Introduction to

Energy Infrastructure Interdependencies

Local Government
Energy Assurance Planning

LEAP

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U.S. DEPARTMENT OF ENERGY

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Local Government Energy Assurance Planning (LEAP)

To find out more about local government energy assurance efforts, we encourage readers to visit www.energyassurance.us. This site, maintained by PTI, is designed to support all local governments, large, medium and small, across the nation that want to learn more about creating energy assurance plans for their communities. Once created, these plans will help ensure that local governments can provide life-saving services during an energy emergency.

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Introduction to Energy Infrastructure Interdependencies

1 Overview and Background

> *Critical infrastructure consists of systems and assets, whether physical or virtual, so vital that the incapacitation or destruction of such may have a debilitating impact on security, the economy, public health or safety, the environment, or any combination of these matters.*
>
> Source: Public Technology Institute (PTI). 2011. *Local Government Energy Assurance Guidelines, Version 2.0.*

The term infrastructure refers to the physical and organizational facilities essential to the function of some larger entity. For example, the infrastructure of a house includes its building envelope (i.e., walls, roof, and foundation), electrical wiring, gas piping, water distribution system, and communication lines. The infrastructure of a local community consists of many more elements, including electricity transmission lines and distribution systems, gas pipelines and storage facilities, water and sewer systems, communication lines, transportation systems, medical and emergency facilities, telephone switching stations, and cell towers. Each element of a community's infrastructure also has its own internal infrastructure. The water and sewer systems, for example, include electrically-driven pumps, water and sewer pipe systems, and communication lines. A disruption in any one asset or system—such as the electricity delivery system—could affect the infrastructure of many other critical systems and, in turn, could disrupt numerous essential services, including those that facilitate infrastructure repair and restoration.

The concept of infrastructure interdependency is based on connectivity between the various elements of an infrastructure. It means that a disruption in one element can affect the functioning of numerous systems that depend on that element, possibly causing a cycle of infrastructure disruption.

To minimize the negative impacts of any given emergency, it is essential for local governments to understand and identify energy sector interdependencies.

Thousands of electricity, oil, natural gas, nuclear, and renewable energy assets are interconnected by vast systems and networks. This energy network is a fundamental driver for personal activities, economic development, government, and essential services. Other critical infrastructures, such as transportation and communications systems, depend on a reliable supply of energy to maintain functionality. Interdependency stems from the fact that the Nation's energy assets, in turn, depend on other critical infrastructures (including transportation and communications systems) to deliver a reliable source of energy.[1]

When developing energy assurance plans (EAPs), local governments will want to identify energy interdependencies at the local, State, regional, and national levels and examine how they may affect local critical infrastructures. Many critical infrastructures are owned by private entities such as investor-owned utilities. Local governments can work with these privately-owned

[1] Public Technology Institute (PTI). *Local Government Energy Assurance Guidelines, Version 2.0.* 2011. p. 8. http://dl.dropbox.com/u/14265518/leap/PTI_Energy_Guidelines.correx.v2.pdf.

entities to ensure that emergency plans or continuity of operations (COOP) plans are in place to help lessen the impacts of an energy disruption. Local governments may also work with their energy service providers to help set priorities for restoring energy services to critical assets such as hospitals, emergency services, and others after an energy disruption.

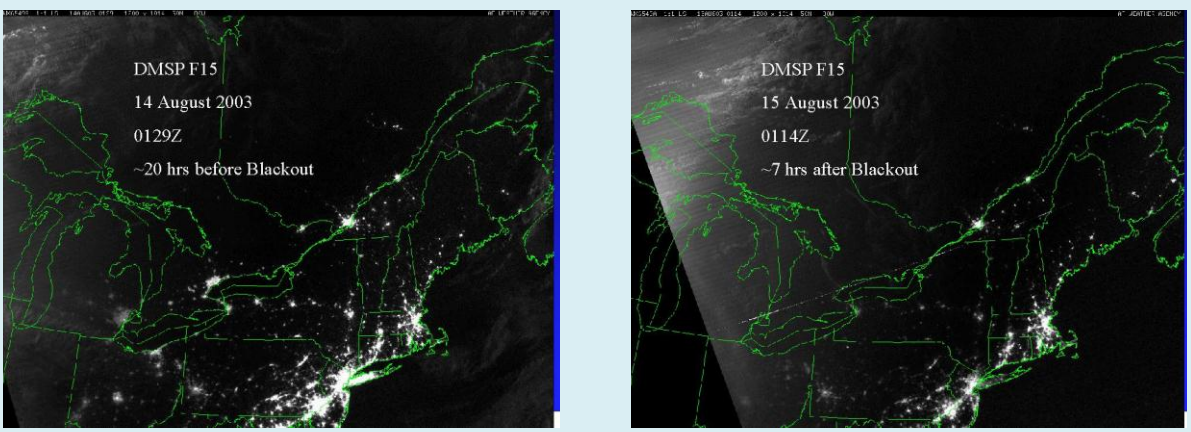
> *Continuity of operations plans generally outline specific actions local governments can take to mitigate an energy emergency.*
>
> Source: Public Technology Institute (PTI). 2011. Local Government Energy Assurance Guidelines, Version 2.0.

This document provides an introduction to infrastructure interdependency. Identifying energy infrastructure interdependencies, and understanding how they work, can help local governments mitigate the negative effects of energy emergencies.

Case Study: The 2003 Northeast Blackout

In August 2003, a major blackout started in northern Ohio, providing a clear example of how a small power disruption can cascade into a large-scale regional blackout. It began when a high-voltage power line sagged due to the heat of the electricity that was transmitted through it. The sagging line bumped into a tree, causing a fault and shutting down the power line. The power company's alarm system should have alerted controllers when this fault occurred; however, the system failed. While the power company tried to resolve the problem, three other power lines sagged into trees, causing additional outages and placing a larger electricity load on other power lines. The overloaded lines then shut down, disrupting power to eight Northeastern States and parts of Canada.[2] The outage lasted for up to two days in some locations, affecting numerous critical infrastructures and a vast number of essential services.

Before and After Photos of the 2003 Northeast Blackout



Source: http://www.noaanews.noaa.gov/nightlights/blackout081403-20hrsbefore.jpg; http://www.noaanews.noaa.gov/nightlights/blackout081503-7hrsafter.jpg.

2 Key Concepts for Local Governments

[2] Minkel, J.R. *The 2003 Northeast Blackout – 5 Years Later.* 2008. Scientific American Web site: http://www.scientificamerican.com/article.cfm?id=2003-blackout-five-years-later.

2.1 Protection of Critical Infrastructure and Key Assets

The concept of critical infrastructure protection was studied extensively in the 1990s by the President's Commission on Critical Infrastructure Protection.[3] The Commission's 1997 report notes that as critical elements of the national infrastructure—such as communications and energy systems—continue to become more complex and interdependent, there is an increasingly greater chance that a seemingly routine disturbance in one jurisdiction could cause cascading impacts in other jurisdictions. The Commission also noted that vulnerabilities could go unidentified until a major disturbance occurs. This warning became a lesson learned after the 2003 Northeast blackout (see Case Study).

The 2009 National Infrastructure Protection Plan (NIPP)[4] builds upon past efforts and outlines recommendations on how to protect and enhance the reliability of critical infrastructure during natural or man-made disasters. Energy is one of the 18 sectors for critical infrastructure[5] and key assets identified in the NIPP. That list of critical infrastructures includes:

- Agriculture and food
- Defense industrial base
- Energy
- Healthcare and public health
- National monuments and icons
- Banking and finance
- Drinking water and wastewater
- Chemical
- Commercial facilities
- Critical manufacturing
- Dams
- Emergency services
- Nuclear reactors, materials, and waste
- Information technology
- Communications
- Postal and shipping

[3] President's Commission on Infrastructure Protection. *Critical Foundations: Protecting America's Infrastructures.* 1997. http://www.fas.org/sgp/library/pccip.pdf.

[4] U.S. Department of Homeland Security. *National Infrastructure Protection Plan.* 2009. http://www.dhs.gov/files/programs/editorial_0827.shtm.

[5] Critical infrastructure includes those physical and cyber-based systems essential to the minimum operations of the economy and government. It includes, but is not limited to, telecommunications, energy, banking and finance, transportation, water systems and emergency services, both governmental and private. (Presidential Decision Directive-63 1998).

- Transportation systems
- Government facilities

In order to gain a workable understanding of interdependencies among these critical infrastructures, local governments will need to identify the relevant assets within their own jurisdictions. Note that not all 18 categories will apply to all local governments. Local governments should focus on identifying critical infrastructures applicable within their own jurisdictions by answering the following three key questions:

- What is the complete route of electricity from the generating plant to the major local end users?
- What is the major energy infrastructure of the locality, and in what single place is its description available? That is, if the energy sources in the locality include electricity, natural gas, oil, motor fuel, and aviation fuel, where can one find an overview of the critical elements of each energy source, e.g., transmission lines, pipelines, storage tanks?
- Who are the local energy suppliers and what are the types of energy supplied to local key assets?

Local governments may be able to coordinate with energy suppliers in the jurisdiction to identify the location of critical infrastructure assets, such as underground pipelines and communications and electricity cables. Local energy suppliers will likely have their own infrastructure identified and may be willing to share this information with their local governments.

In 2003, the U.S. Department of Homeland Security (DHS) was directed by Homeland Security Presidential Directive-7 to identify critical infrastructure at the national level and to develop a database containing that information.[6] Within DHS, the Infrastructure Information Collection Division (IICD) is the lead Federal agency in this effort. To help organize critical infrastructure information, the IICD will provide local governments with a complimentary copy of the Automated Critical Asset Management System. Resources and tools that local governments can use when identifying and cataloging critical infrastructure can be found on the DHS website (http://www.dhs.gov/xabout/structure/gc_1227556492382.shtm).

2.2 Types of Interdependencies

Interdependencies vary in complexity and scale. Some interdependencies have only local linkages. For instance, a loss of electricity in one part of the electric grid may affect the city's drinking water treatment plant. More complex and interdependent systems can have regional, national, and international linkages. For example, a disruption in telecommunications services could affect banking and financial systems locally, and then spiral into a global problem.

There are three types of infrastructure interdependency failures that local governments may want to consider when developing their EAPs, as shown in the table below.

[6] Homeland Security Presidential Directive-7. December 17, 2003. http://www.dhs.gov/xabout/laws/gc_1214597989952.shtm.

Table 1. Types of Infrastructure Interdependency Failure

Failure Type	Description
Cascading failure	A disruption in one infrastructure causes a disruption in a second infrastructure; for example, a loss of energy causes a wastewater treatment plan to shut down.
Escalating failure	A disruption in one infrastructure exacerbates an independent disruption of a second infrastructure; for example, the time it takes to restore banking services is prolonged because telecommunications lines and signals are not available.
Common-cause failure	A disruption of two or more infrastructures at the same time is the result of a common cause; for example, a tornado adversely impacts the availability of electric power, petroleum, clean water, and telecommunications simultaneously.

Source: James P. Peerenboom, Ronald E. Fisher, "Analyzing Cross-Sector Interdependencies,"40th Annual Hawaii International Conference on System Sciences (HICSS'07), 2007 http://www.computer.org/portal/web/csdl/doi?doc=doi/10.1109/HICSS.2007.78.

As noted in the case study above, the August 2003 blackout that began in northern Ohio is an example of a cascading failure. The blackout affected essential services such as banking and finance, emergency services, water, transportation, and communications systems. Many businesses were affected by the loss of electricity and the inability to complete financial transactions. Backup power supplies for cellular sites also failed or backup generators for the cellular sites ran out of fuel, resulting in a loss of cell phone service in many cities. As a result, telephone lines were overloaded by the large volume of calls. Similarly, Internet service and cable systems were down. The loss of wireless communications even affected emergency service departments in some cities. Airports, trains, and subways were shut down or service was delayed until backup power supplies were secured. Drinking water service was lost in some locations where water pumps lost power. The loss in water pressure in some cities also resulted in drinking water quality issues and resulted in advisories to boil water. The loss of electricity also resulted in sewage spills in some cities.[7] Because of this cascading effect, it is no exaggeration to say that a sagging power line in northern Ohio resulted in stopped subways under the streets of New York City shortly thereafter. This is perhaps the best example of the vulnerability caused by the interdependency of the Nation's electricity systems.

The recent earthquake and tsunami that struck Japan in March 2011 is an example of both a common-cause failure and a cascading failure. The earthquake and resulting tsunami (the common-cause event) destroyed businesses, homes, banking institutions, transportation and communication systems, and severely damaged three nuclear reactors. With this significant loss of electricity, cascading effects included requests to non-essential businesses in Japan to curtail electricity use to help conserve supplies. In addition, with transportation systems affected by the natural disaster and electricity loss, manufacturers in Japan were unable to produce or ship products, and halted or suspended production of other goods and services. For example, Toyota

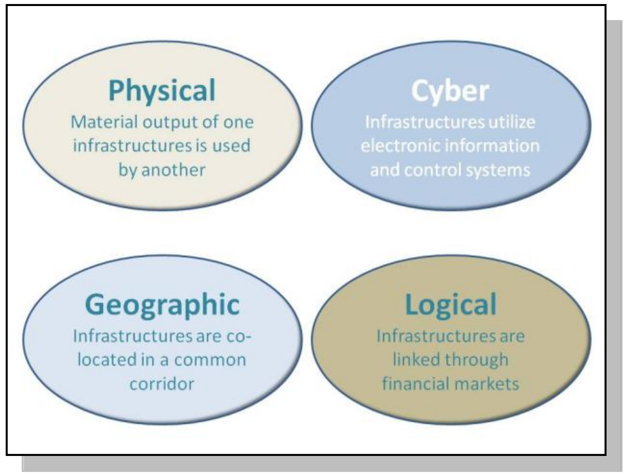
[7] GITA. *The Geospatial Dimensions of Critical Infrastructure and Emergency Response. White Paper Series. No. 1 – Infrastructure Interdependencies.* November 2008. www.gita.org/ciper/Infrastructure%20Interdependencies%20Final.pdf.

Motor Engineering and Manufacturing North America, Inc. altered shipment schedules to China, the United States and Canada until June 2011 at the earliest.[8]

2.3 Categories of Infrastructure Interdependency

Interdependencies between different infrastructure sectors and within the energy infrastructure itself can be discussed in terms of four categories: physical, cyber, geographic, and logical. These four categories assist EA planners in considering the different types of connections that exist within the energy infrastructure.

2.3.1 Physical Interdependency



Physical interdependency refers to situations in which the material output of one infrastructure is used in another infrastructure. One of the most basic examples of physical interdependency can be observed in the supply of water and that of electricity. Water supply infrastructure requires electricity to operate its pumps, while the infrastructure used for most electricity generation relies on water to make steam and cool the equipment.

The 2004 hurricane season, with one tropical storm and five hurricanes in central Florida, provides numerous real-world examples of physical interdependency. The storms caused severe flooding and power failures, damaged roads and bridges, interrupted communications, and interfered with other transportation infrastructures.[9] Without electricity and adequate backup generator capacity, the lift stations used to pump sewage and storm water failed. The lift station failures exacerbated flooding of roadways and storm drainage systems. The lack of electricity also led to decreased water pressure in some water treatment and distribution systems, and prevented shipment of chemicals used to treat drinking water and wastewater, threatening drinking water quality. Damage to the electricity distribution system after Hurricane Charley resulted in failure of railroad and highway control signals, which shut down railroad traffic to parts of central Florida. Because coal is transported to a number of power plants in central Florida by railway, the ability of coal plants to produce electricity was also affected.[10]

[8] CNN Wire Staff. *Toyota making drastic production cuts after Japan quake, tsunami.* April 20, 2011. http://www.cnn.com/2011/US/04/20/us.japan.toyota/index.html.

[9] American Lifelines Alliance. *Power Systems, Water, Transportation, and Communications Lifeline Interdependencies.* Draft. 2006. http://www.cimap.vt.edu/2DOC/ALA%20Lifeline%20Report%20Final%20Draft%20030606.pdf.

[10] American Lifelines Alliance. *Power Systems, Water, Transportation, and Communications Lifeline Interdependencies.* Draft. 2006. http://www.cimap.vt.edu/2DOC/ALA%20Lifeline%20Report%20Final%20Draft%20030606.pdf.

2.3.2 Cyber Interdependency

Cyber interdependency occurs when different infrastructures utilize electronic information and control systems. An increasing number of infrastructures are relying on electronic control, monitoring, and computer systems, including supervisory control and data acquisition (SCADA) systems. SCADA systems are often used in the electric industry to monitor grid conditions, and often rely on Internet-based systems to transfer real-time information back to a central location. This increased reliance on electronic information and control systems increases vulnerability to a loss of electric power, illustrating the need to ensure adequate backup power.

During the 2004 hurricane season in central Florida, reliance on electricity, coupled with inadequate backup power supplies (either generators or batteries), resulted in a loss of cell phone and other telephone systems. BellSouth's central office was closed for almost 24 hours because the pumping system that supplied cooling water shut down once electric power was lost.[11]

2.3.3 Geographic Interdependency

Geographic interdependency occurs when elements of infrastructures are co-located in a common corridor. For example, electric power lines and telecommunications cables that are located in the same area can be affected at the same time by a natural or man-made disaster.[12]

Galveston crane barge accident.
Source: http://galvestondailynews.com/story/186502.

In October 2010 in Galveston, Texas, a wind storm caused a crane on a barge to fall into power lines. Two substations were immediately affected by the accident. The electric service provider was able to switch electricity over to an unaffected transmission line restoring service to 16,000 homes and businesses within a few hours. However, the Intracoastal Waterway was closed for about six hours due to a safety boundary for vessels set up by the Coast Guard.[13]

2.3.4 Logical Interdependency

Some infrastructures are linked through financial markets. For example, when the price of transportation fuel is low, more people may decide to drive to work rather than carpool or use public transportation systems. This shift in fuel prices increases traffic volume on local highways, i.e., the transportation infrastructure. Conversely, when the price of fuel rises, more

[11] American Lifelines Alliance. *Power Systems, Water, Transportation, and Communications Lifeline Interdependencies.* Draft. 2006. http://www.cimap.vt.edu/2DOC/ALA%20Lifeline%20Report%20Final%20Draft%20030606.pdf.
[12] GITA. *The Geospatial Dimensions of Critical Infrastructure and Emergency Response. White Paper Series. No. 1 – Infrastructure Interdependencies.* November 2008. www.gita.org/ciper/Infrastructure%20Interdependencies%20Final.pdf.
[13] Paschenko, Chris. *Wind-driven crane barge cuts power to 16,000.* The Daily News, October 29, 2010. http://galvestondailynews.com/story/186502.

people may decide to carpool or use public transportation, decreasing the traffic on local highways.[14]

The U.S. Congressional Budget Office (CBO) conducted a study entitled *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets in 2008*.[15] The study examined highway speeds and frequency of trips on a few California highways as well as the sale of vehicles in the U.S. from 2003 to 2006, when the price of gasoline began to increase substantially. The study noted a 0.7 percent decrease in the number of trips for every $0.50 increase in the price of gasoline. The use of public transportation increased by 0.7 percent during this same time period. In addition, for every $0.50 increase in gasoline prices, motorists decreased highway speeds by about three quarters of a mile per hour.[16] The sale of light trucks across the United States decreased in 2004. The price of used fuel-efficient vehicles also increased as the price of less-efficient vehicles decreased from 2003 to 2006.

3 Potential Effects of Energy Disruptions on Essential Services

Table 2 shows how different types of energy disruptions (electricity or oil/natural gas) could affect certain interdependent essential services. These interdependencies are explained in more detail following this table.

[14] Gerard Ibarra, Jerrell Stracener, Stephen Szygenda, P.E. *Transportation in the Critical Infrastructure: A Holistic Approach Using Systems Engineering Methodologies for Assessing Risk and Cost Impacts Due to Highway Disconnects.* Systems Research Forum. Volume: 1, Issue: 1(2006). pp. 55-71. http://www.worldscinet.com/srf/01/0101/free-access/S179396660600014X.pdf.

[15] Congress of the United States. Congressional Budget Office. *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets.* January 2008. http://www.cbo.gov/ftpdocs/88xx/doc8893/01-14-GasolinePrices.pdf.

[16] Congress of the United States. Congressional Budget Office. Effects of Gasoline Prices on Driving Behavior and Vehicle Markets. January 2008. http://www.cbo.gov/ftpdocs/88xx/doc8893/01-14-GasolinePrices.pdf. pg. x.

Table 2. Interdependencies between the Energy Sector and Essential Services

Essential Services	Potential Effects by Energy Type	
	Electric Power Systems	**Natural Gas/Oil**
Banking and Finance	Financial transactions; heating, ventilation and air conditioning (HVAC) systems	Fuel for heat, generators, and facilities
Telecommunications (Landline, Cellular, and Cable)	Switches and communication facilities: distribution, supervisory control and data acquisition (SCADA) systems, customer service & repair crew communication	Fuel for heat, generators, and facilities
Transportation	Electricity-powered public transportation; signal and control system; transport of fuel and shipping of goods and materials	Fuel and lubricants for vehicles and facilities: transport of fuel and shipping of goods and materials
Water Supply	Control systems, lift stations, and facilities: transportation of water (pumps); cooling and emission controls; water transport for emergency response	Fuel for treatment, heat, pumps, lift stations, and facilities; water transport for emergency response
Government Systems	Facility HVAC systems; lighting; telecommunications; battery charging (e.g., 800 MHz radios); emergency response and protective services such as EMS, police, fire	Gas-fired HVAC systems; fuel/water pumping/processing etc.
Emergency Response and Protective Services	Limitation of base-to-field communications; recharging of office and field equipment; re-routing of impacted individuals/animals to facility with electrical service	Electrical outages for gas-fired power generation with similar impacts as under electric power systems
Sewage Systems	Curtailment of sewage pumping and treatment for stationary, local/regional scale systems and temporary, site-based pump and treat systems	Curtailment of sewage pumping and treatment for stationary, local/regional scale systems and temporary, site-based pump and treat systems if electrical systems are gas/oil fired

Source: Adapted with permission from the Geospatial Information & Technology Association (GITA). www.gita.org/ciper/Infrastructure%20Interdependencies%20Final.pdf.

The banking and finance industries rely on a reliable source of electricity, natural gas, and heating oil to maintain daily operations. Computer systems, phone lines, and Internet connections used to conduct financial transactions depend on a reliable source of electricity to function, as does equipment used to power networks and servers where customer information is stored. During an electricity outage (and without a backup power supply), most banking and financial systems become compromised and will not be able to function.

The availability of safe drinking water could be limited during an energy disruption or emergency. Electricity, natural gas, or oil are used to pump water to treatment plants, run water treatment and monitoring equipment, and pump water through the distribution system to customers. Water is also used for cooling and emissions control, and for emergency services such as fighting fires. Proactive measures to avoid disruptions in these services can help mitigate the impacts of an energy emergency.

4 Summary and Conclusions

The infrastructure of a local community includes numerous energy-dependent elements. Many of these elements have an internal infrastructure, parts of which are also energy-dependent. Local governments must identify the interdependencies between infrastructure elements and understand how these interdependencies will impact the jurisdiction during an energy disruption or emergency.

Once these interdependencies are understood, local governments can plan appropriate response actions to help lessen the impact of energy disruptions and emergencies. Appropriate plans might include ensuring that critical services such as emergency response, water supplies and wastewater treatment have a ready and adequate source of backup power in case of an energy emergency.

Planning activities might also include working with energy providers to prioritize power restoration for these facilities. In addition, local governments may work with local transportation fuel suppliers to secure additional fuel supplies in advance for critical services during an energy emergency. These plans can then be incorporated into local government EAPs and COOPs.

5 Sources

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