



Assessment of Critical Infrastructure with No Grid Power: Transportation

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Introduction

“There is a lack of understanding of the cascading, cross-sector interdependencies between infrastructure and what that means for prioritizing backup generation and other limited resources to maintain services and functions during a long-term, widespread outage.”- The President’s National Infrastructure Council

“Critical infrastructures are those infrastructure systems and assets that are so vital that their incapacitation or destruction would have a debilitating effect on security, the economy, public health, public safety, or any combination thereof.” - DHS, CISA

There is a general lack of understanding of Critical Infrastructure (CI) in a Black Sky Event (BSE- nationwide or near nationwide grid power outage lasting 30 days) and a corresponding lack of published research. **The purpose of this paper is to portray all Critical Infrastructure (CI) Sectors’ “timeframe to failure” and their cross-sector interdependencies in a Black Sky Event to assist in the understanding of and planning for BSE.** “CI in a BSE” has been poorly analyzed which contributes to current plans and organizations being “overmatched” by a BSE.¹ There are occasionally “bright spots” of planning and preparation in each CI; however, most plans are dated or insufficient.^{2 3} Many of the BSE interdependencies and timelines portrayed in this paper were validated by the Iberian power outage of 2025 (see Appendix B).

This paper demonstrates the fundamental need for a resilient electric grid as none of the fifteen other critical infrastructures can continue to fully function without electricity from the grid. Most fail completely. A small number of CI elements (not the majority of any CI) may continue to function at an insufficient level using on-site natural gas generation, solar, wind, or other sources. This paper demonstrates that all CI rely on the grid.

The analysis of CI “time to failure” in a BSE has largely been ignored despite the key role time plays in a disaster. Every CI fails without power, the question is “When?”. For example, most of the IT Sector likely fails immediately without electricity but much of the Transportation Sector can continue to function for minutes, hours or days. The need for each CI is also based on time. For example, a healthy human can live for weeks without food, but only for days without water⁴ thereby making the Water/Wastewater Sector more BSE time-critical than the Food/Agriculture

¹ The Presidents National Infrastructure Advisory Council, Surviving a Catastrophic Power Outage; How to Strengthen the capabilities of the Nation, Dec 2018

² Ibid

³ DHS/CISA, Critical Infrastructure Sectors (plans are located in each sector), <https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/critical-infrastructure-sectors>

⁴ FEMA, FEMA NATIONAL US&R RESPONSE SYSTEM STRUCTURAL COLLAPSE TECHNICIAN , https://www.fema.gov/pdf/emergency/usr/appen_b.pdf

Sector. Every CI is needed, but an analysis focused on time is required to conduct resilience planning.

“Current planning frameworks focus on sector-by-sector preparedness and response, but in a catastrophic power outage, U.S. infrastructure and services will fail as a system. We need to take a systems approach—from the federal level down to the local level—to plan, design, and respond to these never-before-experienced events. This approach must move beyond existing planning and response frameworks and provide the guidance needed for an integrated cross-sector, cross-government strategy.” - The President’s National Infrastructure Council

This paper benefits leaders and planners involved with resilience and continuity of operations for each CI sector or CI element. The Energy Sector is not fully analyzed as this paper focuses on the impact to the other fifteen sectors by the loss of the grid. Many elements of the Energy Sector not contained in the grid are addressed in specific CI (e.g. gas for automobiles is in the Transportation CI). An Oil and Natural Gas Appendix is included at the end of the paper.

Sector Analysis

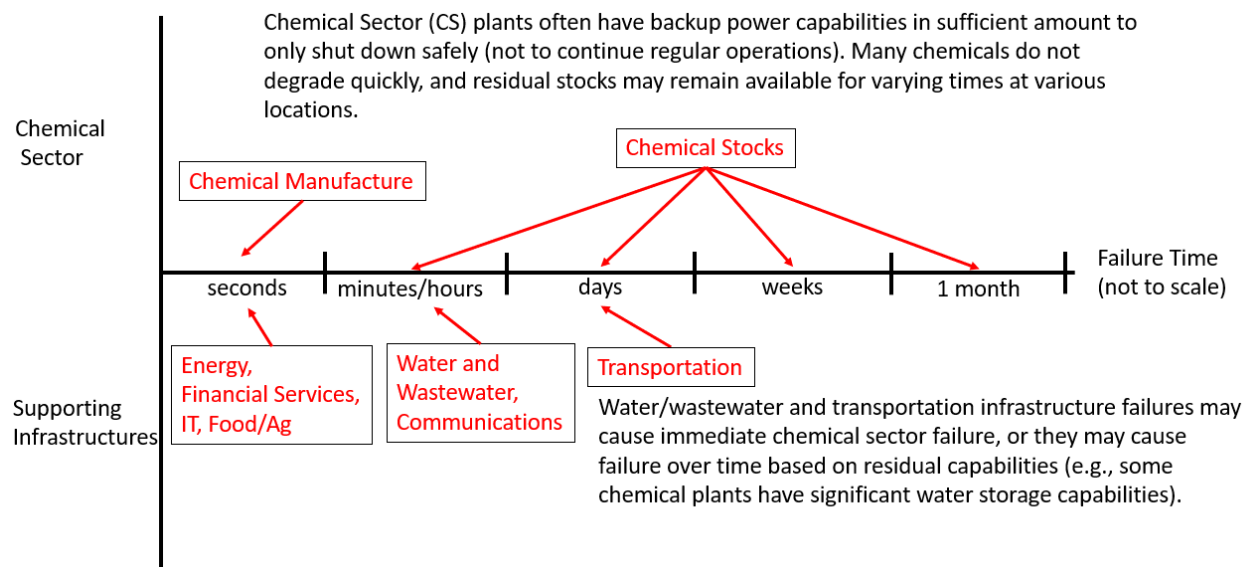
In order to analyze CI timeframes, one must define the CI, deconstruct each CI into its elements (subsectors), and determine supporting infrastructures. This paper therefore defines/describes each CI with their sub and supporting elements. “Time to failure” is then portrayed and assessed. Understanding the timelines of CI failure in a BSE will assist in BSE (and other disaster) planning.

Failure means the majority of that sector or subsector is unable to perform the majority of its function. Consideration is given to the capability of sector specific backup power.

Subsectors are the main elements of the CI that, if failing, would cause the CI to fail. Assessed subsector timelines to failure are at the top of each timeline diagram (see below). Subsector elements assessed failure timelines may be used to plan sector resilience/continuity. If there is no plan to address CI subsectors, the sector will likely fail in a BSE.

Supporting CI (the bottom half of each diagram) shows the assessed failure times of supporting CI. Supporting CI are required for a given CI to function. The impact of the loss of supporting CI is not necessarily felt right away. For example, most water treatment systems have stocks of chemicals on-hand, so the immediate failure of the Chemical Sector will impact water treatment only when stored stocks are depleted and no more chemicals are coming from factories. If unaddressed, supporting CI will cause the given CI to fail anywhere from seconds to weeks (not depicted).

Diagram Example: The Chemical Sector Diagram is depicted below. The Chemical Sector subsectors are chemical plants and chemical stocks (located on the top with arrows depicting assessed BSE failure timelines). The Chemical Sector supporting CI are located on the bottom with their own assessed failure timelines (note that supporting CI will not necessarily cause the Chemical CI to fail in the same “failure time”).



Communications, Energy, Financial Services, and IT are required for the administration of most CI. This includes (and is not limited to) financial transactions for supplies/raw materials, pay for employees, supply chain efforts, and the ability to effectively coordinate and execute operations. These CI are important for CI survival while other CI (e.g., Water) are more important for human survival. As humans are a required element of each CI, food and water become Supporting CI for all other CI.

Sectors are identified as local, regional, or national to assist in assigning planning responsibility. For example, if a CI is national, national planning should occur as well as regional and local planning. If it is local, then local planning is required. For example, wastewater treatment plants require local planning as there is no national wastewater system while the Finance CI requires a national plan.

A brief impact statement for the failure of each CI is included as is a brief recommendation for each CI based on the failure timeline.

Additional Considerations

In addition, the following entities are important in analyzing the impact timelines of BSE in the US (these are not official Critical Infrastructures):

- **People:** People are an element of all CI, and their survival needs to be considered within each CI. For example, a water treatment plant may want to have its personnel and families live at the treatment plant in a BSE (some have planned for this). Much of “power out” planning focuses on human survival vs CI survival. Humans can generally survive for 3 days without water or 3 weeks without food.⁵ As people are an element of each CI, there is a first order need for food and water in each CI. Family concerns and widespread societal panic that could lead to desperate behavior, including looting, rioting and violence, may keep people away from their CI posts (exacerbating CI failure). CI personnel may have old, sick (to include medicated), and very young dependents that have more pressing needs earlier in a BSE. Shelter may be a necessity. Many books and recommendations for family preparedness have been published (to include by FEMA⁶) but it is improbable that preparedness of CI individuals and families can be accurately determined (until an actual emergency occurs). In addition, it is unclear how many CI workers will show up to work without some form of compensation (finance).
- **Fuel:** Fuel is not a CI, but elements of the fuel system are included in several CI. Transportation includes rail, barge/ship, and truck transportation for fuels. Many CI and individuals have backup generation, but the lack of fuel will restrict their usage. If gas stations and bulk fuel distributors are not functioning, then all CI that depends on backup generation will not have (or run out of) the fuel required to function (Commercial facilities, communications (for credit cards) and finance generally are required for the normal function of gas stations.⁷). Previous power outages have shown that gas for automobiles/trucks and generators is generally unavailable.⁸ This problem remains.⁹ Superstorm Sandy demonstrated the need for backup power, especially for the fuel industry.
- **Backup generation:** Many CI have elements that have backup generation. If CI have backup generation, then their “time to failure” is extended. If CI have fuel storage for their backup generation, then their “time to failure” is further extended. There are no CI that have full backup generation for all elements. Some CI have sufficient backup power to last hours and days, but no CI has sufficient backup power to last weeks (due to lack

⁵ FEMA, FEMA NATIONAL US&R RESPONSE SYSTEM STRUCTURAL COLLAPSE TECHNICIAN , https://www.fema.gov/pdf/emergency/usr/appen_b.pdf

⁶ FEMA, Build a Kit, <https://www.ready.gov/kit>

⁷ FEMA, Power Outage, Keep Vehicles Fueled, <https://community.fema.gov/ProtectiveActions/s/article/Power-Outage-Keep-Vehicles-Fueled#:~:text=%E2%80%9CKeep%20your%20car%20fuel%20tank,Several%20Minutes%20or%20Several%20Days>

⁸ FEMA, Power Outage, <https://community.fema.gov/ProtectiveActions/s/article/Power-Outage-Keep-Vehicles-Fueled>

⁹ The Presidents National Infrastructure Advisory Council, Surviving a Catastrophic Power Outage; How to Strengthen the capabilities of the Nation, Dec 2018, page 30 https://www.cisa.gov/sites/default/files/publications/NIAC%2520Catastrophic%2520Power%2520Outage%2520Study_FINAL.pdf

of on hand fuel). A CI plan that relies on continuous fuel resupply for backup generation is assessed as unlikely (due to the failure of CI that are required for continuous resupply). In addition, Superstorm Sandy showed that backup generators require significant maintenance when in constant use.¹⁰

- Military: The Military role in a BSE is governed by the same processes and procedures that apply to hurricanes and other natural disasters.¹¹ In sum, the US Military relies on other local/state/federal organizations for the welfare of its personnel and families that live off-installation (approximately 70 percent¹² of its force). In modern times, the military has not responded to community needs until a DSCA (Defense Support of Civilian Authorities) request is approved.¹³ Certain commanders do have the ability to respond to emergencies without DSCA approvals.¹⁴ There is currently no published military plan that addresses a BSE despite the severe impact it would have on military personnel and the infrastructure required to support military bases.
- Governance: As with the Military, continuity plans that address governance are inadequate for a BSE. Some agencies will have a skeletal capability to function, but the ability to support the population with required governance in a BSE is deficient.^{15 16}

Recommendations

Plan for a BSE. Subsector elements and supporting CI may be used to organize planning for sector resilience (see Food/Ag Sector for example). If there is no plan to address subsector elements or supporting CI, the sector will fail in a BSE.

¹⁰P CISA, Resilient Power Best Practices

for Critical Facilities and Sites with Guidelines, Analysis, Background Material, and References 61,
https://www.cisa.gov/sites/default/files/2023-03/CISA_Resilient_Power_Best_Practices_for_Critical_Facilities_and_Sites_508c.pdf

¹¹ Congressional Research Service, Defense Primer: Defense Support of Civil Authorities,
<https://crsreports.congress.gov/product/pdf/IF/IF11324#:~:text=Courts%20have%20generally%20construed%20this,and%20criteria%20for%20handling%20requests>.

¹² US Dept of Housing and Urban Development, Community Housing Impacts of the Military Housing Privatization Initiative, p 1, https://www.huduser.gov/portal/sites/default/files/pdf/insight_3.pdf

¹³ DODD 3025.18, Defense Support to Civil Authorities,
<https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/302518p.pdf>

¹⁴ Congressional Research Service, Defense Primer: Defense Support of Civil Authorities,
<https://crsreports.congress.gov/product/pdf/IF/IF11324#:~:text=Courts%20have%20generally%20construed%20this,and%20criteria%20for%20handling%20requests>.

¹⁵ The Presidents National Infrastructure Advisory Council, Surviving a Catastrophic Power Outage; How to Strengthen the capabilities of the Nation, Dec 2018, page 10
https://www.cisa.gov/sites/default/files/publications/NIAC%2520Catastrophic%2520Power%2520Outage%2520Study_FINAL.pdf

¹⁶ DHS/CISA, Critical Infrastructure Sectors (plans are located in each sector), <https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/critical-infrastructure-sectors>

There is a lack of redundancy throughout CI (e.g., each household taps into one water system and if that system fails to produce, there is no alternate system). Increasing sector redundancy while eliminating single points of failure will increase CI resilience.

CI are most often considered individually instead of as “strands” of mutually supporting CI. National, state, and local planning should prepare using a “mutually supporting CI” approach.

Explore increasing natural gas generation and solar generation that does not rely on the grid or grid power (based on CI requirements).

Summary Table

The following table summarizes the assessed general failure times for each CI without power. The United States Government published an Energy Sector Specific Plan (SSP) that includes wording stating that each sector is reliant on energy/electricity.¹⁷ While the reliance on electricity was clearly stated, the timeline to failure was not. This table summarizes the assessed “times to failure” based on the more detailed CI analysis contained herein. These failure summaries are assessed for the majority of the CI (every sector will have some well-prepared entities).

Critical Infrastructure (CI)	Failure Within Seconds	Failure Within Minutes/hours	Failure Within Days	Limited Failure
Chemical				
Commercial Facilities				
Communications				
Critical Manufacturing				
Dams				
Defense Industrial Base				
Emergency Services				
Energy				
Financial Services				
Food and Agriculture				
Government Facilities				
Healthcare				
Information Technology				
Nuclear				
Transportation				
Water and Wastewater				

¹⁷ FEMA, DHS, Energy Sector Specific Plan, p 19, <https://www.cisa.gov/sites/default/files/publications/nipp-ssp-energy-2015-508.pdf>

Notes:

“The NIPP [National Infrastructure Protection Plan] 2013 identifies lifeline functions— water, transportation systems, communications, and energy—as services and resources that are essential to the operations of most critical infrastructure partners and communities.”¹⁸

Most Sector Strategic Plans contain a section describing sector dependencies. These provide the bulk of the sector interdependencies discussed in this paper.

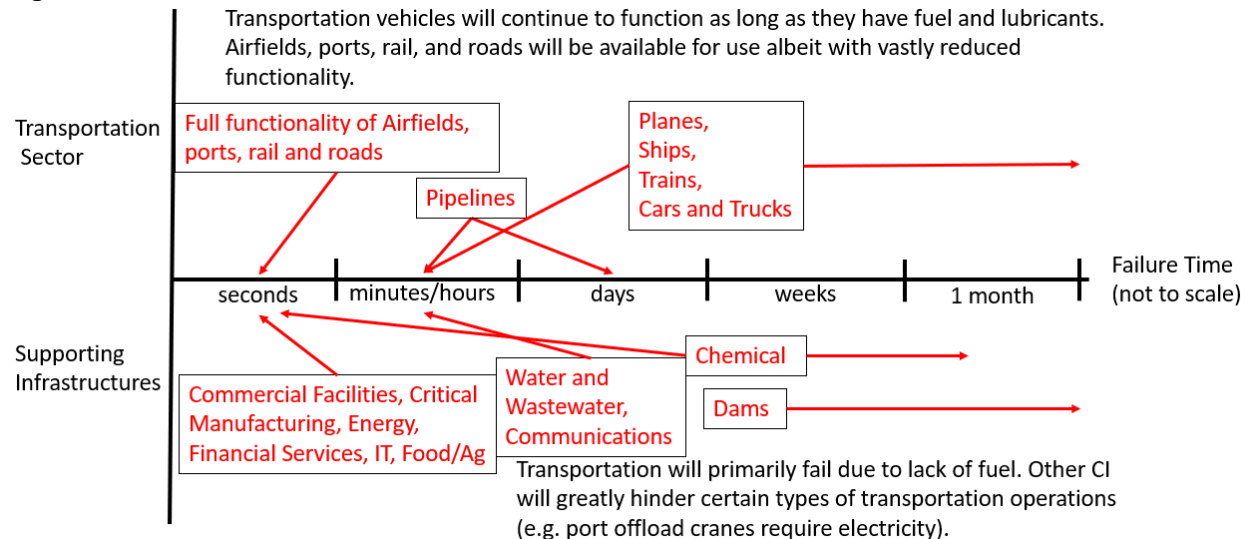
The Financial Services Sector is normally ignored in most Sectors. This paper includes Financial Services in each CI as a “Supporting CI” (except Emergency Services). All CI include personnel who require paychecks (Assumption: Most ES personnel will report for duty without pay...for a period of time). All CI require the ability to pay bills, invoices and conduct other purchase/sell transactions. Required payments don’t become free in a power outage.

No backup effort is considered effective unless it has been planned for and at least partially rehearsed. For example, a food warehouse that relies on IT to receive invoices is not considered functional by simply stating that warehouses can use paper invoices and manual accounting; they have to plan and rehearse this option for it to be viable.

¹⁸ DHS, Chemical Sector Specific Plan, 2015, p 5, <https://www.cisa.gov/sites/default/files/publications/nipp-ssp-chemical-2015-508.pdf>

Transportation Sector

Define/Describe CI: The Transportation Sector “consists of physical infrastructure, control systems, vehicles and people that operate and control aviation, maritime, highway, public transportation, rail, pipelines, and the combinations of these that constitute supply chain logistics”¹⁹



Failure timeline: (subsectors sourced from Transportation SSP) The transportation sector is comprised of many physical assets that can continue to function in a BSE with residual fuels. Airplanes carry enough fuel to get to their destination as do ships. Trains carry enough fuel to get to their next refueling point. Some vehicles will start to run out of fuel within minutes causing a cascade of other vehicles to be stuck in traffic and run out of fuel which continues and cascades until major roads are blocked. Vehicles not in use retain their ability to function based on fuel load. Approximately 10% of natural gas pipelines rely on electric pumps.²⁰ Transportation control systems require electricity.²¹ While Transportation physical assets will continue to exist, their ability to operate is in question due to lack of fuel, maintenance, and transportation infrastructure functionality. Gas stations pumps rely on electricity and immediately lose functionality in a BSE.²²

Describe CI Interdependencies (first order interdependencies that, if failing, will cause (at varying times) the Transportation Sector to fail)

¹⁹ Churchill B, Transportation, in “Powering Through; Building Critical Infrastructure Resilience”, editor Mary Lasky, (NDRC, 2021), p 179

²⁰ Smillie S., Morgan G., Apt J., The Electricity Journal, mar 2023, How vulnerable are US natural gas pipelines to electric outages?, <https://www.sciencedirect.com/science/article/pii/S1040619023000180>

²¹ DHS, CISA, Transportation SSP, p 15, <https://www.cisa.gov/sites/default/files/publications/nipp-ssp-Transportation:systems-2015-508.pdf>

²² FEMA, Power Outage, Keep Vehicles Fueled, <https://community.fema.gov/ProtectiveActions/s/article/Power-Outage-Keep-Vehicles-Fueled#:~:text=Gas%20stations%20rely%20on%20electricity,in%20vehicles%20for%20essential%20use.>

- Communications, Energy, Financial Services, and IT are required for the administration of all CI. This includes (and is not limited to) financial transactions for supplies/raw materials, pay for employees, supply chain efforts, and the ability to effectively coordinate and execute operations. Food/Ag and Water are required to maintain the human element of each CI.
- Commercial Facilities: Commercial facilities create and maintain Transportation assets. Gas stations are critical commercial facilities for transportation/other CI.
- Chemical: Refineries, fuels and lubricants require chemicals.
- Critical Manufacturing: CM creates transportation systems and spare parts.
- Dams: Dams create navigable waterways in some areas of the Country.
- Financial Services: Travel and freight operations rely on financial contracts. Fuel is purchased by electronic means (credit/debit cards) and most gas stations will shut down without a functioning financial process.
- IT: “Cyber technologies upon which transportation services rely include positioning, navigation, tracking, shipment routing, industrial system controls, access controls, signaling, communications, and data and business management.”²³

Sort into local or regional or National entities Transportation has local, regional, and national aspects. Local, regional and national transportation capabilities are needed in a BSE.

Impact of this CI with no power (to CI and to society) “The Chemical, Commercial Facilities, Critical Manufacturing, Defense Industrial Base, and Energy Sectors rely on transportation for the movement of raw materials, feed stocks, and products. The Emergency Services Sector depends on resilient transportation networks to respond effectively to emergencies. The Food and Agriculture Sector depends on the security of truck, rail, and maritime shipments to protect the Nation’s food supply chain. The Healthcare and Public Health Sector depends on transportation, particularly postal and shipping services, for delivery of medical supplies, medicines, and organs, often in urgent circumstances.”²⁴

Conclusion

- **Summary:** While transportation assets can continue to exist for a long time, they may not be able to operate for a long time. Assessment: The lack of fuel will cause this CI to fail in a BSE (days), and the failure of traffic control devices will lead to immediate gridlock in urbanized areas. The transportation sector directly supports most critical infrastructures and indirectly supports the rest. This sector can be very resilient as many assets are able to function long term with the only need being fuel.
- **Point towards broad solutions:** The local nature of much of the transportation required for food/water points towards local solutions in a BSE. Fuel is an over-riding concern and fuel reserves should be established for a BSE. Shipping could provide support from unaffected countries as long as they have ports with offload capability and a

²³ DHS, CISA, Transportation SSP, p 11, <https://www.cisa.gov/sites/default/files/publications/nipp-ssp-Transportation:systems-2015-508.pdf>

²⁴ Ibid, p 15

transportation system for distribution. Planning and coordination for external shipping and aviation support should occur with other Nations.