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GOVERNMENT OF PUERTO RICO
PUBLIC SERVICE REGULATORY BOARD
PUERTO RICO ENERGY BUREAU

IN RE: REVIEW OF THE PUERTO RICO ELECTRIC POWER AUTHORITY'S 10-YEAR INFRASTRUCTURE PLAN – DECEMBER 2020	**CASE NO.**: NEPR-MI-2021-0002 **SUBJECT:** Motion to Inform Reallocation of FEMA 404 HMPG Funds and Request for Approval of Generation Projects

MOTION TO INFORM REALLOCATION OF FEMA 404 HMGP FUNDS AND REQUEST FOR APPROVAL OF GENERATION PROJECTS

TO THE HONORABLE PUERTO RICO ENERGY BUREAU:

COMES NOW the Puerto Rico Electric Power Authority (PREPA), through its counsel of record, and respectfully submits and prays as follows:

I. INTRODUCTION

In September 2017, Hurricanes Irma and María caused most of the transmission and distribution (T&D) system in Puerto Rico to collapse, leading to one of the most extended blackouts in U.S. history and leaving residents in some parts of the territory without electricity for almost a year. Communications, water and wastewater, transportation, healthcare, and critical manufacturing sectors similarly experienced severe disruptions, in most cases caused by electricity infrastructure damage or exacerbated by the underlying instability of the grid.

While the hurricanes caused unimaginable devastation to Puerto Rico, part of the unprecedented Federal Government response was the authorization of historical amounts of federal recovery funding specifically earmarked for the energy sector, totaling over $12 billion from both the Federal Emergency Management Agency (FEMA) and the Department of Housing and Urban Development (HUD). Part of the funds assigned to Puerto Rico was provided under the 404 Hazard Mitigation Grant Program (HMGP). Hazard mitigation has been defined "as any sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects. This definition distinguishes actions that have a long-term impact from those more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage."[1] The proposed HMGP concept was developed by identifying and assessing the vulnerability of the critical facilities to hazards and includes a specific solution that can be set before the occurrence of the disaster with funding from locally matched federal funds.

Due to its geographical location surrounded by the Atlantic Ocean and the Caribbean Sea and by its condition as a tropical island, Puerto Rico annually experiences a great activity of hurricanes and tropical storms between June and November, the Hurricane Season. These atmospheric systems affect the transmission and sub-transmission lines and distribution feeders, causing the interruption of electric service to most of the archipelago and, depending on the magnitude, can affect the whole territory. Multiple important transmission lines run South-North through the mountains in the center of the main island. After storms or hurricanes, these places are inaccessible, causing delays in the restoration of the electric system. With a disrupted South-North transmission system, the generating units at North play a crucial role in supplying the local load as the system is recovered and the power flows from south to north are re-established. It is important to note that the renewable projects do not have a role in the electric system restoration, mainly because their variability would difficult this restoration, especially considering the weakened condition under which both the generation and the transmission systems will be after major events.

Furthermore, extreme events like Hurricane María can cause blackouts of the power system.

[1] Department of Emergency and Military Affairs, *Mitigation*, https://dema.az.gov/emergency-management/operationscoordination/recovery-branch/mitigation (last visited on August 1, 2022).

The availability of distributed, reliable, and fast start generation sources is essential for conducting the restoration process after blackouts, especially on an isolated system like Puerto Rico's grid. In addition, during emergency scenarios such as hurricanes, substantial portions of the grid, PV, and wind generation systems can be damaged, thereby compromising the system's ability to deliver power to critical loads such as hospitals and other essential services during and immediately following an extreme weather event. For example, hurricane María caused significant damage, not only to the electrical grid, but also to PV and wind generation systems. Hence, the existing distributed peaking generation units played an essential role in the restoration of the power service after this event, mainly due to their closeness to load centers.

The inability of the system to provide power to all locations throughout Puerto Rico shortly after a hurricane or tropical storm can result in harsh living conditions and loss of life caused by the unavailability of essential services such as potable water, refrigeration for medication, and communications. Given the vulnerability of the critical facilities or loads to hazards caused by major weather events, it is essential to provide distributed dependable, non-variable, generation sources, including base load generation at Puerto Rico´s load center, that can supply those facilities in a reliable and safe manner. The current condition of PREPA's generating units, including base load and emergency units, is poor and fragile due mainly to their age, which averages more than fifty years. Hence, the provision of reliable and resilient distributed sources can be set before the occurrence of the disaster with 404 HMGP federal funds.

Therefore, in October 2019, PREPA submitted an application to FEMA to develop a project to construct a combined cycle (CC) in the North, mainly considering the site at Palo Seco Power Plant. The combined cycle would have an installed capacity from 300 MW to 400 MW. The application also included a project to install 11 simple cycle (SC) combustion turbines (CTs) with an aggregated capacity from 220 MW to 330 MW, each CT having a capacity from 20 MW to 30 MW. The proposed projects must comply with the *Puerto Rico Energy Public Policy Act*[2], which, among others, support initiatives in Puerto Rico that focus on mitigation, adaptation, and resilience. Another of Act 17-2019's objectives is "[t]o promote the use of small-scale electric power plants with capacity to operate with a diversified fuel mix, one of which shall be natural gas, that reduce greenhouse gas emissions, with more modern technology and associated infrastructure and high efficiency capacity, as defined by the Energy Bureau and capable of integrating distributed generation and renewable energy into the electric power grid." Act 17-2019 at Sec. 1.6 (2). It also provides that "[e]very new or existing electric power plant, as of [April 11, 2019], other than those operating exclusively on renewable energy sources shall have the capacity to generate power from two (2) or more fuels, one of which shall be natural gas[.]" *Id.* at Sec. 1.11(a).

Out of the federal funds assigned by FEMA and HUD to Puerto Rico, the Government of Puerto Rico identified about $853.2 million in 404 HMGP funds for generation projects, $280.82 million for emergency generation (SC combustion turbines), $5 million for engineering studies of the CC in the North, and $567.38 million for the CC project. As explained below, PREPA determined to redistribute the 404 HMPG funds available, particularly the $572.38 million approved by FEMA for the CC. After a thorough analysis, PREPA determined to allocate the 404 HMGP as follows:

Purpose	**Estimated Cost**
Emergency Generation Peaker Units	$490M
Costa Sur and Yabucoa Black-Start Units	$190M
Fuel Conversion of San Juan Units 7 to 10	$138.5M
Small-scale residential PV with storage	$34.7M
Total	**$853.2M**

[2] *Puerto Rico Energy Public Policy Act, Act No. 17 of April 11, 2019,* 22 L.P.R.A. §§ 1141-1141f ("Act 17-2019").

Wherefore, in compliance with the mandate set by the Government of Puerto Rico's Energy Public Policy, PREPA herein presents for the Puerto Rico Energy Bureau of the Public Service Regulatory Board's ("Energy Bureau") evaluation a set of projects that comply with these mandates and further the goal of achieving a reliable, resilient, stable, and cost-effective electrical service.

II. NEW PALO SECO COMBINED CYCLE FEASIBILITY STUDY

On August 24, 2020, the Energy Bureau issued its Final Resolution and Order on the PREPA's Integrated Resources Plan (IRP), in which it authorized a scoping and feasibility analysis that includes a preliminary economic, siting, permitting, and planning analysis for a new combined-cycle (CC) power plant at Palo Seco. In October 2020, FEMA approved funding to develop and build a CC power plant in the North of Puerto Rico. PREPA started the CC scoping and feasibility study in 2021 and submitted the final report to the Energy Bureau on July 15, 2022 (Annex A).[3]

During the feasibility study, PREPA's consultant found that the construction of CC in the Palo Seco Power Plant was feasible, except for the lack of natural gas infrastructure at the site. This means that the Palo Seco Power Plant is not the preferred alternative for a new CC only because there is no natural gas supply at the site. Hence, the consultant evaluated an alternate location at the San Juan Power Plant, where there is currently natural gas supply. The alternative at this site was feasible and was the preferred one due mainly to the availability of natural gas.

It is stressed that a new CC with a capacity from 300 MW to 400 MW, burning natural gas at either Palo Seco or San Juan Power Plant, would increase the resiliency and reliability of the power system. A new CC would replace much older and less efficient generating units, providing

[3] *See Motion to Submit Feasibility Study and July 2022 Status Report* submitted in case no. NEPR-MI-2021-0003, *In Re: Preliminary Studies for a New Combined Cycle Power Plant in Palo Seco*.

dependable generation capacity, lower production costs, and much less emissions, complying with environmental regulations. Furthermore, the smaller steam and combustion turbines of a CC are more suitable to manage low load operations and the variability of renewables than larger steam units. In addition, these smaller units will contribute to lower operational reserve margins and, consequently, lower production costs. Therefore, a new CC can support renewable energy's safe and reliable integration and provide the dependable generation capacity required for electric service restoration after major weather events.

As part of the study, it was analyzed if there were any constraints in developing the CC project. Two main limitations were identified, one related to the project's development time and the second was the estimated cost. Regarding the estimated cost and as initially estimated in 2020 dollars, the funds approved by FEMA were $572.38 million. For the feasibility study, this estimate was updated to reflect 2023 dollars and inflation, resulting in $723.6 million. This means that there are insufficient funds to develop the CC project, as there is a deficiency of $151.22 million.

According to PREPA's experience, a new CC project takes about ten years to be developed in Puerto Rico, including the environmental and construction permitting, design, procurement, construction, commissioning, and operational testing. The projects for the two newest combined cycles in Puerto Rico, EcoEléctrica and San Juan Units 5 and 6, were developed in about ten years each. Given PREPA's current power generation struggles and that the development of the CC project is a long-term effort, short- and medium-term measures to improve the existing thermal generation assets should be considered and executed.

Considering the constraints described above, PREPA found that, even though the construction of the CC in the North is feasible and beneficial for the electrical system, there are not enough funds to complete the project. There are more imperative actions to be taken in the short- and medium-term, for which the CC project-approved funds can be used. These actions include those needed to keep the existing thermal generating units operational and in service to supply the energy demand in Puerto Rico, support the reliable and safe integration of renewable energy, and provide the energy needed during the restoration of the electrical service after major events. The generating units' operations must comply with all environmental regulations.

Therefore, PREPA will request FEMA and the Central Office for Recovery, Reconstruction and Resilience (COR3) to redistribute the approved $853.2 million in 404 HMGP funds into the following generation projects:

Purpose	Estimated Cost
Emergency Generation Peaker Units	$490M
Costa Sur and Yabucoa Black-Start Units	$190M
Fuel Conversion of San Juan Units 7 to 10	$138.5M
Small-scale residential PV with storage	$34.7M
Total	**$853.2M**

The CC project would be delayed until enough funds are available, and its assigned funds of $572.38 million would be allocated to the projects mentioned above:

- <u>Emergency Generation Peaker Units</u> – This generation project is the second approved by FEMA to be funded under 404 HMGP. The original project estimate was $280.82 million in 2020 dollars, but considering inflation, the estimate of executing this project is a minimum of $490 million. Hence, it is needed to add funds to this project to complete it. More information on this project is shown in Section IV of this motion. This project is submitted herein for the evaluation of the Energy Bureau.
- <u>Costa Sur and Yabucoa Black-Start Units</u> – Currently, this project is defined under the Public Assistance Program (FEMA 428) funds with an original assignment of $90.4

million. However, this estimate was updated to account for the inflation and the recent disruption in the supply chain, resulting in a new estimate of $190 million. Hence, it is needed to add funds to this project for executing it and for achieving this, PREPA intends to reallocate this project from FEMA 428 funds to 404 HMGP funds. The Energy Bureau has approved this project.

- Fuel Conversion of San Juan Units 7 to 10 – This project mainly aims to keep the steam units in San Juan Power Plant operational and in service, burning natural gas as their primary fuel. The fuel conversion of these units will allow them to achieve environmental compliance with the Sulfur Dioxide (SO_2) State Implementation Plan in the Non-Attainment area (NAA-SIP) of San Juan and the Mercury and Air Toxics Standards (MATS) rule. More information on this project is shown in Section V of this motion. On February 11, 2022, PREPA submitted this project for the Energy Bureau's evaluation.
- Small-scale residential PV with storage – PREPA intends to invest about $34.7 million, which is the approximate amount of the 404 HMGP funds that will not be used for the projects mentioned above, on the installation of PV plus storage systems behind the meter of customers located at those sectors where the power service was restored last after Hurricane María. This project is submitted herein for the evaluation of the Energy Bureau.

III. RESOLUTION AND ORDER OF MARCH 26, 2021

On March 26, 2021, the Energy Bureau entered a *Resolution and Order* ("March 26 2021 Order") in which it determined that:

> In compliance with the August 24 Resolution, the Energy Bureau **ORDERS** PREPA to submit to the Energy Bureau each new capital investment project. For projects to be funded with FEMA funds and/or any other federal funds, PREPA shall submit the specific projects to the Energy Bureau at least thirty (30) calendar days prior to its submittal to [the Central Office for Recovery, Reconstruction and Resiliency (COR3)], FEMA and/or any other federal agency.

March 26 2021 Order at p. 18, ¶ 10.

In compliance with the March 26 2021 Order, PREPA herein submits several projects for the evaluation and approval of the Energy Bureau.

IV. EMERGENCY GENERATION PEAKING UNITS – PHASE I

In 2020, FEMA approved about $280.82 million to acquire eleven (11) emergency generation peaking units. With this motion, PREPA submits to the Energy Bureau the Emergency Generation Feasibility Report – Existing Peaking Facilities ("Report") (Annex B). The Report supports PREPA's request to the Energy Bureau to proceed with Phase I engineering work[4] for hazard mitigation funding of new simple cycle emergency generation facilities and equipment. This project is essential for restoring the power service after a significant event, including restarting the system following blackouts and supporting renewable energy's reliable and safe integration. FEMA approved this project because it qualifies as a project that will prevent or reduce damages that future disasters may cause, particularly by preventing harsh living conditions and loss of life. The emergency generation capacity that this project provides would replace the existing old, fragile, and inefficient peaking generators and complement the 81 MW peaking generation capacity approved by the Energy Bureau in the IRP Final Order[5] (as discussed in Section VI below).

With the Report, PREPA provides the Energy Bureau with engineering insights into the overall need for new emergency generation in Puerto Rico, the complementary benefits to the ongoing renewable energy transformation work, and other needs and considerations that will support the

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[4] Nomenclature that defines the engineering deliverables is included as required for FEMA 404 HMGP.

[5] *Final Resolution and Order on the Puerto Rico Electric Power Authority Integrated Resource Plan* ("IRP Final Order") entered in case no. CEPR-AP-2018-0001, *In Re: Review of the Puerto Rico Electric Power Authority Integrated Resource Plan*.

implementation of the forthcoming, intermittent renewable energy and energy storage projects. New generation resources are needed to replace the existing aging generation fleet for several reasons, all of which are closely related and discussed in the Report. The reasons may be summarized as follows:

- The immediate need for emergency power generation systems for disaster recoveries.
- Planning for future grid services (*e.g.*, synchronous condensers) to support future renewable portfolio standard (RPS) compliance and grid stability.
- Flexible, multi-purpose thermal generation plants to complement and support reaching future RPS mandates.
- Integrate island-wide black-start capabilities to support the existing generation fleet and independent power producers.

As further discussed below, the Report supports PREPA's request to proceed with the Emergency Generation project and procure eleven (11) gas turbine peaking units to replace existing old combustion turbines at the same locations.

In the aftermath of Hurricanes Irma and María, the assistance of the U.S. Army Corps of Engineers included dispatching approximately 90 MW of temporary emergency generators. A generation capacity of 60 MW was allocated to the San Juan area to serve as a backup, help stabilize the grid and power critical elements of the potable water delivery system to residents. In addition, 30 MW of generation capacity was installed at the Yabucoa power plant and served as the emergency backup unit for the southeast region to provide stability to the area and ensure the Costa Sur power plants had the black-start capability. Furthermore, FEMA provided approximately seven hundred (700) small engine-driven generators to residents within the interior part of the main island, where most of the transmission and distribution (T&D) lines had collapsed. Many electric public utilities from the U.S. mainland sent emergency crews and equipment to assist in repairing T&D lines. Approximately sixty (60) days were required to restore electrical services to about 50% of the population; however, many unreliable and temporary repairs often failed. Electrical interruptions continued for approximately eleven (11) months until most of Puerto Rico's T&D lines were repaired more permanently.

North-South transmission lines are vital connections across the main island; they interconnect the large south coast baseload power generation plants with the primary electrical demands of the north coast. Since most storms that cross Puerto Rico start from the southeast coast of the main island and travel in a northwesterly direction, these interconnecting transmission lines frequently face and weather severe storm crossings. Damage to these lines within the central areas of the main island is often difficult to access and repair due to the mountainous terrain and dense vegetation, thus leading to delays in power restoration efforts. One significant reason for the proposed siting of new simple-cycle (SC) emergency generation facilities at the existing peaking sites is that it significantly reduces the reliance on lengthy transmission lines that are particularly vulnerable to storm damage due to their storm path exposure. Local generation meets the recommendations of both FEMA and the U.S. Department of Energy.

The emergency generation power plant projects were initiated in May 2019. On October 25, 2019, an application was submitted by PREPA under the FEMA 404 HMGP to request funding to develop improvements for critical power facilities to reduce vulnerability during disasters and thus ensure continuity of essential services. As stated within the FEMA hazard mitigation application, the proposed project complies with developing a Puerto Rico more resilient to disasters with less vulnerability and exposure to disasters.

The FEMA 404 HMGP provides funding for the simple cycle (SC) emergency generation across Puerto Rico at various PREPA power generation facilities. This new emergency generation equipment is expected to provide approximately between 220 MW to 330 MW of emergency power to generation facilities distributed across Puerto Rico. This will ensure that power is provided for essential services at multiple locations if these areas become disconnected from the power grid. The equipment may also offer black-start services for these locations and export power to neighboring power plants to assist with their restart.

These new generation projects will replace existing, outdated, unreliable, and inefficient diesel-fired electrical generation units dating from the early era of gas-turbine power projects in the 1970s with advanced technology designed for efficient and reliable power generation to serve the hazard mitigation objectives defined by FEMA. These projects focus on reducing risk, loss of life, and property in future natural disasters. On October 15, 2020, FEMA approved funding to proceed with Phase I – Engineering for new SC gas turbines (GTs) to serve as emergency generators.

The FEMA 404 HMGP program is in two phases: Phase I and Phase II. Phase I – Engineering work consists of preliminary engineering, environmental due diligence, and project cost estimates. Once the required deliverables for Phase I are completed, they are submitted to the Energy Bureau and then FEMA for review and approval before proceeding to Phase II – Construction, where the project is implemented and includes activities such as obtaining all permits, detailed design engineering, procurement of all plant equipment, construction, installation, commissioning, interconnection and starting, operational testing, and normal operation commencement.

PREPA submitted the 404 HMGP application for the SC emergency generation to FEMA with a preliminary cost-benefit analysis. The cost-benefit analysis will be validated during Phase I – Engineering to comply with the Energy Bureau and FEMA's project economic justification requirements once pricing is provided through a competitive request for proposal process for the power plant equipment, construction, and commissioning.

FEMA's justification for adding these new GTs *is not* for continuous duty power generation but for hazard mitigation. According to prudent industry practices, after a blackout, the power system is restored gradually by means of energizing "islands" where there are local generation sources that are started for serving critical and essential loads. Once the service in those "islands" is stable, the utility starts interconnecting them, forming bigger islands until the service is restored to the whole system. The availability of distributed, reliable, and fast start generation sources is essential for this restoration process, especially on an isolated system like Puerto Rico's grid. Thus, these emergency generation systems are an integral part of FEMA's hazard mitigation program to minimize the loss of life and property but may also be readily configured to support the renewable integration plan.

In addition, during emergency scenarios such as hurricanes, substantial portions of the grid, PV, and wind generation systems can be damaged, thereby compromising the system's ability to deliver power to critical loads such as hospitals and other essential services during and immediately following an extreme weather event. For example, hurricane María caused significant damage to PV and wind generation systems and the electrical grid. Hence, the existing peaking generation units played an essential role in restoring the power service after this event, mainly due to their closeness to load centers. The inability of the system to provide power to all locations throughout Puerto Rico shortly after a hurricane or tropical storm can result in harsh living conditions and loss of life caused by the unavailability of essential services such as potable water, refrigeration for medication, and communications. Considered alone, these GT units are intended to serve as backup generation and black start systems distributed around Puerto Rico in the event of an emergency.

Including these new GTs will also support the transition to renewable generation. These plants will be configured to support the extensive influx of future inverter-based renewable generation projects with operating characteristics well-suited to the planned integration of renewable power. Historical data suggests that Puerto Rico can expect to experience significant storms or hurricanes every 5–10 years; however, the frequency and intensity of these weather events appear to be increasing in recent years. In 2020, major earthquakes along the south coast also showed the need for reliable power generation throughout Puerto Rico for hazard mitigation. The new power plant projects use proven technology and draw on HMGP funding to protect human lives and property, continue essential life services, and enable the government to function in the aftermath of a natural disaster. They are conducive to developing a Puerto Rico electric system that is more resilient to natural disasters with less vulnerability and exposure to risk during these events.

PREPA received FEMA 404 funding for Phase I – Engineering of HMGP Project Number 4339-0010, known as the "Simple Cycle Gas Turbines." It consists of installing 11 SC GT power plants, around 20 MW to 30 MW for each GT, for SC emergency generation service at the existing PREPA peaking facilities. This project will be 100% federally funded, up to a total value of $280.82 million. The program funding is provided in two phases.

FEMA has granted $12.7 million for Phase I of the project, which involves detailed engineering studies to ensure the concept at each facility is viable. This engineering feasibility work is currently underway for the approved generation. It will be submitted to the Energy Bureau and FEMA once completed for review and approval, which must be obtained before proceeding with Phase II – Construction. The amount allocated for Phase I may vary depending on the competitive procurement process PREPA may conduct to complete the studies.

There are conditions of approval, including tasks, milestones, and deliverables, that must be completed in Phase I – Engineering before proceeding to Phase II – Construction, which is contingent upon the Energy Bureau and FEMA's approval. These conditions of approval for Phase I – Engineering include all the project initiation and planning tasks (the cost estimates and schedule), preliminary design drawings and technical specifications, a revised cost-benefit analysis, and environmental data collection. Phase II – Construction will include completing the detailed design, procurement of equipment and materials, permitting process, construction and installation, commissioning, and operational testing and startup.

As the Report shows, replacing the existing old peaking generation with new generation with the SC capabilities will provide PREPA with reliable emergency generation equipment and, at the same time, support PREPA's need to integrate renewable energy and storage projects. New SC power emergency generation could be operational between 2024 and 2026. Moreover, projects like the SC GTs and power distribution upgrades and renewables provide an isolated grid with a more resilient and efficient power generation and distribution system, as needed for Puerto Rico. This project complies with Act 17-2019's standard that new power plants shall have the capacity to generate power from two (2) or more fuels, and one is natural gas.

For the reasons stated above, it is respectfully requested that the Energy Bureau grants PREPA leave to proceed with Phase I – Engineering of HMGP Project Number 4339-0010, known as the "Simple Cycle Gas Turbines." Subject to the Energy Bureau's approval, PREPA will submit this project phase deliverable to COR3 and FEMA, including PREPA's request to redistribute the obligated 404 HMGP funds and thus, a total of $490 million will be assigned to this project instead of the $280.82 million that was initially estimated.

V. CONVERSION OF SAN JUAN UNITS 7 – 10 TO BURN NATURAL GAS

PREPA hereby incorporates and restates the arguments made in the documents titled *Petition for Leave to Conduct Works in PREPA's Steam Units to Achieve Environmental Regulatory Compliance* (February 11, 2022), *Motion to Submit Letter Sent By the Oversight Board, to Reiterate the Petition to Initiate Works to Comply with Environmental Regulations, and Request for Technical Conference* (June 3, 2022) and *Second Motion to Reiterate Petition for Leave to Conduct Work to Achieve Environmental Regulatory Compliance and Request for Technical Conference* (June 24, 2022).

It is respectfully restated that the Energy Bureau's approval of the conversion of units 7-10 of the San Juan Power Plant is essential to achieve environmental compliance and, in turn, compliance with the NAA-SIP and MATS rule. PREPA intends to execute this project in two phases: Phase I, the fuel switching works on units 8 and 10; and Phase II will consist of the works on units 7 and 9. This phased approach will allow having at least two units in service during the conversion works of the other two units.

In reassessing the funds that PREPA will allocate to each 404 HMGP-funded projects, PREPA has allocated $138.5 million to convert the four (4) units. This amount may vary depending on the competitive procurement process that PREPA must conduct to complete the conversions. Moreover, this project complies with Act 17-2019's standard that existing power plants shall have the capacity to generate power from two (2) or more fuels, and one is natural gas.

Wherefore, PREPA requests the Energy Bureau to approve the above-mentioned estimated cost as part of the conversion of units 7-10 to burn natural gas considering that PREPA would be formulating this project to be submitted under 404 HMGP funding.

VI. COSTA SUR AND YABUCOA BLACK-START UNITS

In the Final IRP Order, the Energy Bureau approved the procurement of 81MW of generators to provide peaking services. The relevant part of the order provides:

> Unless otherwise approved by the Energy Bureau and consistent with the Optimization Proceeding discussed below, PREPA shall replace no more than 147 MW of gas turbine capacity with fossil-fuel generators providing peaker services if, after a competitive bidding process open to all single or aggregated sources of demand and supply-side options, these services can be procured competitively at lower cost than other options. (147 MW is the sum of the capacity of the seven Frame 5 units identified as in need of a major overhaul or major generator repair in PREPA's response to the Energy Bureau's ROI 9- 2, Attachment 1.) When determining the total required capacity of new peaking generation to replace the retired Frame 5 units, PREPA shall include in its analysis the peaking capacity provided by the MegaGen mobile units totaling 66 MW installed at Palo Seco. This leaves up to 81 MW of new capacity to procure.
>
> In order to provide geographic distribution for peaking resources and increase resilience to forced outages, PREPA shall consider placing peaking resources at locations with zero or only one remaining peaking generator after Frame 5 retirements: Costa Sur, Aguirre, and Yabucoa.

Final IRP Order at p. 275, ¶ 885.

In compliance with the March 26 Order, on April 28, 2021, PREPA submitted to the Energy Bureau a document titled *Motion in Compliance with the Resolution and Order Entered on March 26, 2021*, with a list of projects for the Energy Bureau’s approval (the “April 28, 2021 Motion”). These projects included the following generation projects: (1) Initial SOW no. 164966 - New Black-Start System at Aguirre and (2) Initial SOW no. 164988 - New Black-Start System at Costa Sur. On June 8, 2021 (the “June 8 2021 Order”), the Energy Bureau approved both projects with a Class 5 Cost Estimate of $45.20 million each, for a total of $90.4 for both projects. PREPA submitted this Class 5 Cost based on the analysis conducted when the project was formulated. The

April 28, 2021 Motion included the scope of work (SOW) and cost estimates files of these projects, which are dated December 7, 2020.

On September 7, 2021, PREPA filed a document titled *Motion to Submit Second Group of Generation Projects Initial SOWs,* which included an SOW for procuring and installing two (2) new simple cycle gas turbine generation units of approximately 20 MW and the associated supporting infrastructure, at Yabucoa. This project was submitted to replace the New Black-Start System at Aguirre project approved by the Energy Bureau with the June 8, 2021 Order. On September 28, 2021, the Energy Bureau entered a *Resolution and Order* approving the requested change. The Class 5 Cost Estimate remained unaltered at $45.2 million, initially submitted and approved by the Energy Bureau in the June 8 2021 Order. Therefore, PREPA currently has two (2) black-start system projects, one at Costa Sur and another at Yabucoa, approved by the Energy Bureau.

As explained above, PREPA has decided to postpone the combined cycle in the North due mainly to the lack of sufficient funds to complete the project and to focus the available assigned funds on short- and medium-term improvements needed for hazard mitigation. Hence, it analyzed and redistributed the $853.2 million available for generation projects on those improvements. In this evaluation and redistribution, PREPA reassessed the cost to acquire both black-start systems and has estimated that the current cost to acquire both units would be around $190 million. The substantive price increase from the original $90.4 million to this updated estimate is due to the recent disruption in the supply chain and inflation. However, this cost is subject to revision based on the competitive procurement process to acquire the units, the associated supporting infrastructure and installation costs.

COR3 is in the process of completing the Initial SOW for this project at no cost to PREPA.

Once COR3 completes the preparation of the initial submission package, it will be presented to the Energy Bureau for approval in compliance with the March 26 Order.

Wherefore, PREPA requests the Energy Bureau to approve the revised estimated cost of these projects, which were previously approved by the Energy Bureau, as part of the evaluation of the above-mentioned initial submission package.

VII. SMALL-SCALE RESIDENTIAL PV WITH STORAGE

In the aftermath of hurricanes Irma and María, some clients were left without electricity for almost a year. Reconnecting the central and mountainous part of Puerto Rico represented the most significant challenge due to the location of the transmission and distribution lines that PREPA's crews needed to access to repair and reconnect. With the target of preventing this situation in the future, PREPA determined to develop a project to install small-scale rooftop solar coupled with storage in residential homes in inaccessible sectors of Puerto Rico. Even though these PV and storage systems are vulnerable to weather events like Hurricane María, the restoration works on these systems should be completed much earlier than the repair works on the distribution lines that supply these loads during normal conditions. Therefore, this project will enhance and improve the electrical power system, support long-term recovery and mitigation of risk from natural disasters, and at the same time support the Government of Puerto Rico Energy Public Policy to integrate renewable energy resources and develop plans that address long-term risks and promote resilience.

This solution has been identified by other entities, such as the U.S. Department of Energy, which launched the *Puerto Rico Grid Resilience and Transitions to 100% Renewable Energy Study (PR100)*, a community-driven and locally tailored roadmap to help Puerto Rico meet its target of 100% renewable electricity, improve power sector resiliency, and increase access to more affordable energy and cleaner air and also by several local and federal agencies in the *Memorandum Of Understanding Among The U.S. Department Of Energy, The U.S. Department Of Homeland Security, The U.S. Department Of Housing And Urban Development And The Government Of Puerto Rico - Collaboration For The Recovery And Resilience Of Puerto Rico's Energy Sector* subscribed to in the pursuit of a resilient, sustainable, and equitable energy grid for the citizens of Puerto Rico and which provides that federally funded disaster recovery efforts need to occur in the context of long-term energy objectives to design resilient and sustainable systems that lessen the adverse consequences of future disaster events while addressing clean energy goals.

With the project to install small-scale residential PV with storage, PREPA joins and commits to the previous efforts and, simultaneously, furthers the Energy Public Policy of the Government of Puerto Rico to transition to 100% clean energy. PREPA allocated $34.7 million for this project, which will be available to low- and medium-income customers in sectors mainly located in the municipalities of Utuado, Lares and Adjuntas at the center of the main island. This cost is subject to revision based on the competitive procurement process to acquire the equipment and materials and the associated supporting infrastructure and install them.

COR3 is in the process of completing the Initial SOW for this project at no cost to PREPA. Once COR3 completes the preparation of the initial submission package, it will be presented to the Energy Bureau for approval in compliance with the March 26 Order.

Wherefore, PREPA requests the Energy Bureau to approve this project, including the formulation of the same under 404 HMGP funds with an estimated cost of $34.7 million, as part of the evaluation of the above-mentioned initial submission package.

VIII. CONCLUSION

The subset of projects presented by PREPA above are aimed to comply with the mandates set by the Government of Puerto Rico's Energy Public Policy and will further the goal of achieving a reliable, resilient, stable, and cost-effective electrical service. Wherefore, PREPA respectfully requests the Energy Bureau to

1. note the Report;
2. grant PREPA a technical conference to discuss this motion and the requests for relief made herein;
3. grant PREPA leave to proceed with Phase I of the Simple Cycle Gas Turbines project;
4. grant PREPA leave to initiate Phase I of the fuel conversion of San Juan Units 7-10;
5. grant PREPA leave to amend the Cost Sur and Yabucoa black-start costs to $190 million in total; and
6. note that PREPA is formulating a project for small-scale residential PV with storage.

RESPECTFULLY SUBMITTED.

In San Juan, Puerto Rico, this 2nd day August 2022.

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CERTIFICATE OF SERVICE

It is hereby certified that, on this same date, I have filed the above motion with the Office of the Clerk of the Energy Bureau using its Electronic Filing System at https://radicacion.energia.pr.gov/login, and a courtesy copy of the filling was sent to LUMA through its legal representatives at margarita.mercado@us.dlapiper.com and laura.rozas@us.dlapiper.com.

In San Juan, Puerto Rico, this 2nd day of August 2022.

Annex A

New Palo Seco Combined Cycle Power Generation Scoping & Feasibility Report – Preliminary Economic, Siting, Permitting, and Planning Analysis

Report SL-016478 | Revision 1 | 15 July 2022

New Palo Seco Combined Cycle Power Generation Scoping & Feasibility Report

Preliminary Economic, Siting, Permitting, & Planning Analysis

Prepared by

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Version Log

Version	Issue Date	Sections Modified
Revision 0	30 June 2022	Initial Issue
Revision 1	15 July 2022	General Modifications

Issue Summary and Approval Page

This is to certify that this document has been prepared, reviewed, and approved in accordance with Sargent & Lundy's Standard Operating Procedure SOP-0405, which is based on ANSI/ISO/ASSQC Q9001 Quality Management Systems.

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15 July 2022

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition/Clarification
BESS	battery energy storage system(s)
CC	combined-cycle
DOE	(U.S.) Department of Energy
EFOR	equivalent forced outage rate
FEMA	Federal Emergency Management Agency
Final Resolution and Order	*Final Resolution and Order on the Puerto Rico Electric Power Authority's Integrated Resource Plan 2018–2019*
FSU	floating storage unit
GT	gas turbine
HMGP	Hazard Mitigation Grant Program
IRP	*Puerto Rico Integrated Resource Plan 2018–2019*
LHV	lower heating value
LNG	liquefied natural gas
PREB	Puerto Rico Energy Bureau
PREPA	Puerto Rico Electric Power Authority
PV	photovoltaic
renewables RFP	renewable generation and energy storage request for proposal tranches
RFP	request for proposal
RICE	reciprocating internal combustion engine
RPS	renewable portfolio standard
S&L	Sargent & Lundy Puerto Rico
SC	simple cycle
SLPR	Sargent & Lundy Puerto Rico
T&D	transmission and distribution

Executive Summary

On 15 March 2018, the Energy Bureau of the Puerto Rico Public Service Regulatory Board (Energy Bureau or PREB) issued a Resolution and Order to the Puerto Rico Electric Power Authority (PREPA) to file an updated Integrated Resource Plan (IRP). The purpose of the IRP, as required by law[1], is to develop a roadmap consisting of a detailed planning process that takes into consideration "all reasonable resources to satisfy the demand for electrical services over a twenty-year planning horizon, including resources related to energy supply and demand. In addition, the IRP shall consider resiliency, reliability, and stability of the power system, and be fully compliant with current and future environmental regulations." [2] After several revisions, on 07 June 2019, PREPA filed the final IRP, and on 24 August 2020, PREB issued their review and direction as a Final Resolution and Order.

In several places, the final IRP mentions the need to add approximately 300 MW of new capacity at PREPA's existing Palo Seco power facility utilizing a combined-cycle (CC) power plant configuration fueled with natural gas delivered from a land-based LNG storage and regasification facility. In the Final Resolution and Order, PREB found that this new CC was not part of the IRP's least-cost plan; however, they authorized PREPA to proceed with a scoping and feasibility study for this new power plant at Palo Seco. The scoping and feasibility study was specified to include a preliminary economic, siting, permitting, and planning analysis at a minimum, with the stipulation that the work would not interfere with or delay ongoing renewable energy and battery procurement processes. This report is the result of PREB's request for a scoping feasibility study and it follows PREB's outline and requirements detailed in the Final Resolution and Order.

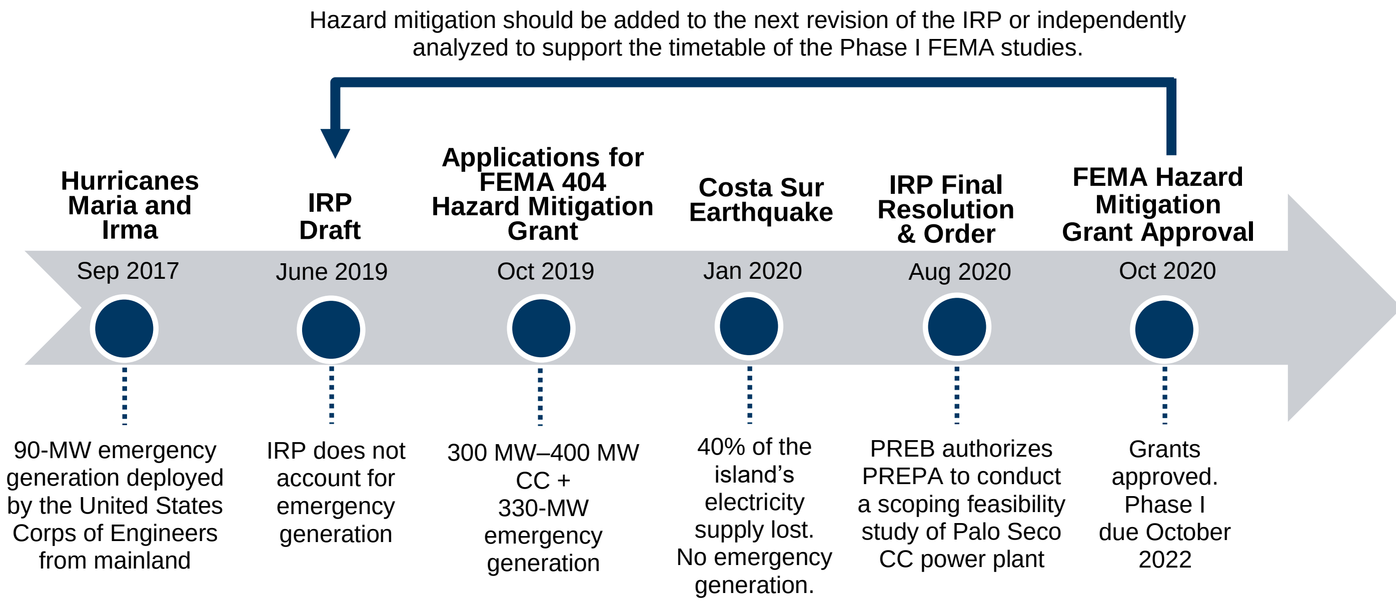
Early in 2019, PREPA was inspecting their facilities and preparing to submit damage assessment reports to the Federal Emergency Management Agency (FEMA) to describe the full impact of hurricanes Irma and Maria across all its power plants. During this time, PREPA was also exploring opportunities to strengthen the northern region of the San Juan metropolitan area with reliable and resilient power generation. Major events can occur which stress the capability of the system—often such that the entire load may not be supplied during recovery. Hurricanes lead to scenarios which require load shedding and a systematic re-energization that may affect the power grid for a long period of time.

The strategy that was developed was aimed at preventing a recurrence of the power delivery shortages and interruptions that were experienced for many months by the citizens of Puerto Rico following the devastation of hurricanes Irma and Maria. One of the main objectives was to make the electric grid more

[1] Puerto Rico Act 57 of 27 May 2014 (Act 57-2014)
[2] Integrated Resource Plan (IRP) page 1-1

resilient when facing future natural disasters by providing more reliable generation in the populated area surrounding San Juan. A modern generation plant adjacent to Puerto Rico's largest population center would provide more dependable service rather than reliance on power transmission via the north-south transmission line corridor from the south coast power plants. To improve the reliability and resiliency in the San Juan area and reduce the dependence on this north-south transmission line corridor against future natural disaster events, PREPA prepared an application with the hope that funding from FEMA under their Hazard Mitigation Grant Program (HMGP) could help achieve this objective. PREPA completed power plant repowering studies to evaluate options for a power plant in the north, and finally an application was prepared and submitted to FEMA in October 2019. Palo Seco was the proposed site for a new CC power plant. However, other alternatives were listed within the FEMA application—the thought from PREPA was that a more comprehensive analysis was needed to finalize a site selection; thus, other options were presented to FEMA in the application. The San Juan power plant site was also a viable option with many advantages and was ultimately proven to be a better location for a new CC power plant than the Palo Seco site within this analysis. Several months of questions and answers between FEMA and PREPA transpired leading to an eventual FEMA Hazard Mitigation Grant Approval. A summary of the major events during this time is presented within Figure ES-1.

Figure ES-1 — Timeline of Major Events Related to FEMA 404 Hazard Mitigation Grant Approval



Source: *Author* © Sargent & Lundy, L.L.C. 2022

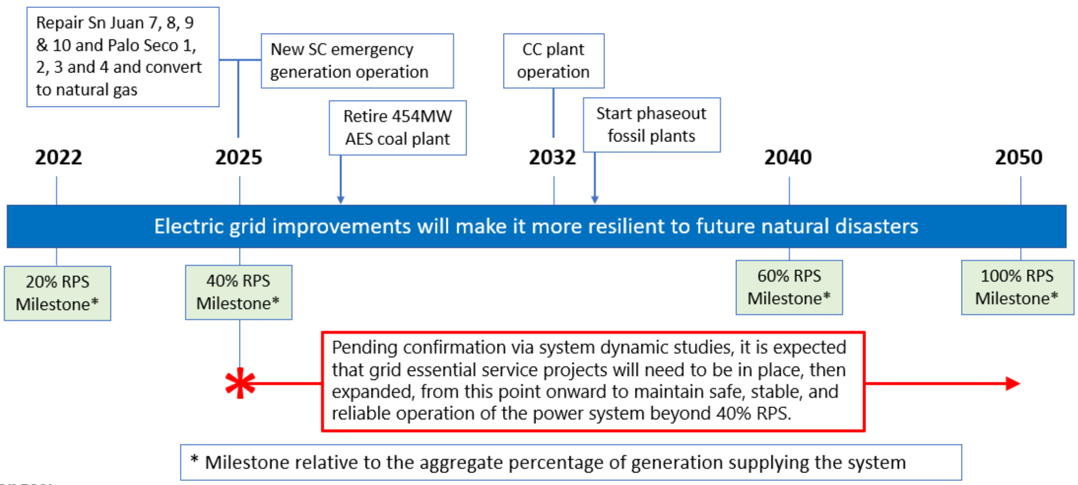
As illustrated in Figure ES-1, PREB's approval of the IRP along with its Final Resolution and Order was issued in August 2020. Two months later, in October 2020, FEMA approved funding to develop and build a CC power plant. FEMA's approval of the project requires two project phases: Phase I consists of basic engineering studies, environmental data collection, and the development of a schedule and budget, all to be submitted to FEMA for review and approval before proceeding to Phase II, the actual project execution. PREPA started preliminary engineering for Phase I work in January 2021 to develop the CC plant which was later refocused to also include the topics required and defined by PREB as the *Scoping and Feasibility Study.*

Since hurricanes Irma and Maria in 2017, Puerto Rico has experienced another major natural disaster and many tropical storms. In January 2020, major earthquakes devastated the southwestern region of the island causing major damage to the Costa Sur power plant—one of PREPA's largest generation facilities. The damages forced the 820-MW power plant to remain in outage for several months until repairs were complete. This event also caused blackouts on the island, and again put both reliability and transmission issues in the forefront of engineering and planning discussions.

PREPA's aged fleet has recently experienced a variety of equipment failures leading to power disruptions. These disruptions are a constant reminder of the conclusions within S&L's independent engineering assessments of PREPA's power plants—that much of the generation fleet has reached the end of its useful life and major repairs are needed with planning for their eventual retirement or replacement. Each equipment failure exacerbates the fragile condition of the power system in Puerto Rico, leading to frequent rolling blackouts—the overall power generation service that has been classified as one of the least reliable systems in North America. Further, as the utility expands their generation capabilities and adds large amounts of inverter-based renewable resources such as photovoltaic and wind generation systems to the existing ailing power system, new challenges, and grid stability issues will emerge that even more sophisticated grid operators in North American and other parts of the world with high levels of renewable penetration are struggling to manage. Preparation and equipment necessary to address these future renewable energy challenges may be accomplished with this FEMA-funded CC project.

Figure ES-2 presents an overview of the anticipated future of PREPA's power generation fleet, highlighting the major events and engineering issues that must be considered. While the figure provides a simplified summary of the changes that must be made, this transformation requires careful planning and integrated engineering strategies for successful implementation. Furthermore, to meet these challenges, improvements to both power generation system and the electric transmission and distribution systems are needed to make the grid more resilient. The transition to inverter-based renewable energy requires special consideration as penetration levels increase to maintain power system stability and inertia, and future emergency generation capacity requires improvements to mitigate the loss of life and property during future events.

Figure ES-2 — Opportunities and Challenges in Power Generation



Challenges:

- Increase in intermittent renewables inverter-based resources could lead to intermittent generation. Need mix of generation technologies.
- System will need fast start generators to stabilize the grid frequency by providing system inertia.
- Repair existing units to meet current demand and transition from fossil to renewables will require fast start generators to add flexibility to the grid since boilers cannot cycle to react to grid stability demand.
- Based upon independent engineering assessments of the Puerto Rico power system, adding the planned renewable generation capacity along with energy storage facilities, while retiring existing thermal power plants such as the 454MW AES coal plant, results in an electricity generation deficit.

Source: *Author* © Sargent & Lundy, L.L.C. 2022

Conclusion and Recommendation

The power generation and transmission systems in Puerto Rico are anticipated to change dramatically in the next five to ten years. Across the power generation industry, multiple examples of overreliance on a single technology, particularly those that generate power in an intermittent manner, have been tied to power generation challenges, grid stability issues, and unplanned outages across many areas of North America—examples are contained within this report. As the world continues to integrate more clean energy into power systems, it is increasingly more important to view the pros and cons of each adjustment to the system and collectively engineer a path to achieve an appropriate generation and energy storage mix to not only achieve future renewable portfolio standard compliance, but to also ensure that the future system is able to provide reliable service to its customers across all future generation needs.

Within this report, a new CC power plant has been evaluated to provide new and modern generation technology for the northern part of Puerto Rico immediately adjacent to the existing San Juan power plant. The power plant design provides robust and proven technology that will provide a new level of resiliency to manage natural disasters, flexibility to react to more demanding future grid demands, a thermal efficiency that is expected to be the best on the island (using less fuel per MW than any other power producer), and reliability in line with North American standards. It will be operated and dispatched with modern FEMA-funded transmission and distribution control system improvements—necessary improvements to support faster operating response times of a more dynamic, clean energy future.

However, given PREPA's current power generation struggles and the time horizon for both simple-cycle and CC projects (defined within the report), transitional measures to improve the existing thermal generation assets should be considered and executed now. This would require PREPA's staff to assess the condition of current thermal generation assets, conduct the necessary repairs to restore service to units that are out of service, and/or improve the reliability of the operating baseload units. Emergency generation units are not discussed in this report as they are the topic of a separate feasibility report (S&L Report SL-017095 -PREPA Emergency Generation Feasibility Report) that will be submitted to PREB for their review and approval.

With consideration given to the above points, Table ES-1 provides a list of potential solutions A through E, for PREPA's consideration, along with the pros and cons of each solution. As an overall solution, based on our evaluation of a new CC power plant, Alternative A which places a new facility at the San Juan power plant location on new property is the preferred solution for the criteria evaluated—not at Palo Seco for the reasons further detailed within this report. However, constructing the CC power plant adjacent to the existing San Juan power plant is a challenge. PREPA does not own this property, therefore it would require i) government approval, ii) negotiations with the Puerto Rico Ports Authority, and iii) negotiations with the port operators. Acquiring the rights to use this property and relocating existing ongoing services at the port that utilize this property is expected to take at least two years before project work may begin. In addition, PREPA's experience with projects of a similar nature in Puerto Rico suggests an overall 10-year time horizon is more realistic; thus, its execution does not provide immediate relief to PREPA's current power generation needs. For this reason, alternatives B through E may be considered. These alternatives utilize the FEMA HMGP to provide improvements to existing equipment to achieve the hazard mitigation objectives, but several of these alternatives also provide a path to prepare for a future baseload power plant at the San Juan site—per the detailed discussions contained herein, configured to address both emergency generation and the support of future renewable generation and storage projects.

Table ES-1 — List of Recommendations for Consideration with Pros and Cons

ALTERNATIVES		PREPA's estimated schedule	Grid support after Tranche #2	Reliability	Total MW	Flexibility for low loads & cycling	COMMENTS
A	New CC power plant fueled by natural gas (NG) and diesel as backup.	Approximately 10 years	H	H	300 - 400	Y	Timeline to implement is based on PREPA's experience to obtain property, permits and approvals; potential demolition and soil remediation, which could delay start of construction. Prepares PREPA for future renewable integration, as it is environmental compliant, efficient, and reliable base generation.
B	Convert existing thermal units to burn NG for SO_2 SIP compliance in non-attainment zones and other environmental compliance	Maximum of 10 years	L	M	~2,575	N	Aguirre ST Unis 1 & 2 = 900MW Aguirre existing CC 1 & 2 = 592MW Palo Seco ST Units 1, 2, 3 & 4 = 602MW Palo Seco Mega Gens = 81MW San Juan ST Units 7, 8, 9 & 10 = 400MW TOTAL = 2,575 MW
C	Convert San Juan (SJ) 7, 8, 9 & 10 to burn NG for SO_2 SIP and other environmental compliance.	2 - 4 years	L	M	400	N	Not expected to use the complete FEMA 404 HMGP funding.
D	Demolition of SJ 10 for the installation of new RICE units (Number of units of 18 MW each, to be determined as space allows)	5 - 6 years for SC with demolition	H	H for New	TBD	Y	Retire and demolish San Juan Unit 10 and install new RICE units as space and funding permits. Permits and approvals, potential soil remediation mainly due to demolition could delay start of construction. Prepares PREPA for future renewable integration, as it is environmental compliant, efficient, and fast response generation.
E	Install GT(s) in SC mode that can be later converted to 300 – 400 MW CC	. 4 - 5 years for SC	H	H for New	350 CC	Y	Location for new SC units TBD. To be located at site with NG availability, likely San Juan. Estimated 4-year duration for SC to CC conversion. Prepares PREPA for future renewable integration, as it is environmental compliant, efficient, and reliable base generation.

Key: L = Low, M = Medium, H = High (impact)| TBD = to be determined | Y = Yes, N = No

Source: *Author* © Sargent & Lundy, L.L.C. 2022

The alternatives presented above may be considered for the future development of a comprehensive overall plan whereby PREPA (i) refurbishes a portion of the existing facilities, (ii) establishes retirement plans for these facilities along with strategic spare part decisions for the refurbished assets, and (iii) executes fundamental planning and partial development of a new power plant in San Juan suitable for emergency generation, baseload power, and the future integration of renewable energy projects. It is our recommendation to reevaluate the expenditures for the options outlined above, including the development of new base load power, and reallocate FEMA HMGP funding in an optimal manner for select refurbishment projects, fundamental planning, and preparation for a future baseload power plant project. In lieu of a CC plant, new baseload facilities that utilize a combination of simple-cycle gas turbine(s) for future conversion to CC power plant, or reciprocating engines, may be evaluated to reduce project costs so that refurbishment projects may be executed and fulfill PREPA's immediate need for improvements to reliability of their generation fleet.

1.0 Introduction

1.1. Scoping and Feasibility Study Objective

The Puerto Rico Energy Bureau's Integrated Resources Plan (IRP) Final Resolution and Order, dated 24 August 2020, authorized a scoping and feasibility analysis that includes a preliminary economic, siting, permitting, and planning analysis for a new combined-cycle (CC) power plant at Palo Seco[3]. The specific items noted in the referenced resolution and order are quoted below[4]. Each item is addressed within this report:

> The approved preliminary work shall include a scoping and feasibility analysis, which shall:
>
> - take into account the response (in volume and pricing) to PREPA's (Puerto Rico Electric Power Authority) Solar and Battery RFP, including evaluation of whether the results indicate that generation at Palo Seco may not be required;
> - include a process to gather information from vendors regarding indicative pricing for CC, reciprocating engine, and combustion turbine generators;
> - include a siting and permitting feasibility analysis for fueling infrastructure, including any necessary pipelines and terminals, for natural gas, LPG/propane, and diesel and other low-sulfur oil fuels;
> - account for any opportunity cost related to the siting of BESS [battery energy storage system(s)] resource or renewable energy resources at or near Palo Seco that would be incurred as a result of fossil fuel generation development at Palo Seco and;
> - include recommendations regarding the specific resources that may be needed at the Palo Seco site in order to most cost-effectively complement the resources being developed and deployed elsewhere in Puerto Rico.

The work herein defines the range of activities required to define, design, and construct new power generation for PREPA; an assessment of the current power challenges at the completion of this report; implications to ongoing transformation towards a renewable energy future; and suggested solutions with advantages and disadvantages of each recommendation.

[3] Page 201 paragraph 654 of PREB's 24 August 2020 Final Resolution and Order
[4] Page 273 paragraph 880 of PREB's 24 August 2020 Final Resolution and Order

Furthermore, the resolution also required the following:

> ***The scoping and feasibility analysis shall include the data and findings from PREPA of the items listed above which includes but are not limited to: renewable energy responses to the RFP as to volume and pricing; vendor pricing information for the thermal generation options; siting and permitting feasibility for fueling infrastructure; and resource needs at the Palo Seco site.[5]***

While replies to the above requirements are included within this report, as the Puerto Rico Energy Bureau (PREB) states above, with respect to the scoping and feasibility analysis, the data and findings must "include, but are not limited to," therefore, we have included additional relevant points of interest. These additional points provide engineering insight into the overall need for generation in Puerto Rico, the complementary benefits to the ongoing renewable energy transformation work, and other needs and considerations that will support the implementation of the forthcoming renewable energy and energy storage projects. New generation resources are recommended to replace the existing, aged generation fleet for several reasons, all of which are closely related to each other and discussed within the report sections that cover the additional points of interest:

- The immediate need for emergency power generation systems. [7]
- The need for an engineered path, including an appropriate generation and energy storage mix, to achieve future renewable portfolio standard (RPS) compliance.
- Planning for future grid services (e.g., synchronous condensers) to support future RPS compliance.
- Multipurpose thermal generation plants to complement and support reaching future RPS mandates.
- Commentary for future renewable generation and energy storage request for proposal (RFP) tranches, hereafter referred to as renewables RFP.

We envision that the entire generation fleet will need to evolve to include a robust mix of renewable energy, thermal power generation, energy storage, and other modern dispatch, control, and communication technologies to complement and support the path towards meeting RPS mandates. As the generation fleet is updated, it must not only continue to serve power demands across all operating scenarios, but it should also function effectively within a dramatically different future power system. As the RPS percentage increases over time, there will be a displacement of grid-stabilizing synchronous generation machines with intermittent inverter-based technologies such as photovoltaic (PV) and energy storage systems. Furthermore, Puerto Rico regularly experiences harsh weather events, such as the 2017 hurricane disasters and the 2020 seismic activity that resulted in damage along the south coast of the island. After

[5] Page 273 paragraph 880 of PREB's 24 August 2020 Final Resolution and Order

each event, emergency power generation systems were required for disaster recovery. Experts from the U.S. Department of Energy (DOE) and the Federal Emergency Management Agency (FEMA) have provided recommendations, and FEMA has approved funding to design and build projects to mitigate the impact of these events. Today, the island remains vulnerable, and a recurrence of the 2017 hurricane aftermath remains probable until these emergency generation mitigation projects are operational.

This report describes the considerations for performing the engineering and design for new thermal generation, such as a CC power plant at Palo Seco and/or the proposed alternative sites defined herein; new simple-cycle (SC) emergency generation; and other suggested improvements—all summarized within Appendix A.

Collectively, these recommendations provide guidance to develop multipurpose electrical generation facilities and supporting system designs that address most issues required for the utility to reestablish itself as a reliable provider of electricity. These recommendations also begin to define the steps and analysis work necessary to establish an engineered path towards implementing renewable generation and energy storage projects, the required complementary systems, and other necessary support to meet the RPS requirements set forth in Act 82-2010 and Act 17-2019.

1.2. Context

This report, prepared by Sargent & Lundy Puerto Rico ("SLPR" or "S&L" hereafter), and other studies prepared for PREPA (referenced herein), along with the historical and continuing power deficit experiences on the island in 2021, and repeated disaster recovery challenges, demonstrate a clear need for new reliable power generation equipment. Both renewable energy and other power generation projects (refurbishments for thermal plants and new generation projects), along with BESS should all move forward in parallel to ensure reliable generation is available to support critical loads[6] and provide stable power delivery services that are aligned with the performance metrics of suitable standards of service established by the North American Electric Reliability Corporation.[7]

Reliable power must be supplied 24 hours a day, 7 days a week to the utility's customers. Given the aged and outdated generation facilities that are in place—along with their inefficiency, reliance on heavy fuel oil (HFO) and diesel, and poor reliability statistics—and with consideration given to future plant retirements, new and modern generation equipment is needed. The new equipment should be fast-starting, fast-

[6] Critical loads include hospitals, emergency rooms, water utilities, governmental agencies, banks, ATMs, gas stations, supermarkets, and telecommunication centers.
[7] The North American Electric Reliability Corporation is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid. North American Electric Reliability Corporation develops and enforces Reliability Standards.

ramping, flexible, efficient, and agile—unlike the large thermal equipment that is currently in place. These capabilities are needed now and are even more important in the future to support the large number of planned renewable energy projects that vary in output based upon the solar or wind resources that are available. Since peak solar and wind generation periods do not coincide with peak power demand periods in Puerto Rico, other reliable generation systems are needed as backup when solar and wind resources are unable to meet demand or are unable to charge depleted energy storage systems. Emergency conditions, including disaster recovery, cannot be excluded.

As described within Section 6.1.5 of this report, PREPA's existing thermal generation sites are not considered reliable based on North American standards. Implementing new renewable energy and energy storage projects into an existing unreliable power system will destabilize the power system as new projects and larger penetration levels are achieved. Alternatively, implementing these same renewable energy and energy storage projects *with* modern, flexible thermal generation equipment specifically configured to function in a renewable generation environment will dramatically improve the power system's reliability and provide an underlying base of dependable dispatchable generation to support the system when needed. This will ensure generation support is available for nighttime periods or during a decline in solar or wind resources. It will also provide reliable generation service during storms and emergencies. When smartly configured, even grid support services such as synchronous condensing may be integrated with this emergency generation equipment—when the equipment is fired, power is produced and when it is unfired, the generators may provide stabilizing power system services, as described at the end of Section 6.1.4. Most of PREPA's existing generation fleet, as described in Table 2-3, is either unreliable or unable to effectively support—meaning provide fast ramping, ability to run at low minimum levels, and quick startups and shutdowns on demand—all of which will be required in the near future for grid stability to enable PREPA's renewable energy transformation and ensure reliable power supply during emergency conditions is available.

The vulnerability of the island to harsh storms and other natural disasters, compounded by the fact that Puerto Rico is not interconnected to any other electrical grids that can provide backup support, highlights the importance of implementing an adequate mix of generation technologies to prevent an overreliance on any one technology. This strategy also minimizes the risk of future generation disruptions under normal and emergency conditions. More specifically, it should be recognized that PV and wind turbine technologies are more vulnerable to damage from hurricane winds and airborne debris, which creates a future risk as these technologies become a larger component of the overall generation mix. This risk should be addressed throughout ongoing planning. As the island weathers these inevitable future storms, it is essential to have distributed emergency backup generation sources that can provide uninterrupted power during and after such events for disaster recovery. This will help mitigate loss of life and other adverse impacts that these events may have on the island's residents, property, and economy, and provide needed improvements to the existing infrastructure—a plan that is supported by FEMA and DOE [4] to avoid recurrence of the harsh disaster aftermath conditions, such as those after the 2017 hurricanes. A well-planned generation mix, including a strategic placement of renewable energy, storage, and other hazard mitigation power generation projects, along with extensive T&D improvements and hardening measures supported by FEMA, will enable the island to transform its power system into one that is significantly better equipped for the utility to minimize the impact and/or manage disaster recovery events while at the same time obtain a better position to achieve the required RPS milestones.

1.3. Report Structure

This Scoping and Feasibility Report is organized as follows:

- Section 1.0 discusses the history and development of new thermal power plant concepts to address hazard mitigation issues following a catastrophic event such as a hurricane, any major tropical storm, or earthquake. It explains the importance of increasing power generation reliability and availability to the island's electricity customers, including during and after tropical storms and harsh weather events. Hazard mitigation concepts have been developed by local and federal agencies to systematically reconfigure and build out a more resilient power system that is inherently better at limiting the risk and impact of future power crises, including loss of life and property, when facing natural disasters or generation fleet failures.
- Sections 2.0 through 6.0 provide pointwise replies to the PREB Final Resolution and Order, Page 273, Section 880, specifically:
    - Section 2.0: Renewable RFP process status.
    - Section 3.0: Process for obtaining new thermal generation capital costs.
    - Section 4.0: Siting and permitting feasibility analysis for fueling infrastructure.
    - Section 5.0: Opportunity cost related to the siting of renewable and BESS resources.
    - Section 6.0: Recommendations for the resources needed to complement new renewable, BESS, and thermal generation resources.
- Section 7.0 provides additional considerations that should be considered as the RPS percentage increases over time, covering such topics as generation mix, renewable integration, power plant configurations, renewable RFP Tranche adjustments, needed improvements in communication and control, and resiliency.
- Section 8.0 concludes with PREPA and S&L's suggested considerations to reestablish reliable electrical generation for Puerto Rico, address emergency generation needs, and integrate renewable energy and storage projects to achieve the required RPS milestones. The conclusion summarizes how FEMA-funded hazard mitigation projects provide a range of benefits that support these immediate needs.
- Section 9.0 provides a list of references mentioned throughout this report.

- Appendix A summarizes the recommendations provided herein and references to relevant sections within this report.

1.4. Background

Catastrophic hurricanes Irma and Maria—and the events that followed the storms starting in September 2017—left most of the island of Puerto Rico without power for many weeks (several months for more remote areas), disrupting basic and essential life services across the island. The restoration of the island's power system was a monumental task—the entire electrical generation, transmission, and distribution system on the island collapsed leaving the residents of Puerto Rico in blackout conditions. On 05 September 2017 and 17 September 2017, the governor of Puerto Rico requested federal disaster declarations for Puerto Rico following the impacts of the back-to-back hurricanes. The federal government subsequently approved each of these disaster and emergency declarations. Support from the U.S. Army Corps of Engineers included the dispatch of approximately 90 MW of temporary emergency generators. 60 MW of generation capacity was allocated to the San Juan metropolitan area to serve as backup, help stabilize the grid, and power critical elements of the potable water delivery system to residents. 30 MW of generation capacity was installed at the Yabucoa power plant and served as the emergency backup unit for the southeast region to provide stability to the area and ensure the south coast power plants had black start capability. In addition, FEMA provided approximately 700 small engine driven generators to residents within the interior part of the island where most of the T&D lines had collapsed. Many electric public utilities from the U.S. mainland sent emergency crews and equipment to assist in repairing T&D lines. Approximately 60 days were required to restore electrical services to about 50% of the population on the island; however, many unreliable and temporary repairs often failed and electrical interruptions continued for approximately 11 months until most of the island's T&D lines were repaired in a more permanent manner.

As services were slowly restored, inspections of the damaged electrical grid infrastructure and generation plants were conducted by FEMA and PREPA inspectors to assess the complete extent of the damage and formulate a method to repair and make substantial improvements for more resilient power infrastructure. One conclusion indicated that Puerto Rico needed *to reinforce its generation capacity in the northern region to mitigate major blackouts in the industrial, commercial, and residential metropolitan area of San Juan* following a similar, future major catastrophic event. PREPA—in alignment with Puerto Rico's central government, FEMA, and the DOE [4]—considered various power generation options and proposed a new, highly efficient and dispatchable generation project in the north to provide reliable electrical power following a natural disaster to mitigate some of the risk associated with Puerto Rico's grid infrastructure.

Resiliency recommendations were prevalent in a report prepared by the DOE [4] for the government of Puerto Rico to consider incorporating recommendations into its recovery plans following the September

2017 hurricanes. Regarding power generation, the DOE recommended to "Evaluate the siting of key generation facilities so that, to the extent practicable, they are *co-located with key load centers* to reduce the criticality of the transmission system when recovering from anticipated extreme events in the future. In particular, analysis on re-powering Palo Seco with alternative fossil fuels is recommended."[4] The current renewable generation and energy storage projects under consideration, with the ongoing RFP and current Tranche 1 proposals, are not likely to support the key aspects of the strategies recommended by FEMA or the DOE experts (underlined in this and the preceding paragraph). The large-scale renewable generation and energy storage projects are expected to be located well outside of the San Juan metropolitan area—primarily due to the amount of land that is required for large-scale utility-scale projects such as these and solar irradiance benefits—therefore, lengthy above-ground transmission lines are expected be used to bring power from these renewable energy and storage projects to the San Juan area, thus providing no support to the expert recommendations from FEMA and the DOE.

North–south transmission lines are vital connections across the island; they interconnect the large south coast baseload power generation plants with the primary electrical demands of the north coast. Since most storms that cross the island start from the southeast coast of the island and travel in a northwesterly direction, these interconnecting transmission lines must frequently face and weather severe storm crossings. Damage to these lines withing the central areas of the island is often difficult to access and repair due to the mountainous terrain and dense vegetation, thus leading to delays in power restoration efforts. The proposed siting of new power generation at the Palo Seco plant significantly reduces the reliance on lengthy transmission lines that deliver power from outside the San Juan area, which are particularly vulnerable to storm damage due to their storm path exposure. Another distinct advantage of situating a new power generation project in the north, near San Juan, is that it would be directly connected to the existing (although currently damaged) underground 115-kV transmission loop that is expected to be restored to service. This underground 115-kV transmission loop surrounds the San Juan metropolitan area—it is protected and less susceptible to damage from severe storms. After restoration work is completed on this transmission loop, the storm-hardened loop will provide an ideal means to distribute electrical services around the San Juan metropolitan area when compared to long, overhead transmission lines that are fully exposed to damaging weather events. Contrast this with the use of local generation in the immediate vicinity of the San Juan area, as both FEMA and the DOE recommend. Local generation meets the recommendations of both FEMA and the DOE. Alternatively, new generation that can be tied into any point around the metropolitan area loop may also be used to safely deliver power to this populated area of the island.

The conceptual emergency generation power plant project evaluated for the proposed Palo Seco site and several other alternative sites, was initiated in May 2019. On 25 October 2019, an application was submitted by PREPA under the FEMA 404 Hazard Mitigation Grant Program (HMGP) to request funding to develop improvements for critical power facilities to reduce vulnerability during disasters, thus ensuring continuity of critical services such as communications, hospitals, banks, and water following any natural disaster. As stated within the FEMA hazard mitigation application, the proposed project complies with the development of a Puerto Rico that is more resilient to disasters and has less vulnerability and exposure. This hazard mitigation program is defined "as any sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects. This definition distinguishes actions that have a long-term impact from those that are more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage." [5]

The FEMA HMGP program is in two phases: Phase I and Phase II. The Phase I – Engineering work consists of preliminary engineering, environmental due diligence, and project cost estimates. Once the required deliverables for Phase I are completed, they are submitted to FEMA and PREB for review and approval before proceeding to Phase II – Construction, where the project is implemented and includes activities such as obtaining all permits, detailed design engineering, procurement of all plant equipment, construction, installation, testing, commissioning, and synchronization with power system. Phase I work for the CC plant started in early 2021 (not a full year). Portions of the preliminary engineering continued under the authorized PREB with a $5 million CC feasibility study for basic engineering; at this time, it is now approximately 31% complete. The new, advanced technology CC generation plant would be in agreement with FEMA's disaster recommendations and satisfy the DOE's expert guidance to ensure a new power plant is "co-located with key load centers." The opportunity would permit PREPA to tailor the design of a new CC plant specifically for base load, emergency generation duties, and the challenges associated with integrating renewable energy projects into the system, which will be explained in further detail within Section 7.0 of this report.

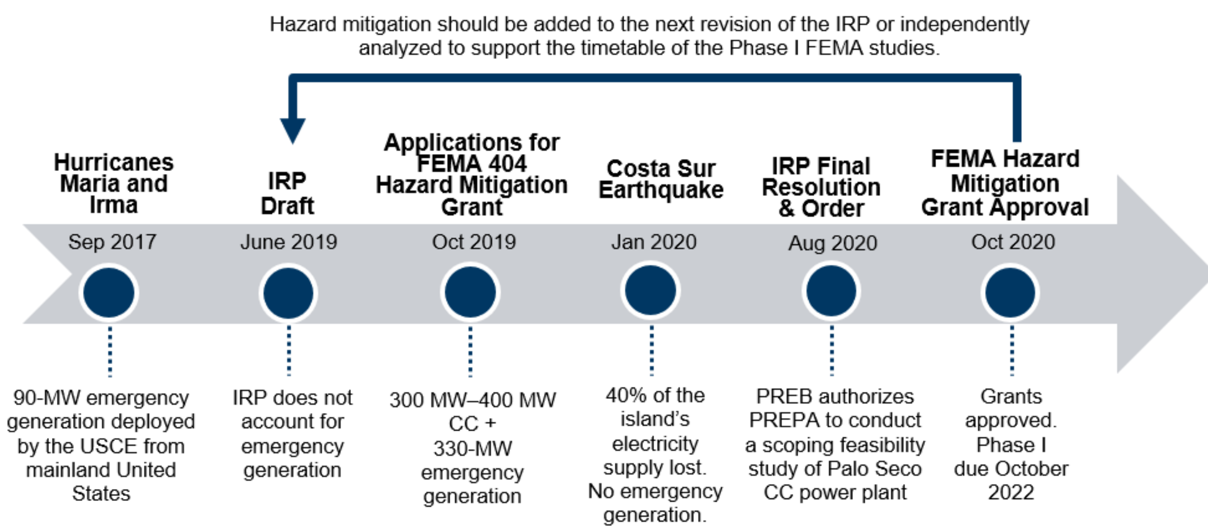
The proposed CC power generation plant at Palo Seco is consistent with both the 2011 and the 2016 Puerto Rico State Hazard Mitigation Plan in conformance with 2011 PEMPN (Plan Estatal de Mitigación de Peligros Naturales) of Puerto Rico goals and objectives [6]. Additionally, the 2021 Puerto Rico State Natural Hazard Mitigation Plan identifies PREPA's power plants as being in moderate to high-risk zones due to earthquakes and hurricanes.

In 2017 and 2018, while hurricane-related damages were being assessed by FEMA and PREPA staff, a new *Puerto Rico Integrated Resource Plan 2018–2019* (IRP) was being developed in parallel and issued in draft form in June 2019. This IRP was based on the February 2018 principles of the PREPA governing board's new vision statement as a guide for the future of the electric utility to develop a more sustainable system and move away from its reliance on inefficient, fossil fuel-based generation and transition to a diverse mix of generation resources. The IRP set a roadmap for the future development of the utility's electrical infrastructure with specific plans for the future of its entire electrical system, reduce the cost of energy to customers, and limit PREPA's future dependency on fossil fuels. PREB reviewed the IRP, including various proposed energy system modernization scenarios, and issued its final resolution and order for the IRP on 24 August 2020 [1], therein providing detailed findings, conclusions, and orders to PREPA.

PREB's final resolution and order dictates the action plan that PREPA must follow as it lays the foundation for the future of Puerto Rico's electrical system. In the final resolution, PREB did not approve the construction of a new CC plant, but rather authorized $5 million in engineering and study expenses for a scoping and feasibility analysis, preliminary economic analysis, siting, permitting reviews, and planning analyses for a new fossil fuel-powered generation unit at Palo Seco, so long as it would not interfere or delay the procurement process for new renewable generation and/or BESS[8] resources. Once pricing is provided through a competitive RFP process for the power plant equipment, construction, and commissioning, a preliminary cost-benefit analysis submitted with the FEMA 404 application for the CC is expected to be validated during Phase I – Engineering to comply with PREB's and FEMA's project economic justification requirements.

PREB's final resolution and order (August 2020) was issued prior to the FEMA 404 HMGP award (October 2020) for new power generation resources as illustrated in the timeline in Figure 1-1.

Figure 1-1 — Timeline of Major Events Related to Hazard Mitigation



Source: *Author* © Sargent & Lundy, L.L.C. 2022

[8] battery energy storage system

The least-cost plan presented in the approved IRP was developed based on optimal generation scenarios to serve all system demand in normal operating conditions. *FEMA's justification for the addition of this new CC plant is not for continuous duty power generation, but rather for hazard mitigation. Thus, this emergency generation system is an integral part of FEMA's hazard mitigation program to minimize the loss of life and property but may also be readily configured to support the renewable integration plan*. The least-cost plan presented in the approved IRP was developed based on optimal generation scenarios to serve all system demand in normal operating conditions. It did not consider emergency scenarios such as hurricanes that can damage substantial portions of the grid, PV, and wind generation systems, thereby compromising the system's ability to deliver power to critical loads such as hospitals and other essential services during and immediately following an extreme weather event. The inability of the system to deliver power to all locations throughout the island shortly after a hurricane or tropical storm can result in harsh living conditions and loss of life caused by the unavailability of essential services such as potable water, refrigeration for medication, and communications. Considered alone, this CC plant is not intended to replace anything in the least-cost plan, but rather is additional to everything included in that plan—to serve as reliable backup generation for the San Juan metropolitan area.

1.5. Project Overview

Among the many projects aimed to make the electrical infrastructure resilient and reliable, PREPA, with the guidance of local and federal agencies, elected to pursue efficient and dispatchable natural gas-fired power plants funded by the FEMA 404 HMGP grant program to provide hazard mitigation in the event of future catastrophic events affecting individuals, public health, safety, and property. As an added benefit, these plants will be configured to support the extensive influx of future inverter-based renewable generation projects with operating characteristics well-suited to the planned integration of renewable power. While the Palo Seco site was initially noted by the DOE as a location of interest and was included within the FEMA application as one of the potential sites for the new CC plant, the results of this feasibility report, as detailed within Section 1.6, overwhelmingly determined that the nearby San Juan Thermal Plant, approximately 4 miles southeast of the Palo Seco site, is better suited for this purpose. The proposed location for the CC power plant is immediately adjacent to the San Juan Thermal Plant. This facility, and the expected restoration of the underground transmission loop around the San Juan area, which is near the area of the island with the highest population density, would reduce the vulnerability of critical services to power loss during and after a disaster. Historic data suggests that Puerto Rico can expect to experience significant storms or hurricanes every 5–10 years; however, the frequency and intensity of these weather events appear to be increasing in recent years.

Since hurricanes Irma and Maria in 2017, Puerto Rico has experienced another major natural disaster and many tropical storms. In January 2020, two major earthquakes devastated the southwestern region of the island causing major damage to the Costa Sur power plant—one of PREPA's largest generation facilities. The damages forced the 820-MW power plant to remain in outage for several months until repairs were complete. This event also caused blackouts on the island, and again put both reliability and transmission issues in the forefront of engineering and planning discussions.

PREPA's aged fleet has recently experienced a variety of equipment failures leading to power disruptions. These disruptions are a constant reminder of the conclusions within independent engineering assessments of PREPA's power plants—that much of the generation fleet has reached the end of its useful life and major repairs are needed with planning for their eventual retirement or replacement. Each equipment failure exacerbates the fragile condition of the power system in Puerto Rico, leading to frequent rolling blackouts—the overall power generation service that has been classified as one of the least reliable systems in North America. Further, as the utility expands their generation capabilities and adds large amounts of inverter-based renewable resources such as photovoltaic and wind generation systems to the existing ailing power system, new challenges, and grid stability issues will emerge that even more sophisticated grid operators in North American and other parts of the world with high levels of renewable penetration are struggling to manage. Preparation and equipment necessary to address these future renewable energy challenges may be accomplished with this FEMA funded CC project.

1.5.1. Combined-Cycle Power Plant for Hazard Mitigation Award

In response to hurricanes Irma and Maria, and their impact on the generation and electrical grid, on 16 October 2020, FEMA granted the funds for Phase I – Engineering of HMGP Project Number 4339-0008, known as the "Palo Seco Generation Plant I." This project includes the installation of a new 300 to 400-MW advanced technology power plant fueled with natural gas as the primary fuel and diesel as secondary backup fuel.

In the IRP approved in 2020, seven representative CC configurations with various capacities and GT manufacturers were evaluated. For these configurations, a specific thermal performance was calculated along with an economic analysis. Capital cost estimates were generated along with calculating a levelized cost of electricity. The results of the IRP evaluation concluded that a 302-MW CC power plant was the optimal configuration for a new CC power plant. However, this economic evaluation presented in the IRP did not account for FEMA funding, as this evaluation was performed prior to the award of the FEMA 404 HMGP grant. In the FEMA 404 HMGP application that PREPA prepared, to provide increased operational flexibility and safeguard against future grid instability after spurious large unit trips, each generating unit in the new CC facility was limited to 140 MW, resulting in a more defined CC power plant project of 300 MW to 400 MW, specifically configured for future generation needs as renewable generation and storage projects become a larger component of the generation fleet. This range of power generation allows for various CC configurations, two or three GTs and an STG, and allows for engineering, procurement, and construction contractors to propose the best technology to meet operational needs.

The conditions of approval included in the FEMA referenced authorization letter details the tasks, milestones, and deliverables that must be completed in Phase I – Engineering before proceeding to Phase II – Construction, contingent upon FEMA's and PREB's approval. These conditions of approval for Phase I – Engineering include all the project initiation and planning tasks (the cost estimates and schedule), preliminary design drawings and technical specifications, a revised cost-benefit analysis, and environmental data collection. Phase II – Construction will include the completion of the detailed design, procurement of equipment and materials, permitting process, and construction and installation through testing and commissioning.

On 04 January 2021, PREPA approved Task Order #4, an architectural-engineering contract to start Phase I – Engineering work with S&L, the engineering firm contracted to perform all the tasks included under this phase. Planning and coordination meetings soon followed between S&L and PREPA staff to develop a plan and schedule to meet the original conditions of approval for deliverables with a due date of 16 October 2021.

On 25 January 2021, PREPA received a resolution and order from PREB with comments regarding PREPA's 10-year infrastructure plan, which included this 300-MW to 400-MW CC project. In this document, PREB made an initial evaluation of these projects included in the plan and their alignment with the IRP, which PREB approved on 24 August 2020. It was PREB's determination that some parts of the 10-year plan were inconsistent with the approved IRP and requested that the plan be revised and resubmitted for their revision and approval. At that moment, Phase I – Engineering work under the FEMA 404 program was suspended, including all feasibility study tasks that were underway.

On 16 February 2021, PREPA responded to PREB's resolution and order, submitting a revised 10-year plan for approval and realigned several black start and emergency generation projects and the CC plant feasibility study to meet PREB's mandates.

On 26 March 2021, PREB issued a resolution and order in response to PREPA's motion to comply with PREB's approved IRP resolution of 24 August 2020 to carry out a thermal generation feasibility study, focusing on preliminary economic, siting, permitting, and planning analyses regarding a new fossil fuel-powered unit near the San Juan area (proposed Palo Seco site). This report describes the thermal feasibility work along with preliminary engineering, siting, permitting, and planning analysis of the new CC power plant, which can be used to continue the FEMA-approved Phase I – Engineering for the hazard mitigation application. All aspects of this plant design will take into consideration ongoing renewable energy generation and storage projects; be configured to work, complement, and support the RPS requirements; and meet the highly efficient generation requirements established by PR Act 60-2019[9].

On 22 April 2021, PREPA informed FEMA of the delays that the order on 25 January 2021 had on the scheduled Phase I deliverables (due on 16 October 2021, as requested by FEMA), and requested an extension. On 23 September 2021, FEMA decided to grant a period of performance extension for Phase I activities until 15 October 2022. FEMA understands that PREPA has made efforts to comply with the Puerto Rico Energy Bureau Resolutions and Orders dated 21 January 2021 and 26 March 2021 and the resulting effects on the progress of Phase I deliverables for 4339-0008 Palo Seco Generation Plant.

1.6. New Combined-Cycle Power Plant Location Evaluation

As part of this report, S&L and PREPA evaluated candidate locations for the new CC power plant. In the CC FEMA 404 HMGP application, the proposed site was provisionally assumed to be at the Palo Seco Steam Plant site, with several alternative sites, as shown in Figure 1-2. Each alternative site is an existing and operational PREPA power generation station, except the Roosevelt Roads site. These alternative sites were all included in the FEMA application to ensure an optimal site selection could be chosen based upon the analysis work of the Phase I feasibility study.

Figure 1-2 — Candidate Sites for New CC Power Plant

Source: *Author* © Sargent & Lundy, L.L.C. 2022

In S&L's process of elimination, the Mayagüez and Yabucoa sites were removed from consideration based on PREB's IRP final resolution, which indicates that PREPA's current resources could not to be expended on the design and development of new natural gas infrastructure at these two sites; therefore, without an

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[9] The proposed PR Act 60-2019 resolution from PREB uses terminology such as "Highly Efficient Fossil Fuel Generation."

adequate supply of natural gas, which must be one of the fuels available for any new power generation project per Puerto Rico Act 17-2019, and is the preferred fuel for a new generation project for many technical and financial reasons, both of these sites were eliminated from consideration and were not evaluated any further. Similarly, the Roosevelt Roads, Cambalache, and Aguirre sites are not considered feasible because they are too distant from any existing point of import or source of natural gas and further, truck transport of either liquified natural gas (LNG) or compressed natural gas is impractical for continuous base load duty power plants of the planned 300-400 MW range. Natural gas imports are currently only available on the south coast at the Penuelas LNG EcoEléctrica import terminal, which also delivers gas via a short pipeline to PREPA's adjacent Costa Sur site and on the north coast at PREPA's San Juan power plant, which receives LNG at the Port of San Juan and is re-gasified onshore for the existing San Juan CC Units 5 and 6. For this reason, given the close proximity of existing, preferred, low-cost, and cleaner fuel and infrastructure, only three candidate sites remained—the San Juan Steam Plant, the Palo Seco Steam Plant, and the Costa Sur Steam Plant. These three sites were sufficiently close to existing ports of import for gas and diesel fuel oil infrastructure. At San Juan and EcoEléctrica, fuel is imported at the point of use—this is a very effective and reliable means to deliver fuel to generation equipment during emergency situations. Distribution of fuels from the point of import to the point of use during emergencies may lead to delays in critical response times, or worse, inability to complete the delivery fuel to the point of use during the emergency. Additionally, these two critical fuel ports are also served with reliable power from the proposed, co-located power generation facility. Reliable power at a port of entry is a distinct advantage of the San Juan and EcoEléctrica (and nearby Costa Sur) sites to ensure power and lighting is available not only for fuel deliveries, but also for disaster response teams that must land at major seaports, then offload and coordinate the distribution of emergency supplies and aid across the island.

1.6.1. Site Evaluation Considerations

The short list of the three candidate sites were evaluated against several criteria:

- Ability to provide on-demand and resilient power supply to critical users such as hospitals
- Ability to serve high load areas
- Limited dependence on electrical transmission lines to reach large populations
- Geographical, ambient, and environmental conditions
- The availability and efficient use of natural gas by the new power plant.

The results of our evaluation, with due consideration given to the scoring for the above criteria, determined the San Juan Steam Plant site was the front-runner for new project development by a wide margin. A few highlights are summarized herein. San Juan is an ideal location because of its proximity to the San Juan metropolitan area, the availability of natural gas as well as diesel backup fuel that is imported, stored, and consumed at this point of import. Contrast this with the Palo Seco location, which depends upon interconnecting systems, such as the existing diesel and fuel oil pipelines that deliver fuel from the San Juan Steam Plant to the Palo Seco Plant. The Palo Seco site is clearly less suitable for a new power plant project due to the following main points:

- Since Palo Seco does not have a seaport, additional fuel handling steps are always required to supply fuel to this site. Whether the fuel is natural gas, diesel, or heavy fuel oil, San Juan and Palo Seco must both be operational for Palo Seco to function following a major natural disaster over a long-term basis.
- While existing, low-pressure pipelines are currently in place to deliver diesel and heavy fuel oil from the San Juan Port to Palo Seco, a new high-pressure gas pipeline would have to be constructed following a similar route across an expanded tract of land. S&L has previously completed conceptual work to evaluate this gas pipeline route. Given the importance of this project for hazard mitigation, the construction of a new gas pipeline is considered a fatal flaw for this site. This conclusion is based upon past failed efforts in Puerto Rico to construct similar gas pipeline projects and should be avoided[10].
- Unlike the San Juan location, Palo Seco does not have a seaport and thus cannot accept large, preassembled power plant modules that are routinely delivered to ports for large construction projects. This capacity can provide tremendous savings in both project costs and significantly shorter project schedules due to large scale assembly work that may be done by experts at OEM facilities prior to arrival at the project site. Direct port access also minimizes the amount of equipment handling, site field assembly work, and eliminates any transportation concerns of moving heavy and large equipment across roads or bridges within Puerto Rico, for example from San Juan to Palo Seco.
- The EcoEléctrica CC power plant is currently the most thermally efficient power plant in Puerto Rico, and it takes advantage of the inherent thermal and operational advantages of its onsite LNG re-gasification process. Chilled LNG fuel used to provide a large heat sink for the power plant, but it may only be practically realized at the point of import for LNG fuel. A similar system may be integrated at the San Juan Steam Plant at the GT compressor inlet to chill the incoming air, thus improving the performance of the GT while at the same time reducing the consumption of natural gas used to fire water-bath heaters, which re-gasify the LNG for use as fuel at the power plant. These efficiency gains could not be practically realized at Palo Seco since it is over four miles from the LNG heat sink. In addition to sacrificing this operational advantage, additional fuel gas must be burned to re-gasify and boost to a higher pressure to overcome pipeline transmission losses to deliver gas from San Juan to Palo Seco. Palo Seco is unable to realize any potential thermal and operational advantages that EcoEléctrica currently uses to drive their production costs and fuel

[10] Gasoducto Via Verde: Natural-gas pipeline project designed to bring natural gas from the Peñuelas LNG terminal to northern Puerto Rico. In October 2012,PREPA withdrew the entire permit application from the U.S. Army Corps of Engineers.
Gasoducto del Sur: Natural-gas pipeline project designed to bring natural gas from the Peñuelas LNG terminal to the Aguirre facility. In August 2009, PREPA canceled the project even though much of the construction had been completed.
Aguirre Subsea Pipeline: FERC granted permission for the construction of the Aguirre offshore FSRU and subsea pipeline project in July 2015, however this project was cancelled after the initial feasibility stage

usage down. The San Juan site is located at the point of LNG fuel import and may be as efficient as EcoEléctrica.

With suitable hardening measures in place that will be defined during FEMA's Phase I – Engineering, PREPA concludes that the optimal location of the new CC generation power plant funded by the FEMA 404 grant is the existing San Juan Steam Plant site, rather than the nearby Palo Seco Power Plant for the reasons outlined immediately above.

As for the T&D system, the permanent reconstruction works to be executed with FEMA funds under the Public Assistance Program shall include the hardening the long-distance transmission lines that connect the southern power generation plants to the northern areas of Puerto Rico. However, the sole reliance on overhead transmission infrastructure to deliver generation to consumers will always be a potential point of failure that can become damaged and cause service interruptions. From a reliability standpoint, the source of primary, first-choice power should be from local generation that does not require vulnerable cross-island power transmission lines to reach the majority of Puerto Rico's population.

2.0 New Power Generation in Puerto Rico

As requested in the IRP Final Resolution and Order, this feasibility report shall:

> ***Take into account the response (in volume and pricing) to PREPA's solar and battery RFP(s), including evaluation of whether the results indicate that generation at Palo Seco may not be required.***

The status of the renewable energy and energy storage RFP process and the resulting need for thermal generation is described in the sections that follow.

2.1. Renewable Energy Projects

Act 82-2010, as amended by Act 17, directed PREPA to procure energy resources in accordance with the following milestones relative to the aggregate percentage of renewable generation supplying its system: 20% by 2022, 40% by 2025, 60% by 2040, and 100% by 2050.

In the final resolution, PREB approved a modified preferred resource plan and a modified action plan for PREPA to follow over the next five years for the procurement of new energy resources and the retirement of many of its fossil fuel generating units. In addition, on 08 December 2020, PREB issued an order directing PREPA to use every effort to comply with the IRP, the modified preferred resource plan, and the modified action plan approved in the final resolution and to achieve the 40% renewable energy generation requirement for 2025, as required by Act 82-2010 and amended by Act 17. PREB also ordered PREPA to implement a procurement plan and develop a renewable energy and energy storage RFP in accordance with the 08 December 2020 Energy Bureau Order.

2.1.1. Requests for Proposals for Renewable Generation Projects

To achieve the established requirements, PREPA began implementing a procurement plan for renewable resources and battery energy storage. The plan consists of issuing six separate renewable RFPs, originally scheduled in six-month intervals, for tranches of renewable generation and energy storage projects that will lead to reaching the renewable energy requirements corresponding to 2025. Table 2-1 provides an outline of this work.

Table 2-1 — Current Renewable Generation Tranche Summary

	Solar PV or Equivalent Other Energy, MW		4-hr Battery Storage Equivalent, MW	
Procurement Tranche	Minimum	Cumulative	Minimum	Cumulative
1	1000	1000	500	500
2	500	1500	250	750
3	500	2000	250	1000
4	500	2500	250	1250
5	500	3000	125	1375
6	750	3750	125	1500

On 22 February 2021, PREPA opened the first procurement tranche to solicit proposals for the design, construction, installation, ownership, operation, and maintenance of renewable energy generation and energy storage projects installed at sites across Puerto Rico as well as for the sale and purchase of energy or capacity made available by such projects. To incentivize the rapid growth of renewable generation, the renewables RFP stipulates that the projects must achieve commercial operation in no more than 24 months from the date on which a selected proponent executes a contract, with preference given to those proposals that can achieve commercial operation within a shorter timeframe.

With this first tranche, PREPA intended to procure at least 1000 MW of renewable energy resource capacity and at least 500 MW of energy storage resource capacity with an effective duration of four hours, including at least 150 MW of virtual power plants. PREPA would accept proposals for all, or a portion, of this capacity, but renewable energy resources offered in response to this RFP on a standalone basis (i.e., those other than resources aggregated into a virtual power plant) must have a generating capacity of at least 20 MW. The proposed projects must comply with a set of minimum technical requirements prepared by PREPA for the specific technology of each type of project.

2.1.2. Proposal Evaluation/Awards for Renewable Generation Projects

The proposals from this first tranche have been evaluated and the negotiation process with the proponents has concluded. PREPA is currently in the process of finalizing the power purchase agreements with the different bidders. The PREB and the Financial Oversight and Management Board have conditionally approved PV power purchase and operating agreements (PPOA) totaling 844 MW of solar capacity. As of this release date, nine PPOAs have been signed. The procurement of battery energy storage proposals and virtual power plant proposals is ongoing. Current material and vendor supply chain circumstances have led to higher project costs and delivery delays across the industry—thus, it has yet to be determined if the remaining PPOAs will be signed and the resulting LCOE for each contract.

2.2. Need for Supplemental Generation

2.2.1. Emergency Support for Hazard Mitigation

From a hazard mitigation perspective, a solar PV generation facility paired with a BESS solution is theoretically capable of supporting the electrical grid under ideal generation and storage conditions. However, the solution raises many concerns regarding the practical implementation and the operation of such solution in an isolated grid system as in Puerto Rico. In addition, it raises concerns regarding the utility's preparedness to manage emergency generation needs when facing inclement weather, its ability to serve critical loads with dispatchable power, and PV's ability to be near key load centers such as San Juan and Ponce such that long transmission lines that are vulnerable to damage during severe weather do not continue to be the weak link during emergencies. Using a seven-day disaster recovery period as an example, the challenges are illustrated via the discussion and analysis below.

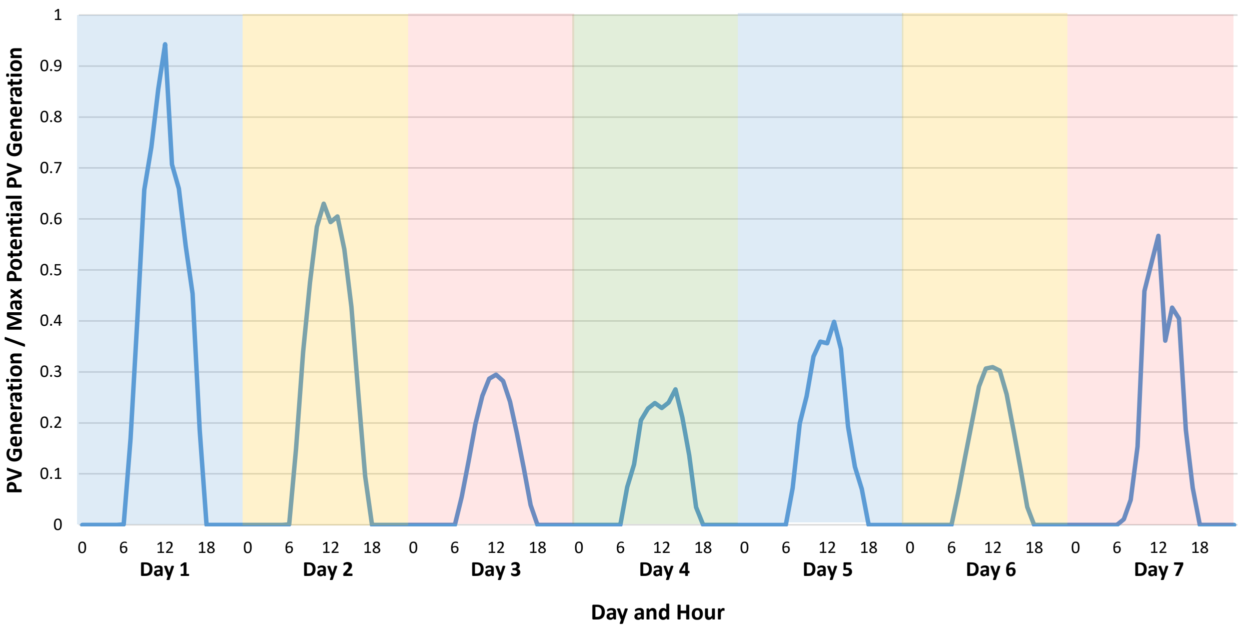
If one considers a seven-day period where a hazard (such as a hurricane, tropical storm, etc.) occurs on day one, a thermal generation technology, such as a CC power plant or similar, sized at 400 MW may be designed to provide continuous power generation of 400 MW for each hour, provided the power plant has enough fuel stored in advance of the hazard. This would total 67,200 MWh to the grid over the seven-day period (400 MW x 7 days x 24 hours/day).

A large solar PV power plant paired with a suitably sized BESS could also be used to supply 400 MW of generation on an hourly basis for this seven-day period. To achieve this generation level, the solar PV would have to be sized large enough to support a total of 67,200 MWh of injection to the grid over the seven-day period, plus any losses associated with BESS round-trip efficiency (a 90% BESS efficiency was assumed for this analysis). During a clear day, a properly sized solar PV facility would be able to provide the 400 MW of injection to the grid, while also having enough excess generation that could be used to charge the BESS. The energy stored in the BESS would then be injected into the grid after the sun went down and through the night/early morning, when the solar PV would be unable to generate.

To size the amount of solar PV needed to provide a similar amount of support to the grid as the thermal generator, PVsyst (a solar PV modeling software platform) was used to estimate the hourly solar PV production. Calculations were based on a P50 solar production level. It should be noted that this production level considers a higher level of solar irradiance than would typically be expected immediately following a major tropical storm due to lingering cloud cover or remaining precipitation; however, this production level was chosen to gauge how well a solar PV paired with BESS solution could meet system electricity needs assuming the solar would not be significantly limited. In other words, solar resources would be 100% available, no damage would have occurred to the PV or its support systems during the storm, and prior to the event, the batteries were fully charged. Potential solar PV production levels vary based on the location in Puerto Rico, technology installed, season, and other factors, but annual capacity factors for a solar PV facility were found to be around 20% and up to 25% for the better locations on island.

Hourly solar PV production forecasts developed using PVsyst include expected variations due to cloud cover. For this calculation, a seven-day period in September, a common month for hurricanes/tropical storms in the Caribbean, was extracted from PVsyst (shown in Figure 2-1). The seven-day period was chosen such that it had initially high PV production, followed by diminished production because of cloud cover. It is important to note that the PVsyst model was not specifically set up to capture a major storm or hurricane-specific scenario. The seven-day period extracted from the PVsyst reflected a stretch of typical cloudy days in an otherwise normal period.

Figure 2-1 — Illustrative PVsyst Hourly PV Production Profile

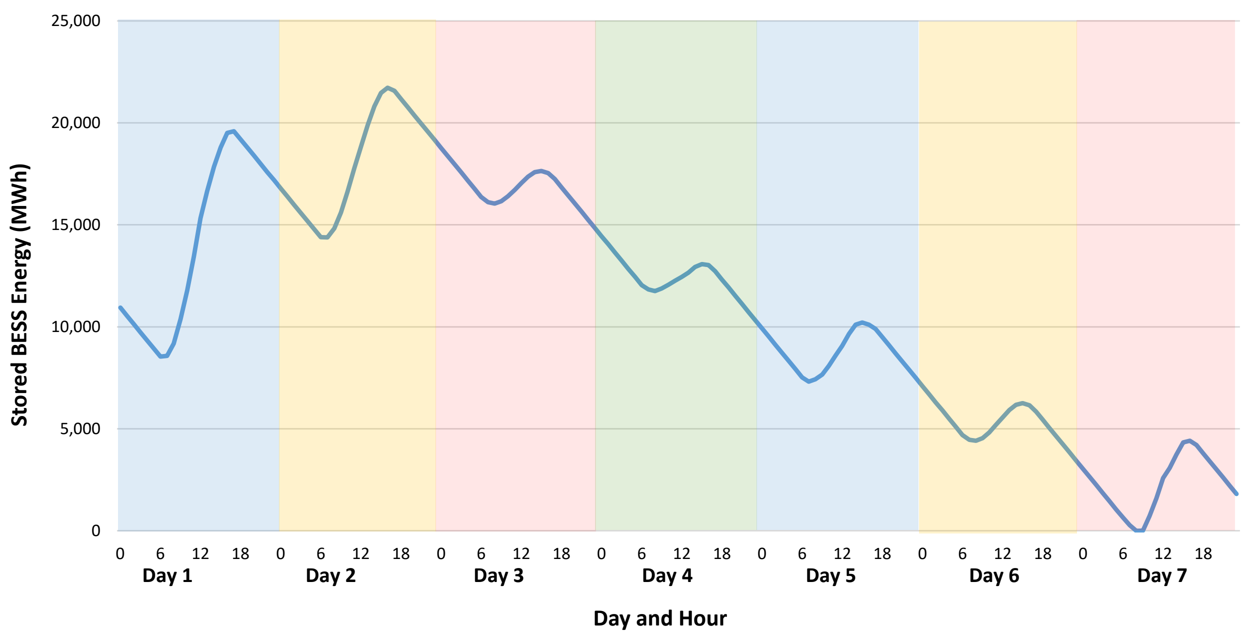


Source: *Author* © Sargent & Lundy, L.L.C. 2022

Based on the hourly solar PV production forecast, it was found that approximately 3,200 MW of solar PV would be needed to both match the 400-MW hourly electricity injection requirement during the day, while also having sufficient *excess* generation capacity to sufficiently charge the BESS. It is important to note that the reason the total installed PV required is high is due primarily to the fact that during the cloudy days there is very low solar irradiance; thus, a significant amount of installed PV capacity is required to generate the equivalent amount of energy. When looking at an actual hurricane or major storm event even more solar PV would be required to produce 400-MW hourly electricity injection into the grid due to significant, lingering cloud cover, and expected storm damage to a portion of the solar panels.

To properly size the BESS, it is critical to consider that the BESS be large enough to meet system demand if PV production drops for some days due to cloud cover, as would typically be expected in the leadup to and following a major storm or hurricane, a hazard type that is reasonably common to Puerto Rico. The cloud cover would reduce PV production, which would reduce the amount of electricity that is able to charge the BESS. It was found that just over 20,000 MWh of storage capacity would be required to meet the 400-MW injection requirements through the seven-day period. This equates to approximately 5,000 MW of 4-hour BESS. Figure 2-2 illustrates BESS operation over the seven-day period, with the amount of MWh stored on the y-axis. As seen in Figure 2-2, low PV production on days three through six results in the BESS not being able to fully replenish its stored energy. Also, this analysis assumes that going into day one there is over 10,000 MWh of stored energy in the BESS. If less energy were stored in the BESS on day one, which is entirely reasonable as lingering hurricanes would do, the solar PV and BESS solution would not be able to fully support the system with 400-MW of hourly energy injection for the full seven-day period.

Figure 2-2 — Illustrative BESS Stored Energy (MWh) Profile



Source: *Author* © Sargent & Lundy, L.L.C. 2022

Table 2-2 summarizes the findings of this analysis. While it was found that a 3,200-MW solar PV and 5,000 MW of 4-hour BESS solution met the generation capabilities of a 400-MW thermal power plant, the sheer size of the PV and BESS solution is likely not practicable from a cost and land area perspective as depicted in Figure 2-3.

Table 2-2 — Technology Comparison

	Peak Generating Capacity	BESS Storage Size (MWh)	Hourly Injection to Grid (MW)	Footprint (sq. miles)
CC Power Plant	400 MW	n/a	400 MW	0.03
Solar PV + Battery Storage	3,200 MW	22,000 MWh (app. 5,000 MW of 4-hour BESS)	400 MW	30 (assuming flat and continuous land available)

It is important to note that while the requirement that the solar PV and BESS be able to continuously supply 400 MW of energy to the grid each hour over a seven-day period is unique from the perspective of normal system operation, the key difference is that this analysis considers hazard mitigation, in which emergency generation equipment for post-disaster events must support critical services. Emergency generation equipment must function continuously as needed to prevent losses during and after an emergency event; it is also expected to be available during the crucial days and weeks that follow the disaster.

A reliable and resilient electric generation system infrastructure with significant amount of industrial, commercial loads, and critical loads, such as hospitals, emergency management facilities, and essential services providers (critical infrastructure) should have a diverse portfolio of efficient, environmentally compliant and dispatchable power generation systems to complement the intermittent renewable generation to ensure customers are served.

Figure 2-3 — Footprint Comparison for Seven Days of Equivalent Emergency Generation

Source: *Author* © Sargent & Lundy, L.L.C. 2022

2.2.2. Other System and Stability Considerations

The achievement of the RPS requirements shall be met in a manner that improves the reliability of the overall power system. Integrating the planned renewable energy and storage projects defined by Tranches 1 through 6 with the aged thermal resources that exist on the island is likely to exacerbate customer service issues related to the current unreliable and unstable power system. Integration steps should be undertaken so the reliability of the system is maintained at the same time renewable energy and storage projects are brought online. Supplemental generation that is specifically configured to support the integration process is required. Details and differences between the aged, existing generation and the supplemental generation required to function with renewable energy and energy storage projects are further defined in Table 2-3. Generation characteristics highlighted in red are unsuitable for the future, renewable dominated generation mix; orange cells indicate marginal performance and green cells note suitable characteristics.

Table 2-3 — Comparison of Generation Features to Support RPS Milestones

Generation Characteristic	Existing PREPA Thermal Generation	New generation
Availability	Poor, with many unit trips. Many units are vintage 1960–1970.	>90%
EFOR (equivalent forced outage rate)	< 10% EFOR for San Juan, Mayagüez, and Costa Sur plants. 10% to 100% for most other plants.	1.5%–4.5% EFOR is typical for new generation equipment.
Ramp Rates	3–5 MW/min. Varies based on technology.	10–40 MW/min (for a GT). Well-suited to work with cloud cover events, storms, or peak demands
Minimum Load	~60%. Equivalent to 60 MW for smaller boilers, San Juan U7–U10 (100 MW each). Reliability and efficiency suffer. 200 to 400 MW boilers are less flexible and unsuitable for renewable load following.	~50% load of 1 GT – maintaining emission compliance. For example, for 2x1 CC this provides an approximate output range of 320 MW to 40 MW while maintaining emissions compliance. Well-suited for renewable generation load following.
Suitability for Frequent Start/Stops	Not capable Not designed for daily start/stops.	Suitable. Modern equipment is capable and will be specified for multiple-daily starts/stops to provide dispatchable generation on-demand to support intermittent renewable energy projects.
Load-Following Capability	Unsuitable. Not designed for load-following service	Suitable Modern equipment, coupled with improved communication, supervisory control and data acquisition, and power management systems are well-suited for load following.
Generator Trip Impact	Existing Units above 200 to 400 MW. Trips of units that contribute a large % to meeting generation demand create large grid disturbances that the existing power system is unable to manage well. This will become worse as more PV, BESS and wind systems are integrated that do not contribute to grid inertia.	Future thermal generation will be specified to be not more than ~140 MW/generator, thus decreasing the risk associated with grid disturbances during an emergency or outage trip. This size unit trip is more manageable, but improvements in the communication, supervisory control and data acquisition, and power management systems and grid services are still needed to maintain grid stability.
Heat Rate (LHV) (higher heat rate means more fuel is required to generate electricity)	~10,000 to 13,000 (or higher) Btu/kWh, (with HFO as fuel) ~11,000 Btu/kWh, (with natural gas as fuel)	**CC:** 6,200 to 6,800 Btu/kWh, (with natural gas as fuel) 6,300 to 7,000 Btu/kWh (with ultra-low sulfur diesel as fuel). The lower heat rate provides a tremendous savings providing roughly 50% reduction in fuel usage for the same power output.

Key		
Not Suitable Inadequate	Suitable Poor	Suitable

As indicated above, the existing PREPA generation in Table 2-3 summarizes the characteristics of the larger, boiler technology PREPA generating units responsible for meeting most of the daily generation needs. It does not portray the attributes associated with the smaller Mayagüez GTs, San Juan Units 5 and 6, Aguirre CC plant, peaking generation, and Palo Seco MegaGen units. The newer units such as Mayagüez and the Palo Seco MegaGen units can provide many of the new generation characteristics that are required in the future. Furthermore, the emergency generation units planned to replace the peaking units may also provide similar support. EcoEléctrica is a modern CC facility that is also capable of meeting these new generation characteristics. The planned CC facility at San Juan would rectify many of the required operating deficiencies shown that are needed for the successful integration of renewable power and provide support for stability in the future and emergency generation.

3.0 New Thermal Generation Preliminary Capital Cost Estimates

As requested in the IRP Final Resolution and Order, this feasibility report shall:

> ***Include a process to gather information from vendors regarding indicative pricing for combined-cycle, reciprocating engine, and combustion turbine generators.***

The indicative capital cost and process to gather information from vendors for CC plant, reciprocating internal combustion engine, and combustion turbine generators is described in the sections that follow.

The original cost estimate submitted by PREPA in the FEMA 404 HMGP application was based on similar indicative pricing for various CC projects between 2010 and 2012 covering a range of 300-400 MW adjusted for 2020 dollars. The 2023 cost estimate is an order of magnitude cost estimate based on 2022 market price for a combined cycle project adjusted for inflation to 2023 dollars. Cost estimates based on conceptual engineering are referred to as Class 4 estimates[11] by the American Association of Cost Engineers. The costs submitted in the FEMA 404 HMGP application were Class 4 estimates. The cost estimate for the CC plant is broken down in Table 3-1.

Table 3-1 — Up to 400 MW CC Power Plant Class 4 Capital Cost Estimate

Ref.: FEMA Form OMB Number: 4040-0008	Original FEMA Grant cost estimate in 2020 Dollars	Revised Cost Estimate in 2023 Dollars
Administrative and Legal Expenses	$30,413,550	$38,448,860
Land, Structures, Rights-of-Way, Appraisals, etc.	$1,900,000	$2,401,983
Architectural and Engineering Fees	$10,250,000	$12,958,067
Project Inspection Fees	$200,000	$252,840
Site Work	$10,000,000	$12,642,016
Demolition and Removal	$40,000,000	$50,568,065
Construction	$285,113,500	$360,440,952
Equipment	$194,500,000	$245,887,217
Estimated Total Project Capital Costs	**$572,377,050**	**$723,600,000**

1. The original cost estimate submitted with the FEMA 404 HMGP application (Ref FEMA Form) was based on conceptual engineering using similar executed combined cycle projects between 2010 and 2012 adjusted to 2020 dollars.
2. The revised 2023 cost estimate is based on an order of magnitude cost for a combined cycle project at 1,675 $/kW in 2022 dollars adjusted to 2023 dollars assuming an 8% CPI inflation rate for an

[11] Class 4 cost estimate as defined by the Association for the Advancement of Cost Engineering (AACE) is based on a 1% to 15% project definition (engineering) and an expected accuracy range of Low: -15% to -30%, High: +20% to +50%.

1,809 $/kW installed. This adjustment includes cost of engineering, raw materials, major equipment, transportation, and construction.

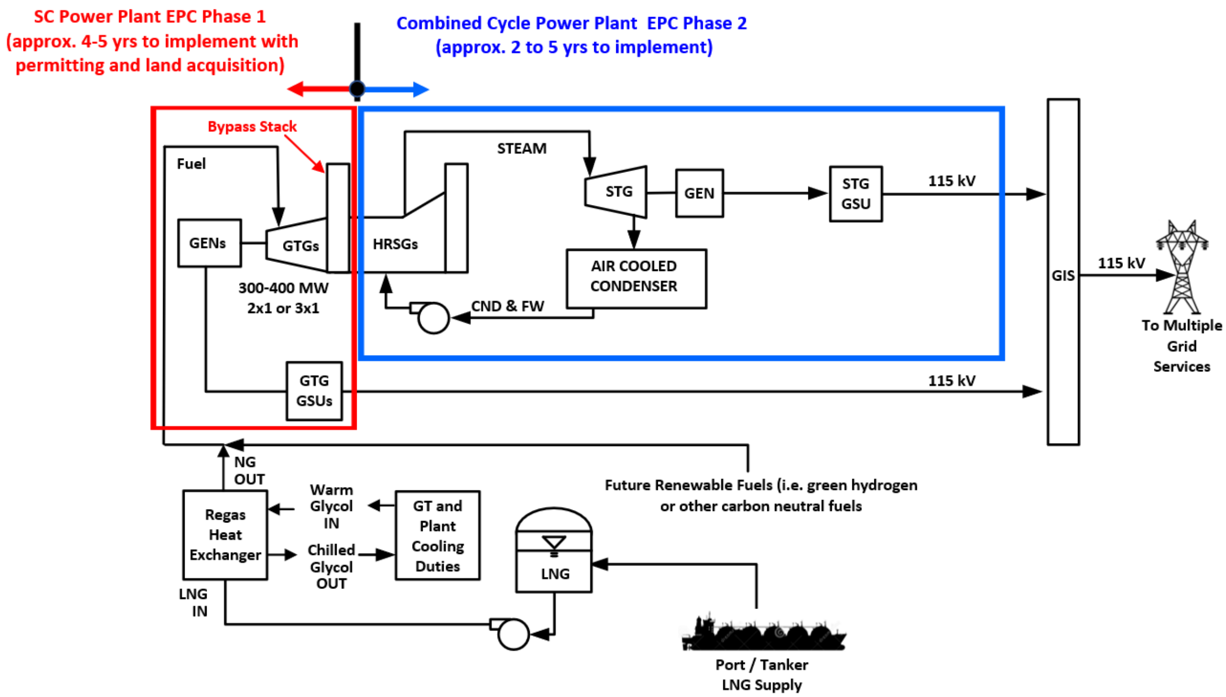
3. Some demolition of existing foundations, underground utilities and buildings may be required
4. Contaminated soil remediation is unknown, and could impact the overall project cost

To validate the PREPA submitted project cost estimate, FEMA requested under the condition of approval (COA), a detailed Class 3 cost estimate[12] breakdown of each category listed above as part of the FEMA Phase I – Engineering deliverables rather than a lump sum price. This can be achieved by developing a detailed work scope supported by preliminary engineering work and studies. The drawings and data developed from this work may then be used produce an RFP package that can be issued to the market via PREPA's competitive bidding process or utilizing a pricing labor, materials, equipment data base. This firm cost can then be compared to the initial indicative cost estimate to determine final project funding. At the same time, the information may be used to validate the cost-benefit analysis submitted to FEMA in the funding request application for the CC generation project. Inflation and fuel costs in 2022 are expected to provide upward pressure on future project costs, therefore it is expected that the cost estimate prepared during Phase I engineering will be greater than the Class 4 cost estimate presented in the original FEMA grant application—however this will be accommodated when the final project funding is established. This final project funding will be the basis for approval to proceed to Phase II – Construction tasks. As indicated earlier, FEMA's Phase I – Engineering is approximately 31% complete for the CC as per the first quarterly report submitted to FEMA in January 2022. FEMA provided a one-year extension to permit these Phase I deliverables to be finished before 15 October 2022.

In the interest of achieving fast-track power, the RFP for the new CC power plant will include provisions for a two-phase installation—the first commercial operation date would be established for a SC installation that may be achieved in a much shorter duration. The second phase of the project work would continue with a SC to CC conversion. Since the CC version of the plant is much more complex than the SC version, smart planning will be used to ensure that terminal points, connections, interfaces, and space are all established or reserved so that the conversion may be made at a later point in time with minimal interruption to the SC operation. In non-attainment areas, such as San Juan, selective catalytic reduction technology may be required to meet emission limits while the GT(s) are operating in SC mode during Phase I of the construction process. Refer to Figure 3-1 for a high-level depiction of this two-phased approach.

[12] Class 3 cost estimate as defined by the AACE is based on a 10% to 40% project definition (engineering) and an expected accuracy range of Low: -10% to -20%, High: +10% to +30%.

Figure 3-1 — Phased SC to CC Plant Conversion Project



Source: *Author* © Sargent & Lundy, L.L.C. 2022

This phased approach process is quite common in the power utility industry but would inherently be more expensive and require additional planning and physical equipment and/or connections to facilitate, but given the dire need for reliable new generation equipment, it is considered an attractive option to be considered at this time, particularly for the San Juan site with access to a seaport where a full range of bulk fuel deliveries including LNG and diesel fuel at present, or green hydrogen or other carbon-neutral fuel in the future.

4.0 Fuel Feasibility Analysis

As requested in the IRP Final Resolution and Order, this feasibility report shall:

> ***Include a siting and permitting feasibility analysis for fueling infrastructure, including any necessary pipelines and terminals, for natural gas, liquified petroleum gas/propane, and diesel and other low-sulfur oil fuels.***

The sections that follow provide a feasibility analysis for the fueling infrastructure required for a CC power plant at the San Juan Steam Plant site and the infrastructure required for the SC emergency generation sites.

Puerto Rico Act 17-2019, the *Puerto Rico Energy Public Policy Act*, established several requirements for the energy and electrical system. Among the stipulations was a program requirement that "existing and future units that generate power from fossil fuels to be capable of operating with at least two (2) types of fossil fuels, one of which shall be natural gas…"[13] This requirement has implications for all future thermal generation plants and has the intention of reducing greenhouse gas emissions with cleaner fuels while fostering, through the two-fuel redundancy, a more resilient Puerto Rico electrical system. (Since there is an exception for legacy power generation assets, this requirement does not apply to existing assets still owned by PREPA.) A plan will be needed to implement natural gas and dual-fuel capability at each *new* power plant, including SC emergency generation plants and black start power plants.

Currently, natural gas provides numerous distinct advantages over other fossil fuels that are currently in use within Puerto Rico. Historically, it has been less expensive than diesel or heavy fuel oil, and it also provides significant environmental advantages. Natural gas is widely used in power generation equipment—such as reciprocating internal combustion engine, boilers, and GTs—and is considered a good replacement of more costly diesel and heavy fuel oils. It has been used by many utilities for facility upgrades, taking advantage of better emissions and lower maintenance costs associated with this cleaner fossil fuel. The fuel is unable to be transported in large quantities easily except by pipeline in gas form or in liquid form via shipment as LNG. S&L has determined that compressed natural gas does not provide sufficient energy content in tanker truck-sized vessels to be a viable alternative for these applications.

LNG is natural gas in its cryogenic liquid form, stored in insulated tanks or insulated pressure vessels at approximately -260°F. Cryogenic pumps draw LNG from the storage tanks/vessels and forward the cold liquid to a vaporization system to re-gasify the LNG in large amounts for baseload or peaking power plants.

[13] Commonwealth of Puerto Rico, Puerto Rico Energy Public Policy Act. Act No. 17-2019, 22 August 2021, Section 5(b).

This process may be designed so that re-gasified natural gas may be delivered at the pressure required for the power plant combustion process without the need or added complexity of compressors. LNG fuel transport trucks may also be used to deliver fuel to SC emergency generators located at various locations across the island. At each site, the tanker trucks transfer fuel from their tanks to onsite storage vessels for use by the SC emergency generators.

Puerto Rico imports all the fossil fuels it consumes. Natural gas arrives by ship in the form of LNG to be re-gasified. Currently, a significant part of the island's LNG is delivered in bulk to EcoEléctrica's terminal at Peñuelas, which is on the south coast, west of Ponce. A second bulk delivery point is on the north side of the island, in San Juan, currently provided by New Fortress Energy for the PREPA-owned San Juan power generation facility.

One of the major factors in selecting the San Juan Steam Plant site as the location for the new CC facility is its proximity to a natural gas fuel source. This limits the required fuel infrastructure and eliminates the need of a natural gas pipeline from the San Juan Harbor to the Palo Seco power plant.

The fuel infrastructure for the new plant is expected to consist of a declared delivery point within the San Juan plant. The gas pipeline from the re-gasification facility to the delivery point is expected to be built by the fuel supplier and included in the fuel price. In addition, provisions should be made for the use of chilled water from the LNG supplier, which will be supplied to the CC plant to reduce auxiliary loads associated with the process, provide facility cooling, and enable the plant to use GT intake air cooling for improved performance during warm environmental conditions. This is an inherent benefit for the San Juan site, which will further improve the efficiency of the fuel delivery process with the net benefit of reducing auxiliary power at the plant. This process is currently not employed with San Juan Units 5 and 6 and as a result, approximately 2 to 3% of the fuel used does not generate power; it is consumed in the regasification equipment to heat LNG from a liquid state to a gaseous state. In the south, EcoEléctrica primarily uses seawater for the regasification process, but also can use GT combustion air to perform the same services, thus providing a 2-3% fuel consumption advantage in the process and providing colder air to the GT combustion process, enabling improvements in the generation process.

Currently, a seven-day supply of LNG is stored aboard the LNG floating storage unit (FSU) at San Juan. The vessel provides LNG storage, which is subsequently pumped from the Port of San Juan to shore through a 10-in. pipe, vaporized within the onshore water-bath heaters, and delivered as gas to San Juan Units 5 and 6 (CC units) for power generation.

Presently, the FSU remains docked for the PREPA contractual required storage. When the FSU requires a refill, a second LNG vessel enters the Port of San Juan, transfers LNG to the docked FSU, and then (typically the next day) exits the Port of San Juan. These *ship-to-ship* refill occurrences are kept to a minimum, estimated at a few times per month, due to the safety exclusion zones around the vessel that interfere with other harbor traffic. Public information on the FSU indicates that it has approximately 27,500 m^3 of LNG storage. Without refilling, the FSU storage capacity allows for 7–10 days of power generation for the existing Units 5 and 6.

PREPA has executed a five-year agreement for supply of natural gas to San Juan Units 5 and 6. The agreement is only for PREPA's purchase of fuel for San Juan Units 5 and 6 and excludes the additional natural gas that would be consumed by new generation. As new generation is installed at San Juan, an increased fuel capacity would be required and must be precured through a competitive RFP process.

S&L estimates that the maximum instantaneous flow and velocity of natural gas to San Juan's Steam Plant may double with the addition of a new CC power plant to the facility. It is unknown whether the existing 10-inch line is acceptable for these higher flow rates; similarly, the same uncertainty applies to the on-ship LNG forwarding pump(s) and water-bath heaters that are needed to vaporize the large capacity required to support the existing and planned new generation.

As Table 4-1 illustrates, the fuel flow increases with the addition of a new power plant. The existing FSU storage capacity is estimated to be 27,500 m^3. We estimate the frequency of replenishing the FSU may increase from a few times per month, to once per week to manage the additional 20,000 m^3 of fuel per week for the envisioned, new natural gas-fired CC generation plant, although LNG suppliers may have alternative solutions for fewer deliveries. The existing fuel supplier has indicated to PREPA that fuel is available to supply an additional 400 to 500 MW of CC power plant power.

Table 4-1 — San Juan Facility LNG Fuel Consumptions

Plant	Generation Capacity MW	Current Weekly Fuel Use (LNG – m^3)	Future Weekly Fuel Use (LNG – m^3)
San Juan Unit 5	220	11,180	11,180
San Juan Unit 6	220	11,180	11,180
San Juan New CC Plant	300 - 400	—	19,380
Totals	**840**	**22,360**	**41,740**
Existing FSU Storage Capacity (m^3)		**27,500**	—

The LNG storage requirement for additional future power generation in San Juan is dependent on delivery capacity limitations, including port accessibility for larger bulk transport vessels. A larger vessel can provide more LNG with fewer scheduled deliveries, extending the ability to increase storage capacity, either as part of a larger FSU or as onshore storage with utility-scale tanks. The existing seven-day storage requirement at the LNG facility must provide some buffer in its storage volume to manage delivery interruptions and delays, particularly for the busy Port of San Juan. The LNG site storage buffer volume may be used to accommodate scheduling logistics; in the event of a disruption, diesel fuel is always available as a backup fuel.

Public information has indicated there is an initiative to upgrade the port to allow admittance of larger vessels. This may specifically include the ability to deliver larger LNG carriers and the capacity to support more power generation between shipments with fewer port interruptions. A larger vessel to make a larger delivery, and refill a larger FSU or shoreside storage unit, is anticipated to be part of a practical plan with expanded fuel use at San Juan.

The addition of a new CC at the San Juan Steam Plant site will require additional LNG deliveries. A few options include: (i) increasing the frequency of deliveries, which will increase traffic interruptions in the harbor; (ii) replacing the existing FSU with a larger vessel; and (iii) providing a larger delivery volume. To accommodate larger vessels, deeper port dredging or port alterations may be required to accommodate larger vessels that require more harbor space to maneuver within the port.

These options will require negotiations with the fuel supplier and require U.S. Coast Guard and Federal Energy Regulatory Commission (FERC) approval. FERC Docket CP20-466-001 must be resolved to allow for an increased frequency of LNG deliveries for expansion of the San Juan facility and to increase the gas supply to serve the new CC power plant and the currently connected San Juan CC plants (Units 5 and 6). Furthermore, this FERC docket must be resolved to determine whether FERC jurisdiction applies and whether further approval or licensing is required for continued and/or increased fuel deliveries for San Juan's operation. Discussion regarding the increased port activities needed to support additional deliveries has not been divulged or discussed with the authorities having jurisdiction at this time.

5.0 Siting of Renewable Energy Resources

As requested in the IRP Final Resolution and Order, this feasibility report shall:

> ***Account for any opportunity cost related to the siting of BESS resources or renewable energy resources at or near Palo Seco that would be incurred as a result of fossil fuel generation development at Palo Seco.***

Detailed cost-benefit analyses are part of the deliverables required by FEMA as part of the Phase I – Engineering that must be prepared for the new CC and emergency generation projects. The preliminary engineering efforts will allow PREPA to obtain firm, current pricing for these projects to be used as input in the cost-benefit analyses. This pricing will also be necessary for PREPA to accurately compare the relative benefit of all the different potential generation alternatives at each site, including renewable energy sources and BESS, as requested by PREB.

The comparison between the alternatives will consider funding from the FEMA HMGP 404 program that have been approved for the thermal generation alternatives that provide hazard mitigation. The capital costs of these thermal generation alternatives will be very low in comparison to unfunded alternatives. Currently, renewable generation resources do not have the same cost advantage because PREPA considers that they do not satisfy the requirements for hazard mitigation funding. Opinions on this subject vary, however utility scale renewable energy projects that would match the 300-400 MWs of planned CC power generation in the San Juan metropolitan area, would not be in this densely populated area, and therefore would be dependent upon lengthy overhead transmission lines to deliver power in the event of an emergency. FEMA and the DOE's expert recommendations, as previously cited and underlined in Section 1.4, would not be satisfied with this alternative. PREPA is of the same opinion and would add that in addition to transmission line risks, wind and debris damage are likely to damage portions of the renewable generation system, reducing the total capacity and introducing unacceptable uncertainty and risk when in fact, the emergency generation system's sole purpose is to "reduce or eliminate long-term risk to people and property from natural hazards and their effects."

In summary, the cost-benefit analysis will be included in the necessary reviews required by PREB when the necessary inputs are available for the CC project with additional commentary on the renewable generation alternatives. It is PREPA's firm opinion that PV and wind are not suitable technologies for circumstances that require hazard mitigation because they are likely to suffer some damage facing strong storms or hurricanes from airborne debris; further, they are inherently high risk because they would not be near the key load center of San Juan, thus dependent upon transmission lines (therefore not located near Palo Seco or San Juan). The opportunity cost incurred due to displaced renewable energy projects at Palo

Seco or San Juan is not relevant because this area does not have the required space to serve the equivalent of 300 MW–400 MW of thermal emergency power generation with PV or wind resources. Further analysis will be provided in due course as the FEMA Phase I – Engineering work is finalized for the CC power plant design. Additional comparison of thermal power versus the equivalent renewable power with consideration given to capacity factor for each technology is provided within Section 2.2.1.

6.0 Resources Needed Across the System

As requested in the IRP Final Resolution and Order, this feasibility report shall:

> ***Include recommendations regarding the specific resources that may be needed at the Palo Seco site in order to most cost-effectively complement the resources being developed and deployed elsewhere in Puerto Rico.***

The sections that follow describe the resources required for the integration of renewable energy across Puerto Rico and how the recommended FEMA-funded thermal generation resources contribute to successfully reaching the mandated RPS requirements.

S&L conducted studies in 2021 with the purpose of identifying areas of concern that would arise in the system with the aggressive growth of renewable generation as required by law and described in the IRP, as well as the necessary steps to resolve such issues. Many of our conclusions matched those identified in the IRP as requiring further study, and others covered issues that could not be analyzed at the time of the IRP because the required inputs were not yet available. The studies have identified important considerations to allow for renewable energy integration as well as recommended future studies, such as dynamic data collection work for existing generation facilities, and engineering work to address any challenges and to complement and address the resources being developed and deployed elsewhere in Puerto Rico. Refer to Appendix A for a summary of the recommendations and the following sections for additional discussion.

6.1. Issues with the Future Integration of Renewable Generation

Key generation challenges of renewable integration work include the following:

6.1.1. New Generation and Energy Storage

Renewable energy resource planning should ensure that the selected mix of generation technologies and profiles is compatible with the limitations for energy storage and necessary load shifting, particularly during the early phases of the RPS ramp. It should also endeavor to minimize renewable energy curtailments. In the initial stages of this transition period, S&L recommends closely studying the benefits of different renewable resource mixes to ensure a diversified range of renewable and other generation technologies is put in place to support a typical 24-hour generation day.

6.1.2. Generation from Existing Fossil Generation

Given the current need to meet actual demand, as well as future demand, and Puerto Rico's transitions to renewable energy, the existing units should be repaired, refurbished, and converted to natural gas. This will improve the power system risk associated with the existing generation units that are in place and are currently derated or suffer from poor availability and reliability. The conversion of units to natural gas is required to meet air quality standards in non-attainment zones. The U.S. EPA has established national ambient air quality standards for six of the most common air pollutants— carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide, and sulfur dioxide—known as "criteria" air pollutants. On 09 January 2018, the EPA designated the San Juan and Guayama-Salinas areas of Puerto Rico as non-attainment areas for the SO_2. A non-attainment area is an area considered to have air quality worse than the national ambient air quality standards as defined in the Clean Air Act Amendments of 1970[14].The non-attainment designations took effect on 09 April 2018. PREPA's power plants affected by the SO_2 non-attainment designation are San Juan, Palo Seco, and Aguirre.

San Juan Power Plant Units 7, 8, 9, and 10, located in SO_2 non-attainment zones, could be refurbished and converted to natural gas first since natural gas is available onsite from the adjacent LNG regasification terminal. The re-fueling of Aguirre Power would require new LNG infrastructure. The Palo Seco Steam Plant would require a fuel gas pipeline from the San Juan point of import to transport re-gasified LNG from San Juan to Palo Seco.

6.1.3. Preliminary Generation Adequacy Evaluation

S&L performed a preliminary analysis for PREPA of generation adequacy in key years—2023, 2025, 2028, and 2030—and at three critical times of the day: evening (the peak demand period of 8 p.m. to 9 p.m. with robust demand spanning from 6:30 p.m. to 11:00 p.m.), early morning (5 a.m.), and midday (the peak battery charging and solar production period). Our work indicated that shortfalls will be common, particularly after tropical storms or hurricanes, but more importantly, during the early RPS phases as batteries alone are unable to meet power demands through evening and nighttime hours.

It should be noted that the peak generation demand has recently increased across Puerto Rico and has been greater than the forecasted peak demand for the summer of 2022. According to PREPA, in June 2021 the peak demand was 2718 MW and in June 2022 the peak load demand reached 3016 MW. The large power usage that occurs from 6:30 p.m. to 11:00 p.m. must be evaluated and power production must be supplemented due to the unavailability of solar generation or adequate load-shifting from BESS projects during those hours.

[14] Clean Air Act Amendments of 1970 (P.L. 91-604, Sec. 109).

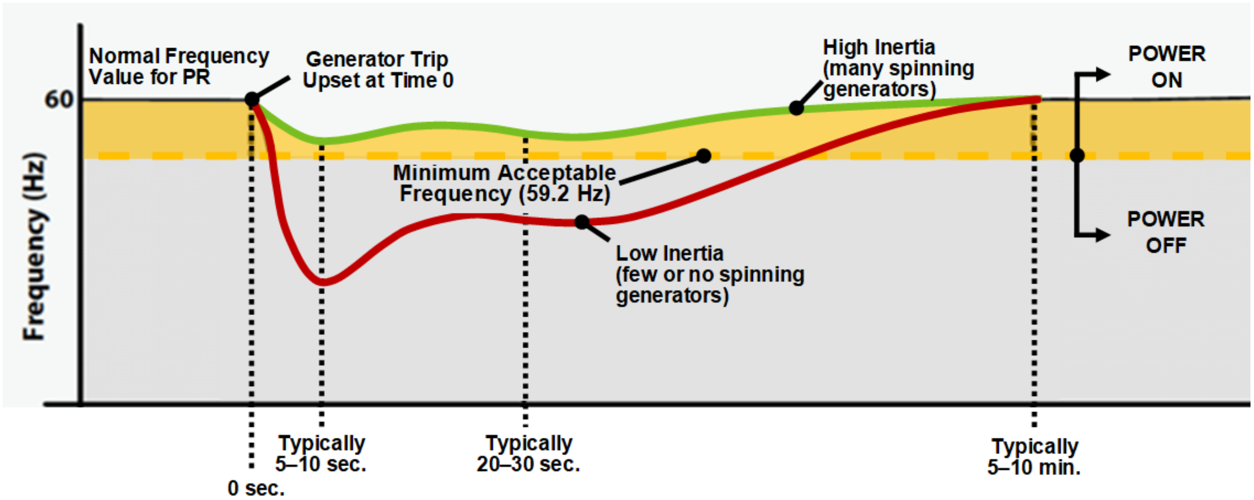
6.1.4. Grid Stability and Support

Renewable energy resource planning should carefully consider grid stability and essential grid services, such as synchronous condensing equipment. This is particularly important to coordinate generation in a manner that provides a stable power system, for instance, to perform PV or wind load following in an effective manner, or immediate response in the event of a forced outage in the system. A key part of grid stability requires the use of synchronous generation or synchronous condensing machines, which is why the IRP specifically highlighted it as an issue requiring further study. The IRP noted that the large generators in the system may be converted to provide grid support; however, new synchronous generation technologies are readily available to enable rotating machinery to generate power, when necessary, but also provide support for grid stability when unfired. These systems are already in place at PREPA's Mayagüez generation plant. As RPS levels ramp upward and inverter-based generation like PV becomes a more predominant component of generation, new synchronous machines may be switched from generation services to grid support services with a simple control panel transfer.

A basic description of system inertia is provided to further explain the importance of grid services in the paragraphs that follow.

The tendency of an object to remain in motion is referred to as its inertia. In a power system, the term applies to the rotational inertia from the kinetic energy within the spinning generators. It is this inertia that acts immediately to restore order when the power grid suffers a frequency disturbance—such as those caused by the loss of a generator or a broken transmission line. When the frequency of the system falls following one of these events, the inertia of the large rotating spinning generator masses helps counteract the frequency drop by immediately supporting it with kinetic energy and momentarily supplies a restorative balance between the power that consumers are extracting from the grid and the power that generators are injecting into the grid. High inertia is a characteristic of a power system with many spinning (synchronous) generators. This inertia helps to reduce drops in system frequency that could result in a need to disconnect power from energy consumers, damage to generators or customer equipment such as motors, or even larger system outages if load shedding occurs due to protective relay trips. Figure 6-1 shows the difference between the behavior of system frequency in a system with high inertia (many spinning generators) and a system with low inertia (few or no spinning generators), such as the characteristics of a system with a large amount of inverter-based PV or wind generation.

Figure 6-1 — Typical Power Grid Frequency Control



Annotated by Sargent & Lundy, L.L.C.

Source: Lee, T., A Market for Primary Frequency Response? The Role of Renewables, Storage, and Demand, 2018.

System frequency in Puerto Rico is maintained at 60 hertz. The dashed orange line illustrates the frequency drop that is permissible—above this line, all customers remain online as the "Power On" in the graphic illustrates, but below this line, some customers may be disconnected as the "Power Off" in the graphic shows. This is to prevent large scale blackouts and to prevent damage to their electrical equipment.

The solid red line shows how frequency will quickly start to drop after a disturbance in a system with low inertia, or one that lacks spinning generators, such as a system that is entirely reliant on PV or battery energy storage. The frequency drops below the minimum allowable threshold so the system disconnects customers to regain balance between power generation and power consumption before the frequency controls have time to start acting to restore the system.

The solid green line shows the behavior of a system with high inertia, or one that contains sufficient spinning machines. The system inertia provides better support of the required frequency so that it does not drop beneath the minimum acceptable level before the frequency controls can act to restore the system.

Generation that uses rotational synchronous generators, such as GTs and steam turbines, help increase the system's inertia and its ability to maintain its frequency within the acceptable range—above the dashed orange line and closer to the target solid green line in Figure 6-1, providing better service and keeping the power on for its customers.

All the conditions described above are more critical in an electrical system that is already a low inertia power system, which is the case of Puerto Rico by virtue of being an island which is not connected to a larger system. As a result, Puerto Rico's system historically has suffered instability events that resulted in load shedding or blackouts due to fault types that do not have the same instability effect in high inertia systems such as the larger, interconnected systems present in the US mainland Therefore, PREPA's system must be composed of redundant transmission and distribution lines along with redundant and distributed generation sources.

6.1.5. Operating Reliability and Performance Metrics

PREPA's power system's operating reliability and performance metrics, when compared to North American standards, is underperforming by a wide margin—clearly a sign of a distressed power system. Few generation improvements have been made since the 2017 hurricanes; a high degree of risk will be present until improvements are made. While a refurbishment plan has been proposed for many the existing generation units, this legacy equipment was never designed for the anticipated future RPS levels and as a result, future generation demands will be more challenging—units will be expected but not able to be turned on and off, ramp up and down—varying their output in coordination with the future renewable energy systems in place. Since solar and wind resources are never constant, new generation facilities with fast start-up characteristics and dynamic ramping capabilities to increase and decrease output on a frequent basis are required. Furthermore, frequent trips of large generation units should be eliminated. In the future, new units that are smaller in size, more agile in their operation, and flexible in their range of service are needed to not only support the grid, but to eliminate the risk of large-scale plant trips. The aged large-scale plants are incapable of serving the future grid requirements and pose grid stability, reliability, and trip hazards—all of which may produce destabilizing conditions for a power system that will be increasingly dependent upon inverter-based generation.

7.0 Additional Relevant Considerations

As continuation of the requirements noted by PREB:

> ***The scoping and feasibility analysis shall include the data and findings from PREPA of the items listed above <u>which includes but are not limited to</u>: renewable energy responses to the RFP as to volume and pricing; vendor pricing information for the thermal generation options; siting and permitting feasibility for fueling infrastructure; and resource needs at the Palo Seco site.***[15]

This section presents additional relevant considerations that are necessary to develop and specify an engineered path towards meeting the required RPS milestones for Puerto Rico. The topics that follow provide support for the immediate addition of new thermal generation across Puerto Rico to:

- Integrate reliable generation to support the intermittent generation periods of renewable energy projects.
- Use natural gas to a greater extent in place of liquid fuels, to regain control of production costs, and reduce emissions
- Engineer a path to not only meet the required RPS milestones, but also retire the existing aged and inefficient power plants as soon as practical as the demand permits.
- Introduce modern and efficient generation systems tailored to complement and support the transformation of PREPA's utility system with the integration of renewable generation and storage projects.
- Convert existing peaker sites to multipurpose generation plants that provide power when fired, grid support when unfired, and emergency generation and black start capabilities across multiple locations.
- Eliminate any continuous use of new and legacy generation equipment and all fossil fuels before 2050.

7.1. Generation Portfolio Mix

As renewable generation and energy storage systems are installed across the island, it is essential that the transformed power system can meet customers' power demands. Based upon independent engineering assessments of the Puerto Rico power system, adding the planned renewable generation capacity along with energy storage facilities, while retiring existing thermal power plants, results in an electricity generation deficit. During the dark, early morning hours when solar is unavailable and battery storage has been depleted, customers are at risk of experiencing unmet demand, or electrical outages. A diverse generation

[15] Page 273 paragraph 880 of PREB's 24 August 2020 Final Resolution and Order

portfolio would be better suited to support the planned renewable energy and storage projects along with the required plant retirements.

The current Renewable Generation and Energy Storage RFP does not provide strict guidance for technology selection; however, it is apparent that an overreliance on technologies with intermittent availability, will eventually lead the utility toward intermittent generation—for example, 100% solar cannot completely cover a generation day without additional energy storage or more diverse generation that is not dependent on solar resources.

Other renewable energy sources should be considered for Puerto Rico's renewable energy transition. The revitalization of the existing hydroelectric power plants is important and potentially beneficial from the perspective that the hydroelectric power plants are both dispatchable and synchronous renewable energy generators. The costs and benefits of revitalization of the existing hydroelectric power plants should continue to be studied and then implemented if feasible. Additionally, evaluating a variety of low or zero-carbon fuels (e.g., hydrogen) would also provide tremendous benefits to improving the generation mix and at the same time achieving RPS credits in proportion to the selected fuel. Any of these emergency generation projects could be configured to support fuel blending or low or zero carbon fuels and thus obtain RPS credits during their operation.

In the long term, to support a reliable generation mix, PREPA is proposing to add a new CC power plant generation to facilitate and, in a short and medium term, refurbish existing fossil power plant converted to natural gas during the transition to renewable energy. In the future, as more renewable energy projects are implemented, as the portfolio becomes more diverse, and as energy storage increases in capacity, the existing large, inefficient thermal generation plants across the island will be run less frequently and ultimately can be retired. This is dependent upon meeting the energy demand in a safe and reliable manner with the new generation resources and must also ensure that safe levels of electrical inertia are maintained. The initial phase of this transformation sees progress across the first several tranches of renewable generation energy storage systems and is complemented with gas-fired turbine technology to enable PREPA to improve their reliability and reduce their operating costs. Over time, the generation mix should become more diverse and less reliant on the use of diesel and heavy fuel oil. Refurbished hydroelectric plants can be recommissioned, other renewable energy projects should be considered, and alternative fuels that achieve RPS credits may be employed to manage nighttime generation or periods of time when solar and wind resources have declined. The future mix of power technologies should ensure that power demand may be satisfied across all hours of a utility's generation day.

7.1.1. Equivalent Forced Outage Rates

EFOR is a measure of the probability that a generating unit will not be available due to forced outages or forced deratings, which does not include planned or maintenance outages. In other words, EFOR is a rating to indicate how the unit is unable to respond, irrespective of system need.

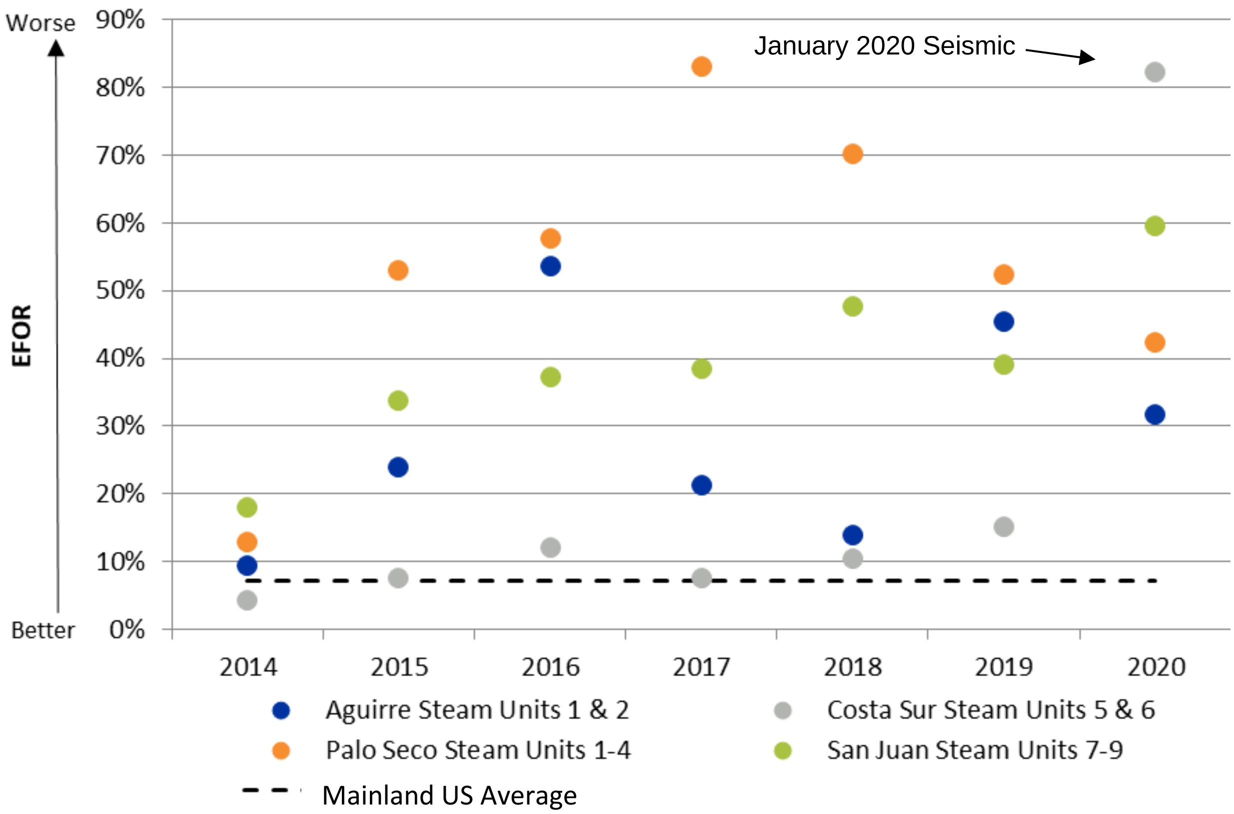
EFOR = (Forced Outage Hours + Equivalent Forced Derated Hours)/(Service Hours + Forced Outage Hours + Equivalent Reserve Shutdown Forced Derated Hours) x 100

EFORs that are high indicate that the generation units are unable to respond to generation demands. PREPA's fleet regularly suffers from significant forced outages and EFORs frequently over 30% and up to 100% in some years. For comparison, the average weighted EFOR for U.S. conventional generation units greater than 20 MW was 7.16% for the five-year period 2015 through 2019.[16] The EFORs for thermal steam generation plants and CC power plants are shown in Figure 7-1 and Figure 7-2**,** respectively. The EFOR for SC power plants is in Figure 7-3. Overall, the lack of funding to repair and maintain facilities has contributed to PREPA's high EFOR statistics; however, the large generation reserve margin (capacity of generation over the amount required to meet PREPA's customer load) allows PREPA to continue to meet the system's requirements.

The major thermal steam generation plants have EFORs that are trending upwards (Figure 7-1). This is indicative of older units with expected maintenance and reliability issues such as high-pressure turbine blade damage problems on Palo Seco Unit 4, accompanied with condenser corrosion issues and Palo Seco Unit 3 boiler feed pump seal problems that contributed to the higher EFOR in 2017. The Aguirre, Costa Sur, and San Juan steam units each had an EFOR with relatively small increases from 2014 to 2020; however, they are higher than acceptable industry standards, generally taken as 20%–26% for a peer group such as this. In 2020, Costa Sur steam units were out of service for extended periods after damage from the January 2020 earthquakes, which has since been repaired.

[16] North American Electric Reliability Corporation, *2020 State of Reliability: An Assessment of 2019 Bulk Power System Performance*, July 2020, https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2020.pdf.

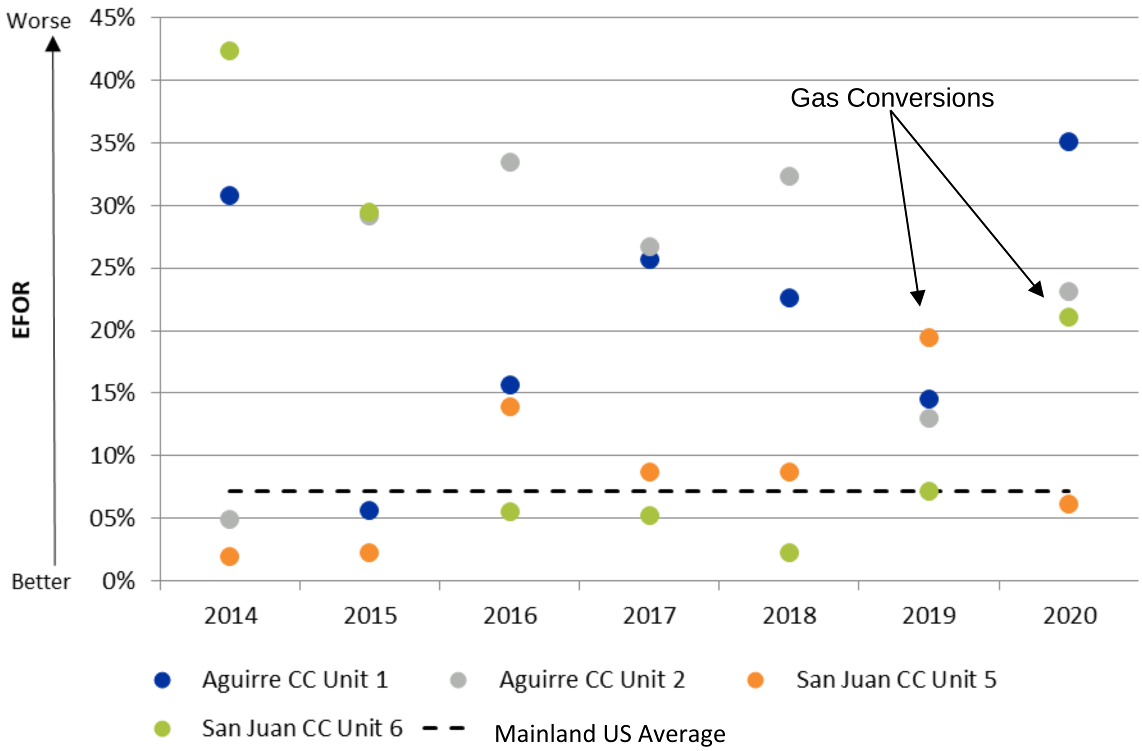
Figure 7-1 — Thermal Steam Generation Plant EFORs



Note: Data for San Juan Unit 10 is not provided; it is currently irreparable.
Source: Author © Sargent & Lundy, L.L.C. 2022

The next figure, Figure 7-2, illustrates the EFORs for the CC plants—the most efficient units in PREPA's fleet. The San Juan CC plants experienced a gradual decrease from 27% in 2014 to 5.5% in 2018 due to a significant amount of planned maintenance that was started in 2015 and finished in 2016. Recently, natural gas was added to San Juan, driving production costs lower and reducing plant emissions.

Figure 7-2 — CC Plant EFORs

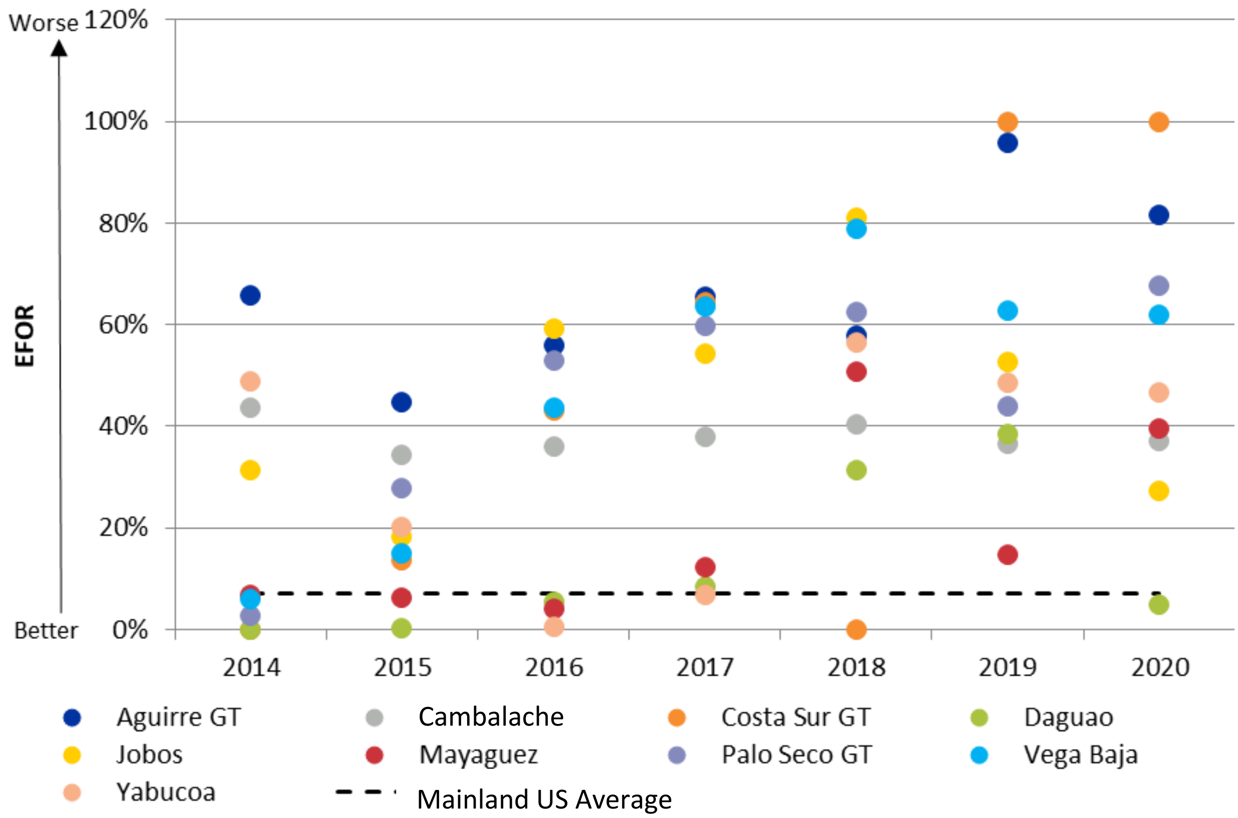


Source: *Author* © Sargent & Lundy, L.L.C. 2022

While the availability of the SC plants (GTs, peaking units) is trending higher, the EFOR rose in response to extended maintenance outages of units within each plant in various years, as shown in Figure 7-3. At the Mayagüez plant, Units 1 and 3 were largely derated with partial generation. Without half of the generating power available for those two units, the EFOR and related values will significantly increase. That skews the average higher and reflects the capital equipment importance of expediting repairs to maintain availability and capacity. The average EFOR at Mayagüez was below 10% through 2016; however, it increased to 12.5% and to 51% in 2017 and 2018, respectively. The EFOR has remained higher over the last two years.

The average EFOR for all GT power plants from 2014 to 2020 was 39%. In 2020, the GT plants had an EFOR of 51%. The increased EFOR from 2014 to 2020 is reflected by the decreasing availability factors because of the increased breakdowns due to the rising operations costs and lower funding for maintenance.

Figure 7-3 — SC Plant EFORs



Source: *Author* © Sargent & Lundy, L.L.C. 2022

PREPA's current power system is aged, distressed, and unable to perform with performance metrics in line with North American averages. For instance, EFORs of PREPA's generation fleet span from levels that are barely acceptable by North American average standards of 7.19%, for thermal plants above 20 MW, to nearly 100%. EFORs above 10% would be considered ***unacceptable*** by most North American standards. EFORs at these levels are typical for an aged fleet. Removing or retiring such units without suitable replacements, despite their age and high EFORs, will inevitably reduce PREPA's ability to respond in an acceptable manner. Even units that are not fully functional contain valuable spare parts for a utility that is faced with these challenges. The risk of not meeting demand will increase as units are removed from service unless suitable dispatchable systems are put in place during the 20-to-30-year transformation to renewable energy systems; furthermore, unlike mainland U.S. utilities, PREPA has no backup interconnection to supply emergency power when faced with disasters or unit failures. Additional reserve margin may provide essential generation services during these circumstances.

New thermal generation in the form of a CC plant may be installed in two phases to provide fast-track power in a SC configuration, then gain additional efficiency and MW by implementing a CC conversion. All the

FEMA projects would prop the ailing power system and permit faster retirements of the old and inefficient existing units, while at the same time be configured specifically for a renewable future.

7.2. Renewable Integration

As Puerto Rico proceeds with installing renewable energy and battery energy storage in the coming years, it will be extremely challenging for Puerto Rico to successfully integrate large amounts of renewable generation while simultaneously (i) improving electrical system reliability and (ii) improving system resiliency in the face of low probability, high severity events. New, highly efficient thermal generation units with rapid startup and ramp rate capabilities are needed to facilitate the successful retirement of legacy thermal generation units and facilitate the successful integration of large amounts of renewable energy projects. In addition, new thermal generation equipment will also help PREPA meet demand and manage the variability of generation from certain renewable resources (i.e., due to cloud cover) or during severe events like tropical storms or hurricanes. During major storms, this new thermal capacity will provide emergency generation, which is vital for the safety and security of the island's residents.

A fleet of distressed equipment and corresponding dismal EFOR rates is not well-suited to provide this support during emergency events, and BESS can only provide needed support if the units are charged (periods of low renewable generation can strain the ability for BESS to charge) and for limited periods of time. By retiring heavy fuel oil and No. 2 fuel oil (diesel) fired units, and replacing them with cleaner, more flexible, and more efficient natural gas-fired generation systems, PREPA could begin its path towards substantial compliance with the laws and PREB requirements, including the need for resiliency, reliability, and stability of the overall Puerto Rico power system.

7.3. Preventative Measures

It should be noted that as an island, Puerto Rico operates in an isolated grid and cannot obtain backup electrical power from other areas or regions and must depend upon its own island grid; however, much of the mainland United States and other areas of the world routinely rely on large balancing areas and interconnectivity to other markets to enable higher service reliability. For example, Pattern Renewable Energy's Operations Group in Houston states that "building out transmission that links geographically diverse generation is essential to enhancing reliability of transmission systems, and their ability to withstand extreme weather events, whether extreme cold, extreme heat waves, wildfires, hurricanes and such.… Studies have shown this time and time again. Planning processes must take these inter-regional benefits into account."[17] Meanwhile, undergrounding main distribution lines may be an appropriate solution in certain

[17] Edward Klump, "10 ways to fix the power grid," *E&E News*, 11 March 11 2021, https://www.eenews.net/stories/1063727199.

areas. Strategies that may be used include placing lines underground, running redundant links from generation centers, or deploying mobile generation units or emergency generation units placed in strategic zones to deliver power to areas that are more prone to isolation.

With the increase of renewable generation there will be a need to operate the existing thermal generation in a manner different than the original design. The existing thermal generation across Puerto Rico was designed to run baseload with their best thermal efficiency point being at full load. These units cannot be turned on and off continuously—they require hours to restart. Given these restrictions, the existing thermal generation units should remain in operation so that they are available to load-follow renewable generation during the day, then provide generation during the peak load demand around 8 p.m. when solar generation is no longer available. To accomplish this, the existing thermal generation units will need to operate at a minimum emission complaint load. Operation at minimum emission complaint load increases each unit’s operating cost—it is no longer operating at its designed, best efficiency point. As the heat rate worsens, so too does the reliability of the unit since it is now relying on many of its auxiliary systems to function at maximum turndown. In addition, as the machines ramp from low load to peak load, the components of the boiler system are exposed to daily stresses that were never planned for during their original installation.

The current solution employed around the world to support renewable load following and load cycling is to employ reciprocating engines or GTs specifically designed for high-turndown capability, fast-ramp rates, and frequent starts and stops. New generation, in the form of a CC power plant, as recommended herein, is necessary to replace the existing thermal generation plants. The existing units are too large, inflexible, and fragile to be used for future cycling and load following. Currently, EcoEléctrica is in the best position and performs these duties; however, it is not sensible to employ the least expensive gas-fired power producer for turndown capability while more expensive diesel and oil-fired units continue to be fully fired. PREPA is in desperate need of equipment that may perform these duties at a lower cost than their existing diesel and heavy fuel oil-fired units and will be in a better position when EcoEléctrica is fully fired rather than turned down for load following.

7.4. Combined-Cycle Power Plant Configuration and Performance Needs

The new CC power plant is envisioned to consist of two or three GTs fueled by natural gas as the primary fuel and diesel as the secondary fuel. This is in compliance with Act 17 of 2019, as amended, the Puerto Rico Energy Public Policy Act, which mandates that all new thermal generation in Puerto Rico shall be able to utilize natural gas.

Within the facility, each GT will drive its own electrical generator. The waste heat, or gas exhaust from the GTs, will be directed to a heat recovery steam generator. This improves the overall thermal efficiency of the power plant by including a steam cycle, which in simple terms, captures the waste exhaust heat, boils demineralized water, and generates high-pressure steam that is used to turn another steam turbine to drive another electrical generator. The design will be classified, according to PREB's definition, as a highly efficient thermal generation plant and will likely be the most efficient power plant on the island. Moreover, with the addition of bypass stacks between the GT and HRSG, the CC plant will be able to operate in SC mode when the steam cycle is not available, increasing the availability of the plant and fast-start dispatch with higher ramp rates to synchronize to the grid. A bypass stack will also enable the project to proceed with a fast-track SC arrangement, which can reduce the project's timeframe by approximately 2 years for initial installation of approximately 105 MW–205 MW (dependent on CC configuration and GT). Once the GTs are commissioned, the second phase of the work may then be carried out to convert the project to a CC arrangement and achieve approximately 300 MW–400 MW of total generating capacity with a significantly better heat rate.

Given the close proximity of LNG systems at San Juan, other considerations can be implemented into future contracts with the fuel gas supplier, such as (i) integration of a chilled-water line to be used for GT inlet-air chilling and integration with other plant cooling duties (the thermal and operational advantages previously mentioned for point-of-use LNG plants); and (ii) integration of a re-gasifier with the power plant to eliminate or reduce the wasteful need for burning natural gas to re-gasify the amount of LNG required to meet the future demand. Integrating the new power plant with the LNG system will improve the plant's heat rate and reduce the fuel consumption. EcoEléctrica has capitalized on these same concepts since its initial commercial operation date—any new CC plant in Puerto Rico should be able to perform better than EcoEléctrica by using the same concepts and employing more modern GT technology.

The power plant will also include all necessary emissions controls to meet the requirements established by the U.S. Environmental Protection Agency, and its emissions will be equal or better than the cleanest thermal-fired generation plant on the island.

With hazard mitigation in mind, the new power generation facility would have to be dispatchable, meaning that it should be able to generate power at any time regardless of prevailing weather conditions. The plant would also be designed to function during severe weather and generate power immediately in an *island mode* situation after such an event with its black start capability. The hardened plant, near the San Juan area and directly connected to an underground transmission loop in the immediate vicinity of critical users, would provide a new and improved level of resiliency for this populated area of Puerto Rico. It would also provide reliable power for critical infrastructures in the north of Puerto Rico to enable effective operations and delivery of emergency supplies and services after disasters.

A new gas-fired CC power plant would be designed to be classified as highly efficient, in accordance with Act 60-2019, and can also include key LNG system integrations for fuel and inlet chilling and cooling duties (if located at San Juan or Costa Sur near LNG supply ports), coupled with a low-load stand-by auxiliary power consumption. Low-load stand-by auxiliary power consumption is essential for a system with large amounts of renewable power generation to limit the power used from the grid to support the CC power plant during standby. It is essential that the CC unit remain in standby to allow for rapid start-up when required to supplement the power generation from renewable resources. Due to the expense of imported fuel, for facilities that use LNG storage and regasification systems, it is preferred that auxiliary cooling, air conditioning, inlet chilling, or other systems are integrated into a regasification glycol circuit to take advantage of the available heat sink during the regasification process. In addition, in the case of a CC, it is recommended to include a bypass stack to allow for SC operation during heat recovery steam generator and ST generator maintenance.

In the future, other technologies, such as BESS, can be incorporated, as space permits, to further develop flexible power supply at both the CC and emergency generation sites.

7.5. Decarbonizing Gas Power

GT technology offers multiple options to achieve lower or zero carbon emissions and contributions towards RPS credits. This can be achieved in the combustion process, by burning zero or carbon neutral fuels, or post-combustion by removing carbon from the plant exhaust.[18] Carbon-neutral fuels include: green hydrogen, green methane, and green ammonia. The term “green” refers to using renewable energy as the power source to produce the fuel. With the proposed GT technology, fuel blending, with manageable changes to the GT combustors and controls system, could be used to introduce hydrogen as a fuel in limited quantities (less than 20%) resulting in reduced greenhouse gas emissions. GT technology, with modifications to the auxiliaries, could use 100% green, carbon-neutral fuel. These modifications are often included as retrofit kits by OEMs so that fleets can easily be converted in the future. Often, these kits include modifications to the combustion system, revisions to plant controls and instrumentation, new fuel delivery system, or modifications to balance-of-plant systems to suit the new fuel or delivery system, as well as NOx emissions treatment. If the process used to synthesize the carbon neutral fuel comes from renewable sources, the cycle can be made carbon-free and be applied toward RPS credits. The advantage is that the GTs are fully dispatchable across a full generation day and do not depend upon solar or wind resources for generation.

[18] Post combustion technologies include carbon capture with liquid or solid solvent and oxy-fuel cycles.

7.5.1. System Resiliency

This section discusses power generation system resiliency considerations, specifically those that should be considered as renewable generation penetration levels increase in Puerto Rico in the future. For reference, the Institute of Electrical and Electronics Engineers defines system resiliency as follows:

> An effective resilience framework should strive to minimize the likelihood and impacts of a disruptive event and provide the right guidance and resources to respond and recover effectively and efficiently when an incident happens. It should also have a feedback loop to foster continuous improvement. This can be accomplished by applying the all-hazards framework toward assessing and developing a program with five focus areas: Prevention, Protection, Mitigation, Response, and Recovery.[19]

Grid resiliency refers to a "power system's ability to continue operating and delivering power even in the event that low probability, high-consequence disruptions such as hurricanes, earthquakes, and cyber-attacks occur."[20] While reliability analyses serve to demonstrate if a utility is prepared for disruptions under relatively normal operating conditions and contingency events, resiliency analyses are needed to evaluate preparedness for events that have low probability of occurrence but can cause major system-wide disruptions.

Analyzing this further, if we were to consider a future slow-moving tropical storm or a hurricane over Puerto Rico, we would expect that while the storm passes over, there would be a significant reduction in solar and wind generation (due to diminished solar resource, emergency outages, and, potentially, damage). In this case, most of the electrical system's load would have to be met by the thermal generation and BESS on the island. Given the historically high forced outage rates of the thermal generators in Puerto Rico, and the likelihood that some of the generators may be in planned maintenance outages when a storm passes, only a subset of this capacity is likely to be available during a storm; thus, it will be challenging for the system to meet load during a storm if load demands are high. This challenge only increases if the storm is slow moving, and the energy storage systems become depleted due to the reduction in the amount of renewable generation that would help charge the storage systems during normal operation.

Since low-probability but high-severity events are often defined by a cascade of system failures, there may be other failures within the electrical system that can arise during a significant tropical storm or hurricane, which would further affect the system. Transmission outages, fuel supply disruptions, flooding, etc. can all

[19] Bill Chiu et al., "Resilience Framework, Methods, and Metrics for the Electricity Sector," IEEE Power & Energy Society, Technical Report PES-TR83 (October 2020), https://resourcecenter.ieee-pes.org/publications/technical-reports/PES_TP_TR83_ITSLC_102920.html

[20] Eric D. Vugrin, Andrea R. Castillo, and Cesar Augusto Silva-Monroy, *Resilience Metrics for the Electric Power System: A Performance-Based Approach*, United States, Sandia National Lab, 01 February 2017, https://doi.org/10.2172/1367499, https://www.osti.gov/servlets/purl/1367499.

place significant stress on the ability of the system to serve load during a storm. As a result, thorough resiliency planning will be important as Puerto Rico transitions towards a future defined by a heavy reliance on renewable generation and energy storage, with particular emphasis on conservative engineering to prevent over-dependence on any one generation source.

7.6. Considerations for Future RFP Tranches

Throughout this report, descriptions of the resources required for the integration of renewable energy generation and storage projects are made, including details of how the envisioned multi-purpose emergency generation system configurations may assist PREPA in reaching the initial 40% RPS milestone in 2025. Subsequent RPS levels may be more difficult to achieve due to daily nighttime renewable generation deficits, occasional cloud cover and storm challenges, installed battery storage capacity, and the ability to fully charge batteries each day. Without a diverse renewable generation mix and new generation projects, loss-of-load risks associated with the intermittency of solar and wind resources and battery storage limitations would continue to be managed with the aged and unreliable thermal generation resources. Thus, the current RPS path may be overly reliant on PV and battery energy storage and supported with large, unreliable boilers and GTs, many of which are from the 1960s and 1970s and are unsuitable for the more dynamic operating conditions that will exist after the renewable RFP projects are commissioned and operated.

In lieu of the above, S&L strongly suggests that the system planner perform resource adequacy studies, continue steady-state and dynamic grid stability analyses, perform economic reviews to systematically select and replace poorly performing facilities, and engineer a path towards meeting the future RPS milestones that include a suitable mix of new generation resources and grid services equipment to serve load demands across all scenarios of a 24-hour generation day. The results from Tranche 1 proposals are overwhelmingly PV solutions. Furthermore, an overreliance on a single technology that is susceptible to damage from strong winds and debris—and are likely to be constructed in multiple locations away from the key load center of San Juan due to the required space of PV or wind systems, thus relying again on long transmission lines—does not follow the previously mentioned guidance provided by the DOE or FEMA to manage future hazard mitigation concerns.

Other green fuels such as hydrogen, or similar carbon-neutral fuels are alternatives that could be delivered to portside thermal generators, possibly making those synchronous generators RPS-contributing units. PREPA's existing portside power plants have extensive diesel and bunker fuel storage systems that may be repurposed to receive carbon-neutral fuel that may be distributed to smaller thermal generation units around the island. For example, the recently constructed 50-MW Schofield Generation Station in Hawaii may use diesel or biodiesel fuel to fire reciprocating internal combustion engine generation systems:

> The facility, owned and operated by Hawaiian Electric, is the first on the island to use flexible and efficient generators that will complement increasing levels of solar and wind power on the Oahu grid. The generators will be capable of quickly starting up, shutting down, or changing their output in response to sudden changes in solar and wind energy resources, which provide varying levels of energy depending on weather, time of day, cloud cover, and other factors.[21]

At present, grid service projects are not part of the renewable RFP, however they are an essential part of achieving the RPS milestone mandates and should be added or addressed separately. As the penetration of renewable generation increases, dedicated grid support systems will be required to maintain stable operation of the grid. For example, synchronous condensers or similar technology will need to be added to strengthen short-circuit levels in some areas of the grid and provide voltage support. Synchronous condensers replace some of the grid essential services of synchronous generators that will, in PREPA's case, be retired with the older fossil-fired generation plants. They may also help the grid by providing frequency response during loss of generation events. These support systems are designated as "grid essential service projects" and can be put in place if instabilities are detected through modeling during the planning and interconnection processes. For example, on 16 May 2021, Kaua'i Island Utility Cooperative lost power during daylight hours to all its customers, which led to an island-wide power outage. While Kaua'i Island Utility Cooperative is still investigating the event, the operator believes that it is likely due to inverter-based generation frequency swings.[22] PREPA will be required to install grid essential service projects to prepare for operational challenges similar to those on Kaua'i but for a larger-scale utility grid.

While the IRP provides recommendations to convert existing generators to perform synchronous condensing services, S&L has performed sufficient field evaluations and determined that it is impractical and not feasible to execute this work as outlined within the IRP. The primary reason is that synchronous condensers are required at very specific locations—largely tied to location and size of new PV projects. The PV project clusters are forming around areas of the island that have available land and are not necessarily near the existing synchronous generation plants. Therefore, the large existing generators are more than likely not in suitable locations and would have to be relocated near the PV clusters. This would have to be done after their removal and return to the manufacturers for refurbishment, then each new installation would be launched as a new project. However, as other areas of the world have determined, grid support services must be as reliable as power generation services to maintain a stable power grid.

[21] "Hawaiian Electric, U.S. Army announce completion of Schofield Generation Station," Hawaiian Electric, 31 May 31 2018, https://www.hawaiianelectric.com/hawaiian-electric-us-army-announce-completion-of-schofield-generating-station.

[22] Stephanie Shinno, "Frequency swings caused island-wide power outage," *The Garden Island, 16* May 2021, https://www.thegardenisland.com/2021/05/16/hawaii-news/frequency-swings-caused-island-wide-power-outage/.

Therefore, 2x100% arrangements of synchronous condensers or some level of redundancy is needed to ensure stability may be maintained. Alternative plans should be made such as new equipment purchases specifically configured for the electrical needs of the PV clusters and short-circuit characteristics of the region. A partial solution exists with the use of FEMA-funded emergency generation equipment for the peaker replacements, addressed in S&L's Emergency Generation Feasibility Report [7].

This work should also be accompanied with the systematic replacement of many thermal generation facilities to provide an expanded range of operating capabilities that are not presently available to support future intermittent generation characteristics of wind and solar projects. Refer to Table 2-3 — Comparison of Generation Features to Support RPS for a complete description of the necessary capabilities that are required. These features become increasingly more important to serve load as RPS levels increase. For this reason, we strongly recommend also proceeding with the replacement of outdated SC power generation facilities, described in the Emergency Generation Feasibility Report [7]. When smartly configured, even grid support services such as synchronous condensing may be integrated with this emergency generation equipment—when the equipment is fired, power is produced and when it is unfired, the generators may provide stabilizing power system services. The new equipment may be configured as multipurpose generation and grid support centers providing a variety of different services, including the need for emergency and black start generation services.

8.0 Conclusion

Noting that PREB's Final Resolution and Order was issued before the FEMA 404 grants were approved, and that the least-cost scenario in the IRP did not consider funding from FEMA 404 grants, and further that the least-cost scenario was in fact a baseload generation scenario rather than a hazard mitigation solution, we believe that the current IRP does not accurately define the needs for reliable and dispatchable emergency generation equipment required in Puerto Rico. This has clearly been illustrated by many lengthy and tragic disaster recovery periods following hurricanes, earthquakes, severe tropical storms, and recent repeated power system failures that have plagued the aged generation and transmission system—all of which have occurred since 2017. Hazard mitigation, as defined earlier in this report, but repeated here again as a reference, is "any sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects. This definition distinguishes actions that have a long-term impact from those that are more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage" [5]. Emergency generation equipment, which may also provide valuable and much needed generation and grid services to PREPA as it transforms the utility into a renewable energy provider, may be installed with the support of FEMA 404 grants. As such, due consideration for a revision to the IRP to include emergency generation equipment at little or no cost to the utility, and reconsideration of PREB's Final Resolution and Order, are certain to yield positive or certainly different results with respect to hazard mitigation for Puerto Rico.

Hazard mitigation measures for Puerto Rico supported by FEMA and the DOE includes the addition of new emergency generation facilities including a new CC power plant and GT or RICE emergency generation equipment distributed across the island to provide power for critical loads following a natural disaster. Fortunately, emergency generation equipment also provides the opportunity to serve other purposes. Phase I – Engineering that has been completed thus far for the CC and SC emergency generation facilities takes full advantage of this opportunity in that the equipment, while primarily configured for emergency use, also serves to improve the generation fleet as the path towards adopting renewable energy generation and storage projects take shape.

This proposed CC generation project should support the following criteria:

- The recommended location for a new CC facility to provide emergency generation services is in the northern grid adjacent to critical loads in the most populous municipality of San Juan. The location follows expert opinions of both the DOE and FEMA for hazard mitigation services.
- All generation equipment will include black start capability for use during emergencies.
- The CC plants and/or repairs to existing fossil plants will be storm hardened to provide resiliency and operating capacity during severe storms or recovery after hurricane events. The plants will

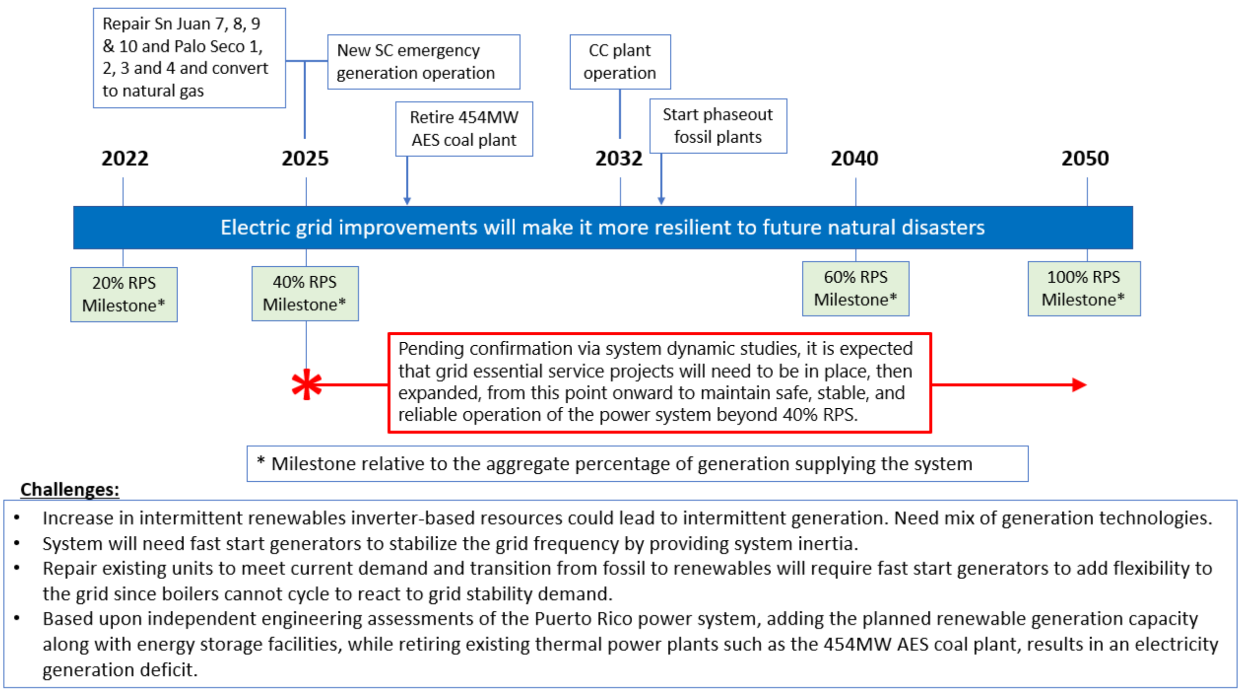
include provisions to be fully functional for a period of seven days without refueling. The CC plant will include a hardened operator control center and facilities to accommodate three full shifts of stationed operators for seven continuous days until the hazard has cleared.

- The CC generation systems will be more reliable and more efficient than the existing sites and provide load-following capability, high turndown ratios to operate at low loads, fast startup capability, rapid ramping capability, and other features that are necessary for the successful integration of renewable energy projects.
- The CC unit will provide steps towards achieving a “highly efficient” generation fleet.
- All units will be fully compliant with U.S. Environmental Protection Agency regulations including the State Implementation Plan.

The addition of new power plants including emergency generators with the capabilities noted above will provide PREPA with reliable generation equipment and will support PREPA’s needs to integrate renewable energy and storage projects. New power generation such as a CC power plant could achieve commercial operation before 2032, however is dependent upon acquisition of property near the existing San Juan power plant, relocation of existing facilities, application for permits, and demolition work. There are alternative options that are possible to pursue for the San Juan Power Station. While the CC power plant offers many advantages, SC GT or RICE generation could be commercially available between 2024–2026, while the refurbishment and gas conversion of select, existing units could be completed and provide improvements to generation facilities in a shorter timeframe.

Figure 8-1 presents an overview of the anticipated future of PREPA’s power generation fleet, highlighting the major events and engineering issues that must be considered. The figure provides a simplified summary of the changes that must be made. Furthermore, to meet these challenges, improvements to both power generation system and the electric transmission and distribution systems are needed to make the grid more resilient; the transition to inverter-based renewable energy requires special consideration as penetration levels increase to maintain power system stability and inertia; and future emergency generation capacity requires improvements to mitigate the loss of life and property during future events.

Figure 8-1 — Opportunities and Challenges in Power Generation



Source: *Author* © Sargent & Lundy, L.L.C. 2022

The power generation and transmission systems in Puerto Rico are anticipated to change dramatically in the next 5–10 years. Across the power generation industry, multiple examples of overreliance on a single technology, particularly those that generate power in an intermittent manner, have been tied to power generation challenges, grid stability issues and unplanned outages across many areas of North America—examples are contained within this report. As the world continues to integrate more clean energy into power systems, it is increasingly more important to view the pros and cons of each adjustment to the system and collectively engineer a path to achieve an appropriate generation and energy storage mix to not only achieve future RPS compliance, but also ensure that the future system is able to provide stable, reliable service to its customers across all future generation needs.

Within this report, a new CC power plant has been evaluated to provide new and modern generation technology for the northern part of Puerto Rico. The power plant design provides robust and proven technology that will provide a new level of resiliency to manage natural disasters, flexibility to react to more demanding future grid demands, a thermal efficiency that is expected to be the best on the island (using less fuel per MW than any other power producer, roughly half the fuel of the existing thermal boilers), and reliability in line with North American standards. It will be operated and dispatched with modern FEMA-funded transmission and distribution control system improvements—necessary improvements to support faster operating response times of a more dynamic, clean energy future.

However, given PREPA's current power generation struggles and the time horizon for both SC and CC projects (defined within the report), temporary measures to improve the existing thermal generation assets may be considered and executed now. This would require PREPA's staff to assess the condition of current thermal generation assets, define project improvement projects to restore the existing equipment's reliability and conduct the necessary repairs to restore units that are out of service. This path would require resolution with the EPA for the refueling the units with NG for SO_2 SIP compliance for non-attainment zones and other environmental compliance concerns. It would also require additional fuel deliveries to the San Juan site, of which PREPA confirms the current fuel gas supplier is able to meet the obligations for gas conversions of San Juan Units 7, 8, 9, and 10 while at the same time supplying gas to the already converted Units 5 and 6. Fastrack results may also be obtained by moving forward with emergency generation equipment at the existing peaker sites. The IRP does not define the need for emergency generation equipment, and as such, emergency generation units are the topic of a separate feasibility report [7] that will be submitted to PREB for their review and approval. Together, refurbishment of existing units combined with replacement of peaker units will provide significant improvements in PREPA's ability to manage future disaster recoveries, provide more reliable power generation facilities, and grid support as renewable penetration continues to increase.

With consideration given to the above points, Table 8-1 provides a list of potential solutions A through E, for PREPA's consideration, along with the of each solution. As an overall solution, based on our evaluation of a new CC power plant, Alternative A which places a new facility at the San Juan power plant location on new property is one preferred solution for the criteria evaluated—not at Palo Seco for the reasons further detailed within this report. However, building the CC power plant adjacent to the existing San Juan power plant requires some planning. PREPA does own this property, therefore it would require i) government approval, ii) negotiations with the port authority, and iii) negotiations with the port operators. Acquiring the rights to use this property and relocating existing ongoing services at the port that utilize this property is expected to take two years before project work may begin. As a result of this front-end work, the best case completion date for the project would be six years from its start whereas PREPA's experience with projects of a similar nature in Puerto Rico suggests a 10-year time horizon is more realistic, thus its execution does not provide immediate relief to PREPA's current power generation needs. For this reason, alternatives B through E may also be considered. These alternatives utilize the FEMA HMGP to provide improvements to existing equipment to achieve the hazard mitigation objectives, but several of these alternatives also provide a path to prepare for a new baseload power plant at the San Juan site—per the detailed discussions contained herein, configured to address both emergency generation and the support of future renewable generation and storage projects.

Table 8-1 — List of Recommendations for Consideration with Pros and Cons

	ALTERNATIVES	PREPA's estimated schedule	Grid support after Tranche #2	Reliability	Total MW	Flexibility for low loads & cycling	COMMENTS
A	New CC power plant fueled by natural gas (NG) and diesel as backup.	Approximately 10 years	H	H	300 - 400	Y	Timeline to implement is based on PREPA's experience to obtain property, permits and approvals; potential demolition and soil remediation, which could delay start of construction. Prepares PREPA for future renewable integration, as it is environmental compliant, efficient, and reliable base generation.
B	Convert existing thermal units to burn NG for SO_2 SIP compliance in non-attainment zones and other environmental compliance	Maximum of 10 years	L	M	~2,575	N	Aguirre ST Unis 1 & 2 = 900MW Aguirre existing CC 1 & 2 = 592MW Palo Seco ST Units 1, 2, 3 & 4 = 602MW Palo Seco Mega Gens = 81MW San Juan ST Units 7, 8, 9 & 10 = 400MW TOTAL = 2,575 MW
C	Convert San Juan (SJ) 7, 8, 9 & 10 to burn NG for SO_2 SIP and other environmental compliance.	2 - 4 years	L	M	400	N	Not expected to use the complete FEMA 404 HMGP funding.
D	Demolition of SJ 10 for the installation of new RICE units (Number of units of 18 MW each, to be determined as space allows)	5 - 6 years for SC with demolition	H	H for New	TBD	Y	Retire and demolish San Juan Unit 10 and install new RICE units as space and funding permits. Permits and approvals, potential soil remediation mainly due to demolition could delay start of construction. Prepares PREPA for future renewable integration, as it is environmental compliant, efficient, and fast response generation.
E	Install GT(s) in SC mode that can be later converted to 300 – 400 MW CC	. 4 - 5 years for SC	H	H for New	350 CC	Y	Location for new SC units TBD. To be located at site with NG availability, likely San Juan. Estimated 4-year duration for SC to CC conversion. Prepares PREPA for future renewable integration, as it is environmental compliant, efficient, and reliable base generation.

Source: *Author* © Sargent & Lundy, L.L.C. 2022

The alternatives presented above may be considered for the future development of a comprehensive overall plan whereby PREPA (i) refurbishes a portion of the existing facilities, (ii) establishes retirement plans for these facilities along with strategic spare part decisions for retired assets, and (iii) executes fundamental planning and partial development of a new power plant in San Juan suitable for emergency generation, baseload power, and the future integration of renewable energy projects. It is our recommendation to reevaluate the expenditures for the options outlined above, including the development of new base load power, and reallocate FEMA HMGP funding in an optimal manner for select refurbishment projects, fundamental planning, and preparation for a future baseload power plant project. In lieu of a CC plant, new baseload facilities that utilize a combination of simple-cycle gas turbine(s) for future conversion to a CC power plant, or reciprocating engine plant, may be planned for the future to dramatically reduce project costs so that refurbishment projects may be executed and fulfill PREPA's immediate need for improvements to the reliability of their generation fleet. At the same time, consideration and planning to provide the foundation for a future CC power plant conversion may be undertaken to reduce operational costs in the future.

Refer to Appendix A for a complete summary of our recommendations for consideration.

9.0 References

1. Puerto Rico Energy Bureau. CASE NO.: CEPR-AP-2018-0001. SUBJECT: Final Resolution and Order on the Puerto Rico Electric Power Authority's Integrated Resource Plan. 24 August 2020.
2. Siemens Industry, Inc. *Puerto Rico Integrated Resource Plan 2018-2019: Draft for the Review of the Puerto Rico Energy Bureau.* RPT-015-19. Rev. 2. 07 June 2019.
3. Sargent & Lundy. *Retirement Plan – PREPA's Expected Capacity Resource Balance.* Report SL-016223. Revision 0. 17 May 2021.
4. Energy Resilience Solutions for the Puerto Rico Grid, Final Report issued June 2018 prepared by the DOE for the Government of Puerto Rico
5. Hazard Mitigation Assistance Guidance Hazard Mitigation Grant Program, Pre-Disaster Mitigation Program, and Flood Mitigation Assistance Program 27 February 2015
6. HMGP Proposal ID#994 Palo Seco Generation Plant I October 2019. Application for Federal Assistance Hazard Mitigation Plan Information
7. Sargent & Lundy. *Emergency Generation Feasibility Report – Existing Peaking Facilities.* Report SL-017095. Revision 0. 28 June 2022.

Appendix A. Requested Guidance and Support

Group A Recommendations — Thermal Generation

Item	Recommended Action	Status	Support	Reference Section(s)
A1	**New 300 MW–400 MW CC for emergency generation in San Juan Area: Long Term Action** Ensure that a robust emergency support system is in place for hazard mitigation by adding dependable, dispatchable emergency generation and black-start systems at San Juan, the major population center in Puerto Rico. This will also improve reliability and provide support and valuable synchronous machine inertia during the renewable energy transformation process expected to be completed by 2050.	Pending the results of A3 and remaining funds.	—	Section 2.2 and Table 2-3
A2	**New 330 MW of SC emergency generation across the island: Short to Medium Term Action** Ensure that robust emergency support systems are in place for hazard mitigation by adding dependable, dispatchable emergency generation and black-start systems in key areas around the island. This will also improve reliability and provide generation support while fired and valuable synchronous condensing services while unfired during the renewable energy transformation process expected to be completed by 2050.	Pending PREB's approval	—	Reference 7
A3	**Develop Plan for Reallocation of FEMA HMGP Funding** PREPA to develop plan to reallocate funding of FEMA HMGP funds to (i) refurbish existing facilities, (ii) define retirement plans for existing facilities and strategic spare parts, and (iii) plan for a new baseload power generation plant at San Juan.	PREPA currently evaluating scope of work, cost, and execution schedule to refurbish San Juan Units 7, 8, 9, and 10 and other thermal plants, including gas conversion. A complete scope of work summary will be submitted by PREPA to FEMA to manage the reallocation of funding.	—	—

Annex B

PREPA Emergency Generation Feasibility Report
Existing Peaking Facilities

Report SL-017095 | Revision 2 | 14 July 2022

PREPA Emergency Generation Feasibility Report

Existing Peaking Facilities

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Version Log

Version	Issue Date	Sections Modified
Revision 0	28 June 2022	Initial Issue
Revision 1	30 June 2022	5.0
Revision 2	14 July 2022	General Updates

Issue Summary and Approval Page

This is to certify that this document has been prepared, reviewed, and approved in accordance with Sargent & Lundy's Standard Operating Procedure SOP-0405, which is based on ANSI/ISO/ASSQC Q9001 Quality Management Systems.

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14 July 2022

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Date

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Figures and Tables

Acronyms and Abbreviations

Acronym/Abbreviation	Definition/Clarification
BESS	battery energy storage system(s)
EFOR	equivalent forced outage rate
FEMA	Federal Emergency Management Agency
Final Resolution and Order	*Final Resolution and Order on the Puerto Rico Electric Power Authority's Integrated Resource Plan 2018–2019*
FO	fuel oil
GT	gas turbine
HMGP	Hazard Mitigation Grant Program
IRP	*Puerto Rico Integrated Resource Plan 2018–2019*
LHV	lower heating value
LNG	liquefied natural gas
PREB	Puerto Rico Energy Bureau
PREPA	Puerto Rico Electric Power Authority
PSD	*Prevention of Significant Deterioration*
PV	photovoltaic
RFP	request for proposal
RICE	reciprocating internal combustion engines
RPS	renewable portfolio standard
S&L	Sargent & Lundy Puerto Rico
SC	simple cycle
SCR	selective catalytic reduction
SLPR	Sargent & Lundy Puerto Rico
T&D	transmission and distribution

1.0 Introduction

1.1. Scoping and Feasibility Study Objective

The objective of this emergency generation feasibility report is to provide support for the Puerto Rico Electric Power Authority's (PREPA) request to obtain permission from the Puerto Rico Energy Bureau (PREB) to proceed with Phase I engineering work (nomenclature that defines the engineering deliverables required for Federal Emergency Management Agency [FEMA] 404 grants) for hazard mitigation funding of new simple cycle emergency generation facilities and equipment. A portion of the required generation was authorized in the PREB Final Resolution of 24 August 2020; however, additional emergency generation is required and the remaining funding from the FEMA 404 grants to implement these critical island generation improvements is likely to be lost in 2022 if PREB approvals are not provided to PREPA.

This report provides engineering insights into the overall need for new emergency generation in Puerto Rico, the complementary benefits to the ongoing renewable energy transformation work, and other needs and considerations that will support the implementation of the forthcoming, intermittent renewable energy and energy storage projects. New generation resources are needed to replace the existing, aged generation fleet for several reasons, as summarized below, all of which are closely related to each other and discussed within this report:

- The immediate need for emergency power generation systems for disaster recoveries
- Planning for future grid services (e.g., synchronous condensers) to support future renewable portfolio standard (RPS) compliance and grid stability.
- Flexible, multi-purpose thermal generation plants to complement and support reaching future RPS mandates.
- Integrate island-wide black-start capabilities to support the existing generation fleet and IPPs.

1.2. Context

This report, prepared by Sargent & Lundy Puerto Rico ("SLPR" or "S&L" hereafter), and other studies prepared for PREPA (referenced herein), along with the historical and continuing power deficit experiences on the island and repeated disaster recovery challenges, demonstrate a clear need for new and reliable power generation equipment. Renewable energy and other power generation projects (refurbishments for thermal plants and new generation projects), along with battery energy storage systems (BESS) are all needed. These projects should all move forward in parallel to ensure reliable generation is available to support critical loads[1] and provide much-needed improvements to stable power delivery services so that

[1] Critical loads include hospitals, emergency rooms, water utilities, governmental agencies, banks, ATMs, gas stations, supermarkets, and telecommunication centers.

Puerto Rico's electrical utility services may be improved and aligned with the performance metrics of suitable standards of service established by the North American Electric Reliability Corporation.[2]

Reliable power must be supplied 24 hours a day, 7 days a week to the utility's customers. Given the outdated generation equipment that is in place—along with its inefficiency, reliance on heavy fuel oil and diesel, and poor reliability statistics—and with consideration given to future plant retirements, new and modern generation equipment is needed. The new equipment should be fast-starting, fast-ramping, flexible, efficient, and agile. These capabilities are needed now and are even more important in the future to support the large number of planned renewable energy projects, which vary in output, and based upon the island's historical solar or wind resource data, will have intermittent non-generation time periods. Also, since daytime peak solar and wind generation periods do not coincide with evening peak power demand periods in Puerto Rico, other reliable generation systems are needed as backup when solar and wind resources are unable to meet demands, or load shifting energy storage systems are depleted or cannot be charged. Emergency conditions, including disaster recovery generation periods, cannot be excluded.

As described and illustrated within this report, PREPA's existing thermal generation power plants are not considered reliable based on North American standards. Implementing new renewable energy and energy storage projects into an existing unreliable power system will eventually destabilize the power system as larger penetration levels are achieved. Alternatively, implementing these same renewable energy and energy storage projects *with* modern, flexible thermal generation equipment specifically configured to function in a renewable generation environment will dramatically improve the power system's reliability and provide an underlying base of dependable dispatchable generation to support the system when needed. This will ensure generation support is available for nighttime periods or during a decline in solar or wind resources. It will also provide reliable generation service during storms and emergencies. When smartly configured, even grid support services such as synchronous condensing may be integrated with this emergency generation equipment—when the equipment is fired, power is produced and when it is unfired, the generators provide stabilizing power system services. Most of PREPA's existing generation fleet is either unreliable or unable to effectively support—meaning provide fast ramping, ability to run at low minimum levels, and quick startups and shutdowns on demand—all of which will be required in the near future for grid stability to enable PREPA's renewable energy transformation and ensure reliable power supply during emergency conditions is available.

The vulnerability of the island to harsh storms and other natural disasters, compounded by the fact that Puerto Rico is not interconnected to any other electrical grids that can provide backup support, highlights

[2] The North American Electric Reliability Corporation is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid. North American Electric Reliability Corporation develops and enforces Reliability Standards.

the importance of implementing an adequate mix of generation technologies to prevent an overreliance on any one technology. This strategy also minimizes the risk of future generation disruptions under normal and emergency conditions. More specifically, it should be recognized that photovoltaic (PV) and wind turbine technologies are more vulnerable to damage from hurricane winds and airborne debris, which creates a future risk as these technologies become a larger component of the overall generation mix. This risk should be addressed and considered throughout ongoing planning. As the island weathers these inevitable future storms, it is essential to have distributed emergency backup generation sources that can provide uninterrupted power during and after such events for disaster recovery. This will help mitigate loss of life and other adverse impacts that these events may have on the island's residents, property, and economy, and provide needed improvements to the existing infrastructure—a plan that is supported by FEMA and the U.S. Department of Energy [4] to avoid recurrence of the harsh disaster aftermath conditions, such as those after the 2017 hurricanes. A well-planned generation mix, including a strategic placement of renewable energy, storage, and other hazard mitigation power generation projects, along with extensive transmission and distribution (T&D) improvements and hardening measures supported by FEMA, will enable the island to transform its power system into one that is significantly better equipped for the utility to minimize the impact and/or manage disaster recovery events while at the same time obtain a better position to achieve the required RPS milestones.

1.3. Report Structure

This scoping and feasibility report is organized as follows:

- Section 1.0 discusses the history and development of new emergency generation plant concepts to address hazard mitigation issues following a catastrophic event such as a hurricane, any major tropical storm, or earthquake. It explains the importance of increasing power generation reliability and availability to the island's electricity customers, including during and after tropical storms and harsh weather events. Hazard mitigation concepts have been developed by local and federal agencies to systematically reconfigure and build out a more resilient power system that is inherently better at limiting the risk and impact of future power crises, including loss of life and property, when facing natural disasters or generation fleet failures.
- Section 2.0 defines the needs for supplemental generation and an evaluation of the existing generation fleet reliability.
- Section 3.0 provides an analysis for fueling infrastructure required at the emergency generation facilities.
- Section 4.0 defines the recommended operating permit approach as it pertains to emissions.
- Section 5.0 provides a summary of the preliminary cost estimate provided in the FEMA 404 application for the new emergency generation units.

- Section 6.0 provides additional considerations that should be considered as the RPS percentage increases over time, covering such topics as generation mix and renewable integration.
- Section 7.0 concludes with PREPA and S&L's suggested considerations to reestablish reliable electrical generation for Puerto Rico, address emergency generation needs, and integrate renewable energy and storage projects to achieve the required RPS milestones. The conclusion summarizes how FEMA-funded hazard mitigation projects provide a range of benefits that support these immediate needs.
- Section 8.0 provides a list of references mentioned throughout this report.

1.4. Background

Catastrophic hurricanes Irma and Maria—and the events that followed the storms starting in September 2017—left most of Puerto Rico without power for many weeks (several months for more remote areas), disrupting basic and essential life services across the island. The restoration of the island's power system was a monumental task—the entire electrical generation, transmission, and distribution system on the island collapsed, leaving the residents of Puerto Rico with blackout conditions. On 05 September 2017 and 17 September 2017, the governor of Puerto Rico requested federal disaster declarations for Puerto Rico following the impacts of the back-to-back hurricanes. The federal government subsequently approved each of these disaster and emergency declarations. Support from the U.S. Army Corps of Engineers included the dispatch of approximately 90 MW of temporary emergency generators. 60 MW of generation capacity was allocated to the San Juan metropolitan area to serve as backup, help stabilize the grid, and power critical elements of the potable water delivery system to residents. 30 MW of generation capacity was installed at the Yabucoa power plant and served as the emergency backup unit for the southeast region to provide stability to the area and ensure the south coast power plants had black start capability. In addition, FEMA provided approximately 700 small engine driven generators to residents within the interior part of the island where most of the T&D lines had collapsed. Many electric public utilities from the U.S. mainland sent emergency crews and equipment to assist in repairing T&D lines. Approximately 60 days were required to restore electrical services to about 50% of the population on the island; however, many unreliable and temporary repairs often failed and electrical interruptions continued for approximately 11 months until most of the island's T&D lines were repaired in a more permanent manner.

North–south transmission lines are vital connections across the island; they interconnect the large south coast baseload power generation plants with the primary electrical demands of the north coast. Since most storms that cross the island start from the southeast coast of the island and travel in a northwesterly direction, these interconnecting transmission lines must frequently face and weather severe storm crossings. Damage to these lines withing the central areas of the island is often difficult to access and repair due to the mountainous terrain and dense vegetation, thus leading to delays in power restoration efforts. One significant reason for the proposed siting of new simple-cycle (SC) emergency generation facilities at the existing peaking sites is that it significantly reduces the reliance on lengthy transmission lines that are particularly vulnerable to storm damage due to their storm path exposure. Local generation meets the recommendations of both FEMA and the U.S. Department of Energy.

1.4.1. FEMA Hazard Mitigation Program

The emergency generation power plant projects were initiated in May 2019. On 25 October 2019, an application was submitted by PREPA under the FEMA 404 Hazard Mitigation Grant Program (HMGP) to request funding to develop improvements for critical power facilities to reduce vulnerability during disasters and thus ensuring continuity of critical services. As stated within the FEMA hazard mitigation application, the proposed project complies with the development of a Puerto Rico more resilient to disasters with less vulnerability and exposure to disasters. This hazard mitigation program is defined “as any sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects. This definition distinguishes actions that have a long-term impact from those that are more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage.” [5]

The FEMA 404 HMGP hazardous mitigation program provided funding for SC emergency generation across the island at the various PREPA power generation facilities. This new emergency generation equipment is expected to provide approximately 330 MW of emergency power to generation facilities distributed across the island to ensure power may be provided for essential services at multiple locations if these areas become disconnected from the power grid. The equipment may also provide black start services for these locations and also export power to neighboring power plants to assist with their restart.

These new generation projects will replace existing, outdated, unreliable, and inefficient diesel-fired electrical generation units dating from the early era of gas-turbine power projects in the 1970s with advanced technology designed for efficient and reliable power generation to serve the hazard mitigation objectives defined by FEMA. These projects are focused on reducing risk, loss of life, and property in the event of future natural disasters. On 15 October 2020, FEMA approved funding to proceed with Phase I – Engineering for new SC GTs to serve as emergency generators. The FEMA HMGP program is in two phases: Phase I and Phase II. The Phase I – Engineering work consists of preliminary engineering, environmental due diligence, and project cost estimates. Once the required deliverables for Phase I are completed, they are submitted to FEMA and PREB for review and approval before proceeding to Phase II – Construction, where the project is implemented and includes activities such as obtaining all permits, detailed design engineering, procurement of all plant equipment, construction, installation, testing, commissioning, and turn over to the operator.

1.4.2. Integrated Resource Plan

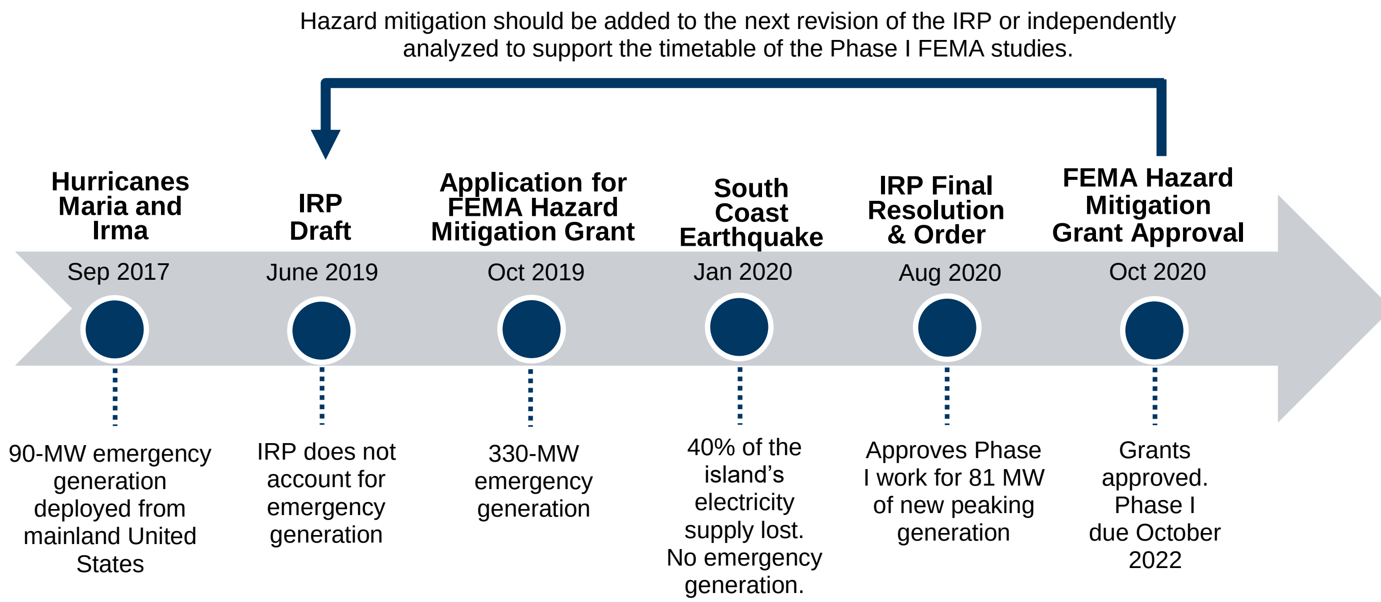
In 2017 and 2018, while hurricane-related damages were still being assessed by FEMA and PREPA staff, a new *Puerto Rico Integrated Resource Plan 2018–2019* (IRP) was simultaneously being developed, with a draft version issued in June 2019. This IRP was based on the February 2018 principles of the PREPA governing board's new vision statement as a guide for the future of the electric utility to develop a more sustainable system and move away from its reliance on inefficient, fossil fuel-based generation and transition to a diverse mix of generation resources. The IRP set a roadmap for the future development of the utility's electrical infrastructure with specific plans for the future of its entire electrical system, reduce the cost of energy to customers, and limit PREPA's future dependency on fossil fuels. PREB reviewed the IRP, including various proposed energy system modernization scenarios, and issued its final resolution and order for the IRP on 24 August 2020 [1], therein providing detailed findings, conclusions, and orders to PREPA.

PREB's order rejected the wholesale replacement of existing peaking resources. However, it did find that the replacement of a small portion of the older GTs with peaking resources was reasonable. A total of 147 MW of new peaking capacity was approved by PREB, with 81MW of capacity being supplied by the new GT units already installed at Palo Seco (referred to by PREPA as "MegaGens"), leaving 66 MW of additional capacity to be procured. The replacement of all peaking units was not approved because PREPA did not provide evidence that new GTs used for peaking services were part of the least-cost plan as described in the IRP; <u>however, it should be noted that the IRP did not consider or address the need for emergency generation services</u>. With FEMA funding available to manage project costs for new peaking generation units that would also serve emergency generation needs, logically the analysis conducted for the IRP's least-cost plan is likely to yield different results. Thus, PREB's final resolution and order may also be revisited to assess and provide appropriate revisions to reflect new results expected with the use of FEMA funding, including a correction for the IRP's omission of the need for emergency generation

PREB's final resolution and order dictates the action plan that PREPA must follow as it lays the foundation for the future of Puerto Rico's electrical system. A preliminary cost-benefit analysis was submitted with the FEMA 404 application for the SC emergency generation. The cost-benefit analysis will be validated during Phase I – Engineering to comply with PREB and FEMA's project economic justification requirements once pricing is provided through a competitive RFP process for the power plant equipment, construction, and commissioning.

<u>PREB's final resolution and order (August 2020) was issued prior to the FEMA award (October 2020) for new power generation resources as shown in Figure 1-1.</u>

Figure 1-1 — Timeline of Major Events Related to Hazard Mitigation



Source: *Author* © Sargent & Lundy, L.L.C. 2022

It is important to note that although the new GTs had not been proven in the IRP to be the least-cost option to cover peaks in demand, *FEMA's justification for the addition of these new GTs is not for continuous duty power generation, but rather for hazard mitigation. Thus, these emergency generation systems are an integral part of FEMA's hazard mitigation program to minimize the loss of life and property but may also be readily configured to support the renewable integration plan*. The least-cost plan presented in the approved IRP was developed based on optimal generation scenarios to serve all system demand in normal operating conditions. It did not consider emergency scenarios such as hurricanes that can damage substantial portions of the grid, PV, and wind generation systems, thereby compromising the system's ability to deliver power to critical loads such as hospitals and other essential services during and immediately following an extreme weather event. The inability of the system to deliver power to all locations throughout the island shortly after a hurricane or tropical storm can result in harsh living conditions and loss of life caused by the unavailability of essential services such as potable water, refrigeration for medication, and communications. Considered alone, these GT units are not intended to replace anything in the least-cost plan, but rather are additional to everything included in that plan—to serve as backup generation and black start systems distributed around the island in the event of an emergency.

1.5. Project Overview

Among the many projects aimed to make the electrical infrastructure resilient and reliable, PREPA, with the guidance of local and federal agencies, elected to pursue dispatchable natural gas-fired power plants funded by the FEMA 404 HMGP grant program to provide hazard mitigation in the event of future catastrophic events affecting individuals, public health, safety, and property. As an added benefit, these plants will also be configured to support the extensive influx of future inverter-based renewable generation projects with operating characteristics well-suited to the planned integration of renewable power. Historic data suggests that Puerto Rico can expect to experience significant storms or hurricanes every 5–10 years; however, the frequency and intensity of these weather events appear to be increasing in recent years. In 2020, major earthquakes along the south coast have also shown the need for reliable power generation throughout the island for hazard mitigation. The new power plant projects use proven technology and draw on HMGP funding to protect human lives and property, continue basic life services, and enable the government to function in the aftermath of a natural disaster. They are conducive to the development of a Puerto Rico electric system that is more resilient to natural disasters with less vulnerability and exposure to risk during these events. The proposed HMGP concept was developed by identifying and assessing the vulnerability of the critical facilities to hazards and includes a specific solution that can be developed prior to the occurrence of the disaster with funding from locally matched federal funds.

1.5.1. Emergency Power Generation for Hazard Mitigation Award

PREPA received FEMA 404 funding is for Phase I – Engineering of HMGP Project Number 4339-0010 known as the “Simple Cycle Gas Turbines.” It consists of the installation of 11 SC GT power plants, around 30 MW for each GT, for SC emergency generation service at the existing PREPA peaking facilities.

This project will be 100% federally funded, up to a total value of US $280.8 million. The program funding is provided in two phases. Currently, FEMA has granted US $12.7 million for Phase I of the project which involves detailed engineering studies to ensure the concept at each facility is viable. This engineering feasibility work is currently under way for the approved generation and will be submitted to FEMA and PREB once completed for review and approval, which must be obtained prior to proceeding with Phase II – Construction.

The conditions of approval included in the referenced authorization letter details the tasks, milestones, and deliverables that must be completed in Phase I – Engineering before proceeding to Phase II – Construction, which is contingent upon FEMA’s and PREB’s approval. These conditions of approval for Phase I – Engineering include all the project initiation and planning tasks (the cost estimates and schedule), preliminary design drawings and technical specifications, a revised cost-benefit analysis, and environmental data collection. Phase II – Construction will include the completion of the detailed design, procurement of equipment and materials, permitting process, and construction and installation through testing and commissioning.

After FEMA and PREB review and approve Phase I – Engineering deliverables, funding will be released for Phase II – Construction of the project which involves procurement and delivery of the major equipment, construction, and then testing/commissioning of the complete facilities. A FEMA environmental planning and historic preservation review is required prior to any ground disturbance, demolition, or construction activity.

Major requirements of this emergency generation project funding for hazard mitigation include:

- Per the funding proposal: Fast-start (including black start) capability (full load from standby in 10 minutes or less) for the GTs selected, such that power can be brought online without delay in the event of an emergency.
- Equivalent availability factor (annual-average equivalent) of 98% or greater for each GT, excluding planned outages.
- Compliance to all applicable regulations and building codes.
- Design of the power plants and any other flood-prone installations (Vega Baja in particular) for 0.2% (500-year) flood elevations.
- Compliance with 2011 and 2016 versions of the Puerto Rico State Hazard Mitigation Plan.
- Adherence to the submitted *Record of Environmental Consideration*.
- Quarterly reporting to FEMA.

Also important is that FEMA approval is required *prior* to making any revisions to the scope of supply or objectives of the project, or for extension to the period of availability of funds.

1.6. Emergency Generation Plant Configuration and Performance Needs

The proposed new generation units will be used for emergency generation, black starts, peaking power services, and may be configured to provide valuable synchronous condensing services for PREPA to address grid stability with the future influx of renewable generation. The new emergency generation units will be better suited than the existing units to provide grid stability, cycling duties, and inertia (via synchronous condensing) to the system as renewable penetration increases in the future.

There are multiple configurations that can be used for the future emergency generation sites. The new SC configurations are expected to have a gross output of approximately 18 to 30 MW per GT and the new reciprocating internal combustion engines (RICE) are expected to have a gross output of approximately 10–19 MW. The GTs are expected to ramp from a start command to full load in 10 minutes or less, and in the case of a RICE unit, the same loading may be achieved in less than 3 minutes. Both the GT and RICE selections will have a better heat rate than the existing units, meet current environmental emission limits, operate on both natural gas and diesel fuel, and include provisions for black start capability across a broad area of the island. The GTs may also be configured to be utilized as synchronous condensers when they are not generating power. In the future, BESS or other types of energy storage can also be added to the emergency generation sites, as space permits and as separate project awards, to provide black start services or immediate response for grid support services prior to starting the SC units.

The existing peaking units, GE Frame 5 combustion gas turbine units fired exclusively with diesel fuel, have no emissions controls in place and can be converted to burn natural gas. The original installation was in 1972. Two GTs are located at each site with each GT having a built-in diesel engine for black start. Palo Seco in the only site that have 6 units installed, where three are available for generation. These GTs each have a gross output of ~21 MW

Each of the existing sites will be repowered with either GT or RICE units, or combination thereof, as summarized in Table 1-1. The new equipment configurations are also anticipated to fit within the existing plant area, so no new property will be required. The expected range in output, 18–30 MW for GT and 10–18 MW for the RICE, allows for multiple original equipment manufacturers (OEM) to provide equipment in a competitive bidding process.

Table 1-1 — Anticipated Site Configurations

Generation Facility	Qty	GT (total MW)	Qty	RICE (total MW)
Aguirre	1	30 MW	-	-
Daguao	2	60 MW	-	-
Jobos	-	-	2	36 MW
Palo Seco	3	90 MW	1	18 MW
Vega Baja	2	30 MW	-	-
TOTAL	**8**	**240 MW**	**3**	**54 MW**
TOTAL FOR ALL SITES				**294 MW**

Ultimately, depending on the final GT and RICE selection for each site, the expected total new SC emergency generation across the island will be between 190–318 MW. This is within the FEMA 404 grant award for 11 GTs with a total output of 330 MW.

A comparison of the advantages of GT and RICE technologies is summarized in Table 1-2.

Table 1-2 — RICE and GT Advantages

RICE Unit Advantages (10 to 18 MW)	Gas Turbine Unit Advantages (18 to 30 MW)
• Very fast starting – full load in < 3 minutes • Suitable for rapid, frequent starts/stops • Adds rotational inertia to the grid • Approximately 47% efficient in SC mode (considered highly efficient power plant as defined by PREB – heat rate < 8200 Btu/kWh) • Dual fuel capable • Stable efficiency during part load operation • Output not affected by ambient temperatures • Maintenance cycle not affected by number of starts	• Fast starting – full load in < 10 minutes • Suitable for rapid, frequent starts/stops • Adds rotational inertia to the grid • Approximately 39% efficient in SC mode • Dry low emissions designs are available that use no demineralized water injection to manage emissions when firing diesel • Dual fuel capable • Small footprint per MW output

GTs that do not require demineralized water injection or selective catalytic reductions (SCR) for NO_X emission controls should be prioritized to minimize layout footprint, capital cost, and frequent and costly ammonia and demineralized water delivery to site via tanker trucks. The RICE units would provide black start ability, grid stability, low load output, and has a much better heat rate than GTs in SC mode. Each of the sites has an existing diesel fuel supply which will be reused, but fuel conditioning equipment will be added to remove water/impurities as required by the GT OEM. For natural gas supply, new LNG storage tanks and vaporization equipment can be installed at each site or ISO containers can also be utilized. RICE units may be utilized to manage boil-off gas from LNG storage. An optimal selection of RICE and GT units will be established during the Phase 1 engineering work.

2.0 Need for Supplemental Generation

2.1. Equivalent Forced Outage Rates

Equivalent forced outage rate (EFOR) is a measure of the probability that a generating unit will not be available due to forced outages or forced deratings, which does not include planned or maintenance outages. In other words, EFOR is a rating to indicate how the unit is unable to respond, irrespective of system need.

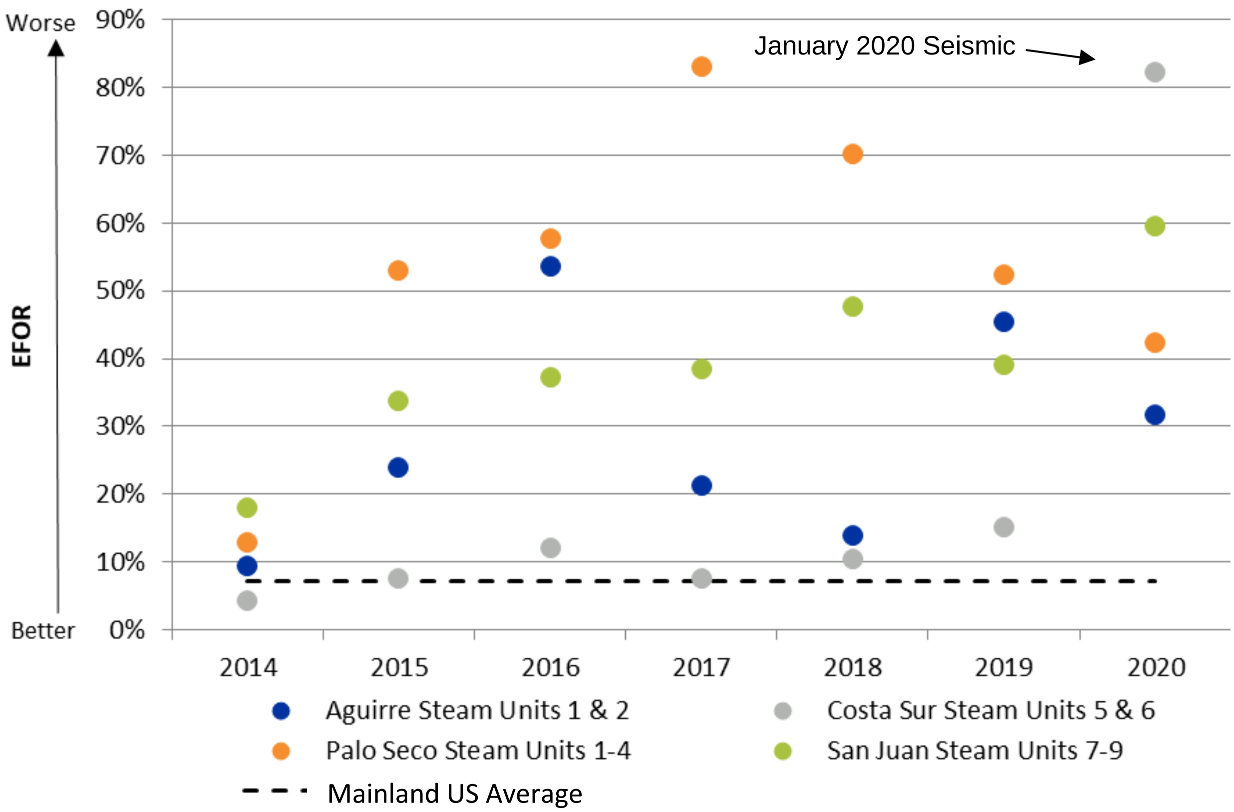
EFOR = (Forced Outage Hours + Equivalent Forced Derated Hours)/(Service Hours + Forced Outage Hours + Equivalent Reserve Shutdown Forced Derated Hours) x 100

EFORs that are high indicate that the generation units are unable to respond to generation demands. PREPA's fleet regularly suffers from significant forced outages and EFORs frequently over 30% and up to 100% in some years. For comparison, the average weighted EFOR for U.S. conventional generation units greater than 20 MW was 7.16% for the five-year period 2015–2019.[3] The EFORs for thermal steam generation plants and combined-cycle power plants are shown in Figure 2-1 and Figure 2-2**,** respectively. The EFOR for SC power plants is in Figure 2-3. Overall, the lack of funding to repair and maintain facilities has contributed to PREPA's high EFOR statistics; however, the large generation reserve margin (capacity of generation over the amount required to meet PREPA's customer load) allows PREPA to continue to meet the system's requirements.

The major thermal steam generation plants have EFORs that are trending upwards (Figure 2-1). This is indicative of older units with expected maintenance and reliability issues such as high-pressure turbine blade damage problems on Palo Seco Unit 4, accompanied with condenser corrosion issues and Palo Seco Unit 3 boiler feed pump seal problems, that contributed to the higher EFOR in 2017. The Aguirre, Costa Sur, and San Juan steam units each had an EFOR with relatively small increases from 2014–2020; however, they are higher than acceptable industry standards, generally taken as 20%–26% for a peer group such as this. In 2020, Costa Sur steam units were out of service for extended periods after damage from the January 2020 earthquakes, which has since been repaired.

[3] North American Electric Reliability Corporation, *2020 State of Reliability: An Assessment of 2019 Bulk Power System Performance*, July 2020, https://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/NERC_SOR_2020.pdf.

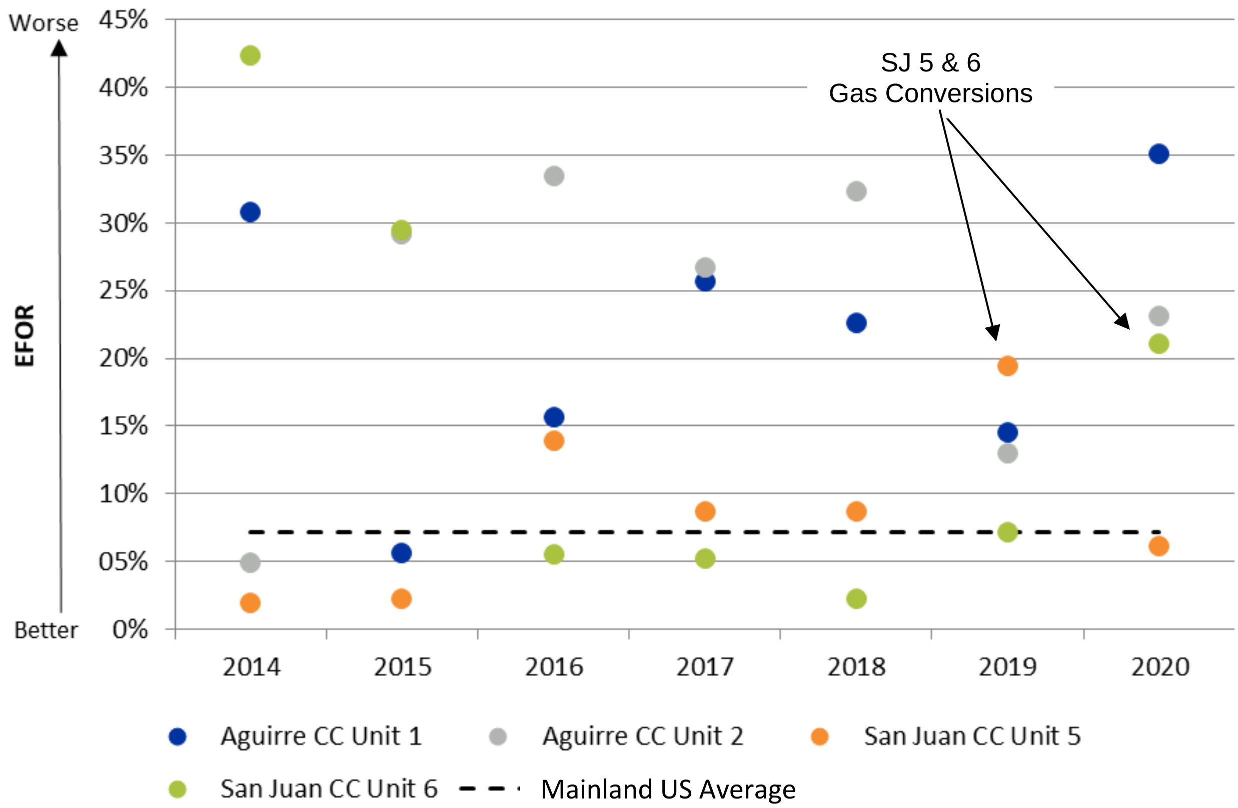
Figure 2-1 — Thermal Steam Generation Plant EFORs



Note: Data for San Juan Unit 10 is not provided; it is currently irreparable.
Source: Author © Sargent & Lundy, L.L.C. 2022

Figure 2-2 illustrates the EFORs for the combined-cycle plants—the most efficient units in PREPA's fleet. The San Juan combined-cycle plants experienced a gradual decrease from 27% in 2014 to 5.5% in 2018 due to a significant amount of planned maintenance that was started in 2015 and finished in 2016. Recently, natural gas was added to San Juan, driving production costs lower and reducing plant emissions.

Figure 2-2 — Combined-Cycle Plant EFORs

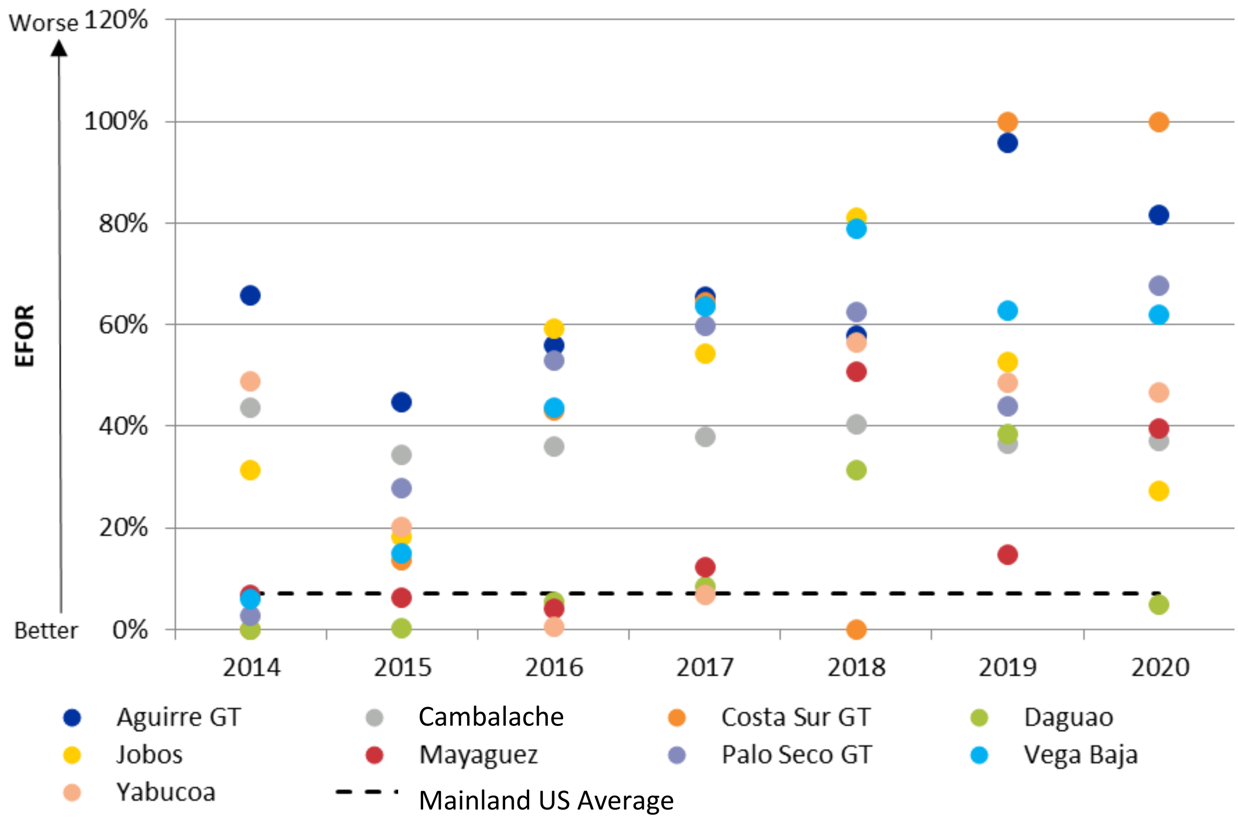


Source: *Author* © Sargent & Lundy, L.L.C. 2022

While the availability of the SC plants (GTs, peaking units) is trending higher, the EFOR rose in response to extended maintenance outages of units within each plant in various years, as shown in Figure 2-3. At the Mayagüez plant, Units 1 and 3 were largely derated with partial generation. Without half of the generating power available for those two units, the EFOR and related values will significantly increase. That skews the average higher and reflects the capital equipment importance of expediting repairs to maintain availability and capacity. The average EFOR at Mayagüez was below 10% through 2016; however, it increased to 12.5% and to 51% in 2017 and 2018, respectively. The EFOR has remained higher over the last two years.

The average EFOR for all GT power plants from 2014–2020 was 39%. In 2020, the GT plants had an EFOR of 51%. The increased EFOR from 2014–2020 is reflected by the decreasing availability factors because of the increased breakdowns due to the rising operations costs and lower funding for maintenance.

Figure 2-3 — SC Plant EFORs



Source: *Author* © Sargent & Lundy, L.L.C. 2022

PREPA's current power system is aged, distressed, and unable to perform with performance metrics in line with North American averages. For instance, EFORs of PREPA's generation fleet span from levels that are barely acceptable by North American average standards of 7.19%, for thermal plants above 20 MW, to nearly 100%. EFORs above 10% would be considered ***unacceptable*** by most North American standards. EFORs at these levels are typical for an aged fleet. Removing or retiring such units without suitable replacements, despite their age and high EFORs, will inevitably reduce PREPA's ability to respond in an acceptable manner. Even units that are not fully functional contain valuable spare parts for a utility that is faced with these challenges. The risk of not meeting demand will increase as units are removed from service, unless suitable dispatchable systems are put in place during the 20-to-30-year transformation to renewable energy systems; furthermore, unlike mainland U.S. utilities, PREPA has no backup interconnection to supply emergency power when faced with disasters or unit failures. Additional reserve margin may provide essential generation services during these circumstances.

2.2. Preventative Measures

It should be noted that as an island, Puerto Rico cannot obtain backup electrical power from other areas or regions and must depend upon its own island grid; however, much of the mainland United States and other areas of the world routinely rely on large balancing areas and interconnectivity to other markets to enable higher service reliability. For example, Pattern Renewable Energy's Operations Group in Houston states that "building out transmission that links geographically diverse generation is essential to enhancing reliability of transmission systems, and their ability to withstand extreme weather events, whether extreme cold, extreme heat waves, wildfires, hurricanes and such. Studies have shown this time and time again. Planning processes must take these inter-regional benefits into account."[4] Meanwhile, undergrounding main distribution lines may be an appropriate solution in certain areas. Strategies that may be used include placing lines underground, running redundant links from generation centers, or deploying mobile generation units or emergency generation units placed in strategic zones to deliver power to areas that are more prone to isolation.

With the increase of renewable generation there will be a need to operate the existing thermal generation in a manner different than the original design. The existing thermal generation across Puerto Rico was designed to run as baseload generation with their best thermal efficiency point being at full load. These units cannot be turned on and off continuously—they require hours to restart. Given these restrictions, the existing thermal generation units should remain in operation so that they are available to load-follow renewable generation during the day, then provide generation during the peak load demand around 7 p.m. when solar generation is no longer available. To accomplish this, the existing thermal generation units will need to operate at a minimum emission complaint load. Operation at a minimum emission complaint load increases each unit's operating cost because it is no longer operating at its best efficiency point. As the heat rate worsens, so too does the reliability of the unit since it is now relying on many of its auxiliary systems to function at maximum turndown. In addition, as the unit ramps from low load to peak load, the components of the boiler system are exposed to daily stresses that were never planned for during their original design.

The current solution employed around the world to support renewable load following and load cycling is primarily to employ RICE units or GTs specifically designed for high-turndown capability, fast-ramp rates, and frequent starts and stops. New generation, in the form of emergency power generation units, as recommended herein, is necessary to replace the existing peaking generation plants. PREPA's existing boiler units are too large, inflexible, and fragile and the existing peaker units are old and have high heat rates. Currently, EcoEléctrica is in the best position to perform these duties; however, it is not sensible to

[4] Edward Klump, "10 ways to fix the power grid," *E&E News*, 11 March 11 2021, https://www.eenews.net/stories/1063727199.

employ the least expensive gas-fired power producer on the island for turndown capability and load following while more expensive diesel and oil-fired units continue to be fully fired. PREPA is in desperate need of equipment that will perform these duties at a lower cost than their existing diesel and heavy fuel oil-fired units and will be in a better position when EcoEléctrica is fully fired rather than turned down for load following.

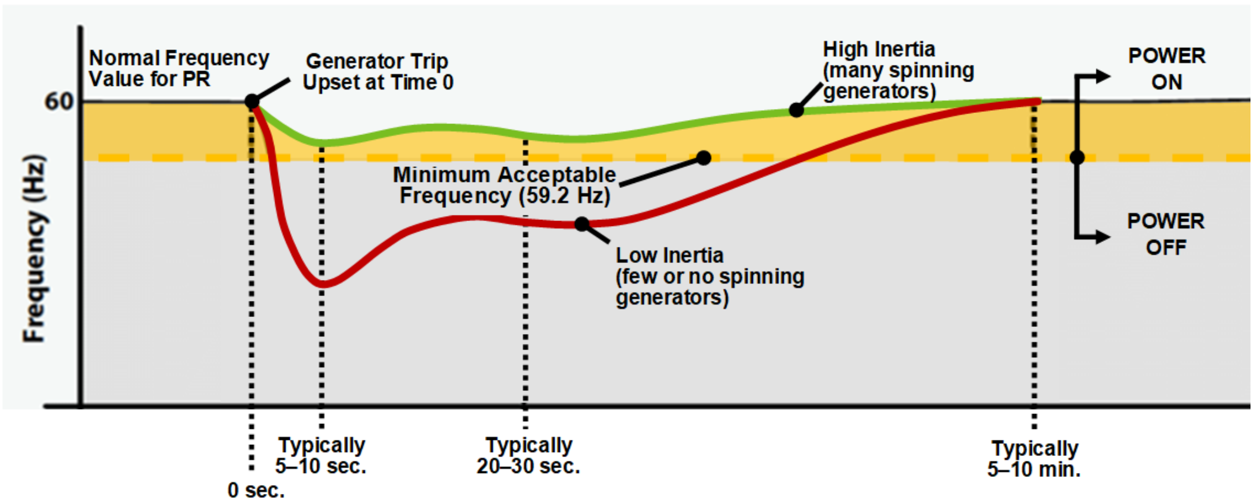
2.3. Grid Stability and Support

Renewable energy resource planning should carefully consider grid stability and essential grid services, such as synchronous condensing equipment. Modern, advanced metering, communications infrastructure, protection, data collection, and control capabilities will provide the grid operator with the necessary information and improvements in response time to operate the power system and improve existing power system models. It is particularly important to coordinate generation in a manner that provides a stable power system, for instance, to perform PV or wind load following in an effective manner, or immediate response in the event of a forced outage in the system. A key part of grid stability requires the use of synchronous generation or synchronous condensing machines, which is why the IRP specifically highlighted it as an issue requiring further study. The IRP noted that the large generators in the system may be converted to provide grid support; however, new synchronous generation technologies are readily available to enable rotating machinery to generate power, when necessary, and provide support for grid stability when unfired. These systems are already in place at PREPA's Mayagüez generation plant. As RPS levels ramp upward and inverter-based generation like PV becomes a more predominant component of generation, new synchronous machines may be switched from generation services to grid support services with a simple control panel transfer.

A basic description of system inertia is provided to further explain the importance of grid services in the paragraphs that follow.

The tendency of an object to remain in motion is referred to as its inertia. In a power system, the term applies to the rotational inertia from the kinetic energy within the spinning generators. It is this inertia that acts immediately to restore order when the power grid suffers a frequency disturbance—such as those caused by the loss of a generator or a broken transmission line. When the frequency of the system falls following one of these events, the inertia of the large, rotating, spinning generators' mass helps counteract the frequency drop by immediately supporting it with kinetic energy and momentarily supplying a restorative balance between the power that consumers are extracting from the grid and the power that generators are injecting into the grid. High inertia is a characteristic of a power system with many spinning (synchronous) generators. This inertia helps to reduce drops in system frequency that could result in a need to disconnect power from energy consumers, damage to generators or customer equipment such as motors, or even larger system outages if load shedding occurs due to protective relay trips. Figure 2-4 shows the difference between the behavior of system frequency in a system with high inertia (many spinning generators) and a system with low inertia (few or no spinning generators), such as the characteristics of a system with a large amount of inverter-based PV or wind generation.

Figure 2-4 — Typical Power Grid Frequency Control



Annotated by Sargent & Lundy, L.L.C.

Source: Lee, T., A Market for Primary Frequency Response? The Role of Renewables, Storage, and Demand, 2018.

System frequency in Puerto Rico is maintained at 60 hertz. The dashed orange line illustrates the frequency drop that is permissible (down to 59.2 Hz)—above this line, all customers remain online as the "Power On" in the graphic illustrates, but below this line, some customers may be disconnected as the "Power Off" in the graphic shows. This is to prevent large scale blackouts and to prevent damage to their electrical equipment.

The solid red line shows how frequency will quickly start to drop after a disturbance in a system with low inertia, or one that lacks spinning generators, such as a system that is entirely reliant on PV or battery energy storage. The frequency drops below the minimum allowable threshold so the system disconnects customers to regain balance between power generation and power consumption before the frequency controls have time to start acting to restore the system.

The solid green line shows the behavior of a system with high inertia, or one that contains sufficient spinning machines. The system inertia provides better support of the required frequency so that it does not drop beneath the minimum acceptable level before the frequency controls can act to restore the system.

Generation that uses rotational synchronous generators, such as GTs and steam turbines, help increase the system's inertia and its ability to maintain its frequency within the acceptable range—above the dashed orange line and closer to the target solid green line in Figure 2-4, providing better service and keeping the power on for its customers. Without proper engineering planning and engineering guidance to achieve a diverse generation mix to meet the RPS milestone mandates, the power system is likely to trend away from acceptable "high inertia" conditions towards the more challenging "low inertia" line as more inverter-based renewable projects are added to the system (fewer spinning machines are used), thus increasing the grid stability challenges for the grid operator.

With this feasibility work, we have concluded that proceeding with emergency thermal units such as combustion turbine projects, also provides the ability to use the generators, while unfired and idle, as synchronous condensing machines at little to no project cost provide future grid support services as part of the renewable integration process. The generators would be installed with selectable service to operate either in fired power generation mode or unfired synchronous generation mode at these five project sites. In addition to the use of these unfired synchronous condensing machines, as space permits and if practical, instantaneous battery projects may be planned for these sites and others as separate, stand-alone projects that may be integrated as future projects.

2.4. Role of Thermal Generation in the New Generation System

Multiple studies have been performed to determine the best way to ensure the safe and reliable operation of the Puerto Rico power system by addressing all the issues described earlier in this section, while following an aggressive program of renewable generation integration to attain the different RPS levels required by law by the required dates.

The studies have concluded that new, reliable, flexible thermal generation resources will play a supporting but integral role in the new power system where renewable generation will increasingly play the main role. Thermal generation helps address many of these issues:

- Replacing existing peaking GTs with new, reliable generation distributed across the island at existing sites will provide robust emergency support systems for hazard mitigation. These units will be dispatchable emergency generation in key areas around the island to improve reliability and provide support and synchronous condensing capability across the 25-year renewable energy transformation process.
- The synchronous generation capability of the new SC emergency power generation will provide the system with inertia and short circuit strength. The inertia provides frequency regulation support that cannot be provided by the renewable generation, whereas the short circuit strength is required in the system to enable the proper operation of inverter-based generation.

2.5. Supporting Future RPS Milestones

While achievement of the RPS requirements is certainly one aspect that PREPA has been tasked with, other aspects of the renewable integration work must be coordinated with the grid operator to ensure that the RPS requirements may be met in a manner that improves the reliability of the overall power system. Integrating the planned renewable energy and storage projects with the aged thermal resources that exist on the island is likely to exacerbate customer services issues related to the current unreliable and unstable power system. Integration steps must be coordinated between the grid operator and generation to renew the reliability of the system at the same time renewable energy and storage projects are brought online. Supplemental generation that is specifically configured to support the integration process is required. Details and differences between the aged, existing peaking generation and the supplemental generation required to function with renewable energy and energy storage projects are defined in Table 2-1. Generation characteristics highlighted in red are unsuitable for the future, renewable dominated generation mix; orange cells indicate marginal performance and green cells note suitable characteristics.

Table 2-1 — Comparison of Generation Features

<table>
<tr><th>Generation Characteristic</th><th>Existing PREPA Peaking Thermal Generation</th><th colspan="2">New SC Emergency Generation</th></tr>
<tr><td>Availability</td><td>Poor, with many unit trips.
Many units are 1960–1970 vintage.</td><td colspan="2">>95%</td></tr>
<tr><td>EFOR</td><td>2014 to 2019: 39%.
2020: 51%</td><td colspan="2">1.5%–4.5% EFOR is typical for new generation equipment.</td></tr>
<tr><td>Ramp Rates</td><td>Unreliable</td><td colspan="2">GT: < 10 min. to full load
RICE: < 3 min. to full load</td></tr>
<tr><td>Minimum Load</td><td>~50% load of 1 GT– maintaining emission compliance. Unreliable at part load operation.</td><td colspan="2">GT: ~50% load
RICE: ~ 15% load</td></tr>
<tr><td>Suitability for Frequent Start/Stops</td><td>Unreliable</td><td colspan="2">Suitable.
Modern equipment is capable and will be specified for multiple-daily starts/stops.</td></tr>
<tr><td>Load-Following Capability</td><td>Unreliable</td><td colspan="2">Suitable
Modern equipment, coupled with improved communication, supervisory control and data acquisition, and power management systems are well-suited for load following.</td></tr>
<tr><td rowspan="2">Heat Rate (LHV)
(higher heat rate means more fuel is required to generate electricity)</td><td rowspan="2">~ 13,000 to 22,000 Btu/kWh (with No. 2 Fuel Oil as fuel)</td><td>with No. 2 FO as fuel</td><td>with Natural Gas as fuel</td></tr>
<tr><td>GT: 8,100 to 9,600 Btu/kWh
RICE: 7,811 to 8,560 Btu/kWh</td><td>GT: 8,000 to 9,500 Btu/kWh
RICE: 7,300 to 8,000 Btu/kWh</td></tr>
</table>

Key		
Not Suitable Inadequate	Suitable Poor	Suitable

3.0 Fuel Feasibility Analysis

This section provides a feasibility analysis for the fueling infrastructure required for the SC emergency generation sites.

Puerto Rico Act 17-2019, the *Puerto Rico Energy Public Policy Act*, established several requirements for the energy and electrical system. Among the stipulations was a program requirement that "existing and future units that generate power from fossil fuels to be capable of operating with at least two (2) types of fossil fuels, one of which shall be natural gas…"[5] This requirement has implications for all future thermal generation plants and has the intention of reducing greenhouse gas emissions with cleaner fuels while fostering, through the two-fuel redundancy, a more resilient Puerto Rico electrical system. (Since there is an exception for legacy power generation assets, this requirement does not apply to existing assets still owned by PREPA.) A plan will be needed to implement natural gas and dual-fuel capability at each *new* power plant, including SC emergency generation plants and black start power plants.

Puerto Rico imports all the fossil fuels it consumes. Natural gas arrives by ship in the form of LNG to be re-gasified. Currently, a significant part of the island's LNG is delivered in bulk to EcoEléctrica's terminal at Peñuelas, which is on the south coast, west of Ponce. A second bulk delivery point is on the north side of the island, in San Juan, currently provided by New Fortress Energy for the PREPA-owned San Juan power generation facility.

Currently, natural gas provides numerous distinct advantages over other fossil fuels that are currently in use within Puerto Rico. Historically, it has been less expensive than diesel or heavy fuel oil, and it also provides significant environmental advantages. Natural gas is widely used in power generation equipment—such as reciprocating internal combustion engine, boilers, and GTs—and is considered a good replacement of more costly diesel and heavy fuel oils. It has been used by many utilities for facility upgrades, taking advantage of better emissions and lower maintenance costs associated with this cleaner fossil fuel. The fuel is unable to be transported in large quantities easily except by pipeline in gas form or in liquid form via shipment as LNG. Compressed natural gas does not provide sufficient energy content in tanker truck-sized vessels to be a viable alternative for these applications.

LNG is natural gas in its cryogenic liquid form, stored in insulated tanks or insulated pressure vessels at approximately -260°F. Cryogenic pumps draw LNG from the storage tanks/vessels and forward the cold liquid to a vaporization system to re-gasify the LNG in large amounts for baseload or peaking power plants. This process may be designed so that re-gasified natural gas may be delivered at the pressure required for the power plant combustion process without the need or added complexity of compressors.

[5] Commonwealth of Puerto Rico, Puerto Rico Energy Public Policy Act. Act No. 17-2019, 22 August 2021, Section 5(b).

LNG trucking provides flexibility with the site infrastructure: LNG can be either delivered to site in individual ISO[6] tank containers[7] (individual ISO containers dropped off at the plant site, and taken back for refill when empty), or pumped from the LNG truck into larger, onsite LNG pressure vessels. Logistically, ISO containers will require more frequent deliveries than refilling an onsite LNG tank, however multiple ISO containers could be stored at each facility. A large (40 ft.) ISO container has approximately 75% the capacity of a 16,000-gallon tanker truck.

As a truck-based site, LNG storage will consist of shop-fabricated cryogenic pressure vessels instead of the near-atmospheric, field-fabricated storage tanks that are typical for large baseload facilities. Main mechanical equipment for each truck unloading/storage/vaporization facility (one such facility at each plant using trucked LNG) includes truck roadways, truck unloading pad, LNG unloading skid, concrete for a sizable containment basin, and equipment inside this containment basin: LNG containers (multiple horizontal or vertical pressure vessels rated for cryogenic storage), LNG sendout pump skids (cryogenic pumps, with multiple stages to achieve the GT and RICE OEM required delivery pressure), and LNG ambient-air vaporizers. During detailed design, attention should be given to the LNG vaporizers: this study assumed they would be finned LNG/air (ambient) heat exchangers, but vaporizers can also be electric, gas-fired, seawater-warmed, or even plant-water-warmed (possibly serving plant cooling duties such as GT inlet air chilling). The final size of the generating capacity will determine the amount of vaporization required.

Additional considerations for LNG storage must include a plan to manage boil-off gas. LNG is natural gas in cryogenic form and is stored in insulated tanks or insulated pressure vessels at approximately -260°F. Over time, LNG will revert to a gaseous state even while in insulated storage. As the LNG returns to its gaseous state, the boil-off gas pressure inside the tank will increase. With constant draw down for natural gas supply demand, boil-off gas is constantly managed. Eventually, if demand is stopped or reduced, pressure rises high enough such that the boil-off gas must be removed from the container in a controlled manner to prevent overpressurization. Ideally, the low-pressure boil-off gas can be used as fuel for an onsite RICE, or otherwise should have measures in place to ensure that flaring is only performed for emergency measures and not an integral part of the plant operations.

Expected lifetime of these LNG equipment and components is 20+ years, assuming the pumps and other equipment are well-maintained by plant personnel.

For the SC emergency generation sites, diesel fuel oil will be used in the event of an emergency. Existing onsite diesel fuel oil storage tanks provide sufficient storage to provide continuous operation for

[6] International Organisation for Standardisation
[7] "Crowley, Eagle LNG net new LNG supply deal in Puerto Rico," *LNG World News*, June 28, 2018: https://www.lngworldnews.com/crowley-eagle-lng-net-new-lng-supply-deal-in-puerto-rico/

approximately one week, without the need for deliveries after an emergency. The primary fuel supply to emergency generation sites will be delivered by LNG trucks. Table 3-1 summarizes the weekly LNG fuel usage for the emergency sites with gas turbines, with 7% and 100% capacity factors. Truck deliveries of LNG to each site are dependent on the power generation capacity of the equipment and the time operated, described as capacity factor.

Table 3-1 — Typical Emergency Generation Site LNG Usage

Plant	Weekly Fuel Use (LNG m^3) – 7% capacity factor	Weekly Fuel Use (LNG m^3) - 100% capacity factor
Emergency Generator 1	263	3,763
Emergency Generator 2	263	3,763
Totals	**526**	**7,526**

The above LNG usage estimates are based upon GT technology. RICE technology will provide heat rates that are roughly 8% better than GT technology, and therefore provide a slight advantage in fuel costs and corresponding truck delivery requirements.

Renewable and low-carbon fuels may be considered and used in the future as economics and viability become more attractive. Most major GT and RICE OEMs have already established technical solutions for the use of low-carbon or carbon-neutral fuels which may be sourced in the future and contribute to RPS credits.

4.0 Emissions Regulations

PREPA's plans for future thermal generation are impacted by local Puerto Rico regulations, PREB oversight, and FEMA funding. Additionally, the plans are also impacted by details of the construction permits linked to air emissions.

For each SC emergency generation facility, one of two distinct permitting strategies could be taken. In the first strategy, emissions increase from the new SC emergency generation would be compared to emissions reductions from the existing generating units which they would replace, and annual operation of the new SC emergency generation units would be limited to an effective *capacity factor* that yields net annual emissions increases that do not exceed thresholds established by the U.S. Environmental Protection Agency. Among satisfying other considerations, this strategy avoids triggering *Prevention of Significant Deterioration* (PSD) permitting which includes installation of best available control technology. Table 4-1 lists typical best available control technology (BACT) requirements for SC GTs.

Table 4-1 — Typical Best Available Control Technology for SC GT Technology

Pollutant	Distillate Oil Firing	Natural Gas Firing
NOx	SCR	SCR
CO	Oxidation Catalyst	Oxidation Catalyst
VOC	Oxidation Catalyst	Oxidation Catalyst
$PM_{2.5}$	Low Sulfur Fuel	Low Sulfur Fuel
SO_2	Low Sulfur Fuel	Low Sulfur Fuel
H_2SO_4	Low Sulfur Fuel	Low Sulfur Fuel
CO_2	Efficient Process	Efficient Process

SCR = selective catalytic reduction

One item to note is most GTs in the 18-30 MW size range require demineralized water for NO_X control when firing diesel fuel or would require an SCR to meet the permit limits for NOx, which typically range from 3 ppm to 74 ppm. Depending on the GT OEM, NOx levels can be lower and under the threshold with dry low NOx (DLN) burners and demineralized water may not be required. Either NO_X compliance option would require trucking of demineralized water or aqueous ammonia to a storage tank on site, depending on the available area. Based on 600 hours of operation per year, approximately 2 million gallons of demineralized water would be required on a yearly basis which could be up to 9 tanker trucks per day.

In some respects, this first permitting approach is preferable because post-combustion controls may not be required. Also, agency review time is much shorter than seen with PSD permitting because the overall change in generation is viewed as only a minor modification. However, just because the new generating units would not be required to install BACT controls does not mean that the new power plant will necessarily operate with *no* post-combustion controls.

Table 4-2 (for natural gas) and Table 4-3 (for diesel oil) identify typical emissions limits for simple cycle units. Based on several presently unverified assumptions about the peaking generation type and its exhaust gases, S&L estimates that $PM_{2.5}$ emissions would be the limiting factor for the SC GTs and would limit plant operation to around a capacity factor of 8%. In a simplification where the plant always operates at 100% load, such a facility would only be able to operate during 8% of the 8,760 hours in a year (~2 hours daily).

Table 4-2 — Typical SC Emergency Generation Permit Limits — Natural Gas

Post-Combustion Controls	If Project Does Not Trigger PSD Permitting	If Project Triggers PSD Permitting (for NOx and CO/VOC)
	Simple Cycle	***Simple Cycle***
	None	***SCR/CO Catalyst***
NOx	25 ppm	3–5 ppm
CO	25–75 ppm	3–10 ppm
VOC	3–6 ppm	2–3 ppm
$PM_{2.5}$	0.01–0.03 lb/MMBtu	0.01–0.03 lb/MMBtu

Note: This table is based on GT technology in the 25 MW–30 MW range

Table 4-3 — Typical Simple and Combined-Cycle Permit Limits — Oil

Post-Combustion Controls	If Project Does Not Trigger PSD Permitting	If Project Triggers PSD Permitting (for NOx and CO/VOC)
	Simple Cycle	***Simple Cycle***
	None	***SCR/CO Catalyst***
NOx	42 – 74 ppm	5 ppm
CO	15–20 ppm	3 ppm
VOC	5 ppm	2–3 ppm
$PM_{2.5}$	0.03–0.08 lb/MMBtu	0.03–0.08 lb/MMBtu

Note: This table is based on GT technology in the 25 MW–30 MW range.

A second permitting strategy is to trigger PSD permitting for the new SC emergency generation units, which would provide the most operational flexibility. Under this second permitting strategy, while the units' capacity factors would not be limited to the low levels required under the first permitting strategy, the maximum capacity factors may need to be limited to comply with EPA's New Source Performance Standards (NSPS) Subpart TTTT (Standards of Performance for Greenhouse Gas Emissions for Electric Generating Units).

Under NSPS Subpart TTTT, new SC GTs that fire more than 90% natural gas on a 12-month rolling average basis, would effectively be limited to a capacity factor equal to the unit's efficiency (e.g., 40% efficient GTs would be limited to 40% capacity factor). However, if the GTs fire less than 90% natural gas, the capacity factor limitation would not apply. NSPS Subpart TTTT does not apply to reciprocating engines.

While this second permitting strategy would provide the most operational flexibility to PREPA, it would likely require that the new units include the BACT controls identified in Table 4-1. There would also be a public involvement phase to the permitting. PSD permitting typically takes around 12 to 18 months. Even though PSD permitting extends the permitting schedule and would likely require installation of SCR and CO catalyst, the units could have the flexibility to operate up to 100% capacity factor if the simple cycle GTs fire less than 90% natural gas on a 12-month rolling average basis, or if reciprocating engines are installed.

5.0 New Thermal Generation Preliminary Capital Cost Estimates

The budget for the proposed SC emergency generation project was for 11 units installed at five existing PREPA sites. The budget was submitted PREPA in the FEMA 404 HMGP application using as a reference similar GT installations between 2002 and 2019 broken down by preliminary engineering to support environmental planning and historic preservation studies, preliminary engineering design services, design criteria to obtain permits and construct each SC facility. These determined the order-of-magnitude project cost for feasibility budgetary purposes. Cost estimates based on high level conceptual engineering are referred to as Class 4 estimates[8] by the American Association of Cost Engineers adjusted to 2020 dollars. The costs submitted in the FEMA 404 HMGP application were Class 4 estimates as shown in Table 5-1.

Table 5-1 — 11 SC Emergency Generators (330 MW) Class 4 Capital Cost Estimate

FEMA Form OMB Number: 4040-0008 Expiration Date: 02/28/202	FEMA Grant cost estimate in 2020 dollars	Revised cost estimate in 2023 dollars
Administrative and Legal Expenses	$15,472,500	$39,880,149
Land, Structures, Rights-of-Way, Appraisals, Etc.	----	-----
Architectural and Engineering Fees	$10,600,000	$27,321,349
Project Inspection Fees	-----	----
Site Work	-----	----
Demolition and Removal	$27,250,000	$70,236,487
Construction	$80,750,000	$208,131,977
Equipment	$146,750,000	$378,246,038
Estimated Total Project Capital Costs	**$280,822,500**	**$723,816,000**

1. The cost estimate submitted by PREPA in the FEMA 404 HMGP application for 11 simple cycle fixed gas turbines was based on similar GT projects built between 2002 and 2019 adjusted to 2020 dollars with no site engineering done since there was no budget to do any engineering at the time when the application was prepared and submitted.
2. The revised 2023 cost estimate is based on current 2022 cost for engineering, materials, major equipment, and commissioning, adjusted for inflation at 8%, transportation, raw materials availability, construction, and geopolitical risks.
3. All new GTs or RICE units are brownfield projects expected to be installed at existing PREPA facilities. Some demolition of existing foundations, underground utilities and buildings may be required.
4. Contaminated soil remediation is unknown and could have a major cost impact on the project
5. The Original cost estimate did not consider indirect cost and overheads like EPC fee and profit which is significant in an EPC contract.
6. The original estimate did not include an estimate for emissions control equipment

To validate the PREPA submitted 2020 project cost estimate, FEMA requested under the condition of approval (COA), a cost estimate breakdown of each category listed above as part of the FEMA Phase I –

[8] Class 4 cost estimate as defined by the Association for the Advancement of Cost Engineering (AACE) is based on a 1% to 15% project definition (engineering) and an expected accuracy range of Low: -15% to -30%, High: +20% to +50%.

Engineering deliverables rather than a lump sum price. This can be achieved by developing a detailed work scope supported by preliminary engineering work and studies. The drawings and data developed from this work may then be used produce an RFP package that can be issued to the market via PREPA's competitive bidding process or utilizing a pricing labor, materials, equipment data base. This firm cost can then be compared to the initial indicative cost estimate to determine final project funding. At the same time, the information may be used to validate the cost-benefit analysis (BCA) submitted to FEMA in the funding request application for the emergency generation projects. Inflation and fuel costs in 2022 and 2023 are expected to provide upward pressure on future project costs, therefore it is expected that the cost estimate prepared during Phase I Engineering will be greater than the Class 4 cost estimate presented in the FEMA grant proposal—however this will be accommodated when the final project funding is established. This final project funding will be the basis for approval to proceed to Phase II – Construction Tasks. FEMA's Phase I – Engineering is approximately 40% complete for the SC (emergency) generators as per the third quarterly report to be submitted to FEMA by the end of July 2022. FEMA provided a one-year extension to complete Phase I engineering deliverables on or before October 15th 2022.

6.0 Additional Relevant Considerations

6.1. Generation Portfolio Mix

As renewable generation and energy storage systems are installed across the island, it is essential that the transformed power system can meet customers' power demands. Based upon independent engineering assessments of the Puerto Rico power system, adding the planned renewable generation capacity along with energy storage facilities, while retiring existing thermal power plants, results in an electricity generation deficit. During the dark, early morning hours when solar is unavailable and battery storage has been depleted, customers are at risk of experiencing unmet demand or electrical outages. A diverse generation portfolio is needed to support the planned renewable energy and storage projects along with the required plant retirements..

The current Renewable Generation and Energy Storage RFP does not provide strict guidance for technology selection; however, it is apparent that an overreliance on technologies with intermittent availability, will eventually lead the utility toward intermittent generation—for example, 100% solar cannot completely cover a generation day without additional energy storage or more diverse generation that is not dependent on solar resources.

Other renewable energy sources should be considered for Puerto Rico's renewable energy transition. The revitalization of the existing hydroelectric power plants is important and potentially beneficial from the perspective that the hydroelectric power plants are both dispatchable and synchronous renewable energy generators. The costs and benefits of revitalization of the existing hydroelectric power plants should continue to be studied and then implemented if feasible. Additionally, evaluating a variety of low or zero-carbon fuels (e.g. hydrogen) would also provide tremendous benefits to improving the generation mix and at the same time achieving RPS credits in proportion to the selected renewable fuel. Any of these emergency generation projects could be configured to support fuel blending or low or zero carbon fuels and thus obtain RPS credits during their operation.

In the short and medium term, to support a reliable generation mix and to provide immediate results, PREPA is proposing to install new SC emergency generation to facilitate the transition to renewable energy. In the future, as more renewable energy projects are implemented, as the portfolio becomes more diverse, and as energy storage increases in capacity, the existing large, inefficient thermal generation plants across the island will be run less frequently and ultimately can be retired. The initial phase of this transformation sees progress across the first several tranches of renewable generation energy storage systems and is complemented with efficient gas-fired turbine technology that will enable PREPA to improve their reliability and reduce their operating costs. Over time, the generation mix of power technologies should ensure that power demand may be satisfied across all hours of a utility's generation day and provide a means for emergency power generation in the case of a natural disaster. Refurbished hydroelectric plants can be recommissioned, other renewable energy projects should be considered, and alternative fuels that achieve RPS credits may be employed to manage nighttime generation or periods of time when solar and wind resources have declined..

6.2. Renewable Integration

If Puerto Rico proceeds with only installing renewable energy and battery energy storage in the coming years, it will be extremely challenging for Puerto Rico to successfully integrate large amounts of renewable generation while simultaneously (i) improving electrical system reliability and (ii) improving system resiliency in the face of low probability, high severity events. New, highly efficient thermal generation units with rapid startup and ramp rate capabilities are needed to facilitate the successful retirement of legacy thermal generation units and facilitate the successful integration of large amounts of renewable energy projects. In addition, new thermal generation equipment will also help PREPA meet demand and manage the variability of generation from certain renewable resources (i.e., due to cloud cover) or during severe events like tropical storms or hurricanes. During major storms, this new thermal capacity will provide emergency generation, which is vital for the safety and security of the island's residents.

A fleet of distressed equipment and corresponding dismal EFOR rates is not well-suited to provide this support during emergency events, and BESS can only provide needed support if the units are charged (periods of low renewable generation can strain the ability for BESS to charge) and for limited periods of time. By retiring heavy fuel oil (HFO) and No. 2 fuel oil (diesel) fired units, and replacing them with cleaner, more flexible, and more efficient natural gas-fired generation systems, PREPA could begin its path towards substantial compliance with the laws and PREB requirements, including the need for resiliency, reliability, and stability of the overall Puerto Rico power system.

6.3. Decarbonizing Gas Power

GT and RICE technology offers multiple options to achieve lower or zero carbon emissions and contributions towards RPS credits. This can be achieved in the combustion process, by burning zero or carbon neutral fuels, or post-combustion by removing carbon from the plant exhaust.[9] Carbon-neutral fuels include: green hydrogen, green methane, and green ammonia. The term "green" refers to using renewable energy as the power source to produce the fuel. With the proposed GT and RICE technology for the emergency generation units, fuel blending, with manageable changes to the GT and RICE combustors and controls system, could be used to introduce hydrogen as a fuel in limited quantities (less than 20%) resulting in reduced greenhouse gas emissions. GT and RICE technology, with modifications to the auxiliaries, could

[9] Post combustion technologies include carbon capture with liquid or solid solvent and oxy-fuel cycles.

use 100% green, carbon-neutral fuel. These modifications are often included as retrofit kits by OEMs so that fleets can easily be converted in the future. Often, these kits include modifications to the combustion system, revisions to plant controls and instrumentation, new fuel delivery system, or modifications to balance-of-plant systems to suit the new fuel or delivery system, as well as NOx emissions treatment. If the process used to synthesize the carbon neutral fuel comes from renewable sources, the cycle can be made carbon-free and be applied toward RPS credits. The advantage is that the GTs are fully dispatchable across a full generation day and do not depend upon solar or wind resources for generation.

6.4. Power Generation System Resilience

This section discusses power generation system resiliency considerations, specifically those that should be considered as renewable generation penetration levels increase in Puerto Rico in the future. For reference, the Institute of Electrical and Electronics Engineers defines system resiliency as follows:

> An effective resilience framework should strive to minimize the likelihood and impacts of a disruptive event and provide the right guidance and resources to respond and recover effectively and efficiently when an incident happens. It should also have a feedback loop to foster continuous improvement. This can be accomplished by applying the all-hazards framework toward assessing and developing a program with five focus areas: Prevention, Protection, Mitigation, Response, and Recovery.[10]

Grid resiliency refers to a “power system’s ability to continue operating and delivering power even in the event that low probability, high-consequence disruptions such as hurricanes, earthquakes, and cyber-attacks occur.”[11] While reliability analyses serve to demonstrate if a utility is prepared for disruptions under relatively normal operating conditions and contingency events, resiliency analyses are needed to evaluate preparedness for events that have low probability of occurrence but can cause major and system-wide disruptions.

Analyzing this further, if we were to consider a slow-moving tropical storm or a hurricane over Puerto Rico, we would expect that while the storm passes over, there would be a significant reduction in solar and wind generation (due to diminished solar resource, emergency outages, and, potentially, damage). In this case, most of the electrical system’s load would have to be met by the thermal generation and BESS on the island. Given the historically high forced outage rates of the thermal generators in Puerto Rico and the likelihood that some of the generators may be in planned maintenance outages when a storm passes, only

[10] Bill Chiu et al., “Resilience Framework, Methods, and Metrics for the Electricity Sector,” IEEE Power & Energy Society, Technical Report PES-TR83 (October 2020), https://resourcecenter.ieee-pes.org/publications/technical-reports/PES_TP_TR83_ITSLC_102920.html

[11] Eric D. Vugrin, Andrea R. Castillo, and Cesar Augusto Silva-Monroy, *Resilience Metrics for the Electric Power System: A Performance-Based Approach*, United States, Sandia National Lab, 01 February 2017, https://doi.org/10.2172/1367499, https://www.osti.gov/servlets/purl/1367499.

a subset of this capacity is likely to be available during a storm; thus, it will be challenging for the system to meet load during a storm if load demands are high. This challenge only increases if the storm is slow moving and the energy storage systems become depleted due to the reduction in the amount of renewable generation that would help charge the storage systems during normal operation.

Since low probability but high severity events are often defined by a cascade of system failures, there may be other failures within the electrical system that can arise during a significant tropical storm or hurricane, which would further affect the system. Transmission outages, fuel supply disruptions, flooding, etc. can all place significant stress on the ability of the system to serve load during a storm. As a result, thorough resiliency planning will be important as Puerto Rico transitions towards a future defined by a heavy reliance on renewable generation and energy storage, with particular emphasis on conservative engineering to prevent over-dependence on any one generation source. For this reason, and others previously noted, we recommend adjustments to future Tranches 2–6 with an emphasis on a diverse mix of generation technologies, that may provide services after high-severity events, such as those described above and in compliance with the recommendations provided by FEMA and the U.S. Department of Energy for hazard mitigation.

6.4.1. Hurricanes and Storms in Puerto Rico

Puerto Rico has experienced several natural, catastrophic events recently, including both hurricanes Irma and Maria, both of which struck the island in September 2017. The historical path of tropical storms and their classification from H1 to H5 is illustrated in Figure 6-1. This figure, from the U.S. Geological Survey website, has been updated by S&L to include the 2017 hurricanes Maria and Irma. It is provided to illustrate the predominant path of hurricanes crossing Puerto Rico, starting from the east and traveling west or northwest across the island.

Figure 6-1 — Historical Strength and Travel of Puerto Rico Hurricanes since 1780

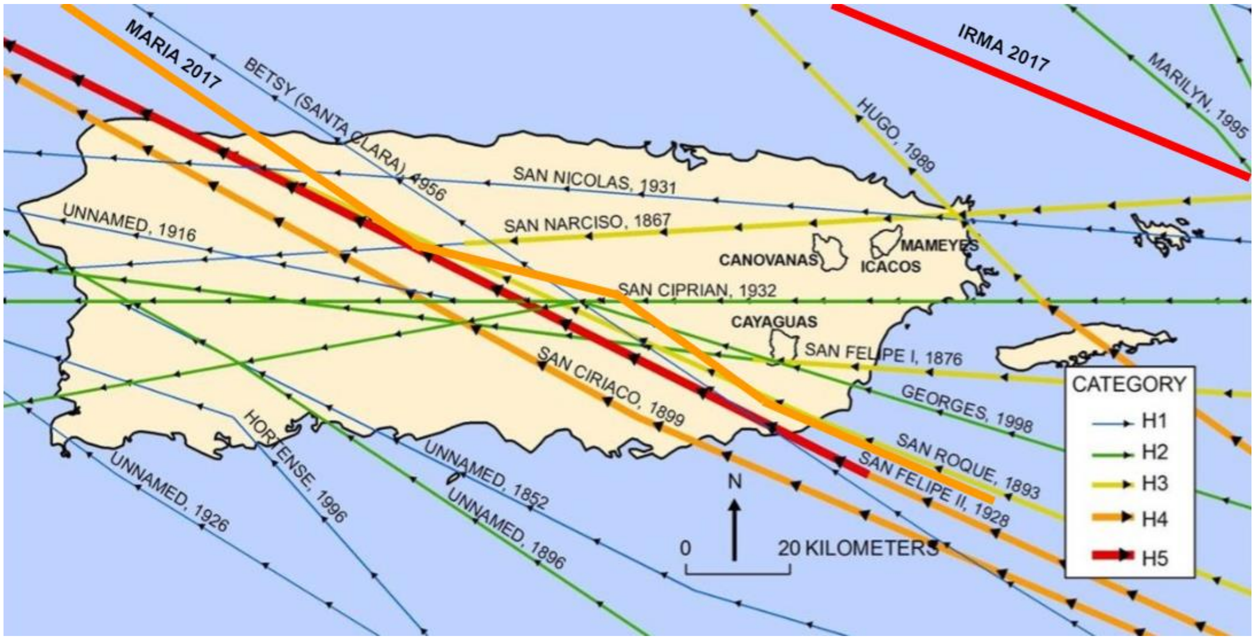


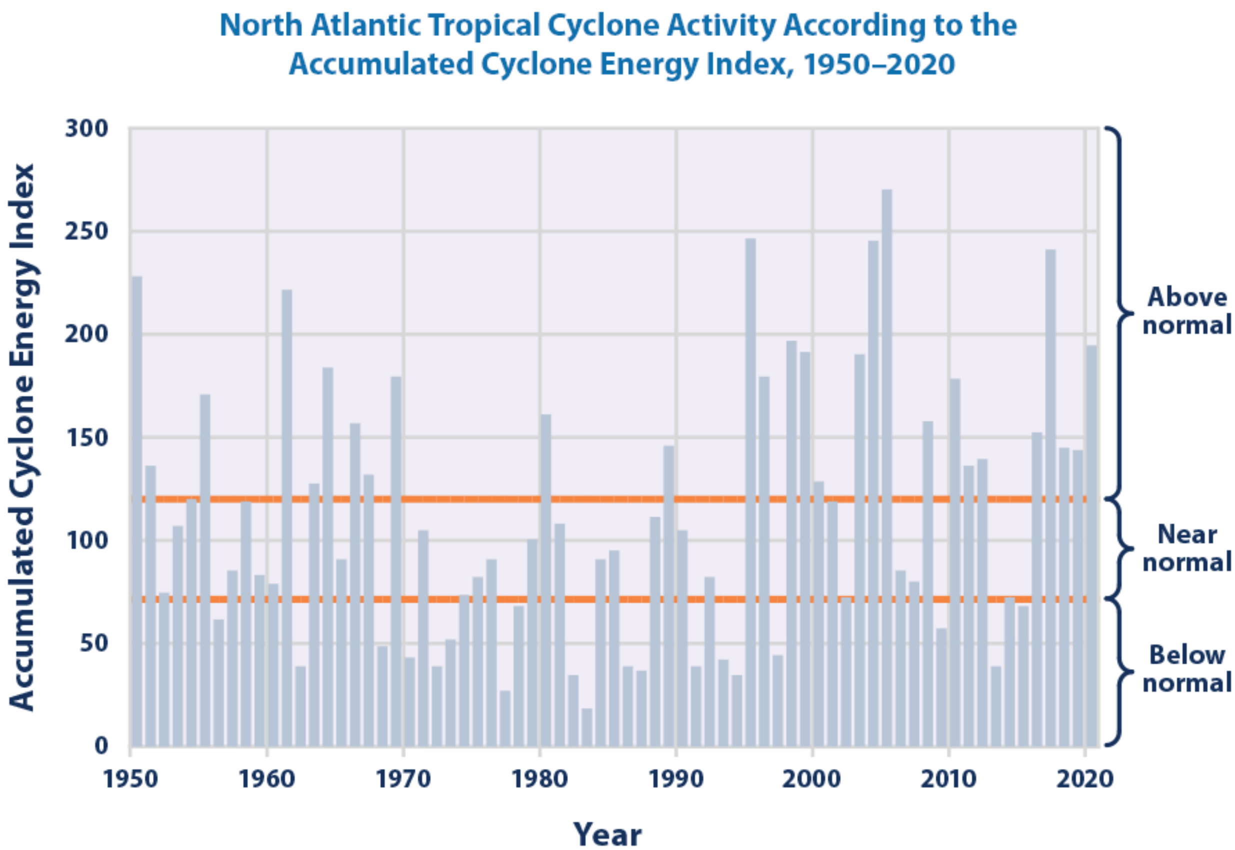
Image modified to add Category H4 Maria 2017 and Category H5 Irma 2017.

Source: Sheila Murphy, *Puerto Rico Hurricanes Map*, n.d., figure, 1435 x 1125, U.S. Geological Survey, Puerto Rico, https://www.usgs.gov/media/images/puerto-rico-hurricanes-map

The hurricane categories are defined by the Saffir-Simpson Hurricane Wind Scale, which is a 1–5 rating based only on a hurricane's maximum sustained wind speed, with 5 being the strongest. As noted in the previous figure, hurricane Irma was classified as an H5 hurricane, while hurricane Maria was classified as an H4 hurricane. Hurricane Irma struck Puerto Rico on 7 September 2017, while hurricane Maria struck on 20 September 2017. These back-to-back hurricanes brought massive devastation to Puerto Rico and nearby islands.

The U.S. Environmental Protection Agency has provided the data shown in Figure 6-2, indicating above normal tropical storm activity in the most recent five years.

Figure 6-2 — North Atlantic Tropical Cyclone Activity



Source: *North Atlantic Tropical Cyclone Activity According to the Accumulated Cyclone Energy Index, 1950–2020,* April 2021, Figure 2, U.S. https://www.epa.gov/climate-indicators/climate-change-indicators-tropical-cyclone-activity

Solar PV and wind power projects are directly exposed to the weather, which can be quite severe during tropical storms or hurricanes. As a result, solar PV modules and wind turbines can be severely damaged during storms if impact damage from projectiles occur or if the severity of the storm exceeds the design criteria of the power generation equipment. As Puerto Rico transitions to a generation portfolio with significant amounts of solar PV and possibly wind power, future system resiliency planning will need to consider how best to (i) minimize the risk of damage to solar PV and wind turbines during storms going forward and (ii) minimize the risk of system disruption if a portion of the island's solar PV and wind power plants are damaged during future storms.

Photos of hurricane damage to PV and wind systems from 2017, in both Puerto Rico and the nearby U.S. Virgin Islands, in the aftermath of both hurricanes Maria and Irma are provided. The photos are not provided to imply that solar PV and wind generators are fragile in the face of severe storms—in fact, the opposite is often true, as properly storm-hardened solar PV and wind generators often demonstrate high levels of resiliency. Instead, these figures are provided to emphasize that recent severe storms in the Caribbean have temporarily disabled solar PV and wind power plants in Puerto Rico and neighboring islands; thus, a comprehensive island storm resiliency plan needs to assume some percentage of solar PV and wind power plants may become disabled by either wind or debris impact from future storms.

Examples of hurricane damage to PV and wind systems are presented in the figures that follow (Figure 6-3, Figure 6-4, and Figure 6-5).

Figure 6-3 — Hurricane Damage at Solar Generation Site

Annotated by Sargent & Lundy, L.L.C.

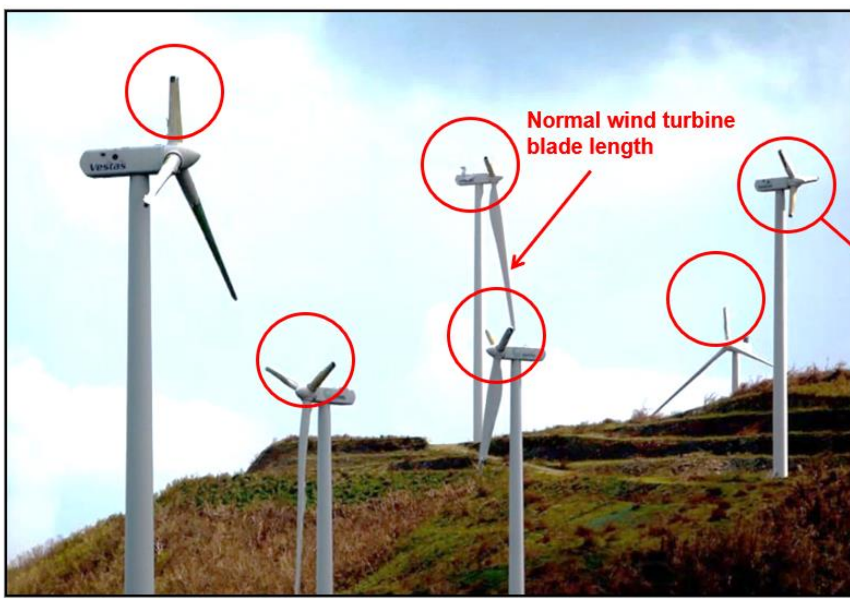
Source: Jocelyn Augustino, *Solar Under Storm*, 10 October 2017, Rocky Mountain Institute.

Figure 6-4 — Hurricane Damage at Solar Generation Site

Annotated by Sargent & Lundy, L.L.C.

Source: FEMA, *Mitigation Teams Assessment Report: Hurricanes Irma and Maria in Puerto Rico*, FEMA P-2020, October 2018, Figure 6-8, p. 6-6.

Figure 6-5 — Hurricane Damage to Wind Turbines



Annotated by Sargent & Lundy, L.L.C.

Source: Ricardo Arduengo, 2 October 2017, AFP/Getty Images.

While preventing such damaging storms from occurring is not possible, mitigation, response, and recovery are possible. Emergency backup generation systems are deployed throughout Puerto Rico for critical services, such as hospitals and municipal services. One such example is the Puerto Rico Capital Building Complex. In this example, two emergency backup generators have been placed to provide backup generation to critical government infrastructure within San Juan, as shown in Figure 6-6. Note that solar PV panels are also in place at this building complex, thus providing two sources of generation—solar panels for daily use and in the event of an interruption in utility services as well as backup generation when such services are required.

Figure 6-6 — Backup Generation System at Puerto Rico Capital Building

Annotated by Sargent & Lundy, L.L.C.

Source: Google Earth

The aftermath of the 2017 hurricanes also helps to highlight that having reliable emergency and black start generation systems is a critically important part of having an effective system resiliency plan. After the 2017 hurricanes, the entire island of Puerto Rico was without power. Although many of PREPA's power plants were operational, they were tripped offline due to damaged T&D lines and grid infrastructure to eliminate hazardous power line conditions associated with the damaged power distribution network. Ordinarily, emergency backup systems are in place to provide black start capability to restart major power generation plants; however, the 1970s era Frame 5 black start GT systems at each of the major power plants in Puerto Rico were unable to provide this service. In contrast, Mayagüez, a more modern plant, was able to restart and operate in island mode, meaning the diesel-fired plant had black start generation equipment onsite and was able to restart. Unfortunately, downed power lines prevented Mayagüez from supplying power to restart

PREPA's nearby power plants in the south of the island, and repairs to T&D lines were needed before the Costa Sur Steam Plant, EcoEléctrica, and Aguirre Power Plant Complex could be restarted.

New thermal generation as emergency generation units may be placed at the existing peaker sites to provide immediate support for the situations described in the preceding paragraph. All the FEMA emergency generation projects will be configured with black start capability. This black start capability may provide startup power from many locations across the island for critical services and support to the existing power generation plants to limit the risk of recurrence of the 2017 restart difficulties for the Costa Sur Steam Plant, EcoEléctrica, and Aguirre Power Plant Complex.

6.4.2. Seismic Events in Puerto Rico

In January 2020, Puerto Rico experienced an earthquake in the southwest corner of the island near the Costa Sur Steam Plant. A recent report by the U.S. Geological Survey described the event as follows:

> Aftershocks (earthquakes clustered spatially and chronologically near the occurrence of a causative earthquake) are ongoing in southwestern Puerto Rico after a series of earthquakes, which include a magnitude 6.4 earthquake that occurred near Barrio Indios, Guayanilla, on January 7, 2020, and affected the surrounding area. This report estimates the expected duration of these aftershocks by incorporating observations of aftershocks as of January 17, 2020, into a well-established statistical model of how earthquake sequences behave. Aftershocks will persist for years to decades, although with decreasing frequency, and earthquakes will likely be felt on a daily basis for up to several months.[12]

Costa Sur Unit 5 and Unit 6 suffered damage during this earthquake. More than five months were required to restore the Costa Sur generation units to service, with extended time required to repair Unit 6. Damage also occurred to the nearby EcoEléctrica power generation plant and its LNG storage tank because of this earthquake and the subsequent aftershocks. While both the Costa Sur and EcoEléctrica power plants have been restored to service, latent and undetected defects may still be present within the power plants (specifically at Costa Sur due to the more extensive damage and the high center of gravity of the thermal equipment). Furthermore, aftershocks, as indicated in the U.S. Geological Survey report extract above, are anticipated to continue for decades. Given the age of the Costa Sur power plant, there is inherent risk to the site if there is a strong aftershock or similar earthquake.

[12] Nicholas van der Elst, Jeanne L. Hardebeck, and Andrew J. Michael, *Potential duration of aftershocks of the 2020 southwestern Puerto Rico earthquake,* U.S. Geological Survey Open-File Report 2020–1009, 2020, 5, https://doi.org/10.3133/ofr20201009.

Like hurricanes, earthquakes cannot be prevented; however, emergency, and black start generation systems designed to current seismic codes, like the units currently being considered, are an effective means to provide mitigation, response, and recovery in the event of earthquake damage.

7.0 Conclusion

Noting that PREB's Final Resolution and Order was issued before the FEMA 404 grants were approved, and that the least-cost scenario in the IRP did not consider funding from FEMA 404 grants, and further that the least-cost scenario was in fact a baseload generation scenario only, rather than one that also considers hazard mitigation issues, we believe that the current IRP does not accurately define the needs for reliable and dispatchable emergency generation equipment needed by Puerto Rico. This has clearly been illustrated by many lengthy and tragic disaster recovery periods following hurricanes, earthquakes, severe tropical storms, and repeated power system failures that have plagued the aged generation and transmission system—all of which have occurred since 2017. Hazard mitigation, as defined earlier in this report, but repeated here again as a reference, is "any sustained action taken to reduce or eliminate long-term risk to people and property from natural hazards and their effects. This definition distinguishes actions that have a long-term impact from those that are more closely associated with immediate preparedness, response, and recovery activities. Hazard mitigation is the only phase of emergency management specifically dedicated to breaking the cycle of damage, reconstruction, and repeated damage" [5]. Emergency generation equipment, which may also provide valuable and much needed generation and grid services to PREPA as it transforms the utility into a renewable energy provider, may be installed with the support of FEMA 404 grants. As such, due consideration for a revision to the IRP to include emergency generation equipment at little to no cost to the utility, and reconsideration of PREB's Final Resolution and Order, are certain to yield positive or certainly different results with respect to hazard mitigation for Puerto Rico.

Hazard mitigation measures for Puerto Rico include the addition of new SC emergency generation distributed across the island to provide power for critical loads following a natural disaster.

These proposed SC emergency generation projects support the following criteria:

- The recommended locations for new SC facilities to provide emergency generation services are located around the island within existing PREPA facilities to serve as backup generation for other key high load areas and critical infrastructure around the island.
- All generation equipment will include black start capability for use during emergencies.
- The SC emergency generation will be storm hardened to provide resiliency and operating capacity during severe storms or recovery after hurricane events. The plants will include provisions to be fully functional for a period of 7 days without refueling.
- The SC emergency generation equipment may be used, in unfired mode, as synchronous condensing machines to provide stabilizing grid support to assist with the integration of inverted-based, renewable energy projects.

- The SC emergency generation systems will be more reliable and more efficient than the existing sites and provide load-following capability, high turndown ratios to operate at low loads, fast startup capability, rapid ramping capability, and other features that are necessary for the successful integration of renewable energy projects.
- All units will be fully compliant with U.S. Environmental Protection Agency regulations.

The addition of new generation with these capabilities will provide PREPA with reliable emergency generation equipment and at the same time support PREPA's needs to integrate renewable energy and storage projects. New SC power emergency generation could be operational between 2024 and 2026.

PREPA appreciates the opportunity to present this report to PREB and to collaborate on the selection of generation projects that leverage the FEMA hazard mitigation funds to reduce Puerto Rico's exposure and risk to natural disasters. The recommended projects will provide numerous other advantages to the utility and grid operator for improvements to the existing fleet, reliability of services, and complementary services for the renewable integration process—including much needed support for intermittent resources, such as solar and wind. These SC projects also provide generation diversity in the initial years of transforming the electric utility to one that primarily serves load with clean, renewable power. Along with these multipurpose generation projects that may be configured to provide grid stability, generation diversity, and even RPS credits, we recommend a comprehensive review of the future renewable energy RFP Tranches 2–6 to engineer a path towards the future RPS requirements and ensure that the proper technical guidance is in place to lead the utility towards a balanced portfolio of generation technologies—and a stable power grid in the future—as the penetration of renewable generation and storage projects increase over time.

FEMA 404 provides funding for the modernization of the emergency generation power supply. These improvements, in conjunction with power distribution upgrades and additions of renewables, provides to an isolated grid a more robust and efficient power generation and distribution system, as the one needed for Puerto Rico.

8.0 References

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5. Hazard Mitigation Assistance Guidance Hazard Mitigation Grant Program, Pre-Disaster Mitigation Program, and Flood Mitigation Assistance Program 27 February 2015
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