A Holistic Analysis of Energy Storage Systems Applied to Single-Family Residences in California

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The technology this paper focuses on is energy storage systems applied to single-family residences in California. This relatively new technology consists of a stationary battery that is connected to a power source, most notably photovoltaic panels on the roof. The holistic nature of this research paper is meant to incorporate the principle aspects surrounding the current state and affordability of these systems such as the type of batteries used, government incentives, the predominant benefits, and emerging trends that will dictate the future of these systems. The information was gathered by conducting an extensive literature review and interviewing ten energy storage experts which provided contemporary information that was not found in databases. The most popular batteries were the LG Chem RESU 10H and the Tesla Powerwall. The main factors that increased affordability was the Federal Investment Tax Credit, Self-Generation Incentive Program, and the reduction of on-peak electricity prices from investor owned utilities. Aside from the return on investment, homeowners can achieve peace of mind from having backup power to withstand power outages, as well as reduce carbon emissions by increasing photovoltaic capabilities. Lastly, emerging trends such as NEM 3.0 and vehicle-to-home will likely shape the future of energy storage.

Key Words: Energy Storage, Battery, Single-Family Residence, Sustainability, California

Introduction

It may seem as though humans began harvesting energy rather recently, however, this has been occurring for centuries. We can look back to the 1750s when Benjamin Franklin studied the capability of lightning as a source of energy or the Industrial Revolution that was fueled by coal. Altogether, the utilization of energy has revolutionized every aspect of life, which indicates that the demand for energy will never cease to exist. Furthermore, our population is growing at an exponential rate, which will yield an even greater demand come future generations. The Canadian Association of Petroleum Producers (CAPP) provided findings from the International Energy Association 2020 Energy Outlook. The findings suggest that by 2040 there will be a population growth of 1.3 billion people across the globe which will contribute to a 19% increase in global energy demand. Even more pertinent, the outlook suggests that twice the amount of energy we produce today would be needed by 2040, if we were to make no further improvements in energy efficiency (CAPP, 2020). Aside from energy efficiency, our current worldwide energy sources consist mainly of nonrenewables which can be seen in Figure 1.

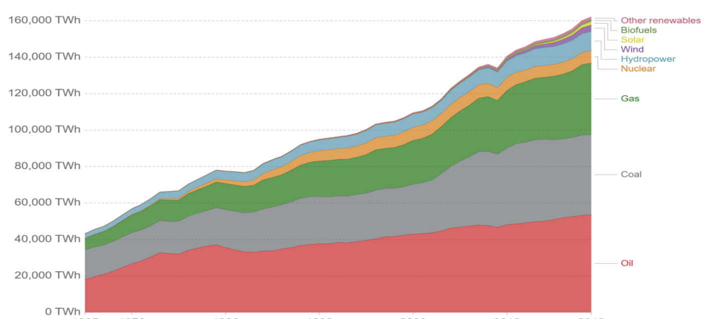

Figure 1: World Energy Consumption by Source
(Ritchie, 2020)

From the chart, we can see that the top two fuel sources are oil (30.93%) and coal (25.29%) which are both notorious for the harmful greenhouse gasses (GHG) they emit. Additionally, these fuel sources are considered nonrenewable, which by definition means they will run out in time and force our population to resort to alternative sources. These findings accentuate the importance of incorporating sustainable practices into the energy sector before we reach a point where we irreparably pollute our planet, as well as run out of fuel to support our growing and bustling world.

California in particular has played a crucial role in this progressive transformation by enacting drivers such as Senate Bill 100 in 2018, which requires that all energy use in California be derived from RES by 2045. Another mandate set forth was Assembly Bill 2514, which set phases for energy storage procurement totaling 1.3GW from 2013 to 2020 (Kumar & Shrimali, 2020). More recently, California passed Assembly Bill 178, also known as the California Solar Mandate, which was enacted on January 1st, 2020. It requires that all new single-family residences (SFR) and apartment buildings under four stories must attain photovoltaic (PV) panels. Naturally, this has placed California as the top solar state in the country with roughly 31,288 MW of solar energy capacity, creating 22.69% of the state's electricity and an expected growth of 19,033 MW over the next 5 years (SEIA, 2020). Despite California being a small region compared to the whole world, it is important to note that the state will serve as an archetype for sustainable energy practices, which will likely catalyze other states and countries to follow the same direction.

California Wildfires

In addition to California's recent expansion of PV panels on homes and apartments, there has been an imminent issue with the state's energy distribution over the past few years. There has been a considerable increase in wildfires which has caused homeowners to lose power to their homes for extended periods due to the destruction of power lines and infrastructure. The California Public Utilities Commission (CPUC) stated that from 2013 to 2019, California experienced over 57,000 wildfires, which averages to roughly 8,000 a year. The CPUC also stated that although electric utility infrastructure has only been responsible for less than ten percent of reported wildfires, fires attributed to power lines result in roughly half of the most destructive fires in California history (CPUC, 2021). Consequently, there has been a surge in public safety power shutoffs (PSPS), which is the intentional shutoff of power lines in areas where severe weather is forecasted. According to the CPUC, "Code Sections 451 and 399.2(a) give electric utilities authority to shut off electric power in order to protect public safety. This allows the energy companies (SDG&E, PG&E, SCE, Liberty, Bear Valley and PacifiCorp) to shut off power for the prevention of fires where strong winds, heat events, and related conditions are present" (CPUC, 2021).

Due to the accumulation of factors, such as the rise in PV panels across California, the recent surge of wildfires causing mass outages, and the requisite improvement in energy standards, there has been a rising demand for a relatively new technology that has surfaced in the energy industry. The aforementioned technology is energy storage systems (ESS), which have numerous applications. For the sake of this research, ESS used for SFR will be the specific application that will be covered in this paper. The primary focus of this paper is to supply the reader with information regarding the:

- Predominate benefits that ESS provide to SFR in California.
- Basic technical logistics and components of an ESS.
- Current incentives offered and the eligibility requirements for ESS on SFR in California
- Environmental benefits that ESS contribute to.
- Current brand and cost of batteries used for ESS on a typical SFR in California.
- Shortcomings and drawbacks of the current batteries used.
- Emerging policies and technology that will shape the industry.

Literature Review

Economical Applications

There are several economic benefits of investing in an ESS depending on how it is utilized. Most of the savings associated with ESS can be attributed to managing the home's grid consumption based on time of use (ToU) rates, which are the electricity rates ($/kWh) established by investor-owned utilities (IOU) to offset peak demand. For example, PG&E currently offers a ToU rate (E-TOU-C) which sells electricity at a much higher price between 4 pm and 9 pm, and a reduced rate during all other hours (PG&E, 2021). By adding an ESS to PV panels, the excess energy that is produced can be stored and utilized once the sun goes down, thus omitting the high energy prices during the on-peak hours. Even without PV panels, an ESS can be utilized for ToU shifting, in which energy is stored from the grid during off-peak hours, and then discharged to the home during on-peak hours. This spares the homeowner from paying the higher on-peak rate as well. A study that was published this month comes from the academic journal, *Applied Energy*, in which several researchers from energy institutes across the UK modeled a typical home (three bedrooms) in London with ToU rates applied to a PV-ESS similar to a typical system found on a SFR in California (Powerwall). The findings revealed that "installing storage (without PV) under ToU tariffs will reduce the electricity bills of consumers by 35%. If storage paired with PV, the electricity bills can decline by 74% compared to PV alone, and by 84% compared to having no technology onsite" (Zakeri, Cross, Dodds & Gissey, 2021). Net energy metering (NEM) is another cost-saving mechanism, and was recently broadened in February 2019 to include ESS instead of just standalone PV panels (CPUC, 2019). Homes with PV panels that generate enough energy during the day to meet the home's load demand and fill the battery to capacity can send any excess energy to the grid and be credited for it. According to the CPUC, to participate in NEM the homeowner must pay a lump sum interconnection fee, which ranges from $75 to $145 depending on the IOU, as well as a small non-bypassable charge for each kWh they consume from the grid. Additionally, the battery storage system must utilize ToU rates and also receive 100% of its energy from PV panels (CPUC, 2021). Although it is now possible for homeowners to qualify for NEM with a PV-ESS installed on their home, there is little research that signifies the economic feasibility with the current costs associated with participating. Furthermore, by adding an ESS, there is less excess energy available to send back to the grid versus standalone PV panels.

Lifespan and Degradation

It was found that two large factors dictate the lifespan of a battery, which is relevant to the economic feasibility of the system. The first factor is the number of times the battery is charged and discharged. Batteries are set to a user-defined preference, in which the charge and discharge rate varies depending on the home's load profile, as well as the amount of energy provided by the PV panels. Professors at the University of Irvine conducted a study that analyzed different charge and discharge rates for an ESS on a SFR, and its effects on battery degradation. This was determined by changing the system's setting to either minimize battery degradation (λ=0) by not cycling, minimize grid cost by utilizing ToU shifting (λ=1), or a combination of the two (0<λ<1). The results portray the direct correlation between the two settings, which can be seen in Figure 2.

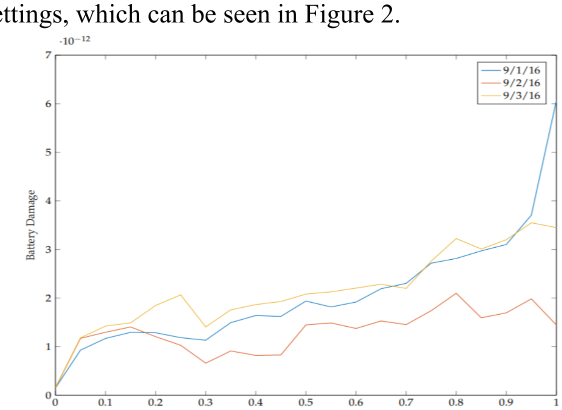

Figure 2: Battery Degradation Based on Cost Parameter (λ)
(Ahmed, Levorato, Li, 2020)

This study did not provide a definitive answer for the optimal system performance based on degradation, however by extrapolating the data from the chart, a range of .3 to .7 appears to minimize battery degradation, while simultaneously reaping the economic benefits of ToU shifting. The second determining factor for the lifespan of a battery is the depth of discharge (DoD) when discharging the battery to the home. According to the same Irvine professors that produced the charge and discharge chart shown above, the "DoD directly affects the battery lifetime and is dependent on the capacity of the battery. If the battery is discharged to maximum capacity, the lifetime of the device will decrease over time… Since most photovoltaic panels have lifetimes of twenty-five to thirty years, at least one battery bank replacement is expected. To maximize the lifetime of the battery it becomes necessary to control the DoD" (Ahmed, Levorato, Li, 2020). The DoD is predetermined and set by the homeowner depending on their preference, and should be considered in the overall life cycle of the battery.

Current Government Incentives

The “Sustainable Finance Initiative”, a net-zero initiative created by Stanford University, conducted a study using different government incentives and external barriers to determine an effective path towards incorporating battery storage technology in California homes. The results concluded that “financial incentives through programs such as [Self-Generation Incentive Program] and [Investment Tax Credit] are critical for addressing the high cost associated with BTM energy storage installations. [Also,] BTM aggregation is a novel way to combine the key elements of both FTM and BTM installations thereby unlocking further potential from energy storage resources” (Kumar & Shrimali, 2020). This study provided solid evidence that the financial investment of an ESS for a SFR is largely influenced by government funding and incentives, particularly the two that were mentioned. The adoption of these systems will also have a lasting effect on the expansion of ESS across the nation.

Self-Generation Incentive Program

As previously stated, there has been a recent surge of wildfires and outages in California, which has led the CPUC towards the Self-Generation Incentive Program (SGIP) to resolve the issue. Initially, the SGIP was created to deal with the 2001 California Energy Crisis, and then in 2011, it refocused its efforts to reduce GHG emissions. However, in 2016, to promote energy storage for power outages caused by fires, SGIP allocated 75% of its funding strictly towards energy storage projects (SDG&E, 2021). This has consequently increased the economic feasibility for homeowners that invest in an ESS. SGIP offers rebates in tiers based on eligibility. According to the CPUC, the three categories for SGIP rebates are Equity Resiliency, Equity, and General Market. Equity Resiliency offers the highest rebate of $1,000/kWh, however, there are strict guidelines that qualify a home for eligibility such as being in a High Fire Threat District (HFTD) or an area that has experienced two or more PSPS, while also relying on power for life support, rely on an electric well pump, or live in a deed-restricted house. The equity rebate also offers a generous return of $850/kWh, and eligibility requires a home to be subject to resale restrictions, be located in a Disadvantaged Community (DAC), or be located in California Indian Country. The General Market rebate offers the lowest return of $250/kWh, however, there are no eligibility requirements other than simply investing in an ESS. It should be noted that the General Market rebate is expected to decrease in the future, however, a monetary amount or expected date was not mentioned (CPUC, 2021). Although the General Market rebate is much lower than the Equity and Equity Resiliency rebate, it applies to all homeowners, and should automatically be incorporated into the investment cost and subsequent savings of purchasing an ESS with the current policy.

Federal Investment Tax Credit

This federal tax credit plays a critical role in the affordability of installing an ESS on a home. Unlike SGIP rebates that are only offered in California, this incentive is recognized on a national level. The Federal Investment Tax Credit (ITC) has historically been a driving force in the expansion of PV panels and solar generation in the United States. Since its introduction in 2006, the United States solar industry has grown more than 10,000% (SEIA, 2021). Recently, this tax credit has expanded its rebates to include ESS as well. The National Renewable Energy Laboratory (NREL), which is a laboratory that works under the US Department of Energy, provided the “U.S. Solar Photovoltaic System and Energy Storage Cost Benchmark: Q1 2020” that details the savings associated with the ITC. Their findings included the Levelized Cost of Solar-plus-Storage (LCOSS) and the Levelized Cost of Energy (LCOE) for standalone PV panels. The report concluded that “LCOSS is calculated to be $201/MWh without the ITC applied, and $124/MWh with the 30% ITC applied for the PV-plus-storage system” (NREL, 2020). While the ITC may be an enticing incentive for homeowners to reap, it is also important to consider the future of this tax credit. The study from the NREL utilized a 30% tax credit, which was the effective percentage in 2019 and used in the benchmark. According to the SEIA, the new tax credits are “26 percent for projects that begin construction in 2021 and 2022. 22 percent for projects that begin construction in 2023. After 2023, the residential credit drops to zero while the commercial credit drops to a permanent 10 percent” (SEIA, 2021). This is a substantial caveat, being that by 2023 there will be no tax credits given to the residential sector, which will have the effect of decreasing the economic feasibility of installing an ESS on a home. Another consideration associated with the ITC is the eligibility for the tax credit based on how the ESS is utilized. According to EnergySage, an unbiased solar and storage advisor, the battery system must be charged by an onsite renewable energy source (PV panels) to be eligible for the ITC, and will only be eligible for up to the amount it is utilized (EnergySage, 2021). Figure 3 provides a great illustration of how the ITC percentage is determined based on ESS utilization. Similar to the NREL study, this illustration utilizes a 30% tax credit that was effective in 2019.

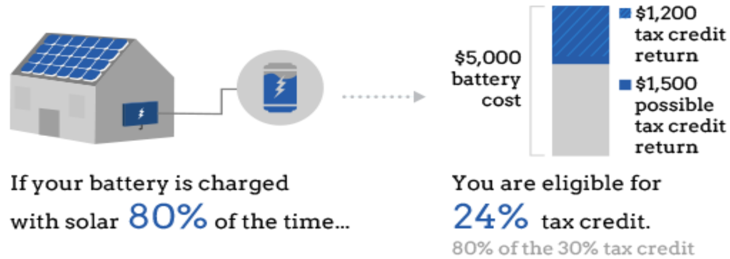

Figure 3: ITC applied to ESS
(EnergySage, 2021)

Environmental Benefits

Researchers from Oxford Brookes University and Columbia University conducted a life-cycle assessment of the environmental and energy burdens that the California electricity grid mix contributes to. They analyzed the 2018 energy mix in California and then made conservative projections for the energy mix in 2030. The main assumptions for the 2030 projection were an energy mix consisting of 80% net renewable energy, an increase in PV panels to reach the 80% mark while other RES maintain the same percentage of the energy mix, a decline in natural gas and imported electricity to accommodate more PV panels, and finally a suitable amount of stationary Lithium-Ion batteries (LIB) based on the detailed Ecoinvent generation and demand model. The first key finding was that the carbon intensity in electricity was cut in half with the projection in just 10 years. This was attributed to the addition of PV panels and their LIB ESS counterpart which emits negligible carbon emissions. We can see the results demonstrated in Figure 5, in which the carbon emissions are expressed as Global Warming Potential (GWP).

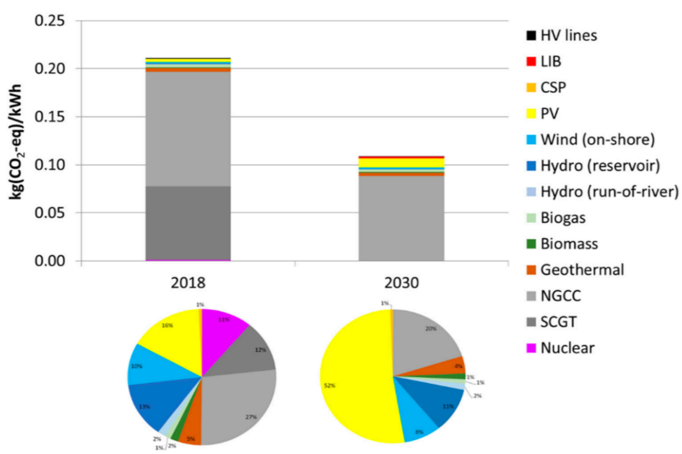

Figure 5: GWP results for California Domestic Grid Mix in 2018 and 2030
(Raugei, Peluso, Leccisi, Fthenakis, 2020)

Although it may seem intuitive that ESS contribute to a reduction in GHG, it is relevant to add an objective and tangible study such as this to reinforce the idea that these systems will aid in the transition towards sustainable energy production, thus substantially reducing GHG emissions.

Methodology

The purpose of this research-based project was to provide a holistic analysis of energy storage systems applied on a SFR in California, including current and emerging trends, policies, and technologies that either foster or suppress the future adoption of this technology. The findings were construed by conducting an extensive literature review of trade journals and peer-reviewed articles relating to the inquired information. Additionally, ten energy experts and battery installers in California were interviewed to supplement the existing information found from the literature review. The interviews were formatted using a semi-structured set of qualitative questions based on the individual's role in the industry and conducted with a conversational tone to give interviewees the freedom to include any relevant information that was not included in the predetermined questions. The interviews were pertinent because they offered contemporary information that was not published to databases yet.

Results and Analysis of Interviews

Application of ESS in a SFR

ESS applied to SFR consist of a stationary battery that is typically mounted on the exterior wall of a home near the main breaker panel and utility meter. The battery connects to an exterior power source such as PV panels, or less frequently straight to the grid, which is how it receives and stores energy. Additionally, there are inverters associated with the system that must be installed depending on what the battery is connected to, as well as if the battery stores alternating current (AC) or direct current (DC). There are predominately three benefits that these systems attain depending on how they are utilized which are: environmental benefits due to a reduction in GHG by expanding the capabilities of PV panels, the economic savings from reducing on-peak grid consumption, and lastly the peace of mind from having backup power if an outage or PSPS occurs. These systems can either be set to float use, cyclic use, or a combination of the two. Although not economical, float use is when the battery remains at full charge and is utilized in case of a power outage or PSPS. Therefore, the battery does not charge and discharge often, which has the effect of increasing the lifespan. Alternatively, cyclic use is when the battery is charged and discharged regularly, typically daily. When installed with solar, PV panels gather solar radiation throughout the day, and that energy is utilized to support the home's load demand. Any excess energy produced by the PV panels is sent to the battery where it is stored for later use. When the sun goes down and stops supplying energy to the PV panels, the battery is then discharged to meet the home's load demand. This increases the self-consumption of energy produced by the PV panels and boosts independence from the grid. For a standalone ESS with no PV panels, it achieves its economic feasibility by charging during off-peak hours when the price of electricity is much lower, and then discharged during on-peak hours to support the home's load demand which is known as peak shaving.

Batteries used for an ESS on a SFR

The brand, size, pricing, features, and relevant parameters of batteries installed on a typical SFR in California was unanimous across the interviews. The interviewees mentioned two commonly used batteries, which are the Tesla Powerwall and LG Chem RESU10H. Both of these are LIB and offer a 10-year warranty. These batteries are depicted in Figure 5.

Figure 5: Tesla Powerwall and LG Chem RESU10H
(Del Sol Energy, 2018)

Tesla Powerwall

Although Tesla is mainly known for its electric vehicles (EV), their Powerwall battery is a promising option for current ESS. It was initially released in 2015, however, after trial and error, the second edition was released in October 2016 which is the product that is sold today. It is an Alternating Current (AC)-coupled battery which means that Distributed Current (DC) from the PV panels must be converted to AC which is then stored in the battery. This can either be done in the panels themselves using a microinverter which is the safer option or by using a solar inverter which is the more commonly used choice. The starting price for the battery itself is $7,500, with an additional $1,000 for the Gateway, which is the accessory device that manages and monitors TOU shifting and self-consumption. Although the Powerwall is a highly versatile and auspicious battery, two major drawbacks were mentioned during the interviews. The first was the availability of these batteries with the current market demand. Numerous interviewees mentioned that the Powerwall had a relatively long lead time across the nation, ranging from nine to twelve months depending on the installer and their relations with Tesla. A senior energy advisor included that the long lead times can be attributed to Tesla outsourcing their battery production, making them less reliable when compared to electrochemical companies that manufacture their batteries in-house. The only way a homeowner could get a Powerwall installed quicker is by going through Tesla themselves, in which lead times range from 10-12 weeks, however, this is where the second drawback comes into play. Tesla has discontinued the sale of a standalone Powerwall from March 8th, 2021 through the end of the calendar year. Currently, Tesla only offers the Powerwall if it is purchased as a package with PV panels according to the interview with Tesla Sales.

LG Chem RESU 10H

The second battery is the (Residential Energy Storage Unit) RESU 10H. This battery is offered by LG Chem which is an electrochemical company that produces their batteries unlike Tesla which makes them widely available with relatively short lead times. They offer batteries in different varieties and capacities, however, the RESU 10H was the unanimous choice for a typical residential application amongst the interviewees. The RESU 10H is a DC-coupled battery, meaning that DC from the PV panels can be sent directly to the battery, and then sent to the inverter for DC-AC conversion to power the home's load demand. This battery has a cheaper starting price of $6,000 and does not need an accessory monitor like the Tesla Gateway. Two main drawbacks were discussed in the interviews. The first is that this battery, although not impossible, is not an ideal option for retrofitting most PV panels. Existing PV panels attain a design with specific inverters and configurations that must be redesigned to accommodate a DC-coupled battery such as the RESU 10H which could drive up the cost. Consequently, this battery is ideal for new PV-ESS installations. The second drawback is that storage capabilities are not as impressive when compared to the Powerwall. The RESU 10H has a capacity of 9.8 kWh while the Powerwall has a capacity of 13.5 kWh. Additionally, a maximum of two batteries can be in parallel with the RESU 10H while Powerwall can have up to ten batteries in parallel making it more versatile.

Emerging Policies and Technology

Information regarding the upcoming policies and technology was a critical component of this research paper. The interviews provided insightful information regarding two industry events that will dictate the future of the current technology used in California.

NEM 3.0

As previously mentioned, NEM affects the adoption of PV panels, as well as ESS. Multiple interviewees mentioned that an emerging policy (NEM 3.0) will succeed the current NEM policy (NEM 2.0), however, it is still unclear as to what exactly the revised policy will include. According to my interviews, there are three major revisions that IOU are pushing for in the updated policy. The first is to reduce the overall compensation rate for each kWh that is sent to the grid, with the claim that homeowners are being over-compensated with the current NEM 2.0 structure. The second proposition is an additional monthly fee of approximately $30-$50 to tie into the grid. The final and arguably most adverse proposition is to not allow homeowners to be grandfathered into NEM 2.0, meaning that every homeowner who is currently participating in NEM 2.0 would be forced to abide by the revised policy if they chose to continue participating in NEM. Currently, NEM 3.0 is still under debate, and a final decision is to be announced in November 2021. If this revised program were to be implemented, homeowners with standalone solar would start investing in batteries at a much higher rate which may seem counterintuitive. This is because the excess energy that is produced from PV panels and sent back to the grid will be compensated at a much lower rate under NEM 3.0, and therefore would not be economically feasible. Therefore, the addition of ESS would allow the homeowner to store the excess solar energy rather than credit it, and use it when the PV panels are not providing energy while also omitting on-peak ToU prices. This application is already utilized by SFR with PV-ESS, however, it would apply to a broader range of homeowners, assuming that NEM 3.0 is implemented with the proposed revisions mentioned above.

Vehicle-to-Home

Like previously mentioned, homes in California have been increasingly susceptible to power outages due to wildfires and PSPS. One of the major selling points and benefits of installing an ESS is the ability to supply backup power during these outages. One trend that was mentioned in the interviews was the integration of EVs as a means of backup power. There has been a considerable growth of EVs in California the past couple of decades, and these vehicles are essentially mobile batteries that attain much greater energy capabilities compared to stationary batteries such as the Powerwall and RESU 10H. For example, the Tesla Model Y has a capacity of 75kWh while the Powerwall has a capacity of 13.5kWh. With that being said, an energy storage expert discussed the emergence of utilizing EVs as means of backup power to homes during these outages. This concept is known as vehicle-to-home (V2H). Although this concept may seem very intuitive, the CPUC has not provided any legislation on its utilization or acceptance, and there was minimal information online surrounding this idea. V2H's counterpart, vehicle-to-grid (V2G) has already been passed and utilized for grid demand response, in which V2H was left out of the legislation. There was a study that supported the viability of V2H, which was conducted by the University of California, Irvine Institute of Transportation Studies that was published only a few months ago. In the study, V2H was modeled in California and the results portrayed that "under grid outages, properly controlled, plugged-in PEVs can be an effective and environmentally friendly resiliency resource for V2G and V2H… [and] can serve local critical loads with minimal system upgrades" (Razeghi, Lee & Samuelsen, 2021). It was quite surprising that V2H has not been publicly accepted as a backup power source. This would essentially give homeowners the freedom to utilize their EV for backup power rather than invest thousands of dollars for an ESS if backup power was their only concern. Nevertheless, V2H could potentially be the future of backup power instead of stationary ESS.

Conclusion

Like many times in the past, California has been a pioneer in sustainable technologies and practices, providing a path that surrounding states and countries can follow. The gradual rise in population will evidently increase energy demand, making the transition towards sustainable energy practices imperative. Since its introduction, solar has proven to be an exceptional means of providing California with clean and sustainable energy, and this transition has catalyzed the adoption of ESS. Aside from expanding the capabilities of PV self-consumption, ESS attain numerous benefits such as omitting on-peak electricity prices, providing backup power to homes during power outages, and stabilizing our overwhelmed grid. These benefits are indisputable and can be reinforced by various studies that objectively support these claims. Conversely, the economic feasibility of ESS with the current cost and government incentives is where the question arises of whether a SFR should invest in this emerging technology. Although the government rebates and credits that are currently offered reduce the costs substantially, it is also important to consider the future of these incentives, as well as the emergence of new technologies. Due to the rapidly evolving nature of the energy industry, current batteries like the Powerwall and RESU 10H will likely be superseded in the near future. Furthermore, these systems have only been utilized by SFR in recent years, meaning that further research and development will have the effect of lowering the cost, making them affordable to the vast majority of Californians. Altogether, ESS will become a standard in California and will likely be utilized by the vast majority of SFR.

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