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SoCalGas Comments Draft IEPR

Additional submitted attachment is included below.

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California Energy Commission
Dockets Office, MS-4
1516 Ninth Street
Sacramento, CA 95814-5512

Subject: Comments on Draft 2019 Integrated Energy Policy Report, Docket # 19-IEPR-01

Dear Commissioners:

I write on behalf of Southern California Gas Company (SoCalGas) in response to the California Energy Commission's (CEC) Draft 2019 Integrated Energy Policy Report (Draft IEPR). SoCalGas appreciates the State's bold attempts to address climate change and wants to continue being a key partner to reduced greenhouse gas (GHG) emissions. SoCalGas believes that a portfolio approach, utilizing all energy sources and technologies to meet our climate goals, will best serve Californians and those that follow our lead. Natural gas and renewable gases (such as hydrogen, synthetic natural gas, and biomethane/renewable natural gas (RNG)) are clean, reliable, affordable, and resilient sources of energy that should be part of the *solution* to California's energy concerns.

The Draft 2019 IEPR is dismissive of natural gas, RNG, and hydrogen solutions offered by SoCalGas and other parties. CEC excludes these solutions as unrealistic in helping the State achieve its long-term climate goals. The CEC is overlooking the importance of providing reliable and resilient energy to the residents of California. Moreover, the Draft IEPR is 240 pages long, which necessitates greater review and discussion. Unfortunately, the less than three weeks allotted by the CEC and cancellation of the Draft IEPR Workshop (originally scheduled on October 24) does not provide the public adequate time to review and to develop comments on an important energy policy document that makes recommendations that could impact energy reliability, resilience, and affordability in the State.

Given the unduly restrictive time to comment, SoCalGas is focusing high-level comments on more significant areas of concern. What has recently become apparent in light of the substantially higher risk of climate-driven wildfires affecting thousands throughout the State, is that the CEC must consider how to maximize the resilience and operational flexibility benefits of the natural gas system to enhance the reliability and resiliency of the State's energy supply (e.g., fuel distributed generation systems, such as fuel cells to power microgrids). Instead of pursuing an all-electrification approach and strategizing how to eliminate the natural gas system, the CEC must explore how the benefits of the natural gas system can be maximized in a changing energy landscape.

In fact, the CEC is mandated by the Legislature to develop an IEPR that "shall present policy recommendations based on an *in-depth* and *integrated analysis* of *the most current and pressing energy issues facing the state*" (emphasis added).[1] As an initial matter, the "most current and pressing energy issues" for the State appear to be large scale blackouts and devastating wildfires and the affordability of housing, not the use of natural gas as part of a balanced energy portfolio. The CEC is also mandated by the Legislature in Assembly Bill (AB) 1257 (the Natural Gas Act), to "identify strategies to maximize the benefits obtained from natural gas, including biomethane."[2] Although the CEC did include a "report" on AB 1257 in the Draft IEPR as an appendix, the material presented does not come close to meeting the mandate to recommend forward-looking strategies and proposals for maximizing the beneficial use of natural gas and RNG.[3] The CEC is required under AB 1257 to maximize these strategies, not minimize nor casually dismiss them.

The CEC appears to turn a blind eye to significant evidence that demonstrates natural gas is essential to a reliable and affordable energy system. At the same time, the CEC ignores the obvious challenges the State is already facing if it restricts itself to a single-source energy system. Increasing incidences and magnitudes of wildfires and power outages are not accounted for in any meaningful way in the Draft IEPR, nor the studies it relies upon (either in terms of GHG emissions, damages costs, and loss of lives, nor the likely increase in electricity costs), in reaching conclusions to transition away from natural gas. These increasing trends are highly unlikely to change in the near-term IEPR cycles, and they should cause the CEC to avoid making recommendations that would cut off investment in natural gas and renewable gas solutions that could be critical to alleviating reliability and affordability challenges while moving toward a carbon-neutral future. The CEC must reverse course, truly consider the evidence before it, and plan based on a holistic view of the evidence rather than locking into a predetermined policy of electrification only.

SoCalGas' comments focus on the following sections of the Draft IEPR:

I. Chapter 9: Natural Gas Assessment
   a. *Recommendation to transition away from gas infrastructure is biased and unfounded*
II. Chapter 2: Building Decarbonization and Energy Efficiency
   a. *Dismisses RNG, hydrogen, and synthetic gas as viable building decarbonization strategies*
   b. *Methane leakage and indoor air quality concerns are unsupported and contradicted by the evidence*
III. Chapter 5: Climate Change Adaptation
   a. *The gas system is proven to significantly enhance local resiliency to climate impacts*

[1] California Energy Commission (CEC). Warren Alquist Act. 2019 Edition. At p. 24. Available at: https://ww2.energy.ca.gov/2019publications/CEC-140-2019-001/CEC-140-2019-001.pdf
[2] FindLaw. California Public Resource Code. Section 25303.5(b). Available at: https://codes.findlaw.com/ca/public-resources-code/prc-sect-25303-5.html
[3] SoCalGas AB 1257 Letter. November 15, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=230747&DocumentContentId=62358

b. *Microgrid examples do not demonstrate resiliency*
c. *Inconsistent with other statewide climate adaptation policymaking efforts*

IV. Chapter 6: Southern California Energy Reliability
a. *Safety is a priority in pipeline repairs*
b. *Aliso Canyon is essential to energy reliability*
c. *Southern California's reliability & price volatility challenges are not primarily due to pipeline outages and can be remedied by removing restrictions on Aliso Canyon*
d. *Winter 2019-2020 Assessment*

V. Chapter 3: Clean Transportation
a. *California needs natural gas and RNG for criteria pollutant reductions today*
b. *Low-NOx trucks and fuel cell electric vehicles should be part of the solution*

I. Chapter 9: Natural Gas Assessment

The CEC treats electrification as a foregone conclusion. A repeating theme in Chapter 9 is how California's fossil natural gas use and consumption will be affected by clean energy and decarbonization policies. However, the chapter fails to recognize how the natural gas system can be leveraged to be a solution by storing and transporting carbon-free fuels. The all-electrification strategy relies on flawed studies from pro-electrification groups notwithstanding, numerous other groups have presented evidence showing the importance of a diverse energy portfolio. Other State agencies recognize this and are pursuing policies accordingly. However, the Draft IEPR ignores the evidence that all-electrification is worse in terms of GHG emissions, reliability, resiliency, and affordability.

a. *Recommendations to transition away from gas infrastructure are biased and unfounded*

Moreover, the recommendation made in the Draft IEPR to "initiate an interagency strategic transition planning process to identify the short- and long-term natural gas needs as the state transitions to cleaner energy sources"[4] is not based on "in-depth and integrated" analysis as required, but rather on a foregone conclusion that the State should move toward an electric-only energy supply. The CEC must reverse course and assess alternative plans based on the comprehensive evidence rather than a predetermined policy of electrification. It would be ill-advised to decommission existing gas infrastructure that will ultimately be indispensable for storing, transmitting and distributing the renewable, non-fossil energy we need to support the reliability and resiliency of the state's future energy system. This is supported by a study developed by the Energy Futures Initiative (EFI), which analyzes the ways California can meet its aggressive 2030 low-carbon energy goals; and it outlines the innovation-focused agenda needed for mid-century deep decarbonization of existing buildings.[5] The report was led by EFI

[4] 2019 Draft IEPR, at p. 217
[5] Energy Futures Initiative. *Optionality, Flexibility, & Innovation. Pathways for Deep Decarbonization in California.* May 2019. Available at: https://tinyurl.com/tqdp47e

founder and Chief Executive Officer Ernest J. Moniz, former U.S. Secretary of Energy under President Barack Obama. The EFI report notes:

> …clean fuels (e.g. RNG, hydrogen, biofuels) are critical clean energy pathways due to the enormous value of fuels to flexible operations of energy systems. Fuels that are durable, storable, and easily transportable play a fundamental role in ensuring that all sectors can operate at the scale, timing, frequency, and levels of reliability that are required to meet social, economic and stakeholder needs.[6]

The EFI report emphasizes that achieving deep decarbonization and meeting GHG emissions reductions goals while managing costs will require technology optionality, flexibility, and innovation (i.e., there is no "silver bullet" technology or fuel to meet our climate goals). The CEC seemingly ignores the importance of developing a comprehensive portfolio of clean fuels and instead relies on policy to restrict the State to an electric-only future.

Troublingly, the purported support for this policy is biased assessments from political organizations, like Gridworks, that support the adoption of all-electric residential and commercial buildings. But the Gridwork's report, *California's Gas System in Transition,*[7] was not discussed nor presented during any IEPR workshops. Any publication referenced or used as the underpinning of such a stark policy recommendation that could impact energy affordability and reliability in the State must be thoroughly reviewed and vetted by a broad range of stakeholders. Moreover, the Gridworks report uses analysis conducted by Energy and Environmental Economics, Inc. (E3) that relies on skewed and technically unsound inputs and assumptions to conclude that a high building electrification scenario is the optimal strategy to meet California's mid-century goals.[8] SoCalGas[9] as well as other organizations, such as the Lawrence Livermore National Laboratory,[10] the Bioenergy Association of California,[11] and the California Hydrogen Business Council[12] have challenged the underpinnings and findings of E3's work. Further, Gridwork's report suggest exploring accelerated depreciation of gas assets to

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[6] *Ibid.*, at p. xix

[7] Gridworks. *California's Gas System in Transition, Equitable, Affordable, Decarbonized, and Smaller*. August 2019. Available at: https://gridworks.org/wp-content/uploads/2019/09/CA_Gas_System_in_Transition.pdf

[8] CEC. *Natural Gas Distribution in California's Low-Carbon Future: Technology Options, Customer Costs, and Public Health Benefits.* October 2019. Available at: https://ww2.energy.ca.gov/2019publications/CEC-500-2019-055/CEC-500-2019-055-D.pdf

[9] SoCalGas Comments on E3 Draft Results: Future of Natural Gas Distribution in California. June 21, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=228835&DocumentContentId=60170

[10] Lawrence Livermore National Laboratory. Comments on E3 Draft Results: Future of Natural Gas Distribution in California. June 21, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=228811&DocumentContentId=60143

[11] Bioenergy Association of California (BAC). Comments on E3 Draft Results: Future of Natural Gas Distribution in California. June 18, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=228817&DocumentContentId=60148

[12] California Hydrogen Business Council (CHBC). Comments on E3 Draft Report: Natural Gas Distribution in California's Low-Carbon Future. November 20, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=230810&DocumentContentId=62426

reduce future natural gas rates without evaluating how this will impact the relative cost of the electrification and renewable gas scenarios. In the near-term, this will increase the cost of natural gas service, but it will also impact the cost of electric service, which continues to rely on in-state natural gas generation for reliability. Artificially setting high natural gas and electric rates during a growing crisis in housing affordability and energy insecurity is counter-productive and will likely receive significant consumer push back. The CEC continues to ignore balanced energy viewpoints that support exploring how existing gas infrastructure is a solution that can be leveraged to meet climate goals and to address energy reliability and affordability, which are "the most current and pressing energy issues facing the State." The CEC has not approached this inquiry objectively and not evaluated all energy sources to comply with its statutory mandates; instead, the CEC is favoring a single-source energy system through all-electric buildings and making policy recommendations supporting the foregone conclusion of eliminating the natural gas system.

Further, the CEC's recommendations in this chapter ignore its sister agencies in understanding the benefits and solutions offered by natural gas, RNG, and hydrogen. Both the California Air Resources Board (CARB) and the California Public Utilities Commission (CPUC) have recognized the importance of these resources and are currently considering ways to further integrate RNG and hydrogen. For example, through its *Short-lived Climate Pollutant Reduction (SLCP) Strategy* and *Climate Change Scoping Plan Update*, CARB has set goals to reduce methane emissions and identified different approaches for "achieving success in clean energy," including "enabling cost-effective access to renewable gas."[13] To meet the goals of the SLCP Strategy, California must put waste resources—including organic sources of methane from sewage, landfills, dairies, and agriculture—towards beneficial uses. The CPUC just opened a fourth phase in the Biomethane Order Instituting Rulemaking (OIR) to address: (1) standards for injection of renewable hydrogen into gas pipelines, and (2) implementation of Senate Bill (SB) 1440 to consider adopting biomethane procurement targets or goals.[14] Further, the CPUC also recognizes that the natural gas system has been and continues to be crucial to energy reliability and resiliency. In connection with Integrated Resource Planning proposed reference system portfolio to achieve GHG emissions targets for 2030, the CPUC states that,

> …heavy emphasis on solar and battery storage in the selected portfolio may be of concern for several reasons... there is risk associated with the lack of diversification among the selected new resources, or putting all of California's eggs in a few baskets. Put simply, it is unknown whether there will be enough reliable energy resources to charge the large amount of storage so that it can discharge when needed to provide reliability services… While it is not quantified or necessarily quantifiable, there is certainly some value in resource diversity in resource planning, to manage risk.[15]

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[13] California Air Resources Board (CARB). *Climate Change Scoping Plan Update*. at p. ESs-11. November 2017. Available at: https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

[14] California Public Utilities Commission (CPUC). Assigned Commissioner's Scoping Memo and Ruling Opening Phase 4 of Rulemaking 13-02-008. November 11, 2019. Available at: http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M320/K307/320307147.PDF

[15] CPUC. Administrative Law Judge's Ruling Seeking Comment on Proposed Reference System Portfolio and Related Policy Actions. November 6, 2019. At p.22-23. Available at: http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M319/K132/319132053.PDF

The CEC ignores these contradictory assessments and actions focused on advancing low and zero-carbon fuels while purporting to coordinate with sister agencies on its transition strategy for the natural gas system. These assessments and actions, however, are critical in developing a comprehensive portfolio to meet the State's goals in a responsible and thoughtful manner.

Moreover, presenting overly optimistic assumptions about a single source all-electric pathway does not assist the State in addressing its concerns with energy reliability and affordability. An all-electric pathway would jeopardize meeting climate goals by overinvesting in one source to the exclusion of others during a critical juncture and may lead the State down a path that may not be reversible (e.g., Germany's experience[16]). The CEC should analyze how dependence on a single energy source (electricity) will increase risk for California's businesses and residents. For example, a recent CEC-sponsored study evaluated the Climate Adaptation risk in San Diego Gas & Electric Company's (SDG&E's) service territory from sea level rise. The study found a range of $300,000 to $25 billion risk based on substations in coastal regions that could be impacted by sea level rise and storm surges.[17] How would this risk change if all energy for traditional uses, transportation, and buildings relied solely on the electric grid? It is premature to determine a single-energy strategy before understanding the broader economic risks.

II. Chapter 2: Building Decarbonization and Energy Efficiency

a. Dismisses RNG, hydrogen, and synthetic gas as viable building decarbonization strategies

The Draft IEPR effectively dismisses as limited and costly the potential of RNG, blending hydrogen into the natural gas system, and synthetic gas, despite its own statement that, "[a]ll these options should be considered when looking at potential decarbonization of the natural gas system."[18] In addition to making these statements, the CEC should take action and conduct a scientifically sound assessment of RNG, hydrogen, and synthetic gas and include it in the IEPR

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[16] Germany embarked on an ambitious plan more than 15 years ago to shift away from fossil fuels and towards renewable energy resources. However, Germany is not on track to meet its GHG emissions reduction goals, which is a wake-up call for governments everywhere who should reconsider their energy policy strategies and re-assess the impact their policy decisions could have on energy reliability and the environment. Bloomberg. *Germany's Failed Climate Goals A Wake-Up Call for Governments Everywhere*. August 15, 3019. Available at: https://www.bloomberg.com/graphics/2018-germany-emissions/

[17] CEC. *Potential Climate Change Impacts and Adaptation Actions for Gas Assets in the San Diego Gas and Electric Company Service Area.* August 2018. Available at: https://www.energy.ca.gov/sites/default/files/2019-07/Energy_CCCA4-CEC-2018-009.pdf

[18] 2019 Draft IEPR, at p. 37

in a meaningful way. Despite SoCalGas'[19] and numerous comments from others[20,21,22] on the importance of the natural gas system, the Draft IEPR undervalues the benefits of using existing infrastructure to transport decarbonized fuels such as RNG, hydrogen, and synthetic gas. SoCalGas asks CEC staff to rectify this in the Final IEPR. Natural gas, RNG, hydrogen, synthetic gas, and the integral role of gas infrastructure to deliver these fuels will be needed to complement renewable energy in a decarbonized future in order to provide reliable and affordable energy.

At the very least, the IEPR should be consistent with the work of other state agencies consistent with the section above. For example, CARB's SLCP Strategy proposes the capture of biogas to be used as a transportation fuel, injected into gas pipelines, and used to generate on-site renewable electricity and heat. Further, CARB's 2017 Climate Change Scoping Order identifies strategies for Achieving Success in Clean Energy, including: "Reduce the use of heating fuels while concurrently making what is used cleaner by minimizing fugitive methane leaks, prioritizing natural gas efficiency and demand reduction, and enabling cost-effective access to renewable gas."[23] In contrast with these other State agencies, the Draft IEPR underestimates the availability of RNG and therefore dismisses it as a viable solution to reduce GHG emissions. This is despite prior comments from SoCalGas, the Bioenergy Association of California,[24] and numerous studies suggesting higher volumes of available feedstock, both in- and out-of-state.[25] The CEC must analyze and consider these important assessments and actions taken by other state

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[19] SoCalGas AB 1257 Letter. November 15, 2019. At Appendix A. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=230747&DocumentContentId=62358

[20] SoCalGas Comments. IEPR Joint Agency Workshop on Energy Efficiency and Building Decarbonization & *2019 California Energy Efficiency Action Plan Draft Staff Report*. At p. 2. September 24, 2019. Available at: https://tinyurl.com/yx7nv4yj

[21] The Natural Fuel Cell Research Center has made several comments in support of RNG and using all solutions to achieve climate goals, see: National Fuel Cell Research Center Comments - on Climate Adaptation TN-230076 Submitted 10/9/2019; National Fuel Cell Research Center Comments on Joint Agency Workshop April 8, 2019 TN-227836 Submitted 4/22/2019; and Dr. Jack Brouwer Comments - 2019 IEPR NFCRC Comments on Joint Agency Workshop (Docket 19-IEPR-06) TN-229844 Submitted 9/25/2019.

[22] The CHBC has made several comments in support of hydrogen and using existing infrastructure, see: CHBC Comments on August 27 Joint Agency Workshop on Energy Efficiency and Building Decarbonization TN-229840 Submitted 9/24/2019; California Hydrogen Business Council Comments on CEC's IEPR Workshop on Advancing Energy Equity TN-229397 Submitted 8/13/2019; California Hydrogen Business Council Comments - CHBC Comments on 2019 IEPR Near Zero Electricity Workshop TN-230262 Submitted 10/17/2019; and California Hydrogen Business Council Comments - CHBC Comments on 2019 IEPR Workshop on the Revised Natural Gas Price Forecast and Draft Outlook.

[23] CARB. California's 2017 Climate Change Scoping Plan Update, adopted November 2017. At ES-11. Available at: https://www.arb.ca.gov/cc/scopingplan/scoping_plan_2017.pdf

[24] BAC Comments. E3 Study and Presentation. June 21, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=228817&DocumentContentId=60148

[25] University of California Davis, Institute of Transportation Studies. *The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute*. At p.ix. June 2016. Available at: https://steps.ucdavis.edu/wp-content/uploads/2017/05/2016-UCD-ITS-RR-16-20.pdf

entities before locking into a single energy source future that fails to substantively address any different viewpoints.

On page 42, the Draft IEPR states, "… it is not clear that the state's 2045 GHG reduction goals are consistent with maintaining the current size and scale of its gas distribution systems."[26] It is equally unclear, however, how the electricity sector will achieve carbon neutrality by 2045. For example, at a CARB workshop on Deep Decarbonization studies, Professor Nate Lewis of California Institute of Technology noted that we can figure out how to get to 80% or 90% carbon neutral with the electric system, but, achieving 100% carbon neutrality will be a much bigger challenge.[27] SoCalGas asks CEC staff to remove this broad, unsupported pronouncement on whether maintaining the gas distribution system is consistent with climate goals; there has been no conclusive evidence showing either way, and no consideration of whether the electric system fares any better vis-à-vis climate goals and State policy concerns with reliability and affordability. A fair valuation of both energy systems' costs, reliability, and environmental benefits/risks needs to be conducted before making policy recommendations that favor one energy delivery system over another—or as SoCalGas and numerous others believe—a holistic solution that includes complementary portfolio of energy sources that is not solely reliant on a single source. Questions that remain to be answered include, what transmission and distribution investments will be required statewide to support increased electric loads if the State were to pursue an all-electric strategy, and at what cost and impact to the environment? Does the electric grid yield a GHG emissions reduction benefit when one takes into consideration impacts from wildfires, and construction of large-scale transmission and renewable energy generation facilities?

In addition, contrary to what the Draft IEPR states,[28] SoCalGas has "made a clear case for a realistic long-term pathway in which most or all retail customers will have a choice of safe, carbon-free gas for use in buildings" many times in previously submitted comments.[29] In March 2019, SoCalGas announced a bold plan to replace 20% of its traditional natural gas supply with RNG by 2030 as part of its vision to be the cleanest natural gas utility in North America.[30] What the CEC overlooks is that by using RNG, SoCalGas is actually removing harmful emissions from other hard-to-decarbonize sectors, such as agriculture and waste streams. This impact should not be understated. And in fact, making this switch can achieve GHG emissions

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[26] 2019 Draft IEPR, at p. 42

[27] CARB Public Workshop to Discuss Carbon Neutrality: Scenarios for Deep Decarbonization. California Institute of Technology Presentation. August 15, 2019. Available at: https://ww3.arb.ca.gov/cc/scopingplan/meetings/081519/caltech_cn_scenarios_aug2019.pdf

[28] 2019 Draft IEPR, at p. 42

[29] SoCalGas AB 1257 Letter. November 15, 2019. At Appendix A. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=230747&DocumentContentId=62358

[30] Sempra Energy. *SoCalGas Announces Vision to Be Cleanest Natural Gas Utility in North America.* March 6, 2019. Available at: https://tinyurl.com/rse95y2. SoCalGas is pursuing regulatory authority to implement a broad RNG procurement program with a goal of replacing 5% of its natural gas supply with RNG by 2022, and has requested that the CPUC allow SoCalGas to offer customers the options of purchasing a portion of their gas as RNG. CPUC. Application of SoCalGas and SDG&E for Renewable Gas Tariff. February 28, 2019. Available at: https://tinyurl.com/wtb5d5n

reductions equivalent to converting 100% of buildings to all-electric.[31] SoCalGas urges the CEC to remove the statement about a lack of solutions and instead include our commitment to a low-carbon future.

b. Methane leakage and indoor air quality concerns are unsupported and contradicted by the evidence

The Draft IEPR states, "[l]eakage and indoor air quality will remain nettlesome issues."[32] But this does not fairly contextualize the relatively minor impacts raised by these two issues, nor does it fairly evaluate their impact in comparison to the environmental impacts of the electric system. The CEC acknowledges methane leakage in the Western Region of the U.S. is only 5% of the national total. Further, it acknowledges that displacing natural gas with renewable gas will eliminate the production emissions, which are the largest source of emissions in the natural gas lifecycle.[33] Still, the CEC devotes a significant portion of its discussion on natural gas in this chapter to these upstream methane emissions and relies on this, in part, as support for its strategy to transition away from natural gas use.

One glaring flaw in the CEC's total-source analysis is that in evaluating the electric grid, the CEC fails to consider the carbon emissions associated with wildfires caused by the electric grid. These wildfires are estimated to have produced over 10% of the State's GHG emissions in 2019[34]—contributing more than the commercial, residential, and agriculture sectors did in 2017. If the CEC is going to weigh the indirect impact of the natural gas system on GHG emissions, then it must also weigh the indirect impacts from the electric grid. This inequity in the evaluation of the GHG emissions reduction potential of different building decarbonization strategies provides a false comparison of these two strategies.

Even more baffling is the CEC's recommendation on assessing the co-benefits of building decarbonization such as indoor air quality,[35] which improperly characterizes methane emissions as a contributor to poor ambient air quality.[36] The CEC cites a May 2018 article by the World Health Organization (WHO) and a study by the U.S. Environmental Protection Agency (EPA) as evidence of the health impacts of natural gas – but neither provide any support for the CEC's conclusions, and in fact completely undermine them.

The WHO article provides no support for the CEC's position, rather it discusses the health impacts of global ambient air quality. First, the IEPR citation suggests a linkage between air quality and methane leakage. But methane is not a significant contributor to poor air quality, rather it is the emissions from food being cooked, and not from burner or heat source operations,

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[31] Navigant Consulting, Inc. *Analysis of the Role of Gas for a Low-Carbon Future.* July 24, 2018. Available at: https://www.socalgas.com/1443741887279/SoCalGas_Renewable_Gas_Final-Report.pdf
[32] 2019 Draft IEPR, at p. 42
[33] *Id.*, at p. 41
[34] CARB. *California Wildfire Burn Acreage and Preliminary Emissions Estimates.* Available at: https://ww3.arb.ca.gov/cc/inventory/pubs/ca_wildfire_co2_emissions_estimates.pdf
[35] 2019 Draft IEPR, at p. 58
[36] *Id.*, at p. 42

that represent the chief source of concern with respect to indoor air quality.[37] SoCalGas previously submitted comments clarifying this common misperception advanced by electrification advocates regarding natural gas appliances and indoor air quality:[38] all heat sources create indoor air quality during cooking,[39] and it is the emissions from the food being cooked, and not from burner or heat source operations, that represent the chief source of concern with respect to indoor air quality.[40] If CEC is truly considering adopting metrics related to indoor air quality, these metrics must be based on sound scientific research and applied equally to electric cooking and gas cooking.

In Southern California, the primary sources of poor ambient air quality are from the transportation sector.[41] Second, the article does not suggest that indoor air quality concerns related to natural gas present a significant health burden. It notes, "[i]n addition to outdoor air pollution, indoor smoke is a serious health risk for some 3 billion people *who cook and heat their homes with biomass, kerosene fuels and coal*" (emphasis added).[42] Further, the only reference to methane emissions in the WHO article is the recommendation regarding the "capture of methane gas emitted from waste sites as an alternative to incineration (for use as biogas)."[43] Thus, the WHO article is actually calling for generating biogas – *exactly what SoCalGas wants to do, what CARB recommends through its SLCP Strategy, and what the CEC says is unrealistic.* The CEC's recommendations would in fact foreclose what WHO recommends – based on an apparently mistaken reading of the WHO's conclusions.

Similarly in relation to the EPA study, the Draft IEPR conflates emissions from oil production with emissions from natural gas production. In many of the regions where the health impacts are significant, natural gas is often a byproduct of oil production. In fact, EPA notes that its projection of oil and gas production in 2025 will be sensitive to the price of oil.[44] By looking at a combined oil and gas study, the CEC implies a greater health impact from natural gas production and use than is merited by this study.

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[37] CARB. *Residential Cook Exposure Study Final Report.* January 2006. Retrieved from https://www.arb.ca.gov/research/indoor/cooking/cooking.htm

[38] SoCalGas Comments on Joint Agency Workshop on Building Decarbonization. April 22, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=227834&DocumentContentId=59209

[39] Nasim Mullen et al. "Impact of Natural Gas Appliances on Pollutant Levels in California Homes" Lawrence Berkeley National Laboratory, 2012. Available at: https://indoor.lbl.gov/sites/all/files/impact_of_natural_gas_appliances.pdf

[40] CEC. *Emissions, Indoor Air Quality Impacts, and Mitigation of Air Pollutants from Natural Gas Appliances.* October 2017. Retrieved from http://www.energy.ca.gov/2017publications/CEC-500-2017-034/CEC-500-2017-034.pdf

[41] Over 90% of NOx emissions, which is a precursor to ozone and PM, are from the transportation sector.

[42] World Health Organization. Air Pollution. Key Facts. May 2, 2019. Available at: https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

[43] *Ibid.*

[44] U.S. Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards. *Assessing Human Health and Ozone Impacts from US Oil and Natural Gas Sector Emissions in 2025.* July 13, 2018. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6718951/

III. Chapter 5: Climate Change Adaptation

The ability to continue energy operations unaffected by climate events, such as wildfires, and to quickly resume service is a significant factor. Natural gas performs highly in this regard.[45,46] It is of utmost importance that the CEC considers how to maximize the resilience and operational flexibility benefits of the natural gas system to enhance the reliability and resiliency of the State's energy supply (e.g., fuel distributed generation systems such as fuel cells to power microgrids). The importance of these technologies will grow in the coming years as climate impacts become more severe and frequent. For this reason, other State agencies, and the CEC itself, have recognized the importance of the natural gas grid to climate adaptation and supported it accordingly. By contrast, the Draft IEPR downplays the importance of natural gas and instead touts electric technologies that are of limited utility, unproven, or even non-existent. The Final IEPR must rectify this shortcoming.

Relatedly, the CEC must consider the evidence before it. SoCalGas has submitted comments regarding climate adaptation and resiliency in response to the Draft 2018 IEPR Update Volume II[47] and the 2019 IEPR Workshop on Climate Adaptation and Resiliency in the Energy Sector[48] which have not been addressed in the Draft IEPR. SoCalGas asks the CEC to re-review these comments as they provide clear, factual information about how the natural gas system is interdependent with the electric system, supports energy system reliability, is resilient because it is underground, and supports community resilience in the face of climate-driven natural disasters. Please also see Appendix A, ICF International, Inc.'s 2019 study analyzing natural gas sector resilience.

a. The gas system is proven to significantly enhance local resiliency to climate impacts

Gas technologies, such as fuel cells and combined heat and power (CHP) systems, can provide needed backup energy more reliably and effectively than the electric grid during and after natural disasters.[49] This, in turn, contributes to overall local community resilience. For example, during the Woolsey Fire, a citizen unable to evacuate used a backup generator connected to the gas system to power her medical devices for several days while the electricity was down.[50] The Draft IEPR recommends that "…the State must pursue 'reach' technologies that are not yet proven."[51] Rather than pursuing non-existent technologies, the CEC should be

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[45] Natural Gas Council. *Natural Gas Systems: Reliable and Resilient*. July 2017. Available at: https://tinyurl.com/y7ffswse

[46] Natural Gas Council. *Report: Weather Resilience in the Natural Gas Industry.* August 6, 2018. Available at: www.naturalgascouncil.org/weather-resilience-in-the-natural-gas-industry/

[47] SoCalGas. Comments on the Draft 2018 IEPR Update Volume II. November 2, 2018. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=225796&DocumentContentId=56469

[48] SoCalGas. Comments in response to 2019 IEPR Workshop on Climate Adaptation and Resiliency in the Energy Sector. August 23, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=229515&DocumentContentId=60926

[49] ICF International, Inc. *Case Studies of Natural Gas Sector Resilience*. September 2019. See Appendix A.

[50] *Ibid.*

[51] Draft IEPR, at p. 134

supporting existing and emerging technologies with proven track records. Gas technologies have just such a record in enhancing local climate adaptation efforts.

b. Microgrid examples do not demonstrate resiliency

The need for resilient backup energy storage has become critical because of the substantially higher risk of climate-driven wildfires affecting thousands of residences and businesses throughout the State. To mitigate this risk and keep communities safe, electric utilities are increasing the number of Public Safety Power Shutoff (PSPS) events. These events leave residents stranded without power for days to weeks at a time, which creates additional risk for critical facilities, individuals on life-saving medical equipment, and low-income communities that may feel a disproportionate impact as they lack financial resources to leave the area or to have backup power. Although the Draft IEPR includes several examples of microgrid projects that can operate during outages, these examples feature battery systems that only provide a few hours of backup power. Given that the IEPR also explains that current power outages, planned or climate-caused, are leaving residents without power for *days at a time*, these examples do not address the need for energy sources that can withstand longer outages, such as fuel cells and CHP systems. The Final IEPR should rectify this.

Additionally, the Draft IEPR does not discuss the benefits of hydrogen as supplemental and backup power source. With the higher frequency of PSPSs, many customers have turned to diesel backup generators, which pose significant health risks. Hydrogen-fueled generators are a zero-emission option that can be used to supplement the grid and should be highlighted in the Final IEPR.

c. Inconsistent with other statewide climate adaptation policymaking efforts

The Draft IEPR's failure to include a discussion of the resiliency of the natural gas system is inconsistent with current statewide climate adaptation policy-making efforts, including at the CEC. Other State agencies, and the CEC itself, recognize the importance of the natural gas system to climate adaptation. For example, the CEC has funded technical reports and studies evaluating gas system resiliency that were used in the Statewide Fourth Climate Assessment, which found the system to be resilient to a majority of climate impacts.[52] Additionally, data from CEC-funded studies is currently being leveraged and integrated into climate adaptation planning efforts by local and regional planning entities. The CEC is also currently awarding millions in grant funding for projects demonstrating natural gas sector resilience.[53]

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[52] CEC. *Potential Climate Change Impacts and Adaptation Actions for Gas Assets in the San Diego Gas and Electric Company Service Area.* August 2018. Available at: https://www.energy.ca.gov/sites/default/files/2019-07/Energy_CCCA4-CEC-2018-009.pdf

[53] CEC. Natural Gas Sector Climate Resilience Request for Comments on Draft Solicitation. September 2019. Available at: https://www.energy.ca.gov/sites/default/files/2019-09/2019-09-30_Presentation_Webinar.pdf

Similarly, the CPUC has an Adaptation Rulemaking proceeding (R.18-04-019)[54] open to develop guidance on climate adaptation strategies and investment for *both electric and gas* investor-owned utilities (mentioned in Draft IEPR, at p. 108). SoCalGas is an active and contributing participant in the proceeding. As both the CEC and the CPUC are currently engaging in adaptation research and policymaking that includes analysis of the gas system, the Final IERP should include discussion of the resiliency of the gas system so as to not engender incompatible policy solutions.

In addition to adding text to the Final IEPR about the resilience of the gas system and how it supports community resilience, SoCalGas recommends CEC staff change the subtitle "Implications of Climate Change on California's Transition to a Carbon Neutral *Electricity* System" on page 115 to "Implications of Climate Change on California's Transition to a Carbon Neutral *Energy* System" so as not dismiss the value of the gas system. Specifically, to make sure there is consistency across policymaking entities, the Final IEPR should include discussion of the importance of flexible energy sources, like the gas system, and how it can be leveraged to support both the electric system and other renewable technologies, overall enhancing the reliability of the energy system as a whole.

The threat of wildfires is expected to increase and become more severe; in the face of increased climate risk, communities must have reliable and resilient energy infrastructure. The CEC should support policies that advance gas- and hydrogen-powered fuel cell technologies and other diverse distributed energy solutions to keep communities energy resilient. It is of the utmost importance that the CEC consider how to maximize the resilience and operational flexibility benefits of the natural gas system to enhance the reliability and resiliency of the State's energy supply, and such consideration should be clearly included in the Final IEPR.

II. Chapter 6: Southern California Energy Reliability

The CEC's discussion of energy reliability in Southern California overstates issues facing the natural gas system while downplaying the problems facing the electric grid. And the Draft IEPR improperly recommends shutting down Aliso Canyon, which would increase reliability problems: while an obvious solution to reliability issues would be to do the opposite: increase supply by removing restrictions on Aliso Canyon.

a. Safety is a priority in pipeline repairs

The CEC recommends that SoCalGas be required to expedite repair of natural gas pipelines to full operating service.[55] SoCalGas repairs natural gas pipelines as quickly as possible and in a safe manner, and there is no justification for a gratuitous recommendation in this regard. Safety is at the foundation of SoCalGas' business. It is prudent for SoCalGas to validate the integrity of its pipelines and complete remediation measures. When outages or pressure reductions occur, SoCalGas works expeditiously to safely bring lines back into service. Our crews often work in

[54] CPUC. Order Instituting Rulemaking to Consider Strategies and Guidance for Climate Change Adaptation, Rulemaking 18-04-019. May 7, 2018. Available at: http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M213/K511/213511543.PDF

[55] 2019 Draft IEPR, at p. 160

parallel on multiple sections of a line(s), and additional resources are added to expedite this process when it can be accomplished in a safe and efficient manner. While completion timelines are prepared based upon experience, sound construction practices, and the safety of employees and contractors, they are often influenced by factors outside SoCalGas' control – such as permitting delays, extreme weather, and unanticipated conditions encountered during excavation and repair operations. Advances in pipeline integrity technology also impact the time involved in safely assessing, remediating, and returning a pipeline to service. Further information regarding the challenges of Line 235-2 remediation were provided in SoCalGas' comments in response to the June 6, 2019 workshop on energy reliability.[56]

SoCalGas disagrees with the Draft IEPR's unsubstantiated assertion that Line 235-2 may be reaching the end of its useful life because "these types of pipelines have a useful life of around 70 to 75 years."[57] SoCalGas is not aware of any research that concludes the useful life of pipelines is 70-75 years, and requests that the CEC provide this study to support such a conclusion.

b. Aliso Canyon is essential to energy reliability

SoCalGas disagrees with the CEC's continued recommendation to develop a long-term strategy to close Aliso Canyon and asks that this be excluded from the Final IEPR for the following reasons. The CEC's recommendation is directly contrary to the findings of an independent study commissioned by multiple State agencies that found underground gas storage, including Aliso Canyon, is critical to energy reliability and resilience. In response to Governor Brown's January 2016 State of Emergency proclamation regarding the Aliso Canyon gas leak, the State sought more information about all currently operating underground natural gas storage fields in California. The CPUC, in consultation with the State Energy Resources Conservation and Development Commission, CARB, and the Division of Oil, Gas, and Geothermal Resources (DOGGR) within the California Department of Conservation commissioned the California Council on Science and Technology (CCST) to conduct an independent, scientific assessment.[58] As a result, the CCST developed a technical report on the *Long-Term Viability of Underground Natural Gas Storage in California* (CCST Study), which found:

- "The overarching reason for the utilities' underground gas storage is to meet the winter demand for gas."[59]
- "Gas storage could increasingly be called on to provide gas and electric reliability during emergencies caused by extreme weather and wildfires in and beyond California. Both

[56] SoCalGas Comments Joint Agency Workshop on Southern California Energy Reliability. June 6, 2019. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=228704&DocumentContentId=59958
[57] Draft 2019 IEPR, at p. 141
[58] California Council on Science and Technology (CCST) is a nonpartisan, nonprofit organization that responds to the Governor, the Legislature, and other state entities who request independent and impartial assessments of public policy issues affecting the State of California.
[59] CCST. Technical Report on *Long-Term Viability of Underground Natural Gas Storage in California*. At p. 511. January 18, 2018. Available at https://tinyurl.com/y9xwzdb8

extreme weather and wildfire conditions are expected to increase with climate change. These emergencies can threaten supply when demand simultaneously increases."[60]

- "Underground gas storage protects California from outages caused by extreme events, notably extreme cold weather that can drastically reduce out-of-state supplies."[61]
- "Nearly every winter has a month with average daily demand that exceeds, or nearly exceeds, pipeline take-away capacity."[62]

Given this, the CEC's recommendation to close Aliso Canyon is not based on sound evidence and shows the CEC's bias towards eliminating the natural gas system. In addition, the CPUC's Winter Assessment concludes that the "SoCalGas system could not support 1-in-10 peak demand in any month, under any scenario, without using Aliso Canyon and/or resorting to curtailments."[63] As such, the CEC's approach cannot ignore and instead must address the potential reliability and economic impacts of closing Aliso Canyon – including the extreme potential impacts of an unreliable or un-resilient system, including customer curtailments – compared to the impact of continuing to operate Aliso Canyon – a facility that the CPUC and the DOGGR formally determined is safe to operate following a comprehensive safety review in 2017.[64]

Additionally, DOGGR's new underground gas storage regulation require operators to take facilities out-of-service for maintenance more frequently, which makes Aliso Canyon's supply all the more important for reliability. For example, these regulations require a high and low shut-in test each year, which will result in each storage facility being entirely out-of-service for approximately one week, twice a year.[65] Further, new well mechanical integrity testing requirements will have wells out-of-service as frequently as every 24 months for testing.[66] As a result, it should be planned that a percentage of a facilities' wells will be out-of-service for some period annually to comply with this ongoing testing, and ultimately increasing the incidence of planned outages in the future when compared to the past. Aliso Canyon provides significant additional system resiliency. Without it, the impacts of these new regulations on system operations will be even more significant.

Moreover, the CPUC is already examining the future of Aliso Canyon through the proceeding it opened pursuant to Senate Bill (SB) 380 (I.17-02-002). In reaching a final determination in that proceeding, SB 380 (Chapter 14, Statutes 2016) requires that multiple

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[60] *Id.*, at p. 506
[61] *Ibid.*
[62] *Id.*, at p. 496
[63] Winter 2019-20 Southern California Reliability Assessment. October 24, 2019. Available at: https://tinyurl.com/wfjo4ny
[64] See, e.g., SB 380 Findings and Concurrence Regarding the Safety of the Aliso Canyon Gas Storage Facility. July 19, 2017. Available at: http://www.cpuc.ca.gov/uploadedFiles/CPUC_Public_Website/Content/News_Room/News_and_Updates/OpenLettertoSoCalGasandPublic.pdf.
[65] See 14 California Code of Regulations Section 1726.7 (Monitoring Requirements). Available at: https://tinyurl.com/snv6ss6
[66] See 14 California Code of Regulations Section 1726.6 (Mechanical Integrity Testing). Available at: https://tinyurl.com/rrfjt5s

stakeholders and "relevant government entities" must be consulted. SoCalGas requests that the appropriate regulatory process be permitted to be completed before the CEC makes any presumptive recommendations regarding Aliso Canyon.

c. Southern California's reliability & price volatility challenges are not primarily due to pipeline outages and can be remedied by removing restrictions on Aliso Canyon

The Draft IEPR mis-diagnoses the causes of price volatility and outages in Southern California, and ignores the clearest solution—removing restrictions on Aliso Canyon. The CEC identifies pipeline outages as the most critical concern affecting energy reliability, and attributes the SoCalGas Citygate price volatility to pipeline outages.[67] This oversimplifies a complex issue and overemphasizes the pipeline outages and reductions as a constraint on supply, as SoCalGas explained in comments in response to the Workshop on Southern California Natural Gas Prices.[68] The CPUC recently recognized this very situation in deciding to loosen restrictions on Aliso Canyon withdrawals:

> The current Withdrawal Protocol, combined with the increased scarcity of gas supply caused by both pipeline outages and the operational restrictions on Aliso Canyon, has strained the overall natural gas infrastructure in Southern California and has led to the curtailment of gas supplies to electric generators.[69]

The most straightforward and immediate solution to address system supply limitations and restrictions is to increase supply by removing restrictions on the use of Aliso Canyon**.**

Moreover, in assessing energy reliability in Southern California, the Draft IEPR ignores the reliability concerns from the electric grid, and only briefly mentions the Saddleridge Fire (Draft IEPR, p.139). In recent months high-risk fire conditions prompted electric utilities to cut service for many residents. The CEC should further evaluate the impact of wildfires and power shutoffs on electric reliability. SoCalGas agrees with the CCST report that underground natural gas storage could increasingly be called upon to provide natural gas and electric reliability during emergencies caused by extreme weather and wildfires, which is expected to increase.[70]

d. Winter 2019-2020 Assessment

SoCalGas agrees with the CEC's winter 2019-2020 season gas balance analysis findings: the reliability outlook has improved over prior years, core reliability is not projected to be at risk, and the risk of noncore curtailment is diminished with the return to service of Line 235-2 and

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[67] 2019 Draft IEPR, at p. 146

[68] SoCalGas Comments on Joint Workshop on SoCal Natural Gas Prices. January 25, 2019. Available at: https://tinyurl.com/r8xcy5y

[69]CPUC. Proposed Revisions to the Aliso Canyon Withdrawal Protocol. July 1, 2019. Available at: https://www.cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/News_Room/NewsUpdates/2019/AlisoCanyonWithdrawalProtocol-ProposedRevisionsAndDraft-2019-07-01.pdf

[70] CCST. *Long-Term Viability of Underground Natural Gas Storage in California*. At p. 506 (Conclusion 2.5). January 18, 2018. Available at https://tinyurl.com/y9xwzdb8

Line 4000, even at reduced operating pressures. However, the CEC (and the CPUC) concludes that "in the best-case scenario with both lines in service and average weather, the gas balance shows sufficient inventory to meet demand and no curtailments."[71] A review of the CEC's gas balance analysis shows this statement to also be valid even under a cold weather assumption. SoCalGas disagrees with the CEC's cold weather conclusion.

The CEC's conclusion is flawed since it is based upon receiving a volume of interstate pipeline supplies equal to 100% utilization of the SoCalGas receipt capacity for the majority of the winter season. As SoCalGas has commented in the past: this is highly unrealistic and not consistent with historical trends.[72] It is not reasonable to assume that SoCalGas customers and shippers will deliver supply at this high level through the coldest period of the winter season. SoCalGas' gas balance analysis used the assumption that *on average* customers would deliver 85% of the system receipt capacity through the winter season, based on an analysis of *historic* delivery patterns. With that assumption, SoCalGas finds that noncore curtailment may be required in January and February *even with both Line 235-2 and Line 4000 in service at reduced operating pressures* if the weather turns cold.

To be clear, SoCalGas is *not* predicting that noncore curtailment will occur. Rather, it is presenting the possibility that noncore curtailment may be required, in contrast to the CEC's overly optimistic analysis which negates even the possibility of that occurring. This should be clarified in the Final IEPR.

III. Chapter 3: Clean Transportation

California has aggressive emissions reduction goals for the transportation sector and should consider all technologies to meet these goals. However, the Draft IEPR focuses solely on plug-in battery electric technologies. This will be insufficient to meet the State's near-term climate goals. Indeed, CARB—the agency tasked with focusing on air-quality issues—concludes that "…the best path forward is to emphasize parallel strategies for reducing SLCP and CO_2 emissions."[73] In contrast, the CEC ignores an alternative fuel solution, particularly for heavy-duty trucks, that would reduce GHG emissions more rapidly. Specifically, the CEC needs to consider and highlight RNG and hydrogen in the Final IEPR to help meet our goals.

a. California needs natural gas and RNG for criteria pollutant reductions today

California has long-term GHG emission reduction goals as well as near-term criteria pollutant goals as outlined in Table 4: GHG, Fuel, and Air Quality Goals and Milestones.[74] The table

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[71] Draft IEPR, at p. 152

[72] SoCalGas Comments. 2018 IEPR Update. Joint Agency Workshop on Energy Reliability in Southern California. At p. 3. May 22, 2018. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=223536&DocumentContentId=53610

[73] CARB. Final SLCP Reduction Strategy. At p. 19. March 2017. Available at: https://ww2.arb.ca.gov/resources/documents/final-short-lived-climate-pollutant-reduction-strategy-march-2017

[74] 2019 Draft IEPR, at p. 63

notes that the Clean Air Act and the California State Implementation Plans require an 80% reduction of nitrogen oxides (NOx) by 2031. While this is accurate, it leaves out the near-term requirements for air basins in nonattainment areas, namely, in the South Coast Air Basin and the San Joaquin Valley which must meet attainment for ozone by 2023 and for particulate matter 2.5 microns or less (PM 2.5) by 2024, respectively. To meet attainment, the regional air pollution control agencies in these areas have developed plans[75] that rely heavily on the turnover of the heavy-duty trucks to low-NOx or near-zero emission trucks that meet or exceed CARB's Optional Low NOx standard of 0.02 grams of NOx per brake horsepower hour.[76,77]

The CEC should not dismiss this strategy—without even addressing the evidence or potential environmental impact—and instead should follow CARB's recommendation "to emphasize parallel strategies for reducing SLCP and CO_2 emissions."[78]

b. Low-NOx trucks and fuel cell electric vehicles should be part of the solution

SoCalGas askes the CEC not to overlook the immediate clean air benefits of using natural gas, RNG, and hydrogen as a low emission/zero-emission fuels for the transportation sector in the Final IEPR. The only commercially available technology to meet CARB's standard is the Cummins Westport low-NOx engines powered by natural gas. Without immediate deployment of low-NOx engines in the heavy-duty truck sector, the State and regions will not meet attainment, which could result in the loss of federal transportation funds and a loss of local control to meet attainment. Additionally, fuel cell electric vehicles of all classes should be considered as the State looks towards advancements and full adoption of zero-emission transportation.

As noted in the Draft IEPR, "…despite the state's overall reduction in GHG emissions, emissions from the transportation sector have increased by roughly 6 percent from 2013 (the lowest point since 2000) through 2017..."[79] When low-NOx engines are paired with RNG, significant GHG emissions reductions can be achieved. The average carbon intensity of

[75] South Coast Air Quality Management District (SCAQMD) developed its 2016 Air Quality Management Plan and the San Joaquin Valley Air Pollution Control District (SJVAPCD) developed its 2018 Supplement to the State Implementation Plan.

[76] "The incentive programs will place the highest priority on on-road vehicles that meet the cleanest optional NOx emission standard and provide their service to the above facilities in the region and have gross vehicle weight ratings of 26,001 pounds or greater." SCAQMD. Final 2016 Air Quality Management Plan. Appendix IV-A MOB-08: ACCELERATED RETIREMENT OF OLDER ON-ROAD HEAVY-DUTY VEHICLES. At p. 157. Available at: https://tinyurl.com/y5htfcat.

[77] SJVAPCD. *San Joaquin Valley Supplement to the 2016 State Strategy for the State Implementation Plan*. Measure: Accelerated Turnover of Trucks and Buses. At p. 22. October 25, 2018. Available at: https://tinyurl.com/y2rkzwsm

[78] CARB. Final SLCP Reduction Strategy. At p. 19. March 2017. Available at: https://ww2.arb.ca.gov/resources/documents/final-short-lived-climate-pollutant-reduction-strategy-march-2017

[79] 2019 Draft IEPR, at p. 62

renewable gas is 60-80% percent lower than diesel. Based on the source, RNG can have a carbon intensity up to 400% percent lower than diesel, and can even be carbon negative.[80]

In addition to RNG, hydrogen as a transportation fuel can help the State to reach its climate and air quality goals. Similar to plug-in battery electric, hydrogen fuel cell electric vehicles are solutions to reduce tailpipe emissions for light- and heavy-duty, and material handling vehicles.[81] Unlike plug-in battery electric vehicles, fuel cell electric vehicles have the capability to refuel quickly, drive long distances, and carry heavy loads. The CEC, through the IEPR, should support the deployment of fuel cell electric vehicles and hydrogen production to meet the requirements of Executive Order B-48-18.

In sum, SoCalGas recommends the Clean Transportation chapter assess potential deployment strategies of all technologies and identify multiple, complementary technology pathways to meet the goals.

Conclusion

The Draft IEPR is flawed in a number of respects, which are all seemingly driven by the goal to lock the state into a single-energy source future of electrification. This approach is shortsighted and not driven by evidence and the State's changing needs. California currently faces many energy challenges: climate-related weather events, electricity-related wildfires, affordability, poor air-quality, and important GHG emissions targets. These difficulties are surmountable, but only if the State has thoughtful and evidence-based energy policy. California is ill-served, however, by an IEPR that pursues pre-ordained conclusions in the face of contrary evidence. Accordingly, the CEC must adequately consider the evidence it has before it, take time to allow for public input, and make appropriate recommendations.

Specifically, the CEC must address the issues that SoCalGas has identified. Most significantly, the Final IEPR should not include sweeping recommendations to transition away from the use of gas infrastructure. This policy, which appears to be based on the recommendations of pro-electricity groups that have not been sufficiently vetted, would stifle California's ability to meet its climate goals in the long-term, weaken the resilience of the energy system, create the risk of additional electricity-related disasters, and exacerbate affordability issues. Instead, the Final IEPR should acknowledge the benefits of natural gas, RNG, hydrogen, and synthetic gas and explore the role they should play in a low-carbon future. Similarly, the CEC should work to build off of the contributions of gas infrastructure in providing reliable

[80] CARB recently awarded the company, AMP Americas, the lowest ever carbon intensity score of -254.94 gCO_2e/MJ. For comparison, the California electric grid has an energy efficiency ratio corrected carbon intensity value of approximately 20 gCO_2e/MJ.

[81] Status of hydrogen fuel cell electric vehicles: Toyota, Honda, and Hyundai are currently manufacturing several light-duty fuel cell electric vehicles and Audi is also developed an fuel cell electric vehicle. Nikola Motors recently has begun production of a Class 8 fuel cell truck. They also plan to build a vast network of 700 heavy-duty truck stop-size hydrogen fueling stations across the U.S. and Canada by 2028. Toyota is currently demonstrating Class 8 fuel cell trucks powered by the same fuel cell technology used in its light-duty model the Mirai. Kenworth is deploying 10 zero-emissions heavy-duty trucks using Toyota's hydrogen fuel cell electric powertrains to be used at the Port of Los Angeles, throughout the Southern California and Central Coast areas, and in Merced County.

energy during climate driven natural disasters to improve energy resiliency in the State. And it should address energy reliability in Southern California accurately and it should support policies that increase rather than decrease energy reliability. Finally, in order to meet California's air quality and climate goals, the CEC must support the use of low and zero-carbon fuels in the transportation sector.

Sincerely,

George Minter
Regional Vice President, External Affairs & Environmental Strategy
Southern California Gas Company

Encl.

APPENDIX A:
Expanded Case Studies of Natural Gas Sector Resilience

Case Studies of Natural Gas Sector Resilience

Submitted in October 2019 to:
SoCalGas
555 West 5th Street
Los Angeles, CA 90013

Submitted by:
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, and the November 2018 wildfires in southern California. 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

Natural gas infrastructure and services were relatively resilient to hurricanes, wildfires, and mudslides. 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.

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 cause more gas leaks throughout 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. 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.

Clear communication and coordination between utilities across sectors and with emergency personnel is critical to a successful disaster response. Emergency responses are most effective when there is clear communication and coordination between utilities across sectors and with emergency personnel. Access to gas infrastructure must be carefully coordinated when conditions are unsafe, and natural gas utilities must communicate the locations of their assets and potential risks to avoid further damage during response activities.

Insights and Recommendations

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. Similarly, SoCalGas is considering increasing the frequency of shut-off valves to stop gas supply to a pipeline network, especially in geohazard areas such as fault lines. This is a particularly useful strategy considering the high cost and time intensity of restoring service post-isolation.

Increase use of technology and smart grids. Modernizing systems will require more communication and data. SoCalGas is deploying fiber optics sensing technologies through debris flow areas above its pipelines. This decision was spurred by the company's experience in the Montecito mudslides, and will enable monitoring of outside force threats and identify any leaks in these vulnerable areas to facilitate swift and targeted responses.

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.
- 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 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. 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 departments of transportation (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.

Mutual assistance agreements between utilities are critical to disaster response and could be further strengthened. 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. Mutual assistance agreements and coordination through bodies such as the CUEA allow for pooling resources when necessary and swelling the labor force in specific areas in need. 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.

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 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.

Contents

Introduction

Goal of Conducting Case Studies

To inform SoCalGas' planning for resilience to climate-related stressors, ICF developed case studies 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 report was first published in summer 2018; this 2019 update contains additional case studies on Hurricane Michael in Florida and significant 2018 southern California fires (Woolsey and Hill fires). The impacts and resilience examples also consider insights from the 2018 Northern California fires (e.g., Camp and Mendocino Complex fires), but these events are not a focus of this report. The case studies summarize damages and disruptions experienced, resilience successes, and lessons learned about opportunities to increase resilience to future climate disasters.

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

It is anticipated that the case studies will 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 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. Since these events are still recent, there remains an incomplete picture on the impacts with little information on long-term changes in operations or planning that resulted from them.

A fuller description of the sources consulted is provided in Appendix A.

How the Case Studies are Organized

An overview of each of the events that are covered within this document appears first, providing summary information about the date, location, and nature of the event as well as the utilities that service the affected area.

Research findings on impacts and resilience are then presented. These findings are divided up by sector to provide insight into the ways that these natural disasters have impacted different aspects of natural gas infrastructure and its related functions. 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.

The report concludes with key takeaways from this research on impacts and resilience, including lessons learned and recommendations for building resilience. This section also includes a list of additional research needs.

References are found at the end of this report. 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 $MMTCO_2e$).[1]
- 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),[2] 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.

[1] "California's Greenhouse Gas Emission Inventory." Accessed June 26, 2019. https://ww3.arb.ca.gov/cc/inventory/data/data.htm.
[2] VOC reported as methane.

- *Key point:* The science research of wildfire management indicates that fuel reduction is effective[3, 4]and can be used strategically to reduce risk in key areas, especially in combination with management efforts for healthier forest structure.[5]

- 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[6] and 80% of California's total natural gas consumption in 2017.[7] 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.

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[3] 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.

[4] 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.

[5] 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.

[6] California Gas and Electric Utilities. 2018. 2018 California Gas Report. Available at: https://www.socalgas.com/regulatory/documents/cgr/2018_California_Gas_Report.pdf.

[7] 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.

Overview of Events

Hurricane Harvey in Texas

Hurricane Harvey made landfall on the coast of South Texas as a Category 4 storm on August 25, 2017. 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 below in Figure 1 and Figure 2, with homes flooded nearly to their roofs and structures destroyed. Power lines throughout the storm's path were downed and caused major outages. The Texas cities of Rockport and Fulton sustained the greatest damages, as they directly experienced the eyewall.[8]

Figure 1. Flooding in Texas. Image sources: Alex Scott/Bloomberg[9] (left) and LM Otero/Associated Press (right).[10]

Figure 2. Damage to electric infrastructure in Texas. Image source: Adrees Latif/Reuters.[11]

[8] National Weather Service. (2017, August). *Major Hurricane Harvey - August 25-29, 2017*. Retrieved April 30, 2018, from https://www.weather.gov/crp/hurricane_harvey

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

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

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

Hurricane Harvey impacted a deep section of coastal and southeast Texas, stretching inland toward central Texas – see Figure 3 for the counties included in FEMA's disaster declaration.

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 1 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.

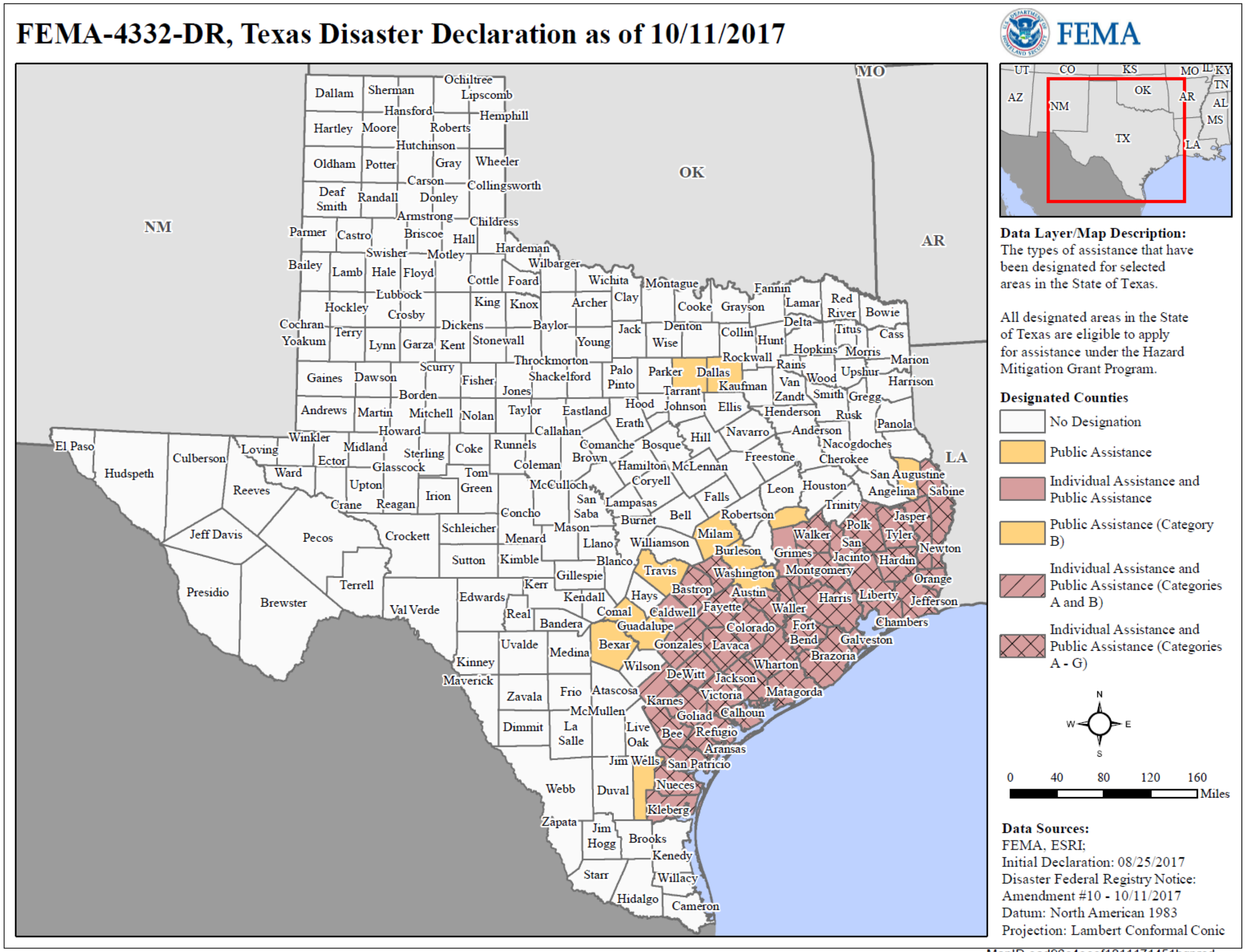

Figure 3. Counties included in FEMA's disaster declaration for Hurricane Harvey. Image source: FEMA[12]

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

Table 1. Relevant Texas natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration.

Utility	Service Territory	Additional Details	Examples of Resilience
American Electric Power Company, Inc. (AEP Texas) (electric)	• Serves 92 counties and 372 cities and towns in south and west Texas (97,000 mi^2) • Part of the American Electric Power system, a large national electric utility	• Assets include 972,853 electric meters and over 51,000 miles of electric distribution and transmission lines (AEP Texas, 2018) • Assets include 874 distribution circuits (U.S. Energy Information Administration, 2019)	**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 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
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 5,000 mi^2 in the Houston area	• Electric assets include 1,683 distribution circuits (U.S. Energy Information Administration, 2019) • Distributes natural gas to over 3,400,000 customers • Assets include 74,000 miles of natural gas mains (CenterPoint Energy, 2016) • Delivered 161,831,484 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
Entergy (electric)		Serves roughly 447,000 electric customers (U.S. Energy Information Administration, 2019) • Electricity assets include 433,557 utility distribution poles, 28,153 transmission poles, 13,194 circuit miles of distribution lines (641 distribution circuits (U.S. Energy Information Administration, 2019)), 2,747 circuit miles of transmission lines, and 335 substations (Entergy Texas, 2016)	

Utility	Service Territory	Additional Details	Examples of Resilience
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 businesses (Texas New Mexico Power Company, n.d.) • Assets include 311 distribution circuits (U.S. Energy Information Administration, 2019)	

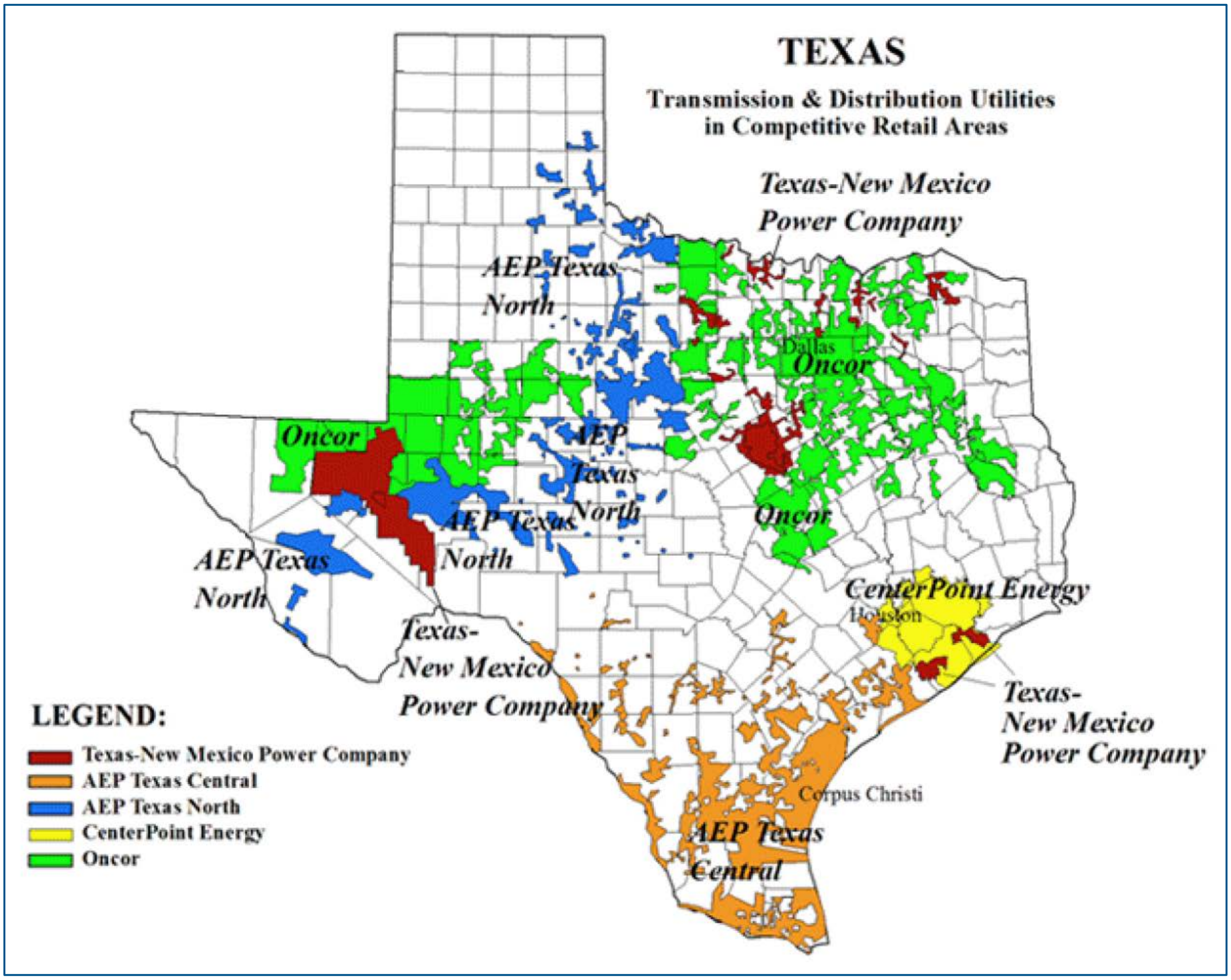

Figure 4. Electric transmission and distribution utilities in competitive retail areas in Texas. Image source: Public Utility Commission of Texas[13]

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

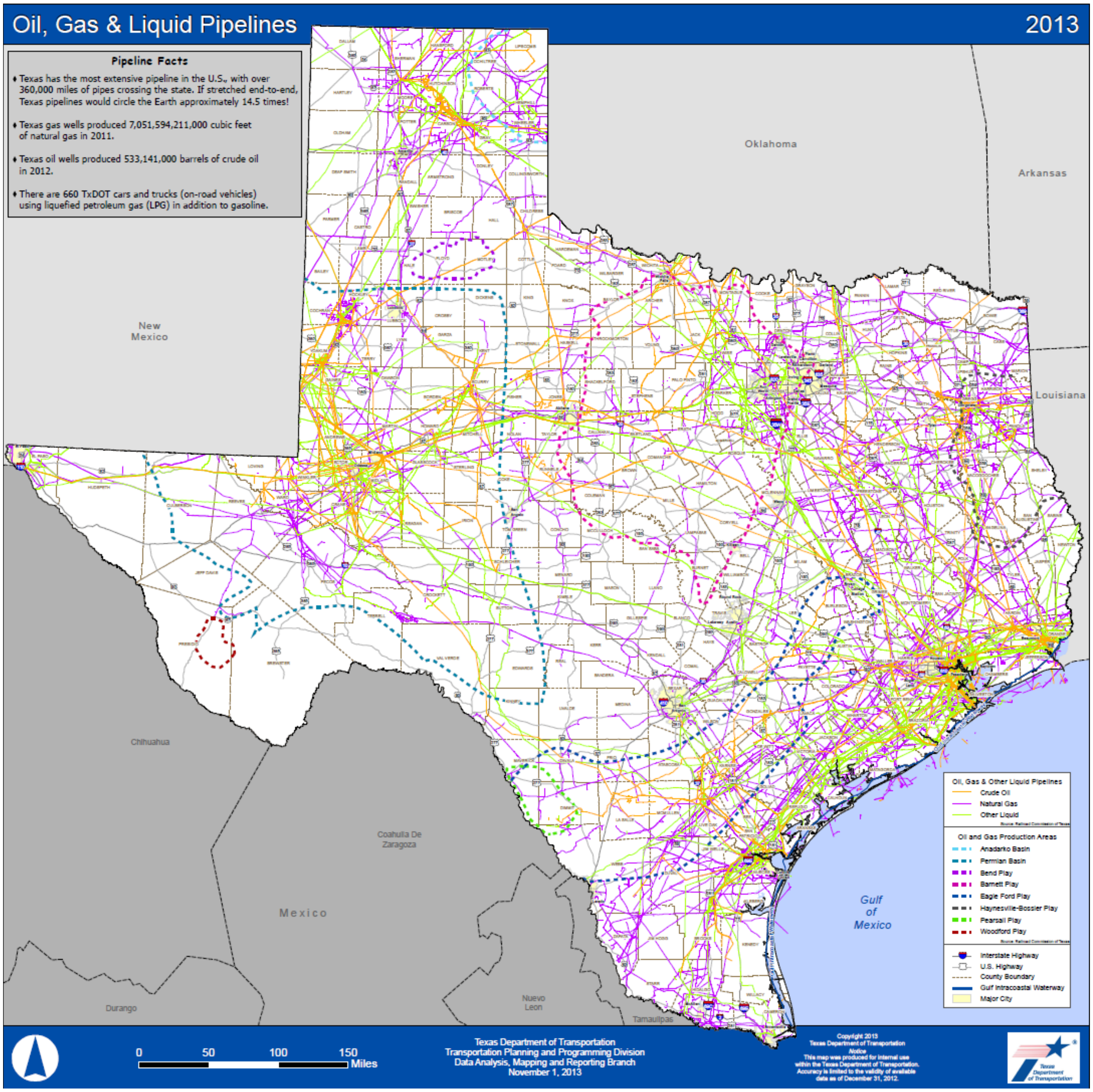

Figure 5. Pipelines in Texas. Image source: Texas Department of Transportation.

Hurricane Irma in Florida

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. Passing over land tempered the storm: Irma first made landfall over the Florida Keys on September 10, 2017, as a Category 4 hurricane with maximum sustained winds of 130 mph, then again on the coast of Florida later that same day as a Category 3 storm with 115 mph winds. By September 11, 2017, Irma had weakened to tropical storm status. Nonetheless, Irma still affected a wide area with strong winds, causing widespread power outages and tree damage. Flooding was also a major issue. For example, downtown Jacksonville, Florida experienced a record-breaking 5.57 feet of storm surge flooding (National Weather Service, 2017). Figures 5 and 6 demonstrate some of this damage.

Figure 6. Flooding in Jacksonville, FL (left) and the Florida Keys (right). Image sources: Reuters (left); Getty Images (right[14])

[14] BBC. (2017, September 12). Hurricane Irma: Damage mapped. https://www.bbc.com/news/world-us-canada-41175312

Figure 7. Damage in Miami Beach, FL (left) and flooding in Naples, FL (right). Image sources: Joe Raedle/Getty Images (left); Daniel William McKnight/Polaris (right)[15]

FEMA issued a Major Disaster Declaration on September 10, 2017, for all of Florida (Figure 8). Ultimately, the incident lasted from September 4 – October 18, 2017, and FEMA approved 771,071 individual assistance applications.[16]

Major utilities impacted by Hurricane Irma in Florida include Duke Energy, Emera, Florida Power and Light, Florida Public Utilities, and Southern Co. (Table 2). Figure 10 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.

[15] Shapiro, Emily; Allen, Karma; Jacobo, Julia. (2017, September 12). Irma death toll in US climbs to 22 as power is restored to over 2 million Florida customers. https://abcnews.go.com/US/irma-death-toll-us-climbs-12-part-florida/story?id=49758372

[16] FEMA. (2017, October 20). *Florida Hurricane Irma (DR-4337)*. Retrieved February 12, 2018, from https://www.fema.gov/disaster/4337

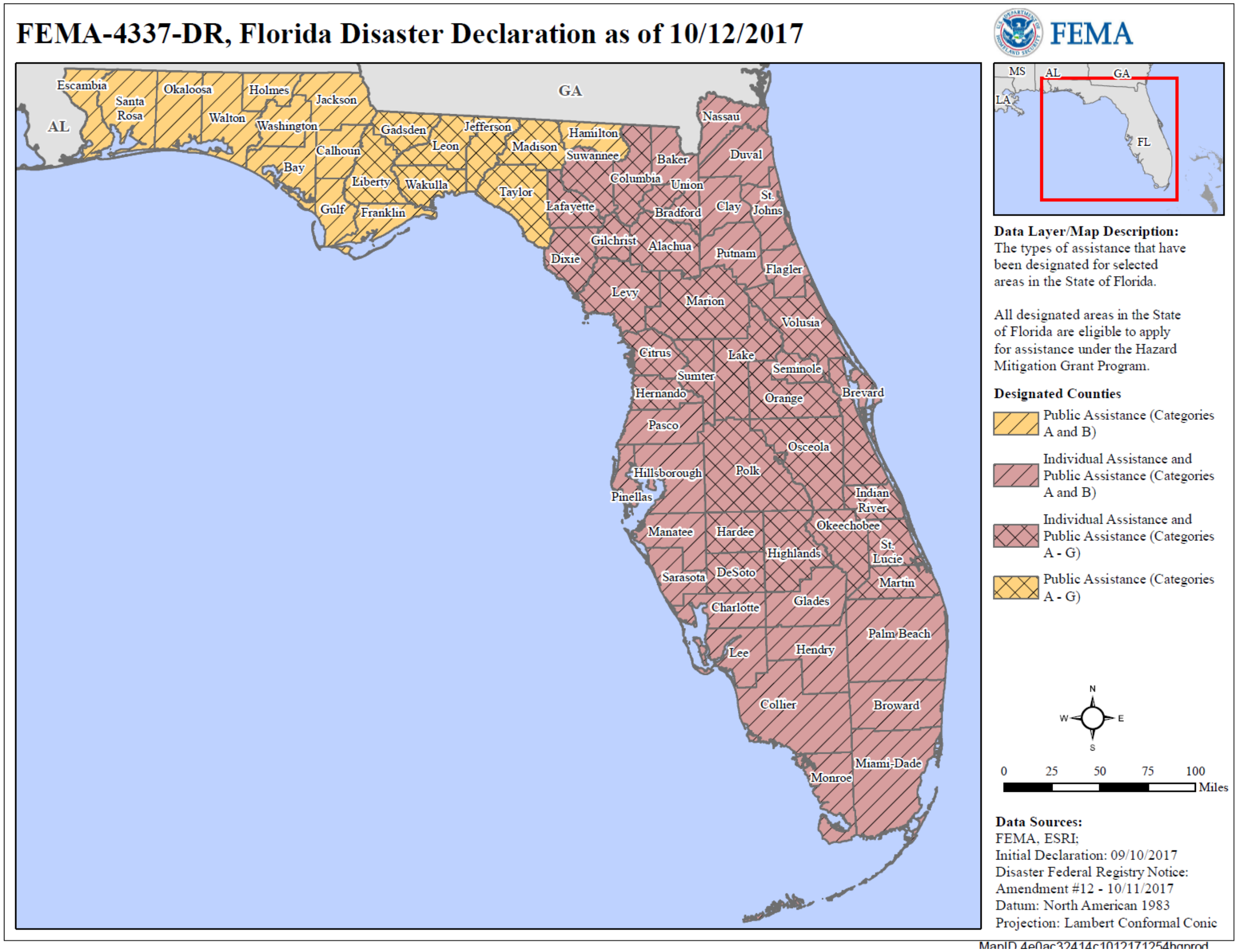

Figure 8. Counties included in FEMA's disaster declaration for Hurricane Irma. Image source: FEMA[17]

[17] FEMA. (2017, October 20). Florida Hurricane Irma (DR-4337). https://www.fema.gov/disaster/4337

Table 2. Relevant Florida natural gas and electric utilities whose service territories overlap with the counties included in FEMA's disaster declaration.

Utility	Service Territory	Additional Details	Examples of Resilience
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) • Total electric assets include 32,200 mi of transmission lines and 268,700 miles of distribution lines (1,281 distribution circuits (U.S. Energy Information Administration, 2019) • Total natural gas assets include 32,900 miles of transmission and distribution pipelines and 26,600 miles of service pipelines (Duke Energy, 2016)	**Natural Gas** • Use of backup gas generators helped to keep critical functionality online at hospitals • No PHMSA incident data reported for natural gas systems impacted **Electricity** • Mutual assistance programs supported utilities in need of emergency personnel
Emera (owns Tampa Electric aka Teco and Peoples Gas) (natural gas and electric)	• Teco serves about 2,000 mi^2 in west central Florida (TECO Tampa Electric, 2019)	• Teco serves 745,000 customers (U.S. Energy Information Administration, 2019) • Teco owns 4,700 megawatts of generating capacity (62% natural gas/oil, 38% coal) (TECO Tampa Electric, 2019) • Teco's assets include 795 electric distribution circuits (U.S. Energy Information Administration, 2019) • Peoples Gas serves roughly 365,000 customers and natural gas assets include about 11,000 miles of gas mains (TECO Peoples Gas, 2019) • Delivered 160,447,839 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
Florida Power and Light (electric)	• Service territory stretches along the east coast from Jacksonville to Miami, serving	• Serves 4.9 million electric customers (estimated 10 million people)[18,19] (U.S. Energy Information Administration, 2019)	

[18] Florida Power and Light. (2011). *FPL Service Territory - Address Search*. Retrieved January 2018, from http://www.fplmaps.com/service_map/map.shtml
[19] Next Era Energy. (2019). *Our Subsidiaries*. Retrieved from http://www.nexteraenergy.com/company/subsidiaries.html

Utility	Service Territory	Additional Details	Examples of Resilience
	almost half of the state	• Assets include 3,290 distribution circuits (U.S. Energy Information Administration, 2019)	
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[20]	• Serves roughly 120,000 customers[21], including 32,000 electric customers (U.S. Energy Information Administration, 2019) • Assets include 30 electric distribution circuits (U.S. Energy Information Administration, 2019) • Delivered 9,381,336 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
Southern Co. (Florida City Gas, Gulf Power, and Southern Power)	• Southern Co. operates in 9 states, including Florida[22] • Florida City Gas serves parts of 7 counties in Florida[23] • Gulf Power serves 8 counties in northwest Florida (7,550 mi^2)[24]	• Florida City Gas serves 108,000 customers.[25] Assets include 3,500 miles of natural gas pipelines.[26] • Florida City Gas delivered 12,348,226 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018) • Gulf Power serves 459,000 customers. Assets include over 9,300 miles of power lines[27] and 308 distribution circuits (U.S. Energy Information Administration, 2019)	

[20] Florida Public Utilities. (2019). *FPU Fact Sheet*. Retrieved May 31, 2019, from https://fpuc.com/about/corporate-fact-sheet/
[21] Florida Public Utilities. (2019). *FPU Fact Sheet*. Retrieved May 31, 2019, from https://fpuc.com/about/corporate-fact-sheet/
[22] Southern Company. (2019). *Service Territory: Our Subsidiaries*. Retrieved May 31, 2019, from https://www.southerncompany.com/about-us/our-business/service-territory.html
[23] Florida City Gas. (2019). *Our Service Area*. Retrieved May 2019, from https://www.floridacitygas.com/about-us/our-service-area
[24] Gulf Power. (2018). *Our Company*. Retrieved January 2018, from https://www.gulfpower.com/about-us/our-company
[25] Florida City Gas. (2018, January). *About Us*. Retrieved from https://www.floridacitygas.com/about-us
[26] Southern Company. (2019). *Service Territory: Our Subsidiaries*. Retrieved May 31, 2019, from https://www.southerncompany.com/about-us/our-business/service-territory.html
[27] Gulf Power. (2018). *Our Company*. Retrieved January 2018, from https://www.gulfpower.com/about-us/our-company

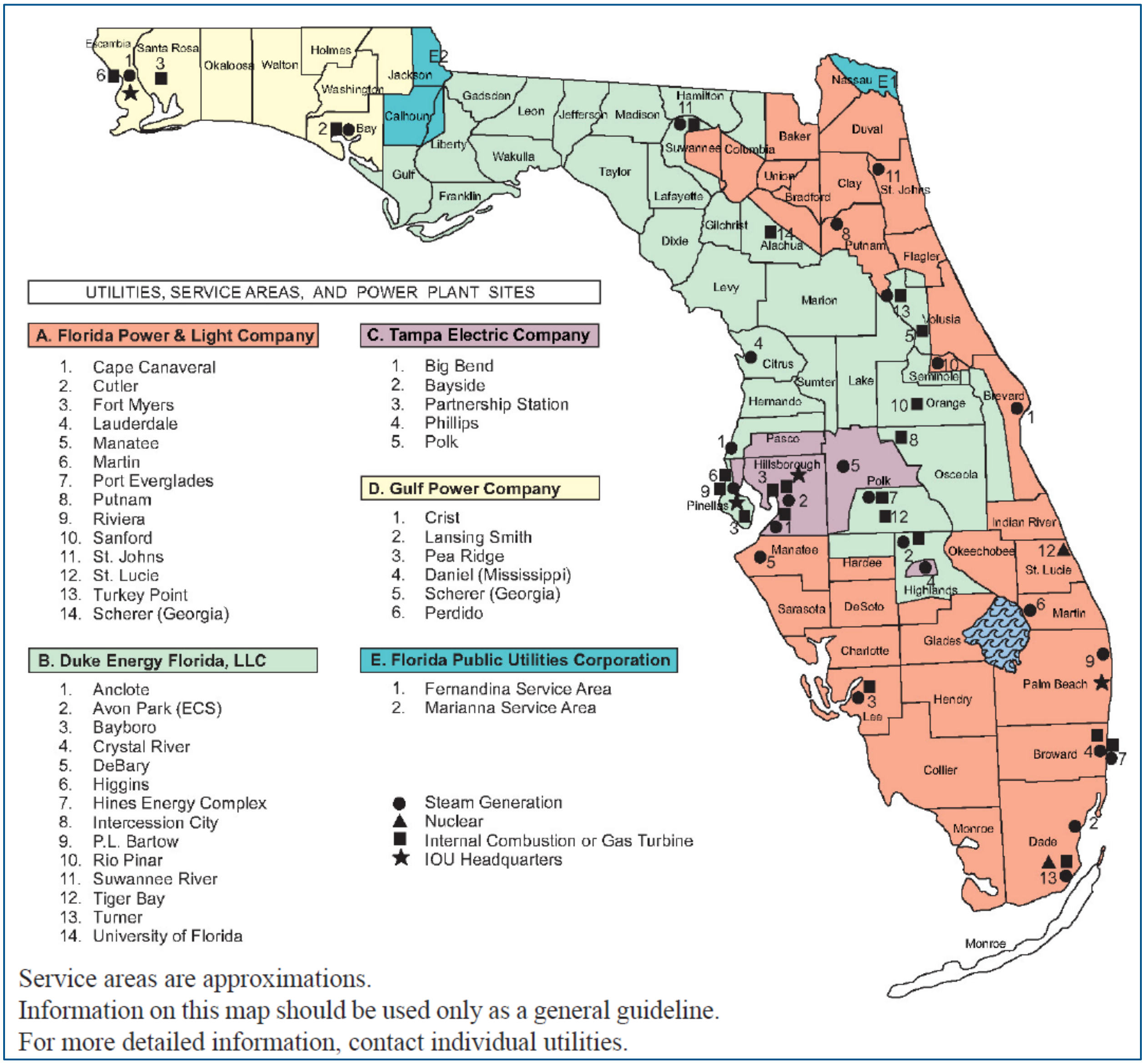

Figure 9. Investor-owned utilities in Florida. Note that this map does not include municipal electric utilities or rural electric cooperatives. Image Source: Florida Public Service Commission[28]

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

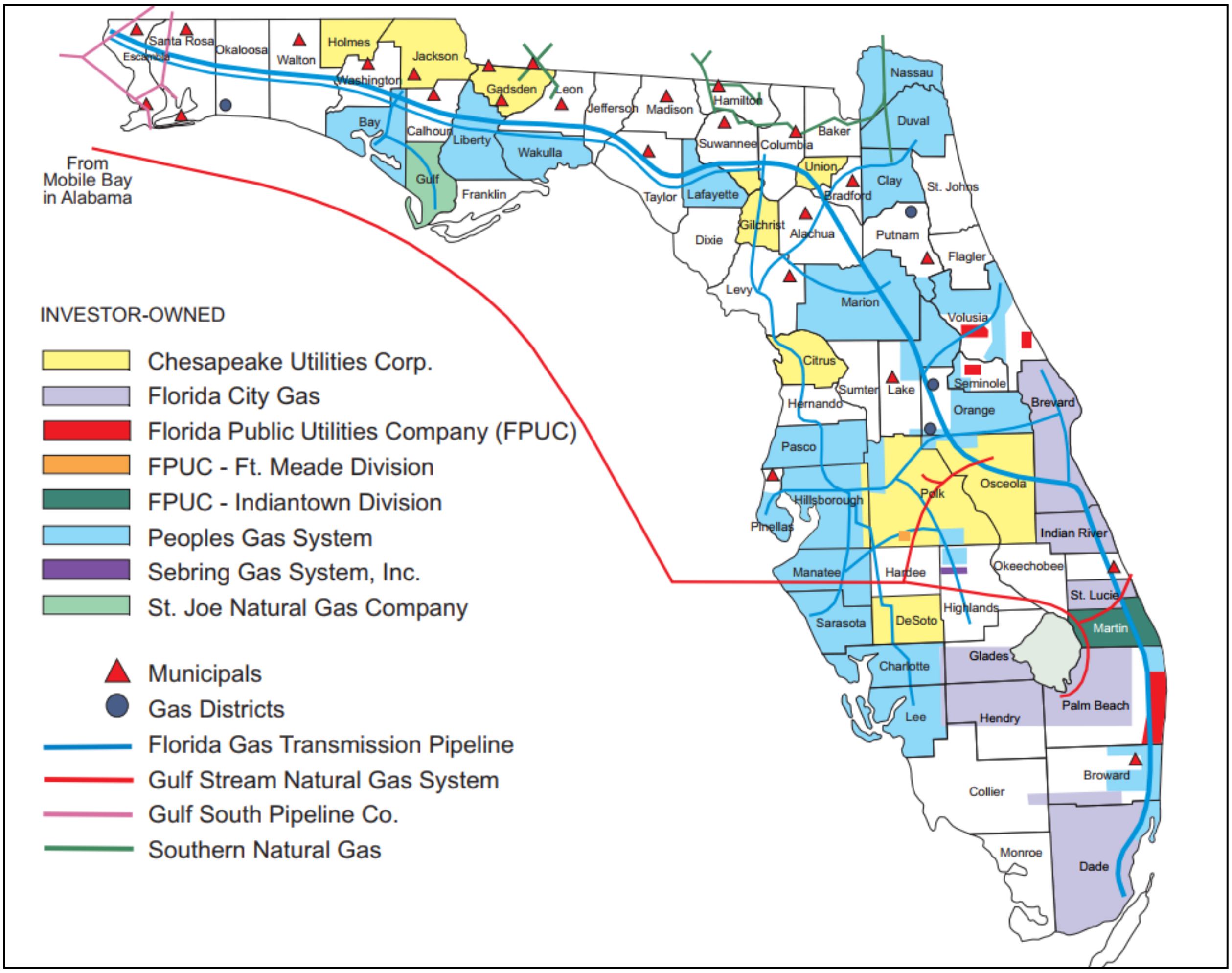

Figure 10. Locations of natural gas pipelines and local distribution companies (LDCs) in Florida. Note that the FPUC is a subsidiary of Chesapeake Utilities Corp. Source: Florida Public Service Commission, March 2016.

Hurricane Michael in Florida

Hurricane Michael made landfall along the Florida panhandle on October 10, 2018 as a Category 5 hurricane.[29] The 160 mph winds ripped through vegetation and infrastructure, leading to at least 45 fatalities and $25 billion in damages.[30] 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.[31]

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.[32] Estimated insured losses from Hurricane Michael exceeded $5.5 billion,[33] and FEMA approved over 31,000 individual assistance applications.[34] FEMA designed 12 counties for individual assistance and 18 counties total in its disaster declaration (Figure 13).

Figure 11. Flooding and destruction in Panama City, Florida (left) and Saint Marks (right). Image source: AP.[35]

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[29] NOAA. (2019b, April 19). *Hurricane Michael upgraded to a Category 5 at time of U.S. landfall*. Retrieved April 25, 2019, from https://www.noaa.gov/media-release/hurricane-michael-upgraded-to-category-5-at-time-of-us-landfall
[30] NOAA. (2019a, February 6). *Assessing the U.S. Climate in 2018*. Retrieved April 10, 2019, from https://www.ncei.noaa.gov/news/national-climate-201812
[31] NOAA. (2019b, April 19). *Hurricane Michael upgraded to a Category 5 at time of U.S. landfall*. Retrieved April 25, 2019, from https://www.noaa.gov/media-release/hurricane-michael-upgraded-to-category-5-at-time-of-us-landfall
[32] NOAA. (2019a, February 6). *Assessing the U.S. Climate in 2018*. Retrieved April 10, 2019, from https://www.ncei.noaa.gov/news/national-climate-201812
[33] The News Service of Florida. (2019, February 7). *Hurricane Michael insured losses near $5.53 billion*. Retrieved April 10, 2019, from https://www.newsherald.com/news/20190207/hurricane-michael-insured-losses-near-553-billion
[34] FEMA. (2018, October 23). *Florida Hurricane Michael (DR-4399)*. Retrieved from https://www.fema.gov/disaster/4399
[35] AP. (2018, October 11). Mexicao Beach, FL is unrecognizable after Hurricane Michael. *WKYC 3*. Retrieved from https://www.wkyc.com/article/news/nation-world/mexico-beach-fl-is-unrecognizable-after-hurricane-michael/507-603416678

Figure 12. Homes destroyed by Hurricane Michael in Panama City, FL. Image source: AP.[36]

[36] AP. (2018, October 11). Mexicao Beach, FL is unrecognizable after Hurricane Michael. *WKYC 3*. Retrieved from https://www.wkyc.com/article/news/nation-world/mexico-beach-fl-is-unrecognizable-after-hurricane-michael/507-603416678

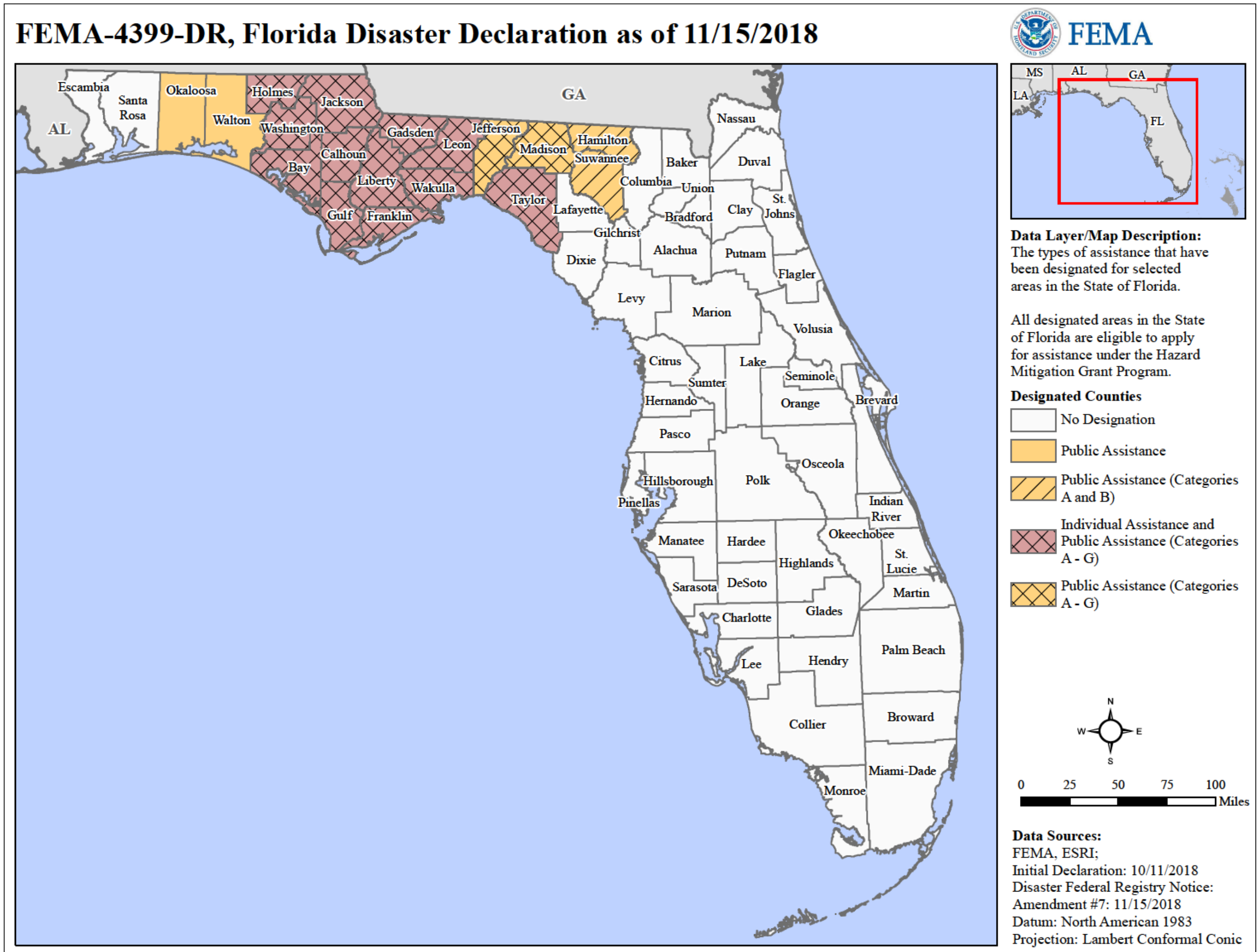

Figure 13. Counties included in FEMA's disaster declaration for Hurricane Michael. Image source: FEMA[37]

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[37] FEMA. (2018, October 23). Florida Hurricane Michael (DR-4399). 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	Service Territory	Additional Details	Examples of Resilience
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) • Total electric assets include 32,200 mi of transmission lines and 268,700 miles of distribution lines (1,281 distribution circuits (U.S. Energy Information Administration, 2019) • Total natural gas assets include 32,900 miles of transmission and distribution pipelines and 26,600 miles of service pipelines (Duke Energy, 2016)	**Natural Gas** • Prompt restoration of service to critical customers **Electricity** • Mutual assistance programs supported utilities in need of emergency personnel
Emera (owns Peoples Gas) (natural gas)	• N/A	• Peoples Gas serves roughly 365,000 customers and natural gas assets include about 11,000 miles of gas mains[38] • Delivered 160,447,839 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
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[39]	• Serves roughly 120,000 customers total[40], including 32,000 electric customers (U.S. Energy Information Administration, 2019) • Assets include 30 electric distribution circuits (U.S. Energy Information Administration, 2019) • Delivered 9,381,336 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
Southern Co. (owns Gulf Power)	• Southern Co. operates in 9	• Gulf Power serves 459,000 customers. Assets include over 9,300 miles of power	

Utility	Service Territory	Additional Details	Examples of Resilience
	states, including Florida[41] • Gulf Power serves 8 counties in northwest Florida (7,550 mi^2)[42]	lines[43] and 308 distribution circuits (U.S. Energy Information Administration, 2019) • Gulf Power serves 459,000 customers. Assets include over 9,300 miles of power lines[44] and 308 distribution circuits (U.S. Energy Information Administration, 2019)	

38 TECO Peoples Gas. (2019). *Our Natural Gas System*. Retrieved May 31, 2019, from https://www.peoplesgas.com/company/ournaturalgassystem/

39 Florida Public Utilities. (2019). *Florida Public Utilities Service Area*. Retrieved May 31, 2019, from https://fpuc.com/customer-service/areas-we-serve/

40 Florida Public Utilities. (2019). *FPU Fact Sheet*. Retrieved May 31, 2019, from https://fpuc.com/about/corporate-fact-sheet/

41 Southern Company. (2019). *Service Territory: Our Subsidiaries*. Retrieved May 31, 2019, from https://www.southerncompany.com/about-us/our-business/service-territory.html

42 Gulf Power. (2018). *Our Company*. Retrieved January 2018, from https://www.gulfpower.com/about-us/our-company

43 Gulf Power. (2018). *Our Company*. Retrieved January 2018, from https://www.gulfpower.com/about-us/our-company

44 Gulf Power. (2018). *Our Company*. Retrieved January 2018, from https://www.gulfpower.com/about-us/our-company

October 2017 Wildfires in Northern California

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 burned a total area greater than 245,000 acres, destroyed an estimated 8,920 structures and damaged an additional 736 structures, taking 44 lives. The fires raged throughout the month of October; as of October 30, 2017, firefighters were still battling five fires (CAL FIRE, 2017). 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. Figure 14 demonstrates some of this damage. On October 9 and 10, 2017, California issued a state emergency declaration, and on October 10 FEMA issued a federal Major Disaster Declaration (Figure 15) (CPUC, 2018). The major utility in these affected counties is Pacific Gas and Electric (PG&E), which provides both natural gas and electricity to the area (Table 4).

Figure 14. Homes destroyed by the Tubbs fire in Santa Rosa, CA on October 11 (left). A burned out and collapsed home in Napa, CA after the Nuns fire (right). Image source: Noah Berger/Special to the Chronicle, Peter DaSilva/Special to the Chronicle[45]

[45] Ho, Lyons, & Rubenstein. (2017, October 16). Live updates: Firefighter dies in Napa County crash; more evacuations lifted. http://www.sfgate.com/bayarea/article/Live-updates-4-more-names-of-people-killed-in-12279908.php#photo-14341576

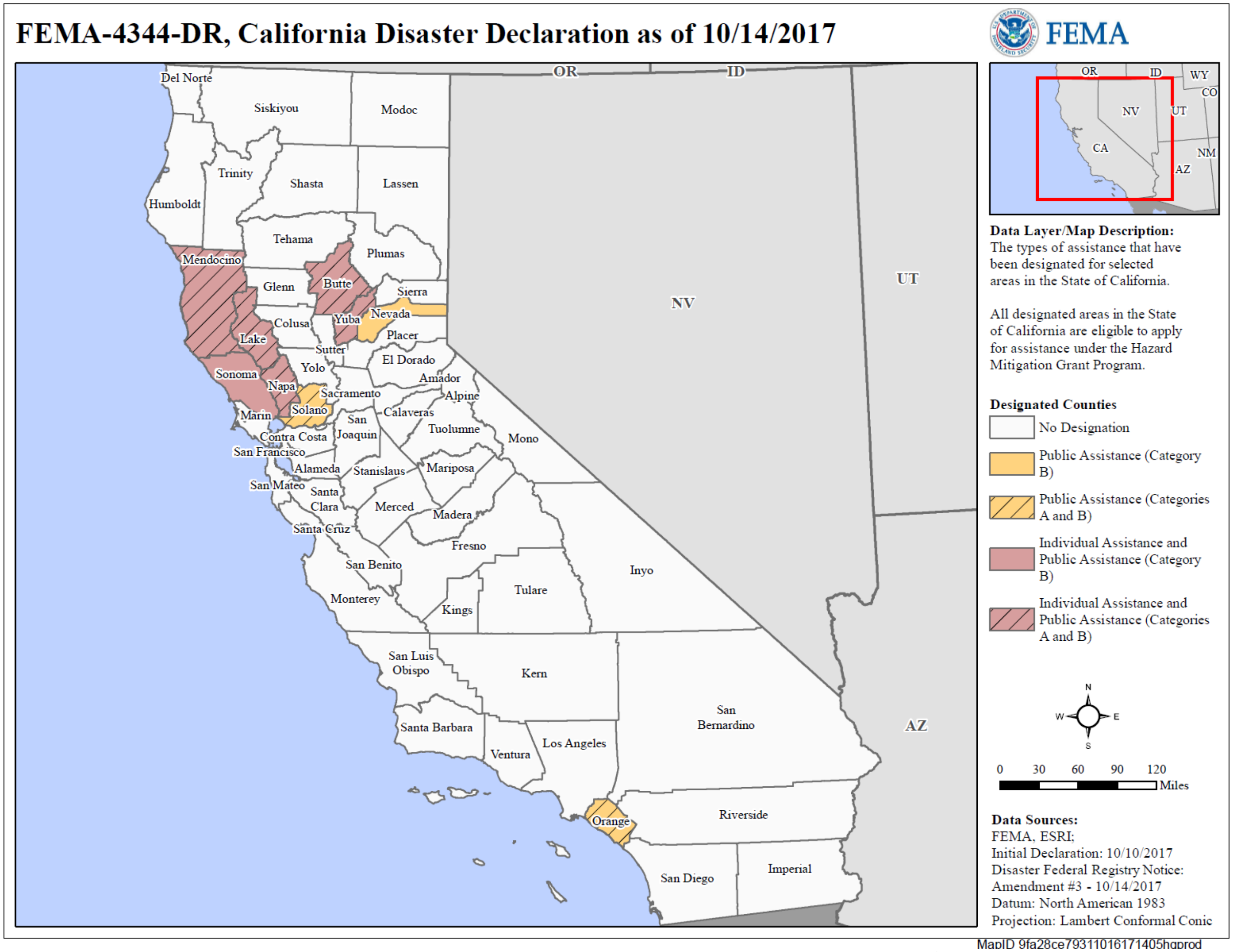

Figure 15. Counties included in FEMA's Major Disaster Declaration for the October wildfires. Image source: FEMA[46]

[46] FEMA. (2017, November 7). California Wildfires (DR-4344).

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

Utility	Service Territory	Additional Details	Examples of Resilience
[Pacific Gas and Electric (PG&E)] (natural gas and electricity)	• $70,000 \text{ mi}^2$ 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) • Electric assets include 106,681 circuit miles of electric distribution lines and 18,466 circuit miles interconnected transmission lines (3,343 distribution circuits) (U.S. Energy Information Administration, 2019) • Natural gas assets include 42,141 miles natural gas distribution pipelines and 6,438 miles transportation pipelines[47] • Delivered 712,384,781 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	**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

[47] Pacific Gas and Electric. (2019). *Company Profile*. Retrieved January 2019, from https://www.pge.com/en_US/about-pge/company-information/profile/profile.page

December 2017 Wildfires in Southern California

Starting December 4, 2017, 122 wildfires broke out in Southern California, five of which grew into large, fast moving fires. 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%.[48] 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[49], Creek[50], Rye[51], Skirball[52], and Lilac[53] fires.

Wildfire scorched 4,100 acres in San Diego County. The Lilac Fire destroyed at least 151 structures and damaged 56 buildings.[54] Ultimately, the Thomas fire grew to be the largest recorded California wildfire, burning 281,893 acres and 1,063 structures (CPUC, 2018).

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 16). Thousands of tons of mud and 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 (Tchekmedyian, Etehad, & Panzar, 2018). FEMA expanded the Presidential Major Disaster Declaration in affect for areas damaged by the December 2017 wildfires to include the mud and debris slides. SoCalGas completed its service restoration efforts to available customers in Montecito on January 31, 2018.[55] Figure 17 shows damage to a home, illustrating the heights the oncoming mud reached with splatters on the roof, as well as a natural gas crew working to repair a line damaged by an RV.

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[48] CPUC. (2018, January 31). *Fire Safety and Utility Infrastructure En Banc*. (California Public Utilities Commission) Retrieved from http://www.cpuc.ca.gov/2018FireEnBanc/
[49] FEMA. (2017, December 5). *California Thomas Fire (FM-5224)*. Retrieved February 12, 2018, from https://www.fema.gov/disaster/5224
[50] FEMA. (2017, December 13). *California Creek Fire (FM-5225)*. Retrieved February 12, 2018, from https://www.fema.gov/disaster/5225
[51] FEMA. (2017, December 8). *California Rye Fire (FM-5226)*. Retrieved February 12, 2018, from https://www.fema.gov/disaster/5226
[52] FEMA. (2017, December 8). *California Skirball Fire (FM-5227)*. Retrieved February 12, 2018, from https://www.fema.gov/disaster/5227
[53] FEMA. (2017, December 8). *California Lilac Fire (FM-5228)*. Retrieved February 12, 2018, from https://www.fema.gov/disaster/5228
[54] Nikolewski, R. (2017, December 11). California fires: SDG&E expects to fully restore power Tuesday. *The San Diego Union Tribune*. Retrieved from https://www.sandiegouniontribune.com/news/public-safety/sd-fi-power-restoration-20171211-story.html
[55] SoCalGas. (2018, February 2). *Montecito Updates*. Retrieved April 18, 2018, from https://www.socalgas.com/cs/Satellite?c=Page&cid=1443741422311&pagename=SoCalGas%2Fscg%2Flayout&rendermode=pre

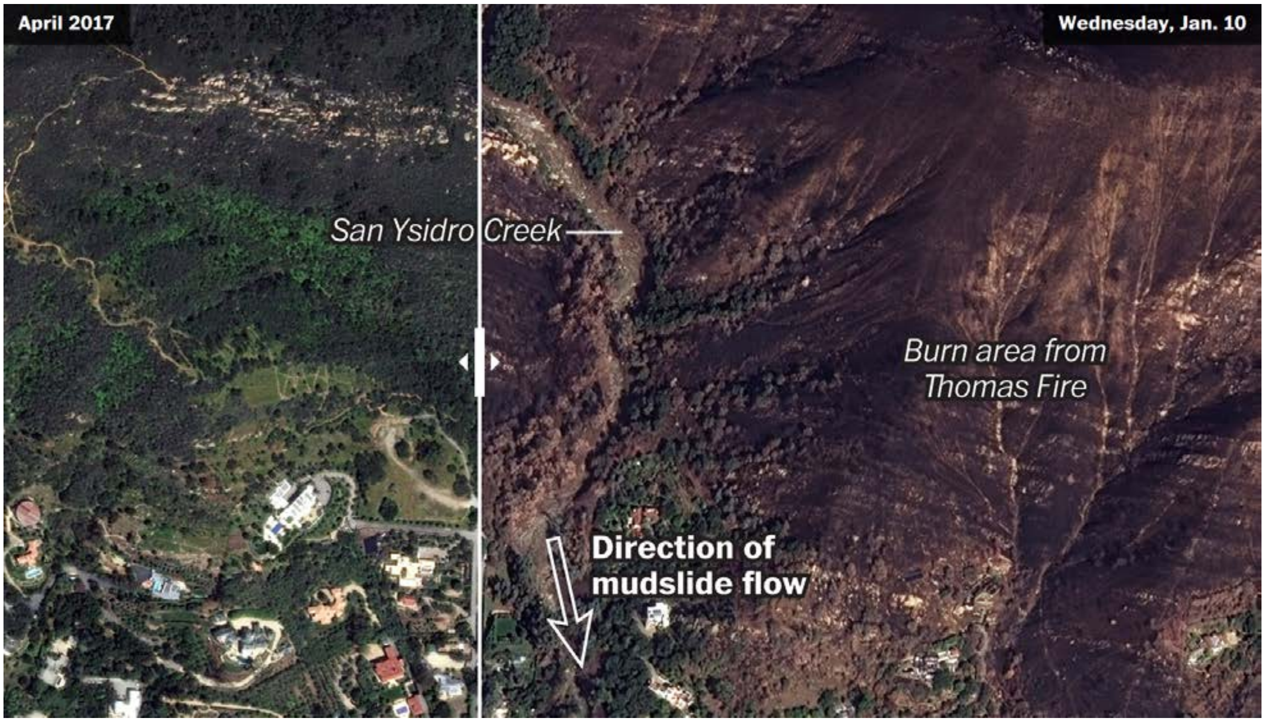

Figure 16. Before and after satellite images of the damage wrought by the Thomas Fire and mudslides in the San Ysidro Creek area. Image source: Karklis, Tierney, & Meko[56]

Figure 17. Damage to a home on Country Club Drive in Burbank, CA. Image source: Rob Kay/ICF. (Left). Gas crews work a damaged line after an RV was carried by the mudslides into a home. Image source: Roa[57] (Right).

[56] Karklis, Tierney, & Meko. (2018, January 19). Before and after the mudslides in Montecito. The Washington Post. https://www.washingtonpost.com/graphics/2018/national/montecito-before-after/?utm_term=.34f49efadc26
[57] Roa, Paul. (2018, January 10). Photo Gallery: Mudslide clean up on Country Club Drive. The LA Times. https://www.latimes.com/socal/burbank-leader/photos/la-mudslide-clean-up-on-country-club-drive-photogallery.html??dssReturn=true.

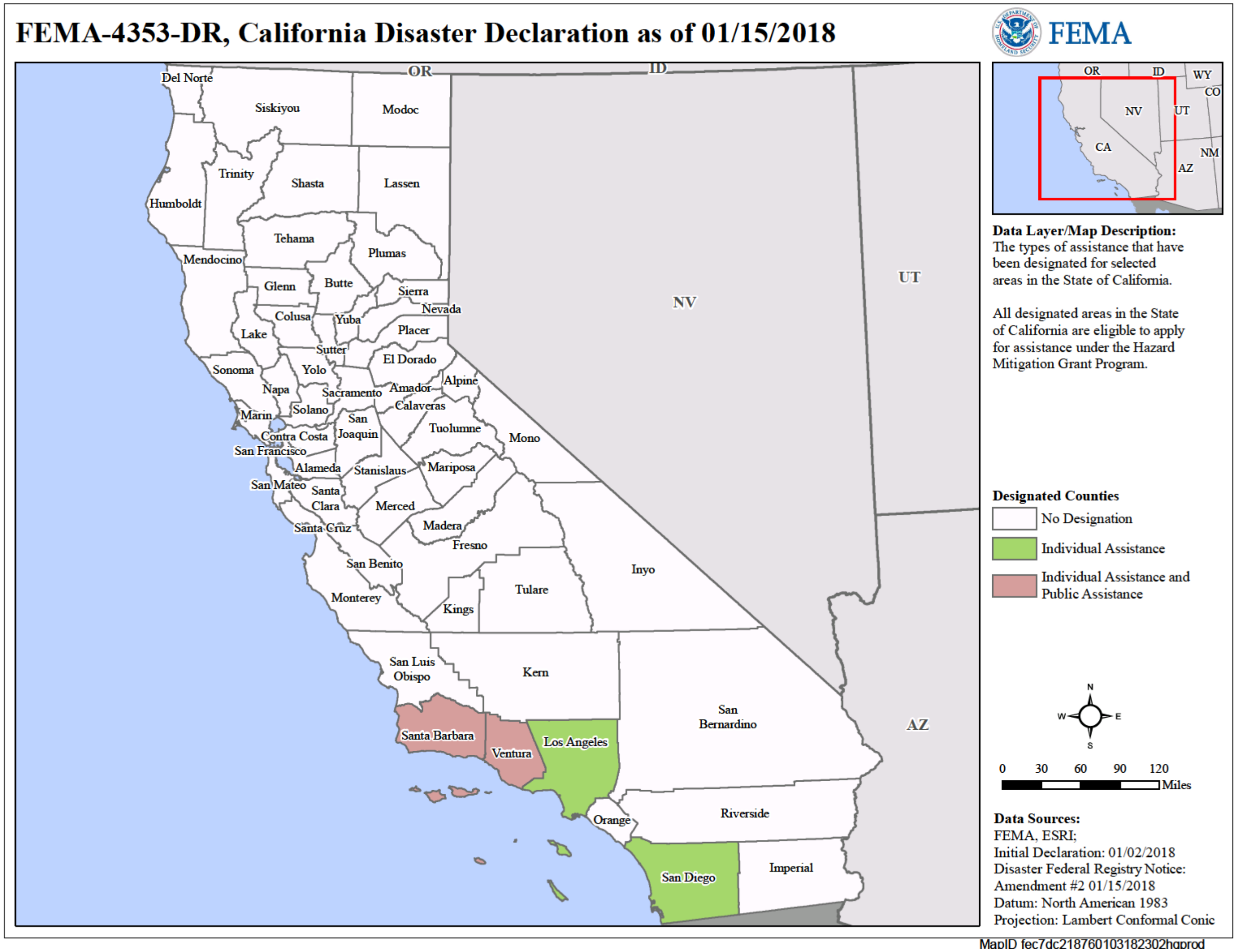

Figure 18. Counties included in FEMA's Major Disaster Declaration for the December – January California wildfires, flooding, mudflows and debris flows. Image source: FEMA.[58]

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

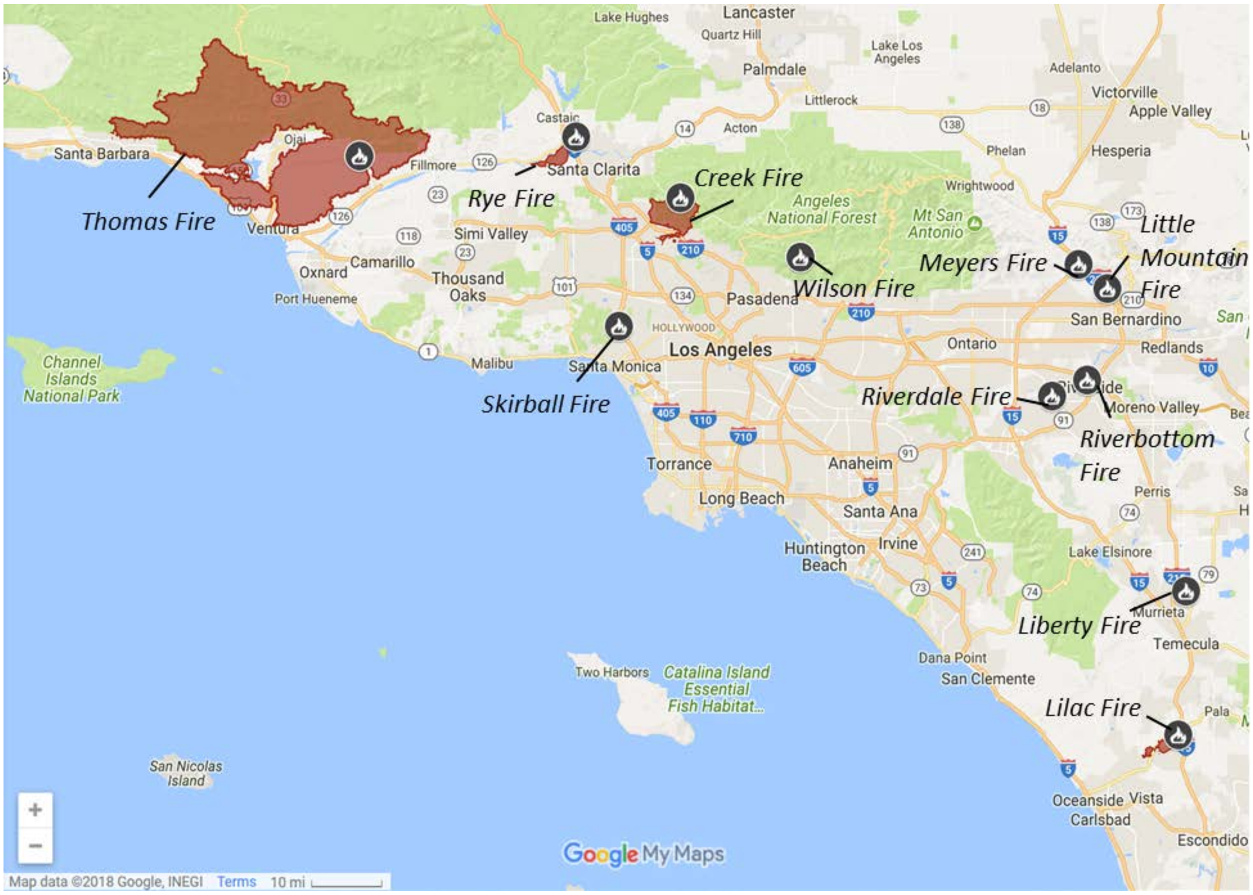

Figure 19. Map of Thomas Fire and adjacent fires. Image courtesy of CalFire. Image source: Google Maps.[59]

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 5).

[59] Google Maps. 2017. 2017 Statewide Fire Map. https://www.google.com/maps/d/u/0/viewer?ll=33.94353536469569%2C-118.42396498641966&hl=en&z=9&source=embed&ie=UTF8&mid=1TOEFA857tOVxtewW1DH6neG1Sm0

Table 5. 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	Service Territory	Additional Details	Examples of Resilience
Pacific Gas and Electric (PG&E) (electric for affected counties) (California Energy Commission, 2015; California Energy Commission, 2017)	• Electric service territory stretches from northern to Southern California and includes the Santa Barbara area	• Serves 5.4 million electric customer accounts • Electric assets include 106,681 circuit miles of electric distribution lines and 18,466 circuit miles interconnected transmission lines (3,343 distribution circuits) (U.S. Energy Information Administration, 2019)	**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
San Diego Gas and Electric (SDG&E) (natural gas and electric)	• Service territory includes San Diego and southern Orange counties (4,100 mi²)	• Provides energy service to 3.6 million people • Assets include 1.4 million electric meters and 873,000 natural gas meters (San Diego Gas and Electric, n.d.) • Electric assets include 1,041 distribution circuits (U.S. Energy Information Administration, 2019) • Delivered 108,838,948 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
Southern California Edison (SCE) (electric)	• Serves 180 cities and 15 counties (50,000 mi²)	• Provides electricity to 15 million people and 285,000 businesses • Assets include 12,635 miles of electric transmission lines, 91,375 miles of electric distribution lines (excluding Streetlight miles), and 1,433,336 electric poles[60] • Assets include 4,502 distribution circuits (U.S. Energy Information Administration, 2019)	

[60] SCE. (2019). *Southern California Edison: Who We Are*. Retrieved May 31, 2019, from https://www.sce.com/about-us/who-we-are

Utility	Service Territory	Additional Details	Examples of Resilience
Southern California Gas (SoCalGas) (natural gas)	• Serves over 500 communities in central and Southern California (20,000 mi^2)	• Serves 21.6 million customers • Assets include 5.9 million natural gas meters[61] • Delivered 757,319,848 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
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	• 31% of power generation (as of 2017) comes from natural gas • Electric assets include 2,335 distribution circuits (U.S. Energy Information Administration, 2019) • Also supplies water to 681,000 active service connections	

[61] SoCalGas. (2019). *Company Profile: About SoCalGas*. Retrieved May 30, 2019, from https://www.socalgas.com/about-us/company-profile

November 2018 Wildfires in Southern California

Starting on November 8, 2018, two wildfires broke out in Los Angeles and Ventura Counties, CA – Hill Fire and Woolsey Fire. The fires started under dangerous conditions with low moisture, abnormally high temperatures, and dry vegetation. They spread quickly due to intense Santa Ana winds.[62]

Figure 20 shows the extent of the Hill and Woolsey Fires. The Hill Fire started in Camarillo and spread north, burning approximately 4,500 acres and four structures over eight days.[63,64] The Woolsey Fire began south of Simi Valley and burned over 97,000 acres, destroyed more than 1,500 structures, damaged 341 structures, resulted in three civilian fatalities, and forced close to a quarter million people to evacuate.[65, 66,67] The Woolsey Fire affected Thousand Oaks, Oak Park, Westlake Village, Agoura Hills, West Hills, Simi Valley, Chatsworth, Bell Canyon, Hidden Hills, Malibu, and Calabasas.[68] Given the high population density and high value properties, the impact of this fire was especially severe.[69]

Figure 21 and Figure 22 show some of the damages caused by these fires.

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

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[62] Folkman, C. (2018, November 19). Camp and Woolsey Fires: A Historical and Numerical Perspective. *RMS*. Retrieved from

[63] CalFire, "Incident Information: Hill Fire," January 4, 2019, http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=2281

[64] Southern California Edison. (2018, November 26). Implementation of Emergency Disaster Relief Program for Hill and Woolsey Wildfire Victims Pursuant to Decision 18-08-004. *Advice Letter 3902-E*. Retrieved from https://www1.sce.com/NR/sc3/tm2/pdf/3902-E.pdf

[65] Goodyear, D. (2019, Februrary 19). Building for Resilience in California's Fire-prone Future. *The New Yorker*. https://www.newyorker.com/culture/culture-desk/building-for-resilience-in-californias-fire-prone-future

[66] County of Los Angeles Fire Department, Los Angeles County Sheriff, and Ventura County Fire Department. (2018, November 19). Woolsey Fire Incident Update. Retrieved from http://cdfdata.fire.ca.gov/pub/cdf/images/incidentfile2282_4307.pdf

[67] Southern California Edison. (2018, November 26). Implementation of Emergency Disaster Relief Program for Hill and Woolsey Wildfire Victims Pursuant to Decision 18-08-004. *Advice Letter 3902-E*. Retrieved from https://www1.sce.com/NR/sc3/tm2/pdf/3902-E.pdf

[68] County of Los Angeles Fire Department, Los Angeles County Sheriff, and Ventura County Fire Department. (2018, November 19). Woolsey Fire Incident Update. Retrieved from http://cdfdata.fire.ca.gov/pub/cdf/images/incidentfile2282_4307.pdf

[69] Folkman, C. (2018, November 19). Camp and Woolsey Fires: A Historical and Numerical Perspective. *RMS*. Retrieved from https://www.rms.com/blog/2018/11/19/camp-and-woolsey-fires-a-historical-and-numerical-perspective/

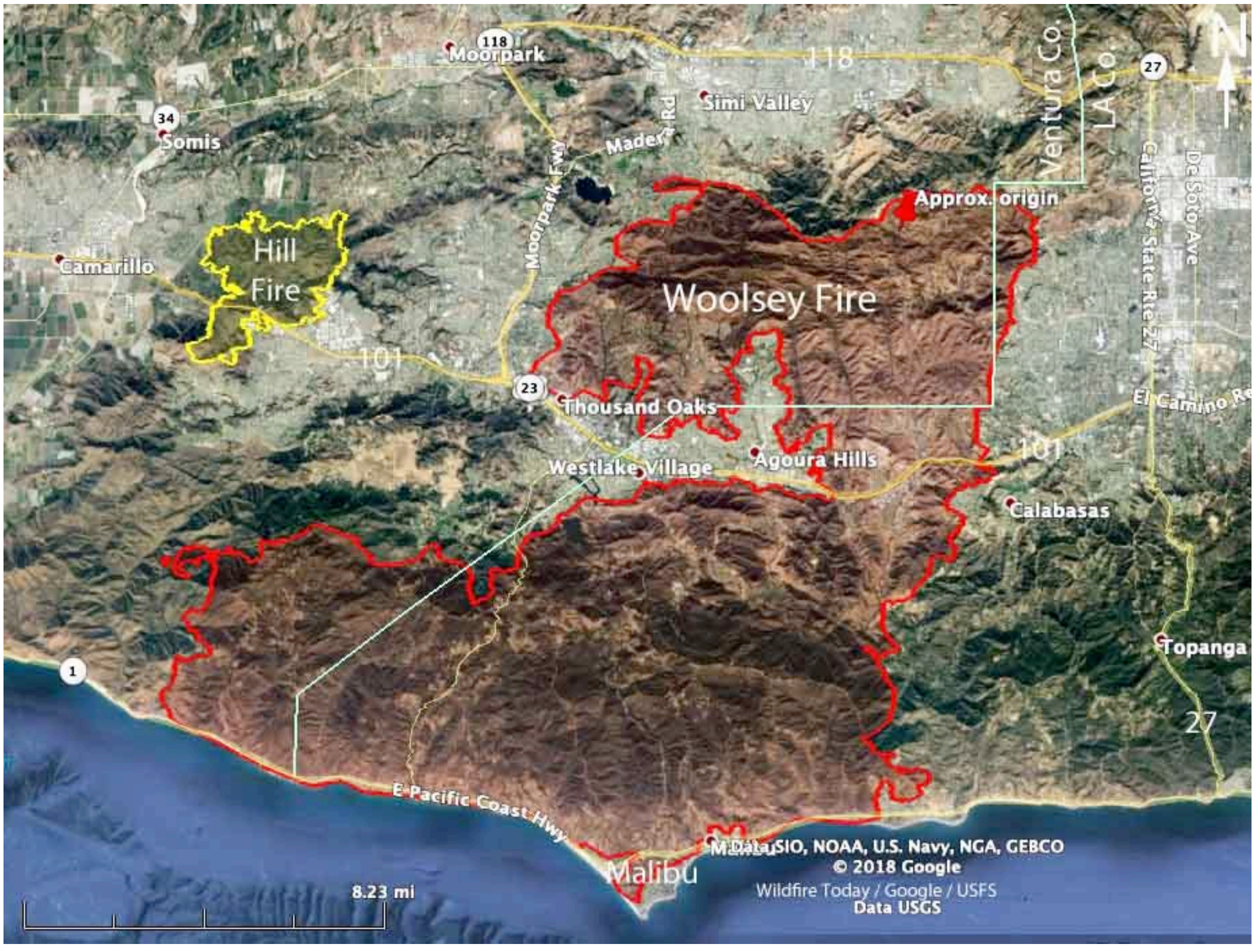

Figure 20. The extent of the Hill and Woolsey Fires. Image source: NOAA

Figure 21. Damages to electric lines along the highway[70] and remains of homes and vehicles in Malibu, CA[71]

Figure 22. The fire moving in on homes in Malibu, CA[72] and traffic backed up as people evacuated.[73]

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.[74] 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.[75]

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[70] Reyes-Velarde, A. (2018, November 20). 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

[71] Brown, Frederic J./AFP/Getty Images. (2018, November 14). *LAist*. Retrieved from https://laist.com/2018/11/14/this_map_shows_where_homes_have_been_destroyed_and_damaged_by_the_woolsey_and_hill_fires.php

[72] McNew, David/Getty Images. (2018, November 14). *Business Insider*. Retrieved from https://www.businessinsider.com/california-wildfires-woolsey-fire-hit-nuclear-research-site-2018-11

[73] McNew, David/Getty Images. (2018, November 10). *The Hollywood Reporter*. Retrieved from https://www.hollywoodreporter.com/news/las-westside-hotels-filling-woolsey-fire-evacuees-1160171

[74] Eavis, P. a. (2019, May 15). California Says PG&E Power Lines Caused Camp Fire That Killed 85. *The New York Times*. Retrieved from https://www.nytimes.com/2019/05/15/business/pge-fire.html

[75] Cal Fire. (2018, November 8). Camp Fire Incident Information. Retrieved from http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=2277

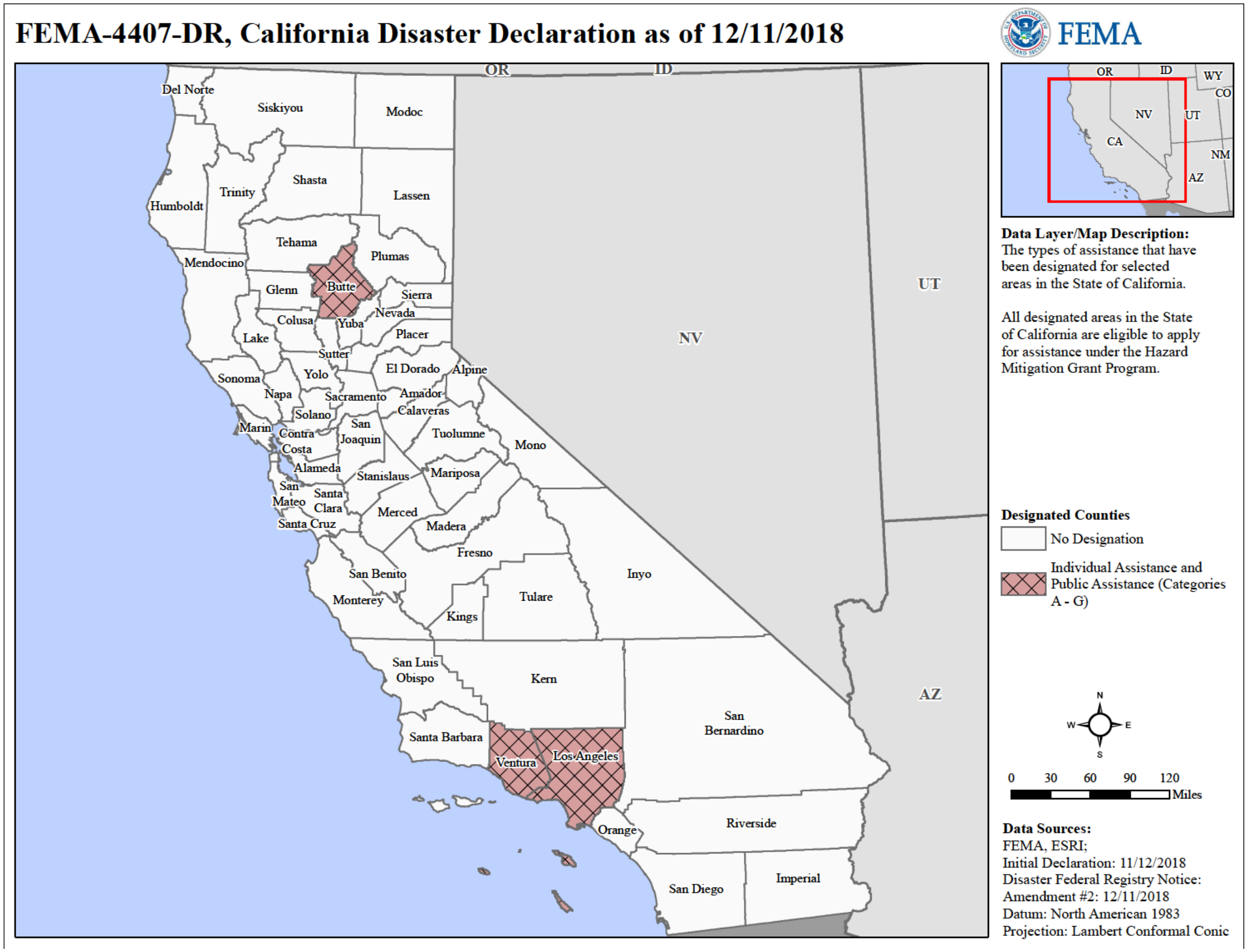

Figure 23. Counties included in FEMA's Major Disaster Declaration for the November 2018 California wildfires (Woolsey and Hill Fires in Southern California).[76]

[76] FEMA. (2018, November 30). California Wildfires (DR-4407). Retrieved from https://www.fema.gov/disaster/4407

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 6 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.[77]

Table 6. Relevant California utilities whose service territories overlap with the counties included in FEMA's disaster declaration for the November 2018 wildfires.

Utility	Service Territory	Additional Details	Examples of Resilience
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 • Total capacity includes over 7,880 MW • Assets include 3,507 miles of overhead transmission lines and 124 miles of underground transmission circuits[78]	**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
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 • Assets include 12,635 miles of electric transmission lines, 91,375 miles of electric distribution lines (excluding Streetlight miles), and 1,433,336 electric poles[79] • Assets include 4,502 distribution circuits (U.S. Energy Information Administration, 2019)	
Southern California Gas (SoCalGas) (natural gas)	• Serves over 500 communities in central and southern	• Serves 21.6 million customers	

[77] LA Department of Water and Power. (n.d.). LADWP's Kittridge Water Tanks & Chatsworth Reservoir Provided Support to Woolsey Fire Response. *LADWP News*. Retrieved June 2019, from https://www.ladwpnews.com/ladwps-kittridge-water-tanks-chatsworth-reservoir-provided-support-to-woolsey-fire-response/

[78] *LA Department of Water and Power*. (2013). Retrieved from Power: Facts and Figures: https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-power/a-p-factandfigures?_adf.ctrl-state=zvddrmwlb_21&_afrLoop=130805769786549

[79] SCE. (2019). *Southern California Edison: Who We Are*. Retrieved May 31, 2019, from https://www.sce.com/about-us/who-we-are

Utility	Service Territory	Additional Details	Examples of Resilience
	California ($20,000 mi^2$) • Serves Los Angeles and Ventura counties	• Assets include 5.9 million natural gas meters[80] • Delivered 757,319,848 thousand cubic feet of natural gas in 2017 (U.S. Energy Information Administration, 2018)	
Water Service	**Ventura County** • *Metropolitan Water District* delivers water to 14 cities, 11 municipal water districts, and one county • *Calleguas Municipal Water District* • City of Thousand Oaks • California – American Water Company • California Water Service **Los Angeles** • Los Angeles Department of Water & Power • Las Virgenes Municipal Water District	• Metropolitan Water District (MWD) owns and operates an extensive water system including: the Colorado River Aqueduct, 16 hydroelectric facilities, nine reservoirs, 819 miles of pipes and five water treatment plants. It is the largest distributer of drinking water in the U.S. • Calleguas Municipal Water District serves roughly three quarters of Ventura County residents, primarily in the southern part of the county. • LADWP serves over 4 million residents with 681,000 active service connections[81] • 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	

[80] SoCalGas. (2019). *Company Profile: About SoCalGas*. Retrieved May 30, 2019, from https://www.socalgas.com/about-us/company-profile

[81] *LA Department of Water and Power*. (2013). Retrieved from Water: Facts and Figures: https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-water/a-w-factandfigures;jsessionid=HnqndMKflHdGxRb9qQ0C6j8l8Zvx9PK06YXGznHx5RfKv3KGldJH!1202172240?_adf.ctrl-state=2tatkv1pe_21&_afrLoop=149070194258933&_afrWindowMode=0&_afrWindowId=null#%40%3F_afrWindow

Utility	Service Territory	Additional Details	Examples of Resilience
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	

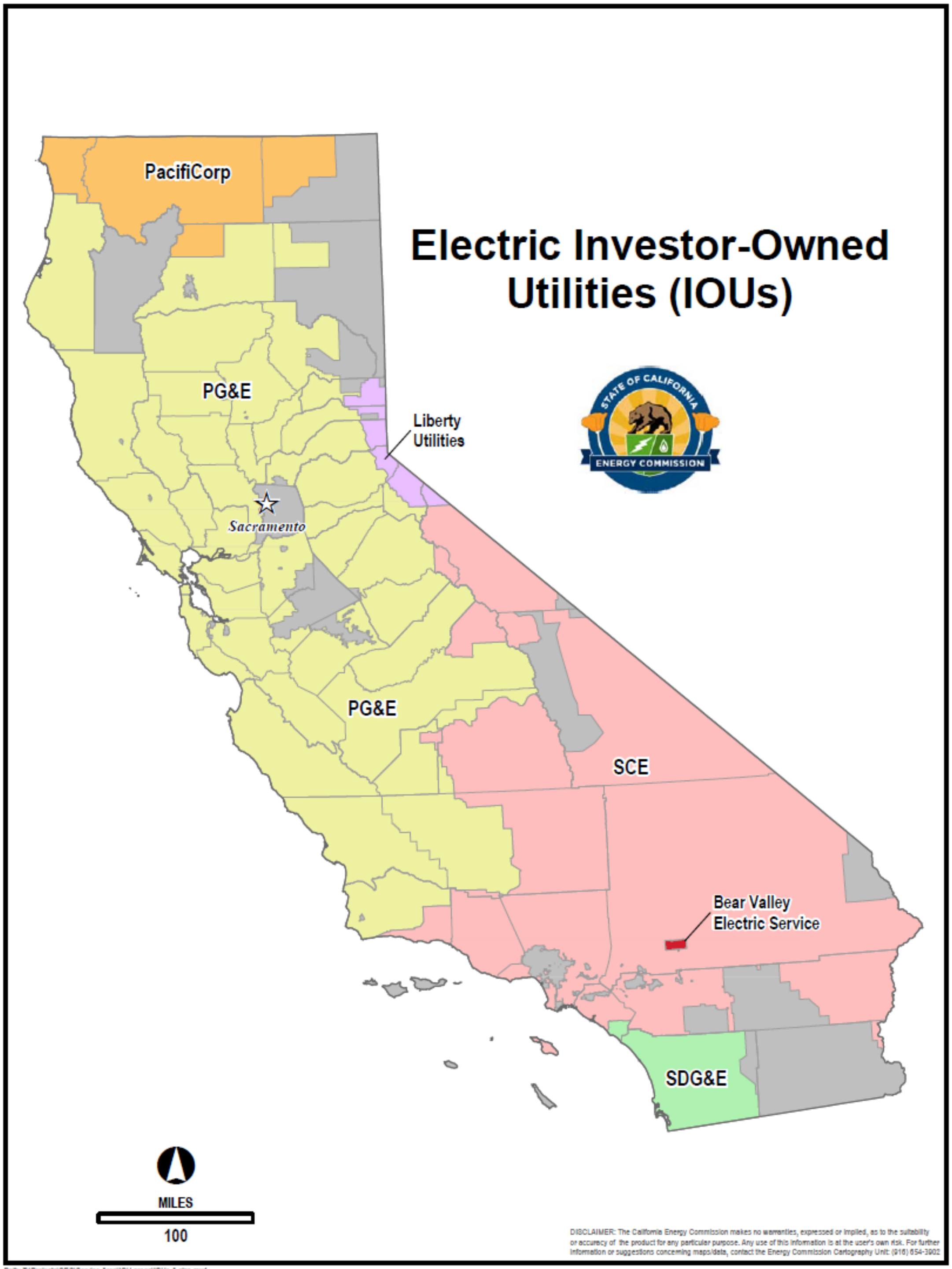

Figure 24. Service territories for California IOUs. Image source: California Energy Commission.[82]

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

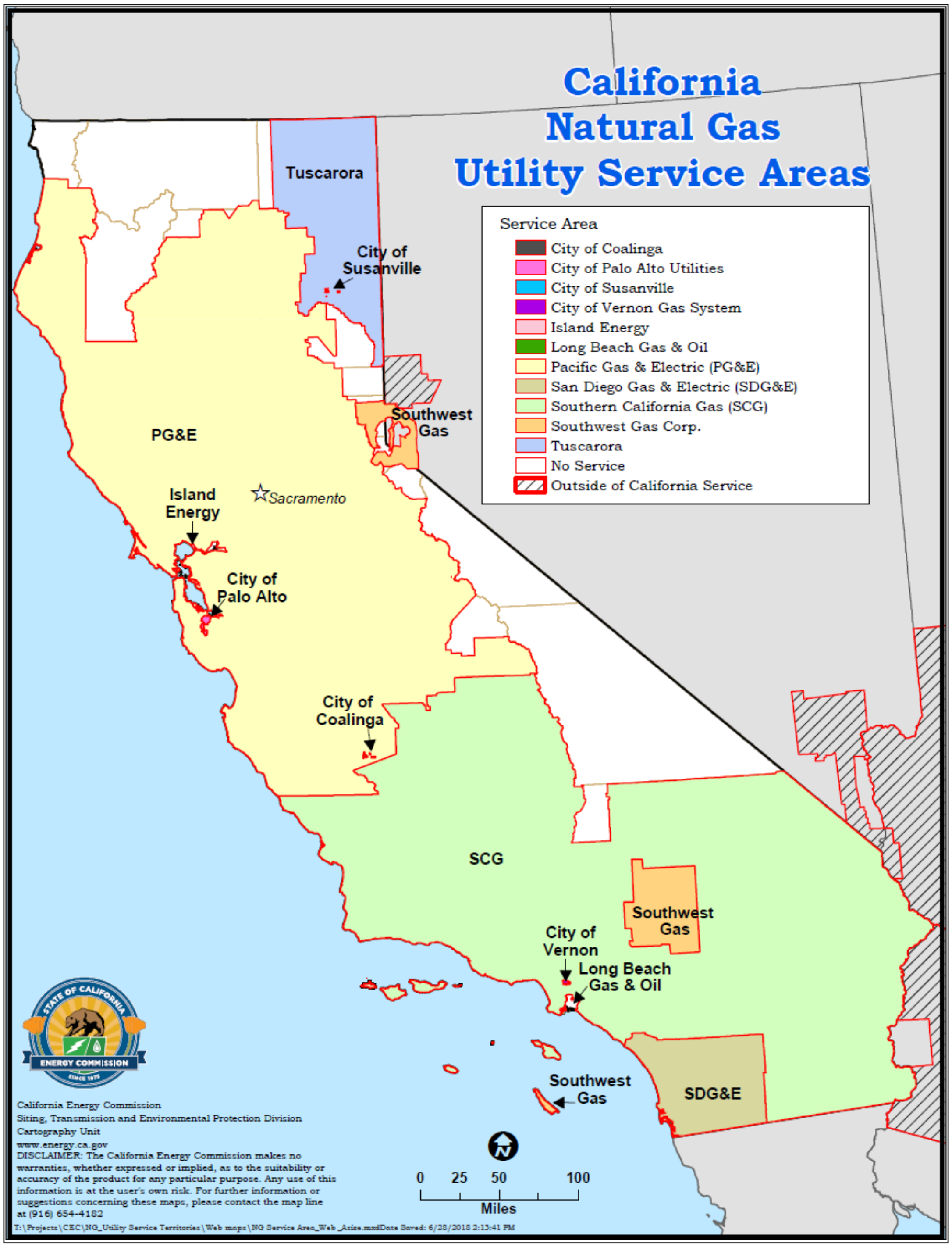

Figure 25. Natural gas utility service areas in California. Image source: California Energy Commission.[83]

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

Summary of Impacts and Resilience

Energy Supply

Asset 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.[84] Other reports noted relatively reduced impacts where there was physical damage to assets but no service disruptions or releases of natural gas. For example, an 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.[85]

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.[86] There were no reported gas

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

[85] Cho, A., Poirier, L., Rubin, D. K., & Rusell, P. R. (2017, August 28). How Badly Has Hurricane Harvey Damaged Texas Infrastructure. *Engineering News-Record (ENR)*. Retrieved from https://www.enr.com/articles/42639-how-badly-has-hurricane-harvey-damaged-texas-infrastructure

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

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.[87] 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]".[88] 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.[89]

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 26), but lowered demand due to power being out (also known as "demand destruction") muted the domestic impact of this shutdown.[90,91,92]

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87 USDOT, Pipeline and Hazardous Materials Safety Administration (PHMSA). (2019, June 5). *Pipeline Incident Flagged Files*. Retrieved from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
88 Ibid.
89 USDOT. 2018. US Department of Transportation Resources for Hurricane Michael. October 15. Accessed April 24, 2019. https://www.transportation.gov/briefing-room/us-department-transportation-resources-hurricane-michael.
90 Clemente, J. (2017, September 3). Hurricane Harvey's Impact On Natural Gas Prices. *Forbes*. Retrieved from https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/#76ba015b5230
91 NGI Staff Reports. (2017, September 11). Irma Takes Down Power, Lowers NatGas Demand for Millions in Florida, Georgia. *Natural Gas Intel*. Retrieved from https://www.naturalgasintel.com/articles/111692-irma-takes-down-power-lowers-natgas-demand-for-millions-in-florida-georgia
92 Clemente, J. (2017, September 20). Hurricanes Harvey and Irma and the Impact to Natural Gas Prices. *Trane*. Retrieved from https://www.trane.com/commercial/north-america/us/en/about-us/newsroom/blogs/Hurricane-Harvey-Irma-NG-Prices.html

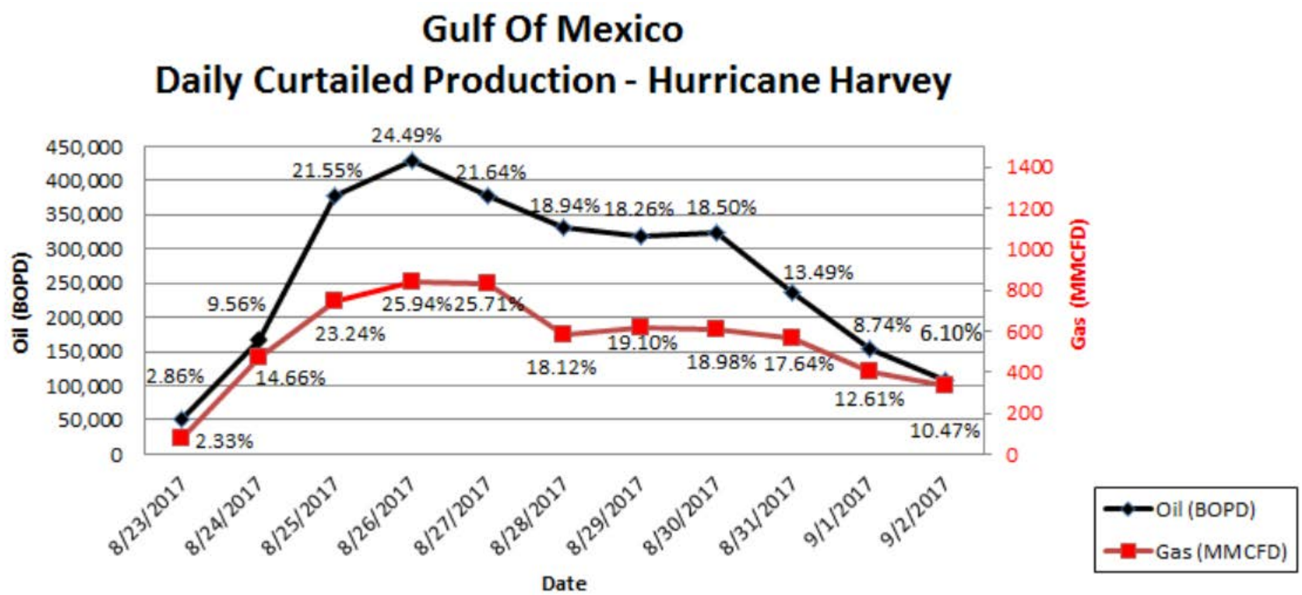

Figure 26. Daily curtailed oil and gas production in the Gulf of Mexico due to Hurricane Harvey. Source: U.S. Bureau of Safety and Environmental Enforcement[93]

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[94]) 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.[95,96] 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.[97] 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.[98]

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[93] Bureau of Safety and Environmental Enforcement. (2017, September 2). BSEE Tropical Storm Harvey Activity Statistics Update: Sept. 2, 2017 . Retrieved from https://www.bsee.gov/newsroom/latest-news/statements-and-releases/press-releases/bsee-tropical-storm-harvey-activity-7

[94] "Force Majeure". (2019). *Business Dictionary*. Retrieved February 2018, from http://www.businessdictionary.com/definition/force-majeure.html

[95] Kinder Morgan. (2017, August 24). Notice Detail. Retrieved from https://pipeline2.kindermorgan.com/Notices/NoticeDetail.aspx?code=TGP&notc_nbr=364475

[96] Kinder Morgan. (2017, August 26). Notice Detail. Retrieved from https://pipeline2.kindermorgan.com/Notices/NoticeDetail.aspx?code=NGPL&notc_nbr=37735

[97] IHS Markit, "IHS Markit Hurricane Harvey Update," September 6, 2017, http://news.ihsmarkit.com/press-release/energy-power-media/ihs-markit-hurricane-harvey-update-september-6-2017

[98] Hart Energy. (2018, October 11). *HEADLINES: Hurricane Michael's Effect on Oil, Gas Production*. Retrieved April 24, 2019, from https://www.hartenergy.com/exclusives/headlines-hurricane-michaels-effect-oil-gas-production-135307

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.[99] In fact, due in part to demand destruction, natural gas prices fell slightly when Hurricane Harvey hit Texas. However, this shift in prices is negligible when compared with the spike caused by previous storms[100] (Figure 27, Figure *28*).

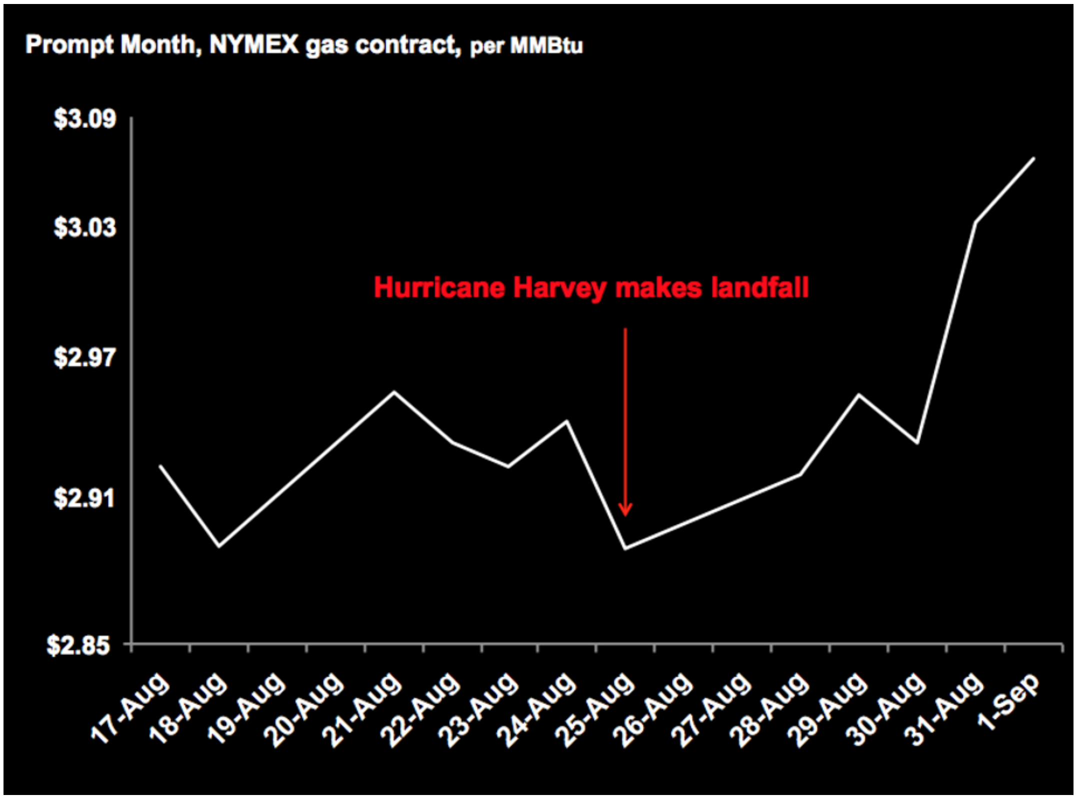

Figure 27. Natural gas prices dipped slightly at the onset of Hurricane Harvey. Data source: EIA. Image source: Forbes[101]

[99] NGI Staff Reports. (2017, September 11). Irma Takes Down Power, Lowers NatGas Demand for Millions in Florida, Georgia. *Natural Gas Intel*. Retrieved from https://www.naturalgasintel.com/articles/111692-irma-takes-down-power-lowers-natgas-demand-for-millions-in-florida-georgia

[100] Clemente, J. (2017, September 3). Hurricane Harvey's Impact On Natural Gas Prices. *Forbes*. Retrieved from https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/#76ba015b5230

[101] Clemente, Jude. (2017, September 3). Hurricane Harvey's Impact On Natural Gas Prices. Forbes. https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/2/#70228e761552

Figure 28. Harvey's impact on natural gas prices is negligible in comparison to that of other storms. Data source: EIA. Image source: Forbes[102]

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.[103] In Florida during Hurricane Irma, 6.1 million customers lost power, including 3.6 million Florida Power and Light customers alone.[104] In some coastal areas, Irma pushed outage rates as high as 97 percent.[105] During Hurricane Michael, about 2 million electric customers in affected states (Alabama, Florida, Georgia, North Carolina, South Carolina, and Virginia) were without

[102] Clemente, Jude. (2017, September 3). Hurricane Harvey's Impact On Natural Gas Prices. Forbes. https://www.forbes.com/sites/judeclemente/2017/09/03/hurricane-harveys-impact-on-natural-gas-prices/2/#70228e761552

[103] ERCOT. (2017, September 6). *ERCOT Responds to Hurricane Harvey*. Retrieved May 31, 2019, from http://www.ercot.com/help/harvey

[104] Reuters/CNBC. (2017, September 11). Irma knocks out power to about 5.8 million: Authorities. Retrieved from https://www.cnbc.com/2017/09/11/irma-knocks-out-power-to-nearly-four-million-in-florida-utilities.html

[105] St. John, J. (2017, September 11). Post-Irma, Utilities Face 'One of the Largest Industry Restoration Efforts in US History'. *Greenteach Media*. Retrieved from https://www.greentechmedia.com/articles/read/post-hurricane-irma-utilities-face-one-of-largest-industry-restoration-effo

power.[106] Downed trees were a major cause of outages in North Carolina,[107] and damage to electric transmission and distribution facilities (e.g., substations, utility poles, and power lines) were a main cause in Florida.[108] Electric outages from Hurricane Michael lasted from a few days to 2 or more weeks.[109,110] 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,[111] 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.[112]

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."[113][114] 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.[115]

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

[106] US DOE. (2018). *Tropical Cyclone Michael | Report #5: October 12.* US Department of Energy Infrastructure Security and Energy Restoration. Retrieved from https://www.energy.gov/sites/prod/files/2018/10/f56/Michael%20DOE%20Event%20Summary%20Report%20%235%20Morning%20October%2012%2C%202018.pdf

[107] Henderson, B. (2018, October 12). *More than 286,000 in Carolinas still without power after Tropical Storm Michael*. Retrieved April 10, 2019, from https://www.charlotteobserver.com/news/local/article219910430.html

[108] Wells, J. (2018, October 12). Hurricane Michael damage so extensive, company inspecting with boats and drones. *Duke Energy*. Retrieved from https://illumination.duke-energy.com/articles/hurricane-michael-damage-so-extensive-company-inspecting-with-boats-and-drones

[109] Panettieri, J. (2018, October 10). *Hurricane Michael Power Outages: Electric Service Restored to More than 1.2 Million Customers*. Retrieved May 3, 2019, from https://www.channele2e.com/technology/business-continuity/hurricane-michael-power-outages/

[110] 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

[111] 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/

[112] Personal communication. (2019, April 19). Florida Rural Water Association.

[113] 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

[114] http://ahca.myflorida.com/MCHQ/Health_Facility_Regulation/Long_Term_Care/docs/Nursing_Homes/Final-Ratified_59A-4.1265.pdf

[115] Fausset, R., Fink , S., & Haag, M. (2018, October 11). Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients. *The New York Times*. Retrieved from https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html

experienced by the state during Hurricane Irma. Such cell outages were less of an issue in Texas, where there were fewer electric outages.[116,117] Cell phone outages from electricity disruptions impede the response time and coordination of emergency responders, which is discussed later in this report.

Asset 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.[118]

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."[119] One PHMSA report detailed such damage, stating that meters in several locations had melted away, allowing gas to ignite.[120] 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.[121] 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.[122] This meant that customers both with and without damaged properties experienced an interruption in service for several days.[123] 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.[124] 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.[125] Properties that could not accept gas service were primarily those destroyed by the fire, rendering restoration of service unnecessary.

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[116] 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

[117] Shannon, T. (n.d.). What Hurricanes Harvey and Irma Tell Us about Wireless Carrier Preparedness. *Battery Power Online*. Retrieved from What Hurricanes Harvey and Irma Tell Us about Wireless Carrier Preparedness

[118] Personal communication. (2019, April 23). CUEA.

[119] Personal communication. (2018, January 15-16). PG&E.

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

[121] CPUC. (2017, October 27). *Oct. 9-27, 2017: Status updates from PG&E to the CPUC*. Retrieved from http://cpuc.ca.gov/general.aspx?id=6442454971

[122] Ibid.

[123] Personal communication. (2018, January 15-16). PG&E.

[124] CPUC. (2017, October 27). *Oct. 9-27, 2017: Status updates from PG&E to the CPUC*. Retrieved from http://cpuc.ca.gov/general.aspx?id=6442454971

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

Table 7. 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.[126]	PG&E begins voluntary natural gas service disruptions.[127]	Utility crews begin gas restoration efforts.[128]	Utility crews complete available restoration efforts.[129]	Northern California wildfires that began October 8-9 end.[130]

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 fire reached houses, shutting off service for about 4,800 customers.[131] 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.

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.[132] 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.[133] 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.[134]

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126 CAL FIRE. (2017, October 30). *California Statewide Fire Summary*. Retrieved from http://calfire.ca.gov/communications/communications_StatewideFireSummary
127 CPUC. (2017, October 27). *Oct. 9-27, 2017: Status updates from PG&E to the CPUC*. Retrieved from http://cpuc.ca.gov/general.aspx?id=6442454971
128 Ibid.
129 USDOT, Pipeline and Hazardous Materials Safety Administration (PHMSA). (2019, June 5). *Pipeline Incident Flagged Files*. Retrieved from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
130 CAL FIRE. (n.d.). *Incident Information*. Retrieved April 24, 2018, from http://cdfdata.fire.ca.gov/incidents/incidents_cur_search_results?search=2017
131 Personal communication. (2018, January 22). SoCalGas.
132 Shatkin, E. (2018, November 19). Woolsey Fire Should Be Fully Contained By Thanksgiving. *LAist*. Retrieved from https://laist.com/2018/11/19/woolsey_fire_fully_contained_thanksgiving.php
133 Ibid.
134 Personal communication. (2018, February 14). CUEA.

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.[135] PG&E's electricity infrastructure has been connected with over 1,500 wildfires between 2014 and 2017, including the Sonoma County Tubbs Fire.[136] CAL FIRE recently found PG&E's electric infrastructure to be the cause of the 2018 Camp Fire.[137]

An estimated 359,000 PG&E customers lost electric power in the October 2017 fires.[138] This was partially attributed to the company proactively de-energizing lines, both voluntarily and at the direction of CAL FIRE.[139] During the October fires, major water leaks occurred in homes that had burned because power was unavailable to shut off the water supply.[140]

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.[141]

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.[142] In addition, an estimated 85,000 Southern California Edison customers lost electric power in the December 2017 fires.[143] 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

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135 VCFD. (2017, December 4). *Investigation Report.* Retrieved from: https://vcfd.org/images/news/Thomas-Fire-Investigation-Report_Redacted_3-14-19.pdf

136 Gold, R., Blunt, K. and Smith, R. (2019, January 13). *PG&E Sparked at Least 1,500 California Fires. Now the Utility Faces Collapse*. The Wall Street Journal. Retrieved from: https://www.wsj.com/articles/pg-e-sparked-at-least-1-500-california-fires-now-the-utility-faces-collapse-11547410768

137 Eavis, P. and Penn, I. (2019, May 15). *California Says PG&E Power Lines Caused Camp Fire That Killed 85*. The New York Times. Retrieved from: https://www.nytimes.com/2019/05/15/business/pge-fire.html

138 PG&E. (n.d.). PG&E's Wildfire Response. Retrieved December 13, 2017

139 CPUC. (2017, October 17). *Data Request and Response from PG&E re: de-energizing*. Retrieved from http://cpuc.ca.gov/general.aspx?id=6442454971

140 Personal communication. (2018, February 14). CUEA.

141 CPUC. (2017, October 27). *Oct. 9-27, 2017: Status updates from PG&E to the CPUC*. Retrieved from http://cpuc.ca.gov/general.aspx?id=6442454971

142 Horn, A., & Estrada, M. (2017, December 11). San Diego Gas and Electric restores power to areas affected by red-flag warning. *ABC 10 News*. Retrieved from https://www.10news.com/news/san-diego-gas-and-electric-crews-inspecting-power-lines-after-high-winds

143 Leventhal, B. (2017, December 10). Thomas Fire Leads to Santa Barbara Area Outage. *Southern California Gas Newsroom*. Retrieved from https://newsroom.edison.com/releases/releases-20171210

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.[144]

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.[145] These smaller publicly owned utilities may lack the resources to combat major wildfire damages and lawsuits.[146] Similarly, SCE found that failures in its electrical equipment was associated with one of the ignition points of the Thomas Fire.[147] SCE is also facing dozens of lawsuits due to the fire.[148]

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 power, as well as 3,238 customers in Ventura County.[149] 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.[150] In addition to outages due to damage, SCE also had to schedule additional power outages to make repairs to transmission lines.[151,152]

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.[153]

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144 Harris, M. (2018, January 4). Lawsuits allege Southern California Edison negligently started Thomas Fire. *Ventura County Star*. Retrieved from http://www.vcstar.com/story/news/local/2018/01/04/lawsuits-allege-southern-california-edison-negligently-started-thomas-fire/991192001/

145 Editor, Contributing. "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/.

146 Stein, Joshua, Andrew Teras, and Christopher Woodward. "Municipal Implications of the California Wildfires." Breckinridge Capital Advisors. Accessed June 25, 2019. https://www.breckinridge.com/insights/details/municipal-implications-of-the-california-wildfires/.

147 Carlson, Cheri. "Woolsey Fire: Power Outage Reported near Where Blaze Started." Ventura County Star. Accessed June 25, 2019. https://www.vcstar.com/story/news/local/2018/11/12/edison-reports-outage-near-woolsey-fire-california-wildfire/1982762002/.

148"Baron & Budd Sues Southern California Edison on Behalf of Los Angeles County and Malibu for Damages from Devastating Woolsey Fire." Business Wire. AP News. Accessed June 25, 2019. https://www.apnews.com/Business%20Wire/eafd087f14844e2182534c8f51b5e574.

149 Gutierrez-Jaime, Nisha. "Thousands of Residents in Vicinity of Woolsey Fire Without Power | KTLA." *KTLA News*, November 9, 2018. https://ktla.com/2018/11/09/thousands-of-residents-in-vicinity-of-woosley-fire-without-power/.

150 Milbourn, Mary Ann. "SCE Works with Fire Officials to Restore Power." Energized by Edison. Accessed June 25, 2019. https://energized.edison.com/sce-works-with-fire-officials-to-restore-power.

151 "Outage Center | Home - SCE." Accessed June 26, 2019. https://www.sce.com/outage-center.

152 "Large Swath Of Malibu Without Power Monday Due to Woolsey Fire Repairs," November 19, 2018. https://losangeles.cbslocal.com/2018/11/19/large-swath-of-malibu-without-power-monday-due-to-woolsey-fire-repairs/.

153 "SCE Provides Update on Woolsey and Hill Wildfires," November 16, 2018. https://www.businesswire.com/news/home/20181115006114/en/SCE-Update-Woolsey-Hill-Wildfires.

Asset 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 had been bringing gas to a home.[154] Debris flow caused a gas leak, resulting in a house fire on January 9, 2018.[155] 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.[156,157,158,159] 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).[160] 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.[161]

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.

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

154 Gazzar, Brenda. Daily News, "SoCalGas crews work to restore service to dozens of customers after gas line damaged in Burbank," 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/
155 Staff Report, NBC Los Angeles, "Thirteen Dead in Powerful Storm, Mudslides in Santa Barbara County," January 9, 2018, https://www.nbclosangeles.com/news/local/Explosion-Debris-Flow-Reported-After-House-Fire-in-Montecito-468430023.html
156 SoCalGas, Tweet, January 13, 2018, https://twitter.com/socalgas/status/952279697529872384
157 SoCalGas, Tweet, January 16, 2018, https://twitter.com/socalgas/status/953423811604488192
158 SoCalGas, Tweet, January 30, 2018, https://twitter.com/socalgas/status/958436290873176064
159 Southern California Gas, Montecito Updates, updated February 2, 2018, accessed February 20, 2018, and April 18, 2018, https://www.socalgas.com/newsroom/montecito.
160 Personal communication. (2018, February 14). CUEA.
161 Personal communication. (2018, January 22). 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.[162] 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. [163] Other compression stations, such as those operated by SoCalGas, can be operated without grid electricity using on-site generation.[164]

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.[165] Without power, gas stations may also be affected, which could affect people who need to evacuate.[166] Additionally, electricity and telecommunications lines are co-located and, in some cases, telecommunications will depend on electricity supply.[167] This can prevent residents from receiving communications and instructions from emergency managers. Examples of these interdependencies are shown in Figure 29. These issues will be discussed further in the following sections.

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[162] 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
[163] USDOT, Pipeline and Hazardous Materials Safety Administration (PHMSA). (2019, June 5). *Pipeline Incident Flagged Files*. Retrieved from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-flagged-files
[164] SoCalGas. 2014. *North-South Project: Updated Report, Adelanto Compressor Station*. Retrieved from https://www.socalgas.com/regulatory/documents/a-13-12-013/Attachment%20A_%20Updated%20Buczkowski%20Supplemental%20Testimony%20Final%20Redacted.pdf
[165] Moser, Susanne and Juliette Finzi Hart. 2018. The Adaptation Blindspot: Teleconnected and Cascading Impacts of Climate Change on the Electrical Grid and Lifelines in Los Angeles. California's Fourth Climate Assessment.
[166] Ibid.
[167] Ibid.

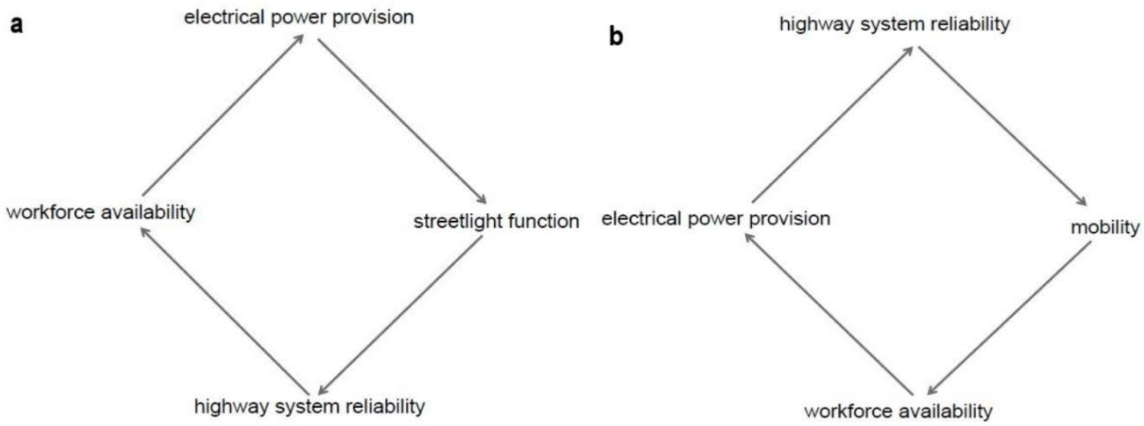

Figure 29. Reinforcing loops that show the impact of electrical power provision on different sectors.[168]

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 IVs, many of whom are housed at home, who would be trapped. Many would not have the financial resources necessary to purchase and maintain a backup power source to support these services.[169] Power outages could also result in risks to food safety due to losses of refrigeration.[170]

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.[171]

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.[172]

[168] Ibid.
[169] Personal communication. (2019, April 23). CUEA.
[170] Moser, Susanne and Juliette Finzi Hart. 2018. The Adaptation Blindspot: Teleconnected and Cascading Impacts of Climate Change on the Electrical Grid and Lifelines in Los Angeles. California’s Fourth Climate Assessment.
[171] California Energy Commission. (2019, April 8). *Joint Agency Workshop on Building Decarbonization.* Retrieved from https://www.youtube.com/watch?v=76L_tNDXSQI&feature=youtu.be&t=2h46m48s
[172] Ellison, James F., Corbet, Thomas Frank, and Robert E. Brooks. Sandia National Laboratories. “Natural Gas Network Resiliency to a ‘Shakeout Scenario’ Earthquake.,” June 1, 2013. https://doi.org/10.2172/1089984.

Examples of resilience

Natural Gas

In general, there is very little evidence that loss of natural gas service negatively impacted the response 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.[173] For example, in response to the service disruptions, PG&E provided temporary LNG/CNG service to critical customers, such as hospitals, in their area as soon as transport access was restored.[174]

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.[175]

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.[176] 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 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

[173] Personal communication. (2018, February 14). CUEA.
[174] Personal communication. (2018, January 15-16). PG&E.
[175] Piazza et al., Proceedings of the 2018 12th International Pipeline Conference, "Advances in Satellite Data Analytics for Natural Disaster Assessment and Application to Pipeline Safety," in press.
[176] SoCalGas, "Natural Gas System Operator Safety Plan: Chapter 8," February 22, 2018. Obtained via personal communication with SoCalGas.

use resources in the time-critical post-event assessment.[177] Similarly, their aerial drones with methane radar sensors and GoPro high definition cameras were able to detect leaks and rapidly assess damage. [178] SoCalGas now performs post-wildfire reconnaissance to determine areas of high risk that need greater monitoring and/or preventative measures.

Figure 30. SoCalGas employees, including CEO Patti Wagner (right) survey damage and prepare for repair and restoration work after the Montecito mudslides. Image 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.[179]

After Harvey made landfall on August 25, 2017, Gas Operations resumed normal operations on September 8.[180]

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

[177] Piazza et al., Proceedings of the 2018 12th International Pipeline Conference, "Advances in Satellite Data Analytics for Natural Disaster Assessment and Application to Pipeline Safety," in press.
[178] Personal communication. (2018, January 22). SoCalGas.
[179] CenterPoint Energy. 2018. Texas Strong: Hurricane Harvey Response and Restoration. https://www.energy.gov/sites/prod/files/2018/02/f49/2_Emergency%20Response%20and%20Resilience%20Panel%20-%20Steve%20Greenley%2C%20CenterPoint%20Energy.pdf
[180] Ibid.

the December 2017 wildfires.[181] 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.[182,183]

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.[184]

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.[185]

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.[186]

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.[187] Similarly, intrastate electric co-ops gathered hundreds of workers in affected Texas areas to restore power and repair damages.[188] In areas affected by Hurricane Irma, as many as 50,000 utility workers from across the country assembled via

[181] Nikolewski, R. (2017, December 11). California fires: SDG&E expects to fully restore power Tuesday. *The San Diego Union Tribune*. Retrieved from https://www.sandiegouniontribune.com/news/public-safety/sd-fi-power-restoration-20171211-story.html
[182] Rafeedie Khoury, F. R. (2019, Februrary 6). *Southern California Edison Company's (U 338-E) 2019 Wildfire Mitigation Plan.* Retrieved from Southern California Edison Company: https://www.edison.com/content/dam/eix/documents/investors/wildfires-document-library/20190206-wildfire-mitigation-plan.pdf
[183] “Grid Resiliency.” SCE.com. Accessed June 25, 2019. http://www.sce.com/ko/safety/wildfire.
[184] CenterPoint Energy. 2018. Texas Strong: Hurricane Harvey Response and Restoration. https://www.energy.gov/sites/prod/files/2018/02/f49/2_Emergency%20Response%20and%20Resilience%20Panel%20-%20Steve%20Greenley%2C%20CenterPoint%20Energy.pdf
[185] Ibid.
[186] Ibid.
[187] Edison Electric Institute, “Harvey Response: Power Restoration Is a Team Effort,” August 30, 2017, www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/ma_map.pdf
[188] Holly, Derrill E. National Rural Electric Cooperative Association, “Texas Co-ops Continue Hurricane Recovery,” August 29, 2017, https://www.electric.coop/texas-co-ops-continue-hurricane-recovery/

mutual assistance to help with restoration and repair efforts.[189] 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.[190]

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.[191]

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.[192]

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[189] Baltz, Tripp. Bloomberg Bureau of National Affairs, "50,000 Utility Workers Strive to Get Power Back Up After Irma," September 12, 2017, https://www.bna.com/50000-utility-workers-n57982087838/

[190] Reil, B. (2018). *Hurricane Michael: Power Restored to 95 Percent of Customers as Industry Works to Rebuild the Most Severely Damaged Infrastructure.* Electricity Subsector Coordinating Council. Retrieved from http://www.electricitysubsector.org/ESCC%20Press%20Release_10.16.18_FINAL.pdf?v=1.0

[191] Personal communication. (2018, February 19). Greater Harris County Local Emergency Planning Committee.

[192] Personal communication. (2018, February 14). CUEA.

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.[193]

In Florida during Hurricane Michael, some remote water systems with natural gas generators lost service when tree roots pulled up the gas lines.[194] A television station in Panama City, FL lost its main power and its backup generator, leaving the area without local television news.[195]

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.[196] 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.[197]

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.[198] According to the CUEA, these water pumps are reliant on the electrical grid and do not have backup generators.[199]

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

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[193] St. John, J. (2017, September 11). Post-Irma, Utilities Face ‘One of the Largest Industry Restoration Efforts in US History’. *Greenteach Media*. Retrieved from https://www.greentechmedia.com/articles/read/post-hurricane-irma-utilities-face-one-of-largest-industry-restoration-effo
[194] Personal communication. (2019, April 19). Florida Rural Water Association.
[195] Venta, L. (2018, October 10). *Hurricane Michael Takes Panama City Off the Air*. Retrieved April 10, 2019, from https://radioinsight.com/headlines/171070/hurricane-michael-takes-panama-city-off-the-air/
[196] Personal communication. (2019, April 23). CUEA.
[197] Personal communication. (2019, April 23). CUEA.
[198] Harris, M. (2018, January 4). Lawsuits allege Southern California Edison negligently started Thomas Fire. *Ventura County Star*. Retrieved from http://www.vcstar.com/story/news/local/2018/01/04/lawsuits-allege-southern-california-edison-negligently-started-thomas-fire/991192001/
[199] Personal communication. (2018, February 14). CUEA.

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.[200]

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.[201]

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.[202]

Examples of Resilience

Customer Resilience

In Florida and Texas, hospitals with gas-fired backup generators cited these systems as an important disaster response strategy. Memorial hospital in Florida was able to maintain critical 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.[203]

Combined Heat and Power (CHP) has allowed emergency services to improve resilience where implemented during instances of electricity disruptions.[204] 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

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[200] Weir, W. (2011, August 29). When Power Generator Fails, Hospital Takes Extreme Measure of Evacuation. *Hartford Courant*. Retrieved from https://www.courant.com/health/hc-xpm-2011-08-29-hc-jmh-hurricane-evacuation-0830-20110829-story.html

[201] CBS and AP. (2012, November 2). What caused generators to fail at NYC hospitals? *CBS News*. Retrieved from https://www.cbsnews.com/news/what-caused-generators-to-fail-at-nyc-hospitals/

[202] Fink, S. (2009, August 27). The Deadly Choices at Memorial. *ProPublica*. Retrieved from https://www.propublica.org/article/the-deadly-choices-at-memorial-826

[203] Cravey, Beth Reese. Florida Times-Union Jacksonville.com, "Hurricane Irma: How Jacksonville-area hospitals responded to latest weather crisis," September 15, 2017 (updated September 18, 2017), http://jacksonville.com/news/metro/2017-09-15/hurricane-irma-how-jacksonville-area-hospitals-responded-latest-weather-crisis

[204] EPA. (2019, May 10). *Combined Heat and Power (CHP) Partnership*. Retrieved June 19, 2019, from https://www.epa.gov/chp

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.[205]

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.[206]

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.[207] 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)[208] and Bay Medical (where no water and a flooded fourth floor made care difficult to administer).[209]

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 disconnected from the grid. This allowed them to maintain full power and keep refrigerators running, avoiding losses.[210,211]

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

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[205] Kogan, Gene. U.S. DOE Pacific CHP Technical Assistance Partnership, "Mitigating Risks & Resiliency with Combined Heat and Power (CHP)," January 18, 2018.

[206] Schuett, Jerry A. PE, "The University of Texas Medical Branch (UTMB) at Galveston: Energy Security on a Barrier Island," December 6, 2017, https://www.districtenergy.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=f2eade25-8123-d65d-e73c-407b0a4b6ced&forceDialog=1

[207] Evans, M. (2018, October 12). Hurricane Michael Forces Florida Hospitals to Shut Down. *The Wall Street Journal*. Retrieved from https://www.wsj.com/articles/hurricane-michael-forces-florida-hospitals-to-shut-down-1539287788

[208] Lohr, D. (2018, October 11). Hurricane Michael Forces Florida Hospitals to Evacuate. *Huffington Post*. Retrieved from https://www.huffpost.com/entry/hurricane-michael-forces-florida-hospitals-to-evacuate_n_5bbfbcb5e4b040bb4e805efe

[209] Fausset, R., Fink , S., & Haag, M. (2018, October 11). Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients. *The New York Times*. Retrieved from https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html

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

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

Association worked to move generators from system to system as power was restored.[212] Similarly, the Florida State Emergency Response Team purchased generators to run traffic signals in impacted areas, with 700 generators available in total.[213]

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.)[214]

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 common that natural gas 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.[215] 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.[216] Southern California Edison 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

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

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

[214] Personal communication. (2019, May 1). LA Water Board.

[215] USDOE. 2019. *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

[216] Personal communication. (2018, February 14). CUEA.

customers who declined.[217] 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.[218]

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.[219] 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. [220]

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.[221] Many other roads in the area were impassible, blocked by debris, obscured by heavy smoke, or cut off to prevent

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[217] Aoyagi-Stom, C. (2017, December 8). SCE Conducts Damage Assessments as SoCal Wildfires Continue to Burn. *Inside Edison*. Retrieved from https://www.insideedison.com/stories/sce-begins-damage-assessments-as-socal-wildfires-continue-to-burn

[218] Personal communication. (2018, February 14). CUEA.

[219] USDOT. (2018, October 15). *US Department of Transportation Resources for Hurricane Michael*. Retrieved April 24, 2019, from https://www.transportation.gov/briefing-room/us-department-transportation-resources-hurricane-michael

[220] Ibid.

[221] "Caltrans District 7 - Category - Page," 2018. http://www.dot.ca.gov/d7/projects/2018fire/index.html.

access.[222] After the wildfires, many roads were also at risk of flooding and mudslides.[223] Although not documented in reports, power outages may also impact traffic signals.[224]

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.[225] 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.[226] The Pacific Coast Highway, the only road south of the Santa Monica Mountains, experienced major traffic jams as people funneled in.[227] 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.[228] While residents drove down the mountain, emergency responders had to move against traffic to fight the fire, maintain safety, and remove debris.[229]

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.[230]

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.[231]

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

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[222] Department of Homeland Security, "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary," National Protection and Programs Directorate, November 10, 2018

[223] Los Angeles County Emergency Operations Center. (2018, November 21). *Press Release.* DEBRIS, MUD, OTHER HAZARDS EXPECTED IN WOOLSEY FIRE AREAS. Retrieved from: https://www.lacounty.gov/wp-content/uploads/PR-No.-51-DebrisMudHazards_11-21-2018.pdf

[224] "Outage Center | Home - SCE." Accessed June 26, 2019. https://www.sce.com/outage-center.

[225] Ibid.

[226] Personal communication. (2019, April 23). CUEA.

[227] Sawicki, Emily. "What Went Wrong With the Woolsey Fire? | News | Malibutimes.Com," December 5, 2018. http://www.malibutimes.com/news/article_8d17aad4-f8c6-11e8-81ff-e7f7f507256c.html.

[228] Nicas, Jack. "Forced Out by Deadly Fires, Then Trapped in Traffic - The New York Times." *The New York Times*, November 11, 2018. https://www.nytimes.com/2018/11/11/us/california-fire-paradise.html.

[229] Personal communication. (2019, April 23). CUEA.

[230] Personal communication. (2019, April 19). Florida Rural Water Association.

[231] "Michael's Death Toll Jumps as Crews Search for Survivors - Live Updates," October 12, 2018. https://www.cbsnews.com/live-news/hurricane-michael-damage-florida-flooding-georgia-power-outage-weather-deaths-today-live-updates/.

disruptions. One estimate found that every week Highway 101 was closed resulted in approximately $6.6 million of visitor spending in Santa Barbara County.[232]

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 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.[233]

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.[234]

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232 Baldwin, Gillian. "Santa Barbara Tourism Reels, Recovers After Fire, Mudslides - The Santa Barbara Independent." Accessed June 25, 2019. https://www.independent.com/2018/02/05/santa-barbara-tourism-reels-recovers-after-fire-mudslides/.

233 Bates, Michael. Next-Gen Transportation News, "Natural Gas Infrastructure in Good Shape During Harvey," September 5, 2017, https://ngtnews.com/natural-gas-infrastructure-good-shape-harvey

234 Personal Communication. (2018, January 31). Caltrans.

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.[235] 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.[236] 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.[237]

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. [238] After the Woolsey Fire, customers of the Los 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

[235] Personal communication. (2019, April 19). Florida Rural Water Association.
[236] Florida Rural Water Association. (2018, October 19). *Hurricane Michael*. Retrieved April 22, 2019, from https://www.frwa.net/hurricane-michael-updates.html
[237] Personal communication. (2019, April 19). Florida Rural Water Association.
[238] Hamilton, Matt, A. Tchekmedyian, B. Oreskes, L. Nelson, J. 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.

could have introduced bacteria and other organisms into the supply.[239] Figure 18 shows the extent of the Las Virgenes Municipal Water District (LVMWD) within the fire zone.

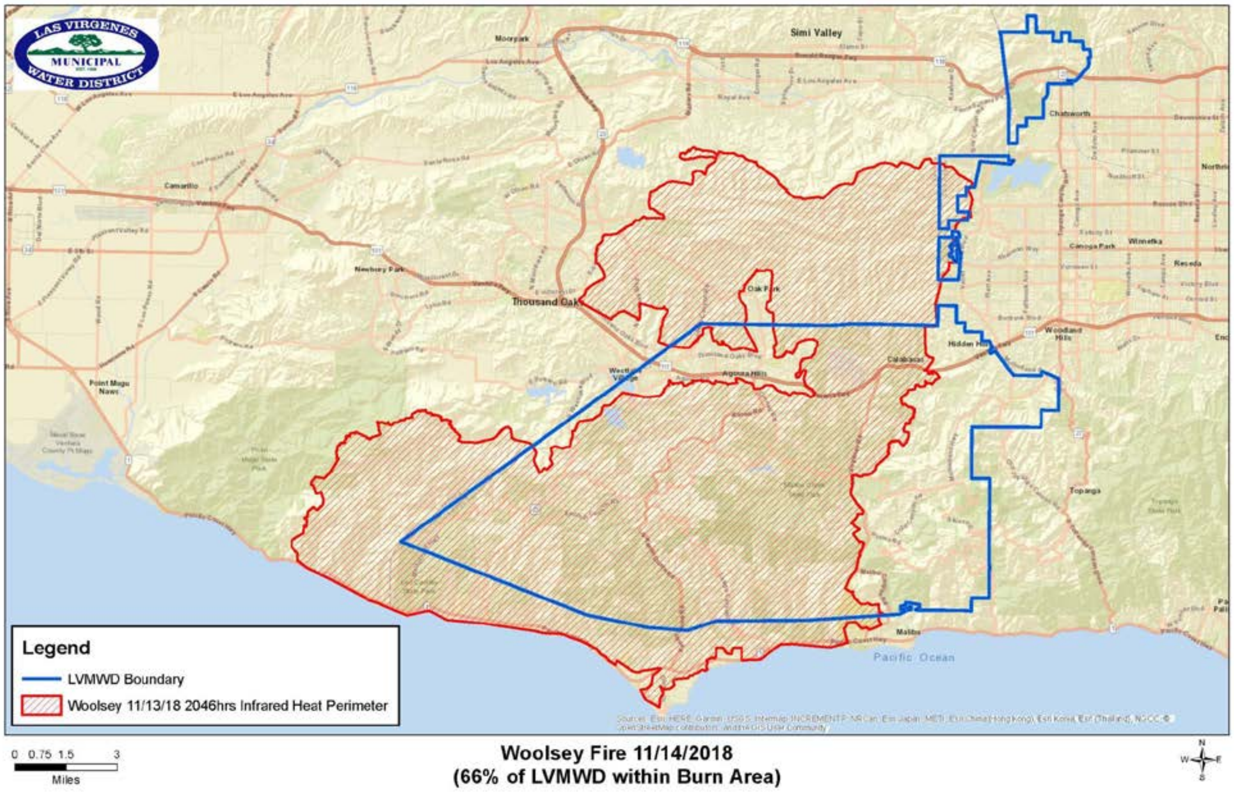

Figure 31. Overlay of Las Virgenes Water District service area with the Woolsey Fire zone.[240]

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.[241] 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.[242] 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.[243] After the Woolsey Fire, the Los Angeles County Department of Public Health warned residents that septic tanks could have

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239 "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.

240 Las Virgenes Municipal Water District, "Woolsey Fire – Recovery Information and Help," January 15, 2019, https://www.lvmwd.com/for-customers/woolsey-fire-help-page

241 Personal communication. (2019, April 23). CUEA.

242 Personal communication. (2019, April 23). CUEA.

243 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.

been damaged by the heat of the fire, and associated collapse or caving could cause contamination.[244] The Camp Fire in Paradise created water contamination impacts where toxic releases entered the damaged distribution system, and state agency representatives have estimated needed replacements at $300M.[245] 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.[246]

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.[247] 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.[248] 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.[249] 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.[250] 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. [251]

[244] County of Los Angeles Public Health. (2018, November 30). Health Alert: Septic Tank Advisory; Advisory in effect for Woolsey Fire burn areas in unincorporated portions of Malibu. Retrieved from: https://www.lacounty.gov/wp-content/uploads/11.30.18-Septic-Tank-Advisory-1.pdf

[245] 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.

[246] Personal communication. (2019, May 1). LA Water Boards.

[247] Personal communication. (2019, May 1). LA Water Boards.

[248] Sawicki, Emily. “What Went Wrong With the Woolsey Fire? | News | Malibutimes.Com,” December 5, 2018. http://www.malibutimes.com/news/article_8d17aad4-f8c6-11e8-81ff-e7f7f507256c.html.

[249] Companion CARB Letter from Jeff O’Keefe

[250] Companion CARB Letter from Jeff O’Keefe

[251] Personal communication. (2019, May 1). LA Water Board.

The fire and fire suppression activities can also contaminate the water supply.[252] 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.[253] 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.[254]

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.[255] The hospital itself did not suffer breaches during the hurricane.[256] 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.[257]

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.[258] 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.[259] In many areas, multiple utilities serve neighboring areas and communicating with the public about public safety,

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252 Department of Homeland Security, "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary," National Protection and Programs Directorate, November 10, 2018

253 "When the Smoke Clears: Aftereffects of Wildfires on Communities' Water Quality." Babcock Laboratories, Inc. Accessed June 26, 2019. https://www.babcocklabs.com/news/when-the-smoke-clears-aftereffects-of-wildfires-on-communities-water-quality/2018.

254 Burns, Melinda. "Next Debris Flow Could Take Different, Unknown Path - The Santa Barbara Independent." Accessed June 26, 2019. https://www.independent.com/2018/03/19/next-debris-flow-could-take-different-unknown-path/.

255 CBS. (2018, October 12). Michael's death toll jumps as crews search for survivors - live updates. *CBS News*. Retrieved from https://www.cbsnews.com/live-news/hurricane-michael-damage-florida-flooding-georgia-power-outage-weather-deaths-today-live-updates/

256 Fausset, R., Fink , S., & Haag, M. (2018, October 11). Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients. *The New York Times*. Retrieved from https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html

257 Ibid.

258 Personal communication. (2019, April 19). Florida Rural Water Association.

259 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/

including boil water advisories; in these cases, some people may have not been aware of issues with their system.[260]

In Paradise, CA, which was severely impacted by the Camp Fire, residents returning to the area have been strictly advised to not use tap water for any purposes. This is 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 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.[261,262]

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.[263]

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.[264] 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.[265]

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

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[260] Personal communication. (2019, May 1). LA Water Board.

[261] Siegler, Kirk. April 16, 2019. "Paradise, Calif., Water is Contaminated but Residents are Moving Back Anyway." NPR. https://www.npr.org/2019/04/16/713430751/paradise-calif-water-is-contaminated-but-residents-are-moving-back-anyway

[262] AP. April 18, 2019. "Water in Paradise, site of worst California fire, contaminated with cancer chemical." San Francisco Chronicle. https://www.sfchronicle.com/bayarea/article/Water-in-Paradise-site-of-worst-California-fire-13779109.php#photo-16588392

[263] Carlson, Cheri. "Water Agencies Band Together, Seek Changes after Destructive Woolsey, Thomas Fires." Ventura County Star. Accessed June 26, 2019. https://www.vcstar.com/story/news/local/2019/03/04/california-water-agencies-band-together-after-destructive-woolsey-thomas-fires/2957790002/.

[264] Personal communication. (2019, May 1). LA Water Board.

[265] Personal communication. (2019, May 1). LA Water Board.

collating the various activity to ensure that response needs were being met and resources were being allocated quickly and effectively.[266]

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.[267] 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.[268] In Bay County, where Hurricane Michael made landfall, all modes of 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).[269,270] Lines were downed due to the high winds, and uprooted trees damaged or destroyed underground fiber lines. Verizon stated that they faced "unprecedented damage."[271]

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.[272]

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

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266 Personal communication. (2019, May 1). LA Water Board.

267 Baron, Ethan. The Mercury News, "Danger, road closures hamper efforts to restore phone and internet service in North Bay fire areas," 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/

268 Venta, L. (2018, October 10). *Hurricane Michael Takes Panama City Off the Air*. Retrieved April 10, 2019, from https://radioinsight.com/headlines/171070/hurricane-michael-takes-panama-city-off-the-air/

269 Chang, A. (2018, October 22). *Hurricane Michael's Damage to Communciations Systems Has Slowed Recovery.* Retrieved April 22, 2019, from NPR: https://www.npr.org/2018/10/22/659611105/hurricane-michaels-damage-to-communications-systems-has-slowed-recovery

270 Brodkin, J. (2018, October 15). *Verizon fiber suffered "unprecedented" damage from Hurricane Michael.* Retrieved April 22, 2019, from ARS Technica: https://arstechnica.com/information-technology/2018/10/verizon-fiber-suffered-unprecedented-damage-from-hurricane-michael/

271 Chang, A. (2018, October 22). *Hurricane Michael's Damage to Communciations Systems Has Slowed Recovery.* Retrieved April 22, 2019, from NPR: https://www.npr.org/2018/10/22/659611105/hurricane-michaels-damage-to-communications-systems-has-slowed-recovery

272 Verizon. (2018, October 23). *Hurricane Michael network updates*. Retrieved April 22, 2019, from https://www.verizon.com/about/news/hurricane-michael-network-updates

smoke can disrupt line-of-sight transmissions.[273] 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.[274] More than 45% of survey respondents reported losing all cellular service during the October 2017 fire.[275] 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.[276,277,278] 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.[279]

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 companies failed due to high traffic on the networks during the fires.[280] 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.[281]

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

[273] Department of Homeland Security, "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary," National Protection and Programs Directorate, November 10, 2018.
[274] North Bay/North Coast Broadband Consortium. (2018). *Northern California Firestorm 2017.* Telecommunications Outage Report. Retrieved from http://www.mendocinobroadband.org/wp-content/uploads/1.-NBNCBC-Telecommunications-Outage-Report-2017-Firestorm.pdf
[275] Ibid.
[276] The Wall Street Transcript. (2018, November 14). Verizon Communications Inc.: California wildfire network updates. Retrieved from https://www.twst.com/update/verizon-communications-inc-california-wildfire-network-updates-2/
[277] Verizon. (2018a, November 21). *California wildfire network updates*. Retrieved April 30, 2019, from https://www.verizon.com/about/news/california-wildfire-network-updates
[278] T-Mobile. (2018, November 9). T-Mobile Responds to California Wildfires. Retrieved from https://www.t-mobile.com/news/cal-wildfire
[279] Personal communication. (2019, April 23). CUEA.
[280] Personal communication. (2019, April 23). CUEA.
[281] Brodkin, J. (2018, October 15). *Verizon fiber suffered "unprecedented" damage from Hurricane Michael.* Retrieved April 22, 2019, from ARS Technica: https://arstechnica.com/information-technology/2018/10/verizon-fiber-suffered-unprecedented-damage-from-hurricane-michael/

people did not receive any warning to evacuate.[282] 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.[283,284] 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.[285] 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.[286] 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."[287] In addition, first responders couldn't communicate among teams, which posed a hurdle to search and rescue operations. Fifteen answering points in Florida and Georgia had to reroute their calls, making it more difficult for people to find help and alert first responders.[288]

Similarly, disruptions to communication networks hindered emergency response and firefighting efforts during the California wildfires.[289] 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.[290]

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

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[282] North Bay/North Coast Broadband Consortium. (2018). *Northern California Firestorm 2017.* Telecommunications Outage Report. Retrieved from http://www.mendocinobroadband.org/wp-content/uploads/1.-NBNCBC-Telecommunications-Outage-Report-2017-Firestorm.pdf
[283] Ibid.
[284] 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/
[285] Serna, Joseph, Paige St. John, and Rong-Gong Lin II. "Alert systems aren't working." Los Angeles Times. 20 November 2018.
[286] Chang, A. (2018, October 22). *Hurricane Michael's Damage to Communciations Systems Has Slowed Recovery.* Retrieved April 22, 2019, from NPR: https://www.npr.org/2018/10/22/659611105/hurricane-michaels-damage-to-communications-systems-has-slowed-recovery
[287] Ibid.
[288] Fausset, R., Fink , S., & Haag, M. (2018, October 11). Hospitals Pummeled by Hurricane Michael Scramble to Evacuate Patients. *The New York Times*. Retrieved from https://www.nytimes.com/2018/10/11/us/hurricane-michael-hospitals-damage-florida.html
[289] Department of Homeland Security, "California Wildfires: Woolsey and Hill – Projected Infrastructure Impact Summary," National Protection and Programs Directorate, November 10, 2018
[290] Personal communication. (2019, May 1). LA Water Board.

means of communication, including phones, TVs, and internet (76% of survey respondents).[291] 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.[292] During the Woolsey and Hill Fires in Southern California, Verizon 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. The telecommunications company 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.[293]

During the Woolsey Fire, service providers also deployed mobile and emergency resources, such as T-Mobile’s and Verizon’s COWs or Cell On Light Trucks (COLTs) to provide coverage where it was safe to do so.[294] Verizon also loaned wireless equipment to emergency responders to compensate for problems on the overloaded networks.[295]

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[291] North Bay/North Coast Broadband Consortium. (2018). *Northern California Firestorm 2017.* Telecommunications Outage Report. Retrieved from http://www.mendocinobroadband.org/wp-content/uploads/1.-NBNCBC-Telecommunications-Outage-Report-2017-Firestorm.pdf

[292] AT&T. (2018, October 31). *AT&T Response to Hurricane Michael*. Retrieved April 22, 2019, from https://about.att.com/pages/hurricane_michael

[293] Verizon. (2018a, November 21). *California wildfire network updates*. Retrieved April 30, 2019, from https://www.verizon.com/about/news/california-wildfire-network-updates

[294] T-Mobile. (2018, November 9). T-Mobile Responds to California Wildfires. Retrieved from https://www.t-mobile.com/news/cal-wildfire

[295] The Wall Street Transcript. (2018, November 14). Verizon Communications Inc.: California wildfire network updates. Retrieved from https://www.twst.com/update/verizon-communications-inc-california-wildfire-network-updates-2/

Lessons Learned

These case studies found that natural gas infrastructure and services were relatively resilient to hurricanes, wildfires, and mudslides. 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. Although not documented at length, 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.

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.

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 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. 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. 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.[296]

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."[297] 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.

[296] Natural Gas Council, "Natural Gas Systems: Reliable & Resilient," July 2017, http://www.ngsa.org/download/analysis_studies/NGC-Reliable-Resilient-Nat-Gas-WHITE-PAPER-Final.pdf
[297] 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/

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. Figure 32 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.

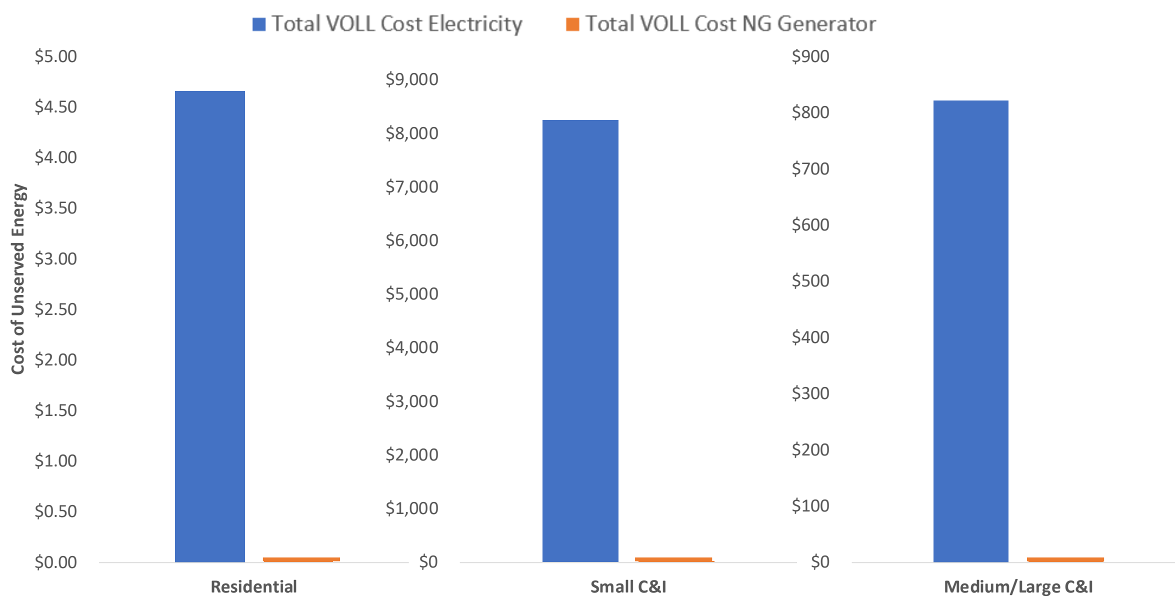

Figure 32. VOLL based on expected disruptions from electric utility and natural gas generator.

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 sent a signal to valves to shut off the flow in that pipeline during mudslides. 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.

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. 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.[298] 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 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.

[298] Personal communication. (2019, April 23). CUEA.

Insights and Recommendations

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.[299] Similarly, SoCalGas is considering increasing the frequency of valves, especially in geohazard areas such as fault lines.[300] This is a particularly useful strategy in light of the high cost and time intensity of restoring service post-isolation.

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.[301] 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.

Coordination and Communication

Expansion of outreach and services to first responders. Interviewees expressed a desire to use natural gas during emergency operations more based on reliability of supply, air quality benefits, and the potential for utilizing low-carbon fuels through 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, fuel storage tanks, tube trailers, and other technologies to support emergency vehicles and generators during events.
- Outreach efforts could center 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 a variety of emergency response personnel. The California Public Utilities Commission (CPUC) and the California Governor's Office of Emergency Services (CalOES) have a 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. CUEA asserts that this is the most aggressive preparation

[299] Personal communication. (2018, January 15-16). PG&E.
[300] Personal communication. (2018, January 22). SoCalGas.
[301] Ibid.

program of this type in any state, and provides a model for other states as a result.[302] 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.[303]

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 resources and staff utilities had on standby. 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.[304] 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.

[302] Ibid
[303] Ibid
[304] Ibid

Additional Research Needs to Better Understand and Improve Natural Gas Resilience

The list below illustrates areas for further research. These recommendations are 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*, is being conducted in partnership with UC Irvine and is due to be finalized in September 2019. This work is investigating the climate vulnerability of natural gas energy infrastructure in southern California given concurrent, compounding, and dependent climate extremes. Hazards included in this analysis are 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?
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.[305] 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.[306]

[305] 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/
[306] Ibid.

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 reduced air pollution from petroleum products and 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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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.

“Welcome to FIRE.” Accessed July 1, 2019. https://calfire.ca.gov/.

Wells, J. (2018, October 12). Hurricane Michael damage so extensive, company inspecting with boats and drones. Duke Energy. Retrieved from https://illumination.duke-energy.com/articles/hurricane-michael-damage-so-extensive-company-inspecting-with-boats-and-drones

“When the Smoke Clears: Aftereffects of Wildfires on Communities’ Water Quality.” Babcock Laboratories, Inc. Accessed June 26, 2019. https://www.babcocklabs.com/news/when-the-smoke-clears-aftereffects-of-wildfires-on-communities-water-quality/2018.

“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.

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,[307] 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,[308] 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.[309]

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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307 Natural Gas Council, "Natural Gas Systems: Reliable & Resilient," July 2017, http://www.ngsa.org/download/analysis_studies/NGC-Reliable-Resilient-Nat-Gas-WHITE-PAPER-Final.pdf.

308 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/

309 Sandia National Laboratories, "Natural Gas Network Resiliency to a 'Shakeout Scenario' Earthquake," June 2013, https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2013/134938.pdf

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.[310] 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 A 1 and Table A 2 proved insightful.

Table A 1. 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)

[310] CPUC. (2018, January 31). *Fire Safety and Utility Infrastructure En Banc*. Retrieved from http://www.cpuc.ca.gov/2018FireEnBanc/

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 A 2. 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)

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

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) 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.

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 A 1 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.

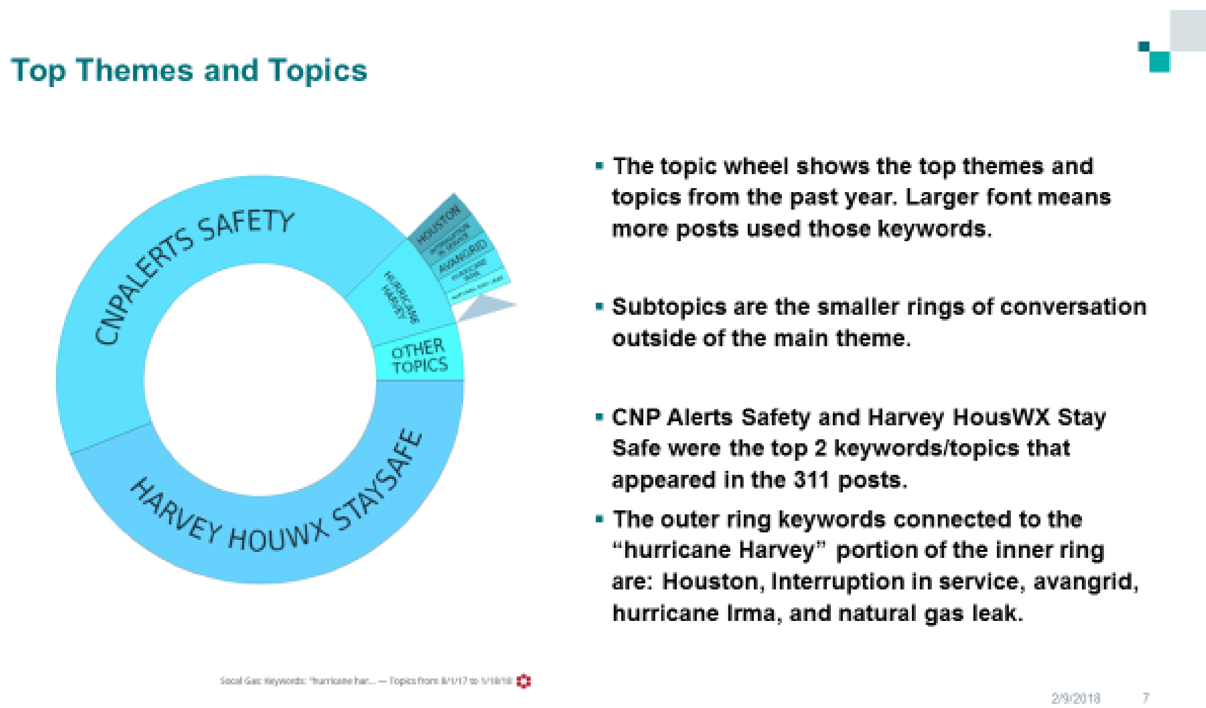

Figure A 1. Example of results from social listening experiment showing top themes and topics for Hurricane Harvey. Image source: ICF

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 was obtained from US EPA's AP-42 database[311], 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 calculate combustion estimates are in line with estimates reported by the California Air Resources Board (CARB)[312].

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.[313] 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.[314]

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

[312] 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

[313] Harvey, A., Jurgensen, M., & Page-Dumroese, D. (2002). Fire and Fire-Suppression Impacts on Forest-Soil Carbon. In J. Kimble, R. Lal, R. Birdsey, & L. Heath (Eds.), *The Potential of U.S. Forest Soils to Sequester Carbon and Mitigate the Greenhouse Effect*. https://doi.org/10.1201/9781420032277.ch13

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

The table below summarizes calculated CO_2 and CH_4 emissions, and loss in carbon stored in forests and provides comparison to other sources.[315]

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

<table>
<tr><th>Year</th><th>Area Burned (acres)[316]</th><th>CO_2 Emissions ($MMTCO_2e$)</th><th>CH_4 Emissions ($MMTCO_2e$)[317]</th><th>Sequestration loss ($MMTCO_2e$)</th><th>Total GHG Impact ($MMTCO_2e$)</th><th>GHGs/Acre Burned (MTCO2e/ acre)</th><th>Total GHG Impact ($MMTCO_2e$)</th><th>GHGs/Acre Burned (MTCO2e/ acre)</th></tr>
<tr><td>Source</td><td></td><td>US EPA</td><td>US EPA</td><td>US FS</td><td>EPA & FS</td><td>EPA & FS</td><td>Winrock</td><td>Winrock</td></tr>
<tr><td>2017</td><td>1,248,606</td><td>30.6</td><td>3.425</td><td>77.4</td><td>111.4</td><td rowspan="2">89.34</td><td>308.4</td><td rowspan="2">247.0</td></tr>
<tr><td>2018</td><td>1,671,203</td><td>41.1</td><td>4.575</td><td>103.6</td><td>149.3</td><td>412.9</td></tr>
</table>

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 $MMTCO_2e$).[318] Figure 32 shows a visual summary of the Table B1 results compared with California's non-wildfire emissions from the 2016 State Inventory.

[315] 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.

[316] CalFire Incident Information, 2017 and 2018. http://cdfdata.fire.ca.gov/incidents/incidents_statsevents.

[317] CO_2 equivalency estimated using AR4 GWP.

[318] California Greenhouse Gas Emission Inventory - 2018 Edition. https://www.arb.ca.gov/cc/inventory/data/data.htm.

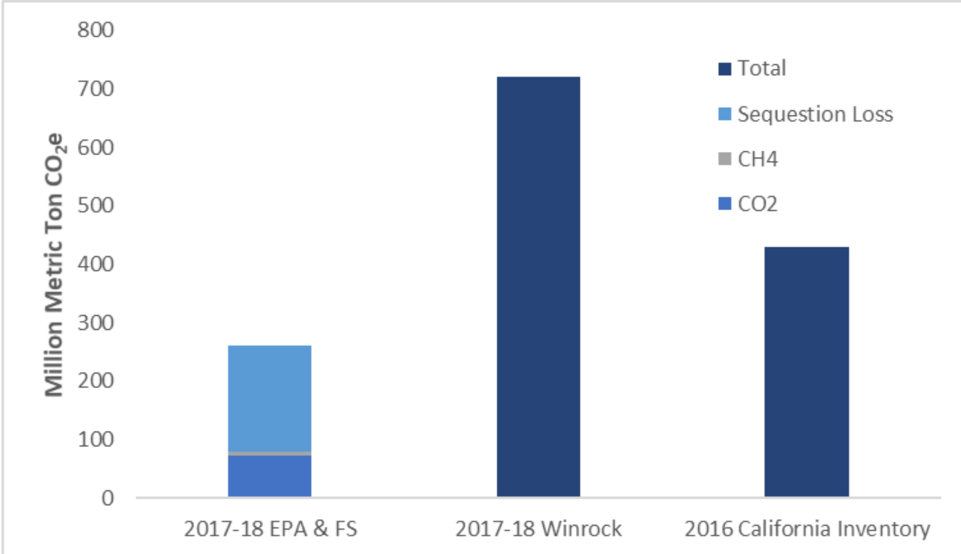

Figure 33. Comparison of two methods for estimating wildfire emissions and California's 2016 non-wildfire emissions.

The results from the combined EPA and USFS method (about 250 $MMTCO_2e$ from 2017-18) is equivalent to the annual emissions from over 50 million passenger vehicles in the US.[319]

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.

[319] 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. [320]

Table C 1 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 C 1. 2017 and 2018 California Fire Statistics.[321]

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.[322] Short-term exposures to the air pollutant emissions associated with wildfires can increase the risk of exacerbating asthma,[323] other respiratory diseases, cardiovascular disease, and stroke.[324] 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 C 1 estimates of acreage burned with emission factors from US EPA's AP-42 database.[325] AP-42, *Compilation of Air Pollutant Emission Factors*, is EPA's primary compilation of emission factor information.[326] 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),

[320] "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.
[321] CalFire Incident Information, 2017 and 2018. http://cdfdata.fire.ca.gov/incidents/incidents_statsevents.
[322] "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
[323] Guarnieri, M. and Balmes, J.R., 2014. Outdoor air pollution and asthma. The Lancet, 383(9928), pp.1581-1592.
[324] 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.
[325] 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.
[326] US EPA, OAR. "AP-42: Compilation of Air Emissions Factors." Policies and Guidance. US EPA, September 26, 2016. https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors.

volatile organic compounds (VOC),[327] 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 C 1 and Table C 2 show the resulting annual, statewide emissions.

Table C 2. 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[328].

Figure 34 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.[329] The top bar shows the total emissions of $PM_{2.5}$ released within the South Coast Air Basin in 2012.[330] The second bar shows the total $PM_{2.5}$ emissions from all on-road activities in the state.[331] Based on these estimates, wildfires should be considered amongst the greatest contributors to particulate matter air pollution and associated public health risk in California.

[327] VOC reported as methane.
[328] Excluding fugitive road dust emissions.
[329] 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.
[330] 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.
[331] 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.

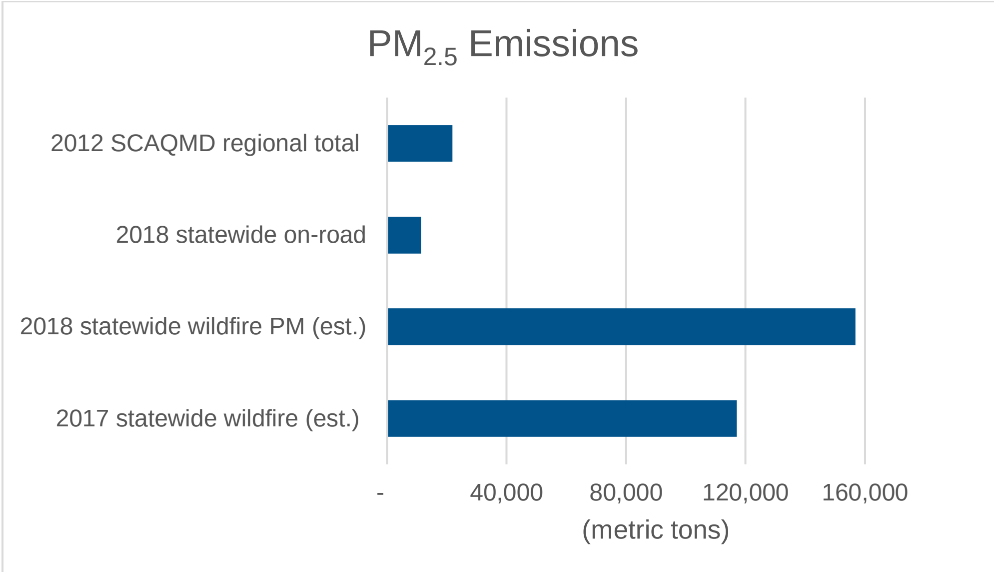

Figure 34. Comparison of statewide wildfire particulate emissions to other California sources.

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.[332] 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.[333] 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.[334]
- *Prescribed burn*, in which ground-level fuel is eliminated through a controlled fire, is considered among the most effective methods of fuel treatment.[335] This process mimics natural fire processes and restores wildland ecosystems, providing significant risk reduction benefits.[336] 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.[337]
- *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

[332] California Senate Bill 901 (2018).
[333] 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.
[334] Hunter, M et al., "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.
[335] 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.
[336] "Welcome to FIRE." Accessed July 1, 2019. https://calfire.ca.gov/.
[337] Hunter, M et al., "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.

reducing risk but may result in nutrient degradation. Finally, if forests are mechanically thinned but slash is not removed promptly, increased risk can result.[338]

- *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.[339]
- *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.[340]

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.[341] 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.[342] 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.[343] 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.[344]

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.[345] 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.

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338 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.

339 Benefeld, Mike, "Southern California Fuels Treatment Effectiveness Review," N.D., Central Oregon Fire Management Service, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5295359.pdf; Omi 2015.

340 Hunter et al. 2015.

341 Ibid.

342 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.

343 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.

344 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.

345 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.

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 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.[346]

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.[347] 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.[348]

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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[346] 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.

[347] 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.

[348] 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.[349] 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.[350] 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 of various feedstocks.

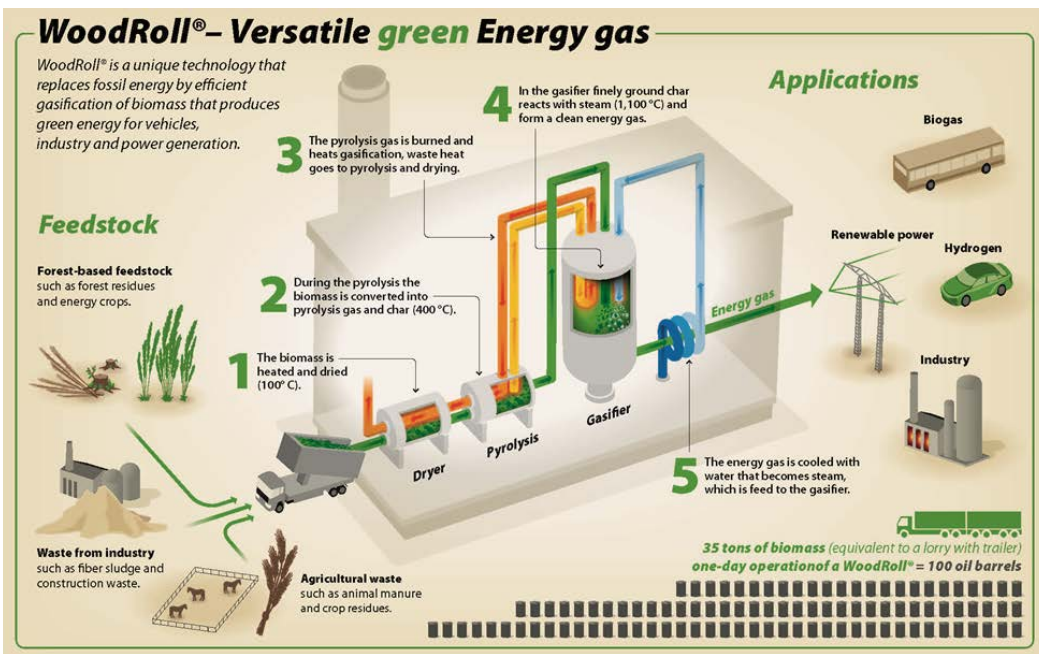

Figure E 1. Thermal Gasification Process Map

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.

[349] The Beck Group. 2017. Dead Tree Utilization Assessment. Portland, OR. Available at http://www.fire.ca.gov/treetaskforce/downloads/WorkingGroup/Beck_Group_Report_5-1-17%20.pdf.
[350] State of California Executive Department. 2015. Proclamation of a State of Emergency. Available at: https://www.gov.ca.gov/wp-content/uploads/2017/09/10.30.15_Tree_Mortality_State_of_Emergency.pdf.

Thermal gasification of woody biomass has only very recently been implemented on a commercial scale.[351]

Gasification as a biomass conversion technology for wood waste

Utilizing wood waste for RNG offers a significant opportunity for generating low cost RNG. [352] 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.[353] 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[354]

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.[355] 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).[356] Using this

[351] California Energy Commission. 2017. Re-Assessment of Renewable Natural Gas. Available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=220203.

[352] Gas Technology Institute. 2019. Low-Carbon Renewable Natural Gas (RNG) From Wood Wastes. Available at: https://www.gti.energy/wp-content/uploads/2019/02/Low-Carbon-Renewable-Natural-Gas-RNG-from-Wood-Wastes-Final-Report-Feb2019.pdf.

[353] Akubo, Kaltume, Mohamad Anas Nahil, and Paul T. Williams. 2018. "Pyrolysis-Catalytic Steam Reforming of Agricultural Biomass Wastes and Biomass Components for Production of Hydrogen/Syngas." *Journal of the Energy Institute*, October. https://doi.org/10.1016/j.joei.2018.10.013.

[354] Christos M. Kalamaras and Angelos M. Efstathiou, "Hydrogen Production Technologies: Current State and Future Developments," Conference Papers in Energy, vol. 2013, Article ID 690627, 9 pages, 2013. https://doi.org/10.1155/2013/690627.

[355] USDA (United States Department of Agriculture) Forest Service. 2019. Press Release: Survey Finds 18 Million Trees Died in California in 2018. Available at: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/FSEPRD609321.pdf.

[356] The Beck Group. 2017. Dead Tree Utilization Assessment. Portland, OR. Available at http://www.fire.ca.gov/treetaskforce/downloads/WorkingGroup/Beck_Group_Report_5-1-17%20.pdf.

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.[357] 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 metric tons of biomass per day and is expected to produce 1.9 million cubic feet of syngas per day.[358] 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.[359] 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.[360] 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[361] and 80% of California's total natural gas consumption in 2017.[362]

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,

357 Simet, Amy. 2017. Planned California biomass plant aims to use dead trees. *Biomass Magazine*. Available at: http://biomassmagazine.com/articles/14181/planned-california-biomass-plant-aims-to-use-dead-trees.
358 GSTC (Global Syngas Technologies Council). 2019. Mariposa Biomass Project. Available at: https://www.globalsyngas.org/resources/world-gasification-database/mariposa-biomass-project/.
359 "Cortus Energy." Accessed October 8, 2019. http://www.cortus.se/technology.html.
360 Cortus Energy produces first RNG/SNG at Koping biomass gasification facility. 2018. *Bioenergy International.* Available at: https://bioenergyinternational.com/biogas/cortus-energy-produces-first-rngsng-koping-biomass-gasification-facility.
361 California Gas and Electric Utilities. 2018. 2018 California Gas Report. Available at: https://www.socalgas.com/regulatory/documents/cgr/2018_California_Gas_Report.pdf.
362 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.

there are currently only three operational biomass gasification plants in California and all are being used for electricity production.[363]

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 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.[364]
- *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.[365]
- *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.[366] 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

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[363] University of California, Division of Agriculture and Natural Resources. 2019. Woody Biomass Utilization Group. Available at: https://ucanr.edu/sites/WoodyBiomass/Project/California_Biomass_Power_Plants/.
[364] 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.
[365] Van Der Drift, B. 2013. Biomass Gasification in the Netherlands. Available at: http://task33.ieabioenergy.com/download.php?file=files/file/country_reports/NL_July2013.pdf
[366] Gas Technology Institute. 2019. Low-Carbon Renewable Natural Gas (RNG) From Wood Wastes. Available at: https://www.gti.energy/wp-content/uploads/2019/02/Low-Carbon-Renewable-Natural-Gas-RNG-from-Wood-Wastes-Final-Report-Feb2019.pdf.

generation could be expanded to a greater state-wide effort in both wildfire resilience and renewable energy generation.[367]

[367] PG&E. 2017. PG&E Hauling, Processing Dead Trees to Enhance Public Safety. Available at: https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20170503_pge_hauling_processing_dead_trees_to_enhance_public_safety