Best Practices in Resilience Planning
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ABSTRACT
All levels of government across the United States and globally rely on energy systems that are vulnerable to numerous threats and hazards; both short-term events (shocks) and longer term changes (stresses). This vulnerability presents both near-term and chronic challenges in providing reliable, affordable, equitable, and sustainable energy services. Within this context, NREL works to identify challenges and solutions in the energy sector, including the need to reliably meet growing electricity demands in developing countries, lesson dependence on imported fuels, expand energy access, and improve stressed infrastructure for fuel supply and electricity transmission for resilience.

CONCLUSIONS
Reliable, safe and secure electricity is essential for economic and social development and a necessary input for many sectors of the economy. However, electricity generation and associated processes make up a significant portion of global GHG emissions (IPCC, 2014). Electricity systems are aging and are vulnerable to numerous threats and hazards; both short-term events (shocks) and longer term changes (stresses). This vulnerability presents both near-term and chronic challenges in providing reliable, affordable, equitable, and sustainable energy services. Within this context, NREL works to identify challenges and solutions in the energy sector, including the need to reliably meet growing electricity demands in developing countries, lesson dependence on imported fuels, expand energy access, and improve stressed infrastructure for fuel supply and electricity transmission for resilience.

Spatial Diversification
The modular nature of renewable energy technologies, such as wind turbines and solar photovoltaics (PV), allows greater spatial diversification of energy supplies compared to conventional power generation systems, which deliver power from a concentrated point or central location. Increased spatial diversification reduces the vulnerability of the energy supply from a single event or a single critical location, which increases overall energy system resilience.

Microgrids
Microgrids capable of islanding based on distributed generation (DG) can disconnect from the central grid during a disruptive event to allow energy to be diverted to critical loads. With microgrids serving critical loads during a blackout, utilities have more flexibility in restoring generation stations, responding to critical outages, and shutting down systems before a major event to prevent damage. Islanded renewable energy DG systems ensure consumers have access to power during long-term power outages that severely impact central grid systems, which can occur after major natural disasters.

Redundancy
Redundancy is critical to most operations, but is essential for resilience. The increased stress on infrastructure systems as a result of threats has the potential to increase the likelihood of failure of one or more parts of a system, increasing supplies, routes, or incorporating redundancy in systems will reduce certain risks. In a community level analysis, NREL determined that pairing renewable energy and energy storage technologies with conventional backup power systems increased the number of days a system could operate without grid connection, illustrated in the image above and to the right.

Water and Energy
The water-energy nexus plays a large role in resilience at many levels. Water is used for energy generation in hydro-electric plants and in cooling systems for nuclear plants. Alternatively, energy is used for treating and pumping water supplies. Technical solutions from making power-generation plants more efficient, using clean-energy technologies, and designing systems to utilize gravity-fed options can enhance resilience of both energy and water systems.

Policies and Financing
New Jersey had more than 1,000 MW of installed solar capacity when Hurricane Sandy hit the Northeast United States. However, only two solar PV systems provided power in the days following the hurricane (Hotchkiss et al., 2013). At the time, a combination of interconnection policies and a lack of dynamic controls or transfer switches or energy storage solutions prevented the islanding of systems. Without appropriate policies and codes, the installed DG capacity in New Jersey did little to aid resilience. Jurisdictions wishing to enhance resilience through islanded renewable energy DG systems should adopt appropriate policy on interconnection and islanding to realize the full benefits of these technical solutions. Identifying and securing financing is an essential part of the process. New Jersey created an Energy Resilience Bank to help fund additional resilience-related technologies.

METHODOLOGIES
At its most basic level, resilience refers to the ability to recover after the application of stress. Taking an all-hazards approach, NREL has worked with numerous communities to increase resilience to various threats and vulnerabilities. Depending on the stakeholders involved in resilience planning and the end-goal, the methodologies deployed could range from community engagement, resilience planning, policy analysis, microgrid modeling, renewable energy feasibility studies, vulnerability and risk assessments. A best practice approach or methodology would include most of the processes highlighted to the right.