Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico

December 2017

Prepared for:

Governor Andrew Cuomo, New York
Governor Ricardo Rosselló, Puerto Rico
William Long, Administrator FEMA

Submitted by:

New York Power Authority, Puerto Rico Electric Power Authority, Puerto Rico Energy Commission, Consolidated Edison Company of New York, Inc., Edison International, Electric Power Research Institute, Long Island Power Authority, Smart Electric Power Alliance, US Department of Energy, Brookhaven National Laboratory, National Renewable Energy Laboratory, Pacific Northwest National Laboratory, Grid Modernization Lab Consortium, and PSEG Long Island, an agent for and on behalf of the Long Island Lighting Company d/b/a LIPA, and Navigant Consulting, Inc.

December 11, 2017

Honorable Governors Andrew Cuomo of New York and Ricardo Rosselló of Puerto Rico,

Thank you for your leadership in convening the Puerto Rico Energy Resiliency Working Group. On behalf of the Working Group, I am presenting the enclosed report *"Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico."* As you will read, this report provides an assessment of the electric power system storm damage caused by hurricanes Maria and Irma, describes a new system design basis, and proposes redesign and rebuild recommendations for strengthening the power grid of Puerto Rico.

The Working Group included the following representatives: New York Power Authority, Puerto Rico Electric Power Authority, Puerto Rico Energy Commission, Consolidated Edison Company of New York, Inc., Edison International, Electric Power Research Institute, Long Island Power Authority, Smart Electric Power Alliance , U.S. Department of Energy, Brookhaven National Laboratory, National Renewable Energy Laboratory, Grid Modernization Lab Consortium, Pacific Northwest National Lab and PSEG Long Island, an agent for and on behalf of the Long Island Lighting Company d/b/a LIPA.

Steering Committee Principals:

Gil Quiniones	President and Chief Executive Officer	New York Power Authority
John McAvoy	Chairman and Chief Executive Officer	Consolidated Edison Company of New York, Inc.
Pedro Pizarro	President and Chief Executive Officer	Edison International and Electric Power Research Institute
Tom Falcone	Chief Executive Officer	Long Island Power Authority
Bruce Walker	Assistant Secretary, Office of Electricity Delivery and Energy Reliability	Department of Energy
Julia Hamm	President and Chief Executive Officer	Smart Electric Power Alliance
Nisha Desai	Board Member	Puerto Rico Electric Power Authority

Our overriding goal is to support the Puerto Rico Governor's Office, PREPA, interested stakeholder agencies, and the Federal Emergency Management Agency in defining first level funding requirements and electric power system rebuild recommendations. Our analysis and recommendations are based on the direct participation, experience, and expertise of the members of the Working Group, many of whom have been working in Puerto Rico alongside Puerto Rico Power Authority personnel to assess the damage to the island's generation, transmission and distribution assets. The *Build Back Better* recommendations are guided by our collective experience with power system recovery, rebuilding, and hardening, as we grappled with hurricanes that have hit the US mainland.

The Working Group offers a roadmap outlining short-term, mid-term and longer-term actions to implement resiliency and hardening measures that are designed to increase the capability of Puerto Rico's electric power grid to withstand future storms. The recommendations include the modernization of the Puerto Rico electric grid, 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, we are recommending the use of increased renewable energy resources, such as wind and solar and incorporating new distributed energy resource technologies, such as energy storage and microgrids to enable energy to become abundant, affordable, and sustainable to improve the way of life for the citizens of Puerto Rico.

Once again, thank you for the opportunity to assist our fellow citizens in Puerto Rico during this difficult period and we remain dedicated to contributing to this most worthwhile effort to rebuild the power grid in Puerto Rico.

Respectfully yours,

Gil Quiniones

President and Chief Executive Officer, New York Power Authority
Chair, Puerto Rico Energy Resiliency Working Group

Table of Contents

List of Figures and Tables

Disclaimer

Executive Summary

Hurricane Irma struck Puerto Rico's northern coastline on September 6 and 7, 2017 as a Category 5 storm, knocking out power to more than one million residents and critical infrastructure. Two weeks later, on September 20, 2017, Hurricane Maria made its way up the Caribbean as a Category 4 hurricane, bringing winds of 150+ mph and dumping 25 inches of rain, resulting in catastrophic damage of historical proportion.

Governor Rosselló calls this a "transformative moment in the history of Puerto Rico." The magnitude of devastation to the Puerto Rico 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. A transformed electric power system for Puerto Rico is one that is designed with the resiliency to withstand future storms and is built with modern grid technologies and control systems. This system will deliver increased renewable energy resources, such as wind and solar; incorporate new distributed energy resource technologies, such as energy storage and microgrids; reduce the dependency on fossil fuels; and enable energy to become abundant, affordable, and sustainable to improve the way of life in the Commonwealth of Puerto Rico.

The purpose of this report is to provide an assessment of the electric power system storm damage, describe a new system design basis, and propose rebuild recommendations for the Puerto Rico Power and Grid Resiliency rebuild initiative. This report is positioned to support the Puerto Rico Governor's Office, Electric Power Authority, interested stakeholder agencies, and the Federal Emergency Management Agency (FEMA) in defining first level funding requirements and electric power system rebuild recommendations.

The information in this report is provided through direct participation, experience, and expertise of the members of the Puerto Rico Energy Resiliency Working Group (Working Group) established under the New York State's Governor's office to aid Puerto Rico in the damage assessment and rebuild planning for the electric power system. The Working Group includes the following members[1]:

> New York Power Authority (NYPA), Puerto Rico Electric Power Authority (PREPA), Puerto Rico Energy Commission, Consolidated Edison Company of New York, Inc. (Con Edison), Edison International, Electric Power Research Institute (EPRI), Long Island Power Authority (LIPA), Smart Electric Power Alliance (SEPA), U.S. Department of Energy (DOE), Brookhaven National Laboratory (BNL), National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Grid Modernization Lab Consortium (GMLC), and PSEG Long Island, an agent for and on behalf of the Long Island Lighting Company d/b/a LIPA (PSEG Long Island).

The rebuild recommendations are based on experience with power system recovery, rebuilding, and hardening from hurricanes encountered on the US mainland over the last decade. The recommendations include the use of modern technology and incorporate lessons learned from the successful rebuild efforts in other regions, post natural disasters, such as Hurricane Sandy in New York. Additionally, the rebuild recommendations align with the DOE's recommendations for power system hardening and resiliency.[2]

Assessment and Recommendations Approach

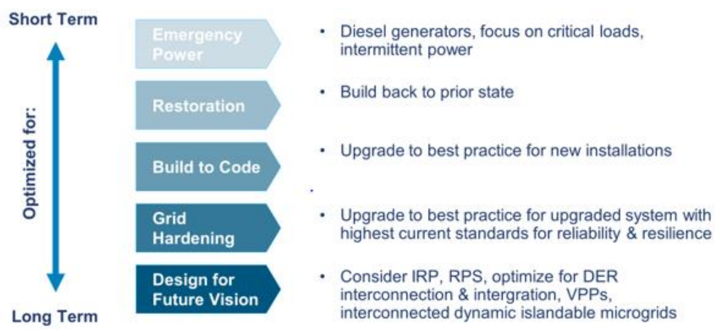
Puerto Rico power system information (pre- and post-storm) was collected, analyzed, and used to define the recommendations and cost estimates included herein. The onsite damage assessments completed to date by NYPA and Con Edison, supported by documentation from PREPA, are high-level condition assessments to support the initial rebuild planning and estimation process. The latest Consulting Engineers report (2013) and the Integrated Resource Plan (IRP) (2015) were key sources for the power system details used to shape the rebuild recommendations in this report.

[1] Navigant Consulting, Inc. is providing power system subject matter expertise, project management and report development as a consultant to the Working Group.

[2] *Hardening and Resiliency: U.S. Energy Industry Response to Recent Hurricane Seasons*, Infrastructure Security and Energy Restoration, Office of Electricity Delivery and Energy Reliability, US Department of Energy, 2010.

Site-by-site engineering studies are required to further catalog all damage, verify weakened infrastructure in need of hardening, and document abnormal conditions to develop site and device specific requirements and next-level cost analysis for the rebuild effort.

FIGURE E-1. POWER AND GRID REBUILD APPROACH



Source: SEPA

Rebuilding for the Future

As illustrated in Figure E-1, there are short-term recovery objectives and longer-term design and rebuild objectives to be considered when building back the system. This report focuses on rebuilding the Puerto Rico electric power system to current codes and industry best practices, hardening for greater storm resiliency, and designing for the future. To harden the transmission and distribution (T&D) infrastructure, physical and structural improvements to lines, poles, towers, substations, and supporting facilities will be needed to make them less vulnerable to the damaging effects of hurricane winds and flooding.

Consistent with observed wind speeds from Maria, PREPA's system should be designed and constructed to withstand an upper Category 4 event (155 mph winds) and heavy flood waters. To harden and enhance the resiliency of PREPA's system, the following measures are proposed:

1. Reinforce existing direct-embedded poles with enhanced support such as perimeter injected concrete grout or other soil stabilization
2. Upgrade damaged poles and structures to a higher wind loading standard
3. Strengthen poles with guy wires
4. Install underground power lines in select areas prone to high wind damage
5. Modernize the T&D system via smart grid investments to make the system less susceptible to extended outages
6. Install automated distribution feeder fault sectionalizing switches to enable fault isolation and reduce outage impact
7. Deploy modern control systems to enable distributed energy resources (DER) integration and encourage their development
8. Adopt effective asset management strategies, such as the targeted inventory of critical spares
9. Institute consistent vegetation management practices
10. Apply enhanced design standards for equipment and facilities damaged in the recent storms

This report includes recommendations to modernize the Puerto Rico electric grid, leveraging proven power system technologies to better contain outages, reduce recovery times, lower operations costs, and enable more sustainable energy resources. This includes using advanced sensors and intelligent fault interrupting devices and developing a condition-based asset management program to increase availability of critical equipment and overall power system reliability.

HARDENING AND RESILIENCY CONSIDERATIONS

- **Generation:** Relocate smaller coastal or river-located facilities, use of load frequency control, build back renewable energy sources, and integrate DER
- **Transmission:** New monopole towers, high strength insulators
- **Substations:** Defense-in-depth (multilayered) flood protection
- **Distribution:** Use of concrete and galvanized steel poles, new backup control center
- **System Operations:** Use of microprocessor-based devices and proven automation and control system technologies

Additionally, the increased use of renewables—in support of the Puerto Rico Renewable Portfolio Standard (RPS) of

20% by 2035[3]—will further reduce reliance on imported fuel, which costs Puerto Ricans more than $2 billion per year.

The updated power system design will encourage DER technology providers to showcase their products and systems for global acceptance of such systems and set a model for the industry while promoting private investments in the use of renewables for a low carbon future.

The evaluation of Puerto Rico's generating fleet considered several issues:

1. Near-term restoration of power to the island
2. Opportunities to increase the use of DER
3. Development of new targets for renewable resources
4. Shift of fossil generation to primarily dual-fuel units, with primary fuel as natural gas
5. Hardening of the generating facilities that will remain
6. Reduction of generation reserve margin to 50%

The issues noted above will require the 2015 IRP to be revisited for modification to ensure all necessary factors are considered, including the potential impact of increased DER, increased renewable targets, shift of fossil generation to natural gas, reduction of system reserve margin, etc. Depending on the results of the updated IRP, some generation plants could be slated for retirement and not require the full level of estimated expenditures for rebuild or hardening.

At the time of this report, it is unclear what percentage, if any, of the PREPA system is being rebuilt to a high Category 4 standard during restoration. As new information on the restoration design basis becomes available, it will be necessary to reassess the quantity of work that will be necessary after restoration.

Rebuild Cost Summary

Table E-1 provides a cost summary for the recommended power system rebuild investments, which are further defined in the following sections. Additional cost detail is also provided in Appendix B of this report.

TABLE E-1. REBUILD COST SUMMARY

Rebuild Recommendations	Total (Millions)
Overhead Distribution (includes 38 kV)	$5,268
Underground Distribution	$35
Transmission - Overhead	$4,299
Transmission - Underground	$601
Substations – 38 kV	$856
Substations – 115 kV & 230 kV	$812
System Operations	$482
Distributed Energy Resources	$1,455
Generation	$3,115
Fuel Infrastructure	$683
Total Estimated Cost	**$17,606[4]**

[3] http://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx#pr

[4] Each line item estimate includes a 30% scope confidence escalator. Final cost estimates require multiple engineering studies and an updated IRP.

1. Introduction

The purpose of this report is to provide analysis of the power system storm damage, describe the new system design basis and rebuild recommendations, and offer initial cost estimations and implementation planning for the Puerto Rico Power and Grid Resiliency rebuild initiative. This report is positioned to support the Puerto Rico Governor's Office, Electric Power Authority, interested stakeholder agencies, and FEMA in defining first level funding requirements and system rebuild recommendations for the Commonwealth of Puerto Rico.

The rebuild recommendations are based on experience with power system recovery, rebuilding, and hardening from hurricanes encountered on the US mainland over the last decade. The recommendations include the use of modern technology and incorporate lessons learned from the successful rebuild efforts in other regions post natural disasters, such as Hurricane Sandy in New York. Additionally, the rebuild recommendations align with the DOE's recommendations for power system hardening and resiliency.[5]

The recommendations address rebuilding for resiliency against future storms, including deploying DERs and industry best practices in automation and control system technologies, resulting in a more flexible system that is resilient, smarter, more efficient, and cleaner for Puerto Rico. DER recommendations leverage the role of renewables, storage, and consumer behavior, with investments in both customer-sited and grid-located technologies. Microgrids are also recommended for critical infrastructure, industrial and commercial, based on the current and forecasted energy demand density and customer mix.

Integrating a higher penetration of renewables and DER as part of a more flexible, reliable, resilient, and efficient power system will require the use of new control system technologies such as an advanced distribution management system (ADMS) and a DER management system (DERMS). In addition, PREPA should consider best practices in integrated system planning to properly manage, forecast, and optimize DER.

Power and Grid Overview

PREPA is a vertically integrated utility that supplies power to 1.4 million total customers in Puerto Rico and the smaller islands of Vieques and Culebra. The power system includes six fossil fuel and seven hydroelectric generation sites, owned and operated by PREPA, as well as privately owned generation facilities consisting of two cogeneration plants, two windfarms, and five solar farms. The electric grid includes 2,478 miles of transmission lines, 31,485 miles of distribution lines across the service territory, and 334 substations.[6] PREPA generates approximately two-thirds of its electricity and purchases the remaining from third parties.

Electric demand has declined from its historical system peak of 3,685 MW in FY 2006 to 3,159 MW in FY 2014[7] and 3,060 MW in August 2017; further decreases are expected with post-storm migration to the mainland. The pre-storm electric power generating capacity was 5,839 MW, which included 961 MW provided by two co-generators (EcoElectrica and AES-PR) through 20-year power purchase operating agreements (PPOAs). EcoElectrica, 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 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 eight to 12 miles and three to eight 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

[5] *Hardening and Resiliency: U.S. Energy Industry Response to Recent Hurricane Seasons*, Infrastructure Security and Energy Restoration, Office of Electricity Delivery and Energy Reliability, US Department of Energy, 2010.

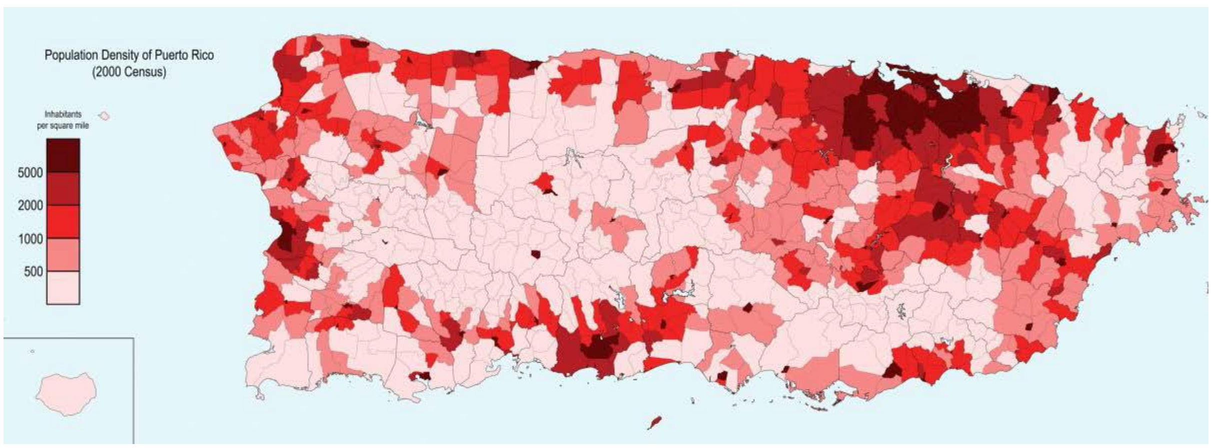
[6] Substation count refers to the number of high side voltage transmission and sub-transmission substation sites.

[7] IRP Volume 1, 2015.

illustrated in Figure 1-1, present many challenges in operating and maintaining the power system.

The electric power system consists of generation, transmission, distribution, communication, and control center facilities and is operated as a single integrated system. PREPA's transmission and distribution (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 recent hurricanes. Significant winds can exceed structural capacity and storm water runoff from the mountains can cause serious flooding issues that result in long duration repairs to the power grid infrastructure.

FIGURE 1-1. POPULATION DENSITY OF PUERTO RICO



Source: 2000 Census

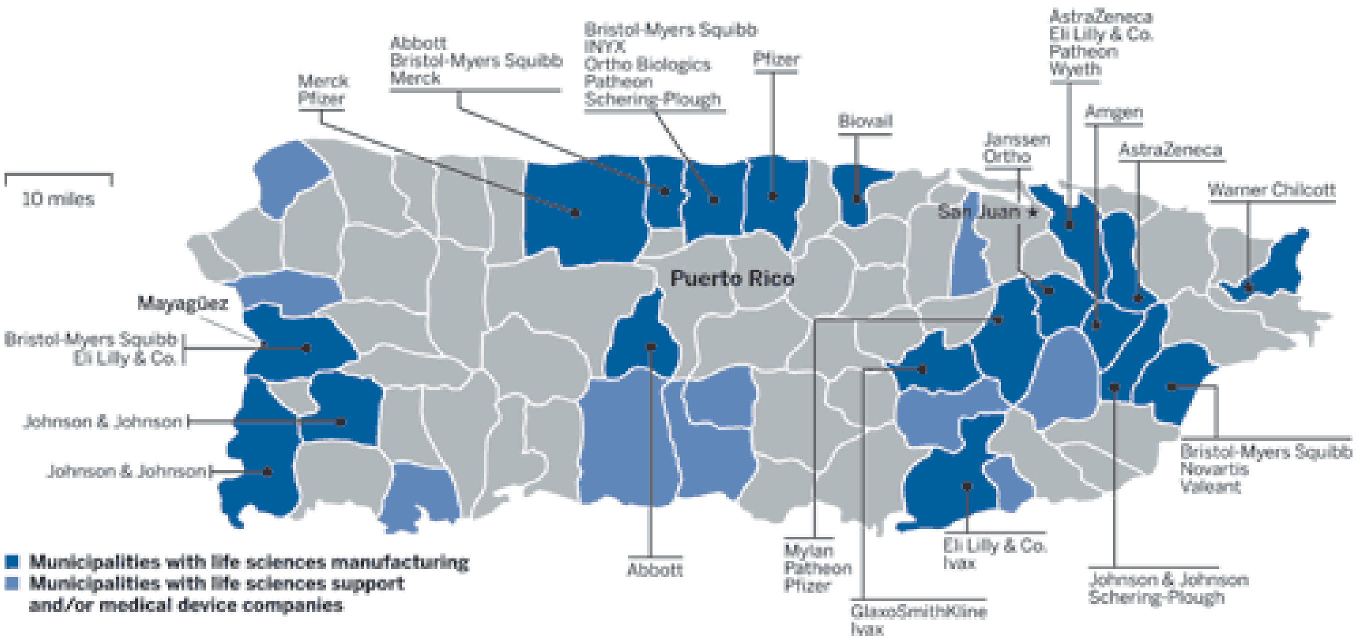
The generation and flow of electricity within the system is maintained and controlled by primary and backup dispatch control centers. The primary dispatch center is located at Monacillos, approximately seven miles south of San Juan. Energy management and supervisory control and data acquisition (SCADA) 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 transmits 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 2,478 circuit miles of lines: 375 circuit miles of 230 kV lines, 727 circuit miles of 115 kV lines, and 1,376 circuit miles of 38 kV lines. Included in these totals are approximately 35 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 north area of the island has two electric power generating facilities, with two of the largest and most critical generating facilities—Aguirre and Costa Sur—located in the south. These two electric power generation facilities are tied to each other using high voltage overhead transmission lines that run over 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 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.

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 1-2. This area accounts for approximately 65% of the system's energy demand.

FIGURE 1-2. MANUFACTURING CENTERS IN PUERTO RICO[8]



Source: ACS Publications[9]

Note: this figure does not represent all manufacturing on the island

Magnitude of Impact

Hurricane Irma struck Puerto Rico's northern coastline on September 6-7, 2017 as a Category 5 storm, killing at least three people and 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.

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 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 the changes in terrain and tore down large transmission lattice towers. Historical storm tracks, illustrated in Figure 1-3, suggest similar impacts can be expected in the future.

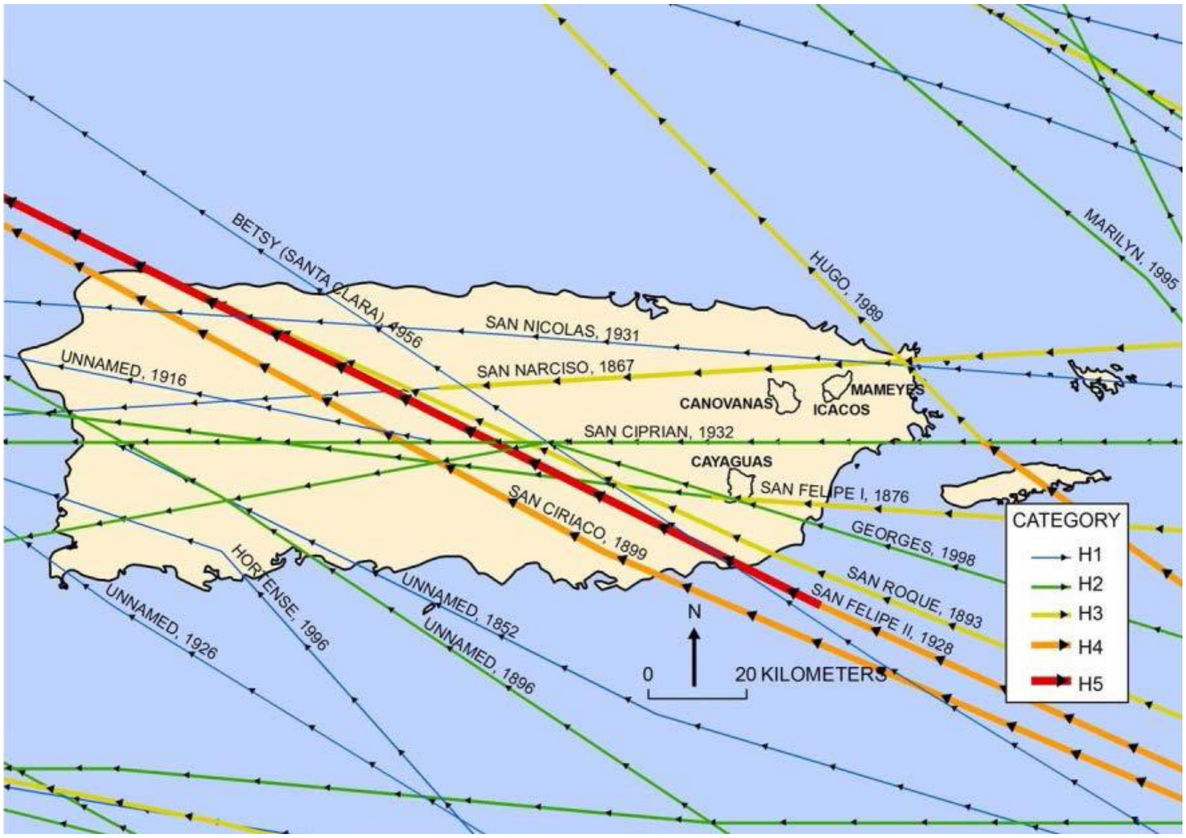
Damaged Poles

Source: NYPA/Con Edison Damage Assessments

[8] This figure is not considered to be inclusive of all the manufacturing on the island. Reference Appendix D for additional manufacturing illustrations.

[9] http://pubs.acs.org/cen/_img/85/i01/8501bus1maplg.gif.

FIGURE 1-3. HISTORICAL STORM TRACKS IN PUERTO RICO



Source: NOAA

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 little hope of a quick recovery. Because of the extended and unprecedented damage, a significant portion of the generation, transmission, and distribution system must be rebuilt, including high voltage transmission lines that often survive lower category hurricanes.

The hurricanes decimated T&D lines across the island and caused widespread wind and flooding damage to substations, generation, and distribution facilities. Damage from the hurricanes resulted in the longest duration power outage in US history. This cataclysmic failure of the power grid provides a unique opportunity to rebuild and update the power system to 21st century technologies and best practices, enabling the rethinking of how power is generated and distributed to customers across Puerto Rico.


Destroyed Wind Generation

Source: NYPA/Con Edison Damage Assessments

2. Vision for The Future

The road to the future requires resiliency and hardening measures that will increase the capability of Puerto Rico's electric power system to withstand future storms. Hardening involves instituting measures to improve the durability and stability of the infrastructure via the use of modern grid technologies, equipment, protective barriers, and enhanced communications and Information Technology (IT) and Operational Technology (OT) systems. Resiliency measures do not prevent damage but rather enable the power system to continue operating, and contribute to a more expeditious return to normal operations, even in the presence of widespread damage.

The incorporation of modern grid technology and DER is key to rebuilding the system to ensure continuity of service to key industries and electric demand centers in the event of future storms. Relying on methods laid out by the DOE on hardening and resiliency, and direct experience with mainland storms, the Working Group suggests the following design principles for rebuilding the PREPA system.

- Hazard resilience will need to be incorporated into the system design and operating plans. Renewable energy sources and distributed energy resources, including energy storage and microgrids should be incorporated into the redesigned system to improve storm resilience, reduce dependence on fossil fuels, and support a more sustainable energy future by reducing carbon producing generation.
- Substations should be enhanced by 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. Substations that are damaged completely from wind or flood waters in low-lying areas should be temporarily bypassed and permanently relocated to higher ground.
- As stated in the 2015 IRP, PREPA seeks new, flexible generation to handle the intermittency of renewables. The grid can be built with smaller distributed generating units that provide greater system flexibility and redundancy, and help in the operating and spinning reserve margins. The PREPA power system could also serve as a model for the future development of advanced power generation, transmission, and distribution systems and the use of renewable resources throughout the Caribbean or other similar global locations.
- A holistic implementation plan for substation and distribution automation, with computer-based control and monitoring technology is recommended to create a highly reliable, highly automated power system that can rapidly respond to real-time events and enable DER development. Technologies such as centralized Energy Management Systems (EMS), automated mapping and facilities management, and geographic information systems (GIS), in addition to the previously mentioned ADMS and DERMS will be integral to the operations technology environment.
- PREPA must adopt a robust asset management approach which includes aggressive vegetation management and optimized maintenance programs with adequate staffing. Because of the tropical growth in Puerto Rico, PREPA will likely need to adopt vegetation management programs that are more aggressive than the industry norm.

T&D System

One of the key features of the 'build back better' strategy is to rebuild the T&D system using design standards capable of withstanding high Category 4 storms, with sufficient design margins to ensure high survivability for Category 5 events in areas where damage is most likely to occur. Using GIS and available weather data, system planners can identify those areas on the island where critical facilities are located and where weather is typically most severe.

This report considers best practices applied by mainland utilities that upgraded power system facilities following Hurricanes Sandy and Irene. For example, electric utilities in New York have identified cost-effective approaches to rebuilding substations in flood-prone areas. This targeted approach and opportunity to build upon lessons learned from other utilities will reduce the number of customers affected and time to restore service following major storms.

The Working Group proposes a holistic approach to rebuild the T&D system—one that integrates technology, distributed generation, and energy storage with generation hardening outlined in subsequent sections of this report.

This includes an electric distribution system designed to readily integrate DER and maintain service continuity to critical customers and loads. Technology plays a key role, as upgraded communications and controls will provide control center personnel with the capability to better visualize and track outages and assess the status of power resources, with options to isolate damaged lines and reroute power to customers via alternate delivery paths.

Additional pragmatic solutions include relocating lines next to existing highways and main thoroughfares to provide better access during reconstruction and reducing lifecycle cost and expeditious repairs in case of failure; improving guying hardware to strengthen distribution lines; and using low cost, wire mesh-lined flood barrier enclosures and sump pumps at transmission substations and electric power generation facilities.

These approaches to rebuilding PREPA's T&D system ensure that proposed investments not only enhance electric system resilience, but do so in a manner that applies technology and lessons learned from other utilities and government agency programs to make the best use of rebuild funding. This approach is consistent with federal policies and initiatives to improve resilience via distributed resources, including renewable generation and storage. It also recognizes the need to enhance supply to critical customers and infrastructure. Hence, the design of the T&D system emphasizes flexibility and reliance on technology to improve the ability of the system to withstand major storms and to rapidly restore service during outages.

The proposed investment to rebuild PREPA's T&D system is $13.9 billion including $4.9 billion for transmission lines, $1.7 billion for substations; $0.5 billion for systems and technology, communications, and control center enhancements; $1.5 billion for DER; and $5.3 billion for distribution lines. The cost of technology, communications, and operational systems used in conjunction with many of the proposed rebuilds is presented in the System Operations section. Many of these investments such as rebuilding distribution lines, can be implemented over the next year. More complex transmission line and substation rebuilds, where procurement of major equipment, various studies and detailed design can take one year or longer, are proposed over the next seven to 10 years.

Per recent assessments addressed in PREPA's 2015 IRP, the plan was to reinforce the transmission system by improving the 115 kV north to south network by adding and upgrading lines to stabilize the system and better withstand critical contingencies. Exploring alternate means of transmission investments, including merchant transmission to improve the reliability and sustainability of the system is a critical component of the Working Group's recommendations. Investments in areas such as distributed resources may involve third parties and private investment options that could affect the proposed level of rebuild investment required.

System Operations

Like most utilities, PREPA maintains operation control centers that monitor, operate, and control generating plants, the transmission network, and distribution facilities. PREPA's primary system control center was spared major damage by the storm; however, given the Working Group's recommendation to introduce new technologies to support PREPA's grid, it is an opportune time to modernize the control center facilities and their associated hardware and software. The recommended upgrades will not only improve the ability of PREPA to restore customers faster following major storms, but enable PREPA to efficiently manage the operation of traditional generating plants along with distributed resources, including energy storage systems capable of shifting mid-day solar output to align with evening peaks.

The Working Group's recommendation includes updating the primary control center to withstand a Category 5 hurricane and associated flooding, abandoning the existing backup control center, and deploying a new mobile and containerized backup facility. Mobile backup control centers have been proven to be a cost-effective form of redundancy on the mainland.

Facility upgrades would also include the consolidation and co-location of storm management centers at or near the control centers. Additionally, 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.

Also, in support of operations described elsewhere in the report, control center capabilities should be upgraded to enable active monitoring and control of distributed generation and microgrids. Upgrades include an enhanced outage management functionality, integrated with an ADMS and DERMS to improve operational control of field devices and visualization of system operating conditions. Cyber and physical asset security must also be incorporated into all systems, including those that communicate with distributed resources, field devices, and customer meter data.

Generation

The generating capability of the PREPA fleet is 5,839 MW, including several power purchase agreements (PPAs) for fossil and renewable generation. The damage to PREPA generating facilities varied from extreme to minor, and several plants not only encountered damage from Hurricane Maria, but also from Hurricane Irma, which caused damage due to sea surge, making the generation system even more vulnerable to severe damage when Maria hit.

The capacity of the generating fleet is notably higher than the PREPA peak of approximately 3,060 MW in August 2017.[10] Given this excess capacity and the need to rebuild, there are several options for modifying the size and technology of the generation fleet, including a potential reduction of reserve margin for PREPA.

In 2015, PREPA completed an IRP that laid out a vision for moving toward more renewable and gas-fired generation and away from oil as a primary fuel. The IRP identifies generating units slated for conversion to gas or repowering with newer, more efficient technology such as F and H-class machines; some of the replacement generating units would have lower installed capacity, while approximately 1,100 MW would be converted to limited use or entirely shutdown.

The IRP also outlines a goal of approximately 20% renewable generation by 2035. Prior to the hurricanes, PREPA had executed over 60 contracts for large scale renewable energy, principally solar and wind. Of those, seven solar farms with a total of 147.1 MW, two wind farms with a total of 121 MW, and two landfill gas facilities with a total of 4.8 MW had been constructed and were in operation to help reach the 20% target.[11] The Working Group recommends that the IRP be revisited to incorporate storm hardening, improved system protection and control, increased use of distributed generation and accelerated penetration of renewables, while ensuring that the capacity meets the current and future energy demand of the island. Additionally, study of establishing new planning and operating generating reserve margins, taking all of these factors into account, to something closer to 50% (approximately 4,000 MW of firm capacity)[12] is recommended.

The estimated investment required to rebuild the plants to operating condition consistent with future needs is approximately $3.1 billion, including an estimated $2.8 billion for replacing the Palo Seco plant with an F-class machine, replacing the steam units at Aguirre with an H-class machine, and the installation of storm hardening for the sites. Much of this estimate is related to issues discussed in PREPA's IRP; particularly Mercury and Air Toxics Standards (MATS), system stability, fuel diversification, and unit flexibility needed to handle intermittent renewable resources. This estimate also includes funding to quickly move forward in restoring generation operability through key actions, including conducting more detailed testing and inspection analysis of each plant to further ensure public and worker safety and assess the true extent of damage sustained at the plant. As an example, if insulation on high pressure piping has been damaged or saturated with water, the integrity of the piping may be compromised. Similarly, ensuring that water has not been introduced into switchgear and/or other electrical equipment is vital to safe operations.

While the storms created several significant challenges, they also now offer an opportunity for overall improvement and stability of the generating fleet, as well as the expedited implementation of the recommendations in the recent IRP. The timing of when the repairs and/or replacement will take place requires strong coordination that allows for the use of existing generating units for the short-term production of needed electricity, as well as the

[10] Peak load figure provided by PERPA. Future loads may decline due to population exodus, greater amounts of behind-the-meter generation, and closure of some businesses.

[11] Per Puerto Rico Act 82-2010, distributed generation does not count directly for the renewable generation goals.

[12] Currently, 961 MW is provided from fossil generation PPA's, another 64 MW from PREPA hydro plants and an additional 122 MW from solar and wind - the remaining 3,200 MW will need to come from the current PREPA fleet and/or distributed resources.

longer-term shift from oil- to gas-fired generation, installation of DER capabilities, and shutdown of existing older generation units. Further, the introduction of large and distributed renewable resources, including energy storage and microgrids, may lessen PREPA's dependence on large central generating stations, with the potential to retire existing plants and/or defer new ones.

Implementation Challenges and Considerations

A rebuild project of this magnitude requires the consideration of several technical and non-technical factors necessary for the success of the project. In general, these include:

- **Management of Cash Flow** – Work that is proposed as a reimbursement from other funding sources, including federal funding, requires upfront expenditures. This is particularly problematic given Puerto Rico's existing financial constraints.
- **Stafford Act Compliance** – Generally, federal funding requires the use of US-sourced material, a strict procurement process, a strong quality assurance capability, strict accounting, and an on-going audit process.
- **Supply Chain** – Competitive bidding on both equipment purchases and construction contracts is needed. Where FEMA funds are used, a strict adherence to an agreed upon protocol is necessary.
- **Labor Force** – This project can provide opportunities for retention of on-island skilled labor and development of new high-quality jobs. Recommendations in this report will require development of the on-island workforce to operate the system with new technologies and methods. Many of the skill sets, such as linemen and mechanics are in short supply generally in the US, making the constant staffing of future projects problematic.
- **Permitting and Environmental Reviews** – Because the next severe weather event can happen any time and the projects recommended in this report will take many years to complete, it is essential that any permitting and required environmental reviews, especially for the recommended transmission enhancements, be expedited.
- **Future Planning** – This report recommends a higher consideration of new distributed generation resources and a careful consideration of the traditional generation requirements. PREPA should incorporate these approaches into a revised IRP and consider permanently retiring excess generation facilities.
- **Stewardship** – It is critical that strong asset management principles and practices are implemented with the reinstallation and replacement of power system equipment. Asset Management practices should include an inventory of assets and the entry of asset records into GIS and Asset Registry systems. Elements of a best practice asset management system includes developing standardized asset strategies, policies, and procedures, optimizing capital programs, optimizing lifecycle management of assets, mitigating operating risk, implementing an optimized maintenance program, and providing for adequate skilled labor.

  Additionally, because of the tropical environment, PREPA may also consider enhancing their vegetation management program to go above and beyond typical industry practices. Finally, PREPA may need to better manage its distribution pole attachments by performing wind loading studies and requiring attachment owners to fund required upgrades.
- **Organizational Change Management** – This report proposes a significant amount of grid modernization and the use of new technologies, systems, and operating methods. PREPA and related stakeholder agencies will need to consider the impacts of these changes and institutionalize new business processes, systems and organizational roles and responsibilities.
- **Stakeholder Engagement** – Many of the Working Group recommendations will require extensive stakeholder engagement. These include incorporating input from technology suppliers, alignment with public agencies and the public in the rebuild process, developing close relationships with federal funding agencies, and developing financing plans and partnerships.
- **Project Management** – Rebuild implementation should be guided by effective project planning, monitoring, control, and reporting throughout the rebuild lifecycle. Effective project management will be required to deliver on these rebuild recommendations, optimize the use of federal funding, provide transparency and accountability,

and comply with federal tracking, control and reporting requirements.

- **Emergency Planning** – PREPA, along with its infrastructure partners in Puerto Rico need to develop an enhanced integrated emergency planning and response capability based on best-in-class Incident Command System (ICS) principles.

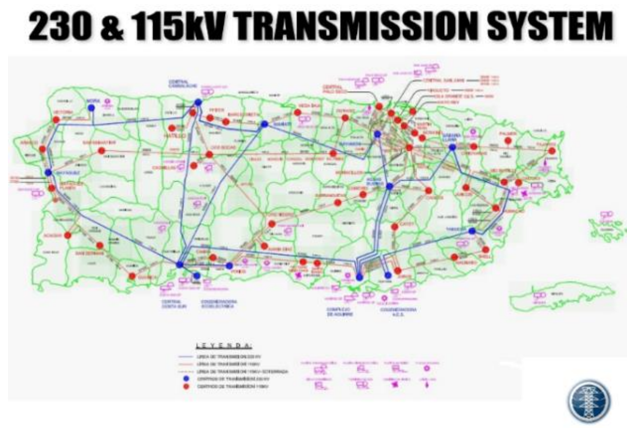
3. T&D System Rebuild and Hardening

Transmission System

PREPA's transmission network consists of 2,478 miles of lines that deliver power from generating stations to 334 transmission and subtransmission substations. Higher voltage lines operate at 230 kV and 115 kV, with lower voltage subtransmission operating at 38 kV. The backbone of the Puerto Rico transmission system consists of 230 kV overhead lines that form an approximate loop around the perimeter of the island.

The transmission network crosses from south to north in two locations; one from the Costa Sur generating plant to the Manati TC, and the second from the Aguirre generating facility to the Aguas Buenas TC. In addition, an existing 115 kV line from Costa Sur to Cambalache was upgraded to 230 kV to create a third south to north tie. The 230 kV network connects to an extensive 115 kV transmission system that supplies power to population centers throughout the island.

FIGURE 3-1. PREPA TRANSMISSION SYSTEM



Source: PREPA

The 230 kV system has two north to south corridors which divide the system into three principal loops: 1) the western loop; 2) the central loop; and 3) the eastern loop. The western loop connects the Costa Sur and EcoElectrica generators in the south with the Mayaguez switchyard and generation on the west coast, and then continues to the northern cities of Aguadilla, Hatillo, and Arecibo. The center loop connects generators in the south to the San Juan area via Aguas Buenas TC south of the city. A parallel 230 kV line in the island center connects the Costa Sur and EcoElectrica generators from the south with San Juan and the Cambalache combustion turbine on the north coast. The central loop is joined by east-west transmission lines connecting the Costa Sur units with the Aguirre plant in the south, and a line in the north connects Manati to Aguas Buenas via Bayamon. The eastern loop connects large generating units in the south (Aguirre units in Salinas and the AES plant in Guayama) to the eastern part of the island through Yabucoa and Rio Blanco, terminating in Sabana Llana, southeast of San Juan.[13]

The 115 kV lines serve all the major load centers on the island. PREPA has proposed several new and rehabilitation capital improvement projects for 115 kV transmission centers and other components of the system as well as new 115/38 kV transmission centers, originally scheduled between 2013 through 2018. PREPA installed a 28-mile 115 kV transmission cable line to link the system in the San Juan urban area to provide additional backup during storms. The 115 kV loop includes three highly reliable gas insulated substations (Isla Grande, Martin Peña, Palo Seco), two

[13] *Fortieth Annual Report On The Electric Property Of The Puerto Rico Electric Power Authority San Juan*, Puerto Rico, URS, 2013.

generating stations (San Juan, Palo Seco), and three additional key load centers (Monacillos, Hato Rey, Bayamón). These newer assets allowed PREPA to bring critical load back online in the first days after the storm in the San Juan Metro area, which otherwise would have taken weeks to power.

The 38 kV subtransmission system serves local load centers and are the primary feeds to the more inaccessible interior regions. This 38 kV subtransmission system feeds two-thirds of PREPA's distribution system. It includes overhead, underground, and two 38 kV submarine service to the islands of Vieques and Culebra.

Many of these lines were built more than 50 years ago, prior to the construction of the major highways crossing the island, and most are in difficult-to-reach locations, with no right-of-ways separating transmission towers and lines from trees or other structures. Due to protected plant and wildlife, the right-of-ways cannot be expanded or properly maintained in their current locations. The Working Group proposes that new transmission lines be installed along major highways throughout the island.

Major highways have established right-of-ways and should limit the environmental impact while reducing the time needed to obtain permits. The rebuild costs will also be lower along the highways because they are easily accessible by road.

Source: NYPA/Con Edison Damage Assessments

Notably, the southeast area of the island is particularly vulnerable to hurricanes, as the most destructive storms typically sweep through this part of the Caribbean on a northwest trajectory. Where possible, relocated transmission lines along highways in this area should be further hardened via shorter spans and greater separation between phases and grounded structures. In addition, these transmission lines should have hardened lightning protection because the island is susceptible to severe lightning. Also, the prospective system should be designed to ensure the system can reliably deliver power from generating plants in the south to population and industries located in the north.

Damage Assessment

Damage information for this report was provided by select on-the-ground assessments by the NYPA and Con Edison teams as well as periodic reports from PREPA. While this information is adequate for developing initial recommendations, several planning and engineering studies are necessary to refine the proposed changes and proceed with project design.

Source: NYPA/Con Edison Damage Assessments

Many of PREPA's transmission lines damaged during the storms were constructed decades ago, located in difficult-to-access areas where nearby highways now exist. PREPA reported that only 15% of the transmission lines are built to a mid-Category 4 criteria and the remaining 85% are built to lesser standards. A key example is the north-south corridor, where damage was extensive, and steep hills and muddy slopes have made access difficult, leading to long repair times. Many transmission corridors, including the North-South line are heavily treed with narrow rights-of-ways. Widening of these corridors is limited due to environmental restrictions to accommodate protected wildlife and vegetation.

The southern portion of the island is more susceptible and more vulnerable to major hurricanes, thereby putting key northern load centers at risk. Table 3-1 presents the extent of damage incurred on 115kV and 230kV structures and conductors (e.g. broken insulators). Damage on the 38kV subtransmission system is included in the distribution system section of this report.

TABLE 3-1. TRANSMISSION DAMAGE ASSESSMENT[14]

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

Several key transmission lines experienced substantial damage during the storms, with lattice tower and pole failures and numerous broken insulators. Transmission poles located in muddy areas were often upended due to unstable footing. Transmission poles and structures that toppled or were damaged during the storms have compromised the electrical integrity of the interconnected grid, with a total loss of supply to many substations. Notably, the recent loss of the north-south transmission line which caused extended outages in San Juan underscores the need for targeted transmission reinforcement.

Rebuild Recommendations

The Working Group recommends relocating and upgrading up to 350 miles of overhead transmission lines, with high strength insulators, structures, and conductor spacing designed to withstand stronger wind loading than the current design standard. At a minimum, structures located in areas prone to high winds should be reinforced to withstand Category 4 storms, including lines along the critical North-South corridor.[15] The Working Group also recommends that the transmission system be designed to enable integration of large renewables and smaller microgrids. This would serve to reduce PREPA's reliance on fossil fuel generation while providing greater resiliency to the island-wide grid.[16]

Monopole designs generally performed better than lattice tower designs.
Source: NYPA/Con Edison Damage Assessments

[14] Executive Report- Huracan Maria, Electric System Reestablishment Plan - Transmission Lines, 11/21/2017

[15] The north-south lines subsequently failed several weeks after the storms, plunging San Juan into darkness after the area was restored.

[16] It is possible that less critical transmission line additions proposed prior to the storms can be deferred, delayed, or reconfigured due to the proposed increase in renewable generation and the integration of microgrids.

In addition to relocating critical lines along readily accessible roadside locations, new transmission should be designed and built with monopole steel poles, high strength insulators, and vertical construction. The proposed 350 miles of new lines should be designed and built to 345 kV construction standards. A 345 kV design provides greater distance between conductors and enables future planning flexibility, and can initially be operated at 230 kV. Several lines should include double circuit construction on steel monopoles to make the most efficient use of transmission corridors.

Many of the existing lines that run over mountains, and are not presently built for Category 4, can be abandoned. Existing 115 kV poles that are otherwise designed for Category 4 located in areas susceptible to leaning or uprooting during high winds, should be considered for reinforcement via concrete grout injection around the base embedment or other means to strengthen and stabilize foundations.

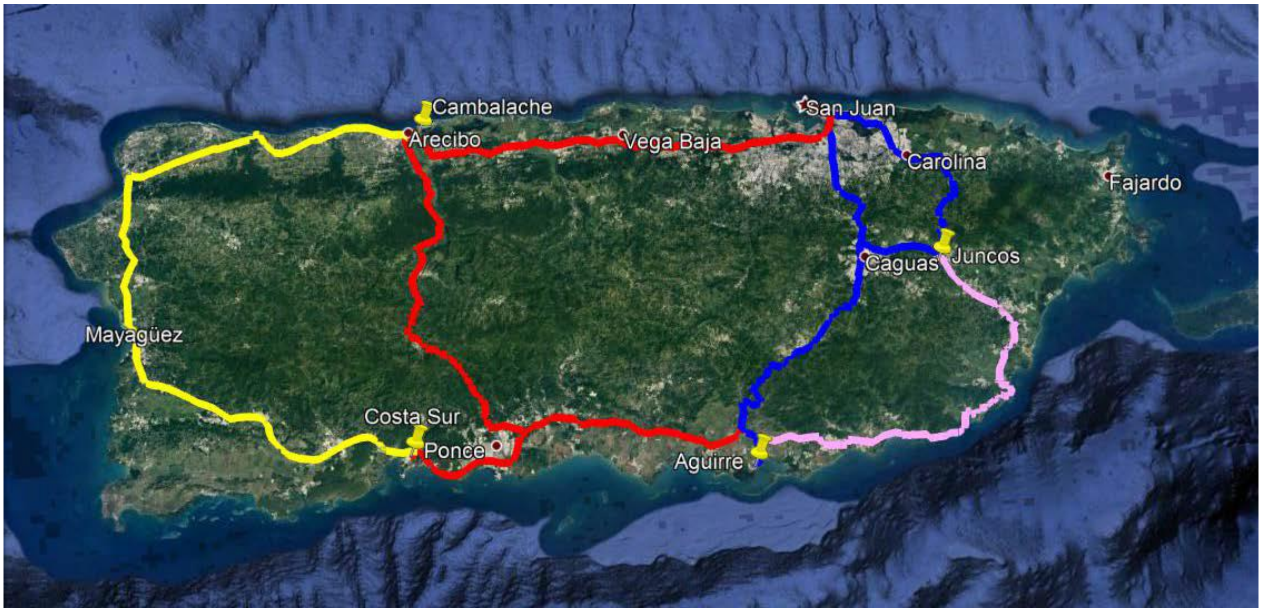
New transmission paths are proposed for the 230 kV lines along the following roadways:

- Mayaguez to Cambalache along Route 2
- Cambalache to San Juan along Route 22
- San Juan to Aguirre along Route 52
- Aguirre to Costa Sur along Routes 52 and 2
- Aguirre to San Juan via Humacao, Juncos and Carolina (various highways)[17]
- Costa Sur to Mayaguez along Route 2
- Caguas to Juncos along Route 30
- Juncos to San Juan via Carolina (various highways)
- PREPA's new Cambalache to Costa Sur should be considered as a part of all engineering and feasibility studies

A new four loop transmission system, as illustrated in Figure 3-2, will give a lot of flexibility without transmission congestion to move power around the island. This will be key in providing reliable and affordable energy to both the population and industrial centers. It will also help attract more industrial production business to the island, which will support economic growth and potential investment opportunities.

[17] This path may optionally be a Direct Current (DC) Marine Cable. To be conservative in estimating, the marine cable is included in the provided cost estimates

FIGURE 3-2. RECOMMENDED UPGRADE OR RELOCATION OF 230 KV TRANSMISSION LINES



Significant permitting challenges exist to implement this recommendation and the proper highway authorities should consider accelerated or legislated approval once initial engineering feasibility studies have been completed.

Cost

For the proposed resiliency and hardening, an estimated cost of about $7 million per mile has been considered for new double circuit 345 kV lines and $1.25 million per mile for 138 kV lines operating at 115 kV. The following table presents these costs by hazard mitigation category.

Funding for the transmission recommendations would primarily consist of FEMA funding for hardening the system.

TABLE 3-2. TRANSMISSION SYSTEM COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Wind Damage	$1,054	Replace poles for higher wind rating and jet grout existing self-embedded poles for higher wind rating, install wider spacing for better insulation, selectively underground high-risk spans, install intermediate poles to reduce galloping and slapping
Insulators Compromised	$20	Replace insulators with higher insulation level in salt contamination areas, replace insulator with higher strength insulators
Flooding	$586	Straighten and grout existing poles or replace with deeper subgrade and/or engineered foundations
Accessibility	$2,639	Develop looped transmission overlay on existing highways
Overhead Subtotal	**$ 4,299**	
Underground	$ 601	SE Puerto Rico underground bypass[18]
Transmission Total	**$ 4,900**	

[18] As noted earlier, this section may alternatively be a conventional overhead transmission line if PREPA chooses to forego some of the advantages of a DC-DC marine cable. Advantages include dynamic voltage response, a solid frequency source, and power flow control.

Timeline

Over the short-term (one to six months), interim repairs are required to restore service. Considering the planning studies, permitting[19] and equipment lead times, the investment in the transmission rebuild is estimated over a period of five to 10 years. Further, due to the large number of substations impacted, careful scheduling and coordination with transmission upgrades is required to ensure the system can operate reliably while new transmission build is underway.

Distribution System

PREPA's distribution system is made up of roughly 1,200 circuits, with over 30,000 miles of overhead and underground lines. Most circuits operate at voltages ranging from 4 kV to 13 kV, which is common among electric utilities. PREPA's distribution system is primarily overhead, with six percent of the circuit miles located underground. The underground lines mostly supply urban areas, including San Juan. The overhead system includes auto loops in some areas (about 30 total on the system) to ensure redundant substation feeds to customer demand centers. Distribution poles are primarily galvanized steel and concrete, with a limited population of wood poles. These poles are susceptible to high winds; concrete poles, in particular, were significantly damaged during Hurricane Maria. In addition, distribution lines are run near transmission poles and other structures, increasing the likelihood of wind causing contact and short circuits.

The distribution system was not originally designed to a Category 4 standard. There were few feeder ties, limited redundancy, or automation to provide backup or aid in the restoration of service. Accordingly, the primary objective for hardening the distribution system is reducing the number of customers impacted and reducing recovery times for future storms.

Damage Assessment

Damage information for this report was provided by select on-the-ground assessments by the NYPA and Con Edison teams as well as damage reports from PREPA. While this information is adequate for developing initial recommendations, several planning and engineering studies are necessary to refine and prioritize recommendations and proceed with project design.

The distribution system encountered significant damage, with up to 75 percent of circuits needing repair. Both the overhead and underground systems were affected. Pre-storm distribution poles were not designed to withstand a Category 4 storm and underground equipment experienced water and contaminant intrusion. The limited use of dead-end breakaways on distribution poles led to a domino effect, with long sections of line failing successively.

Concrete and wood poles both experienced severe damage, while galvanized steel fared better during the storm. Numerous substations located along distribution circuits that step down primary voltages to lower primary, or secondary voltages were also severely damaged. The photos below illustrate the severity of damage encountered on overhead lines, including destroyed concrete and wood distribution poles.

Source: NYPA/Con Edison Damage Assessments

[19] Authorities should consider accelerated or legislated permitting approval once initial engineering feasibility studies have been completed.

Rebuild Recommendations

The Working Group recommends the rebuild and reinforcement up to 75% of its 1,200 distribution circuits. Essential near-term improvements include the following:

- Relocate distribution lines so that they are not on the same side of the street as existing transmission lines to reduce common mode failures.
- Upgrade conductor size and use fully insulated wire (tree wire or bundled conductor) in areas where trees are present.
- Install breakaway service connectors on poles to limit the number of poles impacted by high winds.
- Install automated switching devices and enhance protection and controls by converting from electromechanical relays and SCADA 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.
- Install underground lines in select areas prone to high wind damage.
- Convert lower voltage 4 kV lines to operate at 15 kV, which will improve efficiency and the ability to restore energy demand during storms.

A post-restoration survey will be needed to identify which poles may have been upgraded in the restoration process.

These improvements will greatly reduce the amount of damage caused by storms like Hurricane Maria, thereby lessening cost of repair and number of customers affected in the future. Not all lines can be designed to be immune from storm impacts, but higher design standards and advanced technologies such as self-healing circuits will improve resilience and sustainability, particularly for critical customers and facilities.

Further, the distribution system should be rebuilt to readily integrate renewable distributed resources and energy storage. These proposed upgrades will reduce maintenance and inspection costs while improving reliability metrics and performance. The adoption of advanced control technologies and enhanced operating center functionality described below will improve visibility and control of distributed resources, and support the development of self-healing networks. This includes investing in distribution automation, which includes installing automatic switches, circuit connections, sensors, and communication equipment. These investments will improve system reliability, reduce the impact of outages, and permit greater penetration of DER. Key benefits of recommended distribution automation investments include:

- Near real-time visibility for distribution system operators, with telemetry provided throughout the circuits enabling issues to be identified quickly and accurately;
- Remote fault isolation and service restoration, thereby decreasing outage duration and area of impact;
- Increased operational flexibility with appropriately-sized line sections for circuit switching, which will minimize outages during planned maintenance and unplanned outages; and
- Enhanced situational awareness for DER operations, including the management and control of smart DER interconnections.[20]

The degree to which these capabilities can be achieved is largely dependent on the number of isolating switches and circuit ties installed on a given circuit, as well as the ability to control voltage and loading of distribution circuits. Investments will provide greater benefits in more densely populated areas versus rural systems where there may be longer circuits and fewer connections to other circuits. While cost will vary based on the number of automated devices installed, it is expected to range between $100k to $400k per circuit.

Cost

The following table presents the estimated costs for primary resiliency and hardening categories for overhead and underground distribution.

[20] The use of real-time state estimation system via enhanced distribution load flow simulation software, integrated into advanced distribution management systems, is essential for high levels of DER, and Microgrid management.

TABLE 3-3. DISTRIBUTION SYSTEM COST ESTIMATES

Cost Category	Cost (S Millions)	Description
Wind Damage	$3,432	Replace poles for higher wind loading, install breakaway service connections, install fully insulated wire, relocate distribution away from transmission, selectively underground distribution, install intermediate poles on longer spans, install wider spacing in high debris areas
Insulators Compromised	$208	Replace insulators with higher insulation level in salt contamination areas, replace insulators with higher strength designs in high wind areas
Flooding	$965	Replace poles with deeper subgrade support, selectively underground in areas with water-driven debris
Accessibility	$429	Relocate lines to accessible street level, selectively replace overhead with underground
Operability	$234	Add automated switches with FDIR capability
Overhead Subtotal	**$5,268**	
Distribution Underground	$35	Selectively install submersible equipment, elevate equipment and terminations, spot replace underground with overhead, install engineered protection of cables and conduit in washout areas
Distribution Total	**$5,303**	

Funding for the distribution recommendations would primarily consist of FEMA funds for hardening the system and other Federal or Territory funding sources, such as Community Development Block Grants (CDBG) for the deployment of various recommended technologies and system enhancements.

Timeline

The Working Group recommends 50 percent funding in the first 18 months and the remaining 50 percent over the next two to three years to execute on the distribution rebuild.

Substations

PREPA's power system includes 334 substations owned by PREPA which are generally operated at 230 kV, 115 kV, and 38 kV. The major stations on the transmission system are operated at 230kV and 115 kV and include switching stations, to direct power flow to the various parts of the island, and large substations to step down voltages to the 38 kV subtransmission and distribution system voltages.

These stations are located throughout the island with some being exposed to flooding along the coast and others being more vulnerable to rain runoff and debris from high winds. It is important that these stations be made more resilient to ensure that power flow from generation to the customer remains uninterrupted.

The 38 kV substations account for two-thirds of PREPA's distribution capacity on the island. Distribution substations, though smaller in size, experienced flooding and high winds based on location. Many distribution substations are single transformer stations with three or four medium voltage circuit breakers. They are often located in urban environments or other space-constrained sites due to proximity to the customer and load centers. Real estate is therefore a challenge in these locations and limits the options for physical hardening. PREPA also owns 22 portable distribution substations that enable them to perform substation maintenance. The portable distribution substations range in size from 10 MVA to 44 MVA at 38 kV and 115 kV, and includes two capacitor banks at 38 kV 18 MVAR.

Damage Assessment

Most PREPA substations experienced some degree of damage, with several critically damaged or inaccessible due to mudslides and inundation. Particularly noteworthy is the extensive damage to switchgear, protection, and control systems caused by flooding; which is often visible only by onsite inspection. Additionally, several substation control houses suffered water intrusion from storm water or wind-driven rain. The Working Group field inspectors cautioned that many substations affected by flooding are inoperable due to presence of contaminants and physical damage. We have designated some flooded stations as inaccessible and dangerous for restoration due to damage, as there is a safety risk if these substations were reenergized absent repair or rebuild.

Most of PREPA's assets were installed more than 30 years ago. Accordingly, decisions to rebuild assets such as control systems, protection systems, oil circuit breakers, and communication systems should consider the remaining life of these assets, and replacement, rather than repair should be considered.

Table 3-4. Summary of NYPA Substation Assessment

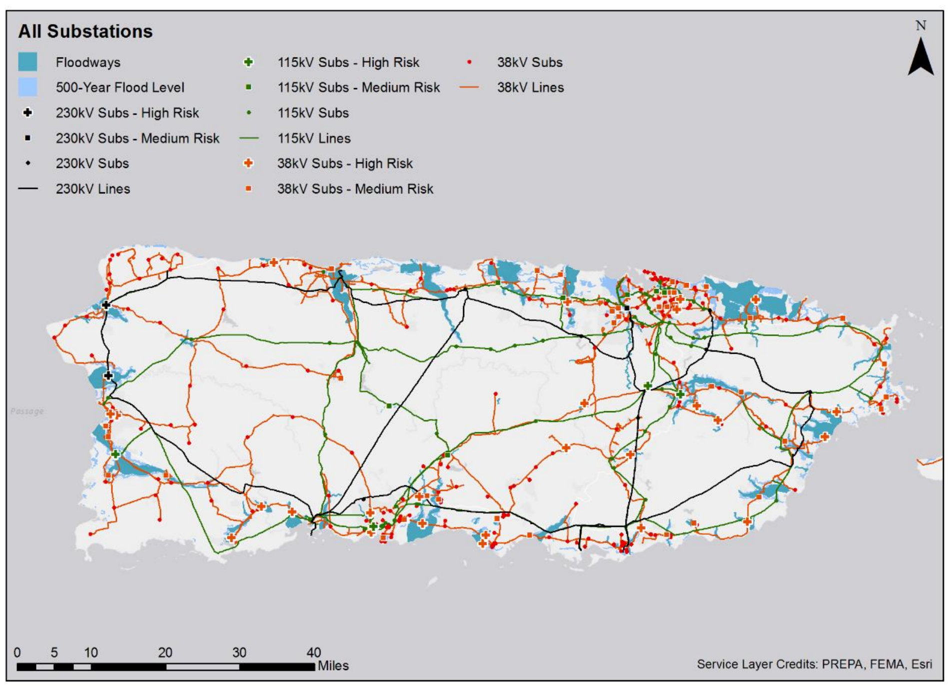
Region	Number of Stations	Good Condition	Some Exposure	Minor Damage	Major Damage	Old Station
Arecibo	41		11	26	3	
Bayamon	60	6	7	28	18	
Caguas	51	6	4	27	11	
Carolina	31		1	3	23	
Mayaguez	54		21	21	10	
Ponce	32			7	24	
San Juan	60		12	8	40	
VIEQUES	5			1	2	1
Grand Total	**334**	**12**	**56**	**121**	**131**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

Table 3-4 includes an assessment of the condition of the substations. These conditions are categorized based on the observations during substation survey conducted by the working group. These are

- Good condition – Station is or may be energized and is good condition
- Some Exposure – Station needs some work such as fencing and vegetation management
- Minor Damage – Significant work needs to be performed. This can include high side de-energized or load isolated, not grounded, blown fuses, equipment replacement needed due to broken insulators, downed microwave tower, blown feeder pothead, containment of transformers.
- Major Damage – Major work needs to be performed. This can include structures or poles broken, flooded substations, trees down on building, equipment damaged and need replacement to operate, dangerous conditions for energizing the substation.

As this survey was done early in the restoration effort some of the stations which might have been inoperable are restored to operable state, but there are improvements needed to these substations for hardening and resiliency. In addition, the Working Group performed an analysis of the existing substation sites using latitude and longitude locations provided by PREPA plotted on GIS mapping of the potential flood zones as identified by the current FEMA mapping (Figure 3-3). Table 3-5 depicts the infrastructure per voltage class and the risk of flooding relative to the flood zone.

Figure 3-3. GIS MAPPING - SUBSTATIONS AND FLOOD RISK AREAS IN PUERTO RICO



Source: Navigant Consulting, Inc.

TABLE 3-5. SUBSTATIONS AT RISK FOR FLOODING IN PUERTO RICO

Substation Voltage (kV)	High Risk	Medium Risk	Grand Total
38	25	43	68
115	4	8	12
230	2	1	3
Grand Total	**31**	**52**	**83**

Finally, the onsite surveys completed to date were for a high-level condition assessment and are not detailed enough to result in specific site-by-site detailed recommendations. The Working Group recommends a detailed site-by-site engineering survey to catalog all damage, deteriorated conditions, and abnormal conditions before developing site-specific requirements.

Rebuild Recommendations

Initial Recovery

Because of the serious damage incurred at substations and long repair times, PREPA will necessarily bypass some substation locations on the transmission system via temporary jumpers or by manually closing and locking substation bus sections. As a result, distribution feeders will be switched to be fed from substations much further away from customers than normal. This will result in decreased reliability and potential overloads during peak energy demand periods. Also, some substations will be energized out of necessity or with unseen damage that will be in a deteriorated state. This will result in some spurious substation operations at best; and perhaps some catastrophic failures.

As substations are reenergized, Puerto Rico should be prepared for a period of reduced reliability. Additionally, some transformers may have been subject to wind-driven rain and flooding, necessitating performing a Dissolved Gas Analysis (DGA) test, testing for insulation strength and moisture, and requiring an extended transformer dry-out procedure.

Substations

The Working Group recommends the reinforcement and storm hardening of approximately 90%+ of the 230 kV, 115 kV and 38 kV substation sites. In general, the rebuild recommendations will include bringing these sites up to a high Hurricane Category 4 design standard for both wind and flooding and the replacement of damaged equipment. Wind studies for 38 kV substations may reveal special wind circumstances as many of the substations have customer-owned buildings on one or more sides. Enhancements for all substations should include the phased replacement of undamaged equipment that, while marginally functional, may present higher operating risks and may hinder expansion of DER.

Hardening for Flood Damage

Hardening of substations consists primarily of defending against flooding, protecting against wind-driven rain intrusion into equipment, and protecting against wind damage.

Flooding Mitigation – Defense in Depth

The analysis that was performed estimates that there are approximately 15 115 kV and 230 kV sites in potential flood zones. It is recommended that future flooding risk at these sites be mitigated through a defense-in-depth approach that was used by several utilities in the New York and New Jersey area after Hurricane Sandy. The analysis also estimates that there are approximately 68 38 kV substations at risk for flooding. However, in the case of 38 kV substations, there may not be enough space for this preferred alternative. Therefore, it is expected that a higher percentage of the 38 kV substations will require elevation of critical equipment.

Flood Barrier
Source: HESCO Corp.

The first level of defense should include a perimeter flooding barrier around the site. While earthen berms and concrete walls may be appropriate in some situations, a cost-effective method to construct these barriers is to use heavy-duty sand bags enclosed in metal mesh.

Design of flood barriers should be based on the observed worst-case flooding, with federal and local flood modeling, plus a foot or more for extremes caused by forecasted ocean rise, in addition to a foot or more for design safety margin.

Several designs exist for accommodating roadway openings in the perimeter. While permanent water-tight doors and earthen rises have been used in some cases in the industry, a less expensive approach would be to use light-weight aluminum tubes that can be dropped into pre-installed tracks and stacked to temporarily close off roadway openings.

Flood Barrier
Source: Con Edison

The second level of defense would include high capacity pumps permanently installed inside the Level 1 perimeter with enough capacity to accommodate both leakage of the Level 1 perimeter and the expected rainfall inside of the perimeter. Those would require redundant power sources, including onsite elevated stand-by generation.

Third, individual critical equipment such as stand-by generators and control buildings would have an individual protection wall and pumps as a backup defense. Finally, individual components such as transformer control cabinets and air vents can be raised where appropriate. The Working Group anticipates that there are some locations where this defense-in-depth approach may not be practical because of space or other considerations. In these individual instances, it may be necessary to elevate control equipment, circuit breakers, and cabling to mitigate flood risk.

Method for Rebuild

Rebuilding substation sites should begin with securing each site. This would include repairs to fences, gates, doors, and other openings. Other physical security equipment such as CCTV and card readers at critical sites should also be installed. Repair of washout areas and stabilization against erosion and washout, especially around fences and foundations, is also a critical first step.

Several classes of equipment should be considered inoperable or destroyed if they have been subjected to flooding. These equipment types include protective relays, communication electronics, battery banks and battery chargers, dry-type transformers, air-blast circuit breakers, potential and instrument transformers, meters, motors and pumps, breaker racking mechanisms, and SCADA, among others. These types of components should be replaced.

Other equipment components, such as control panels and associated wiring and terminals may be salvageable if they are immediately cleaned and dried after the water recedes.

- Any equipment salvaged in such a way should be fully re-commissioned with circuit continuity checks and insulation quality tests.
- If this equipment is successfully salvaged, PREPA should be prepared for unexpected failures and mis-operations due to hidden deterioration and poor electrical connections.
- If this equipment cannot be cleaned and dried to satisfaction then it should be replaced.
- It should be noted that re-wiring switchgear and control houses can be nearly as expensive as replacement. In these cases, replacement is recommended as the more cost-effective solution.
- Install perimeter flood walls (material to be based on site conditions).
    - Wire mesh-lined flood barriers are most cost-effective but require real estate.
    - Where space is constrained, use reinforced concrete walls.
- Purchase deployable flood barriers for personnel gates and driveways.
- Install new dewatering pump stations with elevated backup generators.
- Enclose critical equipment inside the station with interior concrete flood walls.
- Install new prefabricated, modular relay and control houses on elevated platforms.

- Use new microprocessor relays and fiber optic based equipment to improve system protection as well as to enable interconnection of DER.
- Use fiber communications where possible to provide better protection against water intrusion. Include analog to digital convertors connected to fiber optic patch panels on existing equipment such as transformers to communicate with new relay/control houses.

PREPA should expect that much of the flooded equipment cannot be salvaged and will require replacement, which has been accounted for in the rebuild cost estimates.

Hardening for Wind and Rain Damage

Most substations surveyed suffered some amount of wind and rain damage, several extensively. A detailed site survey should be conducted to identify each damaged component.

Rebuilding and hardening for these substations includes new control buildings, upgraded structures and insulators to meet Category 4 design. Equipment with limited capabilities should be replaced if damaged.

In areas subject to salt water contamination, PREPA should consider increasing the dielectric strength of substation equipment. Many utilities have accomplished this by simply designing substations for one voltage class higher than the energized voltage. For example, using 230 kV breakers on the 115 kV system.

In areas with potential for a high amount of wind-driven debris, polymer insulators may be used to replace porcelain or glass insulators. The extent of damage in control houses that were breached is difficult to quantify, even with detailed after-the-fact inspections. Control houses that were breached or do not measure up to a Category 4 wind rating should be replaced with a standardized design. Most utilities have found that modular control houses or for the 38kV modular substations, are an economical alternative to site-built structures.

Also, for 38kV substations, the extent of damage in control cabinets, cubicles, and unit switchgear that were breached is difficult to quantify, even with detailed after-the-fact inspections.

PREPA also has a stated plan to convert the primary distribution system to 13.2 kV. Therefore, damaged

Modular Control Building

Source: Con Edison

equipment should generally be replaced with 15 kV class modular switchgear instead. Control cabinets, cubicles, and unit switchgear that were breached or do not measure up to a Category 4 wind rating should be replaced.

For the 38 kV substations, PREPA should consider a standardized containerized substation design. Generally, this would consist of two containers one with switchgear and the other with relay and control equipment for the urban areas. This way the equipment remains in a water-tight container placed on concrete piers and tied to it with side entrance bushings and wire raceways that are water tight. These standardized designs will be generic and easier to install when rebuilding a substation with minimal outage time. In addition, this design will also provide physical and security benefits and they would be interchangeable, providing lower costs and decreasing the need for multiple spares.

Substation Automation to Modernize Protection, Control, and Security

Substation automation (SA) will provide remote control and data acquisition from substation equipment (such as transformers, breakers, and capacitors, and devices measuring current, voltage, and power flow). SA utilizes an open-standards design to increase interoperability between systems and devices, allow for component upgrades from multiple vendors, and facilitate modern cybersecurity protections. SA is also critical as a base-line technology to enable DER development. A Common Substation Platform (CSP) design provides a critical communications hub that enables a cyber-secure interface between the Field Area

Network and Wide Area Network or SA. It also provides the underlying technology platform that enables remote management of substation functions.

Efficiencies and Synergies

Along with the extensive work required for restoration, recovery, rebuild, and hardening, there are several areas of coordination that could reduce PREPA's overall cost profile. These include coordination of the replacement of end of life circuit breakers and transformers that are leaking fluid, state-of-the-art relay protection systems and SA including supervisory control systems (SCADA) and spill prevention containment (SPCC) for power transformers. In addition, the Working Group recommends design changes such as discontinuation of the use of high side fuses (replace with reclosers or breakers), building reinforcements, communication systems, and installation of distribution automation where lines are being rebuilt. Finally, substation enhancements should include updating both physical and cybersecurity.

Cost

TABLE 3-6. SUBSTATION COST ESTIMATES

Cost Category		Costs ($ Millions)	Description
Substations – 38 kV			
	Wind Damage	$647	Install hurricane-rated fencing, replace or reinforce damaged control buildings, replace bus structures, replace insulators with higher insulation level and Cat 4 strength
	Water Damage	$72	Replace control buildings with a newer modular design, relocate or elevate substations, install water-tight enclosures for control equipment and junction boxes, elevate select equipment and raise air vents, install water barriers and engineered solutions
	Command and Control	$13	Replace damaged SCADA and replace high risk SCADA units, install synchronization and black start relay systems
	Unreliable Operation	$124	Replace high risk circuit breakers, Repair ground systems, Install SPCC containment where needed, install redundant battery systems and backup generators for charging, replace damaged and water-logged transformers, install high side switches or circuit breakers
Substations – 115 kV and 230 kV			
	Wind Damage	$203	Install hurricane-rated fencing, replace or reinforce damaged control buildings, replace bus structures, replace insulators with higher insulation level and Cat 4 strength
	Water Damage	$226	Replace control buildings with a newer modular design, relocate or elevate substations, install water-tight enclosures for control equipment and junction boxes, elevate select equipment and raise air vents, install water barriers and engineered solutions
	Command and Control	$79	Replace damaged SCADA and replace high risk SCADA units
	Unreliable Operation	$304	Replace high risk circuit breakers, repair ground systems, install SPCC containment where needed, install redundant battery systems and backup generators for charging, replace damaged and water-logged transformers, install high side switcher or circuit breakers
Total Substations		**$1,668**	

Funding for the substation recommendations would primarily consist of insurance recovery for damaged equipment, FEMA funds for hardening the system, and other Federal or Territory funding sources for automation and security enhancements.

Timeline

Over the short-term (one to six months), interim repairs are required to restore service. Investment in the recommended transmission rebuild projects will be spread over a period of up to 10 years, as major equipment has long lead times. Further, due to the large number of substations affected, careful scheduling and coordination with transmission upgrades is required to ensure the system can operate reliably while upgrades are underway.

Distributed Energy Resources

Puerto Rico has approximately 157 MW of installed distributed solar PV projects spread across 11,000 projects interconnected to the subtransmission (38 kV) and distribution (13.2 kV and below) systems.

Damage Assessment

Given the vast number of systems, little information is available on status and current condition. However, the Working Group has observed extensive damage on larger solar and wind farms.

Rebuild Recommendations

Two use cases are proposed for DER to build resilience for future emergencies and to reduce fossil fuel imports.

DER for Resiliency

As natural disasters such as Hurricanes Irma and Maria occur in the future, it is imperative that critical infrastructure and remote, isolated communities can restore power to key services in a timely manner. Moreover, these critical loads may need to operate in isolation for days at a time. A large-scale investment in microgrids can pave the way for a more resilient Puerto Rico.

A microgrid is a specific section of the electric grid – representing as large an area as an entire community, down to as small an area as a single building – that has the capability of "islanding" itself from the rest of the electric grid and operate in isolation for hours or even days at a time, while most of the year they retain connection to the centralized grid. This is accomplished via the strategic deployment of DER such as solar, battery storage, backup generators, and control equipment.

The WG recommends pursuit of two specific deployment alternatives to harden portions of the PREPA electrical system, particularly those serving critical infrastructure and loads:

- **Critical infrastructure** such as 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 could operate in isolation and provide much-needed services to Puerto Ricans immediately after a natural disaster. Industrial, airport, sea port, commercial, and telecom sites may be considered, first as an expense to those entities and second, as an alternative to the recommendations provided should implementation become untimely. The installation of onsite backup generation, combined heat and power systems (CHP), rooftop solar, battery storage, and building energy management systems at strategically located sites can create a series of self-powered, autonomous centers to help the local communities recover in the immediate aftermath of a storm.
- **Remote communities** that are more difficult to return to service after an outage, or that are served by a single utility line, could remain disconnected from the grid while still providing much-needed electricity to both critical infrastructure as well as local grocery stores, gas stations, and community centers. The installation of solar, battery storage, feeder automation control systems, load control equipment, and similar technologies could allow for these communities to more quickly recover from natural disasters.

The Working Group recommends that specific emergency services and other critical loads receive investments in onsite generation and islanding equipment, allowing for operations during and after major storms. For certain critical infrastructure, it may not be feasible to pursue microgrid technology deployments at each site. To maximize the impact of these investments while ensuring the broadest possible reach across Puerto Rico, the following assumptions have been made:

- **Hospitals** – Per the American Hospital Directory, there are 58 non-federal, short-term, or acute care hospitals in Puerto Rico.[21] Based upon a review of population density and prioritizing by the number of staffed beds at each hospital, it is recommended that 26 hospitals be provided with the technologies required to operate in a non-grid interconnected (islanded) state for emergency purposes. This includes onsite generation in the form of solar PV, diesel reciprocating internal combustion engines (RICE), CHP, and battery energy storage systems (BESS). Systems would be sized to dispatch the BESS for 6 hours, with the RICE and CHP providing nighttime, shoulder, and shaped production after utilization of the solar generation.

- **Police & Fire Stations** – Based on preliminary research there are 84 fire stations[22] and 13 municipal jurisdictional regions across Puerto Rico for police enforcement.[23] Based upon a review of population density with existing infrastructure and to ensure the availability of police and fire services in the most populated regions of Puerto Rico, it is recommended that 20 of each facility type receive the technologies required to operate in an islanded state. This includes the provision of onsite solar PV, RICE, and BESS at each location, with the BESS sized to dispatch for 4-hours.
- **Emergency Shelters** – The FEMA Shelter Inventory Map identifies 452 shelters across the 78 communities in Puerto Rico.[24] For the preliminary investment in hardening the electric grid to provide emergency services, it is recommended that at least one emergency shelter in each community receive the technology required to operate disconnected from the grid immediately following a natural disaster. For purposes of this analysis, that includes 75 discrete microgrids (with three additional shelters incorporated into broader remote community deployments). These shelters would receive solar PV, BESS, and RICE, with the batteries capable of dispatching for 4-hours.
- **Wastewater & Drinking Water Treatment Facilities** – There are approximately 50 wastewater and 100 drinking water treatment facilities located in Puerto Rico.[25] The initial assumption is that 10% of these facilities would receive solar PV, BESS, and RICE in order to assure that a minimum level of water treatment services are available to communities across Puerto Rico.
- **Remote Communities** – Several remotely located communities exist in Puerto Rico that may be more difficult for PREPA to return to service in a timely manner following a natural disaster. For these types of locations, the investment in a broad feeder-based microgrid can provide for a continuation of services and the provision of electricity to the community for long periods of time. It is assumed that three such communities would be identified, and would include at least one hospital, police station, fire station, emergency shelter, and additional residential and commercial loads. Solar PV, BESS, and RICE would be installed for islanding purposes, with the BESS designed to dispatch for four hours and the RICE units assisting with nighttime minimum loads and the shaping of solar output during the day. These microgrid deployments should be prioritized with other investments related to undergrounding distribution system equipment to enhance resiliency.

All microgrid systems shall be sized to allow for typical daily operations leveraging the dispatch of solar and battery storage during daytime and shoulder periods, and diesel backup generation (and CHP, if applicable) during nighttime hours when solar generation is unavailable. For onsite conventional generation, diesel fuel tanks should be sized to allow for a minimum of 7 to 10 days of planned islanded operations, after which additional diesel fuel would need to be procured and delivered. Remote Communities deployments may leverage larger fuel reserves depending on the anticipated post-hardening infrastructure restoration timeline.

The WG recommends time and consideration be given to investing in local training initiatives, led by PREPA staff, that provide the opportunity for local labor to perform operation and maintenance of the microgrids and associated DER.

[21] https://www.ahd.com/states/hospital_PR.html.

[22] Per data from FireCares and the Puerto Rico State Fire Department (https://firecares.org/departments/92796/puerto-rico-state-fire-department).

[23] http://www.oslpr.org/download/en/1999/0264.pdf.

[24] https://www.floodmaps.fema.gov/ffx/files/739166_PR_CertifiedShelters_Municipios_Barrios_book_20171111_ANSI_C_Portrait_optimized.pdf.

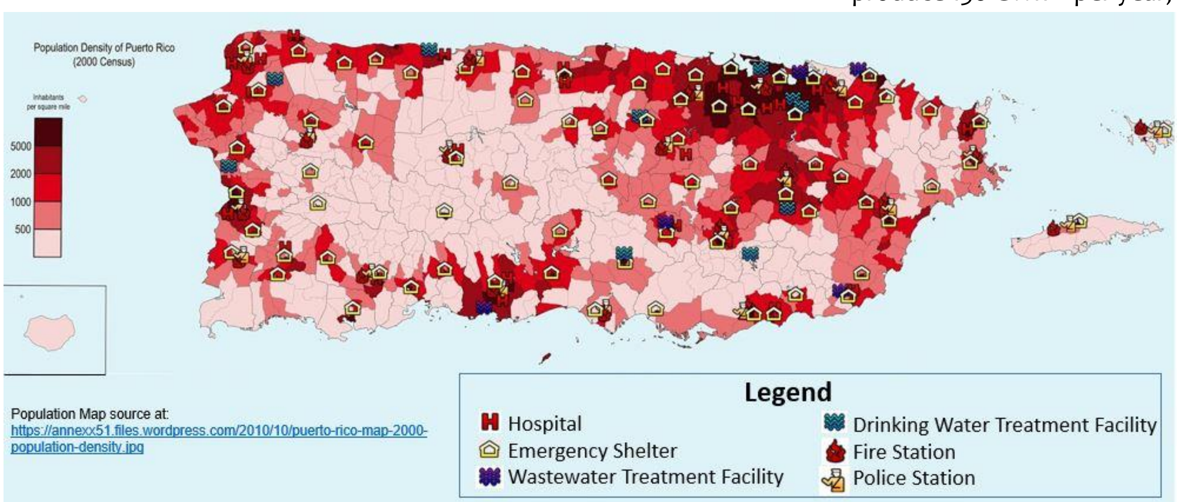
[25] Based upon data provided by the Puerto Rico Aqueduct and Sewer Authority.

For some remote areas of the island, it may be feasible to more fully isolate these communities and design them to operate as separate and discrete grids. The WG recommends the consideration of feasibility studies and stakeholder discussions with local leaders and interested third parties to determine if investments in permanent disconnection from the main PREPA grid are in the public interest, provide more cost-effective resiliency from natural disasters, and provide adequate service quality and reliability.

These efforts could also include procurement processes to identify third party investors and technology providers to provide the capital and equipment necessary to convert these communities into true islanded portions of the grid, if those local communities so desired.

A map of potential critical infrastructure microgrid deployments is included below in Figure 3-4. The exact locations will require further study.

FIGURE 3-4. HYPOTHETICAL ISLANDING OF CRITICAL INFRASTRUCTURE



Sources: Multiple, SEPA

DER for Cost Savings

DER is also proposed to minimize dependency and cost of fossil fuel imports by either reducing energy needs or reducing peak loads, as follows

1. **<u>Passive DER</u>** –Approximately 470,000[26] homes need to be rebuilt or undergo major repair. This presents an opportunity to incorporate energy efficiency and solar PV. These technologies do not require external communications and control infrastructure; therefore, they can be incorporated in the near-term. With the right specifications – such as advanced inverters and guidance from PREPA on ideal locations – passive DER could be installed rapidly with minimal integration costs.[27]

   Puerto Rico's current building codes[28] require solar water heating to be installed in all new homes. This limits the potential for solar PV to be installed because less roof space is available. However, if 20%[29] of the rebuilt homes included an average system size of 1 kW PV system, 128 MW of PV would produce 136 GWh[30] per year, offsetting the equivalent amount of fossil fueled generation.

   In addition, Puerto Rico's building codes[31] require all new construction to comply with IECC 2009 building standards for energy efficiency. We assume this will be met in most[32] of the rebuilt homes. If 15% of the new homes built or rehabbed were to comply with

[26] Source: 11/13 Build Back Better Submission

[27] The exact amount of solar that could be installed without large integration costs requires a separate analysis. This report uses conservative assumptions about system size and penetration in absence of such a study.

[28] Source: https://energy.gov/savings/puerto-rico-building-energy-code-mandatory-solar-water-heating

[29] Source: Navigant assumptions based upon https://www.nrel.gov/docs/fy08osti/42306.pdf

[30] Source: Conservative Navigant analysis using NREL's System Advisory Model for a residential PV system in Puerto Rico that yielded 1443 kWhAC/kWDC production.

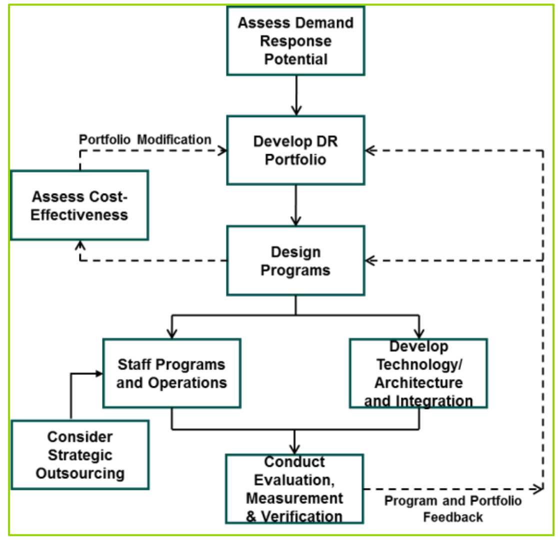
[31] Source: https://www.iccsafe.org/about-icc/government-relations/map/puerto-rico/

[32] Puerto Rico's current goal is 90% compliance with code

IEC 2012, Puerto Rico would save an additional 60 GWh[33] in energy.

2. **Active DER** – Grid interactive DER requires installation of the communications and control infrastructure investment discussed above before it can be realized. Implementation is estimated at three to four years out, but planning should start. Figure 3-5 illustrates the WG's recommended approach to create and launch a DER program. Technologies relevant to Puerto Rico to assess during an initial feasibility study include:
    - Smart thermostats
    - Direct load control of thermostats or compressors
    - Grid interactive water heaters
    - Energy storage – this could be new builds or leveraging the storage deployed for microgrids as discussed above
    - PV
    - Electric vehicle charging modulation

FIGURE 3-5. RECOMMENDED APPROACH TO LAUNCH DR/ACTIVE DER PROGRAM



Cost

DER for Resiliency estimates are shown in

[33] Assumes 17% savings over IECC 2009 per PNNL - 88603 *Energy Use Savings for a Typical New Residential Dwelling Unit Based on the 2009 and 2012 IECC as Compared to the 2006 IECC*

Table 3-7. This does not account for the communications and controls infrastructure required to actively manage DER, as that is accounted for above in previous sections. Associated investment in distribution automation and controls that are expected to operate on common communications platforms are included in the lines and substation sections of the report.

TABLE 3-7. MICROGRID COST ESTIMATES

Facility Type		Number of Sites in Puerto Rico	Technology Required	Estimated Cost per Site	Targeted Microgrid Deployments	Total CAPEX ($ Millions)
Critical Infrastructure	**Hospitals**	58	PV, BESS, CHP, RICE	$19 million	26	$496
	Police Stations	Approx. 100	PV, BESS, RICE	$240,000	20	$5
	Fire Stations	84	PV, BESS, RICE	$240,000	20	$5
	Emergency Shelters	452	PV, BESS, RICE	$4.6 million	75	$345
	Wastewater Treatment Facilities	50	PV, BESS, RICE	$3.6 million	5	$18
	Drinking Water Treatment Facilities	Approx. 100	PV, BESS, RICE	$2.4 million	10	$24
Remote Communities		Multiple	PV, BESS, RICE	$38.1 million	3	$114
TOTAL					**159**	**$1,007**

Our estimates for DER for cost savings are:

- Solar PV on new residential construction - $315M[34]
- Bring 15% of new construction or major rebuilds to IECC 2012 building code - $133M[35]

Funding for the DER recommendations would primarily consist of CDBG, private equity or merchant development, and non-FEMA Federal or Territory funding for DER development.

Timeline

Investments in microgrids would occur strategically over a five to ten-year period, with the most critical loads prioritized first. This effort could be coordinated with both PREPA, FEMA, and USACE input and assistance to ensure that the highest value / highest impact facilities were targeted first and that lower priority sites received interim relief and mitigation assistance.

Implementing the passive DER portion of the Working Group's recommendation should start in early 2018 to achieve the desired timeline. Challenges to implementing this plan include:

- **Workforce availability** - installing solar PV and building energy efficient homes requires specific skills and expertise such as electricians, roofers, and plumbers. Work can begin on mapping labor needs and conducting trainings if needed.
- **Logistics and equipment supply** - this will be a large undertaking. Outside partners with implementation experience on this scale might be required. Solicitations can be developed in early 2018 so bidders can secure a supply of equipment such as solar panels and inverters.

The Active DER portion of the plan cannot be fully implemented until requisite communications and control systems are installed - likely three to five years out. However, planning should start several years earlier.

In addition, the WG recommends the next IRP specifically include a review of DER for both resiliency and cost savings, with considerations given to how strategic investments and locational deployment of DER can offset future conventional generation needs.

System Operations

PREPA maintains both primary and backup system control centers to manage the operations of the interconnected grid. Personnel in these control centers play a critical role during major storms as they are responsible for isolating faulted lines and substations, and dispatching generation in a manner that minimizes the number of customers affected and restoring power as quickly as possible following a storm, assuring customer and work crews and system safety. Control center staff rely on sophisticated

[34] Assumes a cost of $2.5/Watt plus 30%

[35] Working Group estimates $1,500 per home plus 30% based upon an average from http://bcapcodes.org/tools/ica-2012/ Actual costs will vary significantly on a house by house basis.

supervisory control system (EMS and SCADA) and secure communications to efficiently and reliably deliver power from generators to load centers. PREPA's primary control center is in a secure building, elevated above flood levels. The backup control center is rarely used and is not built consistent with current industry practices.

Damage Assessment

The storm surge extensively damaged generation and T&D equipment, which has compromised PREPA's ability to monitor, operate and control electric operations across the island. The Working Group's recommendations will improve PREPA's ability to execute their function as system operator and provide new capabilities associated with distributed resources, each of which are essential to the safe, reliable and secure operation.

Operating Considerations

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

- Black start capability at generating stations and automated synchronization at selected 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.

Rebuild Recommendations

The Working Group recommends the installation of new primary and backup control center equipment, hardware and software, including associated IT and OT system upgrades required for distribution automation, monitoring and control of distributed resources and energy storage. The use of automated systems and advanced outage and distribution management systems for both the primary and backup control centers will improve system resilience, efficiency, and security. To achieve the desired functionality described above, PREPA also will need to build out communication systems as described below.

Communication Systems to Support Automation

The expansion of communications systems, via hardened stand-alone fiber loops, and partly via integrated optical ground wire (OPGW) on the transmission network, can be accomplished cost-effectively during the T&D rebuild process. The communication system upgrades can also have other utility and/or commercial applications that should be considered during the design process.

Communication systems are divided into two major components; a Field Area Network (FAN) supporting the distribution system and a Wide Area Network (WAN) providing backhaul data from substations to the control centers. A modern FAN would include a secure, Internet Protocol (IP)-based, data transmission system that enables information to be sent between the distribution sensors on circuits to transmitters in substations and then to the control centers. The FAN typically consists of a wireless radio system capable of supporting the capacity, speed, connectivity, and security needs of distribution field devices and DER planned for at least the next 15 to 20 years.

The WAN today is made up of a fiber-based, highspeed data system that supports the convergence of voice, video, and data from the field to the control centers. Similar to DA, these systems may more commonly be deployed in urbanized areas to support the distribution system, though they may prove useful in rural areas to provide more secure and reliable data from remote sensors and SCADA systems installed at substations; as well as visualization and control of distribution resources and microgrids.

Advanced Distribution Management System (ADMS)

A modern distribution automation system capable of performing advanced functions outlined in this report will require ADMS operating on a common platform with SCADA and DER monitoring, control and optimization software (DERMS). The ADMS provides advanced distribution operations, switching procedure management, planned and unplanned outage management, and other applications such as Fault Location Isolation and Service Restoration (FLISR), Volt-VAR Optimization (VVO), Conservation Voltage Reduction (CVR), peak demand management, optimization through a single real-time system model, SCADA controls, and other network analysis, operation and planning functionality.

Cost

Funding for the system operations recommendations would primarily consist of FEMA funds for studies related to hardening the system and other Federal or Territory funding sources, such as CDBG, for technology enhancements, and insurance recovery for damaged buildings and equipment.

TABLE 3-8. SYSTEM OPERATIONS COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
System Control	$ 167	Install ADMS System, upgrade communications, add a portable backup Control Center, and install hurricane coverings for the windows
System Studies	$ 55	Post-restoration engineering studies, planning studies, pre-engineering surveys
Customer Communications	$ 165	Upgrade customer system and messaging
Spare Equipment	$ 29	Purchase and store adequate system spares based on new equipment and expected failures
Security	$ 66	Upgrade security at control centers and critical substations
Total	**$482**	

Timeline

The Working Group estimates five to seven years to complete the control system implementations, with the communications infrastructure more closely aligned to the T&D build schedule and continuing two to three additional years.

4. Generation Rebuild and Hardening

The generating capability of the PREPA fleet is almost 5,839 MW, including several PPAs for fossil and renewable generation. The damage to PREPA generating facilities varied from minor to extreme. The pre-storm capacity of the generating fleet is notably higher than the PREPA peak of approximately 3,060 MW in August 2017. Given this excess capacity and the need to rebuild, there are several options for modifying the size and technology of the generation fleet. The Working Group considered the following in evaluating Puerto Rico's generating fleet:

- Near-term restoration of power to the island
- Opportunities to increase the use of DER
- Development of new targets for renewable resources
- Shift of fossil generation to primarily duel fuel units with primary fuel as natural gas
- Hardening of the generating facilities that will remain
- Study establishing new planning and operating generating reserve margins to something nearer to 50% (approximately 4,000 MW of firm capacity).
- The issues noted above will require the 2015 IRP to be revisited for modification to ensure all necessary factors are considered including:

The potential impact of increased DER and renewable targets includes:

- Shift of fossil generation to natural gas
- Reduction of system reserve margin
- Recent operational history of plants (availability, outages, heat rates, etc.)
- Potential hidden damages to piping, electrical and control systems and other system necessary for operations
- A combination of plant age, operational capability, criticality to overall system operations and cost to repair
- Assessment of the viability of the IPP facilities for continued operations.

The issues noted above will require the 2015 IRP to be revisited for modification to ensure all necessary factors are considered including the potential impact of increased DER, increased renewable targets, shift of fossil generation to natural gas, reduction of system reserve margin, etc. Depending on the results of the newly proposed IRP, some of the plants may be slated for retirement and may not require the full level of estimated expenditures.

Damage Assessment

An assessment of generation plants was performed by the NYPA team.[36] Individual generation plant damage assessment reports were prepared, and are included in Appendix A. Some of the representative damage found include:

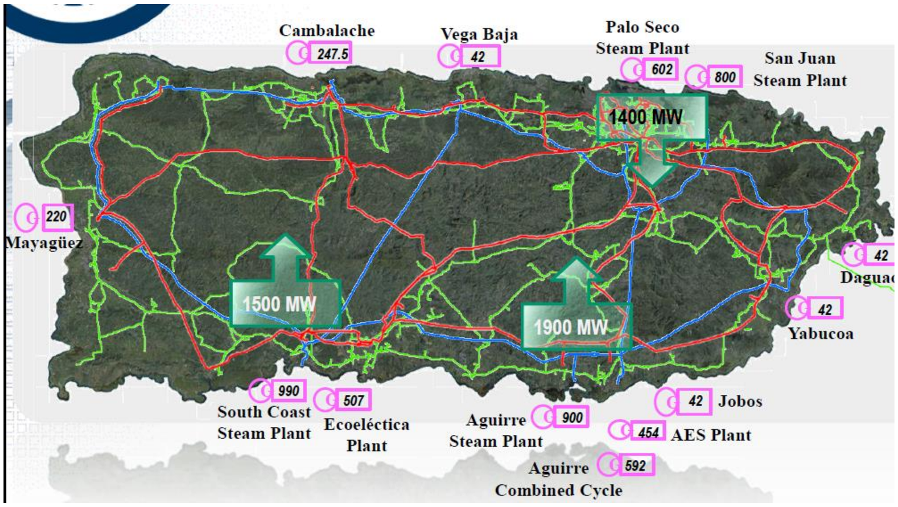
- Critical components of the stations, such as turbines and boilers, are not enclosed in a building and the proximity to the coast results in salt mist being carried by the wind that can corrode the exposed equipment in addition to damage caused by heavy winds and rain
- Damage to louver sets of air intakes by high winds allowing for water to reach air filters
- Extended damage of cooling towers
- Bus and switching gear failure
- Flooding of fuel oil farm including fire protection house
- Water intrusion into administration building (from roof and through doors)

Recommendations

Puerto Rico's generating facilities are concentrated along the north and south coasts of the island. They are vulnerable to flooding, both from coastal storm surge and rain runoff coming down from the mountains. In addition, the critical components of the stations, such as turbines and boilers, are often not enclosed in a building and the proximity to the coast results in salt mist being carried by the wind that can corrode the exposed equipment in

[36] It is important to note that the Working Group did not review or provide specific recommendations for the units on Vieques and Culebra.

FIGURE 4-1. PRIMARY GENERATION FACILITIES IN PUERTO RICO



addition to damage caused by heavy winds and rain. Expecting these facilities will remain in their current location, storm hardening is critical to ensure they withstand future storms.

The primary generation facilities are shown in Figure 4-1. Nine of these sites have been identified in potential flood zones and are further described in the sections to follow. It is recommended that flooding risk at these sites be mitigated through a defense-in-depth approach as described in the Substations section of this report.

A three-level defense-in-depth approach is recommended for generation facility storm hardening and resiliency. As described in the Substations section, this includes building a perimeter flood barrier, installation of required pumps and backup generators, and improvement of the structures roof and walls to withstand the anticipated high winds

As outlined in the Generation section, the Working Group recommends that the IRP be revisited to incorporate storm hardening, increased use of distributed generation and accelerated penetration of renewables, while ensuring that the capacity meets the current and future energy demand of the island.

Additionally, the Working Group recommends a study be conducted to establish new planning and operating generating reserve margins that are closer to a conservative 50% (approximately 4,350 MW of firm capacity).[37]

While implementation of the recommendations in the 2015 IRP is proposed over multiple years, the conversion of some of the severely damaged plants to gas generation will be required in a much shorter timeframe.

Source: PREPA

Source: NYPA/Con Edison Damage Assessments

[37] Currently, 961 MW is provided from fossil generation PPA's, another 64 MW from PREPA hydro plants and an additional 122 MW from solar and wind - the remaining 3,200 MW will need to come from the current PREPA fleet and/or distributed resources.

Cost Estimates

Estimated costs per generation site include additional engineering studies, inspection and testing, base facility repairs, spares replacement, storm hardening, and the installation of new generation equipment where required/already planned. Further cost details are provided in Appendix A, along with a high-level impact assessment and specific recommendations for each plant.

TABLE 4-1. GENERATION FACILITIES RECOVERY AND HARDENING INITIAL COST CONSIDERATIONS

Cost Category	Costs ($ Millions)	Description
San Juan Plant	$38	Test and inspection; base repairs; spares replacement; storm hardening
Costa Sur Plant	$32	Test and inspection; base repairs; spares replacement; storm hardening
Aguirre Plant	$1,545	Test and inspection; base repairs; spares replacement; storm hardening; install H-class machine at Aguirre to address MATS compliance, system stability, and fuel diversification issues
Cambalache Plant	$33	Test and inspection; base repairs; spares replacement; storm hardening
Palo Seco Plant	$1,320	Installation of dual fired F-class machine to address MATS compliance, system stability, and fuel diversification issues; storm hardening
Mayaguez Plant	$13	Test and inspection; base repairs; spares replacement; storm hardening
Vega Baja Plant	$10.5	Test and inspection; spares replacement; storm hardening
Yabucoa Plant	$13	Test and inspection; base repairs; spares replacement; storm hardening
Daguao Plant	$13	Test and inspection; base repairs; spares replacement; storm hardening
Hydro Plants	$32	Test and inspection; base repairs; spares replacement; storm hardening
Renewables Plant	$65	Test and inspection; base repairs; spares replacement; storm hardening
Total Estimated Costs	**$3,115**	

The Working Group recognizes there is a planned shift in the generation mix to more renewables, DER and natural gas fired generation. To this end, options studied by the Working Group and shared with PREPA were later discarded as previously explored and dismissed options for the island. Per input from PREPA, the decision has already been made as a matter of public policy, to pursue the Aguirre Offshore Gas Port floating storage and regasification unit (FSRU) option. Initial high-level estimates range from $300 - $525 million and exclude any funding for damage from the hurricane which is unknown at this time.

Developing the planned Aguirre Offshore Gas Port along with marine infrastructure and pipeline to shore for gas delivery to shore would enable the conversion of the Aguirre generation plant to natural gas.

In addition, PREPA is assessing the feasibility and possible locations for supplying natural gas to the northern power plants, specifically San Juan and Palo Seco.

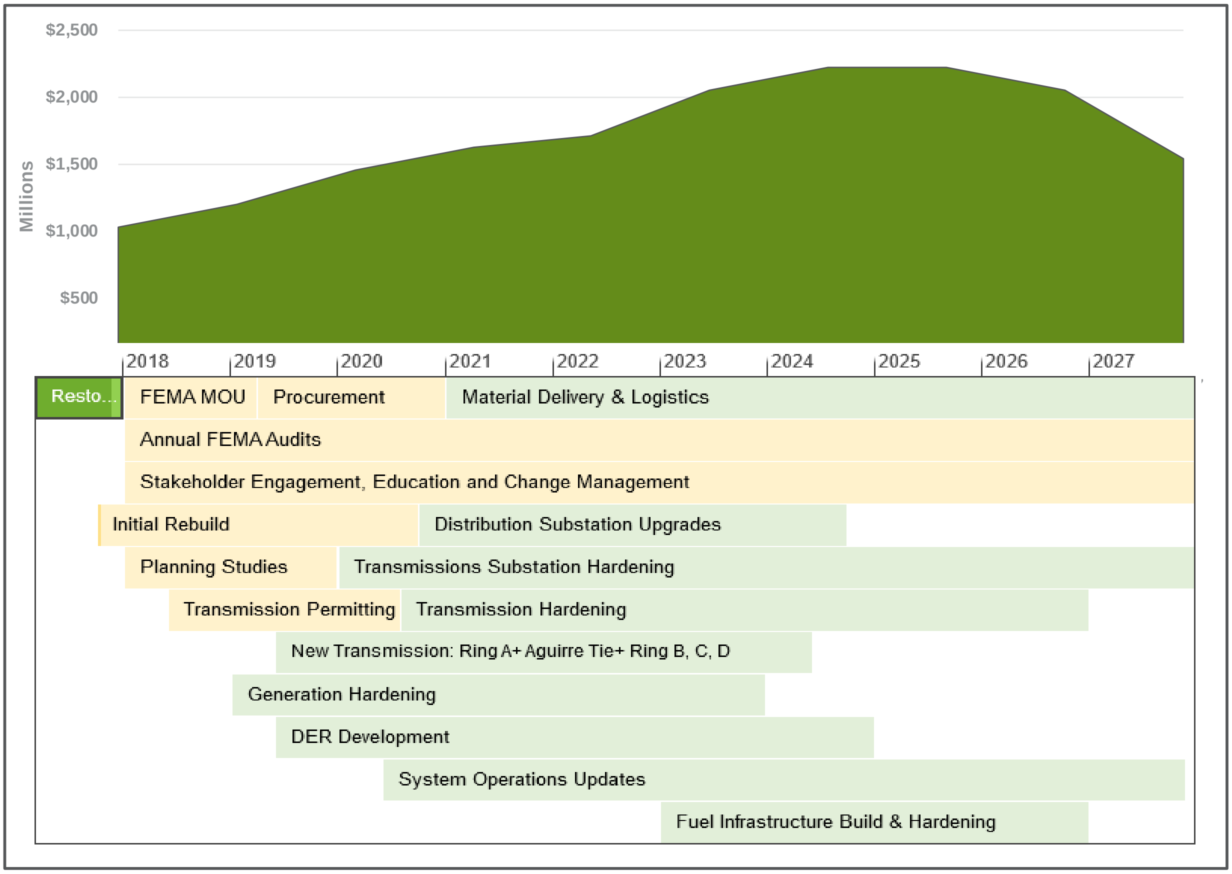
Fuel Considerations

Presently there is a lack of detailed information regarding the current capabilities of fuel delivery, the extent of damage from the hurricanes and needed modifications for reliable future deliveries. The IRP will need to consider the current and future fuel delivery schemes required to support the modified generation fleet. The pre-storm fuel structure is described in Appendix A.

5. Implementation Roadmap

The following diagram presents a high level, 7-10-year cashflow analysis and associated implementation roadmap envisioned for the power system rebuild recommendations provided in this report.

FIGURE 5-1. PUERTO RICO POWER AND GRID RESILIENCY IMPLEMENTATION ROADMAP



The following activities are underway or expected to begin in early Q1 2018:

- Initial Rebuild activities are underway and include the repair of salvageable substation equipment, strengthening and grouting of poles, repairing fences, restoring physical security, and restoring salvageable communications.
- Annual FEMA audits, also known as A-133 or single audits, are required by federal regulations for any entity that expends $750,000 or more of federal assistance. The audits must be filed by September 30 of the year after FEMA money is spent and must be filed every year thereafter while federal assistance funding is spent. Accordingly, the first FEMA audit will likely need to be completed by September 2018.
- Planning Studies include the transmission planning studies, detailed engineering assessments, IRP resource studies, and DER site studies.

Appendix A. Generation – Per Site Impact Overview and Recommendations

San Juan Plant

San Juan Steam Plant (SJSP) is a combination of four steam boiler units and a combined cycle unit all of which have oil as the primary fuel. According to the 2015 IRP, San Juan units 7,8,9, and 10 are subject to MATS, and therefore will face limited use or retirement once the transmission grid has been sufficiently repaired and replacement generation is installed at Palo Seco. San Juan 5 and 6 are combined cycle and newer than the steam units. These units should be able to better handle renewable intermittency and could be converted to burn natural gas.

Damage Assessment

The combined cycle unit is generally available but is still in need of having a thorough test and inspection completed to ensure equipment and personnel safety.

One of the steam boiler units is unavailable while the others are partially or fully available. Units 9 & 10 cooling tower is damaged with temporary fixes in place to allow interim usage. There is no wastewater treatment available and the fuel oil fire protection has been damaged and is functionally questionable. The plant bridge crane has been damaged and in need of repairs. Battery chargers are not in service, and with a loss of AC power, can result in severe damage to equipment.

One significant issue with the loss of battery is the failure of the lube oil system to operate and cause damage to the steam turbine bearings. Unit 10 steam turbine was out of service prior to the hurricanes with the cover removed and the rotor and stationary blades stored outside under a tarp. The extent of damage to this equipment is unknown, but may require significant replacement of spares.

Rebuild Recommendations

The 2015 IRP does not envision any significant change to SJSP and thus would indicate that this plant would be subject to a significant rebuild effort.

The SJSP is a significant portion of the capacity for the island and may be a priority facility to make fully functional as soon as possible. In the longer term, a review of the need and viability of units 7-10 should be considered.

TABLE A-1. SAN JUAN PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.25	Work to further define damage at generation facilities
Base Repairs	$10	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$7.75	Replacement of spares that have been damaged by the storm
Storm Hardening	$20	Storm hardening at existing generation facilities
Total	**$38**	

Repairs to full functionality can be done in a phased approach extending an estimated 18 months. A complete evaluation of the damage and operability assessment is expected to take approximately one month from which a more defined action plan can be prepared.

Costa Sur Plant

A four-unit oil/gas 820 MW station with two Frame 5 turbines and two steam units. The two steam units, Costa Sur 3 and 4, are subject to retirement, and are not used unless there are extreme system conditions. No additional information is available on the two steam units.

Damage Assessment

This station experienced a failure of one combustion turbine (CT) generator stator during the hurricane. The second CT was previously unavailable prior to the hurricane. The blackstart capability at the station in unavailable. The station crane was blown off its rails during the storm. Repairs to the blackstart capability may well be an initial priority. The Costa Sur 6 unit is in service.

Rebuild Recommendations

While the 2015 IRP has the Costa Sur plant being repowered with an H-class combined cycle, that is not expected until the 2030/2031 timeframe.

With a capacity of 820 MW and what now seems to be limited damage, this station could also be placed on the priority list for operability.

TABLE A-2. COSTA SUR PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.25	Work to further define damage at generation facilities
Base Repairs	$10	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$1.75	Replacement of spares that have been damaged by the storm
Storm Hardening	$20	Storm hardening at existing generation facilities
Total	**$32**	

Repair of the facility to operability will require a phased approach. The first step, approximately one month consists of comprehensive inspection and testing to ensure safety of equipment and personnel. Repair of the blackstart capability in conjunction with repairs to the two Frame 5 machines will be heavily dependent on the specific damage and availability of spare parts.

Also in conjunction with this effort, a review of the steam units should be completed which may offer greater capacity in a shorter timeframe. Expected overall time for full operability is six to 18 months.

Aguirre Plant

Source: NYPA/Con Edison Damage Assessments

The 1200 MW Aguirre oil-fired plant consists of 900 MW of steam capacity and 300 MW of combined cycle capacity. The station also includes two Frame 5 machines for blackstart capability. According to the 2015 IRP, PREPA is also pursuing the Aguirre Offshore Gas Port (AOGP) for fuel diversification, cost reduction, and future generation at Aguirre.

Damage Assessment

The plant experienced destruction of the cooling towers and an apparent bus failure on one of the combined cycle units. One of the combined cycle units was taken out of service prior to the hurricane. The steam units appear to have experienced minimal damage. A key issue is the lack of any available transmission lines leading to the switchyard. Depending on the results of the comprehensive inspection and testing, a significant portion of the units may be made functional quickly, but the lack of operating cooling towers will limit their full functionality. As of November 29, Aguirre 1 is in service.

Rebuild Recommendations

The damage to the cooling towers at the station is significant and a major driver of the costs to repair. Repair of the cooling towers will be on the critical path to bring the station into full operability. The cost estimate assumes repairs to the cooling towers versus full replacement. If the cooling towers require replacement, the cost estimate will increase significantly. Restoring blackstart capability and repairs to the cooling towers should take precedence in the schedule.

The 2015 IRP calls for the conversion to gas by 2017; however, this has not occurred. The plan also calls for the replacement of the steam units with H-class combined cycle units in the next 10 years. Given the current state of the PREPA generation fleet, an accelerated move to the H-class machines should be considered.

TABLE A-3. AGUIRRE PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$ .25	Work to further define damage at generation facilities
Base Repairs	$ 41	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$ 3.75	Replacement of spares that have likely been damaged by the storm
New Unit Build	$ 1,500	Install H-class machine at Aguirre
Storm Hardening	$ 20	Storm hardening at existing generation facilities
Total	**$ 1,545**	

The time required to bring this station back to full operability is an estimated 12-24 months depending on the requirements for the cooling tower and spares required to repair the combined cycle units. Additionally, this would assume that the required transmission lines will be available in a timely manner.

Cambalache Plant

Cambalache is a 247 MW oil-fired CT station.

Damage Assessment

Source: NYPA/Con Edison Damage Assessments

A detailed assessment of this station has not been performed. Additional analysis to better understand the extent of the damage is required. The assessment performed indicates several buildings sustained damage to walls and roofs. While the Cambalache plant is in service, the Working Group recommends detailed inspection and testing.

Rebuild Recommendations

Since the 2015 IRP does not anticipate any significant change in the station status, repairs to this station should proceed.

TABLE A-4. CAMBALACHE PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.25	Work to further define damage at generation facilities
Base Repairs	$10.0	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$2.75	Replacement of spares that have likely been damaged by the storm
Storm Hardening	$20.0	Storm hardening at existing generation facilities
Total	**$33.0**	

It is estimated that this plant would be available for operation within 9-12 months.

Palo Seco Plant

Source: NYPA/Con Edison Damage Assessments

Palo Seco is a combination plant with gas-fired steam and CT units onsite. It has a 602 MW rating. According to the 2015 IRP, Palo Seco Units 1, 2, 3 and 4 are subject to MATS.

Damage Assessment

The damage is extensive. Since this plant was slated for conversion to F-class machines or shutdown per the 2015 IRP, additional expenditure is not recommended.

Rebuild Recommendations

With the extent of damage and significant safety concerns, the Working Group recommendation is to shut down or replace this facility.

TABLE A-5. PALO SECO PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
New Unit Build	$1,300	Installation of dual fired F-class machine at Palo Seco
Storm Hardening	$20.0	Storm hardening at existing generation facilities
Total	**$1,320**	

This type of facility would require a 3-4-year timeframe for design and construction of the new facility.

Mayaguez Plant

The Mayaguez plant is a four unit FT8 oil-fired CT plant rated at 220 MW. It is one of the newer plants having commenced operation in 2008.

Damage Assessment

Given the recent construction of the facility plant, it appears the plant saw minimal damage. As of November 26th, Mayaguez is in service.

Rebuild Recommendations

This plant may be capable of generating power as long as fuel is available and the T&D systems is intact/ restored. Additional storm hardening may result in reliable operation in the future. Cost estimates include the necessary repairs and some storm hardening.

TABLE A-6. MAYAGUEZ PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.25	Work to further define damage at generation facilities
Base Repairs	$2.0	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$0.75	Replacement of spares that have been damaged by the storm
Storm Hardening	$10.0	Storm hardening at existing generation facilities
Total	$13.0	

Portions of this plant are capable of running immediately, as long as fuel is available and there is a means to move the power into the system.

Vega Baja Plant

The Vega Baja plant is a 2-unit oil-fired CT plant rated at 40 MW.

Damage Assessment

No major damage from the hurricane was seen during the evaluation. Neither unit was available at the time of the inspection, but repairs were underway on unit 2. It is expected that those repairs have been completed. The unavailability of the units was due to hurricane damage.

Rebuild Recommendations

If fuel supply is available, this site may be available to generate power however, the status of the transmission/distribution infrastructure may limit its capabilities. Additional storm hardening may be beneficial to ensure greater resiliency in the future.

The current estimate to address minor damage and/or replacement of damaged spares and storm hardening is $10.5 million. Further evaluation is required to determine the full scope of work needed at this facility.

TABLE A-7. VEGA BAJA PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.05	Work to further define damage at generation facilities
Replacement of Damaged Spares	$0.45	Replacement of spares that have been damaged by the storm
Storm Hardening	$10.0	Storm hardening at existing generation facilities
Total	**$10.5**	

This plant may be capable of generating power as long as fuel is available and the T&D systems are intact or restored.

Yabucoa Plant

The Yabucoa plant is a 2-unit oil-fired CT plant rated at 40 MW.

Damage Assessment

The building's roofing, doors, fire suppression system, fuel storage tanks suffered damage. As of November 29, one of Yabucoa's units is in service.

Rebuild Recommendations

If fuel supply is available, this site may be available to generate power however, the status of the transmission/distribution infrastructure may limit its capabilities. Additional storm hardening may be beneficial to ensure greater resiliency in the future.

$13 million is the estimate for damage and/or replacement of damaged spares and some storm hardening. Further review should be conducted to consider the need for this facility.

TABLE A-8. YUBUCOA PLANT COST ESTIMATES

Cost Category	Costs ($ Thousands)	Description
Test and Inspection	$0.05	Work to further define damage at generation facilities
Base Repairs	$2.7	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$0.25	Replacement of spares that have been damaged by the storm
Storm Hardening	$10.0	Storm hardening at existing generation facilities
Total	**$13.0**	

This plant may be capable of generating power in three – six months as long as fuel is available and the T&D systems are intact or restored.

Daguao Plant

The Daguao plant is a 2-unit oil-fired CT plant rated at 40 MW.

Damage Assessment

Hurricane damage to this plant was minimal, but there was some damage to the fuel storage tank. According to PREPA, the Daguao units are currently in service.

Rebuild Recommendations

If fuel supply is available, this site may be available to generate power however, the status of the transmission/distribution infrastructure may limit its capabilities. Additional storm hardening may be beneficial to ensure greater resiliency in the future. Further review should be conducted for the needs of this facility in the longer term.

TABLE A-9. DAGUAO PLANT COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.05	Work to further define damage at generation facilities
Base Repairs	$2.7	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$0.25	Replacement of spares that have been damaged by the storm
Storm Hardening	$10.0	Storm hardening at existing generation facilities
Total	**$13.0**	

This plant may be capable of generating power as long as fuel is available and the T&D systems is intact/ restored.

Hydro Plants

PREPA has seven hydro facilities with an available capacity of approximately 60 MW depending on operating conditions. The largest hydro plant is Dos Bocas, a 22.5 MW facility. Other hydro facilities include Rio Blanco (5 MW), Yauco 2 (9 MW), Toro Negro I and II (10 MW), Garzas I and II (12 MW), Caonillas (4 MW), and Patillas (1.4 MW).

Damage Assessment

There was extensive damage to the Dos Bocas plant including intrusion of significant amounts of mud and water as well as damage to the Westinghouse unit due to a ground fault on the stator. Based on this assessment, the Working Group recommends a comprehensive evaluation of the facility including detailed inspection of all switchgear, rotating equipment and control systems. As of November 29, 2017, Yauco 2 and Toro Negro are in service.

Source: NYPA/Con Edison Damage Assessments

Rebuild Recommendations

Since these plants are only a small portion of the capacity of the PREPA fleet, their return to service may not be a high priority. With the repairs to these facilities, there is an opportunity to install barriers and enhance the plants' capability to withstand a Category 4 hurricane, which will help in maintaining power during future storms.

TABLE A-10. HYDRO COST ESTIMATES

Cost Category	Costs ($ Millions)	Description
Test and Inspection	$0.05	Work to further define damage at generation facilities
Base Repairs	$30.0	Repairs to generation facilities to energize the island
Replacement of Damaged Spares	$1.5	Replacement of spares that have been damaged by the storm
Total	**$ 32.0**	

Assuming these are not a high priority to return to service, it is anticipated it will take six to nine months to complete the repairs.

Renewables

The renewables include two privately owned wind farms and five privately owned solar facilities.

Damage Assessment

The Punta Lima wind farm suffered significant damage, with loss of approximately half the blades and damage to vertical posts. The other wind farm (Santa Isabel) was seemingly intact. Of the five solar facilities, at least one solar farm had extensive damage to a large portion of the panels which will need replacement.

Rebuild Recommendations

For the privately-owned renewables, it is typical for the current owner/operators to be responsible for rebuilding the damaged facilities. The 2015 IRP anticipates up to 20% of the island's energy coming from renewables. Achieving this target will require investment in new[38] renewable sources of power and the rebuild of the existing facilities that suffered damage.

Source: NYPA/Con Edison Damage Assessments

The estimated cost of repair of these merchant facilities is $25 million for the wind farm and $40 million for solar farm repairs. Repair/replacement of the existing solar and wind facilities is estimated to take approximately nine to 12 months.

Source: NYPA/Con Edison Damage Assessments

Fuel Infrastructure Pre-Storm Description

Residual Fuel Oil

Puerto Rico has four steam-electric power plants which burn residual fuel oil. These are Palo Seco and San Juan, both located in the San Juan area on the north coast, and Costa Sur and Aguirre, located on the south coast.

The Costa Sur plant is dual fueled, capable of burning either residual fuel oil or natural gas. Its primary fuel is natural gas. The San Juan and Aguirre facilities have additional combined-cycles plants that burn distillate fuel oil.

Residual fuel oil is delivered to Puerto Rico by vessel. It is stored centrally at the former Commonwealth Oil Refinery complex on the south-west of the island. From there it is piped to the nearby Costa Sur plant and delivered by barge to the other three plants.

Each of the four steam-electric plants has onsite storage for residual fuel oil. Palo Seco has capacity to store 450,000 barrels, San Juan 138,000, Costa Sur 800,000 and Aguirre 780,000. Based on 2013 generation figures, this storage capacity corresponds to 36 days for Palo Seco, 14 days for San Juan, 53 days for Costa Sur and 40 days for Aguirre. The plants typically hold at least 15 days' worth on fuel oil on site.

Distillate Fuel Oil

Distillate fuel oil is used at the combined-cycle plants at Aguirre and San Juan and the combustion-turbine plants at Cambalache, Mayaguez and nine further small facilities around the island.

The distillate fuels are delivered storage facilities at Yabucoa and Bayamon and from there are barged to four larger stations (Aguirre, San Juan, Cambalache and Mayagüez). The nine further small facilities around the island operate infrequently and receive fuel deliveries by truck when required.

---

[38] In addition to wind and solar, the Working Group recommends looking at other renewable energy resources such as biogas, biomass, and geothermal energy.

The Yabucoa facility has capacity for four million barrels of crude oil, fuel oil, and refined products. The Bayamon facility has capacity for 3.5 million barrels. There is no information available on what the current storage arrangements for distillate fuel oil are.

The 2013 report indicates that there are two distillate fuel transfer lines between the Palo Seco and San Juan plants went into service. There is no information regarding onsite storage for distillate fuel oil at any of the plants.

Natural Gas

Natural gas is used at the privately-owned EcoElectrica cogeneration facility and at the Costa Sur steam plant which are both located at Guayanilla Bay on the southwestern coast where the Peñuelas terminal and regasification facility is located. Natural gas is imported as LNG, mainly from Trinidad and Tobago.

The EcoElectrica plant is adjacent to the regasification facility and the Costa Sur plant receives gas via a short pipeline. Storage for one million barrels of LNG is available at the regasification facility.

The facility currently receives an average of two LNG deliveries per month and delivers 186 MMcf per day, which is split 50:50 between the EcoElectrica plant and the Costa Sur plant. The facility has two spare regasifiers and earlier this year obtained FERC approval to put one of them into continuous service and to increase LNG deliveries to 40 per year from the current 24. The FERC approval will allow the gas received by the Costa Sur plant to double to 186 MMcf per day from the current 93 MMcf per day.

Some steps were taken prior to 2013 to convert other of the steam plants to natural gas, but these were put on hold due to uncertain gas supply following the cancellation of a cross-island pipeline project. There are current plans to build the Aguirre Offshore GasPort, a floating storage and regasification unit, offshore near the Aguirre plant that would be ready by 2019 and to convert the Aguirre plant to natural gas.

Coal

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

AES maintains a 30-day inactive coal storage supply to cover delivery interruptions and a 20-day active storage supply.

Appendix B. Power System Rebuild Cost Estimates

Hazard Mitigations	Total ($ Millions)	Line Item Rollups ($ Millions)	Rebuild Recommendations[39]
Overhead Distribution (includes 38 kV)	**$5,268**		
Wind Damage		$3,432	Replace poles for higher wind loading; install breakaway service connections; install fully insulated wire; relocate distribution away from transmission; selectively underground distribution; install intermediate poles on longer spans; install wider spacing in high debris areas
Insulators Compromised		$208	Replace insulators with higher insulation level in salt contamination areas; replace insulators with higher strength designs in high wind areas
Flooding		$965	Replace poles with deeper subgrade support; selectively underground in areas with water-driven debris
Accessibility		$429	Relocate lines to accessible street level; selectively replace overhead with underground
Operability		$234	Add automated switches with fault detection, isolation and restoration capability
Underground Distribution	**$35**		
Storm Surge/Flooding/Flowing water		$35	Selectively install submersible equipment; elevate equipment and terminations; spot replace underground with overhead; install engineered protection of cables and conduit in washout areas
Transmission – Overhead	**$4,299**		
Wind Damage		$1,054	Replace poles for higher wind rating and jet grout existing self-embedded poles for higher wind rating; install wider spacing for better insulation; selectively undergrounding risk spans; install intermediate poles to reduce galloping and slapping
Insulators Compromised		$20	Replace insulators with higher insulation level in salt contamination areas; replace insulator with higher strength insulators
Flooding		$586	Straighten and Grout existing or replace poles with deeper sub-subgrade and/or engineered foundations
Accessibility		$2,639	Develop looped transmission overlay on existing highways
Transmission – Underground	**$601**		
		$601	SE Puerto Rico underground bypass

[39] Reference more detailed rebuild recommendations throughout this report.

Hazard Mitigations	Total ($ Millions)	Line Item Rollups ($ Millions)	Rebuild Recommendations[39]
Substations – 38 kV	**$856**		
Wind Damage		$647	Install hurricane-rated fencing; replace or reinforced damaged control buildings; replace bus structures; replace insulators with higher insulation level and Cat 4 strength
Water Damage		$72	Replace control buildings with a newer modular design; relocated or elevate substations; install water-tight enclosures for control equipment and junction boxes; elevate select equipment and raise air vents; install water barriers and engineered solutions
Command and Control		$13	Replace damaged SCADA and replace high risk SCADA units; install synchronization and blackstart relays systems
Unreliable Operation		$124	Replace high risk circuit breakers; repair ground systems; install SPCC containment where needed; install redundant battery systems and backup generators for charging; replace damaged/water impaired transformers; install high side switcher or circuit breakers
Substations – 115 kV and 230 kV	**$812**		
Wind Damage		$203	Install hurricane-rated fencing; replace or reinforced damaged control buildings; replace bus structures; replace insulators with higher insulation level and Cat 4 strength
Water Damage		$226	Replace control buildings with a newer modular design, relocate or elevate substations; install water-tight enclosures for control equipment and junction boxes; elevate select equipment and raise air vents; install water barriers and engineered solutions
Command and Control		$79	Replace damaged SCADA and replace high risk SCADA units
Unreliable Operation		$304	Replace high risk circuit breakers; repair ground systems; install SPCC containment where needed; install redundant battery systems and backup generators for charging; replace damaged and water impaired transformers; install high side switcher or circuit breakers
System Operations	**$482**		
System Control		$167	Install ADMS system; new/upgrade wide area and field area communications; add a mobile, containerized backup Control Center; install hurricane covering for the primary Control Center windows
System Studies		$55	Post-restoration engineering studies, planning studies, pre-engineering surveys
Customer Communications		$165	Update customer system and install customer service portals
Spare Equipment		$29	Purchase and store adequate system spares based on new equipment and expected failures
Security		$66	Install physical and cybersecurity controls at control centers and critical substations

Hazard Mitigations	Total ($ Millions)	Line Item Rollups ($ Millions)	Rebuild Recommendations[39]
Distributed Energy Resources	**$1,455**		
Microgrids		$1,007	Microgrid deployment for critical infrastructure and remote communities (DER for Resiliency)
Solar PV		$315	Solar PV on new residential construction (DER for cost savings)
IECC 2012 Building Code Upgrade		$133	Bring 25% of new construction or major rebuilds to IECC 2012 building code (DER for cost savings)
Generation	**$3,115**		
Test and Inspection		$2	Work to further define damage at generation facilities
Base Repairs		$108	Repairs to generation facilities to energize the island
Replacement of Damaged Spares		$19	Replacement of spares that have likely been damaged by the storm
New Unit Build		$2,864	Installation of dual fired F-class machine at Palo Seco and an H-class machine at Aguirre
Storm Hardening		$122	Storm hardening at existing generation facilities
Fuel Infrastructure	**$683**		
		$683	For the build-out of land and/or sea-based LNG pipelines
Total Estimated Costs	**$17,606**[40]		

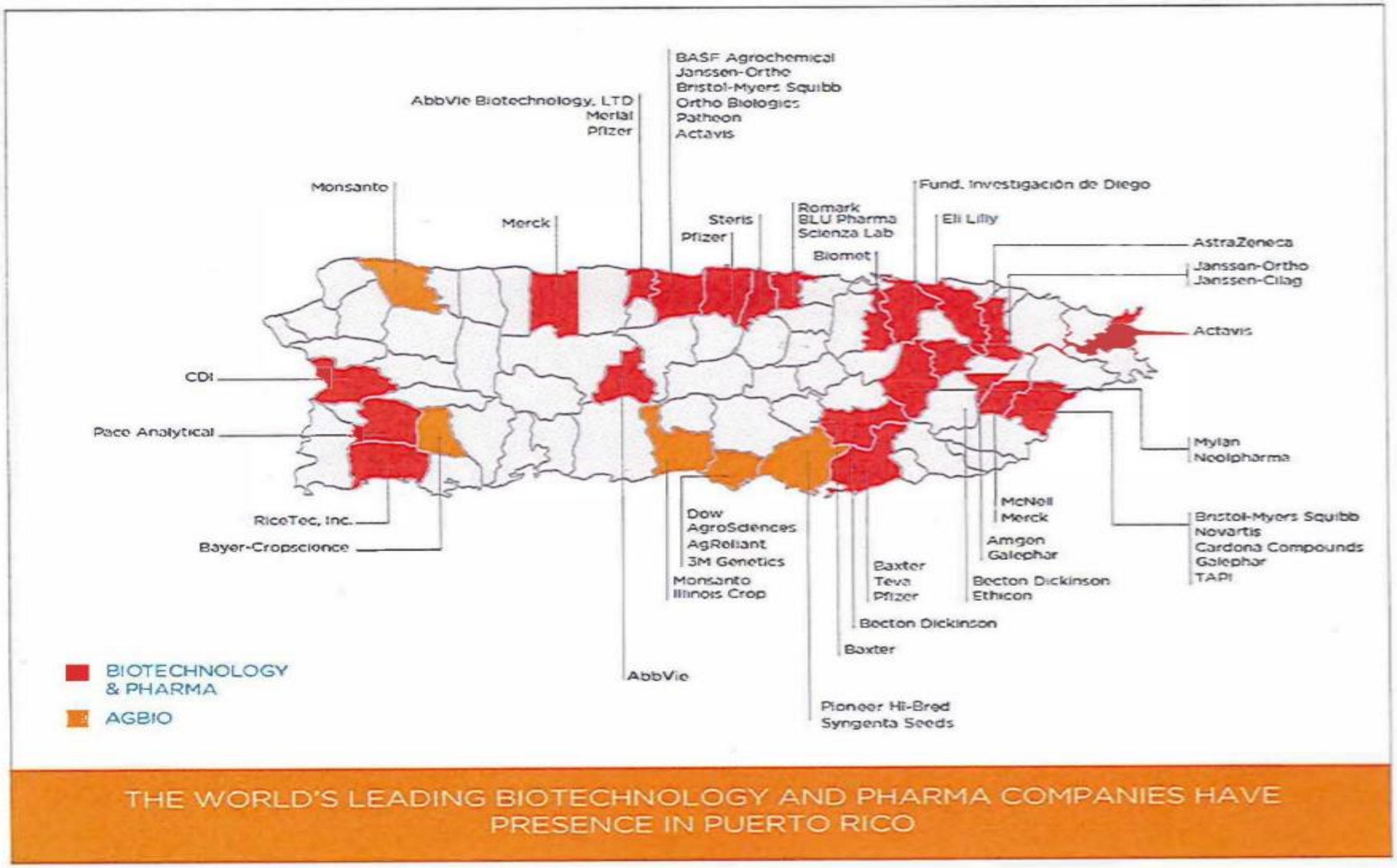
[40] Each line item estimate includes a 30% scope confidence escalator. Final cost estimates require multiple engineering studies and an updated IRP.

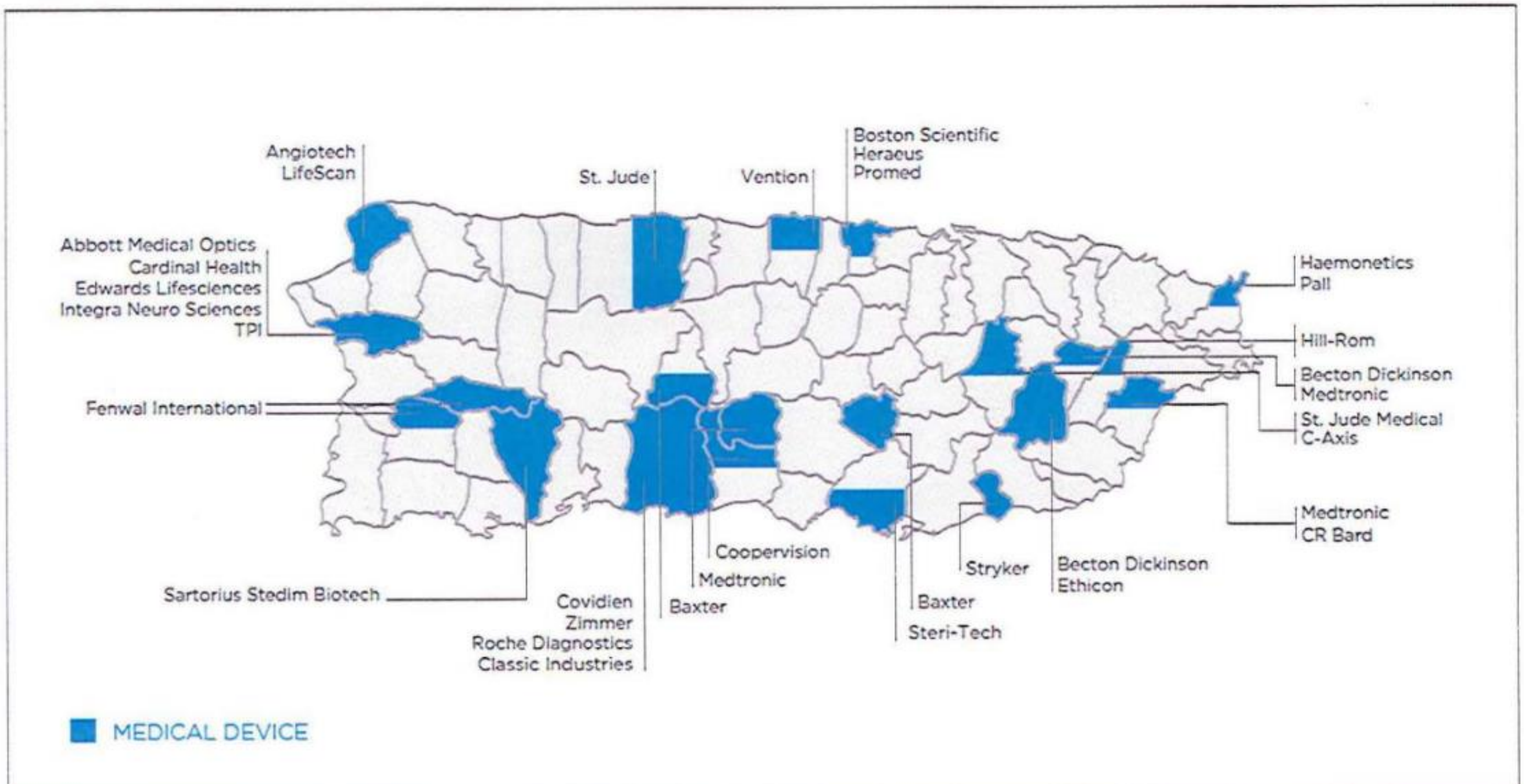
Appendix C. Glossary

Term	Definition
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).
Capacitor Bank	An array of capacitors connected into a circuit. Capacitors are used to control voltages supplied to the customer by eliminating the voltage drop in the system caused by inductive reactive loads.
Capacity	The maximum output of electricity that a generator can produce under ideal conditions.
Capacity Factor	The amount of energy that the system produces at a particular site as a percentage of the total amount that it would produce if it operated at rated capacity during the entire year.
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.
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.
Disconnect Switches	Disconnect switches or circuit breakers are used to isolate equipment or to redirect current in a substation.
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.
Distribution Bus	A steel structure array of switches used to route power out of a substation.
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.
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.
Energy Efficiency	Any number of technologies employed to reduce energy consumption. Examples include more efficient lighting, refrigeration, heating, etc.
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.
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.

Term	Definition
Load Forecast	A forecast of expected future energy demand based on an analysis of underlying economic indicators and past correlation between energy consumption and such economic conditions.
Microgrids	A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.
Oil Circuit Breakers	Oil circuit breakers are used to switch circuits and equipment in and out of a system in a substation.
Photovoltaics (PV)	Method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect.
Pothead	A type of insulator with a bell or pot-like shape used to connect underground electrical cables to overhead lines.
Power Generation Plant	A facility designed to produce electric energy from another form of energy such as fossil fuel, hydroelectric, nuclear, solar energy, or wind energy.
Power Purchase Agreement (PPA)	A contract to purchase energy between one party who generates the energy and the second party who purchases it.
Purchased Power	Power purchased from a third party used to meet retail or wholesale electric demand.
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.
Reserve Margin	A measure of available capacity over and above the capacity needed to meet normal peak demand levels.
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.
Sub-transmission Lines	Lines that carry voltages reduced from major transmission lines.
Transformer	Converts the generator's low-voltage electricity to higher voltage levels for transmission to the load center.
Transmission Lines	Transmission lines carry voltages from 69 kV up to 765 kV.
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.
Virtual Power Plant	A cloud-based distributed power plant that aggregates the capacities of heterogeneous Distributed Energy Resources (DERs) for the purposes of enhancing power generation, as well as trading or selling power on the open market.
Voltage	The effective potential difference between any two conductors or between a conductor and ground.

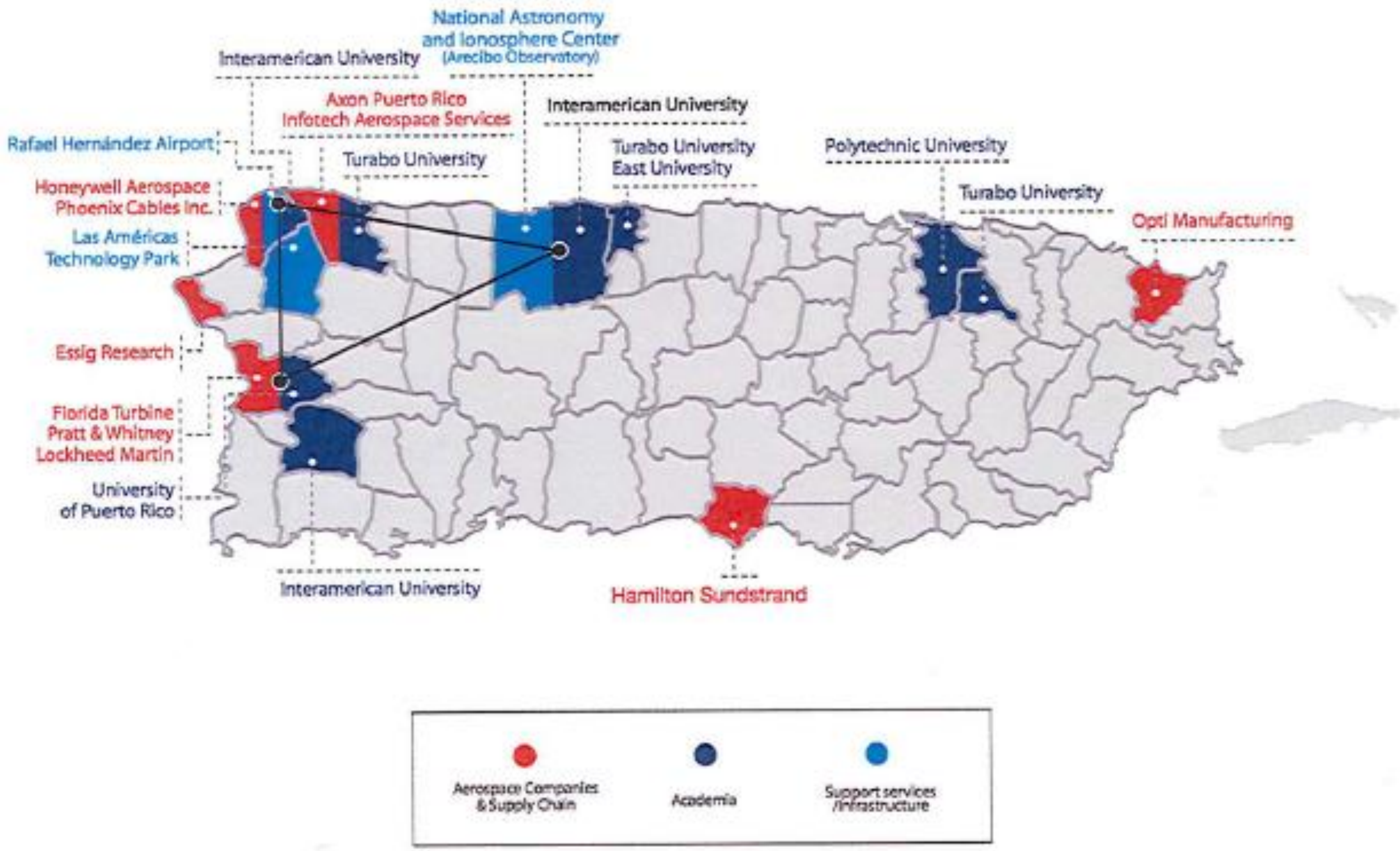
Appendix D. Manufacturing In Puerto Rico



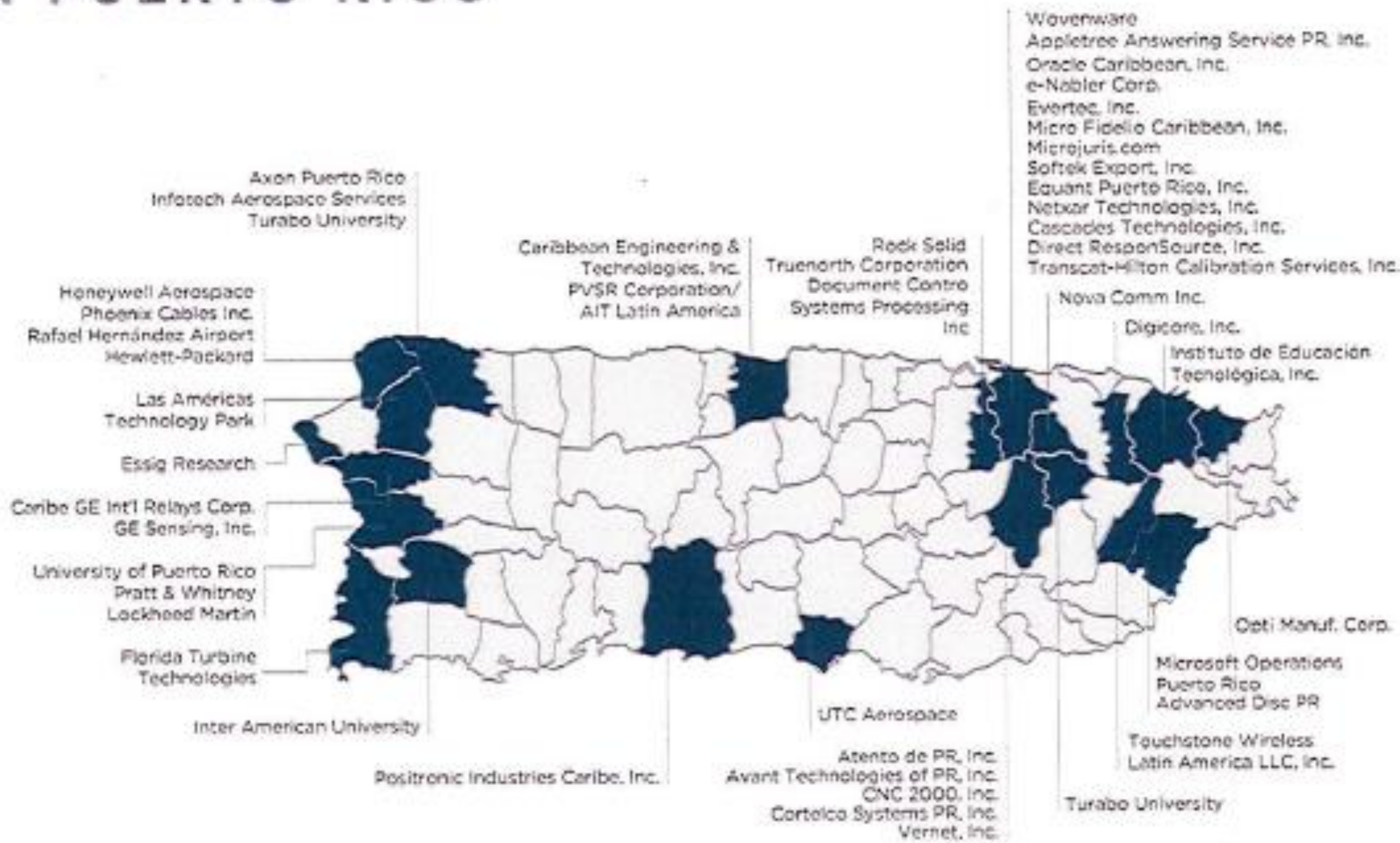


THE WORLD'S LEADING MEDICAL DEVICE COMPANIES HAVE PRESENCE IN PUERTO RICO.

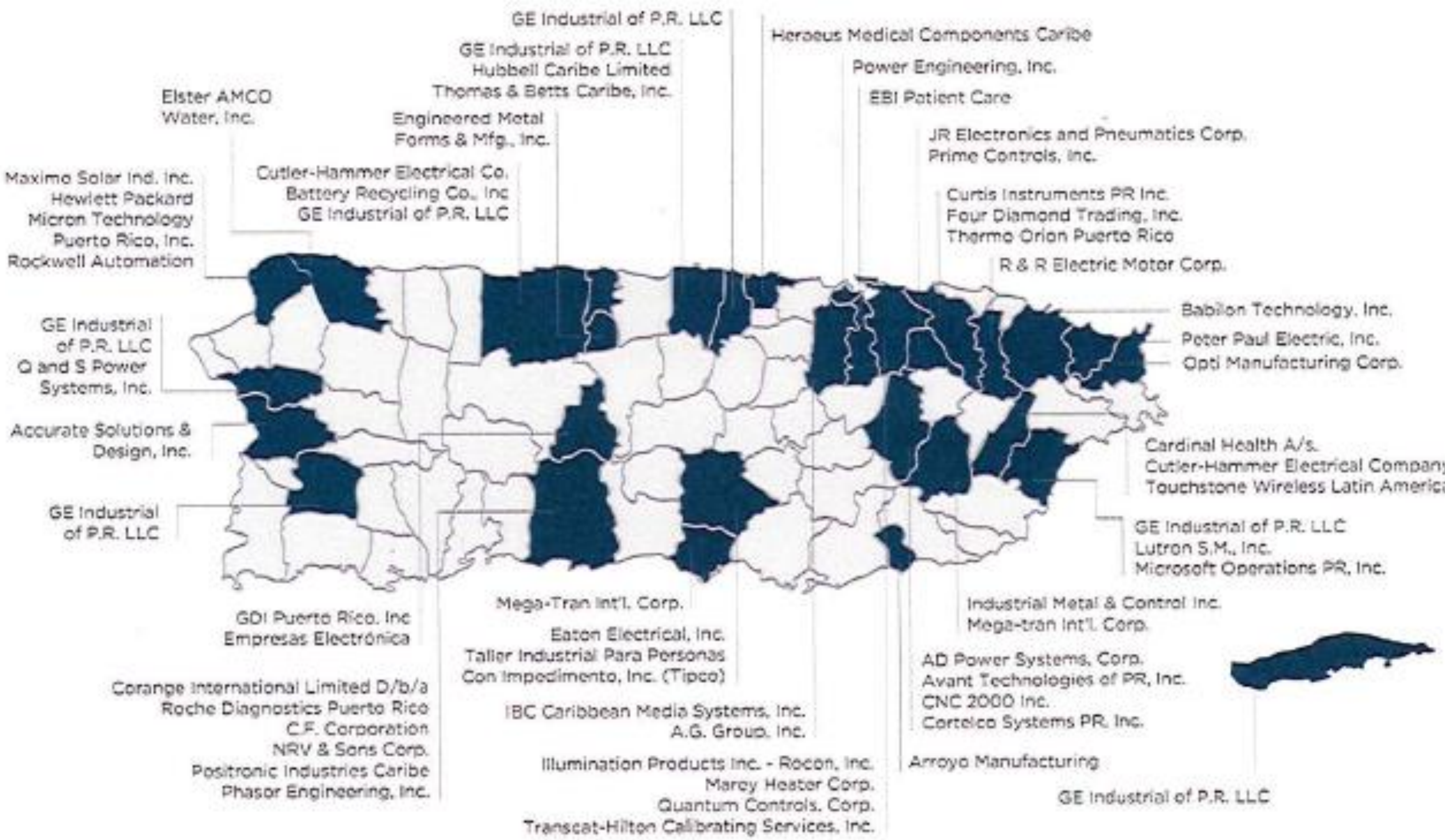
PUERTO RICO'S AEROSPACE ECOSYSTEM



INFORMATION TECHNOLOGY IN PUERTO RICO



ELECTRONIC & ELECTRIC MANUFACTURING IN PUERTO RICO



APPAREL
IN PUERTO RICO