United States Government Accountability Office

Report to Congressional Addressees

March 2021

# ELECTRICITY GRID

# Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes

Accessible Version

A Century of Non-Partisan Fact-Based Work

GAO-21-274

# GAO Highlights

Highlights of GAO-21-274, a report to congressional addressees

## Why GAO Did This Study

Hurricanes pose significant threats to the electricity grid in some U.S. coastal areas and territories and are a leading cause of major power outages. In recent years, hurricanes have impacted millions of customers in these areas. Adoption of technologies and other measures could improve the resilience of the grid so that it is better able to withstand and rapidly recover from severe weather; this could help mitigate the effects of hurricanes.

This report examines (1) measures utilities in selected states have adopted to enhance grid resilience following major hurricanes since 2012 and any challenges utilities face funding such measures; and (2) federal efforts to support the adoption of measures to enhance grid resilience to hurricanes and any opportunities that exist to improve these efforts. For this report, GAO assessed agency and industry actions; reviewed relevant reports, policies, and documents; and interviewed federal, industry, and local officials.

## What GAO Recommends

GAO recommends that DOE (1) establish a plan to guide its efforts to develop tools for resilience planning, and (2) develop a mechanism to better inform utilities about grid resilience efforts at the National Laboratories. DOE agreed in principle with these recommendations, but its proposed actions do not fully address GAO's concerns.

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March 2021

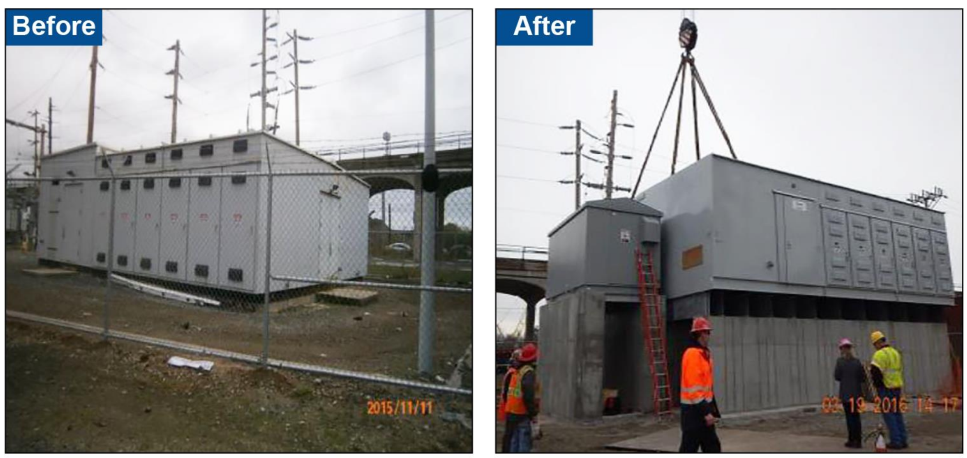
# ELECTRICITY GRID

## Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes

## What GAO Found

Since 2012, utilities have taken steps to improve grid resilience to severe hurricanes, such as (1) implementing storm hardening measures to enable the grid to better withstand the effects of hurricanes; (2) adopting technologies to enhance operational capacity and help quickly restore service following disruptions; and (3) participating in mutual aid programs with other utilities and training and planning exercises. For example, utilities have implemented storm hardening measures that include elevating facilities and constructing flood walls to protect against storm surges. Utilities have also adopted technologies that enhance communication capabilities and monitor systems to detect, locate, and repair sources of disruptions. However, these utilities reported challenges justifying grid resilience investments to obtain regulatory approval, and some utilities have limited resources to pursue such enhancements.

**Example of Hurricane Resilience Improvement: Elevated Substation**




Source: Public Service Enterprise Group, agent of Long Island Power Authority. | GAO-21-274

Various federal agencies can provide funding for efforts to enhance grid resilience to hurricanes, including the Department of Agriculture (USDA) and the Federal Emergency Management Agency (FEMA). However, eligibility for most federal funding for grid resilience, including some USDA and FEMA funding, is limited to publicly owned utilities and state, tribal, and local governments. The Department of Energy (DOE) does not provide direct funding for grid resilience improvements, but it has efforts under way, including through its National Laboratories, to provide technical assistance and promote research and collaboration with utilities. DOE has also initiated preliminary efforts to develop tools for resilience planning, including resilience metrics and other tools such as a framework for planning, but DOE does not have a plan to guide these efforts. Without a plan to guide DOE efforts to develop tools for resilience planning, utilities may continue to face challenges justifying resilience investments. In addition, DOE lacks a formal mechanism to inform utilities about the efforts of its National Laboratories. Such a mechanism would help utilities leverage existing resources for improving grid resilience to hurricanes.

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## Abbreviations

| | |
|---|---|
| AMI | Advanced metering infrastructure |
| BRIC | Building Resilient Infrastructure and Communities |
| CDBG-DR | Community Development Block Grant Disaster Recovery |
| Con Edison | Consolidated Edison Company of New York |
| DOE | Department of Energy |
| EEI | Edison Electric Institute |
| FEMA | Federal Emergency Management Agency |
| FLISR | Fault Location, Isolation, and Service Restoration |
| GMLC | Grid Modernization Laboratory Consortium |
| HMGP | Hazard Mitigation Grant Program |
| HUD | Department of Housing and Urban Development |
| ICE | Interruption Cost Estimate |
| LBNL | Lawrence Berkeley National Laboratory |
| MISO | Midcontinent Independent System Operator |
| NAERM | North American Energy Resilience Model |
| NRECA | National Rural Electric Cooperative Association |
| NYSERDA | New York State Energy Research and Development Authority |
| PA | Public Assistance Program |
| PREPA | Puerto Rico Electric Power Authority |
| PSE&G | Public Service Electric and Gas Company |
| RUS | Rural Utilities Service |
| SCADA | Supervisory Control and Data Acquisition |
| USDA | U.S. Department of Agriculture |

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Congressional Addressees

Hurricanes pose significant threats to the electricity grid in U.S. coastal areas and territories and are a leading cause of major power outages. In 2012, Hurricane Sandy interrupted electricity service to about 8.5 million customers in 24 states across the northeastern and mid-Atlantic U.S. for several months. In 2017, Hurricane Irma struck, causing power outages for 6.7 million customers in Florida—64 percent of all customers in the state—about 100,000 of whom remained without power for over a week. Hurricanes Irma and Maria hit the island of Puerto Rico within two weeks of each other and damaged the island's electricity grid, resulting in the longest blackout in U.S. history. In response, federal agencies, including the Federal Emergency Management Agency (FEMA), provided about $3.9 billion beginning in 2017 to help restore electricity service in Puerto Rico; this effort included temporary or partial repairs.[1]

According to the Department of Energy's (DOE) Quadrennial Energy Review, extreme weather—including hurricanes, blizzards, heat waves, and thunderstorms—is the leading cause of power outages in the United States.[2] Moreover, the growing severity of extreme weather events in recent years has been a principal contributor to an increase in the frequency and duration of U.S. power outages. According to the Congressional Budget Office, extreme weather events are projected to worsen in the future due to climate change.[3] Adoption of technologies and

[1]GAO, *Puerto Rico Electricity Grid Recovery: Better Information and Enhanced Coordination Is Needed to Address Challenges*, GAO-20-141 (Washington, D.C.: Oct. 8, 2019).

[2]Department of Energy, Quadrennial Energy Review (QER) Task Force, *Transforming the Nation's Electricity System: The Second Installment of the QER* (Washington, D.C.: January 2017).

[3]Congressional Budget Office, *Potential Increases in Hurricane Damage in the United States: Implications for the Federal Budget* (June 2016).

other measures could improve the resilience of the electricity grid so that it can better withstand and rapidly recover from severe weather.[4]

Electric utilities, industry regulators, and other stakeholders play various roles in the deployment of technologies that could enhance grid resilience. The federal government also plays a significant role in supporting grid resilience through various funding, research and development, and information-sharing initiatives. In particular, DOE leads federal grid resilience efforts in coordination with the U.S. Departments of Homeland Security, Housing and Urban Development (HUD), and Agriculture (USDA). DOE also conducts research and development and provides analytical support for efforts that aim to ensure the resilience of the electricity grid.

GAO was asked to review the federal government's preparedness, response, and recovery efforts for disasters that occurred in 2017. This report is part of a larger body of work we are conducting on various disaster response and recovery issues, and it follows up on our previous reports that examined the restoration of Puerto Rico's electricity grid after the 2017 hurricane season.[5] Specifically, this report examines (1) measures that utilities in selected states have adopted to enhance grid resilience following major hurricanes since 2012 and any challenges these utilities face in funding such measures; and (2) federal efforts to support the adoption of measures to enhance grid resilience to hurricanes and any opportunities that exist to improve these efforts.

To address both of these objectives, we identified 20 states that have experienced hurricanes and received federal support related to grid

[4]For the purposes of this report, grid resilience refers to preparing for, withstanding, and rapidly recovering from significant service disruptions caused by extreme events, such as hurricanes. Presidential Policy Directive 21 states that the term "resilience" means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. See White House, Office of the Press Secretary, *Presidential Policy Directive—Critical Infrastructure Security and Resilience Presidential Policy Directive/PPD-21* (Washington, D.C.: Feb. 12, 2013).

[5]GAO-20-141; GAO, *Puerto Rico Electricity: FEMA and HUD Have Not Approved Long-Term Projects and Need to Implement Recommendations to Address Uncertainties and Enhance Resilience*, GAO-21-54 (Washington, D.C.: Nov. 17, 2020).

resilience in 2012 through 2020.[6] We analyzed reports and federal agency data for descriptions and funding levels of grid resilience projects. We analyzed federal policy, planning, and guidance documents from DOE, FEMA, HUD, and USDA, as well as documents, reports, and studies to summarize information and views from utilities and state, federal, and electric utility industry stakeholders.[7] In addition, we reviewed reports that we identified as relevant to grid resilience plans and efforts from selected state commission dockets, the Congressional Budget Office, the Congressional Research Service, DOE, the National Laboratories, and nongovernmental organizations such as nonprofits and research institutes. Further, we reviewed prior GAO reports describing the federal role in enhancing grid resilience and funding sources, and our prior recommendations to address challenges hindering grid recovery.

We interviewed representatives of federal and state government agencies involved in utilities' grid resilience efforts, public utility commission officials responsible for evaluating the financing of resilience enhancements, and other stakeholders that play various roles in the development and deployment of technologies that could enhance grid resilience. These included officials from the National Laboratories, the Institute of Electrical and Electronics Engineers, and 16 utilities in the states we reviewed. We interviewed officials from investor-owned, cooperative, and publicly owned utilities of varying customer base size and geographic location.[8] To gain a more comprehensive view of industry perspectives, we also interviewed officials at three organizations that represent these types of utilities: the Edison Electric Institute (EEI), the National Rural Electric Cooperative Association, and the American Public Power Association. We identified these stakeholders by reviewing documents and obtaining recommendations during our interviews about others knowledgeable about grid resilience efforts. We also interviewed officials from federal

[6]The states we selected were Alabama, Connecticut, Delaware, Florida, Georgia, Hawaii, Louisiana, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Texas, Vermont, and Virginia.

[7]We did not include the Department of Defense in our analysis of federal efforts to support the adoption of measures to enhance grid resilience to hurricanes although the department has a significant role in grid resilience on military bases.

[8]To characterize utility officials' views throughout this report, we defined modifiers to quantify the views of the 16 utilities we interviewed as follows: "nearly all" represents officials from 14 or 15 utilities; "most" represents officials from 11 to 13 utilities; "many" represents officials from eight to 10 utilities; "several" represents officials from five to seven utilities; and "some" represents officials from two to four utilities.

agencies, including DOE, FEMA, HUD, and USDA's Rural Utilities Service (RUS).

We conducted this performance audit from May 2020 to March 2021, in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Background

## The Electricity Grid and the Impact of Hurricanes

The electricity grid involves three distinct functions: generation, electricity transmission, and electricity distribution. Electricity is generated at power plants by burning fossil fuels; through nuclear fission; or by harnessing renewable sources such as wind, solar, geothermal, or hydropower. Once electricity is generated, it is sent through the electricity grid, which consists of high-voltage, high-capacity transmission systems, to areas where it is transformed to a lower voltage and sent through the local distribution system for use by residential and other customers. Throughout this process, a grid operator or utility must constantly balance the generation and consumption of electricity. To do so, grid operators monitor electricity consumption from a centralized location using information systems and send minute-by-minute signals to power plants to adjust their output to match changes in demand.

Hurricanes can produce dangerous conditions—such as high winds, storm surge, and flooding—that cause significant damage to the electricity grid. These conditions are estimated to result in increased recovery costs in several hurricane-prone U.S. locations. Storm surge is an abnormal rise of waters (generated by a storm's winds) that can reach heights well over 20 feet, span hundreds of miles of coastline, and travel several miles inland, causing significant damage, particularly along coastal areas. Flooding is the major threat from storms for people living inland. There are two general types of flooding: flash and long term. Flash flooding, defined as a rapid rise in water levels, can occur quickly due to intense rainfall. Long-term flooding caused by rising waters in rivers and streams can persist for several days after a storm. Hurricane-force winds (i.e., 74 miles per hour or more) can stay above hurricane strength well inland, where debris such as signs, roofing material, siding, and other items may become flying hazards.

Power lines and transformers used to provide electricity to customers are particularly susceptible to damage from severe weather.[9] For example, in 2017, Hurricanes Maria and Irma combined to produce storm surges, flooding, and high winds that knocked down 80 percent of Puerto Rico's utility poles and all transmission lines, resulting in the loss of power to essentially all of the island's 3.4 million residents, according to the National Oceanic and Atmospheric Administration. As of November 2020, FEMA obligated approximately $10 billion in funding and HUD awarded about $1.9 billion in grants to rebuild the grid in Puerto Rico.[10] In 2016, the Congressional Budget Office identified the 10 U.S. states most likely to incur damage from hurricanes—Florida, Georgia, Louisiana, Massachusetts, Mississippi, New Jersey, New York, North Carolina, South Carolina, and Texas—and concluded that, over time, the costs associated with hurricane damage will increase more rapidly than the economy will grow.[11]

## Key Stakeholders in the Electric Utility Industry

Providing safe and reliable electricity to consumers involves several key stakeholders, including utilities, state commissions and energy offices, and federal agencies.

There are three types of electric utilities:

- **Investor-owned utilities.**[12] Investor-owned utilities are large, private, electric utilities that issue stock owned by shareholders. Almost three-quarters of utility customers get their electricity from investor-owned utilities, which are most prevalent in heavily populated areas on the

[9]Congressional Research Service, *Hurricanes and Electricity Infrastructure Hardening* (Sept. 20, 2017).

[10]GAO-21-54.

[11]Specifically, the Congressional Budget Office estimated that the expected annual damage amounted to 0.16 percent of GDP (or about $28 billion); by 2075, however, that figure is expected to reach 0.22 percent (equivalent to about $39 billion in today's economy). Congressional Budget Office, *Potential Increases in Hurricane Damage*.

[12]The Edison Electric Institute is a trade association that represents investor-owned utilities. According to EEI, its member utilities provide electricity to about 220 million Americans and operate in all 50 states and the District of Columbia.

East and West coasts of the United States. In 2017, 168 investor-owned electric utilities served an average of 654,600 customers.[13]

- **Publicly owned utilities.** Publicly owned utilities include federal-, state-, and municipal-run utilities.[14] The U.S. has 1,958 publicly owned electric utilities with an average of 12,100 customers each. The largest U.S. publicly owned utility is the Puerto Rico Electric Power Authority (PREPA), which serves 1.47 million customers.[15]
- **Electric cooperatives.**[16] Electric cooperatives are not-for-profit, member-owned utilities and are located in 47 states. Cooperatives are most prevalent in the Midwest and Southeast. There are 812 electric cooperatives in the U.S., serving an average of 24,500 customers each. According to DOE, electric cooperatives tend to serve customers in rural areas that were not historically served by other utilities.[17] Electric cooperatives' members vote for representatives to the Board of Directors who oversee operations and return any revenue in excess of costs to their respective members.

Responsibility for regulating the electricity industry is divided between the states and the federal government. Most electricity customers are served by electric utilities that are regulated by the states, generally through state public utility commissions or equivalent organizations. State public utility commissions regulate utility management, operations, electricity rate

[13]U.S. Energy Information Administration, *Investor-owned Utilities Served 72% of U.S. Electricity Customers in 2017* (Washington, D.C.: Aug. 15, 2019).

[14]Municipal utilities are owned by cities and counties and are generally regulated by a local government rather than by the states or federal government. The American Public Power Association (APPA) represents municipal utilities.

[15]U.S. Energy Information Administration, *Investor-owned Utilities*.

[16]The National Rural Electric Cooperative Association (NRECA) is the national service organization that represents the United States' electric cooperatives.

[17]Additionally, more than 250 distribution cooperatives and NRECA-member public power districts serve an estimated 4.2 million people in these counties, with poverty rates ranging from 20 percent to over 60 percent.

structures, and acquisitions.[18] State public utility commissions have a variety of responsibilities, such as approving utility investments in generation and distribution infrastructure, rates retail customers pay, and how those rates are set. In addition, other state entities, such as energy offices, can play a role in establishing policies and programs that support state goals, such as promoting the use of cleaner and more efficient energy through the use of renewable energy sources.[19]

## Utilities Have Adopted Measures to Enhance Grid Resilience, but Face Challenges Undertaking These Efforts

Since 2012, utilities in selected states have taken steps and adopted various measures to enhance grid resilience to hurricanes and other severe weather. These utilities have also adopted various technologies to enhance operational capacity and help quickly restore electricity service after disruptions caused by severe weather. Further, utilities in selected states have taken steps to enhance grid resilience by collaborating in mutual aid programs as well as training and planning exercises, among other efforts. However, utilities we interviewed identified challenges to funding grid resilience measures primarily related to (1) justifying resilience investments and obtaining regulatory approval, and (2) having limited resources to pursue resilience measures, including conducting research and development of grid resilience technologies.

### Utilities in Selected States Have Adopted Storm Hardening Measures to Improve Grid Resilience and

[18]State regulators approve utility investments either in advance of construction or afterwards when the utility seeks to recover costs in the rates it charges customers. Some states have integrated resource planning processes to determine what facilities should be built. The purpose of integrated resource planning is to meet future power demand by identifying the need for generating capacity and determining the best mix of resources to meet the need on a least-cost, system-wide basis. The integrated approach considers a broad range of feasible supply-side and demand-side options and assesses them with respect to financial, economic, and environmental impacts.

[19]For example, the Connecticut Department of Energy and Environmental Protection asserts that, among other things, it is charged with making cheaper, cleaner and more reliable energy available for state residents. Similarly, the New York State Energy Research and Development Authority (NYSERDA) seeks to lower energy bills, reduce emissions, create economic development, and improve energy system reliability.

## Minimize Damage from Flooding, Storm Surges, and High Winds

Utilities have adopted storm hardening measures to enable the grid to better withstand the impacts of severe weather events, such as hurricanes. Storm hardening measures include physical changes to grid infrastructure such as constructing flood walls, installing network protectors, elevating facilities, undergrounding electrical equipment, and utility pole management. Table 1 includes information about such measures.

**Table 1. Storm Hardening Measures Utilities Have Adopted since 2012**

| Storm hardening measure | Resilience characteristics | States with utilities that adopted measure |
|---|---|---|
| Flood protection and controls: constructing flood walls | Withstand flooding from storm surges. | New York, Texas |
| Flood protection and controls: installing network protectors | Provide protection against flooding and insulate electrical equipment, which enables effective functioning when submerged. | New York |
| Elevating electrical facilities | Decreases the likelihood that water from flooding will inundate electrical facilities. | Florida, Georgia, New Jersey, New York, North Carolina, South Carolina, Texas, Virginia |
| Undergrounding equipment | Make power lines less susceptible to damage and reduce storm-related outages. | Florida, Georgia, New York, North Carolina, Texas, Virginia |
| Pole management | Inspect, repair, and replace utility poles that may be susceptible to damage from high winds. | Florida, Hawaii, Louisiana, New Jersey, New York, North Carolina, Texas, Virginia |

Source: GAO analysis of electric utility information. | GAO-21-274

## Flood Protection and Controls

DOE has identified flooding from storm surges as the most prevalent cause of damage to substations in coastal regions. In response, some utilities in selected states have taken various flood protection measures to prevent damage from flooding and storm surge during severe weather events such as hurricanes. Flood protection measures include the following:

- **Constructing floodwalls.** Floodwalls are often made of concrete or steel and are designed specifically to prevent flooding of electrical equipment and facilities. Most floodwalls were built decades ago, according to DOE. Some utilities, however, have constructed floodwalls since 2012. For example, in New York, Consolidated Edison Company of New York (Con Edison) has constructed more than 3.3 miles of floodwalls—some 6 feet high—around critical equipment (e.g., substations) since Hurricane Sandy in 2012.[20] Con

[20]According to Con Edison documents, it spent $847 million on a broad upgrade project. In addition to floodwalls, these measures included installation of over 800 submersible transformers and network protectors, more than 3,500 waterproofing seals in conduits, and 270 watertight flood doors in electric substations and steam generating stations. Consolidated Edison Company of New York, Inc., *Con Edison Close To Completing $1 Billion In Post-Sandy Storm Protections* (October 2016).

Edison officials stated that these floodwalls allow normal access to the substation while protecting it in the event of flooding.[21]

- **Installing network protectors.** Network protectors are designed to detect when there is an abnormal power flow from a utility to an end user. Network protectors also insulate electrical facility equipment from flooding, thereby enabling the equipment to function when submerged in water. In such a circumstance, the network protector can physically disconnect and isolate the fault, which enables grid operators to take remedial action and reduce the risks of damage to an electrical facility and equipment.

## Elevating Facilities

Electrical equipment and facilities may be elevated above flood levels, as another form of storm hardening.[22] For example, in 2013, FEMA recommended that local communities require certain structures to be elevated in accordance with specified risk categories.[23] To that end, critical equipment in commercial buildings serviced by Con Edison in New York was relocated to higher elevations. Also, a New Jersey-based electric utility, the Public Service Electric and Gas Company (PSE&G), raised seven substations above flood level, which protects 96,323 customers from service disruptions that could occur because of flooding at these substations. Officials we interviewed from PSE&G told us that this was part of a 5-year, $1.2 billion project to elevate 18 substations that

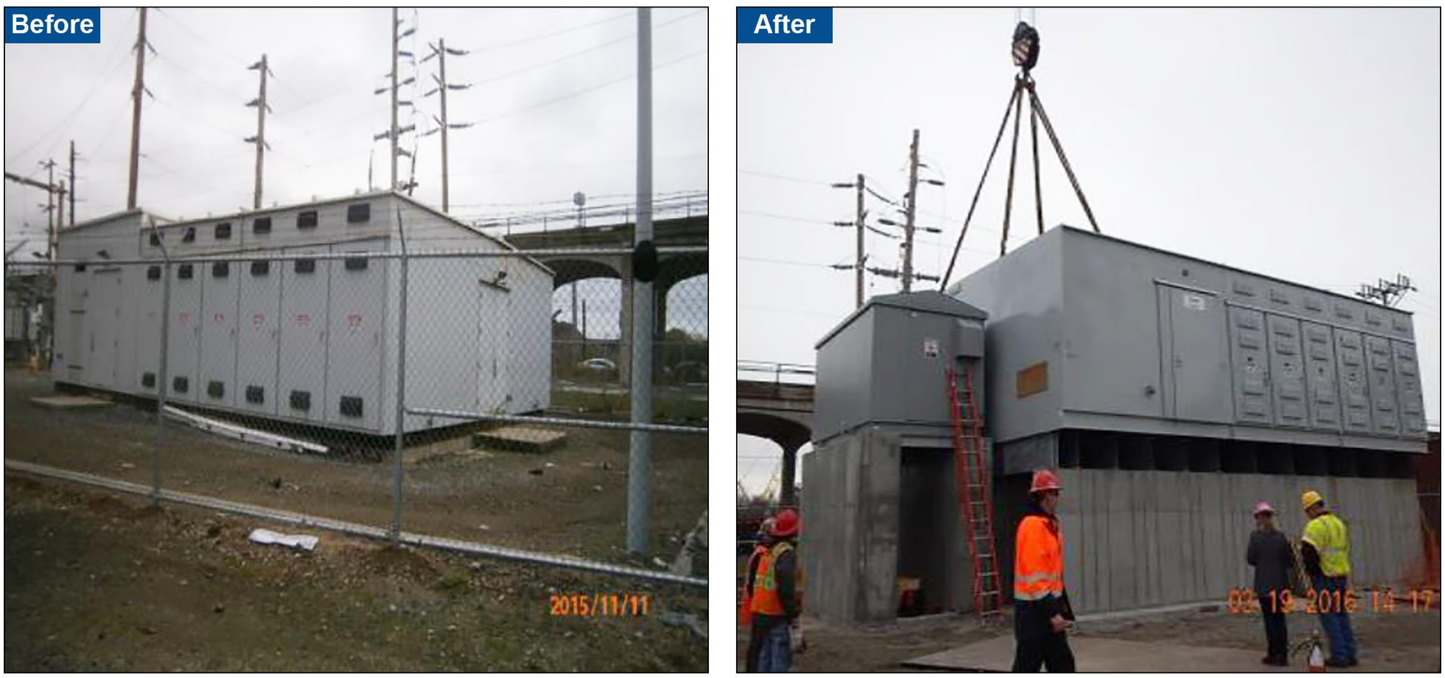
[21]Substations provide crucial links for electricity generation and serve as key nodes for linking transmission and distribution networks to end-use customers. Additionally, a substation generally contains transformers, protective equipment (e.g., relays and circuit breakers), switches for controlling high-voltage connections, electronic instrumentation to monitor system performance and record data, and fire-fighting equipment in the event of an emergency. U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, *United States Electricity Industry Primer*, DOE/OE-0017 (July 2015).

[22]The National Flood Insurance Program restricts the placement of electrical equipment and wiring in buildings in Special Flood Hazard Areas (i.e., land areas subject to a 1 percent or greater chance of flooding in any given year). Such equipment and wiring must generally be above the elevation of flooding having a 1 percent chance of being equaled or exceeded in any given year. Local utilities may also have additional requirements that dictate the location of electrical service components. Federal Emergency Management Agency, *Flood Protection and Elevation of Building Utilities*, RA4 (April 2017).

[23]FEMA recommends that utility systems within Special Flood Hazard Areas must be located at or above elevation of flooding (having a 1 percent chance of being equaled or exceeded in any given year) per National Flood Insurance Program criteria. Moreover, FEMA recommends that all utility systems be elevated as high as practicable for existing, non-Substantially Damaged and non-Substantially Improved construction (see FEMA P-348, Edition 2-Table 4-1). FEMA, *Flood Protection and Elevation of Building Utilities*.

flooded during Hurricane Irene and Sandy. Additionally, CenterPoint, a Texas-based utility, rebuilt and elevated its Galveston substation after the storm surge during Hurricane Ike destroyed it in 2008; the utility repeated the same actions for a substation farther inland after Hurricane Harvey in 2017.[24] Figure 1 shows an elevated substation.

**Figure 1: Elevated Substation in New York to Protect from Flooding**




Source: Public Service Enterprise Group, agent of Long Island Power Authority. | GAO-21-274

## Undergrounding Facilities and Equipment

Power outages from hurricanes are often the result of damage to power lines caused by high winds. To reduce the risk of damage from high winds, some utilities in selected states have placed certain facilities and equipment underground. Placing infrastructure, such as power lines and electrical equipment, in underground trenches and enclosures may require special insulation, such as encasement in conduits or steel pipes.

[24]One utility in Florida has initiated a pilot program to underground power lines in some neighborhoods. Additionally, a utility in North Carolina has undertaken efforts to raise some substations. Utilities in Georgia and North Carolina also elevated at-risk substations to protect against flooding or storm surge.

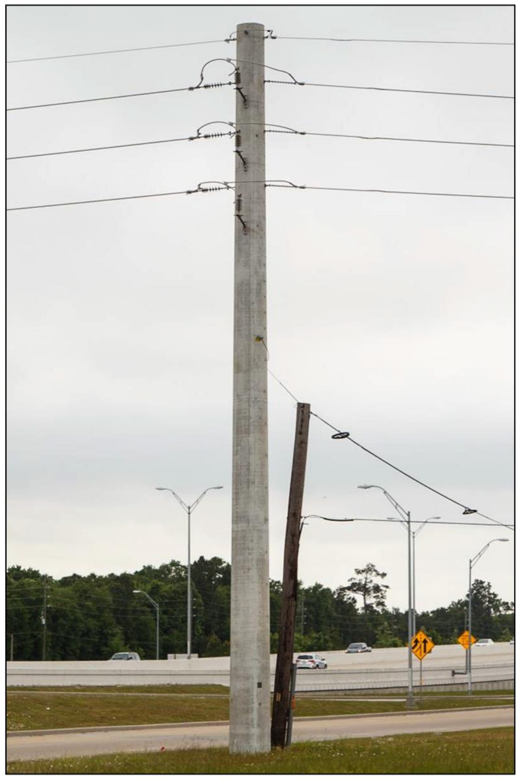
However, undergrounding facilities and equipment carries substantial costs that may preclude some utilities from adopting such measures. According to the Congressional Research Service, the cost of undergrounding power lines can be 5 to 10 times (or more) the cost of an overhead line. Additionally, the University of Florida and some Florida electric utilities conducted a study concluding that undergrounding overhead electric distribution systems is costly and that the costs exceed quantifiable benefits except in rare cases.[25] The study also concluded that the hurricane reliability of underground systems is not perfect due to the potential for storm surge damage. Additionally, officials from one utility we spoke with indicated that undergrounding could hamper grid reliability because underground facilities can be less visible and more difficult for service crews to reach. Also, several industry stakeholders agreed that undergrounding may be counterproductive in areas prone to flooding.

### Utility Pole Management

Pole management includes the inspection, repair, and replacement of utility poles and is another form of storm hardening that can improve grid resilience. Nearly all the utilities that we reviewed in selected states have pole management policies that require periodic inspection of their utility poles to determine whether to repair or replace them. Utilities vary in their pole inspection procedures. For example, some utilities inspect all poles annually, while others inspect a percentage of their poles at specific intervals over a prescribed period of time. Utilities then decide on the appropriate remedy—such as repair or replacement—required to address any defective poles. For example, some utilities repair poles by using composite material or replace wooden poles with stronger, more durable material such as metal or concrete (see fig. 2). These practices can improve grid resilience because the poles are better able to withstand high winds during hurricanes and other extreme weather events.

[25]This study also pointed out that no prior relevant study had recommended broad-based undergrounding, but several did recommend targeted undergrounding to achieve specific community goals. Utilities in Georgia, New York, North Carolina, Texas, and Virginia have adopted targeted undergrounding. Additionally, in New York, Con Edison adopted an innovative-targeted undergrounding strategy to realize the benefits of undergrounding while avoiding its significant costs. The utility has a large underground workforce that manages these undergrounded facilities, which is unique from utilities in other locations, according to Con Edison officials. InfraSource Technology, *Undergrounding Assessment Phase 1 Final Report: Literature Review and Analysis of Electric Distribution Overhead to Underground Conversion* (February 2007).

**Figure 2. Wooden Utility Pole Replaced with a Concrete Pole**



Source: CenterPoint Energy. | GAO-21-274

## Utilities in Selected States Have Adopted Technologies to Enhance Operational Capacity and Can Help Restore Power Quickly after Service Disruptions

Utilities have adopted automated technologies that enhance operational capacity and that can help provide quick restoration of electric service. For example, some automated technologies provide enhanced communication capabilities; monitor electrical systems to detect, locate, and repair sources of service disruptions; and continue service through part of the grid when the central grid experiences a service disruption. See table 2 for examples of automated technologies utilities have adopted that can enhance resilience.

**Table 2. Automated Technologies Utilities in Selected States Have Adopted since 2012**

| Automated technology | Resilience characteristics | State with utilities that adopted automated technology |
|---|---|---|
| Advanced metering infrastructure | Enables two-way communication between utilities and customers through an integrated system of smart meters, communications networks, and data management systems. | Florida, Georgia, Louisiana, New York, North Carolina, Texas |
| Equipment monitoring technology | Monitors and controls electrical equipment by reading meters and checking the status of sensors in regular intervals. | Georgia, Hawaii, Louisiana, New Jersey, New York, Texas, Virginia |
| Microgrids | Enable parts of the grid to independently maintain power during a larger service disruption. | Hawaii, New York, North Carolina, South Carolina |
| Self-healing grid technology | Minimizes service disruptions by automatically isolating damaged areas, rerouting to adjacent circuits, and notifying work crews. | Georgia, North Carolina, Texas |

Source: GAO analysis of electric utility information. | GAO-21-274

## Advanced Metering Infrastructure (AMI)

AMI is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers. AMI can enhance grid resilience because it can improve a utility’s ability to identify and isolate outages, automatically and remotely measure electricity use, connect and disconnect service, detect tampering, and monitor power quality. Combined with customer technologies, such as in-home displays and programmable communicating thermostats, AMI also enables utilities to offer programs and incentives that help customers manage energy consumption and costs.

## Specialized Equipment Monitoring Software

Utilities use specialized equipment monitoring software, such as supervisory control and data acquisition (SCADA), to enhance grid resilience. SCADA is a central control system that gathers data from sensors and instruments throughout the system and relays the data to grid operators if an outage has occurred, which can reduce the duration of power outages. Some utilities we reviewed use a SCADA system as part of their grid resilience efforts.

## Microgrids

Microgrids are systems that can connect to and disconnect from the grid, depending on operating conditions, in order to maintain power for a small area independent of the grid if the grid encounters service disruptions as a result of an extreme weather event, such as a hurricane. In such circumstances, the microgrid operates autonomously to provide power to customers. Microgrids can improve grid resilience by absorbing and withstanding the effects of extreme weather events and providing power to end users, including critical infrastructure such as hospitals. In addition, microgrids can provide black start services—the provision of the power necessary to restore a generation plant when power from the grid is unavailable during a major outage. Our review of selected states identified some utilities in four states that plan to or have integrated microgrids into their systems.

## Self-Healing Grid Technology

Fault Location, Isolation, and Service Restoration (FLISR) technology, sometimes referred to as self-healing grid or self-optimizing technology, assesses the grid and automatically responds to problems. This is possible through the widespread deployment of sensors and other intelligent devices—such as SCADA—as well as distribution and outage management systems, grid analytics, models, and data processing tools. These technologies work in tandem to automate power restoration by automatically isolating faults and restoring service to remaining customers. This can reduce the number of customers that experience service disruptions, as well as the length of those disruptions. For example, in 2014, DOE reported that FLISR operations showed up to a 45 percent reduction in the number of customers who experienced service interruptions; up to a 51 percent reduction in customer minutes of interruption; and about 270,000 fewer customers who experienced sustained interruptions (greater than 5 minutes) compared to estimated outcomes without FLISR. Officials from some utilities that have incorporated FLISR technology into their grid reported that since adopting the technology, they have experienced fewer and shorter outages, lower outage costs, and reduced equipment failure.

## Utilities Have Collaborated with Stakeholders on Mutual Aid Programs, Training, and Exercises to Enhance Grid Resilience to Hurricanes

Most utilities in selected states have participated in several efforts with industry stakeholders to improve grid resilience. For example, through mutual assistance programs, utilities have collaborated with each other and industry stakeholders to develop plans that establish their respective roles and responsibilities for restoring power when significant service disruptions occur. Utilities and industry stakeholders have also collaborated on training and planning exercises.

### Mutual Assistance Programs

Mutual assistance programs support the industry's contingency planning and power restoration after major storms or other emergencies. Restoring power quickly after a major storm requires logistical expertise, skilled line workers, and specialized equipment. Utilities affected by significant outages often rely on these voluntary partnerships to help speed restoration efforts. Such mutual assistance programs are generally formed based on location and type of utility. Through such programs, utilities share information and resources such as emergency vehicles, equipment, and personnel. These utilities also participated in training exercises to determine roles and responsibilities. All of the utilities that we reviewed are partners in at least one mutual assistance program.

### Training and Planning Exercises

Training exercises help mutual aid members and others in the industry identify roles and responsibilities and share best practices. For example, with DOE support, the American Public Power Association held a mutual aid exercise in New York in 2019.[26] This included a tabletop exercise that involved a Category 5 hurricane impacting the U.S. Virgin Islands, Puerto Rico, and the Southeast and Northeast regions of the U.S. The exercise tested the capabilities of the public power mutual aid network, interagency coordination, and the tools and technologies used to support mutual aid coordination. Other stakeholders conduct training exercises that focus on grid resilience. For example, the Midcontinent Independent System Operator (MISO)—a regional grid operator that serves 15 states including

[26] There were a total of 50 participants from 32 different public power utilities and joint action/state associations, federal government partners, and industry partners from EEI.

Louisiana—coordinated annual drills focused on hurricane preparedness, and specific issues such as power system restoration. MISO typically conducts two drills during May that focus on communication and restoration activities.

## Utilities in Selected States Face Two Primary Challenges Adopting Resilience Measures: Justifying Investments and Limited Resources

Utility officials we interviewed identified two primary challenges to funding grid resilience measures: (1) justifying investments and obtaining regulatory approval, and (2) limited resources at some utilities to pursue resilience measures, including conducting research and development on grid resilience technologies.

### Justifying Investments and Obtaining Regulatory Approval

Most utilities recover the cost of resilience measures through rates paid by the utilities' customers. Specifically, to recover costs through rates, investor-owned utilities we spoke with must obtain approval from the state public utility commission.[27] According to utility and National Laboratories officials we interviewed, it can be challenging to justify and obtain approval for investments in resilience measures because (1) utility commissions can be hesitant to approve investments that could affect customer rates; (2) it can be hard to justify large investments to prepare for events that may occur infrequently, such as hurricanes; and (3) there are no clear metrics for grid resilience, making it hard to quantify the costs and benefits associated with investments in resilience measures. For example, officials from several utilities and some National Laboratories we interviewed said that the lack of resilience metrics, and the challenges quantifying the benefits of resilience, have made it challenging for utilities to justify the costs of some resilience measures to their regulators.[28]

[27]Non-utilities, which may include entities such as electric cooperatives, are not subject to this type of review by a state commission, but officials told us they undergo similar rate adjustment reviews within their boards.

[28]DOE oversees 17 National Laboratories, which are charged with conducting research and development on behalf of DOE and can perform such work for other federal agencies and nonfederal or private entities, including utilities.

### Limited Resources

Officials at all of the publicly owned utilities and electric cooperatives, as well as several investor-owned utilities and regulators we interviewed, told us that they have limited resources to undertake resilience enhancements or pursue new technologies or tools that could enhance resilience planning. For example, officials from USDA's Rural Utilities Service (RUS) and one industry stakeholder group told us that rural utilities often have higher costs, due to the ratio of service area size to the number of customers, as well as more low-income customers, making it more challenging to recover the cost of investments through electricity rates. Further, small, rural utilities have limited staff and resources to focus on grid resilience, according to officials from one industry stakeholder group that represents small rural utilities. Officials from one small rural utility said it only has 65 employees and lacks the resources to hire staff that can dedicate their time to grid resilience. Officials from some utilities said that applying for federal funding that could be used to enhance grid resilience and complying with federal program requirements can be burdensome.

### Other Challenges

Utility officials also identified a variety of other challenges that can arise when pursuing grid resilience measures. For example, officials from several utilities and regulators we spoke with cited vegetation management as a key challenge, since trees and vegetation are common contributors to outages and can be challenging to maintain in a way that minimizes the threat posed to the grid during storms.[29] In addition, officials from some utilities stated that convincing customers to allow utility companies to place poles or other structures on their property can be challenging, even when those structures could enhance grid reliability or resilience during storms.

## Various Federal Programs Can Be Used to Support Efforts to Enhance Resilience to

[29]We previously reported that poor vegetation management practices contributed to increased damage to Puerto Rico's grid during Hurricane Maria. See GAO*, 2017 Hurricane Season: Federal Support for Electricity Grid Restoration in the U.S. Virgin Islands and Puerto Rico*, GAO-19-296 (Washington, D.C.: Apr. 18, 2019).

## Hurricanes, but Opportunities Exist to Improve Federal Support

Various federal agencies—including FEMA, HUD, and USDA—can provide funding for efforts to enhance grid resilience, but eligibility for most federal funding is limited to publicly owned utilities and state, local, tribal, and territorial governments. DOE and the National Laboratories do not provide direct funding to utilities, but they have efforts under way that address grid resilience to hurricanes, collaborate with utilities to operationalize technologies, and support grid resilience through basic research. Furthermore, opportunities exist for DOE and its National Laboratories to better support investments in grid resilience.

### Federal Programs Can Provide Funding or Technical Assistance for Some Utilities Investing in Grid Resilience Measures

Eligibility for most federal funding for grid resilience is limited to publicly owned utilities and state, local, tribal, and territorial governments. Investor-owned utilities—which serve the largest share of customers in hurricane-prone states—are generally not eligible for federal funding under these programs. In addition, officials from some utilities said that applying for federal funding and complying with federal program requirements can be burdensome.[30] Table 3 describes federal funding from FEMA, HUD, and USDA that can be used to support grid resilience to hurricanes.

[30]In our July 2015 report on Hurricane Sandy, we found that different federal disaster response programs are initiated at different times, making it challenging for state and local officials to determine how to use federal funds in a comprehensive manner. Specifically, 12 of the 13 states and cities that we surveyed responded that navigating the multiple funding streams and various regulations was a challenge that affected their ability to maximize disaster resilience opportunities. GAO, *Hurricane Sandy: An Investment Strategy Could Help the Federal Government Enhance National Resilience for Future Disasters*, GAO-15-515 (Washington, D.C.: July 30, 2015). In addition, we previously reported that Community Development Block Grant for Disaster Recovery (CDBG-DR) grantees have faced challenges coordinating the use of these funds with other disaster recovery programs that are initiated at different times and administered by other agencies. GAO, *Disaster Recovery: Better Monitoring of Block Grant Funds Is Needed*, GAO-19-232 (Washington, D.C.: Mar. 25, 2019).

**Table 3: Federal Support That Can Be Used for Grid Resilience Efforts**

| Federal agency | Program | Description | Funding |
|---|---|---|---|
| Federal Emergency Management Agency (FEMA) | Public Assistance Program | Federal disaster grant assistance to state, local, tribal, and territorial governments and certain types of private nonprofit organizations to help them respond to and recover from major disasters or emergencies. Category F covers publicly owned utilities. | $4.2 billion in category F funds obligated from 2012 to October 2020 in selected states[a]<br>Approximately $10 billion obligated for grid recovery in Puerto Rico in November 2020. |
| | Hazard Mitigation | Funding to state, local, tribal, and territorial governments so they can rebuild in a way that reduces, or mitigates, future disaster losses in their communities. | Approximately $89 million obligated for utility-related mitigation in selected states since 2012.[b] |
| | Building Resilient Infrastructure and Communities | New pre-disaster hazard mitigation program. Grants applied to projects that help reduce risk to critical systems, such as the grid, before a disaster and to quickly stabilize a community after disaster by preventing cascading impacts. | None. Grant application period opened in fall 2020. |
| Department of Housing and Urban Development (HUD) | Community Development Block Grant for Disaster Recovery (CDBG-DR) | Provides funding to address needs not met by other disaster recovery programs after a disaster, which can include projects to enhance resilience to hurricanes. HUD officials told us that HUD funding has typically been invested in water facilities, rather than in electricity grids. | $47.3 million awarded in selected states since 2012.[c]<br>In addition, approximately $2 billion awarded to Puerto Rico and U.S. Virgin Islands in 2018.[d] |
| Department of Agriculture, Rural Utilities Service (RUS) | Electric Infrastructure Loan and Loan Guarantee Program | Includes financing for construction of electric system enhancements in rural areas. Requires adoption of RUS design standards, which do not specifically address resilience, but officials said adopting them improved system components and reliability, resulting in a more resilient system. | $2.3 billion loaned in 2019 for rural utilities in selected states; $3.2 billion in 2020. |

Source: GAO analysis of FEMA, HUD, and U.S. Department of Agriculture information. | GAO-21-274

Note: In the past, the Department of Energy (DOE) has provided funding that supported some grid resilience measures. The American Recovery and Reinvestment Act of 2009 provided DOE with $4.5 billion for activities to modernize the electric power grid and facilitate recovery from disruptions to the energy supply, among other things. Under the Smart Grid Investment Grant, DOE and the electricity industry jointly invested $8 billion in 99 cost-shared projects involving more than 200 participating electric utilities and other organizations to modernize the electric grid, strengthen cybersecurity, improve interoperability, and collect data on smart grid operations and benefits.

[a]Funding levels are approximate and may not be limited to electricity grid infrastructure.

[b]Funding amount excludes some projects that may not connect to the grid, such as funding for generators.

[c]HUD officials highlighted the $47.3 million as grid-specific projects, but noted that states receiving other CDBG-DR funds could have also used those for grid resilience enhancements, where eligible.

[d]We reported in November 2020 (GAO-21-54) that no projects using the grid-specific CDBG-DR funds had been approved in Puerto Rico.

## FEMA

FEMA funding can be used for grid resilience efforts through the following three programs.

- **FEMA Public Assistance (PA) program.** FEMA's PA program provides federal disaster grant assistance to state, local, tribal, and territorial governments and certain types of private nonprofit organizations to help them respond to and recover from major disasters or emergencies. Through its PA program, FEMA provides funds to support recovery, including (1) permanent work, which includes the restoration of and cost-effective hazard mitigation for disaster-damaged public utilities; and (2) management costs, which include expenses a recipient or subrecipient incurs in administering and managing projects, such as to develop and submit projects for FEMA's approval.[31]
- **Hazard Mitigation Grant Program (HMGP).** The HMGP provides funding to state, local, tribal, and territorial governments so they can rebuild in a way that reduces, or mitigates, future disaster losses in their communities. This grant funding is available after a presidentially declared disaster. HMGP is designed to improve community resilience—the ability to prepare and plan for, absorb, recover from, and more successfully adapt to disasters—to future disasters during recovery. Projects funded through this program are to improve the resilience of either disaster-damaged or undamaged facilities to future events of any kind. The program funds a wide range of projects such as purchasing properties in flood-prone areas, adding shutters to windows to prevent future damage from hurricane winds and rains, and rebuilding culverts in drainage ditches to prevent future flooding damage. To be eligible for HMGP funding, a project must conform to the state and local mitigation plans.
- **Building Resilient Infrastructure and Communities (BRIC).** BRIC is a FEMA pre-disaster hazard mitigation program that began in 2020.[32] States, local, tribal, and territorial governments with major disaster declarations in the past 7 years are eligible for assistance.

[31]FEMA PA funding is subject to a cost share. Generally, a recipient may be responsible for a cost share of up to 25 percent of the total eligible amount of grant assistance. FEMA officials told us that applicants' inability to provide their portion of FEMA cost-share initiatives—particularly in the current economic environment impacted by COVID-19—is the primary challenge that FEMA faces in supporting grid resilience efforts.

[32]The Building Resilient Infrastructure and Communities (BRIC) program replaces the Pre-Disaster Mitigation grant program.

According to FEMA documents, BRIC mitigation grants can go toward projects that help reduce risk to what FEMA calls “lifelines”—critical systems such as the electricity grid—before a disaster and quickly stabilize a community after a disaster by preventing cascading impacts. The BRIC grant application period opened in fall 2020.

In addition to its funding programs, FEMA has supported industry training and planning efforts. FEMA conducted a National Level Exercise in 2018 that examined the ability of all levels of government, private industry, and nongovernmental organizations to protect against, respond to, and recover from a major hurricane. FEMA published lessons learned from this exercise, which found that clear communication regarding power restoration prioritization allowed effective coordination and efficient use of limited resources, but that more work was needed to define the roles of utilities at operations centers and staging areas when responding to disasters. The document also noted several barriers and potential vulnerabilities to effective communication between electric utilities and government partners.[33]

### HUD

HUD’s Community Development Block Grant for Disaster Recovery (CDBG-DR) provides funding to address needs not met by other disaster recovery programs after a disaster, which can include disaster resilience-building projects. Communities can use CDBG-DR grants to address a wide range of unmet recovery needs—losses not met with insurance or other forms of assistance, including federal disaster assistance—related to housing, infrastructure, and economic revitalization.[34]

HUD officials we interviewed told us that HUD funding typically has been used to improve the infrastructure of water systems, rather than of electricity grids. Approximately $2 billion in HUD funding explicitly for electricity grid enhancements was awarded to Puerto Rico and the U.S. Virgin Islands after Hurricanes Irma and Maria caused damage to their

[33]Federal Emergency Management Agency, *National Level Exercise 2018: After-Action Report Executive Summary* (August 2018).

[34]When disasters occur, the federal government often appropriates CDBG-DR funding through supplemental appropriations. These appropriations often provide HUD the authority to waive or modify many of the statutory and regulatory provisions governing the CDBG program, thus providing states with greater flexibility and discretion to address recovery needs.

electricity grids in 2017. However, HUD officials told us this was a new use of CDBG-DR funding.[35] States including Florida and Georgia received CDBG-DR funding, but there was no requirement that grantees use the funding to improve the electricity grid.

## USDA

The Electric Infrastructure Loan and Loan Guarantee Program at USDA's Rural Utilities Service (RUS) provides financing to public and private utilities for the construction of electric distribution, transmission, and generation facilities, including system enhancements to improve service in rural areas, as well as other facilities such as demand side management. RUS officials told us that applicants must agree to adopt RUS design standards. According to these officials, while the RUS standards do not specifically address resilience, adopting these standards drastically improved system components and reliability, resulting in a more resilient system.

In fiscal year 2019, as part of this program, RUS financed $2.3 billion in projects in hurricane-prone states. These funds were not spent exclusively on resilience enhancements, but included upgrades to transmission and distribution lines and smart grid technologies.[36] For example, one project in Georgia included $591,000 to finance smart grid technologies that will enhance communications and provide real-time data to improve the reliability of the distribution system and help reduce outages caused by hurricanes.

## DOE

DOE and its National Laboratories do not have a program specifically targeted to provide funding to support the adoption of measures to enhance grid resilience to hurricanes, but they have efforts under way to collaborate with utilities to operationalize technologies or support grid

[35]The $2 billion included $1.9 billion for Puerto Rico and $68 million for the U.S. Virgin Islands. As we reported in November 2020, no projects using the $1.9 billion had been approved in Puerto Rico. GAO-21-54.

[36]Smart grid technologies include information and communications systems to automate actions with the aim of improving the electric grid's reliability and efficiency and facilitating the use of alternative energy sources.

resilience through state energy assurance plan development, basic research, and other efforts.[37] These efforts include:

- **Industry partnerships.** DOE and the National Laboratories have an array of partnerships with industry designed to support resilience planning efforts, including the Grid Modernization Laboratory Consortium (GMLC). According to DOE and National Laboratories officials, the GMLC is a strategic partnership between DOE and the National Laboratories that aims to bring together leading experts, technologies, and resources to collaborate on the goal of modernizing the nation's grid. The GMLC awards grants through its Grid Modernization Initiative in an effort to develop and validate approaches to enhance the resilience of distribution systems. While GMLC awards do not include direct funding to utilities for resilience enhancements, the initiative frequently includes utility partners. For example, in 2018, the initiative awarded approximately $6 million over three years to a partnership with industry to research the use of a microgrid to help isolate the effect of any damage and minimize outages to the grid.[38]
- **Resilience planning tools.** There are efforts within DOE and across the National Laboratories designed to support the development of tools that could aid in planning to enhance grid resilience. For example, one project involved five National Laboratories partnering with utilities on an effort to explore metrics related to the grid, including metrics focused on grid resilience. This project, led by Sandia National Laboratory, involved researchers developing—with input from utilities, municipalities, and other stakeholders—a set of proposed grid resilience metrics that can be tested and eventually applied by utilities.

  In addition, Lawrence Berkeley National Laboratory's (LBNL) Interruption Cost Estimate, or ICE calculator, is a tool used to

[37]In the past, DOE has provided funding that supported some grid resilience measures. The American Recovery and Reinvestment Act of 2009 provided DOE with $4.5 billion for activities to modernize the electric power grid and facilitate recovery from disruptions to the energy supply, among other things. Under the Smart Grid Investment Grant, DOE and the electricity industry jointly invested $8 billion in 99 cost-shared projects involving more than 200 participating electric utilities and other organizations to modernize the electric grid, strengthen cybersecurity, improve interoperability, and collect data on smart grid operations and benefits.

[38]In addition to researchers at Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and the National Renewable Energy Laboratory, the partnership included Duke Energy (an investor-owned utility), GE Grid Solutions, the University of North Carolina Charlotte, the University of Tennessee, and the Smart Electric Power Alliance.

estimate the cost and impact of power outages, including on economic productivity. The calculator allows planners to look at potential interruption costs and the benefits associated with investments that could enhance resilience. DOE and National Laboratories officials told us that this is a tool used extensively by utilities for planning and justifying the adoption of resilience measures, but that it was not effective for calculating costs from the types of long-term outages that could result from intense hurricanes. According to National Laboratories officials, the ICE calculator is based on customer surveys conducted by multiple utilities, economic modeling, and input from public utility commissions. As of October 2020, LBNL initiated an effort to partner with utilities they selected to update the ICE calculator because the underlying survey data were out of date and not geographically representative, according to DOE and industry officials.[39] This effort, which will be funded by participating utilities, aims to update the tool with more current and representative data by sometime in 2023.

In addition to efforts to develop performance measures and update the ICE calculator, officials at DOE's Office of Electricity are in the early stages of developing tools that focus on helping utilities and relevant stakeholders integrate distributed energy resources—such as solar technology, microgrids, and energy storage—that could enhance grid resilience. Once fully mature, the planning process could help position utilities to effectively integrate new resilience technologies and capabilities into their systems, according to DOE officials and documents. In addition, Argonne National Laboratory developed a state energy resilience plan that seeks to enable state and local governments, in conjunction with energy utilities, to identify resilience concepts, challenges, and vulnerabilities so that they can implement cost-effective and proven measures to enhance resilience. The plan comprises five steps that state and local governments can use to link broad resilience concepts to the implementation of actions tailored to their individual needs and capabilities. In addition, the National Renewable Energy Laboratory developed a resilience roadmap that includes guidance for federal, state, and local entities to plan for resilience at the regional level.[40]

[39]Specifically, the tool uses survey data gathered from as early as 1989, and the most recent survey was conducted in 2012.

[40]E. Hotchkiss and A. Dane, *Resilience Roadmap: A Collaborative Approach to Multi-Jurisdictional Resilience Planning* (Golden, CO: National Renewable Energy Laboratory, 2019). See also https://www.nrel.gov/resilience-planning-roadmap/.

- **Modeling.** Various models developed by the National Laboratories can help utilities prepare for and respond to major weather-related outages such as those caused by hurricanes. For example, Argonne has developed the Hurricane Customer Outage Forecasting Model, which is designed to predict the path of a storm in real time and its impact on customer outages and utility assets. In addition, DOE, its National Laboratories, and industry stakeholders are collaborating on a variety of modeling tools, including the North American Energy Resilience Model (NAERM), which aims to develop a comprehensive resilience model for the infrastructure of the North American energy sector. According to DOE documents, NAERM aims to assist industry in assessing the resilience implications of energy planning decisions for associated infrastructure. As of December 2020, DOE had not yet deployed the model. It is unclear how NAERM could support local electric utilities' efforts to enhance grid resilience to events such as hurricanes. DOE officials we interviewed told us that once the model is live, it may be useful for utilities planning the siting of transmission lines.
- **Development of energy storage technology.** The Pacific Northwest National Laboratory is developing a program called the Grid Storage Launchpad, which aims to accelerate development of next-generation energy storage technology. In addition to the goal of aiding the development of less costly storage options—which may result in lower-cost options for utilities looking to enhance grid resilience—the project also aims to develop and promulgate grid performance standards and requirements for energy storage. As we reported in May 2018, storage can provide services that support resilience by helping features of the grid adapt to changing conditions and potentially disruptive events and, if a disruptive event occurs, to rapidly recover.[41] Specifically, in the event of an outage during which power sources or power lines become unavailable, storage can respond quickly to provide backup power or black start services—the provision of the power necessary to restore a generation plant when power from the grid is unavailable during a major outage. In addition, energy storage can support microgrids that could maintain power for a small area independent of the larger grid.

[41]GAO, *Energy Storage: Information on Challenges to Deployment for Electricity Grid Operations and Efforts to Address Them*, GAO-18-402 (Washington, D.C.: May 24, 2018).

## Opportunities Exist for DOE to Enhance Efforts to Develop Tools for Resilience Planning and Improve Access to National Laboratory Resources

Opportunities exist for DOE and its National Laboratories to enhance efforts to develop tools for resilience planning and improve access to National Laboratory resources. As described above, DOE has a range of efforts under way to enhance grid resilience. These efforts include steps that DOE's Office of Electricity has taken to develop new tools and enhance existing tools for resilience planning in three areas: performance measures, a framework for planning, and information on the cost of power outages. However, DOE has not established a plan to guide efforts to develop these three key tools for resilience planning.

For example, upon concluding the GMLC-led research exploring potential metrics for the grid, including one project focused on resilience, researchers issued a summary report in April 2020 that recommended that next steps include conducting additional work with utilities to test and validate the proposed metrics.[42] In addition to this report, DOE has funded some case studies to explore metrics related to the costs of power outages, but DOE officials we interviewed did not identify a plan for how resilience metrics might be further developed or validated in the future. Moreover, officials said that before further developing resilience metrics, DOE, utilities, regulators, and other stakeholders need to do more work to establish a framework for resilience planning that would account for a range of possible threats to the grid. This framework could help enhance grid resilience by identifying the primary threats to the grid, identifying considerations for how utilities should prioritize these threats, and providing tools or an analytical approach that utilities and other stakeholders could use to weigh different resilience alternatives, according to DOE officials. Officials also told us that such a framework for resilience planning is needed to support utilities' ability to work with state entities, including their regulators, to justify resilience investments.

As mentioned above, DOE and the National Laboratories have completed preliminary efforts that could inform a broader resilience planning framework. For example, Argonne National Laboratory's state energy resilience plan includes ways for utilities to identify grid vulnerabilities and consider different measures to enhance resilience. Similarly, DOE

[42]Pacific Northwest National Laboratory, et al., *Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience,* PNNL-28567 (Richland, WA: April 2020).

officials shared a more recent effort related to developing a potential framework. Specifically, DOE partnered with industry stakeholders on a white paper identifying the need for a resilience framework and appropriate metrics to use within that framework. This paper, which was published in October 2020, included specific recommendations for what a framework and metrics could look like, with existing examples that could be used as a model.[43] However, DOE has not developed a plan to operationalize this and other preliminary efforts so that they result in tools that utilities can use for resilience planning.

In addition, LBNL is working with utilities to update the ICE calculator tool, but this update will not expand the calculator to include the ability to estimate costs for long-term outages like those caused by hurricanes. LBNL officials told us that expanding the calculator to include this capability could provide a needed tool to utilities. These officials said they hope to gather some preliminary data during the planned update that could be used in future efforts to further expand the calculator's capacity to estimate the costs of long-term outages. However, they told us that they do not have the resources to expand the ICE calculator to address long-term outage costs. Further, DOE officials told us that the agency currently has no plans to fund efforts to expand the ICE calculator or create a new tool that could provide this capability because gathering survey data from customers for this purpose would be costly and poses technical challenges. In addition, DOE officials stated that other steps need to be taken before a tool to estimate long-term outage costs could be applied, including developing a framework for resilience planning. However, there is no framework for planning for resilience, nor is there a plan to develop such a framework, which would improve the ability of a tool such as the expanded ICE calculator to quantify the costs and benefits associated with resilience investments.

According to GAO's Disaster Resilience Framework, federal efforts should help decision makers identify and select among disaster risk

[43]Institute of Electrical and Electronic Engineers, *Resilience Framework, Methods, and Metrics for the Electricity Sector,* PES-TR83 (New York, NY: October 2020). This report also states that it is not feasible to develop industry-wide resilience metrics that address all scenarios. Rather, it suggests that there could be specific metrics tailored to particular events or frameworks. DOE officials told us that the wide range of potential resilience scenarios or threats to the grid makes it challenging and impractical to establish one universal set of metrics. Rather, officials believe that a set of broader performance measures, which could include appropriate metrics based on a given scenario, are what is needed to better assess the resilience of the grid.

reduction alternatives, provide technical assistance to help build capacity of nonfederal partners, and contribute to an understanding of approaches for estimating returns on investment.[44] In addition, the framework states that federal efforts can assist decision makers in identifying and selecting among disaster risk-reduction alternatives by contributing to an understanding of returns on various resilience investments. Further, *Standards for Internal Control in the Federal Government* state that agency management should clearly identify program objectives. Attributes of clear objectives include timeframes for achieving these objectives.[45] Without a plan to guide DOE's efforts to further develop tools that could support planning and investments in grid resilience, these efforts could stall or remain incomplete, further delaying the provision of tools that utilities and other stakeholders need to address challenges evaluating and justifying investments in resilience measures.

Lastly, utilities' access to National Laboratory resources could be improved, according to officials we interviewed from utilities and the National Laboratories. Specifically, DOE does not have a mechanism to help ensure utilities have easy access to projects, research findings, and tools. For example, one official from a large investor-owned utility said they had collaborated with the National Laboratories after networking at a conference, but they otherwise did not know how to access or apply information on grid resilience from the National Laboratories. Officials from another utility said they had successfully partnered with a National Laboratory after the utility's CEO set up a meeting with DOE leadership to seek information about potential opportunities, but they were not sure of other ways utilities could connect with the National Laboratories. DOE and National Laboratories officials told us that they share this information with utilities via their public websites, and DOE officials also said they share information through associations and other groups. DOE also has specific programs and activities that include partnerships between the National Laboratories and utilities, such as the GMLC projects mentioned above. However, there is not a clear mechanism to ensure that utilities have access to such opportunities. Rather, utilities generally become

[44]GAO, Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters, GAO-20-100SP (Washington, D.C.: Oct. 23, 2019).

[45]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: Sept. 10, 2014).

aware of, or involved in, National Laboratories projects through ad hoc dissemination of information.

According to GAO's Disaster Resilience Framework, federal efforts can assist decision makers in identifying and selecting among disaster risk-reduction alternatives by (1) providing technical assistance, (2) contributing to an understanding of returns on various resilience investments, and (3) identifying available sources of funding for resilience projects. Without a formal mechanism to connect utilities and industry stakeholders with research at DOE's National Laboratories that could support efforts to enhance grid resilience, the risk exists that utilities may miss opportunities to leverage existing knowledge and technical assistance that could lead to enhanced grid resilience.

## Conclusions

As states and utilities face increased frequency and intensity of hurricanes in the future, they need to enhance grid resilience so that the grid can better withstand and rapidly recover from the impact of these hurricanes. The federal government plays a prominent role in funding and facilitating enhancements to grid resilience. In particular, through research and collaboration with industry, DOE and its National Laboratories play a critical role in developing tools and technologies that can help utilities plan for resilience enhancements and justifying those investments. Developing tools that support planning for grid resilience would help utilities evaluate investments in grid resilience. While multiple grid resilience efforts are under way at DOE, the agency does not have a plan to guide its efforts to develop resilience planning tools. Without a plan to guide DOE's efforts to further develop tools that could support grid resilience planning and investments, these efforts could stall or remain incomplete, further delaying the development of tools needed by utilities and other stakeholders that face challenges evaluating and justifying investments in resilience measures. Finally, DOE plays a key role in facilitating coordination between utilities and the National Laboratories; however, DOE has no formal mechanism for connecting utilities to the work of the National Laboratories, creating a risk of missed opportunities for collaboration and enhanced grid resilience.

## Recommendations for Executive Action

We are making the following two recommendations to DOE:

The Secretary of Energy should establish a plan, including timeframes as appropriate, to guide the agency's efforts to develop tools for resilience planning, such as performance measures for resilience, a framework for resilience planning, and additional information on the cost of long-term power outages. (Recommendation 1)

The Secretary of Energy should take steps to better leverage the National Laboratories' emerging grid resilience efforts and technologies by developing a formal mechanism to share this information with utilities. (Recommendation 2)

## Agency Comments and Our Evaluation

We provided a draft of this report to DOE, the Department of Homeland Security, HUD, and USDA for review and comment. We received written comments from DOE. These comments are reprinted in appendix I and summarized below. The Department of Homeland Security and USDA provided technical comments which we incorporated as appropriate. HUD did not have any comments on the draft report.

In its comments, DOE stated that it concurred in principle with our two recommendations. The comment letter describes steps that DOE has taken, or is in the process of taking, to address the recommendations. However, DOE's actions do not fully address the underlying issues we identified.

With regard to recommendation 1 to establish a plan to guide the agency's efforts to develop tools for resilience planning, DOE stated that its Office of Electricity had recently formed an Energy Resilience Division dedicated to incorporating resilience concerns into DOE's work. This division has established a Resilience Community of Practice, which meets monthly to discuss DOE's ongoing energy resilience projects and other resilience-related efforts. To support ongoing resilience work, this division has also begun compiling a catalogue of existing resilience tools and models to better understand existing energy resilience planning capabilities and better identify gaps. We are encouraged by DOE's efforts to identify existing resilience planning tools and potential gaps. However, we continue to believe that establishing a plan to guide efforts to further develop and operationalize these resilience planning tools is needed to support the grid resilience efforts of utilities and other stakeholders.

With regard to recommendation 2 to establish a formal mechanism to share the National Laboratories' emerging grid resilience efforts and technologies with utilities, DOE described existing mechanisms the agency uses to connect with utilities. For example, DOE stated that its Resilience Community of Practice has helped DOE to better understand partnerships with the National Laboratories. Further, DOE stated that existing mechanisms including the GMLC and DOE's Electricity Advisory Committee help connect the National Laboratories with utilities and other stakeholders. Finally, DOE stated that it plans to use existing relationships with industry organizations as a platform to develop a formal mechanism for sharing information with utilities. We acknowledge DOE's existing mechanisms to partner with utilities. However, as discussed in our report, utility officials told us that existing mechanisms largely result in ad hoc dissemination of information, and utilities may still not be fully aware of available resources at the National Laboratories. We are also encouraged by DOE's plan to work with industry organizations to develop a formal mechanism to share information, but we continue to believe that until DOE more fully develops such a mechanism, there may continue to be missed opportunities for utilities to collaborate with and leverage the resources of the National Laboratories.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Energy, the Secretary of Homeland Security, the Acting Secretary of Housing and Urban Development, and the Secretary of Agriculture.

If you or your staff have any questions about this report, please contact me at (202) 512-3841 or ruscof@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.

Frank Rusco
Director, Natural Resources and Environment

*List of Addressees*

The Honorable Gary C. Peters
Chairman
Committee on Homeland Security and Governmental Affairs
United States Senate
The Honorable Dianne Feinstein
Chairman
The Honorable John Kennedy
Ranking Member
Subcommittee on Energy and Water Development
Committee on Appropriations
United States Senate
The Honorable Chris Murphy
Chairman
The Honorable Shelley Moore Capito
Ranking Member
Subcommittee on Homeland Security
Committee on Appropriations
United States Senate
The Honorable Ron Johnson
Ranking Member
Permanent Subcommittee on Investigations
Committee on Homeland Security and Governmental Affairs
United States Senate
The Honorable Rand Paul, M.D.
Ranking Member
Subcommittee on Emerging Threats and Spending Oversight
Committee on Homeland Security and Governmental Affairs
United States Senate
The Honorable Maxine Waters
Chairwoman
Committee on Financial Services
House of Representatives

The Honorable Bennie Thompson
Chairman
Committee on Homeland Security
House of Representatives

The Honorable Carolyn B. Maloney
Chairwoman
The Honorable James Comer
Ranking Member
Committee on Oversight and Reform
House of Representatives

The Honorable Nydia Velázquez
Chairwoman
Committee on Small Business
House of Representatives

The Honorable Peter DeFazio
Chairman
The Honorable Samuel “Sam” Graves
Ranking Member
Committee on Transportation and Infrastructure
House of Representatives

The Honorable Marcy Kaptur
Chairwoman
The Honorable Mike Simpson
Ranking Member
Subcommittee on Energy and Water Development, and Related Agencies
Committee on Appropriations
House of Representatives

The Honorable Lucille Roybal-Allard
Chairwoman
The Honorable Chuck Fleischmann
Ranking Member
Subcommittee on Homeland Security
Committee on Appropriations
House of Representatives

The Honorable Al Green
Chairman
Subcommittee on Oversight and Investigations
Committee on Financial Services
House of Representatives

The Honorable Marco Rubio
United States Senate

The Honorable Emanuel Cleaver, II
House of Representatives

The Honorable Jim Jordan
House of Representatives

The Honorable Michael McCaul
House of Representatives

The Honorable Gary Palmer
House of Representatives

The Honorable Ann Wagner
House of Representatives

# Appendix I: Comments from the Department of Energy

Department of Energy
Washington, DC 20585

February 24, 2021

Mr. Frank Rusco
Director
Natural Resources and Environment
U.S. Government Accountability Office 441 G Street, NW
Washington, DC 20548

Dear Mr. Rusco:

The U.S. Department of Energy (DOE or Department) appreciates the opportunity to provide a management response to the Government Accountability Office (GAO) draft report titled, *Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes (GAO-21-274.)*

The draft report contained a total of two recommendations to the Department. DOE concurs in principle with GAO's recommendations and is already taking sufficient actions to address them. DOE's full response to each recommendation is included in the enclosure.

GAO should direct any questions to Charles Kosak, Deputy Assistant Secretary for Energy Resilience, at Charles.kosak@hq.doe.gov.

Sincerely,

Patricia A. Hoffman
Digitally signed by Patricia A. Hoffman
Date: 2021.02.24 14:49:03 -05'00'

Patricia A. Hoffman
Acting Assistant Secretary
Office of Electricity

2

**ENCLOSURE**

**GAO Draft Report**
***Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes (GAO-21-274)***
**Response to Report Recommendations**

**Recommendation 1**: *The Secretary of Energy should establish a plan, including timeframes as appropriate, to guide the agency's efforts to develop tools for resilience planning, such as performance measures for resilience, a framework for resilience planning, and additional information on the long-term cost of power outages.*

*Management Response: Concur in Principle*

To reflect the importance of resilience, the Office of Electricity recently reorganized to form an Energy Resilience Division (OE-ER division), a team of full-time staff dedicated to incorporating resilience concerns into applied science work of the Department of Energy (DOE or the Department). OE-ER has established an inter-office group of federal officials whose work in applied science would benefit from an enhanced and coordinated discussion of resilience, from tool development to interagency updates and advances in the state-of-the-art in resilience science, such as the cost of long-duration outages. This group, the Resilience Community of Practice (RCoP), meets monthly to discuss ongoing energy resilience projects that the Department is undertaking or is participating in, new tools for resilience planning, and identified gaps in resilience valuation and planning.

Because the issue of resilience increasingly pervades all of the Department's applied science efforts, and the impact varies significantly from one technology area to the next, this group has focused on improving DOE activities rather than agreeing to the terms of a single document. To support this effort, the OE-ER division has begun compiling a catalogue of existing resilience tools and models developed by elements across the federal government in order to better understand existing capabilities for energy resilience planning and to better identify gaps. Prior and on-going efforts under the Department's Grid Modernization Initiative regarding resilience metrics, as identified in this report, are registered in this catalogue, which has been reviewed by the RCoP and is actively updated as new tools and models are developed.

DOE will continue to leverage the RCoP to enhance coordination on resilience planning, performance measures, as well as information on the long-term impacts, including costs, of long duration power outages. At the time of writing, the Department is awaiting the confirmation of a new Secretary of Energy, after which any additional agency-wide planning efforts may be discussed.

*Estimated Completion Date: Complete*

3

**Recommendation 2:** *The Secretary of Energy should take steps to better leverage the National Laboratories' emerging grid resilience efforts and technologies by developing a formal mechanism to share this information with utilities.*

*Management Response: Concur in Principle*

The OE-ER division further utilizes the RCoP as an information-gathering and coordinating mechanism to better understand ongoing partnerships with the national laboratories across DOE offices. This information helps the OE-ER division identify new opportunities for coordination between various DOE offices and the national laboratories, prevent duplication of efforts, and have a better understanding of how national laboratories are utilizing DOE funding.

The DOE's Grid Modernization Initiative, and related Grid Modernization Laboratory Consortium (GMLC), represents a strategic effort to enhance laboratory coordination, knowledge sharing, and relationship building with local stakeholders and industry. DOE prioritizes funding for projects with active utility partners and the potential for short term impacts. The GMLC is a critical tool for the Department as it expands its resilience work and continues to communicate with relevant stakeholders, including utilities.

The DOE maintains the Electricity Advisory Committee, a formal advisory committee under the Federal Advisory Committee Act, to provide advice on modernizing and improving the resilience of the nation's electricity delivery infrastructure. Membership includes representatives of several utilities, along with representatives of other energy companies and stakeholders. The EAC is a formal channel through which DOE connects National Laboratory researchers and utility stakeholders. Agendas for these meetings are published in the Federal Register, and meeting summaries are available on the Department's website.

In addition, existing DOE relationships with industry organizations, including the American Public Power Association, Edison Electric Institute, and the National Rural Electric Cooperatives Association, among others will be used as the platform for developing a formal mechanism to share DOE and National Laboratory resilience efforts and technologies with the utility industry. The active discussion with the Institute of Electrical and Electronic Engineers, as identified in the report, is one good example of the Department's commitment to working with relevant external stakeholders to ensure the DOE-funded research makes a real-world impact.

*Estimated Completion Date: Complete*

# Text of Appendix I: Comments from the Department of Energy

## Page 1

February 24, 2021

Mr. Frank Rusco Director

Natural Resources and Environment

U.S. Government Accountability Office 441 G Street,

NW Washington, DC 20548

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Sincerely,

Patricia A. Hoffman

Acting Assistant Secretary Office of Electricity

## Page 2

ENCLOSURE

GAO Draft Report, Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes (GAO-21-274) -- Response to Report Recommendations

**Recommendation 1: The Secretary of Energy should establish a plan, including timeframes as appropriate, to guide the agency's efforts to develop tools for resilience planning, such as performance measures for resilience, a framework for resilience planning, and additional information on the long-term cost of power outages.**

**Management Response: Concur in Principle**

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Estimated Completion Date: Complete

Page 3

**Recommendation 2: The Secretary of Energy should take steps to better leverage the National Laboratories' emerging grid resilience efforts and technologies by developing a formal mechanism to share this information with utilities.**

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Estimated Completion Date: Complete

# Appendix II: GAO Contact and Staff Acknowledgments

## GAO Contact

Frank Rusco, (202) 512-3841 or ruscof@gao.gov

## Staff Acknowledgments

In addition to the contact named above, Janice Ceperich (Assistant Director), Jarrod West (Analyst in Charge), Danny Baez, Antoinette Capaccio, John Delicath, Cindy Gilbert, Philip Farah, Rachel Pittenger, and Danny Royer made key contributions to this report.

# Related GAO Products

*Hurricane Sandy: An Investment Strategy Could Help the Federal Government Enhance National Resilience for Future Disasters*. GAO-15-515. Washington, D.C.: July 30, 2015.

*Electricity: Federal Efforts to Enhance Grid Resilience*. GAO-17-153. Washington, D.C.: January 25, 2017.

*Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure*. GAO-17-720. Washington, D.C.: September 28, 2017.

*Energy Storage: Information on Challenges to Deployment for Electricity Grid Operations and Efforts to Address Them*. GAO-18-402. Washington, D.C.: May 24, 2018.

*2017 Hurricanes and Wildfires: Initial Observations on the Federal Response and Key Recovery Challenges*. GAO-18-472. Washington, D.C.: September 4, 2018.

*Puerto Rico Hurricanes: Status of FEMA Funding, Oversight, and Recovery Challenges*. GAO-19-256. Washington, D.C.: March 14, 2019.

*Huracanes de Puerto Rico: Estado de Financiamiento de FEMA, Supervisión y Desafíos de Recuperación*. GAO-19-331. Washington, D.C.: March 14, 2019.

*Disaster Recovery: Better Monitoring of Block Grant Funds Is Needed*. GAO-19-232. Washington, D.C.: March 25, 2019.

*2017 Hurricane Season: Federal Support for Electricity Grid Restoration in the U.S. Virgin Islands and Puerto Rico*. GAO-19-296. Washington, D.C.: April 18, 2019.

*Puerto Rico Electricity Grid Recovery: Better Information and Enhanced Coordination Is Needed to Address Challenges*. GAO-20-141. Washington, D.C.: October 8, 2019.

*Recuperación de La Red Eléctrica en Puerto Rico: Se Necesita Mejor Información y Coordinación para Enfrentar Desafíos*. GAO-20-143. Washington, D.C.: October 8, 2019.

*Puerto Rico Disaster Recovery: FEMA Actions Needed to Strengthen Project Cost Estimation and Awareness of Program Guidance*. GAO-20-221. Washington, D.C.: February 5, 2020.

*Puerto Rico Electricity: FEMA and HUD Have Not Approved Long-Term Projects and Need to Implement Recommendations to Address Uncertainties and Enhance Resilience*. GAO-21-54. Washington, D.C.: November 17, 2020.

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