peaker Replacement	$509
BESS	$2,722
Generation Reliability	$140
Fuel Infrastructure	$497

Table C-8. Detailed Grid Control and Automation Cost Estimates

Grid Control and Automation	Estimated Cost ($M)
SCADA Communications	$200
Distribution Communications	$150
Geographic Information System	$45
Asset Management System	$40
Energy Management System (System Islanding Eight Segments)	$75
Advanced Distribution Management System	$40
Work Management System	$40
Data Center	$20
Historian	$20
Enterprise Service Bus	$20
Damage Assessment & Emergency Response Tools	$20
Emerging Technologies Testing and R&D Center	$50
Data Analytics	$40
Demand Response Management System	$40
Distributed Energy Resource Management System	$20

Table C-9. Detailed Metering Systems Cost Estimates

Metering Systems	Estimated Cost ($M)
AMI (MDMS, meter, installation)	$475
AMI Communications	$225
Smart Street Lighting	$200

Table C-10. Detailed Customer Systems Cost Estimates

Customer Systems	Estimated Cost ($M)
Customer Information Systems	$115