Department of Energy, Office of Electricity Request for Information (RFI): Grid Resilience and Guidance for Enhancing Oil and Natural Gas Resilience

General Information

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Purpose

Sandia National Laboratories (Sandia) seeks to inform the U.S. Department of Energy's Office of Electricity (OE) on their two requests seeking information on cost-effective ways for improving the resilience of America's energy infrastructure. Our response is based on our expertise and laboratory capabilities regarding. Please visit the Sandia Energy website for more information: https://energy.sandia.gov/energy/ssrei/.

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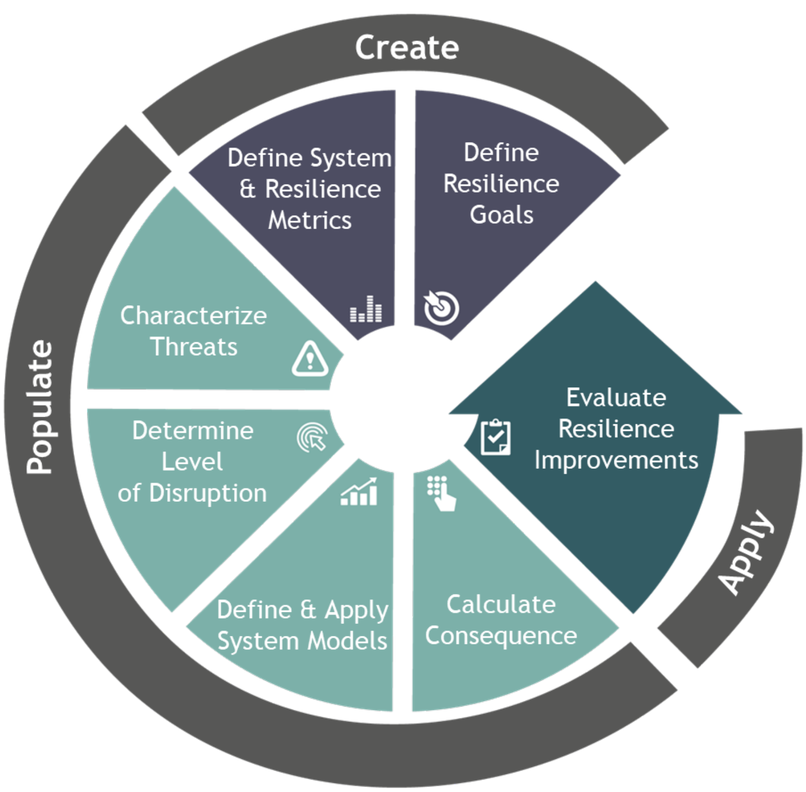
Introduction and Overview

Sandia maintains a broad suite of tools and capabilities related to several aspects of Grid and Oil & Gas infrastructure resilience, including production cost modeling, stochastic unit commitment, energy storage valuation, dynamic grid operations, and transmission/distribution operational and planning tools. All these capabilities are based on a deep understanding of the threat space, be that either natural or human-caused.

Such capabilities are applied to threat scenarios, such as extreme weather, as part of our Resilience Analysis Process (RAP), an intensive and iterative approach to assessing threats, identifying key infrastructures and associated critical nodes, and building and executing systems models – including applicable hardware scenarios and assessing associated consequences. This approach aids grid operators in making effective, defensible decisions to protect local and regional communities from catastrophes related to grid damage. The figure below highlights RAP's comprehensive framework for quantifying resilience and evaluating competing alternatives for resilience improvements. This process was first introduced in the 2015 Department of Energy Quadrennial Energy Review (QER) and is heavily focused on the development and use of performance-based system metrics, thereby enabling comparative analyses of different pathways for grid-based research, investment, policy, planning, and operations. Since its incorporation into the QER, the RAP has been applied with utility partners to assess resilience options for extreme weather, physical interdiction, cyber threats, and wide-scale earthquake damage to natural gas pipelines. (See Appendix A for case study examples.)



The items listed below are a sample of the tools that Sandia has developed to assess and enhance infrastructure resilience, all of which have been applied in the Resilience Analysis Process. It is not a complete set; rather, it is a sampling of how we are constantly developing new approaches to address the most difficult problems related to current and future resilience. As we develop, employ, and transfer these analytical capabilities to the broader community, they provide insights for possible prioritization of research, investment, planning, and even operational approaches with the most impact based on defined natural and human-caused threats. These capabilities have been applied to extreme weather circumstances with utility and US government agency partners. Sandia has worked to inform standards and share best practices throughout the development and execution of these capabilities.

Resilient Node Cluster Analysis Tool (ReNCAT)

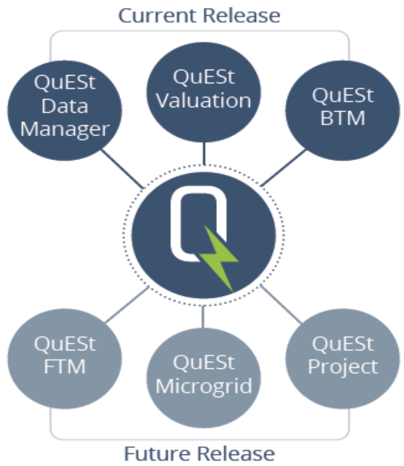
The Resilient Node Cluster Analysis Tool (ReNCAT) is a computational application developed by Sandia National Laboratories for use in community resilience applications. ReNCAT analyzes critical infrastructure throughout a large area, such as a city, and finds dense groupings of buildings that lend themselves to the development of resilience nodes. A resilience node is a region within a populated area where an advanced microgrid, backup generation, or hardening can be deployed to ensure critical assets are available to residents in the aftermath of a natural disaster. Since resilience is in respect to specific threats, ReNCAT uses exclusion profiles to specify the impact of each design basis threat (DBT) included in the analysis. ReNCAT also utilizes a matrix mapping of critical infrastructure types to the critical services they provide to translate buildings to services. The tool then divides the geographic area into a grid whose cell size is specified by the user and evaluates the total critical service score available in that area. A minimum priority score is also set by the user. ReNCAT displays the results of the analysis on a map interface and color-codes each grid cell. Each cell can be expanded to reveal which buildings and services are available in that sub-area, and a tabular report is generated on all potential resilience nodes that are found. Areas with multiple assets whose total service score is at or above the minimum score required will be designated as potential areas for microgrid investment and are shown on the map in green. Areas shown in yellow have critical assets but do not meet the minimum service score, while areas shown in red have no services or have assets that are inundated by the flood and cannot be used.

Jeffers et al. (2018) A Grid Modernization Approach for Community Resilience, Application to New Orleans, LA.
https://www.sandia.gov/cities/_assets/documents/NewOrleans_report.pdf

QuEST

QuEST is and open source, Python-based energy storage analysis software application suite that was developed as a as a graphical user interface (GUI) for the optimization modeling capabilities of Sandia's energy storage analytics group. QuEST estimates a value for a given energy storage system using historical data and a given market structure to determine the maximum amount of revenue that the energy storage device can generate by providing multiple services (e.g., ancillary services, arbitrage).

QuESt currently consists of three distinct yet interconnected applications that individually and collectively help project engineers and researchers evaluate energy storage systems for different use cases:



1. **QuESt Data Manager** - Manages acquisition of ISO market data, US utility rate data, commercial and residential load profiles, etc.
2. **QuESt Valuation** - Estimate potential revenue generated by energy storage systems providing multiple services in the electricity markets of ISOs/RTOs.
3. **QuESt BTM** - Estimate the cost savings for time-of-use/net energy metering customers using behind-the-meter energy storage systems.

Future releases will include applications such as QuESt FTM (for front of- meter analyses), QuESt Microgrids (for microgrid operation and control), and QuESt Projects (for energy storage project planning).

QuESt BTM is aimed at providing analysis tools for behind-the-meter energy storage. It estimates the cost savings provided by energy storage for time-of-use and net energy metering customers. By strategically using energy storage, the customer can reduce his or her time-of-use energy charges or reduce demand charges by peak shaving. Energy storage can also be used with on-site solar power to reduce the customer’s monthly bill by time-shifting.

QuESt BTM uses simulated load profiles of different commercial and residential buildings located around the United States. It leverages a database of U.S. utility rate structures to allow users to select the rate structure most pertinent to his or her project. Additionally, QuESt BTM can utilize simulated solar power profiles for projects with energy storage co-located with, for example, rooftop solar. By simulating different energy storage system configurations, QuESt BTM can help users size the appropriate energy storage system for reducing his or her building’s monthly electricity bills.

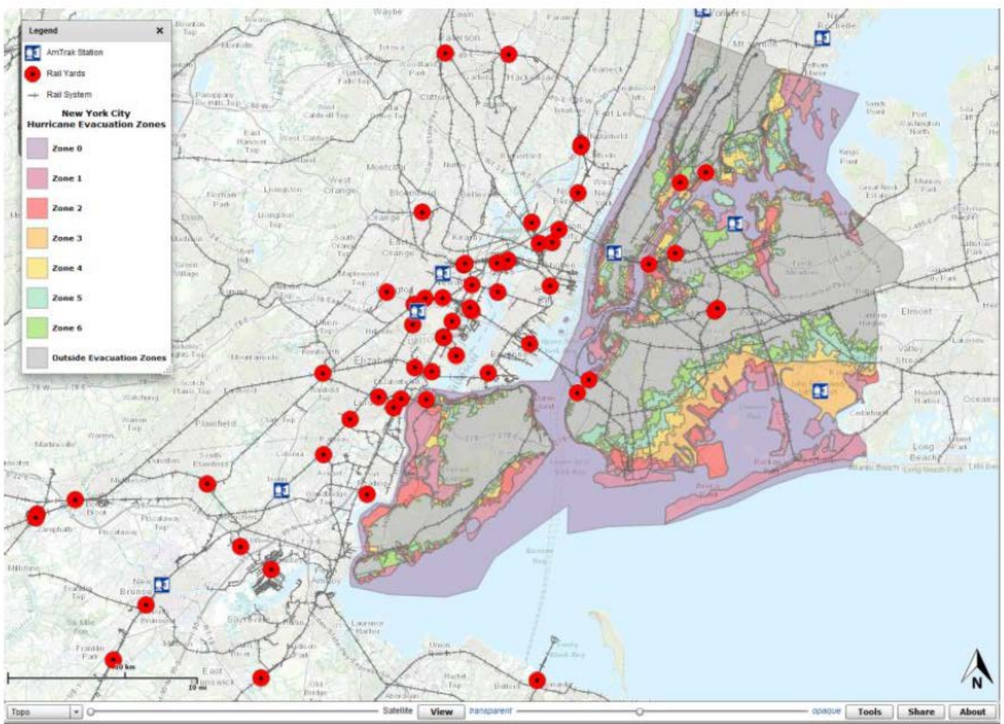
The tool can be used to determine the potential benefit to incorporating an energy storage component into an energy supply system, such as solar or wind power, as described above. It could also be used to determine how much energy storage might be needed to maintain continuous power supply in the event of an emergency situation.

FASTMap

The National Infrastructure Simulation and Analysis Center's (NISAC's) FASTMap is a web- and tablet-based mapping application developed in support of crisis response efforts. FASTMap browses national infrastructure and emergency resources data and can be configured to display results from independent models generating geospatial and/or temporal output. It generates maps and reports of assets at risk within any area of disruption or any analysis area. FASTMap uses the National Geospatial Intelligence Agency's HSIP Gold national infrastructure database and provides immediate data access through a fully symbolized, publication quality, interactive mapping interface available to browsers and mobile tablets alike.

The FASTMap application provides several benefits for responding quickly to events including hurricanes, flooding, earthquakes, wildland fires, planning scenarios, as well as exercise scenarios. An interactive map displays infrastructure and assets and can visually represent what assets are located within a specific area, the number of assets, their capacity and what attributes are associated with each asset. It also generates an automated report that lists assets and asset statistics within specified damage or analysis area. The application is available to first responders in the field via both iOS and Android operating systems.

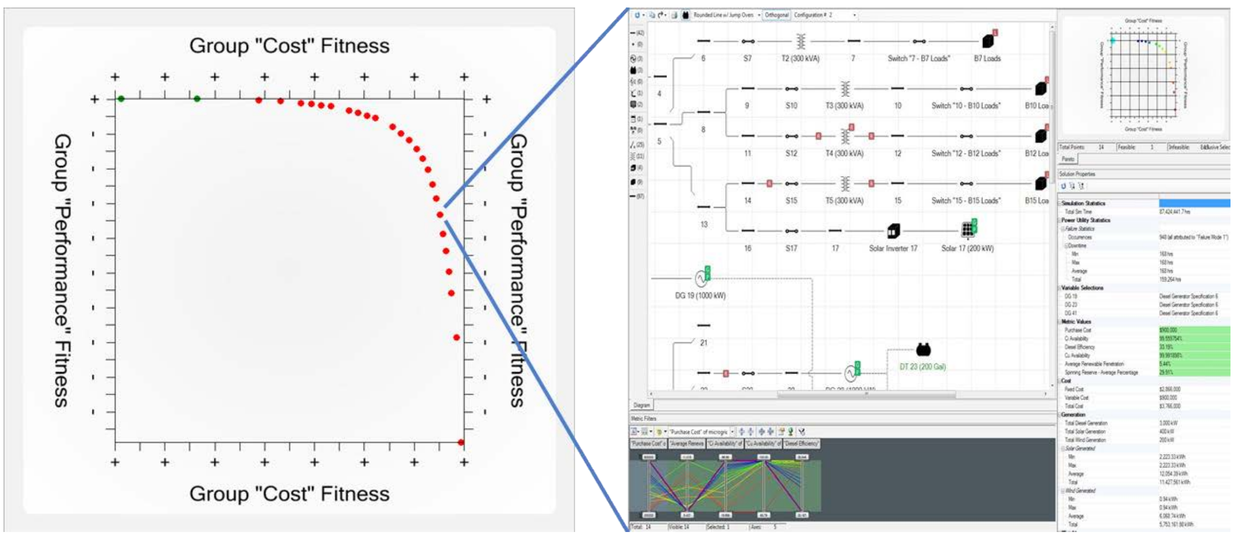
In addition, the data is password protected and is available over a secured network to authorized users, providing responders with dynamic maps and real-time information to provide the most effectively and timely response to the event.



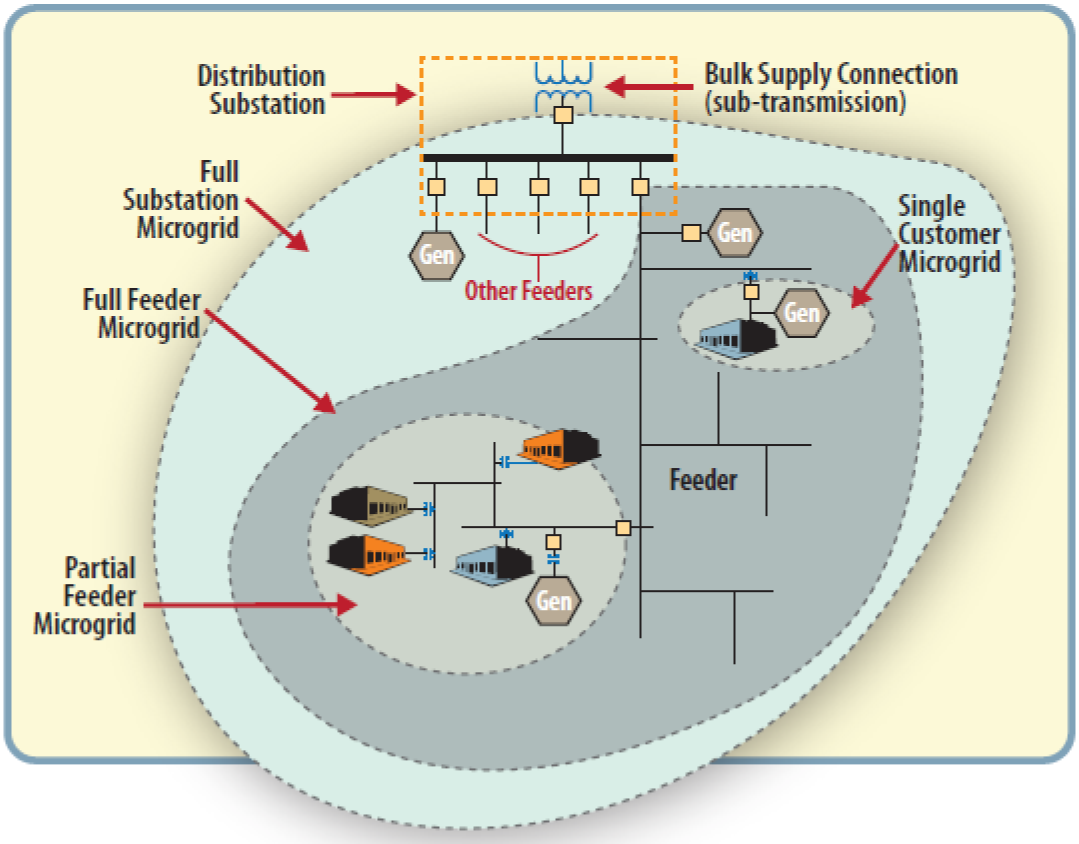
The Microgrid Design Toolkit (MDT)

To ensure safety, security, and well-being, critical installations require a steady supply of power at all times, with no interruptions. Microgrids - collections of distributed energy resources and controls that can provide electrical power independently of the primary grid - offer a means of maintaining power, even when the grid is unavailable. To aid in optimal design of microgrids, and help avoid potential problems with maintenance, safety, power quality, and stability, Sandia has developed the Microgrid Design Toolkit (MDT).

MDT is decision support software that can provide designers the information they need to identify an optimal microgrid design for their needs in the early stages of the design process. Employing powerful algorithms, MDT searches the trade space of alternative microgrid designs in terms of user-defined objectives, such as performance, reliability, and cost. It then produces a Pareto frontier of efficient microgrid solutions—or, the efficient tradeoffs that can be made among multiple user-defined objectives. A range of interactive displays and charts help designers understand the implications of different decisions and tradeoffs on the quality of a microgrid design.



MDT is already building a track record in the design and assessment of microgrid projects. For example, it was used in early design of a backup power system in Hoboken, New Jersey, to ensure a steady supply of power to critical infrastructure, such as hospitals, fire stations, and city hall, in the event of manmade or natural disasters. MDT was also instrumental in the work of the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) program, which created microgrids to ensure that three different military installations can operate independently from the power grid for extended time periods with maximum assurance of uncompromised electrical service.


Distribution Substation
Bulk Supply Connection (sub-transmission)
Full Substation Microgrid
Gen
Other Feeders
Single Customer Microgrid
Full Feeder Microgrid
Gen
Gen
Feeder
Gen
Partial Feeder Microgrid

Oil and Gas Midstream Resiliency

Sandia’s Resilient Energy Systems (RES) Strategic Initiative is investing in identifying and strengthening cross-cutting capabilities across our energy research and development (R&D) portfolio. A combination of factors is contributing to infrastructure that is vulnerable to natural hazards, which includes aging infrastructure (e.g., midstream infrastructure that is at or near full capacity, with little or no ability to meet major demand events in certain regions) and increasing demand. For example, a cold spell in northern Minnesota in early 2019 is the ‘canary in the coal mine’ for midstream. In this instance, natural gas was needed for electricity and heating and the resulting load was too great for the in-place infrastructure (e.g., pipeline). Natural events – including fire, flooding, earthquakes, sea-level rise and severe weather (e.g., ice storms, hurricanes) – when combined with identified degradation events, such as corrosion of aging infrastructure, cause exposure in natural and malevolent attacks. Sea level rise and hurricanes pose particular threats to oil & gas infrastructure because a significant percentage of that capacity is located in coastal regions that are vulnerable to both.

Resilience of the midstream domain could be improved through technological innovation of its physical systems. New refinery construction has slowed due to public concern with and regulation of hydrocarbon and CO2 release from wellheads, pipelines, storage tanks, and flares. Sandia is involved in safety standards development utilizing risk-informed concepts to develop codes and standards for hydrogen, liquid, and compressed natural gas facilities.

Sandia is engaged in analytical studies, research, and development of a diverse set of energy-related and industrial technology topics with a goal of accelerating the development of safe and resilient technologies, including natural gas, heavy hydrocarbons, refrigerants, heat transfer, material mechanics, computational simulation, systems studies, and advanced technology research, development, and demonstrations. Sandia’s goal is to ensure a secure and sustainable energy supply with a safe and resilient delivery infrastructure.

Sandia’s robust and broad-based energy program includes a multitude of innovative research and development programs that can be leveraged to assess resiliency to natural hazards and evaluate mitigation strategies including:

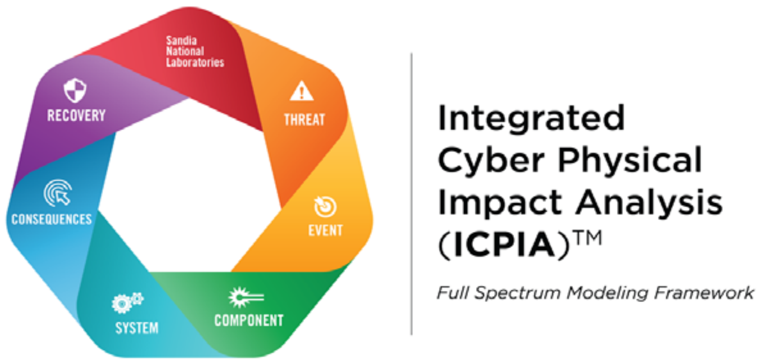
- Quantitative risk assessments and Liquid Natural Gas (LNG) behavior research including leak dispersion, ignition, flame, deflagration, fireball, explosion, and phenomena. Capabilities include the development of simple models for prediction of the effects of a LNG leak. These effects include concentration, combustible mass and location, overpressure, and thermal effects. They may occur inside and outside of the enclosures, depending on leak locations and the development and validation of Computational Fluid Dynamics (CFD) models and codes.
- Independent safety analyses focusing on existing codes and regulations as well as planned policy and regulatory changes for consideration to improve safety. The category includes

performing studies to enhance pipeline safety as well as reviewing pipeline or storage incidents.

- Review of system piping sizes, process conditions, release conditions, design spill selection criteria, and equations used to characterize potential release scenarios during severe weather events.
- Development of critical data necessary for efficiency, cost reduction, and sustainability. The scope of this category includes grid integration, energy storage, geologic storage, advanced fuel dispensing, combined heat, power and fuels systems, and chemical energy storage.
- Technical expertise on requirements, interpretation, and implementation of codes and other industry standards. Technical analysis and regulatory support on rulemaking and congressional mandates (e.g., PIPES Act 2016 for small scale and national security), including reviewing industry technical standards.
- Specialized technical services to obtain laboratory data needed to evaluate incidents, determine causation, and resolve regulatory compliance issues. Specialized technical services in this scientific subfield include, but are not limited to:
    - Metallurgical investigations
    - Material property tests
    - Chemical analysis
    - Corrosion studies
    - Fracture mechanics assessments
    - Stress analysis

Sandia's strategy is to leverage existing capabilities to develop midstream-focused tools and get them in the hands of the people who need them to address midstream resilience challenges. For example, Sandia is exploring current needs in national-scale fuels infrastructure resilience modeling. Emphasis includes reviewing what upgrades to the Sandia National Transportation Fuels Model (NTFM), which simulates how the national petroleum network (circa 2012-2015) performs under specified disruption scenarios, would be needed to include current (2019) infrastructure and also add resilience metrics as part of its output. This capability, once realized, could provide a powerful tool for finding and mitigating vulnerabilities associated with this distribution system.

Integrated Cyber Physical Impact Analysis (ICPIA)



The Integrated Cyber-Physical Impact Analysis (ICPIA) framework demonstrates the value of linking modeling, simulation, and analytical capabilities across the spectrum from threat through broad societal consequences. While the description included in the following example is specific to cyber threats and attacks, the same framework and integrated hardware/software approach applies to natural events.

Sandia conducted an internally-funded effort to develop and demonstrate the Labs' cross-mission ability to model cyber-initiated events on our national energy infrastructure and manage the resulting impact to the system(s), community, state, or nation. As part of the effort, three attack scenarios on our stationary energy components (e.g., transmission, distribution, and nuclear) were used to demonstrate this capability, showing the extended consequences of a cyber-attack from an initiating event to component/system level effects, and ultimately to regional or national-level impacts. As specific scenarios were outlined and modeled, the team proposed a framework for ICPIA. The framework incorporated a holistic view of the causes, consequences, and potential mitigation strategies crossing five domains: threat, cyber-attack, component effects, physical system impacts, and extended consequences.

Discovering and addressing weaknesses introduced into our energy infrastructure by digital systems is an important mission for Sandia. Sandia has the capabilities needed to discover infrastructure weaknesses, avoid them when possible, remove them when practical, and mitigate their impacts when necessary. Consequently, Sandia conducted a mission integration effort that directly leveraged existing simulation tools, cyber emulation and analysis capabilities, and other physical modeling and simulation tools across the Labs' mission areas to demonstrate potential impact to the national critical infrastructure in case of a catastrophic local event, such as a severe storm. Sandia aims to accurately model the impact from insertion of the anomaly all the way through to the national impact. Once developed, the analysis capability can be adjusted to evaluate additional concerns (i.e., capability is extensible and flexible). The work was tested in practical concerns for five energy sectors.

From this effort, the five-stage ICPIA framework was created, which identified five areas where Sandia had unintegrated modeling and simulation capabilities that were needed to demonstrate threat -to-consequence scenarios.

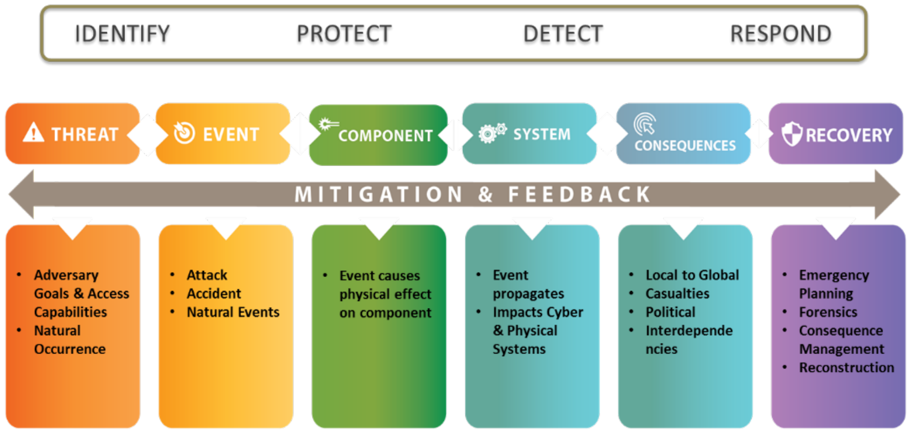
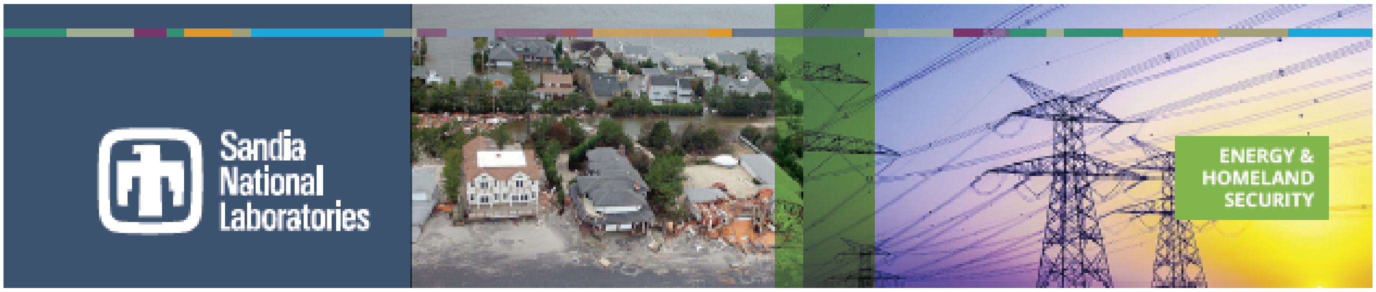


Figure 1: ICPIA Framework – Modeling and Activities

Figure 1 shows the different modeling that occurs in each domain. For example, the "Event" domain includes an attack, accident, or natural occurrence that causes an effect on the digital system. This effect then causes a physical impact to the component or system which is modeled in the "Component" domain. To appropriately manage cyber risk, all domains (from threat-to-consequence) are needed.

The ICPIA framework is not new and has been used to analyze complex systems from threat to extended consequence for years. The integrated capability supports many use cases:

- **Supports new threat analysis** – Explores the impact of previously unidentified threats and vulnerabilities
- **Provides a test bed for integrating systems** – an Intrusion Detection System (IDS) can be installed and tested in the network emulation
- **Designs secure architectures** – evaluates protective measures (e.g., detection, deter, respond), such as encryption
- **Acts as a training tool** – for Red Team attackers or for plant operators to develop cyber-attack response procedures
- **Identifies R&D gaps** – Reduces system risk
- **Supports integrated resilience management** – Recovery metrics, impact and consequence analysis, moving to "all hazards" analysis



DEVELOPING RESILIENT COMMUNITIES WITH GRID MODERNIZATION

Strong, resilient communities depend on a reliable electric infrastructure. Sandia employs advanced methods and new technologies to protect communities against cyber threats and restore communities after natural disasters.

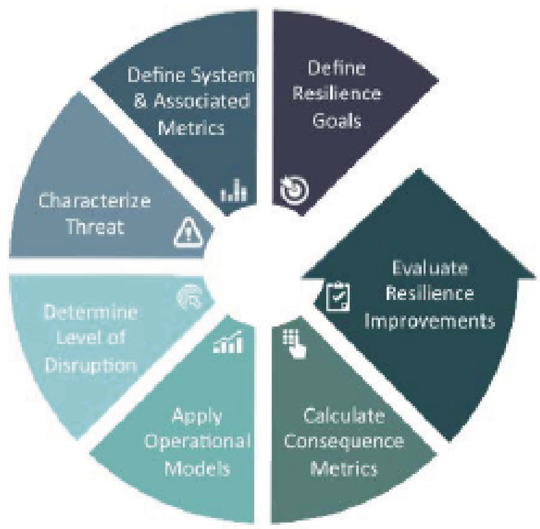
Methodology

Early Sandia R&D related to critical infrastructure resilience focused on the **Infrastructure Security Risk Assessment Methodology (RAM).** The Sandia RAM framework and software tools evaluated the mission, threat, and level of protection to make mitigation decisions for dams, transmission systems, municipal water, communities, chemical facilities, energy systems, airspace facilities, biohazards, and communities.

In 2008, Sandia developed the **energy surety design methodology (ESDM)** that directly links energy surety (safety, security, reliability, sustainability, and cost effectiveness) with critical power needs. It does this by integrating distributed energy resources (DERs), including backup generators, local PV systems, small wind turbines, electrical energy storage, etc., into a local electrical distribution service area (microgrid). This decentralized approach allows the DERs to be managed intelligently, efficiently, and reliably.

Frameworks

To help grid operators make effective, defensible decisions about protecting local and regional communities from catastrophes related to grid damage, Sandia uses the **Resilience Analysis Process (RAP)**, a comprehensive framework for quantifying resilience and evaluating competing alternatives to improve resilience. The RAP is highlighted in the recent U.S. Department of Energy Quadrennial Energy Review and Quadrennial Technology Review.



This multi-step method calls for working closely with stakeholders to identify the most crucial potential threats and high-level consequences in their region. Sandia analysts then create a detailed system model and evaluate the model against the specified threats to determine system response and consequences. Finally, the analysts apply stochastic optimization algorithms to identify changes to the system that minimize consequences and achieve the greatest system resiliency.

Case Studies

Geomagnetic Disturbances Resiliency for PJM: Sandia identified cost-effective ways to increase resilience to the transmission system of independent system operator PJM—which coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia— against geo-magnetic disturbances caused by solar storms.

Physical Threat Resiliency for AEP: Sandia analyzed the resilience of part of the transmission system of American Electric Power—the largest utility in the U.S., serving 5 million customers in 11 states—against extreme weather events and physical security threats. Cost effective planning solutions and operational solutions are being developed to maximize their resilience to these events.

Urban Resilience in New Orleans, LA: After Hurricane Katrina caused catastrophic flooding in 2005, Sandia worked with Los Alamos National Laboratory, Entergy, and the City of New Orleans to provide the city with cost and benefits associated with grid resilience investments. By connecting grid performance to the performance of multiple interdependent infrastructures, this work delivered an assessment of techniques to improve community resilience through investments in grid resilience.

Urban Resilience in Norfolk, VA: Sandia worked with Norfolk and the city's partners from the Port of Virginia, the U.S. Navy, Dominion Power, and the 100 Resilient Cities Initiative to improve Norfolk's infrastructure resilience to better withstand, adapt to, and recover from potential flooding.

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The Microgrid Design Toolkit (MDT) was developed at Sandia and is a decision support tool for early-stage resilience design involving microgrids. It has functions to identify and compare microgrid design options in terms of user defined objectives such as cost, performance, and reliability. The MDT provides many views and features to help explore that trade space and extract information.

Rural Community Resilience in Alaska: Using the MDT, Sandia performed an analysis demonstrating trade-offs between investment levels and fuel savings for the community of Shungnak, AK. The results show that several grid design options can reduce fuel and heating oil requirements by 50% of current usage levels. Some designs provide positive net present value for both utility and customers and positive return on investment percentages.

Transportation Resilience in New Jersey: In the aftermath of Superstorm Sandy, Sandia helped New Jersey Transit Corporation develop the nations largest electric microgrid that will include a large-scale, gas-fired generation facility and distributed energy resources (photovoltaics, energy storage, electric vehicles, combined heat and power) to supply reliable power during storms or other times of significant power failure.

Critical Infrastructure Protection in Hoboken, NJ: Sandia partnered with the City of Hoboken, NJ to conduct a study that identified critical assets and analyzed the effects of Superstorm Sandy. From that analysis, Sandia helped the City design a microgrid consisting of 55 buildings that included a hospital, supermarket, and public safety facilities such as police and fire stations.

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