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## Abstract

This report describes the application of an approach for determining grid modernization investments that can best improve the resilience of communities. 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 community stakeholders in New Orleans, Louisiana on grid modernization strategies for resilience. Past disruptions to the electric grid in New Orleans have contributed to an inability to provide citizens with adequate access to a wide range of infrastructure services. Using a performance-based resilience metric, Sandia and Los Alamos performed analysis on how to improve access to infrastructure services across New Orleans after a major disruption using a system of resilience nodes. Resilience nodes rely on a combination of urban planning with grid investment planning for resilience in order to design clustered infrastructure assets with highly resilient electrical supply. Results of the analysis led to suggestion of 22 draft resilience node locations that can provide a wide range of infrastructure services equitably to New Orleans citizens. This report serves as a proof-of-concept for the Urban Resilience Planning Process, and describes several gaps that should be overcome in order to integrate resilience planning between electric utilities and local governments.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the many officials and experts that 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 U.S. 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, and Siobhan Foley. 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 Seth Cureington, Erica Zimmerer, Brendon Oldendorf, Yarrow Etheredge, Paul Olivier, and Harry Barton. Appreciation is also offered to U.S. 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 their efforts and look forward to further collaborations in the future.

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## NOMENCLATURE

| Abbreviation | Definition |
|---|---|
| **US DOE** | U.S. Department of Energy |
| **Sandia** | Sandia National Laboratories |
| **Los Alamos** | Los Alamos National Laboratories |
| **GMLC** | Grid Modernization Laboratory Consortium |
| **POD** | Point of Distribution |
| **PCC** | points of common coupling |
| **DER** | distributed energy resources |
| **FLISR** | fault location, isolation, and system recovery |

# 1. 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 United States' annual costs of power outages due to severe weather averages between $18 billion to $33 billion.[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. Furthermore, 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 gap in capability by a recent update to the Quadrennial Energy Review.[2]

Due to the technical hurdles and the 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 modernization 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 targeted 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 that the city faced 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?

[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 grid modernization options that will minimize this consequence, thereby best improving community resilience? How would these options be designed to work within the current grid?
- What is 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?

This last question regarding costs and additional benefits (e.g. integration of distributed energy resources) is continuing to be pursued among the project partners and technical assistance team 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. 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 continue to 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."*[3]

Based on this definition, Sandia and colleagues have developed a mathematical framework to calculate, project, and improve resilience.[4] 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 wherein analysts, in conjunction with stakeholders, 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 are provided with 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.[5]

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

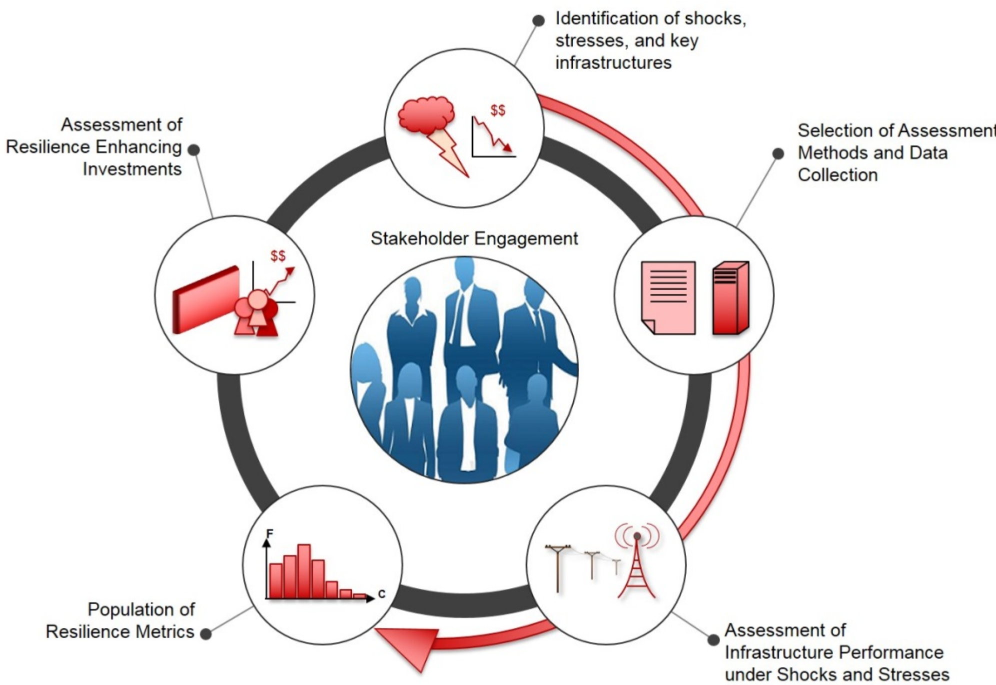


**Figure 1. Sandia's Urban Resilience Planning Process is stakeholder-driven, iterative, and designed to work within stakeholders' existing planning processes.**

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 subject 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, emergency medical services, etc. 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. Because there is significant uncertainty associated with the likelihood and magnitude of power outages into the future, a forward-looking metric should reflect this uncertainty.

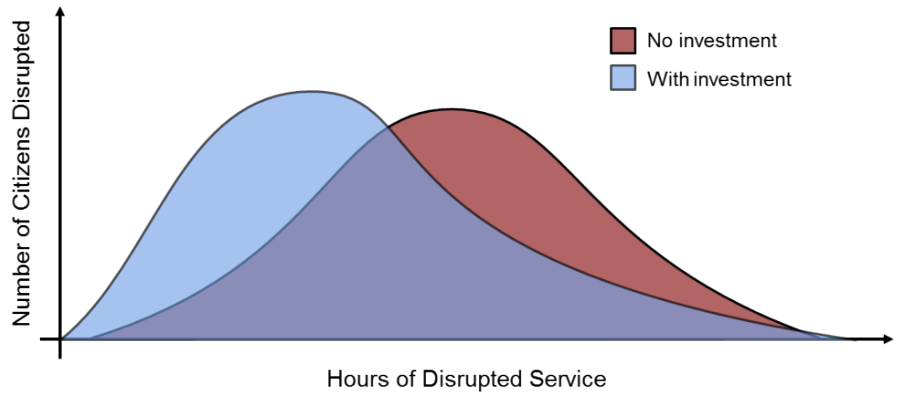


**Figure 2. Suggested metric formulation to measure the impact of resilience investments. Because of existing capability gaps, the percentage of infrastructure assets with reliable backup power was used as a proxy metric.**

In practice, there are significant science and technology gaps that hinder precise forecasting of the metric in Figure 2. Many of these gaps have been discovered directly through this project and are listed in Table 2. Because of the 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 urban infrastructure resilience community's capability 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. 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. The following is a summary of the pertinent results of this analysis which concentrates on the repeatability and usefulness of the approach.

## 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, there are other insults that result in extended power outages such as accidents, tornados, and future considerations such as cyber events. Designing a system to be resilient to hurricanes will provide benefit to 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 through 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 was performed in three stages. First, analysis of wind and inundation impacts of the design basis threat. Second, analysis of power system performance subject to the design basis threat. And third, analysis of all infrastructure services subject to the design basis threat and the power system performance.

### *3.1.1. Hurricane 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 that are thought to represent unique conditions for worst consequence. Hurricane Katrina’s track was chosen because its devastating consequences remain fresh in planners’ minds, and the resulting wind field could push storm surge from Lake Pontchartrain towards New Orleans. The track of a 1947 unnamed storm was chosen because it uniquely approached New Orleans from the southeast and moved directly up the Mississippi River. Because much of the electric power infrastructure and other industrial infrastructure is positioned along the river, and because of the unique impacts associated with potential overtopping of the riverine levees, the 1947 track represents a distinct worst case with which planners have no recent experience. These two tracks are illustrated in Figure 3.

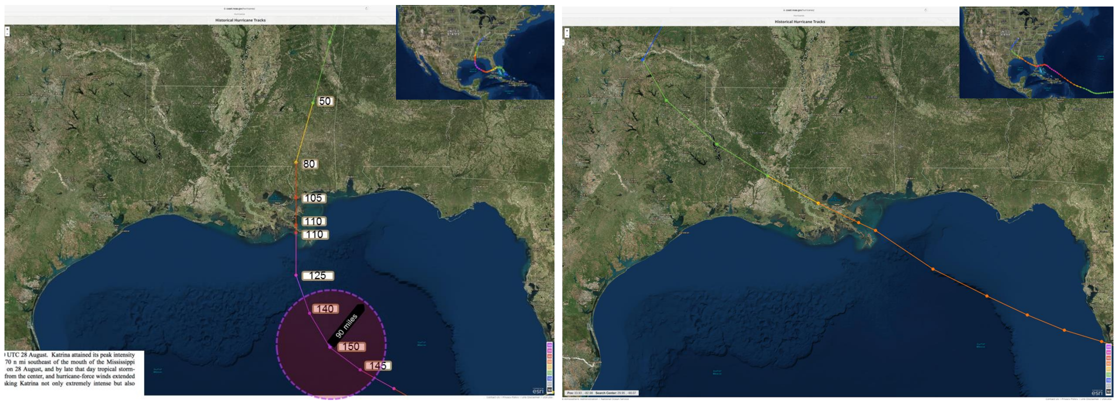


**Figure 3. Two hurricane tracks selected to represent reasonable worst consequence trajectories for New Orleans: Hurricane Katrina from 2005 (left) and an unnamed storm from 1947 that progressed upriver (right).[6]**

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 has a gradation in wind speeds across the city, with stronger wind impacts toward the eastern side of New Orleans, while the 1947 track has 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 different hurricane 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.

### *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, to Entergy's distribution system within New Orleans as well as 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 some which may not be 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

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

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 overhead lines. Overhead distribution lines also have a wide range of wind damage vulnerability depending on their construction, the underlying soils, and the surrounding vegetation type and density.

Based on an assessment of past hurricanes, as indicated in Figure 4, Entergy's service territory can expect anywhere from one week to over three weeks for complete power restoration. Entergy has steadily improved on speed to full power restoration over the past five hurricanes. Hurricanes are not the only source of significant-duration power outages in New Orleans. Many overhead power distribution lines run directly through the canopies of trees, such as the characteristic live oaks throughout the city. This increases the likelihood that lines will be impacted during windy conditions. Other causes of outage not unique to New Orleans include accidents and human error, aging infrastructure, animals, and copper thieves.

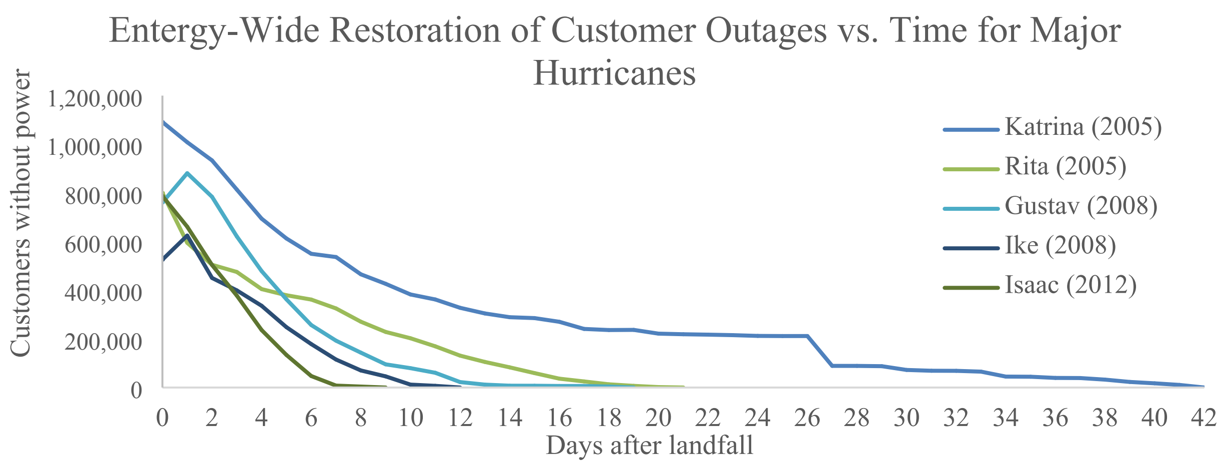


**Figure 4. Customers without power versus time for five past hurricanes across all of Entergy's service territory.**[7]

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. It also provides requirements for grid modernization options that will be designed to support these services when the bulk power grid goes down. As a result of this analysis, the project team recommends that backup power, localized blackstart, 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 seven days, and up to 12-14 days for more critical functions where costs allow. Furthermore, infrastructures served by overhead lines in vegetated areas are at highest outage risk, followed by those served by overhead lines and less vegetation, areas with underground service and high potential for flooding, and finally the most resilient areas are served by underground lines with low flood risk.

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

### *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 grouped into service categories considered for grid modernization support.**

| 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 number of infrastructure services with resilient power provision was calculated over different geographical city zones, which are depicted in Figure 5. This was done to ensure that infrastructure services would be improved by suggestions for grid modernization equitably 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 served by 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. Infrastructures such as sewer pump stations and drainage pump stations are expected to serve their functions even when inundated. In Zone 1, the analysis suggests 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.

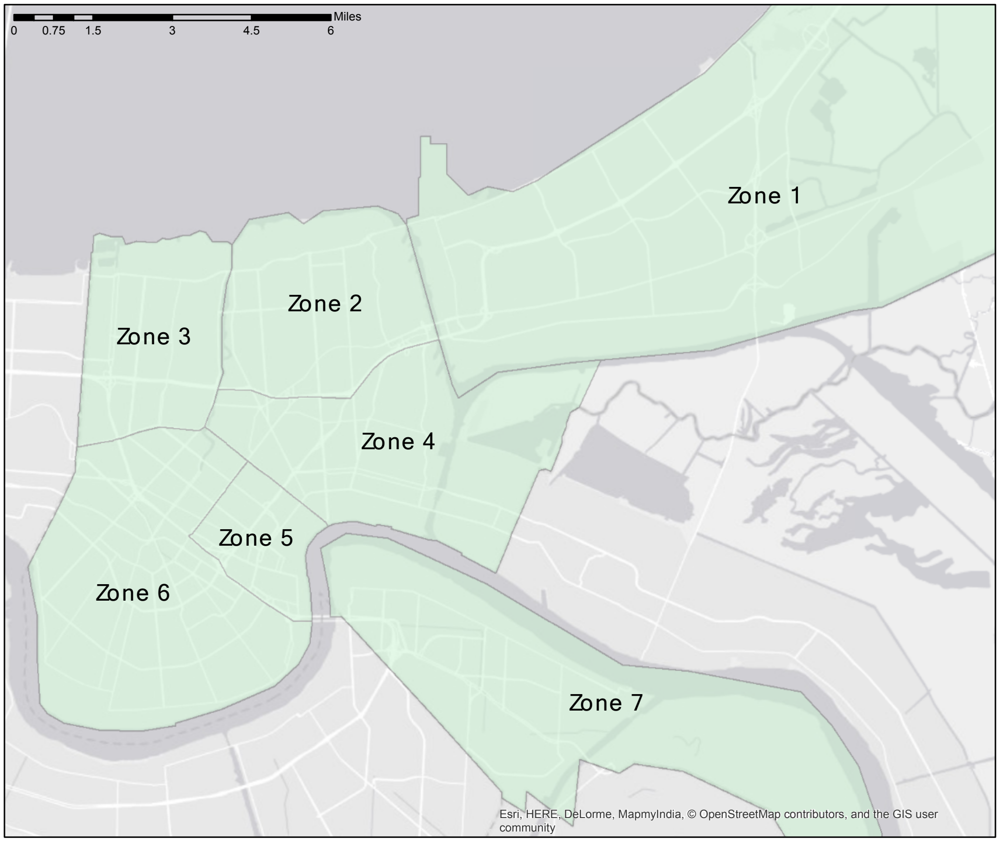


**Figure 5. The analysis of infrastructure services best supported by grid modernization was decomposed by city zones in order to provide equitable distribution throughout the city.**

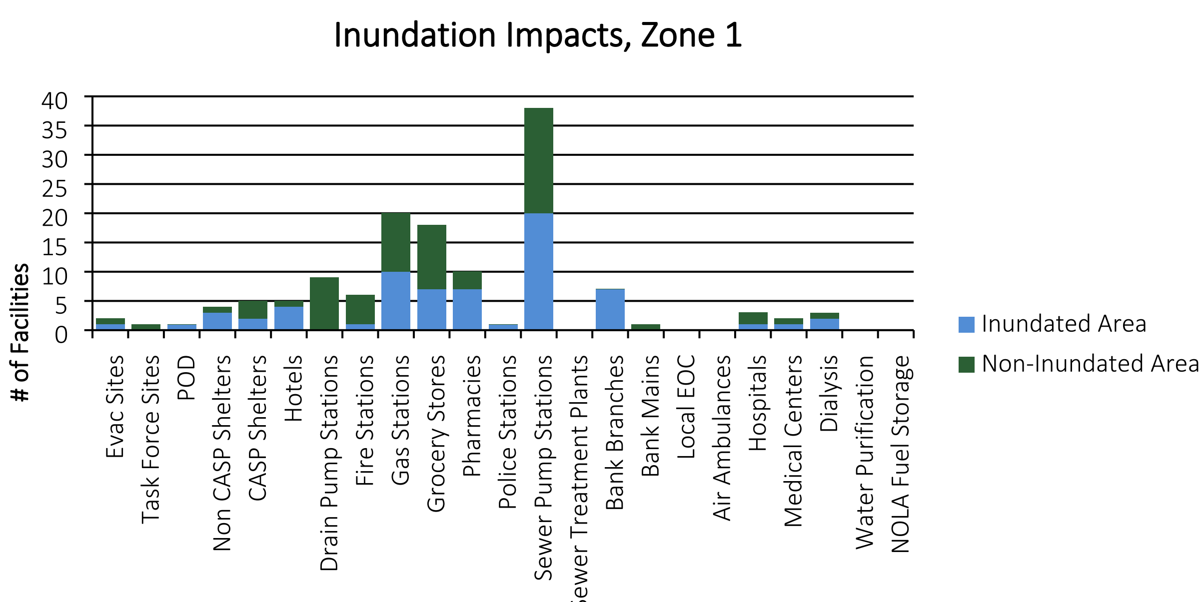


**Figure 6. Infrastructure facilities in and out of the inundation risk area, Zone 1.**

## 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. Proposed energy resilience improvements for New Orleans take into account both the infrastructure services needed in each zone and the cost of added resilience in order to strategically select 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 a list of grid modernization options to be considered for improving New Orleans' community resilience:

1. **Microgrids:** Advanced microgrids utilize automated controls to tie 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. Within the microgrid there are one or more distributed energy resources (DERs) that are integrated to provide stable power to the facilities. Advance microgrids can also provide services when tied to the grid (grid-tied operation), such as peak shaving, renewable energy integration, and demand response.
2. **Distribution System Flexibility and Automation:** The electrical distribution system in New Orleans has been improved to the point that it is heavily meshed in configuration as opposed to radial. A meshed configuration means that power can be delivered 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. 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.
3. **Localized Backup Generation:** Building-tied backup generators are the most common method of supplying power to a facility to keep critical functions powered 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.

Microgrids were identified as a particular grid modernization solution of interest for Entergy and the City of New Orleans. 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," which are areas of a city in which a large number of infrastructure services can be provided in a small geographic area. Resilience nodes offer a cost-effective solution in cases where large portions of the community do not evacuate, and where large portions of population need a wide array of services. Using resilience nodes, 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 the communities' access to infrastructure services. The approach was to specify resilience nodes that could be served by microgrids through an infrastructure clustering analysis, and to suggest backup generation solutions for infrastructures not served by resilience nodes. The "distribution system flexibility and automation" solution referenced above can also improve resilience in New Orleans, but is a less cost-effective option for this particular resilience metric because it is geared toward smaller resilience improvements over a much wider area, and is less helpful when facing nearly city-wide outages such as those suggested by the design basis threat.

Three criteria were used to select candidate resilience node locations. First, the area should have a low probability of inundation. Second, the area should house a large population that needs infrastructure services, even if that population is transient while waiting for floodwaters to recede. Third, the area should have 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). Any facilities in inundated areas are excluded from consideration. Analysts compare suggested node locations to the baseline resilience analysis, adding resilience node locations at lower-density clusters that have high need for services, for example combining two or three yellow dots in Figure 7.

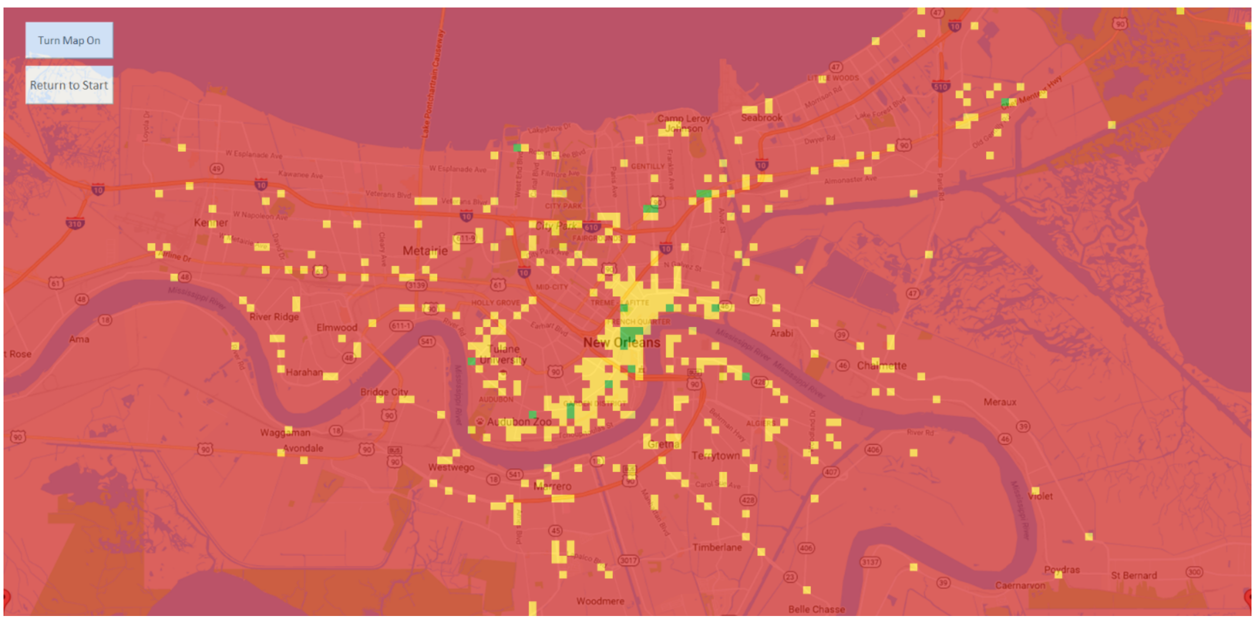


**Figure 7. Results of initial resilience node clustering analysis. Areas of suitable concentration for resilience nodes are shown in green. Areas that have infrastructure buildings but do not meet a pre-determined threshold are shown in yellow.**

Sandia identified 22 potential resilience nodes in New Orleans. Specific resilience node site suggestions for New Orleans are 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.

If all 22 of the suggested resilience nodes are implemented, the city-wide impact to New Orleans' selected resilience metric is shown in Figure 8. City-wide, there are a wide range of services covered at a considerable level by these resilience solutions. 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.

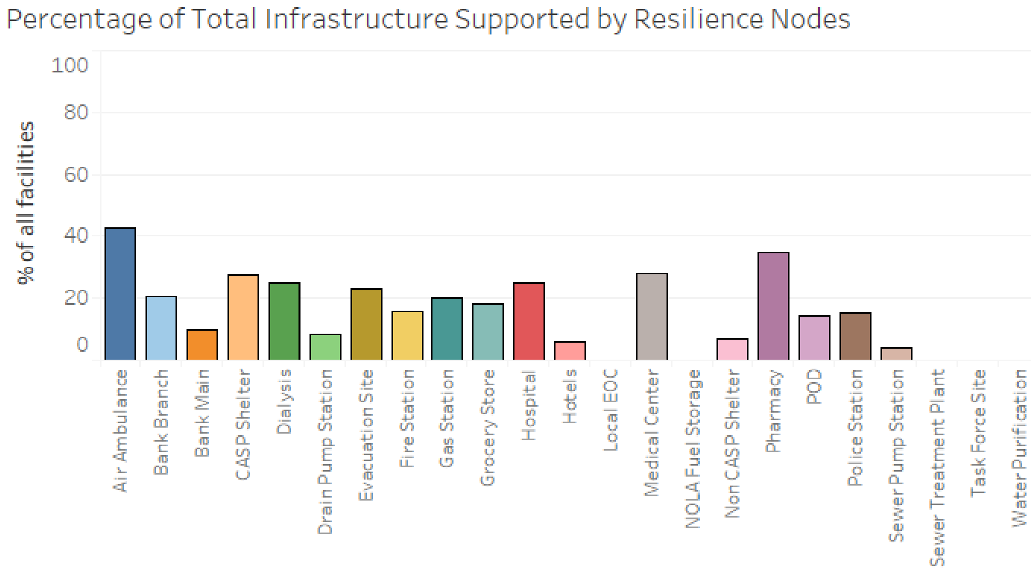


**Figure 8. The city-wide percentage of facilities within each sector supported if all resilience node applications are enacted.**

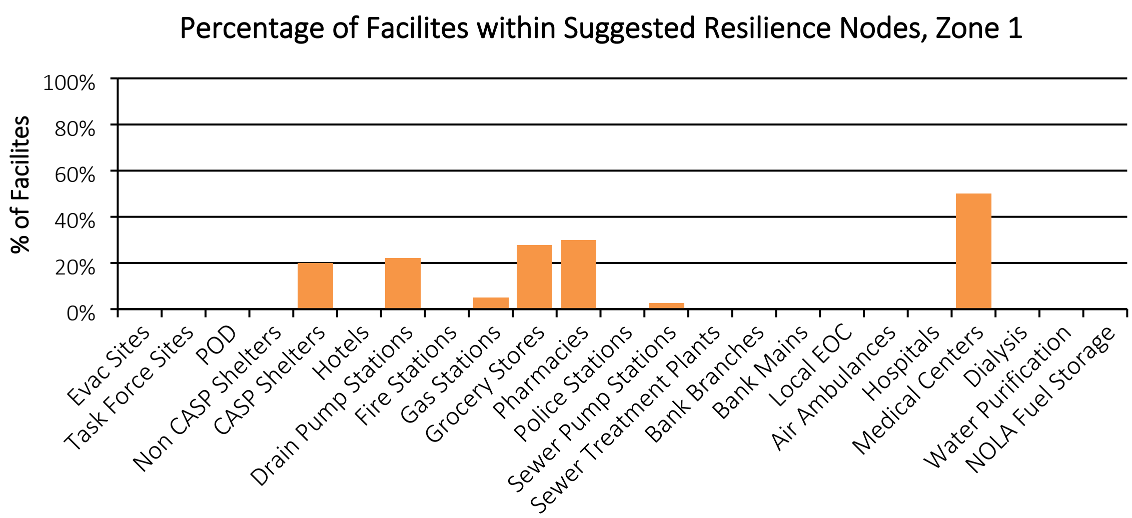


**Figure 9. In Zone 1, resilience nodes can provide services such as medical, pharmaceutical, fuel, food and water, and shelter.**

# 4. 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. The unique aspects of this process are that:

- Performance-based, consequence-focused resilience metrics are used throughout the process to track resilience improvements
- Analyses to support planning are based on a worst consequence threat instead of a worst-case threat—for example, the Category 3 hurricane with no evacuation as opposed to a Category 5 hurricane where the city evacuates
- Stakeholders are heavily engaged at each step in the process, 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.

As applied in New Orleans, the Urban Resilience Planning Process represents a contribution to resilience investment planning for the city, in which performance-based metrics determined by the community are used to inform electric utility investment options. Several lessons have been learned that apply moving forward in New Orleans and to other cities or communities trying 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 no resilience-specific regulations or strong incentives in place. Working toward common resilience goals among cities, state and local utilities regulators, and electric utilities is a crucial hurdle to overcome so that utilities may be rewarded for resilience investments that benefit their communities.
- Partially due to these 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 in addition to emergency response, and the resilience metric suggested herein 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 herein. 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. There is significant work necessary to institutionalize the Urban Resilience Planning Process, in New Orleans and nationwide. The path forward includes:

- 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 more efficient to populate than performance-based metrics. 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, significant science and technology gaps remain in order to populate the community-focused resilience metric suggested for New Orleans (see Figure 2). The four gaps outlined in Table 2 highlight research advancements that would greatly benefit community resilience planners.
- Similarly, more work remains to reveal the many economic benefits of resilience-enhancing investments such as microgrids. The World Bank suggests a triple dividend approach to valuing resilience improvements.[8] 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 actually 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 reduce 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 methods for avoided loss calculations.

[8] 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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