7. Energy Systems

7.1. Introduction

The electricity performance expectations and needs of society have increased dramatically over the past 25 years. In fact, the demand for electricity has increased by over 25% since 1990. However, the aging United States infrastructure is a major issue for all communities. The energy system is making progress in upgrading the existing electric infrastructure with a focused effort to make the system less vulnerable to large catastrophic events. For example, many utility providers are installing smart grid technologies; and grid modernization improvement is a major effort nationwide that is projected to continue for years to come. This translates to a need to upgrade all elements of the energy infrastructure system and build for resiliency. In an effort to build resilient and flexible energy infrastructure there needs to be an understanding and balance of the desired level of resilience, the expected benefits resilience may bring, and the estimated costs associated with improving and replacing this infrastructure.

Electricity and fuel are interdependent, essential, and cross-cutting services for community resilience and reliability. They support society’s most basic human needs for food, water, and shelter. In a hazard event, electricity and fuel supply are critical to supporting human life and restoration of service is a critical activity no matter what the cause or where the event occurred. Post-disaster fuel supply is also critical to electricity generation and transportation. Having available fuel is essential for local generators in managing recovery and for emergency service and supply vehicles.

This section discusses the natural gas and liquid fuels subsystems only as they relate to the reliability and resilience of the electric power system. The pipelines needed to transport natural gas and liquid fuels are discussed as part of the Transportation System (Chapter 6) because the engineering standards for pipeline safety and design are administered by the USDOT.

7.1.1. Social Needs and System Performance Goals

The electrical and fuel supply societal needs of the 21st century are much different from what these needs were a century ago. High quality, high availability, inexpensive power has become a basic societal necessity. Even in day-to-day power delivery, utilities struggle to meet these conflicting consumer expectations. Preparing for and responding to hazard events becomes an even larger challenge when utilities need to pay for necessary infrastructure repairs while experiencing revenue losses when electricity delivery is suspended. This difficult challenge requires careful consideration, especially from regulatory authorities, when addressing utility rate recovery cases and setting public expectations for post-disaster recovery timelines and quality of service expectations.

As communities address issues related to their expectations of energy system performance, improving grid resilience and the costs associated with the associated improvements, communicates must prioritize and balance end user (public safety, hospitals, businesses, and residences) resiliency and restoration requirements. As much as practical, systems need to adapt to the ever-changing environment and be built to either minimize damage and impacts to the system, or rapidly restore the system after hazard events occur. Communities must strike a balance that enables utilities, municipalities and co-operatives to protect, maintain, and recover the system while controlling costs. Involving additional community partners may be necessary if performance or restoration expectations are greater than the energy service provider(s) can economically or practically support.

Electricity consumers should be informed and educated on the costs and benefits of facility and infrastructure hardening and resiliency planning and resulting performance expectations. Generation facilities (including renewable energy and storage options) and substations may need to be located into the communities they serve to ensure these facilities are sited and constructed to be resistant to potential hazards (e.g., flooding, storm surge, wildfire, etc.).

When events occur and recovery efforts are required, the priorities and restoration efforts should address emergency-related societal needs first, and then progress through a tiered response. Although this model of recovery can be complex, for simplicity, the three general tiers on which to focus restoration of services are: 1) emergency facilities and services (Critical and Essential Facilities), 2) critical public works and right of way (access) for critical infrastructure restoration crews, and then 3) systematic restoration of the community at large. Later in this chapter (Section 7.3), these tiers are further investigated for energy systems (by system element such as generation, transmission, and distribution) in example performance goals matrices. These tiers are discussed in Section 7.5, and are related to recovery levels for new and existing infrastructure (Sections 7.5.1.2 and 7.5.2.2, respectively).

7.1.2. Reliability, Energy Assurance, and Resilience

Reliability and resilience are related, but distinct, concepts with different performance goals or metrics. In many cases, the projects and investments to improve day-to-day reliability contribute to resilience; however there is not a one-to-one correspondence. In August 2012, the President's Council of Economic Advisers released a study on the benefits of investing in grid resilience. The study explained the difference between resilience and reliability as:

> *"A more resilient grid is one that is better able to sustain and recover from adverse events like severe weather – a more reliable grid is one with fewer and shorter power interruptions."*

In September 2012, Maryland's Grid Resiliency Task Force adopted similar definitions for resilience and reliability.

> *"[R]eliability [was defined] as the ability of the bulk power and distribution systems to deliver electricity to customer during normal 'blue sky' operations. . . . Resiliency was defined as the ability of the distribution system to absorb stresses without experiencing a sustained outage."*

The Public Service Enterprise Group (PSEG) in New Jersey states in its Energy Strong Program:

> *"Reliability remains fundamental but is no longer enough now that extreme storms have become increasingly common and people are more dependent on electricity than ever before."*

PSEG is looking for a different set of performance metrics for all conditions; performance metrics that have commonality with resilience metrics presented in this framework.

For the purposes of this framework, NIST will use the definition of "resilience" from Presidential Policy Directive/PPD-21: Presidential Policy Directive – Critical Infrastructure Security and Resilience:

> *The term "resilience" means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.*

Quantitative statistics have not yet been compiled to illustrate the effort the electricity system has put into resilience, but those in the industry have thought a great deal about resilience. In recent industry studies (NARUC 2013), NERC defines resilience of the bulk electric system via two main responsibilities – adequacy and security. Adequacy in this context is "the ability of the bulk power system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements." Security is the "ability of the bulk power system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements from credible contingencies." This definition of security may be applied to the bulk electric system, but is not applicable to the distribution system, nor does it address infrastructures of other systems (e.g., gas/fuels, telecommunications and water).

The purpose of this discussion is not to resolve the issue of which term is most appropriate or which approach will make the infrastructure of the grid least susceptible to damage and outages during all types of events. Rather, the purpose is to look at the infrastructure elements of the energy system (generation facilities, substations, transmission and distribution elements) and provide guidelines and performance objectives for design and construction of an electrical grid that is more reliable and also more hazard resistant so as to perform with the least impact or interruption when events (routine, expected, or extreme) occur. Using the terms related to resilience that are used by the other systems will simplify defining performance metrics for resilience in this and the other systems, allowing us to identify and understand interdependencies between the different systems.

The Four R's. When applying the PPD-21 to the energy system to define resilience, a number of scholarly articles and reports on resilience provide an energy industry specific evaluation of what resilience can look like. One article, the NASEO State Energy Assurance Guidelines[1] refer to the 4 Rs of resilience with respect to infrastructural qualities:

1. ***Robustness* -** the inherent strength or resistance in a system to withstand external demands without degradation or loss of functionality
2. ***Redundancy* -** system properties that allow for alternate options, choices, and substitutions when the system is under stress
3. ***Resourcefulness* -** the capacity to mobilize needed resources and services in emergencies
4. ***Rapidity* -** the speed with which disruption can be overcome and safety, services, and financial stability restored

An overall energy resilience strategy is one that actively manages each of these qualities to achieve the desired performance of an energy system. In addition, it can be used to help quantify the following measures of resilience for various types of physical and organizational systems:

1. ***Technical* -** the ability of physical systems (including all interconnected components) to perform to acceptable/desired levels when subject to hazard events
2. ***Organizational* -** the capacity of organizations - especially those managing critical facilities and hazard event-related functions - to make decisions and take actions that contribute to resilience
3. ***Social* -** consisting of measures specifically designed to lessen the extent to which communities and governmental jurisdictions suffer negative consequences due to loss of critical services due to a hazard event
4. ***Economic* -** the capacity to reduce both direct and indirect economic losses resulting from a hazard event

To explore some differences between reliability and resilience, look at recent events. In the wake of Hurricane Sandy, widespread power outages had cascading and disastrous consequences across the New York and New Jersey region, but specifically in lower Manhattan in New York City. The tidal surge flooded a substation in lower Manhattan and knocked out power for customers below 39th Street for nearly five days. "[It was] the largest storm-related outage in our history," according to an October 30, 2012, press release from John Miksad, Senior Vice President for Electric Operations at Consolidated Edison.

The lights in lower Manhattan were hardly back on before Consolidated Edison asked state utility regulators to approve a very large, multi-year capital investment program to harden the electric power grid for future storms. Note, resilience hardening is programmed and funded at lower levels than reliability funding over the same period of time (taken from Pentland 2013) at this utility.

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[1] This report can be found at : http://www.naseo.org/Data/Sites/1/documents/publications/State_Energy_Assurance_Guidelines_Version_3.1.pdf

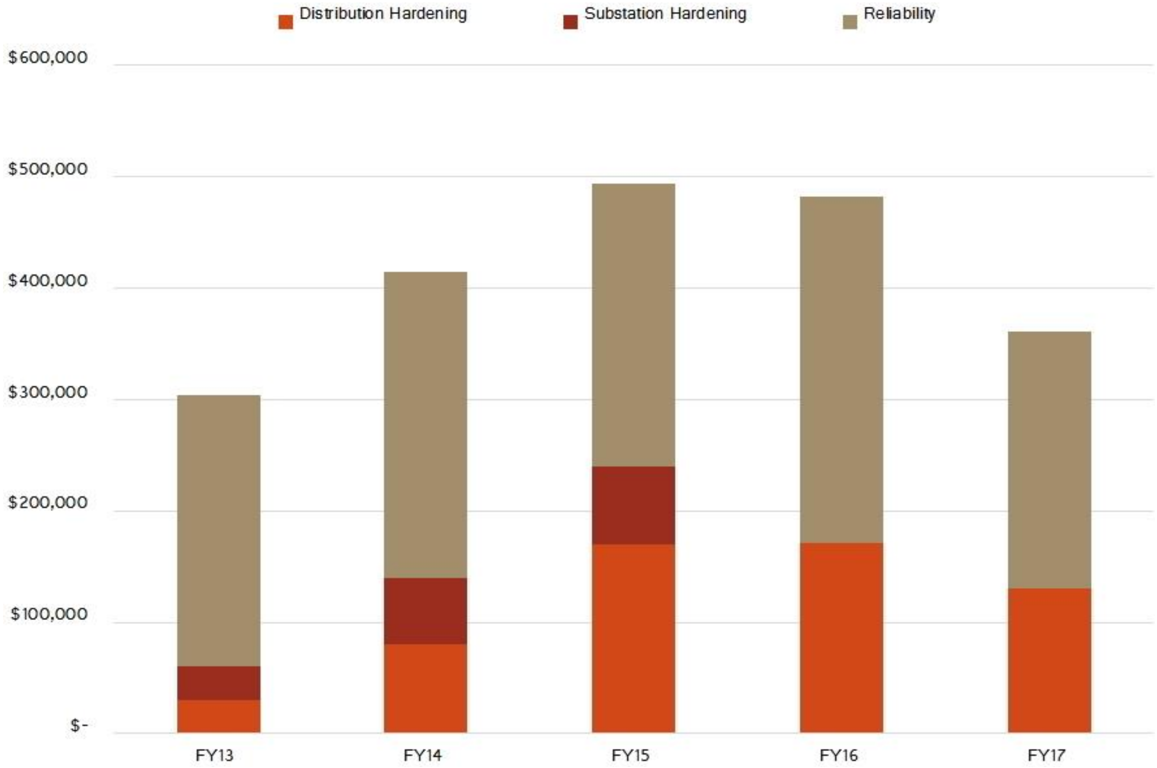


Figure 7-1. Con Edison's Proposed Capital Budget

This spending demonstrates that even a very large commitment to hardening is still not at the same levels as reliability spending for this one entity. Is this a trend? Is it representative of the industry as a whole? The answer to both questions is "no." Nevertheless the spending plan provides a recent example to help our understanding of these two initiatives. Reliability can be stated as a "core goal" of electric service. It can be argued that resilience is a new and growing goal, but is secondary to reliability. There is no clear formula to designate the appropriate balance between the two; and assigning or measuring expenditures as attributable to only reliability or resiliency is not always easy. For example, reliability expenditures, particularly in automation of operations, positively benefit resiliency, so where should these expenditures be tracked?

7.1.3. Interdependencies

Energy is a key aspect of resilience. In fact, every other system presented in this framework depends upon the energy system for the power required to provide a functioning level of resilience for their system. For example, although a hospital or emergency operations center may not be physically damaged by a hurricane, flood, or earthquake (a resilience success for buildings), it still may not be functional without power or electricity for sustained and complete operations of all systems and services (presuming the emergency and backup power systems on site have limitations on the duration and the number of systems they can power when electricity from the grid is unavailable).

Energy systems also have interdependencies with other systems that reduce effectiveness or resilience. Some examples are:

1. Operations and control centers of utilities rely on the communications and information system to send and receive operational information to the generation, transmission, and distribution components within the grid. While the deployment of automated systems to control the switches and controls within the grid will improve resilience, operational control must still be maintained at some level or the resilience of the grid will be affected.

2. Liquid fuels rely on the transportation system to ensure the ability to distribute liquid and natural gas over land (via truck and rail). Disruptions to the transportation system negatively affect the supply chain and resilience of the energy system (see also 6.2.5 Pipelines for additional information).

3. The ability to recover electricity infrastructure in the electrical subsystem can be seriously hampered if buildings or transportation system damage is sustained. The response teams, who are integral to the recovery (and resilience) of the electrical Subsystem, must be able to mobilize and reach impacted areas. If buildings are destroyed and block access or if roads are impassable due to catastrophic events, they cannot perform response and recovery activities, making the energy system less resilient.

Where possible, interdependencies including, but not limited to, those presented here were considered in preparing the example performance goals presented in Section 7.3.

7.2. Energy Infrastructure

Our national infrastructure systems are designed for reliable service with some intent to build a stronger system due to potential hazard events. While these systems are designed to minimum NESC codes (and in many areas, beyond the minimum criteria set forth in the codes), the level or magnitude of the event these systems can withstand without damage is not clearly defined. Over the years, improvements in technology have addressed some vulnerabilities or risks in the system. However, these improvements in technology may have also inadvertently introduced new vulnerabilities or risks. Recent post-disaster studies and reports on climate change shed light on why damage and impacts to these systems from the natural hazard events occurred in the past several years.

The electricity subsystem has spent a great deal of time and money planning, building, rebuilding, and re-planning for reliability and to support energy assurance goals. While much of that effort pre-dates current definitions of resiliency, it should still be stated that the electricity subsystem is working to create and ensure some level of resiliency for communities. The infrastructure continues to improve, with some improvement actually due to hazard events.

The Characteristics of a Resilient Energy System include:

1. Planned, modeled, and prepared; ready for immediate and reliable deployment; robust (hardened) where appropriate
2. Supports emergency response, life safety, restoration effectiveness, and socio-economic continuity during a major event
3. Recovers rapidly after catastrophic events
4. Incorporates redundancy and spare capacity
5. Supports a diversity of energy sources
6. Modular or loosely-coupled architecture
7. Aware and responsive to electrical and environmental conditions
8. Actively monitored and maintained
9. Operates efficiently in non-emergency conditions
10. Provides economic and societal benefits to the communities and stakeholders served

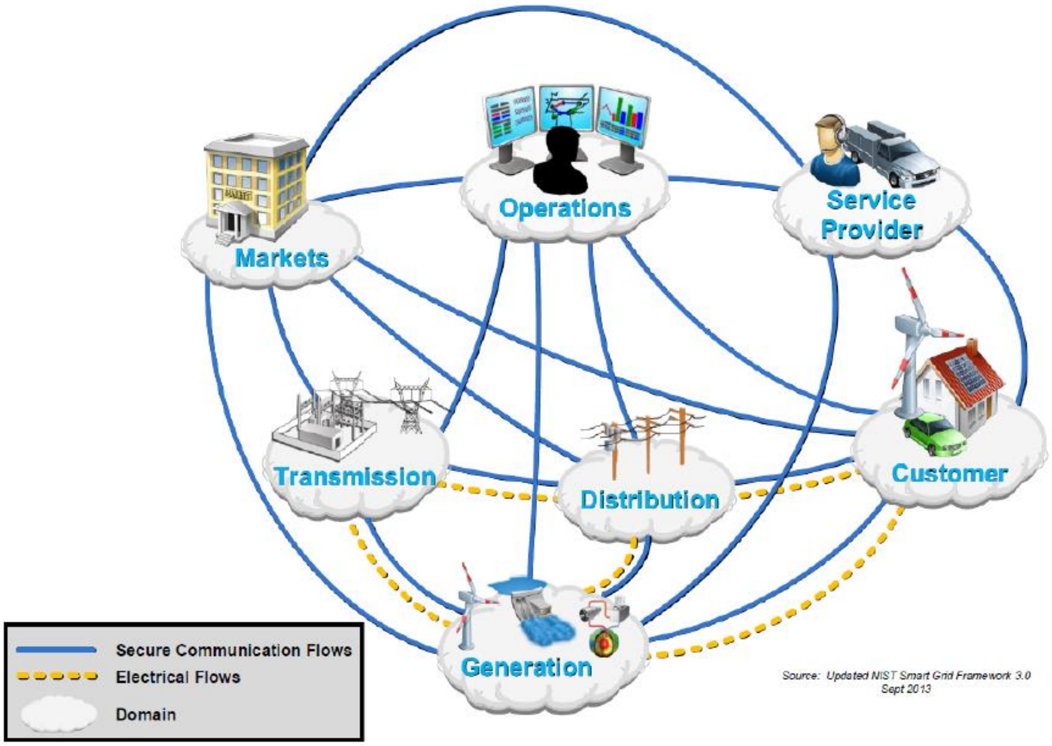
When designing energy infrastructure, resiliency performance metrics should use common vocabulary, understood by both providers and consumers, to ensure clear communication, reduce risk, and increase resilience from different threat and hazard events. Some questions to consider when (re)designing and establishing performance criteria for the critical components of the energy infrastructure include:

1. Why did failures occur?
2. Were the design criteria not correct to account for these hazard events?
3. Can and should higher criteria be used? Or were these hazard events truly rare or extreme events for which it is not feasible to design the systems to resist with minimal to no impact to the services they provide?
4. Was the extent and impact of the failures disproportionate to the magnitude of the event that occurred? And if so, was the degree of the failure or impact due to the design and construction of the infrastructure or was it a result of, or exacerbated by, the inability to respond/repair the damage that was caused by the event (i.e., a poor operational response)?

These important questions need to be discussed and answered to create a framework that provides design and construction guidance in the energy industry so generators, distributors, and users of the bulk power system can set and achieve performance goals. The performance metrics discussed in this guidance must be discussed in a common vocabulary by both providers and consumers within this industry to have a chance to reduce our risk and increase our resilience from these different threat and hazard events.

7.2.1. Electric Power

The electric power subsystem provides production and delivery of electric energy, often known as power, or electricity, in sufficient quantities to areas that need electricity through a grid connection, which distributes electrical energy to customers. Electric power is generated by central power stations or by distributed generation. The other main processes are transmission and distribution. This was illustrated in the *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.*0, shown in Figure 7-2 below.



Source: Updated NIST Smart Grid Framework 3.0 Sept 2013

Figure 7-2: NIST Smart Grid Conceptual Model (NIST 2012)

In 2009, NIST established the Smart Grid Interoperability Panel (SGIP) and developed the Smart Grid Conceptual Model. This model is used worldwide as a simple mechanism for graphically describing the different domains within the Smart Grid. The model is fully described in the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0, which reflects advances in smart grid technologies and developments from NIST's collaborative work with industry stakeholders.

For simplicity, and to remain focused on the primary resilience components within the bulk power electrical network, this document will focus primarily on generation, transmission, and distribution. Note that the natural gas delivery system is very similar in architecture and much of the terminology is interchangeable with the electricity network when describing the domains.

7.2.1.1. Generation

Traditional power generation is supported through bulk power plants that incorporate large spinning electrical generators. In the US, this power is 3-Phase Alternating Current (AC). However, the generation system is evolving and has been for some time. Prior to deregulation of electricity in certain US states, the public utilities owned and managed both the generation (power plants) and the transmission grid over which electricity was delivered. Deregulation separated generation and transmission, with most deregulated states allowing independent power producers (IPPs) to competitively develop generation projects. The term "deregulation" does not imply these utilities are not highly regulated, simply that consumer choice exists, although IPP developers must still negotiate contracts to sell power to the utilities who maintain their responsibility to manage and deliver the electricity via the grid. The US today is a patchwork of regulated and deregulated states so, depending on the state, the utility could control transmission, generation, or both. This patchwork of regulation and deregulation at the state level also applies to the distribution of natural gas by utilities.

In addition, renewable power projects, distributed generation by commercial entities, and demand-side management (such as demand response and energy efficiency and energy storage) are becoming more pervasive. Today the term "generation" increasingly includes "virtual generation," resulting from using load-reduction to offset power demand or the use of storage rather than developing new generation (power plants). Additionally, more of this activity is evolving to be located behind the meter at homes and businesses (rooftop solar, smart meters, etc.).

Renewable power comes in many forms – wind, solar, biomass, hydropower. In some states energy-from-waste (waste-to-energy) plants also meets the definition of renewable power. The public is well-versed in the term "renewable power," but does not typically understand that the rules vary from state to state in the same way the Renewable Portfolio Standards (RPS) or goals for the percentage of power to be generated from renewables vary by state.

"Distributed generation" is an umbrella term typically describing power plants developed for a specific company or industrial location, also known as "in-the-fence" power, which serve the needs of a particular commercial plant, manufacturing facility or industrial park. These plants must be developed in accordance with requirements for their particular state, but are typically single or small group load-serving entities. An example might be an industrial facility that builds its own on-site power plant to serve its electric power supply needs. Often these generating plants are also cogeneration facilities, providing steam for a host establishment or a neighboring industrial/commercial facility for heat or another industrial process use. Many of these smaller facilities are also referred to as Combined-Heat and Power or CHP plants.

In regulated states Demand Side Management (DSM) is best defined by the Energy Information Administration: "the planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand." Thus, DSM can include both Energy Efficiency (EE) or Demand Response (DR) to reduce electric demand.

Energy Efficiency at the utility level is a method or program by which the utility manages or reduces the demand for power rather than building or contracting for new generation (power plants) or having to purchase additional power on the spot market, which can be extremely expensive. These programs can be high-level state-wide improvements to public buildings (efficient light bulbs, improved insulation, etc.) or can entail distribution of energy efficient light-bulbs or sophisticated meters and thermostats for residential users.

Demand Response (DR) is sometimes implemented by a non-utility company that enters into a contract with electric users, usually large users such as universities, high-rise office buildings, chains of retail stores etc., and pays those users to lower their electric use during times of peak demand such as hot summer days. In doing so, the DR company sells that reduced-load to the utility during peak demand periods. This allows large users of electricity to lower their annual electric costs via the DR payment and allows the utility to avoid brown-outs or black-outs and avoid spot market purchases or the need to develop new generation.

Energy Storage comes in many forms, from large-scale batteries, to pump storage, to fuel cells. In the case of pump storage, which has a long history, water is pumped up to a dam or holding basin during periods of low electric demand (non-peak-periods) so it can be released during periods of high demand to meet load. This historical use of pump storage is now being expanded to use compressed air and other technical methods of delayed release of energy, such as flywheels, during peak periods.

As noted earlier, the belief that generation satisfies electric demand is only partly true. Using alternative methods to reduce, offset, or delay peak electric demand plays a larger role and, as such, needs to be considered as a key part of the system by which reliable and efficient power to the US population is ensured.

7.2.1.2. Transmission

In the traditional bulk power system, 3-Phase power exits the generator and enters a transmission substation. Voltages are transformed to very high voltages to travel long distances along three separate transmission lines, each carrying a single phase. The transmission infrastructure is primarily wire and towers carrying high voltage power from generators to distribution substations. It is the “middle-man” of the electric power delivery network.

The overarching issues surrounding the vulnerabilities of the transmission infrastructure stem from the aging physical assets today. As overall customer load requirements grow and the various federal and state regulations change, there is a need for more robust and flexible electric power delivery systems to keep up with demand. The emergence of the renewable generation market, and the transition from coal generation to natural gas generation, has begun new stresses on the power grid beyond its original design. Electrical flows that were designed to be in one direction are now in multiple directions, depending on the generation available at any particular time of day. Transmission constraints, which affect cost and reliability, have become common in operations.

Recently (over the last 10 years), transmission planning has evolved from relatively few new transmission lines being built nationwide to many new transmission lines being planned by most major utilities. The cost and time to build new transmission lines have also increased significantly over the years due to public routing, regulatory and environmental restrictions. But the performance of these transmission lines has improved with the passage and implementation of FAC-003-3 Transmission Vegetation Management Program. The purpose of FAC 003-3 is to provide the guidance needed “*to maintain a reliable electric transmission system by using a defense-in-depth strategy to manage vegetation located on transmission rights of way (ROW) and minimize encroachments from vegetation located adjacent to the ROW, thus preventing the risk of those vegetation-related outages that could lead to Cascading.”*

All of these demands impact electric transmission system reliability. Ever-increasing cyber-based monitoring systems are being developed to reduce the impact of any potential hazard. As new systems are engineered and constructed there is also a need to evaluate ongoing maintenance. Many efforts are underway to strengthen our nation’s transmission systems. Several major Smart Grid transmission projects have been initiated and, in some cases, recently completed to supply power across the nation. Other efforts to increase the power grid's resiliency and efficiency include developing and deploying new technologies (e.g., Demand Response, Micro-grid/Islanding, Synchrophasers (PMU), Dynamic Transfer, Energy Imbalance Markets (EIM) and Dynamic Line Rating (DLR)). The FERC also issued Order 1000, meant to reduce capital costs of transmission for end consumers by introducing competition between utilities and transmission developers.

Transmission infrastructure is vulnerable to a number of hazards. Storms with heavy rain (e.g., hurricanes) can cause flooding of low-lying electrical infrastructure including substations as was the case with Hurricanes Sandy and Irene[2]. The heavy rain that accompanies many thunderstorms and hurricanes adds to the hazards from debris, by potentially washing away the foundations of poles on the sides of hills and exposing underground cabling to the movement of water. There are other examples of flood hazards and events, (ranging from tsunamis, to dam failures, to large water main breaks) that can also cause water to follow electrical lines back to underground electrical conduits and vaults and will have a negative impact on underground substations and splices.

Flooding is not the only hazard that threatens damage and failures of the electric power infrastructure. Strong winds, such as those from tornadoes, hurricanes, and even thunderstorms, can damage electrical infrastructure. Large thunderstorms tend to have strong straight line wind and can destroy trees and structures quickly.

Another potential hazard that can impact electrical power infrastructure is wildfire. Wildfires are a routine part of life in some communities across the country. Depending upon the wildfire risk, communities may need energy resiliency measures to protect against them. Every year, wildfires burn thousands of acres and destroy homes and other structures. Electrical lines have been implicated in starting wildfires, as was the case in the 2007 San Diego Witch Creek, Guejito and Rice wildfires[3].

7.2.1.3. Distribution

In the traditional power delivery system, the distribution system begins at the distribution substation. The substation takes power that is normally delivered at 10s or 100s of thousands of volts and transforms the voltage to less than 10k volts (typically 7200 volts). The distribution substation is a critical piece of the overall power delivery system and is a focus area for resiliency hardening and post-disaster repair. It supports a variety of Operations Technology (OT) and Information Technology (IT) equipment and systems that connect the endpoint loads to the utility's operation center. The distribution system is by far the largest component of the electricity network. With regard to recovery operations, the majority of focus is normally within the distribution network.

Given the aging infrastructure, some real vulnerabilities exist in the energy distribution systems. The distribution systems are typically built and constructed along roadsides but, in some cases, they run through less accessible back lots and other right-of-ways. As overall customer load requirements grow and the changes in regulations continue, there is a need for more robust electric systems; but the ability to provide these robust electric systems is struggling to keep up with the demand.

Maintaining the designed distribution systems is also a challenge. The poles and equipment that are key elements of the distribution system are subject to overloading with additional wire and system components by local service providers who add lines and equipment to existing poles. These additions may directly overload the components that make up the electrical system or increase their vulnerability to wind and ice during storm events.

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[2] United Illuminating announces $11M flood prevention project for substations, July 23, 2013, http://connecticut.news12.com/features/sandy/united-illuminating-announces-11m-flood-prevention-project-for-substations-1.5753215, retrieved 27-July-2013

[3] Power lines cited as cause of largest wildfires". *SAN DIEGO UNION-TRIBUNE*. 2007-11-16. Retrieved 2013-7-27.

Further, as new systems are engineered and constructed there is a need to evaluate the ongoing maintenance. One element of maintenance in the forefront along the distribution system is tree coverage. Most, if not all, utility entities have well-established and adequate tree management programs; but failure to implement these programs has been a leading cause of outages. The reason for this failure is not always simple. Even though the utility may have an established and programmed vegetation management program, public and private land owners may not allow removal of any trees or limbs. Other jurisdictions and environmental entities (state, local, or activist) have also succeeded in stopping tree trimming and clearing programs. Further, the health of trees and vegetation (as well as insect infestation and other natural scenarios that can diminish the performance of trees) should be anticipated and addressed in planning and maintenance programs. The aggregate impact of these actions results in failed implementation of the tree trimming programs, which creates a critical failure point where system vulnerability continues to worsen instead of being mitigated. These tree maintenance programs should consider local factors that can also impact the performance of trees and vegetation and result in localized areas of poor performance during storm events that, if not accounted for, would directly impact the performance of the Distribution Systems.

As discussed for transmission, many cyber-based monitoring systems are being developed annually to reduce the impact of any potential natural hazard such as the hurricanes and flooding.

Many efforts are underway to strengthen our nation’s distribution systems. There are major feeder hardening program/projects underway across the nation. These projects have been focusing on dead-end cross arms, lightning arresters at any identified weak points. In California there is a push for strengthening the systems from fires. They are now “boxing in” fuses so no hot metal will hit the ground and potentially cause fires. Dependent on the location nationally, there has also been a movement away from wood poles. Where wooden poles are still being used, they are increasing the size and class to accommodate the overall design constraints.

The electric energy distribution system is vulnerable to a number of hazard events. Overhead distribution lines are particularly vulnerable to high wind hazards, such as hurricanes and tornadoes. However, most infrastructure failures from wind storms are not from the wind loading directly. Trees often fall onto infrastructure, causing damage and failures to the distribution network. Many neighborhoods have large trees that parallel the overhead infrastructure; and in many cases conductors may actually run through the trees. Therefore, vegetation management is critical to minimizing vulnerability of distribution lines to high wind events[4]. It only takes one property owner resisting a utility tree trimming program to trigger a power outage affecting a large number of people.

The constant push of high winds on utility poles can slowly cause them to lean. Pole toppling events can occur several days after a storm. Heavily loaded poles can be braced if they are likely to be exposed to high straight line winds. Winds that change direction around the clock, such as those experienced in Florida at the end of the 2007 hurricane season, can do more damage than storms where the wind comes from one direction. If it is solidly packed, the pole can crack off at ground level or another weak point. As a result of the observations after the 2007 hurricane season, Florida now requires more pole inspections to look for overloaded poles and poles that show rot at the interface with the ground or other weakness. Instead of a 15-year pole inspection cycle, Florida is considering a 7-year inspection cycle. Poles that look perfectly fine from a visual inspection may not be fine internally or underground. Therefore, new inspection tools and techniques have been developed to help with pole inspection.

Another hazard associated with high wind events such as hurricanes, tornadoes, and thunderstorms is lightning, which is a particular concern for electrical energy infrastructure. When a transformer is overloaded, either by a direct lightning strike or by an overload on the circuit, it typically flashes to a

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[4] EPRI Report 1026889, Enhancing Distribution Resiliency, Opportunities for Applying Innovative Technologies, January 2013

roaring blaze quickly. The resulting blaze can consume not only the transformer, but the pole it is on and the close vegetation as flaming oil falls to the ground. Lines can come down from direct lightning strikes, especially on poles that have hollowed out over time and filled with water. These poles literally explode when the water inside flashes to steam.

Lightning will travel down a conductor until it finds an easier path to travel. Even when a line is already down and de-energized, lightning can strike it traveling the remaining path, until it finds a lightning arrestor or a fusible link. Damage to home appliances and consumer electronics is common when lightning strikes a line beyond an outage point. Reminding people to unplug appliances and other equipment in a major storm is the best way for them to protect this equipment. Having back up or standby power for critical communications needs and data gathering in emergency centers that are fully up to date on software and data is important, even in mobile command posts. Having that back up equipment that is simply stored and not connected to the grid is a good approach to redundancy and resiliency. Too often, backup equipment is used to provide additional capacity on a day-to-day basis, only to leave the location with no working equipment after lightning strikes. Surge protectors, uninterruptible power supply (UPS) systems, and other protection equipment is helpful, but only having the equipment unplugged from the wall is 100% insurance that a lightning strike will not disable it.

Earthquakes can also cause damage to electrical infrastructure. Earthquakes can do widespread damage to the electrical infrastructure with little or no warning. In addition to directly damaging electrical infrastructure, they can cause other failures, such as fires and ruptured water mains, which may in turn cause damage to electrical infrastructure.

Earthquakes that cause ground movement in close proximity to the fault may damage towers and poles or break electrical lines that cross the fault or run parallel to the fault line. Those lines tend to snap because there is not enough slack in the line to allow it to flex with the movement of the fault line, or the movement is so rapid that the line's slack cannot move quickly enough. Overhead lines on proper structures tend to perform better than underground lines near major earthquakes because the lines all have some slack (the sag of the centenary) in them and their supporting structures flex as well.

Top loaded poles (those with transformers, voltage regulators, etc.) tend to fail first in an earthquake, all things being equal with the footing of the pole and the quality of the pole. It is better to ground mount this type of equipment if the poles are close to a fault line.

7.2.1.4. Emerging Technologies

Many smart grid technologies available today are targeted to help the electric utility significantly in improving reliability, operating efficiency, and power quality, and in identifying potential opportunities to harden the current circuits from a resiliency standpoint. Many technologies, considered "plug and play," are working together nicely with the right infrastructure. Many utilities are also evaluating their smart grid plans and working on full integration to allow for predictability as well as corrective action.

Technology has also allowed the utilities to rapidly correct power outage situations. Many utilities have implemented some form of distribution automation with very good results. These results have led to further technological advancements, being implemented today. Today's utilities recognize the real need to build a resilient, safe, and economical electrical network. As the utilities computerize the electric grid, they are opening additional opportunities for predictability and better understanding of communities' usage.

Microgrids

With regards to energy resiliency, one of the most profound emerging technology opportunities is microgrids. Microgrids connect loads with Distributed Energy Resources (DERs) within a defined boundary. The "macro" grid treats the DER as a single entity; the microgrid manages the DERs and loads independently. Microgrids can be connected or disconnected from the grid and can operate independently in an islanded mode. They offer a variety of compelling business opportunities to help meet organizational mission requirements, participate in electricity markets, increase energy surety/resiliency, and incorporate renewable energy resources.

Microgrids can be implemented at numerous points in the electric power system physical hierarchy – transmission, subtransmission, substation, distribution, and consumer. The most fundamental division of location however is customer-side or utility-side implementation. Customer-side microgrids can be designed and implemented with the specific operational and business requirements of the facility in mind. Customer-side microgrids can be thought of as an extensive, highly managed extension of an emergency generator backup system. The difference is that a microgrid is designed to provide full energy services for an extended period of time. A customer-side microgrid can be implemented to ensure business continuity during a major natural hazard. Recently a major Fortune 100 corporation included a microgrid as part of their new company campus headquarters design to allow full operation of the facility for an unlimited time in the aftermath of an earthquake. A clear business case could be made for implementing such a microgrid by extracting value from the technology during normal operations. In contrast, a utility-side microgrid has the challenge of being funded using the existing utility regulatory model for technology investment. Many more stakeholders are involved in deciding whether the investment required is prudent.

Microgrids have been studied as a potential grid hardening solutions by New York, Connecticut, and California, as well as the U.S. Department of Energy. These studies also consider some of the current regulatory frameworks hindering widespread deployment.

There are 6 primary requirement areas to consider when designing a microgrid, which are substantially different for customer-side versus utility-side implementations:

1. ***Mission:*** What is the organization’s mission? How will a microgrid help support the mission?
2. ***Loads and Generation:*** What are the existing and future loads that will need to be addressed by the microgrid? What are the existing suitable generation resources available?
3. ***Infrastructure:*** How is the current grid configured? How will the microgrid interact and take advantage of what is already there? How do the infrastructure elements need to be monitored and controlled to ensure stable operation and meet operational goals?
4. ***Scenarios:*** What are likely events (typical, emergency, opportunistic) that a microgrid can support?
5. ***Policy:*** What policies, incentives, and constraints need to be considered?
6. ***Costs:*** What are current and projected costs of the system?

Microgrids are not simple, interchangeable systems. They require a good business case, should operate and provide value when the grid is operational, and require long-term operational expertise and maintenance commitment. However, in some cases the economic and business value for microgrids may pencil out when loss of critical operations poses a significant risk to public safety or security. Resiliency-related candidates to consider microgrid solutions include:

- Critical facilities for critical events (City Hall, Police, Fire, 911, etc.)
- Hospitals and medical centers
- Local government facilities
- Federal facilities and military bases
- Key businesses including grocery stores, drug stores, large employers, gas stations
- Schools, colleges, and universities

Each of these candidates could be serviced by a customer-side or a utility-side microgrid – or a hybrid approach where the customer side is integrated with a utility-side system to provide enhanced flexibility. All of the following technologies are potential elements of a utility or customer side microgrid:

Renewable Energy Generation

Renewable energy comes from natural sources that are constantly and sustainably replenished. When power is interrupted, renewable energy generation can continue to support uninterrupted or reduced capacity service to energy consumers. Although it is arguable that renewable energy is not emerging technology, the equipment, software, and systems are rapidly becoming pervasive and are maturing at a very accelerated pace. The two primary emerging renewable energy generation resources are solar and wind.

- ***Solar Photovoltaic (PV) -*** The photovoltaic process converts light into electricity. Solar cell modules supply DC electricity at a certain voltage (e.g. 12 VDC). The amount of current is directly dependent on the amount of light that enters the module. When multiple modules are strung together, a solar (or PV) array is constructed that can produce larger quantities of electricity. PV arrays are configured in series or in parallel in order to provide different voltage and current combinations. PV systems are being used in a variety of scenarios, ranging from small rooftop supplemental power all the way to large solar farms providing many megawatts (MW) of power. The technology continues to improve with higher efficiency conversions of light into electricity and stronger, lighter, more flexible materials.
- ***Wind Power -*** Wind power is one of the oldest forms of renewable energy and has been harnessed by man for many centuries. The basic process uses turbines to capture the wind’s energy, convert to kinetic, spinning energy, and convert the energy into mechanical power. The resulting mechanical power has been used historically to pump and move water, and in mills to grind grain and corn. It can also be used to create electricity through a generator. Although the same basic principles are at work, wind generation today is significantly different than those of our ancestors, primarily due to scale. Farms of wind generators are found throughout the Midwest, Texas, the coasts, and deserts. Some wind farms produce many megawatts (MW) of power. The technology trend is better aerodynamics for more efficient conversion of kinetic wind energy to electricity, more efficient and smarter generators, and larger, more powerful wind turbines.

Fuel Cells and Storage

- ***Fuel Cells -*** Fuel cells create electricity through chemical reactions. The reaction is controllable and can be tuned to manage the amount of electricity produced. The types of fuels vary, but require oxygen and hydrogen in their chemistry. The waste from fuel cells is clean, producing H2O. Fuel cells have a variety of uses and have been popular concepts in the automotive industry to support environmentally-friendly hydrogen vehicles. The technology continues to involve with different fuel sources, cheaper solutions, and higher capacities.
- ***Battery Energy Storage -*** Battery storage systems are the next “killer app” for energy resiliency, power quality, and energy efficiency. The concept is simple: when demand is low, charge the batteries; when demand is high or the system is stressed, use battery power. Battery power today is in the same place technologically that solar power was in the 1990s. Batteries are too big, too expensive, and don’t last long enough. Also, there are very few incentives for investment in battery technology. The landscape is slowly changing and states like California are performing battery studies and pilots. This emerging technology could have an enormous impact on how the grid is managed and combined with renewable energy generation, simple microgrids become viable, affordable solutions and our energy becomes more resilient.

Demand-Side Management

The ability for customer-side loads to respond to external controls during an energy system emergency is a key element of energy system resiliency during the event while restorative actions are underway. This is especially important when microgrids are used on the customer side and/or utility side of the meter. A key challenge in managing a microgrid is maintaining load/generation balance to keep the system stable.

Simple customer side backup generation solutions that are not intended for long term operation and support of normal business operations typically only supply emergency loads. More sophisticated systems that integrate renewable energy sources, fuel cells, and energy storage may utilize a building automation system to control building loads to optimize the performance of the system for short or long term operation. Utility-side microgrids may also use demand side management systems (DMS) to effectively manage feeder and substation level microgrids to ensure system stability and maximize the number of customers that can be served by those portions of the system that remain intact after a major event and come on line during restoration. DSM techniques can also be used at the bulk level to manage temporary transmission and subtransmission loading constraints that may exist during a major event.

7.2.2. Liquid Fuel

The most common liquid fuels are gasoline, diesel, and kerosene-based products, such as jet fuels, which are produced from petroleum. Other liquid fuels include compressed natural gas, liquefied petroleum gas (LPG), synthetic fuels produced from natural gas or coal, biodiesel, and alcohols. For resiliency, liquid fuels are critical to back-up power generation and nearly all modes of transportation. In addition, 11% of U.S. homes rely on heating oil or propane, with heating oil usage concentrated primarily in the Northeast and propane usage concentrated in rural areas (USEIA 2009).

Although less than 1% of all electricity in the U.S. is generated in oil-fired plants, there are some isolated markets in which petroleum remains the primary fuel. The leading example is Hawaii, where more than 70% of electricity generation is fueled by petroleum (USEIA 2014a).

Potential failure points for liquid fuel production, storage, and distribution include:

1. Catastrophic loss of major production fields
   - Fires
   - Blowouts
   - Spills
2. Transport of crude oil from production sites to refineries
   - Ports
   - Pipelines
   - Rail
3. Processing at refineries into finished products
   - Onsite storage of raw materials
   - Onsite piping
   - Processing reactors vessels
   - Power supply (grid or backup)
   - Onsite storage of finished products and by-products
4. Transport from refineries to regional distribution centers
   - Ports
   - Pipelines
   - Rail
5. Storage at regional distribution centers
   - Aboveground tank farms are the most common storage systems used at permanent depots
6. Regional distribution
   - Pipelines (e.g., pipeline from Oregon’s CEI Hub to Portland International Airport)
   - Trucks (e.g., distribution from Port of Tampa to Orlando-area fuel stations)

7. End user or retail sale
    - Onsite storage (e.g., above ground tanks at an airport or buried tanks at a retail fuel station)
    - Power for pumps at retail distributors (e.g., New Jersey retail fuel station grant program described below in Section 7.3.4)

Maintaining production of crude oil and safely transporting it to refining centers (Steps 1 and 2) are major national and international security issues that are beyond the scope of this framework.

US refineries (Step 3) tend to be geographically concentrated and operate at 90% or more of capacity during periods of strong economic growth (USEIA 2014b). The reliability and resiliency of US refinery capacity is both a national security issue and a major regional economic issue in those areas of the US where refinery capacity is concentrated.

Regardless of where production and refinery capacity are located, all communities should assess their resiliency with respect to Steps 4-7. Damage to ports, tank farms, pipelines, railways or roadways can cause serious delays to the distribution of liquid fuels which, in turn, can lead to loss of backup power generation when onsite fuel supplies are exhausted and disruptions to all modes of transportation. In cold weather scenarios, an extended disruption to heating fuel supplies also has the potential of becoming a significant issue.

Steps 4-7 focus on the energy portion of the Oregon Resilience Plan, which was developed for a magnitude 9.0 earthquake scenario on the Cascadia subduction zone. The Oregon study identifies the northwest industrial area of Portland along the Willamette River as Oregon’s Critical Energy Infrastructure (CEI) Hub. More than 90 percent of Oregon’s refined petroleum products pass through this six-mile stretch along the lower Willamette River before being distributed throughout the state. For the Cascadia earthquake and tsunami scenario, potential hazards to liquid fuel storage and distribution networks include ground shaking, sloshing, liquefaction, lateral spreading, landslides, settlement, bearing capacity failures, fire, or seiches in the CEI Hub area and tsunami damage at the coast. Fuel is transported to the site via a liquid fuel transmission pipeline from the north and marine vessels. Alternative modes of transporting fuel from the east or south or by air are very limited. Key recommendations for improving the resiliency of the Oregon energy system include conducting vulnerability assessments, developing mitigation plans, diversifying transportation corridors and storage locations, providing alternate means of delivering fuels to end users, and coordinated planning (OSSPAC 2013).

The American Lifelines Association (ALA 2005) identified the high-level performance measures and performance metrics for pipeline systems shown in Table 7-1.

Table 7-1. The American Lifelines Association High-Level Performance Measures and Performance Metrics for Pipeline Systems (ALA 2005).

Desired Outcomes (Performance Targets)	System Performance Metrics					
	Capital Losses ($)	Revenue Losses ($)	Service Disruption (% service population)	Downtime (hours)	Casualties (deaths, injuries)	Lost Product
Protect public and utility personnel safety					X	X
Maintain system reliability			X	X		
Prevent monetary loss	X	X	X	X		X
Prevent environmental damage						X

A qualitative ranking of hazards to typical pipeline system components and facilities from the ALA (2005) study is reproduced in Table 7-2.

Table 7-2. Qualitative Ranking of Hazards to Typical Pipeline System Components and Facilities (ALA 2005).

Hazards	Degree of Vulnerability									
	Transmission Pipelines	Pump Stations	Compressor Stations	Processing Facilities	Storage Tanks	Control Systems	Maintenance Operations Buildings and Equipment	Pressure Regulations / Metering Stations	Distribution Pipelines	Service Lines or Connections
Natural Hazards										
Earthquake Shaking	L	M	M	M	H	M	H	L	L	M
Earthquake Permanent Ground Deformations (fault rupture, liquefaction, landslide and settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Ground Movements (landslide, frost heave, settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Flooding (riverine, storm surge, tsunami and seiche)	L	H	H	H	M	H	H	H	L	M
Wind (hurricane, tornado)	L (Aerial)	-	-	-	-	L	L	-	-	-
Icing	L	-	-	-	-	-	-	-	L	-
Collateral Hazard: Blast or Fire	M	H	H	H	H	M	L	L	L	M
Collateral Hazard: Dam Inundation	L	H	H	H	M	H	H	H	L	M
Collateral Hazard: Nearby Collapse	-	L	L	L	-	L	L	L	M	L
Human Threats										
Physical Attack (biological, chemical, radiological and blast)	M	M	M	M	-	M	M	-	M	-
Cyber Attack	-	L	L	L	-	H	L	-	L	-

Note: Degrees of vulnerability: H = High, M = Moderate, L = Low. When a component or system is located within a building the vulnerability of both the building and component should be considered. For example, where there is a potential for building collapse or mandatory evacuation, the equipment housed within is at risk. The entries in Table 7-2 assume that the component is of recent vintage, i.e., post 1945.

7.2.3. Natural Gas

Natural gas pipelines and storage facilities comprise a vast natural gas infrastructure that services 65 million homes, 5 million businesses, 193,000 factories and 5,500 electric generating facilities (McDonough 2013). There are nominally over 2.4 million miles of natural gas pipelines in the continental US, with pipelines running along roads and private easements under both urban and rural lands (McDonough 2013). Steps need to be taken to safeguard this massive and ubiquitous part of our energy infrastructure from disastrous events.

Natural gas pipelines can be damaged via ground shaking, liquefaction, and ground rupture. Specific points of failure may be predicted when rupture or liquefaction occurs; but the most damaging event on a wide scale is ground shaking (Nadeau 2007). Existing weaknesses, which serve as the first points of failure, can include corrosion, bad welds, and weak or strained material. Regular maintenance can have a beneficial effect, as can upgrading piping from iron (used in older pipeline) to plastic (used for low-pressure distribution lines) or even steel. Extensive work has been done to develop models that predict the impact of natural hazards on natural gas systems, which can help leaders determine the risk to their local facilities.

Generation, in addition to piping, needs to be resilient to hazard events. Fuel cells, which generate power via electrochemical reaction rather than combustion, are already being used as a means to achieve a more resilient natural gas infrastructure. Fuel cells provide a decentralized, reliable source of power that has proven useful in hazard events. They are considered a distributed resource by IEEE. For example, during Hurricane Sandy, one manufacturer put 60 fuel cells in place to provide backup power to cell phone towers. Thanks to the inherent resilience of underground natural gas systems to non-seismic events, these cell towers remained operational during and after the storm. Notably, they were the only cell towers in the area to remain operational throughout the event (Fuel Cell and Hydrogen Energy Association 2014).

Aboveground facilities (e.g., compressor stations, processing plants, meter stations, and wells) are the most vulnerable parts of the natural gas system. Natural gas pipes and storage facilities are inherently protected from many hazard events by being underground, but the facilities aboveground are subject to all the same risks as other commercial structures. For example, unusually cold weather in 2011 caused interruptions in natural gas service in the Southwest, which, in turn, caused outages at gas-fired electric generating facilities that were experiencing high demand for electricity. A joint report by FERC and NERC concluded these outages and disruptions of service were caused by weather-related mechanical problems such as frozen sensing lines, equipment, water lines and valves. The report recommended adopting minimum winterization standards for natural gas production and processing facilities, and suggested that additional underground natural gas storage capacity in the region could have ameliorated the impacts of natural gas supply shortages. In addition to the issues discussed in the section about structure resilience, there are vulnerabilities specific to natural gas facilities – flammability and high pressure hazards, and issues with the surrounding infrastructure. These special vulnerabilities should be recognized and accounted for in addition to the steps taken to mitigate inherent risks of aboveground buildings.

7.2.4. Emergency and Standby Power

Loss of offsite power delivered by the commercial power grid can be triggered by failures in power generation, transmission, or distribution systems or by disruptions to power plant fuel supplies. The vulnerability of offsite power to nearly all hazards and the dependence of nearly all buildings and infrastructure on offsite commercial power combine to make both emergency and standby power key requirements for improving disaster resilience.

IEEE (1995) defines an emergency power system as "an independent reserve source of electric energy that, upon failure or outage of the normal source, automatically provides reliable electric power within a specified time to critical devices and equipment whose failure to operate satisfactorily would jeopardize the health and safety of personnel or result in damage to property."

The National Electric Code (NFPA 2005) defines emergency systems as "those systems legally required and classed as emergency by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. These systems are intended to automatically supply illumination, power, or both, to designated areas and equipment in the event of failure of the normal supply or in the event of accident to elements of a system intended to supply, distribute, and control power and illumination essential for safety to human life."

The NEC (NFPA 2005) divides standby power systems into two categories:

- ***"Legally Required Standby Systems:*** Those systems required and so classed as legally required standby by municipal, state, federal, and other codes or by any governmental agency having jurisdiction. These systems are intended to automatically supply power to selected load (other than those classed as emergency systems) in the event of failure of the normal source. Legally required standby systems are typically installed to serve loads, such as heating and refrigeration systems, communications systems, ventilation and smoke removal systems, sewage disposal, lighting systems, and industrial processes that, when stopped during any interruption of the normal electrical supply, could create hazards or hamper rescue and fire-fighting operations."
- ***"Optional Standby Systems:*** Those systems intended to supply power to public or private facilities or property where life safety does not depend on the performance of the system. Optional standby systems are intended to supply on-site generated power to selected loads either automatically or manually. Optional standby systems are typically installed to provide an alternate source of electric power for such facilities as industrial and commercial buildings,

> farms, and residences and to serve loads such as heating and refrigeration systems, data processing and communications systems, and industrial processes that, when stopped during any power outage, could cause discomfort, serious interruption of the process, damage to the product or process, and the like."

Emergency and standby power systems are essential for continuous operation of critical facilities, such as hospitals and emergency operations centers. Emergency and standby power are also needed to mitigate cascading failures of transportation and infrastructure systems that depend on electric power, including: communications networks, waste water lift stations, waste water treatment plants, water treatment plants, water distribution pumps, transportation fueling stations, traffic signals, traffic monitoring systems, and railway signals (ALA 2006).

Important considerations for safe and reliable operation of onsite emergency and standby power include:

- Elevation of all electrical components, including generators, service panels, outlets, etc., above a design flood level that is appropriate to the importance/criticality of the facility
- Proper ventilation of combustion products and cooling system components
- Availability of adequate uninterruptable power supply (UPS) to support critical systems until emergency or standby power comes on line
- Ability to start emergency or standby power generation without power from the grid ("black start capability")
- Prioritization of power needs and proper sizing of generators and circuits to safely meet essential requirements
- Installation of permanent quick-connect hookups to accept power from temporary generators and label the hook up with the power requirement to enable generator size selection
- Ability to properly disconnect from the utility grid and to avoid feeding power back onto a de-energized grid ("islanding")
- Ability to safely transfer back to the grid when primary power is restored

> The US Army Corps of Engineers (USACE) had developed tool called the *Emergency Power Facility Assessment Tool* (EPFAT). The EPFAT allows public entities to input generator and bill of material requirements into an on-line database with the intention of expediting the support of temporary power installations after events. There are currently over 16,000 facilities in the database. The EPFAT database may be accessed at http://epfat.swf.usace.army.mil/

National Fire Protection Association Standards 110 and 111 provide performance standards for *Emergency and Standby Power Systems* (NFPA 2013a) and *Stored Electrical Energy Emergency and Standby Power Systems* (NFPA 2013b). NPFA 110 recognizes two classification levels: critical to life and safety (Level 1) and less critical (Level 2). Level 1 applications include life safety illumination, fire detection and alarm systems, elevators, fire pumps, public safety communications systems, industrial processes where current interruption would produce serious life safety or health hazards, and essential ventilating and smoke removal systems. Level 2 applications include heating and refrigerating systems, other communications systems, other ventilating and smoke removal systems, sewage disposal, lighting, and industrial processes.

Key considerations for emergency and standby power system fuels include:

- Providing sufficient on-site fuel supply to support essential power loads until an ongoing supply of fuel can be safely and reliably delivered to the site
- Selecting a fuel that is not dependent on electricity from the grid for delivery (e.g., pipe-delivered, natural gas or truck-delivered liquid fuels such as diesel fuel)
- Performing regular tests (at least monthly) and properly maintaining equipment

Alternative fuel sources, such as solar arrays with battery backups, can be considered as a means of maintaining lighting for emergency exit paths or providing water pressure in buildings or for operating transportation system signals or pumps at fueling stations (Andrews et al. 2013).

A partial listing of technologies used for generating emergency or standby power includes:

- Diesel generators
- Combined Heat and Power (CHP)
- Microturbines
- Reciprocating gas engines
- Fuel cells

Diesel generators range from small mobile generators to larger permanently installed systems. Small generators can be easily deployed to power traffic signals, rail crossing signals, or critical circuits in residential or small commercial buildings; but they require frequent refueling, pose safety hazards to inexperienced operators, and may not be reliable due to poor maintenance and infrequent use. Theft of generators is also a problem when left unattended to power transportation system signals, for example. Permanently installed generators may have more substantial fuel capacities and may be safer to operate and more reliable if tested and maintained on a regular schedule.

Following Superstorm Sandy, the State of New Jersey used FEMA HMGP funds to establish a Retail Fuel Station Energy Resiliency Program (NJOEM 2014). Eligibility requirements for the program include:

- Stations must be located within ¼-mile of an identified evacuation route
- Stations with gasoline storage capacity of 30,000 to 35,000 gallons eligible for up to $15,000 grant to purchase quick-connect technology or to offset a portion of the cost of purchasing a generator
- Stations with gasoline storage capacity of more than 35,000 gallons eligible for up to $65,000 grant toward the purchase and installation of an onsite generator
- Stations must sell both gasoline and diesel fuel (except in limited instances)

The program requires a maintenance contract be in place for at least five years from the date of final approval of municipal building inspector. New Jersey’s Office of Homeland Security and Preparedness (OHSP) was also selected by the federal DHS to conduct the Regional Resiliency Assessment Program (RRAP) on the State’s petroleum transportation and distribution system.

Combined Heat and Power (CHP) is a highly efficient method of providing uninterrupted power and thermal (heating or cooling) services to a host facility. CHP systems are typically powered by natural gas fueled turbines or reciprocating engines. Over a dozen case studies of successful CHP system performance during Superstorm Sandy and other recent large scale power outages have been documented by Hampson et al. (2013). Key advantages of CHP systems over conventional diesel generators include better reliability, lower fuel costs, lower emissions, and the ability to address thermal demands in addition to power demands. Texas and Louisiana now require that all state and local government entities identify which government-owned buildings are critical in an emergency and that a feasibility study on CHP is conducted prior to constructing or extensively renovating a critical government facility. In New York, the State Energy Research and Development Authority (NYSERDA) and the State Office of Emergency Management have partnered to educate emergency managers about the benefits of CHP systems in emergency facilities; and the governor has announced a $20 million investment towards CHP projects, with added incentives for projects serving critical infrastructure, including facilities of refuge (Hampson et al. 2013).

The technologies described in this section are mature and widely deployed. All of these technologies may be employed and coupled with a sophisticated control system to support a microgrid. As noted earlier in the emerging technologies section, microgrids can support normal or near-normal business operations depending on the application and implementation of the system.

7.3. Performance Goals

Examples of Performance Goals at the community level were presented in Chapter 3 for different elements of critical infrastructure. This section presents an example of performance goals for the energy system components in fictional community Centerville, USA. Previous work to develop and establish performance goals or levels of performance is found in the efforts undertaken by SPUR (San Francisco), the California Energy Assurance Planning (CaLEAP) program, and Oregon. While these efforts were first developed at the local and state levels, respectively, they represent the most recent examples of major urban centers and an entire state developing a resilience plan to improve hazard resistance and infrastructure performance.

Table 7-3 through Table 7-5 represent example performance goals for the electrical subsystem for **routine, expected, and extreme** events (the three event levels of routine, expected, and extreme events were presented and discussed in Chapter 3 – the expected event is generally synonymous with a “Design Level event” as defined by the relevant codes and standards.). This example is presented for the fictional community in and around Centerville, USA. Since the ability to provide services after a windstorm, ice storm, hurricane, or flood event allows a utility to win support from their customer base, many providers and entities for energy systems have been designing and rebuilding their infrastructure to consider more severe events to make their systems more resilient and reliable for their customers. As such, it is recognized that the 90% desired performance level is already at the existing or current performance level for most electric utilities in the example matrices. However, the target performance levels proposed may not currently be what are being achieved by all utilities and providers.

The example performance goals presented in Table 7-3 through Table 7-5 are based on anticipated performance to support a community in a manner that is considered resilient, based on recent actual events and response times after storm and hazard events that have occurred over the past several years, and anecdotal reporting of response times. It is important to understand that a community may be different than the example community used in the performance goal tables. A community may have different infrastructure (for example, it may not have power generation or transmission assets, just distribution assets that must be evaluated and hardened for improved performance). Also, both the community stakeholders and the utilities supporting them will have different levels of expectation and actual performance (response to outages or interruptions) depending upon their geographic locations and past history of dealing with events of different magnitudes (routine, expected, or extreme). Further, much of the current infrastructure and response efforts managed by larger utilities may meet the 90% restored metric identified and therefore the blue shaded box can be marked with the “X” and 90% are to show that they are “overlapping.” The Centerville, USA example energy performance goals in this chapter do not show this scenario. However, the example performance goals for pipelines in Centerville, USA in Chapter 6 so show this possibility. Again, an important and notable caveat to this is that Municipals and Cooperatives (Muni’s and Co-Ops) are not traditionally performing at this level and across the board they would likely be at least one box to the right of the current condition (X) mapped in the example matrix.

It is also important to note that, for this system, there is a slight difference in the presentation of information related to percent of the system restored. The reality is that the percentage of the infrastructure the utilities desire to get back on line immediately will vary from community to community and is focused on the sub element identified. If the performance goal is to have all Generation infrastructure operating and functional, but the reality is that the distribution sub elements may be damaged and not operational during the same time period, then each gets its own performance metric as shown (perhaps 90% (or 100%) for the generation, but only 30% of 60% for the other sub elements (such as transmission or distribution), and there may be further granularity in these sub elements based on the infrastructure in another community (see table). The sub elements presented and ranks here are a representative set, communities may have a greater or smaller number of sub elements and functions than what has been depicted here. The local planning process should evaluate and establish the sub elements and functions for which the community and the industries should look to set performance goals.

Lastly, these performance goals will not capture or reflect the inability of the generation or transmission capabilities to be easily re-established when critical infrastructure assets are completely destroyed by an event (e.g., a surge that completely destroys a generation station or major transmission substation). Major impact events such as these are generally considered in that the grid will be able to respond and absorb some level of infrastructure failure. However in communities where there is a generation, transmission, or substation single-point-of-failure condition, that impact is not well-reflected in these metrics at this time. Effort should be made to consider short- and long-term solutions to disruptions, outages, and interruptions. The ability of the sub elements and functions to be operational as soon as possible after an event can be achieved through a variety of solutions. Some may require capital investments, while others are operational responses that are labor and personnel dependent. Some solutions will be dependent on technology or even completely dependent upon the resilience of other supporting systems. Additional information on codes, standards, and recovery levels for new and existing construction presented later in this section should be reviewed prior to completing a performance goals matrix for a community.

Table 7-3. Example Electrical System Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Power - Electric Utilities											
Generation		**1**									
Critical Facilities and Infrastructure Systems	R/C		90%								
Emergency Housing and Support Systems	R/C		90%								
Housing and Neighborhood infrastructure	R/C		90%								
Community Recovery Infrastructure	R/C		90%								
Transmission (including Substations)		**1**									
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations / Emergency Operations Centers			90%								
Disaster debris / recycling centers/ Related lifeline systems			90%								
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers			90%								
Emergency shelter for response / recovery workforce/ Key Commercial and Finance			90%								
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices			90%	X							
Houses of worship/meditation/ exercise			90%	X							
Buildings/space for social services (e.g., child services) and prosecution activities			90%	X							
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services			90%	X							
Residential housing restoration			90%	X							
Distribution											
Critical Response Facilities and Support Systems		**1**									
Hospitals, Police and Fire Stations / Emergency Operations Centers			90%	X							
Disaster debris / recycling centers/ Related lifeline systems			90%	X							
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers			90%	X							
Emergency shelter for response / recovery workforce/ Key Commercial and Finance			90%	X							
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices				90%	X						
Houses of worship/meditation/ exercise				90%	X						
Buildings/space for social services (e.g., child services) and prosecution activities				90%	X						
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services				90%	X						
Residential housing restoration				90%	X						

Footnotes:

1 Specify hazard being considered

Specify level -- Routine, Expected, Extreme
Specify the size of the area affected - localized, community, regional
Specify severity of disruption - minor, moderate, severe

2 30% 60%

3 X Estimated restoration time for current conditions based on design standards and current inventory

Relates to each cluster or category and represents the level of restoration of service to that cluster or category
Listing for each category should represent the full range for the related clusters
Category recovery times will be shown on the Summary Matrix
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

4 Indicate levels of support anticipated by plan

R Regional
S State
MS Multi-state
C Civil Corporate Citizenship

5 Indicate minimum performance category for all new construction.
See Section 3.2.6

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Table 7-4. Example Electrical System Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed Expected Hazard Level Phase 1 – Short-Term Days 0	1	1-3	Phase 2 -- Intermediate Wks 1-4	4-8	8-12	Phase 3 – Long-Term Mos 4	4-24	24+
Power - Electric Utilities											
Generation		**1**									
Critical Facilities and Infrastructure Systems	R/C		90%	X							
Emergency Housing and Support Systems	R/C		90%	X							
Housing and Neighborhood infrastructure	R/C		90%		X						
Community Recovery Infrastructure	R/C		90%		X						
Transmission (including Substations)		**1**									
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations / Emergency Operations Centers			90%	X							
Disaster debris / recycling centers/ Related lifeline systems			60%	90%	X						
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers			60%	90%	X						
Emergency shelter for response / recovery workforce/ Key Commercial and Finance				60%	90%	X					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices				60%	90%	X					
Houses of worship/meditation/ exercise				60%	90%	X					
Buildings/space for social services (e.g., child services) and prosecution activities				60%	90%	X					
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					60%	90%	X				
Residential housing restoration					60%	90%	X				
Distribution											
Critical Response Facilities and Support Systems		**1**									
Hospitals, Police and Fire Stations / Emergency Operations Centers			60%	90%	X						
Disaster debris / recycling centers/ Related lifeline systems			60%	90%	X						
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers				60%	90%	X					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance				60%	90%	X					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices				60%	90%	X					
Houses of worship/meditation/ exercise				60%	90%	X					
Buildings/space for social services (e.g., child services) and prosecution activities				60%	90%	X					
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					90%	X					
Residential housing restoration					90%	X					

Footnotes: See Table 7-3, page 22.

Table 7-5. Example Electrical System Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Power - Electric Utilities											
Generation		**1**									
Critical Facilities and Infrastructure Systems	R/C			90%	X						
Emergency Housing and Support Systems	R/C			90%	X						
Housing and Neighborhood infrastructure	R/C				90%	X					
Community Recovery Infrastructure	R/C				90%	X					
Transmission (including Substations)		**1**									
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations / Emergency Operations Centers				60%	90%	X					
Disaster debris / recycling centers/ Related lifeline systems				60%	90%	X					
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers				60%	90%	X					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance				60%	90%	X					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices					60%	90%					
Houses of worship/meditation/ exercise					60%	90%					
Buildings/space for social services (e.g., child services) and prosecution activities					60%	90%					
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					60%	90%					
Residential housing restoration					60%	90%					
Distribution											
Critical Response Facilities and Support Systems		**1**									
Hospitals, Police and Fire Stations / Emergency Operations Centers					60%	90%					
Disaster debris / recycling centers/ Related lifeline systems					60%	90%					
Emergency Housing and Support Systems											
Public Shelters / Nursing Homes / Food Distribution Centers					60%	90%					
Emergency shelter for response / recovery workforce/ Key Commercial and Finance					60%	90%					
Housing and Neighborhood infrastructure											
Essential city services facilities / schools / Medical offices					60%	90%	X				
Houses of worship/meditation/ exercise					60%	90%	X				
Buildings/space for social services (e.g., child services) and prosecution activities					60%	90%	X				
Community Recovery Infrastructure											
Commercial and industrial businesses / Non-emergency city services					60%	90%	X				
Residential housing restoration					60%	90%	X				

Footnotes: See Table 7-3, page 22.

7.4. Regulatory Environment

The electric utility and liquid fuel industries are highly regulated with the goal of keeping prices low, keeping delivery safe, and providing reliable, quality products to consumers. Regulation occurs at the federal and state levels.

The Federal Energy Regulatory Commission (FERC) is the US national regulatory body responsible for interstate transmission of oil, natural gas, and electricity. They are also responsible for reviewing interstate gas pipeline proposals, licensing hydropower plants, and reviewing proposals for developing liquefied natural gas terminals. FERC regulates the interstate wholesale sales and transmission of electricity, reviews and makes decisions on utility mergers and acquisitions, monitors and investigates energy markets, and provides rulings on transmission siting applications. FERC has the authority to provide civil penalties and fines for non-compliance to regulatory rules.

The Western Energy Crisis, the Enron scandal, and a historic East Coast blackout, led Congress to grant broad new authority to the FERC in 2005. After this third event, the Northeast Blackout, a joint US-Canada task force studied the causes and effects of the 2003 blackout and identified the need to make reliability standards mandatory and enforceable with penalties for noncompliance. So, in the Energy Policy Act of 2005 - Public Law 109-58 - (EPAct 2005), Congress entrusted FERC with a major new responsibility to oversee mandatory, enforceable reliability standards for the nation's Bulk Power System—that is, the wholesale power grid. The importance of this change cannot be overstated. The business of reliability became not just a set of industry best practices; it became a matter of national importance.

Through Section 215 of the Federal Power Act, Congress authorized FERC to certify a national electric reliability organization. That ERO is the North American Electric Reliability Corporation (NERC). NERC is a not-for-profit entity whose mission is to ensure the reliability of the Bulk Power System (BPS) in North America. This means that it is the responsibility of NERC to develop and enforce Reliability Standards. Further, they are to annually assess seasonal and long-term reliability, monitor the BPS through system awareness, and educate, train, and certify industry personnel.

Each state has a regulatory commission whose responsibility is to represent the electricity consumers in their jurisdiction. State commissions regulate retail electricity and gas, approve physical construction of infrastructure projects, provide rulings on local distribution of electricity and gas, and provide general regulatory oversight of local utilities and gas distribution companies. The commission meets regularly with state utilities and performs performance assessments. If performance metrics are not met, utilities may be punished or fined.

7.4.1. Federal

At the federal level there is regulation by FERC which is "an independent agency that regulates the interstate transmission of electricity, natural gas, and oil." FERC does not have siting authority for electric transmission facilities, but it does regulate reliability standards through NERC.

NERC is also at the federal level which, as defined, is "a not-for-profit international regulatory authority whose mission is to ensure the reliability of the bulk power system in North America. NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the bulk power system through system awareness; and educates, trains, and certifies industry personnel. NERC's area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization for North America, subject to oversight by the Federal Energy Regulatory Commission and governmental authorities in Canada."

The Nuclear Regulatory Commission (NRC), another federal regulator, focuses primarily on nuclear power plants. The NRC is responsible for licensing and inspecting nuclear reactors, and providing regulations, guidelines, and best practices for their operation. They are also responsible for any nuclear fuel manufacturing oversight and for coordinating and participating in nuclear energy research and development.

Each of the various state and federal authorities regulates different and overlapping aspects of the electric system. The requirements, standards and codes for each are lengthy and complex and are ever evolving but it is these that must form the basis for future refinements to facilitate reliability and preparedness improvements.

7.4.2. State

The utilities are constantly in a complex regulatory dance with state public service commissions, regarding the rapidly changing rules governing their roles and responsibilities. Recently, one of the biggest issues for utilities and commercial generators, particularly rooftop solar companies, involves the regulation of “behind the meter” load (such as rooftop solar) and their ability to sell power back into the grid to the utility. This is referred to as “net metering” and, again, the rules vary from state to state. The concern from utilities is that they remain responsible for upgrade and maintenance of a grid interconnection system that would receive less revenue and would also need to handle the varying bi-directional load demands that can add complexity to an already stressed infrastructure.

Although the push to lower greenhouse gas emissions and increase self-reliance using on-site methods, such as roof-top solar (and potentially storage), has merit, so does improving the backbone and efficiency of our electric grid. Grid improvements can also dramatically reduce line loss, thereby increasing environmental benefits and reliability; but those improvements are expensive and require significant investment. The debate is escalating as additional unique and beneficial “generation” and “virtual generation” options arise.

This push-pull is being played out right now in the headlines and before state public service commissions (PSCs) and utilities across the country. It is therefore imperative that these evolving rules of conduct be formulated with an eye to cost, reliability, safety, disaster preparedness and environmental benefit. The rules themselves will be primarily administered by state PSCs and utilities; but the oversight roles of the regional Independent System Operators (ISOs) and the Regional Transmission Organizations (RTOs) is also key, particularly with respect to cost and reliability.

The ISOs and RTOs serve much the same function, though the RTOs have greater responsibility for their regional transmission network as established by FERC. However, both the ISOs and RTOs operate regional electricity grids, administer the wholesale electricity markets, and provide reliability planning for the bulk electric system. Some of these systems such as the New York ISO (NYISO) are single state systems, and some are more regional such as the ISO New England (ISO-NE) system and the Southwest Power Pool (SPP). Due to the inter-relatedness of the North American grid, the ISO/RTO systems are international and include for example, the Alberta Electric System Operator.

7.4.3. Local

At the State and Local levels, codes and standards are adopted by the State PSCs, PUCs, ISOs, and RTOs to govern design and construction of the infrastructure. There is a wide variation in the level of design guidance that is provided by the codes and standards adopted by these entities. While some have best-practices, others reference ANSI-approved, consensus codes and standards. But even when the codes and standards are adopted, there is an apparent lag in adopting the most current version of these standards.

7.5. Codes and Standards

A number of codes and standards are used in the power industry for design and construction of generation, transmission, stations/substations, and distribution assets. While ASCE 7 (mentioned earlier in this document) is now incorporated by reference and used more frequently than in the past, most of the Transmission and Distribution assets are designed to the National Electric Safety Code (NESC) or the Rural Utilities Service (RUS), respectively. There are many variables related to design and construction of these assets. As such, not all elements may be addressed here or will require additional cross checking with additional codes, standards, and regulations.

In 2009, NIST established the Smart Grid Interoperability Panel (SGIP). The SGIP is a private-public partnership that identifies electricity delivery standards gaps, fills the gaps through requirements analysis, and coordinates with Standards Setting Organizations (SSOs) to create or modify interoperability standards and guidelines. The SGIP maintains a Catalog of Standards (CoS) that lists many standards that have been vetted through a regimented process with regards to cybersecurity and architectural integrity.

The electric code that is adhered to by the Investor-Owned Utilities (IOUs), who design and construct the Transmission assets, is the National Electric Safety Code (NESC); Sections 24 (Grades of Construction), 25 (Loading Requirements) and 26 (Strength Requirements). NESC Rules 215 (grounding) and 218 (trees) present information important to vegetation management. While this is truly a safety code, it is used as a design code in lieu of other guidance. Each utility also has a Standards department that evaluates the various codes and standards (safety or design) that are applied during design and construction of their assets. They evaluate any new equipment to ensure it meets or exceeds these standards. From the baseline set forth in the NESC, it is important to note that all IOUs have developed their own standards for their respective systems. While most of these standards exceed the minimums set forth by the NESC, the question that exists is whether the baseline set forth in the NESC addresses the performance desired for resiliency when considering all hazards (flood, wind, seismic, ice, and other natural hazards and man-made threats).

In a similar fashion, but working from a different set of criteria, the Co-operatives and Municipalities responsible for Distribution assets use the design manuals/standards from the Rural Utilities Service (RUS). The RUS distribution line design manuals consist of RUS bulletins 1724-150 through 1724-154. These refer to the identification of critical loads/customers and poles/equipment. In all cases, each utility is applying more constringent wind and ice loading conditions from these codes.

The information in the following subsections is provided to help communities better develop their own performance metrics for new (or recent) construction by identifying some of the performance criteria that was likely considered in the design of these assets.

7.5.1. New Construction

For some elements of the energy system, the design criteria for hazards have been aligned with building standards such as ASCE 7 Minimum Design Loads for Buildings and Other Structures. However, performance goals for these systems for each event are less defined. Definitions are also less clear regarding what are considered “routine,” “expected,” “extreme,” or “catastrophic” events. As resilience becomes better defined, this framework is working to bring together different interpretations and definition of these events as they are defined and used in practice within the existing industries and codes/standards used in each industry.

The following is a summary of hazards considered by the NESC (Part 2, Section 25):

- ***250B – Combined Ice and Wind –*** This is the basic loading criteria and is known as the District Loading. It incorporates both wind and ice with overload and strength factors. This applies to all structures and references the map presented in Figure 250-1. The boundaries of the districts follow county lines. Data was obtained from a small number of weather stations which were far apart. While the industry has discussed replacing this map with appropriate maps from ASCE 7, this issue is still being evaluated.
- ***250C – Extreme Wind –*** These criteria account for the higher winds typically found along the coastline and during extreme events. These criteria are only used for structures that are higher than 60’ above ground (70’ pole and longer). Appropriate maps are Figures 250-2a through 250-2e. Due to their typical tower height, transmission lines are designed to these criteria. The overload and strength factors used are generally 1 since this is an extreme event map (note, the

nomenclature of "extreme wind" used here is not consistent with the extreme wind event used for the design and construction of buildings or storm shelters per the ICC-500 *Standard for the Design and Construction of Storm Shelters*). These criteria were first introduced into the NESC in 1977. The 2002 NESC incorporated the wind maps from ASCE 7-98; where the wind data was much more comprehensive. The 2012 NESC uses the wind maps from ASCE 7-05. The ASCE 7-10 wind maps were revised to better represent the wind hazard. The maps now are based on new modeling efforts, refinements to understanding of wind performance, and incorporation of the contribution of the Importance Factor [I] into the data presented by the maps. However, these maps are currently not used by the NESC based on a decision by their code committee to retain the use of the ASCE 7-05 wind maps.

Most distribution structures are lower than the 60 ft. height limitation; therefore, most utilities will not design their distribution lines to the ASCE 7 criteria (something that may need to be reconsidered depending upon performance of these systems during hurricanes and tornadoes over the past 2 decades).

- ***250D – Combined Ice and Wind –*** This criterion was added in the 2007 NESC to account for extreme ice events. This criterion is similar to the Extreme Wind loading. Most Transmission assets will be designed to this criterion while distribution assets will not. Over the years most utilities had their own extreme ice loading for the design of Transmission assets. The maps from ASCE 7-05 have been retained and referenced for this criterion.
- Additional Standards related to hazard-resistant design include:
    - ASCE 7-10 exempts electrical lines from seismic design
    - ASCE 113 applies design criteria for stations. Seismic design is addressed in this standard
    - ANSI O5 applies to wood poles
    - ANSI C29 applies to insulators

Some utilities on the east coast are now starting to look at station hardening due to hurricane Sandy. This includes raising structures and control buildings at existing stations, or relocating the station outside the flood zone. Much of this guidance is a result of state and local floodplain management practices and requirements as opposed to specific codes, standards, or regulations from the energy industry itself. And while NSEC rules exist for vegetation management, there is a lack of Codes, Standards, and industry-accepted Best Management Practices that consistently address maintenance requirements.

7.5.1.1. Implied or stated Performance Levels for Expected Hazard Level

As discussed in the previous section, structures greater than 60 feet tall are designed for ASCE 7 wind and ice hazards. Though the NESC defines these as an "extreme" loading case, these loads are consistent with the expected event as defined in this framework. Therefore, new/future energy infrastructure greater than 60 feet tall should experience very few failures in an expected event. However, energy infrastructure less than 60 feet tall (i.e., most distribution structures) is not required to be designed to the NESC "extreme" loads. Rather, they are designed to Rule 250B criteria, which is less than an expected event as defined in Chapter 3. Therefore, failures in the energy distribution system are likely to occur in an expected ice or wind event. As seen in the example performance goals in Section 7.3, it is anticipated that some failures in the distribution system would also occur to the routine wind or ice event, though these will likely be limited, resulting in less outages.

Many failures of the energy infrastructure are due to tree fall or debris impact rather than direct wind/ice loading itself. Therefore, the electric utility's ability to maintain an effective tree-trimming program will greatly impact the performance levels of the infrastructure when a hazard event does occur.

7.5.1.2. Recovery levels

As discussed, failures of energy infrastructure less than 60 feet are likely to occur in an expected event, particularly wind and ice events. The time to recover and restore service so the system is fully functional will depend on a number of factors, such as whether distribution lines are overhead or underground, effectiveness of the energy utility tree-trimming program, mobility of emergency repair crews, availability of resources for repair, and size of the impacted area. Overhead distribution lines may fail more frequently due to wind or ice events. However, these failures are easier to access and repair than underground lines, which may occur due to other events.

For earthquakes, overhead structures would be anticipated to perform well due to their flexibility. However, buried distribution lines may fail due to liquefaction or if there is not enough slack in the lines to resist the forces from earthquakes. Flooding may also lead to failure of underground infrastructure if not adequately protected. As previously stated, underground infrastructure damage is more difficult to access and fix. Therefore, while overhead distribution infrastructure may have more widespread failures, it will only take days to weeks to recover, whereas only a few underground failures may result in the same recovery time. However, widespread underground failures may result in weeks (rather than days) of recovery time to achieve full functionality of the system.

7.5.2. Existing Construction

For the older infrastructure elements of the energy system, the design criteria used for hazards varies greatly. In many cases, little to no consideration was given to the forces and loads imparted onto this infrastructure because the infrastructure pre-dated the modern codes such as ASCE 7 Minimum Design Loads for Buildings and Other Structures that provide criteria to calculate and apply such loads. In some instances, most hazard resistance was incorporated through anecdotal information such as siting of critical infrastructure based on past-historical storms or it was provided through conservative design approaches and uses of materials that, by their nature, happen to provide some level of resilience. Further, performance goals for these systems were likely never considered or defined. As a result, old infrastructure has inherent vulnerabilities because many of the systems were not designed for these specific hazard loads. This section discusses the anticipated or implied performance from existing infrastructure elements to help develop better performance metrics for communities.

Existing infrastructure in the energy system was designed and constructed to codes and standards that did not address hazards to the level of current codes and standards. Because of this a number of vulnerabilities exist in both the electrical system, and the communications infrastructure used to control it. As a result, these older assets remain vulnerable (with existing equipment and systems) unless the equipment is replaced due to age or new codes/regulations or enforced internal utility best practices require an upgrade. Examples of these vulnerabilities are:

- ***Clustered, below grade transformers.*** Transformers tightly clustered in underground vaults and small substation yards – many at or below grade (to hide the ugly infrastructure). These below grade vaults often fill with water and debris during floods, mud slides, and earthquakes. Redundant means must be provided to mitigate these hazards to enjoy the otherwise substantial benefit of below grade, protected infrastructure.
- ***Single pole substation high and low voltage feeds.*** Using single poles to take both the incoming and outgoing lines from substations add a potential single point of failure. If separated and the incoming high voltage pole/tower fails, distributed generation may still be able to feed the station. If a low side feeder exit pole fails, the incoming high voltage feed remains as do other low voltage feeder poles.
- ***Fuses, not breakers in many locations.*** Using fuses rather than breakers/reclosers in different parts of a distribution system is cost based. Using more breakers and reclosers may be a new best practice when considering resiliency. Also, the lack of sectionalizers in many utility systems can mean that a single fault prevents all customers from having power turned back on while the damaged circuit is being repaired.
- ***Underground ducts run close together and crossing in many shallow manholes.*** A potential common mode failure challenge not generally considered in existing design practices.

- ***Lack of automation.*** Most switching in the distribution grid today is local and manual – meaning that to turn on power using alternate configurations, a person has to get to the gear when staff to do that is the most scarce.

Other vulnerabilities present in existing communications and control equipment include supporting the energy system:

- ***Single communications card/frequency in devices.*** Single point of failure issue and potential interference issue with increased radio traffic used in major disaster response scenarios.
- ***Single encryption key or worse (default passwords) for all devices in a system.*** This is a well-known security issue being addressed in critical infrastructure – but presently most distribution systems are not considered critical infrastructure.
- ***Very small batteries/super capacitors in devices.*** This leads to very short communications windows – on narrow channels – which progresses to notable numbers of dropped or missed communications during outages limiting the ability to optimize crew dispatch.
- ***Mesh networks performance on cold start.*** Some mesh network implementations being used for field area networks tend to be very fragile when the system starts to have outages, and take time to reform after an outage – while the mesh design is supposed to be highly resilient in the most critical moments – it can be its own worst enemy as implemented today (e.g. small batteries, deep mesh designs, lack of stored cold start parameters, etc.)
- ***Common right of ways.*** Fiber and other communication circuits tend to run in the same rights of ways (on the same poles) as the electrical service – breaking one normally breaks both.
- ***Telecommunications Route Diversity.*** This concept is often a myth because of the small number of telecomm switches/and actual central offices/as well as multiplexing thousands of VPNs in a single fiber
- ***Cellular Communications Emergency Operating Practices.*** While cellular towers offer dual coverage in many places, the tendency is to only put batteries at some and back up generation at fewer locations – so the towers revert to emergency calling only when the grid goes down – locking out grid communications that use cellular communications for backhaul.
- ***Digital Phone System Powering Requirements.*** Unlike the POTS system – the new digital phone systems requires power at each street box – in some cases there are batteries, in others there are not – Cable companies have the lowest installation of batteries in their VOIP = data systems compared to other telecomm providers
- ***Wireless Communications Spectrum Clustering and Frequency Agility.*** Wireless frequencies tend to be highly clustered, meaning that even low power jammers can disrupt all of the wireless related communications to the grid (e.g. Push to talk and DA/SA/AMI, etc.)
- ***Signaling System Security Vulnerabilities.*** SS7 vulnerabilities have not been closed for G3 or G4 cellular systems – meaning that they can be jammed or intercepted by a knowledgeable person with little in the way of specialized equipment in an unencrypted form.

Most of these issues do not have explicit codes and regulations – but some do. Most come under the category of best practices on both customer and utility sides of the meter. These vulnerabilities will remain until new construction undertaken using new codes and best practices that consider resilience replaces the older infrastructure.

7.5.2.1. Implied or stated Performance Levels for Expected Hazard Level

Some existing utility infrastructure is up to 30 years in age and most infrastructure 10 years or newer are highly dependent on communications and control networks to operate effectively in adverse conditions. This is especially true for those systems with some level of automation that permit automatic or remote controlled circuit switching, sectionalizing and reconfiguration. Situational awareness to know the availability and operational state of field assets is also directly impacted by the availability of communications equipment.

There are multiple failure modes for communications and control equipment. One that is addressed by codes and standards for new construction is the ability of this electronic equipment to operate correctly in harsh environmental conditions. Early implementations of network gear in substations were based on consumer gear (think LinkSys) that had very low tolerance for temperature, humidity, shock, vibration, and the electromagnetic environment. Even first generation industrial quality gear intended for utility applications did not consider the environment found in substation and feeder applications. New standards, such IEC 61850-3 and IEEE 1613, begin to address these concerns. The IEC standard used around the world, but especially in Europe, have good environmental (temperature, shock, and vibration) guidelines – but the equivalent IEEE standard used primarily in North America does not. In North America there is presently no code or regulation that requires communications and control equipment to comply with any standard – and utility enforced best practices are still emerging. The bottom line is that the system will be vulnerable to communications and control failures in extreme conditions for some time to come.

7.5.2.2. Recovery levels

When events do occur and recovery efforts are required, the priorities and restoration efforts should address emergency-related societal needs first and progress through a tiered response. While the model of recovery can be complex, for simplicity, three general tiers to focus on are the restoration of services for emergency facilities and services (Critical and Essential Facilities), for critical public works and right of way (access) for critical infrastructure restoration crews, and then the systematic restoration of the community at large. Samples of how the infrastructure elements may (and could) perform was discussed in Section 7.3. Additional suggestions for how the infrastructure and facilities should respond when impacted by a Routine, Expected, or Extreme event are also expanded upon below:

1. ***Emergency Facilities and Services Restoration:*** Technologies and systems that address core emergency services should be properly planned, tested, maintained, and restored first. These facilities normally include 911 call centers, police, fire, and emergency medical dispatch stations. They also include centers identified for emergency shelter, food, and water, such as community centers, schools, and stadiums. When planning for disaster responsiveness, also consider communication infrastructure that links critical emergency resources (wire line communications, cellular radio, and third party managed radio systems).

2. ***Critical Rights of Way and Infrastructure Restoration:*** The next priorities to address include systems necessary to dispatch and manage road and right of way clearing crews, electric repair crews, and other non-emergency yet vital restoration related organizations and services. This list includes critical government facilities and communications paths to allow government to function effectively, manage the crisis, and maintain civil order. Energy resiliency in this sense covers emergency power for utility crew dispatch centers, key city buildings such as city hall, public works crew facilities. It also covers the business processes in place to ensure generators and UPS systems in these facilities are sized appropriately and tested periodically.

3. ***Socio-Economic Continuity Restoration:*** The next priority is to support socio-economic continuity. Full restoration typically requires days or even weeks. This aspect of restoration is often unplanned and the biggest utility clients or loudest complainers often move to top of the priority list. This element should be carefully prioritized and integrated into a community resilience plan. First, ensure citizens outside of the community shelters have access to food, water, fuel/energy, and communications. After these immediate needs are met, identify businesses supporting the basic needs of citizens such as water and sewage utilities, grocery stores, gas stations, drug stores, internet and telephone service providers, and make them priorities for restoration.

4. Mitigation projects or resiliency efforts may include hardening distribution systems and employing technologies such as backup generation, renewable energy, or microgrids to ensure these facilities remain online throughout the event or can be rapidly restored. Key infrastructure

elements also need protecting, such as sewage lift stations and water pumping stations. All these equipment and systems should be periodically tested and properly maintained in order to achieve the economic and societal benefit of the investment.

7.6. Strategies for Implementation of Community Resilience Plans

Section 7.2 discusses components of the energy infrastructure system. The discussion includes some potential vulnerabilities observed in the past encouraging the reader to think about the different hazards that could impact the energy infrastructure in their community. The number, types, and magnitudes of hazards that need to be considered will vary from community to community.

Section 7.3 discusses the performance goals of the energy infrastructure strived for by the community. Section 7.3 does provide example performance goals for the routine, expected and extreme event. However, the performance goals should be adjusted by the community based on its social needs.

Sections 0 and 7.5 outline some of the regulatory levels and issues, and codes and standards that the reader should keep in mind when planning to make upgrades/changes to existing energy infrastructure. The objectives of this section are to use the information from Section 7.2 through 7.5 and provide guidance on how a community should work through the process of assessing their energy infrastructure, define strategies to make its infrastructure more resilient, and narrow the resilience gaps.

7.6.1. Available Guidance

Another term is often used to describe energy system resiliency and reliability – Energy Assurance. Energy Assurance refers to the entire process of managing all aspects of energy delivery, resiliency and reliability to ensure a desired outcome for how energy services will perform during normal and abnormal situations.

Energy Assurance is often focused on assisting local governments to become more resilient to loss of energy. Becoming more energy resilient will help local governments prepare for, respond to, recover from, and mitigate against potential emergencies that impact energy while minimizing economic loss and protecting public health and safety. For the purposes of this framework, Energy Assurance is about:

- Ensuring “key assets” are functional when needed;
- Fostering critical public-private partnerships before incidents happen;
- Gaining awareness of energy dependencies; and,
- Identifying actions and projects to move toward increased energy resiliency.

Examples of how Energy Assurance is used as a means to collect the multitude of disciplines, characteristics and dimensions of energy delivery, resilience, and reliability planning processes together include the DOE’s Energy Assurance program (http://energy.gov/oe/services/energy-assurance), The National Association of State Energy Officials (NASEO) State Energy Assurance Guidelines (http://www.naseo.org/Data/Sites/1/documents/publications/State_Energy_Assurance_Guidelines_Version_3.1.pdf), and the California Local Energy Assurance Planning (CaLEAP) process (http://www.caleap.org).

Energy Assurance, as a whole, is about assuring that essential services are maintained in the event of an energy disruption. The first step is to identify the “key assets” of the essential services in the community and determine their vulnerabilities. The key assets could be as big as an entire building (e.g., Police or Fire Station) or as small as an element within a building (e.g., communications or HVAC system).

Building relationships is another part of Energy Assurance. Many emergency managers know that building partnerships after a disaster is too late. Attempting to identify who to reach and working around potential obstacles to reach them (e.g., limited or down telecommunications) is difficult. Establishing these relationships helps local governments anticipate actions and clarify roles and responsibilities prior to events; thus increasing the likelihood of a successful and efficient response and recovery.

Gaining an awareness and/or understanding of energy interdependencies is also a very important piece of energy assurance. Our communities have become very complex and many elements within them rely upon another element within the community. In some instances, water systems need energy for their services, but energy providers also need water to produce energy. Understanding these relationships is vital in decision making.

With a good understanding of the key assets and interdependencies, a local government, working with the local energy provider, can identify actions and projects to become more energy resilient.

Because resilience is new, there is a significant need for tools to help both the community and the industry assess resilience. Tools and methods exist to measure reliability, but again, these calculated values typically look at systems during blue sky events and not during natural hazard events.

An example of how resilience has been addressed during recent initiatives is found in energy assurance planning programs. A first step toward implementing resilience in the energy industry is to develop an Energy Assurance Plan tailored for a community. The flowchart developed by the CaLEAP program illustrates the overall approach for developing such a plan including forming an EAP team. Notice that this flowchart is similar to that shown in Chapter 3 of this document outlining the approach to achieve community resilience.

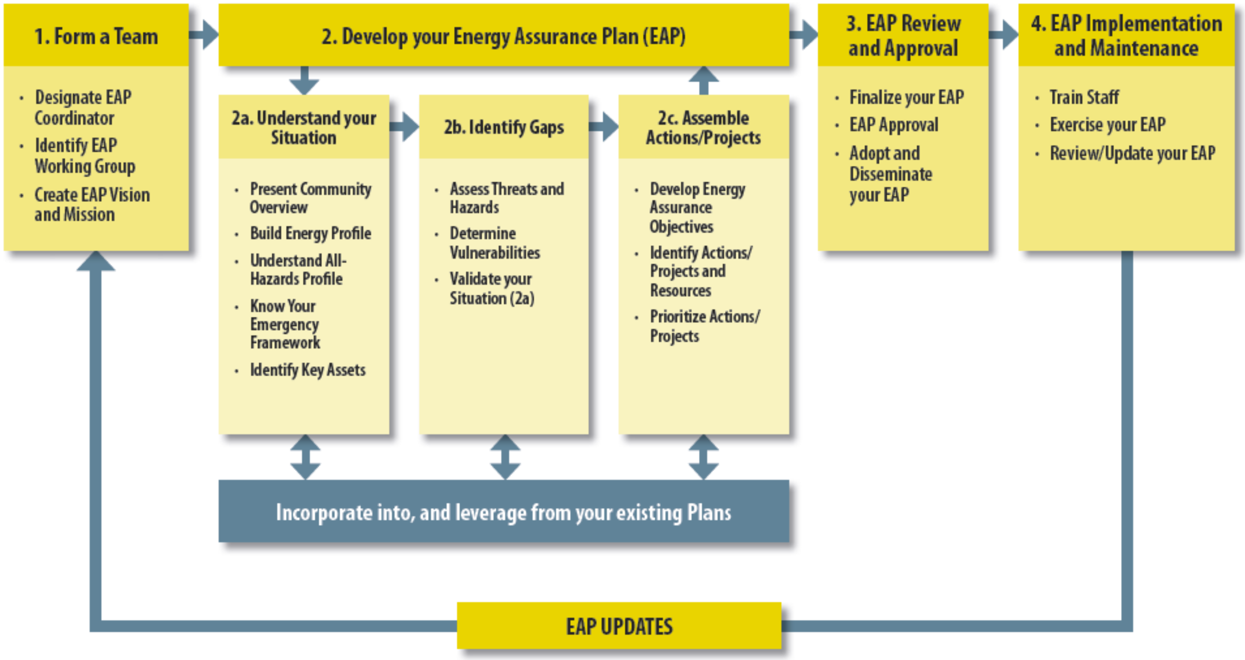

Figure 7-3: Energy Assurance Flowchart Developed by CaLEAP

Thinking about resilience as an aspect of reliability might be the quickest means to develop assessment methodologies to assess and score resilience – especially from the energy service provider perspective. It may allow the ability to explicitly consider large-scale events and non-traditional hazards that were sometimes neglected in previous assessments. It would also set up a means to consider resilience in the current industry mode that allows for variable pricing for duration and a better understanding of scale by adapting to risk-based frameworks that capture interdependencies and likelihood. By assimilating resilience into the factors that assure reliability, regulators might not be charged with setting new criteria for utility performance.

The length of time to restore electric service is a traditional metric of grid reliability. Similarly, the grid's ability to ride through minor disturbances or avoid cascading outages is already considered within existing grid reliability indices. While these metrics and indices (such as System Average Interruption

Duration Index [SAIDI], the Customer Average Interruption Duration Index [CAIDI], the System Average Interruption Frequency Index [SAIFI], the Customer Average Interruption Frequency Index [CAIFI], and others) exist, there are limitations to how these apply to the grid, including the fact that most reliability indices and metrics are blue-sky indicators. When looking at and defining resilience, the events that cause us to measure and evaluate the performance of the grid take place in much harsher and significant conditions (such as natural hazard events and acts of vandalism, crime, and terrorism). Performance goals tables, such as those in Section 7.3, can be used by communities and energy utility providers to set goals for recovery times during hazard events. However, these tables can also be used define to determine the anticipated performance of the infrastructure (i.e., the "X" in the performance goals tables) for a given event. The community or utility can then define the resilience gaps (i.e., the difference between the "90%" and "X" in the performance goals tables) and prioritize strategies for enhancing the resilience of the energy infrastructure system.

7.6.2. Strategies for new/future Construction

In general, when identifying equipment, and other components within the energy system, one of the qualifying criterion should focus on resiliency. When evaluating different vendors and system components, check their track record and references, and collaborate with others.

Construction Strategies. There are several construction strategies that can be used to help improve resilience of energy infrastructure from hazard events, including the following:

- Strengthening and reinforcing critical lines leading to population centers or other critical loads. For instance, adding line reinforcements to lines that serve a hospital or fire station makes them more resilient to wind, ice, and branch loads.
- Establish pole depth standards based on local soil conditions for each pole height. Ensure that poles are planted to the correct depth and the foundation will support the loads.
- Do not overload poles.
- Consider using National Electrical Safety Code (NESC) Grade B construction standards for critical distribution lines. This grade of construction is commonly used in the utility industry and utility surveys show that using Grade B for storm hardening is a popular and effective resiliency construction strategy.
- Consider undergrounding. There are definite pros and cons to using undergrounding. They are less vulnerable to weather, fire, and man-made hazards, but certainly not earthquakes. It is expensive and when faults do occur, they are difficult to locate, take much longer to get to, and are expensive to fix. For an event like Hurricane Sandy or the ice storms of 2012 and 2013, underground cables would have dramatically reduced the amount of damage and restoration times. For an earthquake in California, it could have the opposite effect. Due to the increased costs associated with undergrounding, some options include:
    - Underground circuits based on the largest number of customers services.
    - If there are circuits that will be difficult to access (especially during weather-related hazard events), underground those circuits.
    - If there are circuits whose terrain and surrounding environment make it relatively easy and inexpensive to install underground cable, underground those circuits.
- Consider Covered aerial medium-voltage (CAMV) systems. This hardware attaches to poles and overhead wires to add strength and stability to the wires. The added stability makes the distribution network more resilient to contact with trees and debris, and is especially useful in narrow rights of way with large concentrations of trees.
- Other potential solutions include various pole line configurations that can help minimize restoration efforts.

- In fire prone areas, consider using concrete, heavy steel, or other non-flammable and warp resistant structures to put conductors and equipment overhead. This makes the survival of the line more likely. However, consider driver safety in this upgrade. Because these structures are stronger, consider moving them further from the road rights-of-way so the likelihood of hitting a pole is reduced if an automobile leaves the road.

Non-Construction Strategies. As discussed in Section 7.2, the effects of a number of natural hazards can be mitigated without hardening or other construction strategies of the infrastructure. Some possible non-construction strategies for improving the resilience of energy infrastructure include the following:

- Trim trees and other potential obstructions as far as practical within the right of way.
- Use submersible equipment in underground substations, which can be accomplished in the case of city-run electric utilities or city-owned substations. Submersible equipment stops almost any water-based issue with substation operation, whether from weather events, water main breaks or flooding from other sources.
- Minimize the number of splices in conductors and in ducts that carry the splices. Where possible, position splices in conductors and ducts as far away from water mains as possible and in easily-accessible locations. Note: in high volume rain areas, storm drains can be as large an issue as water mains.
- Consider heavy wall insulation cables, type TC cables, and type MC cables. Heavy wall insulation cables are more resistant to physical damage and moisture, providing better resilience to severe weather conditions than thin wall insulation cables. Type TC cables are used in industrial applications for power and control applications. TC cables have a moisture-resistant jacket and are rated for use in wet conditions. Type MC cables are also moisture-resistant and rated for use in wet conditions. In addition, MC cables are also crush-resistant.

Electrical Infrastructure in Buildings. Specific to energy infrastructure in buildings, the National Institute of Building Sciences recommends that "during the facility design and/or re-build development process, building projects have a comprehensive, integrated perspective that seeks to:

- ***Reduce Heating, Cooling, and Lighting Loads through Climate-Responsive Design and Conservation Practices***
    - Use passive solar design; orient, size, and specify windows; and locate landscape elements with solar geometry and building load requirements in mind.
    - Use high-performance building envelopes; select walls, roofs, and other assemblies based on long-term insulation and durability requirements.
- ***Employ Renewable or High-Efficiency Energy Sources***
    - Renewable energy sources include solar water heating, photovoltaic (PV), wind, biomass, and geothermal.
    - Evaluate the use of building scale to take advantage of on-site renewable energy technologies such as day lighting, solar water heating, and geothermal heat pumps.
    - Consider the use of larger scale, on-site renewable energy technologies such as photovoltaics, solar thermal, and wind turbines.
    - Evaluate purchasing electricity generated from renewable sources or low polluting sources such as natural gas.
- ***Specify Efficient HVAC and Lighting Systems***
    - Use energy efficient HVAC equipment and systems that meet or exceed 10 CFR 434.
    - Use lighting systems that consume less than 1 watt/square foot for ambient lighting.

  - Use Energy Star® approved and/or FEMP-designated energy efficient products or products that meet or exceed Department of Energy standards.
  - Evaluate energy recovery systems that pre-heat or pre-cool incoming ventilation air in commercial and institutional buildings.
  - Investigate the use of integrated generation and delivery systems, such as co-generation, fuel cells, and off-peak thermal storage.

- ***Optimize Building Performance and System Control Strategies***
  - Employ energy modeling programs early in the design process.
  - Use sensors to control loads based on occupancy, schedule and/or the availability of natural resources such as daylight or natural ventilation.
  - Evaluate the use of modular components such as boilers or chillers to optimize part-load efficiency and maintenance requirements.
  - Evaluate the use of Smart Controls that merge building automation systems with information technology (IT) infrastructures.
  - Employ an interactive energy management tool that allows you to track and assess energy and water consumption.” 5

The CaLEAP organization has identified additional recommendations for building and retail owners, including:

- Ensuring emergency, life safety, high priority, and general building circuits are well segregated in building wiring design and breaker panel layouts.
- Ensuring building automation systems take advantage of segregated load grouping mentioned above, are standards based (e.g. BACNet), and are capable of accepting utility load control signals (e.g. OpenADR).
- Key community facilities necessary to ensure socio-economic continuity without internal backup generation capability are configured to permit easy, safe connection to external mobile generation (e.g. through standardized connectors at the outside service entrance)

7.6.3. Strategies for Existing Construction

The previous section on strategies for new construction discussed recommendations by the National Institute of Building Sciences in detail. Most of the ideas expressed also apply to existing construction strategies. However, in new construction, there is a larger set of opportunities for energy efficiency and resiliency since nothing has been built yet.

In general, when replacing equipment, and other components within the energy system, each component should be considered and, where more resilient, better reliability choices are available, communities should not replace with the same equipment when practical.

Construction Strategies. Similarly to new/future infrastructure, construction strategies, including the following, can be used to enhance the resilience of existing infrastructure:

- Strengthen and reinforce critical lines leading to population centers or other critical loads. For instance, adding line reinforcements to lines that serve a hospital or fire station makes them more resilient to wind, ice, and branch loads.
- When adding new equipment to poles, perform loading assessment to ensure that the pole is not over-stressed.
- Consider Covered aerial medium-voltage (CAMV) systems.
- Consider replacing overhead lines with underground systems. As discussed previously, this requires careful consideration and a cost/benefit analysis. However, in many cases, the ability of

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[5] Source: National Institute of Building Sciences, http://www.wbdg.org/design/minimize_consumption.php

underground systems to provide uninterrupted service (or service with limited outages) during severe weather events has societal and economic benefits that deserve consideration. Due to the increased costs associated with undergrounding, some options include:

  - Underground only the worst performing circuits, or section(s) of a circuit.
  - Underground circuits based on the largest number of customers services.
  - Underground circuits that are difficult to access (especially during weather-related hazard events).

- Consider moving overhead equipment higher so the fire has to reach further to do significant damage.
- A second electrical system path to critical buildings is a resilient design. The alternative electrical path can be from local generation or from an independent path into the area that can be traced back to a power source without crossing the other path.
- Make sure the soil types and insulation properties of the soils are known when burying a line. If the line is buried too shallow, the line will end up out of commission as often as an overhead system and the resulting problems will take far longer to find and fix. Broken overhead infrastructure is typically found by simple visual inspection, while failed underground infrastructure requires investigation by digging or specialized equipment. In some instances, one costly option is to abandon in place and replace the whole distance of the splice to restore the system quickly.
- Use modern flexible fuel lines for the run between the fuel tank and the shelter or skid upon which the generator sit. This installation not only minimizes leaks from vibration, but keeps pipes with lower thermal tolerance away from hot parts of the generator. A cracked or broken insulated fuel line may take hours to detect in an emergency situation because of the chaos. Typically the leak gets worse as the generator vibrates, and the loss of fuel can become significant. A visual inspection of the fuel lines after an earthquake should be conducted as quickly as possible to prevent a hazmat event, fire, or an early shutdown of a back-up generator.

Non-Construction Strategies. In many cases, improving the resilience of existing infrastructure may be more easily accomplished through non-construction strategies. Some possible non-construction strategies for improving the resilience of existing energy infrastructure include the following:

- Trim trees and other potential obstructions as far as practical within the right of way.
- Perform regular tree trimming and line inspections.
- Perform regular pole inspections. Look for excessive pole loading due to telephone, cable (television), and internet-related equipment. If the pole is wooden, check for decay. Check the foundation of the poles to ensure they are properly embedded and stable. If there is erosion around the footing or the pole is leaning, add guy wires or reset/replace the pole. Consider heavy wall insulation cables, type TC cables, and type MC cables.
- Inspect underground splices and equipment on a scheduled basis to make sure seals are intact and that nothing has destroyed the waterproof capability of the connections.
- Using bulkheads that are strong enough to resist the water pressure on the other side in ducts can help protect equipment and minimize damage as well as close off a path of least resistance that will spread the damage from a break. If a duct runs down a 200 foot high hill and the main breaks at the top, the bulkhead would have to resist approximately 400 psi of pressure in the duct. Understanding this in inspection and design is useful. A strong bulkhead at the top of the hill can provide a simple solution that ensures the duct never fills with water.
- Have an adequate stock of spares (poles, transformers, line, etc.) on hand for fire prone areas, and do not use them for routine work. If emergency spares are used in routine work, then it will take even longer to do restoration.

- Aggressive vegetation management is critical to the safety of both overhead and underground infrastructure[6]. This includes removing trash that is illegally dumped on rights-of-way. Recently, over 200 tires were removed from an illegal dumping pile on a right-of-way. These tires would have burned hot enough to destroy the line if they had ignited.
- If possible, cutting off power before wildfire gets to the line allows equipment and lines time to cool and may save the system from destruction. If people have been removed from an area, do not hesitate to turn off power a couple of hours before the fire reaches the area, allowing equipment maximum time to cool. This proactive action can also avoid having fires start as the result of a power line going down or overheating equipment, thereby negating any perimeter that may have been created.
- Controlled burns for vegetation management and invasive species reduction can impact infrastructure if vegetation is close to rights of way. Ensure that precautions are taken prior to controlled burns – about 20% of electrical outages from fires are from controlled burns.
- Proper grounding and inspections of grounding equipment greatly minimize the chance transformer fire can occur from lightning. Standards exist both for how to ground and how to inspect the grounding. Poles in areas that are susceptible to fire should be inspected more often or, the use of non-flammable poles, like concrete, is an intelligent hardening mitigation effort.

Installing and maintaining lightning arrestors and cut outs in the distribution grid can minimize the area that a single lightning strike affects but, in the case of cut-outs, once it is triggered, manual fuse replacement is required. Replacing cutouts with sectionalizers means that the equipment has a chance to stop the lightning and automatically attempt a reset to restore power. On the customer side of the meter, existing construction can be readily retrofit with external generation support connectors as previously noted for new construction. If an existing facility is considering adding any form of self-generation systems, consider upgrading building circuits at the same time to segregate load types. If a building automation upgrade is being considered, ensure that it meets the suggestions previously noted for new construction. As noted previously, consider using the USACE Emergency Power Facility Assessment Tool (EPFAT), which allows public entities to input generator and bill of material requirements to expedite temporary power installation support services.

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