Case Studies of Multi-Sectoral Resilience to Natural Disasters

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SoCalGas

ICF

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Executive Summary

The Southern California Gas Company (SoCalGas) developed this study to better understand how recent natural disasters have impacted natural gas and other key sectors, how these sectors remained resilient in the face of such disasters, and how natural gas utilities can better prepare for future events. The study team developed case studies for the following natural disasters: Hurricane Harvey in Texas, Hurricanes Irma and Michael in Florida, the October 2017 wildfires in northern California, the December 2017 wildfires and subsequent mudslides in southern California, the November 2018 wildfires in southern California, and the February 2021 Winter Storm Uri in Texas. These case studies are meant to help inform planning efforts at SoCalGas for increasing resilience to climate stressors. The case studies are also designed to be of value to other utilities, municipalities, and communities that are undertaking similar resilience and hazard mitigation planning efforts. The Key Lessons Learned presented below highlight the findings of these case studies, focusing on the impacts to natural gas infrastructure and the role of natural gas in supporting resilience.

Key Lessons Learned

In the following summary table and narrative of key lessons learned, we use icons to note to which hazard(s) and sector(s) the lesson is relevant.

Hazards:	Wildfires	Winter Storms	Hurricanes
Sectors:	Natural Gas	People	Multiple

Key Lesson	Hazard(s)	Sector(s)
Natural gas infrastructure and services were relatively resilient to hurricanes, wildfires, mudslides, and the winter storm	Wildfires, Winter Storms, Hurricanes	Natural Gas
Natural gas' interdependence on other sectors is a greater point of weakness than the natural gas infrastructure itself	Wildfires, Winter Storms, Hurricanes	Multiple
Clear communication and coordination between utilities across sectors and with emergency personnel is critical to a successful disaster response	Wildfires, Winter Storms, Hurricanes	Multiple
The greatest impact to natural gas provision during the wildfires came from the utilities' need to selectively isolate service by turning off the supply to targeted areas affected by fire	Wildfires	Natural Gas

Key Lesson	Hazard(s)	Sector(s)
Natural gas contributed to resilience during emergencies		
Natural gas supply is significantly more reliable than electricity		
Technology supported the resilience of natural gas		
Safety investments in gas infrastructure are also providing resilience benefits		
Diversity in fuel supplies improve resilience		
The increasing focus on resilience and availability of backup generation may worsen air quality		
Inadequate consumer knowledge can affect safety and limit the ability to reap the benefits of the resilience of natural gas		
Marginalized communities suffered disproportionately		

Natural gas infrastructure and services were relatively resilient to hurricanes, wildfires, mudslides, and the winter storm. Most natural gas infrastructure is belowground, which is inherently less vulnerable to natural disasters than aboveground infrastructure. The greatest observed impact to natural gas infrastructure was due to intensive scouring of creeks during flood events, uprooted trees during hurricanes, and large boulders carried by mudslides.

Natural gas' interdependence on other sectors is a greater point of weakness than the natural gas infrastructure itself. This is illustrated by the inability to export gas supply when ports are closed in a hurricane or when downed electric infrastructure reduces the demand for natural gas used in electricity generation.

Clear communication and coordination between utilities across sectors and with emergency personnel is critical to a successful disaster response. Utilities cannot operate in siloes and they must recognize their interdependencies—particularly to address any weak points as mentioned above. Access to infrastructure must be carefully coordinated when conditions are unsafe, and natural gas, electric and telecommunication utilities must communicate the locations of their assets and potential risks to avoid further damage during response activities. Organizations such as the California Utilities Emergency Association (CUEA), in which points of contact for all utilities are brought together and facilitated by expert responders, are an excellent example of how organized, institutionalized coordination can streamline responses and minimize damage while maximizing efficiency.

The greatest impact to natural gas provision during the wildfires came from the utilities' need to selectively isolate service by turning off the supply to targeted areas affected by fire. Reductions in natural gas supply during the wildfires were primarily caused by the utilities' efforts to selectively isolate service (turn off the supply to targeted areas affected by fire). Selective isolation, a protective measure that can be put in place quickly to avoid damages during wildfires, can also be time-consuming and expensive to reverse while impacting customers without service in the interim. Increasing the number of valves to further enhance isolation can create more potential leak points on the system, so tradeoffs must be evaluated.

Natural gas contributed to resilience during emergencies. Backup generation for electricity service disruptions is an important component of overall resilience from climate hazards. In most examples of backup generation explored in these case studies, facilities successfully maintained power because of such investments. In particular, natural gas provides a cleaner source of fuel for backup generators than diesel and can be more reliable than diesel in certain circumstances. Natural gas can be a reliable source of energy over long-term disruptions of electricity service (i.e., multiple days) where current battery capacity for renewable systems may not be adequate. Diesel fuel supply can be interrupted by the very climate disasters that created the need for the use of generators.[1] Compressed natural gas (CNG) and liquefied natural gas (LNG)-fueled vehicles can help to maintain functionality, especially when access to other fuel sources is disrupted by climate hazards.

Natural gas supply is significantly more reliable than electricity. Two recent reports from the Natural Gas Council and Gas Technology Institute (GTI) found that characteristics of natural gas's transmission and distribution infrastructure, such as greater storage capacity and underground assets, make natural gas a more reliable energy source than electricity. Only one in almost 800 gas customers experience service disruptions annually, whereas every electric customer will experience an outage annually. The economic impacts of disruptions to gas customers are insignificant when compared to those of electricity customers.

Technology supported the resilience of natural gas. SoCalGas improved resilience through technologies such as pressure sensors, which detect dramatic pressure drops and send signals to valves that immediately shut off flows for specific lines. SoCalGas' use of drones and satellite imagery was also useful, providing visibility into areas inaccessible by personnel to closely assess damage. Satellite imagery was particularly helpful immediately following the event, when (FAA) restrictions prohibited flights from third parties to avoid conflict with first responders' rescue efforts.

Safety investments in gas infrastructure are also providing resilience benefits. As utilities replace bare steel and cast-iron gas pipe to address infrastructure aging and safety issues, they also reduce the potential for water entry and disruption of gas service, making the systems more resilient. Also, the plastic pipe used for many of these replacements is more flexible and less likely to break when there is ground shifting due to water flow from hurricanes or seismic activity.

Diversity in fuel supplies improve resilience. Energy backup systems with diverse fuel supplies such as onsite diesel storage with bi-fuel connections that allow a switch to natural gas will provide greater flexibility and higher levels of resilience. Recovery after an event can also be better supported with more diverse vehicle fleets that include compress natural gas fueled vehicles in addition to petroleum fueled vehicles since

[1] Ericson, S., and Olis, D. "A Comparison of Fuel Choice for Backup Generators." National Renewable Energy Laboratory, 2019. https://www.nrel.gov/docs/fy19osti/72509.pdf

petroleum fuel supplies may be limited after an event. The PG&E remote microgrid program which improves reliability and significantly reduces wildfire risk by replacing the overhead distribution powerlines serving small groups of customers in High Fire-Threat Districts with microgrids, uses several resources including photovoltaic panels, battery storage and propane generation for backup supply.

The increasing focus on resilience and availability of backup generation may worsen air quality. As the number of extreme events continues to increase, more residents are installing backup generation in their homes. Since the majority of these generators still using petroleum fuels, it is likely that this increasing adoption will have an adverse impact on air quality. During the October 2019 PSPS events, a CARB report identified that an estimated 1,800 stationary diesel generators contributed an additional 125 tons of nitrous oxides (NOx) to the environment.[2] Converting the estimated 1,800 stationary backup generators used during the October 2019 PG&E PSPS event from diesel to natural gas would have reduced emissions by 70%, avoiding 88 tons of NOx pollution.[3]

Inadequate consumer knowledge can affect safety and limit the ability to reap the benefits of the resilience of natural gas. During Winter Storm Uri, many consumers were unaware that many gas stoves and fireplaces are capable of operating during a power outage, either by being lit with a match or by using a small 9-volt battery to power the electronics. Without such knowledge, some residents unnecessarily went without heat, hot water, or the ability to cook. On the flip side, some Texans suffered carbon monoxide poisoning when they ran outdoor generators indoors. Thus, it is of the utmost importance that residents understand what power source are and are not available during power outages—and how to use them safely.

Marginalized communities suffered disproportionately. The most marginalized communities with the poorest ability to withstand and recover from events (e.g., live in older homes with outdated infrastructure, have fewer financial resources, not have fluency in English, and/or depend on public transportation) are also often the communities most affected by proactive load shedding and delayed restoration, longer outages.

Insights and Recommendations

Based on the above findings, the study team provided the following recommendations for increasing resilience to climate events.

System Modifications

Further sub-divide the system to minimize the extent of service isolation. PG&E is working to sub-divide their system so that when service isolation is necessary, it can be more targeted and affect smaller populations.[4] Similarly, SoCalGas is considering increasing the frequency of valves, especially in geohazard areas such as fault lines.[5] This is a particularly useful strategy in light of the high cost and time intensity of restoring service post-isolation.

[2] California Air Resources Board. (2020). "Emission Impact: Additional Generator Usage Associated with Power Outage." https://ww2.arb.ca.gov/sites/default/files/2020-01/Emissions_Inventory_Generator_Demand%20Usage_During_Power_Outage_01_30_20.pdf
[3] ICF analysis of CARB data.
[4] Personal communication with PG&E. January 15-16, 2018.
[5] Personal communication with SoCalGas. January 22, 2018.

Increase use of technology and smart grids. Modernizing systems will require more communication and data. It is useful for cities to monitor gas consumption in order to know where disruptions occur.[6] SoCalGas is deploying fiber optics sensing technologies through debris flow areas above its pipelines. This technology will enable monitoring of outside force threats and identify any leaks in these vulnerable areas to facilitate swift and targeted responses.

Make weatherization a requirement for power plants and critical natural gas facilities. FERC recommendations on weatherization for power plants in Texas were advisory. Texas implemented these recommendations with Senate Bill 3 and as of 2022, 98% of power plants were properly winterized. Only natural gas facilities deemed "critical" are required to winterize equipment. To ensure adequate supply of natural gas, winterize wellheads, install backup power at compressor stations, and ensure that underground storage facilities maintain a minimum supply (e.g., based on withdrawal during Winter Storm Uri).

Examine adding more regional interconnections to the Texas grid to compensate for future power production shortfalls. Cities in Texas outside of ERCOT's jurisdiction suffered few power outages during Winter Storm Uri because they were connected to other grids.

Backup generation mandates should allow for natural gas as a fuel source. Mandates for backup generation for critical facilities such as nursing homes have sought to ensure the continuity of electric supply after an extreme event as well as the duration of that supply, often by mandating minimum onsite fuel storage. Given the proven resilience of natural gas to extreme events, including gas as fuel supply option can help build the resilience of a greater number of critical facilities by addressing such issues as available space for fuel tanks and the uncertainty of obtaining fuel after an event.

Coordination and Communication

Expand services and outreach to first responders. Interviewees expressed a desire to increase use of natural gas during emergency operations based on reliability of supply, air quality benefits, and the potential for utilizing low-carbon fuels through renewable natural gas (RNG). Some specific ideas include:

- SoCalGas could enhance efforts to coordinate and supply emergency responders through investments in mobile supply infrastructure and outreach with emergency responders. Mobile infrastructure could include mobile gas compressors or fuel storage tanks, tube trailers, and other technologies to support emergency vehicles and generators during events.
- Utilities could center outreach efforts on educating emergency responders about best practices for using natural gas supply lines in the field. Additionally, natural gas utilities must communicate to other utilities and response organizations where their infrastructure is located and what sort of risk it faces, all of which is key information for responses such as digging in the aftermath of mudslides or for assessing damage to infrastructure. For example, during the California wildfires, gas utilities were able to work with emergency managers to proactively isolate at-risk areas, therefore preventing damage both to and from natural gas infrastructure. After events, restoring services requires close coordination with emergency responders regulating access.

Enhance cross-training exercises with emergency response personnel. The California Public Utilities Commission (CPUC) and the California Governor's Office of Emergency Services (CalOES) have a

[6] Ibid.

memorandum of understanding (MOU) to facilitate gas utility and fire service emergency response collaborations in which the two groups of organizations undergo cross-training on how to address, secure, and suppress gas fires at both residential and commercial locations. California Utilities Emergency Association (CUEA) asserts that this is the most aggressive preparation program of this type in any state and provides a model for other states as a result.[7] However, there should also be more cross-training beyond the fire service: utilities must work with public service agencies to pre-plan, and to involve law enforcement officials and state DOTs to know how their requirements and procedures will play into utility emergency response protocols. Such interdisciplinary collaboration and preparation will allow for a more coordinated and informed response.[8]

Mutual assistance agreements between utilities are critical to disaster response but can be strengthened further. In times of emergency, mutual assistance agreements were effective complements to the limited standby utility resources (e.g., backup generators) and staff (e.g., qualified technicians) utilities can maintain. There are only so many units, such as backup generators, that utilities can maintain in their inventory on standby. The same goes for qualified technicians; there are limitations to the size of utilities' labor forces. Mutual assistance agreements and coordination through bodies such as the CUEA allow for the pooling of resources when necessary and for the swelling of the labor force in specific areas in need; for example, the CUEA was able to send extra technicians to PG&E from unaffected utilities during the October wildfires.[9] However, these mutual assistance agreements could be further strengthened to increase responsiveness, proactively address challenges (e.g., transportation and telecommunication service disruptions), and provide a larger array of assets during emergency events.

Plan for potential scenarios that could impact natural gas pipelines. The case studies show that natural disasters have the potential to impact natural gas pipelines. Other studies investigating additional hazards, such as a 2013 Sandia National Laboratories study on a major earthquake scenario in southern California, have drawn similar conclusions. In order to build resilience to these events, utilities can develop plans centered around potential impacts, possibly using models to estimate such impacts.

Educate consumers to better understand the capabilities of their appliances. In Winter Storm Uri, many consumers were unaware that their gas ranges and fireplaces may have been operable during power outages by using manual ignition with a match. Also, some units require that small backup batteries be maintained and changed periodically to provide functionality during power outages, but many consumers did not know this.

Planning and Operations

Develop longer-term plans to build resilience. Cities and counties across Texas are working towards establishing goals and strategies to increase their resilience to extreme weather and storms. For example, the City of Austin Strategic Direction 2023 and Travis County Vision, Mission, and Goals establish pathways to address inequities, foster community engagement, expand preparedness programs, and increase staffing to handle emergency operations.[10]

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[7] Personal communication with SoCalGas. January 22, 2018.
[8] Ibid.
[9] Ibid.
[10] City of Austin and Travis County. "2021 Winter Storm Uri After-Action Review Findings Report." 2021. https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf

Revise risk assessments to account for future climate change, including increasing frequency of winter storms and heat waves.[11]

Improve customer communication and warning systems, especially for non-English speaking households. In Winter Storm Uri, if warnings had been issued earlier, residents would have had more time to prepare and what to expect.[12]

Require carbon monoxide alarms in all homes. During Winter Storm Uri, more than 1,400 people went to emergency rooms or urgent care clinics for carbon monoxide poisoning due to the use of outdoor equipment (grills, smokers, propane heaters, generators) indoors for heating and electricity. Local governments in Texas have discretion to establish carbon monoxide rules. As a result, many older or single-family homes do not have carbon monoxide alarms.[13]

Improve equity in rolling blackouts and service restoration so that historically disadvantaged communities do not suffer longer losses of service. During Winter Storm Uri, 76% of African Americans lost power compared to 66% of Anglos.[14]

Supplemental Research: Natural Gas Resilience and Wildfires

The report appendices provide a deeper look at decreasing the vulnerability of landscapes to wildfire and of strengthening the system's ability to withstand or recover from wildfire. This research provides a high-level estimate of impacts from greenhouse gas (GHG) and criteria air pollution emissions from the 2017-18 California wildfires (Appendices B and C). GHG emissions ranged from 250 to 700 $MMTCO_2e$; a similar amount to California's total non-wildfire GHG emissions in 2016 (430 $MMTCO_2e$). Air quality impacts from particulate matter (PM) were roughly seven to ten times the total PM from all on-road mobile sources in the state in 2017-18. To mitigate these impacts, we examined best practices in forest management for wildfire prevention in Appendix D, and fuel reduction was found to be an effective management practice. In Appendix E, we examined the potential of using dead trees as feedstock for renewable gas production, which could utilize a latent resource created during fuel reduction if barriers to implementation are addressed.

Our supplemental research found that dead-tree removal for renewable gas generation offered significant benefits in wildfire resilience, and GHG emission and air pollution reduction. However, thermal gasification and dead-tree removal are currently lacking in investment and should be considered state-wide to realize these benefits.

[11] Smith, Robert. "A Climate Black Swan: The Lessons Learned from Uri." *VettaFi,* March 11, 2021. https://etfdb.com/esg-channel/climate-black-swan-lessons-learned-from-uri/
[12] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. 2021. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science*, 77:102106. https://doi.org/10.1016/j.erss.2021.102106.
[13] Trevizo, Peter, Ren Larson, Lexi Churchill, Mike Hixenbaugh, and Suzy Khimm. "Texas Winter Storm: Worst Carbon Monoxide Poisoning Catastrophe in Recent U.S. History." *Deceleration News,* April 29, 2021. https://deceleration.news/2021/04/29/texas-winter-storm-carbon-monoxide-poisoning/
[14] University of Houston. "Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri." Houston: Hobby School of Public Affairs. 2021. https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf

CHAPTER 1

Introduction

Background and Goal of Conducting Case Studies

To inform SoCalGas' planning for resilience to climate-related stressors, ICF developed case studies in 2019 to assess the lessons learned from natural disasters, starting with Hurricane Harvey in Texas; Hurricane Irma in Florida; the October 2017 wildfires in northern California; and the December 2017 wildfires and subsequent mudslides in southern California. This 2022 update to the report provides any new information from resilience lessons learned after the previous case studies and provides an analysis of Winter Storm Uri, which hit Texas in 2021.

For the 2022 update on resilience measures, the study team was particularly interested in discovering the actions taken to improve end-user resilience and examples of legislation proposed after the events. The research also focused on how resilience measures implemented in response to these disasters fared during subsequent events. While some measures were taken as a direct result of a specific natural disaster, others were the result of the compounded effect of seeing similar disasters in close succession.

Several resilience measures and community actions emerged as common themes among all case studies, often despite geographic differences. Thus, this report is meant to illustrate the breadth of possible resilience measures taken in the wake of disasters. Overall, findings indicate that installed microgrids, upgrades to electric grid infrastructure, alternative fuel vehicles, and dispatched generators were the most common successful resilience measures observed across all events. These measures allowed energy customers to gain access to power during power outages caused by the events, which helped residents maintain health and well-being and fueled response and recovery activities or safeguarded against further damage during the disaster.

These case studies do *not* offer a comprehensive post-disaster incident or damage report, nor do they prescribe actions that should have been taken. Instead, they illustrate observed vulnerabilities and resilience based on information available shortly after the disasters struck and distill from those observations key lessons learned and recommendations to inform future research and planning.

Intended Audience

These case studies are meant to help inform planning efforts at SoCalGas for increasing resilience to climate stressors. The case studies are also designed to be of value to other utilities, municipalities, and communities that are undertaking similar resilience and hazard mitigation planning efforts.

Overview of Sources Consulted

The document draws upon a diversity of sources to create a picture of the events and what can be learned from them, including: utility and Department of Energy (DOE) reports, news articles, social media postings, first-hand observations (obtained through interviews); and studies that examined similar events elsewhere. A fuller description of the sources consulted is provided in Appendix A.

How the Report is Organized

This report provides several case studies on impacts from and examples of resilience during natural disasters, as well as findings on resilience measures taken after these events.

Chapter 2 presents an overview of each of the events that are covered within this document, providing summary information about the date, location, and nature of the event as well as the utilities that service the affected area. This chapter also provides the full additional case study on Winter Storm Uri.

Chapter 3 provides research findings on impacts and resilience. These findings are divided by sector to provide insight into the ways that the natural disasters have impacted critical infrastructure sectors. In addition, there is also discussion of the compounding consequences, in which impacts to one sector cascade into impacting related, interdependent sectors. The sectors include:

- **Energy Supply**, focusing on transmission and distribution of electricity and natural gas;
- **Backup Generation,** including its role in maintaining critical community infrastructure and responding to natural disasters;
- **Mobility and Transportation**, which highlights the role of CNG and LNG;
- Water and Wastewater Services; and
- Telecommunications.

Note that while the research findings were grouped into these sectors, the previously mentioned interdependencies create continual overlaps between the sectors throughout the report. For example, the Backup Generation and Mobility and Transportation sections highlight impacts to energy supply during emergency operations.

Chapter 4 presents the 2022 findings on post-event resilience, including the success of existing resilience measures, measures implemented as a result of the events described in the case studies, and how such measures fared in later events.

Chapter 5 presents key takeaways from this research on impacts and resilience, including lessons learned and a list of additional research needs.

Appendix A contains details on the research methodology and sources used.

Appendices B-E include supporting research on related impacts and best management practices related to the climate induced extreme events discussed in this report, namely the 2017-18 California wildfires. These supplemental assessments identify opportunities, namely through dead tree removal and gasification, for natural gas utilities to contribute to wildfire management and impact mitigation.

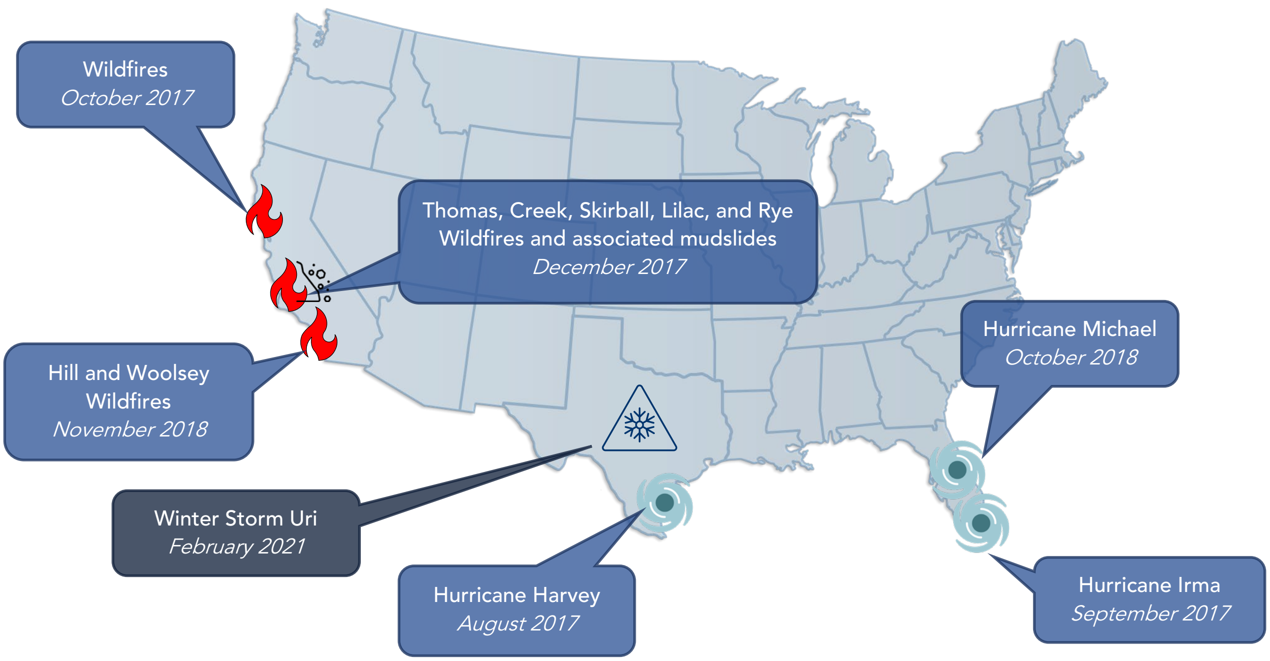
- Appendix B: GHG Impacts from Forest Fires in 2017 and 2018 in California estimates the GHG emissions from combustion, or burning of forest biomass, and carbon sequestration losses to create a total estimate for GHG emissions from California's 2017-18 wildfires.
  - Key point: Net GHG emissions from California forest fires in 2017 and 2018 are estimated at a range of 250 to 700 $MMTCO_2e$, comparable to California's entire non-wildfire GHG emissions in 2016 (430 $MMTCO_2e$).[15]
- Appendix C: Criteria Air Pollutant Emissions from Forest Fires in 2017 and 2018 in California estimates the total emissions of particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOC),[16] and nitrogen oxides (NOx) from the 2107 and 2018 California wildfires.
  - Key point: Particulate matter emissions from 2017 and 2018 were roughly seven to ten times the total emissions of PM from all on-road mobile sources in the state in those same two years. Based on these estimates, wildfires should be considered amongst the greatest threats to air pollution in California.
- Appendix D: Best Practices in Wildfire Risk Reduction provides a brief overview of current state of knowledge and best practices in fuel treatment for wildfire risk mitigation, both in living forests and in areas of high tree mortality.
  - Key point: The science research of wildfire management indicates that fuel reduction is effective[17, 18] and can be used strategically to reduce risk in key areas, especially in combination with management efforts for healthier forest structure.[19]
- Appendix E: Renewable Natural Gas Potential from Gasifying Deceased Trees in California Forests provides a quantitative estimation of RNG production from gasification of deceased trees.
  - Key point: California's dead trees have the potential to produce 1.7 trillion cubic feet of Renewable Natural Gas through gasification, nearly double SoCalGas' total gas demand in 2018[20] and 80% of California's total natural gas consumption in 2017.[21] While there is currently little infrastructure to support dead tree gasification, dead-tree gasification offers considerable benefits in wildfire resilience, renewable energy generation, and GHG emission and air pollution reduction.

[15] "California's Greenhouse Gas Emission Inventory." Accessed June 26, 2019. https://ww3.arb.ca.gov/cc/inventory/data/data.htm.
[16] VOC reported as methane.
[17] Stephens, Scott L., et al. "Drought, tree mortality, and wildfire in forests adapted to frequent fire." Bioscience 68.2 (2018): 77-88. https://www.fs.fed.us/psw/publications/fettig/psw_2018_fettig002_stephens.pdf.
[18] Martinson, Erik J., and Philip N. Omi. "Fuel treatments and fire severity: a meta-analysis." Res. Pap. RMRS-RP-103WWW. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 38 p. 103 (2013), https://www.fs.fed.us/rm/pubs/rmrs_rp103.pdf.
[19] Stephens, Scott L., et al. "Drought, tree mortality, and wildfire in forests adapted to frequent fire." Bioscience 68.2 (2018): 77-88. https://www.fs.fed.us/psw/publications/fettig/psw_2018_fettig002_stephens.pdf.
[20] California Gas and Electric Utilities. 2018. 2018 California Gas Report. Available at: https://www.socalgas.com/regulatory/documents/cgr/2018_California_Gas_Report.pdf.
[21] U.S. Energy Information Administration. 2019. Natural Gas Consumption by End Use. Available at: https://www.eia.gov/dnav/ng/NG_CONS_SUM_A_EPG0_VC0_MMCF_A.htm.

CHAPTER 2
Overview of Events

This chapter provides a brief summary of each of the natural disasters covered in this report, organized by chronological order (Figure 1). Key information includes when the event occurred, standout features of the event, which areas were affected—including the coverage of FEMA disaster declarations—and power utilities serving the affected area. Chapter 3 provides a deeper discussion on how each event impacted key sectors and examples of resilience.

Figure 1. The seven events covered in this report include California wildfires and associated mudslides, Winter Storm Uri, Hurricane Harvey, Hurricane Michael, and Hurricane Irma.



February 2021 Winter Storm Uri in Texas

Dates: Winter Storm Uri was a major ice storm that affected parts of the southwest United States from February 13-17, 2021.

Standout features: Texas' energy infrastructure was not prepared to withstand sustained freezing temperatures. During the storm, an estimated 246 people lost their lives, at least 4.5 million electricity customers in Texas lost power, and about 12 million people received "boil notices" because of poor water quality that could impact health.[24,25]

As a result of the high demand on the power grid, many Texans went without heat and electricity for days during the storm and were hit with exorbitant power bills in the months following the storm. In the end, Winter Storm Uri caused an estimated $295 billion in economic damages.[26]

Area affected: All 254 counties in Texas and parts of Louisiana were affected. A disaster declaration was issued for the entirety of the state.[27]

A snow-covered street in Austin, Texas on February 15, 2021. Source: Montinique Monroe/Getty Images. [22]

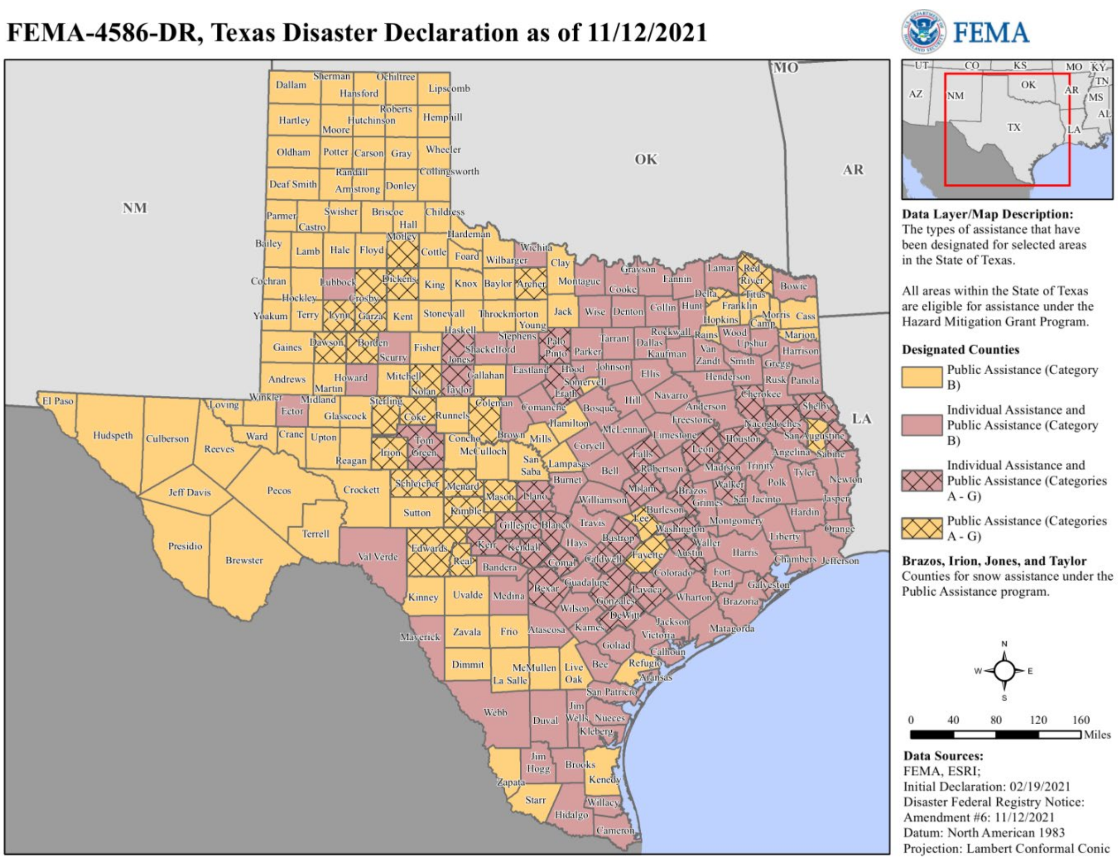
Grocery shoppers in a Houston supermarket on February 21, 2021. Source: Francois Picard/ Getty Images.[23]

[22] Monroe, Montinique. Getty Images. https://www.gettyimages.com/detail/news-photo/people-carry-groceries-from-a-local-gas-station
[23] Picard, Francois. "US-WEATHER-TEXAS." AFP via Getty Images. https://www.gettyimages.com/detail/news-photo/shoppers-are-seen-wandering-next-to-near-empty-shelves
[24] Norton, Kara. 2021. "Why Texas was not prepared for winter storm Uri." *PBS,* March 25, 2021. https://www.pbs.org/wgbh/nova/article/texas-winter-storm-uri/
[25] University of Houston. *Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri.* (Houston: Hobby School of Public Affairs, 2021), https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf
[26] Ibid.
[27] Texas Department of Emergency Management. n.d. "Texas Severe Winter Storm DR-4586." Accessed on July 14, 2022. https://www.tdem.texas.gov/disasters/winter-storm-uri

Utilities: Nearly all elements of the electric energy system were impacted by the freezing temperatures, including energy extraction, storage, delivery, and power generation. Wind turbines iced over, piles of coal froze, and cold temperatures impacted natural gas pipelines and electric generation facilities.[29] A multitude of factors contributed to the failure of the power grid and cascading impacts on transportation, emergency response, and water supply.

Houston residents wait in line to refill propane tanks on February 17, 2021. Source: David J. Phillip/ AP and Shutterstock.[28]

Figure 2. All 254 counties in Texas were included in FEMA's Major Disaster Declaration for Winter Storm Uri.



Source: FEMA.[30]

[28] Wurzburger, Andrea. "See Photos from the Record-Setting Winter Storm Uri: Its Impact on Texas and Beyond." *People,* February 21, 2021. https://people.com/human-interest/winter-storm-texas-snow-photos/?amp=true
[29] De Lune, Marcy and Amanda Drane. 2021." Bitter cold deepens state's power crisis", *Houston Chronicle*, February 16, 2021. https://www.houstonchronicle.com/business/energy/article/Power-tight-across-Texas-winter-storm-blackouts-15953686.php
[30] FEMA. 2021. "Winter Storm Uri (DR-4586)." February 19, 2021. https://www.fema.gov/disaster/4586.

Summary of Impacts and Resilience

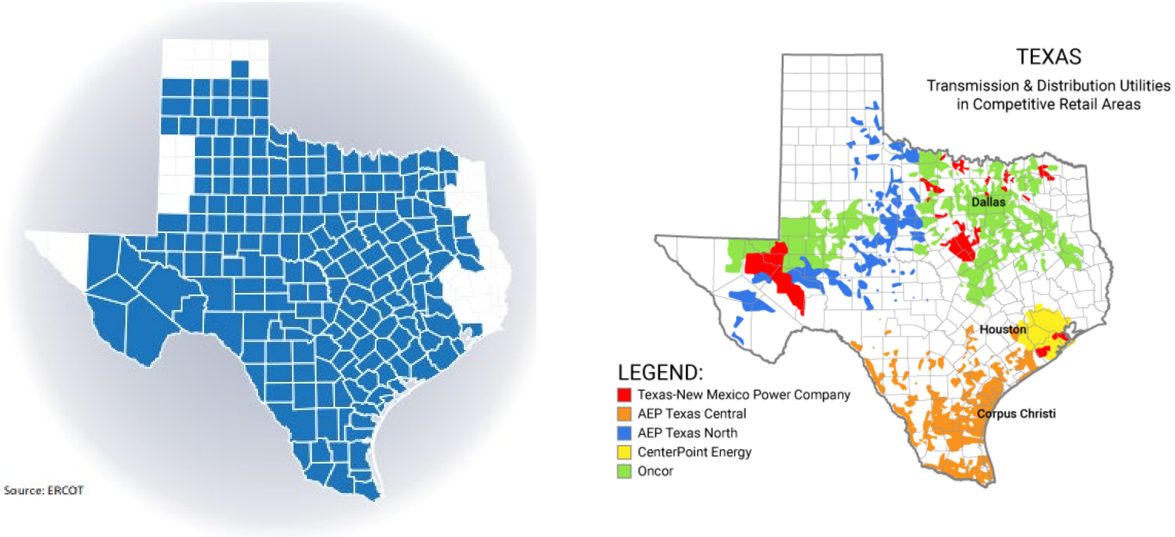
The following sections detail the events of Winter Storm Uri and compounding impacts on energy systems, water services, transportation, and communities. Each section provides examples of resilience and highlights gaps for future improvements. Note that this narrative is provided here for Winter Storm Uri as part of the 2022 updates to this report; narratives on impacts and resilience for the other events are provided in Chapter 3 below.

Overview of Texas's Energy System

Several factors contributed to the power crisis that occurred during Winter Storm Uri. Chief among these were a lack of winterization for most Texas energy infrastructure and Texas's independent power grid, which made it difficult to import power from other states. The following sections describe the causes of the power crisis and the impact of the storm on electricity and natural gas.

Texas is the only state in the U.S. with a power grid that is largely isolated from the rest of the U.S. The grid is managed by the Electric Reliability Council of Texas (ERCOT) and supplies electricity to 25 million customers, or 90% of all residential homes and businesses within the state (Figure 3). Texans outside of ERCOT are served by the Midcontinent Independent System Operator (MISO) and the Southeast Power Pool (SPP). As a state grid, ERCOT is not subject to requirements set by the Federal Energy Regulation Commission (FERC), including regulations to winterize equipment and maintain a minimum reserve capacity.[31]

Figure 3. ERCOT grid coverage by county (left)[32] and transmission and distribution company service areas (right).[33]



ERCOT does not have its own grid infrastructure, relying instead on power generation companies, electric utilities, and transmission and distribution utility (TDU) companies that participate in the deregulated market.[34] Customers purchase power from retail electricity providers (REPs), who

[31] University of Houston. *Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri.* (Houston: Hobby School of Public Affairs, 2021), https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf
[32] ERCOT. "Maps." n.d. Accessed on April 20, 2022 from https://www.ercot.com/news/mediakit/maps/.
[33] Direct Energy. n.d. "Who is My Texas Electric Utility Company?" Accessed on May 2, 2022 from https://www.directenergy.com/learning-center/who-is-my-texas-electric-utility.
[34] Hegar, Glenn. 2021. "Winter Strom Uri 2021." *Fiscal Notes*, October 2021.

compete to buy power from the grid.[35] ERCOT manages over 1,800 active market participants that generate, distribute, and sell electricity. Though highly interdependent, natural gas and electricity are regulated by different agencies: the Texas Railroad Commission (RRC) oversees natural gas and the Public Utilities Commission of Texas (PUCT) oversees the electricity industry, including TDUs and ERCOT.[36]

Texas is the largest producer and consumer of natural gas in the U.S. In 2020, the state produced a quarter of the nation's natural gas and accounted for 15% of the natural gas consumed in the U.S.[37] Texas is also the largest producer of electricity in the U.S. In Texas, electricity is largely produced by natural gas (approximately 50%), wind (20%), and coal (20%).[38] Nuclear energy and biogas provide the rest.

Winter Storm Impacts on Texas Energy Supply

Winter Storm Uri was one of the most severe winter storms on record in Texas and caused the greatest loss of power crisis and loss of electricity the state had ever seen.[39] In the days preceding the storm, a major storm developed over North and Central Texas, bringing freezing rain and snow. Temperatures in Texas reached record lows of 6°F in Austin, 8°F in Dallas, and 10°F in Houston.[40] On February 10 and 11, 2021, ERCOT issued an extreme cold weather event advisory and watch, directing generators to review fuel supplies, prepare to preserve fuel, and issue notices in advance of any expected fuel restrictions.[41] Governor Greg Abbott issued a disaster declaration for all 254 counties in Texas on February 12.[42] Between February 10 and 14, freezing infrastructure forced power plants offline, including nuclear reactors, coal and gas generators, and wind farms.[43]

Freezing of generator components was the primary cause of generating unit unavailability during the storm.[44] Over the course of the storm, 1,045 individual generating units (58% natural gas-fired, 27% wind, 6% coal, and 2% solar) collectively experienced 4,124 outages or failures. Of these issues, 75% were caused from complications related to freezing (44.2%) or fuel (31.4%).[45] Extreme winter weather led to freezing of power generation infrastructure, frozen line intakes, and icing on

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[35] Houston Advanced Research Center (HARC). 2021. *Winter Storm Uri's Impacts & Pathways to Resilience in Texas.* https://experience.arcgis.com/experience/cc48fcfebfae414b99b3d18f86c72c27

[36] Energy Institute at the University of Texas at Austin. 2021. "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts." https://www.puc.texas.gov/agency/resources/reports/UTAustinEventsFebruary2021TexasBlackout.pdf.

[37] Energy Information Administration. 2021. "Texas State Profile and Energy Estimates." April 15, 2021. https://www.eia.gov/state/analysis.php?sid=TX

[38] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." Energy Research & Social Science 77 (2021): 102106. https://doi.org/10.1016/j.erss.2021.102106.

[39] Energy Institute at the University of Texas at Austin. 2021. "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts." https://www.puc.texas.gov/agency/resources/reports/UTAustinEventsFebruary2021TexasBlackout.pdf.

[40] FERC, NERC, and Regional Entities* 2021. *The February 2021 Cold Weather Outages in Texas and the South Central United States*. November 16, 2021. https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and

*Regional entities include the Midwest Reliability Organization, Northeast Power Coordinating Council, Reliability First Corporation, SERC Corporation, Texas Reliability Entity and Western Electricity Coordinating Council.

[41] Energy Institute at the University of Texas at Austin. 2021. "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts." https://www.puc.texas.gov/agency/resources/reports/UTAustinEventsFebruary2021TexasBlackout.pdf.

[42] City of Austin and Travis County. *2021 Winter Storm Uri After-Action Review Findings Report.* (Austin: City of Austin and Travis County, 2021). https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf

[43] Sullivan, Brain K. and Naureen S. Malik. 2021. "5 Million Americans Have Lost Power From Texas to North Dakota After Devastating Winter Storm", *Time,* February 15, 2021. https://time.com/5939633/texas-power-outage-blackouts/#:~:text=5%20Million%20Americans%20Have%20Lost,on%20Feb.%2015%2C%202021.

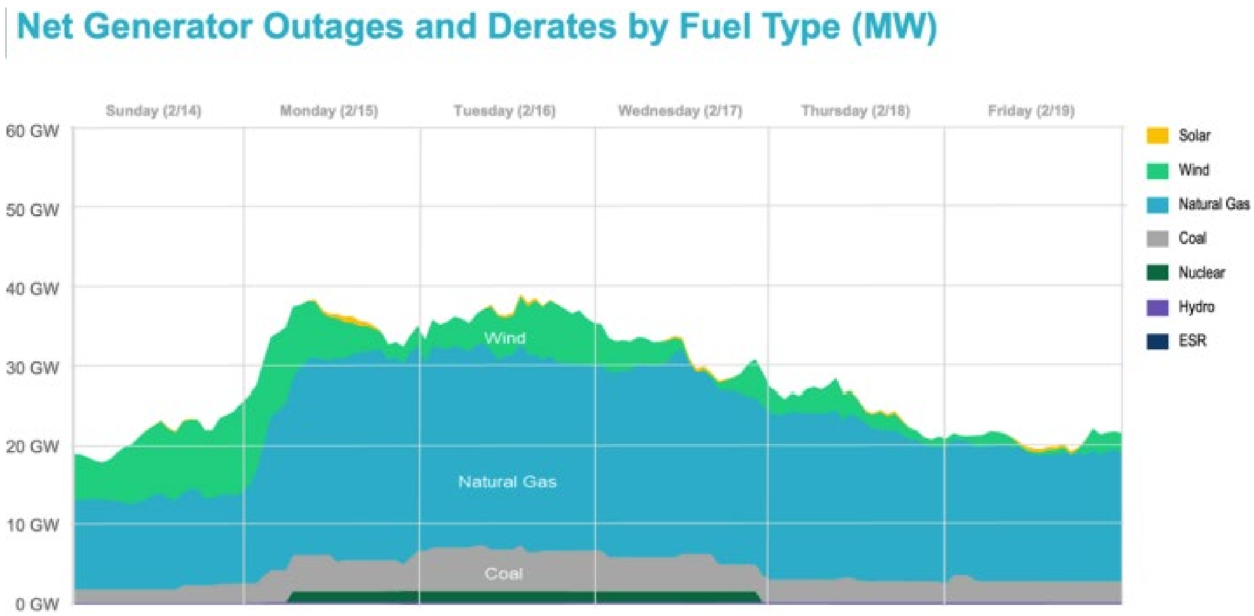
[44] FERC, NERC, and Regional Entities. 2021. *The February 2021 Cold Weather Outages in Texas and the South Central United States*. November 16, 2021. https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and

[45] Ibid.

wind turbines. Of the freeze-related generating unit outages, 81% occurred at temperatures above the units' stated ambient design temperature.[46] In many cases, failures could have been avoided if infrastructure and assets had been winterized for cold weather, but in Texas, infrastructure is typically designed to handle extreme heat rather than extreme cold.[47]

Approximately 87% of utility-scale generator outages caused by fuel issues were related to production and processing of natural gas, while 13% were related to issues with coal and oil. Figure 4 shows the net generator outages by fuel type. The power outages fed into a closed loop cycle that further limited power generation, as facilities that relied on power to operate were forced offline or to reduce load.[48]

Figure 4. Net capacity outages by fuel type from February 14-19, 2021.[49]



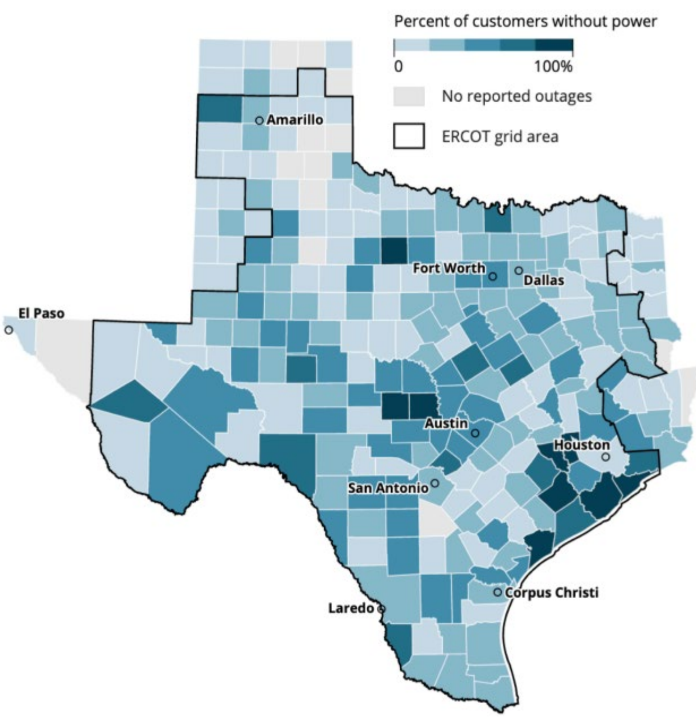
ERCOT plans for extreme events in its seasonal winter resource adequacy assessment. Table 1 compares the actual generation during the event with the expected capacity, both for normal planning and during extreme events. Relative to the planned output for an extreme scenario, gas and coal underperformed, nuclear performed as expected, and wind and solar performed above expectations.[50]

[46] FERC. 2021. *Final Report on February 2021 Freeze Underscores Winterization Recommendations*. November 2016, 2021 https://www.ferc.gov/news-events/news/final-report-february-2021-freeze-underscores-winterization-recommendations.
[47] Norton, Kara. 2021. "Why Texas was not prepared for winter storm Uri." *PBS,* March 25, 2021. https://www.pbs.org/wgbh/nova/article/texas-winter-storm-uri/
[48] Enervus. "Winter Storm Uri – Natural Gas Analysis." April 2022. Prepared for the Texas Gas and Oil Association.
[49] Energy Institute at the University of Texas at Austin. 2021. "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts." https://www.puc.texas.gov/agency/resources/reports/UTAustinEventsFebruary2021TexasBlackout.pdf.
[50] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science* 77 (2021): 102106. https://doi.org/10.1016/j.erss.2021.102106.

Table 1. Comparison of Fuels Sources: Expected Capacity and Actual Generation, Feb. 15 - 19th. Source: ERCOT data compiled by Blake Shaffer.[51]

Fuel Source	Expected Capacity (GW)	Extreme Scenario Capacity (GW)	Actual Average Generation (GW)	% Deficit (from Expected Capacity)	Deficit Extreme Scenario (GW)	% Deficit (from Extreme Scenario Capacity)
Gas	48.4	38.4	30.3	-37%	8.1	-21%
Coal	13.6	10.8	7.8	-43%	3	-28%
Wind	7.1	1.8	3.8	-46%	-2	111%
Nuclear	5.2	4.1	4.1	-21%	0	0%
Solar	0.3	0.3	0.77	157%	-0.47	157%

Figure 5. Power outages on February 16, 2021.[52]



To ration the energy supply, ERCOT began ordering rotating outages of electricity for consumers, a practice called "load shedding."

During the period of load shedding, the grid's frequency declined significantly, reaching a low of 59.4 hertz, a frequency low enough that there was a significant risk of grid collapse if operators

[51] Ibid.
[52] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science* 77 (2021): 102106. https://doi.org/10.1016/j.erss.2021.102106.

were not able to reverse the decline.[53] ERCOT averted the collapse by ordering more load to be shed, helping the frequency to recover. The load shedding caused power outages throughout ERCOT's service area. Usually, these outages are rotated on a frequent basis, so no customer is without power for more than an hour, but generation shortfalls were so large that, in many cases, available power was reserved for critical infrastructure, such as hospitals and fire stations.[54]

Grid Close to Collapse

During the period of load shedding, the grid's frequency declined to 59.4 hertz, a frequency low enough that there was a significant risk of grid collapse if operators were not able to reverse the decline.

Over the course of the storm, more than 9.9 million people in the United States and Mexico lost power, including 4.5 million homes and businesses in Texas (Figure 5).[55] At first the rotating blackouts lasted 10 to 40 minutes, but some lasted 48 hours or more, leaving households without heat and electricity during record cold temperatures.[56]

The storm resulted in increased demand at the same time power supply was becoming increasingly restricted. As temperatures dropped, the cold resulted in historically high customer demand. Before the storm, ERCOT's worst case scenario for power demand was approximately 67,200 megawatts. However, due to the cold temperatures, demand reached 69,150 megawatts on February 14. [57]

ERCOT and the PUC drastically raised electricity prices to $9,000 per megawatt hour, leading to rapid inflation of the electricity market. In 2020, Texans spent $9.8 billion total on electricity. On February 16, 2021 alone, they spent approximately $10.3 billion, and electricity costs for all of February reached more than $50 billion.[58] The Texas legislature issued bonds to pay back some of these costs that result in the equivalent of $200 for every Texas resident.[59]

Natural Gas

As of 2020, natural gas accounted for half of Texas' power and supplied 46% of the energy Texans use to heat their homes.[60] In Texas, about 40% of homes are heated with natural gas and the remaining 60% with electricity.[61] During the summer, natural gas is used by power plants to generate electricity to power air conditioning and stoves for cooking. In the winter, natural gas is also used for cooking as well as for heating homes and buildings and providing fuel for electricity. Usually, the

[53] Gold, Russell. "The Texas Electric Grid Failure Was a Warm-Up." *Texas Monthly*, January 18, 2022. https://www.texasmonthly.com/news-politics/texas-electric-grid-failure-warm-up/
[54] Joshua W. Busby, Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, Michael E. Webber (2021), Cascading risks: Understanding the 2021 winter blackout in Texas, Energy Research & Social Science, Volume 77, 2021,102106, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2021.102106.
[55] Sullivan, Brain K. and Naureen S. Malik. 2021. "5 Million Americans Have Lost Power From Texas to North Dakota After Devastating Winter Storm." *Time*, February 15, 2021. https://time.com/5939633/texas-power-outage-blackouts/.
[56] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. 2021. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science* 77: 102106. https://doi.org/10.1016/j.erss.2021.102106.
[57] Gold, Russell. "The Texas Electric Grid Failure Was a Warm-Up." *Texas Monthly*, January 18, 2022. https://www.texasmonthly.com/news-politics/texas-electric-grid-failure-warm-up/
[58] Ibid.
[59] Ibid.
[60] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. 2021. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science* 77: 102106. https://doi.org/10.1016/j.erss.2021.102106.
[61] Zelinksi, Andrea. 2021. "What Went Wrong With Texas's Main Electric Grid and Could It Have Been Prevented?" *Texas Monthly,* February 17, 2021. https://www.texasmonthly.com/news-politics/what-went-wrong-with-texass-main-electric-grid-and-could-it-have-been-prevented/

demand for air conditioning in the summer is greater than the demand for heat in the winter, but during the storm demand for natural gas to both heat homes and generate electricity skyrocketed.[62]

Natural gas was available throughout the storm, but infrastructure damage and electric power interruptions impacted the ability of natural gas infrastructure to deliver gas to generation facilities. Freezing temperatures during Winter Storm Uri led to natural gas infrastructure damage and shut down 38 of Texas's 176 gas processing plants.[63] Ice prevented flow to wellheads via plugging[64] starting as early as the week before the storm.[65] However, residential customers still had access to their gas service.

By February 16, natural gas production in Texas and the south-central U.S. had declined 30% from average due to wellhead freezes and processing plant shutoffs.[66] The Energy Information Administration reported that Texas natural gas production fell almost by half during the storm, from 21.3 billion cubic feet per day (Bcfd) during the week ending February 13, to about 11.8 Bcfd at its lowest point on February 17.[67] Natural gas fuel supply issues represented 27% of all generating unit outages during the event.[68] Despite these shutoffs, natural gas still supplied most of Texas' power during the storm.

Power outages also created issues in getting the gas to the generation facilities. Most of the natural gas in Texas is sourced from the Permian Basin, which produces a type of gas known as "associated gas," a by-product of shale oil.[69] The production process for associated natural gas is different than for deliverable natural gas, which comes from a pressurized gas reservoir and can flow on its own. Associated gas comes to the surface at low pressure and relies on electricity to compress it to be transported to gas plants. During the storm, power outages meant there was no electricity to compress gas into usable products. Reduced natural gas production lowered pressure in pipelines, making it harder for power plants fueled by natural gas to operate.[70] Luckily Texas had a hearty reserve of natural gas in storage facilities: at least 300 billion

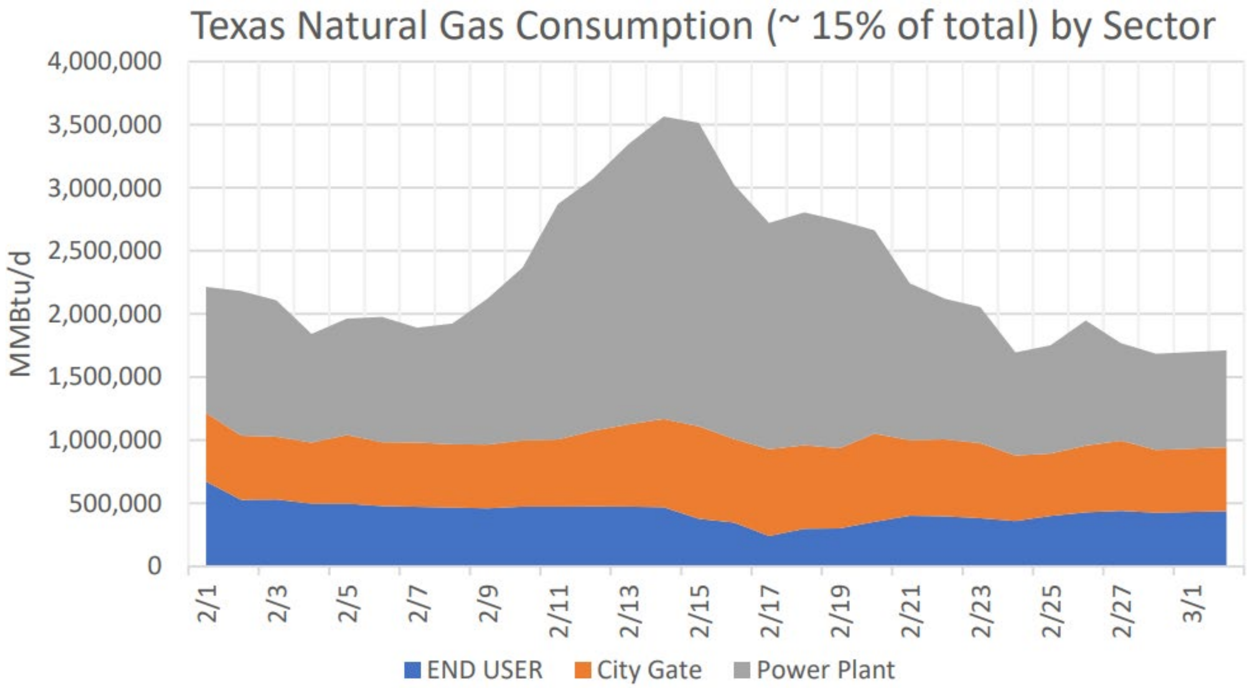
"Associated Gas" More Vulnerable to Disruption

Most of the natural gas in Texas is sourced from the Permian Basin, which produces "associated gas," a by-product of shale oil that requires pressurization via pumps that use electricity and is therefore more vulnerable to disruption than deliverable natural gas which comes from pressurized reservoirs and can flow on its own.

[62] Ibid.
[63] Golding, Garrett, Anil Kumar and Karel Mertens. "Cost of Texas' 2021 Deep Freeze Justifies Weatherization", *Federal Reserve Bank of Dallas*, April 15, 2021. https://www.dallasfed.org/research/economics/2021/0415
[64] A wellhead is a system of spools, valves, and adapters that provide pressure control at an oil or gas well. Source: Schlumberger Oilfield Glossary. Accessed April 15, 2022 from https://glossary.oilfield.slb.com/Terms/w/wellhead.aspx
[65] Wellhead plugging occurs during cold spells when the water produced with natural gas crystallizes inside the pipeline.
[66] Department of Energy. 2021." Extreme Cold & Winter Weather Update #6." February 21, 2021. https://www.energy.gov/sites/prod/files/2021/02/f83/TLP-WHITE_DOE.pdf
[67] Energy Institute at the University of Texas at Austin. 2021. "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts." https://www.puc.texas.gov/agency/resources/reports/UTAustinEventsFebruary2021TexasBlackout.pdf.
[68] FERC, NERC, and Regional Entities. 2021. *The February 2021 Cold Weather Outages in Texas and the South Central United States.* November 16, 2021. https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and
[69] Pickrell, Emily. "Getting The Gas You Need Was A Key Problem For Texas In Storm." *Forbes,* March 5, 2021. https://www.forbes.com/sites/uhenergy/2021/03/05/getting-the-gas-you-need-was-a-key-problem-for-texas-in-storm/?sh=5fdefd081e47
[70] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. 2021. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science*, 77:102106. https://doi.org/10.1016/j.erss.2021.102106.

cubic feet, more than enough to meet energy demand across the state.[71] During the storm, underground natural gas storage facilities were operating at maximum withdrawal rates.[72]

Figure 6. Texas consumption of stored natural gas by sector during Winter Storm Uri.



Data are from storage facilities representing 25% of the state's total number of storage facilities. These storage facilities produce 15% of Texas's natural gas. End users represent industrial customers. City Gate refer to residential, commercial, and small industrial customers.[73]

Power plants and residential, commercial, and small business customers increased their consumption during the storm as industrial users decreased consumption (Figure 6). This corresponds with the Texas Railroad Commission's Emergency Order issued on February 12 to prioritize natural gas for power generation and residential homes.[74]

Natural gas shortages resulted in soaring prices. Prices at the Henry Hub in Louisiana, a major trading point for North America, reached all-time highs of $23.81 MMBtus. The average is around $3.00.[75] Energy Transfer, a Dallas-based pipeline company, was able to provide gas throughout the storm due to winterization efforts that included installing heat tracing on pipeline systems and processing plants. In the days leading up to the storm, additional gas was injected into pipelines as a line pack and steam trucks and steam generators were brought into plants to prevent equipment from freezing.[76]

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[71] Pickrell, Emily. "Getting The Gas You Need Was A Key Problem For Texas In Storm." *Forbes,* March 5, 2021. https://www.forbes.com/sites/uhenergy/2021/03/05/getting-the-gas-you-need-was-a-key-problem-for-texas-in-storm/?sh=5fdefd081e47
[72] Energy Institute at the University of Texas at Austin. 2021. "The Timeline and Events of the February 2021 Texas Electric Grid Blackouts." https://www.puc.texas.gov/agency/resources/reports/UTAustinEventsFebruary2021TexasBlackout.pdf.
[73] Ibid.
[74] Texas Railroad Commission. "Emergency Order." February 12, 2021. https://rrc.texas.gov/media/cw3ewubr/emergency-order-021221-final-signed.pdf
[75] American Gas Association 2014.
[76] Good, Allison. 2021. "$2.4B winter storm windfall drove Energy Transfer's earnings bonanza." *S&P Global Market Intelligence*, May 6, 2021. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/2-4b-winter-storm-windfall-drove-energy-transfer-s-earnings-bonanza-64143456

Petroleum and Petrochemicals

Cold temperatures caused by Winter Storm Uri forced oil refinery shutdowns, rate reductions, and process unit outages. Refinery shutdowns accounted for 20% of all U.S. refinery capacity.[77] U.S. oil production dropped by more than four million barrels per day.[78] Petrochemical plants shut down as they lost power, triggering a global plastics shortage and disruptions in the supply chain.[79] Prices for polyethylene, polypropylene, and other chemicals used to make auto parts, computers, and other plastic products grew higher than they had in years.

Water and Wastewater Services

During the storm, water services were affected due to power outages and extreme cold, compromising water quantity, quality, and availability.

Energy and water are highly interdependent. Water is needed in the production and cooling phases for most energy sources, while water services rely on energy during extraction, treatment, transportation, distribution, and wastewater management and treatment.[80] Power outages at many water treatment plants during the storm meant they were unable to treat and distribute water. This was largely the case for smaller water agencies without backup generation systems, some which took over a week to regain full control of operations after the storm.[81]

Texas residents received mixed messaging about what to do with their water during the storm. Many Texas homes have water pipes in uninsulated areas, such as exterior walls or attics, which makes them more likely to freeze. To prevent freezing, many residents were advised to slowly drip hot water through their pipes. However, the over-dripping of pipes combined with treatment plant failures caused low pressure in the water system and led to low water levels. To conserve water, residents were urged to turn off their taps to conserve water for hospitals and fire departments. Hospitals still lost access to water to supply boilers, leaving the most vulnerable members of the population without heat. At least one hospital transferred high risk patients to other facilities after the water supply was shut off.[82]

Low pressure in the water system increases the risk of bacterial contamination since ground water can seep into cracks in old pipes. Over the course of the storm, more than 2,300 Boil Water Notices were issued affecting 14 million people and the Emergency Operations Center ordered a million gallons of water to be distributed to residents.[83] The notices were lifted on February 22.

Water freezing in pipes causes pipes to swell, crack, or burst. When the water came back on, burst pipes began to leak. Over 31% of Texas homes and businesses suffered water damage. Demand

[77] Department of Energy. 2021." Extreme Cold & Winter Weather Update #6." February 21, 2021. https://www.energy.gov/sites/prod/files/2021/02/f83/TLP-WHITE_DOE.pdf

[78] Presley, Jennifer Lynn. 2021. "Opinion: Texas freeze exposes flaws in energy system." *Upstream,* February 23, 2021. .https://www.upstreamonline.com/opinion/opinion-texas-freeze-exposes-flaws-in-energy-system/2-1-967019

[79] Matthews, Christopher, Austen Hufford and Collin Eaton. 2021 "Texas Freeze Triggers Global Plastics Shortage." *Wall Street Journal,* March 17, 2021. https://www.wsj.com/articles/one-week-texas-freeze-seen-triggering-monthslong-plastics-shortage-11615973401

[80] Houston Advanced Research Center (HARC). Winter Storm Uri's Impacts & Pathways to Resilience in Texas. 2021. https://experience.arcgis.com/experience/cc48fcfebfae414b99b3d18f86c72c27

[81] Glazer, Yael R., Darrel M. Tremaine, Jay L. Banner, Margaret Cook, Robert E. Mace, John Nielsen-Gammon, Emily Grubert, Ken Kramerjj, Anne M. K. Stoner, Briana M. Wyatt, et al. 2021. "Winter Storm Uri: A Test of Texas' Water Infrastructure and Water Resource Resilience to Extreme Winter Weather Events." *World Scientific,* December 31, 2021. https://www.worldscientific.com/doi/epdf/10.1142/S2345737621500226

[82] Helsel, Phil and Yuliya Talmazan. "Texas water shortage adds to power crisis as new winter storm moves in." *U.S. News*, February 17, 2021. https://www.nbcnews.com/news/us-news/texas-contending-water-nightmare-top-power-crisis-n1258208

[83] City of Austin and Travis County. *2021 Winter Storm Uri After-Action Review Findings Report.* (Austin: City of Austin and Travis County, 2021). https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf

for plumbers far outpaced the number available, and supply chain delays meant a shortage of the parts and materials necessary to fix plumbing.[84]

Mobility and Transportation

Extreme winter conditions led to road closures, car accidents, and flight cancellations. Emergency responders lacked the equipment and training necessary to travel in snow and ice. Lack of capacity for emergency vehicles to traverse highways and roads led to delayed emergency response during the storm, an increase in injuries and fatalities, and difficulty in transporting patients to hospitals.

An empty interstate on February 15th in Fort Worth. Credit: Ron Jenkins/Getty.[85]

There were numerous accidents reported on interstate highways. The Austin Fire Department responded to 739 traffic incidents,[86] and a 130-vehicle pileup on I-35 in Fort Worth led to six fatalities.[87]

Roadway closures and a shortage of all-wheel drive vehicles caused disruptions in the supply chain and limited access to transport residents to shelters.[88]

Those who took to the roads had to plan their routes with care, as gasoline was limited due to frozen lines.[89]

Winter conditions forced airlines to cancel over 3,800 flights nationwide. Dallas/Fort Worth, Houston Hobby, and George Bush Intercontinental airports closed their airfields during portions of the storm due to icing on the runway.[90]

Texas Department of Transportation employees worked 12-hour shifts the two weeks of the storm to clear roads, bring medical staff to work, help people reach warming shelters, and respond to requests for aid from Emergency Management departments.[91]

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[84] Agnew, Duncan. "Plumber shortage and supply chain issues are delaying storm recovery efforts in Texas." *Texas Tribune*, February 26, 2021. https://www.texastribune.org/2021/02/26/texas-plumber-shortage-winter-storm/

[85] Wurzburger, Andrea. "See Photos from the Record-Setting Winter Storm Uri: Its Impact on Texas and Beyond." *People,* February 21, 2021. Accessed May 20, 2022. https://people.com/human-interest/winter-storm-texas-snow-photos/?slide=eb22eef3-eddb-4aa7-9fbf-059dfec995f5

[86] City of Austin and Travis County. *2021 Winter Storm Uri After-Action Review Findings Report.* (Austin: City of Austin and Travis County, 2021). https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf

[87] Traffix. "Winter Storms in Texas Disrupt Supply Chains." March 18, 2021. https://traffix.com/blog/winter-storms-in-texas-disrupt-supply-chains.

[88] City of Austin and Travis County. *2021 Winter Storm Uri After-Action Review Findings Report.* (Austin: City of Austin and Travis County, 2021). https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf

[89] Traffix. "Winter Storms in Texas Disrupt Supply Chains." March 18, 2021. https://traffix.com/blog/winter-storms-in-texas-disrupt-supply-chains.

[90] Travel off the Path. "Winter Storm Uri Causes Mass Disruptions – What Travelers Need To Know." February 15, 2021. https://www.traveloffpath.com/winter-storm-uri-causes-mass-disruptions-what-travelers-need-to-know

[91] Texas Department of Transportation. 2021. "TxDOT Responds to the 2021 Winter Storm. Accessed April 19, 2022. https://www.youtube.com/watch?v=CLPnWEq3-Zw

Community Impacts and Support

Millions of Texans suffered from loss of electricity to heat their homes, a lack of clean drinking water, and gasoline limitations. Low-income communities were hit particularly hard since they had fewer resources for relocating, replacing damaged food and property, and paying exorbitant power bills.

Among those Texans who remained in their homes without power, more than one in four (26%) used their gas oven or cooktop as a source of heat, and desperate to avoid hypothermia, 8% used a grill or smoker indoors and 5% used an outdoor propane heater indoors.[92] Using outdoor equipment indoors increased the risk of carbon monoxide poisoning. The Texas Department of State Health reported 450 calls related to carbon monoxide poisoning by February 15 and more than 1,400 people went to emergency rooms or urgent care clinics for carbon monoxide poisoning during the storm.[93] One family lost five members after running a generator in the garage to produce electricity.[94]

The Texas Energy Poverty Research Institute (TERPI) surveyed 953 Texans about their experiences during the storm. Almost 75% lost electricity at some point during the storm, with 33% of respondents indicating losing electricity for more than two days.[95] Residential natural gas service was more reliable, with only 25% of respondents surveyed reported losing gas. However, since many gas furnaces need electricity to operate, many families who had gas service but who had lost power were unable to stay warm.[96]

> **Reliability of Residential Gas Supply**
>
> While approximately three-fourths of customers surveyed lost electric service at some point during the storm, only about one-fourth of customers reported losing gas service.

As described earlier, in addition to losing power, a majority of Texans faced water restrictions. Nearly 65% of respondents from the TERPI survey said they had to boil water at some point, and over 40% went more than two days without clean water. Over 30% of respondents said they did not have running water for two days or longer.[97] A different survey suggested that half of all Texans lost access to running water for an average of 52 hours during the storm.[98] While electricity was restored within days, it took weeks for potable water to be restored in communities served by small water systems.[99] One resident in Pflugerville boiled snow to flush the toilet and to use as reserve drinking water.[100]

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[92] University of Houston. *Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri.* (Houston: Hobby School of Public Affairs, 2021), https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf

[93] Trevizo, Peter, Ren Larson, Lexi Churchill, Mike Hixenbaugh, and Suzy Khimm. "Texas Winter Storm: Worst Carbon Monoxide Poisoning Catastrophe in Recent U.S. History." *Deceleration News,* April 29, 2021. https://deceleration.news/2021/04/29/texas-winter-storm-carbon-monoxide-poisoning/

[94] Berlin, Carly and Amal Ahmed. "Nobody warned Texans about the public health risks of the winter storm." *Southerly,* March 11, 2021. https://southerlymag.org/2021/03/11/nobody-warned-texans-about-the-public-health-risks-of-the-winter-storm/

[95] Jones, Eric, Jacquie Moss and Tam Kemabonta. "Lived Experiences of Winter Storm Uri." *Texas Energy Poverty Research Institute,* March 17, 2021. https://www.txenergypoverty.org/2021/03/blog-lived-experiences-of-winter-storm-uri/

[96] Ibid.

[97] Ibid.

[98] University of Houston. "Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri." *Hobby School of Public Affairs*, https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf

[99] Glazer, Yael R., Darrel M. Tremaine, Jay L. Banner, Margaret Cook, Robert E. Mace, John Nielsen-Gammon, Emily Grubert, Ken Kramerjj, Anne M. K. Stoner, Briana M. Wyatt, et al. 2021. "Winter Storm Uri: A Test of Texas' Water Infrastructure and Water Resource Resilience to Extreme Winter Weather Events." *World Scientific,* December 31, 2021. https://www.worldscientific.com/doi/epdf/10.1142/S2345737621500226

[100] Samuels, Alex. "Nearly 12 million Texans now face water disruptions. The state needs residents to stop dripping taps." *The Texas Tribune*, February 17, 2021. https://www.texastribune.org/2021/02/17/texas-water-boil-notices/

Utility prices rose rapidly in response to fuel shortages and power plant shutoffs. The price of electricity peaked at $9,000 per megawatt-hour, where the week before the storm it had been $30 per megawatt-hour.[101] The price affected Retail Energy Providers, who passed the expenses on to customers who were able to use electricity. One family in Fort Worth was left with less than $100 after a $6,000 energy bill drained their bank accounts.[102] Households without financial safety nets were unable to repair damaged property, relocate when their homes lost heat or pipes burst, and replenish food that spoiled.

Disproportionate Impacts

The impacts from Winter Storm Uri were not distributed evenly throughout Texas. Households least prepared for extreme winter weather, such as those without backup generators or those who live in older poorly insulated homes, were heavily impacted by power outages and water shortages. In cities such as Austin and Houston, electricity was kept on in neighborhoods that share circuits with critical facilities such as hospitals. The areas where power was kept on rarely overlapped with poor communities or predominantly Black or Hispanic communities.[103] Hispanic, Black, and Asian Texans representing 57% of the state's total population suffered 75% of reported carbon monoxide poisonings.[104] During the storm, 76% of African Americans lost power compared to 66% of Anglos.[105] In Houston, there was a strong correlation between the number of building code violations in a neighborhood and the share of Black residents or residents in poverty before the storm, leaving communities of color vulnerable to impacts from extreme cold.[106] Over 200 people died from impacts during the storm, including an 11-year-old boy from Honduras who froze to death after his house lost power.[107] Following Hurricane Harvey in 2017, Black and Latinx residents experienced difficulties accessing city services, making it difficult for them to recover. Houston

Disproportionate Impacts to Communities

Communities of color and low-income communities were less equipped to deal with extreme cold. They disproportionately dealt with freezing indoor temperatures, burst pipes, power outages, and unsafe drinking water. Some households could not afford to replace rotten food or the high price of heat, even if power was available.

[101] University of Houston. *Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri.* (Houston: Hobby School of Public Affairs, 2021), https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf

[102] Associated Press. 2021. "In anti-government Texas, catastrophic storms prompt calls for regulation." *The Guardian*, February 21, 2021. https://www.theguardian.com/us-news/2021/feb/25/texas-regulation-power-grid-winter-storm-blackouts

[103] Ura, Alexa and Juan Pablo Garnhma. "Already hit hard by pandemic, Black and Hispanic communities suffer the blows of an unforgiving winter storm." *Texas Tribune*, February 19, 2021. https://www.texastribune.org/2021/02/19/Texas-winter-storm-suffering-inequities/

[104] Trevizo, Peter, Ren Larson, Lexi Churchill, Mike Hixenbaugh, and Suzy Khimm. "Texas Winter Storm: Worst Carbon Monoxide Poisoning Catastrophe in Recent U.S. History." *Deceleration News,* April 29, 2021. https://deceleration.news/2021/04/29/texas-winter-storm-carbon-monoxide-poisoning/

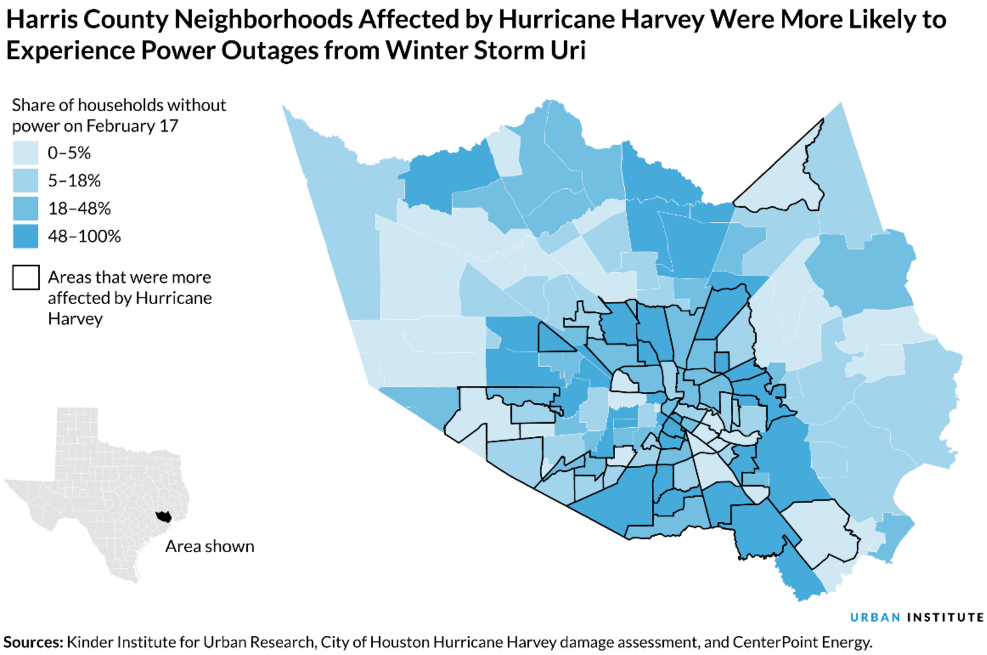
[105] University of Houston. *Reliability and the Texas Power Grid in the Aftermath of Winter Storm Uri.* (Houston: Hobby School of Public Affairs, 2021), https://uh.edu/uh-energy/research/forbes-blog/failure-of-texas-power-grid/content/tegs-report-6-24-2021.pdf

[106] Rodriguez, Sonia Torres, Fay Walker, and Carlos Martin. "Winter Storm Uri's Impacts on Houston Neighborhoods Show Why It's Urgent to Build Equity into Climate Resilience." *Urban Institute,* March 10, 2021. https://www.urban.org/urban-wire/winter-storm-uris-impacts-houston-neighborhoods-show-why-its-urgent-build-equity-climate-resilience

[107] Valentine, Brittany. 2021. "Cristian Pineda's death amid Texas' winter storm crisis didn't have to happen." *Aldia News,* February 23, 2021. https://aldianews.com/politics/policy/preventable-death

neighborhoods with high populations of color were found to also have high rates of building code violations and longer power outages during Winter Storm Uri (Figure 7).[108]

Figure 7. Outage rates on February 17 and neighborhoods affected by Hurricane Harvey in Harris County.



In neighborhoods with above average outage rates on February 17, 16.8% of households had been affected by Hurricane Harvey, compared with 10.5% of households affected in Harris County.[109]

When the extent and frequency of power outages was overlaid with census tracts, researchers found that neighborhoods with long outages were more likely to have multifamily housing, more residents who did not speak English, and more people who rely on public transportation for commuting.[110] Neighborhoods with more renters in Harris County, which encompasses Houston, had long outages lasting until February 19th, when 99% of the county had power restored.[111] Areas with a higher proportion of single-family homes had lower outage rates during the recovery phase. Disadvantaged populations were more likely to live in older homes with outdated plumbing and pipes. A survey found that 38% of low-income respondents experienced burst water pipes, compared to 25% of high-income respondents. Low-income respondents were also more likely to have fallen trees, roof or structural damage, and damaged appliances.[112]

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[108] Rodriguez, Sonia Torres, Fay Walker, and Carlos Martin. "Winter Storm Uri's Impacts on Houston Neighborhoods Show Why It's Urgent to Build Equity into Climate Resilience." *Urban Institute,* March 10, 2021. https://www.urban.org/urban-wire/winter-storm-uris-impacts-houston-neighborhoods-show-why-its-urgent-build-equity-climate-resilience
[109] Ibid.
[110] Nejat, Ali, Laura Solitare, Edward Pettitt. "Equitable Community Resilience: The Case of Winter Storm Uri in Texas." *3rd International Conference on Natural Hazards and Infrastructure,* July 2022. https://www.researchgate.net/publication/357925305_Equitable_Community_Resilience_The_Case_of_Winter_Storm_Uri_in_Texas
[111] Rodriguez, Sonia Torres, Fay Walker, and Carlos Martin. "Winter Storm Uri's Impacts on Houston Neighborhoods Show Why It's Urgent to Build Equity into Climate Resilience." *Urban Institute,* March 10, 2021. https://www.urban.org/urban-wire/winter-storm-uris-impacts-houston-neighborhoods-show-why-its-urgent-build-equity-climate-resilience
[112] Texas Poverty Research Institute. "When the Lone Star Froze Over: Winter Storm Uri and the lived experiences of Texas low-income communities.", July 2021. https://www.txenergypoverty.org/wp-content/uploads/2021/07/When-the-Lone-Star-Froze-Over.pdf

"I have had power off and on, mostly off, for 3 days now in 30-degree weather because TX officials were completely unprepared for a winter storm. I have been lucky enough to have running water and a gas stove, but many are in a far worse position."

— Colin Lowry

The ongoing COVID-19 pandemic exacerbated the impacts of the storm, as low-income communities and communities of color had already been disproportionately affected by the virus and unemployment.[113] Older homes with poor insulation experienced higher electric bills, as they use more energy trying to stay warm. One mother in a majority Hispanic and Black neighborhood of Dallas recounted not having the funds to spend the night in a hotel after sleeping the night before in near-freezing temperatures. Several members of her family had lost their jobs during the pandemic, and over the summer they had gone into debt to cover utilities.[114]

Power outages and water shortages affected the health of vulnerable populations, compounded by the ongoing pandemic. As hospitals lost power, medical centers rushed to administer covid vaccines before they expired.[115] In Houston and Austin, backup generators allowed hospitals to keep running but issues with water pressure and burst pipes prevented some facilities from operating.[116] Nurses were seen gathering rainwater and snow to flush toilets.[117]

Disability Rights Texas, an advocacy group, conducted a survey to understand the impact of Winter Storm Uri on those with disabilities. More than 75% of respondents lost power, which can be devastating for those who rely on battery-powered medical devices such as ventilators and nutrition delivery systems. One mother reported being stranded in her home with three autistic children without power or water, while another was forced to choose which critical life support machines to continue running for her son.[118] Nearly 60% of those surveyed lost access to water, with 80% of the affirmative respondents losing access for more than 24 hours. Water is especially important for those who are immunocompromised as it helps flush toxins and waste to fight disease, and some medications must be taken with water.[119]

[113] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. 2021. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science,* 77:102106. https://doi.org/10.1016/j.erss.2021.102106.
[114] Ura, Alexa and Juan Pablo Garnhma. "Already hit hard by pandemic, Black and Hispanic communities suffer the blows of an unforgiving winter storm." *Texas Tribune*, February 19, 2021. https://www.texastribune.org/2021/02/19/Texas-winter-storm-suffering-inequities/
[115] Sullivan, Brain K. and Naureen S. Malik. 2021. "5 Million Americans Have Lost Power From Texas to North Dakota After Devastating Winter Storm." *Time*, February 15, 2021. https://time.com/5939633/texas-power-outage-blackouts/.
[116] Srikanth, Anagha. "Emergency evacuations now taking place in Texas hospitals because of freezing temperatures." *The Hill*, February 18, 2021. https://thehill.com/changing-america/resilience/natural-disasters/539387-emergency-evacuations-now-taking-place-in-texas/.
[117] Associated Press. "In anti-government Texas, catastrophic storms prompt calls for regulation." *The Guardian,* February 21, 2021. https://www.theguardian.com/us-news/2021/feb/25/texas-regulation-power-grid-winter-storm-blackouts
[118] Disability Rights Texas. n.d. "The Forgotten Faces of Winter Storm Uri: The Impact on Texans with Disabilities When We Fail to Conduct Inclusive Disaster Planning and Preparedness." https://media.disabilityrightstx.org/wp-content/uploads/2021/04/06100917/apr-5-2021-DRTX-winter-survey-report-FINAL.pdf
[119] Ibid.

Examples of Resilience

Building Resilience to Future Winter Storms

Among the actions to build resilience to future winter storms are requirements that all power generators weatherize and install retrofits to withstand extreme cold temperatures, the building of new generating units and the revision of ERCOT reliability standards to require generator owners to identify and protect cold weather components.

Infrastructure failures during the storm revealed several areas for energy resilience improvements. FERC recommended that regulatory agencies require natural gas facilities to maintain and implement cold weather preparedness plans and weatherize infrastructure. Additional recommendations included increasing the flexibility of manual load shedding, real-time monitoring of gas wellheads, increasing the number of emergency response centers, improving near-term load forecasts, analyzing intermittent generation effects to improve load forecasts and improving load shed training for system operators.[120] Two bills approved by the Texas state Senate require all power generators to weatherize, the ERCOT to revise its reliability standards to require generator owners to identify and protect cold weather components, build new generating units and retrofit existing units to withstand specific extreme temperatures, and provide annual training on winterization plans.[121] In January 2022, ERCOT announced that 321 out of 324 electric generation and transmission facilities passed inspection for new winterization requirements.[122] One of the bills, SB3, requires the Texas Department of Public Safety to develop and implement a statewide alert system that ERCOT or the PUC can activate when the power supply is endangered.

The requirement for natural gas facilities is limited to those facilities deemed "critical." Critical facilities include gas wells producing more than 15 Mcf/day, oil leases producing casinghead gas in excess of 50 Mcf/day, gas processing plants, natural gas storage facilities, local distribution pipelines and pipeline facilities, and natural gas pipelines and pipeline facilities including associated compressor stations and control centers.[123] Some research concludes that the gas industry has not escalated efforts to weatherize infrastructure, and little has been done to improve the resiliency of the power grid since the storm, though winter blackouts are expected to happen again.[124] Winterizing equipment costs $20,000 to $50,000 per well, so annual winterizing of Texas's natural gas plants is estimated to cost $85 to $200 million, the equivalent of one or two days of revenue from the gas industry in Texas and 50 times less than the gas industry's profits during the storm.[125]

Efforts to winterize solar panels and wind turbines are ongoing. Winterizing wind turbines includes outfitting blades with internal warming equipment at the factory, which costs $400,000 per unit.

[120] FERC, NERC, and Regional Entities. 2021.The February 2021 Cold Weather Outages in Texas and the South Central United States. November 16, 2021. https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and

[121] Federal Energy Regulatory Commission (FERC). 2021. "February 2021 Cold Weather Grid Operations: Preliminary Findings and Recommendations - Full Presentation." *FERC,* September 23, 2021. https://www.ferc.gov/media/february-2021-cold-weather-grid-operations-preliminary-findings-and-recommendations-full

[122] ERCOT. 2022. "Final Winterization Report: Texas Grid Ready for Winter Weather Operations." January 18, 2022. https://www.ercot.com/news/release?id=50d48648-2119-1c22-e9e9-a32f57650203

[123] McGinnis, David, Cathy Webking, and Eleanor D'Ambrosio. 2022. "RRC's New Rule Designates "Critical Gas Suppliers." *Scott Douglass McConnico*, January 3, 2022. https://www.scottdoug.com/rrcs-new-rule-designates-critical-gas-suppliers/

[124] Gold, Russell. "The Texas Electric Grid Failure Was a Warm-Up." *Texas Monthly*, January 18, 2022. https://www.texasmonthly.com/news-politics/texas-electric-grid-failure-warm-up/

[125] Golding, Garrett, Anil Kumar and Karel Mertens. "Cost of Texas' 2021 Deep Freeze Justifies Weatherization", *Federal Reserve Bank of Dallas*, April 15, 2021. https://www.dallasfed.org/research/economics/2021/0415

Retrofits to Texas' 13,000 existing wind turbines is not feasible since it would require deconstructing each wind turbine, but blade coatings, cold weather lubricants, and de-icing drones can mitigate ice formation for future installations.[126]

Across the state, families found creative ways to stay warm. Those with certain types of gas-powered stoves or fireplaces were able to stay warm even if the power went out.[127] For those without power, community-based organizations rallied to fulfill unmet needs during the storm. The disruption in food supply chains and grocery store closures limited access to food, disproportionately affecting individuals without the resources to travel long distances or who already faced food insecurity.[128] Community-based organizations gave families money for gas, transported families without cars to warming centers, and delivered food. The Catholic Charities Foundation of Forth Worth helped 83 families across North Texas apply for disaster assistance through FEMA and provided over $75,000 to cover hotels, rent, car repairs, and furniture.[129] Other groups identified alternative housing and assisted vulnerable individuals in finding warm shelters.

The American Red Cross of North Texas provided warming stations, information, food, water, and mental health support throughout the storm. More than 300 trained staff worked with community and government partners to provide and distribute meals, blankets, and shelter.[130] Before and during the storm, volunteers distributed 500 cots, 1,000 blankets, 140,000 meals, and 12,000 comfort supplies (e.g., hygiene kits) to those in need.[131] Home and apartment fires increased as people invented ways to stay warm. By the end of February, the Red Cross had responded to 285 fires and helped over 1,400 people, more than double the previous year.[132]

Winter Storm Uri - Technology Solutions for Building Resilience

Residents that had gas service were more likely to be able to keep warm, continue to cook and boil water to make it potable. The following section discusses the resilience characteristics of selected technologies that supply essential functions.

Gas Ranges

About 12 million people received "boil notices" because of poor water quality. ICF conducted a social media listening study and identified residents that had gas stoves and ranges that were able to boil water and cook food during the event.

Older gas ranges with pilot lights continued to function as usual without any specific customer intervention. Although ranges with pilot lights are still available for purchase, many newer gas ranges have electronic igniters which use electricity to ignite the burners. However, these ranges can typically function without electricity. For example, although the oven cannot be used, the stovetop burners of the GE Hotpoint RGBS200DMWW can be used during a power failure as the burners can be lit with a match by following the manufacturer's instructions.[133] It is unclear to what

[126] Ibid.
[127] Halsey, Anne. Twitter Post. February 16, 2021, 3:03 PM. https://twitter.com/anne_halsey/status/1361768250762088449
[128] City of Austin and Travis County. *2021 Winter Storm Uri After-Action Review Findings Report.* (Austin: City of Austin and Travis County, 2021). https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf
[129] Catholic Charities of Fort Worth. "Disaster Response: Reflecting on Winter Storm Uri." *Catholic Charities of Fort Worth,* July 22, 2021. https://catholiccharitiesfortworth.org/disaster-response-reflecting-on-winter-storm-uri/
[130] Hegar, Glenn. 2021."Winter Strom Uri 2021." *Fiscal Notes*, October 2021.
[131] Torres, Leticia. (2021, October). Texans Respond During and After the Storm. *Fiscal Notes.* Retrieved from https://comptroller.texas.gov/economy/fiscal-notes/2021/oct/winter-storm-response.php
[132] Hegar, Glenn. 2021."Winter Strom Uri 2021." *Fiscal Notes*, October 2021.
[133] General Electric. *Thermostat Gas Ranges.* Accessed June 3, 2022. https://products.geappliances.com/MarketingObjectRetrieval/Dispatcher?RequestType=PDF&Name=49-2000315-4.pdf

extent homeowners with electronic gas ranges are aware that the stovetop burners can be used even if there is no electricity.

Several manufacturers offer what are called battery ignition, battery operated or cordless natural gas and propane ranges that do not require AC power and in which the standing pilot light is replaced by an electronic spark igniter. General Electric offers a version of the GE Hotpoint RGBS200DMWW that operates via a 9-volt battery that lasts 3 years. The range can also be lit manually, with a match, if the battery goes out.[134]

It is possible that some residents with electronic gas ranges may not have been aware that even their ranges could be lit manually and thus were not able to benefit from the resilience of natural gas.

Electronic Gas Ranges Resilient to Electric Outages

Even though electronic ranges use electricity for igniting gas, they can function without electricity. Although the oven typically won't work without electricity, the stovetops can be lit with a match if the user follows the manufacturer's instructions. Other ranges use backup batteries to allow them to operate during a power failure.

Heating Systems

Most home heating systems became unavailable due to loss of electrical power either because the system relied on electricity as the primary energy source or because key components of the system required electricity to function. Electric resistance heating and forced air electric furnaces are examples of systems that use electricity as the direct source of energy and thus are unavailable during power outages. Electric heat pumps, gas powered heat pumps, gas furnaces that use blowers to circulate hot air and oil furnaces that use electricity to run a pump are examples of systems that don't use electricity as the primary energy source but require electricity for key components to function and so won't function during power outages.

The social media listening study found posts from several residents that were able to stay warm with gas fireplaces. Although many gas fireplaces use electricity to power functions such as air blowers and remote controls, most manufacturers of gas fireplaces offer battery backup accessories to allow the units to work without electrical power. On battery backup, although functions such as air blowers and remote controls will not be available, the fireplaces can still provide heat via convection. Some manufacturers offer specific units with integrated battery backup such as the "Heatilator" models that have the "IntelliFire" Intermittent Pilot Light system that includes a battery backup to allow the fireplace to run during a power outage.[135]

Gas Fireplaces and Resilience

During Winter Storm Uri, some residents were able to stay warm by using their gas fireplaces. Many gas fireplaces offer battery backup features that allow the fireplace to continue to operate without electricity, although at slightly reduced functionality.

With regard to building resilience against future events, electrical resistance heating and electric furnaces would require higher capacity and more expensive backup generation systems than gas

[134] Ibid.

[135] "Heatilator." Accessed on June 3, 2022. https://www.heatilator.com/

or oil furnaces or a natural gas heat pumps that require electricity mainly to run a fan, a pump or a compressor.

Hot Water Heaters

Hot water heating systems can be powered by electricity or gas. Gas powered systems include tank type and tankless heaters. Tank type heaters have a reservoir of hot water and are available with continuous pilot lights or electronic ignition. Heaters with continuous pilot lights do not require electricity to function and will continue to supply hot water during a power outage. Some heaters with electronic ignition require an external electric supply and will not function during a power outage. For either type of tank type heater, the reservoir can supply hot water for many hours after electric supply is lost. Tankless water heaters supply water on demand and typically have controls that are powered by electricity and consequently will not work during a power outage.

Conclusions – Winter Storm Uri

Cities and counties across Texas are working towards establishing goals and strategies to increase their resilience to extreme weather and storms. For example, the City of Austin Strategic Direction 2023 and Travis County Vision, Mission, and Goals establish pathways to address inequities, foster community engagement, expand preparedness programs, and increase staffing to handle emergency operations.[136] Based on ICF's review of Winter Storm Uri and its impacts, we offer the following recommendations for building resilience to future events:

- Make weatherization a requirement for power plants and critical natural gas facilities. FERC recommendations on weatherization for power plants were advisory. Texas implemented these recommendations with Senate Bill 3 and as of 2022, 98% of power plants were properly winterized. Only natural gas facilities deemed "critical" are required to winterize equipment.
- To ensure adequate supply of natural gas, winterize wellheads, install backup power at compressor stations, and ensure that underground storage facilities maintain a minimum supply (e.g., based on withdrawal during Winter Storm Uri).
- Revise risk assessments to account for future climate change, including increasing frequency of winter storms and heat waves.[137] Include vulnerable populations as a component of this risk assessment to help target subsequent resilience measures to such communities.
- Improve emergency communication and warning systems, especially for non-English speaking households. If warnings had been issued earlier, residents would have had more time to prepare and what to expect.[138]
- Examine adding additional regional interconnections to compensate for future power production shortfalls. Cities in Texas outside of ERCOT's jurisdiction suffered few power outages during the storm because they were connected to other grids.

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[136] City of Austin and Travis County. *2021 Winter Storm Uri After-Action Review Findings Report.* (Austin: City of Austin and Travis County, 2021). https://www.austintexas.gov/sites/default/files/files/HSEM/2021-Winter-Storm-Uri-AAR-Findings-Report.pdf

[137] Smith, Robert. "A Climate Black Swan: The Lessons Learned from Uri." *VettaFi,* March 11, 2021. https://etfdb.com/esg-channel/climate-black-swan-lessons-learned-from-uri/

[138] Busby, Joshua W., Kyri Baker, Morgan D. Bazilian, Alex Q. Gilbert, Emily Grubert, Varun Rai, Joshua D. Rhodes, Sarang Shidore, Caitlin A. Smith, and Michael E. Webber. 2021. "Cascading Risks: Understanding the 2021 Winter Blackout in Texas." *Energy Research & Social Science*, 77:102106. https://doi.org/10.1016/j.erss.2021.102106.

- Require carbon monoxide alarms in all homes. Local governments in Texas have discretion to establish carbon monoxide rules. As a result, many older or single-family homes do not have carbon monoxide alarms.[139]
- Examine ways to make rolling blackouts and power, gas, and water restoration efforts more equitable so that historically disadvantaged communities do not suffer longer losses of service. This may involve mapping population demographics and using these data to help inform blackout and restoration plans and prioritizing backup power or resilience hubs in historically disadvantaged communities.

[139] Trevizo, Peter, Ren Larson, Lexi Churchill, Mike Hixenbaugh, and Suzy Khimm. "Texas Winter Storm: Worst Carbon Monoxide Poisoning Catastrophe in Recent U.S. History." *Deceleration News,* April 29, 2021. https://deceleration.news/2021/04/29/texas-winter-storm-carbon-monoxide-poisoning/

November 2018 Wildfires in Southern California

Dates: On November 9, 2018, Acting Governor Newsom declared a State of Emergency for Los Angeles and Ventura counties, and the federal Emergency Declaration was also issued on November 9th.

Standout features: The Woolsey Fire destroyed more than 1,500 structures, damaged 341 structures, resulted in three civilian fatalities, and forced close to a quarter million people to evacuate.[142, 143,144] Given the high population density and high value properties, the impact of this fire was especially severe.[145]

Firefighting crews struggled to reach and protect people and properties due to the steep terrain and narrow roads limited access to the affected areas.

Area affected: The Hill Fire started in Camarillo and spread north, burning approximately 4,500 acres and four structures over eight days.[146,147] The Woolsey Fire began south of Simi Valley and burned over 97,000 acres in Ventura and Los Angeles Counties. The Woolsey Fire affected Thousand Oaks, Oak Park, Westlake Village, Agoura Hills, West Hills, Simi Valley, Chatsworth, Bell Canyon, Hidden Hills, Malibu, and Calabasas.[148]

Damages to electric lines along the highway. Image Source: Alejandra Reyes-Velarde | Los Angeles Times.[140]

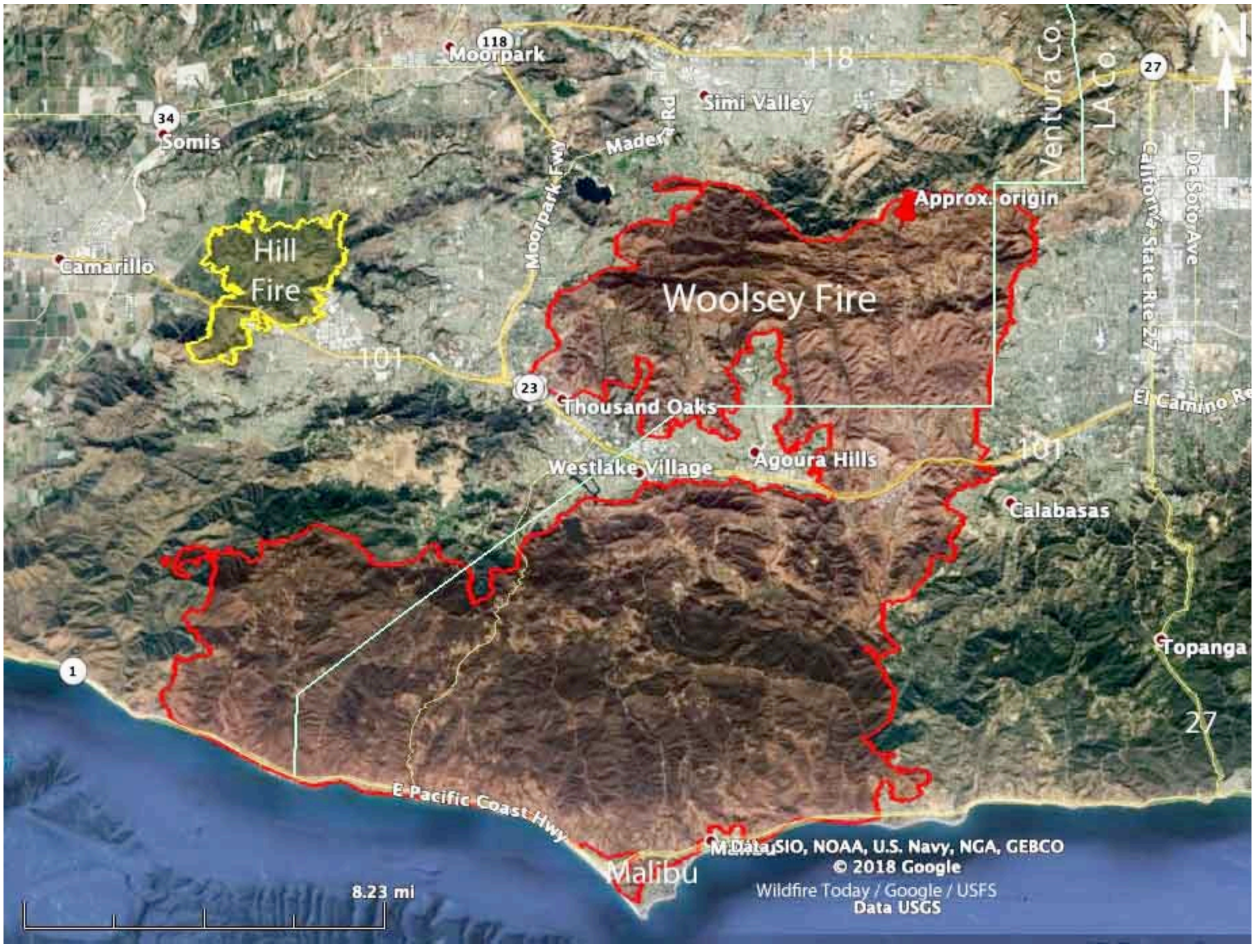
Remains of homes and vehicles in Malibu, CA. Image Source: Frederic Brown | Getty Images.[141]

[140] Reyes-Velarde, Alejandra, November 20, 2018. "Woolsey fire victims file lawsuit against Southern California Edison." *Los Angeles Times*. Retrieved from https://www.latimes.com/local/california/la-me-california-fires-woolsey-hill-camp-victims-of-the-woolsey-fire-file-lawsuit-1542736465-htmlstory.html
[141] Brown, Frederic J./AFP/Getty Images. *LAist*, November 14, 2018. https://laist.com/2018/11/14/this_map_shows_where_homes_have_been_destroyed_and_damaged_by_the_woolsey_and_hill_fires.php
[142] Goodyear, Dana. "Building for Resilience in California's Fire-prone Future." *The New Yorker*, Februrary 19, 2019. https://www.newyorker.com/culture/culture-desk/building-for-resilience-in-californias-fire-prone-future
[143] County of Los Angeles Fire Department, Los Angeles County Sheriff, and Ventura County Fire Department. "Woolsey Fire Incident Update." November 19, 2018. http://cdfdata.fire.ca.gov/pub/cdf/images/incidentfile2282_4307.pdf
[144] Southern California Edison. "Implementation of Emergency Disaster Relief Program for Hill and Woolsey Wildfire Victims Pursuant to Decision 18-08-004." *Advice Letter 3902-E*, November 26, 2018. https://www1.sce.com/NR/sc3/tm2/pdf/3902-E.pdf
[145] Folkman, Chris . "Camp and Woolsey Fires: A Historical and Numerical Perspective. *RMS*, November 19, 2018. https://www.rms.com/blog/2018/11/19/camp-and-woolsey-fires-a-historical-and-numerical-perspective.
[146] CalFire. "Incident Information: Hill Fire." January 4, 2019. http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=2281
[147] Southern California Edison. "Implementation of Emergency Disaster Relief Program for Hill and Woolsey Wildfire Victims Pursuant to Decision 18-08-004." *Advice Letter 3902-E*, November 26, 2018. https://www1.sce.com/NR/sc3/tm2/pdf/3902-E.pdf
[148] County of Los Angeles Fire Department, Los Angeles County Sheriff, and Ventura County Fire Department. "Woolsey Fire Incident Update." November 19, 2018. http://cdfdata.fire.ca.gov/pub/cdf/images/incidentfile2282_4307.pdf

Utilities: Southern California Edison (SCE) is the major electric utility and Southern California Gas (SoCalGas) provides natural gas in the counties affected by the Woolsey and Hill fires. Table 2 provides additional information about key utilities in Los Angeles and Ventura counties, including water and wastewater utilities, although this list is not comprehensive. LADWP provided water to fight the fire from its reservoirs, but its facilities were not affected directly by the fire.[150]

The fire moving in on homes in Malibu, CA. Image Source: David McNew | Getty Images.[149]

Figure 8. The extent of the Hill and Woolsey Fires.

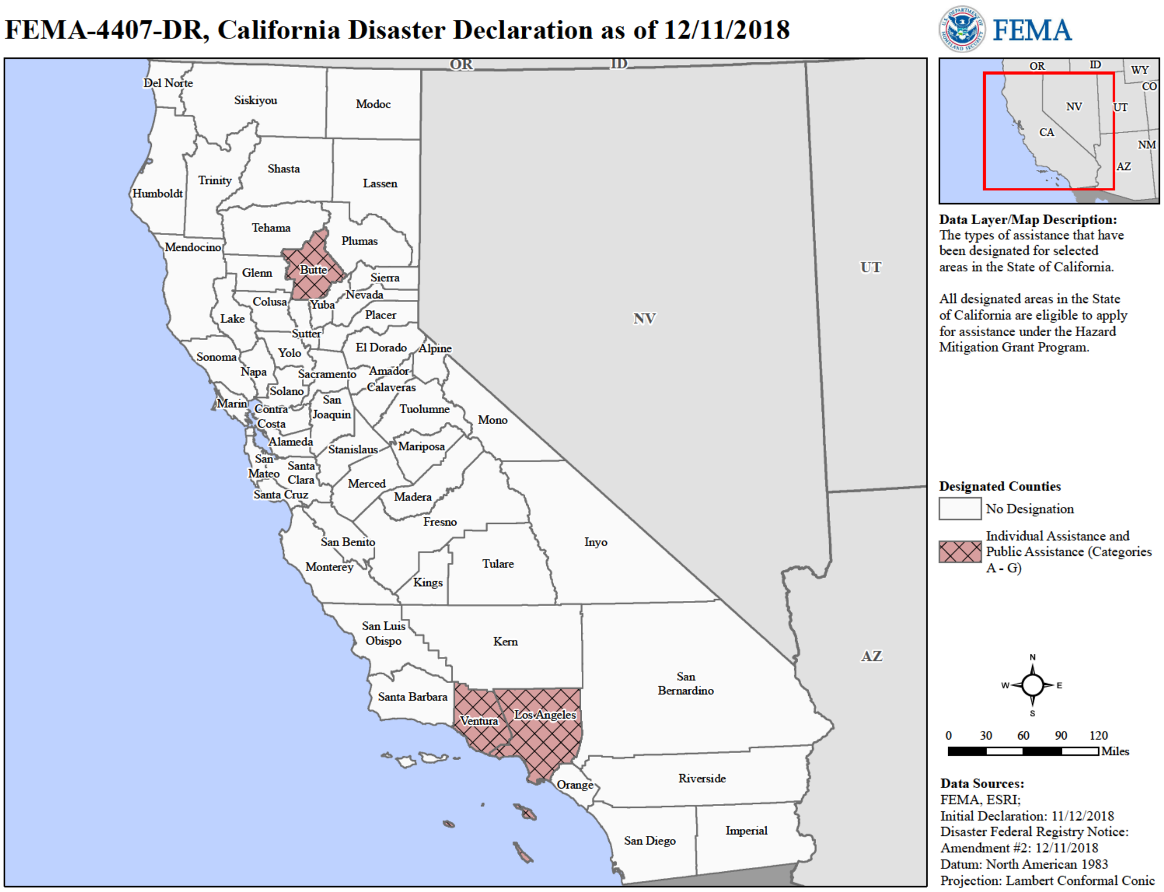


Source: NOAA

[149] McNew, David/Getty Images. *Business Insider*, November 14, 2018.
[150] LA Department of Water and Power. "LADWP's Kittridge Water Tanks & Chatsworth Reservoir Provided Support to Woolsey Fire Response." *LADWP News,* n.d. Accessed June 2019. https://www.ladwpnews.com/ladwps-kittridge-water-tanks-chatsworth-reservoir-provided-support-to-woolsey-fire-response/

While the Woolsey and Hill Fires burned in the south, the Camp Fire broke out in Butte County in Northern California. The Camp Fire became the deadliest and most destructive wildfire in California.[151] This fire was in the PG&E service territory, driven by strong, hot winds, extremely dry conditions, and downed power transmission lines. The fire destroyed the community of Concow and town of Paradise, CA, and residents were evacuated. However, the fire caused at least 85 casualties, making it the deadliest fire in California history.[152]

Figure 9. Counties included in FEMA's Major Disaster Declaration for the November 2018 California wildfires (Woolsey and Hill Fires in Southern California).[153]



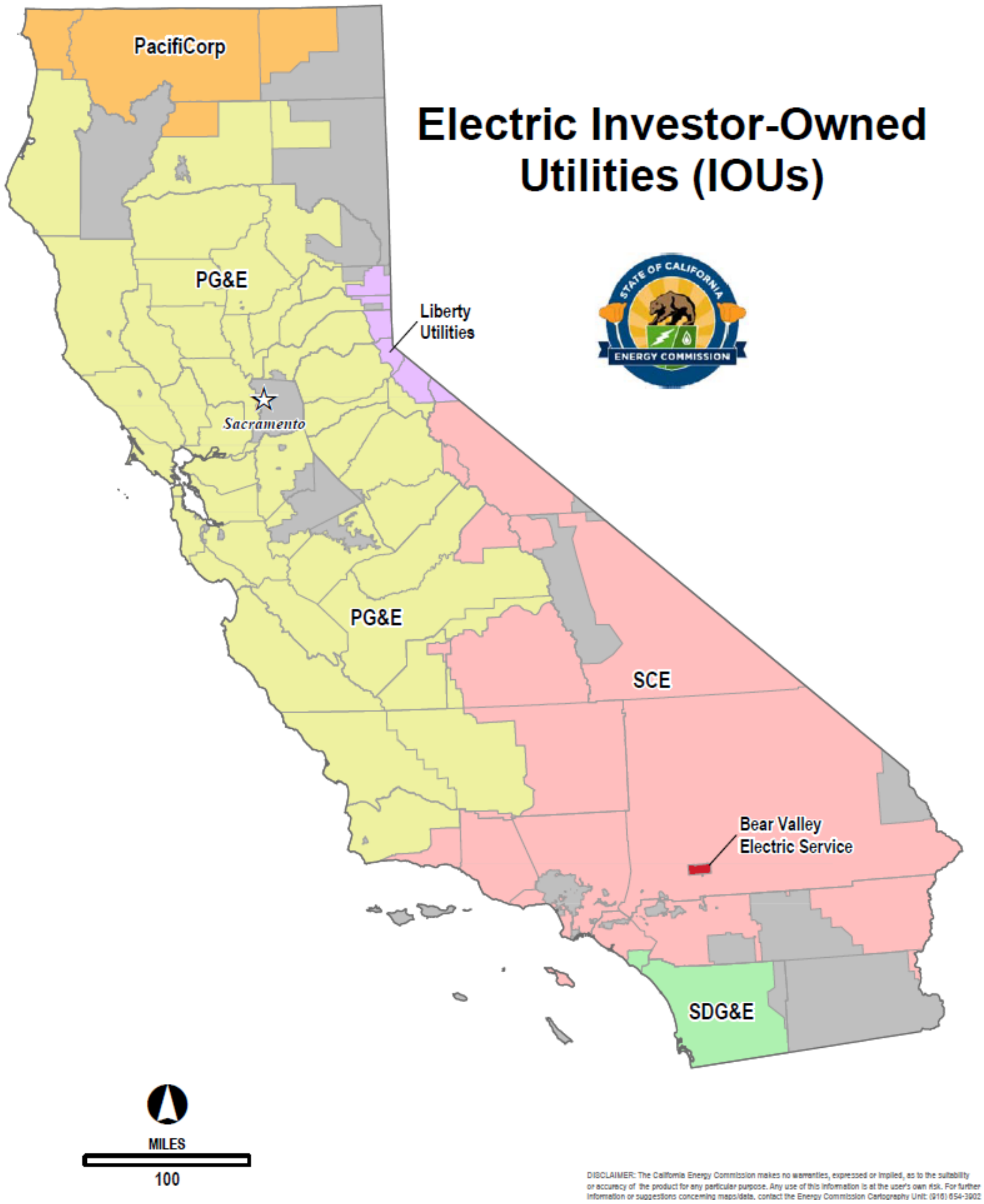
[151] Eavis, P. A. "California Says PG&E Power Lines Caused Camp Fire That Killed 85." *The New York Times*, May 15, 2019. https://www.nytimes.com/2019/05/15/business/pge-fire.html
[152] Cal Fire. "Camp Fire Incident Information." November 8, 2018. http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=2277
[153] FEMA. "California Wildfires (DR-4407)." November 30, 2018. https://www.fema.gov/disaster/4407

Table 2. Relevant California utilities whose service territories overlap with the counties included in FEMA's disaster declaration for the November 2018 wildfires.

Utility	Overview
Los Angeles Department of Water and Power (electric)	• Covers 465 mi^2 • Serves over 4 million residents, with 1.5 million power customers in Los Angeles and 5,000 in the Owens Valley
Southern California Edison (SCE) (electric)	• Serves 180 cities and 15 counties (50,000 mi^2) • Serves Los Angeles and Ventura counties • Provides electricity to 15 million people and 285,000 businesses
Southern California Gas (SoCalGas) (natural gas)	• Serves 21.6 million customers in over 500 communities in central and southern California (20,000 mi^2) • Serves Los Angeles and Ventura counties
Water Service	Ventura County • *Metropolitan Water District* delivers water to 14 cities, 11 municipal water districts, and one county • *Calleguas Municipal Water District* • Calleguas Municipal Water District serves roughly three quarters of Ventura County residents, primarily in the southern part of the county. • City of Thousand Oaks • California – American Water Company • California Water Service Los Angeles • Los Angeles Department of Water & Power • Las Virgenes Municipal Water District • LADWP serves over 4 million residents with 681,000 active service connections[154] • Las Virgenes provides potable water, wastewater treatment, recycled water, and composting for more than 75,000 residents of the cities of Agoura Hills, Calabasas, Hidden Hills, Westlake Village, and unincorporated areas of western Los Angeles County
Wastewater Service	• City of Thousand Oaks • Triunfo Sanitation District (serves Westlake, Lake Sherwood, and part of North Ranch) • Ventura Regional Sanitation District • Triunfo serves approximately 33,000 residents of east Ventura County, including wastewater collection and treatment • Provides sanitation services to more than 600,000 residents of Ventura County
Examples of Resilience	
Natural Gas • SoCalGas initiated Emergency Response Operations Protocol for proactive pressure adjustments ahead of emergency events • Satellite and drone imagery were used to pinpoint impacted pipeline areas Electricity • Mutual assistance programs supported utilities in need of emergency personnel Water/Wastewater • System redundancies allowed for continued water delivery despite damage to assets • Mutual assistance programs supported utilities in need of emergency personnel • Support from state agencies in coordinating response efforts	

[154] LA Department of Water and Power. 2013. "Water: Facts and Figures." https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-factandfigures

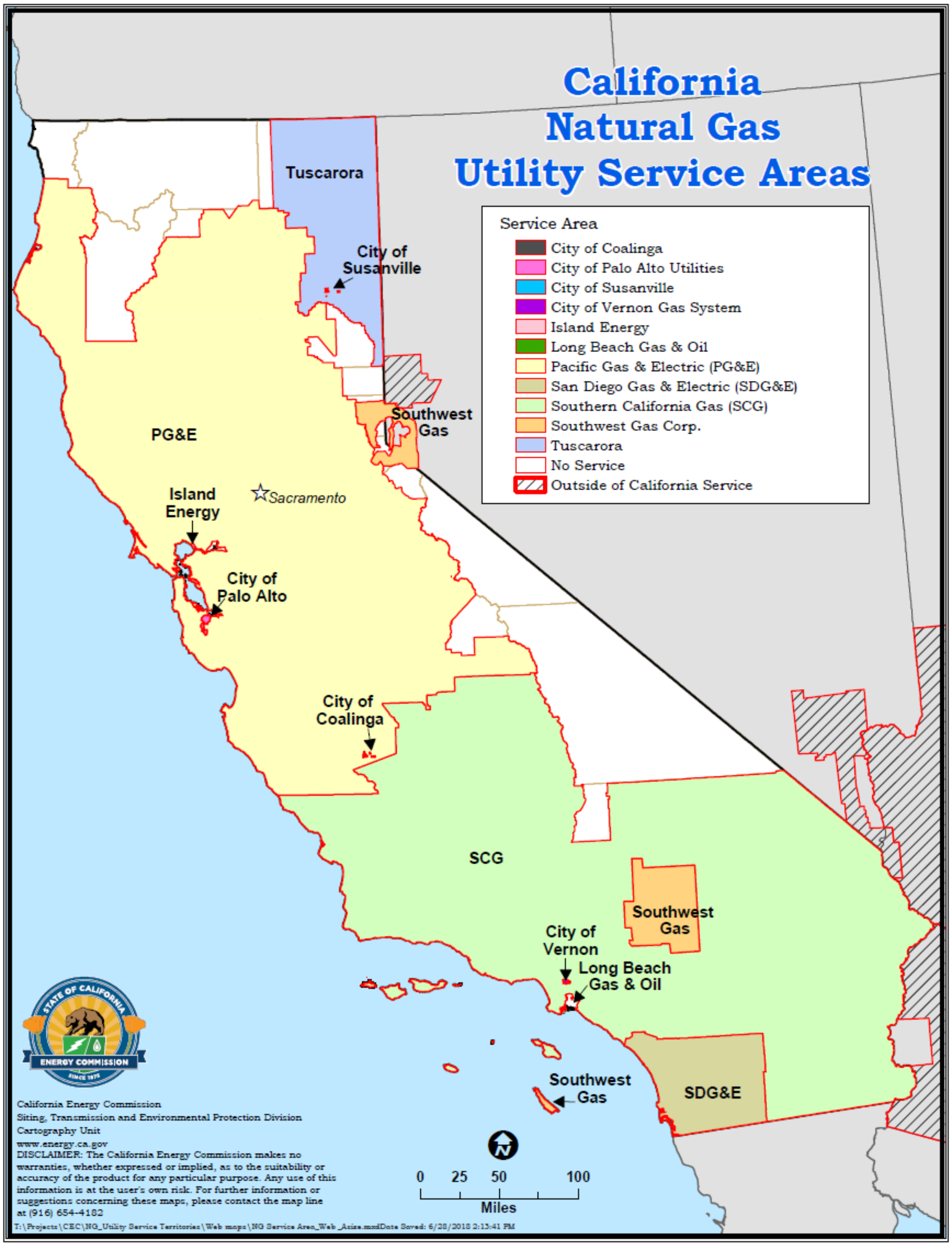
Figure 10. Service territories for California IOUs.



Source: California Energy Commission.[155]

[155] California Energy Commission. 2016. "California's Electric Investor-Owned Utilities (IOUs)." October 24, 2016. https://www.energy.ca.gov/maps/serviceareas/CA_Electric_Investor_Owned_Utilities_IOUs.html

Figure 11. Natural gas utility service areas in California.



Source: California Energy Commission.[156]

[156] California Energy Commission. "California Natural Gas Utility Service Areas Map." June 28, 2018. https://www.energy.ca.gov/maps/serviceareas/naturalgas_service_areas.html

October 2018 Hurricane Michael in Florida

Dates: October 10, 2018 Hurricane Michael made landfall along the Florida panhandle on October 10, 2018 as a Category 5 hurricane.[160]

Standout features: The 160 mph winds ripped through vegetation and infrastructure, leading to at least 45 fatalities and $25 billion in damages.[161] Michael is only the fourth hurricane on record to make landfall in the United States as a Category 5 storm, and the first to do so since Hurricane Andrew in 1992.[162]

Hurricane Michael was one of the costliest weather and climate disasters of 2018 – a year that saw 14 weather and climate disasters with losses each exceeding $1 billion in the United States.[163] Estimated insured losses from Hurricane Michael exceeded $5.5 billion,[164] and FEMA approved over 31,000 individual assistance applications.[165]

Area affected: A stretch of land in the North and Northwestern portion of Florida were hit. FEMA designed 12 counties for individual assistance and 18 counties total in its disaster declaration (Figure 12).

Utilities: Major utilities impacted by Hurricane Michael in Florida include Duke Energy, Emera, Florida Public Utilities, and Southern Co. (Table 3).

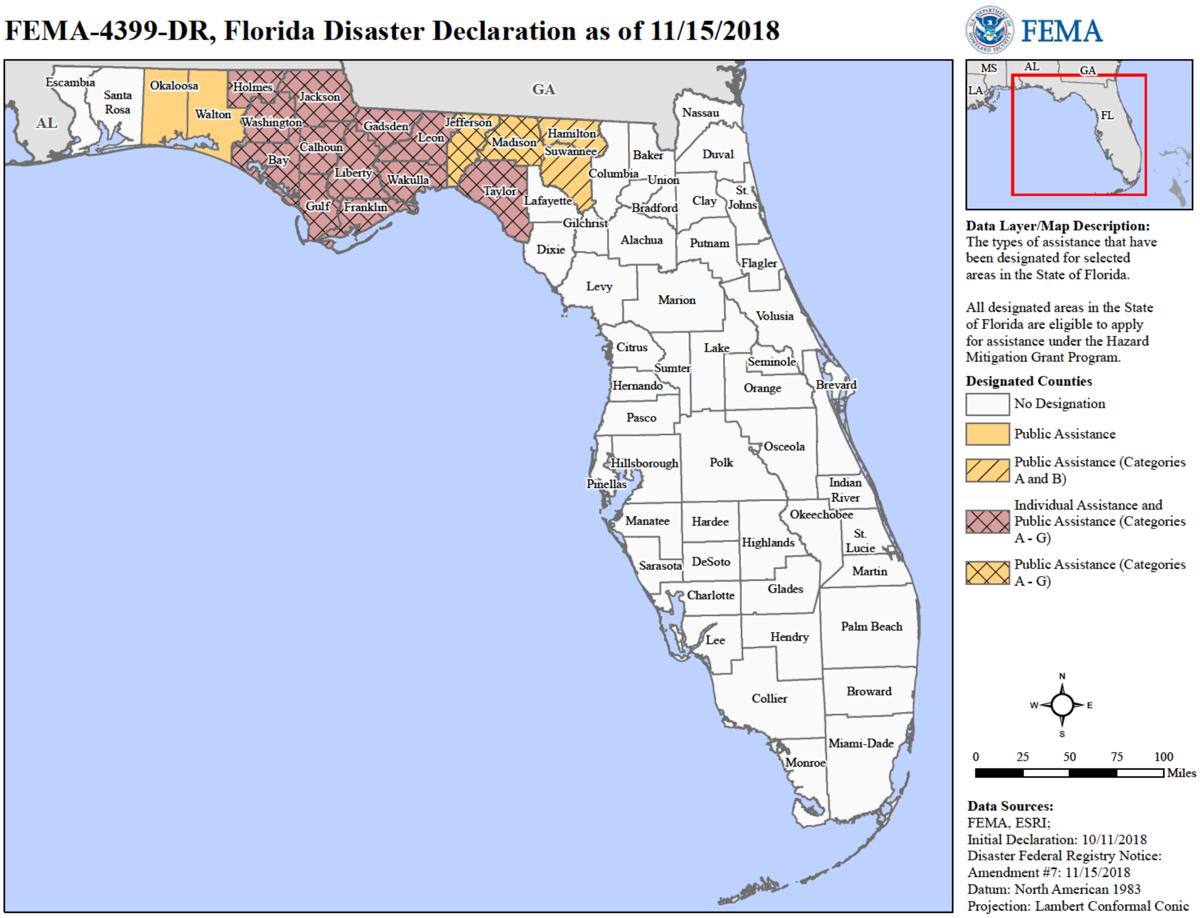
Flooding and destruction in Panama City, Florida. Image source: AP.[157]

Homes destroyed by Hurricane Michael in Panama City, FL. Image source: P.[158]

Flooding and destruction in St. Marks, Florida. Image source: AP.[159]

[157] AP. "Mexico Beach, FL is unrecognizable after Hurricane Michael." *WKYC 3*, October 11, 2018. https://www.wkyc.com/article/news/nation-world/mexico-beach-fl-is-unrecognizable-after-hurricane-michael/507-603416678
[158] Ibid.
[159] Ibid.
[160] NOAA. "Hurricane Michael upgraded to a Category 5 at time of U.S. landfall." *NOAA,* April 19, 2019. https://www.noaa.gov/media-release/hurricane-michael-upgraded-to-category-5-at-time-of-us-landfall
[161] NOAA. "Assessing the U.S. Climate in 2018." *NOAA National Center for Environmental Information,* February 6, 2019. https://www.ncei.noaa.gov/news/national-climate-201812
[162] NOAA. "Hurricane Michael upgraded to a Category 5 at time of U.S. landfall." *NOAA,* April 19, 2019. https://www.noaa.gov/media-release/hurricane-michael-upgraded-to-category-5-at-time-of-us-landfall
[163] NOAA. "Assessing the U.S. Climate in 2018." *NOAA National Center for Environmental Information,* February 6, 2019. https://www.ncei.noaa.gov/news/national-climate-201812.
[164] The News Service of Florida. "Hurricane Michael insured losses near $5.53 billion." *News Herald,* February 7, 2019. https://www.newsherald.com/news/20190207/hurricane-michael-insured-losses-near-553-billion
[165] FEMA. "Florida Hurricane Michael (DR-4399)." October 23, 2018. https://www.fema.gov/disaster/4399

Figure 12. Counties included in FEMA's disaster declaration for Hurricane Michael.



Source: FEMA.[166]

[166] FEMA. "Florida Hurricane Michael (DR-4399)." October 23, 2018. https://www.fema.gov/disaster/4399

Table 3. Relevant Florida natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration.

Utility	Overview
Duke Energy (natural gas and electric)	• Provides electric service to 6 states (95,000 mi^2 total, 13,000 mi^2 in Florida) • 1.6 million natural gas customers (none in Florida) • 8.5 million electric customers (1.9 million in Florida)[167]
Emera (owns Peoples Gas) (natural gas)	• Peoples Gas serves roughly 365,000 customers and natural gas assets include about 11,000 miles of gas mains[168]
Florida Public Utilities (natural gas, electric, and propane)	• Provides natural gas service to 21 counties throughout Florida • Provides electric service to 4 counties in northern Florida[169] • Serves roughly 120,000 customers total[170], including 32,000 electric customers[171]
Southern Co. (owns Gulf Power)	• Southern Co. operates in 9 states, including Florida[172] • Gulf Power serves 8 counties in northwest Florida (7,550 mi^2)[173] • Gulf Power serves 459,000 customers
Examples of Resilience	
Natural Gas • Prompt restoration of service to critical customers Electricity • Mutual assistance programs supported utilities in need of emergency personnel	

[167] Duke Energy. "About Us." Accessed July 19, 2022. https://www.duke-energy.com/our-company/about-us
[168] TECO Peoples Gas. "Our Natural Gas System." Accessed May 31, 2019. https://www.peoplesgas.com/company/ournaturalgassystem/
[169] Florida Public Utilities. "Florida Public Utilities Service Area." Accessed May 31, 2019. https://fpuc.com/customer-service/areas-we-serve/
[170] Florida Public Utilities. "FPU Fact Sheet." May 31, 2019. https://fpuc.com/about/corporate-fact-sheet/
[171] US Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." *EIA Electricity,* January 5, 2019. https://www.eia.gov/electricity/data/eia861/
[172] Southern Company. (2019). *Service Territory: Our Subsidiaries*. Retrieved May 31, 2019, from https://www.southerncompany.com/about-us/our-business/service-territory.html
[173] Gulf Power. "Our Company." Accessed January 2018. https://www.gulfpower.com/about-us/our-company

December 2017 Wildfires and Mudslides in Southern California

Dates: Starting December 4, 2017, 122 wildfires broke out in Southern California, five of which grew into large, fast-moving fires. The state of California put out Declarations of Emergency on December 5 and December 7, 2017, and a federal Emergency Declaration was issued on December 8, 2017, after declaring Fire Management Assistance Declarations from December 5-7, 2017 for the Thomas[176], Creek[177], Rye[178], Skirball[179], and Lilac[180] fires.

Standout features: The Santa Ana winds and critically dry conditions aided the rapid growth and spread of these fires. The state experienced a record for continuous red flag fire conditions, topping at 13 days. On one day, humidity registered as 0%.[181,182] Wildfire scorched 4,100 acres in San Diego County. The Lilac Fire destroyed at least 151 structures and damaged 56 buildings.[183] Ultimately, the Thomas fire grew to be the largest recorded California wildfire, burning 281,893 acres and 1,063 structures.[184] Heavy rains on January 9, 2018, followed this destruction. The lack of vegetation and hydrophobic soils in the wake of the burns, combined with the intensity of precipitation, led to hillside-scouring downpours, resulting in flash flooding and deadly mudslides (Figure 14). Thousands of tons of mud and

Gas crews work a damaged line after an RV was carried by the mudslides into a home. Source: Roa.[174]

Satellite imagery of smoke from the December wildfires. Image Source: NOAA.[175]

[174] Roa, Paul. "Photo Gallery: Mudslide clean up on Country Club Drive." *The LA Times,* January 10, 2018. https://www.latimes.com/socal/burbank-leader/photos/la-mudslide-clean-up-on-country-club-drive-photogallery.html??dssReturn=true.
[175] Liberto, Tom. "December wildfires scorch southern California in 2017." *NOAA Climate.gov*, December 15, 2017. December wildfires scorch southern California in 2017 | NOAA Climate.gov
[176] FEMA. "California Thomas Fire (FM-5224)." December 5, 2017. https://www.fema.gov/disaster/5224.
[177] FEMA. "California Creek Fire (FM-5225)." December 13, 2017. https://www.fema.gov/disaster/5225.
[178] FEMA. "California Rye Fire (FM-5226)." December 8, 2017. https://www.fema.gov/disaster/5226.
[179] FEMA. "California Skirball Fire (FM-5227)." December 8, 2017. https://www.fema.gov/disaster/5227.
[180] FEMA. "California Lilac Fire (FM-5228)." December 8, 2017. https://www.fema.gov/disaster/5228.
[181] CPUC. "Fire Safety and Utility Infrastructure En Banc." January 31, 2018. http://www.cpuc.ca.gov/2018FireEnBanc/
[182] Tchekmedyian, Alene; Melissa Etehad and Javier Panzar. "As Montecito cleanup continues, a search for where to dump thousands of tons of mud." *Los Angeles Times,* January 17, 2018. http://www.latimes.com/local/lanow/la-me-ln-montecito-mud-20180117-story.html
[183] Nikolewski, R. "California fires: SDG&E expects to fully restore power Tuesday." *The San Diego Union Tribune*, December 11 2017. https://www.sandiegouniontribune.com/news/public-safety/sd-fi-power-restoration-20171211-story.html
[184] CPUC. "Fire Safety and Utility Infrastructure En Banc." January 31, 2018. http://www.cpuc.ca.gov/2018FireEnBanc/

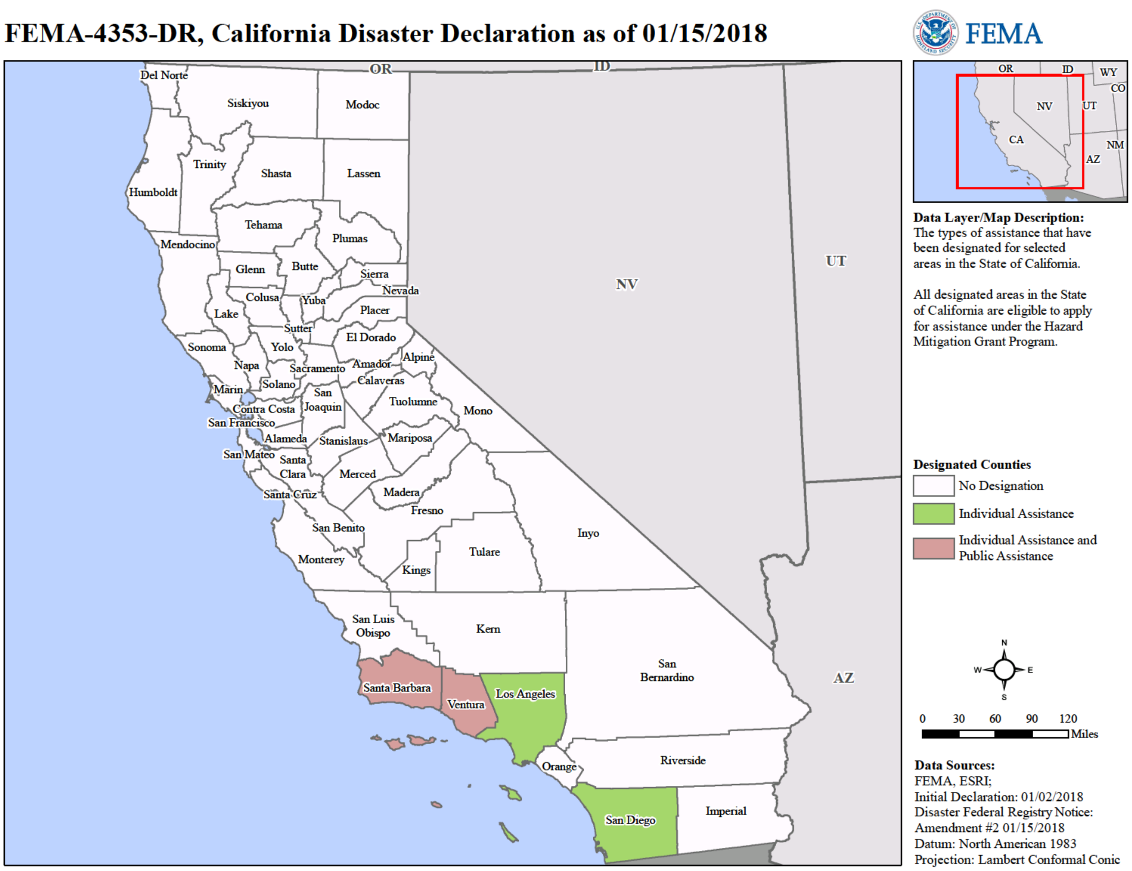
debris swept through the Montecito community, carrying along boulders, cars, and anything else in its path. The disaster destroyed over 100 homes and tragically led to 22 deaths.[185]

Area affected: FEMA expanded the Presidential Major Disaster Declaration in affect for areas damaged by the December 2017 wildfires to include the mud and debris slides.

Utilities: SoCalGas completed its service restoration efforts to available customers in Montecito on January 31, 2018.[186]

Damage to a home on Country Club Drive in Burbank, CA. Image source: Rob Kay/ICF.

Figure 13. Counties included in FEMA's Major Disaster Declaration for the December –January California wildfires, flooding, mudflows and debris flows.



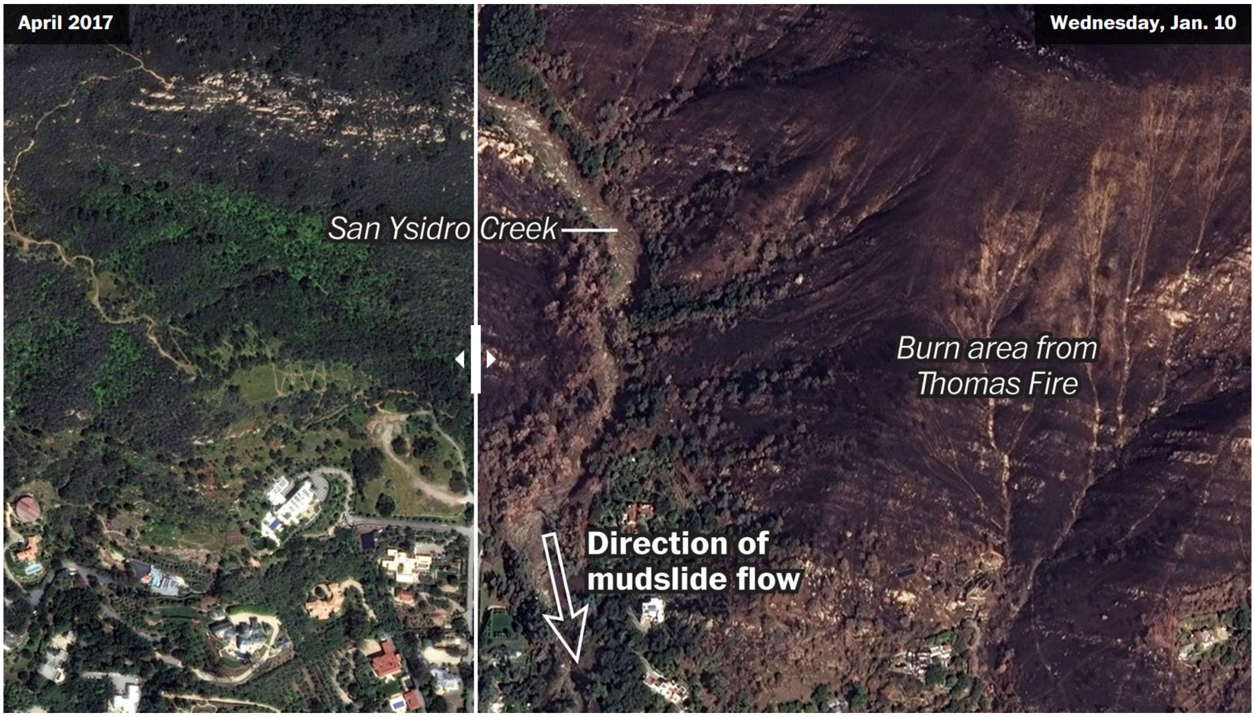
Source: FEMA.[187]

[185] Tchekmedyian, Alene; Melissa Etehad and Javier Panzar. "As Montecito cleanup continues, a search for where to dump thousands of tons of mud." *Los Angeles Times,* January 17, 2018. http://www.latimes.com/local/lanow/la-me-ln-montecito-mud-20180117-story.html

[186] SoCalGas. "Montecito Updates." February 2, 2018. https://www.socalgas.com/cs/Satellite?c=Page&cid=1443741422311&pagename=SoCalGas%2Fscg%2Flayout&rendermode=pre

[187] FEMA. "California Wildfires, Flooding, Mudflows, And Debris Flows (DR-4353)." September 7, 2018. https://www.fema.gov/disaster/4353.

Figure 14. Before and after satellite images of the damage wrought by the Thomas Fire and mudslides in the San Ysidro Creek area.



Source: Karklis, Tierney, & Meko.[188]

[188] Karklis, Laris; Tierney, Laura; and Meko, Tim. "Before and after the mudslides in Montecito." *The Washington Post,* Updated January 19, 2018. https://www.washingtonpost.com/graphics/2018/national/montecito-before-after/?utm_term=.34f49efadc26

Figure 15. Map of Thomas Fire and adjacent fires.

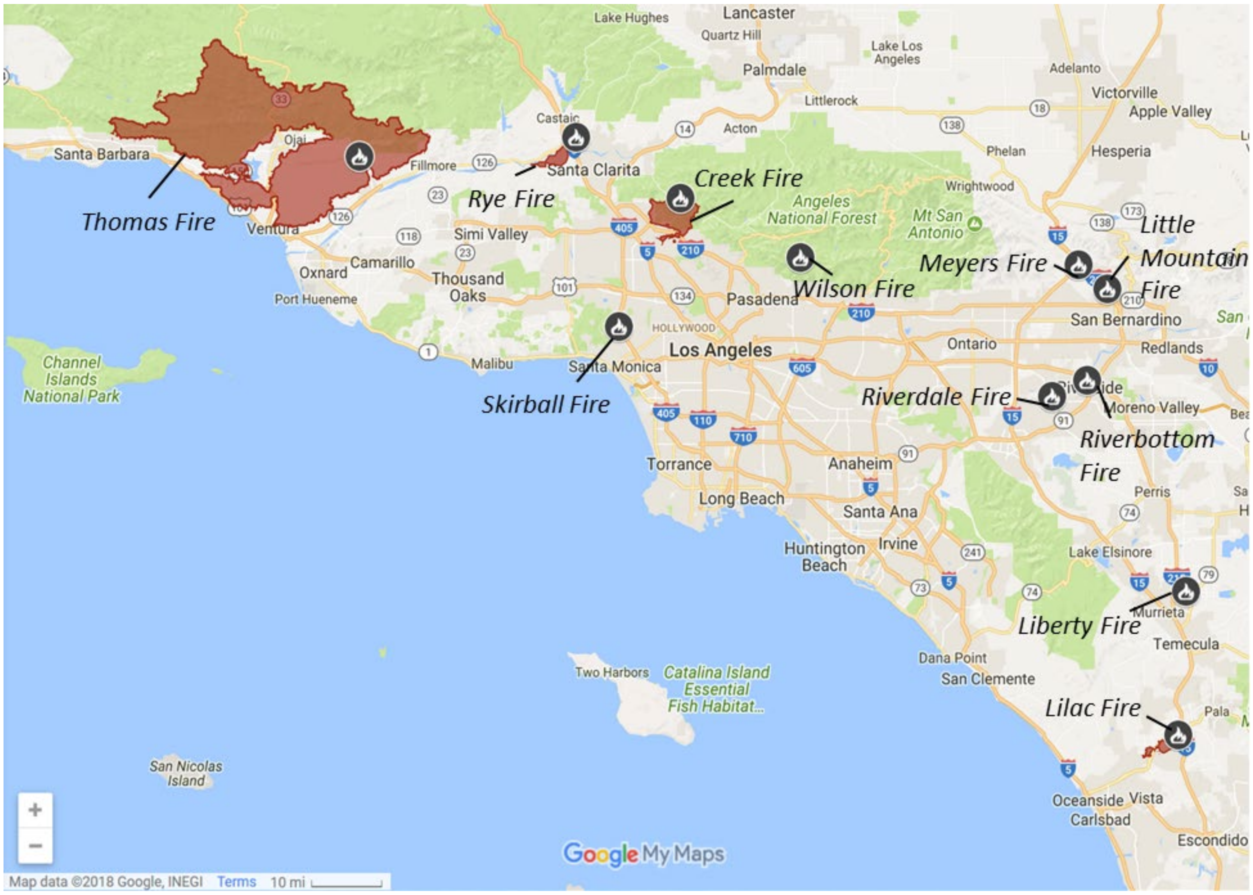


Image courtesy of CalFire. Source: Google Maps.[189]

San Diego Gas and Electric (SDG&E) and Southern California Gas (SoCalGas) are the major natural gas providers in the counties affected by the December wildfires and January mudslides. Pacific Gas and Electric (PG&E), SDG&E, Southern California Edison (SCE), and Los Angeles Department of Water and Power (LADWP) are the major electric utilities for this area (Table 4).

[189] Google Maps. "2017 Statewide Fire Map." https://www.google.com/maps/d/u/0/viewer?ll=33.94353536469569%2C

Table 4. Relevant California natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration for the December-January wildfires and mudslides.

Utility	Overview
San Diego Gas and Electric (SDG&E) (natural gas and electric)	• Service territory includes San Diego and southern Orange counties (4,100 mi^2) • Provides energy service to 3.6 million people
Los Angeles Department of Water and Power (LADWP) (electric)	• Serves over 4 million residents, including 1.5 million power customers in LA and 5,000 in Owens Valley
Pacific Gas and Electric (PG&E) (electric for affected counties)	• Electric service territory stretches from northern to Southern California and includes the Santa Barbara area • Serves 5.4 million electric customer accounts
Southern California Edison (SCE) (electric)	• Serves 180 cities and 15 counties (50,000 mi^2) • Provides electricity to 15 million people and 285,000 businesses
Southern California Gas (SoCalGas) (natural gas)	• Serves over 500 communities in central and Southern California (20,000 mi^2) • Serves 21.6 million customers
Examples of Resilience	
Natural Gas • Automatic shut off valves and advanced meter network avoided potential impacts from breaches during mudslides • Satellite and drone imagery were used to pinpoint impacted pipeline areas Electricity • Mutual assistance programs supported utilities in need of emergency personnel	

October 2017 Wildfires in Northern California

Dates: Starting Sunday, October 8, 2017, multiple conflagrations that finally totaled one hundred and seventy-two wildfires burned northern California. There were ultimately 21 major wildfires that raged through the month of October. On October 9 and 10, 2017, California issued a state emergency declaration, and on October 10 FEMA issued a federal Major Disaster Declaration.[192]

A burned out and collapsed neighborhood in Napa, CA after the Nuns fire. Source: Peter DaSilva/Special to the Chronicle[190]

Standout features: There were ultimately 21 major wildfires that burned a total area greater than 245,000 acres, destroyed an estimated 8,920 structures and damaged an additional 736 structures, taking 44 lives. Four of the October wildfires are now among the top 20 most destructive fires in terms of structures burned in the history of California, with the Tubbs fire alone burning 5,636 structures.

Damage to a hotel in Santa Rosa, California. Source: Adam Grossberg/KQED.[191]

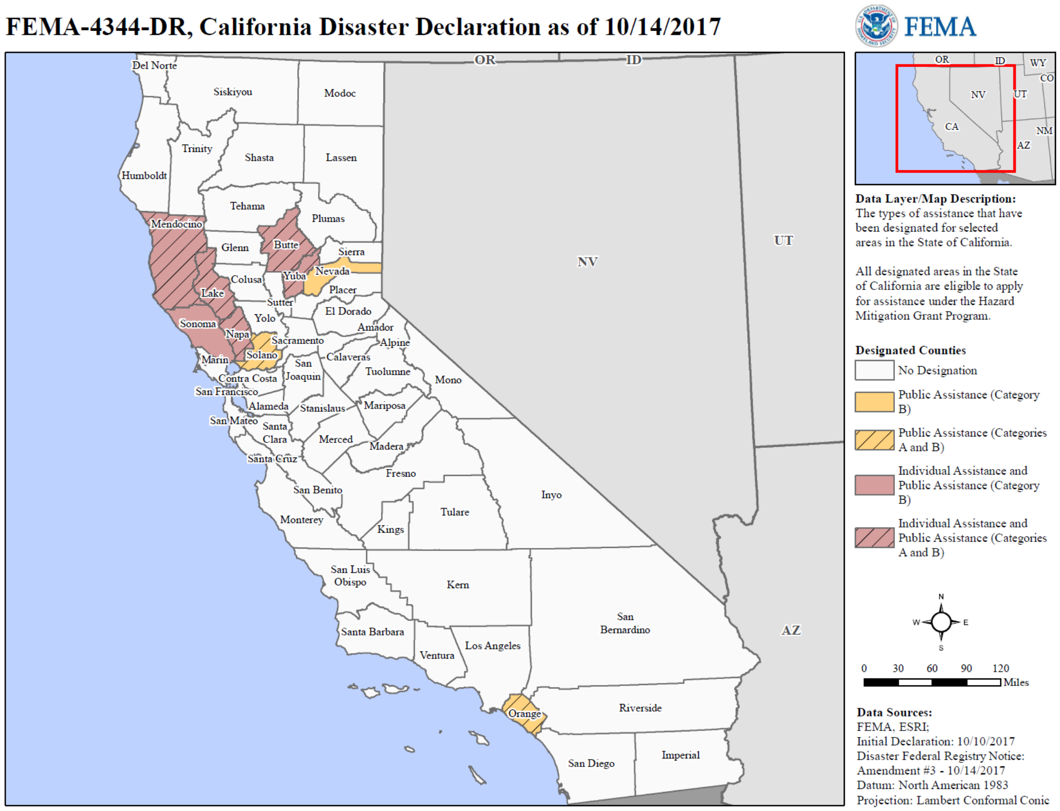
Hurricane Michael was one of the costliest weather and climate disasters of 2018 – a year that saw 14 weather and climate disasters with losses each exceeding $1 billion in the United States.[193] Estimated insured losses from Hurricane Michael exceeded $5.5 billion,[194] and FEMA approved over 31,000 individual assistance applications.[195]

Area affected: A The fires affected Napa, Sonoma, Butte, Humboldt, Mendocino, and Del Norte Counties, as well as in the areas surrounding Grass Valley and Yuba City.

Utilities: The major utility in these affected counties is Pacific Gas and Electric (PG&E), which provides both natural gas and electricity to the area.

[190] Ho, Vivian, Jenna Lyons, and Steve Rubenstein. "Live updates: Firefighter dies in Napa County crash; more evacuations lifted." *SF Gate,* October 16, 2017. http://www.sfgate.com/bayarea/article/Live-updates-4-more-names-of-people-killed-in-12279908.php#photo-14341576
[191] Marks, David. "PHOTOS: Massive Wildfires Tear Through Wine Country." *KQED,* October 9, 2017. https://www.kqed.org/news/11621829/photos-massive-wildfires-tear-through-north-bay
[192] CPUC. "Fire Safety and Utility Infrastructure En Banc." January 31, 2018. http://www.cpuc.ca.gov/2018FireEnBanc/
[193] NOAA. "Assessing the U.S. Climate in 2018." *NOAA National Center for Environmental Information,* February 6, 2019. https://www.ncei.noaa.gov/news/national-climate-201812.
[194] The News Service of Florida. "Hurricane Michael insured losses near $5.53 billion." *News Herald,* February 7, 2019. https://www.newsherald.com/news/20190207/hurricane-michael-insured-losses-near-553-billion
[195] FEMA. "Florida Hurricane Michael (DR-4399)." October 23, 2018. https://www.fema.gov/disaster/4399

Figure 16. Counties included in FEMA's Major Disaster Declaration for the October wildfires.



Source: FEMA[196]

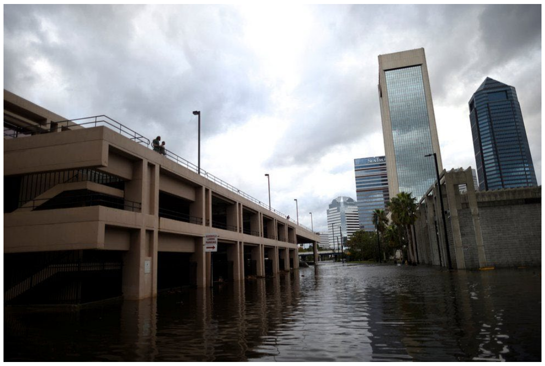
Table 5. Relevant California natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration.

Utility	Overview
Pacific Gas and Electric (PG&E) (natural gas and electricity)	• 70,000 mi^2 natural gas service territory in northern and central California • Serves roughly 16 million people (5.4 million electric customer accounts, 4.3 million natural gas customer accounts)
Examples of Resilience	
Natural Gas • Gas utilities were able to bring semitrailers of gas to specific locations in order to feed systems that needed the natural gas Electricity • Mutual assistance programs supported utilities in need of emergency personnel	

[196] FEMA. California Wildfires (DR-4344). November 7, 2018. https://www.fema.gov/disaster/4344

September 2017 Hurricane Irma in Florida

Dates: Irma made landfall over the Florida Keys on September 10, 2017 as a Category 4 hurricane then again on the coast of Florida later that same day as a Category 3 storm. Ultimately, the incident lasted from September 4 – October 18, 2017.



Flooding in Jacksonville, FL. Source: Reuters.[197]

Standout features: Hurricane Irma approached Florida as a Category 5 hurricane and one of the strongest Atlantic storms on record, with maximum winds of 185 mph sustained over 35 hours. When Irma first made landfall as a Category 4 storm, maximum sustained winds of 130 mph were registered. When it landed on the coast of Florida later that same day as a Category 3 storm Irma had 115 mph winds. By the following day it had weakened to tropical storm status. Florida experienced a record-breaking 5.57 feet of storm surge flooding. Irma was the strongest hurricane to hit the continental United States since Hurricane Katrina in 2005. FEMA approved 771,071 individual assistance applications to help cope with the damage.

Flooding in the Florida Keys. Source: Getty Images.[198]

Area affected: FEMA issued a Major Disaster Declaration on September 10, 2017, for all of Florida (Figure 17). The northeastern Caribbean and Florida Keys experienced widespread damage and flooding.

Damage in Naples, FL. Source: Daniel William McKnight/Polaris.[199]

Utilities: Major utilities impacted by Hurricane Irma in Florida include Duke Energy, Emera, Florida Power and Light, Florida Public Utilities, and Southern Co. (Table 6). Figure 19 shows the geographic distribution of natural gas pipelines and local distribution companies (LDCs) in Florida. Because Irma's path covered nearly all of Florida, it can be reasonably assumed that all pipelines represented in this map experienced the hurricane.

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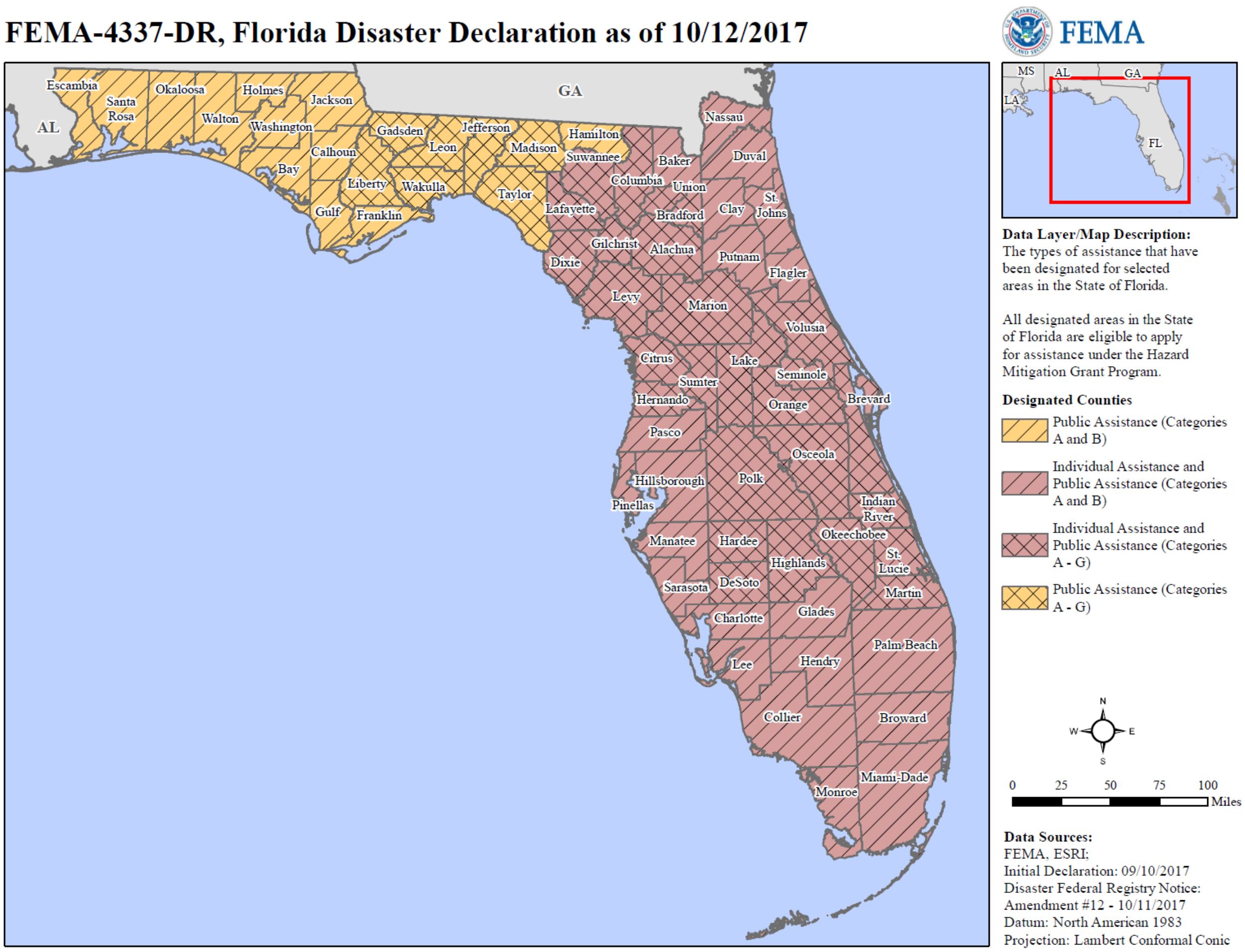
[197] BBC. "Hurricane Irma: Damage mapped." September 12, 2017. https://www.bbc.com/news/world-us-canada-41175312
[198] Ibid.
[199] Shapiro, Emily; Allen, Karma; Jacobo, Julia. "Irma death toll in US climbs to 22 as power is restored to over 2 million Florida customers." 2017, September 12. https://abcnews.go.com/US/irma-death-toll-us-climbs-12-part-florida/story?id=49758372

Figure 17. Counties included in FEMA's disaster declaration for Hurricane Irma.



Source: FEMA.[200]

[200] FEMA. "Florida Hurricane Irma (DR-4337)." October 20, 2017. Accessed February 12, 2018. https://www.fema.gov/disaster/4337

Table 6. Relevant Florida natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration.

Utility	Overview
Duke Energy (natural gas and electric)	• Provides electric service to 6 states (95,000 mi^2 total, 13,000 mi^2 in Florida) • 1.6 million natural gas customers (none in Florida) • 7.5 million electric customers (1.8 million in Florida)
Emera (owns Tampa Electric aka Teco and Peoples Gas) (natural gas and electric)	• Teco serves about 2,000 mi^2 in west central Florida[201] • Teco serves 745,000 customers[202] • Peoples Gas serves roughly 365,000 customers and natural gas assets include about 11,000 miles of gas mains[203]
Florida Public Utilities (natural gas, electric, and propane)	• Provides natural gas service to 21 counties throughout Florida • Provides electric service to 4 counties in northern Florida[204] • Serves roughly 120,000 customers,[205] including 32,000 electric customers[206]
Southern Co. (Florida City Gas, Gulf Power, and Southern Power)	• Southern Co. operates in 9 states, including Florida[207] • Florida City Gas serves parts of 7 counties in Florida[208] and 108,000 customers.[209] Assets include 3,500 miles of natural gas pipelines[210] • Gulf Power serves 8 counties in northwest Florida (7,550 mi^2)[211] • Gulf Power serves 459,000 customers. Assets include over 9,300 miles of power lines[212] and 308 distribution circuits[213]
Florida Power and Light (electric)	• Service territory stretches along the east coast from Jacksonville to Miami, serving almost half of the state • Serves 4.9 million electric customers (estimated 10 million people)[214,215,216]

Examples of Resilience

Natural Gas

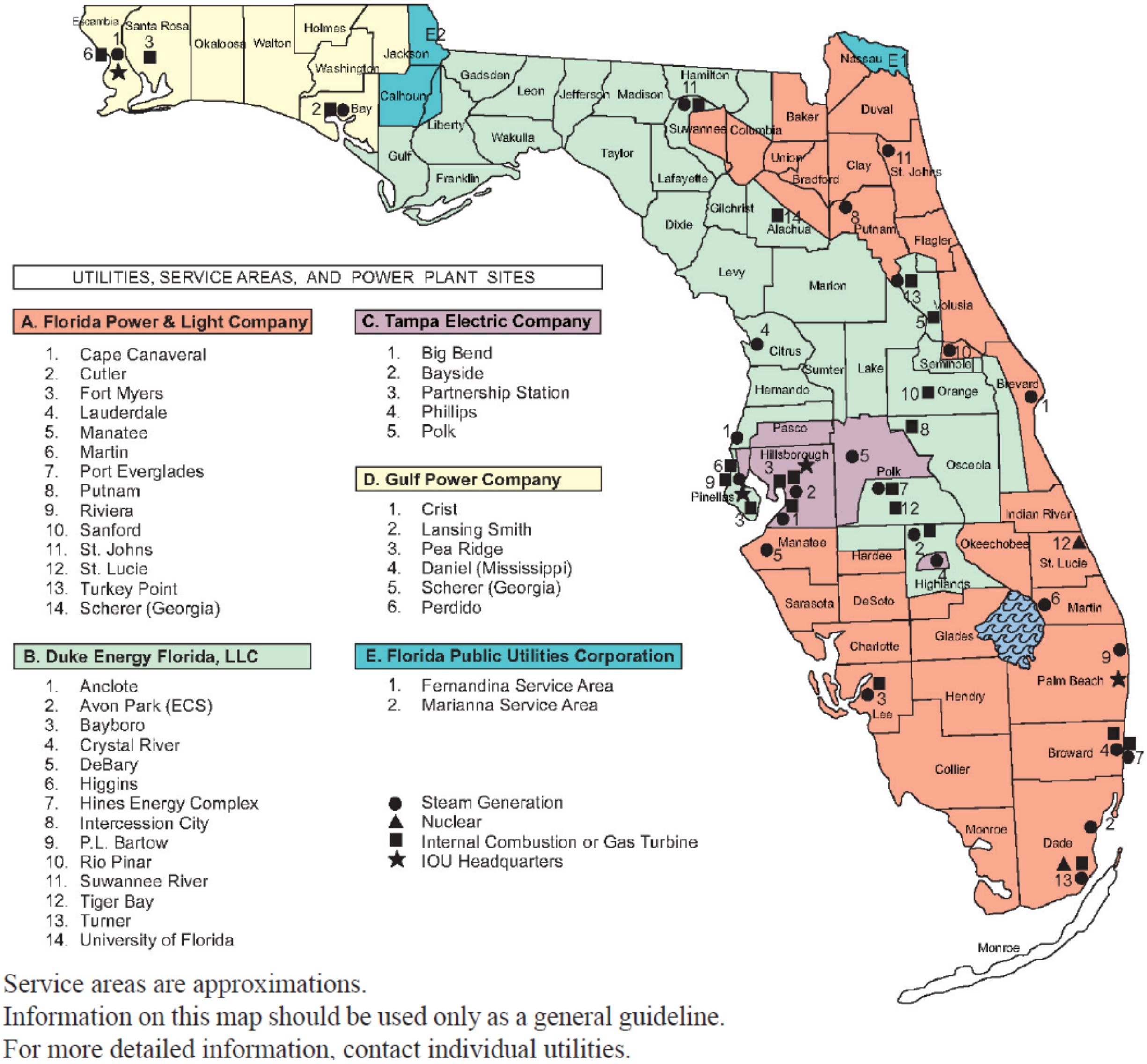
- Use of backup natural gas generators helped to keep critical functionality online at hospitals
- No *Pipeline and Hazardous Materials Safety Administration (PHMSA)* incident data reported for natural gas systems impacted

Electricity

- Mutual assistance programs supported utilities in need of emergency personnel

[201] TECO Tampa Electric. "Vital Statistics." 2019. Accessed January 2019. https://www.tampaelectric.com/company/about/vitalstatistics/
[202] US Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." *EIA Electricity,* January 5, 2019. https://www.eia.gov/electricity/data/eia861/
[203] TECO Tampa Electric. "Vital Statistics." 2019. Accessed January 2019. https://www.tampaelectric.com/company/about/vitalstatistics/
[204] Florida Public Utilities. "FPU Fact Sheet." 2019. May 31, 2019. https://fpuc.com/about/corporate-fact-sheet/
[205] Ibid.
[206] US Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." *EIA Electricity,* January 5, 2019. https://www.eia.gov/electricity/data/eia861/
[207] Southern Company. "Service Territory: Our Subsidiaries." 2019. Accessed May 31, 2019. https://www.southerncompany.com/about-us/our-business/service-territory.html
[208] Florida City Gas. "Our Service Area." 2019. Accessed May 2019. https://www.floridacitygas.com/about-us/our-service-area.
[209] Florida City Gas. "About Us." 2019. Retrieved from https://www.floridacitygas.com/about-us
[210] Southern Company 2019.
[211] Gulf Power. "Our Company." Accessed January 2018. https://www.gulfpower.com/about-us/our-company
[212] Ibid.
[213] US Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." *EIA Electricity,* January 5, 2019. https://www.eia.gov/electricity/data/eia861/
[214] Florida Power and Light. "FPL Service Territory - Address Search." 2011. Accessed January 2018. http://www.fplmaps.com/service_map/map.shtml
[215] Next Era Energy. "Our Subsidiaries." 2019. http://www.nexteraenergy.com/company/subsidiaries.html
[216] US Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." *EIA Electricity,* January 5, 2019. https://www.eia.gov/electricity/data/eia861/

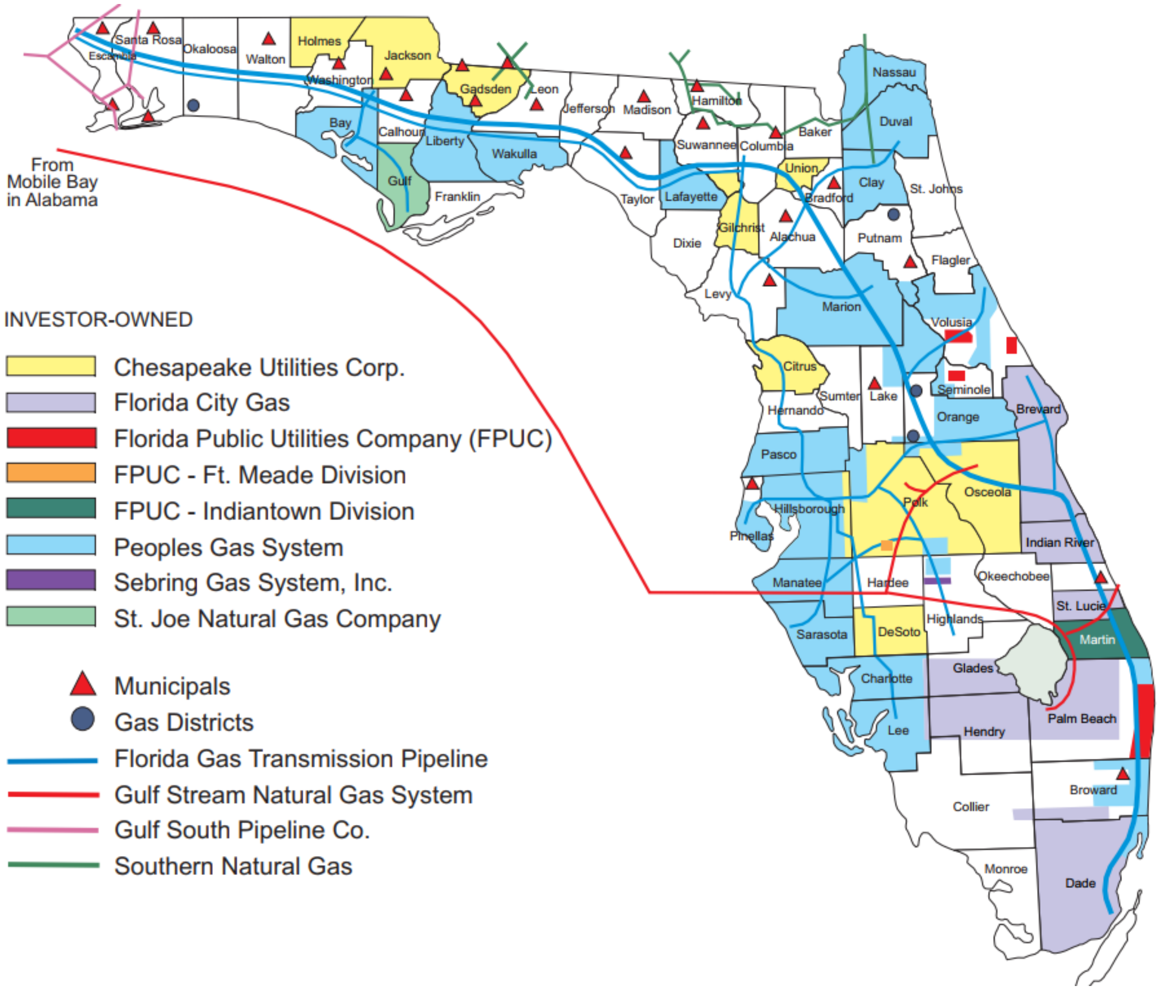
Figure 18. Investor-owned utilities in Florida.



Note that this map does not include municipal electric utilities or rural electric cooperatives.
Source: Florida Public Service Commission.[217]

[217] Florida Public Service Commission. "Facts and Figures of the Florida Utility Industry." 2016. http://www.psc.state.fl.us/Files/PDF/Publications/Reports/General/Factsandfigures/March%202016.pdf

Figure 19. Locations of natural gas pipelines and local distribution companies (LDCs) in Florida.



Note that the FPUC is a subsidiary of Chesapeake Utilities Corp.
Source: Florida Public Service Commission, March 2016.

August 2017 Hurricane Harvey in Texas

Dates: Hurricane Harvey made landfall on the coast of South Texas as a Category 4 storm on August 25, 2017.

Standout features: Wind gusts up to 132 mph and storm tides over 12 feet above ground level were observed as Harvey stalled over the region, with record-breaking precipitation dropping as much as 51.88 inches of rainfall. The storm lasted 4 days, leaving many south Texans flooded out of their homes and many structures destroyed. While typical hurricanes move quickly through their path, Harvey stalled over the Houston area, which worsened flooding there. Examples of this immense flooding and destruction are shown in the photos, with homes flooded nearly to their roofs and structures destroyed. Power lines throughout the storm's path were downed and caused major outages.

Area affected: Hurricane Harvey impacted a deep section of coastal and southeast Texas, stretching inland toward central Texas – see Figure 20 for the counties included in FEMA's disaster declaration. The Texas cities of Rockport and Fulton sustained the greatest damages, as they directly experienced the eyewall.[221] This area has a large concentration of Texas' oil, natural gas, and other liquid pipelines (Figure 22).

Utilities: Major utilities whose service territory overlaps with these counties include American Electric Power Company, Inc. (AEP Texas), CenterPoint Energy, Entergy, and Texas New Mexico Power Company. See Table 7 for a description of their system details, including areas and populations served in Texas. CenterPoint Energy represents the natural gas and electric utility for the affected area, while the others are solely electric utilities.

Damage to electric infrastructure in Texas. Source: Adrees Latif/Reuters.[218]

Flooding in Texas. Source: Alex Scott/Bloomberg.[219]

Flooding in Texas. Sources: LM Otero/ Associated Press.[220]

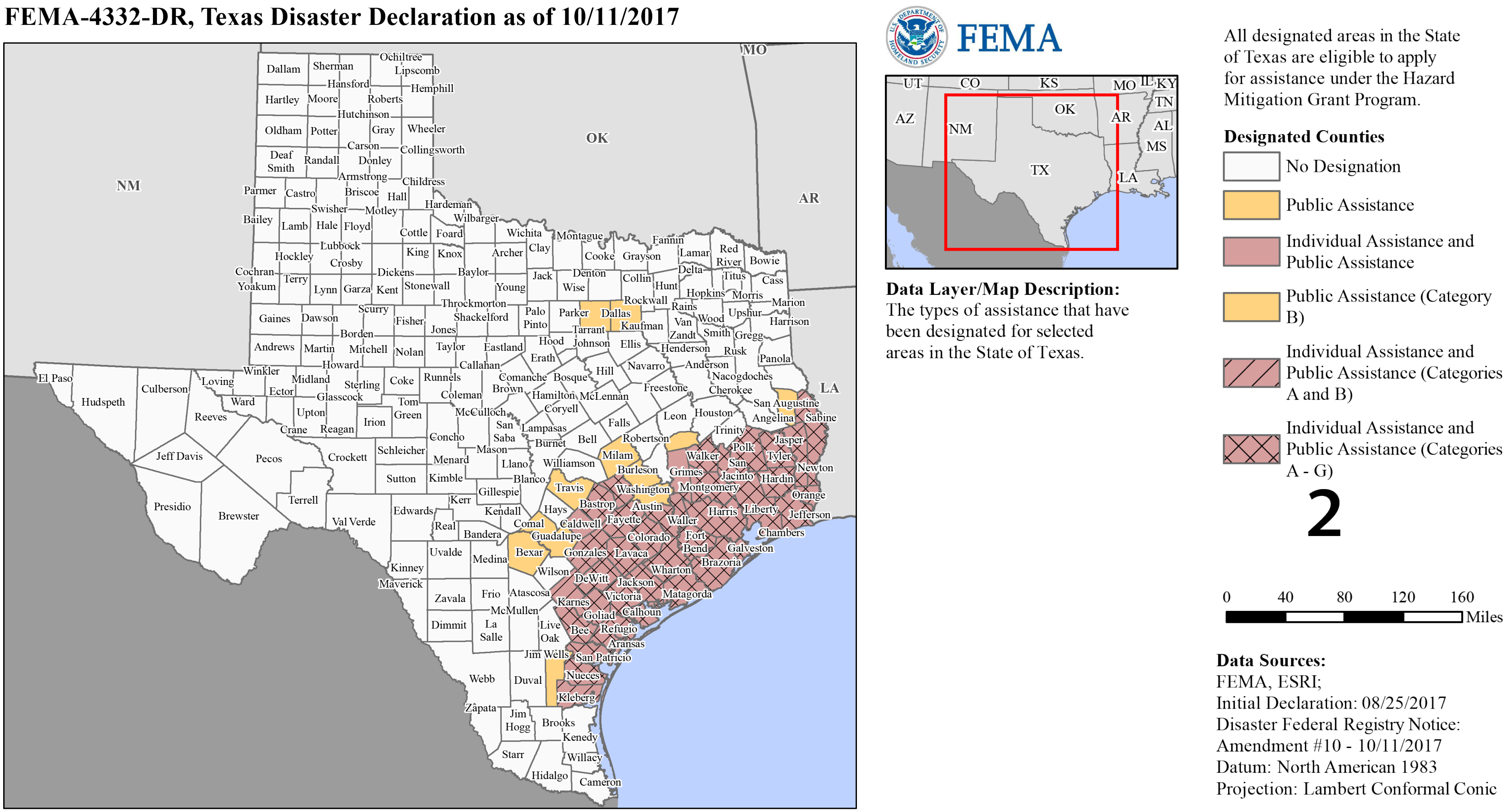
[218] Sputnik. "Texas Town Residents Told to Take Shelter After Chemical Leak." *Sputnik,* August 29, 2017. https://sputniknews.com/environment/201708291056871653-la-porte-texas-chemical-leak/

[219] Bloomberg. "Harvey's 'Catastrophic' Flooding Could Cost Billions in Damage." *Fortune*, August 27, 2017. http://fortune.com/2017/08/27/harvey-economic-damage-texas/

[220] Mosher, Dave. "This incredible map lets you explore Texas before and after Harvey's flooding." *Business Insider,* September 1, 2017. http://www.businessinsider.com/harvey-damage-aerial-survey-photos-map-2017-9

[221] National Weather Service. "Major Hurricane Harvey - August 25-29, 2017." Accessed April 30, 2018. https://www.weather.gov/crp/hurricane_harvey

Figure 20. Counties included in FEMA's disaster declaration for Hurricane Harvey.



Source: FEMA.[222]

[222] FEMA. September 15, 2017. Texas Hurricane Harvey (DR-4332) https://www.fema.gov/disaster/4332

Table 7. Relevant Texas natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration.

Utility	Overview
CenterPoint Energy (natural gas and electric)	• Provides energy services in Texas and 31 other states • Natural gas distribution in southeast Texas • Electric transmission and delivery services cover 5,000 square miles in the Houston area • Distributes natural gas to over 3,400,000 customers annually
American Electric Power Company, Inc. (AEP Texas) (electric)	• Serves 92 counties and 372 cities and towns in south and west Texas (97,000 mi2) • Part of the American Electric Power system, a large national electric utility
Entergy (electric)	• Serves roughly 447,000 electric customers223
Oncor (electric)	• Serves over 13 million customers in 98 counties • Network consists of 140,000 miles of transmission and distribution lines in north central and west Texas224
Texas New Mexico Power Company (electric)	• Network includes pockets in western Texas, and around Dallas and Houston, serving 20 communities • Provides electricity to over 245,000 homes and businesses225

Examples of Resilience

Natural Gas

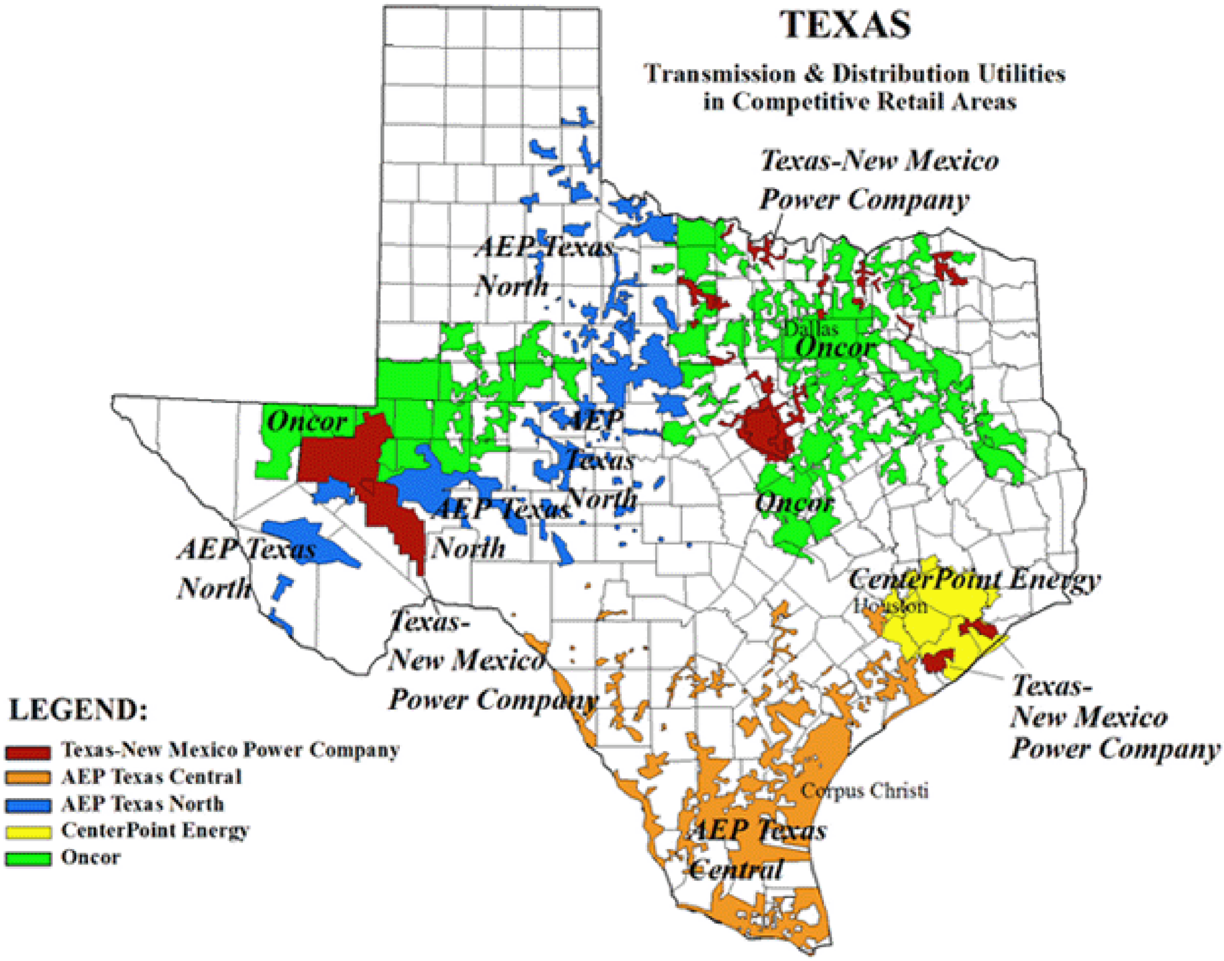
- CenterPoint emergency operations heightened inspection and maintenance operations ahead of Harvey landfall, with only one breach recorded
- Colonial Pipeline Company used satellite data to optimize maintenance efforts along a critical pipeline and short-term disruptions
- Large hospital campuses in Texas were able to remain online due to on-site natural gas-fueled CHP system
- CNG stations remained open and provided fuel to fleets

Electricity

- Intelligent grid switches quickly isolated grid issues and remotely restored service
- Used drone imagery to inform real time decision making during the restoration process
- Flood walls protected substations for critical services
- Mutual assistance programs supported utilities in need of emergency personnel

[223] US Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." *EIA Electricity,* January 5, 2019. https://www.eia.gov/electricity/data/eia861/
[224] Oncor. "About Us." Accessed July 19, 2022. https://www.oncor.com/content/oncorwww/us/en/home/about-us.html
[225] Texas New Mexico Power Company. "About Us." Accessed January 2018 http://www.tnmp.com/about/

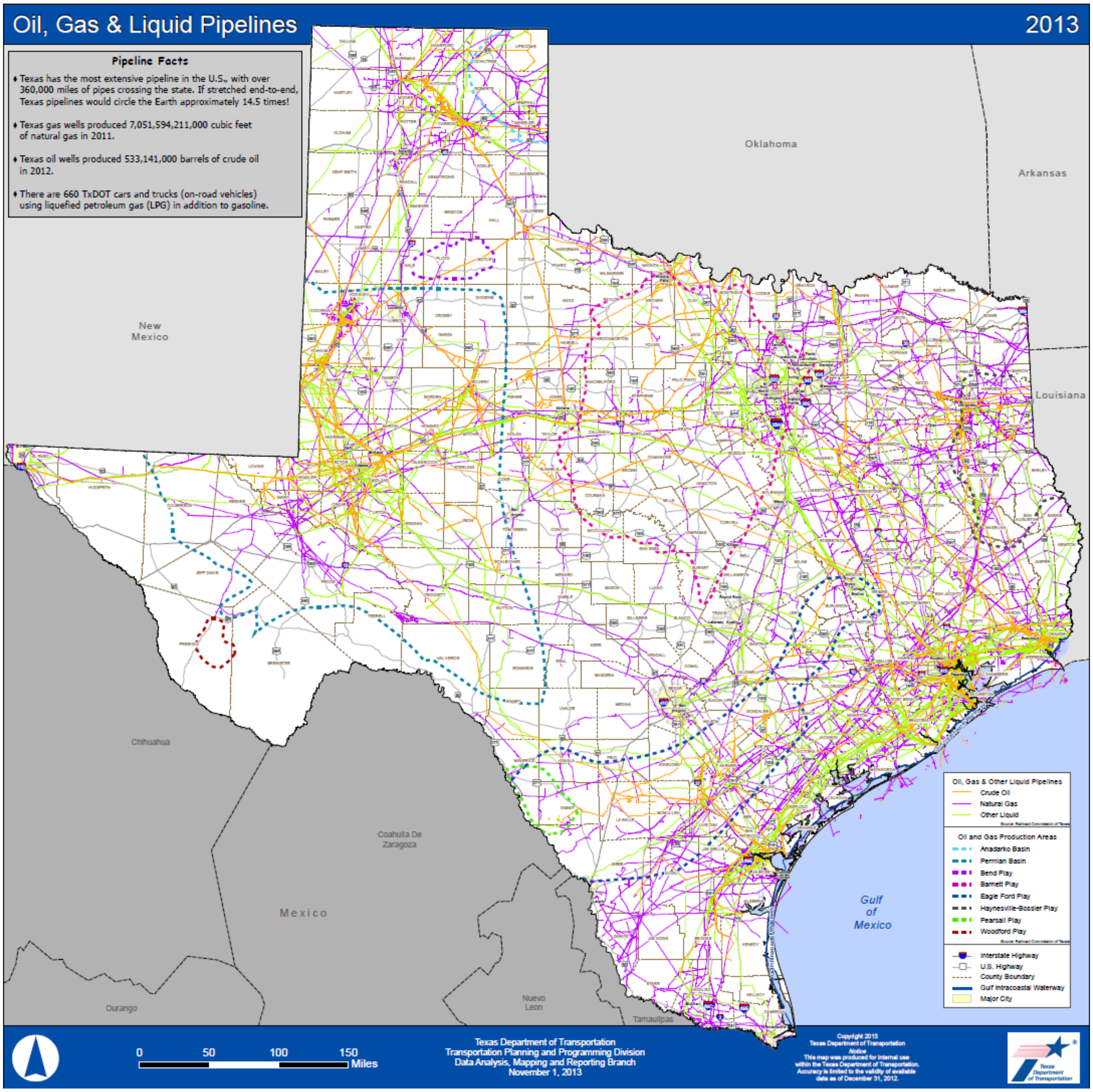
Figure 21. Electric transmission and distribution utilities in Texas.



Source: Public Utility Commission of Texas.[226]

[226] Public Utility Commission of Texas. "Electric Maps." 2019. https://www.puc.texas.gov/industry/maps/Electricity.aspx

Figure 22. Pipelines in Texas.



Source: Texas Department of Transportation.

CHAPTER 3

Original 2019 Report: Summary of Impacts and Resilience

This chapter presents findings from the original 2019 case studies, which included all events except Winter Storm Uri. ICF examined damage and service disruptions, compounding consequences, and examples of resilience for key infrastructural sectors: energy supply, backup generation, mobility and transportation, water and wastewater services, and telecommunications.

Energy Supply

Damage and Service Disruptions: Hurricanes Harvey, Irma, and Michael

Natural Gas

Natural gas supply infrastructure and consumer systems were largely found to be resilient in the face of the hurricanes, with a few instances of vulnerability. The US DOT Pipeline and Hazardous Materials Safety Administration (*PHMSA*) pipeline incident data concerning gas distribution for the Gulf Coast region included reports of one incident for each hurricane: in Boca Raton, Florida during Irma, in Vidor, Texas during Harvey, and in Colquitt, GA during Michael.

In Florida, a downed power line – likely damaged by Hurricane Irma – arced a hole in an underground Florida Public Utilities Co. gas main, igniting the escaping natural gas. The line was shut down from the evening of September 12, 2017, to the afternoon of September 15, 2017, and a total of two customers (both commercial) experienced an interruption in service. In Texas, an underground rupture to a CenterPoint Energy pipeline resulted in the release of 14,000 thousand cubic feet (MCF) of natural gas. However, the affected section was isolated with valves, and a shutdown of the pipeline was avoided due to the fact that this was a two-way fed line. Even so, two industrial customers were affected by the incident. The cause of the damage is under investigation but is likely related to the high flood waters and severe turbulence during Hurricane Harvey.

During Hurricane Michael, uprooted trees from the high winds damaged City of Colquitt Gas System underground lines and released natural gas in the City of Colquitt, GA, resulting in the City shutting off the gas distribution system.[227] Other reports noted relatively few impacts where there was physical damage to assets but no service disruptions or releases of natural gas. For example, an

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[227] USDOT and Pipeline and Hazardous Materials Safety Administration (*PHMSA*). "Pipeline Incident Flagged Files." *PHMSA,* June 5, 2019. https://www.*PHMSA*.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files

LNG terminal under construction in Corpus Christi, TX, only suffered minor cosmetic damages during Hurricane Harvey, and LNG production continued at that company's Sabine Pass facility west of Houston.[228]

The *PHMSA* gas transmission, gas gathering, and underground natural gas storage incident report data included a few reports linked to the hurricanes. In Texas during Hurricane Harvey, one of the Tennessee Gas Pipeline Company's compressor stations was shut down and placed in by-pass mode as a precautionary measure. Later, a power outage caused an emergency shut down at this station, which caused a by-pass valve to open and 17,811 MCF of natural gas to be released. During Hurricane Michael, a power outage resulted in service interruption at a Florida Gas Transmission Company station in Chipley, Florida.[229] There were no reported gas transmission, gathering, or underground storage incidents reported to *PHMSA* during Hurricane Irma.

There were neither fatalities nor injuries involved in any of these reported incidents.[230] Incidents involving the release of natural gas do carry the risk of fires, explosions, and other impacts that could lead to injuries and even fatalities. For example, in October 2012, Keyspan Energy Delivery of Long Island, NY reported that Superstorm Sandy uprooted a tree at a house, which pulled out the gas service at the house foundation wall. Some natural gas escaped, which led to ignition and an explosion, non-fatally injuring one member of the general public and resulting in "significant damage to the [house]".[231] This is the only gas distribution incident reported to *PHMSA* from 2010-2019 resulting from a natural disaster (hurricane or wildfire) that involved an injury.

Two cities in Florida (Chipley and Chattahoochee), however, did report their local gas distribution systems to be out of service due to Hurricane Michael. Chipley's interruption was due to the power outage discussed above and lasted from October 11, 2018 to October 15, 2018. Service was restored quickly to critical facilities such as a water well pump and hospitals.[232]

Offshore production of natural gas and petroleum products was shut down in the Gulf region due to evacuations in anticipation of hurricanes Harvey and Irma (Figure 23), but lowered demand due to power being out (also known as "demand destruction") muted the domestic impact of this shutdown.[233,234,235]

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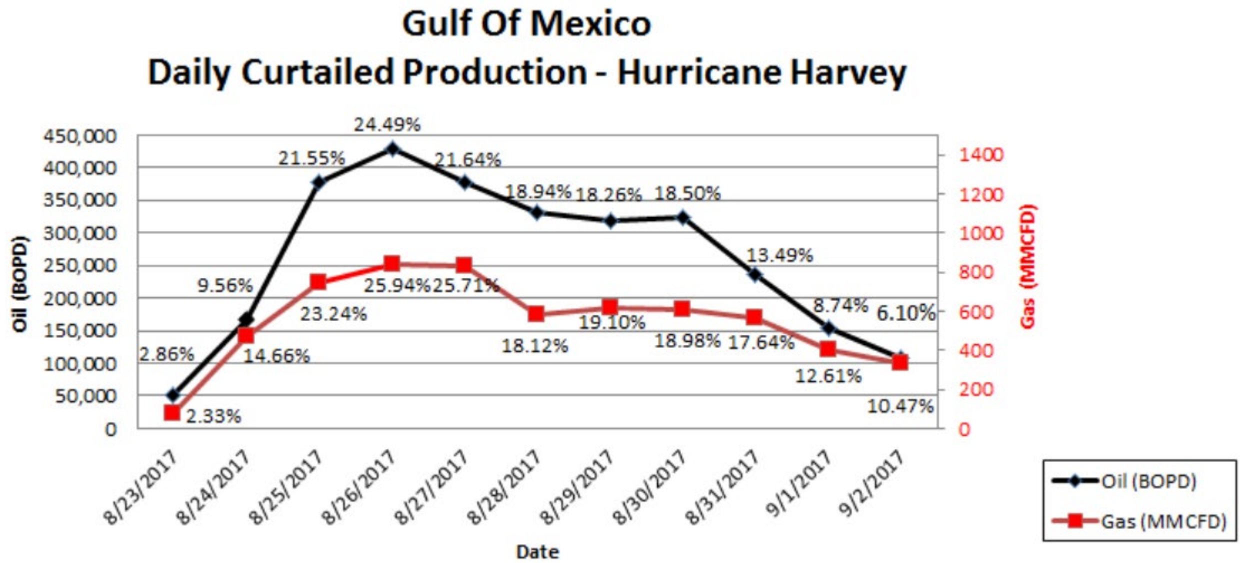
[228] Cho, Aileen, Louise Poirier, Debra K. Rubin, and Pam Radtke Rusell. "How Badly Has Hurricane Harvey Damaged Texas Infrastructure." *Engineering News-Record (ENR)*, August 28, 2017. https://www.enr.com/articles/42639-how-badly-has-hurricane-harvey-damaged-texas-infrastructure
[229] USDOT and Pipeline and Hazardous Materials Safety Administration (*PHMSA*). "Pipeline Incident Flagged Files." *PHMSA,* June 5, 2019. https://www.*PHMSA*.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
[230] Ibid.
[231] Ibid.
[232] U.S. Department of Transportation (DOT). "US Department of Transportation Resources for Hurricane Michael, Storm Response Highlight Report." USDOT, October 15, 2018. https://www.transportation.gov/briefing-room/us-department-transportation-resources-hurricane-michael
[233] Clemente, Jude. "Hurricane Harvey's Impact On Natural Gas Prices." *Forbes*, September 3, 2017. https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/#76ba015b5230
[234] Natural Gas Intel Staff Reports. "Irma Takes Down Power, Lowers NatGas Demand for Millions in Florida, Georgia." *Natural Gas Intel*, September 11, 2017. https://www.naturalgasintel.com/articles/111692-irma-takes-down-power-lowers-natgas-demand-for-millions-in-florida-georgia
[235] Clemente, Jude. "Hurricanes Harvey and Irma and the Impact to Natural Gas Prices." *Trane,* September 20, 2017. https://www.trane.com/commercial/north-america/us/en/about-us/newsroom/blogs/Hurricane-Harvey-Irma-NG-Prices.html

Figure 23. Daily curtailed oil and gas production in the Gulf of Mexico due to Hurricane Harvey.



Source: U.S. Bureau of Safety and Environmental Enforcement[236]

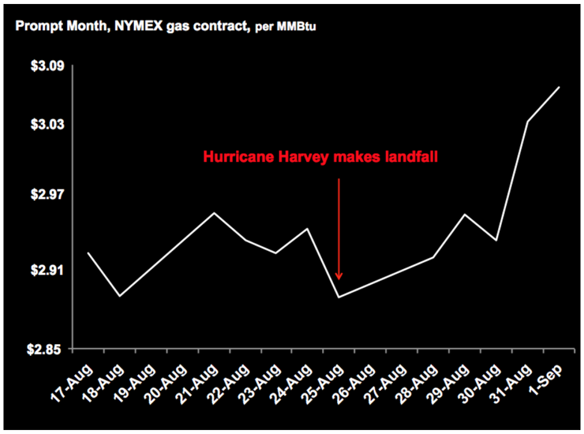
Onshore, several force majeure declarations (a clause that exempts contracting parties from fulfilling their contractual obligations in the face of unanticipated or uncontrollable circumstances, such as a natural disaster[237]) were put into place in anticipation of the 2017 hurricanes: one was by Tennessee Gas Pipeline on August 24, 2017 and another was by Natural Gas Pipeline Company on August 26, 2017, limiting flow from compressor stations.[238,239] A larger impact was felt as Gulf ports were shut in during Harvey, making the United States a net importer of natural gas for the first six days of September 2017 as exports from the Gulf were cut off.[240] During Hurricane Michael in 2018, roughly one-third of natural gas production in the Gulf was shut in and 13% of manned platforms in the Gulf of Mexico were evacuated.[241]

Demand destruction, as mentioned above, was experienced in Florida during Irma, where aggregate natural gas demand fell by 1.69 Bcf/d, over 40% of the previous 30-day average. This drop occurred between September 7 and September 11, 2017, largely due to lost demand from electric power.[242] In fact, due in part to demand destruction, natural gas prices fell slightly when

[236] Bureau of Safety and Environmental Enforcement. "BSEE Tropical Storm Harvey Activity Statistics Update." September 2, 2017. https://www.bsee.gov/newsroom/latest-news/statements-and-releases/press-releases/bsee-tropical-storm-harvey-activity-7
[237] "Force Majeure." *Business Dictionary*. Accessed February 2018. http://www.businessdictionary.com/definition/force-majeure.html
[238] Tennessee Gas Pipeline Company, LLC. "Notice Detail." August 24, 2017. 2017. https://pipeline2.kindermorgan.com/Notices/NoticeDetail.aspx?code=NGPL&notc_nbr=37735
[239] Ibid.
[240] IHS Markit. "IHS Markit Hurricane Harvey Update." *IHS Markit,* September 6, 2017. http://news.ihsmarkit.com/press-release/energy-power-media/ihs-markit-hurricane-harvey-update-september-6-2017
[241] Hart Energy. "HEADLINES: Hurricane Michael's Effect on Oil, Gas Production." *Hart Energy,* October 11, 2018. https://www.hartenergy.com/exclusives/headlines-hurricane-michaels-effect-oil-gas-production-135307
[242] Natural Gas Intel Staff Reports. "Irma Takes Down Power, Lowers NatGas Demand for Millions in Florida, Georgia." Natural Gas Intel, September 11, 2017. https://www.naturalgasintel.com/articles/111692-irma-takes-down-power-lowers-natgas-demand-for-millions-in-florida-georgia

Hurricane Harvey hit Texas. However, this shift in prices is negligible when compared with the spike caused by previous storms[243] (Figure 24, Figure 25).

Figure 24. Natural gas prices dipped slightly at the onset of Hurricane Harvey.



Source: EIA. Image source: Forbes[244]

Figure 25. Harvey's impact on natural gas prices is negligible in comparison to that of other storms.

Source: EIA. Image source: Forbes[245]

Electricity

Electrical infrastructure was relatively less resilient than natural gas systems during these recent hurricanes. While natural gas service disruptions were limited to isolated cases and customers, electricity disruptions were widespread. The Electric Reliability Council of Texas (ERCOT) reported widespread outages, with more than 293,000 customers suffering outages and an estimated 157 circuits out of service on August 26, 2017, one day after Harvey made landfall.[246] In Florida during Hurricane Irma, 6.1 million customers lost power, including 3.6 million Florida Power and Light customers alone.[247] In some coastal areas, Irma pushed outage rates as high as 97 percent.[248] During Hurricane Michael, about 2 million electric customers in affected states (Alabama, Florida, Georgia, North Carolina, South

Electric Service Fared Worse Than Gas Service

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[243] Clemente, Jude. "Hurricane Harvey's Impact On Natural Gas Prices." Forbes, September 3, 2017. https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/#76ba015b5230
[244] Clemente, Jude. "Hurricane Harvey's Impact On Natural Gas Prices." Forbes, September 3, 2017. https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/#76ba015b5230
[245] Ibid.
[246] ERCOT. (2017, September 6). *ERCOT Responds to Hurricane Harvey*. Retrieved May 31, 2019, from http://www.ercot.com/help/harvey
[247] "Irma knocks out power to about 5.8 million: Authorities." *Reuters/CNBC*, September 11, 2017. https://www.cnbc.com/2017/09/11/irma-knocks-out-power-to-nearly-four-million-in-florida-utilities.html
[248] St. John, J. "Post-Irma, Utilities Face 'One of the Largest Industry Restoration Efforts in US History." *Greentech Media,* 2017, September 11, 2017. https://www.greentechmedia.com/articles/read/post-hurricane-irma-utilities-face-one-of-largest-industry-restoration-effo

Carolina, and Virginia) were without power.[249] Downed trees were a major cause of outages in North Carolina,[250] and damage to electric transmission and distribution facilities (e.g., substations, utility poles, and power lines) were a main cause in Florida.[251] Electric outages from Hurricane Michael lasted from a few days to 2 or more weeks.[252,253] One reason for the prolonged outages was customer infrastructure – for example, some homes were damaged such that it would have been dangerous to turn the power on,[254] and some water utilities wanted to storm-harden and elevate their infrastructure before re-connecting to the grid, leaving them on diesel generator power for 6 months after the hurricane.[255]

For some, such power outages had deadly consequences. Twelve nursing home residents in Hollywood, FL, died due to heat exposure after the facility's air conditioning's power was knocked out during Hurricane Irma. The portable cooling units and fans set up by nursing home staff were not enough to keep the heat at bay. Governor Scott responded to this tragedy with an emergency order that all nursing homes and assisted-living facilities install backup generators and keep four days' worth of fuel on hand in case of power outages. This ruling did not require a certain type of generator, only stipulating that the equipment must be available to maintain a "safe indoor temperature."[256,257] In the nursing homes that had been able to meet this new state generator requirement by the time Hurricane Michael hit Florida, this requirement had helped with their preparation and resilience. However, not all nursing centers had been able to install permanent generators in time, and mobile generators and coolers had to be brought in.[258]

Other sectors were impacted by the electric outages. In Florida, cellphone service outages were as high as 82 percent (in Monroe County) due to the widespread electric power outages experienced by the state during Hurricane Irma. Such cell outages were less of an issue in Texas, where there were fewer electric outages.[259,260] Cell phone outages from electricity disruptions impede the response time and coordination of emergency responders, which is discussed later in this report.

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[249] U.S. DOE. "Tropical Cyclone Michael | Report #5." *US Department of Energy Infrastructure Security and Energy Restoration*, October 12, 2018. https://www.energy.gov/sites/prod/files/2018/10/f56/Michael%20DOE%20Event%20Summary%20Report%20%235%20Morning%20October%2012%2C%202018.pdf
[250] Henderson, B. "More than 286,000 in Carolinas still without power after Tropical Storm Michael." *The Charlotte Observer,* October 12, 2018. https://www.charlotteobserver.com/news/local/article219910430.html
[251] Wells, J. (2018, October 12). Hurricane Michael damage so extensive, company inspecting with boats and drones. *Duke Energy*. https://illumination.duke-energy.com/articles/hurricane-michael-damage-so-extensive-company-inspecting-with-boats-and-drones
[252] Panettieri, J. (2018, October 10). *Hurricane Michael Power Outages: Electric Service Restored to More than 1.2 Million Customers*. https://www.channele2e.com/technology/business-continuity/hurricane-michael-power-outages/
[253] Reeves, B. F. (2018, October 22). *Power Outages Still Plague Florida Panhandle Nearly 2 Weeks After Michael*. Retrieved May 3, 2019, from https://www.insurancejournal.com/news/southeast/2018/10/22/505288.htm
[254] Rogers, E. (2018, October 16). Hurricane Michael power outages being restored at rapid pace. *Pensacola News Journal*. Retrieved from https://www.pnj.com/story/news/2018/10/16/hurricane-michael-power-outages-being-restored-panama-city-rapid-pace/1660275002/
[255] Personal communication. (2019, April 19). Florida Rural Water Association.
[256] Allen, G. (2017, December 24). After Deaths During Hurricane Irma, Florida Requiring Changes For Nursing Homes. *NPR*. Retrieved from https://www.npr.org/2017/12/24/573275516/after-deaths-during-hurricane-irma-florida-requiring-changes-for-nursing-homes
[257] http://ahca.myflorida.com/MCHQ/Health_Facility_Regulation/Long_Term_Care/docs/Nursing_Homes/Final-Ratified_59A-4.1265.pdf
[258] Fausset, Richard, Sheri Fink, and Matthew Haag. "Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients." *The New York Times*, October 11, 2018. https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html
[259] Reid, A. (2017, September 14). Hurricane Irma testing South Florida's cell service patience | Opinion. *Sun Sentinel*. Retrieved from http://www.sun-sentinel.com/opinion/todays-buzz/fl-op-buzz-irma-cellphones-20170914-story.html
[260] Shannon, T. "What Hurricanes Harvey and Irma Tell Us about Wireless Carrier Preparedness." *Battery Power Online*, n.d.

Damage and Service Disruptions: California Wildfires 2017 and 2018

Natural Gas

Most natural gas infrastructure is sub-surface and therefore has limited exposure to wildfires. The biggest risk, then, is to self-supporting structures that span above-ground over canyons. At these points, not only does the gas line become exposed but so does the supporting infrastructure. If support structures burn, or if flame retardants are dropped in canyons, the pipelines could be damaged.[261]

During the October 2017 wildfires, some natural gas infrastructure in northern California was damaged. The research team's contact at PG&E reported that the company suffered damage to "above-ground measurement and control assets, as well as damage to meter set assemblies and some damage to distribution assets."[262] One *PHMSA* report detailed such damage, stating that meters in several locations had melted away, allowing gas to ignite.[263] PG&E voluntarily disrupted service beginning October 9, 2017, to 30,000 customers (and ultimately to 42,000 customers) in order to isolate damaged assets and to prevent further damage.[264] The initial October 9 shut-in occurred before PG&E was able to assess damage to gas facilities, meaning that it was a proactive safety decision.[265] This meant that customers both with and without damaged properties experienced an interruption in service for several days.[266] Gas restoration efforts began on October 11, 2017, with the help of mutual assistance crews from SoCalGas and San Diego Gas and Electric, which allowed for faster service inspections and restorations.[267] By October 19, PG&E had either restored or made at least one attempted relight to all affected customers whose property could accept gas service.[268] Properties that could not accept gas service were primarily those destroyed by the fire, rendering restoration of service unnecessary.

Table 8. Timeline of October wildfire, natural gas outages and restoration of power.

October 8, 2017	October 9, 2017	October 11, 2017	October 19, 2017	October 31, 2017
Northern California wildfires start.[269]	PG&E begins voluntary natural gas service disruptions.[270]	Utility crews begin gas restoration efforts.[271]	Utility crews complete available restoration efforts.[272]	Northern California wildfires that began October 8-9 end.[273]

[261] Personal communication with CUEA. April 23, 2019.
[262] Personal communication with PG&E. January 15-16, 2018.
[263] USDOT and Pipeline and Hazardous Materials Safety Administration (*PHMSA*). "Pipeline Incident Flagged Files." *PHMSA*, June 5, 2019. https://www.*PHMSA*.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
[264] CPUC. "Oct. 9-27, 2017: Status updates from PG&E to the CPUC." October 27, 2017. http://cpuc.ca.gov/general.aspx?id=6442454971
[265] Ibid.
[266] Personal communication with PG&E. January 15-16, 2018.
[267] CPUC. "Oct. 9-27, 2017: Status updates from PG&E to the CPUC." October 27, 2017. http://cpuc.ca.gov/general.aspx?id=6442454971
[268] USDOT and Pipeline and Hazardous Materials Safety Administration (*PHMSA*). "Pipeline Incident Flagged Files." *PHMSA,* June 5, 2019. https://www.*PHMSA*.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
[269] CAL FIRE. *California Statewide Fire Summary*. October 30, 2017. http://calfire.ca.gov/communications/communications_StatewideFireSummary
[270] CPUC. "Oct. 9-27, 2017: Status updates from PG&E to the CPUC." October 27, 2017. http://cpuc.ca.gov/general.aspx?id=6442454971
[271] Ibid.
[272] USDOT and Pipeline and Hazardous Materials Safety Administration (*PHMSA*). "Pipeline Incident Flagged Files." *PHMSA*, June 5, 2019. https://www.*PHMSA*.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
[273] CAL FIRE. "Incident Information." n.d. Accessed April 24, 2018. http://cdfdata.fire.ca.gov/incidents/incidents_cur_search_results?search=2017

SoCalGas reported that the December 2017 fires in Southern California were a limited threat to equipment, as facilities are mostly underground. Disruptions occurred when SoCalGas worked with first responders to turn off gas preemptively before fires reached houses, shutting off service for about 4,800 customers.[274] Thus, most of the natural gas impacts from the December fires were voluntary and pre-emptive. SoCalGas reported that these service shutoffs were well coordinated via the overall incident command structure established to tackle the blaze.

Most Natural Gas Outages Due to Pre-emptive Turn Offs

Most of the natural gas outages were due to SoCalGas taking the preemptive safety measure of shutting off service before fires reached houses, since gas is flammable and could explode. These safety shutoffs affected around 4,800 customers.

During the 2018 Woolsey Fire, SoCalGas had to shut off natural gas service to the Peter Strauss Ranch community, Oak Forest Mobile Home Park, Seminole Mobile Home Park, and in the vicinity of Morning View Drive and Bonsall Drive in Malibu as a safety precaution.[275] At Peter Strauss Ranch, SoCalGas' 4-inch steel main crossing a bridge along Mulholland was impacted by structural failure of the bridge brought on by the fire. The service isolation for Oak Forest Mobile Home Park was preemptive, done at the request of the fire department. Service was shut down to Seminole Mobile Home Park because all mobile homes were destroyed by the fire, so SoCalGas isolated service at the master meter there.

The utility also had to respond to issues at homes where gas service lines were damaged or destroyed but there were no reports of major breaks or leaks within the fire area.[276] Shutoffs may also be required if aboveground infrastructure such as gas meters are incinerated; these shutoffs affect both damaged and undamaged buildings in the affected area.[277]

Electricity

Electricity infrastructure suffered heavily during the California wildfires of 2017 and 2018. Since the infrastructure is aboveground, it is more exposed than natural gas systems. In addition, many electricity providers have been blamed for igniting wildfires due to faulty equipment or improper maintenance. CAL FIRE and Ventura County Fire Department found SCE's lack of maintenance on an electric transmission line the cause for the 2017 Thomas Fire.[278] PG&E's electricity infrastructure has been connected with over 1,500 wildfires between 2014 and 2017, including the Sonoma County Tubbs Fire.[279] CAL FIRE recently found PG&E's electric infrastructure to be the cause of the 2018 Camp Fire.[280]

An estimated 359,000 PG&E customers lost electric power in the October 2017 fires.[281] This was partially attributed to the company proactively de-energizing lines, both voluntarily and at the

[274] Personal communication with SoCalGas. January 22, 2018.
[275] Shatkin, Elina. "Woolsey Fire Should Be Fully Contained By Thanksgiving." *LAist*, November 19, 2018. https://laist.com/2018/11/19/woolsey_fire_fully_contained_thanksgiving.php
[276] Ibid.
[277] Personal communication with CUEA. February 14, 2018.
[278] Ventura County Fire Department. *Thomas Fire Investigation Report*. Camarillo, CA (December 4, 2017). https://vcfd.org/wp-content/uploads/2020/02/Thomas-Fire-Investigation-Report_Redacted_3-14-19.pdf
[279] Gold, Russell, Katherine Blunt, and Rebecca Smith. "PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse." *The Wall Street Journal*, January 13, 2019. https://www.wsj.com/articles/pg-e-sparked-at-least-1-500-california-fires-now-the-utility-faces-collapse-11547410768
[280] Eavis, P. A. "California Says PG&E Power Lines Caused Camp Fire That Killed 85." *The New York Times*, May 15, 2019. https://www.nytimes.com/2019/05/15/business/pge-fire.html
[281] PG&E. "PG&E's Wildfire Response." n.d. Accessed December 13, 2017

direction of CAL FIRE.[282] During the October fires, major water leaks occurred in homes that had burned because power was unavailable to shut off the water supply.[283]

Restoration of electric service is less labor intensive than for gas. For example, PG&E crews were able to restore 5,000 power outages overnight from October 11-12, 2017 but relit just 700 pilots on October 11th. However, as mutual aid provided more and more technicians and further access was granted to affected areas, the electric and natural gas service restoration processes came to proceed at a similar speed. As of October 26th, 2017, there was only a small percentage of customers still without power or gas. The main difficulty in restoration at that point for either set of assets was access to the area.[284]

In Southern California, around 17,000 customers had their power lines preemptively de-energized by SDG&E in the days leading up to the December 2017 fires. Due to the power outages, some people were not able to receive calls about evacuations and many were not able to access well water. Some customers went for more than a week without power.[285] In addition, an estimated 85,000 Southern California Edison customers lost electric power in the December 2017 fires.[286] A December lawsuit filed by residents of Southern California cities of Ventura, Santa Paul, and Ojai claims that water-pumping stations in the county of Ventura lost electrical power and the city did not have functional backup generators, making it impossible to take water from fire hydrants to douse the blazes consuming homes.[287]

In the wake of the December 2017 fires, some utilities were criticized for contributing to fire ignition. For example, the Los Angeles Department of Water and Power (LADWP) faces lawsuits due to its alleged contribution to the Creek Fire. Plaintiffs allege that the utility was negligent in maintenance of electrical equipment and power lines, although the LADWP denies these claims.[288] These smaller publicly owned utilities may lack the resources to combat major wildfire damages and lawsuits.[289] Similarly, SCE found that failures in its electrical equipment was associated with one of the ignition points of the Thomas Fire.[290] SCE is also facing dozens of lawsuits due to the fire.[291]

During the Woolsey and Hill fires, fire damage to substations and electrical transmission lines resulted in power outages. In Los Angeles County, nearly 24,000 SCE customers were without

[282] CPUC. (2017, October 17). *Data Request and Response from PG&E re: de-energizing*. Retrieved from http://cpuc.ca.gov/general.aspx?id=6442454971
[283] Personal communication with CUEA. February 14, 2018.
[284] CPUC. "Oct. 9-27, 2017: Status updates from PG&E to the CPUC." October 27, 2017. http://cpuc.ca.gov/general.aspx?id=6442454971
[285] Horn, Allison. "San Diego Gas and Electric restores power to areas affected by red-flag warning." *ABC 10 News*, December 11, 2017. https://www.10news.com/news/san-diego-gas-and-electric-crews-inspecting-power-lines-after-high-winds
[286] Leventhal, Brain. "Thomas Fire Leads to Santa Barbara Area Outage." *Southern California Gas Newsroom,* December 10, 2017. https://newsroom.edison.com/releases/releases-20171210
[287] Harris, Mike. "Lawsuits allege Southern California Edison negligently started Thomas Fire." Ventura County Star, January 4, 2018. http://www.vcstar.com/story/news/local/2018/01/04/lawsuits-allege-southern-california-edison-negligently-started-thomas-fire/991192001/
[288] Contributing Editor. "Lawsuit Faults LADWP for Massive Creek Fire; Utility Denies Culpability." *MyNewsLA.Com* (blog), November 9, 2018. https://mynewsla.com/crime/2018/11/08/lawsuit-faults-ladwp-for-massive-creek-fire-utility-denies-culpability/.
[289] Stein, Joshua, Andrew Teras, and Christopher Woodward. "Municipal Implications of the California Wildfires." *Breckinridge Capital Advisors*. Accessed June 25, 2019.
[290] Carlson, Cheri. "Water Agencies Band Together, Seek Changes after Destructive Woolsey, Thomas Fires." *Ventura County Star*, March 4, 2019. https://www.vcstar.com/story/news/local/2019/03/04/california-water-agencies-band-together-after-destructive-woolsey-thomas-fires/2957790002/.
[291] "Baron & Budd Sues Southern California Edison on Behalf of Los Angeles County and Malibu for Damages from Devastating Woolsey Fire." *Business Wire and AP News,* April 29, 2019. Accessed June 25, 2019. https://www.apnews.com/Business%20Wire/eafd087f14844e2182534c8f51b5e574.

power, as well as 3,238 customers in Ventura County.[292] Initial assessments found that around 500 poles, 750,000 feet of wire, and other electrical equipment were destroyed or damaged in the Woolsey and Hill fires.[293] In addition to outages due to damage, SCE also had to schedule additional power outages to make repairs to transmission lines.[294,295]

Multiple lawsuits have been filed against SCE for its alleged partial responsibility for the Woolsey Fire. SCE reported to the California Public Utilities Commission (CPUC) that they experienced power outages minutes before the ignition of the Woolsey fire. After investigations, SCE indicated that electrical issues at the Chatsworth Substation may have contributed to the start of the fire.[296]

Damage and Service Disruptions: California Mudslides

Natural Gas

The mudslides resulted in some damage to natural gas assets. For example, a vehicle was carried into and damaged above-ground infrastructure that served a home.[297] Debris flow caused a gas leak, resulting in a house fire on January 9, 2018.[298] Fast-moving water that was scouring the earth exposed two natural gas pipelines. One pipeline was battered by boulders in one creek and shut down to prevent future incidents, then was replaced in 2018. The other remained unharmed, though its protective concrete slab was destroyed. SoCalGas depressurized this second line until a safety inspection took place. Approximately 2,900 SoCalGas customers in Montecito experienced disruption to their gas service due to requests from first responders to isolate service to areas for safety reasons, and restoration efforts were completed in about three weeks.[299,300,301,302] Generally speaking, areas in which sub-surface infrastructure becomes exposed (e.g., creek crossings) are more vulnerable to damage from both the elements and the disaster itself (e.g., water, mudflow, and debris in the case of the mudslides).[303] Restoring service in the wake of the mudslides posed a greater challenge than after the fires, as boulders had to be removed and damage had to be assessed before pipes could be re-pressurized.[304]

To delve further into the impacts to utility customers during the disasters, we conducted a social listening exercise. This included a systematic review of social media posts using refined search strings and resulted in an analysis of nearly 900 posts. For more information on the methodology, see Appendix A.

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[292] Gutierrez-Jaime, Nisha. “Thousands of Residents in Vicinity of Woolsey Fire Without Power.” *KTLA News*, November 9, 2018. https://ktla.com/2018/11/09/thousands-of-residents-in-vicinity-of-woosley-fire-without-power/.
[293] Milbourn, Mary Ann. “SCE Works with Fire Officials to Restore Power.” *Energized by Edison*, November 9, 2018. Accessed June 25, 2019. https://energized.edison.com/sce-works-with-fire-officials-to-restore-power
[294] Southern California Edison. “Outage Center.” Accessed June 26, 2019. https://www.sce.com/outage-center.
[295] “Large Swath Of Malibu Without Power Monday Due to Woolsey Fire Repairs.” *CBS Los Angeles,* November 19, 2018. https://losangeles.cbslocal.com/2018/11/19/large-swath-of-malibu-without-power-monday-due-to-woolsey-fire-repairs/
[296] “SCE Provides Update on Woolsey and Hill Wildfires,” November 16, 2018. https://www.businesswire.com/news/home/20181115006114/en/SCE-Update-Woolsey-Hill-Wildfires.
[297] Gazzar, Brenda. “SoCalGas crews work to restore service to dozens of customers after gas line damaged in Burbank.” *Daily News*, January 10, 2018. https://www.dailynews.com/2018/01/10/socalgas-crews-work-to-restore-power-to-dozens-of-customers-after-gas-line-damaged-in-burbank/
[298] Staff Report. “Thirteen Dead in Powerful Storm, Mudslides in Santa Barbara County.” *NBC Los Angeles,* January 9, 2018. https://www.nbclosangeles.com/news/local/Explosion-Debris-Flow-Reported-After-House-Fire-in-Montecito-468430023.html
[299] SoCalGas. Twitter Post. January 13, 2018, 3:42 PM. https://twitter.com/socalgas/status/952279697529872384
[300] SoCalGas. Twitter Post, January 16, 2018, 7:28 PM. https://twitter.com/socalgas/status/953423811604488192
[301] SoCalGas. Twitter Post. January 30, 2018, 3:26 PM. https://twitter.com/socalgas/status/958436290873176064
[302] Southern California Gas. “Montecito Updates.” Updated February 2, 2018. Accessed February 20, 2018 and April 18, 2018. https://www.socalgas.com/newsroom/montecito.
[303] Personal communication with CUEA. February 14, 2018.
[304] Personal communication with SoCalGas. January 22, 2018.

The social listening results showed that despite the impacts described above, most of the discussion surrounding the fires and mudslides in relation to natural gas was to provide information regarding service restoration (e.g., in the form of tweets from SoCalGas). There were a few widely distributed articles dealing with the emotional impact felt by homeowners as they returned to their burnt residences, but natural gas was not a part of this narrative. These observations regarding how customers discussed natural gas (or did not mention it much) further supports the overall finding that natural gas is widely regarded as resilient.

The area was in high alert when rainstorms followed the November 2018 wildfires. However, the impacts of rainfall on the fire-stricken land was less severe than the previous year. SoCalGas increased its patrolling and monitoring of its pipelines during the rainy season as a proactive measure.

Compounding Consequences

There also compounding effects to natural gas and fuel when electricity outages occur. Electrical power outages can affect petroleum refineries, gas processing plants, fuel storage facilities, petroleum pipeline pump stations, terminals, and retail gas stations, potentially affecting supply of petroleum fuels and natural gas.[305] Natural gas compression systems may also be impacted by outages, but this can vary depending on facility and system. In the Hurricane Harvey example previously discussed, Tennessee Gas Pipeline Company created service disruptions and a gas release from a power outage at a compression station. [306] Other compression stations, such as those operated by SoCalGas, can be operated without grid electricity using on-site generation.[307]

Electricity generation is dependent on supply from natural gas. As mentioned previously, this is particularly true in California where electricity is primarily based on natural gas.

Power outages can result in a variety of consequences for other sectors, including mobility and telecommunications. For example, downed power lines may shut off streetlights and traffic signals, which can affect mobility.[308] Without power, gasoline stations may also be affected, which could affect people who need to evacuate.[309] Additionally, electricity and telecommunications lines are co-located and, in some cases, telecommunications will depend on electricity supply.[310] This can prevent residents from receiving communications and instructions from emergency managers. Examples of these interdependencies are shown in Figure 26. These issues will be discussed further in the following sections.

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[305] Department of Homeland Security. "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary." *National Protection and Programs Directorate*, November 10, 2018. https://www.hsdl.org/?abstract&did=818743

[306] USDOT and Pipeline and Hazardous Materials Safety Administration (*PHMSA*). "Pipeline Incident Flagged Files." *PHMSA,* June 5, 2019. https://www.*PHMSA*.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files

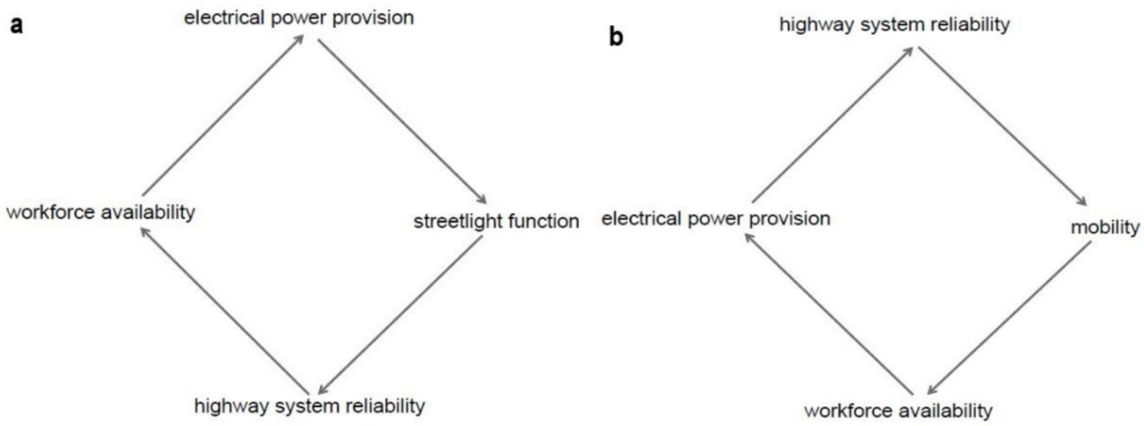
[307] SoCalGas. *North-South Project: Updated Report, Adelanto Compressor Station*. Los Angeles, CA (November 2014). https://www.socalgas.com/regulatory/documents/a-13-12-013/Attachment%20A_%20Updated%20Buczkowski%20Supplemental%20Testimony%20Final%20Redacted.pdf

[308] Moser, Susanne and Juliette Finzi Hart. "The Adaptation Blindspot: Teleconnected and Cascading Impacts of Climate Change on the Electrical Grid and Lifelines in Los Angeles." *California's Fourth Climate Assessment*, August 2018. https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-008_ADA.pdf

[309] Ibid.

[310] Ibid.

Figure 26. Reinforcing loops that show the impact of electrical power provision on different sectors.[311]



Damages to the electricity supply can have severe consequences for public health, particularly for vulnerable populations who are dependent on life support or other critical services. There is a small but significant population on respirators and intravenous machines, many of whom are housed at home, who would be trapped. Many do not have the financial resources necessary to purchase and maintain a backup power source to support these services.[312] Power outages could also result in risks to food safety due to losses of refrigeration.[313]

One such patient was unable to evacuate during the Woolsey fire due to old age and concern for her health. This family was able to shelter in place with a HEPA filter and a backup generator connected to the gas grid. While her electricity was down for four to seven days, she was able to use the backup generator to provide essential services.[314]

Examples of Resilience

Natural Gas

In general, there is very little evidence that loss of natural gas service negatively impacted the response to events or caused further harm in the case examples we explored. The interviewee at the California Utilities Emergency Association (CUEA), which coordinated all utility responses in the California wildfires and mudslides, reported that he did not know of any infrastructure or functions that were impacted by a lack of natural gas. Part of the reason for this is that in response to service isolations, gas utilities were able to bring semitrailers of gas to specific locations in order to feed systems that needed the natural gas.[316] For example, in response to the service disruptions, PG&E

[311] Moser, Susanne and Juliette Finzi Hart. "The Adaptation Blindspot: Teleconnected and Cascading Impacts of Climate Change on the Electrical Grid and Lifelines in Los Angeles." *California's Fourth Climate Assessment*, August 2018. https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-008_ADA.pdf
[312] Personal communication with CUEA. April 23, 2019.
[313] Moser, Susanne and Juliette Finzi Hart. "The Adaptation Blindspot: Teleconnected and Cascading Impacts of Climate Change on the Electrical Grid and Lifelines in Los Angeles." *California's Fourth Climate Assessment*, August 2018. https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-008_ADA.pdf
[314] California Energy Commission. "Joint Agency Workshop on Building Decarbonization." April 8, 2019. Youtube. https://www.youtube.com/watch?v=76L_tNDXSQI&feature=youtu.be&t=2h46m48s
[315] Ellison, James F., Corbet, Thomas Frank, and Robert E. Brooks. "Natural Gas Network Resiliency to a 'Shakeout Scenario' Earthquake." *Sandia National Laboratories*, June 1, 2013. https://doi.org/10.2172/1089984.
[316] Personal communication with CUEA, February 14, 2018.

provided temporary LNG/CNG service to critical customers, such as hospitals, in their area as soon as transport access was restored.[317]

After Hurricane Harvey, Colonial Pipeline Company needed to determine flooding impacts to a shut-down pipeline between Louisiana and Texas facilities. Weather conditions made it impossible to use standard methods of aircraft and helicopter flyovers to collect data. Colonial turned to satellite imagery to rapidly assess the extent of flooding along the pipeline, which allowed Colonial to perform targeted follow-up inspections on-site. This allowed Colonial to better allocate its personnel and resources, shortening the disruption period on the pipeline.[318]

SoCalGas assets were resilient to the wildfires and performed well overall during the mudslides. As outlined above, the mudslides caused significant, albeit localized, impacts. Pipelines shut off automatically after sensing a drop-in pressure when damaged during the January mudslides; their pressure sensors, which detect dramatic pressure drops and send signals to valves that immediately shut off flows for specific lines, functioned as intended. SoCalGas' Advanced Meter network provided meter responses and meter throughput data that were used to identify possible impacted areas and to support search and rescue activities in tandem with first responders.[319] As a result of the Montecito event, SoCalGas now has an Emergency Response Operations Protocol to proactively lower the pressure of a transmission pipeline prior to a predicted disaster event based on information from the National Weather Service and local alerts.

Furthermore, SoCalGas was able to make good use of satellite and drone imagery during these recent events, similar to the post-Harvey flooding satellite assessment performed by Colonial Pipeline Company. These technologies allowed access to terrain not physically accessible to humans as well as to pinpoint geographic areas needing attention and to stay up to date on impacts. SoCalGas obtained their satellite images from a private company with whom they hold a contract. Based on an analysis of these images, SoCalGas was able to pinpoint where mudslides had occurred and how

Natural Disasters and Gas Storage

A 2013 Sandia National Laboratories study found that under a "ShakeOut" scenario (magnitude 7.8 earthquake on the southernmost 200 miles of the San Andreas Fault), it is likely that SoCalGas transmission pipelines conveying gas from the Arizona border into Southern California would fail. Impacts could involve greatly reducing the supply to the Los Angeles Basin (by 40-50%) if storage levels in the Aliso Canyon storage facility are constrained to historical levels. If the Aliso Canyon storage facility were allowed to increase its withdrawal levels to compensate for the reduced supply into Southern California, then the supply would only be reduced by 15-25%. Based on these findings, Sandia recommends "the most important action that could be taken prior to an earthquake such as this" is to conduct stakeholder discussions on the use of gas in the Aliso Canyon storage facility and the possibility of emergency arrangements for increased withdrawal rates.[315]

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[317] Personal communication with PG&E. January 15-16, 2018.

[318] Piazza, Mark, Karineh Gregorian, Gillian Robert, Nicolas Svacina, and Lesley Gamble. "Satellite Data Analytics for Natural Disaster Assessment and Application to Pipeline Safety." *2018 12th International Pipeline Conference* (September 2018). 10.1115/IPC2018-78695.

[319] SoCalGas. "Natural Gas System Operator Safety Plan: Chapter 8." *SoCalGas,* February 22, 2018. Obtained via personal communication with SoCalGas.

those locations overlapped with their pipeline network, facilitating more targeted responses. Importantly, by sending utility staff and external resources to the locations identified as highly affected by the mudslides, SoCalGas was able to efficiently use resources in the time-critical post-event assessment.[320] Similarly, their aerial drones with methane radar sensors and GoPro high definition cameras were able to detect leaks and rapidly assess damage. [321] SoCalGas now performs post-wildfire reconnaissance to determine areas of high risk that need greater monitoring and/or preventative measures.

Figure 27. SoCalGas employees, including CEO Patti Wagner (right) survey damage and prepare for repair and restoration work after the Montecito mudslides.

Sources: SoCalGas Twitter https://twitter.com/socalgas/status/953423811604488192 (left) and https://twitter.com/socalgas/status/956622591090868224 (right).

In Texas, CenterPoint Energy activated their Electric and Gas Operations Emergency Operating Plans a day in advance of Harvey's landfall. During the hurricane, the company activated their Incident Command Center, coordinated mutual assistance crews, and issued news on damage assessments and restoration updates. In total, the Gas Operations team inspected 460 gas crossings, of which only 7 required remediation. They also inspected 130,016 gas meters for damage and found that 53,000 gas meters that were submerged under water and required remediation. Of the 863 gas stations inspected, 83 were submerged under flood waters, 75 of which required remediation such as relief valves, debris removal, and fencing. The Gas Operations team also helped the City of Beaumont address a breach in the 18-inch pipeline below the Neches River. A remote methane leak detector mounted on a drone to check methane levels helped to alert CenterPoint and the City to the issue.[322]

After Harvey made landfall on August 25, 2017, Gas Operations resumed normal operations on September 8.[323]

Electricity

The destruction caused by fires provided electric companies with an opportunity to build resilience. For example, SDG&E crews replaced damaged wooden poles with fire-resistant steel poles and thicker, stronger wires through the wood-to-steel replacement program in the wake of the December

[320] Piazza, Mark, Karineh Gregorian, Gillian Robert, Nicolas Svacina, and Lesley Gamble. "Satellite Data Analytics for Natural Disaster Assessment and Application to Pipeline Safety." *2018 12th International Pipeline Conference* (September 2018). 10.1115/IPC2018-78695.
[321] Personal communication with SoCalGas. January 22, 2018.
[322] Greenley, Steve. "Texas Strong: Hurricane Harvey Response and Restoration." *CenterPoint Energy*, February 21, 2018. https://www.energy.gov/sites/prod/files/2018/02/f49/2_Emergency
[323] Ibid.

2017 wildfires.[324] After the 2017 fires in the SCE service area, the utility created a program for Grid Safety and Resilience, with the goal of improving system resilience to wildfires. This program included system hardening, including replacing standard "bare" overhead wire with insulated wires and replacing traditional wooden poles with composite, fire-resistant poles.[325,326]

CenterPoint Energy's Electricity Operations team worked diligently and coordinated with mutual assistance workers to respond to Hurricane Harvey. The utility hailed grid modernization as key to its resilience during the event, citing smart grid technology such as distribution automation devices (e.g., intelligent grid switches) that allowed them to quickly isolate grid issues and remotely restore service to customers, which increased performance and upheld safety. The utility estimated that using this technology avoided almost 41 million outage minutes for their customers. The smart grid technology, plus use of drones, also created greater situational awareness and better inform decision-making.[327]

CenterPoint Energy's Memorial substation was impacted by several feet of floodwater. In response, the utility installed a 50 MVA mobile substation in a week, which provided electric service to more than 9,000 customers without power. At CenterPoint's Grant substation, the flood wall helped to protect the substation and maintain service for Texas Medical Center.[328]

Grid Modernization Reduces Storm Impact

CenterPoint Energy estimated that during Hurricane Harvey, its use of grid modernization technology such as distribution automation devices (e.g., intelligent grid switches) that allowed them to quickly isolate grid issues and remotely restore service to customers, avoided almost 41 million outage minutes for their customers.

In total, CenterPoint Energy experienced a 10-day outage (755 million total minutes out). Electric Operations resumed normal operations on September 7 after performing more than 1.27 million restorations.[329]

Mutual Assistance

Mutual assistance agreements among utilities proved to be another contributor to resilience. In Texas, investor-owned electric utilities from at least 21 states assembled over 10,000 workers for the Harvey restoration process.[330] Similarly, intrastate electric co-ops gathered hundreds of workers in affected Texas areas to restore power and repair damages.[331] In areas affected by Hurricane Irma, as many as 50,000 utility workers from across the country assembled via mutual assistance to help

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[324] Nikolewski, Rob. "California fires: SDG&E expects to fully restore power Tuesday." *The San Diego Union Tribune*, December 11, 2017. https://www.sandiegouniontribune.com/news/public-safety/sd-fi-power-restoration-20171211-story.html
[325] Fadia, Khoury R., Russell Archer, and Margarita Genvondyan. "Southern California Edison Company's (U 338-E) 2019 Wildfire Mitigation Plan." *Southern California Edison Company,* February 6. 2019. https://www.edison.com/content/dam/eix/documents/investors/wildfires-document-library/20190206-wildfire-mitigation-plan.pdf
[326] Southern California Edison. "Grid Resiliency." Accessed June 25, 2019. http://www.sce.com/ko/safety/wildfire
[327] Greenley, Steve. "Texas Strong: Hurricane Harvey Response and Restoration." *CenterPoint Energy*, February 21, 2018. https://www.energy.gov/sites/prod/files/2018/02/f49/2_Emergency
[328] Ibid.
[329] Ibid.
[330] Edison Electric Institute. "Harvey Response: Power Restoration Is a Team Effort." August 30, 2017. www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/ma_map.pdf
[331] Holly, Derrill E. "Texas Co-ops Continue Hurricane Recovery." *National Rural Electric Cooperative Association,* August 29, 2017. https://www.electric.coop/texas-co-ops-continue-hurricane-recovery/

with restoration and repair efforts.[332] In response to Hurricane Michael, 35,000 workers from 27 states and Canada worked together to restore electricity to roughly 95% of affected customers within a week of the storm's landfall.[333]

However, some federal resources that had been sent to Texas in response to Hurricane Harvey had to be pulled out in order to go to areas affected by Hurricane Irma, which did put a strain on federal aid resources.[334]

According to the CUEA, gas companies were able to send technicians and other personnel and supplies to one another in order to support the necessary response forces after both the October and December 2017 wildfires in California. It is not always feasible for utilities to each maintain emergency-level workforces and resource bases, and so they have successfully relied on such mutual aid agreements to build up personnel and supplies when and where necessary in times of emergency.[335]

Backup Generation

Damage and Service Disruptions: Hurricanes Harvey, Irma, and Michael

The Arkema chemical plant in Crosby, TX, lost both its grid electric power and backup diesel-powered trailers due to floods from Hurricane Harvey. When volatile compounds being stored at the plant were no longer refrigerated, noxious fumes were emitted into the atmosphere and created the possibility for explosions.[336]

In Florida during Hurricane Michael, some remote water systems with natural gas generators lost service when tree roots pulled up the gas lines.[337] A television station in Panama City, FL lost its main power and its backup generator, leaving the area without local television news.[338]

Damage and Service Disruptions: California Wildfires

Overall, there was very little information about disruptions or damage in relation to backup generation. However, contacts at CUEA confirmed that thousands of generators were distributed during the California wildfires. In remote, mountainous areas, propane generators dominate because they are easier and cleaner energy sources. Yet, they are difficult to transport because the FAA bans transport by air. Therefore, most major facilities use diesel generators.[339] The main challenge of using generators is that they require refueling. During an active wildfire and recovery, accessing the sites to refuel may be impossible.[340] In addition, diesel has a shelf life and cannot be kept on-site indefinitely.

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[332] Baltz, Tripp. "50,000 Utility Workers Strive to Get Power Back Up After Irma." *Bloomberg Bureau of National Affairs,* September 12, 2017. https://www.bna.com/50000-utility-workers-n57982087838/
[333] "Power Restored to 95 Percent of Customers as Industry Works to Rebuild the Most Severely Damaged Infrastructure." *T&D World,* October 17, 2018. *Electricity Subsector Coordinating Council.* https://www.tdworld.com/electric-utility-operations/article/20971805/power-restored-to-95-of-customers-after-hurricane-michael
[334] Personal communication with the Greater Harris County Local Emergency Planning Committee. February 19, 2018.
[335] Personal communication with CUEA, February 14, 2018.
[336] St. John, Jeff. "Harvey's Devastation Shows the Need for Distributed Energy, Microgrids During Disasters." *Greentech Media*, September 1, 2017. https://www.greentechmedia.com/articles/read/harveys-devastation-shows-the-need-for-distributed-energy-microgrids-during#gs.Gln6KiE
[337] Personal communication with the Florida Rural Water Association. April 19, 2019.
[338] Venta, Lance. "Hurricane Michael Takes Panama City Off the Air." *RadioInsight*, October 10, 2018. Accessed April 10, 2019. https://radioinsight.com/headlines/171070/hurricane-michael-takes-panama-city-off-the-air/
[339] Personal communication with CUEA, April 23, 2019.
[340] Ibid.

Lawsuits filed by residents of Ventura, Santa Paul and Ojai claim that functional backup generators were not available during the Thomas Fire, and so loss of electrical power from the grid made it impossible for water pumping stations to function.[341] According to the CUEA, these water pumps are reliant on the electrical grid and do not have backup generators.[342]

Compounding Consequences

Backup diesel, propane, and natural gas generators were generally found to be resilient during the events discussed in this report and enhanced resilience where they were used. However, since they pose a line of defense (hence "backup" generators) against power outages, impacts to generators have compounding consequences.

This has been especially true at critical facilities such as hospitals. While most hospitals have back-up power for critical functions, these generators, which are primarily diesel, need to be refueled frequently to remain operational. Also, in some cases, even the generators fail. During Tropical Storm Irene in 2011, Johnson Memorial Medical Center in Stafford, CT suffered a power outage as well as a generator failure. The hospital evacuated 43 patients – every patient except those in the emergency and obstetrics departments – over the course of 4.5 hours. While the cause of the generator failure was uncertain, hospital officials did acknowledge that the generator was decades old. Luckily, no patients suffered negative consequences from the loss of power and generator failure.[343]

During Hurricane Sandy in 2012, New York University Langone Medical Center and Bellevue Hospital center both lost power as well as their backup diesel generators. In these cases, the generators had been situated on high floors, protected from floodwaters, but other critical system components (e.g., diesel fuel pumps and tanks) were located in the basement and suffered flood damage. Roughly 1,000 patients between the two hospitals were safely evacuated.[344]

However, the picture was much darker at Memorial Hospital during Hurricane Katrina in 2005. There, 45 patients died as power outages and generator failures left the facility in a severe state of emergency. The generators stopped working roughly two days after Katrina made landfall near New Orleans. As the hospital struggled over the course of three days to evacuate its patients, difficult conditions created by the civil unrest throughout the city, the hurricane, and the power outages led doctors and hospital officials to make difficult triage decisions.[345]

Examples of Resilience

Customer Resilience

In Florida and Texas, hospitals with natural gas-fired backup generators cited these systems as an important disaster response strategy. Memorial hospital in Florida was able to maintain critical

[341] Harris, Mike. "Lawsuits allege Southern California Edison negligently started Thomas Fire." *Ventura County Star*, January 4, 2018. http://www.vcstar.com/story/news/local/2018/01/04/lawsuits-allege-southern-california-edison-negligently-started-thomas-fire/991192001/
[342] Personal communication with CUEA, February 14, 2018.
[343] Weir, W. "When Power Generator Fails, Hospital Takes Extreme Measure of Evacuation." *Hartford Courant*, August 29, 2011. https://www.courant.com/health/hc-xpm-2011-08-29-hc-jmh-hurricane-evacuation-0830-20110829-story.html
[344] CBS and AP. "What caused generators to fail at NYC hospitals?" *CBS News*, November 2, 2012. https://www.cbsnews.com/news/what-caused-generators-to-fail-at-nyc-hospitals/
[345] Fink, Sheri. "The Deadly Choices at Memorial." *ProPublica*, August 27, 2009. https://www.propublica.org/article/the-deadly-choices-at-memorial-826

functionality throughout Irma, as it had fuel trucks on standby to refill their two generators' gas cylinders and had a third backup generator tied into their power plant.[346]

Combined Heat and Power (CHP) has allowed emergency services to improve resilience where implemented during instances of electricity disruptions.[347] CHP is a form of distributed generation and is generally located at or near the building or facility using the energy, often powered by natural gas. In CHP systems, the heat of generation is recaptured and used to provide thermal energy for space and process heating, cooling, and dehumidification, thus increasing energy efficiency. These systems can increase resiliency when they use generators that are capable of starting and operating in the face of grid outages, and when the system is able to disconnect from the grid and support critical loads when necessary.[348]

Medical Center (a large hospital campus) "was able to sustain its air conditioning, refrigeration, heating, sterilization, laundry, and hot water needs throughout [Harvey]" due to their on-site CHP system fueled by natural gas, despite grid outages and major flooding. The University of Texas Medical Branch at Galveston fared quite well during Harvey despite electrical grid outages due to its ability to operate in "island mode" on its on-site CHP system, which was installed post-Hurricane Ike to build resilience. This enhanced resilience from CHP avoided impacts from the previous loss of its underground steam distribution system, which was unable to operate for 90 days due to Hurricane Ike in 2008.[349]

During Hurricane Michael, medical services relied heavily on backup generation, even when buildings were damaged and flooded and water and electric services were down. In Georgia, 20 hospitals and 15 nursing homes were left on generator power.[350] Some hospitals in Florida were able to remain partially open due to generator power but having partial power from generators was not the main challenge faced by these hospitals. Rather, structural damage and subsequent risk to patients resulted in the greatest impacts. Such damages were experienced by Sacred Heart (where a collapsed roof posed the greatest challenge)[351] and Bay Medical (where no water and a flooded fourth floor made care difficult to administer).[352]

Other important infrastructure was able to rely on backup generation. For example, the H-E-B grocery store chain had 18 stores operating in "island mode," where they were able to maintain power via natural gas-fired backup generators fueled by underground pipelines while being

[346] Cravey, Beth Reese. "Hurricane Irma: How Jacksonville-area hospitals responded to latest weather crisis." *The Florida Times Union*, September 15, 2017 (updated September 18, 2017).
[347] EPA. *Combined Heat and Power (CHP) Partnership*. May 10, 2019. https://www.epa.gov/chp
[348] Kogan, Gene. "Mitigating Risks & Resiliency with Combined Heat and Power (CHP)." *U.S. DOE Pacific CHP Technical Assistance Partnership*, January 18, 2018.
[349] Schuett, Jerry A. PE. "The University of Texas Medical Branch (UTMB) at Galveston: Energy Security on a Barrier Island." Presented to Energy Master Planning for Resilient Military Installations. *Affiliated Engineers,* December 6, 2017. https://www.iea-ebc.org/Data/Sites/4/media/events/2017-12/presentations/16--schuette--energy-security-on-barrier-island.pdf
[350] Evans, Melanie. "Hurricane Michael Forces Florida Hospitals to Shut Down." *The Wall Street Journal*, October 12, 2018. https://www.wsj.com/articles/hurricane-michael-forces-florida-hospitals-to-shut-down-1539287788
[351] Lohr, David. "Hurricane Michael Forces Florida Hospitals to Evacuate." *Huffington Post,* October 11, 2018. https://www.huffpost.com/entry/hurricane-michael-forces-florida-hospitals-to-evacuate_n_5bbfbcb5e4b040bb4e805efe
[352] Fausset, Richard, Sheri Fink, and Matthew Haag. "Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients." *The New York Times*, October 11, 2018. https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html

disconnected from the grid. This allowed them to maintain full power and keep refrigerators running, avoiding losses.[353,354]

During Hurricane Michael, the Florida Rural Water Association supplied mobile generators to water systems in affected counties to help restore power and functionality to these systems. By October 16 (six days after landfall), their inventory of generators had been depleted. The Association worked to move generators from system to system as power was restored.[355] Similarly, the Florida State Emergency Response Team purchased generators to run traffic signals in impacted areas, with 700 generators available in total.[356]

During the Woolsey and Hill Fires, water utilities in Southern California relied on backup generators to maintain water pressure when the power went out. Especially in areas of varied terrain, the utilities normally rely heavily on booster stations to maintain pressure and flow throughout their service territories. Having backup generators at these stations meant that water could be made available where it was needed (barring other factors such as physical damage to pipes or stations.)[357]

An important consideration in back up generation is the reliability of resources. In our research and interviews, we found that diesel generators were much more commonly used that natural gas generators during emergencies. However, interviewees noted issues in the reliability in diesel supply during events, and natural gas supplied through a pipeline would be preferable. In California, natural gas generators can allow generators to operate without concerns over local air quality permit issues.

While not a part of our case study research, generators can also provide long-term reliability advantages over current available technologies for commercial battery back-up systems, which can have a limited amount supply capacity.[358] Natural gas powered generators provide a combination of advantages (i.e., air quality, supply reliability, long-term capacity) over diesel and battery back-up systems.

Utility Actions

It is also a regular practice for gas utilities to supply cylinders of gas to areas that have had their service isolated (once access is allowed). Having these cylinders on hand allows for continuity of supply despite network outages. This mobile gas supply can also be set up in locations that suddenly need gas in the face of natural disasters. For example, an ambulatory nursing home in Napa, CA, had to be evacuated and the residents were relocated to a building that was not built to provide care for the additional residents. Having both backup water and natural gas cylinders and generators brought to this evacuation site meant that the residents had continuous access to air conditioning, power, fresh water, and other necessities. This sort of standby generation is available for other critical infrastructure, such as city halls and police stations.[359] Southern California Edison

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[353] St. John, Jeff. "Harvey's Devastation Shows the Need for Distributed Energy, Microgrids During Disasters." *Greentech Media*, September 1, 2017. https://www.greentechmedia.com/articles/read/harveys-devastation-shows-the-need-for-distributed-energy-microgrids-during#gs.Gln6KiE

[354] Chapa, Sergio. "Microgrids pass crucial test for H-E-B during Hurricane Harvey in Houston." San Antonio Business Journal, August 28, 2017. https://www.bizjournals.com/sanantonio/news/2017/08/28/microgrids-pass-crucial-test-for-heb-during-harvey.html?msclkid=9c46fe60caea11ecafbbb5cd69a2caf8

[355] Florida Rural Water Association. 2018. *Hurricane Michael.* October 19. Accessed April 22, 2019. https://www.frwa.net/hurricane-michael-updates.html.

[356] Florida Association of Counties. 2019. *Hurricane Michael*. Accessed April 22, 2019. http://www.fl-counties.com/hurricane-michael.

[357] Personal communication with LA Water Board. May 1, 2019.

[358] USDOE. "Using Backup Generators: Alternative Backup Power Options." Accessed August 7, 2019. https://www.energy.gov/ceser/emergency-preparedness/community-guidelines-energy-emergencies/using-backup-generators-0

[359] Personal communication with CUEA. February 14, 2018.

contacted all its Medical Baseline, Critical Care, and Essential Use customers during the Thomas Fire and subsequent outages, providing generators to all but the three customers who declined.[360] In Montecito, SoCalGas provided a temporary gas supply cylinder to residents until service was reestablished after the mudslides.

Backup generation was also key in one case of keeping gas compressors online to maintain pipeline functionality. In California, hydrocarbon gas had to be moved to a Kinder Morgan pipeline, which required an additional power input, some of which was provided by backup generation from natural gas.[361]

SoCalGas's compression stations have the ability to operate during electricity outages. Stations can source energy generated on-site to self-start during these instances.

Mobility and Transportation

Damage and Service Disruptions

The impacts to natural gas did not translate into changes in mobility during or after any of the disaster events (e.g., there were no reports of customers with liquefied natural gas fleets being impacted by disruptions in natural gas service). In fact, the greatest impact to mobility came from the disasters themselves: floodwaters, fire areas, and mud all created unsafe and physically inaccessible conditions.

For example, Governor Scott advised Floridians against returning to their homes immediately after Hurricane Michael due to road closures from flooding, downed trees, and power lines. US-98 along the Florida coastline experienced numerous washouts, and as of October 15, 2018 (5 days after Michael made landfall), there was no time estimate for reopening of the interstate.[362] Similarly, the Federal Rail Administration reported that "significant concerns" for restoration efforts included wind damage and downed trees, as well as heavy rainfall and potential flooding. The CSX Railroad experienced related issues, with thousands of downed trees and power lines crossing the tracks. [363]

The mudslides in Santa Barbara blocked Highway 101 with water, mud, and debris, forcing Caltrans to close a large chunk of the highway through January 22nd. As a major thoroughfare, disruptions to these key transportation routes disrupts trade and mobility for the region. Many people had to take detours.

Due to the Woolsey Fire, the Pacific Coast Highway was closed for multiple days, and then access was limited while Caltrans completed repairs. The fire burned hundreds of feet of guardrail, damaged signs, and resulted in closures of US-101 and SR 23.[364] Many other roads in the area were impassible, blocked by debris, obscured by heavy smoke, or cut off to prevent access.[365] After the

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[360] Aoyagi-Stom, Caroline. "SCE Conducts Damage Assessments as SoCal Wildfires Continue to Burn." *Inside Edison,* December 8, 2017. https://www.insideedison.com/stories/sce-begins-damage-assessments-as-socal-wildfires-continue-to-burn
[361] Personal communication with CUEA. February 14, 2018.
[362] U.S. Department of Transportation (DOT). "US Department of Transportation Resources for Hurricane Michael, Storm Response Highlight Report." *USDOT,* October 15, 2018. https://www.transportation.gov/briefing-room/us-department-transportation-resources-hurricane-michael
[363] Ibid.
[364] Caltrans. "Caltrans District 7." Accessed August 7, 2019. https://dot.ca.gov/caltrans-near-me/district-7
[365] Department of Homeland Security. "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary." National Protection and Programs Directorate, November 10, 2018. https://www.hsdl.org/?abstract&did=818743

wildfires, many roads were also at risk of flooding and mudslides.[366] Although not documented in reports, power outages may also impact traffic signals.[367]

During the wildfires and mudslides, the utilities were able to coordinate through the CUEA to receive permission to access damaged areas, be escorted by emergency personnel, and work with the Department of Transportation to find accessible pathways.[368] The situational awareness compiled and disseminated by the CUEA was critical to the success of response efforts. The main issue restricting responders' mobility during and after the fires was the navigability of roads.

In Malibu, the narrow roads and steep terrain made it difficult for emergency responders to reach their destinations and also made it challenging for residents to evacuate.[369] The Pacific Coast Highway, the only road south of the Santa Monica Mountains, experienced major traffic jams as people funneled in.[370] People trapped on the road could have been especially vulnerable if the wildfire moved south, as occurred during the Camp Fire in Northern California (Paradise, CA) where three of the five roads leading out of town were closed.[371] While residents drove down the mountain, emergency responders had to move against traffic to fight the fire, maintain safety, and remove debris.[372]

Compounding Consequences

The obstruction of and damage to roads and other transportation infrastructure meant that other elements of the disaster response were hindered or slowed. For example, it took peninsular water utilities in Florida a week to travel 100 miles up to affected panhandle counties to provide assistance due to downed trees and other damage to transportation infrastructure.[373]

The largest psychiatric hospital in Florida was physically cut off due to Hurricane Michael's destruction, and water and food had to be airdropped via helicopters.[374]

Disruptions to major transportation thoroughfares in Southern California caused logistical challenges for trade and mobility through the region. Truckers, in particular, were affected. All drivers had to take lengthy detours to find ways around damaged highways that were closed for extended periods. In addition, the region experienced economic losses due to transportation disruptions. One estimate found that every week Highway 101 was closed resulted in approximately $6.6 million of visitor spending in Santa Barbara County.[375]

Examples of Resilience

In Texas, Freedom CNG (a refueling station developer) reported that Texas' over 150 natural gas stations all had supply during the storm, with no shortages or price fluctuations. Fleets such as

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[366] Los Angeles County Emergency Operations Center. "DEBRIS, MUD, OTHER HAZARDS EXPECTED IN WOOLSEY FIRE AREAS." Press release, November 21, 2018.
[367] Southern California Edison. "Outage Center." Accessed June 26, 2019. https://www.sce.com/outage-center.
[368] Ibid.
[369] Personal communication with CUEA. April 23, 2019.
[370] Sawicki, Emily. "What Went Wrong With the Woolsey Fire?" Malibu Times, December 5, 2018.
[371] Nicas, Jack. "Forced Out by Deadly Fires, Then Trapped in Traffic." *The New York Times*, November 11, 2018. https://www.nytimes.com/2018/11/11/us/california-fire-paradise.html
[372] Personal communication with CEUA. April 23, 2019.
[373] Personal communication with the Florida Rural Water Association. April 19, 2019.
[374] CBS News. "Michael's Death Toll Jumps as Crews Search for Survivors - Live Updates." *CBS News,* October 12, 2018. https://www.cbsnews.com/live-news/hurricane-michael-damage-florida-flooding-georgia-power-outage-weather-deaths-today-live-updates/
[375] Baldwin, Gillian. "Santa Barbara Tourism Reels, Recovers After Fire, Mudslides." *The Santa Barbara Independent,* February 5, 2018. https://www.independent.com/2018/02/05/santa-barbara-tourism-reels-recovers-after-fire-mudslides/

Houston METRO transit buses, garbage trucks, and AT&T service vehicles in the greater Houston area were able to be fueled in the face of disaster.[376]

Caltrans, the state Department of Transportation for California, did not experience natural gas-related issues during the October or December 2017 wildfires. Even in the case of maintenance stations in areas that experienced interruptions in natural gas services, no issues were reported.[377]

Water and Wastewater Services

Damage and Service Disruptions

Water and wastewater utilities were heavily affected by the hurricanes. Hurricane Irma traveled through the center of Florida, affecting roughly 85% of water utilities there. Utilities from other states, such as Alabama and Tennessee, had to be called upon to supplement the aid provided by the 15% of Florida water utilities that were unaffected by Irma.[378] While a smaller area of Florida was hit by Hurricane Michael, water utilities experienced widespread service disruptions. In Mexico Beach, FL, an elevated full water tank was blown down and created a wave that nearly washed away high service pumps and generators.[379] The Florida Rural Water Association (FRWA), which supplies equipment and aid to affected water and wastewater utilities during disasters, was also experiencing an equipment shortage during Hurricane Michael: some of their equipment was still in the Carolinas, where they had sent it to help with the response to Hurricane Florence just the month before.

The recovery from Hurricane Michael proved to be more challenging than the immediate disaster response. While generators were able to get water systems back online in relatively short order, permanent fixes were a longer time coming. The affected water utilities invested heavily in restoring infrastructure, which quickly exhausted financial reserves. Compounding this, water and wastewater utilities' primary source of revenue comes from water sales and volume of wastewater treated. The reduction in customers due to evacuations and destruction of homes and commercial infrastructure meant that these utilities have not been bringing in the necessary revenue to recover their costs.

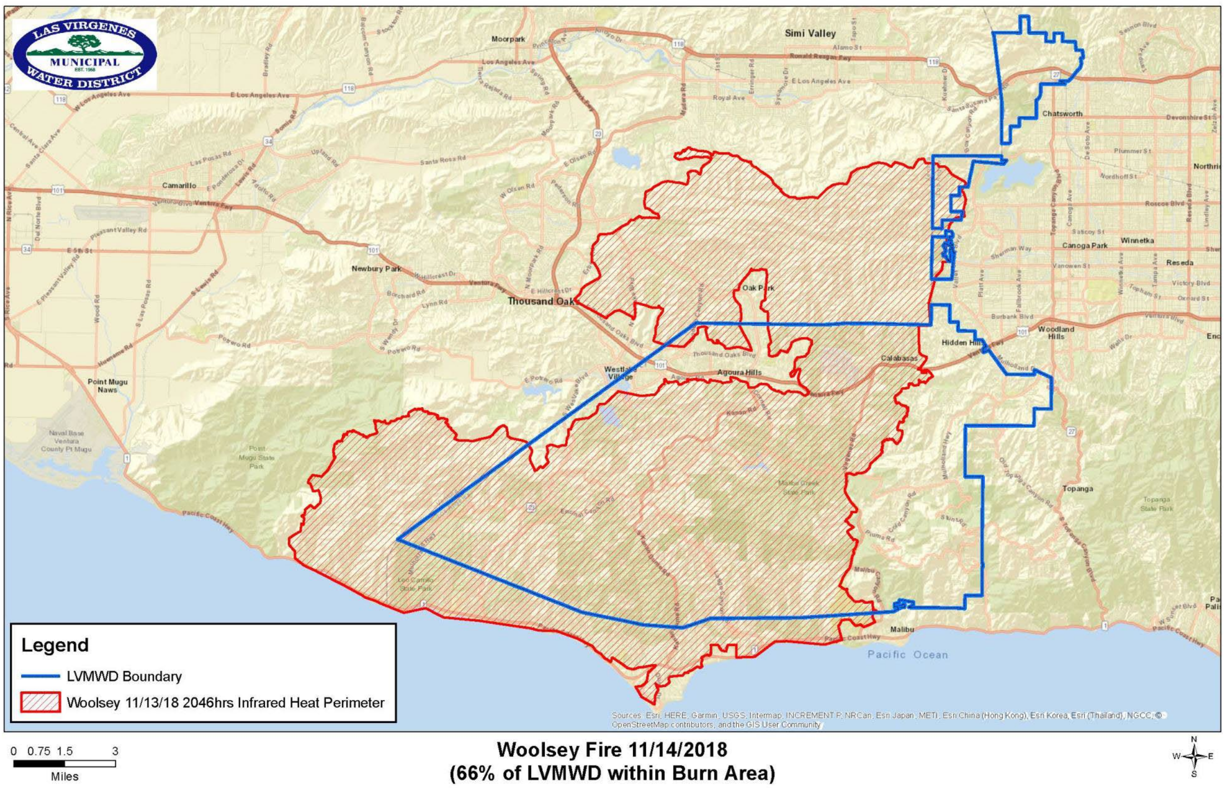
Physical asset recovery has been slow for water and wastewater utilities. In some cases, it took six months to replace control panels that had been destroyed. Some systems were still running off generators in late April 2019, half a year later, while replacement infrastructure was rebuilt and elevated. Due to the extreme strength of Hurricane Michael, damages were not limited to aboveground infrastructure: lines were washed out of the ground and had to be replaced.[380]

California's wildfires produced numerous issues for water utilities and overall water quality. During wildfires, firefighting efforts require a large amount of water, which can depressurize the system and create opportunities for contamination. For example, the Los Angeles County Waterworks District No. 29, which serves Malibu, lost pressure in the water distribution system during the Woolsey Fire. This disrupted the ability of residents to protect their homes, and some reported that even firefighters lost water pressure from fire hydrants. [381] After the Woolsey Fire, customers of the Los

[376] Bates, Michael. "Natural Gas Infrastructure in Good Shape During Harvey," *Next-Gen Transportation News*, September 5, 2017. https://ngtnews.com/natural-gas-infrastructure-good-shape-harvey
[377] Personal Communication with Caltrans. January 31, 2018.
[378] Personal communication with the Florida Rural Water Association. April 19, 2019.
[379] Florida Rural Water Association. "Hurricane Michael." October 19, 2018. https://www.frwa.net/hurricane-michael-updates.html
[380] Personal communication with the Florida Rural Water Association. April 19, 2019.
[381] Hamilton, Matt, Alene Tchekmedyian, Benjamin Oreskes, Laura Nelson, Jaclyn Cosgrove. "As Toll Mounts from Malibu to Thousand Oaks, How Did the Woolsey Fire Become a Monster?" *Los Angeles Times*, November 13, 2018. https://www.latimes.com/local/lanow/la-me-woolsey-fire-spread-20181113-story.html.

Angeles County Waterworks District No. 29 and the Las Virgenes Municipal Water District were under boil water advisories due to low pressure in the system that could have introduced bacteria and other organisms into the supply.[382] Figure 28 shows the extent of the Las Virgenes Municipal Water District (LVMWD) within the fire zone.

Figure 28. Overlay of Las Virgenes Water District service area with the Woolsey Fire zone.[383]



There are thousands of water companies in California, many of them very small. Since water and wastewater facilities are immobile, they are at greater risk due to wildfires.[384] Also, if they are damaged, there can be wide-ranging impacts, such as loss of potable drinking water or biohazard risks if wastewater facilities are affected.[385] For example, during the Tubbs Fire in 2017, plastic water supply pipes melted and leached toxic benzene into Santa Rosa's drinking water supply. In the long-term, the water utility will have to replace the entire water system, including water mains that did not melt during the fire.[386] After the Woolsey Fire, the Los Angeles County Department of Public Health warned residents that septic tanks could have been damaged by the heat of the fire, and associated collapse or caving could cause contamination.[387] The Camp Fire in Paradise created

[382] "Some Residents in Woolsey Fire Area Advised to Boil Water - NBC Southern California." November 12, 2018. Accessed June 25, 2019. https://www.nbclosangeles.com/news/local/Woolsey-Fire-Boil-Water-Wildfires-500265341.html.
[383] Las Virgenes Municipal Water District, "Woolsey Fire – Recovery Information and Help," January 15, 2019, https://www.lvmwd.com/for-customers/woolsey-fire-help-page
[384] Personal communication with CUEA. April 23, 2019.
[385] Ibid.
[386] Weiser, Matt. "After Deadly Wildfire, a New Problem for Santa Rosa: Contaminated Water." Water, April 3, 2018. https://www.newsdeeply.com/water/articles/2018/04/03/after-deadly-wildfire-a-new-problem-for-santa-rosa-contaminated-water.
[387] County of Los Angeles Public Health. "Health Alert: Septic Tank Advisory; Advisory in effect for Woolsey Fire burn areas in unincorporated portions of Malibu." November 30, 2018. https://www.lacounty.gov/wp-content/uploads/11.30.18-Septic-Tank-Advisory-1.pdf

water contamination impacts where toxic releases entered the damaged distribution system, and state agency representatives have estimated needed replacements at $300M.[388] Las Virgenes MWD suffered some main breaks that contributed to their loss of pressure, and the utility had to make repairs before they could re-pressurize the affected system. Most of the physical damage to water infrastructure occurred close to the coast, where terrain is steeper and there are canyon and creek crossings that can more easily expose otherwise underground water pipes.[389]

Water and wastewater systems have many interdependencies with the power system. For example, if there is a power outage, residents who depend on wells will not be able to pump water. Likewise, wastewater collection systems often need to pump sewage to the final treatment plant if they are not gravity fed. Those who rely on local water and wastewater services may still have service access unless the local utilities lose power and do not have backup generation.

Before the Woolsey Fire, water utilities wanted to fill water tanks before any power outages occurred so that they would be able to maintain pressure in the water system.[390] Then, the water utilities coordinated with the County of Los Angeles and SCE to get generators to keep water going while the electricity was shut off in an effort to maintain pressure, as the firefighting efforts take a toll on the water system.[391] After the Woolsey Fire broke out, the Las Virgenes MWD lost power at nearly all of its facilities. Emergency generators were deployed to refill water storage tanks depleted by firefighting. However, many of these generators failed due to the extreme load for an extended period.[392] Previous annual testing of these generators had not been able to test the full generator capacity and predict these failures due to restrictions and regulations from the California Air Boards on the use of diesel fuel. Under the Airborne Toxic Control Measure (ATCM) for Stationary Compression Ignition Engines, there is a time limit of 20 hours per year for testing generators, which restricts full testing ahead of emergencies.[393] The failure of these generators meant that the Las Virgenes MWD had to place a last-minute request to borrow extra generators from a neighboring utility, the City of Beverly Hills, and a mutual aid organization. [394]

The fire and fire suppression activities can also contaminate the water supply.[395] For example, the fire suppressant chemicals used to control a fire can make their way into the water supply and increase the demands for water treatment. In addition, the loss of forest cover and impact on soil can have effects on water quality. Particularly, when rainstorms follow wildfires, sediment and other surface particles can be washed downstream into surface water resources. This impacts a drinking water quality and requires additional costs and resources in filtration and treatment.[396] In one case, the Thomas Fire in 2017 scorched the ground, drying it out and creating a water-repellent surface, which exacerbated the flooding and debris impacts downslope and downstream.[397]

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388 Nawaguna, Elvina. "Rare Toxic Cocktail from Camp Fire Is Poisoning Paradise Water. It Could Cost $300 Million to Fix." *The Sacramento Bee*, April 18, 2019. https://www.sacbee.com/news/local/environment/article228969259.html.
389 Personal communication with the LA Water Board. May 1, 2019.
390 Personal communication with the LA Water Board. May 1, 2019.
391 Sawicki, Emily. "What Went Wrong With the Woolsey Fire?" *Malibu Times,* December 5, 2018.
392 Companion CARB Letter from Jeff O'Keefe.
393 Ibid.
394 Personal communication with the LA Water Board. May 1, 2019.
395 Department of Homeland Security. "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary." National Protection and Programs Directorate, November 10, 2018. https://www.hsdl.org/?abstract&did=818743
396 "When the Smoke Clears: Aftereffects of Wildfires on Communities' Water Quality." *Babcock Laboratories, Inc,* December 18, 2018. https://www.babcocklabs.com/news/when-the-smoke-clears-aftereffects-of-wildfires-on-communities-water-quality/2018.
397 Staff, Indy. "Next Debris Flow Could Take Different, Unknown Path." *The Santa Barbara Independent,* March 19, 2018. https://www.independent.com/2018/03/19/next-debris-flow-could-take-different-unknown-path/.

Compounding Consequences

A loss of water to several hospitals in Florida during Hurricane Michael's devastation made an already difficult situation worse. A broken water line due to a downed tree at Florida State Hospital in Chattahoochee, along with inaccessible roads, meant that food and water had to be airdropped via helicopters during Hurricane Michael. The Hospital is the oldest and largest hospital in the state, and houses patients that have been committed via civil and criminal cases.[398] The hospital itself did not suffer breaches during the hurricane.[399] Bay Medical, one of the largest hospitals in Panama City, FL, was able to run on partial electricity from generators and maintain some functionality. However, its water supply was cut off, and the building took physical damage, both of which hindered its ability to serve patients.[400]

Drinking Water Contamination During Extreme Events

During extreme events, loss of electric supply to municipal water systems as well as damage to water pipes can result in low pressure that allows sewage to enter pipes. As a result of the Camp Fire, 173 miles of water pipe was contaminated with benzene and other carcinogens caused by burnt plastic pipes and meters, or by toxic waste from burnt structures, requiring residents to find alternative sources of water until the system was tested and cleared.

Damages to the water supply and wastewater systems could cause contamination of drinking water and other biohazards that endanger public health. In some instances, during the hurricanes, wastewater utilities sewage collection was hampered because they are not gravity fed and outages disabled pumps, creating public health concerns over untreated sewage.[401] As discussed in the proceeding section, hundreds of people in the area affected by the Woolsey fire were under boil water advisories due to possible contaminants. However, if residents did not heed these warnings, they may have experienced health complications.[402] In many areas, multiple utilities serve neighboring areas and communicating with the public about public safety, including boil water advisories; in these cases, some people may have not been aware of issues with their system.[403]

In Paradise, CA, which was severely impacted by the Camp Fire, residents returning to the area had been strictly advised to not use tap water for any purposes. This was due to contamination of the water system with benzene and other volatile organic compounds – aka carcinogens. The contamination may have been caused by burnt plastic pipes and meters, or by toxic waste from burnt structures that was sucked into water pipes as the water system lost pressure due to high demand from firefighting. Up to 173 miles of pipeline in Paradise's water system may be contaminated. The

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[398] CBS. "Michael's death toll jumps as crews search for survivors - live updates." *CBS News*, October 12, 2018. https://www.cbsnews.com/live-news/hurricane-michael-damage-florida-flooding-georgia-power-outage-weather-deaths-today-live-updates/
[399] Fausset, Richard, Sheri Fink, and Matthew Haag. "Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients." The New York Times, October 11, 2018. https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html
[400] Fausset, Richard, Sheri Fink, and Matthew Haag. "Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients." The New York Times, October 11, 2018. https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html
[401] Personal communication with the Florida Rural Water Association. April 19, 2019.
[402] Atagi, Colin. "Woolsey Fire sparks recommendations to use bottled or boiled water in affected areas." *Palm Springs Desert Sun*, November 12, 2018. https://www.desertsun.com/story/news/2018/11/12/woolsey-fire-sparks-recommendations-use-bottled-boil-water/1977261002/
[403] Personal communication with the LA Water Board. May 1, 2019.

testing process is likely to take at least two years, and in that time, residents are on their own to decide whether they want to take the risk of using and consuming potentially contaminated tap water or to make the investment in other sources, such as on-site water tanks.[404,405]

Examples of Resilience

As mentioned previously, the Los Virgenes Municipal Water District, which serves more than 65,000 residents, was affected by power outages during the Woolsey Fire. Las Virgenes utilized resources from CalWARN, a mutual assistance system that connects agencies statewide to borrow staff and equipment in case of emergency. The water company requested equipment, including generators, to maintain operations. This helped the District hold up while firefighting efforts were underway, although there were some water main breaks and leaks that lowered pressure in the system. Roughly 500 customers were issued temporary boil water orders due to the loss of pressure.[406]

While there were some instances of infrastructural damage to water utilities, other areas (such as closer to the origin point of the Woolsey and Hill Fires) fared better than expected. This resilience was attributed to good defensible space around key facilities.[407] In areas that did suffer physical impacts, such as Malibu, there were redundancies in the water distribution system the utility was able to use to continue delivering water to customers.[408]

In the case of the California wildfires, a key component of successful emergency response was coordination. Having a dedicated point of contact at the Emergency Operations Center and/or Governor's Office was key to coordinating responses across areas and water systems and collating the various activity to ensure that response needs were being met and resources were being allocated quickly and effectively.[409]

Telecommunications

Damage and Service Disruptions

During the hurricanes, electric outages led to loss of cellphone and internet services. In the case of the fires, damage to telecommunications assets themselves (e.g., melted fiber cables) contributed further to these outages.[410] This was a key impact in both scenarios, as reliable communication and information-sharing networks are a vital component of response and recovery.

Hurricanes had a severe impact on telecommunications infrastructure. The same day Hurricane Michael made landfall in Florida, almost all radio broadcast facilities were offline due to downed towers and power outages.[411] In Bay County, where Hurricane Michael made landfall, all modes of

[404] Siegler, Kirk. "Paradise, Calif., Water is Contaminated but Residents are Moving Back Anyway." *NPR,* April 16, 2019. https://www.npr.org/2019/04/16/713430751/paradise-calif-water-is-contaminated-but-residents-are-moving-back-anyway
[405] Associated Press. "Water in Paradise, site of worst California fire, contaminated with cancer chemical." *San Francisco Chronicle,* April 18, 2019. https://www.sfchronicle.com/bayarea/article/Water-in-Paradise-site-of-worst-California-fire-13779109.php#photo-16588392
[406] Carlson, Cheri. "Water Agencies Band Together, Seek Changes after Destructive Woolsey, Thomas Fires." *Ventura County Star,* March 4, 2019. https://www.vcstar.com/story/news/local/2019/03/04/california-water-agencies-band-together-after-destructive-woolsey-thomas-fires/2957790002/
[407] Personal communication with LA Water Board. May 1, 2019.
[408] Ibid.
[409] Ibid.
[410] Baron, Ethan. "Danger, road closures hamper efforts to restore phone and internet service in North Bay fire areas." *The Mercury News*, October 10, 2017 (updated October 13, 2017), https://www.mercurynews.com/2017/10/10/danger-road-closures-hamper-efforts-to-restore-phone-and-internet-service-in-fire-areas/
[411] Venta, Lance. "Hurricane Michael Takes Panama City Off the Air." *RadioInsight,* October 10, 2018. Accessed April 10, 2019. https://radioinsight.com/headlines/171070/hurricane-michael-takes-panama-city-off-the-air/

communication (satellite, fiber, and cellular) went down, largely due to destructive high winds damaging above ground infrastructure and causing uprooted trees to damage belowground infrastructure. Even eleven days after landfall, a third of cell service remained out in the county (initial outages peaked around two-thirds).[412,413] Lines were downed due to the high winds, and uprooted trees damaged or destroyed underground fiber lines. Verizon stated that they faced "unprecedented damage."[414]

Competing response efforts contributed to the ongoing challenge of restoring telecommunications service in the wake of Hurricane Michael. In some cases, including Tyndall Air Force Base, fibers that had been restored or replaced by Verizon were freshly cut by other response teams trying to work around equipment, causing setback and delays in restoration efforts.[415]

Failure of communications equipment can have serious implications during disasters, particularly during evacuations. Wildfires cause physical damages to telecommunications networks due to damage to pole-mounted systems and cellular towers. In addition, dense smoke can disrupt line-of-sight transmissions.[416] For example, during the October 2017 wildfires, counties in northern California lost service to around 160,000 landline and 85,000 wireless connections, including Public Safety Answering points; over 340 cell sites were completely destroyed or damaged.[417] More than 45% of survey respondents reported losing all cellular service during the October 2017 fire.[418] Then, during the Tubbs Fire in 2017, cell towers burned down; Verizon service was down and Comcast was out for a week. During the Woolsey Fires, Verizon and T-Mobile lost service in many areas. In particular, fiber damage impacted network performance for several days, cell sites relied on backup diesel generators or batteries, and access to cell sites was limited due to the extent of the fire.[419,420,421] In some cases, major carriers depended on third-party companies for backhaul (transmitting a signal from a remote site or network to a central one). Thus, damage to the infrastructure of these third-party companies can disrupt telecommunications, and it is not always clear which companies run these systems to facilitate recovery.[422]

Even when the telecommunications infrastructure has not been damaged directly, the system can become overloaded due too many people using the network simultaneously. For example, during the California wildfires, some major telecommunication systems failed due to high traffic on the

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[412] Chang, Alisa. "Hurricane Michael's Damage to Communications Systems Has Slowed Recovery." NPR, October 22, 2018. Accesed April 22, 2019. https://www.npr.org/2018/10/22/659611105/hurricane-michaels-damage-to-communications-systems-has-slowed-recovery

[413] Brodkin, Jon. "Verizon fiber suffered "unprecedented" damage from Hurricane Michael." *ARS Technica*, October 15, 2018. Accessed April 22, 2019. https://arstechnica.com/information-technology/2018/10/verizon-fiber-suffered-unprecedented-damage-from-hurricane-michael/

[414] Chang, Alisa. "Hurricane Michael's Damage to Communications Systems Has Slowed Recovery." NPR, October 22, 2018. Accesed April 22, 2019. https://www.npr.org/2018/10/22/659611105/hurricane-michaels-damage-to-communications-systems-has-slowed-recovery

[415] Verizon. "Hurricane Michael network updates." October 23, 2018. Accessed April 22, 2019. https://www.verizon.com/about/news/hurricane-michael-network-updates

[416] Department of Homeland Security. "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary." National Protection and Programs Directorate, November 10, 2018. https://www.hsdl.org/?abstract&did=818743

[417] North Bay/North Coast Broadband Consortium. Northern California Firestorm 2017. Telecommunications Outage Report, April 2018. http://www.mendocinobroadband.org/wp-content/uploads/1.-NBNCBC-Telecommunications-Outage-Report-2017-Firestorm.pdf

[418] Ibid.

[419] The Wall Street Transcript. Verizon Communications Inc: California wildfire network updates. https://www.twst.com/update/verizon-communications-inc-california-wildfire-network-updates-2/

[420] Verizon. "California wildfire network updates." November 21, 2018. Accessed April 30, 2019. https://www.verizon.com/about/news/california-wildfire-network-updates

[421] T-Mobile. "T-Mobile Responds to California Wildfires." T-Mobile News, November 9, 2018. https://www.t-mobile.com/news/cal-wildfire

[422] Personal communication with CUEA. April 23, 2019.

networks during the fires.[423] In addition to endangering residents by making it more difficult to receive updates and evacuation notices, it hinders communications between utilities and agencies coordinating emergency response. Additional limitations set on communications can also be disruptive. For example, Verizon Wireless has been widely criticized for throttling the data service speed for the Santa Clara County Fire Department while it was responding to the Mendocino Complex Fire in 2018 because the department had reached certain data limits. Until the department updated to a newer plan, their communication was slowed, and these disruptions had significant effects on the department's ability to provide emergency services.[424]

Data Plan Limit Impacts Fire Department Response

The response of the Santa Clara County Fire Department to the Mendocino Complex Fire in 2018 was impacted as a result of their service provider reducing the data service speed for the department because the department had reached certain data limits.

There were also issues with the emergency warning systems themselves. For example, a survey of residents in areas affected by the October 2017 wildfires found that over 23% of people did not receive any warning to evacuate.[425] During the December 2017 wildfires, Los Angeles did not use the Wireless Emergency Alert System, which left people unaware of the dangers. Many people were warned by emergency personnel coming house-to-house or friends informing them to evacuate.[426,427] The Ventura County Sheriff's Office sent out three Wireless Emergency Alerts during the Hill and Woolsey fires, although some of these just reached landlines.[428] Due to these fires, many weaknesses in the emergency alert systems were identified which has sparked changes, such as opt-out enrollment in emergency alerts and fewer restrictions on data usage by emergency personnel.

Compounding Consequences

Loss of communications was called an "Achilles' heel" of response efforts during Hurricane Michael.[429] Bay County's emergency services chief Mark Bowen cited the downed communication as a challenge for distributing humanitarian aid: "Here's all these resources flooding in, but you can't even find out where to go get them."[430] In addition, first responders couldn't communicate among teams, which posed a hurdle to search and rescue operations. Fifteen answering points in

423 Ibid.
424 Brodkin, Jon. "Verizon fiber suffered "unprecedented" damage from Hurricane Michael. ARS Technica," October 15, 2018. Accessed April 22, 2019. https://arstechnica.com/information-technology/2018/10/verizon-fiber-suffered-unprecedented-damage-from-hurricane-michael/
425 North Bay/North Coast Broadband Consortium. Northern California Firestorm 2017. Telecommunications Outage Report, April 2018. http://www.mendocinobroadband.org/wp-content/uploads/1.-NBNCBC-Telecommunications-Outage-Report-2017-Firestorm.pdf
426 Ibid.
427 Burkitt, Bree, and Perry Vandell. "As California wildfires force evacuations, lawmakers hope new alert system will save lives." *VC Start*, November 9, 2018. https://www.vcstar.com/story/news/local/california/2018/11/09/how-effective-emergency-alerts-natural-disasters/1950249002/
428 Serna, Joseph, Paige St. John, and Rong-Gong Lin II. "Alert systems aren't working." *Los Angeles Times,* November 20, 2018.
429 Chang, Alisa. "Hurricane Michael's Damage to Communications Systems Has Slowed Recovery." *NPR,* October 22, 2018. Accessed April 22, 2019. https://www.npr.org/2018/10/22/659611105/hurricane-michaels-damage-to-communications-systems-has-slowed-recovery
430 Ibid.

Florida and Georgia had to reroute their calls, making it more difficult for people to find help and alert first responders.[431]

Similarly, disruptions to communication networks hindered emergency response and firefighting efforts during the California wildfires.[432] Many command centers and organizations wanted to reach employees in the affected areas to receive updates on damages, but this was impossible when communication networks went down. For example, members of the California State Water Resources Control Board found that they experienced the automated "busy circuits" message when they tried to use cell service due to the overloaded system; luckily, the Division of Drinking Water (which supplies municipalities) has a Guest Card that can give them telecommunications service priority if necessary, during emergencies.[433]

Telecommunications networks also depend on reliable power networks. During the October 2017 wildfire, residents reported that power outages resulted in the loss of their ability to access means of communication, including phones, TVs, and internet (76% of survey respondents).[434] In some cases, this impeded evacuation.

Examples of Resilience

Resilience strategies for telecommunications included the use of mobile service extenders. For example, AT&T deployed their "Flying COW," or Cell on Wings, which hovered 200 feet above the ground in Mexico Beach, FL after Hurricane Michael and helped provide cell service to affected residents and first responders.[435] During the Woolsey and Hill Fires in Southern California, Verizon and T-Mobile deployed mobile communications trailers at fire stations, fire centers, and police departments, and their "cell on light truck" (COLT) to make up for lost coverage.[436] Verizon also dealt with widespread power outages by bringing portable generators to cell sites and having a refueling plan in place, and by bringing communications technology (internet-connected laptops, phones, and cell phone charging) to evacuation centers for community use and to emergency response and relief organizations to facilitate emergency response.[437] Verizon also loaned wireless equipment to emergency responders to compensate for problems on the overloaded networks.[438]

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[431] Fausset, Richard, Sheri Fink, and Matthew Haag. "Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients." *The New York Times*, October 11, 2018. https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html

[432] Department of Homeland Security. "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary." National Protection and Programs Directorate, November 10, 2018. https://www.hsdl.org/?abstract&did=818743

[433] Personal communication with LA Water Board. May 1, 2019.

[434] North Bay/North Coast Broadband Consortium. *Northern California Firestorm 2017*. Telecommunications Outage Report, April 2018. http://www.mendocinobroadband.org/wp-content/uploads/1.-NBNCBC-Telecommunications-Outage-Report-2017-Firestorm.pdf

[435] AT&T. "AT&T Response to Hurricane Michael." October 31, 2018. Accessed April 22, 2019. https://about.att.com/pages/hurricane_michael

[436] T-Mobile. "T-Mobile Responds to California Wildfires." *T-Mobile News,* November 9, 2018. https://www.t-mobile.com/news/cal-wildfire

[437] Verizon. "California wildfire network updates." November 21, 2018. Accessed April 30, 2019. https://www.verizon.com/about/news/california-wildfire-network-updates

[438] The Wall Street Transcript. "Verizon Communications Inc.: California wildfire network updates." November 14, 2018.

CHAPTER 4

Post-Event Resilience—2022 Update

In 2022, ICF updated the original 2019 case studies to further examine resilience measures during and after the events described in Chapter 3 above. This chapter presents the findings—both updated information on how resilience measures fared during the events themselves, but also resilience measures implemented in response to the vulnerabilities laid bare by the events. The findings are organized by end user resilience (e.g., households, businesses), legislative and utility responses, resilience measures in subsequent events, and Federal-level support after the hurricanes.

End User Resilience

Hurricane Harvey – End User Resilience

Microgrids have proven useful for resilience against hurricanes as well as wildfires. In 2016, Enchanted Rock, a company that designs backup power systems for businesses, signed a deal with the H-E-B supermarket chain and installed microgrids at locations throughout Houston.[439] The systems receive natural gas from underground pipelines that are very resilient to flooding and high winds, increasing resilience to extreme weather events. H-E-B supermarkets made the decision to invest in microgrids after previous storms affected the chain's ability to move its diesel-power backup generation sets among stores, as they needed to be transported by truck. These systems were among some of the first in the region to have natural gas as the primary fuel.

When Hurricane Harvey hit in 2017, 18 H-E-B stores were able to disconnect from Houston's main power grid and switch to the on-site generators.[440] Though not all stores remained open due to the storm, they were able to keep their refrigerators running and continue to receive shipments from suppliers after the storm had hit. Many H-E-Bs became community hubs for residents, and the H-E-B's emergency preparedness team is reported to have fed thousands of evacuees and first responders during the recovery period.[441]

[439] "Enchanted Rock / Texas Microgrid Powers H-E-B." *Business Wire*, July 12, 2016. https://www.businesswire.com/news/home/20160712005443/en/Enchanted-Rock-Texas-Microgrid-Powers-H-E-B?msclkid=42c1999fcbb511ecaecd52c827b546c7

[440] Marcacci, Silvio. "Hurricanes Harvey and Irma Show U.S. Must Boost Grid Resiliency. Energy Storage is Doing Just That." *Forbes,* September 8, 2017. https://www.forbes.com/sites/energyinnovation/2017/09/08/hurricanes-harvey-and-irma-show-u-s-must-boost-grid-resiliency-energy-storage-is-doing-just-that/?sh=7e1afe24c9f8

[441] Knapp, Gwendolyn. "High Efficiency: How H-E-B Delivered Relief After Harvey". *Houston Press*, October 11 2017. https://www.houstonpress.com/restaurants/h-e-b-kept-houston-hydrated-and-nourished-after-hurricane-harvey-9865473

"Natural gas is more reliable after a weather event than diesel. It's difficult to maintain two or three days' worth of diesel on site."

— Thomas McAndrew, CEO of Enchanted Rock

Enchanted Rock CEO Thomas McAndrew stated that "Hurricane Harvey has served as a 'proof of concept' for the technology, which has allowed the H-E-B stores to have 100 percent of the electricity they need at a time when power may be out in the surrounding area."[442] The on-site generators were fed by underground natural gas pipelines that remained unaffected by flooding and fallen trees.

"Natural gas has lower emissions," McAndrew said. "Natural gas is also more reliable after a weather event than diesel. It's difficult to maintain two to three days' worth of diesel on site."[443]

Forbes notes that while natural gas-powered microgrids with on-site generation and storage were effective to keep power on for larger facilities during Hurricane Harvey, these systems are too expensive for smaller businesses and homeowners. Microgrids with solar and storage are getting cheaper as technology costs go down and can generate revenue by sending excess power back to the grid, with no need to refuel—potentially providing a more affordable solution for such customers.[444]

Understanding whether a backup power source can provide sufficient energy to last through a grid outage during a multi-day extreme event such as a hurricane is important to building resilience. However, comparing the relative reliability of different fuel types for on-site backup generators, microgrids, and distributed energy resources is an ongoing field of study among energy experts.

Backup emergency generators are usually diesel-fueled and require on-site fuel tanks to provide reliable power. The runtime of the generator is largely dependent on the size of the fuel tank, the load and capacity being used, and fuel consumption rate. During major events that require use of backup generators such as storms, users have the risk of running out of on-site fuel as the generator runs for an extended time—and then having difficulty refueling due to roadways being blocked or supply chains being disrupted. However, some backup generators can be fueled by natural gas lines—in which case, the duration of generator runtime is not limited by the need to refuel.

In terms of reliability, microgrids are generally more reliable than backup generators:

- As mentioned above, fuel supply introduces risk to diesel-fueled backup generators.
- Maintenance also plays a big role in the reliability of diesel generators: a recent study found that poorly maintained generators have only a 50% reliability at 48 hours of operations while well-maintained generators have an 80% reliability at two weeks of operation.[445] Note that this

[442] Chapa, Sergio. "Microgrids pass crucial test for H-E-B during Hurricane Harvey in Houston." *San Antonio Business Journal*, August 28, 2017. https://www.bizjournals.com/sanantonio/news/2017/08/28/microgrids-pass-crucial-test-for-heb-during-harvey.html?msclkid=9c46fe60caea11ecafbbb5cd69a2caf8
[443] Ibid.
[444] Marcacci Silvio. (2017). Hurricanes Harvey and Irma Show U.S. Must Boost Grid Resiliency. Energy Storage is Doing Just That. https://www.forbes.com/sites/energyinnovation/2017/09/08/hurricanes-harvey-and-irma-show-u-s-must-boost-grid-resiliency-energy-storage-is-doing-just-that/?sh=7e1afe24c9f8
[445] Marqusee, Jeffrey, Sean Ericson, and Don Jenket. *Emergency Diesel Generator Reliability and Installation Energy Security.* (Golden, CO: National Renewable Energy Laboratory, 2020). NREL/TP-5C00-76553. https://www.nrel.gov/docs/fy20osti/76553.pdf

study measured failure of the generator itself and did not include events where the generator ran out of on-site fuel.

- A 2021 study found that hybrid systems were more resilient and cost-effective than diesel-only systems.[446]
- The authors of the 2021 study also found that during a hurricane, solar photovoltaic (PV) systems did experience decreases in solar irradiance, but only for a few days—which is shorter than often assumed. During the first 24 hours after the hurricane's landfall, these systems experience the greatest dip in irradiance, but it rises steady over the next 48 hours to be back to normal within 3 days.[447] Another study reported similar results, with PV generation ranging from 18 to 60% of clear sky potential during hurricanes, never going to zero during daytime hours, and rising to 46-100% for the 72 hours following a hurricane.[448]

When considering the best backup power solutions, emergency backup generators fueled by packaged diesel should not be relied on for long duration outages unless they are networked or combined with other distributed energy resources (DERs). Solar PV have relatively high reliability but should be used with batteries and spinning generation (which can be powered by natural gas) for greatest reliability.[449] Further, reliability is better for larger systems and worsens for smaller systems, so smaller customers and community resources should not rely on single backup sources to provide power throughout an extended outage. Utilities could work with smaller customers to help build greater resilience by installing microgrids and/or hybrid/double-backup systems.

Hurricane Irma - End User Resilience

Backup generators proved useful to bolstering the resilience of both larger and smaller businesses. "After the 2004–2005 hurricane season, we made a specific investment in generators for our stores," said Maria Brous, director of media relations for Publix Super Markets. "During hurricane season, our job is ensuring that store generators are working and have fuel. Then it's working on logistics, looking at inventory levels and sending orders to the stores."[450]

"Every storm is different," Brous continued. "Right before Irma you had Harvey, and many suppliers had already sent aid and product to Texas. That was an interesting challenge for us. Our team worked around the clock. We switched our production area to 24-hour runs. Water was a high-need commodity, and there wasn't enough of it in the supply chain.[451] Brous applauded Publix for their ability to remain open, due to emergency generators installed at all Publix supermarkets in Tallahassee. The majority of these 500 generators included a 1,000-gallon diesel fuel tank and a bi-fuel connection allowing them to switch to natural gas.[452] This system allowed stores to operate for a 72-hour minimum, including all necessary refrigeration and air conditioning. This system also enabled them to provide spaces to receive and distribute emergency supplies to community members. Publix

[446] Marqusee, Jeffrey, William Becker, and Sean Ericson. "Resilience and economics of microgrids with PV, battery storage, and networked diesel generators." *Advances in Applied Energy* Volume 3 (August 2021) ISSN 2666-7924. DOI: 10.1016/j.adapen.2021.100049
[447] Ibid.
[448] Wheeler, Cole, Daniel Greer, and Katharine Lamb. "The potential for using local PV to meet critical loads during hurricanes." *Solar Energy* (2020): 205: 37-43. DOI: 0.1016/j.solener.2020.04.094
[449] Personal communication. June 7, 2022.
[450] Hoover, Erin. "What Hurricanes Irma and Harvey Taught Us About the Business Impacts of Disaster." *850 Business Magazine,* March 7, 2018. https://www.850businessmagazine.com/what-hurricanes-irma-and-harvey-taught-us-about-the-business-impacts-of-disaster/?msclkid=902d38fecaea11ec9074f80342812d84
[451] Ibid.
[452] FEMA. "Publix Powers Up When the Power Goes Down." Last updated February 11, 2021. https://www.fema.gov/case-study/publix-powers-when-power-goes-down

has allocated more than 100 million dollars toward this generator program as part of their corporate mission, purchasing over 400 generators serving 575 different communities. Jonathan Marsh of Senior Helpers of South Palm Beach, a private homecare organization, reported his biggest concern after the hurricane was to purchase a backup generator.[453] He also considered the limitations with communication, which could be brought on by not having wi-fi or signal in the area after the hurricane hits. He stated he was changing post-storm procedures to deal with that contingency.

Hurricane Irma shed light on the end-user resilience of natural gas. Nearly 7 million people lost electric service during the historic event, compared to 300 customers who lost access to natural gas.[454] The study team found in an interview that this was mostly due to natural gas lines being underground, protecting them from high winds and downed trees that usually damage power lines. James Featherstone, Committee Chair for the Committee on Building Adaptable and Resilient Supply Chains After Hurricanes Harvey, Irma, and Maria, reported "Hurricane Irma brought visibility to the limited number of major transit corridors, which impeded the availability of fuel in South Florida."[455] Even those with diesel generators can be impacted by these shortages, whereas generators reliant on the continuous supply of natural gas can retain their access.

However, there is still room for improvements to natural gas resilience. The next step in furthering resilience is replacing steel pipes with flexible pipes, which are less likely to leak when there is ground shifting due to water flow from hurricanes. Personal communication with Peoples Gas, a natural gas utility in Florida, has confirmed their commitment to harden their system after each storm and looking for areas that needed upgrades due to aging infrastructure, specifically to reevaluate regulator station locations in the context of flooding.[456] They are nearing the end of their bare steel replacement program and now intend to update meter sets and regulators in low lying areas to raise them for resilience against flooding. Some of the above ground crossings (on bridges for instance) will be moved underground.[457]

Underground Gas Lines Resilient to Storms

While nearly 7 million people lost electric service in Hurricane Irma, only 300 customers lost gas service, mainly due to underground gas lines being resilient to high winds and damage from trees.

Further, there are disparities in access to resilience measures across demographic groups. The Natural Hazards Review interviewed residents in Highlands and Orange Counties, Florida, and found that households with "white respondents, higher incomes, and fewer elderly, very young, or non-English speaking" residents had increased resilience to Hurricane Irma as compared to other socioeconomic statuses, genders, ages and other neighborhood characteristics. White identifying respondents were 2.5 times more likely to use a generator than any other racial group. Households with children under the age of six were 5 times more likely to have difficulty accessing food and

[453] Rosenburg, Joyce M. "Learning curve: Hard lessons for businesses in hurricanes." *AP News,* October 4, 2017. https://apnews.com/article/65506ae60e1740b9b3fe437e7a6f5fac
[454] Johnson, Mary. "The resiliency of natural gas boosts its growth for commercial and residential use". *Tampa Bay Business Journal*, February 14, 2019. https://www.bizjournals.com/tampabay/news/2019/02/14/the-resiliency-of-natural-gas-boosts-its-growth.html
[455] National Academies of Sciences, Engineering, and Medicine. *Strengthening Post-Hurricane Supply Chain Resilience: Observations from Hurricanes Harvey, Irma, and Maria.* Washington, DC: The National Academies Press, 2020. https://doi.org/10.17226/25490
[456] Personal communication with Peoples Gas. 2022.
[457] Ibid.

water.[458] The findings from this study and similar studies could help provide insight to utilities seeking to harden infrastructure or fund areas with increased blackout hazards.

Hurricane Michael - End User Resilience

After Hurricane Michael hit, customers learned the importance of having upgraded equipment that is capable of weathering future storms. In an interview with Dale Calhoun of the Florida Natural Gas Association (FNGA), Dale noted the increase in residential and commercial customer requests for gas service to support on-site generation. These requests required meter and pressure upgrades and needed to upgrade regulators. Dale reported seeing on average 15 request for these upgrades per week, and that ramps up to 45 or more when they get close to hurricane season.[459]

Prior to Hurricane Michael, the U.S. Department of Defense had tasked the National Renewable Energy Laboratory (NREL) with developing a framework "to identify hazards and threats to the energy grid, analyze risks to energy infrastructure, and identify and prioritize investments in making bases and installations more resilient."[460] NREL's study notes that "because federal agencies are diverse and specialized, national resilience depends on each agency implementing a resilience program that anticipates critical service-specific vulnerabilities and fosters recovery and adaptation to new hazards."[461] NREL's approach to resilience analysis is to "(1) identify and score hazards and vulnerabilities at the site level (e.g., a building, campus, or base); (2) analyze risks to energy – and in some cases, water – infrastructure; and (3) identify and prioritize energy resilience investments."[462]

NREL was able to validate its approach when Hurricane Michael swept through the Tyndall Air Force Base in Florida. An initial resilience assessment of the base was completed two months before Hurricane Michael hit, allowing NREL to evaluate where the initial assessment effectively identified risks and mitigation strategies. NREL found that Tyndall's diesel backup power options were adequate during and immediately after the storm, but that a reliance on a single type of fuel for backup generators and transportation creates more risk in the event that the fuel becomes unavailable during a weather event due to supply chain issues.

Fuel Diversity Supports Resilience at Tyndall Air Force Base

Increasing the diversity of fuel sources for backup generation and transportation systems to improve resilience at Tyndall Air Force base was one of the key recommendations in an analysis conducted for the Department of Energy by The National Renewable Energy Laboratory (NREL).

Energy-related mitigation actions recommended for Tyndall by NREL included implementing a base-wide microgrid to serve all critical loads, implementing critical load-specific backup power, purchasing flexible and alternative fuel vehicles,

[458] Chakalain, Paul M., Liza C. Kurtz, and David M. Hondula. "After the Lights Go Out: Household Resilience to Electrical Grid Failure Following Hurricane Irma." *Natural Hazards Review* 20(4):05019001 (November 2019). DOI:10.1061/(ASCE)NH.1527-6996.0000335
[459] Personal Communication with Dale Calhoun. 2022.
[460] National Renewable Energy Laboratory (NREL). "Hurricane Puts NREL Resilience Analysis Tool to the Test." *NREL,* September 2, 2020. https://www.nrel.gov/news/program/2020/hurricane-puts-nrel-resilience-analysis-tool-to-test.html
[461] Ibid.
[462] Ibid.

along with the relevant infrastructure to support fuel diversification, and installing submeters and advanced metering for great granularity of energy needs and management.[463]

Local communities are also taking hardening requirements into their own hands. The City of Crescent City submitted a notice of intent to apply to the Florida Department of Economic Opportunity (DEO) for a grant, funded by the Community Development Block Grant – Mitigation program (CDGB-MIT), to harden existing infrastructure from the impacts of rain, wind, and future hurricanes by addressing at-risk areas of the main line, new regulator stations, a new odorized and static suppression system, and two new service lines to nursing homes.[464]

October 2017 Wildfires - End User Resilience

Microgrids that operate on island power, or independently from the grid, provide significant resilience during response and recovery phase of natural disasters; such was the case during the October 2017 wildfires in northern California. For example, the Stone Edge microgrid in Sonoma, CA provides power to the Stone Edge Farm Estate Vineyards and Winery's 16-acre farm, whose property survived the 2017 Northern California fires. The microgrid is a combined 600 kW system that includes 160 kW of total solar capacity, three batteries, three fuel cell hives and a hybrid natural gas and hydrogen-fired 65 kW microturbine.[465] The microturbine can provide backup power within three minutes and function in a master role during island mode, designed for long-term operation. Of note, the microgrid's communications loop and trunk line are underground, further increasing resilience against wildfires.

The Stone Edge Farm Microgrid

The Stone Edge Microgrid is an example of achieving resilience by integrating a variety of technologies and energy sources including solar, hydrogen and natural gas. The microgrid allowed the farm's irrigation system to continue operation during a power outage as a wildfire raged just five miles away.

"We had built a number of use cases for events that might affect the microgrid, but none covered a fire assault on the Sonoma Valley or our project," reported Craig Wooster, project manager, in a 2017 interview.[466] "At 5 am I got a phone call from an employee who couldn't get into work because everything was burning… I reached for the light and there was no light at my place, which instantly told me we needed to get the microgrid into island mode."[467]

During the October 2017 wildfires, the Stone Edge microgrid ran islanded for ten days while surrounding areas experienced utility outages and nearby infrastructure burned. The islanded microgrid allowed the farm's irrigation system to continue operation via remote monitoring and coordination, as the load from the microgrid included the pumps that supplied water from wells

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[463] Anderson, Kate, Eliza Hotchkiss, Lissa Myers, Sherry Stout, Nick Grue, Nicholas Gilroy, Josh R. Aldred, and Michael Rits. "After the hurricane: Validating a resilience assessment methodology." *International Journal of Disaster Risk Reduction* Volume 51 (December 2021). https://doi.org/10.1016/j.ijdrr.2020.101781

[464] Florida Division of Emergency Management. n.d. *Mutual Aid Branch Standard Operating Guide (SOG)*. February 2020. https://www.floridadisaster.org/globalassets/dem/response/logistics/smaa/mutual-aid-sog-published.pdf

[465] Stone Edge Farm Microgrid Website. (n.d). "A Continuous Power Loop." https://sefmicrogrid.com/overview/tour/

[466] Danigelis, Alyssa. "Developing a Self-Sustaining Microgrid: Q&A with Stone Edge Farm's Craig Wooster." *Environmental Leader,* January 29, 2018. https://www.environmentalleader.com/2018/01/stone-edge-farm-microgrid-craig-wooster/

[467] Cohn, Lisa. "Microgrid Kept Power On Even as the California Wildfires Caused Outages." *Microgrid Knowledge*, October 17, 2017. https://microgridknowledge.com/islanded-microgrid-fires/

to the vineyard.[468] This enabled irrigation lines to spray water on the farm as the wildfire raged just five miles away.

The experience illustrated the microgrid could operate as a shelter during future fires. With more preparation in other facets of resilience such as stocking up on face masks and high efficiency particulate air filters, the farm could end up serving as a resilience hub for their community. The Urban Sustainability Directors Network (USDN) has identified resilience hubs as "community-serving facilities augmented to support residents, coordinate communication, distribute resources and reduce carbon pollution while enhancing quality of life."[469] These hubs are valuable assets for community resilience and emergency management, among other goals. The USDN has partnered with organizations such as American Microgrid Solutions to deliver microgrid systems and ensure these resilience hubs have reliable power during emergency events.[470]

Another lesson shared was the necessary curtailment of solar during the height of the fire burning through the property. The farm invested in a smart inverter system that enabled the operator to toggle individual panels on or off during an event, which could help draining batteries reach saturation charges. Detailed levels of data monitoring give a level of visibility and control over assets during disasters which can promote energy resilience.

Further collaboration with local agencies and communication stations could better prepare Stone Edge and similar islanded properties for subsequent events. Other groups may seek to partner with utilities to help ensure resilience hubs have reliable power. For example, Pacific Gas and Electric Company (PG&E) offers a Resilience Hubs Grant Program that allocates funding for communities who are actively scoping or building resilience hubs. During the 2021 grant cycle, the City of Richmond, CA won a grant to install portable solar panels at existing community centers to create 'power hubs' to provide community members with power and Wi-Fi during outages and emergencies.

California utilities have also taken steps to improve the safety and resilience of the grid during extreme weather events. For example, the California Public Utilities Commission (CPUC) issued a decision in January of 2020 authorizing ratepayer collections to fund the Self-Generation Incentive Program (SGIP) which provides incentives for battery storage to increase resilience benefits during service outages.[471] The program can provide additional funding for Equity or Equity Resiliency rebates that lower the cost of energy storage technologies to minimal or no costs, especially to disadvantaged communities, those living in a Tier 2 or Tier 3 High Fire Threat District, communities facing more than two Power Safety Public Shutoff (PSPS) events, or low income and medically vulnerable customers.[472] These are available through Pacific Gas and Electric (PG&E), Southern California Edison (SCE), Southern California Gas Company (SoCalGas), and San Diego Gas and Electric Company (SDG&E).

CPUC Commissioner Clifford Rechtschaffen noted "These programs will provide resiliency for customers and critical facilities that are most likely to experience wildfires and PSPS events, and most in need of financial assistance." Commissioner Genevieve Shiroma added, "Today's decision

[468] Ibid.
[469] Urban Sustainability Directors Network. "Resilience Hubs." Accessed June 4, 2022. http://resilience-hub.org/
[470] American Microgrid Solutions. "Powering Security, Savings & Sustainability." Accessed June 4, 2022. https://www.americanmicrogridsolutions.com/
[471] California Public Utilities Commission (CPUC). "Self-Generation Incentive Program Revisions Pursuant to Senate Bill 700 and Other Program Changes." R.12-11-005.
[472] CPUC. "Self-Generation Incentive Program (SGIP) Fact Sheet." Self-Generation Incentive Program (SGIP): Energy Storage Rebates for Homes and Critical Care Facilities Available NOW

reflects the CPUC's continuing commitment to assist vulnerable customers through Public Safety Power Shut-offs."[473]

Furthermore, in 2020 the CPUC approved the framework for a community microgrid enablement program.[474] Program eligibility targeted communities located in Tier 2 to 3 High Fire-Threat Districts (HFTDs), prior PSPS events, or those prone to outages that serve at least one critical facility and one additional customer. Eligible equipment includes sections of the grid that disconnect from the larger grid (isolation devices), equipment to operate the microgrid, and equipment to ensure safe operation (fault protection devices and hardening).[475]

Eligible microgrids in the program include systems that run solely on fuels such as natural gas, solar-plus-storage, and hybrid systems. A report completed by the Brattle Group indicated natural gas serves as one go-to energy source for sustained backup power from microgrids, citing high battery capacity would be needed to provide electricity for extended periods of time. The analysis indicated hybrid systems combining solar, storage and gas generators can provide an optimal mix of resilience during outage events while maintaining greenhouse gas benefits.[476]

A Diverse Fuel Mix is Best for Microgrids

A study by the Brattle group found that hybrid microgrids with a diverse fuel mix, including natural gas, solar and energy storage, would provide optimal resilience while maintaining greenhouse gas benefits.

Hybrid microgrid systems are attracting investment for pilot programs across the country. For example, in Downey California, SoCalGas is presently in the developmental phase of a project dubbed "[H2] Hydrogen Home", a house powered by a hybrid clean energy system.[477] Operable as a microgrid, this system utilizes solar energy collected by photovoltaic cells in combination with battery storage to partially power the home when energy is sufficient. Excess energy is passed through an electrolyzer, where the solar energy is converted into hydrogen in an on-site fuel cell to power the house. The fuel cell can also be used when the solar or batteries may be insufficient due to factors such as weather. Additionally, the hydrogen may be blended with up to 20% natural gas to power home appliances and the heating, ventilation, and air conditioning system.[478]

The investments from both the PGE grants and SoCalGas' Hydrogen Home project demonstrate growing recognition in the energy industry that alternative fuels will play a key role in on-site generators and microgrids to support local resilience.[479]

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473 CPUC. (2020). CPUC Further Expands Energy Programs In Advance Of Next Wildfire Season."
474 California Public Utilities Commission (CPUC). Docket: D.20.06.017.
475 Pacific Gas and Electric Co (PG&E). "Community Microgrid Enablement Program: Disadvantaged Communities Advisory Group Meeting." *CPUC,* 2020.
476 Ryan Hledik et. al. (2020). "Decarbonized Resilience: Assessing Alternatives to Diesel Backup Power". The Brattle Group.
477 Arnes Biogradlija. (2022). "SoCalGas begins assembling H2 hydrogen home in Downey." Webpage. https://energynews.biz/socalgas-begins-assembling-h2-hydrogen-home-in-downey/
478 Ibid.
479 In their report "Decarbonized Resilience: Assessing Alternatives to Diesel Backup Power", The Brattle Group, sponsored by Enchanted Rock, performed an analysis indicating that providing two to four days of backup power for 10-megawatt community microgrid from battery and solar would require up to 350 MWh of batteries for only 10 MW of load, and up to 90 acres of solar PV to reliably charge over that time.

December 2017 Wildfires - End User Resilience

The Federal Emergency Management Agency (FEMA) coordinates with local and state entities to provide federal aid before, during and after disasters to local communities. To be eligible for certain non-emergency disaster assistance grants from FEMA, communities must have an approved Local Hazard Mitigation Plan.[480] During the 2017 wildfires, FEMA dispatched assets such as Mobile Emergency Response Vehicles to provide internet and radio communications while conducting site assessments, despite destroyed cell towers that knocked out service.[481] Though providing resilience, these vehicles still rely on gasoline as a primary fuel source during extreme events, which can experience disruptions and shortages during these types of events and thus limit resilience benefits. To improve the resilience of emergency vehicles, organizations may invest in vehicles that run on fuel types that are less likely to experience disruptions.

Mudslides caused massive destruction in residential areas after the December 2017 wildfires. During the FEMA Survivor Story video series, members of the Montecito-based Marcillac family recalled how quickly trees fell in their living space and created space for mudflow, rocks and debris to quickly begin filling their house—despite the nearest creek being several miles away.[482] Post-event, the Marcillac family used flood insurance from the National Flood Insurance Program (NFIP) to rebuild their home on an elevated surface, add flood vents, and work with their county flood control team.[483] These infrastructure hardening actions exemplify a way to rebuild beyond previous conditions to bolster resilience to future events.

"This is game-changing technology. It will help keep our communities safe and allow us to more quickly address accidental dig-ins by third-party contractors and service outages that happen every year."

—Jimmie Cho, senior vice president of gas operations & system integrity, SoCalGas[484]

SoCal has installed fiber optic cable along miles of gas pipelines to send early warning of pressure changes or vibrations, such as those caused by ground movement or contractors, that could indicate a leak or an impact to the gas line.

The monitoring technology will help the company quickly identify threats to a pipeline from heavy equipment operation, unexpected earth movement, or physical impact to an accuracy of 20 ft. When a threat is detected, information will be sent via the fiber cable to a remote monitoring station. Early warning will improve resilience by giving SoCalGas crews and first responders more time to plan, allocate resource and respond to events.

November 2018 Wildfires - End User Resilience

California counties have created emergency notification systems that offer detailed information for local counties, but not all residents register for or know about the offerings. The Camp Fire hit the

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480 FEMA. "Mitigation Planning and Grants." Accessed December 2021. https://www.fema.gov/emergency-managers/risk-management/hazard-mitigation-planning/requirements
481 FEMA. "FEMA's Mobile Emergency Response Support Vehicle". *YouTube*, October 15, 2017. https://www.youtube.com/watch?v=HdGZdZRKg_o&list=PL720Kw_OojlK_KATjYeDJxlAI86Xbe5mR&index=3
482 FEMA. "Survivor Story: The Marcillas Family (90)." *YouTube*. https://www.youtube.com/watch?v=chN3EknzQPw
483 Ibid.
484 Available at: SoCalGas Will Use Fiber Optics to Monitor its System (napipelines.com)

town of Paradise within four hours of ignition. City officials issued evacuation orders, but only a quarter of the town's 26,000 residents had opted to receive them. Of 6,000 cell phone calls in the first ten minutes of the evacuation, only 60% connected to a person or voicemail.[485] Paradise resident Zachary Byrd further reported losing AT&T and Verizon service on the morning of the blaze, during the time evacuation orders were being issued.[486]

The State of California Alert and Warning Guidelines were updated in 2019, as recent disasters had exposed inconsistencies among various alert and warning programs across California. These guidelines set minimum expectations and authorities for jurisdictions to implement alert and warning programs, including coordinating Red Flag warnings, weather alerts, evacuation orders, and locations of points of distribution for food, water, medicine, and other necessities during extreme events.[487] This effort aimed to increase organization and coordination between state, local, and tribal governments to communicate during extreme events, a key foundation of community resilience.

To help fill in the emergency communications gap, utility companies can consider dispatching their own emergency messages during disasters to increase the likelihood of reaching customers before communication services experience outages.

In October 2019, Governor Newsom announced the launch of a new state website, RESPONSE.CA.GOV, which serves as a one-stop portal for tools and resources available to Californians who have been impacted by wildfires and utility-directed power shutoffs, as well as community and business partnerships to support residents impacted by wildfires and shutoffs.[488] Tools such as the California Department of Public Health and Emergency Medical Services Authority "Realtime Situational Awareness" application were developed for end users to see a map of available facilities and agencies for residents to access emergency services and shelter during extreme events.[489] The infrastructure highlighted in tools such as these can help identify key facilities where implementing resilience measures such as on-site backup power can confer the greatest benefits.

Legislative and Utility Responses

Hurricane Harvey – Legislative and Utility Responses

As a direct response to Hurricane Harvey, House Bill 6 from the 86th Legislative Session created the Disaster Recovery Task Force (DRTF) for the State of Texas. This group was created to assist jurisdictions that have been impacted by emergencies or disasters and catalyze efficient recovery by starting the recovery process early in the response phase.[490] The DRTF is a state resource that is

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[485] Lisa Krieger. (2017). "Lessons from Camp Fire: Staying alive in California fire country". Mercury News. https://www.mercurynews.com/2018/11/17/lessons-from-paradise-staying-alive-in-fire-country/
[486] Ibid.
[487] Governor's Office of Emergency Services. (2019). "State of California Alert and Warning Guidelines." State of California.
[488] Office of Governor Gavin Newsom. (2019). "Governor Newsom Announces California Wildfire Safety Advisory Board and California Catastrophe Response Council Members." State of California.
[489] California Department of Public Health and California Emergency Medical Services Authority. "Realtime Situational Awareness Application (Version 8)." ArcGIS. https://cdphdata.maps.arcgis.com/apps/webappviewer/index.html?id=b51b90ede1a04039830701fa4d17834a
[490] The Texas A&M University System. "Disaster Recovery Task Force". https://www.tdem.texas.gov/recovery/disaster-recovery-task-force?msclkid=1f8c5e2ecbcf11ec9a55aede449ddde5

comprised of the Texas Department of Emergency Management and rosters of local subject matter experts to assist with mission requests.[491]

On a local level, compressed natural gas (CNG) vehicles can provide local transportation options in the aftermath of extreme weather events. Faced with fuel shortages and loss of power after Harvey's landfall, the Metropolitan Transit Authority of Harris County (METRO) ran their CNG transit buses thanks to generators at CNG stations and an uninterrupted fuel supply. METRO transported 10,000 people to emergency shelters and assisted organizations such as the Red Cross to move supplies to local hubs.[492]

Resilience from CNG

After Hurricane Harvey made landfall, CNG vehicles were still able to be fueled and transported 10,000 people to emergency shelters and assisted organizations such as the Red Cross to move supplies to local hubs.

Officials like Andrew DeCandis, Houston-Galveston Clean Cities coordinator, were monitoring the situation. In an interview for the Alternative Fuels Data Center, DeCandis noted that "following its emergency plan, METRO was able to pre-position buses to save them from flooding, prepare facilities, and stock them with supplies for overnight stays and sheltering."[493]

Eddie Murray, who leads Business Development and Operations for Freedom CNG, noted Harvey served as a clear proof of concept that natural gas transit buses are reliable. "Hurricane Harvey put METRO's decision to use CNG buses to the test," Murray said.

> *"When the power went out, our generator went on but the CNG never ran out. Our supply to the station was not interrupted and natural gas flowed through the underground pipe network without interruption."*
>
> —Eddie Murray, Business Development and Operations, Freedom CNG[269]

"When the power went out, our generator went on but the CNG never ran out. Our supply to the station was not interrupted and natural gas flowed through the underground pipe network without interruption."[494] He noted that all their CNG stations have backup diesel generators to ensure their CNG fueling service is available at all times, including during major events such as hurricanes. The generators range in size between 400 to 1800 kVA. To ensure they can run the generators for days at a time during prolonged outages (such as during a natural disaster), Mr. Murray reported that Freedom CNG runs the generators monthly to ensure they remain operable, has 600-gallon tanks to store fuel on-site, and purchases and stages additional fuel when they expect an event that will require prolonged generator usage.[495]

Fleets with alternative fuel such as CNG vehicles can provide local transportation options for residents, communication services, and other community services such as waste pickups. METRO

[491] The Texas A&M University System. "Texas Emergency Management Assistance Team". https://www.tdem.texas.gov/response/temat#:
[492] Department of Energy. (2019). "Compressed Natural Gas Fuels Houston's Recovery". Alternative Fuels Data Center, Department of Energy. https://afdc.energy.gov/case/3078
[493] Ibid.
[494] Department of Energy. (2019). "Compressed Natural Gas Fuels Houston's Recovery". Alternative Fuels Data Center, Department of Energy. https://afdc.energy.gov/case/3078
[495] Personal communication. June 17, 2022.

will continue to explore other alternative fuel options, such as testing three to five hydrogen Fuel Cell Electric Buses during the 2022 – 2023 fiscal year.[496]

Hurricane Irma - Legislative and Utility Responses

After Hurricane Irma, Florida House Bill 7099 required emergency generators be provided at all nursing homes in light of the fatalities such facilities suffered.[497] The original proposal would have required a minimum amount of on-site fuel. However, the Florida Natural Gas Association interviewed all the gas utilities in the state and learned that there were 307 gas meters impacted during the hurricane (most resolved within 24 hours) out of 800,000 total gas meters in the state. As a result of the survey, the final legislation allowed for natural gas as a backup fuel for the generators rather than mandating on-site fuel. As an additional bonus to this strategy, natural gas-powered generators have a smaller carbon footprint than typical on-site fuel types.

> **Improving the Resilience of Nursing Homes in Florida**
>
> By expanding the permissible fuels for backup generation to include natural gas, the Florida Legislature improved the resilience of nursing homes by addressing issues such as limited space for storage tanks and the uncertainty of obtaining fuel resupply after an extreme event.

Legislation similar to this was proposed in California State Bill 1207, which would have required skilled nursing facilities to have an alternative source of power to protect resident health and safety for at least 96 hours after a power outage. However, the governor vetoed the bill on the grounds that it used an unclear federal standard as justification and did not give facilities enough time to complete renovations to install backup generation.[498]

Florida also encouraged used of the Emergency Bridge Loan Program to cope with the hurricane's aftermath. This program is administrated by the Small Business Development Center (SBDC) and has been activated more than 20 times since its first deployment following Hurricane Andrew in 1992.

"The loan helps small businesses bridge that time between a disaster and receiving FEMA money or a long-term loan from SBA [U.S. Small Business Administration] or insurance proceeds. It's quick money. If you're a restaurant that flooded and your refrigerator went out, the program could help you open up again," said Cissy Proctor, executive director of Florida Department of Economic Opportunity.[499]

Loss of refrigerator power is exactly what happened to Patrick Ko, owner of a local grocery store in Sarasota. "Two walk in coolers and two freezers, none of it is working right now; air conditioner, none of it is working right now," said Ko after the storm.[500] Ko had to throw away over $35,000 of

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[496] Houston METRO. (2022). "Houston METRO Climate Action Plan." Page 17. https://www.ridemetro.org/MetroPDFs/News/Houston-METRO-Climate-Action-Plan.pdf
[497] Florida Senate. (2018). HB 7099: Ratification of Agency for Health Care Administration Rules. https://www.bizjournals.com/tampabay/news/2019/02/14/the-resiliency-of-natural-gas-boosts-its-growth.html
[498] California Legislative Information. SB-1207 Skilled nursing facilities: backup power system (2019 – 2020). https://leginfo.legislature.ca.gov/faces/billStatusClient.xhtml?bill_id=201920200SB1207
[499] Erin Hoover. (2018). "What Hurricanes Irma and Harvey Taught Us About the Business Impacts Of Disaster." 850 Business Magazine. https://www.850businessmagazine.com/what-hurricanes-irma-and-harvey-taught-us-about-the-business-impacts-of-disaster/?msclkid=902d38fecaea11ec9074f80342812d84
[500] Paul LaGrone. (2017). "Hurricane Irma's impact on small businesses cuts deep into the community." ABC Action News. https://www.abcactionnews.com/news/hurricane-irmas-impact-on-small-businesses-cuts-deep-into-the-community?msclkid=239af89dcbd111ecae3638e82f583d60

meat, not only a waste of food for his customers but a huge financial loss for a small business. He then applied for a relief loan.

Florida Power and Light (FPL) officials say that investments made in software technology and grid hardening allowed the utility to restore power to customers more quickly following Hurricane Irma. It took the utility 10 days to restore power to all customers, whereas it took them 18 days following Hurricane Wilma in 2005. From 2013-2016, FPL focused on investing in infrastructure updates, including its "Smart Grid Investment Grant" to connect customers with a modernized electric grid with strengthened cybersecurity enhancements and detailed operational data.[501] This advancement allowed operators to pinpoint outages in real time, making the restoration process more efficient.

Hardening investments meant enhancing infrastructure to withstand weather events more effectively, such as replacing wooden power poles with concrete ones, and constructing hurricane-proof buildings. Pole failure, typically driven by trees which fall on wires, breaking utility poles, is a significant cause of storm driven outages. FPL also installed smart circuit breakers which allowed lines to turn themselves back on if a branch circuit short-circuited. The successful use of the circuit breakers kept 5,000 customers on during and after the storm. Following Hurricane Irma, FPL admits there is still more to be done and will continue to make progress in improving grid resilience, such as the "Right Tree, Right Place" program which will work to place trees in positions where they are less likely to topple over into electricity lines during a weather event.[502]

Hurricane Michael - Legislative and Utility Responses

New legislation introduced after the disasters included the federal 2018 Disaster Recovery Reform Act, which mandated numerous relevant reforms and changes to FEMA processes. Of relevance is the establishment of the National Public Infrastructure Pre-Disaster Hazard Mitigation fund. This program requires FEMA to set aside up to 6 percent of the money it spends on disaster relief for local projects aimed at improving community resilience and to reduce the likelihood of damage during future disasters.[503]

As a direct result of Hurricane Michael, Florida Division of Emergency Management introduced a Mutual Aid branch to set guidelines on collaboration and coordinating aid in Florida, including training and fast-tracking emergency authorizations during state disasters.[504] Cross-sectoral training and resilience prove critical to responding to disasters locally. Dale Calhoun spoke to the great coordination with FNGA and with other utilities. Depending on the scale of the incident, Peoples Gas may use their own resources to respond or may call on mutual assistance, such as when they used their own resources for Hurricane Michael in their Panama City office.

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[501] Department of Energy Website. "Recovery Act: Smart Grid Investment Grant (SGIG) Program." https://www.energy.gov/oe/recovery-act-smart-grid-investment-grant-sgig-program
[502] Von Ancken, Erik. (2017). FPL shares lessons learned after Hurricane Irma knocked out power statewide. https://www.clickorlando.com/news/2017/10/17/fpl-shares-lessons-learned-after-hurricane-irma-knocked-out-power-statewide/
[503] Consensus Study Report. (2020). Strengthening Post-Hurricane Supply Chain Resilience. https://www.nap.edu/catalog/25490/strengthening-post-hurricane-supply-chain-resilience-observations-from-hurricanes-harvey
[504] Florida Division of Emergency Management. (2020). Mutual Aid Branch Standard Operating Guide (SOG) Version 1.0. https://www.floridadisaster.org/globalassets/dem/response/logistics/smaa/mutual-aid-sog-published.pdf

December 2017 Wildfires - Legislative and Utility Responses

In response to growing wildfire danger and other climate concerns, California passed SB 379 in January 2022 requiring all cities and counties to include climate adaptation in general plans and local hazard mitigation plans.

Utilities have responded to the growing dangers of wildfire in various ways, including installing microgrids. Microgrids can be strategically installed in order to build resilience as an alternative to rebuilding, hardening and maintaining distribution lines, especially when strategies that depend on existing above-ground power lines face higher wildfire risks.

For example, Liberty Utilities, which serves about 50,000 customers near Lake Tahoe in California, was considering how to improve the wildfire resilience of its at-risk transmission lines. However, the utility found that it would be more cost-effective to de-energize the lines during high-risk weather, and instead provide power through a 20-kW, 68kWh solar/battery system with propane backup.[505] Installation of the system began in fall 2020. The short-term goal, besides reducing fire risk, is to allow the utility to not to have to inspect the lines during fire season, and the longer-term goal is to eventually rely fully on the system rather than the transmission lines themselves once more generation is in place.

Microgrids Minimize the Impact of PSPS

Utilities such as PG&E and Liberty Utilities are deploying multi-fuel microgrids using solar, battery storage and fossil fuels to maintain service to customers during wildfire events where the utilities implement Public Safety Power Shutoffs (PSPS).

Similarly, as part of PG&E's 2021 Wildfire Safety Plan, the utility is deploying microgrids to help avert PSPS events. Remote microgrids are to be deployed at the end of wildfire-prone distribution lines, key resources, and substations, with a target to install 20 systems by Q4 of 2022.[506] Ten of these systems will be installed as distribution microgrids designed to keep key community resources, such as gas stations and hospitals, operating during PSPS events. "This is a new approach to utility service," said Paul Doherty, spokesman for PG&E. "The whole point of the remote microgrid is to remove those power lines that run through high fire threat areas."[507]

November 2018 Wildfires - Legislative and Utility Responses

Building on lessons learned from previous catastrophic wildfires, in 2019 California Governor Gavin Newsom proclaimed a State of Emergency on Wildfires to protect over 200 communities most prone to fire risk and unlock a $50 million public campaign on preparedness to build resilience among vulnerable populations.[508] Doing so provided time-saving waivers of administrative and regulatory requirements to protect public safety ahead of the wildfire season. A joint effort between Cal Volunteers and the Governor's Office of Emergency Services, the "California for All Emergency Preparedness Campaign" proved to augment the efforts of first responders by reaching one million of the most vulnerable citizens to ensure they are connected to linguistically and culturally

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[505] BoxPower. (2022). "BoxPower Microgrid Proves to be Ideal Solution for Californian Utility." https://boxpower.io/boxpower-microgrid-proves-to-be-ideal-solution-for-california-utility/
[506] Lisa Cohn. (2021). "PG&E Turns to 3 Kinds of Microgrids to Avert Wildfire Power Shutoffs." Microgrid Knowledge. https://microgridknowledge.com/microgrid-strategy-pge-wildfire/
[507] Lisa Cohn. (2021). "PG&E Turns to 3 Kinds of Microgrids to Avert Wildfire Power Shutoffs." Microgrid Knowledge. https://microgridknowledge.com/microgrid-strategy-pge-wildfire/
[508] Office of Governor Gavin Newsom. (2019). "Governor Newsom Proclaims State of Emergency on Wildfires to Protect State's Most Vulnerable Communities." State of California.

competent support.[509] Of the $50 million, $24.5 million was allotted to community-based organizations to prepare residents for natural disasters, including wildfires, through resources designed to bolster resilience. $12.6 million was allotted to assist local efforts to build resilience and respond to disasters by dispatching expert disaster teams to key regions and expand citizen emergency response teams.

State and federal funding continue to be allocated to wildfire prevention and resilience projects. In 2022, the California Governor's Office of Emergency Services (Cal OES) has released funding to reduce long-term risks of disasters by investing in infrastructure improvements designed to protect communities. Ryan Buras, Deputy Director of Recovery Operations at Cal OES, mentioned in a brief that programs such as 'Prepare California' "targets funds to areas where they are needed most to improve infrastructure, mitigate disasters, and save lives."[510] This include The CAL OES website identifies the types of projects that will be funded, including:

- Mitigation and Preparedness Planning
- Local Capacity Building
- Whole Community Planning
- Property Protection
- Public Education and Awareness
- Nature-Based Solutions to Hazard Risk
- Emergency Preparedness
- Structural Projects

Resilience Measures in Subsequent Events

December 2017 Wildfires - Resilience Measures in Subsequent Events

The 2017 CA Governor's budget included critical resilience investments to help the state prepare for wildfires, including $75 million to build resilience and surge capacity among state and local agencies in the event of a utility-dictated PSPS, $60 million to upgrade California's 9-1-1 system and first responder broadband network, $130.3 million for better communication equipment for first responders, and $24.7 million for CAL FIRE to procure innovation solutions to the wildfire crisis via the Innovation Procurement Sprint. The Innovation Procurement Sprint aimed to place and operate Fire Detection Cameras across the state, enhance situational awareness staffing and continue to develop consistent early warning technologies.[511] Such cameras have proven useful in battling wildfires. For example, ALERTWildfire is a network of fire detection cameras across the southwestern United States, including California. In 2019, the ALERT North Bay network allowed for monitoring of the Kincade Fire from its start and helped ensure that no lives were lost, or injuries were sustained in the first 24 hours of the fire as widespread evacuations took place.[512]

[509] Ibid.
[510] Governor's Office of Emergency Services. (2021). "Prepare California – Building More Resilient Communities." State of California.
[511] Office of Governor Gavin Newsom. (2019). "Governor Newsom Announces New Partnerships and Tools to Help California's Most Vulnerable Residents During Power Shutoffs." State of California.
[512] ALERTWildfire. (2022). "About." https://www.alertwildfire.org/about/

Hurricane Harvey - Resilience Measures in Subsequent Events

Many residential and small business customers have learned the importance of having back-up generators from previous hurricanes. When Hurricane Harvey hit, many energy customers were prepared with on-site generators. For example, Crocker Moving and Storage in Corpus Christi had previously taken hurricane-readiness precautions that included having back-up generators in place. In the days after the storm, the company was already preparing for customers who may need to have their furniture removed for storm repairs or debris removal.[513]

Generators also play a large role in preventing communication outages at cell towers. Diesel generators are typically used to provide backup power to cell towers. When 95% of cell towers were out of service when Harvey made landfall, carriers such as Verizon provided refueling trucks on standby to ensure they topped off fuel.[514] Understanding from previous hurricanes that the primary reason generators were unable to maintain power to cell towers was due to running out of fuel, carriers purchased spare fuel and deployed extra crews at key locations in the hurricane's path. As a result, Verizon self-reported over 98% of its sites were able to resume service, including those with backup generators and a command center to assess damage.[515] Note that this risk is specific to diesel emergency generators, which require sufficient supply of on-site fuel to work. Other options that afford greater resilience by avoiding this particular risk include natural gas fuel cell backup generators, solar PV, and hybrid systems.

Preparing Strategically Deployed Generators

Verizon transformed lessons learned from previous hurricanes to methodically dispatch spare fuel and crews to key locations in the hurricane's path, allowing a self-reported 98% of sites to resume service.

In 2017, wireless carriers in Florida noted that there was no regulatory requirement that mandated how much of telecommunications infrastructure must maintain minimum standards for backup power. Regina Costa, chair of the telecommunications committee of the National Association of State Utility Advocates, reported in an interview that having infrastructure reliant only on commercial power can become a liability during natural disasters or even cyberattacks.[516] Furthermore, diesel prices significantly increased, in part due to transportation challenges in the wake of the storm. In subsequent events, carriers can investigate hosting diverse fuel types to provide increased resilience.

In the last several years, other states have proposed or adopted requirements for backup power using a variety of state authorities and commissions. In 2019, California State Senate Bill 431 (SB431) was introduced to obligate carrier companies to provide battery backup to their cell towers

[513] Ali Montag. (2017). "These small businesses in Texas are bracing to help others rebuild after Hurricane Harvey". https://www.cnbc.com/2017/08/25/small-business-owners-get-ready-for-hurricane-harvey.html?msclkid=cf4ea673caea11ecb60f1fc2736f9664
[514] Worldwide Power Products. "How Did Backup Generators Keep Cell Phones Working During Hurricane Harvey?". https://www.wpowerproducts.com/news/generator-role-helping-cell-towers-during-harvey/?msclkid=b860d0becbb611ec934603e0745b9ea2
[515] John Eggerton. (2018). "Verizon Offers communications Help to Harvey-Affected Customers". Broadcasting+Cable. https://www.nexttv.com/news/verizon-offers-communications-help-harvey-affected-customers-168167
[516] Marguerite Reardon. (2017). "How the wireless carriers fared during Hurricane Harvey". CNET. https://www.cnet.com/tech/mobile/hurricane-harvey-phone-service/?msclkid=4d9fd460cbcd11ec8e4d2ef51337e266

and issue warnings to cellular users when backup is running low.[517] However the bill became inactive 2020 and thus can take no further action.

Nevertheless in 2021, the CPUC issued Decision 21-02-029 to require all cell towers to have a minimum of 72-hours of emergency backup power for all facilities in Tier 2 (elevated risk) and Tier 3 (extreme risk) High Fire Threat Districts (HFTDs).[518] Furthermore, this decision requires all wireline providers to submit annual Emergency Operations Plans and Resiliency Plans. All facilities in Tier 2 and Tier 3 HFTDs must have the minimum backup power by August 2022. As of April 2022, 77% of all facilities had between 1 – 72 hours of backup power, 10% exceeding 72 hours, and 14% with no backup power.[519]

The U.S. Department of Energy's National Renewable Energy Lab (NREL) fact sheet on Fuel Cells for Backup Power in Telecommunications Facilities indicates that fuel cells provide the best option for backup power to cell towers when considering the objectives of reliability, lifespan environmental impact and operations and maintenance costs.[520] Integrating hydrogen into the energy system is an integral part of SoCalGas's long-term strategy, including the use of hydrogen fuel cells in its H2 Hydrogen Home Project.[521] Several manufacturers, such as GenSure, already offer hydrogen fuel cell based backup power systems for critical services.[522]

Hydrogen Supports Resilience for Cell Phone Towers

Cell phone towers are critical for managing and recovering from extreme events and fuel cells are particularly suited as backup generation for cell phone towers. The increasing integration of hydrogen into the energy system will help improve the resilience of telecommunications.

Hurricane Michael - Resilience Measures in Subsequent Events

As a result of the pandemic, there has been a tremendous uptick in purchases of residential emergency generators due to concerns about having to potentially evacuate to a crowded location. Dale Calhoun noted more electric co-ops are offering financing programs for backup generators to support the increasing number of remote employees working from residential areas brought on by the pandemic. Those programs were oversubscribed, with demand exceeding supply. This demand is further exacerbated by newer homes built to recent, more robust, construction standards, so people are more likely to want to ride out a storm in their homes rather than evacuate, increasing the demand for backup generation.[523]

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[517] California Legislative Information. (2022). "SB-431 Telecommunications service: backup electrical supply rules." https://leginfo.legislature.ca.gov/faces/billStatusClient.xhtml?bill_id=201920200SB431

[518] California Public Utilities Commission. (2021). "Decision Adopting Wireline Provider Resiliency Strategies." R-18-03-011. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M366/K625/366625041.PDF

[519] California Public Utilities Commission. (2022). "Wireline Resiliency - Service Quality & ETC". https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/communications-division/meeting-documents/wireline-resiliency/webinar_wireline-resiliency-_040722.pdf

[520] National Renewable Energy Laboratory. (2009). "Fuel Cells for Backup Power in Telecommunications Facilities." https://www.nrel.gov/docs/fy09osti/44520.pdf

[521] Southern California Gas Company. (2022). "Aspire 2045 SoCalGas Sustainability Strategy." https://www.socalgas.com/sites/default/files/2022-01/SoCalGas_Sustainability_Strategy-final.pdf

[522] Plug. (2022). "Scalable Backup Power for Critical Applications." https://www.plugpower.com/fuel-cell-power/gensure-backup-power/

[523] Personal interview with Dale Calhoun. 2022.

While backup generators provide important power during emergencies, increased usage can negatively impact air quality. The California Air Resources Board (CARB) collected data on portable generator use during PSPS events. CARB tracks the nitrous oxide (NOx) and particulate matter (PM) from various types of backup generator assets. During the October 2019 PSPS events, a CARB report identified that an estimated 1,800 stationary diesel generators contributed an additional 125 tons of nitrous oxides (NOx) to the environment. The report indicates an average exhaust emissions factor of 6.7 grams of NOx per braking horsepower-hour (g/bhp-hr.).[524] Natural gas or propane powered generators can operate with significantly lower emissions of between 2.0 and 0.5 g/bhp-hr., depending on conditions and electronic controls. [525] Had the 1,800 generators been gas powered, NOx emissions during the October 2019 PSPS would have been reduced by approximately 70% to 37.5 tons. [526]

Reducing Emissions from Backup Generation During PSPS

Converting the estimated 1,800 stationary backup generators used during the October 2019, PG&E PSPS event from diesel to gas would have reduced emissions by 70%, avoiding 88 tons of NOx pollution.

California utility companies offer incentives for residential and commercial customers who install on-site energy storage and distribution systems. Customers of PG&E, SDG&E, Southern California Edison, and SoCalGas are eligible to participate in the State of California Self-Generation Incentive Program (SGIP), which provides incentives to support distributed energy resources, including solar batteries. Qualifying equipment includes wind turbines, waste heat to power technologies, pressure reduction turbines, internal combustion engines, microturbines, and gas turbine, fuel cells, and energy storage systems.[527] The California State Emergency Program, launched in 2021, allows utilities to compensate customers for load reduction activities achieved through reduced usage or backup generation.[528] Additionally, the Net Energy Metering Program allows customers who generate their own energy to receive a financial credit on electric bills for surplus energy fed back to the utility. Energy must come from one of the following renewable energy sources: solar photovoltaic, wind, fuel cell, biogas, geothermal, hydroelectric, landfill gas, municipal solid waste conversion, ocean thermal, or tidal current.[529] The rebate rate is roughly two to four cents per kilowatt hour. These programs provide excellent examples of ways in which governments and utilities can accomplish the two goals of bolstering community energy resilience and reducing emissions associated with energy generation and usage.

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[524] California Air Resources Board. (2020). "Emission Impact: Additional Generator Usage Associated with Power Outage." https://ww2.arb.ca.gov/sites/default/files/2020-01/Emissions_Inventory_Generator_Demand%20Usage_During_Power_Outage_01_30_20.pdf
[525] Kohler Power Systems. "Gas Generator Set Performance Characteristics". Webpage. https://resources.kohler.com/power/kohler/industrial/pdf/GasGeneratorSetPerformance_WhitePaper.pdf
[526] ICF analysis.
[527] San Diego Gas and Electric. "Self-Generation Incentive Program." Webpage. https://sites.energycenter.org/sgip/incentives
[528] California Department of Finance. "California State Emergency Program". Webpage. https://dof.ca.gov/programs/california-state-emergency-program/
[529] Southern California Edison. "Net Energy Metering 101". Webpage. https://www.sce.com/residential/generating-your-own-power/net-energy-metering/getting-started

October 2017 Wildfires - Resilience Measures in Subsequent Events

Additionally, in May 2018, a joint effort between CAL FIRE, California Natural Resources Agency, Cal EPA, and members of the California Forest Climate Action Team released the California Forest Carbon Plan.[530] Citing the October 2017 Tubbs Fire among one of the most destructive recent events in California history and reason for the initiative, the Forest Carbon Plan considers opportunities to establish California's forests as resilient and reliable carbon sinks by strategic fuel treatments and forest restoration.

Under the direction of legislative responses such as the Forest Carbon Plan, organizations such as the Sierra Nevada Conservancy have funded numerous forest management projects for wildfire prevention in recent years. One such project in northeast California was completed in 2019 in the Caples Creek watershed district.[531] The prescribed burning practices over 8,800 acres were specifically accredited to protecting the Caples Creek area during the 2021 Caldor Fire, when surrounding communities remained largely unburned despite being surrounded by the rapidly growing wildfire.[532]

Other proactive measures include training individuals and community members, which are crucial to resilience during events. The Feather River Resource Conservation District (Feather River RCD) exemplifies the power of advancing organizational resilience and community-based disaster response. During the 2021 Dixie Fire, staff were able to utilize previous training to join on-call fire crews and assist with fire suppression, structure preparation, and cutting hand lines.[533] Staff had joined on-call fire crews with the Plumas National Forest to receive training in fire suppression, including cutting hand lines, structure preparation, initial attack, and mop-up. Additionally, the Feather River RCD was capable of previously providing community members with training to join Forest Service fire crews.[534] This was particularly valuable when the Feather River RCD lost staff due to the destruction of their homes and evacuation measures.

Federal Support after Hurricanes Michael, Irma, and Harvey

The National Business Emergency Operations Center (NBEOC), which is activated by FEMA following disasters or emergencies, engages stakeholders from the private sector and federal and state agencies to enhance communication and collaboration, to help FEMA offices with situational awareness, and to facilitate exchange of information for response and recovery.[535]

In the 2017 hurricane season, in conjunction with other state emergency management organizations, NBEOC hosted voice and web conferences, which allowed for a rapid distribution of high-level information to a broad audience. These NBEOC calls had upwards of 1,000 participants during the height of the storm activations and utilized a structured agenda for reporting, along with a question-and-answer component, and utilized an interactive web-based dashboard where static

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[530] California Natural Resources Agency. (2018). "California Forest Carbon Plan Managing Our Forest Landscapes in a Changing Climate."
[531] Sierra Nevada Conservancy. (2021). "Good fire project protects Caples watershed from Caldor Fire." State of California.
[532] Yoohyun Jung and Paula Friedrich. (2021). "These maps show where prescribed burns helped curb the Caldor Fire's rapid growth". San Francisco Chronicle. https://www.sfchronicle.com/projects/2021/caldor-fire-prescribed-burn/
[533] Sierra Nevada Conservancy. (2021). "Feather River Resource Conservation District's capacity for resilience."
[534] Training included Basic 32 tests for citizens to become a volunteer firefighter.
[535] FEMA. "National Business Emergency Operations Center." Accessed April 29, 2019. https://www.fema.gov/business-industry/national-business-emergency-operations-center

information such as briefings or reports were published.[536] There is evidence that in some cases the web-based dashboard allowed for business-to-business mutual aid and resource sharing,[537] though challenges identified include:

- Storm-related destruction of communications infrastructure impeded efforts to distribute information, coordinate activities, and identify arising problems.
- Small businesses are more likely to be unaware of these calls and more likely to not have the time and resources to participate.
- The natural gas sector can learn from these challenges as they plan future resilience measures.

Furthermore, in 2019 FEMA updated the 2008 National Response Framework to include what was learned from the hurricanes and wildfires in 2017.[538] As part of this update, FEMA has established a new emergency support function, ESF14, which "supports the coordination of cross-sector operations, including stabilization of key supply chains and community lifelines, among infrastructure owners and operators, businesses, and their government partners."[539]

Conclusions

Successful resilience measures encompass both proactive and reactive actions from end-users. Preventative measures such as infrastructure upgrades or forest management can mitigate the extent of the damage faced by communities. During short-term recovery processes, it is critical for community hubs and small businesses to retain access to power to support community members and recovery activities, such as restoring communications, facilitating medical attention, or providing/distributing critical resources. In addition, California is expecting to see an increase in the need for cooling centers as climate change leads to hotter overall temperatures and an increase in the frequency and severity of heat waves—and so the need for cooling centers that have reliable power sources to stay functional during outages (which can be triggered by heat events) will also increase. As such, it is important for utilities to coordinate with community groups that run community hubs to ensure that these places not only provide traditional resilience benefits (shelter, food, water, potentially power or wi-fi) but are also physically cool and protect users from the heat.

Long-term processes tend to focus on rebuilding with larger investments in resilient infrastructure, as homes and businesses that are built to building codes with more stringent standards will fare better than their older counterparts.

The following observations indicate how natural gas can support these activities and bolster utility and community resilience to extreme climate events:

- Microgrids that rely on one fuel type are subject to risk from supply chain shortages (propane, gasoline, diesel) and resource scarcity (solar panels unable to produce during extreme weather events). Microgrids are increasingly incorporating hybrid fuel systems that provide better

[536] The National Academic Press. "Strengthening Post-Hurricane Supply Chain Resilience: Observations from Hurricanes Harvey, Irma and Maria." *Congressional Briefings,* January 30, 2020. https://www.nationalacademies.org/ocga/briefings-to-congress/strengthening-post-hurricane-supply-chain-resilience-observations-from-hurricanes-harvey-irma-and-maria
[537] The National Academic Press. "Strengthening Post-Hurricane Supply Chain Resilience: Observations from Hurricanes Harvey, Irma and Maria." *Congressional Briefings,* January 30, 2020. https://www.nationalacademies.org/ocga/briefings-to-congress/strengthening-post-hurricane-supply-chain-resilience-observations-from-hurricanes-harvey-irma-and-maria
[538] U.S. Department of Homeland Security. *National Response Framework, Fourth Edition*. Washington, DC: FEMA, 2019. https://www.fema.gov/sites/default/files/2020-04/NRF_FINALApproved_2011028.pdf
[539] The National Academic Press. "Strengthening Post-Hurricane Supply Chain Resilience: Observations from Hurricanes Harvey, Irma and Maria." *Congressional Briefings,* January 30, 2020. https://www.nationalacademies.org/ocga/briefings-to-congress/strengthening-post-hurricane-supply-chain-resilience-observations-from-hurricanes-harvey-irma-and-maria

resilience during disasters. Microgrids that include several fuel types have a higher likelihood of providing resilience during a variety of extreme weather events. Natural gas is one fuel type that demonstrated resilience during natural disasters.

  - Small businesses in particular benefitted from the ability of microgrids to provide power when the grid experienced outages, allowing them to provide services or even function as community hubs.

- Natural gas providers can foster collaboration with electric utilities, microgrid installers and community organizations to increase the use of hybrid fuel systems, especially in communities vulnerable to these events. As with microgrids, natural gas can serve as a more resilient and continuous fuel supply for backup generators when fuel scarcity drives up other fuel prices.
- Gasoline and diesel-fueled backup generators are the most common types of generators in use. They do however have relatively unfavorable emissions profiles and contribute to air pollution; utilities can provide support to smaller customers seeking cleaner and greener backup power solutions.
- Natural gas companies can support further deployment of CNG vehicles to support critical community activities such as transiting personnel or supplies during recovery.
- There are several upgrades that can be made to existing gas networks such as replacing underground steel pipes with flexible materials to better withstand impacts from natural disasters like shifting soil during hurricanes.
- Newer technologies, such as fiber optic cables, can be installed near existing infrastructure for a level of data monitoring and control that adds granularity to a utility's response. This efficiency can aid in faster restoration timelines.
- Increased use of technology such as drones and satellite monitoring allow for more detailed and up-to-date evaluation of vulnerabilities and real-time impacts from disasters.
- Organizations have partnered with local community groups to provide fire suppression and emergency response training to specific communities. Natural gas companies can partner with community organizations to provide information on how natural gas lines may fare during these events, and better prepare local emergency response groups on safety and security during the response phase of extreme weather events.

CHAPTER 5
Lessons Learned

These case studies found that natural gas infrastructure and services were relatively resilient to hurricanes, wildfires, mudslides and severe winter storms. Most natural gas infrastructure is belowground, which is inherently less vulnerable to natural disasters than aboveground infrastructure. This was repeatedly demonstrated as natural gas pipelines largely remained online until utilities performed voluntary shutoffs for safety reasons.

However, extreme conditions *can* affect belowground infrastructure, and such was the case when severe mudslides carrying large boulders in California scoured channels and exposed pipelines, or when uprooted trees in Florida damaged pipelines and caused an interruption in natural gas service during Hurricane Michael. As such, it is important to protect the areas where natural gas infrastructure is suspended above ground such as over canyons. In these areas where pipelines are exposed, there is greater susceptibility for damage. Relatedly, critical aboveground infrastructure should be made resilient. This may include weatherizing wellhead and installing backup power at compressor stations.

Natural gas' interdependence on other sectors is a greater point of weakness than the natural gas infrastructure itself. For example, ports closing in the Gulf of Mexico due to the hurricanes caused a bottleneck as shippers were not able to export their supplies, putting pressure on storage facilities. Natural gas production itself was also somewhat affected during hurricanes, as force majeures were put into place and personnel were evacuated from production facilities. The loss of electricity due to damages to grid infrastructure created "demand destruction" in some areas where natural gas provides fuel to power plants.

Clear communication and coordination between utilities across sectors and with emergency personnel is critical to a successful disaster response. Utilities cannot operate in siloes and they must recognize their interdependencies—particularly to address any weak points as mentioned above. Electric power is needed to support facilities that compress natural gas, and for telecommunications vital to coordinating workforces and emergency personnel. This power supports fueling infrastructure to ensure mobility for emergency responders and the transportation network to reach facilities for repairs.[540] Portable generators are also often needed when electrical power grids fair during emergency events. Such portable generators can be natural gas or diesel powered. Energy-system interdependency was emphasized in conversations with emergency response personnel. Access to infrastructure must be carefully coordinated when conditions are unsafe, and natural gas, electric and telecommunication utilities must communicate the locations of

[540] Personal communication with CUEA. April 23, 2019.

their assets and potential risks to avoid further damage during response activities. Organizations such as the CUEA, in which points of contact for all utilities are brought together and facilitated by expert responders, are an excellent example of how organized, institutionalized coordination can streamline responses and minimize damage while maximizing efficiency.

The greatest impact to natural gas provision during the wildfires came from the utilities' need to selectively isolate service by turning off the supply to targeted areas affected by fire. This process in and of itself is relatively quick and inexpensive, but the subsequent loss of service may impact critical infrastructure such as backup generators, and the process to restore service is time-consuming and expensive. Shut-offs must also carefully consider impacts to customers, and critical services (e.g., hospitals, generators) may need to be provided a separate source of gas before isolation can be completed. Pipelines must be assessed for leaks or other damages before they can be re-pressurized, and utility staff have to physically visit each house that experienced the service interruption and manually turn the gas back on, and they can only do this if occupants are present.

Additionally, given the relatively coarse distribution of gas shut-off valves in the distribution system, crews must dig new trenches to manually cap lines. A possible response to lessen this burden is to further sub-divide the system so that the utility can perform smaller and more targeted isolations when necessary. For example, SoCalGas added isolation valves during its restoration efforts to make it easier to isolate sections of the distribution system in the future. However, certain barriers will always remain, such as losing physical access to service areas when they are blocked by fire or floodwaters. Increasing the number of valves can also increase the amount of gas leaks throughout the system.

Natural gas contributed to resilience during emergencies. Backup generation during electricity service disruptions is an important component of overall resilience from climate hazards. In most examples of backup generation explored in these case studies, facilities successfully maintained power because of such investments, whether in the form of backup generators or microgrids. Natural gas provides a cleaner source of fuel for backup generators than diesel and can be more reliable than diesel in certain circumstances. Natural gas can be a reliable source of energy over long-term disruptions of electricity service (i.e., multiple days) where battery capacity for renewable systems may not be adequate. Diesel fuel supply can be interrupted by the very climate disasters that created the need for the use of generators because of supply disruptions or the inability for resupply vehicles to access roads. Further, microgrids that include several fuel types are more likely to maintain power and thus provide energy resilience during a variety of extreme events.

Compressed natural gas (CNG) and liquefied natural gas (LNG)-fueled vehicles can help to maintain functionality, especially when access to other fuel sources is disrupted by climate hazards. In the case of the hurricanes, backup generation was a key component to maintaining critical functionality, especially at hospitals. CNG remained online and was able to fuel response vehicles in Texas during hurricanes and California during wildfires.

Natural gas supply is significantly more reliable than electricity. A survey by the Texas Energy Poverty Research Institute (TERPI) found that During Winter Storm Uri, 75% of respondents lost electric service at some point during the storm while only 25% of respondents surveyed reported losing gas service.

The resilience of natural gas is addressed in a 2017 white paper released by the Natural Gas Council. This report found that natural gas can attribute its resilience to operational characteristics such as:

- The slow movement of natural gas through pipelines (relative to electricity), which gives pipeline operators time to react to disruptions should they occur;
- Natural gas' ability to be stored after production, which provides a supply cushion and flexibility;
- Placing the majority of assets underground and therefore protecting them from weather-related events;
- Production facilities being largely onshore rather than offshore and therefore reducing vulnerability to hurricanes;
- Using modern monitoring and remote-control valve technology as well as pressure sensors that all work to quickly respond to incidents;
- The ability to flexibly adjust flows to meet changes in demand; and
- The ability to re-route deliveries among multiple pathways as well as maintaining pipeline loops to increase resilience via redundancy.[541]

This strong resilience was also reflected in the findings of the 2018 Gas Technology Institute (GTI) report, "Assessment of Natural Gas and Electric Distribution Service Reliability."[542] GTI found that most natural gas outages are planned (e.g., natural gas outages are due to maintenance), and that natural gas systems often do not experience outages during extreme weather. In fact, only about 1 in 800 natural gas customers experience unplanned outages per year. For reference, electric distribution systems average one outage per year per customer. Pulling data from the *PHMSA*, GTI notes that excavation damage was the number one cause of serious incidents for natural gas distribution and transmission from 2005-2016. Altogether, natural gas transmission and distribution exhibit a very high standard of reliability. These results from the GTI study align with our findings in the case studies: natural gas had much shorter and fewer disruptions than electricity systems during extreme events.

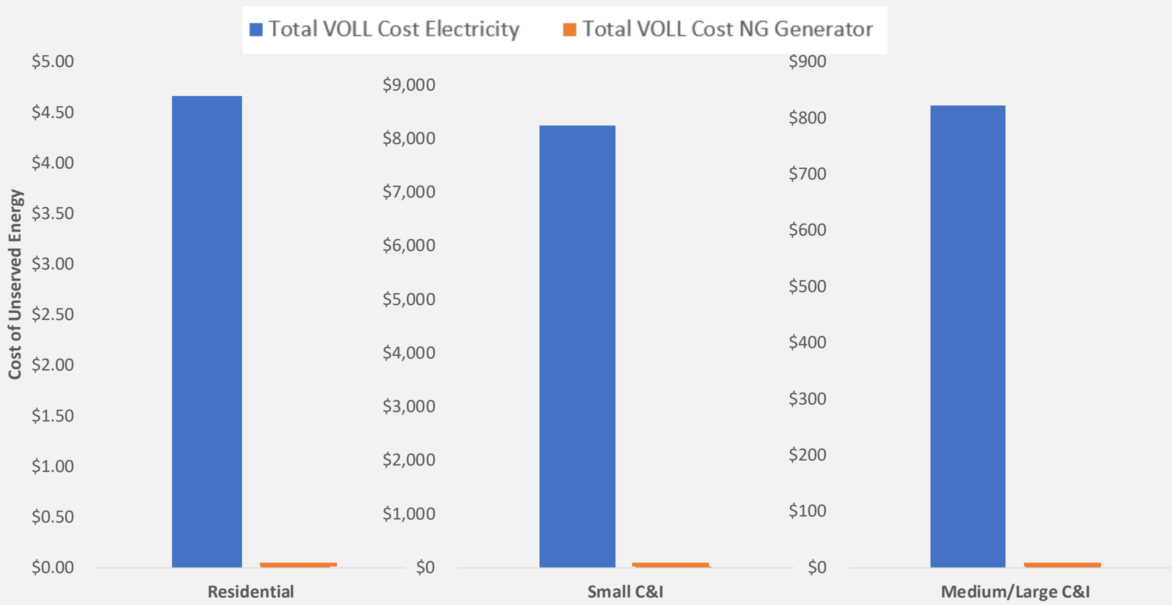
[541] Natural Gas Council. "Natural Gas Systems: Reliable & Resilient." July 2017. https://www.ipaa.org/wp-content/uploads/2017/07/NGC-Reliable-Resilient-Nat-Gas-WHITE-PAPER-Final.pdf
[542] Gas Technology Institute. "Assessment of Natural Gas and Electric Distribution Service Reliability." July 2018. https://www.gti.energy/delivering-quantitative-data-to-support-natural-gas-standby-and-emergency-generators/

Figure 29. VOLL based on expected disruptions from electric utility and natural gas generator.

GTI Report Results and the Value of Lost Load (VOLL)

The GTI report results mentioned above provide estimated rates for annual outages for natural gas and electric distribution services. GTI found that natural gas is much more reliable in distribution (1 in 800 customers experience an outage annual) than electricity (every customer experiences an outage annually).

We applied the Value of Lost Load (VOLL) method recently used in the California Fourth Climate Change Assessment (CA4A) to determine the economic impact to residential, commercial, and industrial customers (Bruzgul et al. 2018). Using the CA4A data for the cost per unit energy lost by customer ($/kWh), we examined the annual expected costs from outages to three categories of customers: residential, small commercial and industrial (C&I), and medium/large C&I. The chart below shows the results based on a scenario where the customer used electricity from an electric utility and a natural gas generator. For all customer categories, the expected natural gas disruption impacts are insignificant compared to the electricity disruption costs.



Technology supported the resilience of natural gas. This was the case with SoCalGas' pressure sensors being able to detect a drop in pressure and immediately send a signal to valves to shut off the flow in the affected pipeline during mudslides. This type of monitoring technology aids both identifying locations for proactive protection before an issue becomes too severe, as well as pinpointing damage if it does occur and making restoration efforts more efficient and targeted.

SoCalGas' use of drones and satellite imagery was also useful, as it gave them visibility into areas inaccessible by personnel to closely assess damage. Satellite imagery was particularly helpful immediately following these events, when FAA restrictions prohibited flights from third parties to avoid conflict with first responders' rescue efforts. Colonial Pipeline Company also utilized satellite imagery in the Harvey aftermath to shorten disruptions in a critical gas pipeline. Such imagery allows for more detailed and up-to-date evaluation of vulnerabilities and real-time impacts from disasters.

Finally, the natural gas network itself can undergo upgrades to become more resilient, such as replacing underground steel pipes with flexible materials to better withstand impacts from natural disasters like shifting soil during hurricanes.

Safety investments in gas infrastructure are providing resilience benefits. As utilities address aging infrastructure and replace bare steel and cast-iron gas pipe, they reduce the potential for water entry and disruption of gas service, making the systems more resilient. Also, the plastic pipe used for many of these replacements is more flexible and less likely to break when there is ground shifting due to water flow from hurricanes or seismic activity.

Diversity in fuel supplies improve resilience. Energy backup systems with diverse fuel supplies such as onsite diesel storage with bi-fuel connections that allow a switch to natural gas will provide greater flexibility and higher levels of resilience. Recovery after an event can also be better supported with more diverse vehicle fleets that include compress natural gas fueled vehicles in addition to petroleum fueled vehicles since petroleum fuel supplies may be limited after an event. The PG&E remote microgrid program which improves reliability and significantly reduces wildfire risk by replacing the overhead distribution powerlines serving small groups of customers in High Fire-Threat Districts with microgrids, uses several resources including photovoltaic panels, batter storage and propane generation for backup supply.

The increasing focus on resilience and availability of backup generation may worsen air quality. As the number of extreme events continues to increase, more residents are installing backup generation in their homes. Since the majority of these generators still using petroleum fuels, it is likely that this increasing adoption will have an adverse impact on air quality. Converting the estimated 1,800 stationary backup generators used during the October 2019, PG&E PSPS event from diesel to gas would have reduced emissions by 70%, avoiding 88 tons of NOx pollution.[543]

Inadequate consumer knowledge can limit the ability to reap the benefits of the resilience of natural gas. During Winter Storm Uri, many consumers were unaware that many gas stoves and fireplaces are capable of operating during a power outage, either by being lit with a match or by using a small 9-volt battery to power the electronics. Without such knowledge, some residents unnecessarily went without heat, hot water, or the ability to cook. On the flip side, some Texans suffered carbon monoxide poisoning when they ran outdoor generators indoors. Thus, it is of the utmost importance that residents understand what power source are and are not available during power outages—and how to use them safely.

Marginalized communities suffered disproportionately. In Winter Storm Uri, the most marginalized communities with the poorest ability to withstand and recover from events were often the communities most affected by proactive load shedding and delayed restoration. Neighborhoods with long outages were more likely to have multifamily housing, more residents who did not speak English, and more people who rely on public transportation for commuting.[544] Disadvantaged populations were more likely to live in older homes with outdated plumbing and pipes. A survey found that 38% of low-income respondents experienced burst water pipes,

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[543] ICF analysis.

[544] Nejat, Ali, Laura Solitare, Edward Pettitt. "Equitable Community Resilience: The Case of Winter Storm Uri in Texas." *3rd International Conference on Natural Hazards and Infrastructure,* July 2022. https://www.researchgate.net/publication/357925305_Equitable_Community_Resilience_The_Case_of_Winter_Storm_Uri_in_Texas

compared to 25% of high-income respondents. Low-income respondents were also more likely to have fallen trees, roof or structural damage, and damaged appliances.[545]

Additional Research Needs to Better Understand and Improve Natural Gas Resilience

The list below illustrates areas for further research based on the findings from these case studies and other natural gas resilience work. Note that many of the recommended research activities would greatly benefit from or may even require engagement by utilities to ground them in the realities utilities face in preparing for, and responding to, natural disasters.

Additionally, SoCalGas and San Diego Gas & Electric has sponsored active research partnerships to further its understanding of climate resilience. The company has partnered with research groups through a project under the Californian 4th Climate Assessment funded by the California Energy Commission (CEC). The project, entitled *Potential Climate Change Impacts and Adaptation Actions for Gas Assets in the SDG&E Company Service Area*, in partnership with ICF, analyzed the exposure of gas assets in the SDG&E Service Area to climate change-driven hazards, including coastal hazards, inland flooding, wildfire, extreme heat, and landslides and mudslides. A second project, *Multi-Hazard Investigation of Climate Vulnerability of the Natural Gas Energy System in Southern California*, was conducted in partnership with UC Irvine. This work investigated the climate vulnerability of natural gas energy infrastructure in southern California given concurrent, compounding, and dependent climate extremes. The analysis considered hazards including land subsidence, sea level rise, extreme precipitation, and extreme events.

1. **Identify cost-effective priorities for increasing resiliency from natural gas.** Additional research should consider the role that natural gas plays in building resilience to natural disasters. Key research questions include:
   - Since natural gas is anticipated to experience overall limited impacts from natural disasters, should natural gas service be expanded in order to increase energy resiliency? In what areas or types of usage should this be prioritized?
   - How can natural gas systems limit service disruptions during extreme events through infrastructure investments to improve robustness (e.g., increasing pipeline depth to avoid exposure to scour)?
   - Which customers would benefit from installing backup generators, and how much fuel should they store on-site to prepare for potential service isolations?
   - How does the availability of CNG and LNG to fuel vehicles affect responses considering potential petroleum access issues?
   - How can natural gas resilience efforts be incorporated into cost-benefit assessments to understand the cost of investment compared to resilience benefits?

[545] "When the Lone Star Froze Over: Winter Storm Uri and the lived experiences of Texas low-income communities." *Texas Poverty Research Institute,* July 2021. https://www.txenergypoverty.org/wp-content/uploads/2021/07/When-the-Lone-Star-Froze-Over.pdf

2. **Improve the understanding of how technology can be used and deployed to improve resilience.**

   Key research questions include:

   – What role do Advanced Meters and other technologies such as fiber optics play in natural gas system resiliency?

   – Where should technology upgrades be prioritized from a resiliency perspective?

   – Is there additional regulatory support needed to ensure deployment of these technologies are optimized from a resiliency perspective? For example, some communities push back on the installation of equipment that supports smart infrastructure. Granting utilities more authority to install infrastructure as needed could be beneficial in some cases.

   – Are there specific barriers to expanding smart infrastructure more quickly that the CPUC could help address?

   – Additionally, how can acquisition and use of technologies such as drones and satellites build resilience? We observed an example of these technologies at work in SoCalGas' response to the mudslides. These assets aided in visibility to damages and access to difficult-to-reach areas, and so it is worth pursuing a more robust discussion of how these tools can be used to their fullest potential.

3. **Examine costs and benefits of isolating service areas to improve resilience.** The greatest impact of natural disasters to natural gas service and infrastructure was found to be the voluntary service isolations put in place during the California wildfires. While an important strategy, the ramifications were costly. Future research into system modifications or other strategies for mitigating the extent of the impact would be useful for strengthening the response to future natural disasters. Key research questions include:

   – How might utilities better prepare for the need to isolate areas?

   – Is there technology that could aid in the restoration process?

   – What are strategies for minimizing the area experiencing a service isolation?

4. **Address the main drivers of natural gas incidents.** Based on incident report data gathered by the *PHMSA* as well as the anecdotal evidence presented in this report, natural disasters are not the main driver behind natural gas incidents. Rather, excavation damage is the most common cause for "serious incidents," according to *PHMSA* statistics from 2005-2016.[546] A serious incident is one that includes fatality or injury and was not first caused by fire. Key research questions include:

   – Which strategies might reduce incidents due to excavation damage (to help increase overall reliability of natural gas)?

   – Examples may include improving underground asset identification, enhancing utility notification and 811 call center education and effectiveness, and using technology to help monitor underground assets and deliver real-time awareness during excavation activities.[547]

5. **Research potential for natural gas to support emergency services.** Interviewees mostly expressed a preference for CNG/LNG in operating vehicles and generators during emergency services. Natural gas has greater reliability and pollutes less than petroleum products and

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[546] Gas Technology Institute. "Assessment of Natural Gas and Electric Distribution Service Reliability." July 2018. https://www.gti.energy/delivering-quantitative-data-to-support-natural-gas-standby-and-emergency-generators/
[547] Ibid.

provides the opportunity to use low-carbon fuels with renewable natural gas. Our research also found successes in gas-fired CHP systems and water pumps during extreme events. Key research questions include:

– How might utilities expand access for vehicles and generators, as well as CHP and other gas-fired back up system? The interviewees noted a lack of access to natural gas during extreme events and cited this as the primary driver in expanding natural gas use.

– Given these benefits over diesel, how can natural gas be better utilized during emergency events for generators and vehicles through tube trailers or other technologies?

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APPENDIX A
Research Methods and Sources Consulted in Developing Case Studies

Desk Review

Over the course of developing the case studies, the research team searched for news articles and other publications and posts related to the disasters that would shed light on the impacts to and role of natural gas. The research team used search terms such as "Houston Harvey CNG," "California fire natural gas pipeline," and "Florida Michael natural gas backup generator," to find information on how natural gas played a role across various sectors and responses. Most of the articles concerning Texas had to do with production, as facilities employed emergency response protocols and shut down production days in advance of Harvey. In Florida, the research team found more discussion surrounding the loss of electrical power, as natural gas is a major power source for electric generation in the state; however, such articles dealt with the destruction of electrical infrastructure rather than any impacts to natural gas. In California, most articles had to do with the voluntary isolation by gas utilities to customers. This review also included reading the Natural Gas Council's report, "Natural Gas: Reliable and Resilient," which detailed the strength of natural gas infrastructure,[548] the Gas Technology Institute's report, "Assessment of Natural Gas and Electric Distribution Service Reliability," which analyzed the high reliability of natural gas transmission and distribution,[549] and Sandia's report "Natural Gas Network Resiliency to a 'Shakeout Scenario' Earthquake," which looked at impacts to natural gas supplies in Southern California in the event of a large earthquake.[550]

The research team also obtained and reviewed Official Use Only reports from the Department of Energy with mandated reporting from utilities on infrastructure damage, service interruptions, and other impacts from the disasters. While the research team is not able to cite these reports in the case studies, they did serve as a guide, highlighting information that we were able to track down in other publicly available sources and therefore streamlining our search process. Ultimately, the research team was able to find citable sources detailing virtually all information from these reports.

One such source was the publicly available U.S. Department of Transportation's Pipeline and Hazardous Materials Safety Administration (*PHMSA*) database on mandated reports for pipeline incidents. The research team filtered the spreadsheet of all reports down to the states affected by the disasters and the years 2017 and 2018. From these results, the research team was able to pull examples of pipeline damage that are detailed in the report. The *PHMSA* pipeline incident data concerning gas distribution for the Gulf Coast region included reports of one incident for each hurricane: in Boca Raton, Florida during Irma, in Vidor, Texas during Harvey, and in Colquitt, GA during Michael. The *PHMSA* gas transmission, gas gathering, and underground natural gas storage incident report data included two reports – one during Hurricane Harvey and the other during Hurricane Harvey.

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[548] Natural Gas Council. "Natural Gas Systems: Reliable & Resilient." July 2017. https://www.ipaa.org/wp-content/uploads/2017/07/NGC-Reliable-Resilient-Nat-Gas-WHITE-PAPER-Final.pdf
[549] Gas Technology Institute. "Assessment of Natural Gas and Electric Distribution Service Reliability." July 2018. https://www.gti.energy/delivering-quantitative-data-to-support-natural-gas-standby-and-emergency-generators/
[550] Ellison, James F., Corbet, Thomas Frank, and Robert E. Brooks. "Natural Gas Network Resiliency to a 'Shakeout Scenario' Earthquake." Sandia National Laboratories, June 1, 2013. https://doi.org/10.2172/1089984.

CPUC En Banc

One of the team members attended the CPUC Fire Safety and Utility Infrastructure En Banc on January 31, 2018 via webinar. This included a panel on the fire threat in California by CAL FIRE's Deputy Director of Fire Protection and the Fire and Rescue Chief of the California Office of Emergency Services; a panel on national standards and best practices by representatives from CAL FIRE, SDG&E's electric operations, and a utility vegetation management expert; a focused discussion on proactive utility disconnection with representatives from SDG&E, SCE, PG&E, and CALFIRE; a panel on climate adaptation and infrastructure impacts by representatives from the California Governor's Office of Planning and Research, Reax Engineering Inc., CAL FIRE, and a Hoover Institution Research Fellow; and a final panel on supporting utility customers in emergencies by representatives from The Utility Reform Network, Cal OES, CPUC, and the Office of Ratepayer Advocates.[551] While most of the discussions centered on electrical infrastructure, the En Banc was useful for gaining insight into the details of the damages from the fires as well as a coordinated response between utilities, emergency personnel, and the government.

One-on-One Interviews

To gain information and perspective from emergency-, utility- and infrastructure-related personnel who had played a role in the response to the disasters, we conducted a series of interviews. We reached out to contacts at Texas utilities and the Harris County Office of Homeland Security and Emergency Management, the Miami-Dade County Government, Caltrans, CUEA, California utilities, California and Florida water agencies, the American Gas Association, and ICF colleagues with natural gas expertise and contacts.

Due to the recency of the events when contacted, many of these contacts were still facilitating the response and were unavailable for comment. However, the conversations we were able to have with the contacts listed below in Table A1 and Table A2 proved insightful. Table A3 lists the contacts with whom we were able to have conversations as part of the 2022 update.

Table A1. Contacts consulted for the case studies in round one.

Name	Association, Position	Type
Kit Batten	Pacific Gas & Electric, Corporate Sustainability, Climate Resilience Chief	Utility
Christine Cowsert, Terry White	Pacific Gas & Electric	Utility
Deanna Haines	SoCalGas, Director of Policy & Environmental Strategy	Utility
Karineh Gregorian	SoCalGas, Senior Gas Engineer	Utility
Dana Hendrix	Caltrans Office of Emergency Management and Infrastructure Protection, Acting Chief	Government
Don Boland	California Utilities Emergency Association, Executive Director	Utility, government (interdisciplinary)

[551] CPUC. "Fire Safety and Utility Infrastructure En Banc." January 31, 2018. http://www.cpuc.ca.gov/2018FireEnBanc/

Name	Association, Position	Type
David Wade	Harris County Office of Homeland Security and Emergency Management, Industrial Liaison	Government
Lori Traweek	American Gas Association	Trade Association
Richard Meyer	American Gas Association	Trade Association
Kevin DeCorla-Souza	ICF, Senior Project Manager	Consultant
Joel Bluestein	ICF, Expert Consultant	Consultant
Meegan Kelly	ICF, Combined Heat & Power Expert	Consultant
Anne Hampson	ICF, Combined Heat & Power Expert	Consultant

Table A2. Contacts consulted for the case studies in round two.

Name	Association, Position	Type
Deanna Haines	SoCalGas, Director of Policy & Environmental Strategy	Utility
Karineh Gregorian	SoCalGas, Senior Gas Engineer	Utility
Dr. Wen Yang, Russ Colby	LA Water Boards, Emergency Coordinators	Water agency/utility
Jeff O'Keefe, Sutida Bergquist, Jeff Densmore, Cliff Cheng, Bill Liang	State Water Resources Control Board, Drinking Water Division	Water agency/utility
Gary Williams, Jim McClaugherty	Florida Rural Water Association, Executive Director (Williams) and Vulnerability Assessment Coordinator (McClaugherty)	Water agency/utility
Dana Hendrix	Caltrans Office of Emergency Management and Infrastructure Protection, Acting Chief	Government
Don Boland	California Utilities Emergency Association, Executive Director	Utility, government (interdisciplinary)

Table A3. Contacts consulted during the 2022 update to the case studies.

Name	Association, Position	Type
Deanna Haines	SoCalGas, Director of Policy & Environmental Strategy	Utility
Krikor Tasmajian	SoCalGas	Utility
Eric Carter	Travis County TX, Chief Emergency Management Coordinator	Government
Jay Semple	Disaster Response, Catholic Charites Fort Worth	Non-profit
N/A	Edwards County Senior Activity Center	Community Organization
Robert Graves	Florida Public Service Commission	Utility
Doug Moreland	Florida Public Utilities in South Florida	Utility
Dale Calhoun	Florida Natural Gas Association	Utility
Chris Durost	Peoples Gas	Utility
Eddie Murray	Business Development and Operations, Freedom CNG	Utility

Social Listening

We performed a social listening exercise to better understand customers' responses to the natural disasters and whether natural gas was factoring into the conversations via social media. We also used the results of this social listening to scan news articles dealing with the disasters for details on natural gas. This effort was performed in version one of the case studies, which dealt with Hurricanes Irma and Harvey and the 2017 California wildfires.

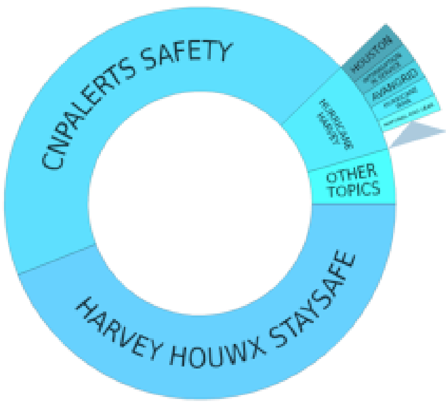
ICF social listening experts ran search terms through Crimson Hexagon, a tool that pulls from social media and news articles based on tailored search strings. See the text box for the search strings used. Note that the minus sign before the last search string (each search string is enclosed by parentheses) means that these terms were negative searches, purposefully excluding articles or social posts that employed them. Those terms were chosen to be excluded because of the types of results being returned by Crimson Hexagon without such a negative string: many articles dealt exclusively with the market-side impacts of reduced oil production during Harvey, or of safety tips being tweeted out by agencies warning customers to not shut off gas at their meters themselves.

Search Strings Used in Social Listening

("interruption in service" OR "natural gas service" OR "natural gas leak" OR "natural gas utilities" OR "natural gas repairs" OR "natural gas infrastructure") AND ("wildfire" OR "wild fire" OR #thomasfire OR #LAfire OR #SDfire OR hurricane OR leaks OR mudslide OR #Irma OR #Harvey OR #NunsFire OR #TubbsFire OR #AtlasFire OR #LilacFire OR #CreekFire OR #RyeFire OR #SoCalFires OR #mudslide) AND -(author:@socalgas OR prices OR oil OR spikes OR "safety tips" OR coal OR Trump OR Obama)

The results were filtered by time and specific hashtags to dial in on the posts and articles for each event. For each of the four events, we were able to determine number of posts; sources of the posts (e.g., what percentage was coming from Twitter versus from news sources); the frequency with which hashtags were being used; top themes and topics; and examples of top tweets. See Figure A1 below for an example of the top themes and topics for Hurricane Harvey in Texas. The size of the portion of the wheel indicates the frequency with which that topic or theme appeared in the search results.

Figure A1. Example of results from social listening experiment showing top themes and topics for Hurricane Harvey.



- The topic wheel shows the top themes and topics from the past year. Larger font means more posts used those keywords.
- Subtopics are the smaller rings of conversation outside of the main theme.
- CNP Alerts Safety and Harvey HousWX Stay Safe were the top 2 keywords/topics that appeared in the 311 posts.
- The outer ring keywords connected to the "hurricane Harvey" portion of the inner ring are: Houston, Interruption in service, avangrid, hurricane Irma, and natural gas leak.

Source: ICF

Winter Storm Uri – 2022 Social Media Listening Study

ICF conducted a social media listening study to gain more detailed insight as to the impact of the storm on customers and understand how those customers responded to the event. Issues of interest included residential customer's ability to keep warm, cook food, and boil water to make it safe for use, as well as the event's impact on small businesses and the community. The effort was particularly focused on understanding how low-income and underserved communities were impacted and responded to the event.

ICF selected four counties in Texas for analysis based on the fraction of customers out of service over the period of the event,[552] the poverty rate in the county,[553] and whether a local gas distribution company serves the county. The study captured social media activity within a 25-mile radius around the cities listed below. Note that Austin County is different from and not located near the City of Austin.

- Wharton County (City of El Campo, TX)
- Edwards County City of Rocksprings, TX)
- Austin County (Cities of Bellville and Industry, TX)
- Waller County (City of Katy, TX)

[552] ICF used a subscription service to retrieve customer outage data
[553] Poverty rates obtained from: Texas Poverty Rate by County (indexmundi.com)

The analysis was conducted using the social media listening tool Sprinklr, which supports research across various social media platforms. The platforms searched included Twitter, Instagram, YouTube, and Facebook.

Some key takeaways from the analysis include:

- There was widespread confusion and misinformation about energy source availability and scarcity. Users disagreed on which energy sources and companies were to blame for scarcity.
- There were many mentions about natural gas availability including personal anecdotes from users who were grateful to have gas appliances, and users that wished they had gas appliances to heat, boil water and cook food.
- Other mentions included users that had natural gas heating but were unable to use it due to lack of electricity to power the fans or ignition/pilot lights of their appliances.

Selected posts from media platforms are listed below. Our review of such posts revealed the following insights:

- Texans with gas stoves that did not require electricity to operate were able to stay warm even if their power went out. It is important to note that it is not advisable to use a gas oven to heat a home.[554]
- Many Texans were frustrated by the government's lack of cold weather preparedness both in preparation for and during the storm.

The tweets below illustrate the critical role natural gas played for some Texans during the storm.

Melissa H, @mrsviv08

We are now at the point in this Texas winter storm where we can't let our faucets drip because the water levels in our town are getting so low that a boil order may need to happen. Except some people won't be able to boil water b/c they have electric stoves and no power.

Anne Halsey, @anne_halsey

8+ hours without power. Luckily, we have a gas stove, running water, plenty of food, and blankets. But the roads are really slick and I worry about those nearby who are less prepared for a cold weather event of this proportion. Y'all hang in there. XO

Eddie Sigala, @eduardokenya

If it hadn't been for our gas stove letting us warm up food/water in the winter storm this year in TX, we would've been in real trouble.

For people with unreliable electric connections, we need to resolve those issues before sticking to one fuel source.

[554] U.S. Center for Disease Control. "Carbon Monoxide Poisoning." Accessed July 8, 2022. https://www.cdc.gov/co/faqs.htm.

Amanda Glaser, @AmandaL_Glaser

I have had power off and on, mostly off, for 3 days now in 30 degree weather bc TX officials were completely unprepared for a winter storm. I have been lucky enough to have running water and a gas stove, but many are in a far worse position.

Colin Lowry, @colinglennlowry

My >80YO mom sleeping in front of our gas stove during Winter Storm Uri made this lifelong Texan realize just how FRAGILE and DEPENDENT and PATHETIC my home state actually is.

I've been progressively disgusted and hating TX since February…

Kay Marley-Dilworth, @ATXFoodNews

Next month is the anniversary of our brutal winter storm in Texas, in which at least 246 people died. I made a list of prep ideas, in case we lose power and water again. Thankful for a gas stove! https://amzn.to/3nBDGyl

Jenny B, @JennyLovesBingo

Things suck in Texas right now. I've lived in the north, I promise you this is not the same thing as a winter storm there. We are very lucky our pipes haven't frozen and we have a gas stove. People are freezing to death and politicians are doing nothing. 🤬

Grace Green, @gracefacegreen

after the way the texas gov handled the winter storm I WISH I had a gas stove👀👀👀

SthrnFairytale
@sthrnfairytale

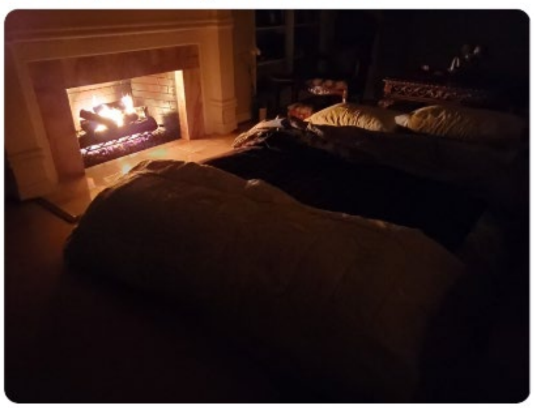
No power, but we have a gas stove, so I taught the 14 year old how to make stovetop popcorn. He's a fan! (Power is back on after 44 hours without) #texas #houston #weather

11:21 AM · Feb 17, 2021 · Twitter for iPhone

10 Likes

Rupal Patel
@rupalPT

No power but thankful to have a gas fireplace. Camping out in front of the fireplace tonight. #houstonpoweroutage #houstonfreeze



11:56 PM · Feb 16, 2021 from Missouri City, TX · Twitter for Android

1 Retweet 41 Likes

Miranda Sewell
@plymgal69

Due to the extreme weather we're currently experiencing, I've kept our gas fireplace running just in case we lose power. We just lost power, albeit for a moment, but the fireplace also went out. If it's gas, why would a power cut shut it off?

9:04 PM · Feb 14, 2021 · Twitter for iPhone

1 Retweet 7 Likes

APPENDIX B
GHG Impacts from Forest Fires in 2017 and 2018 in California

Wildfires burn biomass, which generates GHG emissions through carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions. Wildfires also damage forests, and forest soils, that would otherwise sequester (or store) CO_2. This reduced sequestration potential of forests, which are a large sink for GHGs, can compound the impacts of climate change from wildfires. In this section of the report, we estimate the GHG emissions from combustion, or burning of forest biomass, and sequestration losses to create a total estimate for GHG emissions from California's wildfires.

First in this section, we estimate CO_2 and CH_4 emissions from combustion of California's wildfires. To achieve this, we estimate acres burned, and combine this with the fuel density of biomass and a corresponding emission factor from California-specific resources. The emission factors and the fuel loading information were obtained from US EPA's AP-42 database[555], which lists estimates for wildfires by gas and region. The data source for areas burned was California Department of Forestry and Fire Protection's (CalFire). The calculated combustion estimates are in line with estimates reported by the California Air Resources Board (CARB).[556]

Second, in this section we assess the loss of carbon storage potential of soils. In addition to burning trees and creating GHG emissions, wildfires also impact the soil, which in turn has an impact on the climate. Fire alters the amount and distribution of carbon pools in the soil and forests. After the fire, while some of the carbon survives and continues to thrive as vegetation, the remainder of the carbon turns to either deadwood, soot or charcoal. Deadwood decomposes over time, causing more emissions from its decomposition. Soot and charcoal are stable forms of carbon that remain unchanged for a long period of time.

To estimate the biomass and soil sequestration losses regional sequestration loss factors, we relied on a study by the US Forest Service.[557] Here, we combined the area burned with a carbon loss factor, to estimate the amount of carbon pool lost due to the wildfire. The study assumes that California's pine forests lose 2% to 23% of carbon stored per hectare of forest area burned. We combined the combustion emission method and sequestration loss to determine a net GHG impact of wildfires in California in 2017 and 2018 (Table B1).

Third, we benchmarked the previously described method with a method that combines both sequestration and combustion emissions in a single "land use change" emission factor. For this, we used an emission factor, published by Winrock.[558]

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[555] EPA. "Development of Emissions Inventory Methods for Wildland Fire." *EPA,* February 2002. https://www3.epa.gov/ttn/chief/ap42/ch13/related/firerept.pdf

[556] California Air Resources Board. March 5, 2019. California Wildfire Burn Acreage and Preliminary Emissions Estimates. https://www.arb.ca.gov/cc/inventory/pubs/ca_wildfire_preliminary_co2_emissions_estimates.pdf

[557] Harvey, Alan., Jurgensen, M., Deborah Page-Dumroese. "Fire and Fire-Suppression Impacts on Forest-Soil Carbon." In *The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect*, CRC Press, 2003.

[558] Harris, N., S. Grimland, and S. Brown. *GHG emission factors for different land-use transitions in selected countries/regions of the World.* Winrock International report to EPA, 2009.

The table below summarizes calculated CO_2 and CH_4 emissions, and loss in carbon stored in forests and provides comparison to other sources.[559]

Table B1. 2017 and 2018 California GHG impacts from wildfires.

Year	Area Burned (acres)[560]	CO_2 Emissions ($MMTCO_2e$)	CH_4 Emissions ($MMTCO_2e$)[561]	Sequestration loss ($MMTCO_2e$)	Total GHG Impact ($MMTCO_2e$)	GHGs/Acre Burned (MTCO2e/ acre)	Total GHG Impact ($MMTCO_2e$)	GHGs/Acre Burned (MTCO2e/ acre)
Source		US EPA	US EPA	US FS	EPA & FS	EPA & FS	Winrock	Winrock
2017	1,248,606	30.6	3.425	77.4	111.4	89.34	308.4	247.0
2018	1,671,203	41.1	4.575	103.6	149.3		412.9	

For context, the approximately 700 MMT CO_2e emitted between 2017-2018 using the Winrock land use change method represents more than California's entire non-wildfire GHG emissions in 2016 (430 $MMTCO_2e$).[562] Figure B1 shows a visual summary of the Table B1 results compared with California's non-wildfire emissions from the 2016 State Inventory.

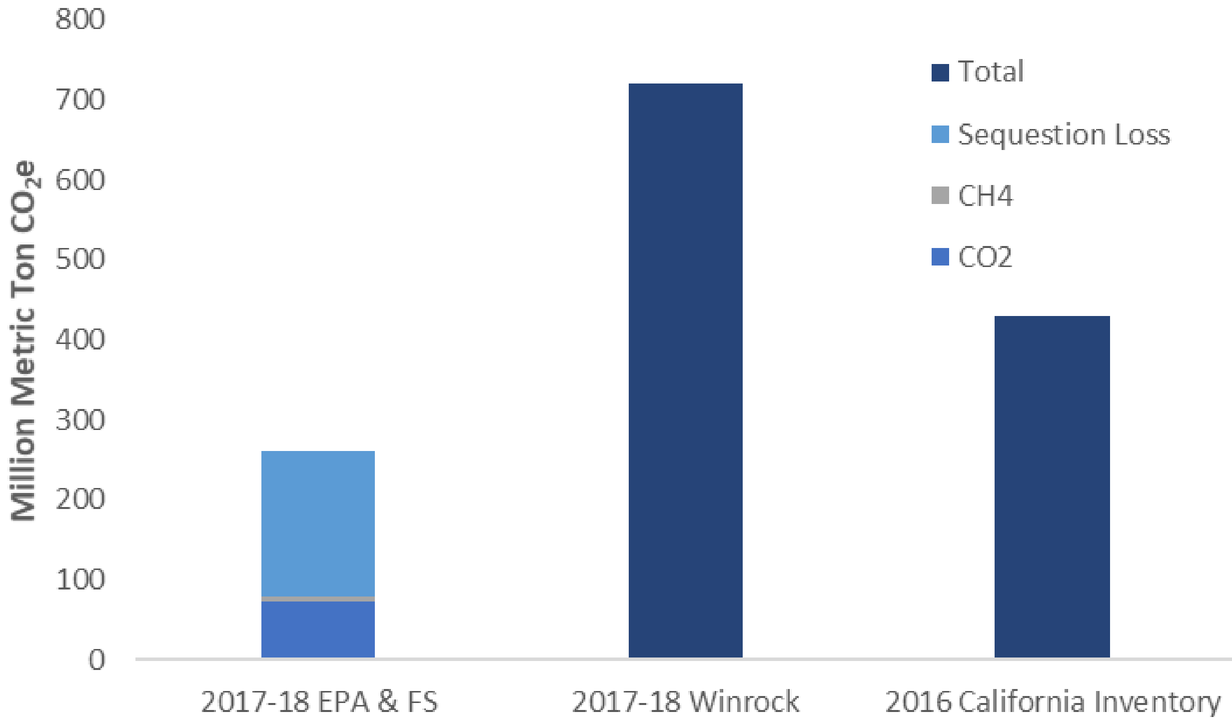
559 Black carbon from biomass burning (and other sources) may also be a significant contributor to global warming but is highly uncertain due to the many complicated pathways aerosols have to impact climate. IPCC AR5 (2013) WG1 estimates a 100-year global warming potential for black carbon of 900 with a range of 100-1700 on a global basis. Location, surface albedo, and other parameters influence this parameter. Bond et al. (2013), cited in IPCC AR5 notes that "Black carbon and CO_2 emission amounts with equivalent 100-GWPs have different impacts on climate, temperature, rainfall, and the timing of these impacts. These and other differences raise questions about the appropriateness of using a single metric to compare black carbon and greenhouse gases." Due to these uncertainties, we have only reported the impacts from the well mixed GHG emissions here.

560 CAL FIRE. "CalFire Incident Information, 2017 and 2018." http://cdfdata.fire.ca.gov/incidents/incidents_statsevents.

561 CO_2 equivalency estimated using AR4 GWP.

562 California Air Resources Board. "California Greenhouse Gas Emission Inventory - 2018 Edition." https://www.arb.ca.gov/cc/inventory/data/data.htm.

Figure B1. Comparison of two methods for estimating wildfire emissions and California's 2016 non-wildfire emissions.



The results from the combined EPA and USFS method (about 250 MMTCO$_2$e from 2017-18) is equivalent to the annual emissions from over 50 million passenger vehicles in the US.[563]

The net GHG impacts estimated using combined factors from Winrock is approximately 3 times higher than the calculated estimates from US federal data. This is generally because of the high uncertainty associated with sequestration factors of forests. While all factors used were specific to California forests, factors such as forest type, age, and condition of the forest was not distinguished, each of which, can have a substantive impact on emissions and loss of carbon sequestration. These factors above have an impact on the amount and type of biomass contained within the burned area, which influences how much carbon is originally stored, and the shift in carbon pools due to the fire. Fire intensity, air temperature, and duration of fire can also have an impact on emissions and loss of sequestration potential. Thus, the values presented here should be regarded as high-level estimates only.

[563] US EPA, OAR. "Greenhouse Gas Equivalencies Calculator." Data and Tools. US EPA, August 28, 2015. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

APPENDIX C

Criteria Air Pollutant Emissions from Forest Fires in 2017 and 2018 in California

The 2017 wildfire season in California was among the worst on record. 2018 showed the greatest burned acreage due to wildfire in the state in at least 15 years. 2017 included extensive wine country fires in addition to those in Southern California. 2018 included Butte County's Camp Fire, the deadliest in California's history, and the Woolsey Fire in the Malibu area. [564]

Table C1 lists the California Department of Forestry and Fire Protection's (CalFire) estimates for the number of fires and total combined acreage burned, in fires under the jurisdiction of both CalFire and the US Forest Service.

Table C1. 2017 and 2018 California Fire Statistics.[565]

Year	Fires	Acres Burned
2017	9,133	1,248,606
2018	7,571	1,671,203

Depending on the acreage burned and type of land burned, wildfires can severely impair local air quality, and air quality throughout the state. During the November 2018 Northern California wildfires, areas in the state recorded some of the worst Air Quality Index (AQI) ratings globally. Emergency room visits spike in regions impacted by wildfire smoke, particularly for populations over 65.[566] Short-term exposures to the air pollutant emissions associated with wildfires can increase the risk of exacerbating asthma,[567] other respiratory diseases, cardiovascular disease, and stroke.[568] Chronic exposure to particulate matter from wildfire smoke has been associated with adverse neurologic and metabolic outcomes. Furthermore, carbon monoxide levels surge during the smoldering phases of a fire and intoxication can result in death.

Air quality impacts are estimated in this report through analysis of the state-wide criteria air pollutant emissions from 2017-2018 California wildfires. To achieve this, we paired the Table C1 estimates of acreage burned with emission factors from US EPA's AP-42 database.[569] AP-42, *Compilation of Air Pollutant Emission Factors*, is EPA's primary compilation of emission factor information.[570] We used emission factors and fuel loading factors for wildfires from AP-42, Chapter 13.1, to estimate the total emissions of particulate matter (PM), carbon monoxide (CO), volatile

[564] Kasler, Dale. "Worst wildfire year since when? More California acres have burned in 2018 than the past decade." *The Sacramento Bee*, November 16, 2018. https://www.sacbee.com/latest-news/article221788220.html.
[565] CALFIRE. "CalFire Incident Information, 2017 and 2018." http://cdfdata.fire.ca.gov/incidents/incidents_statsevents.
[566] Turkewitz, Julia and Matt Richtel. "Air Quality in California: Devastating Fires Lead to a New Danger." *The New York Times*, November 16, 2018. https://www.nytimes.com/2018/11/16/us/air-quality-california.html
[567] Guarnieri, M. and John R. Balmes.. "Outdoor air pollution and asthma." *The Lancet*, 383(9928), pp.1581-1592.
[568] Balmes, John R. "Where There's Wildfire, There's Smoke." *New England Journal of Medicine* 378, no. 10 (March 8, 2018): 881–83. https://doi.org/10.1056/NEJMp1716846.
[569] US EPA, OAR. "AP-42: Compilation of Air Emissions Factors." Chapter 13. Policies and Guidance. *US EPA*, September 26, 2016. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors.
[570] Ibid.

organic compounds (VOC),[571] and oxides of nitrogen (NOx) for these same two years. The provided emission factors report wildfire emissions per area burned by region. Emission factors are reported by geographic area.

This AP-42 approach is a simplified method and relies on readily available information compiled by EPA. However, the emissions and emission factors for forest wildfires are given a rating of "D". Thus, the values presented here should be considered estimates only.

We applied the factors for California (Region 5) in units of kg emitted per Hectare burned to the total acreage burned from Table C1 to show the resulting annual, statewide emissions in Table C2.

Table C2. 2017 and 2018 Estimated Statewide Total Wildfire Emissions, metric tons.

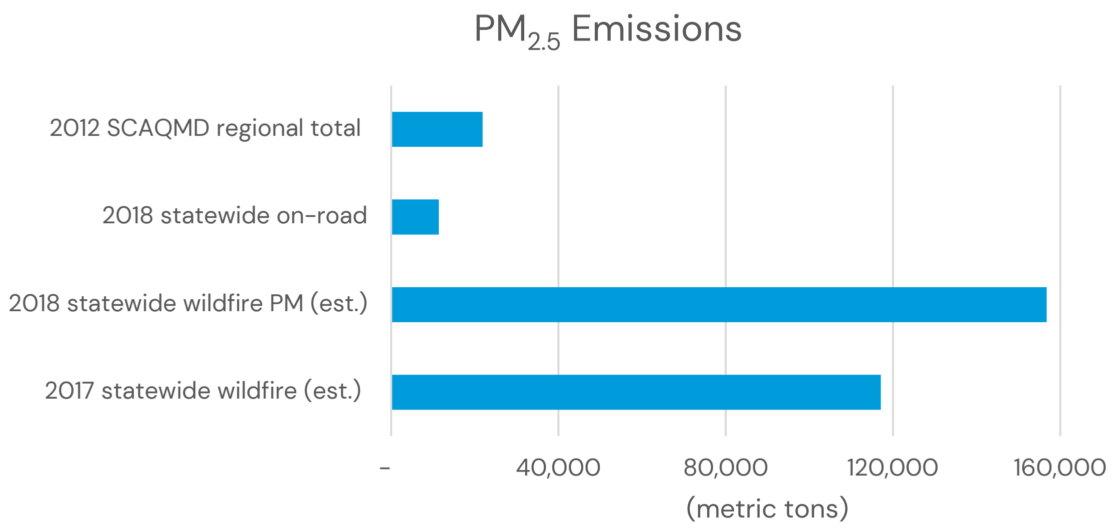
Year	PM	CO	VOC	NO_x
2017	173,316	1,429,985	245,068	40,929
2018	231,976	1,913,970	328,013	54,781

For context, these values are roughly seven (2017) to ten (2018) times the total emissions of PM_{10} from all on-road mobile sources in the state in those same two years[572].

Figure C 1 shows a comparison of wildfire emissions of $PM_{2.5}$ to other sources to demonstrate the magnitude of the emissions. $PM_{2.5}$ was selected as a common metric for comparison given the health effects associated with fine particulate matter. Emissions of $PM_{2.5}$ from the two years of wildfires statewide, estimated from the values calculated above, are shown in the two bottom bars.[573] The top bar shows the total emissions of $PM_{2.5}$ released within the South Coast Air Basin in 2012.[574] The second bar shows the total $PM_{2.5}$ emissions from all on-road activities in the state.[575] Based on these estimates, wildfires should be considered amongst the greatest contributors to particulate matter air pollution and associated public health risk in California.

[571] VOC reported as methane.
[572] Excluding fugitive road dust emissions.
[573] AP-42 only includes emission factors for total particulates for wildfires. PM2.5 emissions shown here for comparison are estimated from total particulate emissions using the ratio of PM2.5 to total particulate emission factors from AP-42 for controlled burning of conifer forests.
[574] Including fugitive road dust emissions. These values represent the baseline year, 2012, from SCAQMD's most recent regional Air Quality Management Plan for year 2016. Values are taken from Chapter 3, Table 3-2. These values include fugitive road dust. More information at http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/final-2016-aqmp.
[575] Statewide, annual emissions inventory for calendar years 2017 and 2018 obtained with EMFAC2017 (v1.0.2). Available at https://www.arb.ca.gov/emfac/2017/. These values do not include fugitive road dust emissions but do include vehicle exhaust, brake, and tire wear emissions.

Figure C1. Comparison of statewide wildfire particulate emissions to other California sources.



APPENDIX D
Best Practices in Wildfire Risk Reduction

Managing vegetation to mitigate the spread and impact of wildfire, a practice known as *fuel reduction* or *fuel treatment*, is a core element of California's recently expanded wildfire risk reduction effort.[576] This assessment provides a brief overview of current state of knowledge and best practices in fuel treatment for wildfire risk mitigation, both in living forests and in areas of high tree mortality.

Best Practices in Fuel Treatment

Fuel treatment seeks to remove or thin flammable material from vegetated areas that may be at risk of wildfire. Done properly, this can reduce the severity of fires when they occur, allowing for slower spread and more effective control by firefighting personnel. The following are core principles and practices of fuel treatment:

- "*Thinning from below*" is a standard principle of effective fuel treatment. Forest managers seek to remove ground-level dead plant debris, live brush, and smaller, lower-canopied trees—leaving in place larger, fire-resistant trees.[577] This practice eliminates "ladder fuels" and reduces the chance of ground-level fire reaching and spreading within the forest canopy. Thinning may also be intended to reduce forest canopy density, decreasing the potential for wildfire spread within the canopy. Thinning for wildfire risk reduction differs from thinning practices intended to maximize a forest's economic return.[578]
- *Prescribed burn*, in which ground-level fuel is eliminated through a controlled fire, is considered among the most effective methods of fuel treatment.[579] This process mimics natural fire processes and restores wildland ecosystems, providing significant risk reduction benefits.[580] However, given the risk or perceived risk of escaped fire, forest managers may choose not to pursue this technique, especially in proximity to populated areas.[581]
- *Mechanical thinning* is the practice of manually removing or redistributing vegetation using chainsaws or other equipment. Thinned material ("slash") can be removed, piled and burned, or redistributed within the surrounding area. Mechanical thinning may carry risks and downsides depending on the method of handling the resultant slash. Redistributing slash in the surrounding landscape may reduce fire intensity in the thinned area, but it may increase spread risk in other areas. Removing slash is most effective in reducing risk but may result in nutrient degradation.

[576] California Senate Bill 901 (2018).
[577] Omi, Philip N. "Theory and practice of wildland fuels management." *Current Forestry Reports* 1.2 (2015): 100-117, https://link.springer.com/content/pdf/10.1007%2Fs40725-015-0013-9.pdf.
[578] Hunter, M.E., W.D. Shepperd, L.B. Lentile, J.E. Lundquist, M.G. Andreu, J.L. Butler, and F.W. Smith. "A Comprehensive Guide to Fuels Treatment Practices for Ponderosa Pine in the Black Hills, Colorado Front Range, and Southwest." *U.S. Forest Service*, 2007. https://www.fs.fed.us/rm/pubs/rmrs_gtr198.pdf.
[579] Martinson, Erik, and Philip Omi. "Fuel Treatments and Fire Severity: A Meta-Analysis," *U.S. Forest Service,* 2013. https://www.fs.fed.us/rm/pubs/rmrs_rp103.pdf.
[580] CAL FIRE. "Welcome to FIRE." Accessed July 1, 2019. https://calfire.ca.gov/.
[581] Hunter, M.E., W.D. Shepperd, L.B. Lentile, J.E. Lundquist, M.G. Andreu, J.L. Butler, and F.W. Smith. "A Comprehensive Guide to Fuels Treatment Practices for Ponderosa Pine in the Black Hills, Colorado Front Range, and Southwest." *U.S. Forest Service*, 2007. https://www.fs.fed.us/rm/pubs/rmrs_gtr198.pdf

Finally, if forests are mechanically thinned but slash is not removed promptly, increased risk can result.[582]

- *Fuel breaks* are areas where fuel has been thinned substantially or removed entirely, aiming to halt the spread of wildfire. These breaks can be strategically placed to protect communities or assets or to provide anchor points for fire suppression.[583]
- *Computer modeling* can be used to predict the stand-level and landscape-level impacts of fuel treatment, providing information about where and how much vegetation should be removed.[584]

Deceased Tree Management

Removal of dead standing trees has precedent in wildfire risk reduction, particularly as a means of protecting key areas and assets and reducing the risk of fire spread.[585] However, removal of dead trees does not feature prominently in the literature on effective wildfire prevention practices, potentially due to the fact that the climate-driven epidemic of dead trees is a relatively new phenomenon.

There are few empirical studies on the impacts of tree mortality on wildfire, but in general, dead trees are known to be more subject to ignition.[586] Simulation-based studies have modeled tree mortality, and have found that varying rates of tree death may increase wildfire the rate of wildfire spread a factor of 1.2 to 2.7.[587] A 2018 analysis by Stephens et al. points out that large areas of contiguous tree mortality threaten to create a homogenous forest landscape that will be continually subject to large-scale wildfire. As a result, the study recommends an increased emphasis on the management and protection of *living* forests, as opposed to a sole focus on dead tree removal, to create a diverse and therefore resilient landscape.[588]

Efficacy of Fuel Treatment

The efficacy of vegetation management in reducing wildfire risk is notoriously difficult to quantify, given that landscape-scale wildfire dynamics cannot be easily studied using controlled trials and that other variables (e.g., fire suppression activities) have interacting effects.[589] However, a collection of scientific research conducted over the past two decades appears to validate core principles of fuel treatment for wildfire control. A 2013 meta-analysis from the U.S. Forest Service found an average reduction of 60% in canopy scorch and 38% in flame height in treated versus untreated vegetation stands. The study also found that effectiveness of fuel treatment varied

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[582] Omi, Philip N. "Theory and practice of wildland fuels management." *Current Forestry Reports* 1.2 (2015): 100-117. https://link.springer.com/content/pdf/10.1007%2Fs40725-015-0013-9.pdf.
[583] Benefeld, Mike. "Southern California Fuels Treatment Effectiveness Review." *Central Oregon Fire Management Service*, n.d. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5295359.pdf
[584] Hunter, M.E., W.D. Shepperd, L.B. Lentile, J.E. Lundquist, M.G. Andreu, J.L. Butler, and F.W. Smith. "A Comprehensive Guide to Fuels Treatment Practices for Ponderosa Pine in the Black Hills, Colorado Front Range, and Southwest." *U.S. Forest Service*, 2007. https://www.fs.fed.us/rm/pubs/rmrs_gtr198.pdf.
[585] Ibid.
[586] Stephens, Scott L., et al. "Drought, tree mortality, and wildfire in forests adapted to frequent fire." *Bioscience* 68.2 (2018): 77-88. https://www.fs.fed.us/psw/publications/fettig/psw_2018_fettig002_stephens.pdf.
[587] Perrakis, Daniel DB, et al. "Modeling wildfire spread in mountain pine beetle-affected forest stands, British Columbia, Canada." *Fire ecology* 10.2 (2014): 10-35 and Hoffman, Chad M., et al. "Modeling spatial and temporal dynamics of wind flow and potential fire behavior following a mountain pine beetle outbreak in a lodgepole pine forest." *Agricultural and Forest Meteorology* 204 (2015): 79-93, cited in Hunter et al. 2015.
[588] Stephens, Scott L., et al. "Drought, tree mortality, and wildfire in forests adapted to frequent fire." *Bioscience* 68.2 (2018): 77-88. https://www.fs.fed.us/psw/publications/fettig/psw_2018_fettig002_stephens.pdf.
[589] Omi, Philip N. "Theory and practice of wildland fuels management." *Current Forestry Reports* 1.2 (2015): 100-117, https://link.springer.com/content/pdf/10.1007%2Fs40725-015-0013-9.pdf.

significantly by vegetation type, with grasslands and mixed coniferous forest—landscape types common to Southern California—showing the greatest effect of fuel treatment. These landscape types are particularly subject to rapid fuel accumulation.[590]

While the landscape-scale dynamics of large wildfires are more difficult to predict, computer modeling studies have provided some insight into the benefits of vegetation management. A 2012 study from Cochrane et al. used a simulation methodology to reconstruct conditions underlying 14 actual U.S. wildfires and infer the impact of fuel treatments. This modeling indicated a complex relationship between wildfire and fuel treatment, in which fuel treatment activities within a landscape increase fire activity in some portions of the landscape (e.g., by allowing rapid spread through a grassy understory), while protecting other well-defined areas. This finding, the authors conclude, holds promise for the benefits of fuel treatment in providing strategic protection at the woodland-urban interface.[591] A 2010 simulation-based study from Ager et al. indicated similarly that strategic fuel reduction can reduce the impacts of wildfire at defined locations at the wildland-urban interface, but the authors advised to manage the buildup of fuels in surrounding wildlands that could lead to larger fires in the future.[592]

Conclusion

Overall, while the science of wildfire management is characterized by need for further research, the existing body of knowledge is sufficient to indicate that fuel reduction is effective and can be used strategically to reduce risk in key areas. Wildfire management in the context of mass tree mortality in particular is an area in need of further study. Natural gas systems could participate and benefit from fuel reduction efforts. Removed fuel (i.e., dead trees) can serve as a feedstock for the dead tree gasification into RNG assessed in Appendix E.

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[590] Martinson, Erik J., and Philip N. Omi. "Fuel treatments and fire severity: a meta-analysis." Res. Pap. RMRS-RP-103WWW. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 38 p. 103 (2013), https://www.fs.fed.us/rm/pubs/rmrs_rp103.pdf.

[591] Cochrane, M. A., et al. "Estimation of wildfire size and risk changes due to fuels treatments." *International Journal of Wildland Fire* 21.4 (2012): 357-367, http://www.publish.csiro.au/wf/pdf/WF11079.

[592] Ager, Alan A., Nicole M. Vaillant, and Mark A. Finney. "A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure." *Forest Ecology and Management* 259.8 (2010): 1556-1570, https://www.fs.fed.us/pnw/pubs/journals/pnw_2010_ager001.pdf.

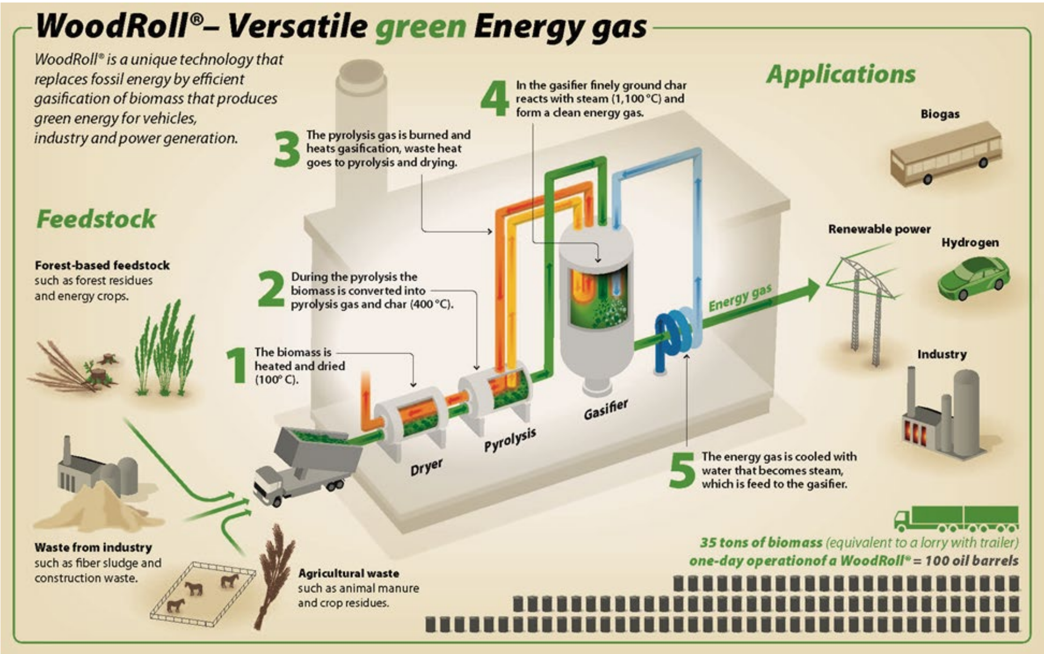
APPENDIX E

Renewable Natural Gas Potential from Gasifying Deceased Trees in California Forests

In the recent years, California has experienced high levels of tree mortality due to an extended drought and bark beetle epidemics. These dead trees act as fuel for wildfires, inhibit the reestablishment of productive forests, and create a public safety hazard.[593] The Southern Sierra Nevada region experienced a relatively larger tree die-off than the rest of California in 2015-2016, causing the declaration of a Tree Mortality State of Emergency.[594] One potential solution to reduce excess fuel is to utilize the deceased trees as feedstock for renewable natural gas (RNG) production.

To produce RNG, low moisture feedstocks such as forestry waste must be gasified via thermal gasification. Standing dead trees may have an advantage compared to typical forest fuels due to a much lower moisture content. Thermal gasification is a series of processes where carbon-containing feedstocks are converted into a mixture of gases known as syngas at high temperatures and varying pressures. Figure E1 shows a process diagram for gasification and applications of various biofuel feedstocks.

Figure E1. Thermal Gasification Process Map



The synthetic gas produced from gasification includes carbon monoxide, steam, carbon dioxide, methane, and trace amounts of other gases. To produce pipeline quality RNG, the syngas requires other processing such as methanation, conditioning, clean-up, and compression. Thermal gasification of woody biomass has only very recently been implemented on a commercial scale.[595]

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[593] The Beck Group. "Dead Tree Utilization Assessment." *Presentation,* 2017.
[594] State of California Executive Department. "Proclamation of a State of Emergency." 2015.
[595] California Energy Commission. 2017. Re-Assessment of Renewable Natural Gas. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=220203.

Gasification as a biomass conversion technology for wood waste

Utilizing wood waste for RNG offers a significant opportunity for generating low cost RNG. [596] Researchers recommend thermochemical conversion technologies for conversion of wood waste to RNG over biological or biochemical conversion technologies because they allow use of a variety of feedstocks, including wastewater solids, animal and agricultural wastes, and waste paper. Thermochemical conversions also use much shorter conversion processes. Thermochemical conversion technologies include gasification and direct combustion. Though direct combustion is more technologically simple, gasification is more efficient and cleaner than direct combustion. Furthermore, gasification eliminates 99% of criteria pollutants, can be easily scaled in accordance with a biomass collection radius, provides high biomass-to-fuel ratios, and can be stored when combined with synthesis technologies.

Though here we focus on the potential for transformation of biomass into syngas via gasification in this section, it stands to mention that steam reformation can also be used to create syngas from biomass waste. Pyrolysis gases created during biomass decomposition under high temperatures are transformed into syngas using catalytic steam in a catalytic reactor.[597] While steam reformation of methane is currently the most widely used method of hydrogen production, it requires capture and storage of greenhouse gases, while biomass gasification has the advantage of being a renewable energy resource. However, gasification for hydrogen production is limited by the logistics and costs of biomass collection and removal of tars to acceptable level for hydrogen production[598]

Estimate of Possible RNG Production

In this analysis quantitative estimation was undertaken of RNG production from gasification of deceased trees. The United States Department of Agriculture (USDA) recently reported that there are approximately 147 million dead trees in California since the most recent drought began in 2010.[599] An unpublished report from the U.S. Forest Service estimates standing dead tree volume of 102 million dead trees to equate to 178 million bone dry tons (BDT).[600] Using this ratio, the current estimate of 147 million dead trees in California will provide approximately 227 million BDT of dead trees.

To estimate the amount of possible RNG production from dead trees, specifications of the Mariposa Biomass Project (MBP) were used, which is currently under construction in Mariposa. MBP is specifically designed to use nearby forest waste as fuel for its state-of-the-art multi-stage gasification technology.[601] The plant will produce syngas that could be upgraded to RNG for injection into distribution pipelines. The Mariposa Biomass Project has a capacity to process 50

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[596] Gas Technology Institute. "Low-Carbon Renewable Natural Gas (RNG) From Wood Wastes." 2019. https://www.gti.energy/wp-content/uploads/2019/02/Low-Carbon-Renewable-Natural-Gas-RNG-from-Wood-Wastes-Final-Report-Feb2019.pdf.

[597] Akubo, Kaltume, Mohamad Anas Nahil, and Paul T. Williams. "Pyrolysis-Catalytic Steam Reforming of Agricultural Biomass Wastes and Biomass Components for Production of Hydrogen/Syngas." *Journal of the Energy Institute*, October 2018. https://doi.org/10.1016/j.joei.2018.10.013.

[598] Christos M. Kalamaras and Angelos M. Efstathiou. "Hydrogen Production Technologies: Current State and Future Developments." *Conference Papers in Energy*, vol. 2013, Article ID 690627, 2013. https://doi.org/10.1155/2013/690627.

[599] United States Department of Agriculture (USDA) Forest Service. "Press Release: Survey Finds 18 million Trees Died in California in 2018." *Press Release,* February 11, 2019. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/FSEPRD609321.pdf.

[600] The Beck Group. "Dead Tree Utilization Assessment." Presentation, 2017. .

[601] Simet, Amy. "Planned California biomass plant aims to use dead trees." *Biomass Magazine*, 2017. http://biomassmagazine.com/articles/14181/planned-california-biomass-plant-aims-to-use-dead-trees.

metric tons of biomass per day and is expected to produce 1.9 million cubic feet of syngas per day.[602] Using these specifications for gasification, California's dead trees could potentially produce almost 8 trillion cubic feet of syngas.

The Mariposa Biomass Project will utilize Cortus Energy's Woodroll technology (Figure E1), which integrates existing technologies including zero tars, a steam char gasifier, and an allotherm process.[603] The Woodroll process produces a syngas composed of 55-60% hydrogen and 25-30% carbon monoxide. This 2:1 ratio of hydrogen to carbon monoxide enables cost effective upgrading of syngas to biomethane.[604] The simplified CO-methanation reaction is:

$$CO + 3H_2 \leftrightarrow CH_4 + H_2O$$

Thus, hydrogen is the limiting reagent. Based on this chemical reaction and the estimated syngas production volume, **California's dead trees have the potential to produce almost 1.7 trillion cubic feet of RNG**. This is nearly double SoCalGas's total gas demand in 2018[605] and 80% of California's total natural gas consumption in 2017.[606]

While the potential is significant, **full utilization of dead trees for RNG production is improbable**. Critical barriers include:

- *Limited access* – There is limited or no access for large scale collection and transportation for large areas of dead trees.
- *Feedstock competition* – Wood waste is commonly used as fuel to produce electricity or steam.
- *Capacity constraints* – Thermal gasification technology required to generate biogas from forestry resources has only just begun to be implemented at commercial-scale. According to the University of California, Division of Agriculture and Natural Resources, there are currently only three operational biomass gasification plants in California and all are being used for electricity production.[607]

As thermal gasification technologies improve and become economically competitive, we may begin to see RNG production from dead trees.

Benefits of Dead Tree Gasification for RNG

Building on the conclusions of this report's Appendices, gasification of dead trees can provide several critical benefits for renewable energy development, air pollutant and GHG emission reduction, and wildfire risk reduction:

- *Wildfire risk reduction:* Fuel (i.e., dead trees) removal in target areas, particularly in woodland-urban interfaces, is currently accepted as best practice in reducing wildfire risk. Though dead

[602] GSTC (Global Syngas Technologies Council). "Mariposa Biomass Project." 2019. https://www.globalsyngas.org/resources/world-gasification-database/mariposa-biomass-project/.
[603] Cortus Energy. "Cortus Energy." Accessed October 8, 2019. http://www.cortus.se/technology.html.
[604] Bioenergy International. "Cortus Energy produces first RNG/SNG at Koping biomass gasification facility." *Bioenergy International,* June 8, 2018. https://bioenergyinternational.com/biogas/cortus-energy-produces-first-rngsng-koping-biomass-gasification-facility
[605] California Gas and Electric Utilities. "2018 California Gas Report." 2018. https://www.socalgas.com/regulatory/documents/cgr/2018_California_Gas_Report.pdf.
[606] U.S. Energy Information Administration. "Natural Gas Consumption by End Use." 2019. https://www.eia.gov/dnav/ng/NG_CONS_SUM_A_EPG0_VC0_MMCF_A.htm.
[607] University of California, Division of Agriculture and Natural Resources. "Woody Biomass Utilization Group." 2019. https://ucanr.edu/sites/WoodyBiomass/Project/California_Biomass_Power_Plants/.

trees can provide habitat and return nutrients to the soil, selectively thinning dense forests contributes to forest health and water resource management, and California's dry forests are in need of such active management.[608]

- *Renewable energy development*: California will need a diverse set of renewable fuel options to achieve its emission reduction goals. RNG can support both transportation fuel and electricity generation, and dead tree gasification can contribute to a portfolio of alternatives in RNG supply. For example, wood waste gasification has become an increasing source of RNG in the Netherlands to both reduce waste burdens and expand renewable energy production that can be utilized in existing power infrastructure.[609]
- *Air pollution and human health* – air quality impacts from wildfires potentially pose a greater threat to human health in California than all on-road emissions combined. Curtailing wildfire risks through dead tree removal for gasification could have significant health benefits.
- *GHG emission reduction* – a recent report by GTI found that woody biomass gasification had a carbon intensity of 16.8 gCO2e/MJ – an 82% reduction from conventional gasoline, and a 66% reduction from average bio-based CNG.[610] This carbon intensity number could be much lower (i.e., a net carbon sink) when considering the potential for wildfire GHG emission reduction, which we found as a significant source of recent GHG impacts to California.

These benefits should spur expanded investments into dead-tree removal for beneficial end use purposes. For example, PG&E's recent investments in dead-tree removal for biomass power generation could be expanded to a greater state-wide effort in both wildfire resilience and renewable energy generation.[611]

[608] Agee, James K., and Carl N. Skinner. 2005. "Basic Principles of Forest Fuel Reduction Treatments." *Forest Ecology and Management* 211 (1–2): 83–96. https://doi.org/10.1016/j.foreco.2005.01.034.
[609] Van Der Drift, B. "Biomass Gasification in the Netherlands." 2013. http://task33.ieabioenergy.com/download.php?file=files/file/country_reports/NL_July2013.pdf
[610] Gas Technology Institute. "Low-Carbon Renewable Natural Gas (RNG) From Wood Wastes." 2019. https://www.gti.energy/wp-content/uploads/2019/02/Low-Carbon-Renewable-Natural-Gas-RNG-from-Wood-Wastes-Final-Report-Feb2019.pdf.
[611] PG&E. "PG&E Hauling, Processing Dead Trees to Enhance Public Safety." 2017. https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20170503_pge_hauling_processing_dead_trees_to_enhance_public_safety