Application: A.24-12-XXX
Exhibit No.:
Witness: Josh Schellenberg

PREPARED DIRECT TESTIMONY OF
JOSH SCHELLENBERG
ON BEHALF OF
SOUTHERN CALIFORNIA GAS COMPANY

(CHAPTER 5 – VALUE OF ELECTRIC GRID RELIABILITY AND RESILIENCE)

BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF CALIFORNIA

December 20, 2024

TABLE OF CONTENTS

PREPARED DIRECT TESTIMONY OF
JOSH SCHELLENBERG
(CHAPTER 5 – VALUE OF ELECTRIC GRID RELIABILITY AND RESILIENCE)

I. INTRODUCTION

My name is Josh Schellenberg, and I am Principal and Chief Operating Officer of H&S Insights, where I lead the clean energy consulting practice and specialize in electric grid reliability and resilience planning. I have over 15 years of professional consulting experience, including for large utilities throughout the country, the U.S. Department of Energy, and Lawrence Berkeley National Laboratory. Among other things, I developed the interruption cost model that estimates the value of electric reliability, informing over $50 billion of grid investments, including climate risk mitigation. I have also assisted California utilities on surveys and studies focusing on value of service and outage costs. I review and advise on resilience plans, best practices and performance metrics that utilities are implementing throughout the United States to mitigate the impacts of climate change. I have an MBA from the Wharton School at the University of Pennsylvania, an M.A. in International and Development Economics from the University of San Francisco and a B.A. in Economics from the University of Connecticut.

My testimony supports Southern California Gas Company's (SoCalGas) Application for Authorization to Implement a Revenue Requirement for Costs to Enable Commencement of Phase 2 Activities for Angeles Link (Application). In this testimony, I describe the value of electric grid reliability[1] and resilience[2] as California decarbonizes and adapts to climate change,

---

[1] Electric reliability refers to maintaining the delivery of power under normal operating conditions and has established valuation methods in California, as described in this testimony.

[2] Resilience is the "ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents". *See* the White House – *President Barack Obama, Presidential Policy Directive -- Critical Infrastructure Security and Resilience* (February 12, 2013), *available at:* https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil. Given that the electric utility industry has not established a method for directly valuing grid resilience, this testimony stresses its importance in the context of decarbonization and climate change, including impacts to disadvantaged communities.

including costs to customers in SoCalGas's service territory[3] and Los Angeles County from electric service interruptions. These costs underscore the need to invest in clean firm power[4] to enhance energy system reliability and resilience. Further, this testimony describes why SoCalGas's proposed Phase 2 activities to develop firm, in-basin clean energy resources should continue expeditiously.

Reliable electric service is vital for the California economy as homes and businesses become increasingly reliant on electricity for transportation and building end uses, including additional air conditioning needs due to more extreme heat waves. Grid resilience is also essential to prevent, respond to, and recover from major blackouts that compromise public safety, especially as climate change exposes vulnerabilities in existing reliability standards and planning practices. To inform these rapidly changing system needs and risks, grid planners are increasingly incorporating the value of reliability and criticality of resilience into planning priorities and resource allocation.

Value of Service (VOS) is the economic value that utility customers (including residential, commercial, and industrial) place on service reliability. In the electricity sector, researchers estimate VOS by measuring the costs that customers experience during a power outage, typically by conducting a customer interruption cost survey.[5] A utility investment that improves reliability delivers VOS benefits to the customer through a reduction in customer interruption costs. As a primary benefit stream from electric reliability improvements, VOS as measured by avoided customer interruption costs is a key factor for informing investment prioritization.

Electric reliability planners face a rapidly changing resource mix, extreme weather complexities and other risk factors that have led to a "hyper-complex risk environment," as

---

[3] The analysis in this testimony focuses on six of the counties that SoCalGas serves – Los Angeles, Orange, Kern, Riverside, Ventura, and Santa Barbara.

[4] As defined by the Energy Information Administration (EIA), firm power is "intended to be available at all times during the period covered by a guaranteed commitment to deliver, even under adverse conditions". *See,* EIA, *Glossary*, *available at:* https://www.eia.gov/tools/glossary/index.php. Given the emphasis on availability during adverse conditions, firm power supports resilience by avoiding major grid disruptions, including from extreme heat waves.

[5] Sullivan, Michael, Myles Collins, Josh Schellenberg and Peter Larsen (2018). Estimating Power System Interruption Costs: A Guidebook for Electric Utilities. https://emp.lbl.gov/publications/estimating-power-system-interruption

characterized by the North American Electric Reliability Corporation (NERC) President and CEO.[6] With this increasing complexity, VOS remains critical for understanding how power interruptions impact electric utility customers. This is especially the case for California, which will increase reliance on intermittent renewable resources as it moves toward a fully decarbonized grid,[7] leading to potentially significant reliability impacts in the absence of firm clean energy resources to supplement and displace the role currently served by natural gas.[8] VOS will also increase in importance in Southern California as electricity consumption is expected to double by 2045 and high value end-uses such as heating, transportation and certain industrial processes are electrified.[9]

Furthermore, the resource adequacy framework in California currently lacks sufficient incentives (or penalties) to ensure reliable capacity performance, as recent demand response research has shown.[10] Borenstein et al. (2023) also identify the lack of incentives or penalties as a broader issue for electricity markets with capacity requirements.[11] Borenstein et al. further emphasize that electrification of transportation and building energy use is "raising the stakes for reliability as so many services become dependent upon this single source of energy."[12] Climate

---

[6] NERC is a regulatory authority that develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the bulk power system through system awareness; and educates, trains, and certifies industry personnel. *See,* NERC, *Challenges to Reliability and Resilience* (December 7, 2023), *available at:* https://cdn.misoenergy.org/20231207%20Board%20of%20Directors%20Item%2007a%20NERC%20CEO%20Update631092.pdf.

[7] *See*, e.g., Senate Bill (SB) 100 (De León, 2018), *available at: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100* (SB 100 requires that renewable energy and zero-carbon resources supply 100 percent of electric retail sales to end-use customers, and 100 percent of electricity procured by state agencies, by 2045).

[8] California Energy Commission (CEC), *Adopted 2023 Integrated Energy Policy Report with Errata* (February 14, 2024) at A-1, *available at:* https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2023-integrated-energy-policy-report ("In 2021, fossil gas made up about 40 percent of the state's total power generation mix. It plays an important role in maintaining electric reliability because of the ability of this gas to be dispatched on command.").

[9] Edison International, *Countdown to 2045*, *available at:* https://www.edison.com/our-perspective/countdown-to-2045.

[10] *See* Decision (D.) 24-04-006.

[11] Borenstein, Severin, James Bushnell, and Erin Mansur (2023). "The Economics of Electricity Reliability." Journal of Economic Perspectives, 37 (4): 181-206.

[12] *Id.* at 183.

change is raising the stakes even further, especially for disadvantaged communities in Southern California, as extreme heat waves become longer, hotter and more frequent.

With the societal impacts[13] of power outages expected to increase precipitously as the grid fully decarbonizes, utility customers in Southern California benefit from long-term planning that proactively identifies system needs, particularly for firm, in-basin clean energy resources. The infrastructure for hydrogen production, transmission, distribution, storage and consumption will take decades to fully develop and support net load ramping, inter-seasonal storage, and unprecedented peak load growth in the California Independent System Operator (CAISO) market. Therefore, the rigorous planning steps for firm in-basin clean energy resources, including the potential role of Angeles Link, should continue expeditiously.

The remainder of this testimony proceeds as follows:

- Section II briefly summarizes prior VOS research in California
- Section III summarizes the results of the 2019 SCE VOS Study and explains why it is the authoritative source for estimating power interruption costs in Southern California
- Sections IV and V provide customer interruption cost estimates for outages up to 24 hours in SoCalGas service territory and Los Angeles County, including the potential impacts to in-basin employment in energy-intensive industries
- Section VI discusses the impact of climate change on extreme heat waves, including the disproportionate impact to vulnerable communities
- Section VII addresses the critical importance of firm, in-basin power resources for avoiding major outages
- Section VIII summarizes why the planning steps for firm, in-basin clean energy resources should continue expeditiously
- Section IX provides conclusions
- Section X provides works cited

---

[13] In this testimony, societal impacts include, but are not limited to, outage costs for residential and non-residential electric utility customers, impacts to employment and the broader California economy, and damages from losing power during extreme heat waves, particularly for vulnerable communities. Customer interruption cost surveys measure direct costs for the businesses and households that experience outages of varying duration. Businesses and households that do not lose power are also impacted through spillover effects from an outage, leading to indirect costs that increase the broader societal impact.

II. PRIOR VOS RESEARCH

California investor-owned electric utilities (IOUs) have a long history of using customer surveys to measure the VOS.[14] Starting in 1983, Pacific Gas & Electric (PG&E) has conducted VOS surveys of the residential, commercial, industrial and agricultural customer classes, including its most recent study in 2012.[15] Southern California Edison (SCE) has also conducted systemwide VOS surveys of residential, commercial and industrial customers in 2000 and 2019.[16, 17]

I was the lead analyst and project manager for the 2012 PG&E study and Principal-in-Charge of the 2019 SCE study – the two most recent VOS surveys that California electric IOUs have conducted. I also led PG&E's Downtown San Francisco Long Duration Outage Cost Study,[18] which is the only VOS survey that has focused on the value of grid resilience by measuring the costs that business customers experience for outages that last multiple days to weeks. Finally, I was the lead developer for the current version of the Interruption Cost Estimate (ICE) Calculator, which the CPUC recommended that electric IOUs use for valuing electric reliability in the Risk Assessment and Mitigation Phase (RAMP) of their General Rate Case filings.[19]

This research has consistently demonstrated that the value of reliability and resilience is far greater than the price of electricity and marginal cost to serve those customers, even during CAISO emergencies when the wholesale market price increases to $1,000 per MWh. This disconnect between the societal value of reliability and resilience and the marginal incentive for

---

[14] Burns, Sandra and George Gross (1990). *"Value of Service Reliability.*" IEEE Transactions on Power Systems, Vol. 5, No. 3. https://gross.ece.illinois.edu/files/2015/03/1990-Aug.pdf.

[15] Sullivan, Michael, Josh Schellenberg et al. (2012). "Pacific Gas & Electric Company's 2012 Value of Service Study." http://www.caiso.com/Documents/AttachmentB_ISOResponsesCommentsDraft2012-2013TransmissionPlan.pdf

[16] D.04-07-022.

[17] Collins, Myles, Michael Sullivan, Josh Schellenberg and Stephanie Bieler (2019). "Southern California Edison: 2019 Value of Service Study." 2021 GRC Workpapers: Exhibit No. SCE-02 Vol.04, Pt 01, Ch II, Bk A.

[18] Sullivan, Michael and Josh Schellenberg (2013). "Downtown San Francisco Long Duration Outage Cost Study." PG&E Application No. 12-12-004.

[19] D.22-12-027.

supply resources to perform when they are needed most could lead to catastrophic consequences as the system fully decarbonizes without firm clean energy resources to supplement and displace the role currently served by natural gas. Steps must be taken now to properly plan for and address these risks.

III. 2019 SCE VALUE OF SERVICE (VOS) STUDY

The 2019 SCE VOS Study is the authoritative source of information for estimating electric power interruption costs in Southern California. First off, it details the only available survey-based estimates for the region. Secondly, the 2019 SCE study is the only customer interruption cost study that has been completed and made publicly available in the past 12 years in the United States, including all of the ICE Calculator's underlying data. Finally, while the CPUC has ordered SCE to participate in the initiative to update the ICE Calculator,[20] it is unclear when the results will be available and whether the study will produce more precise estimates as compared to the 2019 study, which had over 1,100 respondents.[21] Therefore, this testimony draws from the 2019 SCE study to estimate the direct customer costs of a power outage in SoCalGas service territory.

Figure 1 summarizes the SCE systemwide average cost per customer by outage duration. Losing power for 24 hours costs the average SCE customer $1,174 per outage event. The costs are lower for shorter outages, but importantly, a momentary power interruption (up to 5 minutes) still has a cost of over $66 per outage event. Therefore, widespread outages of any duration will have significant impacts in Southern California. Furthermore, on a per MWh basis, the SCE study found that all customer classes value reliability far more than the price of electricity and marginal cost to serve those customers, even during CAISO emergencies when the wholesale market price increases to $1,000 per MWh. For example, the 2019 SCE study found that the systemwide cost of unserved energy[22] is nearly $180,000 per unserved MWh for a 1-hour interruption.

---

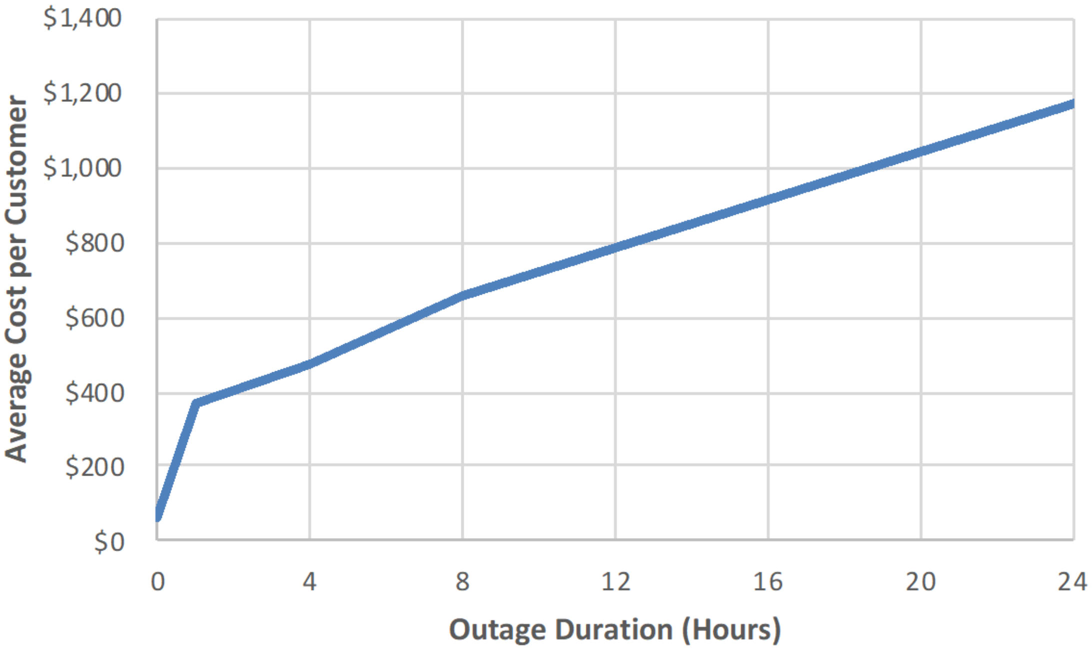
[20] D.22-12-027. Progress update available here: https://icecalculator.com/recent-updates.

[21] This statistically representative sample included residential and non-residential customers of varying sizes throughout SCE service territory, as detailed in the report. Non-residential customers include manufacturing, transportation, wholesale and retail trade, offices, hospitality, schools and institutional/government facilities.

[22] Unserved energy is defined as the amount of usage (in kWh or MWh) that customers would have consumed from the grid during an outage.

The systemwide cost per unserved MWh is useful as a comparison to wholesale energy prices to assess the extent to which supplier incentives align with the value of reliability. Given that the SCE systemwide value of reliability for a 1-hour interruption ($180,000/MWh) is nearly *180 times higher* than the peak energy price during CAISO emergencies ($1,000/MWh), the energy market alone does not sufficiently incentivize the level of infrastructure investment required to ensure reliability. Therefore, California also has a capacity market and Resource Adequacy program, one of the primary goals for which is "to incentivize the siting and construction of new resources needed for future grid reliability."[23] However, with a rapidly changing resource mix, extreme weather complexities, and other risk factors, this program most likely does not sufficient incentivize reliability, even after accounting for resource adequacy penalties (Borenstein et al. 2023).

Figure 1: SCE Systemwide Average Cost per Customer by Outage Duration (2019 $)



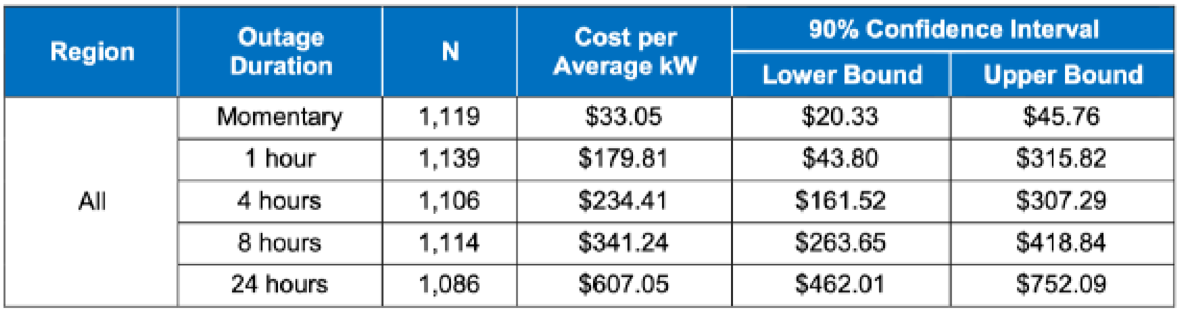
The 2019 SCE study also estimated the systemwide cost per average kW (Table 1), which is the average cost per customer (Figure 1) normalized by average demand. This metric is useful because the total customer interruption cost for an outage scenario can be estimated as the product of cost per average kW and the average hourly demand for a group of customers. As an example, consider a customer group that consumes 876,000 kWh annually. The average demand

---

[23] CPUC, *Resource Adequacy Homepage, available at:* https://www.cpuc.ca.gov/ra.

for this group of customers is 100 kW (equal to 876,000 kWh divided by 8,760 hours in a year). The total interruption cost estimate for each outage scenario equals 100 kW multiplied by the cost per average kW values in Table 1. If all customers in this example lose power completely, the total interruption cost estimates range from $3,305 for a momentary outage to $60,705 for a 24-hour outage.

Table 1: SCE Systemwide Cost per Average kW Estimates – Systemwide Results (2019 $)



Region	Outage Duration	N	Cost per Average kW	90% Confidence Interval	
				Lower Bound	Upper Bound
All	Momentary	1,119	$33.05	$20.33	$45.76
	1 hour	1,139	$179.81	$43.80	$315.82
	4 hours	1,106	$234.41	$161.52	$307.29
	8 hours	1,114	$341.24	$263.65	$418.84
	24 hours	1,086	$607.05	$462.01	$752.09

Note: N refers to the sample size of survey respondents

Source: 2019 SCE Value of Service Study

IV. CUSTOMER INTERRUPTION COST ESTIMATES IN SOCALGAS SERVICE TERRITORY

To estimate the amount of electricity usage in SoCalGas service territory, the analysis in this testimony uses the California Energy Commission (CEC) database of total consumption by county.[24] In six of the counties that SoCalGas serves – Los Angeles, Orange, Kern, Riverside, Ventura, and Santa Barbara – the CEC database shows that total annual electricity consumption was 129,733.14 GWh in 2022 (the most recent year available). Therefore, average demand is 14,809,719 kW (equal to 129,733.14 GWh multiplied by 1,000,000 kWh/GWh divided by 8,760 hours in a year). SoCalGas also serves customers in six additional counties (or portions thereof) (see Figure 2), but this analysis focuses on Los Angeles, Orange, Kern, Riverside, Ventura, and Santa Barbara counties because they would potentially be priority areas for hydrogen infrastructure, given the industrial customer base and value of firm, in-basin power resources. While any SoCalGas customer who also consumes electricity would be expected to benefit from hydrogen infrastructure, focusing on Los Angeles, Orange, Kern, Riverside, Ventura, and Santa

---

[24] CEC, *Electricity Consumption by County, available at:* https://ecdms.energy.ca.gov/elecbycounty.aspx.

Barbara in this analysis ensures that electricity usage (and thus the outage cost) in SoCalGas service territory is not overestimated.

Figure 2: SoCalGas Service Territory

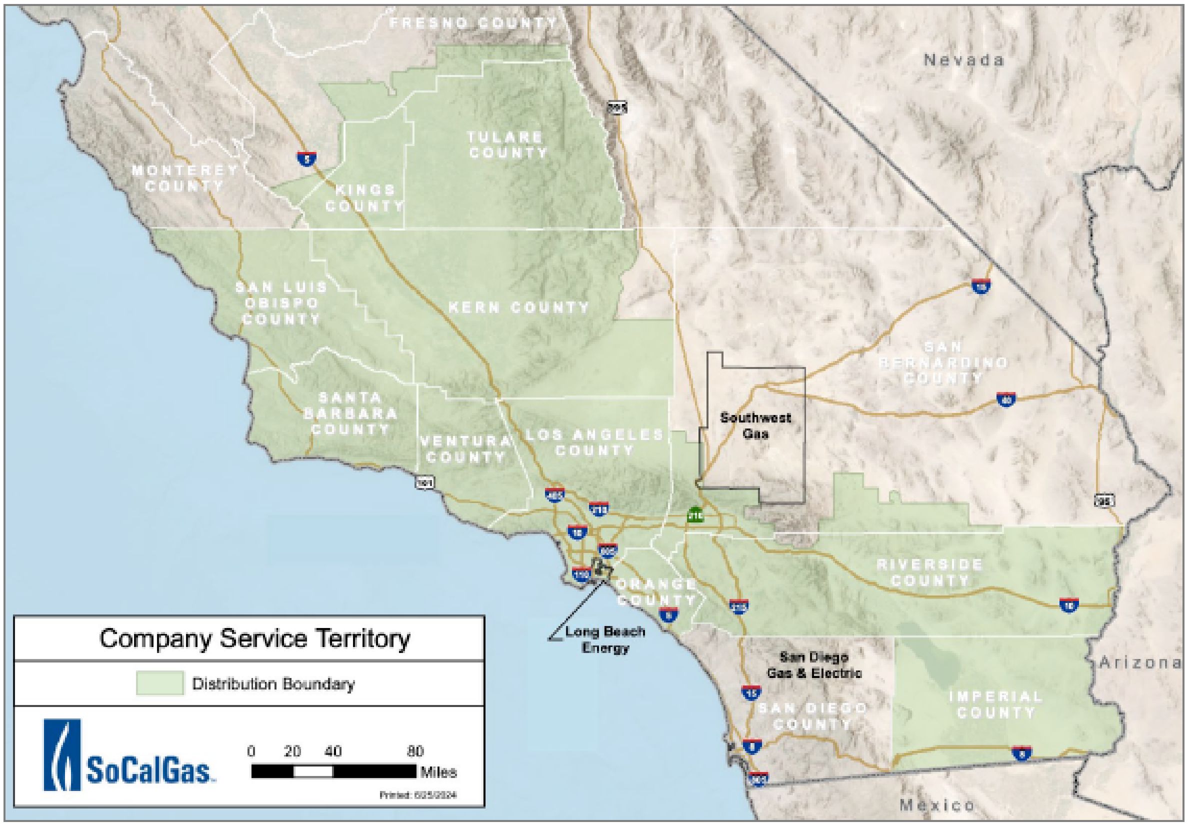


Table 2 summarizes the estimated outage costs in SoCalGas service territory, based on the average demand of 14,809,719 kW multiplied by the cost per average kW estimates from the 2019 SCE study (Table 1), adjusted for inflation.[25] The total direct cost per outage under normal weather conditions varies from around $590 million for a momentary outage to nearly $11 billion for a 24-hour outage. These costs would be higher under extreme weather conditions. These are direct costs for the businesses and households in SoCalGas service territory that experience outages of varying duration. For example, direct costs for a retail store include lost revenue and spoiled goods due to an outage. Businesses and households that do not lose power

---

[25] From July 2019 to December 2023, the Consumer Price Index showed 20% inflation, according to the U.S. Bureau of Labor Statistics. *See, U.S.* Bureau of Labor Statistics, *CPI Inflation Calculator, available at:* https://data.bls.gov/cgi-bin/cpicalc.pl?cost1=1.00&year1=201907&year2=202312.

are also impacted through indirect (i.e., spillover) effects.[26] For example, a wholesaler incurs indirect costs, including lost revenue and spoilage, if it is unable to deliver goods to a retail store that has lost power.[27] These indirect costs propagate through the economy and could increase the total outage cost by 50% to 200%, based on a review of literature on hazard losses.[28] Furthermore, an outage in one location could lead to calls for broader load reduction and cascading blackouts, such as during the 2003 Northeast blackout and the 2011 Southwest blackout that caused 1.4 million customers in San Diego County to lose power for over 11 hours. As described in Section VII, the overall CAISO area depends on power from Los Angeles Department of Water and Power (LADWP) during extreme heat waves.

Table 2: Outage Cost Estimates for SoCalGas Service Territory by Duration (2023 $)

Outage Duration	Cost per Average kW (Adjusted for Inflation)	Total Direct Cost per Outage ($ Billions)
Momentary	$39.66	$0.59
1 hour	$215.77	$3.20
4 hours	$281.29	$4.17
8 hours	$409.49	$6.06
24 hours	$728.46	$10.79

Importantly, these estimated costs are based on 2022 usage. The proposed Angeles Link could be expected to deliver benefits over a long time period and would provide greater value as electricity consumption is projected to double by 2045 in Southern California.[29] Therefore, the estimated outage costs are likely to at least double by 2045, especially as high value end-uses

---

[26] As described in Larsen et al. (2024), "surveys are not designed to estimate indirect or 'spillover' effects of interruptions as their impacts propagate across regional economies. These result from market interactions, whereby firms or sectors experiencing a power loss may temporarily both stop purchasing inputs from other firms and selling outputs to their customers, resulting in economic impacts above and beyond direct costs."

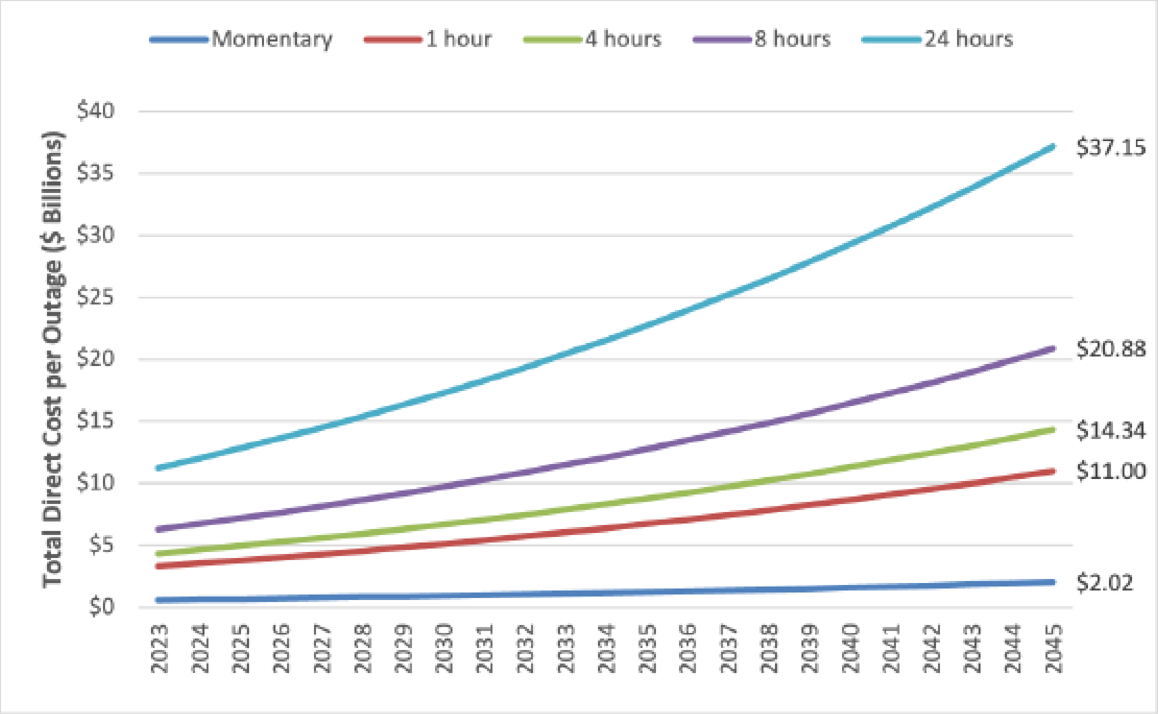
[27] Larsen et al. (2024) finds that the wholesale trade and transportation sectors are highly sensitive to widespread, long-duration power interruptions, as compared to other industries.

[28] Sullivan, Michael and Josh Schellenberg (2013). "Downtown San Francisco Long Duration Outage Cost Study" (Appendix B). PG&E Application No. 12-12-004.

[29] Edison International, *Countdown to 2045*, *available at:* https://www.edison.com/our-perspective/countdown-to-2045.

such as heating, transportation and certain industrial processes are electrified. Furthermore, this analysis assumes that inflation will continue to increase at a rate of 2.5% per year. Based on these projections, Figure 3 shows how total direct costs per outage are expected to increase between 2023 and 2045. The total direct cost per outage for SoCalGas service territory in 2045 varies from around $2 billion for a momentary outage to over $37 billion for a 24-hour outage.

Figure 3: Per Outage Cost Estimates for SoCalGas Service Territory by Year (Current $)



The electrification of heating, transportation and certain industrial processes could also exacerbate the indirect (i.e., spillover) costs, especially if widespread outages increase in frequency and duration, leading to broader impacts to the economy and employment. Therefore, the total cost of an electrical outage of 24 hours or more in SoCalGas service territory could be more than $100 billion in 2045.

Planners can apply the 2019 SCE VOS study to a wide variety of outage scenarios, including specific counties (see next section). While it may be unlikely that all six counties lose power simultaneously during a CAISO emergency, utilities may be required to implement rolling blackouts, which occurred during the 2000-01 Energy Crisis and August 2020 heat wave. In this type of scenario, customers in all six counties may lose power for one to four hours at separate times as utilities implement rotating outages to curtail load.[30] Even though customers would experience outages at different times, the total direct cost estimate of $3.2 billion for a 1-hour outage to $4.2 billion for a 4-hour outage would still apply, escalating to $11 billion to $14.3 billion by 2045.

V. CUSTOMER INTERRUPTION COST ESTIMATES IN LOS ANGELES COUNTY

For Los Angeles County, the CEC database shows that total 2022 electricity consumption was 68,485 GWh – by far the most usage of any county in California, and nearly 3.4 times more usage than the next highest consumption counties (Orange and San Diego, both of which consumed around 20,243 GWh in 2022). In terms of non-residential usage specifically, Los Angeles County accounts for nearly as much consumption as the combined total of the four counties with the next highest non-residential usage (Santa Clara, San Diego, Orange and Kern), underscoring the vital importance of the in-basin commercial and industrial sectors to the broader California economy.

Table 3 summarizes the estimated outage costs in Los Angeles County, based on the average demand of 7,817,917 kW multiplied by the SCE cost per average kW estimates, adjusted for inflation. The total direct cost per outage varies from around $310 million for a momentary outage to $5.7 billion for a 24-hour outage. These are direct costs for the businesses and households in Los Angeles County that experience outages of varying duration. Businesses and households that do not lose power are also impacted through spillover effects from an outage, leading to indirect costs that could increase the total outage cost by 50% to 200%.

---

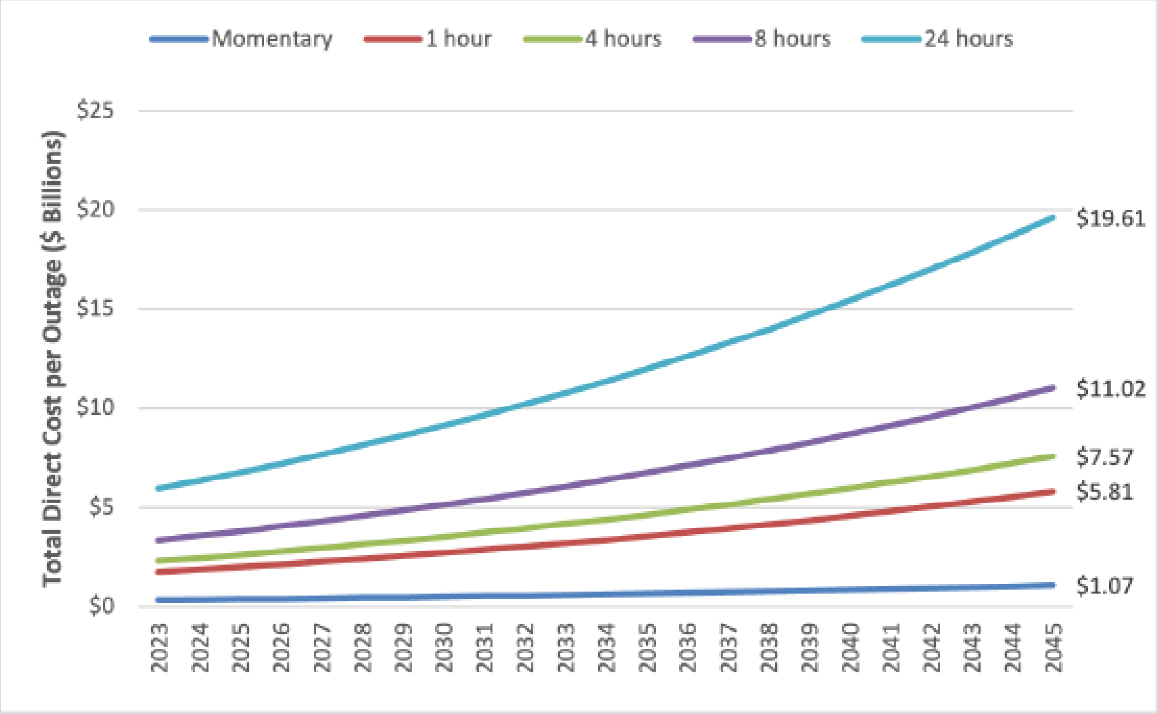
[30] For an example of this type of rolling blackout cost study, see Schellenberg, Josh, Barney Speckman and Le Xu (2015). "Puget Sound Energy Energize Eastside Outage Cost Study." *Available at:* https://www.energizeeastsideeis.org/uploads/4/7/3/1/47314045/pse_energize_eastside_outage_cost_study_-_final__10.30.2015_.pdf

Table 3: Outage Cost Estimates for Los Angeles County by Duration (2023 $)

Outage Duration	Cost per Average kW (Adjusted for Inflation)	Total Direct Cost per Outage ($ Billions)
Momentary	$39.66	$0.31
1 hour	$215.77	$1.69
4 hours	$281.29	$2.20
8 hours	$409.49	$3.20
24 hours	$728.46	$5.70

With inflation and the doubling of electricity consumption by 2045, Figure 4 shows how the total direct costs per outage in Los Angeles County are expected to increase between 2023 and 2045. The total direct cost per outage in 2045 varies from around $1 billion for a momentary outage to nearly $20 billion for a 24-hour outage. With indirect (i.e., spillover) costs leading to broader impacts to the economy and employment, the total cost of an outage of 24 hours or more in Los Angeles County could be more than $50 billion by 2045.

Figure 4: Per Outage Cost Estimates for Los Angeles County by Year (Current $)



For Los Angeles County in particular, it is also important to consider that declining reliability and rising energy costs in Southern California could have a major impact on energy-intensive industrial facilities, their employees and the broader economy. While there is no perfect analogue, the impact of less reliable and more expensive energy on German industry after Russia's invasion of Ukraine in February 2022 serves as a cautionary example. As the worst performing major economy in 2023,[31] German industrial production is around 15% below 2021 levels for energy-intensive industries.[32] This has led to layoffs that are expected to continue in late 2024, especially for highly skilled and well-paid jobs in energy-intensive industries.[33] This example involves a natural gas supply shock, but it could apply to energy-intensive industrial processes that electrify and then experience declining reliability and rising costs.[34]

VI. CLIMATE CHANGE AND EXTREME HEAT WAVES

While electricity consumption forecasts typically focus on growth driven by electrification, climate change will lead to longer, hotter and more frequent heat waves that will further increase peak load and the value of reliability and resilience. More extreme heat waves will stress the bulk power system, such as during the August 2020 heat wave, which caused CAISO to issue a Stage 3 Emergency for the first time in nearly twenty years. A similar heat wave stressed the CAISO system in September 2022.

As shown in Figure 5, the Cal-Adapt[35] forecast shows that extreme heat days[36] will increase precipitously in Los Angeles County. During the mid-century period (2035-2064), Cal-Adapt forecasts that Los Angeles County will have 19 to 23 extreme heat days per year with a

---

[31] Arnold, Martin (2024). "Germany was worst-performing major economy last year." Financial Times. *Available at:* https://www.ft.com/content/792a1a09-701c-4c9d-aa77-0d9575d5bda9

[32] Statistisches Bundesamt. 42153-0001: Index of production in manufacturing. *Available at:* https://www-genesis.destatis.de/genesis/online?operation=sprachwechsel&language=en

[33] Storbeck, Olaf, and Patricia Nilsson (2024). "Germany faces jobs crisis 'of a thousand cuts': Highly paid manufacturing work is no longer so easy to come by in Eurozone's largest economy." Financial Times. *Available at:* https://www.ft.com/content/b8dd41dc-4fd9-4673-8b07-6af70e7f4213

[34] Certain industrial processes may be unable to fully electrify and would benefit from a stable supply of clean fuels to decarbonize.

[35] Cal-Adapt (funding and oversight by the California Energy Commission), *Local Climate Change Snapshot*, *available at:* https://cal-adapt.org/tools/local-climate-change-snapshot/ (for Los Angeles County). Cal-Adapt provides peer-reviewed data that portrays how climate change might affect California at the state and local level. Cal-Adapt is a collaboration between state agency funding programs, university, national lab and private sector researchers.

[36] Cal-Adapt defines extreme heat days as a day in a year when the daily maximum temperature exceeds the 98th historical percentile of daily maximum temperatures based on observed historical data from 1961–1990 between April and October.

daily maximum temperature above 94.4 °F, relative to 4 days in the baseline period (see Table 4). Riverside County is expected to have 23 to 29 days per year with temperatures above 106.0 °F. Across the six counties, the number of extreme heat days during the mid-century period is 3.3 to 7.3 times higher than the baseline period, which will stress the decarbonized bulk power system both in terms of higher peak load and potentially lower performance for battery storage and other resources under extreme heat.

Figure 5. Cal-Adapt Forecast of Extreme Heat Days for Los Angeles County

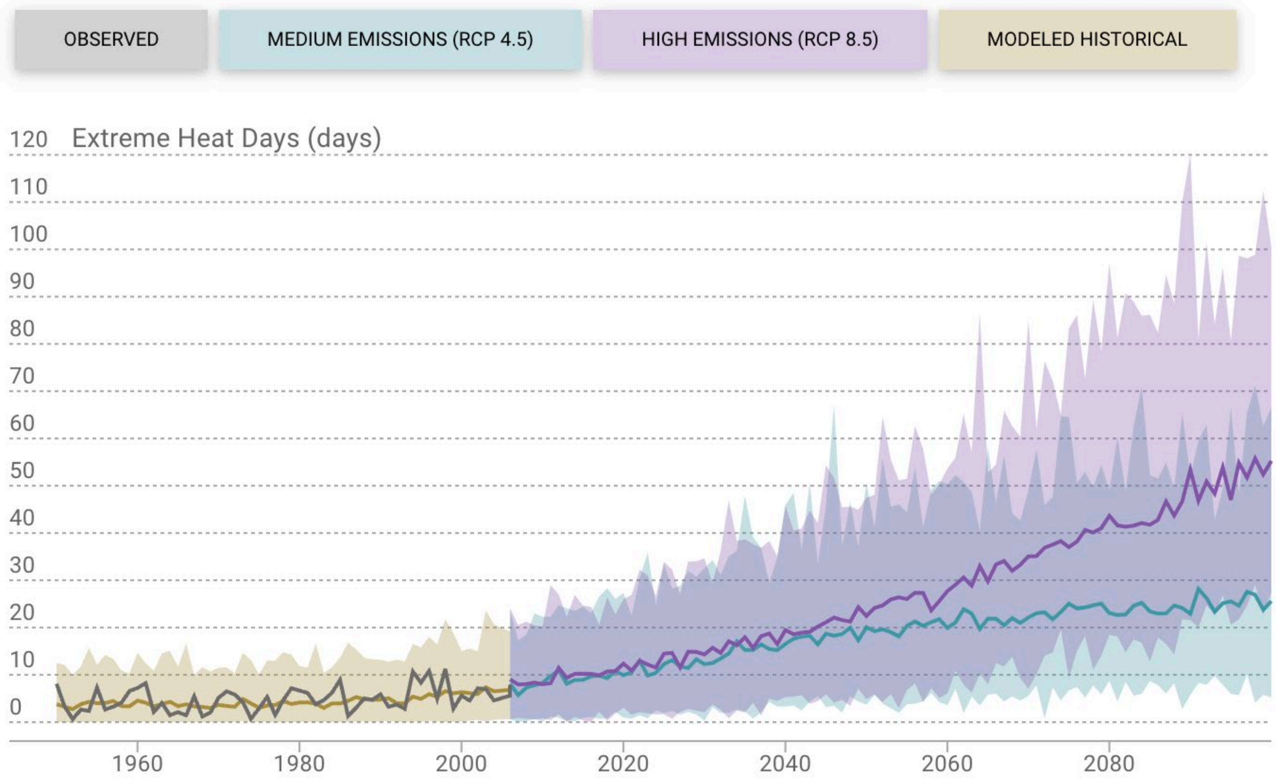


Table 4. Cal-Adapt Mid-Century Forecast of Extreme Heat Days per Year by County

County	Temperature Threshold[37]	Baseline (1961-1990)	Mid-Century (2035-2064)	
			Medium Emissions (RCP 4.5)	High Emissions (RCP 8.5)
Los Angeles	94.4 °F	4	19	23
Orange	93.4 °F	3	10	12
Kern	100.8 °F	4	22	28
Riverside	106.0 °F	4	23	29
Ventura	88.8 °F	3	16	20
Santa Barbara	87.5 °F	3	10	13

While the more temperate counties – Ventura and Santa Barbara – are not expected to experience as extreme temperatures, heat pump adoption may drive cooling usage even higher, especially in areas that currently have low air-conditioning penetration, further increasing peak load. For example, state initiatives to electrify space heating will result in increased heat pump adoption. Many homes or businesses in more temperate areas do not have air-conditioning, but if they replace their gas furnace with a heat pump, it is reasonable to expect that they would use the heat pump for space cooling as well. This additional cooling load will stress the reliability and resilience of the electricity system further, especially during extreme heat waves.

Importantly, these more extreme heat waves will have a disproportionate impact to vulnerable communities, which lack the adaptive capacity to mitigate damages.[38] For example, a higher income suburban Californian may have a car, pool or backup power source to mitigate damages if a power outage occurs during an extreme heat wave. They may also be able to relocate to an area with electric service and continue working with mobile data service and a battery-powered laptop. Many low income, disadvantaged Californians in rural areas and dense

---

[37] The extreme heat temperature thresholds vary by county, given that they are based on location-specific historical temperatures.

[38] The Intergovernmental Panel on Climate Change defines adaptive capacity as, "The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences" (*See,* IPCC, *Glossary, available at:* https://apps.ipcc.ch/glossary).

urban environments lack this adaptive capacity if a power outage occurs during an extreme heat wave or other conditions.

In a study for Commonwealth Edison, Larsen et al. (2024) found that low-income households (annual income below $50,000) experience proportionately larger losses during multi-day power interruptions, adding that "survey responses imply that high income households are more likely to relocate during longer duration power interruptions and consume goods and services in micro-regions not impacted by the power interruption." Similarly, an analysis of PG&E Public Safety Power Shutoffs (PSPS) events by Abatzoglou et al. (2020) found that "Disproportionately adverse impacts were felt in disadvantaged communities both in rural areas and across portions of the urbanized San Francisco Bay Area, including the direct financial impact of preparing for and recovering from outages of initially unknown duration (e.g. temporary loss of wages, spoilage of stored food, and securement of backup power supplies). In addition, individuals with disabilities who rely on electricity for respiratory support systems such as breathing aids and mobility devices such as electric wheelchairs faced substantial challenges during PSPS in 2019." As the PSPS events increasingly occur during periods of extreme heat, as many PG&E customers experienced on July 2-3, 2024, these disproportionate impacts to disadvantaged and vulnerable populations will increase.

VII. IMPORTANCE OF FIRM, IN-BASIN POWER RESOURCES FOR AVOIDING MAJOR OUTAGES

As defined by the Energy Information Administration (EIA), firm power is "intended to be available at all times during the period covered by a guaranteed commitment to deliver, even under adverse conditions."[39] Firm natural gas generation, particularly in the Los Angeles Basin, has been of critical importance for avoiding major outages under adverse conditions, most notably heat waves and wildfires over many years. On October 10, 2019, LADWP nearly had to curtail load for up to a million customers during the Saddleridge Fire north of Los Angeles, after losing power from three transmission lines that come into its service territory. In a 2021 IEPR Joint Agency Workshop,[40] LADWP details how it had to rely on local resources in the City of

---

[39] *See,* EIA, *Glossary*, *available at:* https://www.eia.gov/tools/glossary/index.php.

[40] CEC, *IEPR Joint Agency Workshop on Summer 2021 Electric and Natural Gas Reliability - Day 2, Session 4* (July 9, 2021), *available at:* https://www.energy.ca.gov/event/workshop/2021-07/iepr-joint-agency-workshop-summer-2021-electric-and-natural-gas-1.

Los Angeles during the Saddleridge Fire, adding, "Luckily, at the time we had 400 MW of solar, so that helped out a little bit. And then we have 3,400 MW of gas capacity in the City, so between that, we were able to make sure that there was no interruption of power, but we were very close." In a previous CEC workshop,[41] LAWDP also stated, "if we had the load on October 24th on the 10th – the same day as the Saddleridge fire – we could have lost up to a million customers and had some very significant outages." Without the 3,400 MW of gas capacity in the City of Los Angeles, there would have been catastrophic outages.

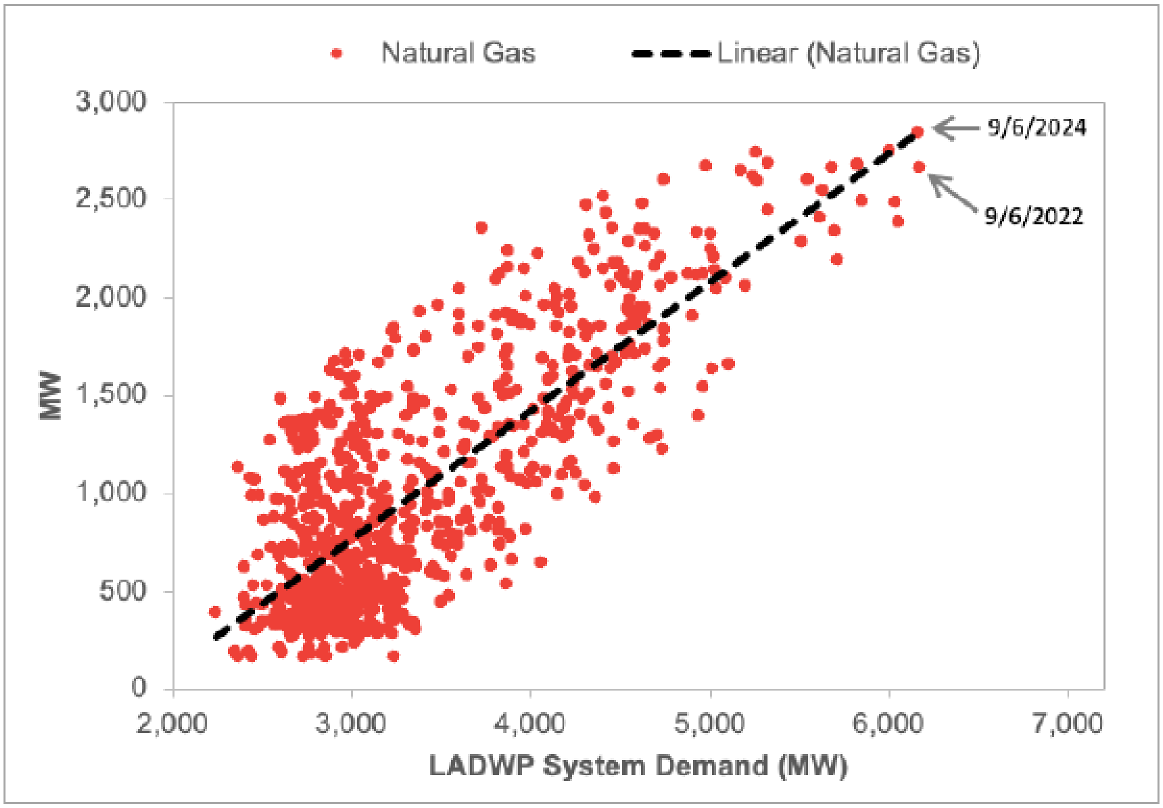
Since 2019, LADWP has continued to rely on in-basin, firm gas capacity to maintain system reliability and resilience, particularly during the September 2022 heat wave. Based on hourly electricity demand and supply data from EIA,[42] Figure 6 shows the relationship between LADWP system demand during the peak hour of each day (x-axis) and the MW of natural gas generation during that hour (y-axis), including the best-fit line. From July 1, 2022, through October 9, 2024, natural gas generation is highly correlated with peak demand (correlation coefficient of 0.78), demonstrating its capability to respond to system needs, including during adverse conditions. Ten of the highest 13 peak demand days were during the heat wave from August 31, 2022, through September 9, 2022. During those ten daily peak hours, natural gas served 38% to 47% of demand, around the same or more than the next three highest producing resources combined (coal, solar and hydropower). On September 6, 2024, the LADWP highest system peak since the September 2022 heat wave, natural gas served 46% of demand, and at 2,843 MW, had its highest peak production in over two years.

---

[41] CEC, *Southern California SB 100 Scoping Workshop* (October 29, 2019), *available at:* https://www.energy.ca.gov/event/2019-10/southern-california-sb-100-scoping-workshop.

[42] EIA, *Hourly Electric Grid Monitor – Los Angeles Department of Water and Power (LDWP) Electricity Overview*, *available at:* https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/balancing_authority/LDWP.

Figure 6. LADWP Natural Gas Generation during Daily System Peak Demand Hour July 1, 2022, through October 9, 2024 (each dot represents the peak for one day)



Importantly, when in-basin, firm gas capacity prevents major outages under adverse conditions for LADWP, there are broader benefits to the CAISO grid throughout California, due to the potential for cascading outages, such the 2003 Northeast blackout that impacted more than 50 million people (Borenstein et al. 2023) and the 2011 Southwest blackout that caused 1.4 million customers in San Diego County to lose power for over 11 hours. In fact, the CAISO grid consistently imports power from other balancing authorities,[43] especially LADWP, to meet the State's electricity demand. For example, CAISO system load set a new all-time peak on September 6, 2022, between 4 and 5 pm. At 52,061 MW, the load was 1,791 MW higher than the

---

[43] LADWP is a separate authority that balances demand and supply on its grid, but it also exchanges power with CAISO, known as "imports" and "exports." CAISO is "the largest of about 38 balancing authorities in the western interconnection, handling an estimated 35 percent of the electric load in the West." *See,* CAISO, *Balancing Authority, available at:* https://www.caiso.com/about/our-business/balancing-authority.

previous peak over 16 years earlier (in July 2006).[44] According to EIA data, LADWP delivered 2,463 MW to the CAISO grid during the all-time peak hour, serving nearly 5% of CAISO load (and more than the incremental load from the prior system peak in 2006). During the same hour, the LADWP gas plants were generating 2,666 MW, delivering 44% of its own demand and supporting stability for the broader CAISO grid. While it is not feasible to track which specific electric generator produces the power that CAISO imports, the EIA data consistently shows that the CAISO grid relies on neighboring balancing authorities for firm power, which may include a large portion of natural gas (or even coal) generation in many situations, particularly during heat waves that impact large portions of the entire Western Interconnection.

More recently, CAISO experienced an extreme heat wave that culminated in peak demand of 47,753 MW at 5:55 pm on September 5, 2024 – the highest peak load day since the September 2022 heat wave. Figure 7 summarizes the CAISO energy sources in 5-minute increments on that day. After renewables production from solar declined precipitously in the evening, natural gas generation increased to 22,995 MW and imports increased to 5,017 MW at 6:55 pm, totaling 28,012 MW between the two sources, or 60.4% of total demand at that time.[45] Grid-scale batteries also increased to meet demand after the decline in solar production, peaking at 6,406 MW at 6:45 pm. However, batteries production subsequently declined to below zero (charging from the grid) by 11:50 pm while imports increased to 5,025 MW to support overnight load (including grid-scale battery charging).

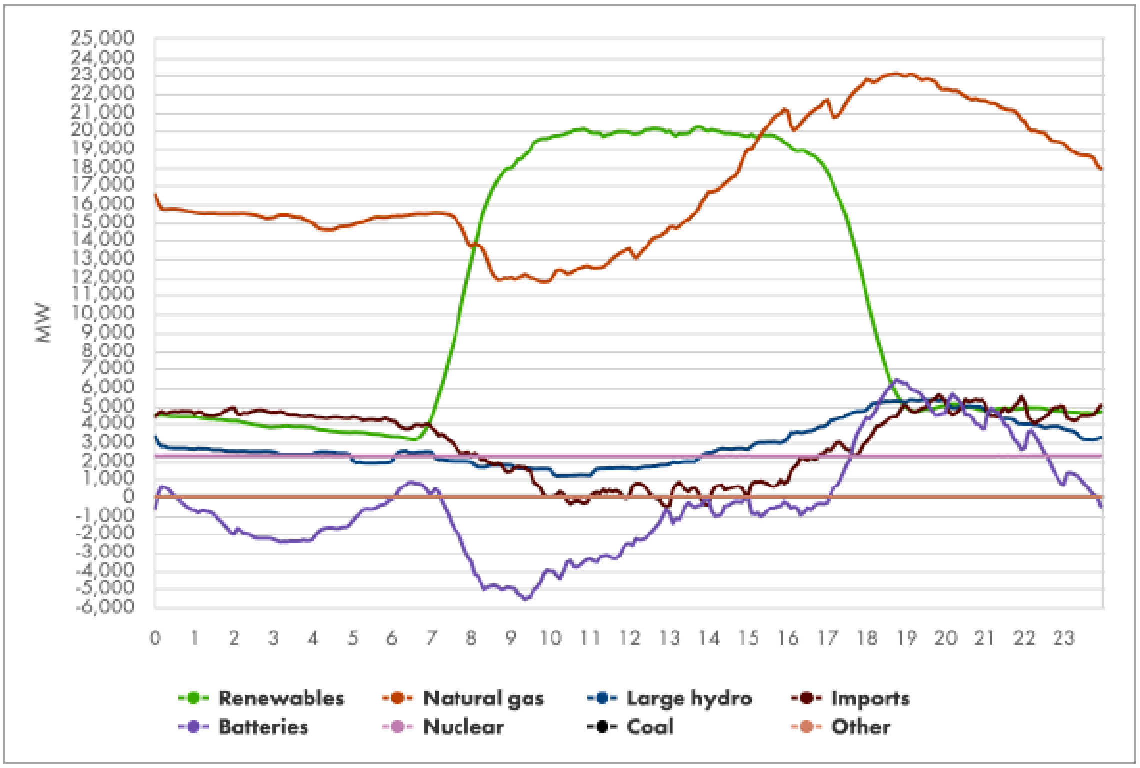
---

[44] CAISO, *California ISO Peak Load History 1998 through 2023, available at:* https://www.caiso.com/documents/californiaisopeakloadhistory.pdf.

[45] While the CAISO system demand of 46,403 MW at 6:55 pm was lower than the peak at 5:55 pm, it coincides with the peak in *net* demand (after subtracting intermittent renewable generation from the load to measure the remaining portion that dispatchable resources must meet).

Figure 7. CAISO Supply Trend for September 5, 2024

Energy by Resource in 5-minute Increments



Source: https://www.caiso.com/todays-outlook/supply (September 5, 2024)

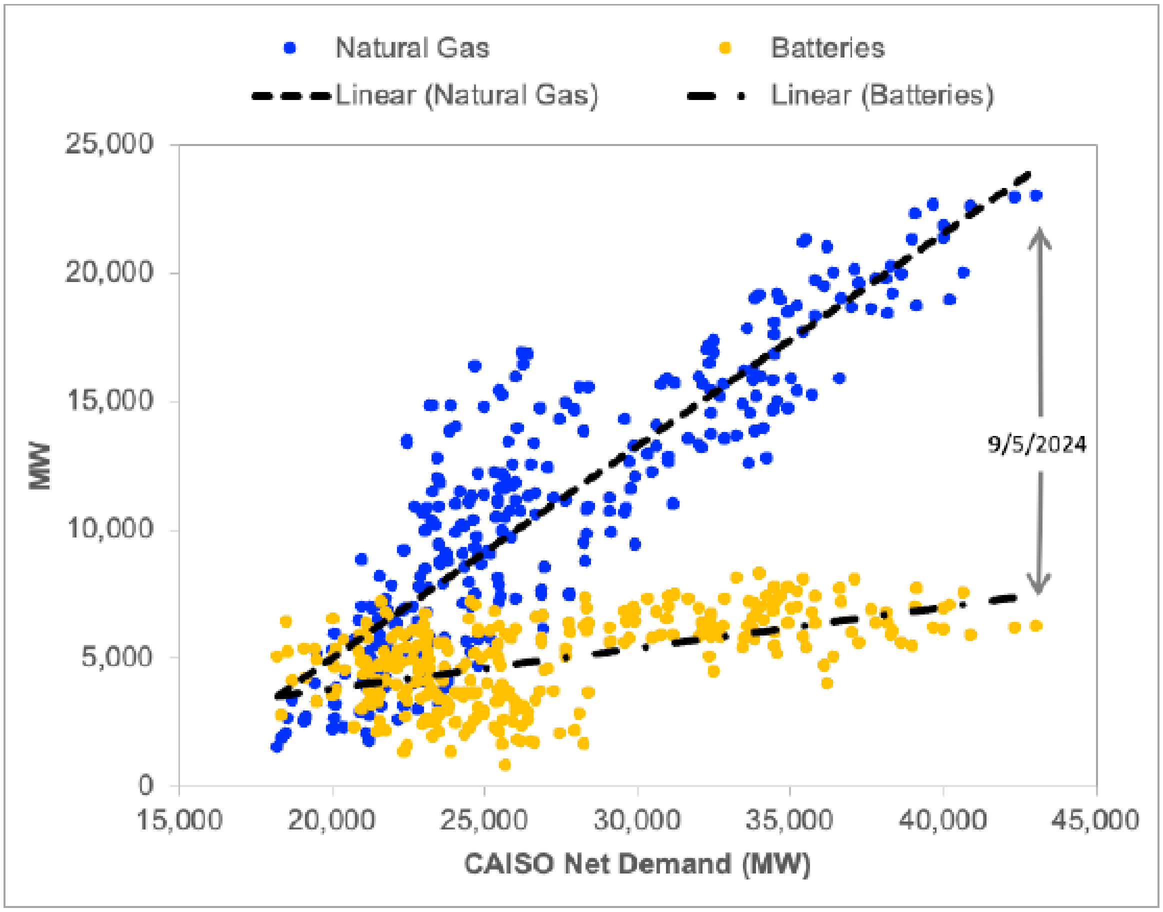
This recent heat wave is part of a broader trend in which natural gas generation (including via imports) has remained an essential firm resource for avoiding major outages throughout California, even with the rapid growth of battery capacity. CAISO recently updated its power plant database to accurately identify natural gas resources starting on December 13, 2023, so a direct comparison of batteries and natural gas on the system was not possible until recently. Using CAISO data from December 13, 2023, through October 9, 2024, Figure 8 compares CAISO natural gas and batteries production during the daily system peak in terms of net demand.[46] With a correlation coefficient of 0.88, gas generation is highly correlated with peak net demand, whereas batteries have a moderate correlation (coefficient of 0.54). Natural gas delivered its highest production during the most adverse conditions in this timeframe (September 5), comprising 53.4% of peak net demand, compared to 14.5% for batteries. Furthermore, on 77 days during this timeframe, batteries had higher production during the net

---

[46] In this analysis, net demand is a better metric than system demand, given that it aligns with the time of highest grid need for dispatchable resources.

demand peak as compared to September 5, suggesting that these resources were not operating at full capacity during adverse conditions.

Figure 8. CAISO Natural Gas and Batteries Production during Daily Peak Net Demand December 13, 2023, through October 9, 2024 (each dot represents the peak for one day)



This trend during the heat wave is concerning given that new battery capacity is continually being added to the CAISO system, so higher production would be expected toward the end of the timeframe analyzed. To understand the relationship between batteries production and net demand further, Table 5 provides results of a regression analysis for natural gas and batteries production during daily peak net demand. A simple regression of CAISO net demand on production yields coefficients of 0.83 MW for natural gas and 0.16 MW for batteries, which aligns with the slope of the best fit lines in Figure 8. Basically, as the CAISO daily peak net demand increases by 1 MW, natural gas production increases by 0.83 MW and batteries increases by 0.16 MW. While both of these coefficients are statistically significant (p-value < 0.05), the R-squared value for batteries is substantially lower (0.29 as compared to 0.78), suggesting that the batteries regression may have additional key variables other than CAISO net demand.[47] While data on recent capacity additions is not available, the regression can account for the general increase in battery capacity by including a daily time trend. As shown in the last column of Table 5, this daily time trend coefficient is statistically significant and increases R-squared from 0.29 to 0.72, suggesting that it is a key variable. After controlling for the daily time trend that accounts for the general increase in battery capacity, the CAISO net demand coefficient decreases to 0.01 and is not statistically significant (p-value = 0.46). Basically, there is at best a weak relationship between CAISO net demand and batteries production since December 13, 2013.

Table 5. Regression Analysis Results for Natural Gas and Batteries Production during Daily Peak Net Demand (based on same data from Figure 8)
December 13, 2023, through October 9, 2024

Regression Results	Dependent Variable		
	Natural Gas (MW)	Batteries (MW)	Batteries (MW)
CAISO Net Demand Coefficient	0.83*	0.16*	0.01
Daily Time Trend Coefficient			15.79*
R-squared	0.78	0.29	0.72

* Statistically significant ($p\text{-value} < 0.05$)

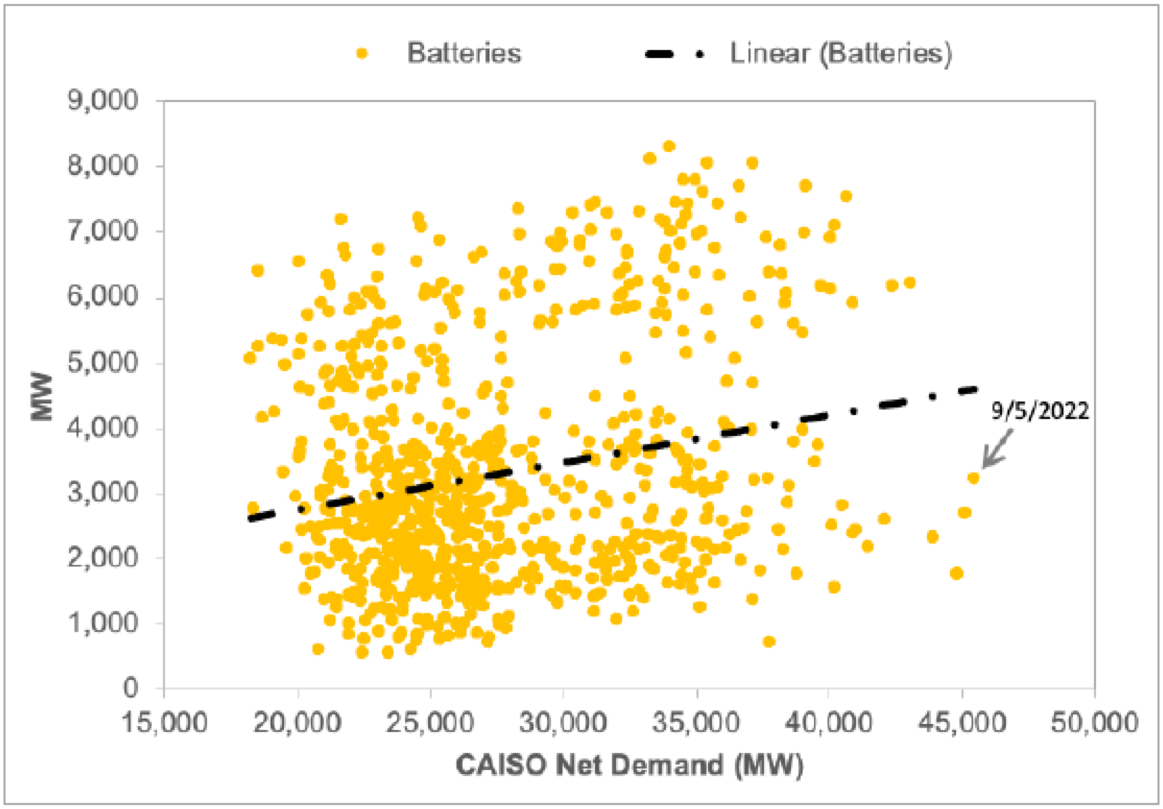
Given that batteries production data is available for a longer time period, Figure 9 compares production during the daily system peak in terms of net demand from July 1, 2022, through October 9, 2024. During this timeframe, batteries production shows a slight positive relationship with CAISO net demand (statistically significant regression coefficient of 0.08 MW, including the daily time trend). The low performance during the periods of highest net demand, most notably the extreme heat waves in September 2022 and 2024, suggests that batteries are not able to displace the essential role of natural gas generation (including via imports) in avoiding major outages throughout California. In a special report on battery storage, the CAISO

---

[47] R-squared represents the portion of variation explained by a regression model (up to 1.0), so a value of 0.29 suggests that there may be additional key variables to account for.

Department of Market Monitoring (2023) details the many issues that CAISO faced with optimally dispatching batteries during the September 2022 heat wave, leading to lower performance relative to capacity. These issues include the requirement to maintain a minimum state-of-charge for batteries, needing to have "sufficient headroom to fulfill their ancillary service awards," interconnection limits for co-located resources, and other factors. The CAISO and battery storage providers may have mitigated some of these issues. However, the recent data summarized in this section, both for LADWP and CAISO (including its imports), strongly indicates that firm clean energy resources, particularly in the Los Angeles Basin, are needed to supplement and displace the role currently served by natural gas.

Figure 9. CAISO Batteries Production during Daily Peak Net Demand
July 1, 2022, through October 9, 2024 (each dot represents the peak for one day)

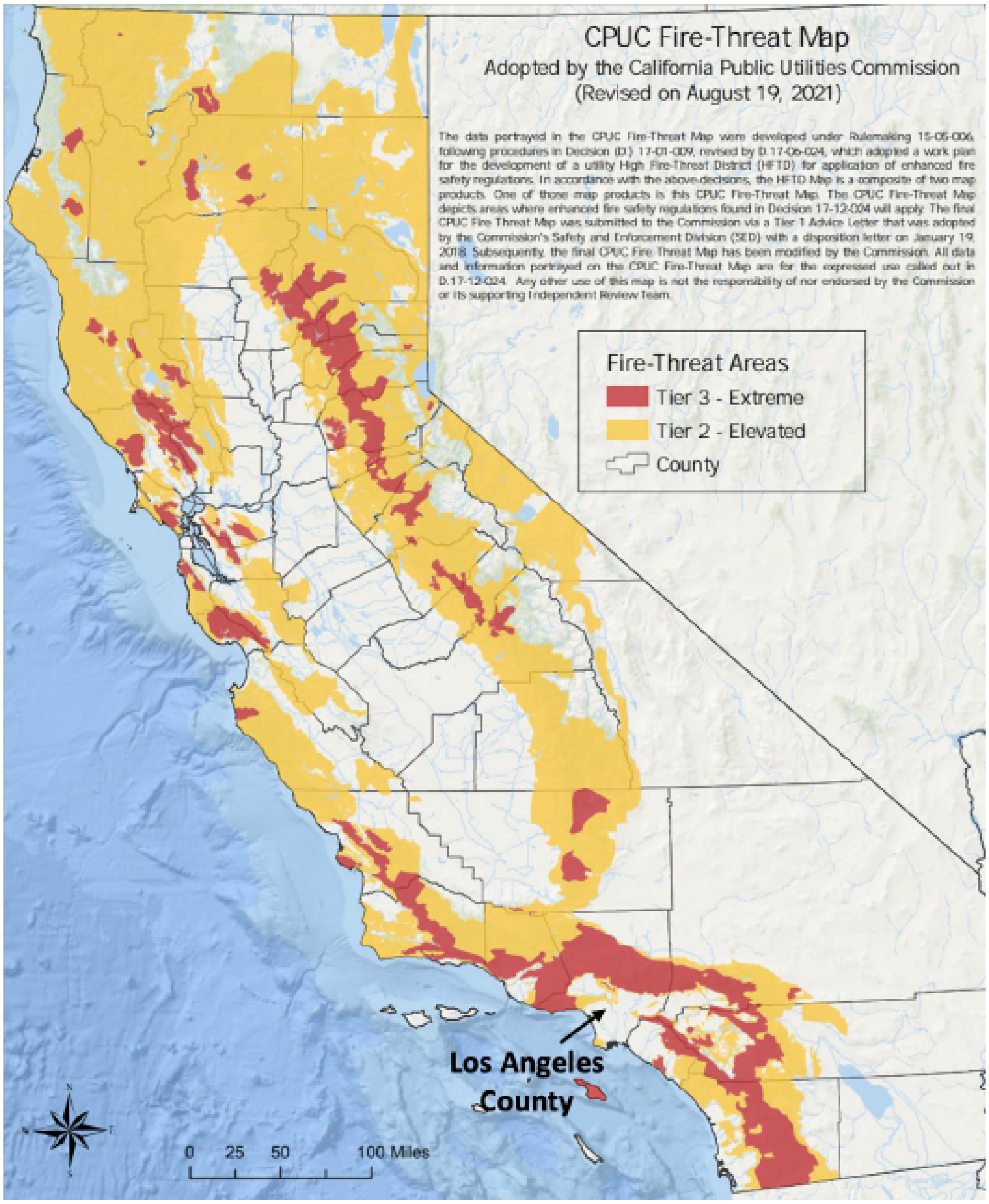


Another major issue with in-basin battery storage is that it relies on electric transmission lines to bring power into the basin for daily charging during off-peak periods, even more so in the absence of in-basin firm generation. As Figure 7 shows, CAISO batteries were a net user of power for nearly 10 consecutive hours on September 5, 2024, reaching 5,561 MW demand to charge from the CAISO grid at 9:20 am. The Los Angeles Basin is a load center with long transmission lines leading into it, going through some of the highest wildfire risk areas in the state (resulting in potentially catastrophic outages such as during the Saddleridge Fire in 2019). As shown in Figure 10, the Los Angeles Basin is surrounded by the most extreme fire-threat areas (Tier 3), based on the CPUC Fire-Threat map.[48] Therefore, expanding battery storage to displace in-basin gas generation could further exacerbate the risk of major outages during adverse events, particularly heat waves and wildfires, given that transmission lines may be down or significantly constrained during those conditions. One way to mitigate this rapidly increasing risk is by developing firm, in-basin clean energy resources that do not rely on electric transmission lines for energy input. A hydrogen pipeline such as the proposed Angeles Link that delivers fuel to firm, in-basin power plants and storage facilities is uniquely positioned to meet this critical system need because the infrastructure is underground and the energy can be stored in the Los Angeles Basin for long periods.

---

[48] CPUC, *CPUC Fire-Threat Map* (August 19, 2021), *available at:* https://files.cpuc.ca.gov/safety/fire-threat_map/2021/CPUC%20Fire%20Threat%20Map_v.3_08.19.2021.Letter%20Size.pdf.

Figure 10. CPUC Fire-Threat Map (Los Angeles County Indicator Added)



The data portrayed in the CPUC Fire-Threat Map were developed under Rulemaking 15-05-006, following procedures in Decision (D.) 17-01-009, revised by D.17-06-024, which adopted a work plan for the development of a utility High Fire-Threat District (HFTD) for application of enhanced fire safety regulations. In accordance with the above decisions, the HFTD Map is a composite of two map products. One of those map products is this CPUC Fire-Threat Map. The CPUC Fire-Threat Map depicts areas where enhanced fire safety regulations found in Decision 17-12-024 will apply. The final CPUC Fire Threat Map was submitted to the Commission via a Tier 1 Advice Letter that was adopted by the Commission's Safety and Enforcement Division (SED) with a disposition letter on January 19, 2018. Subsequently, the final CPUC Fire Threat Map has been modified by the Commission. All data and information portrayed on the CPUC Fire-Threat Map are for the expressed use called out in D.17-12-024. Any other use of this map is not the responsibility of nor endorsed by the Commission or its supporting Independent Review Team.

VIII. MOVING FORWARD EXPEDITIOUSLY WITH PLANNING STEPS

Angeles Link is a proposed pipeline system that would connect hydrogen producers, consumers and storage providers, so its value is directly tied to the scale and number of third parties that are connected to the network. This concept of "network effects" that accelerate value creation with each new connection is a well-established concept for utilities. In 1908, AT&T's annual report highlighted the incremental value of consolidating the thousands of isolated phone networks at the time, explaining that the value of a telephone "depends on the connection with the other telephone – and increases with the number of connections."[49] This concept was further popularized in the 1980s with Metcalfe's Law, starting with the expansion of ethernet. Basically, the value of one interconnected phone or ethernet network is far greater than the sum of its parts. Similarly, the value of a hydrogen system increases with the number (and scale) of connections on the supply and demand side.

The network effects concept continues to influence business more broadly, perhaps even more so in the recent tech boom. Many of the largest companies in the world apply network effects to reach unprecedented penetration. For example, Apple sells computers, tablets and smart phones, but a primary source of value for these devices is the App Store that connects buyers (Apple users) and sellers (software or app providers), creating network effects that sustain over decades, and leading to a wide range of applications. If the iPhone did not have a critical mass of users, software or app providers would not invest in developing the ubiquitous software applications for the App Store. Similarly, the iPhone benefits from a critical mass of software applications to attract buyers. Technology companies, including Airbnb, ride share companies, and electronic payment companies, meticulously manage this delicate balance between demand and supply to achieve success with network effects at the core of their business models.[50]

Policymakers in Europe and the United States also recognize the importance of network effects, particularly for expanding hydrogen infrastructure and other mission-oriented industrial strategies.[51] The European Commission emphasizes the need for coordination on the hydrogen supply and demand side to realize self-reinforcing network effects that will accelerate the clean energy transition. Its hydrogen strategy report concludes, "Renewable and low-carbon hydrogen can contribute to reduce greenhouse gas emissions ahead of 2030, to the recovery of the EU economy, and is a key building block towards a climate-neutral and zero pollution economy in

---

[49] Romero, Jesse (2018). "Network Effects." Federal Reserve Bank of Richmond. Econ Focus: Second Quarter 2018. *Available at:* https://www.richmondfed.org/-/media/RichmondFedOrg/publications/research/econ_focus/2018/q2/pdf/jargon_alert.pdf.

[50] Chen, Andrew (2021). "The Cold Start Problem: How to Start and Scale Network Effects." Harper Collins Publishers.

[51] Shih, Willy C. (2023). "The New Era of Industrial Policy is Here." Harvard Business Review. *Available at:* https://hbr.org/2023/09/the-new-era-of-industrial-policy-is-here.

2050,"[52] adding that hydrogen can create economic growth and jobs across the European Union. However, the report highlights the need for ambitious and well-coordinated policies that cover "the entire value chain, as well as the industrial, market and infrastructure angles together with the research and innovation perspective and the international dimension, in order to create an enabling environment to scale up hydrogen supply and demand for a climate-neutral economy."[53] As one of the largest economies in the world, California can also demonstrate how hydrogen infrastructure at a large scale helps the State meet ambitious decarbonization goals, while mitigating impacts to grid reliability and resilience.

Similarly, the 2024 Economic Report of the U.S. President, Chapter 6 on Accelerating the Clean Energy Transition states: "When future demand is uncertain, firms may find investing in the necessary production technology or infrastructure more challenging, in part because financing is more difficult to obtain under such conditions. However, in the absence of adequate supply, investments in technologies and infrastructure to create demand are often also difficult to justify. Policy interventions can resolve such coordination challenges."[54] In particular, California can help resolve such coordination challenges by reducing regulatory uncertainty and moving forward expeditiously both with planning steps and further systems needs assessment for firm, in-basin clean energy resources and development of these long lead-time projects.

The infrastructure for hydrogen production, transmission, distribution, storage and consumption would take many years to develop and support net load ramping and unprecedented peak load growth in the CAISO market. To realize the transformative value of a hydrogen system at scale, power generators and other industrial facilities need to make early, major long-term investments with potentially highly uncertain returns. The overall value of a hydrogen system that includes the Angeles Link, which would connect demand and supply to realize self-reinforcing network effects, could be greatly diminished if there is prolonged regulatory uncertainty (including related to planning when and where the pipeline will be built).

---

[52] European Commission, *A hydrogen strategy for a climate-neutral Europe* (2020) at 21, *available at:* https://energy.ec.europa.eu/system/files/2020-07/hydrogen_strategy_0.pdf.

[53] *Id.*

[54] The White House, *Economic Report of the President* (March 2024) at 240 (Chapter 6: Accelerating the Clean Energy Transition), *available at:* https://www.whitehouse.gov/wp-content/uploads/2024/03/ERP-2024.pdf.

IX. CONCLUSION

With the societal impacts of power outages expected to increase precipitously in the next 10 to 20 years, utility customers in Southern California benefit from long-term planning that proactively identifies system needs to mitigate these risks, especially as climate change leads to more frequent and extreme heat waves. Firm, in-basin clean energy resources are expected to support the State’s electrification goals and mitigate rapidly changing risks that are exposing vulnerabilities in existing reliability standards and planning practices. If the rigorous planning steps for firm, in-basin clean energy resources enabled by solutions such as Angeles Link do not continue expeditiously, regulatory uncertainty and delayed development timelines could lead to catastrophic consequences, particularly for disadvantaged communities and in-basin employment in energy-intensive industries.

This concludes my prepared direct testimony.

X. SELECT TECHNICAL REFERENCES

Abatzoglou, John T et al. (2020). Population exposure to pre-emptive de- energization aimed at averting wildfires in Northern California. Environ. Res. Lett. 15 094046.

Arnold, Martin (2024). "Germany was worst-performing major economy last year." *Financial Times.* Available at: https://www.ft.com/content/792a1a09-701c-4c9d-aa77-0d9575d5bda9

Borenstein, Severin, James Bushnell, and Erin Mansur (2023). "The Economics of Electricity Reliability." Journal of Economic Perspectives, 37 (4): 181-206.

Burns, Sandra and George Gross (1990). "Value of Service Reliability." IEEE Transactions on Power Systems, Vol. 5, No. 3.

CAISO Department of Market Monitoring (2023). "Special Report on Battery Storage." https://www.caiso.com/documents/2022-special-report-on-battery-storage-jul-7-2023.pdf

California Energy Commission (CEC), Adopted 2023 Integrated Energy Policy Report with Errata (February 14, 2024) at A-1, available at: https://www.energy.ca.gov/data-reports/reports/integrated-energy-policy-report/2023-integrated-energy-policy-report

Chen, Andrew (2021). "The Cold Start Problem: How to Start and Scale Network Effects." Harper Collins Publishers.

Collins, Myles, Michael Sullivan, Josh Schellenberg and Stephanie Bieler (2019). "Southern California Edison: 2019 Value of Service Study." 2021 GRC Workpapers: Exhibit No. SCE-02 Vol.04, Pt 01, Ch II, Bk A.

Economic Report of the President (2024). Chapter 6: Accelerating the Clean Energy Transition. https://www.whitehouse.gov/wp-content/uploads/2024/03/ERP-2024.pdf

Edison International, Countdown to 2045, available at: https://www.edison.com/our-perspective/countdown-to-2045

European Commission (2020). A hydrogen strategy for a climate-neutral Europe. https://energy.ec.europa.eu/system/files/2020-07/hydrogen_strategy_0.pdf

Larsen, Peter et al. (2024). Power Outage Economics Tool: A Prototype for the Commonwealth Edison Service Territory. https://eta-publications.lbl.gov/sites/default/files/poet_final_report_6may2024.pdf

White House – President Barack Obama, Presidential Policy Directive -- Critical Infrastructure Security and Resilience (February 12, 2013), available at: https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

NERC, Challenges to Reliability and Resilience (December 7, 2023), available at: https://cdn.misoenergy.org/20231207%20Board%20of%20Directors%20Item%2007a%20NERC%20CEO%20Update631092.pdf

Romero, Jesse (2018). Network Effects. Federal Reserve Bank of Richmond. Econ Focus: Second Quarter 2018. https://www.richmondfed.org/-/media/RichmondFedOrg/publications/research/econ_focus/2018/q2/pdf/jargon_alert.pdf

Schellenberg, Josh, Barney Speckman and Le Xu (2015). "Puget Sound Energy Energize Eastside Outage Cost Study." Available at: https://www.energizeeastsideeis.org/uploads/4/7/3/1/47314045/pse_energize_eastside_outage_cost_study_-_final__10.30.2015_.pdf

Shih, Willy C. (2023). "The New Era of Industrial Policy is Here." *Harvard Business Review.* Available at: https://hbr.org/2023/09/the-new-era-of-industrial-policy-is-here

Storbeck, Olaf, and Patricia Nilsson (2024). “Germany faces jobs crisis ‘of a thousand cuts’: Highly paid manufacturing work is no longer so easy to come by in Eurozone’s largest economy.” *Financial Times.* Available at: https://www.ft.com/content/b8dd41dc-4fd9-4673-8b07-6af70e7f4213

Sullivan, Michael, Josh Schellenberg et al. (2012). “Pacific Gas & Electric Company’s 2012 Value of Service Study.” http://www.caiso.com/Documents/AttachmentB_ISOResponsesCommentsDraft2012-2013TransmissionPlan.pdf

Sullivan, Michael and Josh Schellenberg (2013). “Downtown San Francisco Long Duration Outage Cost Study.” PG&E Application No. 12-12-004.

Sullivan, Michael, Myles Collins, Josh Schellenberg and Peter Larsen (2018). Estimating Power System Interruption Costs: A Guidebook for Electric Utilities. https://emp.lbl.gov/publications/estimating-power-system-interruption

White House Council of Economic Advisors (2024). Economic Report to the President. Chapter 6: Accelerating the Clean Energy Transition. Page 240. https://www.whitehouse.gov/wp-content/uploads/2024/03/ERP-2024.pdf

XI. QUALIFICATIONS

My name is Josh Schellenberg. I am Principal and Chief Operating Officer of H&S Insights, LLC. My business is located in Lafayette, California. I have over 15 years of professional consulting experience, including for large utilities throughout the country, the U.S. Department of Energy, and Lawrence Berkeley National Laboratory. Prior to H&S Insights, I worked at C3 AI as a Senior AI Solution Manager (2022-2023), Nexant, Inc. in various roles (2014-2022), and Freeman, Sullivan & Co. in various roles (2008-2013). I received an MBA from the Wharton School of the University of Pennsylvania in 2023, an M.A. in International and Development Economics from the University of San Francisco in 2008, and a B.A. in Economics from the University of Connecticut in 2006. A copy of my resume is attached as **JS-ATTACHMENT A**.

I developed the ICE Calculator, which the CPUC recommended that electric IOUs use for valuing electric reliability in the Risk Assessment and Mitigation Phase of their General Rate Case filings. The ICE Calculator has informed over $50 billion of grid investments, including climate risk mitigation. I review and advise on resilience plans, best practices and performance metrics that utilities are implementing throughout the United States to mitigate the impacts of climate change. I also was the lead analyst and project manager for the 2012 PG&E VOS study and Principal-in-Charge of the 2019 SCE VOS study – the two most recent outage cost surveys that California electric IOUs have conducted. I led PG&E's Downtown San Francisco Long Duration Outage Cost Study, which is the only survey that has focused on the value of grid resilience by measuring the costs that business customers experience for outages that last multiple days to weeks. I led planning, evaluation and reporting for the SoCalGas Conservation Campaign as part of its Advanced Meter deployment, including annual reports and presentations to the Commission. Finally, I led a statewide evaluation for the Commission on the Demand Response Auction Mechanism (DRAM), including battery storage and electric vehicles integrated into the CAISO market as demand flexibility resources.

I have previously testified before the Commission.

ATTACHMENT A

JOSH SCHELLENBERG RESUME

Josh Schellenberg

Energy Policy | Grid Reliability and Resilience | Wharton MBA

Lafayette, CA
Josh@hsinsights.com

SUMMARY

With over 16 years of consulting and policy experience in the electric utility industry, Josh supports the development of rigorous plans and cost-effectiveness analyses that provide clear insight into investment options and enable sound decision-making based on overall net benefits. His areas of expertise are resilience planning, value of reliability and demand flexibility.

Key Accomplishments:

- Developed interruption cost model that estimates the value of reliability and resilience, informing over $50 billion of grid investments, including climate risk mitigation
- Integrated model into the Interruption Cost Estimate (ICE) Calculator, which has hundreds of users and received recognition from President Barack Obama's Council of Economic Advisors and the Assistant Secretary of the Dept. of Energy
- Served as expert witness for SCE's $2 billion grid modernization proposal as part of its 2018 General Rate Case – conducted follow-up Value of Service study in 2019
- Led economic impact studies for major transmission line investments, including PG&E's Embarcadero-Potrero line, SDG&E's South Orange County Reliability Enhancement (SOCRE) and PSE's Energize Eastside project
- Conducted audit for SCE to assess underperformance of participants in the Demand Response Auction Mechanism (DRAM) – led follow-up statewide study to identify operational improvements for the $100+ million initiative
- Developed locational valuation framework for distributed energy resources (DERs)

EDUCATION

The Wharton School, University of Pennsylvania
MBA (2023)

- Graduated with Honors (Top 20% of Class)
- Major in Entrepreneurship & Innovation

University of San Francisco
M.A. (2008), International and Development Economics

- Specialization in Regression Analysis
- Survey-based field research in Guatemala for thesis

University of Connecticut
B.A. (2006), Economics

EXPERIENCE

H&S INSIGHTS — **Lafayette, CA**
Principal and Chief Operating Officer — **2023-Present**

- Lead energy consulting practice, with a focus on grid resilience and demand flexibility
- Support the development of rigorous utility plans and analyses that provide clear insight into investment options and enable sound decision-making based on overall net benefits

LAWRENCE BERKELEY NATIONAL LABORATORY — **Berkeley, CA**
Affiliate (Independent Consultant) — **2023-Present**

- Review and advise on resilience plans, best practices and performance metrics that utilities are implementing throughout the United States to mitigate the impacts of climate change
- Deliver reports and presentations for utilities, state energy offices, public utilities commissions, and other stakeholders to highlight resilience planning best practices and define key concepts

C3 AI — **Redwood City, CA**
Senior AI Solution Manager — **2022-2023**

- Supported utilities use case prioritization and value estimation for C3 AI applications, including Generative AI, Demand Forecasting and Predictive Maintenance
- Led team of 20+ engineers, data scientists, solution architects and product managers in the successful production deployment of an enterprise AI application for a large multinational company with over 400,000 employees

NEXANT, INC. (Acquired by Resource Innovations) — **San Francisco, CA**
Senior Vice President of Advanced Analytics (2019-2022), Vice President (2016-2019), Principal (2015-2016), Managing Consultant (2014-2015) — **2014-2022**

- Led team of 15+ analysts and PMs through development of business cases and analytics solutions for the Dept. of Energy and large IOUs through the country
- Scoped ICE Calculator 2.0 initiative to overhaul data, models and APIs for model and calculator that have informed over $50 billion of grid modernization investments
- Served as expert witness for SCE's $2 billion grid modernization proposal as part of its 2018 General Rate Case – conducted follow-up Value of Service study in 2019

- Conducted audit for SCE to assess underperformance of participants in the Demand Response Auction Mechanism (DRAM) – led follow-up statewide study to identify operational improvements for the $100+ million initiative
- Evaluated business case for large Midwestern utility's $5 billion plan to modernize aging transmission and distribution infrastructure
- Estimated benefits of AMI-OMS Integration to evaluate $550 million AMI business case for NYSEG and RG&E
- Developed cloud data warehouse and customer analytics platform for one of the largest utilities in the United States, delivering over $10 million in annual cost savings
- Participated with leading academics in expert workshop on grid resilience in response to climate change at the US Department of Energy in Washington DC

FREEMAN, SULLIVAN & CO. (Management consulting firm focused on the utilities industry) **San Francisco, CA**
Senior Consultant (2013-2014), Consultant II (2012-2013), Consultant (2010-2012), **2008-2013**
Senior Analyst (2008-2010)

- Led development of national interruption cost model and ICE Calculator 1.0
- Conducted innovative analyses using large datasets of AMI data (1+ billion records) to identify operational improvements for pilots and programs related to time-of-use pricing, pre-pay, demand response, behavioral conservation and energy storage
- Conducted Value of Service study for a large Southeast utility to evaluate the business case for a significant increase in its generation reserve margin
- Led study to identify operational improvements for SCE's 10/10 conservation program in response to the SONGS closure
- Designed and conducted conjoint study for a large utility to forecast electric vehicle adoption at the ZIP Code level and identify the most cost-effective incentive structure to increase EV market penetration
- Built customer engagement platform that delivered over 2% savings using AMI data

---

Certifications: Wharton Public Policy Certificate (Penn Wharton Budget Model), AWS Certified Cloud Practitioner, Machine Learning Specialization (Stanford Online), Text Mining and Analytics (University of Illinois)

Skills: Python, SQL, R, Stata, Excel, Jira, Spanish

PUBLICATIONS AND REGULATORY REPORTS

Resilience Planning

Evaluation of United Illuminating's Resilience Programs. October 2, 2024. (with Anna-Elise Smith, Dhawal Joshi and George Jiang).

Grid Resilience Plans: State Requirements, Utility Practices, and Utility Plan Template. July 2024. (with Lisa Schwartz).

Benefit-Cost Analysis of AVANGRID's 2023-2027 Resiliency Proposals for United Illuminating. October 7, 2022. (with Anna-Elise Smith and Dhawal Joshi).

Pacific Gas & Electric Martin Substation Cost Study. January 2020. (with Barney Speckman, Sundar Venkataraman and Tyler Lehman*)*.

Monetization methods for evaluating investments in electricity system resilience to extreme weather and climate change. The Electricity Journal, 32(9). November 2019. (with Zamuda, C.D., P.H. Larsen, M.T. Collins, S. Bieler and S. Hees).

Benefit-Cost Analysis of Avangrid's 2019-2020 Resiliency Plans for Rochester Gas & Electric and New York State Electric and Gas. May 17, 2019. (with Myles Collins, Stephen George, Ty Lehman and Gary Fauth)

Benefit-Cost Analysis of Central Maine Power's 2019-2020 Resiliency Plan. April 5, 2019. (with Myles Collins, Stephen George, Robert Gottlieb, Ty Lehman and Gary Fauth).

Frontiers in the Economics of Widespread, Long-Duration Power Interruptions. "Data Landscape: Challenges and Opportunities." Proceedings from an Expert Workshop. January 2019. (with Myles Collins, Michael Sullivan, Shannon Hees and Stephanie Bieler).

Puget Sound Energy Energize Eastside Outage Cost Study. October 30, 2015. (with Barney Speckman, Le Xu and Adrianna Ciccone).

Value of SDG&E's South Orange County Reliability Enhancement (SOCRE). 2015. Report and written testimony submitted to the California Public Utilities Commission on behalf of SDG&E. (with Michael Sullivan).

ICE Calculator Case Study: EPB Chattanooga Distribution Automation (under major storm conditions). 2015. (with Michael Sullivan and Joe Eto).

Downtown San Francisco Long Duration Outage Cost Study. 2013. Prepared for Pacific Gas & Electric Company's Embarcadero-Potrero Transmission Line Proposal. Written testimony submitted to California Public Utilities Commission. (with Michael Sullivan).

Value of Reliability

Evaluation of United Illuminating's Reliability Programs. October 4, 2024. (with Anna-Elise Smith, Dhawal Joshi and George Jiang).

Toronto Hydro: 2018 Value of Service Study. January 30, 2020. (with Myles Collins, Michael Sullivan and Trevor Cummings).

Elicitation of Electric Utility Customer Power Interruption Costs: A Roadmap for Conducting a National Survey. December 2019. (with Michael Sullivan, Myles T. Collins, Peter H. Larsen, Michael Hanemann, Granger Morgan, Alex Davis, Sunhee Baik and Parth Vishnav).

Southern California Edison: 2019 Value of Service Study. July 2019. (with Myles Collins, Michael Sullivan and Stephanie Bieler).

Changes to the Underlying Econometric Models for the Interruption Cost Estimate (ICE) Calculator. March 2018. (with Peter Larsen).

Benefit-cost Analysis of AMI-OMS Integration. 2018. Prepared for New York Public Service Commission on behalf of NYSEG and RG&E. (with Michael Sulllivan).

Estimating Power System Interruption Costs: A Guidebook for Electric Utilities. July 2018. (with Michael Sullivan, Myles Collins and Peter Larsen).

Portland General Electric Strategic Asset Management Value of Service Reliability Analysis. March 14, 2018. (with Adriana Ciccone).

Integrating Customer Interruption Costs into Outage Management Systems. July 2016. (with Barney Speckman and Joe Eto).

Southern California Edison Customer Interruption Cost Analysis. June 15, 2017. Report and written testimony submitted to the California Public Utilities Commission on behalf of SCE. (with Jennifer Gai).

ICE Calculator Case Study: Central Maine Power Distribution Automation. 2015. (with Michael Sullivan and Joe Eto).

Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States. January 2015. (with Michael Sullivan and Marshall Blundell).

Incorporating Customer Interruption Costs into Reliability Planning. Published in IEEE. August 2014. (with Michael Sullivan and Joe Eto).

Pacific Gas & Electric Company's 2012 Value of Service Study. May 17, 2012. (with Michael Sullivan, Michael Perry, Jason Burwen, Sam Holmberg and Sarah Woehleke).

Smart Grid Economics: The Cost-Benefit Analysis. April 2011. (with Michael Sullivan). Prepared for Renew Grid Magazine.

Evaluating Smart Grid Reliability Benefits For Illinois: How to Assess the Economic Consequences of Smart Grid Reliability Investments. November 29, 2010. (with Michael Sullivan).

How to Estimate the Value of Service Reliability Improvements. July 2010. Conference Proceedings: 2010 IEEE Power & Energy Society General Meeting. Minneapolis, MN. (with Michael Sullivan, Matthew Mercurio and Joseph Eto).

Estimated Value of Service Reliability for Electric Utility Customers in the United States. June 2009. (with Michael Sullivan and Matthew Mercurio).

Demand Flexibility

Interactive Decision Framework for Integrated Distribution System Planning. July 2024. (with Lisa Schwartz, Guillermo Pereira, Paul De Martini, Jason Ball and Natalie Mims Frick).

State Requirements for Electric Distribution System Planning. March 2024. (with Lisa Schwartz, Natalie Mims Frick, Sean Murphy, Guillermo Pereira, Jessica Shipley and Alisha Fernandez).

Demand Response Auction Mechanism Evaluation (includes battery storage and EVs integrated into CAISO market). May 23, 2022. Statewide evaluation prepared for the California Public Utilities Commission. (with George Jiang, Candice Potter, Aimee Savage, Jeremy Smith, Andrew Hauser, Dan Lesperance, Anna-Elise Smith and Kallie Wells).

Demand Response Auction Mechanism Audit. December 2018. Prepared for Southern California Edison. (with Myles Collins and Stephanie Bieler).

SoCalGas 2016-2017 Winter Demand Response Load Impact Evaluation. September 2017. (with Aimee Savage and Adriana Ciccone).

Evaluation of the SoCalGas 2013-2017 Advanced Meter Conversation Campaign. 2014-2018 (four annual evaluation reports). (with Eric Bell and Amanda Stansell).

Xcel Energy Colorado Smart Thermostat Pilot – Evaluation Report. May 12, 2017. (with Alana Lemarchand and Alexandra Wein).

2016 Load Impact Evaluation of Southern California Edison's Save Power Days Program. April 2017. (with Myles Colins and Rachel Flaherman).

2016 Load Impact Evaluation of Southern California Edison's Summer Discount Plan. April 2017. (with Myles Colins and Amanda Stansell).

PG&E Behavioral Demand Response Study. December 30, 2016. (with Marshal Blundell).

Beyond the Meter: Addressing the Locational Valuation Challenge for Distributed Energy Resources, Establishing a Common Metric for Locational Value. September 2016. (with Josh Bode and Alana Lemarchand).

2015 Load Impact Evaluation of San Diego Gas and Electric Company's Commercial Thermostat Program. April 2016. (with Dan Thompson).

Losing Control: What Will Happen if Randomized Control Trials are Phased Out of Behavioral Program Evaluation. IEPEC Submission, 2015. (with Aimee Savage, Marshall Blundell, Jonathan Cook and Brian Smith).

Comparison of Methods for Estimating Energy Savings from Home Energy Reports. November 2015 (with Aimee Savage, Marshall Blundell and Jonathan Cook).

2014 Load Impact Evaluation of California's Statewide Non-residential Critical Peak Pricing Program. April 2015 (with Stephen George and Marshall M. Blundell).

SMUD SmartPricing Options Pilot Evaluation. August 6, 2014. (with Stephen George, Christine Hartmann, Michael Sullivan, Jonathan Cook and Josh Bode).

2013 Load Impact Evaluation of the California Statewide Permanent Load Shifting Program. April 2014. (with Ankit Jain).

2013 Load Impact Evaluation of Pacific Gas and Electric Company's Residential Time-based Pricing Programs. April 2014. (with Stephen George and Aimee Savage).

2013 Load Impact Evaluation of San Diego Gas & Electric Company's Opt-in Peak Time Rebate Program. April 2014. (with Stephen George, Marshall Blundell and Jeeheh Oh).

2012-2013 Load Impact Estimates for Southern California Edison's Demand Response Programs: Agricultural and Pumping Interruptible Program Real Time Pricing. 2013-2014 (two annual evaluation reports). (with Stephen George, Jeeheh Oh and Christine Hartmann).

Southern California Edison's 2010-2012 Demand Response Load Impact Evaluations Portfolio Summary. 2011-2013 (three annual evaluation reports). (with Stephen George and Josh Bode).

2008-2012 Load Impact Evaluations of California's Statewide Base Interruptible Program. 2009-2013 (five annual evaluation reports). (with Stephen George, Josh Bode and Aimee Savage).

2012 Evaluation of Southern California Edison's 10/10 Program. March 19, 2013. (with Stephen George, Michael

Sullivan and Sam Holmberg).

2009-2011 Load Impact Estimates for SCE's Demand Response Programs. 2010-2012 (three annual evaluation reports). (with Stephen George, Peter Malaspina and Dries Berghman).

2009-2010 Impact Evaluation of Ontario Power Authority's Commercial & Industrial Demand Response Programs. 2010-2011 (two annual evaluation reports). (with Josh Bode, Peter Malaspina and Liz Hartmann).

Electric Vehicle Forecast for a Large West Coast Utility. July 24, 2011. (with Michael Sullivan). Prepared for 2011 IEEE Power & Energy Society General Meeting.

2010 California Statewide Non-Residential Critical Peak Pricing Evaluation. April 1, 2011. (with Stephen George, Josh Bode and Sam Holmberg).

2009 Load Impact Evaluation of San Diego Gas & Electric Company's Summer Saver Program. April 1, 2010. (with Stephen George, Josh Bode and Seth Morgan).

Load Impact Estimates for Southern California Edison's Demand Response Program Portfolio. September 25, 2008. (with Stephen George and Josh Bode).