ELECTRICITY-WATER CRITICAL INFRASTRUCTURE INTERDEPENDENCIES:

How States Can Enhance Resilience and Reduce Risks.

NASEO

National Association of
State Energy Officials

Contents

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ABOUT NASEO

NASEO is the only national non-profit association for the governor-designated energy officials from each of the 56 states and territories. Formed by the states in 1986, NASEO facilitates peer learning among state energy officials, serves as a resource for and about State Energy Offices, and advocates the interests of the State Energy Offices to Congress and federal agencies.

Executive Summary

Electricity is essential for the operation of virtually all other critical sectors, such as water, telecommunications, natural gas, transportation, and petroleum products. Further, in many cases each of these other vital sectors are critical to the generation and operation of the electric grid. During a power outage caused by a human or natural disaster, impacts are not limited to one sector, and the resulting economic and human consequences ripple across multiple sectors and impact the lives and livelihoods of not only the community affected by the disaster, but oftentimes neighboring communities and states as well.

This report explores the importance of considering interdependencies in energy security plans, broader state energy plans, and relevant resilience policies and programs. It specifically focuses on the interdependencies between the electric and water/wastewater sectors, but aspects of the report also apply more broadly across sectors that are reliant on electricity as a critical component to their operation. This report provides a foundation for State Energy Offices to understand electricity and water sector interdependencies, thus supporting energy emergency planning and preparedness and longer-term energy planning. It does not focus on other equally important and complex interdependencies among petroleum, electricity, and natural gas, for example.

To assist State Energy Offices in developing energy security plans, broader state energy plans, and relevant resilience policies and programs, this report outlines the general types of interdependencies and then explores the specific interdependencies between the electricity and water sectors. It then details three steps that State Energy Offices can take to consider and mitigate these interdependencies:

1) Identifying potential interdependencies between sectors as the baseline of vulnerabilities;
2) Undertaking a scenario analysis to examine interdependencies based on different hazards; and
3) Considering how to address interdependencies in various planning processes, such as state energy plans, energy security plans, and utilities' integrated resource planning.

The report concludes with a list of relevant questions and other resources that State Energy Offices can use to examine interdependencies between the electricity and water sectors.

Introduction

Interdependencies are defined as "the quality or condition of being interdependent, or mutually reliant on each other."[1] Electricity is used by and supports all sectors of the economy. Power outages have very significant economic and human impacts. Clean water and wastewater are essential for public health and safety and help drive economic activity across the U.S. Experience has shown that a power loss can have devastating impacts on drinking water and wastewater utilities and the communities they serve. Pressure loss allows contaminants to enter the drinking water distribution system from surrounding soil and groundwater. Lack of water makes firefighting difficult and force local health care facilities and restaurants to close. For wastewater utilities, pump failure may lead to direct discharge of untreated sewage to rivers and streams or sewage backup into homes and businesses. Power loss also impacts water utilities through cascading infrastructure failures. For example, a chemical plant without power could discharge contaminants into source water supplies.[2]

Extreme weather events, such as polar vortexes in the Midwest and the Northeast, and the extreme high temperatures and droughts in the west and other parts of the country over the last few years, are creating new demands on our power grid and water systems. These events are also highlighting the interdependency of the electricity and water sector.

Two events in 2021 alone illustrate the significant interdependence between the electricity and water sectors. Power outages that occurred in Texas and some other Southern and Midwestern states during the historic severe winter weather in February 2021 caused widespread power outages affecting millions of customers. The loss of power forced some communities to shut down their water systems, while others issued boiled water advisories. These issues persisted in some areas weeks after power was restored. At its peak on February 19, 2021, the number of people affected by water disruptions totaled 14.9 million and more than 1,100 boiling water notices were issued after the storm.[3] Almost a week later water had been restored to most customers, but 1.4 million customers were still experiencing water supply disruption and 20,000 customers still had no water. The damage to the water system included broken water mains, disrupted supply lines, and flooded residences. The costs were estimated to be in the billions of dollars. Economically disadvantaged communities that might not have been able to properly maintain their water systems may have experienced more severe impacts due to a greater rate of failure and higher repair costs.

In August 2021, Hurricane Ida made landfall in Louisiana and severely damaged the power grid causing power outages for more than a million customers. The water systems were significantly impacted. The New Orleans Sewerage and Water Board (S&WB)'s co-generation and backup power systems were able to supply electricity to its pumping stations, which manage flood control for the city, and retain pressure for the drinking water system. However, S&WB relies on grid-generated power for its wastewater management. Due to the prolonged outage, S&WB received emergency approval to divert untreated wastewater and sewage into the Mississippi River.[4]

Many states and the Federal Government have examined critical infrastructure interdependencies after energy disruptions. Following the 2003 Northeast blackout, studies conducted by numerous states and federal agencies described the cascading impacts that took place across different critical sectors, including the water sector. The U.S. Environmental Protection Agency (EPA) has identified some of the key interdependencies that occur when water and wastewater systems are disrupted due to power outages and the U.S. Department of Energy (DOE) has extensively studied interdependencies between the energy and water/wastewater sectors. States have addressed these interdependencies and their impacts in their energy security plans.[a]

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[a] Energy security plans are the same as energy assurance plans.

Power outages affect millions of Americans each year. During each hurricane season on the East Coast, 3.5 million Americans can expect to lose power.[5] Studies have shown that, intermittent outages cost the U.S. economy billions of dollars every year (excluding large, longer-term power outages). For example, a report by the President's Council of Economic Advisers and the DOE's Office of Electricity has found that "the average annual cost of power outages caused by severe weather [is] between $18 billion and $33 billion per year. In a year with record-breaking storms, the cost can be much higher. For example, weather-related outages cost the economy between $40 billion and $75 billion in 2008, the year of Hurricane Ike." [6] Other studies for the total cost of power outages from all hazards suggest total costs that are greater than $100 billion annually.[7] In August 2003, the heat-induced sagging of several local power lines in northern Ohio – a situation that might have normally lead to a temporary local power outage – resulted in a massive regional collapse of the power transmission and delivery system due to cascading failures. Within eight minutes, the blackout affected over 50 million people in eight states and one Canadian province and ultimately resulted in a U.S. financial impact of between $4 and $10 billion.[8]

These estimated costs try to take interdependencies into account, although it is not always clear what is included in the estimations. Studies specifically estimating impacts of natural disasters on the water system augment some of these estimates. For example, one study estimated the economic impacts on business and residential customers from a 7.9 magnitude earthquake from the San Andreas Fault that affected one of the major water systems serving the San Francisco Bay Area of California. The study estimated that the economic loss to businesses would total $14.4 billion and the cost to residential customers would be $279 million.[9]

Over the next decade trillions of dollars will be invested nationally in water, wastewater, and electrical systems. These investments will be necessary to replace aging infrastructure, integrate new technologies, offer greater cybersecurity protections, and address the increasing extreme weather events exacerbated by climate change.

State Energy Offices will have unique planning and programmatic opportunities to ensure that these investments can improve the efficiency and resiliency of the electricity and water systems. For example, wastewater systems can capture waste products to meet the facilities' energy needs, provide efficiencies, decrease environmental impacts, and improve resilience. The Robert W. Hite Treatment Facility in Denver, which treats wastewater, includes a 6 MW cogeneration facility that uses biogas to generate electricity and heat.[10] The facility was a participant in DOE's Sustainable Wastewater Infrastructure of the Future (SWIFt) Accelerator, which worked with over 70 wastewater recovery facilities to increase their energy efficiency, and is currently entering into its second phase.[11] Furthermore, DOE has estimated that "that there is over 260 MW of CHP technical potential at roughly 1,015 municipal wastewater treatment plants in the U.S. today.[12]

Extreme weather events are creating new demands on our power grid and water systems and are highlighting the interdependencies of the electricity and water sector. Simply looking at direct impacts of a disaster on one specific sector (i.e., electricity), policymakers might underestimate the true costs of disasters. When interdependencies are properly considered, they reflect the significant costs to the economy and human health/welfare. Despite the challenges in considering interdependencies fully, investments to mitigate negative impacts in one sector can also have resilience benefits in another sector – amplifying the benefits and reach of the investments.

Types of Interdependencies and Failure Modes

In the National Infrastructure Protection Plan, risk is defined as a function of human and economic consequence, threats, and vulnerabilities.[13] Interdependencies are vulnerabilities; thus, it is important to identify interdependencies to accurately mitigate risk associated with them and to account for their economic consequences. Argonne National Laboratory (ANL) categorizes interdependencies into four types – physical, cyber, geographic, and logical – and three types of failures.[14] Water and energy sectors are primarily linked through physical and geographic interdependencies.

Physical Interdependencies

Physical interdependencies describe the physical linkages between sectors — something that is produced by one sector is a critical input in another sector. This physical interdependency includes supply chains, which often highlight additional interdependencies. Examples of physical interdependencies between the electricity and the water sectors include the necessity for water as coolant for many power plants and the need for electricity for water treatment plants. As of 2014, the U.S. Energy Information Administration found that "power plants that require the use of cooling water account for a little more than 70% of all the electricity in the nation and nearly 60% of the electric generating capacity,"[15] making water a critical component of electricity generation.

Geographic Interdependencies

This describes the locational interdependence of critical infrastructures due to their proximity. Water plants can be located close to other critical energy infrastructure. During the 2003 Northeast blackout the loss of power unexpectedly shut down a refinery and led to concern about chemical leaks that forced evacuations and the shutdown of an interstate highway next to the refinery. At the same time, a large water system next to the refinery was losing pressure due to the power outage. To get partial power restored to the water system, the utility needed to access a major electrical substation inside the refinery but because of the chemical leak utility crews needed to take extra precautions prior to restoring substation connection to the waters system.

Cyber Interdependencies

Cyber interdependencies are the linkage between information outputs that serve as inputs in another sector**.** Water systems rely on Industrial Control Systems (ICS) to operate pumps and detect drops in water pressure that may signal leaks or major water line breaks. These systems require power to function although water utility operators may have some capability to manually check pressure gauges and operate valves. ICS also monitors water quality at intake points. Failure of the system would risk contamination of the water supply.

Logical Interdependencies

Logical interdependencies are interdependencies other than physical, cyber, and geographic, such as interdependencies based on human decisions and actions. This is a factor that is relevant for both electric and water utilities. For example, a major ice storm in December 2013 caused a large-scale power outage in Michigan.[16] The management of one local electric utility underestimated the scope of the damage, which slowed the resource mobilization needed to restore power. This delay exacerbated both the economic and human consequences. Due to the very cold temperatures during the power outage, many residences experienced damages to their waiter system, compounding the overall damage.

In addition to the categories, ANL describes interdependencies as subject to three types of failure modes:[17]

Cascading Failure
This describes a disruption or unavailable supply of products or services in one infrastructure sector or organization that causes a disruption in a second. This is the most common type of failure, and it can cause much broader geographic impacts. For example, the winter storm in Mid-February 2021 directly resulted in millions of customers losing power in Texas and nearby states. The loss of power had a cascading effect in the water sector, where pipes froze in buildings and flooding occurred as a result.

Common Cause Failure
Common cause failure is a simultaneous disruption of two or more assets because of co-location (e.g., right-of-way corridor or immediate proximity). This most often occurs in critical infrastructure clusters. A power plant might be located next to a water system and rely on multiple circuits to assure reliability. This may be less costly than having on-site backup power. Power outages can then cause a loss of pressure in a water system, leading to a boil water advisory due the risk of contamination or loss of water supply all together.

Escalating Failure
Escalating failure describes the disruption in one infrastructure that exacerbates or impedes recovery of an independent disruption elsewhere. Both common cause and cascading failures can be exacerbated by escalating failures as hazardous conditions become more severe. For water and electricity interdependencies, a power outage can lead to water systems issuing water advisories. This announcement can cause a surge in water demand as people fill up extra containers to assure that they have water. This increased demand can in turn cause water pressure to fall further.

In the most extreme events, sometimes referred to as black or dark sky scenarios, the damage can be catastrophic causing numerous infrastructure failures across sectors.

Options for Considering Interdependencies in Energy Planning

Given the importance of interdependencies and the significant impact of failures, the challenge for states is how to address interdependencies in their state energy and energy emergency response and security planning.

The three-step approach outlined below provides State Energy Offices a means to identify interdependencies, the types and failure modes, risks, and economic and human consequences, and reflect these considerations in the resulting plans with actions that reduce risk and enhance resiliency. This approach includes:

- Crating a baseline of vulnerabilities by identifying potential interdependencies between sectors (step 1).
- Quantifying the economic and human impacts of infrastructure disruptions based on historical events or scenario-based analysis to make comprehensive cost-benefit assessments (step 2).
- Developing and updating state energy plans and state energy security plans that explicitly recognize and address interdependencies by understanding the threats and vulnerabilities that they pose in the state, and their economic and human consequences. State plans should also guide longer term energy infrastructure investments and policies and programs that enhance resiliency and mitigate risks. These investments should be judged based on cost-benefits-analysis; however, states should consider additional costs and benefits that take interdependencies into account (step 3).

Step 1: Identify Potential Interdependencies Between Sectors to Create a Baseline of Vulnerabilities

When examining interdependencies, consider the following: first, interdependencies exist between community lifeline[b] infrastructures and are vital to mutual operations under normal conditions; second, interdependencies may shift depending on the nature or scope of the disaster or the disruption.

DOE and the Federal Emergency Management Agency (FEMA) have each outlined how different sectors are interdependent. Figure 1 provides examples of interdependencies between the electricity, water, natural gas, telecommunications, oil, and transportation sectors.

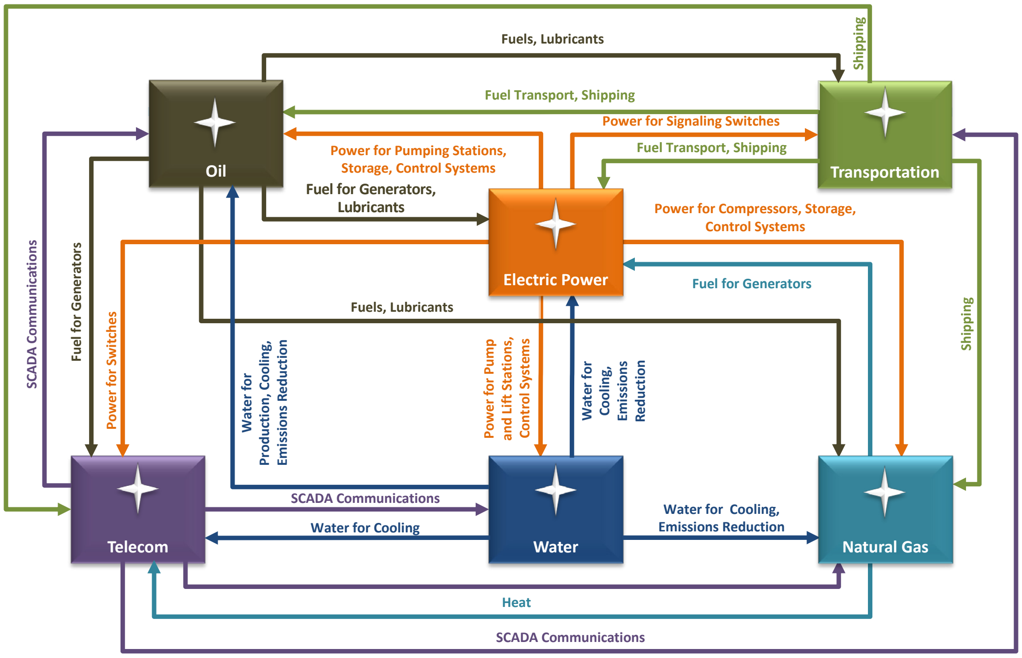

Figure 1: Examples of Interdependencies between Lifeline Networks[18]

The National Conference of State Legislators (NCSL) also outlined these linkages between the energy and water sectors further.[19] The electricity needs for moving and treating water and wastewater by public and private entities were estimated to be around four percent of national electricity generation in 2002.[20] Although this is the national average, regional numbers vary greatly. A 2005 study by the California Energy Commission found that "water-related energy use consumes 19 percent of the state's electricity."[21]

In addition, electricity is used by consumers for a wide variety of tasks, such as household water heating. The U.S. Energy Information Administration's (EIA) 2015 Residential Energy Consumption Survey found that households in the U.S. use 173 billion kWh of electricity for water heating. However, regional disparities are again great – ranging from 21 billion kWh of electricity in the Northeast to 95 billion kWh in the South. This difference is partly due to electricity providing 69 percent of Southern total residential energy consumption compared to 30 percent in the Northeast, as the coldest areas in the U.S. consume primarily oil and natural gas for space heating needs.[22]

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[b] FEMA defines community lifelines as lifelines that enable the continuous operation of critical government and business functions and is essential to human health and safety or economic security FEMA has identified seven community lifelines: safety and security; food, water, shelter; health and medical; energy; communications; transportation; and hazardous material (see https://www.fema.gov/emergency-managers/practitioners/lifelines).

In addition to the outlined linkages, water is also a critical component of hydropower, making a large portion of carbon-neutral electricity generation susceptible to drought. The National Oceanic and Atmospheric Administration (NOAA) maintains a drought monitor which provides a seasonal outlook across the United States (see box with data resources). Although federal agencies such as the DOE, the U.S. Geological Service (USGS) and NOAA provide numerous data sources on electricity and water usage, more granular and state-specific data is often more limited. This data is important to understanding the degree of interdependencies between the electricity and water sectors. State Energy Offices and other state decision-makers cannot evaluate the full extent of interdependencies or vulnerabilities in their decision-making process without good and more detailed data.[23]

Data Resources

- Climate Prediction Center, Drought Information, **NOAA**
- U.S. Energy Consumption by Source and Sector, 2019, **EIA**
- Water Data for the Nation, **USGS**
- State and Regional Risk Profiles, **DOE**
- River Observations, **NOAA**
- State Electricity Data, **EIA**
- Energy Atlas, **EIA**

Although the steps for establishing a baseline of existing vulnerabilities are similar for both electric and water sectors, they are addressed separately in the following section as the sources for the required information are different.

Electric Sector

1. **Identify critical electric infrastructure**. EIA has detailed state electricity data. Select your state and go to the electricity link for further details. Identifying power plants, their location, and net generation capacity is the first step. This information also may be available from the state Public Utility Commission. A map of the geographic area served by each utility identifies common cause failures and geographic interdependencies. The EIA Energy Atlas is another tool states can use that contributes to understanding geographic proximity dependencies.
2. **Determine what inputs, including fuel, power plants rely on to operate**. For example, most thermal plants need cooling water. This assessment might require a detailed discussion with operators of power plants about their water sources and potential redundancies. Fuel supply chains might be disrupted if they pass through flood prone areas.
3. **Assess the degree to which major critical infrastructures are dependent on electricity to operate.** This includes water and wastewater treatment plants.
4. **Summarize existing emergency response measures in electric utility plans in local and state plans.** Include any specific reference in these plans to how water systems might be prioritized.
5. **Document known or potential vulnerabilities based on historical events that may have caused significant power outages.** This information can be found in After Action Reports following storms and hurricanes, earthquakes, disruption in fuel needed for generators, transmission and distribution system failures, cyber-attacks, etc. These reports also include actions that may have been taken to reduce these risks. Public Utility Commissions may conduct investigations after major storms, which can contain useful details.
6. **Identify electricity resiliency measures that mitigate risk and options for the future along with environmental, economic, safety, and other benefits they might provide.** Include those options in state energy plans and consider them for state or federal funding opportunities.

Water Sector

1. **Identify critical water infrastructure.** This might be done by meeting with the state agency responsible for water and wastewater facilities. The information may also be available from a state supported geographic information system. A map of the geographic area served by each water and wastewater utility can be used to identify common cause failures and geographic interdependencies. It is important to know the capacities of key water facilities and their back-up capabilities and to what degree, and for how long they can sustain operations.
2. **Determine what the water sector relies on to operate and the degree they are dependent on electricity to operate.** This might include detailed discussions between water utility and electric utility representatives. It is useful to know their power capacity requirements, fuel burn rates and on-site storage capacity for liquid fuels.
3. **Identify existing emergency response measures and requirements.** America's Water Infrastructure Act of 2018 (AWIA) Section 2013 requires community water systems serving populations greater than 3,300 to conduct a Risk and Resilience Assessment and develop an Emergency Response Plan (ERP). Water utilities should review the section on Power Loss in EPA's Community Water System Emergency Response Plan Template.[24]
4. **Identify known or potential vulnerabilities based on historical events that may have caused significant impact on water utility operations due to a power outage**. Review actions water utilities undertook during a power outage and asses what potential improvements could be made.
5. **Identify water resiliency measures that mitigate risk and options for the future along with other benefits they might provide, such as environmental, economic, and safety.** Include those options in state energy plans and consider them for state or federal funding.

Power Preparedness Resources for Water and Wastewater Utilities

- Power Resilience Guide for Water and Wastewater Utilities, EPA
- Is your Water or Wastewater System Prepared? What you need to know about generators, EPA
- Incident Action Checklists for Water Utilities, EPA

Step 2: Undertake a Scenario Analysis to Examine Interdependencies in Detail

The nature and degree of the interdependencies may change depending on the nature and scope of the disaster or the disruption. To consider primary and secondary impacts, a disaster scenario analysis can be used to help identify additional interdependencies. Scenarios can help identify specific impacts and, working backwards, be used to find linkages. The following two scenarios illustrate some of the interdependencies between the electricity and water sectors.[c] These examples reveal common cause and cascading failures, both of which are subject to escalating severity and consequences. The interdependencies identified in these scenarios are the major linkages, there may be other linkages that are unique to specific geographic locations or system configurations. State Energy Offices, therefore, might want to include unique regional and state specific circumstances in their scenario analyses.

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[c] NASEO and DOE held an Energy Assurance and Interdependency Workshop in 2013. Participants from State Energy Offices, Public Utility Commissions, state emergency management agencies, federal agencies, governors' offices, and local jurisdictions as well as the energy industry worked through three independent scenarios to identify impacts on other sectors. The scenarios did not identify all interdependencies or secondary impacts.

Scenario One: Long-Term Drought

The first scenario envisions drought conditions that build slowly over time and have a long-lasting effect over 18 months to 2 years. Prolonged drought conditions in a severe, long-term drought scenario can lead to reduced outputs from thermal and hydroelectric power plants by as much as 17 percent and 62 percent, respectively. Drought conditions can lead to reduced reserve margins below 15 percent in several North American Electric Reliability Cooperative (NERC) regions, reduced plant and transformer efficiency, reduced availability of cooling water for power plants, and increased energy costs. The water and wastewater sectors might experience the use of water being restricted by as much as 50-70 percent in many areas causing certain water-intensive businesses to cease operation to preserve public health and safety. Water supply reductions and more extensive use of alternative water sources having lower water quality can challenge existing treatment systems. Such conditions are currently occurring in the Western U.S. with counties in moderate to exceptional drought conditions. As a result of these conditions, the following interdependencies were identified in scenario one (Figure 2):

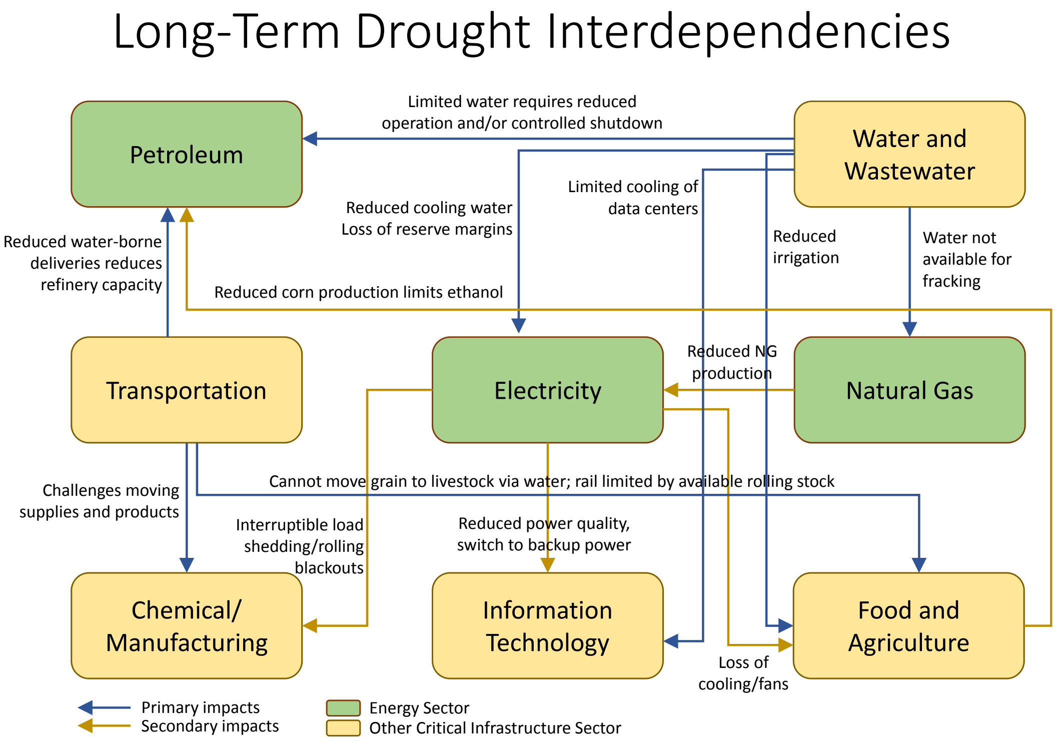

Figure 2: Long-Term Drought Interdependencies

Scenario Two: Cyber-Attack

The second scenario is a cyber-attack on the electric and natural gas systems. The attack damages the transmission system surge arresters and transient voltage surge suppressors and causes widespread damage. Due to the significant cascading damage, the restoration times to both the transmission and distribution systems are expected to be lengthy and available crews and spare parts for restoration are limited. The output of the natural gas pipeline is significantly reduced due to the power outages and parts of the pipeline system might stop operating due to low gas pressure. The water system is directly impacted by the loss of power and the extensive outage might lead to curtailments of some water systems' operations. If the water systems' back-up power generation fails, the system might be at risk of shutting down entirely. Partially treated wastewater might have to be released into rivers and lakes. Additionally, SCADA systems in the water system might be unable to communicate with the control rooms due to power loss impacts to the telecommunication system. Full restoration of the electricity system might take weeks with significant repercussions for the water system. As a result of these conditions, the following interdependencies were identified in scenario two (see Figure 3):

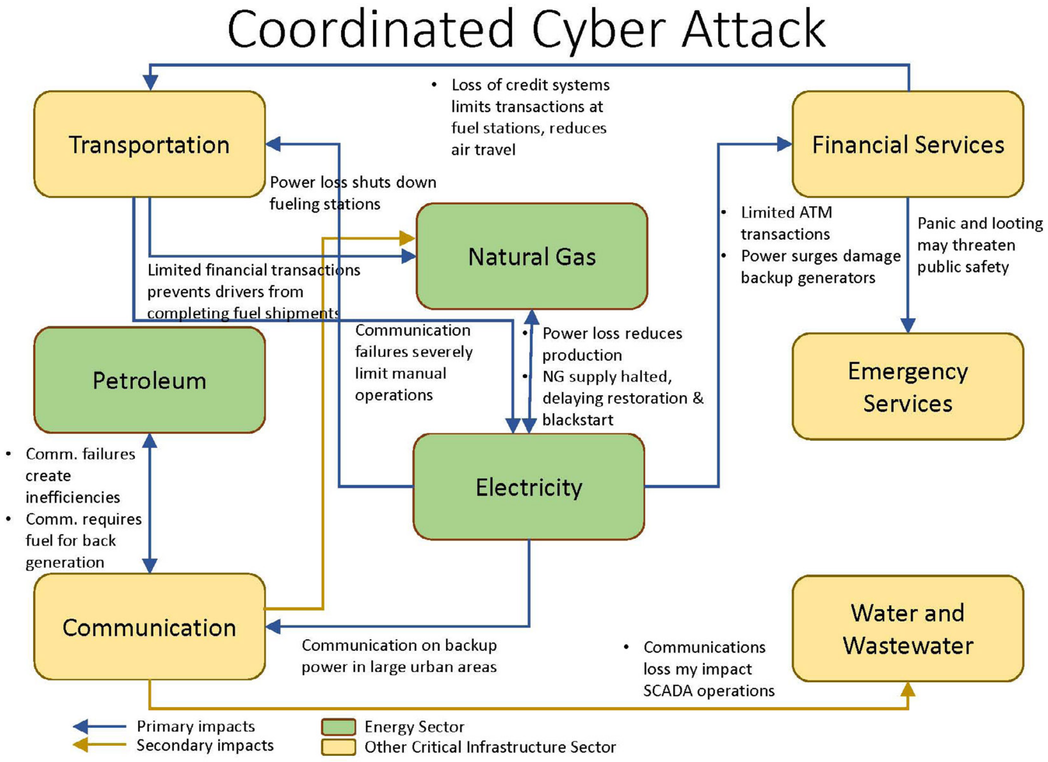

Figure 3: Coordinated Cyber Attack Interdependencies

Step 3: Consider Interdependencies in Planning Processes

Energy planning varies significantly across states. Not all states have energy planning processes, and some may be less extensive and smaller in scope. Others may not explicitly take interdependencies into consideration, and some may implicitly take considerations of risk, vulnerabilities, resiliency, and reliability into account. The following lists several types of state level planning processes in which interdependencies might be considered, and there may be more. Some state Public Utilities Commissions may have special proceedings outside the scope of Integrated Resources Planning in which analysis of interdependencies could lead to resiliency investments designed to reduce risks.

EXPANDING EXISTING STATE ENERGY RESILIENCE AND ENERGY SECURITY PLANS TO CONSIDER INTERDEPENDENCIES MORE FULLY

This section describes some of the state planning processes in which interdependencies could be considered. Planning is a complex process and assessing risks and analysis of interdependencies only adds to the complexity and scope of the planning which may lead to resistance from some stakeholders or make it more difficult for stakeholders to participate in the planning process. However, consideration of interdependencies is necessary, especially because the cost-benefit analyses of resiliency investments will shift if the avoided costs of power outages factor in the costs of impacts in other sectors, as well as the overall costs to the economy and society.

Comprehensive State Energy Plans

Many states have adopted, or are required to develop, comprehensive energy plans that are used to guide energy programs and policy. These plans may be updated periodically and revised to reflect changing conditions, circumstances, new policies, and new technologies.

These long-term energy plans can also help stage new energy efficiency and renewable energy programs funded by the U.S. State Energy Program (SEP). SEP is administered by DOE and provides resources directly to the states. SEP was authorized under the Energy Policy and Conservation Act, which included a requirement for states to submit a contingency plan for energy emergencies as a supplement to their energy conservation plans to the Secretary of Energy. Planning objectives may include assisting small businesses and manufacturers in reducing energy costs which, in turn, improves competitiveness and creates jobs; aiding farms and homeowners in developing homegrown energy solutions to lower energy costs; and supporting local governments in retrofitting schools, police stations, and other public facilities to reduce utility bills paid by taxpayers.[25] The preceding planning objectives do not necessarily explicitly consider the benefits of risk reductions that results from investments which contribute to resiliency. However, SEP-supported programs in many cases improve energy sector resiliency through grid modernization and diversification of energy resources, including cogeneration and microgrids to reduce risks of power outages. SEP-supported energy programs may also benefit the water sector by reducing energy use. Even improved home weatherization can contribute to resiliency by retaining building heat or cool air longer during power outages, allowing utilities to restore power before the consequences become severe.

State Energy Offices place great emphasis on comprehensive energy plans. This is evident in two surveys conducted by NASEO. According to the 2021 survey, nearly two-thirds of State Energy Offices, 61 percent, are currently updating their comprehensive energy plan or intend to do so within the next two years. This is essentially the same as the 2018 survey NASEO conducted (64 percent). The plans are a logical place to incorporate consideration of interdependencies.

EPA, DOE, and National Laboratories, and other federal entities are actively examining interdependencies between the electricity and water sectors. It is important to consider these studies and to incorporate them in state energy planning. NASEO also released a paper in January 2019 examining the energy-water nexus overall and potential policies and programs to improve energy performance of water systems.[26] This paper includes a list of resources that may be helpful in providing a greater understanding of and approaches to these complex questions.

Energy Security Planning

The importance of state energy security plans is reinforced by severe weather events impacting the energy sector, geopolitical events, and, more recently, cyber-attacks. The plans outline responses to energy emergencies and identify longer-term efforts to mitigate the risk of a future disruption. In 2010, DOE funded states to undertake a three-year planning effort to develop state energy security plans that encompass how states would respond to energy emergencies and mitigate the longer-term risk to all hazards. These plans are periodically tested by states in energy emergency exercises, both regionally and at a state level.

A key element of both emergency response planning and longer-term risk mitigation efforts is the need to consider all hazards in the planning process. There are a significant number of response capabilities that are common such as internal and external communications and public information needs; the ability to have well-defined organization roles and responsibilities clearly assigned; and having in-depth knowledge of energy infrastructures and their interdependencies. It is also important to look at a range of consequences - from those that many be of shorter duration and scope to those that could cause prolonged power outages such as a new Madrid or Cascadia subduction zone earthquake. Regional multi-state exercises such as the DOE sponsored Clear Path[27] series have postulated scenarios and estimated the consequences of those scenarios, along with their cascading interdependencies. These exercises provide After Action Reports, which are useful mechanisms for identifying opportunities to mitigate risk in the energy sector and identify additional interdependencies.

The *Infrastructure Investment and Jobs Act* passed in November 2021 includes provisions that strengthen the ability of states, in consultation with owners and operators of energy infrastructure, to secure a state's energy infrastructure from all physical and cybersecurity threats; to mitigate the risk of energy supply disruptions to the state; to enhance the response to, and recovery from, energy disruptions; and to ensure that the state has reliable, secure, and resilient energy infrastructure. The bill further outlines that a state energy plan should provide a risk assessment of energy infrastructure and **cross-sector interdependencies; provide a risk mitigation approach to enhance reliability and end-use resilience;** [*emphasis added*] and address multi-state and regional coordination, planning, and response.[28] The bill not only provides states with an opportunity to further consider interdependencies and risk assessment, but also includes relevant funding support.

Hazard Mitigation Plans

All 50 states, the District of Columbia, and five territories have a FEMA approved Hazard Mitigation Plan.[29] Additionally, local governments and tribal governments have also submitted their Hazard Mitigation Plans to FEMA. These plans can include funding for risk mitigation projects that meet the required criteria in the electric and water sectors. These plans aim to reduce potential losses from future disasters by identifying hazards, outlinining hazard mitigation actions, and establishing an implementation plan.[30] The hazard mitigation planning process includes the following 4 steps (see Figure 4):

Figure 4: Hazard Mitigation Planning Process[31]

FEMA's Building Resilient Infrastructure and Communities (BRIC) program requires subapplicants to have a FEMA-approved local or tribal hazard mitigation plan. BRIC supports states, local communities, tribes, and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards. It replaced the former Pre-Disaster Mitigation (PDM) program. BRIC projects must:

- Be cost-effective
- Reduce or eliminate risk and damage from future natural hazards
- Meet either of the two latest International Building Codes (i.e., 2015 or 2018)
- Align with the applicable hazard mitigation plan
- Meet all environmental and historic preservation (EHP) requirements

Integrated Resource Plans

Electric utilities have developed long term Integrated Resource Plans (IRP) at their own initiative or due to state statutes or Public Utility Commissions' regulatory requirements. This planning originated in the 1980s when there was an increased emphasis on options for balancing long-term electric supply and demand needs, in addition to capacity needs that may have necessitated new power plant construction. IRPs consider power plant retirements, the need for new conventional power plants, the use of renewable resources, how energy efficiency and load management can be used to reduce loads, and how to balance supply and demand on an hourly basis. IRPs also look at meeting longer-term power needs with new technologies such as microgrids, distributed generation, storage, grid modernization, optimization of distribution and transmission, etc. IRPs should consider how different portfolios of resource plans vary in terms of cost, environmental impacts such as CO_2 emissions, and job creation.

This planning should also take interdependencies into account, as failing to do so could result in new, unintended vulnerabilities. For example, the 2003 Northeast blackout revealed several interdependencies that resulted in new considerations for future planning. The IRP planning process has also focused on enhanced resiliency. In assessing the relative resiliency of various options, interdependencies should be given explicit consideration.

Integrated Resource Planning is oftentimes an activity encouraged or required by Public Utility Commissions. Certain State Energy Offices are engaged in this planning process based on programs that include energy efficiency, demand side management, and renewable resources. All are options that should be given consideration in integrated resource planning. As such, the expertise of an energy office may serve as a valuable input to this planning effort.

Water Utilities Planning

The America's Water Infrastructure Act requires community water systems serving populations greater than 3,300 to have an Emergency Response Plan that includes the unexpected loss of power. In addition, EPA has a Power Resilience: Guide for Water and Wastewater Utilities, which identifies longer term options for water utilities' consideration that will improve their overall resiliency to power outages. It also identifies potential funding sources for these improvements. This guidance addresses the need for backup generators and contingency plans to assure adequate fuel supplies to handle potentially extended outages. It also identifies distributed resources which include:

- Anaerobic digestion
- Photovoltaic Solar
- Battery storage
- Fuel cells
- Combined Heat and Power
- Microgrids

To incorporate information on how water utilities are considering these back-up generation options in their planning, initial discussions between state water agencies and State Energy Offices are critically important. Coordination should include a review of the states' regulatory requirements for addressing power outages. For example, New Jersey and Connecticut have specific requirements for backup generation to support water system operations. In New Jersey, auxiliary power is required for drinking water and wastewater facilities.[32] Other states might not require but encourage backup generation or a combination of generation and interconnects with multiple circuits. For planning purposes, it should not be assumed that water facilities have back-up power without first verifying.

For wastewater utilities, while EPA has issued the above-referenced resilience guide for water and wastewater utilities[33], it has been principally left to the states to determine requirements that wastewater facilities may need to maintain operations in the event of a power outage. Some states encourage operation capabilities in power outages and in some cases, there may be regulatory requirements for some level of backup generation for essential operations, multiple circuit connections, and/or elevated water supply to sustain pressure for a certain duration. Since there is such a great variation from state to state, coordination between state agencies that are responsible for wastewater systems and the energy sector are critical. This will allow states to develop a clear understanding of existing requirements and what enhancements could be developed in the future.

DEVELOP NEW WAYS TO CONSIDER INTERDEPENDENCY RISKS MORE FULLY

Quantify Interdependencies

Estimating the cost of power outages which can then be used in cost-benefit analyses for resilience investments remains a challenge. A study done by the Lawrence Berkeley National Laboratory (LBNL) explored this question.[34] Some of the case studies presented provide ways to begin approaching this problem. Cost-benefit analyses could be included in IRP planning, in proceedings to address cost recovery cases associated with a major power outage, or in investigative proceedings on causes and solutions to reduce the impacts of future outages. LBNL's Interruption Cost Estimate (ICE) Calculator is a tool that can be used to "estimate interruption costs and/or the benefits associated with reliability improvements in the United States ".[35] Currently, the ICE Calculator has not been used for long-duration, widespread power interruptions but LBNL is working on a 2.0 version, which would address long-term consequences and take economic considerations into account.

The key to a full analysis of costs and benefits is to consider including the economic and human costs of cascading interdependencies. This will often result in higher benefits to the investment. However, there are several challenges to conducting a full quantitative analysis that includes cascading interdependencies. First, there are no generally accepted quantifiable methods to analyze interdependencies and data at the state level is somewhat limited. An additional challenge is drawing the economic impact boundaries that result from cascading interdependencies.

The winter storms that affected Texas in February of 2021 serve as an example of additional costs that can occur when interdependencies are not fully considered. Power generating facilities had not been weatherized because it was seen as uneconomical by a utility-based analysis. Had this analysis taken into consideration the cost of the damage to water systems in Texas, along with the much larger geographic scope of the power disruptions that affected several other states, it would have yielded a significant positive cost-benefit ratio.

State Energy Offices would benefit from examining case studies that show how different states have worked to address this complex analysis and use it in their decision-making processes. However, as the study by LBNL pointed out, "there is little or no evidence that avoided societal impacts other than customer cost are being formally included in cost-benefit analyses or as a supplement to cost-effectiveness analysis."[36]

Studies that focus more specifically on the critical relationship between the electric sector and the water sector could focus on case studies that examine the economic impacts of historical events as a means of quantifying the impacts. These studies could include existing information and then explore the degree to which it might be extrapolated to similar future events as a way of coming up with avoided cost estimates. The challenge with this approach is that such long-term power outages can be caused by a variety of events that result in different interdependencies being manifested as outlined in the earlier scenario analysis diagrams.

It is important to consider that there is a limit to the extent that these costs are considered when quantifying economic impacts. Clearly primary and secondary impacts should be considered; however tertiary impacts (3rd order) might be limited to only those items that have greatest significance. In addition, it is important to distinguish between causality and concurrence in estimating the economic cost. Clearly a power outage, which results in an inoperable sump pump causing flooding in buildings, is a direct economic impact. Water pipes breaking in buildings where there is inadequate weatherization to protect against extreme cold, however, is a concurrent impact.

A more simplified approach would be to evaluate critical electrical and water infrastructure at a facilities level using a comparative measure to gauge their interdependencies. This would require a facility to identify how many critical inputs are required for them to operate and how many of their customers or other businesses depend on their operation. The higher the number, the more highly interdependent they are. This is similar to the system that Oregon included in its critical earthquake study, which monetizes the values of the inputs and outputs (see Figure 5).[37] After aggregation, an input-output (I-O) analysis was conducted to produce the input-output table. The inside 19 by 19 matrix of the table (labeled 1 through 19) shows amounts of sales and purchases between the 19 sectors. The columns represent the purchasing of inputs (payments) to create the respective sector's products or services. Hotter colors (red, orange) indicate higher dollar value. Red indicates $100 million or greater. It also provides a consistent foundation for comparing interdependencies across a variety of facilities. In a simplified version, the absolute value is not as important as the relative value. This approach requires careful attention to ensure that there are appropriate and consistent equivalencies in terms of how the critical inputs and outputs are identified.

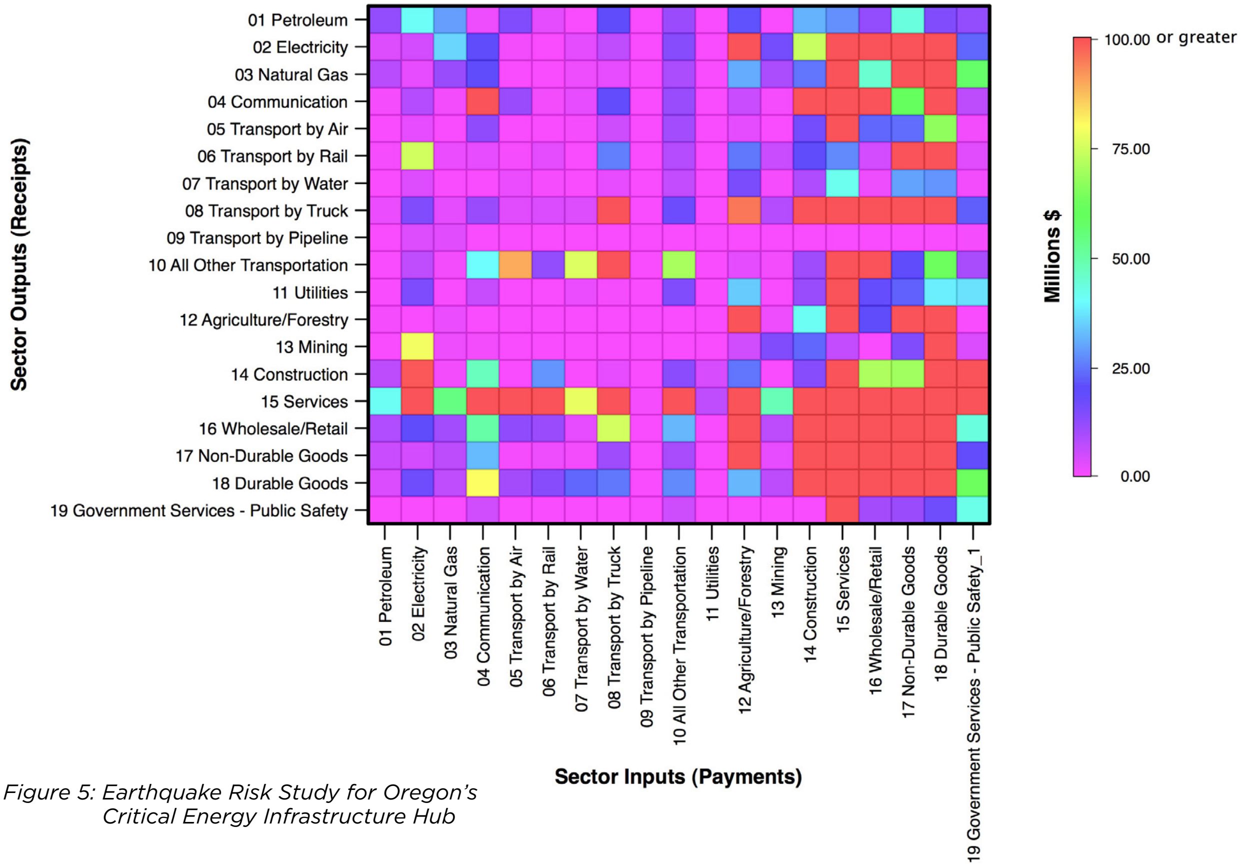

Figure 5: Earthquake Risk Study for Oregon's Critical Energy Infrastructure Hub

Overall Resilience Planning

More and more states are considering resilience to natural and manmade hazards holistically by developing resilience plans. These resilience plans are often a state-wide effort involving multiple state agencies and the plans tend to include risk assessments for a wide variety of sectors. North Carolina and Rhode Island are among several states that have developed resilience plans.

Rhode Island's resilience plan outlines how to leverage the energy security plan to "design and implement a comprehensive, targeted strategy addressing energy security vulnerabilities at the municipal or facility level. This strategy should address risks specific to discrete critical infrastructure assets, including hospitals, police and fire stations, water and sewage treatment plants, senior centers and nursing homes, shelters, correctional facilities, fueling stations, and grocery stores. Smart energy security investments at these locations and energy resilience solutions could alleviate the impacts of power outages and fuel supply disruptions in energy emergencies. Examples of such solutions are backup generation, fuel reserves, distributed generation, combined heat and power, energy storage, and microgrids."[38]

North Carolina is using a resilience modeling method to understand the cascading impacts of proposed grid infrastructure improvements by the electric utilities on other sectors and on community goals. Through a stakeholder process, the state is attempting to quantify indirect community benefits of suggested resilience improvements. A community goal might be to have reliable power for a wastewater treatment facility, but this might not be a priority of the utility and, therefore, not included in proposed grid improvements. As the North Carolina resilience plan notes "localized generation does not necessarily benefit all ratepayers on a normal basis, but it may be essential to meeting key community functions during and after major storms. The stakeholder process is intended to quantify these indirect community benefits. Legislative change may be needed for the utility commission to be able to evaluate such proposals, but a key outcome of the process is to expose such issues for further evaluation and discussion."[39]

In resilience planning, it is important to consider interdependencies in state energy and water planning processes. Argonne National Laboratory developed a State Energy Resilience Framework, which is designed to support state and local governments, in conjunction with energy utilities, to identify resilience concepts, challenges, and vulnerabilities so that they can implement cost-effective and proven resilience enhancement options. The framework comprises five steps that State and local governments can use to link broad resilience concepts to the implementation of actions tailored to their individual resilience needs and capabilities" [40] (See Figure 6).

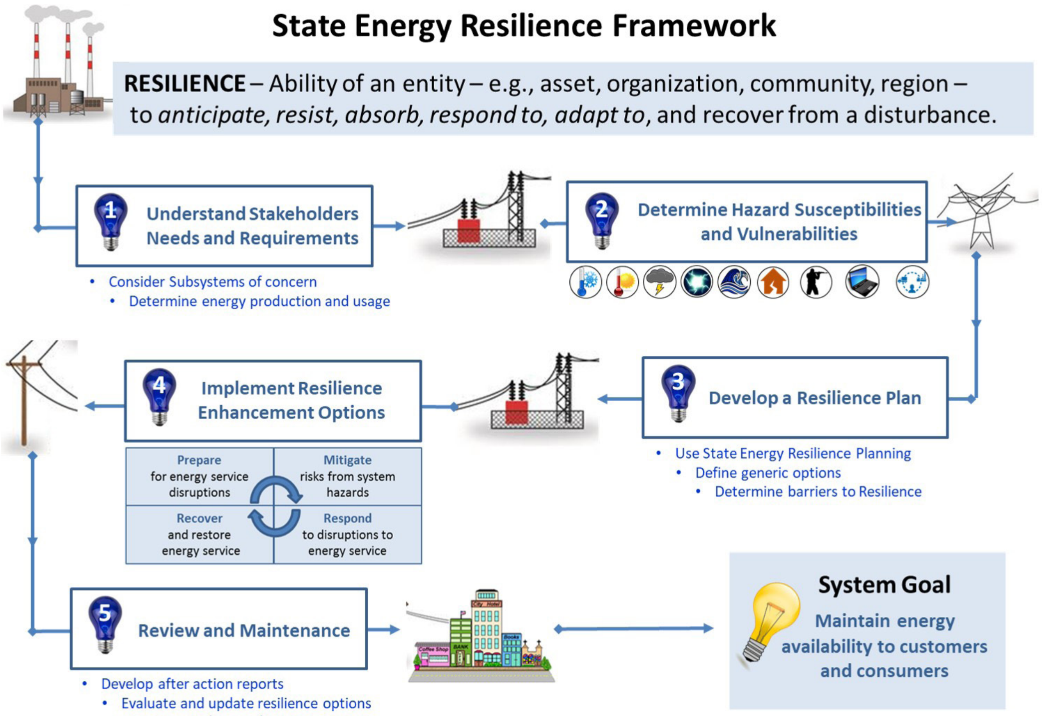

Figure 6: State Energy Resilience Framework

Considerations and Questions for State Energy Offices

Regardless of which planning tool is the most appropriate for each state, interdependencies between electricity and water sectors should be included. The following questions and considerations provide a starting point for states to further the discussion between the two sectors specifically but can also be used to discuss other critical sector interdependencies:

Critical Facilities

- Does your state define, and identify, critical infrastructure facilities?
  - If yes, are water and wastewater facilities included?
  - Does this include both treatment plants as well as critical pumping and lift stations?
  - Are these facilities prioritized in any way?

Energy Sources for Critical Facilities

- Are the water and wastewater facilities in your state required to have back-up power generation sources?
  - If yes, for how long?
  - What is the specific statue or regulation that provided for this?
  - If they are not, what is the plan to secure power during an extended power outage?
- What are the energy requirements for the back-up power generation sources?
  - If it is fuel dependent (natural gas or liquid fuel for example), where does the fuel come from?
  - For liquid fuels, is there on-site fuel storage?
  - Are the fuel supply contracts sufficient to meet your generation needs in a protracted outage or are there potential supply limitations?
- What kind of power and fuel contracts do the water/wastewater plants have in your state (i.e., firm, interruptible etc.)?
- Does your state have a program to phase out diesel generation in favor of renewable energy back-up generation sources?

State-Level Coordination

- Is there a standing working group established between the energy and water agencies in your state?
- If you hold energy emergency exercises, do they include interdependencies scenarios and if so, are these sectors included as participants in the exercises?
- Do your After Action Reports address the impacts of interdependencies with other sectors?
    - Do you do a hotwash after an emergency that includes all utilities (water, electricity, natural gas, telecommunication)?
- Given the various state level electricity and water planning activities identified in this report, do these planning activities include considerations of the economic and human consequences of interdependencies?
- How can you engage with local communities and ensure that consideration of the electricity and water interdependencies are included in hazard mitigation plans?

Arizona Utility Regulators Water Preparedness Task Force

In summer 2021, Arizona implemented a task force to hold stakeholder meetings on water drought conditions. The task force is designed to investigate the drought conditions in the state and provide more transparency between linkages of critical infrastructure, such as water and electricity. *(see https://www.azcc.gov/lmarquezpeterson/news/2021/07/19/arizona-utility-regulators-establish-water-preparedness-meeting-task-force-to-prepare-for-prolonged-drought-shortage-declaration-on-colorado-river)*

Evaluating Customer Impacts

- Do water utilities have data on the critical customers and vulnerable populations they serve? Are they identifying customers that have a critical reliance on water, such as hospitals, nursing homes, dialysis centers, 911/EMS facilities, national defense assets, etc.?
    - If yes, are water utilities sharing this information to their electricity providers to identify critical water facilities serving these customers that potentially have priority for electricity service restoration?

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