Project Report on

University Retirement Community
Energy Resiliency

University of California, Davis

Path to Zero Net Energy

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1. Executive Summary

During the summer of 2021, the University Retirement Community (URC) in North Davis experienced a power outage that lasted several hours. Power outages in the summer can result in potentially fatal injuries due to the extreme heat. Concerned about the health and safety of the community, this event inspired a group of residents to form the URC Energy Sustainability and Resilience Committee, to advocate for a more sustainable and resilient living facility for their senior community members. Home to about 400 residents, the URC mainly consists of independent living quarters in its 332,000 sq ft campus. The campus also offers assisted living, skilled nursing, and memory care, all of which use medical equipment that must be kept in continuous operation. Striving toward energy resilience, the Committee sought the expertise from a team of energy, engineering, and physics graduate students at UC Davis to design a solar photovoltaic (PV) and battery storage system to increase the energy resiliency of the facility.

Our team performed this study using 4 years of PG&E gas and electricity utility bills, available schematics, and site visits. Solar PV designs were made using HelioScope, an online software tool, and considered various combinations of rooftop, carport, and ground-mount arrays. Battery size was determined based on load capacity and duration of operation. Nine solar with battery storage configurations at varying load capacities and durations were designed. The recommended solar design utilizes all available rooftop, carport, and ground-mount space that the URC has. The system size is an 1875 kWp system that can cover 69% of URC current usage and with a payback of 3.3 years. The top three recommended solar and battery system options are:

1. System 9: Full solar with an 823 kWh battery that will cover 30% of load for 4 hours. Capital cost is $2.83 million and payback is 5.53 years. For 400 kWp rooftop only solar, this system costs $0.83 Million with a payback of 5.19 years.
2. System 6: Full solar with a 1371 kWh battery that will cover 50% of load for 4 hours. Capital cost is $2.99 million and payback is 5.54 years. For 400 kWp rooftop only solar, this system costs $0.99 Million with a payback of 5.29 years.
3. System 8: Full solar with a1646 kWh battery that will cover 30% of load for 8 hours. Capital cost is $3.07 million and payback is 5.62 years. For 400 kWp rooftop only solar, this system costs $1.07 Million with a payback of 5.50 years.

We hope that the system configurations developed in this study are able to assist the residents of the community to advocate for their resiliency goals and to ultimately achieve them.

2. Introduction

During the summer of 2021, the University Retirement Community (URC) in North Davis experienced a power outage that lasted several hours. This incident inspired a group of residents to form the URC Energy Sustainability and Resilience Committee to advocate for a more sustainable and resilient living facility for their senior community members.

2.1 Our Client: The University Retirement Community

Home to about 400 residents, the URC mainly consists of independent living quarters in its 332,000 sq ft campus. The campus also offers assisted living, skilled nursing, and memory care, all of which use medical equipment that must be kept in continuous operation. These facilities are considered medical facilities and are required by state and federal law to have a backup generator. Consequently, the URC has a diesel generator that keeps essential equipment in these medical facilities running in the event of a power outage. However, the rest of the community remains at risk. Power outages can cause food and medication to spoil and can result in heat-related injuries that could become fatal. In addition, lack of lighting and elevator access may put residents at a higher risk for falls and other mobility-related injuries. The health and safety of the URC residents are the Committee's top priorities. This Committee and the rest of the community are our clients.

2.2 Problem Description

Today's climate is seeing extreme effects of climate change: hotter summers, colder winters, and increasing occurrences of natural disasters such as forest fires and droughts. These events are becoming increasingly common in California and are resultantly leading to power outages. Over the past 7 years, Davis, CA has seen an average increase of 3 degrees Fahrenheit during the summer months[1]. URC residents are particularly vulnerable to the adversities of power outages. The URC does not have a robust and reliable energy backup or storage system, leaving most residents susceptible to unexpected power outages. To address this problem, the URC reached out to a team of students in the Path to Zero Net Energy (ZNE) course at the University of California, Davis. Our group of energy, engineering, and physics graduate students make up the URC Resiliency team.

2.3 Project Scope

The URC Resiliency team is tasked with analyzing the solar power production and battery backup potential at the URC facility to increase their energy resiliency. We will design and assess the financial feasibility of a combined solar and battery storage system that will keep critical URC facilities and functions in operation for at least 4 hours in the event of an outage. Notable activities that are outside the scope of this project are advanced studies including, but not limited to, an ALTA study to assess property boundaries and easements, a geotechnical analysis to assess soil composition and mount bearing capacity, a Phase I Environmental Site Assessment to check for endangered wildlife and floodplains, and a utility feasibility study to approve system interconnections. These activities are often performed by third party, licensed engineering consultants hired to conduct a full feasibility analysis for a property.

2.4 Relevant Literature

There has been an increased focus on resiliency in the wake of climate induced power outages[2]. Our team analyzed studies that reaffirmed the importance of climate independent energy systems[3]. The approaches and considerations in those studies allowed us to better understand the motivation of our client and to frame rational objectives for the project. Having understood the similarities of the URC with healthcare facilities, we found studies focusing on resiliency for large buildings and similar facilities. The technical approaches to the micro grids and the reported techno-economics of some studies on system design and optimization were useful in making assumptions for financial modeling of our system[4], [5]. We also looked at relevant studies that were carried out on the subject site. These included feasibility studies on combined heat and power and solar energy systems at the facility[6], [7]. The latter was particularly relevant to us since we had a set of reference findings to compare our results with. It also helped us identify deficiencies in the analysis and improve on them to come up with better and more realistic system design parameters. A feasibility study, conducted by Sacramento Engineering Consultants (SEC), on the solar power potential for URC was delivered to the facility in 2018. However, the proposed solution was financially impractical at the time.

There are many factors that should be considered when designing an optimal and efficient solar PV system. These factors include the collector material, mounting location, orientation (tilt and azimuth) of the collector, temperature, levels of sunlight and shading, and weather conditions[8], [9]. The mounting location and orientation of solar panels is an important consideration for installation costs[10]. Ground-mounted solar systems are generally cheaper than rooftop but the latter does not have any land availability constraints. Battery storage systems are key to storing and deploying energy on demand. In URC's case, batteries can be used to store excess solar energy, be charged directly from the grid, and provide power during outage periods. Batteries can be integrated into either side of a direct current (DC) or alternating current (AC) side[11]. Solar panels generate DC current, which flows in one direction, and storage devices usually charge as discharge in DC. Inverter devices convert DC to AC. AC alternates between positive and negative, and is what most powered devices use. Most new solar and storage systems use batteries on the DC side. If a system already has solar in place, but is adding storage, the storage will likely be on the AC side instead[12].

3. Methodology for the Design of Solar and Storage Systems

Our team conducted a comprehensive literature review and client meetings to understand the landscape of solar and storage technologies. Two site visits to the URC facility were made to scope out the available areas for installation of solar panels and battery systems, and tie-in points (where in the existing electrical infrastructure the solar PV and battery systems will connect). A comprehensive methodology was then developed for the design of the solar and storage systems which is discussed in the following sections.

3.1 Solar PV Design Methods

A solar photovoltaic (PV) system design shows a layout of solar PV modules, the direction they face (azimuth), and the angle they are mounted at (tilt). The modeling software HelioScope uses local weather data to predict the annual energy production of the proposed system, including effects of shading from any trees and structures that are added to the model. The solar PV system is defined in terms of the DC and AC capacity. DC is the sum of the ratings of the solar PV modules given in kWp or kW-DC. AC is the sum of the inverter capacity and is the maximum amount of DC power that can be converted to usable AC power, and is given in units of kilowatts (kW).

The procedure for this design of the solar PV system was as follows:

- Determine the maximum annual energy use;
- Select appropriate equipment for the application;
- Review site-specific constraints;
- Generate a model of the PV system and determine the expected annual energy generation;
- Iterate the model generation and select a layout that maximizes generation while minimizing expected costs.

An early-stage PV system design is used to evaluate financial feasibility, to get stakeholder approval, and can be submitted as part of a Request for Proposals. The expected annual energy generation is used for the financial analysis. The early stage model also provides layouts and renderings of the proposed PV system showing the location and orientation of the modules, which can be shared with stakeholders to review for approval.

Average annual energy consumption was 4,762,000 kWh (See Appendix A: Energy Usage Data). The maximum recommended solar PV system size should generate up approximately this value. This ensures the maximum value of the solar PV system, as the URC would be compensated at the purchase rate of approximately \$0.15/kWh; excess energy production from the solar PV system beyond the URC's self-use would be compensated at the generator's rate of approximately \$0.05/kWh.

See Appendix B for additional design considerations.

3.2 Battery Storage Design Methods

Battery storage system design aims to show the capacity of installed batteries in terms of energy (kWh) and power (kW). Our design was based on the energy demand of the facility and three different load profiles were modeled to be providing a backup of three different periods of duration. Full, half and 30% of the total load were assumed to be supported for 24, 8 and 4 hours for the battery storage system design. This resulted in 9 different configurations for the storage system and all of them were techno-economically modeled. Important design considerations included the following:

- Facility load profile assessment and the determination of critical load
- Estimation of the depth of battery discharge
- Availability of the battery capacity for load serving
- Demand charge savings from battery systems
- Battery lifetime and replacement costs

Some of the parameters in the key design considerations like demand charge savings were evaluated using the available data, whereas others like the depth of discharge, lifetime, and load serving capacity of batteries were taken from the relevant literature and National Renewable Energy Lab's REopt® platform. For the requirement of the area for installing the battery systems, commercial battery sizing was analyzed to calculate an average square footage number of 0.041 ft^2/kWh.

3.3 Economic Modeling of the Systems

The team developed a dedicated financial model to present an economic outlook of a selection of different system configurations. These configurations vary in the sizing of solar and battery systems. The battery systems range from a 24-hour backup for full load to a 4-hour backup for 30% of the load for the facility. The purpose of these models is to compare the techno-economic performance of each of these system configurations and to recommend the ones with highest returns.

3.3.1 Modeling Assumptions & Considerations

Key assumptions for the solar and storage systems pertain to the costs of photovoltaic modules, inverters and battery systems. Since the battery systems do not last as long as the solar photovoltaic (PV) systems, a cost of battery replacement after an assumed lifetime of 10 years was incorporated into the techno-economic models. NREL's forecasting for the cost of battery systems after 10 years was considered for this purpose. Daily generation for the solar photovoltaic system was assumed to be 7 hours per day on average across the year. The energy consumption at the facility and the average unit electricity cost was calculated from the multi-year energy bills provided by the client. Demand charges for the facility were also incorporated into the model for estimating battery system savings. For subsidies and incentives, Pacific Gas and Electric's (PG&E) Self Generation Incentive Program (SGIP) and the Federal Tax Credit were considered. The former offsets the capital cost of a battery system by 20-30%, with 25% being the average for this range and was used for the techno-economic models. For the Federal Tax Credit, a credit of 20% of the cost of a solar system was incorporated into the system costs and savings.

For the battery system, the depth-of-discharge was assumed to be 80% and the peak to off-peak electricity charge difference was conservatively assumed to be $0.07/kWh. The total cost of a solar system was calculated by adding the module, inverter and miscellaneous (auxiliaries and installation) costs. The incentives were incorporated by subtracting 20% of the total cost from the calculated total cost (80% of the total cost) as per the Federal Tax Credit for solar energy systems. The cost of auxiliaries and installation was estimated to be $0.10/Watt. For the battery system, the cost was calculated by multiplying the per kWh cost of a battery system reported by NREL with the system capacities. Please refer to Table 1 in Appendix D for a summary of the assumed input parameters.

3.4 Equity Framework

Renewable energy transitions often leave behind underserved and marginalized communities. These communities are left out of the decision-making process, and once decisions are made, either do not see the benefits of such transitions, are burdened with the costs, or both[13]. Our team realizes that the elderly residents of the URC are a vulnerable group and are often unable to advocate for themselves[14]. URC residents are also more vulnerable to extreme temperature and climate conditions. This means their living facilities require additional resilience measures. In addition, many residents are on fixed incomes. As per the residents, they pay a monthly rent fee, which includes the costs of utilities, amenities, and healthcare services. Our team has taken into consideration the possibility that the installation costs of solar and battery storage systems may be burdened on the residents of the URC. So, we wish to equip the Committee and residents with the necessary information and tools to advocate for their health and safety, all while using clean energy. We aim to design an optimal solution such that installation costs will be greatly offset by savings in utilities, and any increases in monthly fees will be minimal.

4. Results and Discussion

4.1 Solar System Design Configuration

The maximum feasible solar PV capacity including the 4 acre parcel north of W Covell Blvd is 1.8 MW-dc, which would generate approximately 3.4 GWh per year or about 69% of the URC's annual energy use. Over half of this system capacity is proposed here as a 1.12 MWp ground mount, single-axis tracking system on the parcel north of Covell Blvd. This site is very good for solar, reflected by the very high specific energy of 2046.4 kWh/kWp. The aerial view of the proposed system is given in Figure 1.

Figure 1: The maximum feasible solar capacity, including rooftop, carport, and ground-mount subsystems

The rooftop system totals 391 kWp with an annual energy production of 527 kWh/yr or 11% of annual energy use. The rooftop and carport systems total 795 kWp, with an average specific energy of about 1500 kWh. The carport system totals 391 kWp, of which 113 kWp is installed on existing carport structures. Therefore, a total system capacity of about 520 kWp could be installed on existing structures only (main facility rooftop and existing carports). The details of the individual capacities offered by the carports, ground-mount and rooftop systems is given in Table 1 of the report.

Description	**AC** (kW)	**DC** (kWp)	**Specific Energy** (kWh/kWp)	**Annual Energy** (MWh/yr)	**Percent of Annual Demand**
Carports	337	391	1484	580	12%
Ground-mount (SAT)	890	1080	2046	2220	46%
Rooftop, S/E/W surfaces	336.8	404.1	1581	527.1	11%
Total	**1564**	**1875**		**3327**	**69%**

Table 1: Breakdown of the maximum power system

4.2 Battery System Design Configuration

The designed storage systems vary in their capacity to serve loads as well as the number of hours they can support their respective loads. An important consideration during the design of these systems was to ensure the coverage of a breadth of different capacities for the client so that they can opt for the best system as per their specific needs. A detailed description of these systems in terms of their energy profile, load serving capacities, area requirement and gross cost of each system is given in Table 2. It can be seen that the batteries supporting any amount of load for 24 hours have a significantly high area requirements with the full load battery for 8 hours also having a similarly high area requirement. The largest battery pack has been sized to backup the whole facility for 24 hours, its capacity with a depth of discharge of 80% has been calculated to be 16.456 MWh and it takes the largest amount of space. Values for the load serving capacities are the highest for the larger battery systems (system 1-4 and system 7) whereas the smaller battery systems do not have any load serving capacity as they have been designed to support their designated loads for a least 4 hours.

The recommended systems are the system 9, 6 and 8 and although they have been preferred over the others based on their techno-economic performance, they also have a reasonable estimated size as compared to the other systems. For comparison, the largest battery system that is able to support the full load of the facility as a backup for 24 hours has an impractical area requirement of 344 m^2 or 3,703 ft^2. The system configuration 9, which offers the best techno-economics among all the systems, has an area requirement of 0.86 m^2 or 9.257 ft^2 with a power backup capacity of 4 hours for 30% of the facility load. Similarly, the system configuration with the second best techno-economics is the configuration 6 and it has the area requirement of 2.39 m^2 or 25.726 ft^2 which is more than twice the size of the configuration 9 but is still reasonable for the size of the University Retirement Community. For reference, the size of a large 40-ft shipping container is 380 ft^2. The analysis did not establish a direct correlation between the techno-economics and the footprint of the battery systems, but the results seems to suggest that there is some kind of a linear correlation between the two.

Energy Storage System Configurations			
Parameter	**Value**	**Area (m^2)**	**Without Incentive Cost (M$)**
Storage Configuration 1 (Full Load 24h)	16456 kWh	344	6.385
Available Capacity for Load Serving	83%		
Load Serving Capacity of System 1	10927 kWh		
Storage Configuration 2 (Half Load 24h)	8228 kWh	85.9	3.192
Available Capacity for Load Serving	83%		
Load Serving Capacity of System 2	5463 kWh		
Storage Configuration 3 (Full Load 8h)	5485 kWh	38.2	2.128
Available Capacity for Load Serving	50%		
Load Serving Capacity of System 3	2194 kWh		
Storage Configuration 4 (Half Load 8h)	2743 kWh	9.55	1.064
Available Capacity for Load Serving	50%		
Load Serving Capacity of System 4	1097 kWh		
Storage Configuration 5 (Full Load 4h)	2743 kWh	9.55	1.064
Available Capacity for Load Serving	0%		
Load Serving Capacity of System 5	0 kWh		
Storage Configuration 6 (Half Load 4h)	1371 kWh	2.39	0.532
Available Capacity for Load Serving	0%		
Load Serving Capacity of System 6	0 kWh		
Storage Configuration 7 (30% Load 24h)	4937 kWh	30.9	1.915
Available Capacity for Load Serving	66%		
Load Serving Capacity of System 7	3291 kWh		
Storage Configuration 8 (30% Load 8h)	1646 kWh	3.44	0.638
Available Capacity for Load Serving	50%		
Load Serving Capacity of System 8	658 kWh		
Storage Configuration 9 (30% Load 4h)	823 kWh	0.86	0.319
Available Capacity for Load Serving	0%		
Load Serving Capacity of System 9	0 kWh		

Table 2: Designed storage system specifications, area requirement and gross cost

4.3 Economic Analysis

All the energy storage configurations were combined with the recommended 1875 kWh solar system to assess the overall techno-economics of the systems. Figure 2 has the techno-economic overview of all the combined system configurations. On the left, lifetime savings from each of the system is compared with the capital cost and the benefit-cost ratio is shown. On the right, internal rate of return (IRR) and the payback period for each of the systems is plotted. It can be seen that the system 9, 6 and 8 offer the best combination of benefit-cost ratio, payback and IRR. System 9 has the highest benefit-cost ratio of 3.92, payback period of 5.53 years and IRR of 18% with a capital cost of $ 2.83 Million including incentives. System 6 offers the second best returns on investment by offering a benefit-cost ratio of 3.87, payback period of 5.54 years and IRR of 18% at a capital cost of $2.99 Million. It is to note that the best returns on investment are offered by the solar only system, which costs $2.59 Million but it only offers selective daytime resiliency which counters the resiliency goals of the client. The impact of installing these systems on the 20-year energy cost and investment returns for each of the system for 1875 kW and 400 kW solar systems are given in Figure 1, Table 2 and Table 3 of the Appendix D respectively.

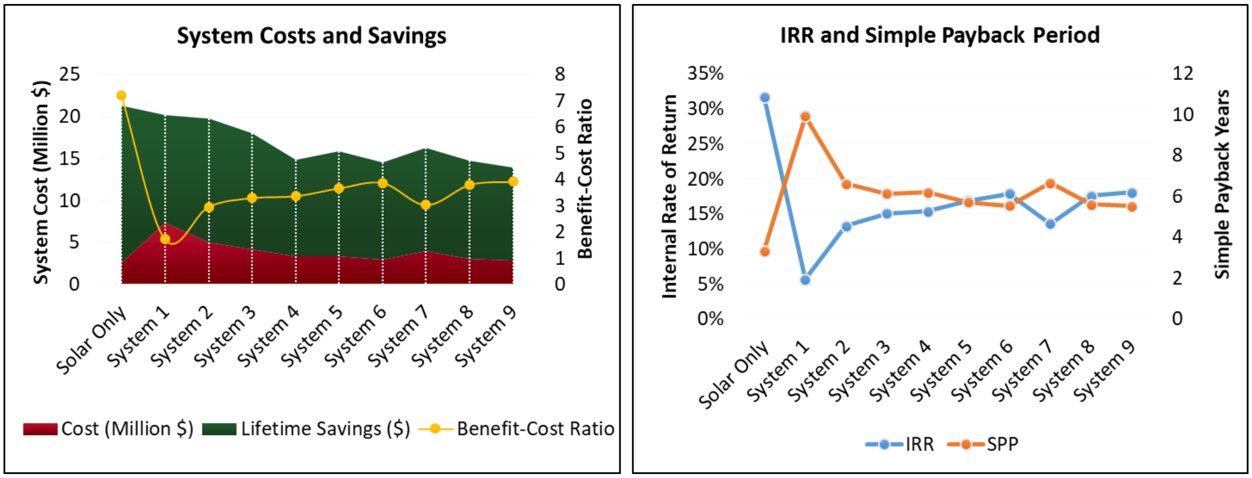

Figure 2: System costs and savings (left) and system returns on investment in terms of internal rate of return and simple payback period (right)

5. Conclusion and Recommendations

Our team was able to extensively analyze and develop a number of different configurations to achieve the resiliency goals of the clients. Two solar system configurations are noteworthy, one without the carports and ground-mount system and the other with it. The capital cost of the solar system with only the rooftop is $0.59 Million and it is able to generate 400kWp, which is able to supply for 11% of the facility demand. In contrast, the 1875 kWp solar system costs $2.594 Million and is capable of supplying for 69% of the total facility demand. For the 400 kWp solar system design, the recommended battery systems are systems 9, 6 and 8 costing $0.83, $0.99 and $1.07 Million respectively. The same systems are recommended for 1875 kWp solar system and they cost $2.83, $2.99 and $3.07 Million respectively. The results from this study give the client a range of different avenues to consider for resiliency. Even among the recommended systems, there is diversity in load capacities as well as the number of hours for backup for the respective capacities. We believe that the residents of the community are going to be able to use the results of this study as tools and means to better advocate for the resiliency at the University Retirement Community.

Having extensively worked on the design of solar and storage system for this facility, there are certain challenges that we would like to particularly highlight to avoid for any similar studies in the future. The availability of high resolution energy use data needs to be provided to enable the team in performing accurate system design calculations. Availability of schematics is another important resources to be provided for a more granular estimation of the critical loads and for the assessment of the suitability of the designed system to support it. Similarly, organizational hierarchy made the access to information a bit challenging which should be addressed for any future studies. Overall, despite the aforementioned challenges, the team was able to successfully design a number of system designs for the client to consider to achieve resiliency. We recommend the clients to assess the provided solution options and bring them to the URC leadership. We hope that the results of this study enable them to be more resilient to climate induced power and energy insecurity.

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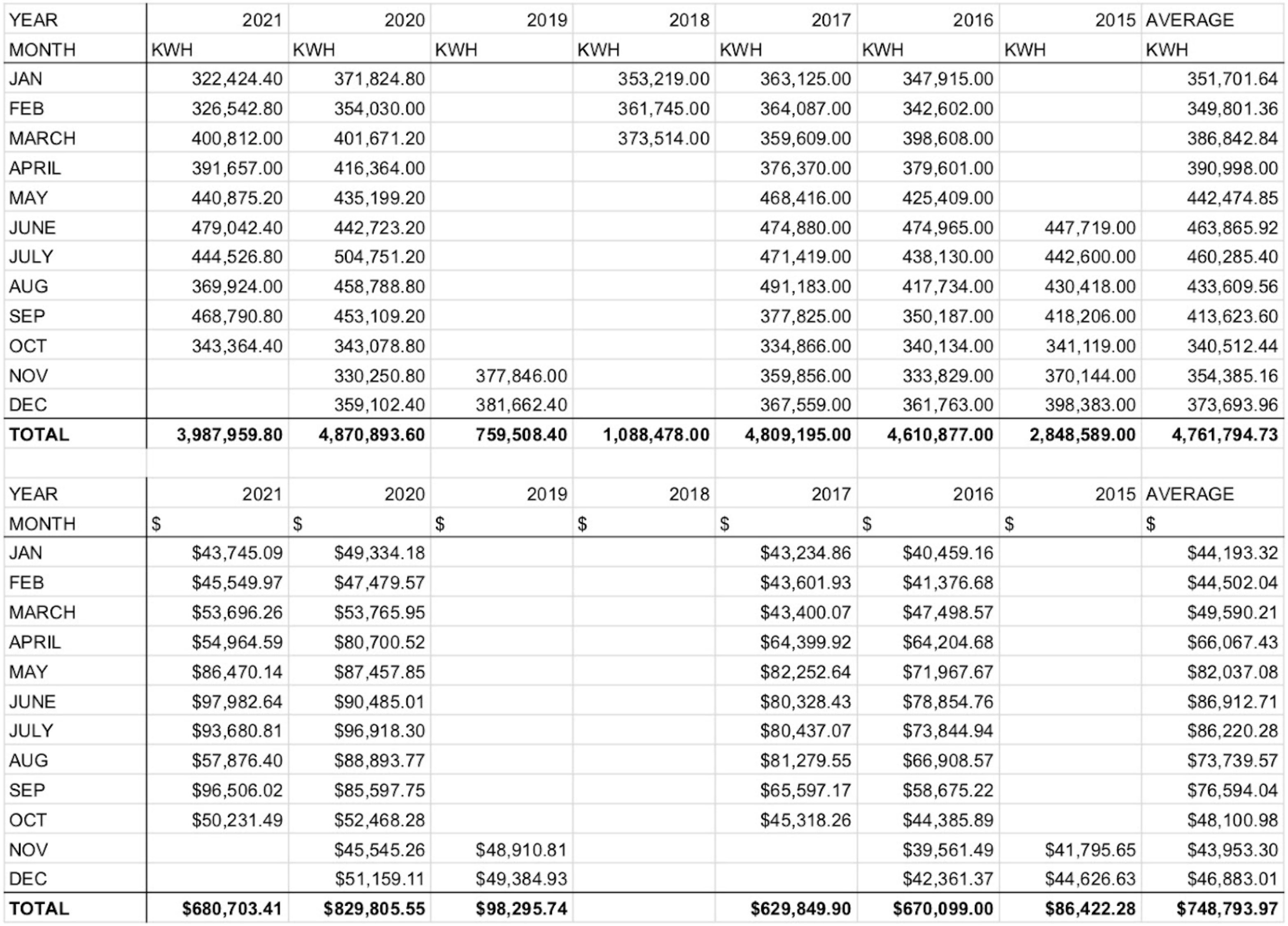
7. Appendix

7.1 Appendix A: Energy Usage Data



YEAR	2021	2020	2019	2018	2017	2016	2015	AVERAGE
MONTH	KWH	KWH	KWH	KWH	KWH	KWH	KWH	KWH
JAN	322,424.40	371,824.80		353,219.00	363,125.00	347,915.00		351,701.64
FEB	326,542.80	354,030.00		361,745.00	364,087.00	342,602.00		349,801.36
MARCH	400,812.00	401,671.20		373,514.00	359,609.00	398,608.00		386,842.84
APRIL	391,657.00	416,364.00			376,370.00	379,601.00		390,998.00
MAY	440,875.20	435,199.20			468,416.00	425,409.00		442,474.85
JUNE	479,042.40	442,723.20			474,880.00	474,965.00	447,719.00	463,865.92
JULY	444,526.80	504,751.20			471,419.00	438,130.00	442,600.00	460,285.40
AUG	369,924.00	458,788.80			491,183.00	417,734.00	430,418.00	433,609.56
SEP	468,790.80	453,109.20			377,825.00	350,187.00	418,206.00	413,623.60
OCT	343,364.40	343,078.80			334,866.00	340,134.00	341,119.00	340,512.44
NOV		330,250.80	377,846.00		359,856.00	333,829.00	370,144.00	354,385.16
DEC		359,102.40	381,662.40		367,559.00	361,763.00	398,383.00	373,693.96
TOTAL	**3,987,959.80**	**4,870,893.60**	**759,508.40**	**1,088,478.00**	**4,809,195.00**	**4,610,877.00**	**2,848,589.00**	**4,761,794.73**

YEAR	2021	2020	2019	2018	2017	2016	2015	AVERAGE
MONTH	$	$	$	$	$	$	$	$
JAN	$43,745.09	$49,334.18			$43,234.86	$40,459.16		$44,193.32
FEB	$45,549.97	$47,479.57			$43,601.93	$41,376.68		$44,502.04
MARCH	$53,696.26	$53,765.95			$43,400.07	$47,498.57		$49,590.21
APRIL	$54,964.59	$80,700.52			$64,399.92	$64,204.68		$66,067.43
MAY	$86,470.14	$87,457.85			$82,252.64	$71,967.67		$82,037.08
JUNE	$97,982.64	$90,485.01			$80,328.43	$78,854.76		$86,912.71
JULY	$93,680.81	$96,918.30			$80,437.07	$73,844.94		$86,220.28
AUG	$57,876.40	$88,893.77			$81,279.55	$66,908.57		$73,739.57
SEP	$96,506.02	$85,597.75			$65,597.17	$58,675.22		$76,594.04
OCT	$50,231.49	$52,468.28			$45,318.26	$44,385.89		$48,100.98
NOV		$45,545.26	$48,910.81			$39,561.49	$41,795.65	$43,953.30
DEC		$51,159.11	$49,384.93			$42,361.37	$44,626.63	$46,883.01
TOTAL	**$680,703.41**	**$829,805.55**	**$98,295.74**		**$629,849.90**	**$670,099.00**	**$86,422.28**	**$748,793.97**

7.2 Appendix B: Solar PV Design Methodology - Additional Design Considerations

Equipment used for this model includes:

- Solar PV Module: First Solar, FS-6450 (450 watt)
- Inverter: SMA, Sunny Tripower 24000TL-US (24 kW)
- Racking: multiple considered, including: rooftop, parking canopy, and ground mount.

All equipment selections for the early stage design are for preliminary modeling only. Final equipment selection must be made with the Engineering, Procurement and Construction (EPC) contractor. Solar PV modules in particular vary in availability and specific models are typically released in annual cycles, so the PV module model should be selected 6-12 months prior to construction. Similar guidelines apply to the inverter and racking.

Other equipment includes step-up transformers, racking, Supervisory Control And Data Acquisition (SCADA) system, and Balance of System (BOS). BOS includes all conductors, enclosures, fence, switches, and overcurrent protection devices as required by the National Electric Code. These equipment will be specified by the EPC during final engineering and are not specified in this early stage model.

Constraints considered for this early stage model include: available area for rooftop mounting, canopy mounting, and ground mounting; shading due trees and structures.

Figure 1: FEMA flood zone map, indicating portions of the URC campus are in Zone A.
https://msc.fema.gov/

The **FEMA Flood Map** webtool indicates some portions of the URC campus are classified as Zone A, meaning 1% chance of flooding annually, also known as a 100-year flood. This does not pose an immediate impediment to installing solar. However, if the URC were to pursue a ground-mount solar PV solution on the parcel north of W Covell Blvd, some mitigations may be necessary, such as mounting critical infrastructure (such as inverters, transformers, and combiner boxes) above the floodplain height. No other special constraints have been identified at this time. Other special constraints might include: presence of habitat for endangered species; utility or other easements, or other “keep-out” zones; structural limitations of the rooftop.

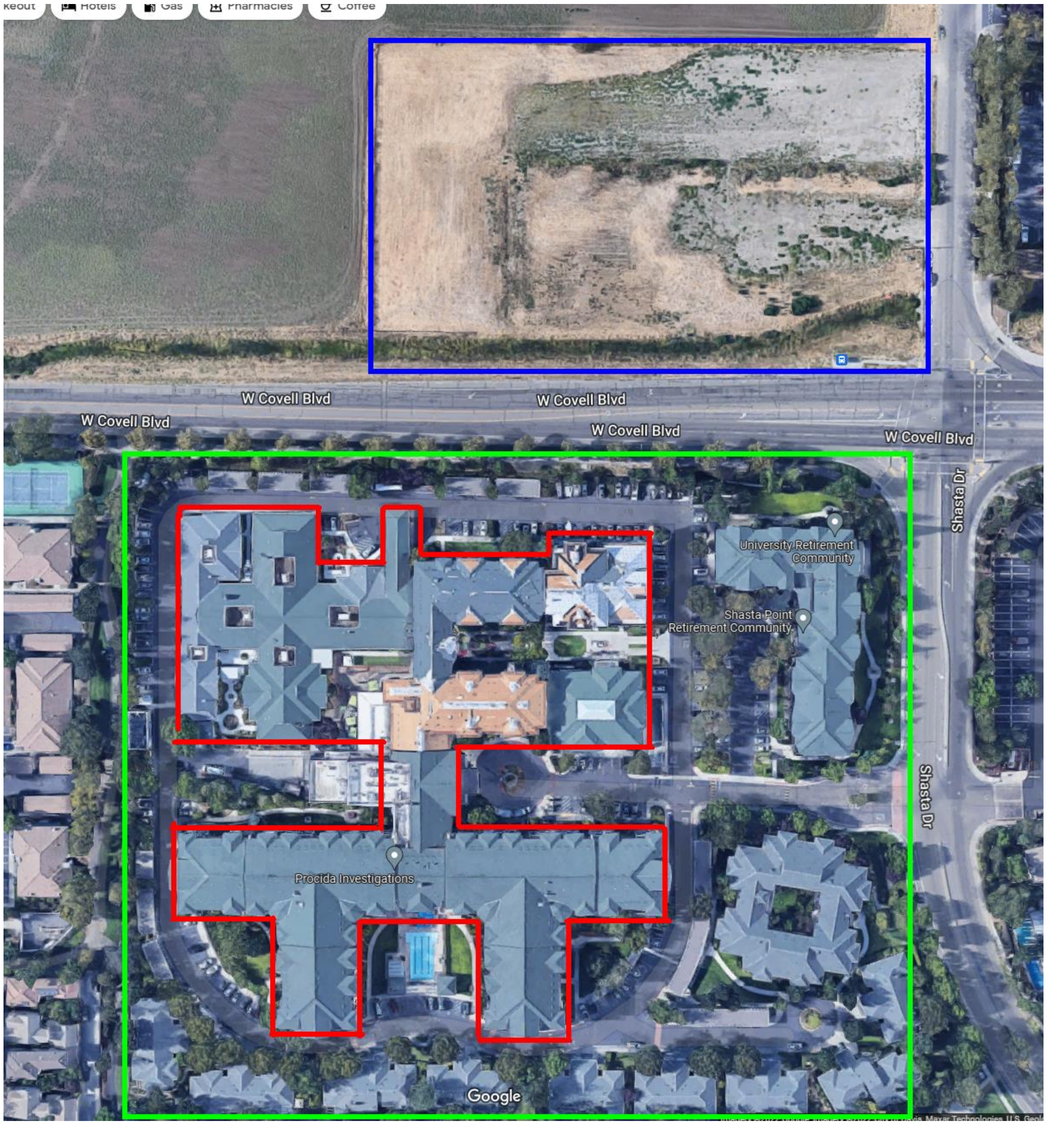


Figure 2: URC area constraints for solar PV; GREEN is URC campus including all condos and secondary structures; RED is the main URC facility; BLUE is an undeveloped brownfield site.

Areas considered for solar PV installation included:

- Rooftop of main facility, facing south and east/west
- Existing parking canopies
- Potential new parking canopies
- Brownfield site north of W Covell

The main facility (outlined in red above) is approximately 332,000 sq ft, with A-frame style shingled rooftop. The rooftop pitch is approximately 20°. The facility azimuth is approximately 180° and all surfaces on the rooftop face cardinal directions. The T-24 Sec. 140-10 calculation for new construction for rooftop solar is approximately 1 watt per sq. ft., or about 300 kWp. The following sections show various layout iterations. All models were generated with HelioScope. All rooftop modules are mounted with 20° pitch. Parking canopies assume 7° pitch. Building heights and tree heights are estimated, assuming approximately 12’ per floor for buildings, and tree heights approximately 25’ to 50’ (generated using the HelioScope tree shade tool).

7.3 Appendix C: Various Solar PV Models

Solar Model 1: Main Facility Rooftop, south-facing only. This HelioScope model excludes the secondary structures on site, shown in red in the figure above. These secondary structures have unique ownership, jurisdiction, or electrical infrastructure characteristics that preclude them from the scope of this analysis.

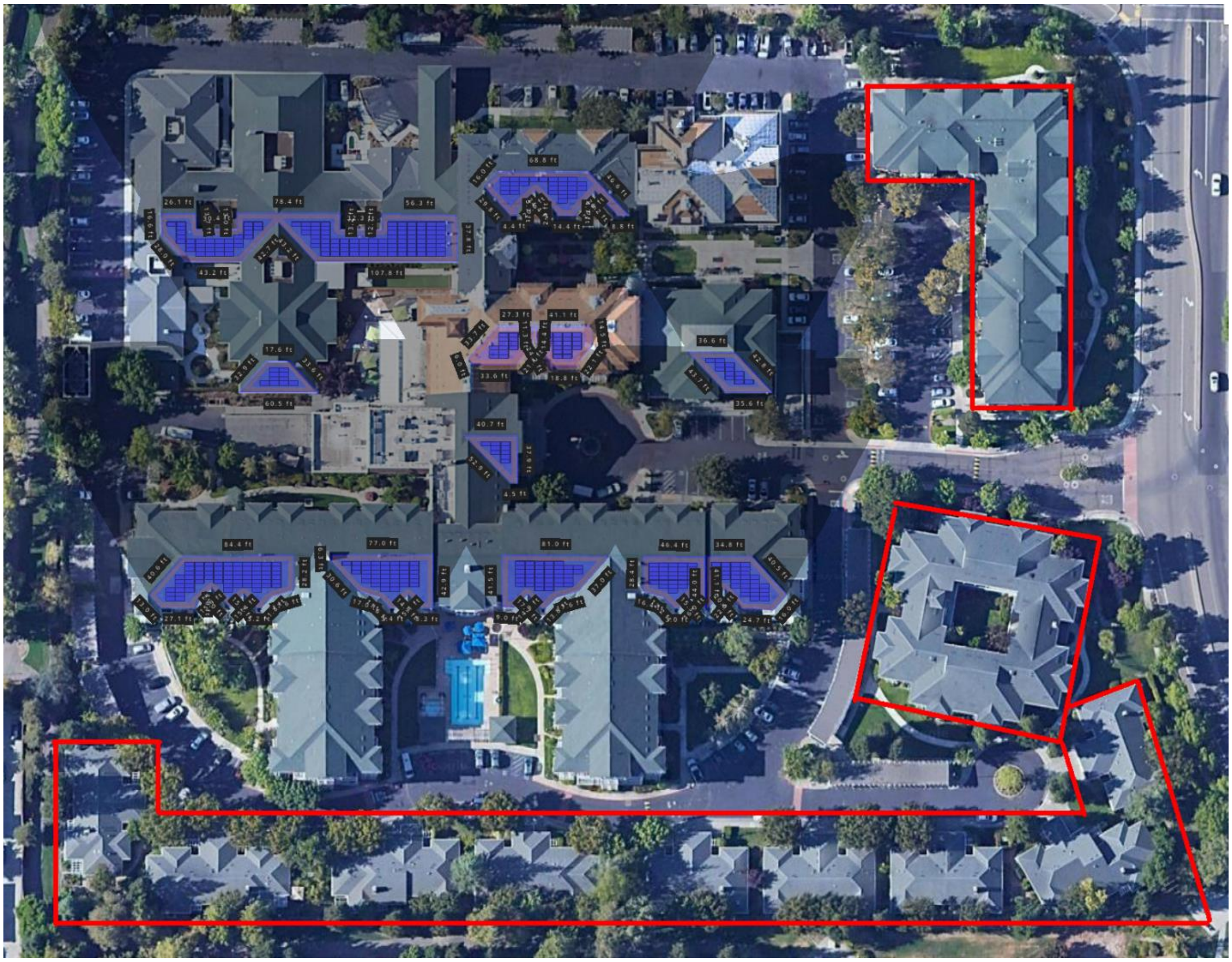


Figure 3: HelioScope model 1 – main facility rooftop, south-facing only. Outlined in **red** are secondary structures not considered in this study.

Solar Model 1 Summary. At 1706 kWh/kWp, this iteration represents the highest value option other than options on the parcel north of W Covell Blvd. All other iterations of rooftop, carport, or both produce less energy annually per number of solar PV panels. This model assumes flush-mount only, meaning solar PV panels are placed only on south-facing rooftop sections where there is enough space to accommodate multiple PV panels and an offset from the panels to the edge of the rooftop or other obstructions.

Solar Model 2: Main facility rooftop with south/east/west-facing surfaces. This model adds east and west faction rooftop surfaces to the previous model. Also an alternate solar PV module is considered (Hanwha Q.Peak Duo 470-watt). See Solar Model 9 for an identical model with the First Solar module used on all other models.

Figure 4: HelioScope model 2 – main facility rooftop considering north, south, and east-facing surfaces. Hanwha 470-watt modules used here.

Solar Model 2 Summary. This model represents the maximum recommended rooftop capacity. The actual viable capacity may be somewhat higher or lower than the 406 kWp shown here. Some sections may be too small to install practically, or conversely, additional racking structure material might be added to make other areas, previously non-viable, viable. This model is less than a previous solar PV study, which proposed a similar rooftop solar PV system, rated at 575 kWp. It is reasonable to conclude that the maximum rooftop installed capacity is approximately 400-500 kWp, resulting in annual energy production of approximately 650 MWh/yr.

Solar Model 3: Maximum system size based on energy use. This model demonstrates the minimum area needed to generate 100% of annual energy demand (approximately 4.8 GWh/yr); the system is 2.75 MW-dc.

Figure 5: Model 3 showing the minimum system size to generate 100% of annual energy demand.

Solar Model 3 Summary. This model shows a 2.75 MWp fixed-tilt ground-mounted array. The expected energy generation for this system is 4.909 GWh/yr, which is slightly more than the URC annual energy use of 4.8 GWh/yr. This model is for demonstration only. The array layout exceeds the property boundary under control of the client. The area required for this system is about 7 acres, or close to twice the area under the control of the URC.

Solar Model 4: Maximum fixed-tilt ground-mount system that fits in area. This model represents the largest fixed-tilt ground-mount system that fits in the 4-acre parcel north of W Covell Blvd.

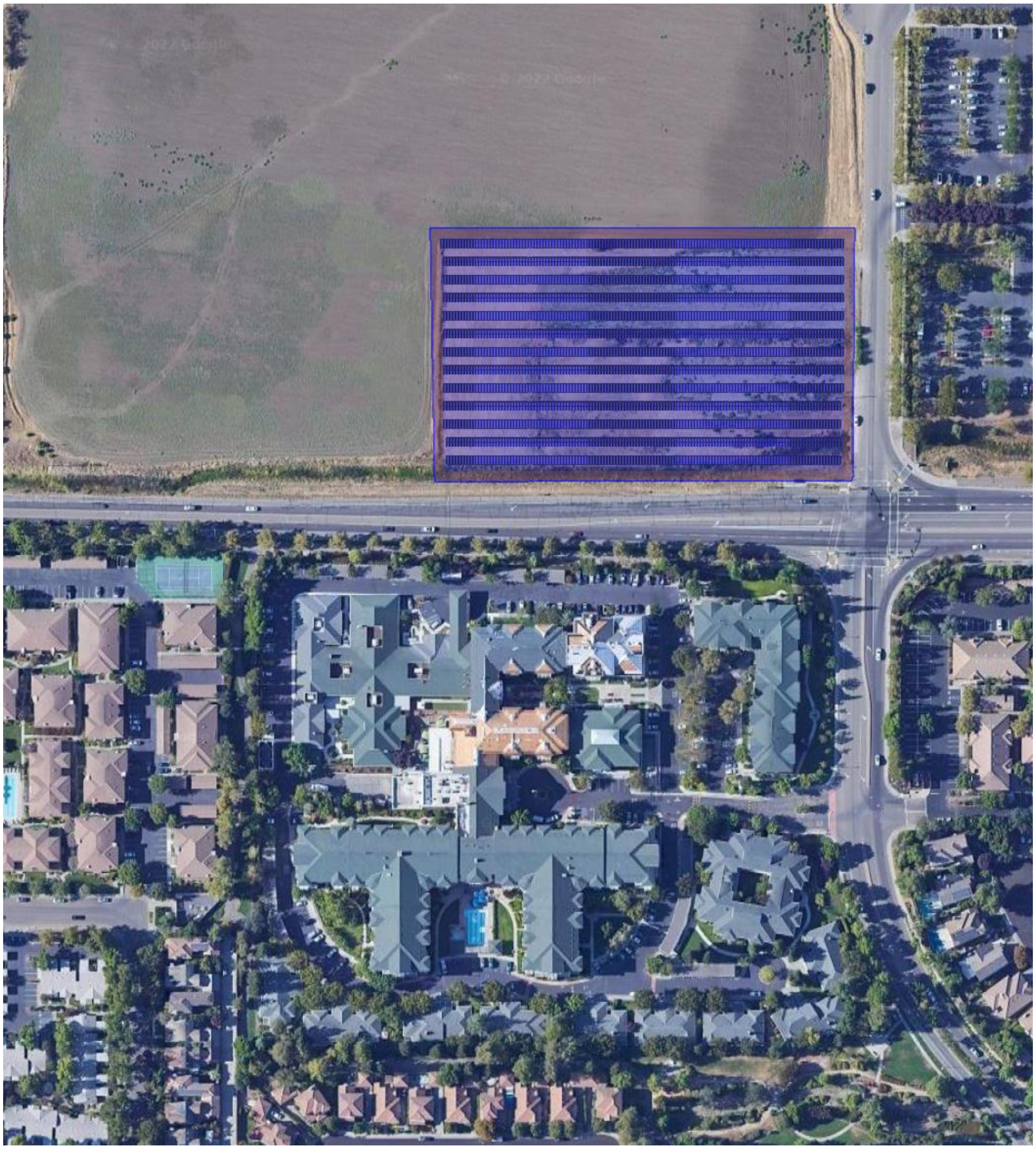


Figure 6: Model 4 showing the largest fixed tilt system that fits in the 4-acre parcel north of W Covell Blvd.

Solar Model 4 Summary. Fixed-tilt ground-mount solar PV systems offer excellent energy performance and low maintenance costs. The excellent specific energy of this design at 1790 kWh/kWp is second only to the single-axis-tracking model. However, this fixed-tilt system does not have the moving parts of the tracking system. Note that all ground-mount models do not reflect a keep-out zone for inverters, transformers and other equipment, and therefore the final system size will be somewhat less than shown here.

Solar Model 5: maximum carport capacity. This model shows the maximum recommended system capacity for carports, including existing and new carport structures.

Figure 7: Maximum carport capacity, showing carports (blue), and for shade modeling, structures (orange) and trees (green).

Solar Model 5 Summary. This carport model considers existing carport structures and proposed new carport structures. Total system capacity is 391 kWp. See model 7 for a version considering existing carports only, total system capacity 124 kWp. The HelioScope shading model default is to exclude modules from areas that are shaded during 10am-2pm on the winter solstice (the point at which sun angle is lowest and losses due to shading are greatest throughout the year). Enabling this criteria would increase the annual production per PV module, but decrease the overall quantity of PV modules and total annual energy generation; the reduced system size would be 221 kWp or almost half the system size; energy generation would be 331 MWh/yr versus 580 MWh/yr for the larger system with additional shading losses.

Solar Model 6: Single-axis tracking (SAT) ground mounted system using maximum available area. This model shows the largest SAT system that fits on the parcel north of W Covell Blvd.

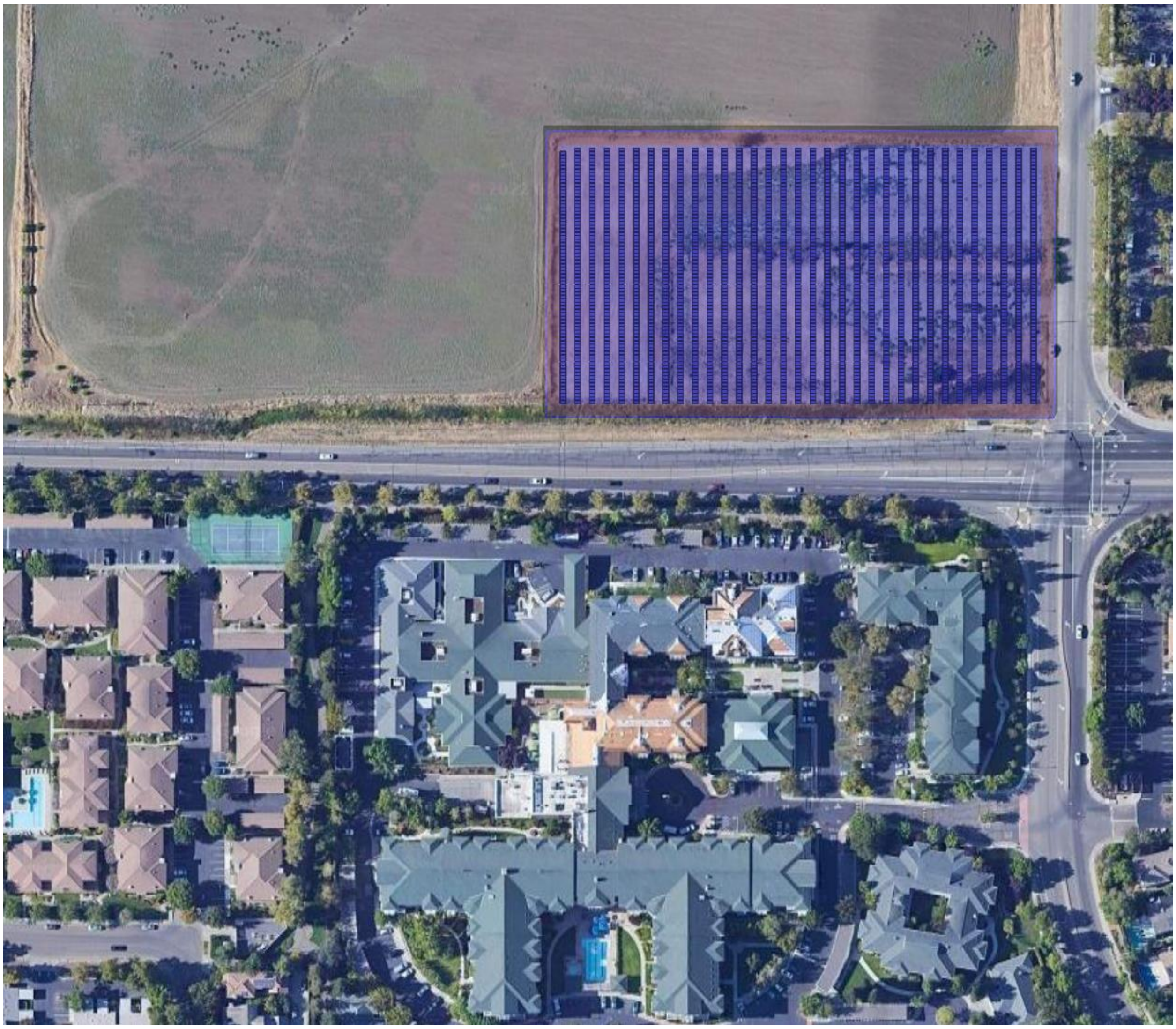


Figure 8: Model 6 showing proposed single-axis tracking (SAT) PV system north of W Covell Blvd.

Solar Model 6 Summary: This model shows the recommended ground-mount system, a single-axis tracking solar PV system up to 1080 kWp. Note that actual system size may be somewhat lower as this model does not account for the inverter, transformer, and power equipment. This SAT system has the highest efficiency of all models at 2046.4 kWh/kWp, and generates 2220MWh/yr or slightly less than half the annual energy use of the URC.

Solar Model 7: Carports using existing structures only. This model checks the maximum solar PV capacity available using only the existing carport structures, which is about 124 kWp.

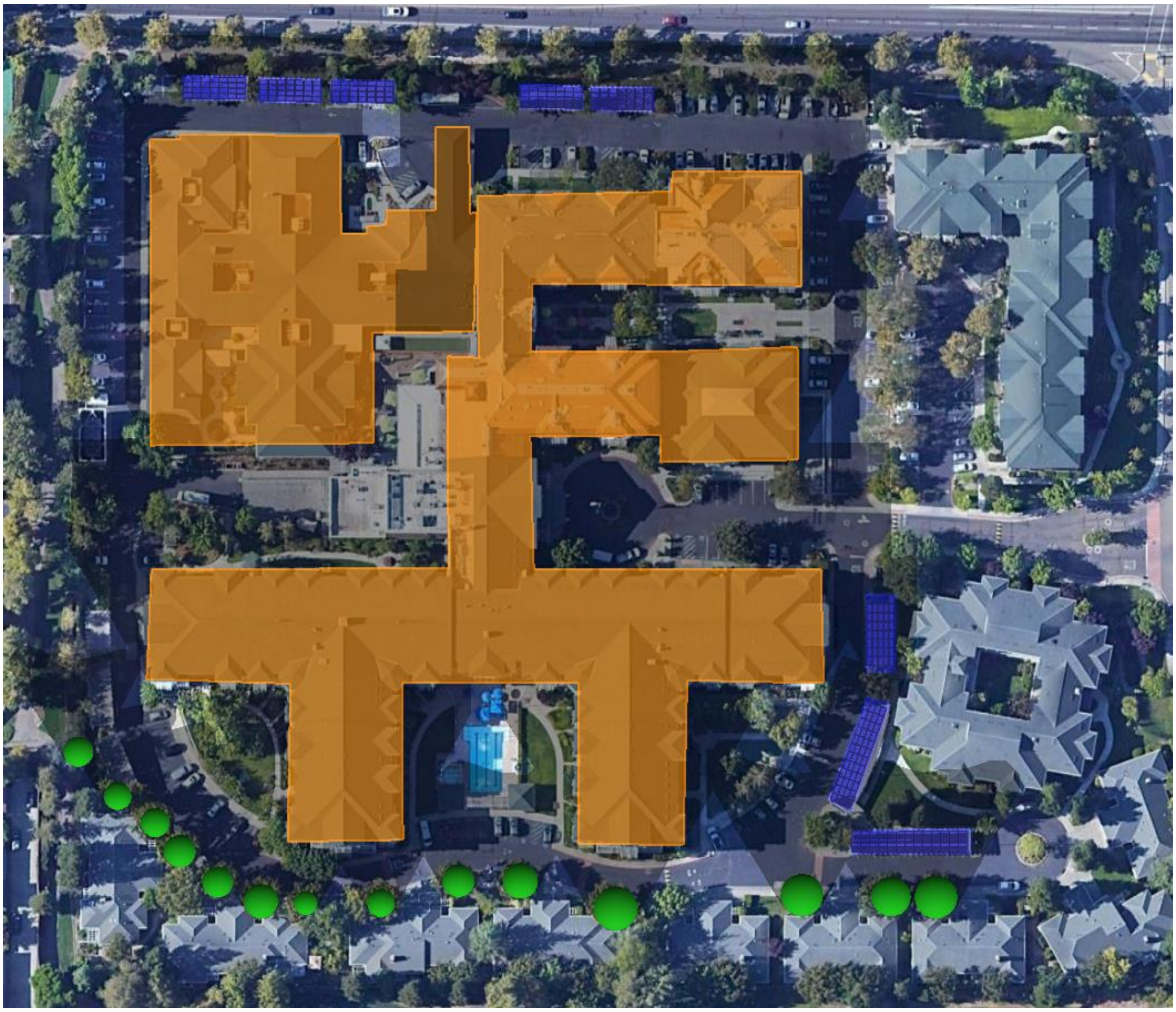


Figure 9: Model 7 showing carport PV capacity using only the existing carport structures.

Solar Model 7 Summary. This model is identical to model 5, except it uses only existing carport structures. The tilt of the carport structures was assumed to be 7° with azimuth 180° +/- 90°. No modules were excluded due to shading, resulting in a somewhat lower specific energy which maximizes total annual energy production. The model shown represents 124 kWp nameplate capacity and 188 MWh/yr, or about 4% of the URC annual energy use.

Solar Model 8: Proposed Rooftop, carport, and single-axis tracking ground-mount system. This model shows the maximum recommended installed solar PV capacity, essentially combining models 5, 6, and 8.

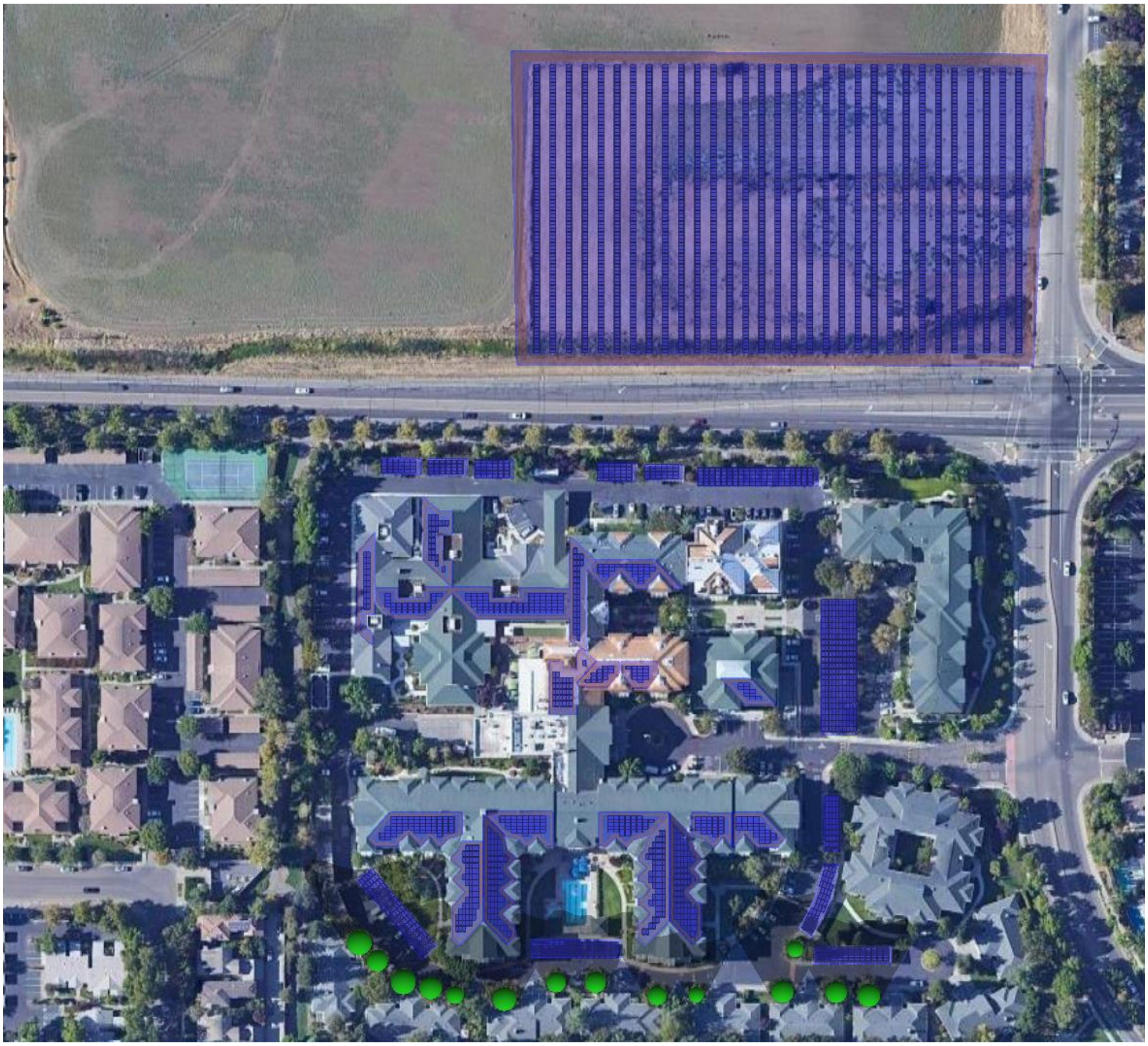


Figure 10: Model 8 combining rooftop, carport, and ground-mount systems from other models. Total system size shown is 1800 kWp with 3390 MWh/yr annual energy production.

Solar Model 8 Summary. This model simply combines the largest recommended variations of the rooftop, carport, and ground-mount systems from other models.

Solar Model 9: Rooftop S/E/W iteration using First Solar 450-watt modules. This model is an iteration of model 2 which used another solar PV module manufacturer, Hanwha.

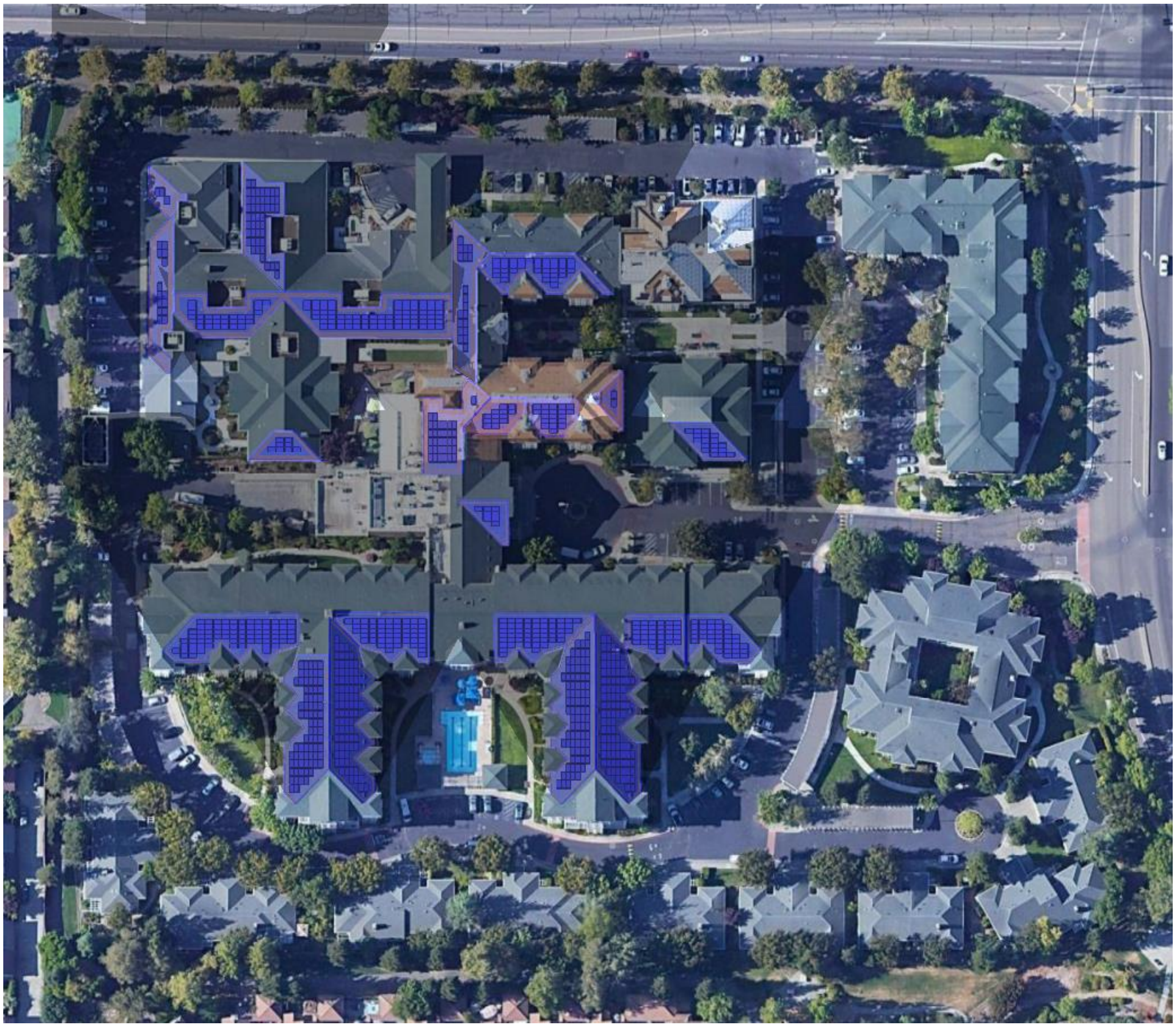


Figure 11: Model 9 showing rooftop system from model 2 using First Solar modules.

Solar Model 9 Summary: This model uses approximately the same layout as model 2 while switching the module manufacturer to First Solar. The Hanwah module used in model two is a bifacial polycrystalline silicon module; the First Solar module shown here and used throughout the other modules is a Made In The USA thin film module. The system size is the same as model two (DC and AC nameplate ratings), but module quantity increased from 865 to 898 modules.

7.4 Appendix D: Economic Modeling Results

Input Parameters			
Parameter	**Value**	**Unit**	**Source**
Solar System Capacity	**1797.3**	**kW**	**System Design**
Facility Power	549	kW	Calculated
Daily Generation	12581	kWh	Estimate
Daily Energy Use at the Facility	13165	kWh	Calculated
Annual Generation	4592102	kWh	Estimate
Annual Demand	4805197	kWh	Calculated
Average Per Unit Electricity Charges	0.169370268	$/kWh	Calculated
Peak to Off-Peak Difference Per Unit	0.07	$/kWh	Assumed
Federal Tax Credit	22	%	PG&E
Self Generation Incentive	25	%	PG&E
Cost of Panels	1.6	$/W	NREL
Module Size	**450**	**W**	**System Design**
Number of Modules	**3994**		**System Design**
Number of 24kW Inverters	**60**		**System Design**
Cost of a Module	720	$	NREL
Cost of an Inverter	4500	$	Market Rate
Cost of Auxiliaries and Installation	0.1	$/W	Estimate
Cost of Battery System	388	$/kWh	NREL
Cost of Battery Replacement	220	$/kWh	NREL
Depth of Battery Discharge	80	%	Assumed

Table 1: Input parameters and key assumptions for the systems design (changing the boldfaced values gives results for other solar system designs)

System Overview					
System	**Cost (Million $)**	**Lifetime Savings (Million $)**	**Benefit-Cost Ratio**	**IRR**	**Payback (Yr)**
Solar Only	$ 2.59	$ 18.71	7.21	32%	3.33
System 1	$ 7.38	$ 12.75	1.73	6%	9.93
System 2	$ 4.99	$ 14.77	2.96	13%	6.62
System 3	$ 4.19	$ 13.82	3.30	15%	6.14
System 4	$ 3.39	$ 11.43	3.37	15%	6.21
System 5	$ 3.39	$ 12.45	3.67	17%	5.72
System 6	$ 2.99	$ 11.58	3.87	18%	5.54
System 7	$ 4.03	$ 12.22	3.03	14%	6.67
System 8	$ 3.07	$ 11.69	3.80	18%	5.62
System 9	$ 2.83	$ 11.10	3.92	18%	5.53

Table 2: Returns on investment analysis results for 1875 kWp solar system with battery configurations

System Overview (400 kWp - Rooftop Only)					
System	**Cost (Million $)**	**Lifetime Savings (Million $)**	**Benefit-Cost Ratio**	**IRR**	**Payback (Yr)**
Solar Only	$ 0.59	$ 4.23	7.2	32%	3.34
System 1	$ 5.38	$ 4.98	0.9	-1%	13.77
System 2	$ 2.98	$ 7.00	2.3	10%	7.46
System 3	$ 2.18	$ 6.05	2.8	12%	6.63
System 4	$ 1.39	$ 3.65	2.6	11%	7.17
System 5	$ 1.39	$ 4.67	3.4	16%	5.79
System 6	$ 0.99	$ 3.81	3.9	18%	5.29
System 7	$ 2.02	$ 4.44	2.2	9%	8.07
System 8	$ 1.07	$ 3.91	3.7	17%	5.50
System 9	$ 0.83	$ 3.33	4.0	19%	5.19

Table 3: Returns on investment analysis for 400 kWp solar system with battery configurations

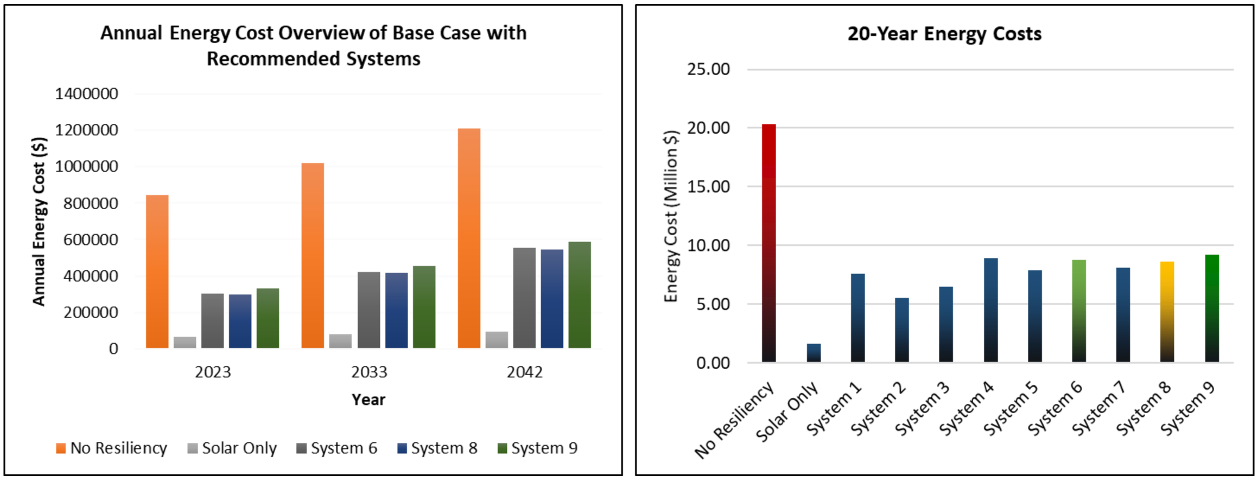


Figure 1: 20-year energy cost comparison between no resiliency and recommended systems (left) and no resiliency and all systems (right)