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Impact of Decarbonization on the Resiliency of Single-Family Homes in Palo Alto

CITY OF PALO ALTO

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EXECUTIVE SUMMARY

The 2021 Shultz Fellowship at Stanford University sponsored a summer fellowship at City of Palo Alto Utilities (CPAU) to explore the resiliency impacts of electrifying natural gas appliances and gasoline vehicles in single-family residences (SFRs) in Palo Alto.

This study suggests that some homes with multiple fuel sources such as electricity, natural gas and gasoline can have resiliency advantages in some major disruptions; however, these resiliency advantages appear to be more limited than one might think. For example, most natural gas furnaces will not function in the event of an electric outage and most gasoline stations will not be able to dispense gasoline after a power outage as they do not have back-up power. Therefore, a fully electrified home with backup power may be more resilient than a mixed-fuel home without backup power across a wide array of natural disasters or service disruptions, because all of the energy needs can be served if they have sufficient onsite generation. But providing backup power to a mixed-fuel home requires less onsite electricity generation (with storage) than providing backup power to an all-electric home due to the larger electric load in an all-electric home.

The analysis explored the relative resiliency of electricity versus natural distribution systems in the event of natural disasters but was not able draw any definitive conclusions. For example, natural gas systems are more reliable during normal weather events, while electrical systems experience more regular outages annually. Using data from the past five years, customers in Palo Alto on average experienced 500 electrical outages compared to seven gas service interruptions per year per 1000 customers. However, research suggest that in the event of major outage scenarios such as earthquakes the restoration times for natural gas service tend to be longer but more variable than those for the electrical services, though the number of people affected by electric service outages in an earthquake is likely greater than those affected by gas service outages.

The study also found an array of energy supply products that homeowners could invest and operationalize to make their homes more resilient to withstand natural disasters and service disruptions. In summary, the Stanford Fellow hopes this exploration will assist the community further the conversations as it seeks to electrify and decarbonize homes to meet the climate challenge while enhancing community resiliency.

BACKGROUND

Natural gas use in buildings and fossil fuel-based transportation are the two major sources of emissions in Palo Alto. Decarbonizing these two sectors is critical to meeting the community's climate goals. Though the community has chosen the path of electrifying these two sectors with Palo Alto's carbon neutral electric supplies, questions arise regarding the resiliency impact of relying on electricity as the single energy source and weaning from natural gas appliances and internal combustion engines vehicles (ICE vehicle). This report summarizes the exploration and findings on the relative resiliency of a mixed fuel versus all-electric single-family home.

The study defines *reliability* to be "how frequently and for what duration customers experience energy service outages absent a major emergency" and *resiliency* to be "the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions."[1] Therefore reliability mainly deals with high probability low consequence events that focus on impact to the systems while resiliency deals with low probability high consequence hazards that focus on measuring impacts to humans. In ordinary use these two terms are not so clearly distinguishable, but the distinction was useful for this study.

The study was composed of the following steps, in which the Fellow:

A. Undertook a home appliance survey which categorized the capability of appliance operation during electricity and natural gas service disruptions
B. Explored the electric vehicle (EV) options available, vehicle range, and ability to provide back-up electricity to homes in comparison to internal combustion engine vehicles (ICE vehicles)
C. Estimated electricity use of a mixed fuel home in Palo Alto compared to a fully-electrified home, with one EV.
D. Researched ways to enhance the resiliency of a home in the event of service disruption or natural disaster scenario
E. Explored the relative frequency and duration of electricity versus natural gas service outages and service restoration times under: a) normal operating conditions, b) earthquake scenario, c) electrical outage in Palo Alto only, d) cyber attack.

DISCUSSION

A. Home Appliance Survey and Appliance Ability to Operate During Service Disruptions

Appendix A provides a full list of common natural gas appliances and electric alternatives.

In the appliance assessment, the Fellow worked with City staff to review all of the appliances used in a home and categorized them by energy dependencies. The team then the measured impact of electrical outages on the homeowner, based on outage duration for each appliance.

The study found that:

The major uses of electricity in a home are for:

i. Refrigerators and freezers
ii. Air Conditioning
iii. Lighting
iv. TV, PC, and Office Equipment
v. Dishwashers
vi. Cooking
vii. Electric Vehicles

[1] Resilience Metrics for the Electric Power System: A Performance-Based Approach (comacloud.net)

The major uses of natural gas in a home are for:

i. Space Heating
ii. Water Heating
iii. Cooking
iv. Laundry
v. Pool and Spa Heating

From the appliance assessment the team found that:

1. The main appliances that required natural gas to run were space heaters, water heaters, stoves/ovens, clothes dryers, and pool heaters.
2. Only **tank gas water heaters** and **gas stoves** would work during a power outage since other appliances require electricity to power fans, pumps, igniters or other necessary electronics.
    a. That means that gas powered space heating, clothes drying, pool heaters, tankless gas water heaters, and ovens will be inoperable during electricity outages.
    b. None of the electrically powered space heating, water heating, cooking, and clothes drying appliances would work during an electrical outage. It is worth noting that although they will not heat additional water during an outage, electric water heaters with tanks, both electric heat pump and traditional electric water heaters will have between 1-2 days of hot water stored, depending on usage and hot water level at time of outage.
3. Stoves would require ignition by hand during a power outage since they normally operate with an electronic igniter. Stoves have required ventilation which need electricity to operate in a safe and healthy way. Though some people may cook without using their hood fans, cooking indoors without proper hood fans can lead to long term health impacts, and a 2016 EPA integrated science assessment[2] noted there was some evidence linking NO_2 exposure to asthma attacks, so even during a short outage some people may need to avoid the use of gas stoves without an operational fan.
4. Traditionally electronic appliances will not operate during a power outage unless they have battery capabilities like phones and laptops which then have a limited use time until charge runs out.

B. Electric Vehicles (EVs) vs Internal Combustion Engine Vehicles (ICE vehicles)

Another important fuel source that most Palo Alto households rely on is gasoline for transportation. While many people believe that having a gasoline powered car adds another resiliency layer to a home it might not be as resilient as is commonly assumed.

The team found that:

[2] U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, Jan 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=310879, link retrieved September 3, 2021.

1. Gasoline systems also rely on electricity to operate and cannot run without it.
    a. Gas stations use electric pumps to pull gasoline out of the underground storage tanks and rely on electricity powered measurement equipment to determine how much gas customers are buying.
    b. A majority of gas stations in the city have to be refilled every day so during a large disaster scenario, if large tanker trucks cannot make their way to the gas stations, they cannot be refilled
2. A majority of gas stations in CA do not have back-up generators for pumping gas
    a. Only a few states such as Florida, New York, and Louisiana began mandating backup generators at gas stations due to events such as Superstorm Sandy and Hurricane Katrina.
3. EVs and ICE vehicles have a similar range of 300 miles on a full tank/full charge
    a. Assuming that all vehicles have on average 50% fuel capacity at any given moment gives EV and ICE vehicle vehicles 150 miles of range during an outage
4. Gasoline can be stored cheaply and for long periods of time unlike electrical storage, however storing gasoline at home is uncommon and can be a dangerous fire hazard
5. Plug in Hybrid Electric Vehicles (PHEV) can use both electricity and gasoline which provides more flexibility but only have a small battery storage capacity and then have the same downsides as ICE vehicles
6. Having an electric vehicle with rooftop solar and storage can add resiliency to the home.
    a. Rooftop solar and storage can allow customers to self-generate their own electricity even when the grid is down and gas stations are unable to pump gas.
7. In resiliency terms the team conclude that ICE vehicles and EVs are equal unless you have a solar + storage option in which case EVs are much more resilient since they can continue to be charged during an outage
8. EVs also could potentially serve as an electricity backup system utilizing vehicle to home (V2H).
    a. This would allow electric vehicles to provide about 40 – 80 kWh of backup power to homes which can provide full power to a home from 1 – 3 days at a much cheaper cost than traditional home battery storage.
    b. However, most EVs do not have V2H backward charging capabilities yet, so this benefit won't be useful until that operability is created.

C. Electricity Use of Mixed Fuel Homes Versus All Electric Homes

Appendix B provides energy uses for an average CA Home using data from the 2019 Residential Appliance Saturation Survey (RASS 2019)[3] and then a simulated electrified home from that data. *Appendix C* provides energy uses specifically from Palo Alto's SFRs and then a simulated electrified home from that data.

An important step in determining the resiliency of electrified homes is to compare the electricity uses between traditional mixed fuel homes and fully electrified homes. This will be useful to determine the effectiveness of certain resiliency measures such as solar + storage if a home fully

[3] 2019 California Residential Appliance Saturation Study - Executive Summary pg. 3, 9

electrifies.

We have found that:

1. The average home in CA (RASS 2019) uses about 360 therms/yr and 6,174 kWh/yr. This average includes both SFRs and multi-family residences (MFRs).
    a. Over 90% of gas use is for space and water heating and about 50% of electricity is used for refrigeration, air conditioning, and lighting.
2. After modeling an electrified home from the above RASS data, the team found that the average electrified CA home would now use about 10,500 kWh/yr or 13,500 kWh/yr with 1 EV.
    a. Those are increases in electricity use of about 70% and 120% respectively.
3. The average single-family residence (SFR) in Palo Alto uses about 600 therms/yr and 8,000 kWh/yr with a peak natural gas use of 110 therms/month in January and uniform electricity use throughout the year.
4. After modeling an electrified home from the above Palo Alto SFR data the team found that the average electrified Palo Alto SFR would now use about 12,500 kWh/yr (55% increase) or 14,500 kWh/yr (80% increase) with 1 EV with a peak in January of 1,600 kWh/month and 1,800 kWh/month respectively.

D. Methods to Enhance the Energy Resiliency of Single-Family Homes in Palo Alto

Appendix D provides a list of energy resiliency options for homes that experience electrical outages or loss in natural gas services.

First, the team determined if standard-sized solar + storage could meet 100% all of the needs of a fully electrified home with EVs in the most adverse conditions, on a January day with highest electricity needs and lowest solar generation. For all-electric homes in the Bay Area, the recommended solar PV size is 6.5 kW, and given that Palo Alto single-family homes use more energy than other homes in the Bay Area, our team assumed a 7.6 kW solar PV system and one 14 kWh battery (13.5 kWh usable). This is generally enough to provide 85-90% of annual energy for the average all-electric with EV single-family Palo Alto home. Since the NEM 2.0 rate for excess solar is lower in Palo Alto than in PG&E territory, further optimization around hourly usage and building envelope is possible.

The team did an analysis for the month of January to simulate the most adverse month to have an electrical outage, when the electrical load is highest, and the solar production is lowest. For this scenario for the modelled home, the team found that:

1. The Peak daily consumption for a fully electrified + EV home in January could be around 1800 kWh/month or **60 kWh/day.**
2. The daily solar production in January for a **7.6 kW** system is **20.3 kWh/day, and with a 13.5 kWh battery this would meet** or only **56%** of energy needs, including charging the EV.
    a. This January scenario represents the most adverse conditions. Mid-February through the October the system would provide roughly 100% of the energy needs.
    b. For a 24-hour outage, the home owner could consider not charging their EV, and

or drawing down the hot water in their tank. If the home owner did not need to charge their EV, about 62% of their energy needs would be met. If they chose to not charge their EV and not to run their hot water tank (draw down the hot water in their tank) roughly 78% of their needs would be met by this system, on a typical January day.

3. If the goal is to provide 100% of the energy needs from solar and storage in January, a homeowner could compare increasing the size of the solar array beyond 7.6 kW, increasing the battery storage, or increase the energy efficiency and/or the insulation of homes rather than purchasing a much larger solar array. A **15.3 kW** PV system and single **13.5 kWh** battery could produce the 55 kWh/day energy to meet the needs of the modelled all-electric home if the EVs did not need to be charged during this 24-hour outage. This solar PV system would provide 182% of the modeled home's annual electricity needs (including EV charging), so it would have very large over-generation. A 15.3 kW solar array requires about 1,090 square feet of roof space, on a moderately complex roof. It is also worth noting that solar PV systems or generators over 10 kW in size require additional approvals.

4. The size of the solar PV system and the potential cost and payback period depends on the level of resiliency desired (e.g 100% of loads covered for a week-long outage in January), efficiency of the home, roof shading, NEM 2.0 rate, and size of storage system. For homes with inefficient building envelopes and shaded roofs, providing 100% of the needs of an all-electric home from solar and storage onsite could be costly and potentially difficult.

The analysis the team found that solar + storage systems would need to be 7-15 kW solar PV and one 13.5 kWh battery, for most of the current Palo Alto SFR building stock in order to provide enough electricity supply for a home to be fully resilient throughout a 24-hour outage event, depending on the season and weather. The home's daily energy use would need to be curtailed to match the daily solar production, buffered to some extent by storage. Larger solar arrays are needed for all-electric homes, and single-family homes with shaded roofs and renters would be challenged to install solar.

Listed below are further home energy resiliency options. A fuller description can be found in *Appendix D*.

1. Rooftop Solar + Storage
2. Mobile Power Stations
3. Uninterruptible Power Supply (UPS)
4. Solar Inverter System
5. Propane, Gasoline, and Natural Gas Backup Generators
6. Propane and Charcoal Cookware and Barbeques
7. Air Drying Clothes
8. Electric Vehicles (with home solar)

9. Biking
10. Vehicle to Home (V2H) charging
11. Community Microgrid
12. Smart Electrical Panels
13. Increased Home Energy Efficiency and Weatherization
14. Emergency Kit

E. Reliability Comparison of Palo Alto's Electricity and Natural Gas Systems

Appendix E provides Palo Alto specific reliability statistics of SAIDI, CAIDI, and SAIFI for electrical services and the corresponding imputed value for natural gas services.

The team first examined the reliability of Pao Alto's electricity and natural gas systems using 11 years of natural gas outage data from 2011 to 2021 and 5 years of electricity outage data from 2015 to 2019. The results of those averaged data are shown below in the form of SAIDI, CAIDI, and SAIFI.

System Average Interruption Duration Index (SAIDI) - Measure of the total duration of an interruption for the average customer during a given time frame.

SAIDI = (Sum of Customer Minutes Interrupted) / (Total Customers Served)

System Average Interruption Frequency Index (SAIFI) - the average number of times a customer will experience an interruption during a given time frame.

SAIFI = (Total Customers Interrupted) / (Total Customers Served)

Customer Average Interruption Duration Index (CAIDI) - the average time to restore service.

CAIDI = (Sum of Customer Minutes Interrupted) / (Total Customers Interrupted)

Table 1: Palo Alto's Natural Gas and Electricity Service Reliability Statistics

Yearly SAIDI, CAIDI, and SAIFI Reliability Metrics	Natural Gas	Electricity
SAIDI (min/ # total customers)	0.95	74.9
CAIDI (min/ # interrupted customers)	124	151
SAIFI (# interrupted customers/ # total customers)	0.0073	0.52

In *Table 1* above the team can see that all three of the SAIDI, CAIDI, and SAIFI measurements are lower for the natural gas grid than for the electrical grid showing that for reliability, there are fewer interruptions to natural gas customers than for electricity customers. The average Palo Alto natural gas customer has on average 1 minute of interruption per year in gas service while the average electricity customer has on average 75 minutes of interruption per year for electricity service. Or using SAIFI, on average there are 7 gas interruptions each year for every 1000 customers in Palo Alto, while there are over 500 electric interruptions for every 1000 customers. The average gas interruption lasts for about 2 hours, while the average electric interruption lasts about 2.5 hours.

This shows that under normal operating conditions the electricity system experiences many more outages compared to natural gas supply system. The City of Palo Alto Utilities natural gas is much more reliable than electricity during normal operating conditions.

Power outages can especially impact customers that relied on home electrically powered medical equipment, in which case having small portable power station could meet those short term outage needs.

F. Resiliency Comparison of Palo Alto's Electricity and Natural Gas Systems

Appendix F provides an analysis into the three outage scenarios chosen for this study which includes why the team chose those specific scenarios, background information about the scenarios, and more in-depth impacts of each.

The three outage scenarios chosen for the resiliency study of Palo Alto's natural gas and electricity services include:

1. Earthquake scenario
    a. Modeled from the USGS Haywired Earthquake Study (primary focus for this study)
2. Palo Alto localized power outage scenario
    a. Due to the failure of all three transmission lines serving Palo Alto
3. Cyberattack scenario
    a. Potential Power loss to all of the WECC

The major findings on Palo Alto's energy resiliency from those scenarios include:

1. The resiliency differences between a mixed energy use home and fully electrified home are inconclusive for an earthquake scenario since recent reports and studies still lack extensive data on specific infrastructure fragility models.
2. For an earthquake scenario in Palo Alto (and from past earthquake events), natural gas system outages initially affect fewer people than electrical outages but would take much longer to restore the affected natural gas customers than impacted electricity customers.
    a. Northridge Earthquake: 1.4 million people initially lost power but 50% of customers got back power after 8 hours and power was fully restored after 3 days except for 7,500 customers, while it took 12 days to restore service to the 120,000 impacted natural gas customers.
    b. Loma Prieta Earthquake: 1.4 million customers initially lost power but a majority regained power within 7 hours and all but 12,000 customers had power within 2 days, while it took 9 days to restore natural gas service to 150,000 impacted customers. While there were 1,000 pipeline leaks due to the earthquake, a majority of the gas restoration time was due to the need for customer pilot light relights.
3. Palo Alto's natural gas system would recover much faster than the surrounding Bay utilities natural gas systems due to the smaller size of Palo Alto, and the higher number of natural gas valves, making it easier to isolate leaks for repairs.
4. Above ground power lines are more susceptible to non-earthquake natural disasters than below ground power lines and the natural gas infrastructure system.
5. The duration of the utility outage is extremely important to determine the impact an outage can have on residents during natural disasters.

6. Looking into the resiliency of the gasoline system the team found that "Damage to marine terminals, oil refineries, fuel storage tanks, fuel transmission lines, and fuel dispensaries is likely in a large San Francisco Bay region earthquake. As a result, there will likely not be enough transportation fuel supplies available after a large earthquake." [4]
7. The City and County of San Francisco Lifelines Restoration Performance Improvement Plan had a few important conclusions and recommendations including:
    a. Restoration of many systems can be further improved by adding backup generators or solar + battery storage systems.
    b. It is recommended to reduce reliance on petroleum fuel to increase the restoration of all systems and increase reliance on solar + storage for transportation
        - The bay area relies on Kinder Morgan fuel pipelines and Bay Area refineries for gasoline which are more susceptible to damage and have much longer restoration times. During a large earthquake event, transportation capabilities can be cut off to the whole region.
    c. The San Francisco Department of Building Inspection should require all new building to be fully electric and should require the electrification of all existing buildings with gas shutoff valves as an interim measure.
    d. The full restoration of the natural gas system can take up to 6 months because of the time it will take to integrity test the lines prior to depressurizing, and the number of qualified personnel required to relight pilot lights.
    e. Natural gas is primarily dependent on electric power and communications for remote operation of gas shutoff valves and is also critically dependent on the road network to access manual gas shutoff valves and repair damaged pipes.
        - However, the vast majority of gas regulation and control equipment are not affected by power outages as they are mechanical devices that are powered by pressure in the gas system.[5]
8. The CPAU has 4 connection points or (Gas Gates) and two separate gas transmission pipelines from PG&E coming into the city. Since there are 4 connection points and 2 pipes from PG&E, a single point of failure is not likely to cause natural gas shutoffs for the city. In comparison Palo Alto has 3 electricity transmission lines, which all pass through one corridor. Therefore, if there is a disaster event in that one location, all of Palo Alto's electricity supply is vulnerable.
9. Transmission line loss into Palo Alto is still a major issue that could cause a power outage to all of Palo Alto from 12 hours to 3 days.
    a. This type of outage would not directly affect the natural gas system so mixed energy use homes would fair better, except for fully electrified homes with ample solar + storage.
    b. Since this is a localized incident, residents could drive out of the city to refill their gas, buy groceries, food, and medical supplies as needed.

[4] G. Schremp, California Energy Commission, written commun., 2018
[5] 70_Lifelines-Report_1020.indd (onesanfrancisco.org)

10. A cyberattack scenario would be similar to a transmission line loss scenario for Palo Alto except that the cyberattack scenario can affect much larger grid systems (potentially shutting down all of the WECC) and can last from weeks to months. The gas distribution will most likely not be affected.
    a. The much longer power outage duration and larger area affected means people would no longer be able to simply leave Palo Alto to buy food, gasoline, or access WIFI since the whole grid will be down.
    b. While mixed energy use home would fair slightly better in this scenario due to having a working stove and water heater, they would face the same issues as fully electrified homes in terms of space heating, cooling, transportation, refrigeration, and WIFI.

G. CPAU Initiatives to Enhance Energy Reliability and Resiliency

While CPAU is undertaking a number of initiatives to maintain and enhance the community's energy resiliency, additional measures may also be explored, albeit it may be technically and economically challenging to implement them.

CPAU resiliency initiatives that are underway or being discussed include:

1. Adding a second set of electric transmission lines into the city
2. Undergrounding overhead electric distribution lines (reducing risks from wildfires, branches, and animals), though this process is currently on a very slow timeline.
3. Replacing distribution PVC natural gas pipes with more flexible and resilient PE pipes
4. Routine replacement of ageing infrastructure
5. Fund efficiency/weatherization measures through rebates

SUMMARY OF FINDINGS

1. Though many might assume that a natural gas + electric (mixed fuel) home will be more resilient than a fully electrified home due to having multiple fuel sources, this might not be so in many cases
    A. Many natural gas appliances need electricity to function (or cannot operate safely without it) during an electricity outage
        - Only gas stove tops and some gas tank water heaters will be operational while most gas space heating, gas dryers, gas tankless water heaters, and gas ovens will not work. Note: All water heaters with tanks will have between one to two days of hot water in the tank
    B. In the immediate aftermath of an earthquake, the electric system tends to experience more widespread disruption but can recover faster than natural gas
    C. After an earthquake, damaged natural gas infrastructure takes longer to repair, and gas service restoration times have been more variable across events than electric restoration times.
    D. During a Palo Alto electric only outage scenario, a mixed energy use home could be more resilient. It could potentially be less costly to add backup power to a mixed energy use home.

2. Energy resiliency in both mixed fuel and all-electric homes could be enhanced with a wide-array of products
    A. Simple and low-cost products such as small battery packs to propane/gasoline electric generators to outdoor propane barbeques
    B. Higher cost solutions such as large solar + storage systems or large 20 kW natural gas powered stationary generators
3. The reliability (absence of short-term outages caused by standard non-disaster incidents) is much higher for natural gas services than electricity services
    A. Reliability issues are life-threatening for customers who rely on medical devices, and small portable batteries could be enough to mitigate this issue
4. The relative resiliency of electricity vs natural gas infrastructure in an earthquake is still inconclusive:
    A. Overhead powerlines sway and can cause immediate outages due to circuits tripping, but service could be restored in short-order
    B. Underground infrastructure is prone to ground movement and damaged natural gas systems take much longer to restore than damaged underground or overhead electricity systems
    C. Most delays in natural gas restoration time is due to pilot relights
5. The resiliency of EVs is equal or better than ICE vehicles
    A. Range of EVs are currently similar to ICE vehicles and the level of fuel in the car can be similar for both
    B. Gas stations cannot function in the event of an electrical outage and most do not have backup generators
    C. EVs at home could be charged with a solar PV system
6. A standard-sized 7.6 kW PV system with one 13.5 kWh battery is enough to meet the needs of a fully electrified home nine months out of the year, and could meet 62-78% of the needs in January (not including charging the EV). A customer would need a large 15.3 kW PV system to meet the daily needs of the home modelled in January)
7. Transmission line loss scenarios and cyberattack scenarios would be more harmful to fully electrified homes than for mixed energy use homes.
    A. However fully electrified homes with ample solar and storage would likely be the most resilient in this and other major disasters.

AREAS FOR FURTHER RESEARCH

This study only began to delve into the complex tradeoffs between the resiliency of the natural gas and electricity system, and the following areas below would yield very important information for further research.

1. Examine costs more thoroughly for resiliency improvement options for mixed energy and all-electric homes.
2. Explore and incorporate resiliency, social, fiscal, health, and climate change metrics to better compare the consequences that electrification of SFRs can have
3. Overlay the GIS Haywired Scenario model onto Palo Alto's natural gas and electricity systems (or other natural disaster models) to determine more accurate damage scenarios

to estimate restoration times

4. Continue to examine, with a more focused scope, the resiliency differences between mixed energy used homes and fully electrified homes due to cyberattacks
5. Calculate the impact of building envelope improvements on energy use and resiliency
6. Determine costs and resiliency benefits of adding backup generators to gas stations
7. Explore the costs and resiliency benefits of adding solar and storage at major employers
8. Examine the costs and resiliency benefits of adding backup gas generators around the city and determine the best locations for those generators if cost effective

APPENDICES

Appendix A: Appliance Characterization

The following appliance matrix results are assuming a power outage for homes with no backup solar + storage systems.

Methodology

Impact levels:
The impact of electricity outages of varying durations on residential customers was noted for each appliance. The impact was denoted using 5 levels and their corresponding colors:

None: The customer would feel no impact or change in service during an outage: Green

Low: The customer would feel little to no impact from outage and would not have to change daily activities: Yellow

Moderate: The customer would feel some impact from outage and would have to change daily activities. Might not be able to use certain appliances for a time but no major inconveniences: Orange

High: The customer would feel a great impact during a power outage. This would include major inconveniences causing delays in productiveness, monetary loss, or difficulty in utilizing appliances that are necessary to support everyday needs: Red

Extremely High: The customer would be extremely impacted during a power outage. This would include life threatening situations and prolonged lack of access to everyday needs: Purple

Impact characterization:
The levels of impact characterization were defined by three key factors, which include:

1. Frequency of appliance use
2. Ability of appliance to self-sustain itself for periods of time (i.e. thermal water storage, battery storage)
3. Importance in meeting customer's basic life needs

Other factors that were not considered for this initial analysis but may play an important role include: the customer's location, age, personal preferences and life habits, time of day, season/weather, vulnerable populations vs general population… etc. Therefore, this impact rating from "low" to "extremely high" can be seen as subjective and situational, so in this case it is more of a rough initial guide since impact can change from person to person.

Table A1: Space Heating

In *Table A1* below, the team can see the impact that power outages have on residential customer's with regards to space heating. We found that in the event of a power outage most heating systems, including both natural gas and electric systems, will not operate. This is a surprising finding since it is commonly believed that natural gas heating systems can operate without electricity, however the team found this to be incorrect. We found that both the central gas (forced air) furnace and the radiant heating (gas boiler) systems, which both use natural gas, could not operate in the event of a power outage since they require electric fans and pumps respectively to move the fluids in the heating systems. This was found to be similarly true with regards to the electric heating systems which include electric resistance, packaged terminal heat pumps, central (ducted forced air) heat pumps, and minisplit heat pumps, which also cannot operate during a power outage.

Only two “heating” methods were found to operate during a power outage. The first is a natural gas powered fan-less wall heater which can operate without electricity. However, this heating method is extremely uncommon in single-family residential homes and more often found in multifamily buildings. Because it uses stack ventilation, it does not require electricity and can operate during a power outage. The second method is increasing the building’s envelope insulation. This method work’s regardless of power being supplied to the building and can simultaneously provide thermal resiliency during outages and save customers money on heating and cooling costs throughout the year. However better insulation alone will not provide the full capabilities of a heating system.

Since spaces have decent thermal resiliency to temperature (indoor temperature swings take some time to occur), only after a 2-hour period does lack of heating begin to have consequences, and the team can see that after 24 hours the impact can be High to Extremely High affecting resident’s comfort and even health and safety depending on the climate zone and season. For the impact assessments below, the outage is assumed to occur in winter.

It is important to note that electric heat pump heating systems are much more efficient that gas systems (often 4 to 8 times more efficient), and most heat pumps with a COP (coefficient of performance) of 3.5 or higher allow for cheaper heating that their gas counterparts.

Space Heating	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Central Gas Furnace (forced air); **Radiant Heating (Gas Boiler)**	No (requires electric fans or pumps respectively)	N/A	None	Moderate	High	Extremely High
Electric Resistance; **Packaged Terminal Heat Pumps;** **Central Heat Pump (Ducted Forced Air);** **Mini Split Heat Pump**	No	N/A	None	Moderate	High	Extremely High
Fan-less Wall Heater (multifamily)	Yes	Yes (only if no blockage in stack venting)	None	None	None	None
Better Envelope Design (Increased Insulation)	Yes (But will not provide full warming capabilities of heating)	Yes	None	None	None	None

Table A2: Water Heating

In *Table A2* below, the team can see the impact that a power outage has on various methods of residential water heating. It was found that only one method of water heating (namely a gas tank water heater) would work in the event of a power outage. The gas tankless water heater is unable to work during a power outage since it requires an electric pump. Furthermore, all of the electric heating options including electric resistance tankless, electric resistance tank, heat pump tank, and solar thermal water heaters would not work during a power outage. Another thing to note is that the thermal storage of hot water in heat tanks can last one to two days, so depending on hot water usage, electric water heaters with tanks will provide a day or so of hot water. Similarly to space heating, an electric water heat pump is much more efficient that its gas counterpart and most Heat Pumps with a COP (coefficient of performance) of 3.5 or higher, allow for lower cost heating that their gas counterparts.

Water heater	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Electric Resistance Tankless **Gas Tankless**	No; Gas Tankless requires electric pumps	N/A	None	Moderate	High	High
Electric Resistance Tank; **Heat Pump Tank; Solar Thermal Water Heating**	No (has 40-50 gal storage); Solar thermal required electric pumps	N/A	None	None	Moderate	High
Gas Tank	Yes (may require lighter)	Yes (only if no blockage on venting)	None	None	None	None

Table A3: Cooking

In *Table A3* below, the team can see the different traditional gas appliances used for cooking and their electric counterparts. For inside use the only appliance that will work during an outage is the gas stove. However, because most gas stoves use electric lighters they will need to be lit by hand with a match or lighter. Furthermore, even though gas stoves will continue to operate during an outage, it is important to note that operating gas stoves during an outage could have adverse health effects. This is due to the fact that all gas stoves must also be coupled with a dedicated stove fan or hood range which need electricity to operate. These stove fans reduce the amount of pollutants people breathe from the cooking combustion process, such as carbon monoxide, oxides of nitrogen, combusted natural gas, smoke, and particulate matter. While many of the effects of cooking without a fan or hood that the team is aware of take place over the longer term, staff is aware of a 2016 EPA integrated science assessment noted there was some evidence linking NO2 exposure to asthma attacks, so even during a short outage people with lung conditions may need to avoid the use of gas stoves without an operational fan.[6] Therefore, dedicated stove fans or hoods are especially important for natural gas systems. Induction stoves are much more efficient than gas stoves, emit no indoor air pollutants from fossil fuel combustion, and reduce the risk of fires and burns.

Another interesting finding is that while gas stovetops could operate during an outage, gas ovens will not. Gas ovens will not operate since their self-lighting feature also relies on electricity, is usually difficult to access, and requires ventilation as well. Other options that could work during a power outage are barbeque grills (propane, charcoal, or cordless electric). However, it is important to note that all three of these grill options must be operated outside to decrease the risk of carbon monoxide poisoning and inhalation of other pollutants that are created in the combustion/cooking process.

It is important to note that over the longer term, induction cooktops are a healthier option. As noted in the April 2020 Zero Emissions All-Electric Single-Family Construction Guide by Redwood Energy, “gas stoves cause unhealthy level of nitrous oxides that would be illegal if it were a gas power plant. After just twenty minutes of cooking and a sunny window, a kitchen can have actual smog and trigger asthma. Furthermore, gas cooking appliances are 25-40% efficient while electric cooking appliances are 70-90% efficient, so electric cooking uses 1/3 the energy and require 1/3 as much cooling.”[7]

[6] U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, Jan 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=310879, link retrieved September 3, 2021.
[7] SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 44

Cooking	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Gas Stove	Yes (requires lighter)	No (requires electric ventilation)	None	None	None	None
Electric Stove; **Induction Stove;** **Electric Oven;** **Gas Oven**	No	N/A	Low	Low	High	Extremely High
Barbeque grill- Propane/Charcoal	Yes	Yes (must be outside)	None	None	None	None
Barbeque grill- Electric	Yes (if cordless)	N/A	None	None	Low	Moderate

Table A4: Clothes Drying

Table A4 below shows that both gas and electric clothes drying will not work during a power outage. This is because gas dryers still need electricity for turning the laundry and operating other electronic aspects of the device. However traditional methods like airdrying with a clothesline could be a viable alternative.

It is important to note that "while washing machines and clothes dryers use about the same amount of motor energy per load, boiling the water out of wet laundry uses 81% of all the energy in an average laundry load when using a standard 30% efficient gas dryer vs a 250% efficient electric heat pump dryer."[8]

[8] SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 46

Clothes Dryer	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Gas; Electric	No	N/A	Low	Low	Moderate	High
Air Dry (clothesline)	Yes (takes longer than with dryer)	N/A	None	None	None	None

Table A5: Transportation

Many people believe that an electrified society (one that relies solely on EVs for transportation), will be less resilient to one that relies on gasoline. However, the team found that the majority of gas stations also rely on electricity to pump out gasoline and operate the credit card systems. Most of these gas stations do not have backup generators and would therefore also heavily rely on electrify to operate effectively. Therefore ICE vehicles, HEVs, PHEVs, and EVs would have to operate with the level of gasoline/battery they have until the electricity is up and running again. However, for a home with solar + storage, EV's can be charged during a power outage whereas ICE vehicles would require gas stations to be operational and would require tanker trucks (that also rely on gasoline) to transport the fuel to the stations. That further means that if key transportation infrastructure is down (such as highways and traffic lights), gas stations might not be able to refuel if tanker trucks cannot bring in the fuel to the gas stations. The regional fuel infrastructure also has vulnerabilities. The San Francisco Lifelines Study noted the potential for fuel shortages in the wake of a major earthquake.[9]

Other transportation options to explore are public transportation. Gasoline buses feel the same affects as ICE vehicle passenger vehicles and rely on pumps to be operational. Electric buses and subways (BART) also require electricity and might not be operational during an outage unless large amounts of solar or backup generation is available. Electric bikes which, need very little charge, or traditional bicycles that run on human power can be resilient alternatives during an outage, especially for Palo Alto which is known for being an extremely pedestrian and bike friendly city.

[9] City and County of San Francisco Lifelines Council, Lifelines Interdependency Study Report, April 17, 2014 https://sfgov.org/sfc/sites/default/files/ESIP/Documents/homepage/LifelineCouncil%20Interdependency%20Study_FINAL.pdf

Transportation	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
ICE vehicle's; HEV's: PHEV's	Yes (if gas pumps are operational)	Yes	None	None	Low	Extremely High
EV's	Yes (limited by charge capacity)	Yes	None	None	Low	Extremely High
Biking	Yes	Yes	None	None	None	None
Public Transportation	Yes (if gas pumps are operational); No if require electricity	Yes	None	None	Low	High

Table A6: Fireplaces

For homes with fireplaces, the team found that gas and wood fireplaces will operate during an outage but will require manual lighting and are only safe to operate if no electrical ventilation is needed (i.e. has a proper stack ventilation fireplace). Electric fireplaces will not be operational. Electric fireplaces are "swirling fire-like mist lit with LED's that are less expensive than gas fireplaces, safer, and cleaner. They provide heat in a smokeless way and can warm spaces up to 800 square feet."[10]

Fireplaces	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Gas; Wood	Yes (requires lighter)	Yes (if no electrical ventilation needed)	None	None	None	None
Electric	No	N/A	Low	Low	Low	Moderate

[10] SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 49

Table A7: Pools and Hot Tubs

During a power outage both natural gas and electric pool heaters will not operate. This is because they also rely on electric pumps to circulate the water and there is no self-ignition option for natural gas pool heaters which rely on electrical ignition.

Pools and Hot Tubs	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Natural Gas	No (ignition; pumps)	N/A	None	None	Low	Moderate
Electric	No	N/A	None	None	Low	Moderate

Table A8: Yard Tools

All yard tools that rely on diesel or gasoline will be operational during an outage. All cordless electric tools will be operational but will only last up until their battery runs out (which usually means a few hours of yard work available).

Yard Tools	Working During Outage?	Safe to Operate in Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Blower-gas; Trimmer gas; Lawn Mower - Gas	Yes	Yes	None	None	None	None
Blower-electric; Trimmer-electric; Lawn Mower - Electric	Yes (if cordless)	Yes	None	None	Low	Low

Table A9: Traditionally Electric Appliances

Now that the team has discussed the different options and resiliency affects between similar home appliances that use varying fuel sources, the team will also explore appliances that are traditionally electric only. The team found that all of these appliances will not work during an outage unless they are cordless and have their own battery storage such as laptops, phones, some hair dryers, and hair trimmers. These devices range from extremely impactful if functionality is lost to very low impact. Devices such as refrigerators, fans, toasters, microwaves, lights, WIFI, and phone access are extremely important to save and prepare food, contact emergency assistance, or work from home. Many of these appliances such as hair dryers, electric razors, and clothes irons are not life threatening or high impact if power is lost. Refrigerators can stay cold for up to 4 hours and freezers can stay cold for up to 24 hours without electricity.

Electric Only Appliances	Working During Power Outage?	Safe to Operate in Power Outage?	Impact: 10 Min Outage	2 Hour Outage	24 Hour Outage	1 Week Outage
Refrigerator	No	N/A	None	None	High	Extremely High
Plug in Kitchen Hot Water Heater	No	N/A	Low	Moderate	High	Extremely High
Microwave	No	N/A	Low	Moderate	High	Extremely High
Toaster	No	N/A	Low	Moderate	High	Extremely High
Blender	No	N/A	Low	Moderate	High	Extremely High
Fans	No	N/A	Low	Moderate	High	Extremely High
Washing Machine	No	N/A	Low	Low	Moderate	High
TV	No	N/A	Low	Low	Moderate	High
Laptops/Desktops	Yes (if cordless)	Yes	None	None	Moderate	High
Phones	Yes (if cordless)	Yes	None	None	Moderate	High
WIFI/Internet	No	N/A	High	Extremely High	Extremely High	Extremely High
Lights	No	N/A	High	Extremely High	Extremely High	Extremely High
Electric Reclining Chairs/Beds (nonmedical)	No	N/A	Low	Low	Low	Moderate
Clothes Iron	No	N/A	Low	Low	Low	Moderate
Hair Dryer	Yes (if cordless)	Yes	Low	Low	Low	Moderate
Trimmer/Electric Razor	Yes (if cordless)	Yes	Low	Low	Low	Moderate
Portable Air Conditioner	No	N/A	None	Low	High	Extremely High

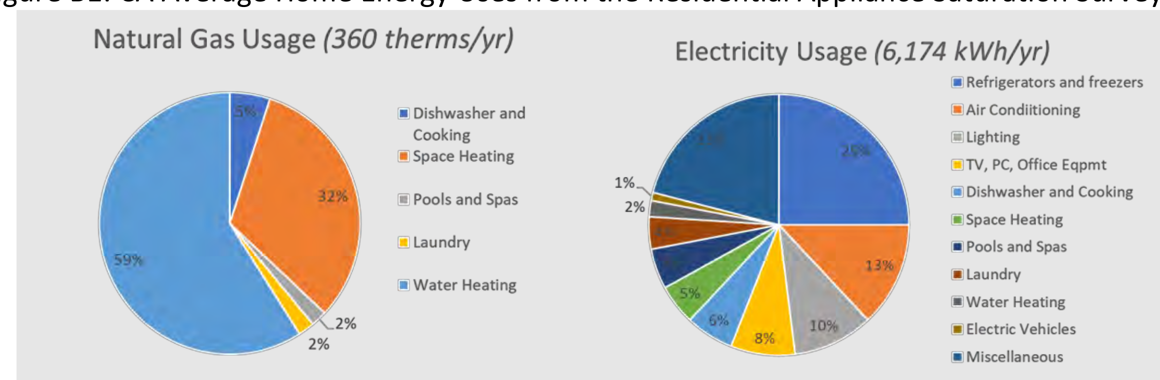
A10: Home Medical Devices:

We find that many home medical devices rely on electricity and the team would recommend having a backup power supply for these important devices. We would recommend having a small to midsized portable energy storage device in case the resident needs to evacuate their home, and also a larger home storage and PV system to provide continuous power throughout longer duration emergency events.

Appendix B: RASS Energy Use Data

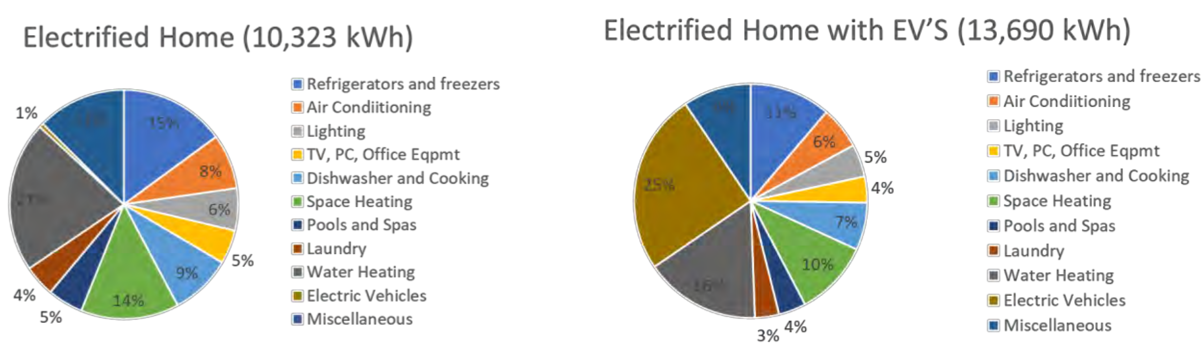
We can see the breakdown of energy uses for the average CA home in *Figure B1* below which was created by data taken from the 2019 RASS (Residential Appliance Saturation Study). The 2019 RASS report shows that the average CA home uses around 360 therms/yr of natural gas mostly for space and water heating and uses around 6,200 kWh/yr mostly for refrigeration, AC, lighting, and other appliances. These energy consumptions are useful to gain a general sense of where energy is being used in a home, however since these are California averages natural gas use will be lower than for Palo Alto due to Southern CA having much lower gas demand. Furthermore, for Palo Alto this study focused on single-family residences (SFR's) so these averages, which also include apartments, will be lower than Palo Alto SFR averages.

Figure B1: CA Average Home Energy Uses from the Residential Appliance Saturation Survey[11]



The pie charts in *Figure B2* below, show the energy use for approximated electrified average CA homes with and without 1 EV respectively.

Figure B2: CA Average Electrified Home Energy Uses



The following assumptions were used for the electrification approximation shown above in *Figure B2*:

1. Used RASS 2019 Data for CA mixed energy use
2. Assumed Electric heat pumps for space and water heating have a COP of 3

[11] 2019 California Residential Appliance Saturation Study - Executive Summary

3. For the electric vehicle scenario, assumed an average household to have 1 EV
    a. Assumed 12,000 miles travelled per year per vehicle
    b. Assumed 3.5 mi/kWh vehicle efficiency
4. Assumed that other efficiency improvements created from switching natural to gas to electric cooking, laundry, and pool heating were negligible and were not included. One therm of gas use when electrified would consume 29.3 kWh assuming a 100% conversion ratio with no changes in efficiency.

The bar chart in *Figure B3* below, shows the increased electricity use from the mixed electricity scenario to a fully electric scenario, to a fully electric scenario with 1 EV. We can see a 67% increase from Mixed use (6,000 kWh/yr) to an Electrified home (10,500 kWh/yr). And there is a 120% increase from Mixed use (6,000 kWh/yr) to Fully Electric + EV's (13,500 kWh/yr).

Figure B3: Bar Chart of CA SFR Electricity Use per Year

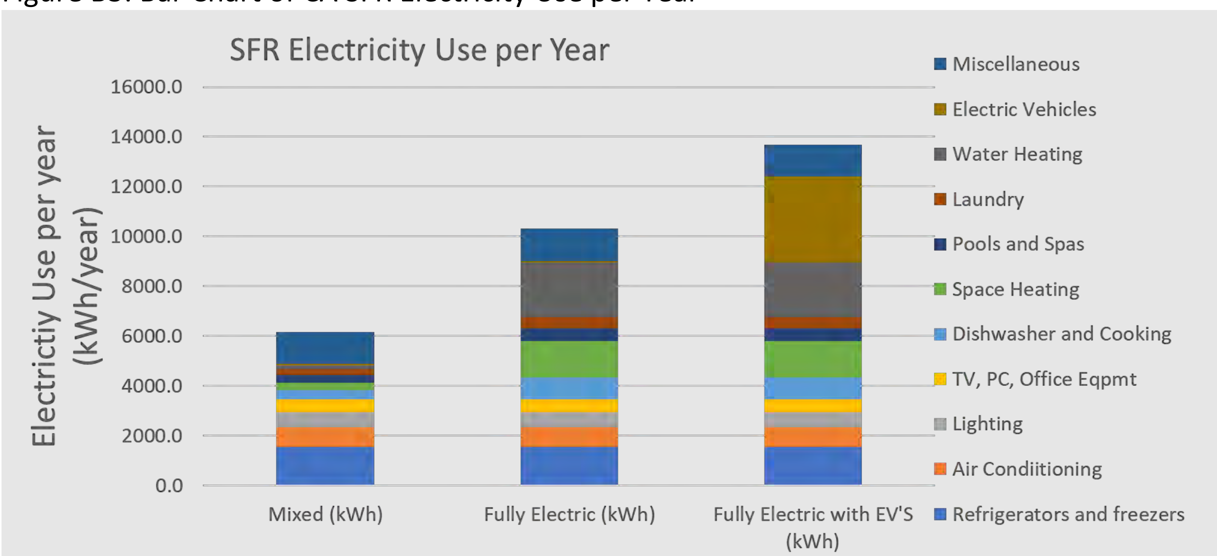
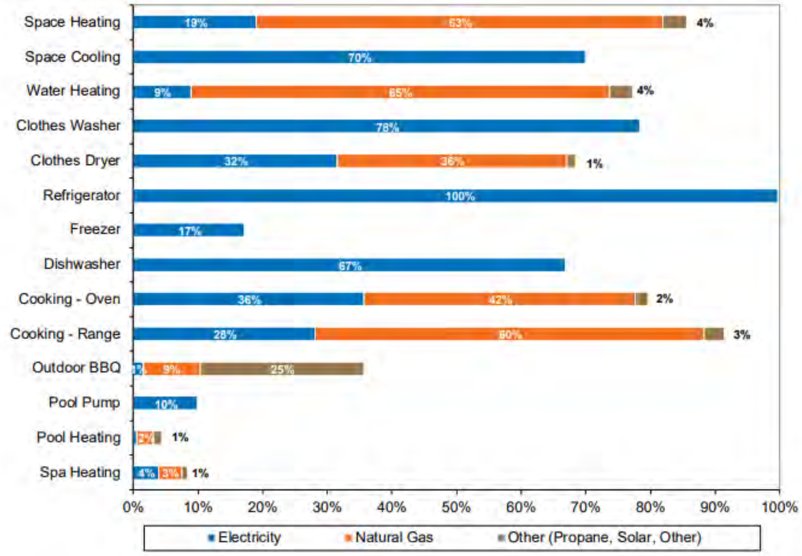


Figure B4 shows the combined electric, natural gas, and other fuel saturation for various appliances in a CA home. We can see that space heating, water heating, clothes drying, ovens, and stove ranges will be the primary targets for electrification. Furthermore, it is clear that a large amount of clothes drying, ovens, and stove ranges are already electrified in the current CA home stock.

Figure B4: Appliance Saturation for the Average CA Home from the RASS Report[12]

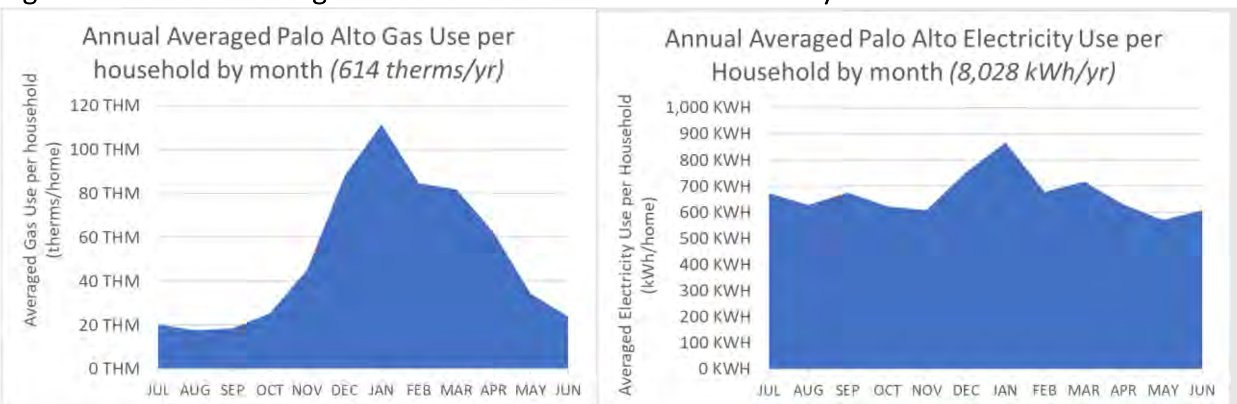


[12] 2019 California Residential Appliance Saturation Study - Project Overview pg. 14

Appendix C: Palo Alto Energy Use Data

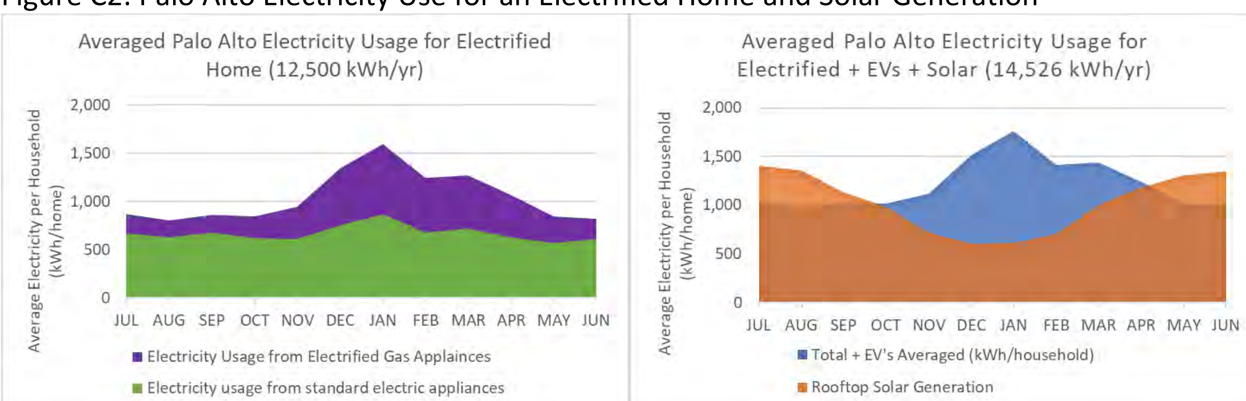
Figure C1 below shows Palo Alto's actual natural gas and electricity usage for SFRs. These results are averaged from Palo Alto individual SFR data from July 2019 to July 2021. I summed all of the individual monthly energy uses and averaged them over the 2 year time period and approximately 15,000 SFRs.

Figure C1: Annual Averaged Palo Alto Natural Gas and Electricity Use



We can see that the average Palo Alto SFR uses around 600 therms per year with highs in the winter of 110 therms due to increased space and water heating and lows in the summer of 20 therms. We can further see that the electric demand for SFRs is constant throughout the whole year with a total electricity use of around 8,000 kWh/yr with highs of 850 kWh/month in the winter and lows of 600 kWh/month in the summer.

Figure C2: Palo Alto Electricity Use for an Electrified Home and Solar Generation



Now *Figure C2* above on the left shows the combined energy demand from the previous two graphs for an electrified home. The purple denotes new electricity use from electrified natural gas appliances, and the green shows the electricity use for standard electric appliances where the two combined become the total energy use for an electrified home. We can see that electrifying the home increase the yearly energy usage from 8,000 kWh/yr to 12,500 kWh/yr (55% increase) and increases the winter monthly peak from 850 kWh to 1,600 kWh.

Finally, Figure C2 above on the right adds EV electricity demand and the total electricity demand is in blue. The team also overlaid the rooftop solar generation for a 7.6 kW system in Palo Alto as shown in orange. That means that all of the area left in blue is the home's energy demand that solar generation cannot meet. The total yearly energy use per SFR is now 14,500/yr (80% increase) and the total solar generated is 12,350 kWh/yr, or 85% of the annual usage. Larger solar PV systems can fit on most SFR homes, but might have longer payback periods depending on the NEM 2.0 rate and the degree of onsite usage from smart devices.

The following assumptions were used for the electrification model shown above:

1. Assumed COP of 3.5 for heat pump water heater and space heating.
2. Also accounted for the fact that older gas furnaces had efficiencies of only around 70%.
3. Assumed that each home will have 1 Electric Vehicle
4. Assumed that 3,500 out of Palo Alto's current 5,000 EVs were attributable to SFRs: so only 11,500 more EV's were added (15,000-3,500=11,500)
5. Rooftop PV system is assumed to be 7.6 kW and energy output data is modeled using PV Watts

Figure C3: Palo Alto Single-Family Home Monthly Electricity Use per Household

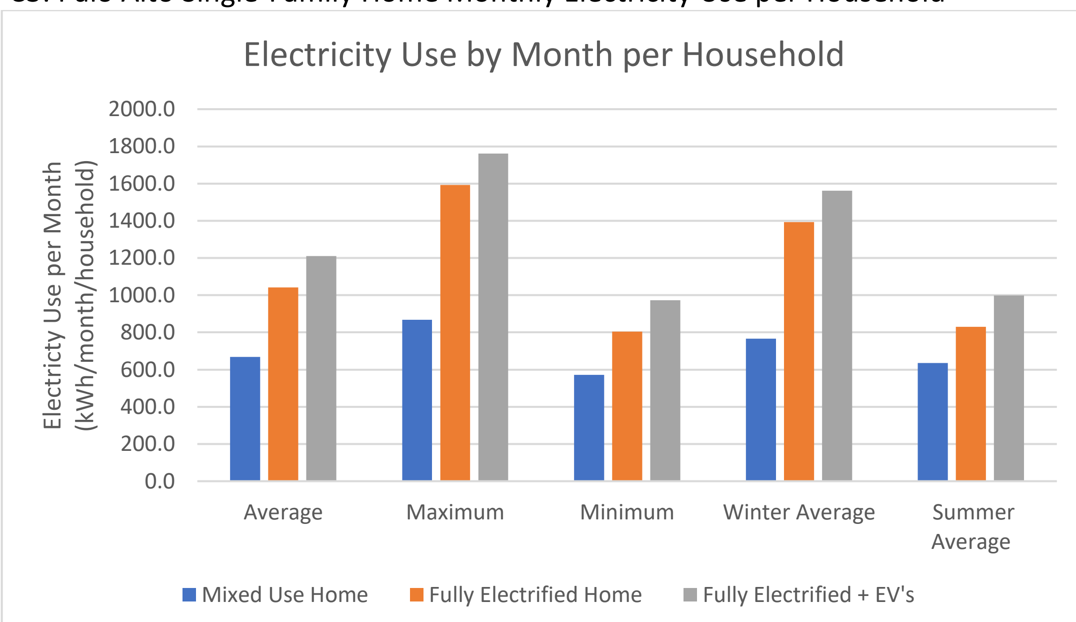


Figure C3 shows the electricity usage per month per household over various scenarios and can see that the highest electricity demands will be during the winter across all three scenarios.

Appendix D: Home Energy Resiliency Measures

1) Rooftop Solar + Storage

Rooftop solar + storage is one of the most effective methods to increase a home's resiliency. While it is much more expensive than other resiliency methods such as gasoline generators, it works year-round, saving money on energy bills and can provide full-service coverage for mixed energy use homes, and can meet most of the demand during the summer for electrified homes. However, for electrified homes in Palo Alto during the winter, a 7.6 kW solar PV system with 13.5 kWh battery can only meet around 62% of energy demand and electrical storage will quickly be used up.

Therefore, to be fully resilient off grid in the months of November through February, the solar array must be scaled up past 7.6 kW and the home must be designed with more energy efficient technologies to decrease the amount of solar needed. Home battery storage can have a storage capacity of 10-14 kWh and can have a total product and an installation cost between $8000-11,000. The average Palo Alto mixed energy home uses 20-30 kWh per day and a fully electrified home uses 30-60 kWh per day with higher energy uses in the winter for space heating. Solar PV systems of 15.5 kW or so will be required to make it through multiple days of outages if the home energy efficiency are not increased.

Furthermore, cost of solar panels can vary on size and whether the product is being bought outright or leased. Many people prefer the leasing option since they are not responsible for solar panel damage and pay monthly lease installments that are often cheaper than their energy bills, in affect saving money for no cost. The costly part of the system is the battery storage. Solar and storage systems can currently be financed, because of the monthly energy savings, but the minimum bill and NEM 2.0 rate of City of Palo Alto Utilities will extend the payback period of these systems.

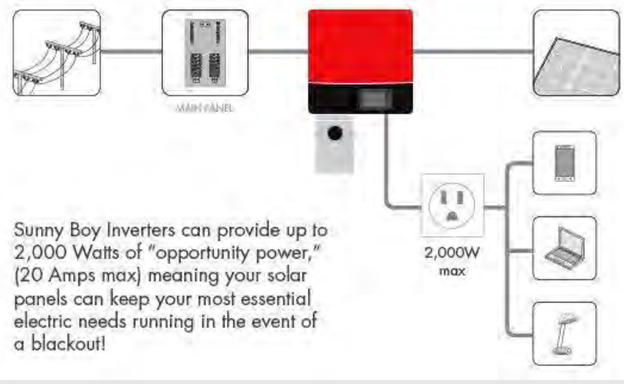
2) Mobile Power Stations

Mobile power stations are another method to increase home resiliency. They are essentially large movable battery packs, holding anywhere from 500 Wh - 2 kWh of electricity, that can run between $200 and $600. These devices can be charged by plugging into a wall outlet or with small solar panels if off-grid. However, these battery packs cannot support a whole home which uses 20-30 kWh/day for mixed use homes and 30-60 kWh/day for fully electrified homes. Mobile power stations are perfect for charging small devices such as phones, laptops, small electric cookstoves, small fans and other devices, or a single large appliance such as a refrigerator. Also, since they are portable unlike large home battery storage, people can take them out of the house if the home is unsafe and can continue to provide energy for their medical devices inside and outside of the home as well.

3) UPS (uninterruptible power supplies)

Uninterruptible power supplies can also add to the resiliency of a home by providing a little more backup storage and surge protection for sensitive devices. A UPS is traditionally connected to WIFI routers, phones, laptops, desktops, and other small devices. While a UPS is relatively cheap ($50 to $300), it is usually meant for short term outages (more reliability focused than resiliency) and can only support these small devices between 2 to 5 hours.

4) Solar Inverter Systems



[13]

Solar inverter systems are products that allow customers to utilize rooftop solar energy during power outages without having battery storage. Rooftop solar either feeds into the grid or a home battery system. If there is no home storage option and the grid is down, typical rooftop solar won't produce any energy for the home. However, solar inverter products such as the Sunny Boy and Enphase Ensemble allow the solar energy to be directly sent to devices. However, these inverter systems have a power draw capacity limit and can only send about 2 kW of electricity which is enough to power small devices such as phones, laptops, two refrigerators, or a single microwave/toaster oven, or a single burner on an induction stove. Therefore, it is often recommended to purchase the home battery storage as well, due to the limited power cap of these solar inverter systems. The cost of a solar inverter systems is about $1,500-$2,500 not including the price of the solar panels and installation.

5) Propane, Gasoline, Natural Gas Backup Generators

Propane, gasoline, and natural gas backup generators can range from $300 with a 2kW mobile capacity allowing one to power small appliances, to $3,000 with a 15kW mobile capacity allowing one to power most of the home's needs, finally to $5,500 with a 20 kW stationary capacity which can fully meet the home's needs but require 4 gallons propane/hour or 280 cubic feet of natural gas/hour. The installed cost of the stationary generator is generally close to $10,000 or slightly more. For those larger systems the fuel cost is about $3 to $15 per hour depending on the type

[13] What Happens If You Have Solar And The Power Goes Out? (solarreviews.com)

of fuel used. Natural gas generators have a distinct advantage in that they can be connected directly into the natural gas distribution lines in the home, which eliminates the need for refueling since there will be a continuous supply of natural gas (unless the natural gas grid is out).

While these systems are substantially cheaper than solar + battery storage and more effective that small mobile power stations, they do have their drawbacks. First off, the fuel costs are quite expensive and unlike solar + storage, they do not provide revenue and other energy services throughout the year. Furthermore, since they are burning fuel, they create harmful air pollution (including CO_2 emissions) and should always be used outside. Lastly, they are also more prone to causing fires. In addition, only those generators which are wired directly into the electrical panels (not mobile generators) will allow natural gas furnaces to heat a home, since the HVAC system is powered from the panel and cannot be bypassed to run off of a mobile generator.

6) Propane and Charcoal Cookware and Barbeques

Propane and charcoal cookware (only when used outside due to indoor health threats including fires and carbon monoxide poisoning) can be great resiliency tools to have during an outage. They can be used for fully electrified homes in an outage or for mixed energy homes if the stove top, oven, microwave and toaster are not working. Since propane and charcoal can be easily stored this is a simple and relatively cheap resiliency alternative.

7) Air Drying Clothes

When power is out, clothes dryers and washing machines will not work. People often forget that clothes can be handwashed in the sink and air-dried outside on a clothesline without any power use whatsoever.

8) Electric Vehicles

Electric vehicles, paired with solar and battery storage, are another important tool one can have to increase their resiliency. Since a majority of gas stations require electricity to pump gas and are usually refilled once per day from large tanker trucks that also require gas, having an electric vehicle charged from home can provide transportation services that might have been incapable with ICE vehicles.

9) Biking

During an outage, relying on mechanical human-powered energy such as biking is an extremely cheap, resilient, healthy, and effective way to get from one place to another, if gas stations are down and electric vehicles + battery storage + solar panels is too expensive.

10) Vehicle to Home (V2H) Charging

Vehicle to Home can potentially be a resiliency and electricity storage solution by using electricity stored in an electric vehicle (EV) to power the home. Current electric vehicles can have battery storage between 50 kWh and 100 kWh (40 to 80 kWh usable) which is enough to fully support a home's electricity needs from 1 to 4 days depending on the time of year and if the home is fully electrified. The one vehicle is equivalent to having 3 to 6 battery storage units and can also be used for transportation purposes. However, while this type of technology would provide immense resiliency opportunities, it is not common in the US or compatible with most electric vehicles, and is therefore not currently available, except for a few specific models such as the Nissan Leaf.

11) Community Microgrid

A community microgrid could be another effective resiliency measure for homeowners who might not be able to install solar panels on their own homes due to tree shading, structurally weak roofs, or lack of home ownership. There are many ways one could implement a community microgrid, and the concept requires more study to determine its feasibility and most effective implementation in Pao Alto.

12) Smart Electrical Panels

Smart electrical panels allow battery systems to work much more effectively, letting the customer choose where energy is used in a home during outage situations if there is limited battery supply. This allows the customer to prioritize their most important electricity needs if they need to ration out their battery storage during an outage.

13) Increased home energy efficiency/weatherization

Energy efficiency and weatherization can be beneficial for a homeowner in 3 main ways. Firstly, an energy efficient home and properly weatherized home requires less energy to function. This means that during an outage, less solar and fewer backup storage batteries will be needed to supply the home. It will be less costly and much simpler to power an energy efficient home with solar throughout the whole duration of an outage. Secondly, properly weatherized and energy efficient homes have better insulation and ventilation, and thereby can retain heat/coolth better during power shutoffs when space heating and AC might not be operational. So, while a normal home might begin to get cold in the winter after only 6 hours, a properly weatherized home with good insulation might not change indoor temperature for 18 hours. Lastly since energy efficient homes use less energy throughout the whole year, residents are continuously saving money throughout the whole year, unlike a propane or gasoline generator, which does not provide any sources of income or reduce electricity bills.

14) Emergency Kit

A basic emergency kit that includes water, a flashlight, non-perishable food, a can opener, a space blanket, a radio, and a can opener can be extremely useful to meet hydration, food, warmth, communication and other safety needs during an outage.

Appendix E: Reliability Comparison between Palo Alto's Natural Gas and Electricity Service

System Average Interruption Duration Index (SAIDI) - Measure of the total duration of an interruption for the average customer during a given time frame.

SAIDI = (Sum of Customer Minutes Interrupted) / (Total Customers Served)

System Average Interruption Frequency Index (SAIFI) - the average number of times a customer will experience an interruption during a given time frame.

SAIFI = (Total Customers Interrupted) / (Total Customers Served)

Customer Average Interruption Duration Index (CAIDI) - the average time to restore service.

CAIDI = (Sum of Customer Minutes Interrupted) / (Total Customers Interrupted)

Figure E1 below, shows the SAIDI, CAIDI, and SAIFI of Palo Alto's natural gas service.

Figure E1: SAIDI, CAIDI, and SAIFI of Palo Alto's Natural Gas Service

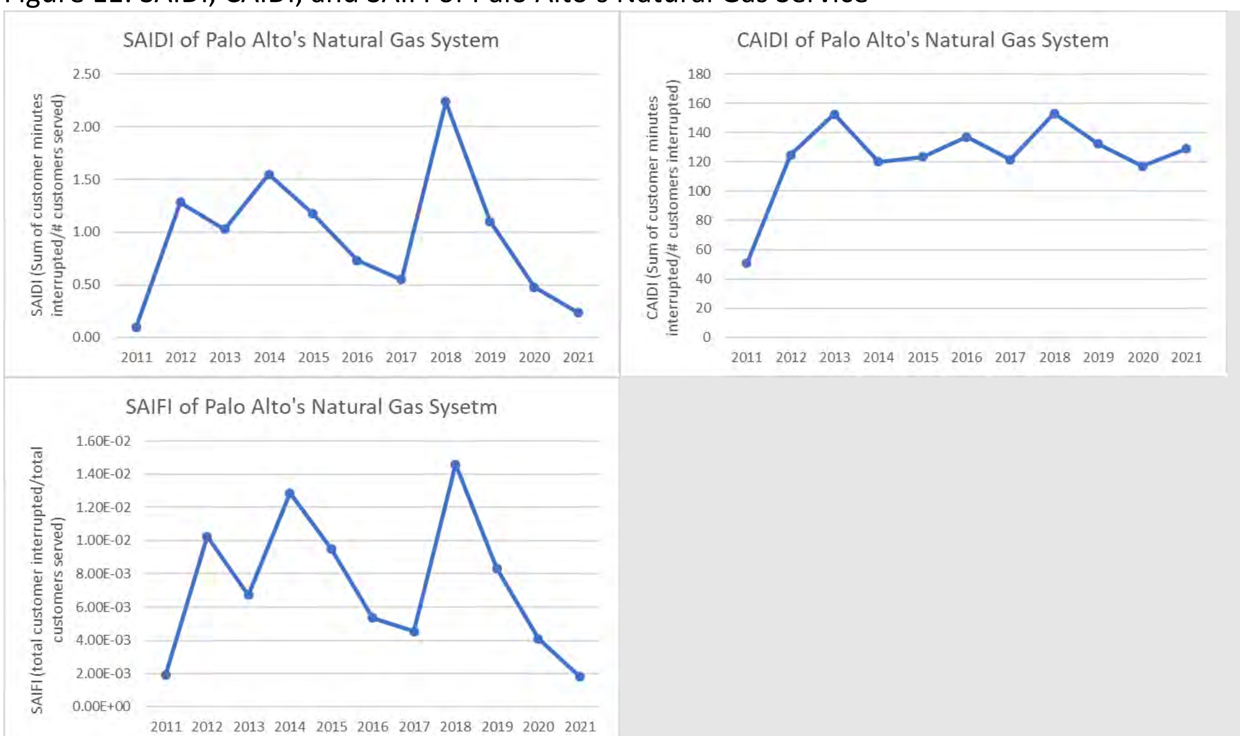
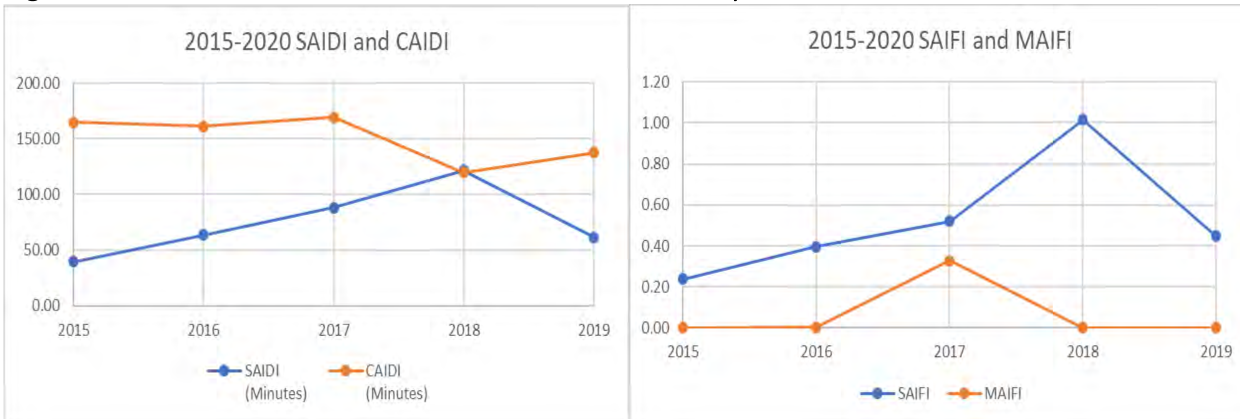


Figure E2 shows the SAIDI, CAIDI, and SAIFI of Palo Alto's electricity service.

Figure E2: SAIDI, CAIDI, and SAIFI of Palo Alto's Electricity Service



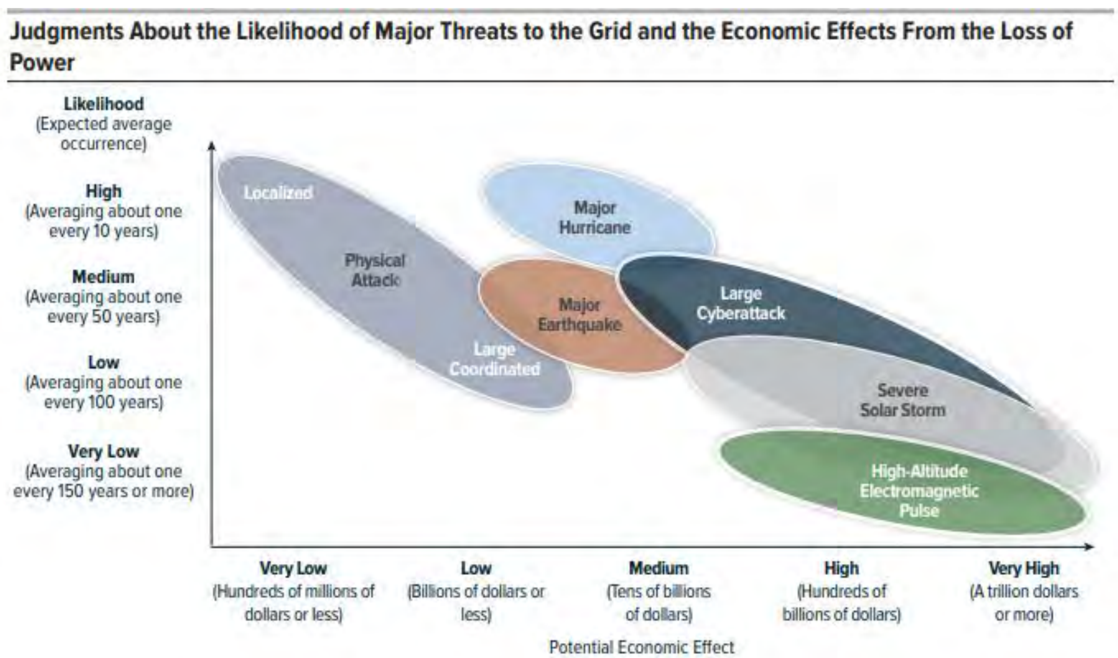
These charts show that the natural gas service is much more reliable than the electricity service for Palo Alto customers under normal circumstances.

Appendix F: Resiliency Comparison for Various Outage Scenarios

This report will mainly focus on outages due to an earthquake scenario; specifically the Haywired Earthquake scenario which was a 7.0 earthquake with an epicenter in Oakland, CA modeled by the USGS. The study also considered two other scenarios which include a Palo Alto specific outage similar to the Plane Crash incident of February 2010 which took down all of the transmission lines coming into Palo Alto which happen to be located in the same corridor, and a Cybersecurity event which could potentially wipe out all of CA's or even the whole WECC's grid.

These three scenarios were chosen after considering data from the CBO North American Grid Security paper and taking into account CA and Palo Alto specific threats. *Figure F1* below shows the likelihood of major threats on the y-axis with the estimated economic damage plotted on the x-axis. The team decided to choose the Haywired earthquake scenario as this paper's main focus since Palo Alto lies in an earthquake prone area, and the likelihood and damage from the event are both medium to high.

Figure F1: Judgements About the Likelihood of Major Threats to the Grid and the Economic Effects from the Loss of Power[14]



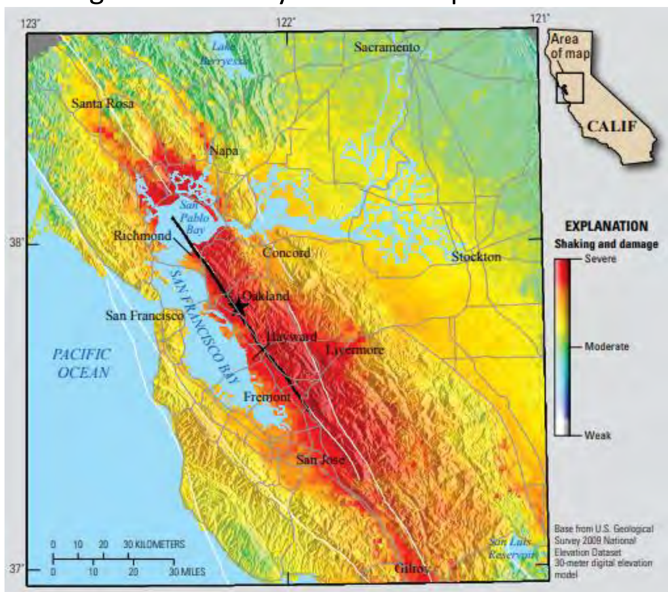
The Haywired Scenario

The Haywired Earthquake Scenario is a 2018 study led by the United Stated Geological Survey (USGS) which anticipates the impacts of a hypothetical magnitude 7.0 earthquake on the Hayward fault with the epicenter located in Oakland, CA on the East side of the San Francisco Bay. For the past 2,000 years scientists have documented a major earthquake occurring along

[14] Enhancing the Security of the North American Electric Grid (cbo.gov) pg. 9

this fault every 150 ± 60 years. The last big earthquake on the Hayward Fault was in 1868, over 150 years ago.

Figure F2: Shaking and Damage Chart of Haywired Earthquake Scenario[15]



The geological impacts of the Haywired Earthquake include:

- Ground shaking
- Fault offsets or ground displacement of up to 6 feet (with slower displacement occurring up to months after incident)
- Liquefaction
- Landslides
- Aftershocks as high as 6.5 (up to 2 years after main quake)

The casualties and losses from this event could include:

- **800 deaths** and **18,000** nonfatal injuries from structural damage
    - 2,500 people could require rescue from collapsed buildings
    - 22,000 people could require rescue from stalled elevators.
- **77,000 (3%** of Bay Area**)** displaced households due to structural building damage or **152,000 (6%** of Bay Area**)** households displaced if including other factors such as utility outages
- Of current building stock in the Bay Area:
    - 0.4% could collapse
    - 5% could be unsafe to occupy
    - 19% could have restricted use
- **$82 billion** in property damage and business losses
    - Most losses from shaking damage, then liquefaction, and finally landslides

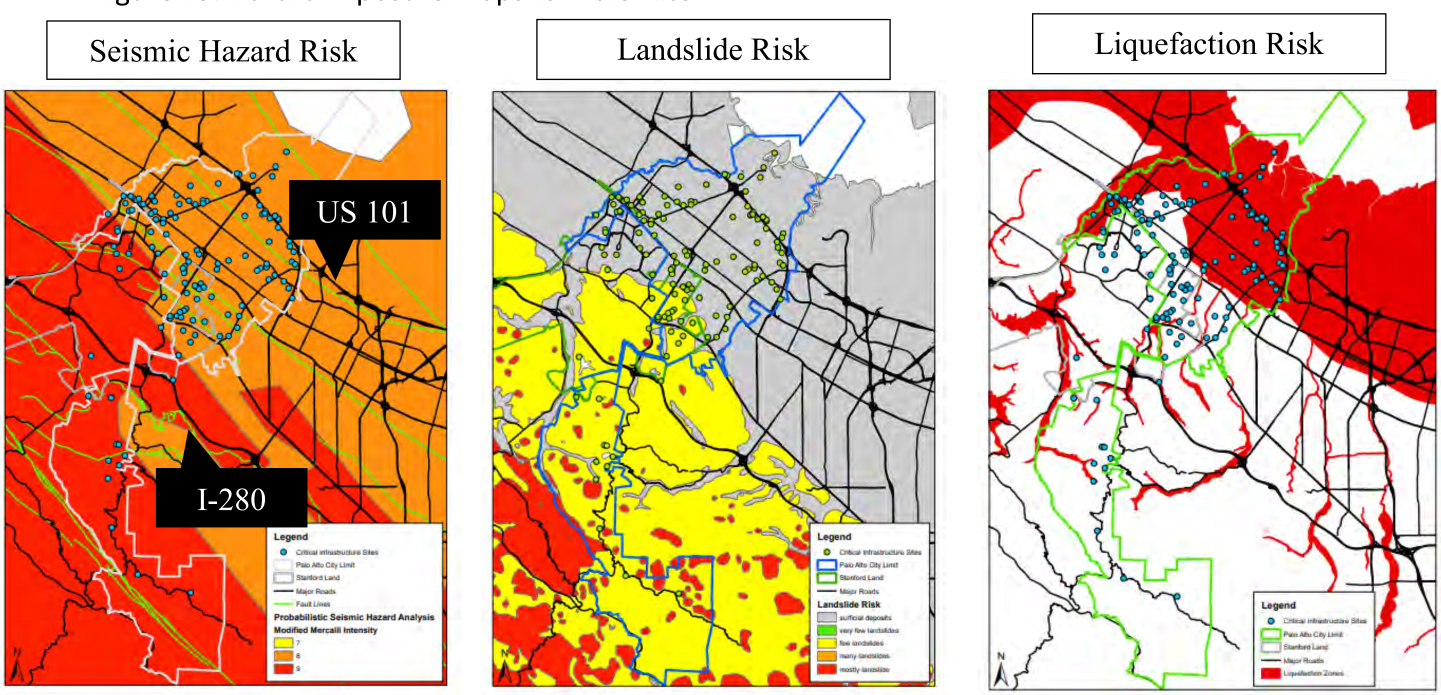
[15] SIR 2017-5013 v1.2: The HayWired Earthquake Scenario—Earthquake Hazards (usgs.gov) pg. 32

In general Palo Alto is vulnerable to several natural disaster events including:

a. Earthquakes (main shaking, surface displacement, landslides, liquefaction, aftershocks)
b. Flooding
c. Wildfires
d. Sea Level Rise

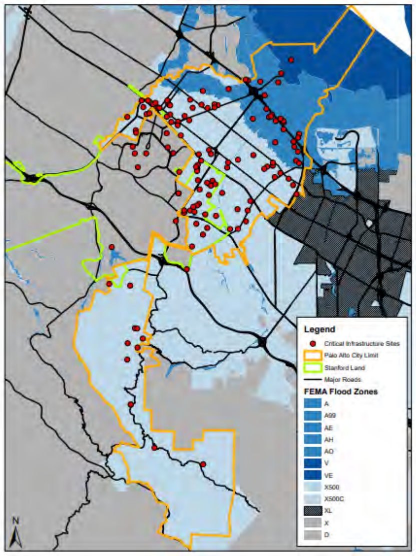
Figure F3 shows Hazard Exposure Maps for Palo Alto. In the first image on the left, the white lines depict the city limits of Palo Alto, the black lines depict important highways and freeways and the blue dots depict other important infrastructure. We can see that all of Palo Alto is earthquake prone, shown in orange and red. The northern side of Palo Alto, closer to the San Francisco Bay, is more vulnerable to liquefaction, flooding, and sea level rise (and can affect areas that contain important infrastructure), while the southern more hilly part of Palo Alto is more vulnerable to landslides and wildfires. While southern Palo Alto contains less infrastructure at risk, wildfires and landslides can still affect housing and distribution lines in the area.

Figure F3: Hazard Exposure Maps for Palo Alto[16]

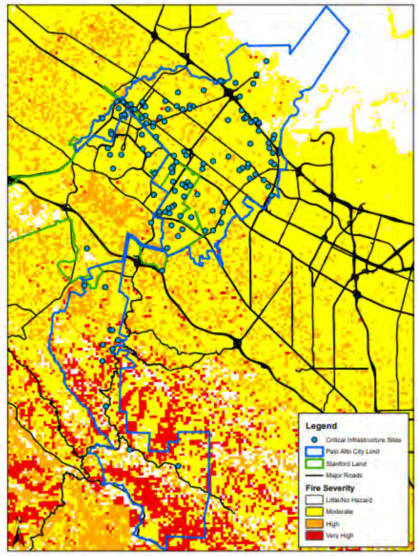


[16] [Local Hazard Mitigation Plan – City of Palo Alto, CA]

Flood Risk



Fire Severity Risk



Sea Level Rise Risk

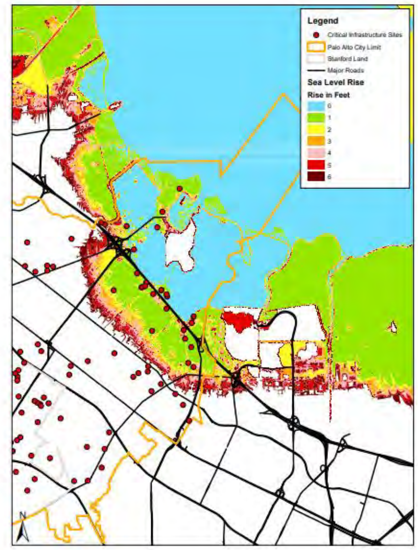
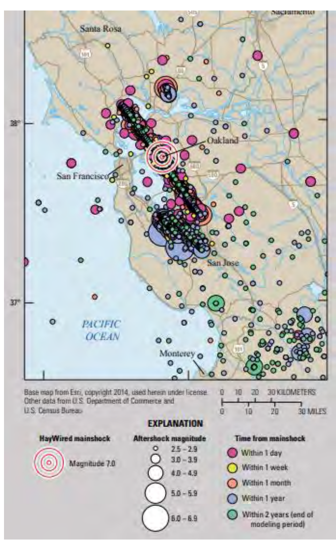
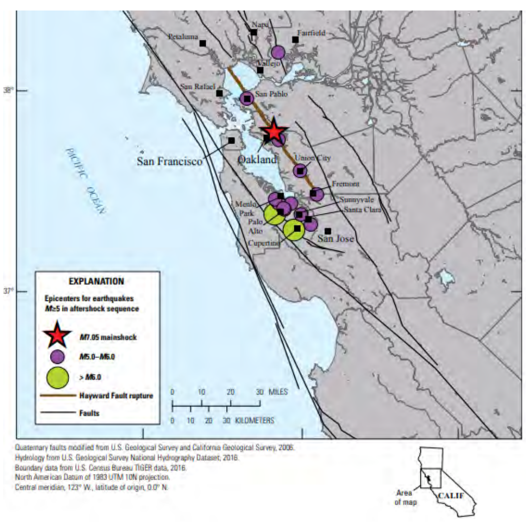


Figure F4 below from the Haywired Scenario shows the aftershocks simulated to occur. The image on the left shows all of the simulated aftershocks which can occur up to 2 years after the 7.0 mainshock in Oakland. The graph on the right shows the largest of those aftershocks of which a few affect Palo Alto. Those aftershocks that are mainly focused around Palo Alto and Menlo Park can be as large as 6.5 magnitude earthquakes.

Figure F4: Simulated Aftershocks from Haywired Scenario[17,18]





[17] [SIR 2017-5013 v1.2: The HayWired Earthquake Scenario—Earthquake Hazards (usgs.gov)]
[18] [SIR 2017-5013 v1.2: The HayWired Earthquake Scenario—Earthquake Hazards (usgs.gov)] pg 23

The biggest risks to Palo Alto for the Haywired scenario include

a. Ground Shaking
b. Liquefaction
c. Aftershocks
d. Loss of water, gas, and electricity due to loss of transmission outside of Palo Alto's boundaries

It was found that the natural gas distribution system, below ground electric distribution, and aboveground electric distribution all have their own strengths and weaknesses with regards to resiliency and speeds of recovery. Those findings are summarized below:

1. Overhead electric lines: Not as impacted by shaking damage and liquefaction as underground lines and natural gas pipes. However, can be affected by storms, lightning, wildlife, wildfires, wind, and falling trees. They may also sway and trip in the event of an earthquake. They are more likely to get damaged but are the fastest to repair.
2. Underground electric lines: Not as impacted by storms, lightning, wildlife, wildfires, wind, and falling trees but are more susceptible to liquefaction, shaking, landslides, and surface displacement. They are less likely to be damaged than overhead lines but once damaged take longer to repair.
3. Natural Gas lines: Like underground electric lines they are not as impacted by storms, lightning, wildlife, wildfires, wind, and falling trees but are more susceptible to liquefaction, shaking, landslides, and surface displacement. They are less likely to be damaged but once damaged takes longer to repair than both overhead and underground electric lines.
    a. Newer PE and Steel materials allow lines to withstand more shaking and movement than the older PVC lines which Palo Alto is slowly replacing.
    b. Steel pipes are stronger than both PVC and PE but take 4 to 5 times longer to replace/repair according to Palo Alto Utilities' engineering team.

The Haywired report also completed a utility disruption analysis but did not complete one specifically for Palo Alto. Therefore, the team is using San Francisco and Oakland as references.

Electricity and natural gas service restoration duration due to hypothetical 7.0 magnitude Haywired earthquake are shown in *Table F1*.

Table F1: Projected Natural Gas and Electricity Restoration Time from Haywired Report[19]

San Francisco, CA	50% Restoration	Tail Restoration
Natural Gas	~ 9 days	90% at ~ 33 days
Electricity	1 day	99.5% at 30 days

Oakland, CA	50% Restoration	Tail Restoration
Natural Gas	~ 10 days	90% at ~ 36 days
Electricity	2 days	96% at 30 days

Since there are no estimated restoration times for the Palo Alto electricity and natural gas systems, the team used the data in *Table F1* above as an initial approximation. *Table F1* shows restoration times for San Francisco for natural gas being 9 days to achieve 50% restoration while electricity only takes 1 day. *Table F1* shows similar timelines for Oakland. There, natural gas takes 10 days to restore to 50% while electricity only takes 2 days. These projections imply a much faster restoration time for the electric system.

However, after digging further into the origin of these results, while the electricity restoration data was found to be accurate, the natural gas restoration estimates were found to have some possible inadequacies.

Those inadequacies for the report include:

1. "Though a large amount of lifeline infrastructure was assessed, the available data was incomplete… which is particularly true for last-mile distribution infrastructure…"[20]
2. "Other important lifeline infrastructure (such as city gates for natural gas transmission and distribution) … would be useful inputs but were not publicly available."[21]
3. "Hazard exposure assessments pick up the presence but not performance of lifeline infrastructure… Different types of facilities (for example above and belowground) have different responses to the various hazards and have different design standards … and fragility functions for different hazards may be approximated or unavailable."[22]
4. "Fire was not considered in any of the Haywired scenario lifeline infrastructure damage assessments or restoration estimates."[23]

Figure F5 shows the electric power restoration curve for various counties in the Bay Area due to the Haywired Scenario. The county of Santa Clara (which encompasses Palo Alto) could be considered a reference for restoration time for Palo Alto, which is depicted by the orange curve.

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[19] SIR 2017-5013IQ: The HayWired Earthquake Scenario—Engineering Implications (usgs.gov) pg.281

[20] Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 53

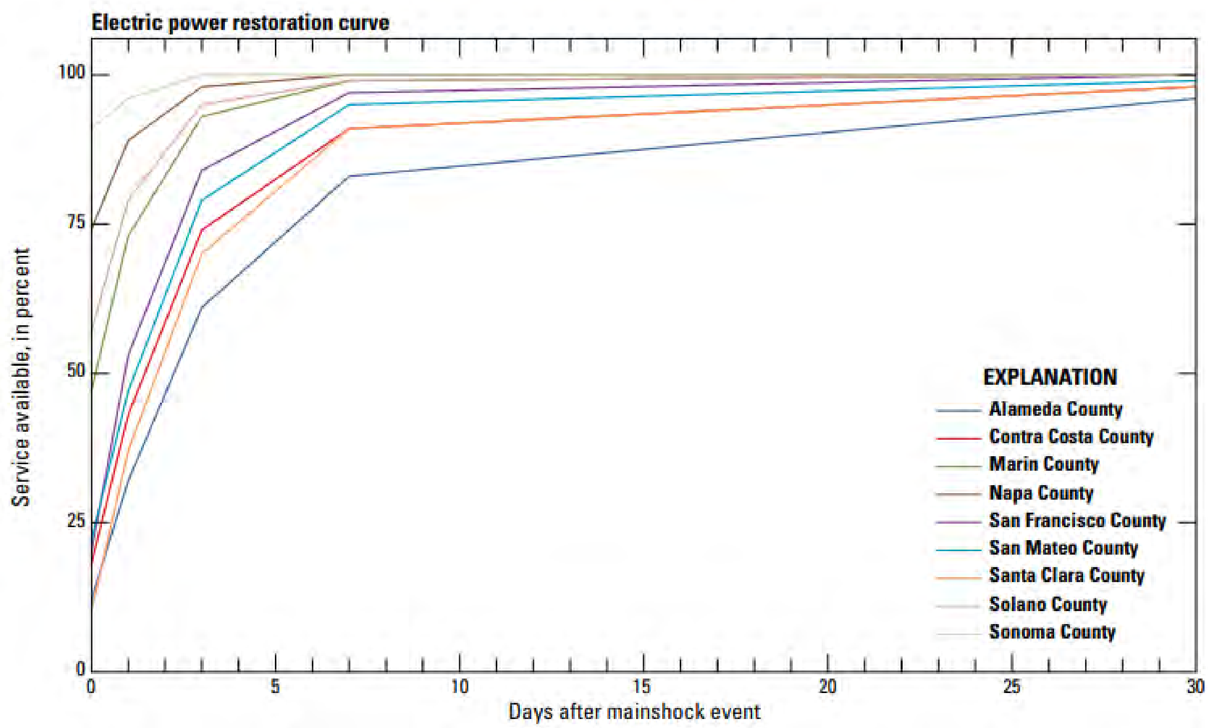
[21] Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 53

[22] Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 54

[23] Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 55

This shows 25% electricity restoration after 1 day, 50% after 2 days, 75% after 5 days, and 97% after 30 days which matched with the San Francisco and Oakland electricity restoration results from above.

Figure F5: Electric Power Restoration Curve for Various Counties After Haywired Earthquake[24]



However, from the Haywired study, there is no specific natural gas restoration data for Palo Alto or even Santa Clara County. Since the team needed this restoration data for natural gas to compare and contrast the electric and gas systems, **this study was unable to make conclusive comparisons between Palo Alto's natural gas and electricity restoration times and resiliency.**

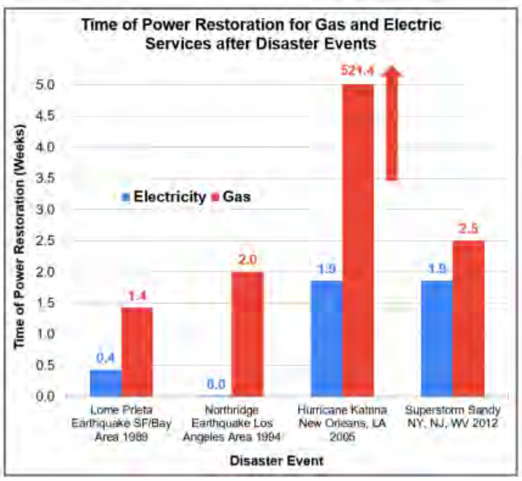
From the Haywired report: "PG&E provided a written statement that their gas transmission model for the Haywired scenario estimates approximately 40 locations in need of repair, whereas their gas distribution model estimates at least 2,000 gas leaks. However, PG&E also noted that actual damage from a similar event will likely be different from what the model estimates (E. Hickey and G. Molnar, PG&E, written commun., 2019). PG&E surmises that the majority of its gas restoration work would be dedicated to leak surveys because the location of a repair or a leak cannot be found without extensive leak surveys or patrols. **The amount of time to assess, repair, and restore gas service to customers would be significantly longer than that of electric power restoration.** In addition, because there would be preemptive gas shut-offs and subsequent loss of gas service to many PG&E customers, the pilot relight effort would take many months to

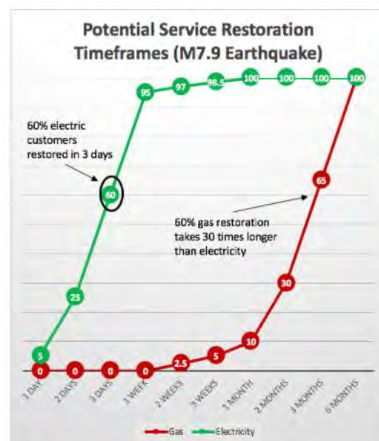
[24] Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—
A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg. 50

complete. PG&E estimates that **more than 200,000 customers could require pilot relights** after the event, not including those who proactively shut off gas to their homes and businesses and the gas safety shut-ins performed by PG&E (E. Hickey and G. Molnar, PG&E, oral commun., 2017)."[25]

Due to a lack of data, the team examined the electricity and natural gas restoration times from past case studies. *Figure F6* below shows more case studies that compare restoration times for actual disaster events on the left and a theoretical M7.9 earthquake on the right. *Figure F6* on the left depicts electricity restoration time in blue and natural gas restoration time in red. We can see that the electricity system restoration time is faster in all 4 of those scenarios which include the Loma Prieta Earthquake, the Northridge Earthquake, Hurricane Katrina, and Superstorm Sandy. Furthermore, for hurricane Katrina while electric was restored in 2 weeks, natural gas took up to 10 years to be fully restored. The hypothetical M7.9 earthquake depicted on the right also shows restoration times to be much faster for the electricity system than for natural gas.

Figure F6: Natural Gas and Electricity Service Restoration for Various Scenarios[26,27,28]





However, it is not mentioned in *Figure F6* on the left that while natural gas restoration time did take longer in the two earthquake events, there were also fewer natural gas service losses than electrical outages. Looking back at past data the team found that 1.4 million people initially lost power in the Northridge Earthquake while only 120,000 people lost gas services (mostly due to requiring relighting services). But 50% of electricity customers got power back in the first 8 hours and power was fully restored after 3 days except for 7,500 customers, while it took 12 days to restore service to the 120,000 natural gas customers.[29]

[25] Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) Pg 49
[26] SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 14
[27] Disaster resilience - Clean Coalition (clean-coalition.org)
[28] Lifelines Interdependency Study (sfgov.org) pg. 18
[29] Timeline: The 1994 Northridge Earthquake – NBC Los Angeles

Similarly, for the Loma Prieta Earthquake 1.4 million customers initially lost power (a majority regained power within 7 hours) and all but 12,000 customers had power within 2 days, while it took 9 days to restore natural gas service to 150,000 customers. While there were 1,000 pipeline leaks due to the earthquake, a majority of the restoration time was due to customer relights.[30] This shows that after an earthquake scenario while electrical outages initially affect more customers than natural gas outages, power can be restored much faster than for natural gas services that were lost.

Figure F6 above on the right shows that restoration is also much faster for electrical systems than for natural gas, however that data was primarily due to modeling transmission natural gas pipeline failure.

Another report breaks down the differences in restoration time between natural gas and electrical systems for various past earthquakes and defines what the main contributing factor causing delays in restoration were. The main points from that analysis and table summary can be found below.

> **Electrical:** "Electrical systems recover quickly, ranging from 2 days to over 14 days for full service disruption. They perform better than other utilities due to their high level of redundancy and ability to bypass or reroute power. Power generating stations and transmission lines performed well in earth quakes and received little to no damage while substations and distribution lines have the most vulnerability and governed restoration times for both the Northridge and Loma Prieta earthquakes." [31]

> **Natural Gas:** "Natural restoration time were much more variable than electricity with full restoration ranging from 7 to 84 days. Service-critical components in the natural gas system performed well, but the major cause of disruption for most earthquakes was relighting and re-pressuring the gas services to individual buildings." [32]

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[30] 5. Lifeline Perspective | Practical Lessons from the Loma Prieta Earthquake | The National Academies Press (nap.edu)

[31] https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 57

[32] https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 57

Table F2: Electricity Service Restoration Time for Various Past Events[33]

	Loma Prieta 1989	Northridge 1994	Kobe 1995	Niigata 2004	Maule 2010	Darfield 2010	Christchurch 2011
Magnitude M_w	6.9	6.7	6.9	6.6	8.8	7.1	6.3
Range of PGA	0.07 - 0.65[1] (0.33 in SF)[1]	17 - 94[1]	-	-	0.3 in Concepcion[2]	0.18 - 0.35 (Urban) 0.5-0.9 (Epicenter)	-
Liquefaction	Minor	Minor[2]	Severe	-	Severe	Severe[1]	Severe[1]
Electrical Systems							
Power Generating Stations	Minor	Minor	Minor	-	-	-	-
Substations	Severe	Moderate	Moderate	-	Minor	Minor	Moderate
Transmission Lines	No Damage	Minor	Moderate	-	Minor	No Damage	Minor
Distribution Lines	Minor	Minor	Severe	-	Severe	Severe in Liquefaction Zones	Severe
Duration to Complete Service Restoration	2 days	3 days	6 days	Over 8 days	14 days	4 days	Over 14 days
Primary Source of Overall Disruption	Substations[1]	Substations[2]	Distribution	-	Distribution[2]	Distribution	Distribution[1]

Table F3: Natural Gas Service Restoration Time for Various Past Events[34]

	Loma Prieta 1989	Northridge 1994	Kobe 1995	Niigata 2004	Maule 2010	Darfield 2010	Christchurch 2011
Gas Systems							
Gas Storage Field/Distribution Stations	Out of Impact Zone	Moderate	No Significant Damage[1]	-	-	-	-
Gas Transmission	Virtually Undamaged[1]	Minor[2]	Moderate	-	-	-	-
Gas Distribution Repair Rate (Repairs/km)	Nearly 0	0.011	0.60	-	-	0	0
Duration to Complete Service Restoration	1 month[1]	Over 1 month[1]	84 days	28 days[1]	-	No Disruption[1]	14 days[2]
Primary Source of Overall Disruption	Re-lighting[1]	Re-lighting[2]	Distribution[1]	-	-	-	Re-pressurizing[1]

Another important point the team needed to consider when comparing the distribution resiliency for the natural gas and electrical system is that Palo Alto is a much smaller utility than the ones studied, such as PG&E and LAWDP. **Palo Alto has a much smaller operating area with many more valves for gas pipelines, allowing CPAU to reroute gas to customers without having to cut off service to a large swathe of people, since it is easier to isolate leaks.** Therefore, during gas line breaks, fewer people will be affected by gas shutoffs when repairs are needed.

Looking into the resiliency of the gasoline system the team found that "Damage to marine terminals, oil refineries, fuel storage tanks, fuel transmission lines, and fuel dispensaries is likely

[33] https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 58

[34] https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 59

in a large San Francisco Bay region earthquake. As a result, there will likely not be enough transportation fuel supplies available after a large earthquake." [35]

Another recent 2020 study conducted by the City and County of San Francisco called the Lifelines Restoration Performance Improvement Plan, also shows the resiliency advantages of the electrical system over the natural gas system. This scenario is also an earthquake scenario with a magnitude of 7.9 on the San Andreas fault and a magnitude 7.0 earthquake on the Hayward fault (similar to the Haywired Scenario).

The City and County of San Francisco Lifelines Restoration Performance Improvement Plan had a few important conclusions and recommendations which are extremely relevant to our study. A few of those include:

1) Restoration of many systems can be further improved by adding backup generators or solar panels with solar + battery storage.
2) It is recommended to reduce reliance on petroleum fuel to increase the restoration of all systems.
    a. The bay area relies on Kinder Morgan fuel pipelines and Bay Area refineries which are more susceptible to damage and have much longer restoration times. During a large earthquake event, transportation capabilities can be cut off to the whole region. Therefore, utilizing solar + storage can allow for increased resiliency and increased transportation capabilities which all lifeline sectors rely on.
3) The San Francisco Department of Building Inspection should require all new building to be fully electric and should require the electrification of all existing buildings with gas shutoff valves as an interim measure.
4) Generation is not seen a main issue for electrical outages. Significant damage is expected to happen to underground transmission and distribution lines in San Francisco as well as to the telecom equipment which is responsible with communicating with those devices. Above ground lines may also be damaged by falling debris. Substations have been recently upgraded to withstand earthquake damage.
5) The full restoration of the natural gas system can take up to 6 months because of the time it will take to integrity test the lines prior to depressurizing and number of qualified personnel required to relight pilot lights.
6) Natural gas is primarily dependent on electric power and communications for remote operation of gas shutoff valves and is also critically dependent on the road network to access manual gas shutoff valves and repair damaged pipes.
    a. However, the vast majority of gas regulation and control equipment are not affected by power outages as they are mechanical devices that are powered by pressure in the gas system.[36]

[35] G. Schremp, California Energy Commission, written commun., 2018
[36] 70_Lifelines-Report_1020.indd (onesanfrancisco.org)

Furthermore, when comparing gas and electric transmission coming into the city, CPAU is again different from those larger utilities. Palo Alto has 4 connection points or (Gas Gates) and two separate gas transmission pipelines from PG&E (8-12" steel pipes) coming into the city. Since there are 4 connection points and 2 pipes from PG&E, a single point of failure is less likely to cause natural gas shutoffs for the city. In comparison Palo Alto has 3 electricity transmission lines, which all pass through one corridor. Therefore, if there is a disaster event in that one location, all of Palo Alto's power supply is vulnerable. A past airplane crash incident in that corridor hit all three transmission lines and took out power to the whole city back in 2010.

Transmission line loss into Palo Alto is still a major issue that could cause a power outage to all of Palo Alto from 12 hours to 3 days. The City is working to add a second transmission line to prevent these issues. Until then, this type of outage would not directly affect the natural gas system so mixed energy use homes would fare better (except for fully electrified homes with ample solar + storage). Since this is a localized incident, residents could drive out of the city to refill their gas, buy groceries, food, and medical supplies as needed.

Palo Alto's Engineering team believes that cybersecurity is a large threat to consider as cities electrify and decarbonize their buildings. This is because cyberattacks can affect whole regions potentially taking down all of the WECC grid from weeks to months. Furthermore, electric grids are much more vulnerable to cybersecurity issues than water and natural gas systems. This is because electrical systems have many more automated and computerized components than their water and natural gas counterparts. Furthermore, if water or natural gas systems are hacked, these physical resources allow backup storage and other means to retrieve the resources. Whereas with the electrical grid, a targeted cyberattack might not just take out power but also cause cascading failures, destroying many key components of the grid including substations, wires, and transformers. Since water and natural gas pipelines can't have cascading failures, they can be repaired much faster after a cyberattack than the electric grid.

A cyberattack scenario would be similar to a transmission line loss scenario for Palo Alto except that the cyberattack scenario can affect much larger grid systems (potentially shutting down all of the WECC). The gas distribution will most likely not be affected. The much longer power outage duration and larger area affected means people would no longer be able to simply leave Palo Alto to buy food, gasoline, or access WIFI since the whole grid will be down. While mixed energy use home would fair slightly better in this scenario due to having a working stove and water heater, they would face the same issues as fully electrified homes in terms of space heating, cooling, transportation, and WIFI.

REFFERENCES

1. Resilience Metrics for the Electric Power System: A Performance-Based Approach (comacloud.net)
2. U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, Jan 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=310879, link retrieved September 3, 2021.
3. 2019 California Residential Appliance Saturation Study - Executive Summary pg 3, 9
4. G. Schremp, California Energy Commission, written commun., 2018
5. 70_Lifelines-Report_1020.indd (onesanfrancisco.org)
6. U.S. EPA. Integrated Science Assessment (ISA) for Oxides of Nitrogen – Health Criteria (Final Report, Jan 2016). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/068, 2016. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=310879, link retrieved September 3, 2021.
7. SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 44
8. SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 46
9. City and County of San Francisco Lifelines Council, Lifelines Interdependency Study Report, April 17, 2014 https://sfgov.org/sfc/sites/default/files/ESIP/Documents/homepage/LifelineCouncil%20Interdependency%20Study_FINAL.pdf
10. SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 49
11. 2019 California Residential Appliance Saturation Study - Executive Summary
12. 2019 California Residential Appliance Saturation Study - Project Overview pg. 14
13. What Happens If You Have Solar And The Power Goes Out? (solarreviews.com)
14. Enhancing the Security of the North American Electric Grid (cbo.gov) pg. 9
15. SIR 2017-5013 v1.2: The HayWired Earthquake Scenario—Earthquake Hazards (usgs.gov) pg. 32
16. Local Hazard Mitigation Plan – City of Palo Alto, CA
17. SIR 2017-5013 v1.2: The HayWired Earthquake Scenario—Earthquake Hazards (usgs.gov)
18. SIR 2017-5013 v1.2: The HayWired Earthquake Scenario—Earthquake Hazards (usgs.gov) pg 23
19. SIR 2017-5013IQ: The HayWired Earthquake Scenario—Engineering Implications (usgs.gov) pg.281
20. Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 53
21. Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 53
22. Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 54
23. Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg 55
24. Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) pg. 50
25. Lifeline Infrastructure and Collocation Exposure to the HayWired Earthquake Scenario—A Summary of Hazards and Potential Service Disruptions — SIR 2017-5013 Chapter T (usgs.gov) Pg 49
26. SF-Guide-4-10-2020.pdf (fossilfreebuildings.org) pg. 14
27. Disaster resilience - Clean Coalition (clean-coalition.org)
28. Lifelines Interdependency Study (sfgov.org) pg. 18
29. Timeline: The 1994 Northridge Earthquake – NBC Los Angeles
30. 5. Lifeline Perspective | Practical Lessons from the Loma Prieta Earthquake | The National Academies Press (nap.edu)
31.https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 57
32.https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 57
33.https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 58

34.https://www.researchgate.net/publication/326331951_REDi_Rating_System_Resilience-based_Earthquake_Design_Initiative_for_the_Next_Generation_of_Buildings pg 59
35. G. Schremp, California Energy Commission, written commun., 2018
36. 70_Lifelines-Report_1020.indd (onesanfrancisco.org)