A Grid Modernization Approach for Community Resilience

Application to New Orleans, Louisiana

April 2018

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Abstract

This report describes the application of the Urban Resilience Planning Process, an approach to identify and prioritize infrastructure investments aimed at improving community resilience. Under the direction of the US Department of Energy's Grid Modernization Laboratory Consortium, Sandia National Laboratories (Sandia) and Los Alamos National Laboratory (Los Alamos) collaborated with stakeholders from New Orleans, Louisiana, to develop grid modernization strategies for community resilience. Past disruptions to the electric grid in New Orleans along with localized flooding have contributed to inadequate citizen access to a wide range of infrastructure services. Using a performance-based resilience metric, Sandia and Los Alamos performed analysis to identify options for improved access to infrastructure services across New Orleans during and after a major disruption. By combining urban and grid investment planning techniques, the team designed a system of resilience nodes that can provide clustered infrastructure assets with highly resilient electrical supply. Results of the analysis led to the suggestion of 22 draft resilience node locations that can provide a wide range of infrastructure services equitably to New Orleans citizens. This effort served as a proof-of-concept for the Urban Resilience Planning Process, and this report describes several gaps that should be overcome to successfully integrate resilience planning across electric utilities and local governments.

Acknowledgments

The authors wish to acknowledge the many officials and experts who provided their knowledge and guidance through the New Orleans resilience improvement process. Thanks first and foremost are offered to the City of New Orleans, Sewerage and Water Board of New Orleans, Entergy New Orleans, and the US Army Corps of Engineers' New Orleans District. From the City of New Orleans, we appreciate the expertise and insight of Charles Allen III, Cedric Grant, Aaron Miller, Jeff Hebert, David Lessinger, Greg Reece, Siobhan Foley, Ryan Mast, and Jared Genova. We are extremely grateful to Joe Becker and Tyler Kiehle from the Sewerage and Water Board of New Orleans for their engagement. We would like to thank Entergy New Orleans staff for their contributions to this work. Appreciation is also offered to US Army Corps of Engineers representatives Bobby Duplantier, Frederick Wallace, and Antoine Jackson.

Further appreciation is offered to the Department of Energy and the Grid Modernization Laboratory Consortium for recognizing the importance of resilience when addressing the modernization of our nation's electric grid.

We appreciate all of these efforts and look forward to further collaborations in the future.

Acronyms and Abbreviations

CASP	City Assisted Sheltering Plan
DER	distributed energy resources
EOC	Emergency Operations Center
FLISR	fault location, isolation, and system recovery
GMLC	Grid Modernization Laboratory Consortium
Los Alamos	Los Alamos National Laboratories
PCC	points of common coupling
POD	point of distribution
Sandia	Sandia National Laboratories
US DOE	US Department of Energy

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1.0 Project Overview and Rationale

The electric grid is central to the web of interconnected systems that must operate resiliently to serve communities during times of extreme disruption. Nearly every service that citizens depend on—from medical treatment to dry shelter, food, and clean water—is heavily dependent on electricity. Because of this substantial dependence, the annual costs of power outages due to severe weather averages between $18 billion to $33 billion in the United States.[1] Investments in modern grid technologies, such as advanced microgrids and automated fault isolation and recovery, can substantially decrease this impact to society.

However, as many communities understand, investments in grid resilience come at costs, which must be weighed against benefits and evaluated in close cooperation among municipalities, electric utilities, and other community stakeholders. Complicating matters, resilience investments are often expected to pay off during a very small number of potential events, with value to a wide array of stakeholders. Economic valuation of resilience-focused grid investments has been called out as a critical capability gap in a recent update to the Quadrennial Energy Review.[2]

To address the technical hurdles and large number of stakeholders involved, the US Department of Energy (US DOE) funded a team of researchers from Sandia National Laboratories (Sandia) and Los Alamos National Laboratory (Los Alamos) to develop and apply an approach for identifying and prioritizing grid investments targeted at improving community resilience. This project, funded through US DOE's Grid Modernization Laboratory Consortium (GMLC), is the first of its kind to collaboratively address grid investments aimed at minimizing extreme consequences to the community.

The community of New Orleans, LA, has been an integral partner in proving the concept of this community resilience improvement approach. In 2005, Hurricane Katrina caused devastating losses to the City of New Orleans (New Orleans) and surrounding communities. Challenges faced by the city due to the widespread flooding during the hurricane and its aftermath were exacerbated by power outages, and New Orleans recognizes that enhancing the resilience of its power grid infrastructure is essential to improving the overall resilience of its community.

This report describes the results of the GMLC project "Grid Analysis and Design for Energy and Infrastructure Resiliency for New Orleans." The project was scoped with the following questions:

- According to community stakeholders, what are the characteristics of extreme events that would result in worst consequence to the community? How is that consequence measured?
- In the case of these events, how does the grid perform? What other infrastructure services will be impacted due to loss of power? What is the consequence of these service outages?
- What grid modernization options will minimize this consequence, thereby best improving community resilience? How would these options be designed to work within the current grid?

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[1] Executive Office of the President of the United States. (2013). Economic Benefits of Increasing Electric Grid Resilience to Weather Outages. Prepared by the President's Council of Economic Advisers and the US Department of Energy's Office of Electricity Delivery and Energy Reliability, with assistance from the White House Office of Science and Technology.
[2] US Department of Energy. (2017). Quadrennial Energy Review, Transforming the Nation's Electricity System: The Second Installment of the QER. US Department of Energy's QER Task Force.

- What are the scale and cost of grid improvements needed to improve community resilience? How would resilience metrics be best defined and utilized for future community planning and adaption to future resilience challenges and needs?

The project partners and research team continue to pursue this last question regarding costs and additional benefits (e.g., integration of distributed energy resources) to help accelerate improvements and long-term community planning.

The project partners have been engaged continuously through all phases of the project:

1. **US Department of Energy** – project funder and reviewer
2. **Sandia National Laboratories** – technical lead, infrastructure resilience, electric grid analysis, microgrid and controls design
3. **Los Alamos National Laboratory** – threat analysis, electric grid damage assessment
4. **City of New Orleans** – primary recipient of technical assistance, subject matter expertise
5. **Entergy New Orleans** – electric utility, core stakeholder
6. **Sewerage and Water Board of New Orleans** – potable water, wastewater, and drainage utility, core stakeholder
7. **US Army Corps of Engineers** – flood risk reduction expertise, reviewer
8. **100 Resilient Cities Organization** – relationship catalyst, information dissemination

2.0 Defining, Measuring, and Improving Community Resilience

The science of measuring and improving resilience has grown over the past few decades, but multiple definitions and frameworks still exist. Sandia uses a definition popularized by Presidential Policy Directive 21:

"Resilience is defined as the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. [This] includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."[1]

Based on this definition, Sandia and colleagues have developed a mathematical framework to calculate, project, and improve resilience.[2] This framework relies on estimating the performance of systems of interest during extreme events and translating this performance into metrics of consequence that are most useful to stakeholders' existing planning paradigms. To apply this resilience framework to communities, Sandia has worked with cities to propose measurement units for resilience metrics that work within current planning paradigms and adequately convey the goals and benefits of resilience-enhancing investments. Table 1 describes the two most common categories of metrics that urban stakeholders have suggested to measure consequence to major disruptions.

Table 1. Two primary classifications of consequence for community resilience metrics

Measure Classification	Common Examples
Community Measures	Number of People Without Necessary Services
	Lives at Risk
	Net Population Change
Economic Measures	Gross Municipal Product Loss
	Change in Capital Wealth
	Business Interruption Costs

Sandia has also developed a method for analyzing and improving urban resilience that calls for analysts, in conjunction with stakeholders, to populate resilience metrics and either suggest or evaluate resilience-enhancing solutions. The process is cyclical and requires consistent stakeholder interaction throughout each stage. At the end of this process, stakeholders gain measurable resilience metrics useful in their existing planning processes and an analysis of how potential resilience-enhancing solutions will improve these metrics. The stages of the urban resilience planning process are outlined in Figure 1. The process begins at the top of the diagram and continues in a clockwise fashion iteratively until sufficient resilience-enhancing investment suggestions have been provided. It was first developed and applied to Norfolk, VA, using an economic measure, and is being applied in New Orleans using a community measure.[3]

[1] The White House, Office of the Press Secretary. (2013). Presidential Policy Directive/PPD-21, Critical Infrastructure Security and Resilience.
[2] Biringer, B., Vugrin, E., and Warren, D. (2013). Critical Infrastructure System Security and Resiliency. CRC Press.
[3] Jeffers, R., Fogleman, W., Grazier, E., Walsh, S., Rothman, S., Shaneyfelt, C., Aamir, M., Gibson, J., Vargas, V., Vugrin, E., Conrad, S., and Passell, H. (2016). Development of an Urban Resilience Analysis Framework with Application to Norfolk, VA. Sandia National Laboratories. SAND2016-2161.

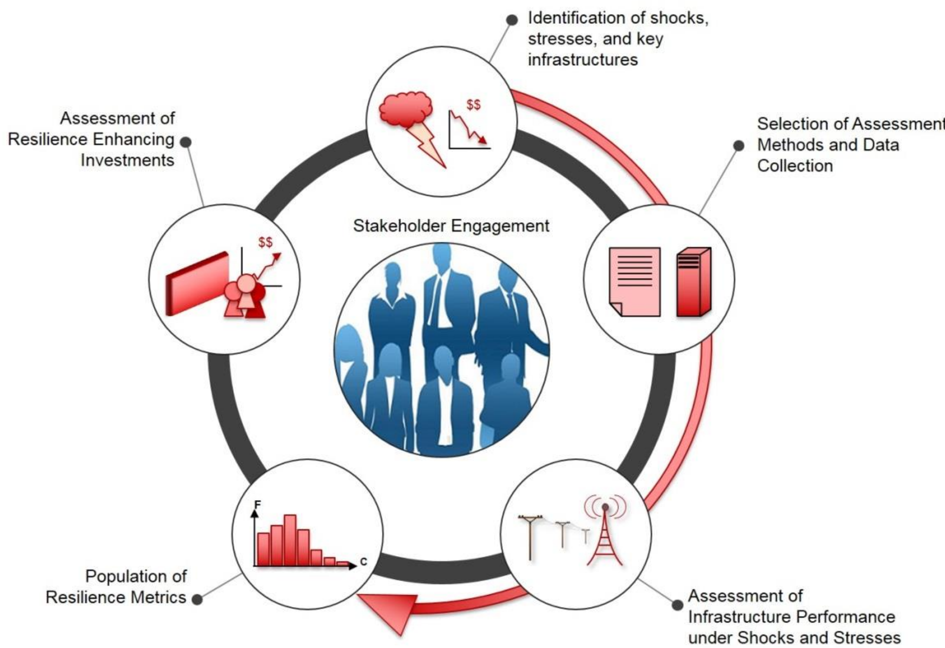

Figure 1. The Urban Resilience Planning Process is stakeholder-driven, iterative, and designed to work within stakeholders' existing planning processes.

Performance of the electric grid during major shocks can be described by outage frequency, the number of customers impacted, outage duration, or a combination of these, such as customers impacted multiplied by duration. However, the City of New Orleans' primary community resilience goal related to a major storm event is to provide their citizens with critical infrastructure services as quickly as possible. To meet this goal, we suggest the metric shown in Figure 2, which accounts for the number of citizens without infrastructure services and the expected duration of disruption for these citizens. In a planning context, this metric would be projected over a planning horizon for multiple services, such as electric power, water, food, and emergency medical services. The goal is to decrease both the number of citizens expected to be disrupted, as well as the duration of those disruptions. For a grid investment such as advanced microgrids, the planning horizon could be thirty years or more, and a forward-looking metric should reflect the significant uncertainty associated with the likelihood and magnitude of power outages into the future.

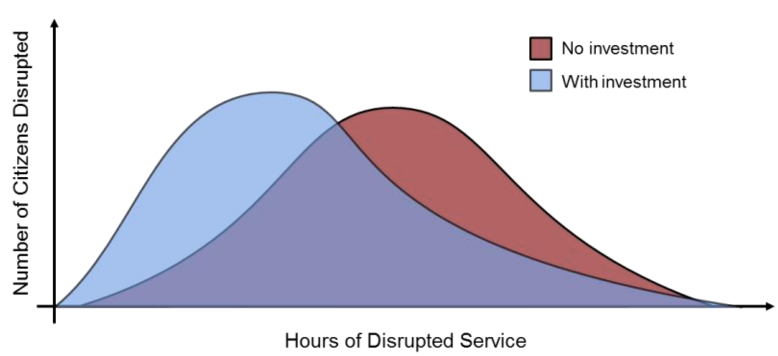

Figure 2. Suggested metric formulation to measure the impact of resilience investments. Because of existing capability gaps, the percentage of infrastructure assets with reliable backup power was used as a proxy metric.

Listed in Table 2 are the significant science and technology gaps, many discovered directly through this project, that in practice hinder precise, high-confidence forecasting of the metric in Figure 2. Because of these gaps, a proxy metric was employed for New Orleans in coordination with project partners. This proxy metric is the percentage of infrastructure-serving assets throughout the city with reliable backup power.

Table 2. Gaps in the capability of the urban infrastructure resilience community to project performance-based resilience metrics

Capability Gap	Description
Projection of future threats	Because of the rare nature of extreme events, characterizing the likely events that will occur over the next 30 years involves significant uncertainty.
Projection of population needs	In many extreme events, significant portions of the population are displaced. Understanding the probable location and the needs of this displaced population remains a challenging exercise.
Interdependent infrastructure performance estimation	Impacts to power-dependent infrastructures, such as communications and natural gas, can feed back to cause larger or longer power outages. These dynamics are not well modeled in existing tools.
Consequence estimation	The economic and societal value of improved infrastructure resilience is dependent on understanding the total consequence of disruptions to infrastructure services. Some of these consequences extend many years after the initial event and are difficult to attribute precisely.

3.0 Implementation of the Urban Resilience Planning Process for Grid Modernization Investments

Using the Urban Resilience Planning Process in Figure 1, Sandia, Los Alamos, and project partners defined and executed an analysis to inform New Orleans stakeholders of the primary resilience benefits of grid modernization investments. Below is a summary of the pertinent results of this analysis, which concentrates on the repeatability and usefulness of the approach, followed by the suggested specifications of grid improvements to support community resilience.

3.1 Reasonable Worst Consequence Analysis

The first step in this process is the identification of primary threats and infrastructures of concern. While the primary threat of concern to New Orleans partners is a hurricane, other incidents—including accidents, tornados, and such future considerations as cyber events—can result in extended power outages. Designing a system to be resilient to hurricanes will provide benefits that address these threats as well, but future iterations of the planning process should incorporate additional threats directly.

By concentrating on a reasonable worst consequence scenario instead of a reasonable worst threat scenario, this analysis process addresses the resilience goals of city planners. For New Orleans, hurricanes and severe storms accompanied by large rainfall totals are the threat of highest concern. Partners indicated that a reasonable worst consequence storm is a Category 2 or low Category 3 hurricane in which the city does not issue a mandatory evacuation, and the storm stalls over New Orleans, dropping 20 to 25 inches of rain over a period of 24 hours. In this case, the New Orleans partners indicated that many people would be displaced and in need of infrastructure services. This represents the design basis threat for selection of potential grid resilience improvements.

For the second step in the Urban Resilience Planning Process, the analysis team worked with project partners to identify data and tools already in use for infrastructure resilience planning in New Orleans. The team augmented these capabilities with tools and data developed at Sandia and Los Alamos with support from the US DOE and US Department of Homeland Security.

The third step of the Urban Resilience Planning Process calls for assessing the performance of infrastructures of concern subject to the threats of concern. This assessment involved analysis of three factors:

1. Wind and inundation impacts of the design basis threat
2. Power system performance subject to the design basis threat
3. Infrastructure services subject to the design basis threat and the power system performance

These analyses are described in the subsections below.

3.1.1 Wind and Inundations Impacts

Los Alamos and Sandia characterized and simulated wind and inundation impacts for a set of hurricane parameters that represent the reasonable worst consequence threat. The scenarios chosen by the analysis team include two hurricane tracks, illustrated in Figure 3, thought to represent unique conditions for worst consequence:

- Hurricane Katrina’s track, chosen for two reasons: its devastating consequences remain fresh in planners’ minds and the wind field resulting from this track could push storm surge from Lake Pontchartrain towards New Orleans.

- The track of a 1947 unnamed storm, chosen much of the electric power and industrial infrastructure is positioned along the Mississippi, directly within this storm’s unique path—it approached New Orleans from the southeast and moved directly up the river. Further, because of the unique impacts associated with potential overtopping of the riverine levees, the 1947 track represents a distinct worst case not experienced recently by planners.

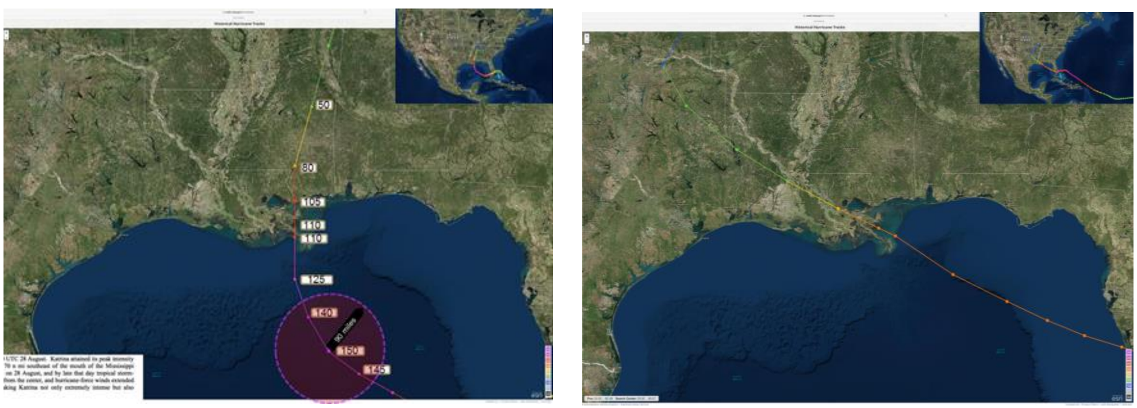

Figure 3. Two hurricane tracks selected to represent reasonable worst consequence trajectories for New Orleans: Hurricane Katrina from 2005 (left) and an unnamed storm from 1947 that progressed upriver (right).[1]

Results of the hurricane analysis indicate that maximum sustained wind speeds for the worst consequence storm could range between 40 to 100 miles per hour across the city. A primary takeaway is that the Katrina track exhibits a gradation in wind speeds across the city, with stronger wind impacts toward the eastern side of New Orleans, while the 1947 track features more uniform high wind speeds across the city and continuing upstream.

A simulation-driven analysis of Category 2, 3, and 4 hurricanes for these trajectories found no significant differences between maximum inundation depths among the categories, largely because none of these simulations predicted significant overtopping of levees and surge barriers. The assumption of 20 inches of rainfall dominates the inundation estimates.

[1] National Oceanic and Atmospheric Administration. (2017) Digital Coast: Historical Hurricane Tracks. NOAA Office for Coastal Management. <https://coast.noaa.gov/hurricanes/>

3.1.2 Electric Power Resilience Assessment

An assessment of the resilience of New Orleans's electrical grid provides a baseline for the potential benefits of grid modernization options targeted at improving community resilience. In collaboration with Entergy New Orleans, Sandia and Los Alamos investigated the projected performance, subject to the design basis threat, of Entergy's distribution system within New Orleans and of the high voltage transmission system in southern Louisiana.

Partially due to Entergy's substation upgrades since Hurricane Katrina, inundation is not expected to be the primary driver of outage extent, but will likely contribute to outage duration. For example, inundation limits the utility's ability to restore power to many areas, even to some not flooded. The simulated hurricane winds result in distribution system damage, causing significant outages throughout New Orleans. Power distribution lines (lower voltage lines running through neighborhoods) are significantly more vulnerable to wind damage than are power transmission lines (higher voltage lines running along major corridors). Within the distribution system, underground lines are significantly less vulnerable to wind and more vulnerable to flooding damage than are overhead lines. Wind damage vulnerability of overhead distribution lines varies widely depending on line construction, the underlying soils, and the surrounding vegetation type and density.

Based on an assessment of past hurricanes, as indicated in Figure 4, complete power restoration in Entergy's service territory could require from one week to over three weeks. Entergy has steadily improved its speed to full power restoration over the past five hurricanes.

Notably, hurricanes are not the only source of significant-duration power outages in New Orleans. Many overhead power distribution lines run directly through tree canopies, such as those of the characteristic live oaks throughout the city, which increases the likelihood that lines will be impacted during windy conditions; even those not associated with hurricanes. Further, outages can also be caused by accidents, human error, aging infrastructure, animals, and copper thieves—and other factors not unique to New Orleans.

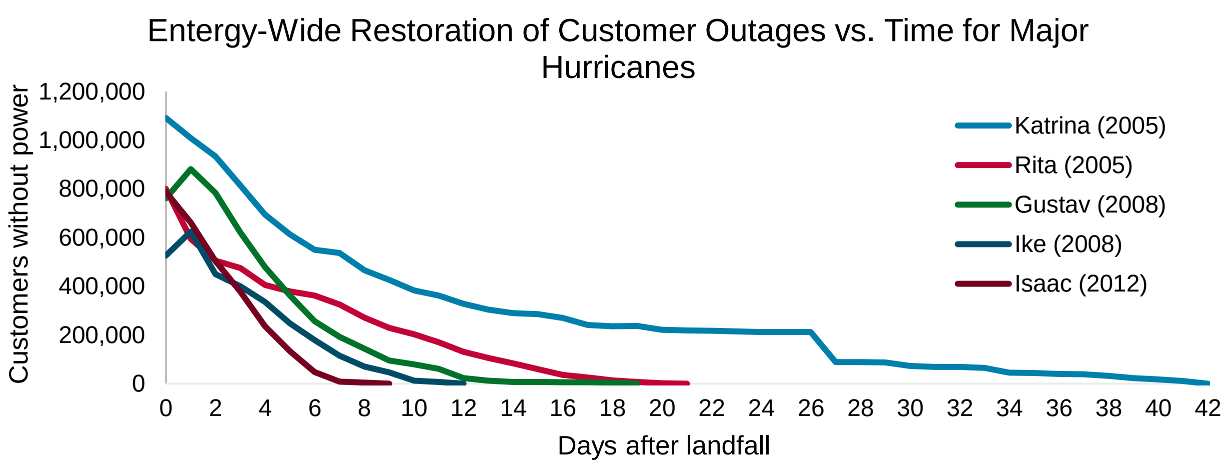

Figure 4. Customers without power versus time for five past hurricanes across all of Entergy's service territory[1]

[1] Re-formatted from: Olivier, P. (2017) Entergy Restoration Curves for Katrina, Rita, Gustav, Ike, Isaac. Entergy Corp.

The grid resilience analysis provides a basis for analyzing the infrastructure services that may be impacted in the event of future hurricanes and extended power outages. Specifically, the analysis showed that infrastructures served by overhead distribution lines in vegetated areas are at highest risk of extended outage due to extreme storms, followed in order of higher to lower risk by infrastructures served by overhead lines and less vegetation, areas with underground service and high potential for flooding, and underground lines with low flood risk.

The analysis also provides requirements for grid modernization options that will be designed to support these services when the bulk power grid goes down. The project team recommends that backup power, localized blackstart capacity, and/or advanced microgrid options be designed so that New Orleans and/or Entergy New Orleans can operate localized sections of the grid without centralized utility power or communications for at least 7 days, and, where costs allow, up to 12–14 days for more critical functions.

3.1.3 Mapping Grid Resilience to Infrastructure Services

The New Orleans partners were primarily concerned with community well-being in the aftermath of a large storm or hurricane. Therefore, the resilience metric chosen for this study—the percentage of infrastructures with sufficient backup power—focuses on lifeline infrastructure services and the ability to support critical needs of the community. The baseline for this metric is calculated through an analysis of the infrastructures listed in Table 3, subject both to direct storm impacts as well as the likelihood of power outage at their locations. A detailed infrastructure resilience analysis was provided to the project partners as a deliverable for the study.

Table 3. Infrastructures considered for grid modernization support, grouped by service category

Infrastructure Facility Types Considered for Grid Modernization Support	
911 System	**Medical Services**
911-Supporting Wire Centers	Hospitals
Public Safety Answering Point	Air Ambulance
City Emergency Support	Medical Centers
Emergency Operations Center (EOC)	Dialysis Centers
Evacuation Pickup Sites	**Provisions**
Task Force Sites	Pharmacies
Points of Distribution (PODs)	Gas Stations
Fire Stations	Grocery Stores
Police Stations	Bank Main Offices
NOLA City Fuel Storage	Bank Branches
Shelter	**Water and Wastewater**
Shelters – City-Assisted Sheltering Plan (CASP)	Sewer Pump Stations
Potential Shelters - Non-CASP	Drainage Pump Stations
Hotels	Water Purification Facilities
	Sewer Treatment Plants

Based on the detailed infrastructure performance analysis, the team calculated the number of infrastructure services with resilient power provision over different geographical city zones, depicted in Figure 5—a step intended to ensure that suggestions for grid modernization would result in equitable improvement of infrastructure services throughout the city. Infrastructure services that have low baseline resilience are those with no backup power, multiple assets in areas at risk of inundation, or those served by a less-resilient power distribution infrastructure.

An example output of the detailed analysis is provided in Figure 6, showing infrastructures in and out of the simulated inundated areas. In Zone 1, the analysis identifies dialysis centers, shelters, police stations, the city's point of distribution (POD), and pharmacies as infrastructures with high need for resilience support due to a high fraction of inundation and/or insufficient backup power. Notably, many assets can perform their services even under significant inundation, and some assets currently have significant backup solutions in place. These include sewer pumping stations, drainage pumping stations, hospitals, and some shelters.

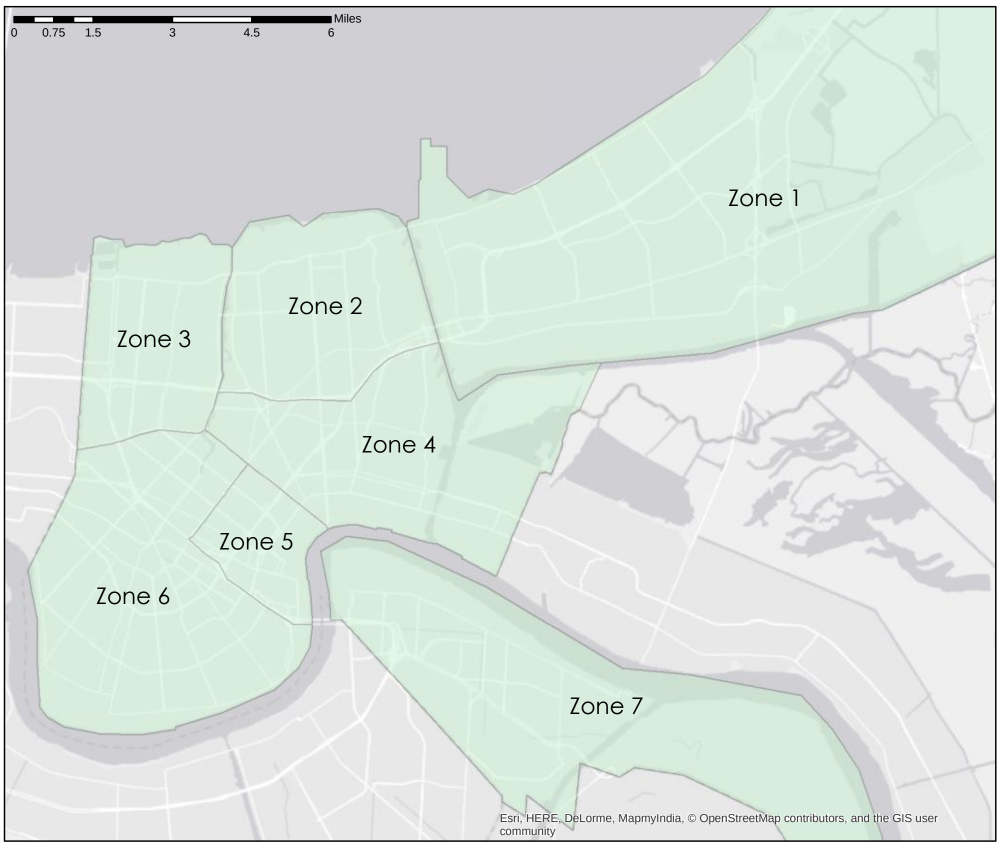

Figure 5. The analysis of infrastructure services best supported by grid modernization was decomposed by zones in order to provide equitable distribution throughout the city.

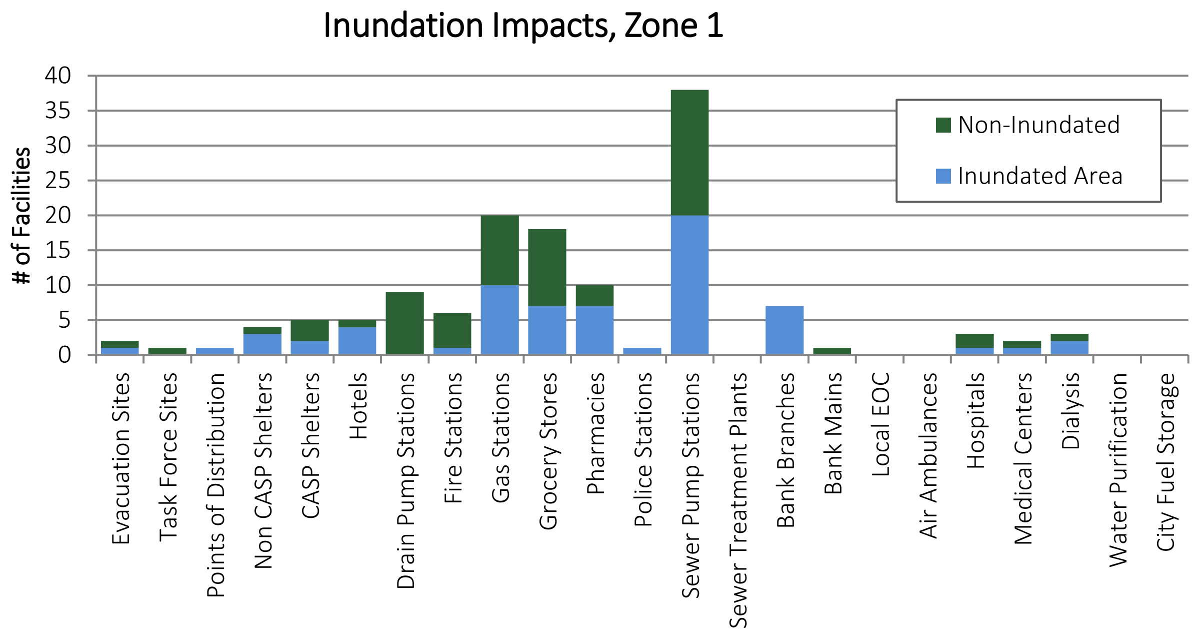

Figure 6. Infrastructure facilities in and out of the inundation risk area, Zone 1

3.2 Specification of Grid Improvements for Community Resilience

The final step in the urban resilience planning process involves specifying infrastructure improvements that improve the community resilience metric. For this study, the improvements are grid modernization technologies for New Orleans that take into account both the infrastructure services needed in each zone and the cost of added resilience. Analysis of these factors enabled strategic selection of a set of critical assets that should be supported to a level adequate for the reasonable worst consequence threat.

Through consultation with DOE and the project partners, Sandia developed the following list of grid modernization options to be considered for improving New Orleans' community resilience:

- **Advanced Microgrids:** Advanced microgrids utilize automated controls to tie together a collection of facilities within a relatively small geographical area using one or more points of common coupling (PCCs) to the utility. These PCCs are switching devices that can automatically segregate the microgrid from the distribution system in an outage situation. Integration of one or more distributed energy resources (DERs) within the microgrid provide stable power to the facilities. Advanced microgrids can also provide services such as peak shaving, renewable energy integration, and demand response when tied to the grid (grid-tied operation).

- **Distribution System Flexibility and Automation:** The improved electrical distribution system in New Orleans is heavily meshed, as opposed to radial, in configuration. A meshed configuration allows for reconfiguration to deliver power to loads via different pathways, making the system more resilient to loss of any one line or asset. However, reconfiguration of this network currently involves manual operation of switchgear, which can limit operation following a flood event. Grid modernization options, such as automated reclosers and automated fault location, isolation, and system recovery (FLISR) software, can provide the grid operator with much faster control over distribution switching and reconfiguration, thereby greatly decreasing outage durations especially for smaller disruptions.

- **Localized Backup Generation:** Building-tied backup generators are the most common method of supplying power to a facility to enable operation of critical functions during utility outages. This option may also include provisions for backup generation (e.g., pin and sleeve portable generator connection) that are not housed on-site, but are moved on-location before or during an outage.

Entergy and the City of New Orleans identified microgrids as a grid modernization solution of particular interest. Over small areas, microgrids are highly effective at providing resilient power supply to a limited number of facilities. This capability fits in well with the concept of "resilience nodes," or parts of a city that can provide a large number of infrastructure services within a small geographic area. Resilience nodes offer a cost-effective solution in the circumstances suggested by the design basis threat: large portions of the community that do not evacuate and that need a wide array of services. Using resilience nodes enabled by advanced microgrids, a relatively small amount of backup generation can provide several infrastructure services to a large population. Once these nodes are specified, the city can plan to co-locate other beneficial resources, such as shelter facilities, points of distribution, or post-storm evacuation sites within the nodes.

For New Orleans, the analysis team investigated areas of the city that, when enabled with resilient power solutions, would most improve community access to infrastructure services. This investigation, along with an infrastructure clustering analysis described below, allowed the team to specify resilience nodes that could be served by microgrids, and to suggest backup generation solutions for infrastructures not served by resilience nodes.

In the clustering analysis, the team identified three criteria for identifying candidate resilience node areas:

- Area has low probability of inundation from flooding
- Area houses a large population in need of infrastructure services, even if that population is transient while waiting for floodwaters to recede
- Area contains a cluster of less inundated infrastructure facilities that would benefit from backup power or from improved electric power flexibility

Output from the first round of the infrastructure clustering analysis is shown in Figure 7. Using location information, all facilities in Table 3 are mapped and areas containing concentrations of different types of facilities are marked as potential resilience node locations (green dots in Figure 7). Per the first criterion, any facilities in inundated areas were excluded from consideration. Analysts compared suggested node locations to the baseline resilience analysis, adding resilience node locations at lower-density clusters that have high need for services. This might involve, for example, combining two or three of the yellow dots in Figure 7.

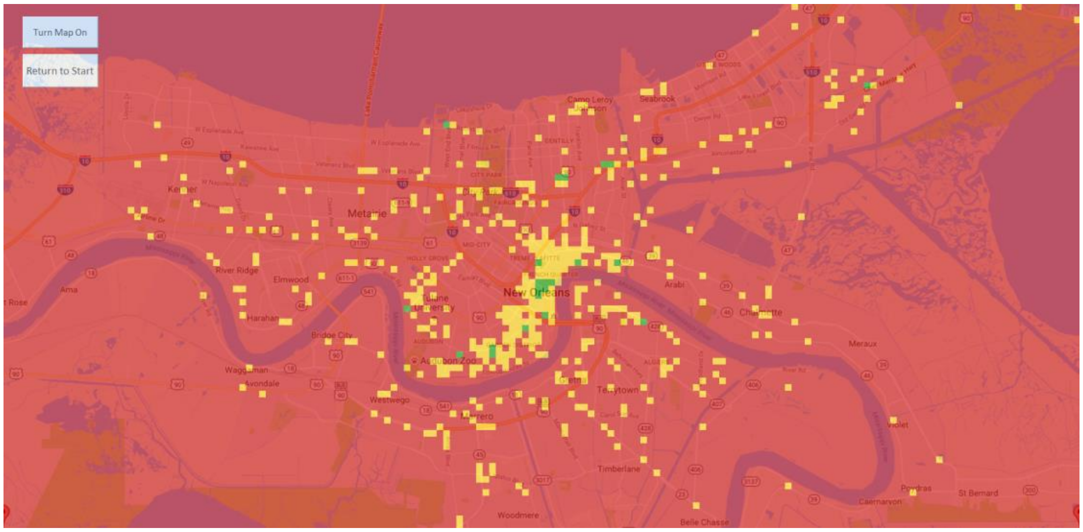

Figure 7. Results of initial resilience node clustering analysis. Areas of suitable concentration for resilience nodes are shown in green. Areas that have infrastructure buildings but do not meet a pre-determined threshold are shown in yellow.

Sandia identified 22 potential resilience nodes in New Orleans, which are now undergoing further review by project partners. To improve this analysis, infrastructure facilities will be weighted by their impact to community well-being, which may result in different locations for resilience nodes.

Implementing all 22 of the suggested resilience nodes should create the city-wide impact to New Orleans' selected resilience metric shown in Figure 8. City-wide, these resilience solutions cover a wide range of services covered at a considerable level. However, within each analysis zone of the city, there remain services that cannot be picked up economically by microgrids. For example, the three resilience nodes identified in Zone 1 are unable to power the dialysis center, fire stations, or police stations in the area, as indicated by Figure 9. These facilities are good candidates for localized backup generation solutions.

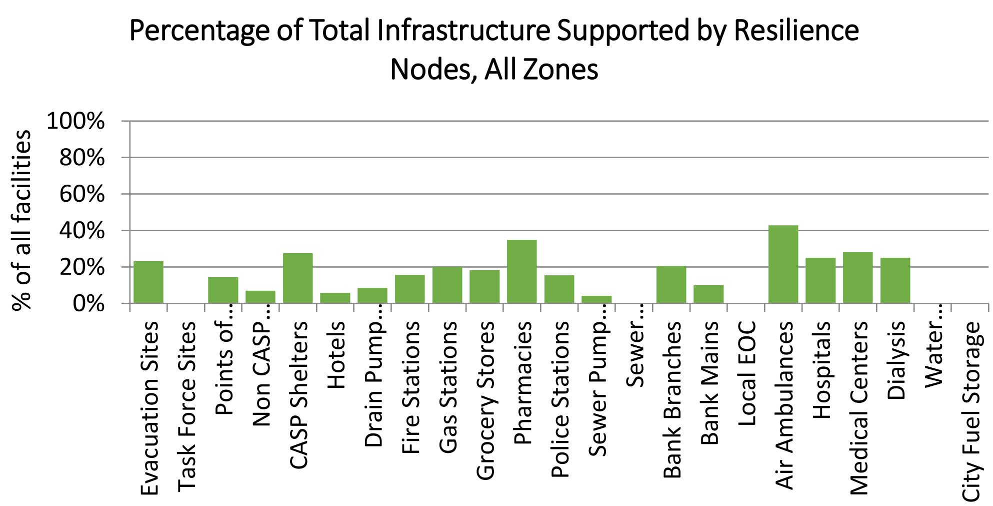

Figure 8. The city-wide percentage of facilities within each sector supported if all resilience node applications are enacted

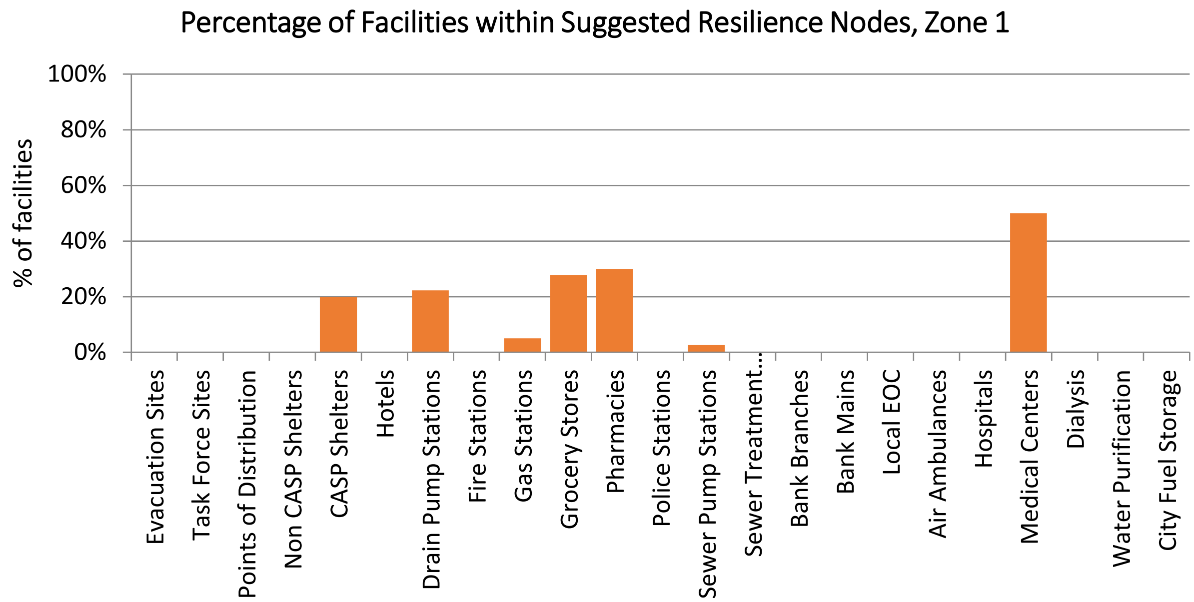

Figure 9. In Zone 1, resilience nodes can provide services such as medical, pharmaceutical, fuel, food and water, and shelter.

4.0 Conclusions, Lessons Learned, and Path Forward

This report describes the application of a new approach to community resilience planning, termed the Urban Resilience Planning Process. This process includes the following unique aspects:

- Performance-based, consequence-focused resilience metrics are used throughout to track resilience improvements.
- Analyses to support planning are based on a worst consequence threat instead of a worst case threat. For example, the case described here involves a high Category 2 or low Category 3 hurricane with no evacuation rather than a Category 5 hurricane with a city-wide evacuation.
- Stakeholders are heavily engaged at each step, which improves quality and ownership of the resilience solutions.
- The process supports analysis of interdependencies and supply chain impacts, even when a single infrastructure is being analyzed for improvement. For example, in the detailed infrastructure resilience analysis provided directly to project partners, supply chain impacts were identified for transportation fuels that highlight a need to work with entities outside of New Orleans city limits.

The Urban Resilience Planning Process described here contributed to resilience investment planning for New Orleans by applying performance-based metrics determined by the community to inform electric utility investment options. Several lessons were learned that New Orleans can apply moving forward and other cities or communities can consider in seeking to improve their resilience:

- Investor-owned electric utilities such as Entergy New Orleans work within the confines of their regulatory environment. For Entergy New Orleans and similarly structured utilities throughout the United States, there are few resilience-specific regulations in place. Yet cities are increasingly performing resilience planning and finding that electric power resilience is critical to community resilience. It is important for regulators to establish goals, incentives, streamlined process requirements, and appropriate cost recovery mechanisms so that utilities may be rewarded for resilience investments that benefit their communities.
- Partially due to a lack of regulatory drivers, Entergy New Orleans and the City of New Orleans have slightly different resilience definitions. The city is primarily focused on providing citizens with a wide array of infrastructure services, hence the metric used herein. The utility is primarily focused on restoring power to as many customers as possible, as quickly as possible, and they have worked with the city to establish some infrastructure customers with higher restoration priority (e.g., hospitals). It is important that these two goals converge for the purpose of investment planning, as well as for emergency response. The resilience metric suggested in this report is a step in that direction.
- The resilience node concept merges the needs of cities with advanced grid modernization concepts from industry, academia, vendors, and the national laboratories. By designing the grid to intelligently split into self-sustaining and hardened islands, resilient power solutions can be provided to the most critical loads, such as the infrastructure clusters suggested in this report. City planners will also be able to use the resilience node concept for zoning, emergency planning, and economic development. Infrastructure clusters that can become resilience nodes should be encouraged where major physical impacts are unlikely, and where the city projects a high community need. The

northern and southern ridges of New Orleans East (Zone 1) in this analysis are prime examples of areas that could benefit from infrastructure clustering and resilience nodes.

In order to realize repeatable, evidence-based resilience investment in cities, the Urban Resilience Planning Process will need to be adopted and accepted within an institutional framework. Significant work is needed to institutionalize the Urban Resilience Planning Process, in New Orleans and nationwide. The following are steps in the path forward:

- In the near-term, prioritization of resilience nodes will be accomplished via further research and demonstration by the Department of Energy's Grid Modernization Laboratory Consortium with New Orleans partners. Economic metrics, such as the avoided economic losses of faster community recovery, are being populated and compared to attribute-based metrics that are populated via surveys and describe aggregate system abilities in the categories of preparedness, mitigation, response, and recovery. The practical goal of this research is to enable New Orleans and Entergy New Orleans to make decisions based on the costs and benefits of each resilience node to multiple stakeholders.

- In the long-term, populating the community-focused resilience metric suggested for New Orleans requires overcoming significant science and technology gaps (see Figure 2). The four gaps outlined in Table 2 highlight research advancements that would greatly benefit community resilience planners.

Similarly, more work is needed to reveal the many economic benefits of resilience-enhancing investments, such as in microgrids, improved distribution automation, and system hardening. The World Bank suggests a triple dividend approach to valuing resilience improvements.[1] The three benefit categories suggested are avoided losses, co-benefits, and unlocked development potential. Avoided losses can be both immediate and long-term, but few capabilities exist to determine the long-term benefits of improved disaster recovery. Co-benefits reference the day-to-day (often referred to as "blue sky") benefits of resilience improvements. Many resilience investments pay for themselves with co-benefits even if they never operate during a disaster. The development dividend refers to the entrepreneurship and innovation that occur under a reduced risk profile enabled by resilience-enhancing investments. This third dividend is very rarely applied in a cost-benefit framework. Capabilities will need to be developed that are as accepted and turn-key as are methods for avoided loss calculations.

[1] Overseas Development Institute, International Bank for Reconstruction and Development (2015) "Interim Policy Note: Unlocking the 'Triple Dividend' of Resilience,' Why investing in disaster risk management pays off." The World Bank Group, Washington, DC.

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