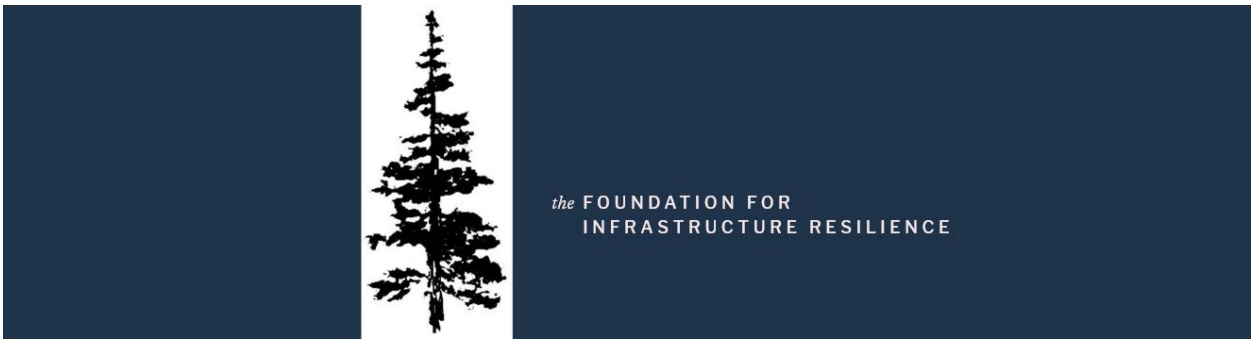


# Assessment of Critical Infrastructure with No Grid Power: Chemical Sector

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**29 July 2025**

# 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 water[4] 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**

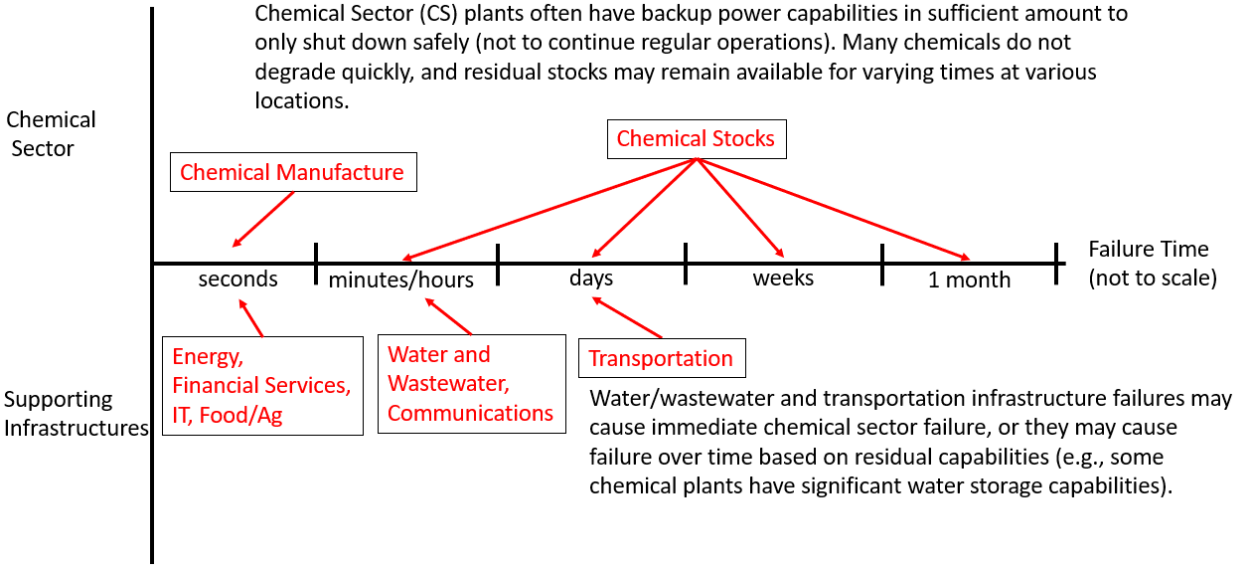
In order to analyze CI timeframes, one must define the CI, deconstruct each CI into its elements (subsectors), and determine supporting infrastructures. This paper therefore defines/describes each CI with their sub and supporting elements. "Time to failure" is then portrayed and assessed. Understanding 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 FEMA[6]) 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 percent[12] 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.

[10]P CISA, Resilient Power Best Practices
for Critical Facilities and Sites with Guidelines, Analysis, Background Material, and References 61, ttps://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.

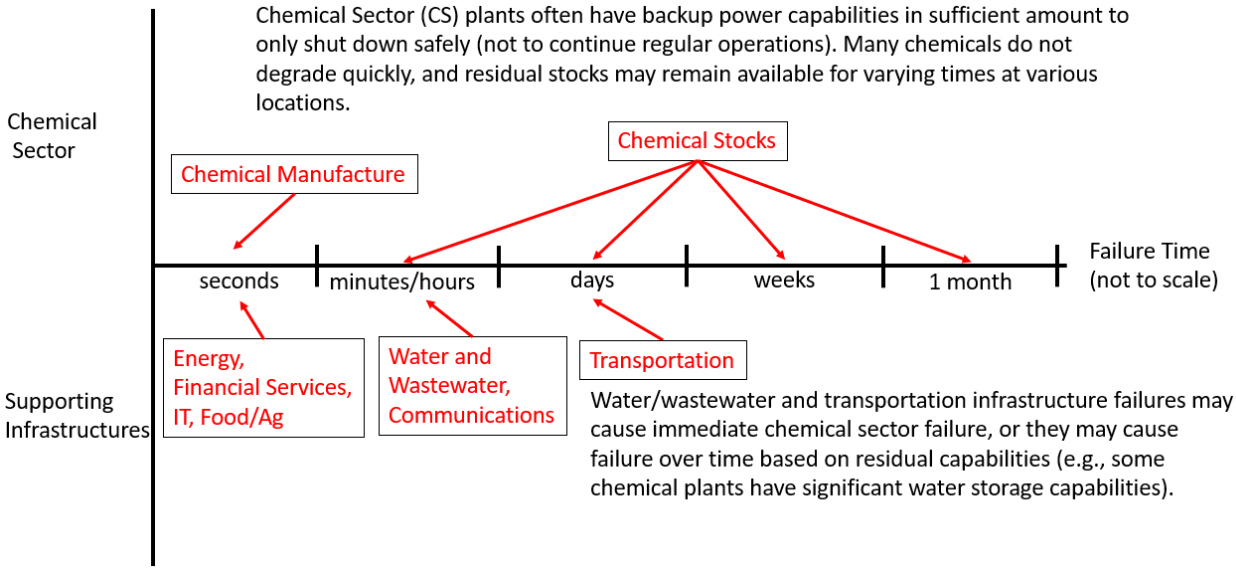
The Financial Services Sector is normally ignored in most Sectors. This paper includes Financial Services in each CI as a "Supporting CI" (except Emergency Services). All CI include personnel who require paychecks (Assumption: Most ES personnel will report for duty without pay…for a period of time). 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

# Chemical Sector

**Define/Describe CI:** "The Chemical Sector converts raw materials into more than 70,000 diverse products and is a major component of the U.S. economy, contributing approximately 25 percent of the Nation's gross domestic product (GDP). The Chemical Sector employs nearly 800,000 workers who manufacture, store, and transport chemicals to customers in multiple critical infrastructure sectors. About 96 percent of U.S. goods in 2013 were manufactured using Chemical Sector products, making uninterrupted chemical production and transportation essential for national and economic security."[19] "A chemical plant may include such equipment as reactor vessels, filters, compressors, pumps, valves, furnaces, fractionating columns, generators, centrifuges, stripping units, blenders, mixers, evaporators, distillation columns, heat exchangers, storage tanks, pipelines and other similar equipment."[20] The chemical sector is one of the top energy consuming CIs. The chemical sector includes pharmaceuticals, agricultural pesticides, fertilizer, and everyday household products.[21] Many chemical plants (less than 50%) use a direct supply of natural gas to run their own power generation. Some also generate electricity by using waste heat from their own chemical processes (called CHP or "Combined Heat and Power").




[19] DHS, Chemical Sector Specific Plan, 2015, p v, https://www.cisa.gov/sites/default/files/publications/nipp-ssp-chemical-2015-508.pdf

[20] James LeBlanc, Chemical, in "Powering Through; Building Critical Infrastructure Resilience", editor Mary Lasky, (NDRC, 2021), p 273

[21] DHS, Introduction to Chemical SSA, https://www.cisa.gov/sites/default/files/publications/chemical-ssa-fact-sheet-2017-508.pdf

**Failure timeline:** (subsectors sourced from Chemical SSP[22], chemical transportation included in Transportation section) Chemical plants will generally fail in their primary mission (producing chemicals) within seconds of a power outage.[23] "Most chemical facility operators have developed sound contingency plans for responding to various types of plant utility interruptions, including electric power outages."[24] Those plants that use natural gas for power generation may last longer as natural gas will be able to continue to flow (based on non-electric compressor stations and residual natural gas pressure in pipelines). These procedures are not always tested and sometimes they fail, causing harmful toxic chemical release.[25] Most chemicals have a lengthy shelf life and can last months. Other CI failure times due to chemical sector failure will vary based on the chemical and the CI need.

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

- 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.
- Chemical: Chemicals are required as both elements of other chemicals as well as parts of a chemical development process (e.g., lubricants for machines). On-hand stocks will shape chemical plant failure times due to lack of chemicals.
- Energy: Energy is required to operate chemical plants and the chemical distribution system.
- Information Technology (IT): IT is required in many chemical factories (e.g., SCADA data systems).
- Transportation: Transportation is required to move chemical products. Natural gas is required to manufacture many chemical products, either as feed stock or fuel.
- Water and Wastewater (WW): Water is required to process many chemicals and is an element of many chemicals.

[22] DHS, Chemical Sector Specific Plan, 2015, p v, https://www.cisa.gov/sites/default/files/publications/nipp-ssp-chemical-2015-508.pdf

[23] EPA, Chemical Accidents from Electric Power Outages, Sept 2001 (updated 2023), p 2, https://www.epa.gov/sites/default/files/2013-11/documents/power.pdf

[24] EPA, Chemical Accidents from Electric Power Outages, Sept 2001 (updated 2023), p 3, https://www.epa.gov/sites/default/files/2013-11/documents/power.pdf

[25] EPA, Chemical Accidents from Electric Power Outages, Sept 2001 (updated 2023), p 1-2, https://www.epa.gov/sites/default/files/2013-11/documents/power.pdf

**Sort into local or regional or National entities.** Most chemical plants require raw materials and other chemicals from all over the country if not overseas.[26] From 2018 to 2019 "U.S. general imports of chemicals and related products increased by $9.7 billion (3.1 percent) to $320.1 billion."[27] Chemicals are used locally but the supply chain may be local to national.

**Impact of this CI with no power.** (to CI and to society) The chemical sector with no power is often an underappreciated problem. For example, most drinking water requires chlorine.[28] Most food contains chemicals.[29] Without power the chemical sector fails causing the "lifeline" CIs (and the Chemical CI) to rely on "on-hand" stocks. Chemical plants that do not execute their shutdown procedures correctly may discharge toxic chemicals causing widespread illness/death.[30] Nearby or adjacent water ways could become contaminated. A no-power scenario would have a gradual impact on the availability of chemicals as on-hand stocks are depleted.

**Conclusion**

- **Summary**: Assessment: The chemical sector will fail in seconds. Several of the interdependencies that the chemical sector relies upon will fail within seconds. The lack of chemicals will cause an ever-increasing impact on other CI as stocks dwindle. Some chemicals are understood to be more important than others (e.g., chlorine), but the analysis of chemical requirements during a BSE has not been done.
- **Point towards broad solutions:** Analysis (including exercises) is required to determine the type and amounts of chemicals that critical infrastructures need to keep on-hand for a BSE. Alternatives to these required chemicals should be identified. On-hand stocks should be increased to allow continued CI functionality in a BSE. Critical chemical plants should be identified and plans for continued production should be established. A corresponding effort for the entire chemical sector supply chain should be undertaken.

[26] DHS, Chemical Sector Specific Plan, 2015, p 2 and 5, https://www.cisa.gov/sites/default/files/publications/nipp-ssp-chemical-2015-508.pdf

[27] US International Trade Commission, Chemicals and Related Products, https://www.usitc.gov/research_and_analysis/trade_shifts_2019/chemicals.htm

[28] CDC, Drinking Water, 2024, https://www.cdc.gov/drinking-water/about/about-water-disinfection-with-chlorine-and-chloramine.html?CDC_AAref_Val=https://www.cdc.gov/healthywater/drinking/public/water_disinfection.html

[29] Academy of Nutrition and Dietetics, Buyer Beware: 60% of Foods Purchased by Americans Contain Technical Food Additives — a 10% Increase Since 2001, Mar 2023, https://www.eatrightpro.org/about-us/for-media/press-releases/60-percent-of-foods-purchased-by-americans-contain-technical-food-additives

[30] EPA, Chemical Accidents from Electric Power Outages, Sept 2001 (updated 2023), p 1-2, https://www.epa.gov/sites/default/files/2013-11/documents/power.pdf