HSx: AGING & FAILING INFRASTRUCTURE

June 2017

CONTEXT

- U.S. infrastructure systems are at risk from failure due to a variety of trends converging, including: age, overuse, material and design characteristics, insufficient inspection and maintenance, and other factors.
  - Changing weather patterns and climate conditions beyond those planned for when the infrastructure was designed can further affect the vulnerability of assets.
  - Population shifts can result in higher use rates than originally anticipated.
  - Increasing complexity of operational systems for critical infrastructure introduces new failure or disruption modes from cyber systems.
- In their 2017 Infrastructure Report Card, the American Society of Civil Engineers rates U.S. infrastructure as a D+ using a methodology that assesses factors such as capacity, condition, funding, future needs, and operation and maintenance.
- Aging and failing infrastructure threatens to have wide-ranging economic and national security impacts.

INFRASTRUCTURE FAILURE

- Failing infrastructure can range from over-capacitation resulting in an inefficient system, to short term disruption(s) in order to implement frequent repairs, to catastrophic failures that result in loss of life and/or damage to property.
  - Over time, the demands on infrastructure may increase due to changes in the overall system. If the population dependent on an infrastructure increases or lifestyle or business practices change in a way that increases demand on the infrastructure this could lead to chronic over-capacitation. Examples of this could include rolling brownouts in the electric power sector or regular delays due to traffic on a transportation system.
  - Lack of investment in upgrades to and maintenance of critical infrastructure can lead to episodic disruptions due to make repairs. Examples include weekend closures of mass transit systems to make overdue repairs, water main breaks, and blackouts due to vegetation breaking power lines.
  - Occasionally infrastructure failures are catastrophic, causing loss of life, damage to property, and necessitate replacement of the failed asset. Examples include bridge collapses and dam and levee failures.

MECHANISMS THAT INDUCE FAILURE

- Material Fatigue: Constant loading and unloading can cause material fatigue. Examples include but are not limited to load carried by bridges, increases and decreases in electrical load carried by power lines, and frequent cycling of the gates of a river lock.
- Corrosion: The chemical reaction between the material that makes up the infrastructure asset (e.g., concrete, steel, iron) and elements of the environment. Proper maintenance such as cleaning and painting/coating can slow the process, but not stop it.
- Erosion: Constant surface processes in which wind and precipitation remove or dissolve material and transport it to another location. Erosion can impact the physical structure of the infrastructure or the land on which it sits.
- Extreme Weather & Natural Disasters: Aging and failing infrastructure is more vulnerable to extreme weather and natural disasters due to the effects of material fatigue, corrosion, and erosion.
- System Stress: Changes in usage patterns can increase the stress on a system as more is asked of it than was anticipated at the time it was designed and constructed.

INFRASTRUCTURE FAILURE: A REPORT CARD

Infrastructure report card

CNBC

SOURCE: ASCE

Category	2001	2005	2009	2013	2017	
Overall GPA	D+	D	D	D+	D+	NC
Aviation	D	D+	D	D	D	NC
Bridges	C	C	C	C+	C+	NC
Dams	D	D+	D	D	C+	↑
Drinking Water	D	D-	D	D	D	NC
Energy	D+	D	D+	D+	C+	↑
Hazardous Waste	D+	D	D	D	D+	↑
Inland Waterways	D+	D	D-	D	D-	↓
Levees	NA	NA	D-	D	D	NC
Ports	NA	NA	NA	C	C+	↑
Public Parks/ Recreation	NA	C-	C-	C	D+	↓
Rail	NA	C	C	C+	B	↑
Roads	D+	D	D	D	D	NC
Schools	D	D	D	D	D+	↑
Solid Waste	C+	C+	C+	B	C+	↓
Transit	C	D+	D	D	D-	↓
Wastewater	D	D-	D	D	D+	↑

- The overall Infrastructure GPA assessed by the American Society of Civil Engineers (ASCE) came to a D+.
- Some minor changes have been seen over the last few years; however, the ASCE estimates that the total cost to improve has increased from $1.3T in 2001 to $4.59T in 2017.

IMPACTS OF INFRASTRUCTURE FAILURE

- Direct impacts of infrastructure failure are those that are the immediate result of the event, incidence or occurrence. Direct impacts may include any of the following: injuries, fatalities, on-site business interruption, immediate remediation costs, and damage to property and the environment.
- Indirect impacts of infrastructure failure are those that result from the direct impacts including cascading failures and lingering impacts. Indirect impacts may include any of the following: New regulatory requirements, reduction in property values, and depressed economic activities.
- Specific impacts depend on the sector affected.
  - Bridge failures can impact local and regional traffic patterns, delivery of goods, and access to homes and businesses.
  - Dam failures can result in extensive flooding, loss of power generation capacity.
  - Continued use of aging lead water delivery components can result in lead leaching into the potable water supply.

DEPENDENCIES AND INTERDEPENDENCIES

- The increasing complexity of U.S. infrastructure and interdependence among assets and systems means that individual failures can have wide-ranging consequences.
  - Impacts of infrastructure failure can extend beyond just the asset or system, to other infrastructure sectors, and can affect security and resilience nationally.
  - Sectors with a large interdependence footprint can cause greater impacts in the event of a failure (e.g. energy/electricity, water/wastewater, transportation, etc.).
  - For example, a failure in the electric grid may cause shutdowns in the local water system, traffic signals, and communications infrastructure, among others.

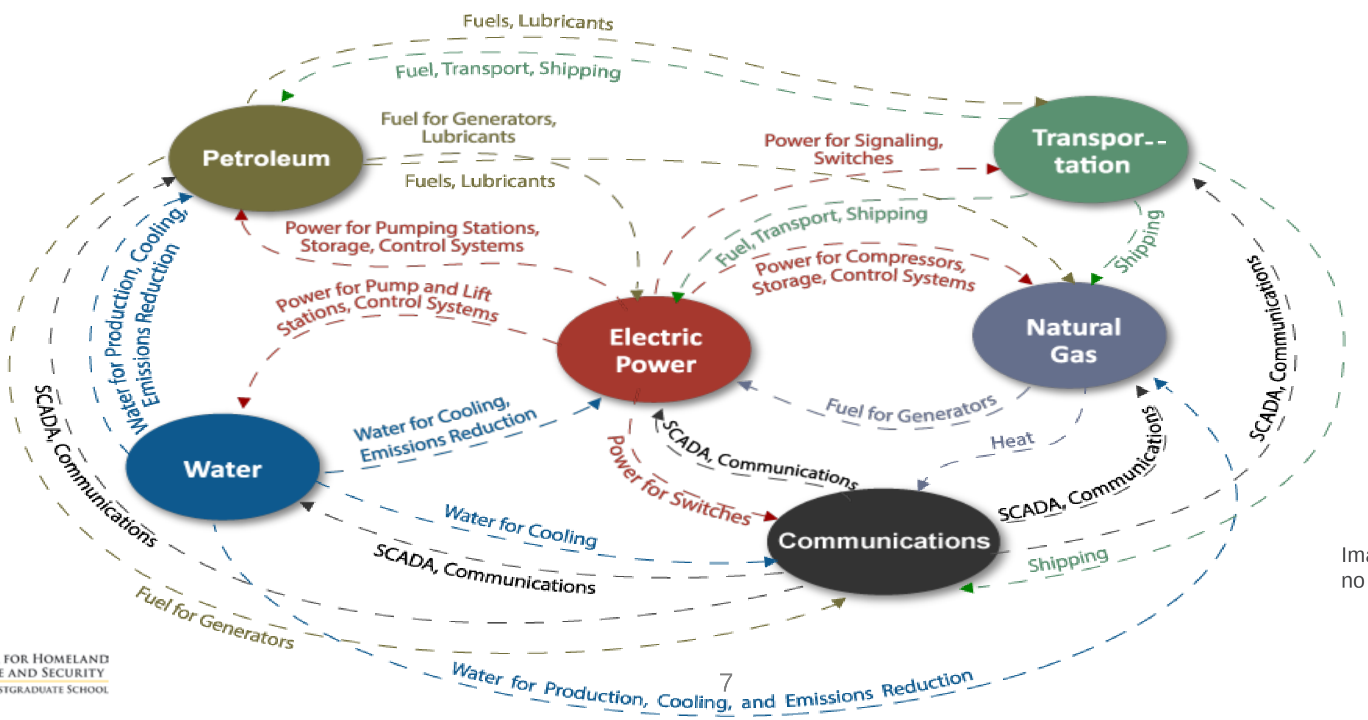


Image source: Argonne analysis, no date.

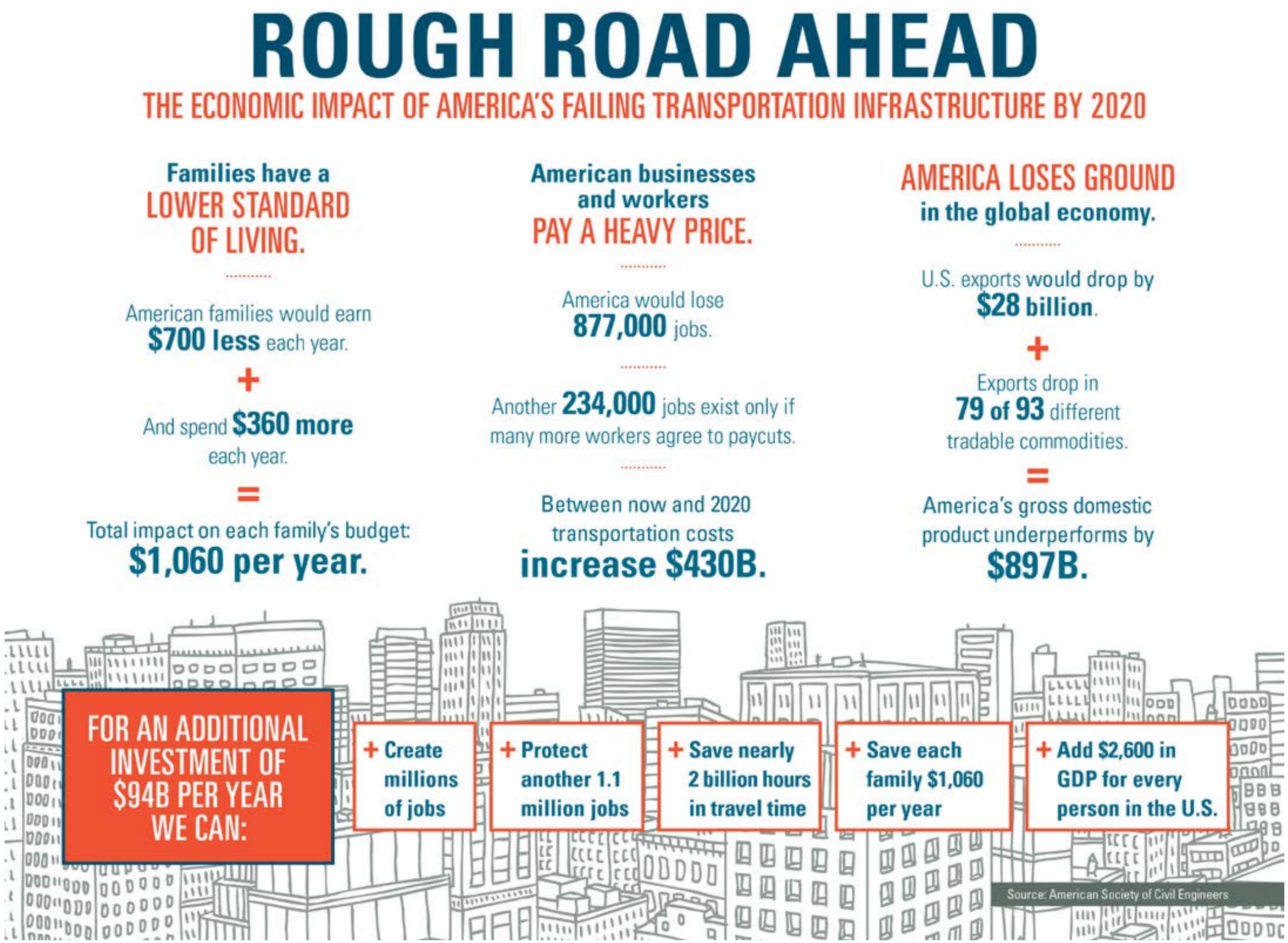
IMPACTS OF INFRASTRUCTURE FAILURE: ENERGY

- The Energy Sector includes electric, petroleum, and natural gas infrastructure. Hydroelectric facilities and commercial nuclear power facilities are additional pieces of the national energy infrastructure system.
- Infrastructure failure in the Energy sector has the potential to have wide-ranging impacts locally, regionally, and nationally.
  - Portions of the current electric grid are over 100 years old, although much of the infrastructure was built in the mid-twentieth century with an intended life span of 50 years.
  - As demand has steadily increased, oil and gas pipelines continue to experience system stress to meet needs for petroleum and natural gas. When pipeline infrastructure is at capacity and unable to meet demand, crude oil is often transported by rail, which can stress the rail network and pose safety concerns. Derailments of rail cars carrying crude can result in explosions that cause extensive damage and can require local evacuations.
  - Failures in oil and gas pipelines which result in leaks pose environmental and public health risks when water supplies or crop land are contaminated.
  - Although not an instance of infrastructure failure due to age or overuse, the 2003 Northeast Regional Blackout resulted in 61,800 megawatts of customer load lost, and affected 50 million individuals. Seven major petroleum refineries were shut down, the city of Cleveland had no potable water, police had to direct traffic in cities affected, air traffic ceased at major airports, gasoline pumps were inoperable, and many had difficulty placing cell phone calls due to system overload.

IMPACTS OF INFRASTRUCTURE FAILURE: TRANSPORTATION

- The American Society of Civil Engineers assesses that 9.1% of bridges in the United States are structurally deficient.
- Roadways and surface transportation that are overly crowded or in disrepair result in an estimated 6.9 billion hours delayed in traffic per year.
  - Increasing volume results not only in congestion, but also more wear and tear on roadways, which can lead to unsafe driving conditions.
  - Delays can also affect delivery of goods and services, having cascading impacts to industrial and food/agriculture supply chains.
- Transit systems in the United States have experienced increased ridership in recent years, while underfunding is an issue in many areas. This, coupled with aging systems, increases potential for failures with cascading local impacts.
  - For example, the Washington Metropolitan Area Transit Administration, which operates the Washington, D.C. Metro system (the second busiest transit system in the U.S. in terms of ridership), is 40 years old, has experienced a number of significant failures in recent years, and is facing the need to conduct extensive repairs, while also experiencing funding shortages.

ECONOMIC IMPLICATIONS: TRANSPORTATION CASE STUDY



Source: *ASCE Surface Transportation Report, 2011*

CASE STUDY: WASHINGTON METROPOLITAN AREA TRANSPORTATION AUTHORITY (WMATA)

- The “Metro” as it is known opened in 1976 as the model of a modern public transit system for a growing urban area. The Metro serves Washington, DC and surrounding suburbs in Virginia and Maryland. It is the second busiest mass transit system in the United States with more than 630,000 average weekday boardings in 2016. However, in recent years beginning in 2013 ridership has been declining due to chronic delays lengthening commutes and significant safety incidents resulting in injuries and loss of life attributable to insufficient maintenance.
- WMATA lacks a consistent funding source due in part to its multijurisdictional footprint.
- Decline in ridership reduces revenue worsening the fiscal stress on the system.
- System design consists of two tracks throughout making maintenance and repairs challenging without causing significant delay or complete shutdown.
- Delays in 2014-2015 amounted to 1.2 million person-hours of lost time, the equivalent of 586 FTE.

WMATA Incidents Attributable to Maintenance

Date	Incident Type	Injuries	Fatalities
29-Jul-16	Derailment	3	0
12-Jan-15	Electrical Fire	91	1
22-Jun-09	Collision	52	9

Data source: National Transportation Safety Board (NTSB)

CASE STUDY: OHIO RIVER LOCK AND DAM NO. 52 AND NO. 53

- Lock and Dam structures 52 and 53 on the Ohio River between Illinois and Kentucky are the busiest on the U.S. inland navigation system. In 2015 each structure accounted for more than 70 million tons of freight. The dams were built in 1929 and are well past their design life. A replacement dam has been under construction for more than 25 years.
- It can take more than five days to travel 100 miles under normal conditions, and over a week if there is a delay.
- Army Corps of Engineers estimates that delays caused by the locks cost the country $640 million/year.
- Cost of delays to tow boat industry 2013-2015: $46.5 million.

Dependent industries include:

- Agriculture
- Manufacturing
- Energy

Even the local water supply for nearby Paducah, KY can be impacted. If the pool is lowered for repairs and repairs last more than 96 hours, then the city would need to temporarily find a new source for drinking water.

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IMPACTS OF INFRASTRUCTURE FAILURE: WATER

- Drinking water infrastructure in the U.S. is nearing the end of its intended lifespan, with much of the infrastructure dating to the early to mid-twentieth century. The intended lifespan was only 75-100 years.
  - Water main breaks can leave homes, offices, and factories without treated potable water.
  - Leaking pipes and main breaks can result in wasted water, which has been estimated at 6 billion gallons of non-revenue daily.
  - Aging water delivery systems can leach contaminants such as lead into the water supply.
    - Elevated blood lead levels among residents of Flint, Michigan, a result of contaminated drinking water caused by corroded pipes, has created a public health emergency in the city.

CASE STUDY: AGING INFRASTRUCTURE AND THE FLINT WATER CRISIS

- In 2014, the City of Flint, Michigan water system changed its water source from purchased treated water from the Detroit Water System to treating water from the Flint River in a local treatment plant. The change in water chemistry led to lead from old water pipes leaching into the water delivered to customers. Water in the city contained lead levels well beyond the legal limit.
- Population of the city has been on the decline for decades reducing revenues into the water system.
- The size of the Flint, MI water system exceeds demand on the system. Design capacity is for a population of 200,000 while current population is less than 100,000.
- Financial stress caused by growing gap between cost of water and operations and water system revenues led to making the change in water source.

Direct Costs	USD (millions)
Response personnel	$ 3.6
Bottled water, logistics services, etc	$ 19.0
Water utility refunds	$ 29.0
Indirect Costs	
Water treatment plant upgrades	$ 108.0
Pipe replacement	$ 55.0
Future issues	$ 50.0
Social Cost	
Future health problems of exposed children	$ 395.0
Total Cost	$ 659.6

Data Source: Detroit Free Press

POLICY IMPLICATIONS

- Addressing the risks of infrastructure failure through policy is a complex issue.
- Ownership, operations, and funding mechanisms of infrastructure systems vary across sectors and regions.
  – In 2012 82 percent of non-defense infrastructure spending was accountable to the private sector.
  – Some sectors like roads and bridges are almost entirely owned and operated by the public sector
  – Electric power generation is a mix of public ownership and private sector
  – The water sector, both drinking water and wastewater is largely owned and operated by the public
  – Energy systems outside of electricity (petroleum, natural gas) is entirely owned and operated by the private sector
- The necessity of critical infrastructure systems and the mix of ownership structures means coordination between the public and private sectors is important.
- Strong planning and risk analysis, coupled with dedicated and consistent long-term funding mechanisms will be necessary to address many of the most pressing infrastructure needs.

POLICY IMPLICATIONS (CONT'D)

- Because necessary infrastructure upgrades can require significant investment beyond the capacity of localities or individual owners and operators, innovative funding mechanisms and legislative solutions may be necessary. Examples include bond programs, infrastructure banks, public-private partnerships (P3s), and increased use of usage fees.
  - Bond programs—in which state or local governments incur debt, subsidized by the Federal government—are the most common way in which infrastructure projects have historically been funded. Bonds are also issued for infrastructure projects within Tax Increment Financing (TIF) districts.
  - State Infrastructure Banks have been established in 39 states, which hold Federal and state funds and administer loans to finance various infrastructure projects within the state.
  - P3s have become more common in recent years as a way for state and local governments to address funding gaps. Successful recent examples include the expansion of I-595 in Florida, an expansion of the Seagirt Marine Terminal in the Port of Baltimore, and the construction of a courthouse in Long Beach, California.

POLICY IMPLICATIONS (CONT'D)

- Usage fees are a charge individual users of the infrastructure, commonly through specific taxes or tolls.
  - The federal motor fuel tax (part of the Highway Trust Fund used for major roadway improvements) does not automatically adjust for inflation, and this, coupled with increasingly efficient vehicles consuming less fuel results in a shortfall for highway funding.
  - Tolls, including variable-rate tolls, are another common type of usage fee which aims to fill this gap. Drawbacks include the costs associated with administration of toll collection, as well as the potential for disproportionate impact on low-income users.
  - Taxes on vehicle miles traveled (VMT) have been proposed in some states, but has only been piloted in limited instances. In this model, VMT taxes would be administered with use of a GPS-enabled tracker on the vehicle.

RESOURCES

- The following resources provide further information on this topic:
  - 2017 Infrastructure Report Card: Published by the American Society of Civil Engineers, this report, issued every four years, assesses the current condition of infrastructure across the country. Additional reports include sector-specific or region-specific analysis, as well as economic impacts. http://www.infrastructurereportcard.org/, Web, 10Mar 2107
  - Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future: Report by the American Society of Civil Engineers, pdf https://www.infrastructurereportcard.org/wp-content/uploads/2016/05/ASCE-Failure-to-Act-2016-FINAL.pdf, Web, 10 March 2017.
  - 40 Proposed U.S. Transportation and Water Infrastructure Projects of Major Economic Significance: Prepared by the Department of the Treasury as part of the Build America Investment Initiative, this report discusses the economic impact of infrastructure investments. https://www.treasury.gov/connect/blog/Documents/final-infrastructure-report.pdf, Web, 10 March 2017.
  - 2014 Quadrennial Homeland Security Review: Interdependent and aging critical infrastructure systems and networks were identified in the 2014 QHSR as key driver in the strategic homeland security environment, https://www.hsdl.org/?abstract&did=755060, Web, 10 March 2017.
  - Quadrennial Energy Review: Transforming the Nation's Electricity System: Published as the second installment of the U.S. Department of Energy, Office of Energy Policy and Systems Analysis Quadrennial Energy Review, https://www.energy.gov/epsa/quadrennial-energy-review-second-installment, Web, 10 March 2017.
  - National Risk Estimate: Aging and Failing Critical Infrastructure Systems. U.S. Department of Homeland Security, Office of Cyber and Infrastructure Analysis.

- Additional research materials and information sources regarding this topic can be found in the associated *Literary & Scholastic Resource List*.

Literary and Scholastic Resources – Aging and Failing Infrastructure

Date of information: 10 March 2017

Overview: While not exhaustive, the following resources provide a roadmap to understanding trends that lead to infrastructure failure, and potential impacts to the nation's critical infrastructure systems. These resources provide a baseline understanding of key issues related to the complex problem of aging and failing infrastructure systems, and may be updated as new data becomes available.

Module Resource Lists to Cross-Reference: Challenges in Infrastructure Funding

Organizations:

- American Society of Civil Engineers: Publishes the Report Card for America's Infrastructure, which is widely referenced in discussions of the condition of infrastructure assets and systems. The latest Infrastructure Report Cards and subreports can be accessed at http://www.infrastructurereportcard.org/.

- Department of Homeland Security, Office of Infrastructure Protection: Leads and coordinates national programs and policies on critical infrastructure security and resilience, and has established partnerships across government and private sector to coordinate infrastructure protection activities with stakeholders for 16 critical infrastructure sectors identified in Presidential Policy Directive 21. Conducts vulnerability and consequence assessments and offers tools to help stakeholders understand and address risks. More information at https://www.dhs.gov/office-infrastructure-protection. Information on the 16 critical infrastructure sectors and their Sector-Specific Agencies can be found at https://www.dhs.gov/critical-infrastructure-sectors. Additional specific sector resources are listed below.

- Department of Homeland Security, Office of Cyber and Infrastructure Analysis: Conducts analysis on a range of infrastructure topics in support of DHS efforts to protect the nation's critical infrastructure through integrated analytical approaches, evaluating consequences of disruption from physical or cyber incidents. More information at https://www.dhs.gov/office-cyber-infrastructure-analysis. Products are restricted-access.

- George Mason University, Center for Infrastructure Protection and Homeland Security: Publishes the CIP Report, which has dedicated numerous issues to the topic of aging infrastructure and infrastructure failure. Current and past editions can be found at http://cip.gmu.edu/category/the-cip-report/.

Sector-Specific Resources:

- U.S. Army Corps of Engineers: Maintains the National Inventory of Dams. The full 2016 inventory, including interactive report and maps, is accessible at http://nid.usace.army.mil/cm_apex/f?p=838:1:0::NO.

- U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration: Responsible for ensuring safe transportation of energy and hazardous materials, their most recent report on the state of the national pipeline infrastructure can be found at https://opsweb.phmsa.dot.gov/pipelineforum/docs/Secretarys%20Infrastructure%20Report_Revised%20per%20PHC_103111.pdf.

- U.S. Department of Transportation, Federal Highway Administration: Maintains the National Bridge Inventory, National Tunnel Inventory, and list of Deficient Bridges by Highway System, which can be accessed at https://www.fhwa.dot.gov/bridge/deficient.cfm.

- U.S. Energy Information Administration: Provides statistics and analysis on energy infrastructure. The 2016 International Energy Outlook report can be accessed at https://www.eia.gov/outlooks/ieo/world.cfm.

- U.S. Environmental Protection Agency: Sector-specific agency for the Water and Wastewater Sector. Information on Sustainable Water Infrastructure initiative can be found at https://www.epa.gov/sustainable-water-infrastructure.

Recent Publications:

- 2017 Infrastructure Report Card: Published by the American Society of Civil Engineers, this report, issued every four years, assesses the current condition of infrastructure across the country. Additional reports include sector-specific or region-specific analysis, as well as economic impacts. Reports and roll-ups can be found at https://www.infrastructurereportcard.org, Web, 10 March 2017.

- Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future: Report by the American Society of Civil Engineers. An update to their previous report, "Failure to Act: The Impact of Infrastructure Investment on America's Economic Future." Discusses the complex economic impacts of investment in infrastructure, or lack thereof.
    - *Citation*: American Society of Civil Engineers, "Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future," 2016.
    - *Citation*: Link to pdf https://www.infrastructurereportcard.org/wp-content/uploads/2016/05/ASCE-Failure-to-Act-2016-FINAL.pdf, Web, 10 March 2017.

- 40 Proposed U.S. Transportation and Water Infrastructure Projects of Major Economic Significance: Prepared by the Department of the Treasury as part of the Build America Investment Initiative, this report discusses the economic impact of infrastructure investments.
- *Citation*: Information at https://www.treasury.gov/connect/blog/Pages/Importance-of-Infrastructure-Investment-for-Spurring-Growth-.aspx, full text at https://www.treasury.gov/connect/blog/Documents/final-infrastructure-report.pdf, Web, 10 March 2017.

Other Resources:

- 2014 Quadrennial Homeland Security Review: Interdependent and aging critical infrastructure systems and networks were identified in the 2014 QHSR as key driver in the strategic homeland security environment.
    - *Citation:* Department of Homeland Security, "2014 Quadrennial Homeland Security Review," 18 June 2014.
    - *Citation*: Abstract and link to pdf can be found at https://www.hsdl.org/?abstract&did=755060, Web, 10 March 2017.

- Quadrennial Energy Review: Transforming the Nation's Electricity System: Published as the second installment of the U.S. Department of Energy, Office of Energy Policy and Systems Analysis Quadrennial Energy Review, this document discusses the strategic security and economic criticality of the electric system.
    - *Citation*: Information at https://energy.gov/epsa/quadrennial-energy-review-qer, full text at https://www.energy.gov/epsa/quadrennial-energy-review-second-installment, Web, 10 March 2017.

- Presidential Policy Directive 21—Critical Infrastructure Security and Resilience: While it does not directly address aging infrastructure, PPD-21 provides executive branch direction focusing on improving resilience of infrastructure systems, understanding the complex nature of cascading consequences of infrastructure failures, and developing comprehensive research and development.

- *Citation*: "Presidential Policy Directive 21—Critical Infrastructure Security and Resilience," 12 February 2013.
- *Citation*: Full text at https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil, Web, 10 March 2017.
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- Fixing America's Surface Transportation Act, or "FAST Act": Signed in 2015 to provide long-term funding for planning and investment in surface transportation.
  - *Citation*: Information at https://www.fhwa.dot.gov/fastact/, full text at https://www.fhwa.dot.gov/fastact/legislation.cfm, Web, 10 March 2017.