# Electric Vehicles as Mobile Power

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*1 National Renewable Energy Laboratory*
*2 Arcos Mobility*
*3 Texas Military Department / U.S. Army National Guard*

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**Technical Report**
NREL/TP-5400-91358
December 2024

Contract No. DE-AC36-08GO28308

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*Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.*

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# List of Acronyms

| | |
|---|---|
| ATO | authority to operate |
| B75 | Building 75 |
| B8 | Building 8 |
| BESS | battery energy storage systems |
| CCS | Combined Charging System |
| DER | distributed energy resource |
| DOD | U.S. Department of Defense |
| DODIN | Department of Defense Information Network |
| EV | electric vehicle |
| EV-AMP | electric vehicles as mobile power |
| EVI-LOCATE | Electric Vehicle Infrastructure-Locally Optimized Cost Assessment Tool and Estimator |
| EVSE | electric vehicle supply equipment |
| GM | General Motors |
| GSA | General Services Administration |
| HVAC | heating, ventilating, and air conditioning |
| IDIQ | indefinite demand, indefinite quantity |
| JOC | Joint Operations Command |
| NIST | National Institute of Standards and Technology |
| NPV | net present value |
| NREL | National Renewable Energy Laboratory |
| PV | photovoltaics |
| RC | readiness center |
| RMF | Risk Management Framework |
| SCIF | Sensitive Compartmented Information Facility |
| SOC | state of charge |
| SOD-A | Special Operations Detachment – Africa |
| TXARNG | Texas Army National Guard |
| V2B | vehicle to building |
| V2G | vehicle to grid |

# Executive Summary

Conventional approaches to providing emergency power such as diesel generators and battery energy storage systems (BESS) do not always meet the two key parameters for these systems: high reliability and affordable cost. Therefore, the National Renewable Energy Laboratory (NREL), Arcos Mobility, and the Texas Army National Guard (TXARNG) decided to explore an alternative that could offer both high reliability and cost effectiveness. Electric vehicles as mobile power (EV-AMP) can allow TXARNG and others to leverage as few as four electric vehicles (EVs) to provide emergency energy storage for 24 hours by installing bidirectional chargers and associated dark-start equipment. The presence of four or more EVs operating within a regional context creates a more resilient network than a single diesel generator or BESS, and the fleet of vehicles can travel to one of several locations equipped with bidirectional chargers for the service of critical loads.

There were several facets of analysis required to assess whether EV-AMP was appropriate for TXARNG applications. First, our team surveyed TXARNG facilities in the Austin, Texas area and identified four bases (Camp Mabry, Camp Swift, Bee Caves, and San Marcos) where a single set of vehicles might be able to support the critical load at five individual buildings: Mabry Building 8, Mabry Building 75, Swift Readiness Center (RC), Bee Caves Special Operations Detachment – Africa (SOD-A), and San Marcos RC. We collected data to support the analysis and analyzed what bidirectional charger market options were available to support.

We then completed a series of analytical steps. We first explored whether the loads we were meeting could feasibly be met by electric vehicles (EVs) for 24 hours with one or two charging ports and TXARNG fleet vehicles. We then identified whether the TXARNG fleet had enough vehicles operating within approximately 1 driving hour of the TXARNG facilities. We assessed whether additional charging stations would provide a positive net present value for the facilities and whether we should incorporate additional photovoltaics (PV) and BESS. We estimated the costs to install the required charging stations at the TXARNG facilities where EV-AMP was deemed appropriate. Finally, we explored the resilience value of EV-AMP at each of the individual facilities. This report includes a significant focus on cybersecurity to ensure that the resilience benefits of EV-AMP are not outweighed by the introduction of cyber risks.

This report is organized into the following sections:

1. **Introduction:** The introduction explains what the report intends to accomplish: assessing whether EV-AMP can provide power with the reliability and cost effectiveness that other backup power solutions lack for Army National Guard critical loads.
2. **Data Collection:** The report team first identified five critical buildings within an approximately 50-mile diameter in the Austin area and collected time-series data on their critical loads. At the same time, the team identified fleet vehicles operating in the vicinity that could be replaced with bidirectional EVs and outfitted them with telematics to track trip origins, destinations, and charging requirements. The team also reviewed utility bills, tariff schedules, and incentive program materials.
3. **Bidirectional Chargers:** The authors explored the bidirectional charging market, collected technical specifications on different options, and spoke to vendors and

manufacturers. This section explores the Ford and General Motors (GM) hardware in more detail, finding that they are very similar in design and would both work in the context of this project. The GM hardware is recommended for this particular application because it is compatible with the 2024 extended-range Silverado EV, which has a larger battery pack than the 2024 extended-range F-150 Lightning; at present, GM also offers more bidirectionally capable vehicle models than Ford. The deployment plan includes a system design for the infrastructure, as well as cost estimates associated with those designs.

4. **Methodology:** The methodology was multifaceted. The authors first compared the time-series power load data on building critical loads to the energy associated with a given number of Chevrolet Silverado EVs with extended-range battery packs. They then analyzed vehicle travel patterns and fueling data for fleet vehicles to determine how much energy would be available at any given point in time. They entered the building and expected charging load into the REopt® tool and solved for the ideal combination of distributed energy resources, including bidirectional chargers.
5. **Feasibility:** The feasibility section discusses the results of the analysis and identifies locations where the critical loads could feasibly be served by bidirectional chargers and EVs. The feasibility section narrows the focus from five locations to three with peak critical loads that could be served by a single bidirectional charger. The authors first identified 21 vehicles that could support grid operations and provide 3,037 kWh of maximum energy storage. Depending on proximity of the vehicles to the buildings in question and state of charge at the time of a grid blackout, vehicles could arrive in less than an hour with 1,300–2,600 kWh of available storage. In extreme cold temperatures with battery-electric vehicles operating at 50% efficiency (estimated at -2°F), the available storage could be as low as 900 kWh. REopt found that EV-AMP was the most cost-effective approach to supporting critical operations, reducing capital costs by at least $43,700 in all situations compared to the capital cost of stationary BESS that would provide the same amount of operational time. In simulations based on average SOC across the prospective EV fleet, seven EVs returning to base operating at rated efficiency could support the peak critical load of three buildings for 72 hours, and nine EVs driving at 50% efficiency could support those same loads. The team also assessed the absolute worst-case scenario as well with peak critical loads across all three buildings, the lowest total SOC of the EVs, and 50% EV efficiency. In that case, eight EVs could support 48 hours of critical load, but 72 hours of operations would require more than ten vehicles. The authors recommended installing four chargers: only one is required at each location for backup power, but a second charger at Camp Swift would support typical fleet operations and could generate revenue from energy arbitrage.
6. **Discussion:** The discussion focuses on a few key aspects for consideration outside of the methodology and results: expected reliability, utility interconnection requirements, and cybersecurity. The reliability for EV-AMP is expected to be significantly better than for diesel generators and is comparable to BESS. However, more deployments are necessary to prove the systems work properly in the field. The utility interconnection requirements are not a concern in this application because the EVs will not backfeed power to the grid; the EVSE will connect only to a service panel for critical loads and incorporate an automatic transfer switch that protects the distribution system. Cybersecurity is the

greatest area of concern. There are various issues of concern, including potential connection points to the Department of Defense Information Network (DODIN). System engineering analysis and penetration testing would be beneficial to the deployment of this technology.

7. **Deployment Plan:** This section includes a system design for installing electric vehicle supply equipment (EVSE) at the Camp Swift RC, Bee Caves SOD-A, and San Marcos RC. The designs show the location for the EVSE and service panel, the conductor path, and what material is required for installation. The plan also describes the cybersecurity pathway to an authority to operate and recommends laboratory equipment testing. It includes a procurement plan for a deployment phase of this project and considerations for procurement outside of a pilot. It also describes the requirements for operation and maintenance of the system.
8. **Conclusion:** The report concludes that EV-AMP is feasible at three of the five locations analyzed and could be best supported by a total of four chargers and six to eight electric pickup trucks (Figure ES-1). Ultimately, EV-AMP appears to be an excellent candidate for enhancing resilience at TXARNG facilities and likely many other U.S. Department of Defense facilities as well. EV-AMP could save TXARNG $355,900 for 72 hours of resilience benefits at Camp Swift RC, Bee Caves SOD-A, and San Marcos RC. Leveraging the EVSE for energy arbitrage at Camp Swift would add another $24,800 in value, and the participating in the Austin Energy demand response program at Bee Caves would add another $130,800. Accounting for the $93,600 estimated costs to install equipment, the net benefit to TXARNG would be $486,700.

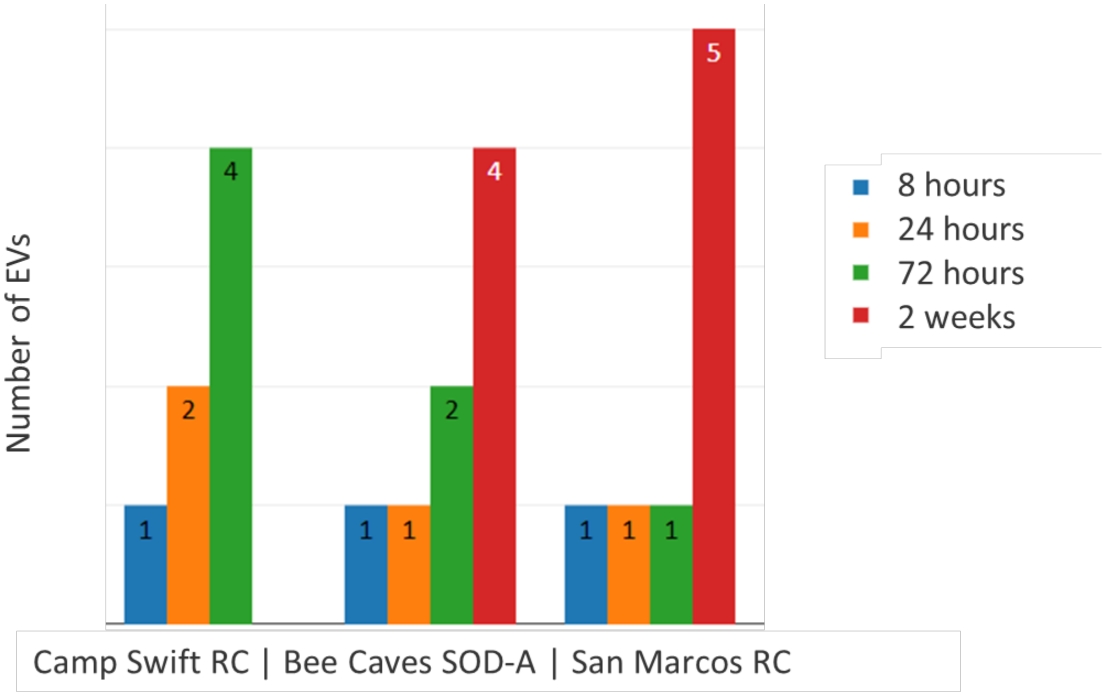

**Figure ES-1. Number of EVs required to power critical loads at peak power, average state of charge, and rated efficiency**

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# 1 Introduction

The legacy utility systems and infrastructure providing power to National Guard readiness centers (RCs) lack the resilience required to operate reliably during a disaster. As electric vehicles (EVs) achieve performance parities with internal combustion vehicles, opportunities have emerged for the U.S. Department of Defense (DOD) to leverage EVs as dual-purpose assets providing fleet transportation and powering RCs or other critical facilities during electrical blackouts. The use of this technology can improve resilience and generate positive cash flow through demand response program participation. This report assesses the feasibility of EVs as mobile power (EV-AMP) at Texas Army National Guard (TXARNG) facilities to improve reliable functionality of critical loads at a lower cost than comparable options such as stationary storage and emergency diesel generation.

## 1.1 Objective Functions

The objectives of bidirectional chargers are twofold (Table 1). Primarily, the chargers are meant to provide backup power to facilities such as RCs that would not otherwise be able to operate during a grid blackout. Secondarily, the chargers can provide power at a lower cost than other options like emergency diesel generators and battery energy storage systems (BESS). To meet the first objective, bidirectional chargers must be capable of providing sufficient power to meet the building critical loads, bidirectional EVs must be available with sufficient energy storage, and the charging systems must be reliable. To meet the second objective, these systems must generate cost savings through a combination of lower installation costs and/or operational cost savings, including participation in utility incentive programs such as demand response or time-of-use rates.

**Table 1. Control Objectives and Requirements**

| | | |
|---|---|---|
| **Control Objectives** | • Backup power to RC critical loads during grid blackout | • Cost savings compared to conventional alternatives |
| **Requirements** | • Chargers with sufficient power<br>• EVs with sufficient energy<br>• Reliable functionality | • Affordable installation<br>• Generate operational cost savings |

## 1.2 Cybersecurity

To ensure that EV-AMP coordinates with other loads in a secure manner, the team identified the major considerations of DOD’s Risk Management Framework (RMF) process as outlined in DODI 8510.01 specific to EVs, EV charging stations, and any associated control networks that would enable EV-AMP implementation in the future. This involved close coordination with the U.S. Army National Guard’s cybersecurity team to outline the required inputs, roles, and responsibilities during the RMF approval process of control networks specific to EV charging systems for fleets.

# 2 Data Collection

To ascertain the system requirements and availability of backup power generation for EV-AMP, the authors collected data directly from TXARNG facilities used for National Guard operations and existing vehicles. TXARNG, the National Renewable Energy Laboratory (NREL), and Arcos Mobility compared the building power requirements and vehicle travel patterns to determine the extent to which EVs operating the same routes as existing National Guard gasoline vehicles could arrive at National Guard facilities and power critical loads during electricity blackouts.

## 2.1 Building Selection

The authors selected facilities based on their criticality to TXARNG emergency operations, their proximity to one another, and the feasibility of powering their loads with 10 or fewer EVs. TXARNG identified five key bases in the Austin, Texas, area: Camp Mabry, Camp Swift, San Marcos, Bee Caves, and a TXARNG enclave at Austin–Bergstrom International Airport. Initial metering data revealed that the airport load was too large for EVs to support, so the Austin–Bergstrom assessment was excluded from the project. Then, NREL and TXARNG toured several buildings at the other key bases and identified five total buildings at the four remaining bases as having the most important operational roles during emergencies that could coincide with a grid power outage. These buildings were identified via discussions with staff at the bases and ultimately the TXARNG energy program manager's determinations. The following locations were selected:

- Camp Mabry Building 8 (B8) Joint Operations Command (JOC).
- Camp Mabry Building 75 (B75) Sensitive Compartmented Information Facility (SCIF).
- Camp Swift RC.
- Bee Caves Special Operations Detachment – Africa (SOD-A).
- San Marcos RC.

Each of these locations is within a 52-mile drive of one another (Table 2), making it feasible to deploy vehicles from one location to provide power to another location. For example, a 131 kWh F150 Lightning Extended Range parked at San Marcos could arrive at Camp Swift with over 80% state of charge (SOC) (109 kWh) remaining to power the Camp Swift RC.

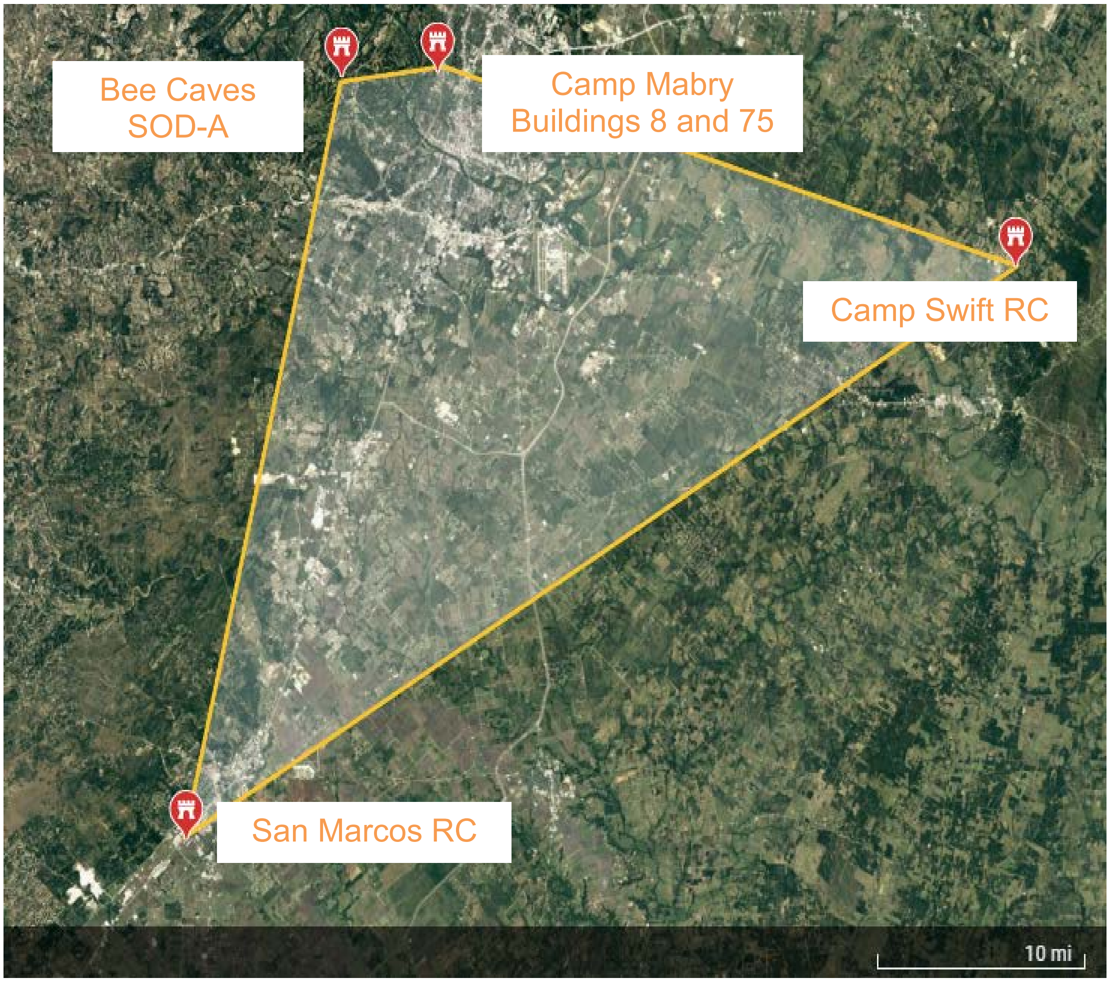

**Figure 1. TXARNG locations assessed in the EV-AMP study.**

Image from Google Maps

**Table 2. Building Assessment Summary Information**

| Campus | Building | Critical Load Description | Square Footage | Distance to Farthest Location |
|---|---|---|---|---|
| Camp Mabry | B8 | All JOC loads | 144,458 | 38 miles to San Marcos |
| Camp Mabry | B75 | All SCIF loads | 88,805 | 37.6 miles to San Marcos |
| Camp Swift | RC | Lighting, ventilation, and telecom | 25,454 | 52 miles to San Marcos |
| Bee Caves | SOD-A | Lighting, ventilation, and telecom | 19,897 | 35.6 miles to San Marcos |
| San Marcos | RC | Lighting, ventilation, and telecom | 10,776 | 52 miles to Camp Swift |

## 2.2 Targeted Loads for Metering

Based on assessments completed by TXARNG, NREL, and Arcos Mobility, Arcos installed meters to monitor critical loads at each of the facilities shown in Figure 1. The facilities selected for the study represent a diverse mix of building use types, layouts and ages. The building types included very large buildings with several stories and mixed uses (Camp Mabry B8 and B75) and smaller, dedicated RCs (San Marcos and Camp Swift). One site (Bee Caves SOD-A had a solar array on the roof. Buildings were of different electrical capacities and ages of construction.

The sites were assessed to determine critical loads associated with communication systems, lighting, and ventilation that would allow staff to continue operational and logistics support during an outage. These loads were specified, and electricity monitoring was deployed to measure the consumption for purposes of defining a specific energy demand for analysis of capabilities for meeting this specific electrical need with bidirectional EV charging infrastructure and associated fleet EVs.

The sites were monitored with equipment that allowed a distinct and separate communication connectivity solution through a dedicated cellular signal separate from the on-site network. This provided resilience in case of a network outage, as well as a secure and independent network solution. The modem with the ethernet connection was located in the metering enclosure. There was no connection to the actual building.

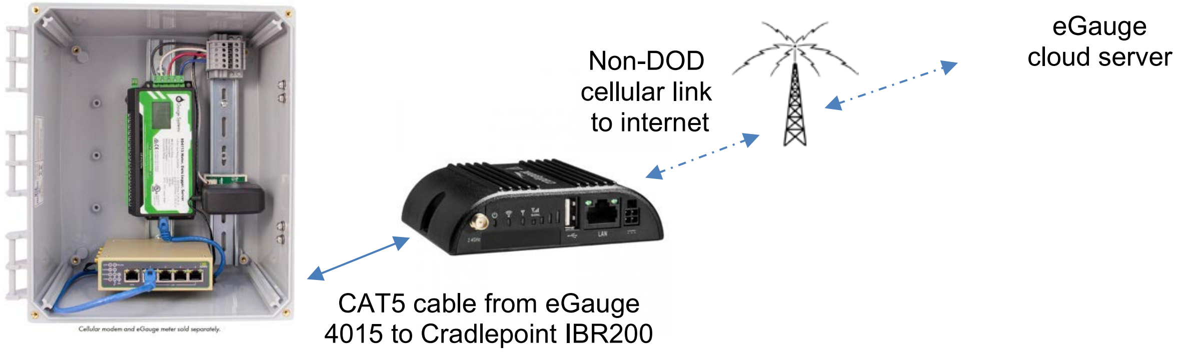

**Figure 2. Communication systems schematic**

Design criteria required specifying equipment that had functionality for different voltages and amp capacity. The metering equipment that was installed is listed in Appendix A.

### 2.2.1 Camp Mabry B8 JOC

The JOC circuit breaker is sized to protect 400 A at 480 V. While this load may exceed the capacity of bidirectional chargers, the NREL and Arcos team would like to understand the capacity requirements and suitability of bidirectional EVs as a backup source of power alone, or in conjunction with other power sources. There is a 150-kW solar array carport connected to the B8 infrastructure through a separate meter. The primary building meter was not functioning at the time of the visit, but the main disconnect was 2,000 kVA. Arcos installed a meter in the subpanel of the electrical room downstream from the main breaker. Figure 3 shows the location of the meter on an aerial image, and Figure 4 is a picture of the metering equipment. This location captures 100% of communication equipment, outlets, lighting, and ventilation electrical loads for the JOC facility.

**Figure 3. Camp Mabry B8 meter location.**

Image from Google Maps

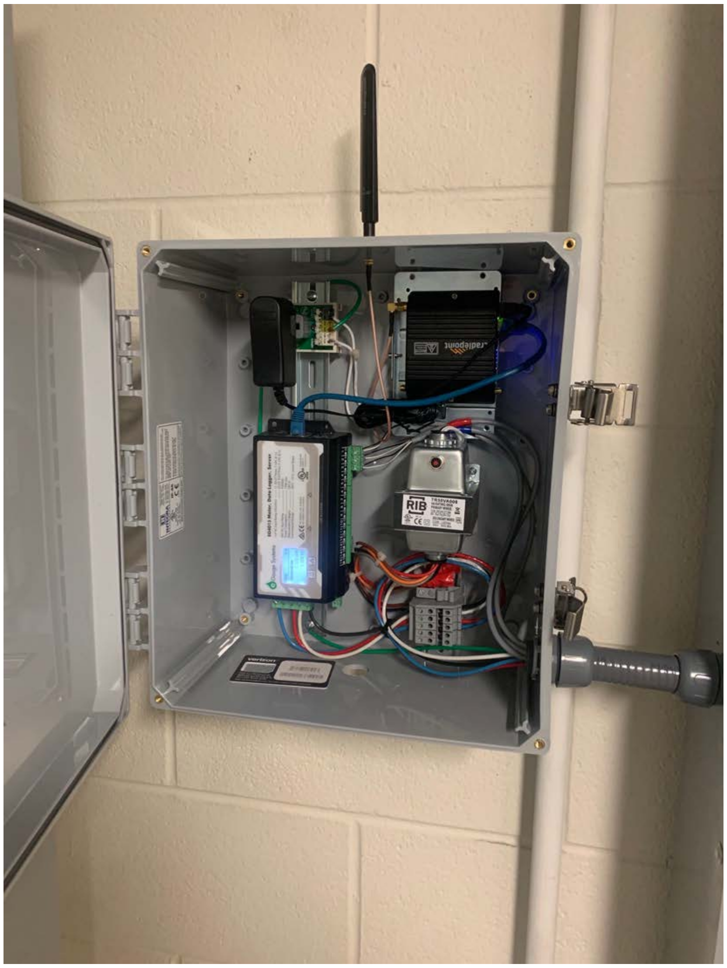

Figure 4. Metering system installed at B8 JOC at Camp Mabry

### 2.2.2 Camp Mabry B75 SCIF

At 88,805 square feet, B75 is too large to be supported by one or two bidirectional chargers connected to light-duty vehicles. However, the SCIF has a 208-Y/120-V, 400-A dedicated main distribution panel connected to at least two other panels, as shown in Figure 5, and a 30-kW backup diesel generator. The electrician on staff noted that the 30-kW diesel generator was not sufficient for the existing SCIF load. NREL, TXARNG, and Arcos decided to meter the main power feed in the SCIF main distribution panel shown on the left in Figure 5. The router was installed at least 15 feet away from the SCIF wall in accordance with a TXARNG requirement.

Based on a site assessment and discussions with former staff who completed construction activities on the facility, Arcos determined the most suitable electrical circuit for monitoring was at the primary main distribution panel located immediately downstream from the service transformer. The installation of this metering required the entire building to be shut down for a period of roughly 4 hours. This circuit captures 100% of the electrical loads to operate the SCIF including servers, outlets, lighting, and heating, ventilating, and air conditioning (HVAC). The location is shown with the orange meter icon in Figure 6.

**Figure 5. Camp Mabry SCIF dedicated service panels**

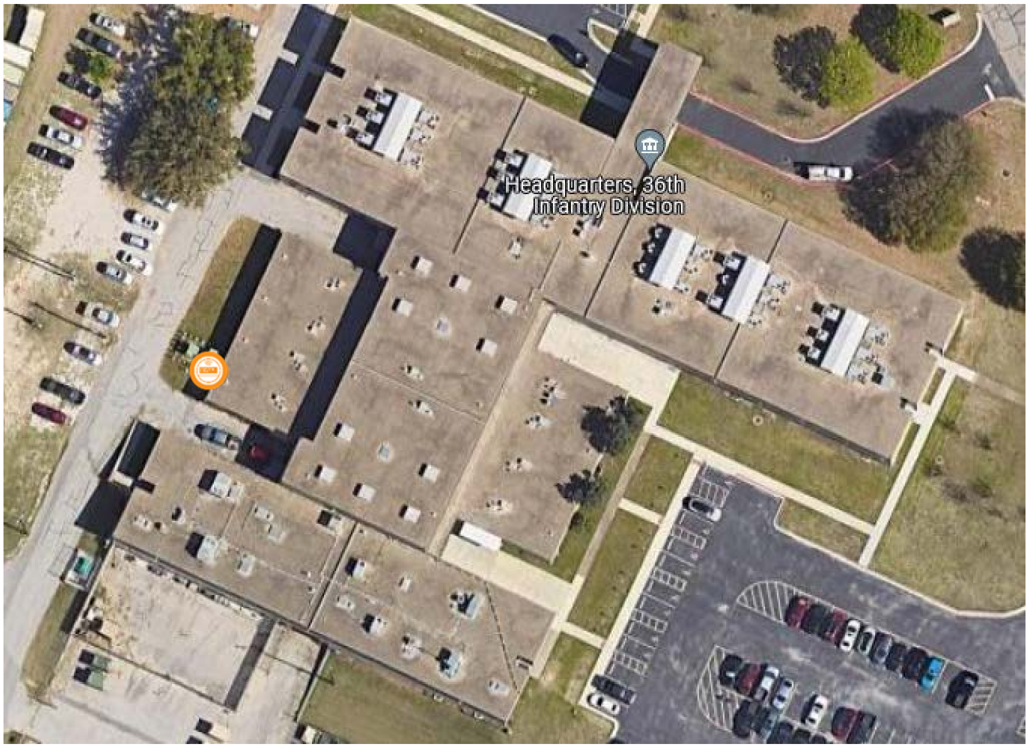

**Figure 6. Camp Mabry B75 meter location.**

Image from Google Maps

### 2.2.3 Camp Swift RC Building and Individual Critical Loads

The Camp Swift RC was renovated during this project. An existing 300-kVA transformer serves the RC, and the planned load was 155 kVA (Table 3). Arcos metered the main power feed and the critical loads at the RC: the telecommunications room panelboard, lighting throughout the building, and ventilation. These loads were isolated on panels HP1 and LPTR. This involved metering the main breaker on the MDP, as well as the main breaker on HP1 and main breaker on LPTR. The electrical equipment was not yet installed at the time of the visit, but the information in Table 3 was gathered from the site construction plans. MDP, HP1, and LPTR should all be connected to individual meters. The location is shown with the orange meter icon in Figure 8.

**Table 3. Camp Swift RC Electrical Load Plan Summary**

| Panel Name | PLAN Connected Load (kVA) | CURRENT Protection (A) | Voltage | Primary Function | Secondary Functions |
|---|---|---|---|---|---|
| **MDP** | **155** | **400** | **480** | **Building power** | |
| **HP1** | **37** | **100** | **480** | **Lighting** | **Ventilation (exhaust and circulation)** |
| LPM1 | 50 | 225 | 208 | HVAC | Water heater, elevator |
| LPM2 | 20 | 100 | 208 | HVAC | Air handling units, heaters, water coolers, condenser units |
| LPA1 | 37 | 225 | 208 | Receptacles | Break room, microwave, refrigerator |
| LPA2 | 15 | 100 | 208 | Receptacles | |
| **LPTR** | **19** | **100** | **208** | **Telecom** | **Receptacles, condenser units, air handling units** |

**Figure 7. Camp Swift RC with metering installed**

**Figure 8. Camp Swift RC meter location.**

Image from Google Maps

### 2.2.4 Bee Caves SOD-A Headquarters

Power enters SOD-A through a 240-V/416-Y, 200-A blue service panel, and then routes to the HVAC system, hot water pump, and the transformer feeding the 208-Y/120-V gray panel. The gray service panel is connected to a 30-A disconnect switch and to an approximately 20-kW solar array on the roof through a three-phase, 80-A circuit breaker. Neither service panel has a dedicated main breaker. Arcos metered power entering the gray panel, as well as the solar array (Figure 9). The location is shown with the orange meter icon in Figure 11.

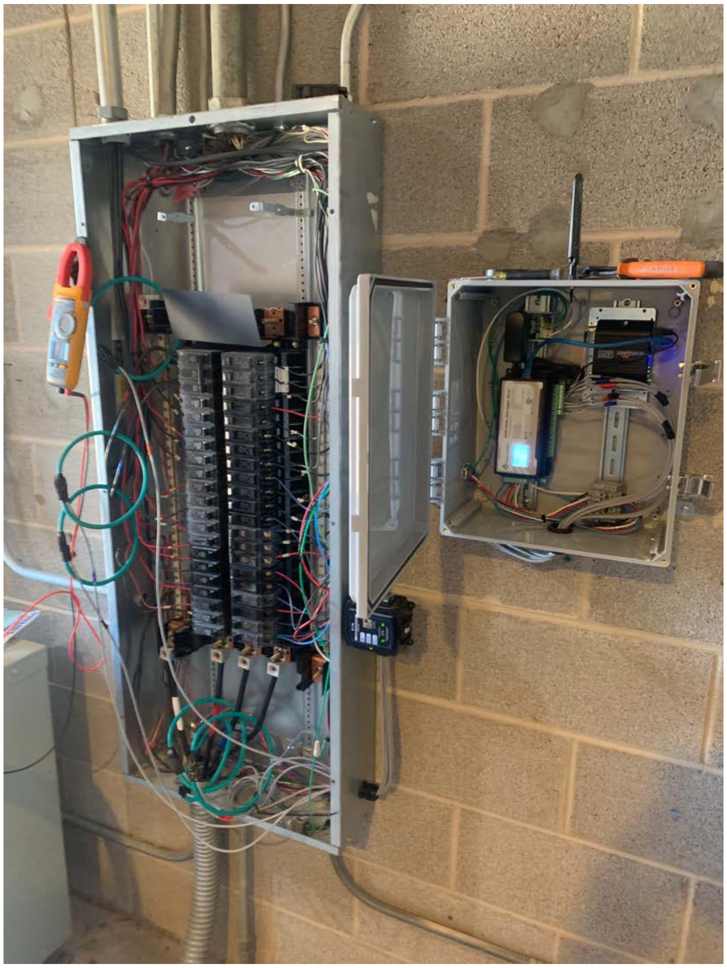

Figure 9. SOD-A electrical room with metering installed

**Figure 10. SOD-A 240-V/416-Y blue service panel**

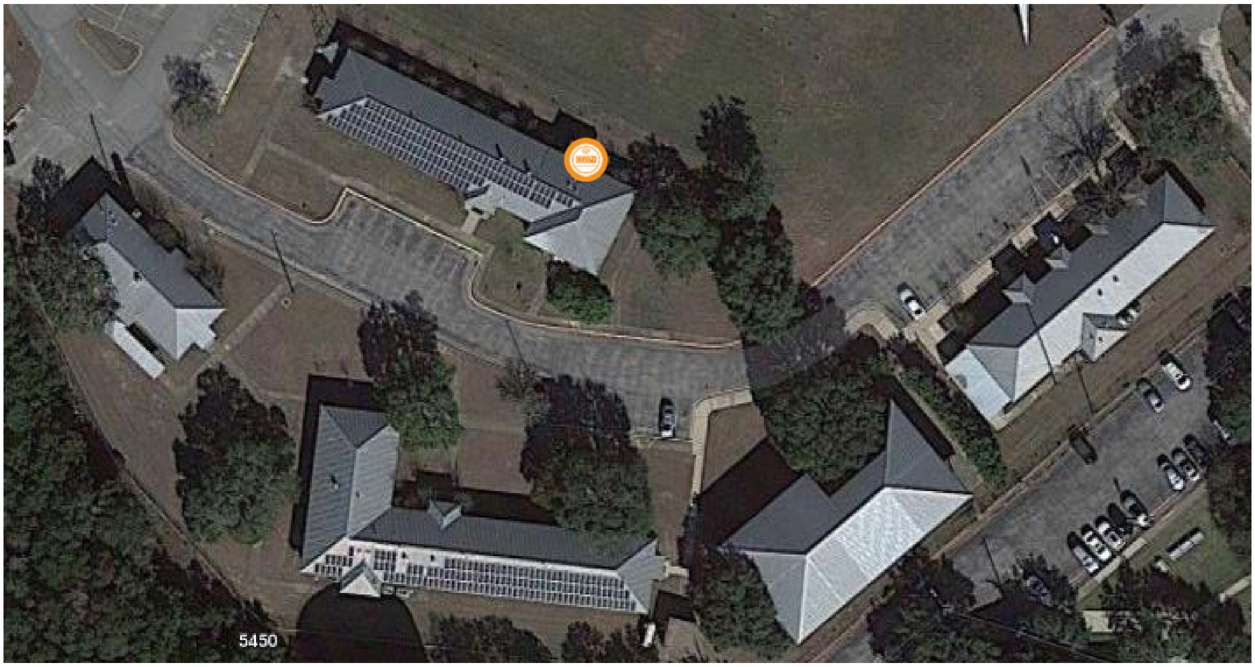

**Figure 11. Bee Caves SOD-A meter location.**

Image from Google Maps

### 2.2.5 San Marcos RC Building

Based on its representational size as an RC (10,776 ft$^2$), NREL and Arcos decided to meter the main breakers in the San Marcos MDP, EMLB, and LA. The EMLB panel is in IT Room 112, while all of the other panels are located in the drill hall. The service panel schedules are summarized in Table 4, and the electrical equipment inside the RC is shown in Figure 12. The location is shown with the orange meter icon in Figure 13.

**Table 4. San Marcos RC Electrical Load Plan Summary**

| Panel Name | Plan Connected Load (kVA) | Current Protection (A) | Voltage | Primary Function | Secondary Functions |
|---|---|---|---|---|---|
| **MDP** | **91** | **400** | **480** | **Building power** | |
| HA | 11 | 100 | 480 | Big Ass Fan | Surge protection devices, small heat recovery unit, exhaust fans |
| EMHA | 51 | 125 | 480 | Large heat recovery unit | EMLA transformer |
| EMLA | 27 | 125 | 208 | Break room | Lighting loads, air handling units, EMLB |
| **EMLB** | **6** | **60** | **208** | **IT equipment** | **IT room receptacles** |
| **LA** | **29** | **125** | **208** | **Receptacles** | **Bathrooms, lights, TV, projector, heat trace** |

**Figure 12. San Marcos RC service panels with metering installed at center (right to left: MDP, HA, EMHA, EMLA, LA).**

Note: Panel EMLB is located in IT Room 112

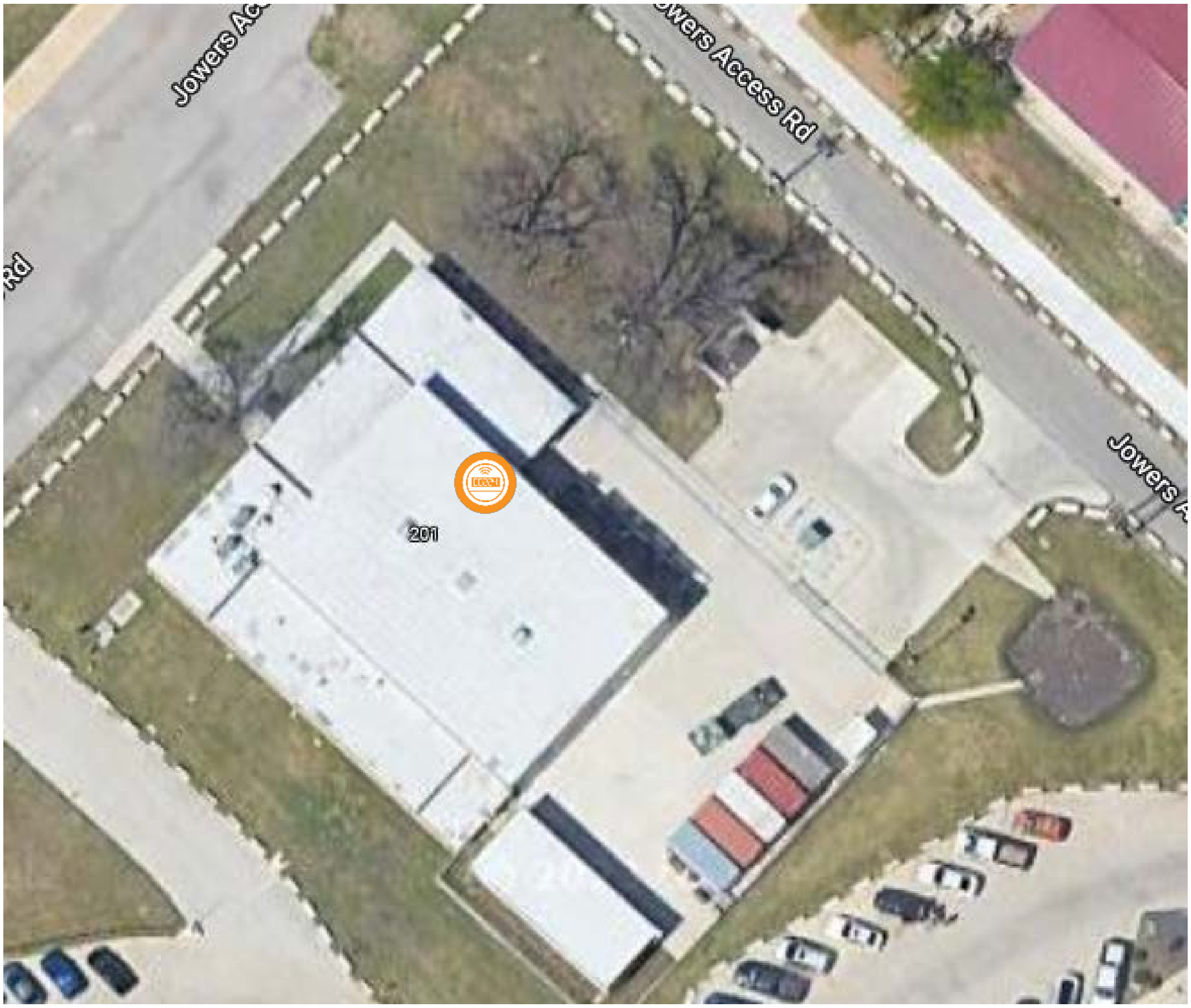

**Figure 13. San Marcos RC meter location.**

Image from Google Maps

## 2.3 Vehicle Screening in FleetDASH

NREL reviewed General Services Administration (GSA) leased vehicle data available in the FleetDASH database[1] and identified 115 Army National Guard vehicles with garage ZIP codes in the vicinity of Camp Mabry, San Marcos, Camp Swift, or Bee Caves.

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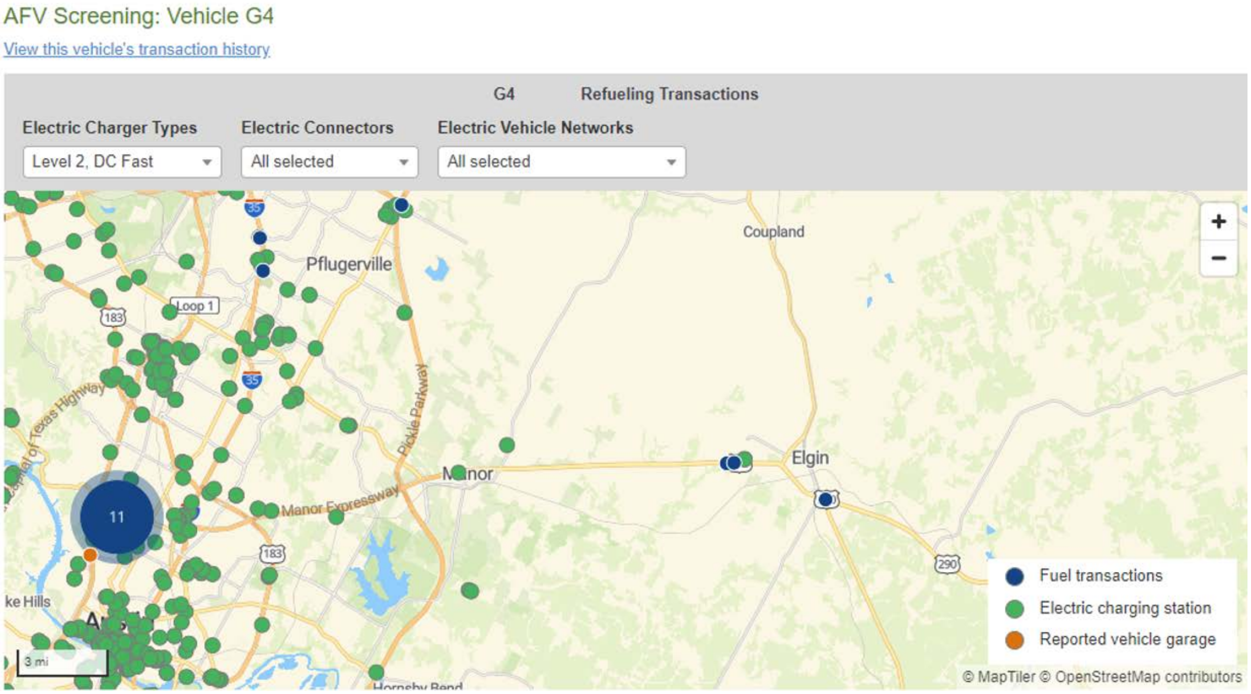
[11] "The Fleet Sustainability Dashboard, or FleetDASH [https://federalfleets.energy.gov/FleetDASH/], measures compliance with the EPAct 2005 Section 701 requirement to use alternative fuel in dual fueled vehicles, and it tracks participating Federal agencies' fleet fuel consumption, greenhouse gas emissions, and vehicle inventories throughout the year." (DOE 2024).



AFV Screening: Vehicle G4

View this vehicle's transaction history

G4 Refueling Transactions

Electric Charger Types: Level 2, DC Fast

Electric Connectors: All selected

Electric Vehicle Networks: All selected

● Fuel transactions

● Electric charging station

● Reported vehicle garage

**Figure 14. FleetDASH screenshot of TXARNG vehicle fuel transactions, garage location, and nearby public EV charging stations**

TXARNG requested access to data for those 115 vehicles. However, they were only granted permission to install telematics and transmit data on 46 of those vehicles. At the same time, the Army G9 embarked on an effort to install or activate existing telematics devices throughout the Army, including TXARNG. This led to the activation of 77 additional vehicles in the TXARNG fleet for a total of 123 vehicles that NREL could analyze.

## 2.4 Vehicle Telematics Trip Data

NREL worked with the telematics provider (Geotab) to develop a report of vehicle stops including prior trip distance, stop location latitude and longitude, and stop begin and end times. The 123 vehicles tracked completed 49,246 trips from Oct. 2, 2023, through March 30, 2024. Of the 123 vehicles, 43 park at least occasionally in proximity to Camp Mabry, San Marcos, Camp Swift, or Bee Caves.

**Table 5. Example Telematics Vehicle Stop Records**

| VIN | Make and Model | Prior Trip Distance (mi) | Stop Latitude | Stop Longitude | Stop Time Begin | Stop Time End |
|---|---|---|---|---|---|---|
| 1C6XXXXXXXXXXX58 | Ram 1500 | 88.3 | 30.XXXXXX | −97.XXXXXXX | 2023-10-10 11:32:30 | 2023-10-10 11:37:45 |
| 1C6XXXXXXXXXXX58 | Ram 1500 | 0.722 | 30.XXXXXX | −97.XXXXXXX | 2023-10-10 11:42:12 | 2023-10-10 14:40:00 |
| 1C6XXXXXXXXXXX58 | Ram 1500 | 10.2 | 30.XXXXXX | −97.XXXXXXX | 2023-10-10 15:08:32 | 2023-10-10 15:11:39 |

## 2.5 Vehicle Travel Patterns

NREL analyzed the travel patterns of the current vehicle fleet to determine the implications of replacing current fleet vehicles with battery-electric vehicles and installing charging infrastructure at primary parking locations. The initial investigation identified clusters of the current vehicle stop locations that aligned with project National Guard location parking lots.

Figure 15. Bee Caves SOD-A vehicle stop cluster

Once vehicle clusters were identified for the National Guard locations, the battery-electric vehicle impacts analysis detailed in this report focused on the 43 vehicles that regularly parked at the project sites or the site campuses (e.g., other parking locations at Camp Mabry).

# 3 Bidirectional Chargers

The authors assessed the current market options for bidirectional charging systems, considering their features, compatibility, and potential advantages for the EV-AMP project. The bidirectional charging market presents a variety of options from different manufacturers, each offering unique features and capabilities at different price points. Overall, the market is in an early stage, with innovations being made frequently and new products entering the market. Many electric vehicle supply equipment (EVSE) manufacturers either announced EV chargers with bidirectional capabilities recently or plan to release them in 2025. Aside from the technological capabilities, manufacturers must tackle many hurdles from grid compliance to changing regulations. This stems largely from the difficulty of creating vehicle-to-grid (V2G) standards, which must consider power, safety, electrical, and communication requirements.

There are multiple applications of bidirectional chargers. V2G chargers allow EVs to feed energy back into the grid during times of high electricity demand. Consumers can purchase energy at a low cost (i.e., overnight) and then sell it back to the grid at a higher rate, offering benefits for both the utility managing the grid and the consumer; V2G also enables participation in ancillary services markets such as frequency regulation. Vehicle-to-building (V2B) applications allow EVs to charge and discharge power to homes and other buildings in times of need. EVs can then be used as an off-grid battery providing supplementary power during power outages. This technology typically requires an offboard grid-forming inverter and dark-start battery to power the system during a blackout.

## 3.1 Market Options

There are several bidirectional-capable chargers that are either readily available or soon to be released. Table 6 summarizes the bidirectional EV charger market. N/A indicates not applicable or information that was not found.

- Sunrun offers the Ford Charge Station Pro with home integration, dark-start capability, and a battery-integration solution. This system is designed specifically for residential use but could be installed as a single charger in a fleet application (Sunrun 2024).
- General Motors (GM) is following a similar approach with the GM Energy PowerShift Charger that is capable of dark-start, designed for residential applications that could be used as a single charger in a fleet application.
- Fermata Energy's FE-20 units are operational in the field but lack off-grid capabilities, although the company suggests the possibility of dark-start functionality and API support for software integration in the future (Fermata Energy 2024).
- IoTecha provides bidirectional support with its controller and DC fast charging internal hardware, adhering to UL 1741-SA standards. The company was awarded through the California Energy Commission Redwood project, emphasizing true bidirectional support through its control signal.
- Nuvve focuses on load management and grid services by creating partnerships to provide solutions for EV-to-EVSE communication. These market options showcase the diverse landscape of bidirectional charging technology, offering potential solutions for the EV-AMP project's objectives.

- BorgWarner’s offerings include 60-kW and 120-kW DC fast charging units, with more than 100 operational units worldwide (BorgWarner 2024). These units operate within a voltage range of 270 to 800 V and are currently in development with additional features such as a dark-start add-on for grid-forming solutions and dual-cord DC fast chargers with V2G capability. Units have successfully been utilized for utility services at the Montgomery County school district in Maryland utilizing electric school buses.
- Wallbox is introducing the Quasar 2, a low-cost DC charger with a CCS connector at 11 kW, set to be released in the third quarter of 2024. While the unit is UL listed, its availability may affect project timelines (Wallbox 2024).
- Heliox is still in the development phase, planning a release of a V2G Combined Charging System (CCS) product in the first or second quarter of 2025, aiming for a demand response project.
- Enphase’s bidirectional charger was not yet available in the market at the time of writing, but it will work similarly to SolarEdge’s system.
- Some other recent announcements of bidirectional chargers include the Powershare from Tesla that will work directly with Tesla’s Powerwall and Cybertruck.
- SolarEdge’s DC-coupled EV charger is not yet available but will connect with solar PV to offer off-grid capabilities.

**Table 6. Bidirectional EV Charger Market**

| Manufacturer | Charger | Amps | Max Charging Output (kW) | Discharge Output (kW) | Status | Price/ Port | Plug | Dark-Start Capable | Offboard Equipment | Equipment Cost |
|---|---|---|---|---|---|---|---|---|---|---|
| Nuvve | PowerPort | 80 | 19.2 | N/A | Available | $3,350 | SAE J1772 | No | N/A | N/A |
| Ford and Sunrun | Ford Charging Station Pro | 80 | 19.2 | 11.5 | Available | $1,310 | CCS1 | Yes | Yes | $3,895 |
| GM | GM Energy PowerShift Charger | 80 | 19.2 | 11.5 | Available | $1,799 | CCS1 | Yes | Yes | $5,500 |
| BorgWarner | RES-DCVC125-480-V2G | 200 | 125 | N/A | Available | $25,000 | CCS1 | No | N/A | N/A |
| Fermata | FE-20 | 56 | 20 | 20 | Available | $1,150 | CHAdeMO | No | N/A | N/A |
| Wallbox | Quasar 2 | 48 | 11.5 | 7.4 | Unknown | $7,500 | CCS1 | No | N/A | N/A |
| Delta | V2H11A-22 | 56 | 22 | 22 | Not available | N/A | CCS1 | No | N/A | N/A |
| Enphase | Bidirectional charger | N/A | 5 | N/A | Not available | N/A | CCS1 | No | Yes | N/A |
| Tesla | Powershare | 80 | 9.6 | 9.6 | Available | $2,500 | NACS | Yes | Yes | N/A |
| SolarEdge | DC-coupled EV charger | N/A | 12 | N/A | Not available | N/A | CCS1 | Yes | Yes | N/A |

A further consideration for the project is the software capabilities to support the EV-AMP project outcomes. Software capabilities to support the ability of users to receive alerts on projected grid outages or weather-related impacts, status of vehicle charge levels, and other actionable information will be critical. The integration with a third-party software vendor is one potential avenue. Key software solutions provided by IoTecha, Synop, and Highland Electric Fleets are viable options in managing the user charging experience.

## 3.2 Most Suitable Market Options for EV-AMP at TXARNG

In evaluating the most robust and widely used bidirectional charging systems, we narrowed our selection to the Ford Charge Station Pro and the GM Energy PowerShift Charger for the following reasons:

- The Ford and GM systems are currently available in the market,
- They offer dark-start capability,
- The units pair EVSE with small backup batteries,
- They integrate with the original equipment manufacturer’s pickup truck offerings,
- They integrate with solar PV arrays,
- They have been proven in field deployments, and
- The vehicle manufacturer systems are partnering directly with charging component manufacturers to ensure vehicle-to-charging communication is robust and reliable.

Therefore, TXARNG, NREL, and Arcos believe that these two are the most applicable to the facilities being evaluated within the Army National Guard. However, the systems were designed for residential applications with a single vehicle and critical loads within a single home. The authors have spoken with Ford and GM about scaling their products to critical National Guard building loads involving cycling multiple vehicles on a single charger during a grid blackout and deemed the application feasible with support from the original equipment manufacturers.

Table 7 outlines a more in-depth comparison between the two. Both systems are notable for their extensive deployment and proven reliability in the EV market. They support high amperage (80 A) and voltage (240 V), providing maximum charging power of 19.2 kW and maximum discharging power of 11.5 kW, making them suitable for both residential and fleet applications. A critical feature of these chargers is their dark-start capability, which allows them to operate independently from the grid by utilizing integrated dark-start batteries. This ensures operational readiness during power outages, which is the most important consideration for EV-AMP. The Ford system also offers offboard energy storage with LG Chem batteries with capacities of 10/17 kWh, while the GM system offers stackable battery options of 10.6 or 17.7 kWh, up to 35.4 kWh. They also incorporate microgrid interconnect devices, transfer switches, and backup subpanels, which facilitate seamless integration into existing infrastructure and enhance energy resilience.

Compatibility with a broad range of vehicles further enhances the utility of these systems. The Ford Charge Station Pro supports the Ford F-150 Lightning, which has a substantial battery capacity of 131 kWh. GM’s charger is compatible with several upcoming EV models, including the 2024 Silverado EV RST and future versions of the Blazer, Equinox, and Sierra EV Denali, with battery capacities of 85–212 kWh. The broad compatibility offered by GM gives it a significant edge and ensures that fleet operators can utilize diverse vehicle models within the same charging infrastructure. In terms of cost, the Ford Charge Station Pro offers a lower upfront cost ($1,310 compared to GM’s $1,699) and a more economical overall offboard equipment cost ($3,895 versus $5,500 for GM). Section 5.5 provides estimates for installing the units.

**Table 7. Ford Charger Station Pro vs. GM Energy PowerShift Charger**

| Parameter | Ford Charge Station Pro | GM Energy PowerShift Charger |
|---|---|---|
| Amperage | 80 | 80 |
| Voltage | 240 V | 240 V |
| Max charging speed (kW) | 19.2 | 19.2 |
| Cord length (ft) | 25 | 25 |
| EVSE price | $1,310 | $1,699 |
| Inverter | Delta BDI inverter | GM inverter |
| Discharge Output (kW) | 11.5 | 11.5 |
| Dark-start battery | Delta dark-start battery | GM dark-start battery |
| Dark-start battery nominal voltage (V) | 240 | 240 |
| Microgrid interconnect device | Yes | Yes |
| Inputs | Solar (14 kW) + energy storage system | Yes, unknown |
| Transfer switch | Yes | Yes |
| Backup subpanel | Yes | Yes |
| Vehicle compatibility | Ford F-150 Lightning Pro | 2024 Silverado EV RST<br>2024 Sierra EV Denali [a]<br>2024 Chevrolet Blazer EV [b]<br>2024 Chevrolet Equinox EV [b]<br>2024 Cadillac LYRIQ [b] |
| Vehicle battery size (kWh) | Lightning (131 kWh) | Silverado (200/212 kWh); GM Defense has an electrified platform (Infantry Squad Vehicle) |
| Battery size | LG Chem (10/17 kWh) | 10.6 or 17.7 kWh stackable, up to 35.4 kWh |
| Standard offboard equipment price | $3,895 | $5,500 |

[a] Model coming soon

[b] Vehicle software update required

## 3.3 V2X Case Studies

Several vehicle-to-everything (V2X) case studies demonstrate the practical applications of bidirectional charging technology. BorgWarner partnered with Highland Electric Fleets to discharge >10 MWh to the Massachusetts grid over 158 hours and in doing so accumulated an estimated revenue of $23,500 (BorgWarner 2023). V2G applications such as this one can reduce the life cycle costs of an electric school bus by up to $13,000. The technical specifications of the chargers used are included in Table 7.

Dominion Energy has been promoting electric school bus adoption through its Electric School Bus Infrastructure Program that took advantage of the U.S. Environmental Protection Agency's

Clean School Bus Rebate funding in 2022 (U.S. Environmental Protection Agency 2024). Dominion offers continued support to Virginia schools by providing fast charging (which also helps the schools receive funding), utility coordination (including grid upgrades), construction, and charger installation. Dominion covered the costs for the chargers for 15 years and 50% of the cost of the battery warranty. As of 2022, there were a total of 50 electric buses in operation that had been driven more than 300,000 emission-free miles. It was found that 95% of the time, the buses had 3 MWh of available capacity for grid services. The agreement also included a 15-year participation agreement in which Dominion Energy will take over the battery to continually support the grid through fast-response ancillary services, transmission and distribution upgrade deferral, or energy shift services (Dominion Energy 2022). Figure 16 displays a V2G test of one bus discharging at different power levels.

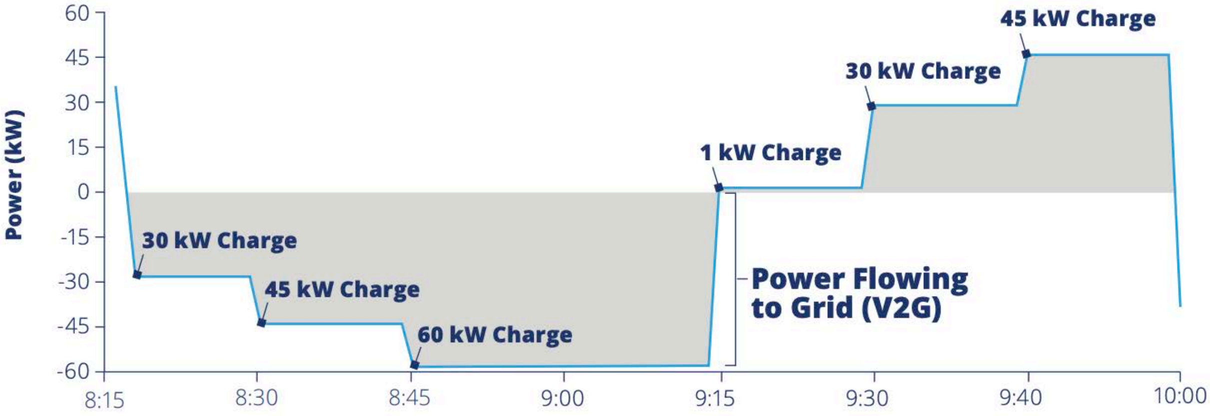


**Figure 16. Dominion's V2G demonstration.**

Source: Blair, Moran, and Fitzgerald 2023

Other examples include North Boulder Recreation Center implementing V2B with a Nissan Leaf and Fermata Energy's FE-15 charger. This system is specifically aimed at reducing peak demand and generates energy cost savings at around $270/month (Fermata Energy 2022). Fermata Energy has also partnered with Revel ride-share in Brooklyn, New York. This project uses multiple Nissan Leafs from Revel's ride-share fleet, which is capable of exporting 45 kW back to the grid during peak demand periods. This project has proved to support the grid by preventing the local utility from blackouts or brownouts, especially during high-demand periods (Shahan 2022).

# 4 Analysis Methodology

## 4.1 Load Analysis

NREL analyzed time-series power load data captured via eGauge meters for the facilities and loads described in Section 2.2. The authors summed the loads from specific circuits to calculate the critical load for each location. They screened the power loads to determine whether 11.5 kW V2B chargers could support building operations around the clock and then assessed the energy requirements to determine whether light-duty electric pickup trucks could feasibly provide backup power for the critical loads.  This led to the authors identifying three locations at which to conduct more detailed analysis: San Marcos RC, Camp Swift RC, and Bee Caves SOD-A. Additional details on the load analysis and results are described in Section 5.1.

## 4.2 Vehicle Energy Use Analysis

The 43 vehicles identified in Section 2 were evaluated to determine which vehicles could be replaced by market-available vehicle options capable of providing backup power through the bidirectional charging infrastructure. The analysis ultimately focused on 21 vehicles that could potentially be replaced by the Chevrolet Silverado, Chevrolet Blazer, or Chevrolet Equinox.

**Table 8. Existing TXARNG Vehicles and Bidirectional Battery-Electric Vehicle Replacements**

| VIN | Existing Vehicle Make and Model | Replacement Vehicle Model | Battery Capacity (kWh) | Efficiency (kWh/mi) | Range (mi) | Onboard Charger Capacity (kW)[b] |
|---|---|---|---|---|---|---|
| 2C4XXXXXXXXXX99 | Chrysler Voyager | Blazer | 102 | 0.315 | 324 | 11.5 |
| 2C4XXXXXXXXXX00 | Chrysler Voyager | Blazer | 102 | 0.315 | 324 | 11.5 |
| 2C4XXXXXXXXXX82 | Chrysler Voyager | Blazer | 102 | 0.315 | 324 | 11.5 |
| 2C4XXXXXXXXXX81 | Dodge Grand Caravan | Blazer | 102 | 0.315 | 324 | 11.5 |
| 2C4XXXXXXXXXX82 | Dodge Grand Caravan | Blazer | 102 | 0.315 | 324 | 11.5 |
| 2C4XXXXXXXXXX47 | Dodge Grand Caravan | Blazer | 102 | 0.315 | 324 | 11.5 |
| 3FAXXXXXXXXXX28 | Ford Fusion | Equinox | 85 | 0.266 | 319 | 11.5 |
| 3FAXXXXXXXXXX16 | Ford Fusion | Equinox | 85 | 0.266 | 319 | 11.5 |
| 5NPXXXXXXXXXX62 | Hyundai Elantra | Equinox | 85 | 0.266 | 319 | 11.5 |
| KMHXXXXXXXXXX34 | Hyundai Ioniq Hybrid | Equinox | 85 | 0.266 | 319 | 11.5 |
| KMHXXXXXXXXXX25 | Hyundai Ioniq Hybrid | Equinox | 85 | 0.266 | 319 | 11.5 |
| 1GCXXXXXXXXXX51 | Chevrolet Silverado | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 1GCXXXXXXXXXX53 | Chevrolet Silverado | Silverado [a] | 200 | 0.509 | 393 | 19.2 |

| VIN | Existing Vehicle Make and Model | Replacement Vehicle Model | Battery Capacity (kWh) | Efficiency (kWh/mi) | Range (mi) | Onboard Charger Capacity (kW)[b] |
|---|---|---|---|---|---|---|
| 1GCXXXXXXXXXX18 | Chevrolet Silverado | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 1GCXXXXXXXXXX81 | Chevrolet Silverado | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 1FTXXXXXXXXXX96 | Ford F-350 | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 1FT8XXXXXXXXX03 | Ford F-350 | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 1N6XXXXXXXXXX18 | Nissan Titan | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 3C6XXXXXXXXXXX66 | Ram 3500 | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 3C6XXXXXXXXXXX58 | Ram 3500 | Silverado [a] | 200 | 0.509 | 393 | 19.2 |
| 3C6XXXXXXXXXXX66 | Ram 3500 | Silverado [a] | 200 | 0.509 | 393 | 19.2 |

[a] TXARNG could replace the pickup trucks with bidirectional F-150s instead of Silverados. However, the authors modeled Silverado replacements due to the larger battery size of the extended-range version (200 kWh instead of 131 kWh for the F-150).

[b] The onboard charger capacity refers to the vehicle's ability to accept AC charge from the EVSE. Charging and discharging capacity is limited in all cases by the EVSE as well the vehicle. The GM Energy V2X charger can charge EVs at the lesser of 19.2 kW or the onboard capacity rating and can discharge EVs at the lesser of 11.5 kW or the onboard capacity rating.

NREL assigned battery-electric vehicle replacement attributes according to Table 8 to model energy consumption and charging effects. Key attributes included the replacement vehicle battery capacity in kilowatt-hours, range in miles, efficiency in kilowatt-hours per mile, and onboard charger capacity for AC charging. The efficiency determination provided a metric to estimate energy consumption given a distance traveled, and the onboard charger capacity provides a limit of the rate of charging given the time and charging infrastructure capacity. The sum of the vehicle battery capacities resulted in 3,037 kWh of maximum energy storage.

## 4.3 Vehicle Energy Use Modeling

NREL conducted analysis to determine (1) the energy consumed between vehicle stops based on the distance traveled and the replacement vehicle efficiency and (2) the energy replaced through charging with modeled chargers at parking clusters during vehicle stops. NREL modeled 19.2-kW charging ports—based on the GM PowerShift detailed in Section 3.2—at the project site locations that could potentially support electric power outages. NREL also modeled 7.7-kW unidirectional charging ports at locations where the vehicle regularly parked besides the site locations.

NREL found TXARNG vehicles travel regionally, with some long-distance travel to cities beyond the Austin area. When vehicles travel distances beyond the battery range capacity, or to sites apart from the modeled charging infrastructure, these trips are flagged as midday charge events where a vehicle would need to charge publicly or at a location without modeled infrastructure.

To account for common manufacturer direction to avoid regularly charging a vehicle to 100% SOC, NREL limited charging events to a maximum of 90% SOC. The blue dots in Figure 17 represent the available battery energy in kWh at the beginning of each stop event for the given vehicle. NREL did not model steady SOC change between stop events; rather, the line is provided to support visualizing the order of stop events. The authors assumed that EVs would only be charged midday if they were approaching 0% SOC, although they are likely times that EV drivers will choose to charge midday to avoid approaching 0% SOC.

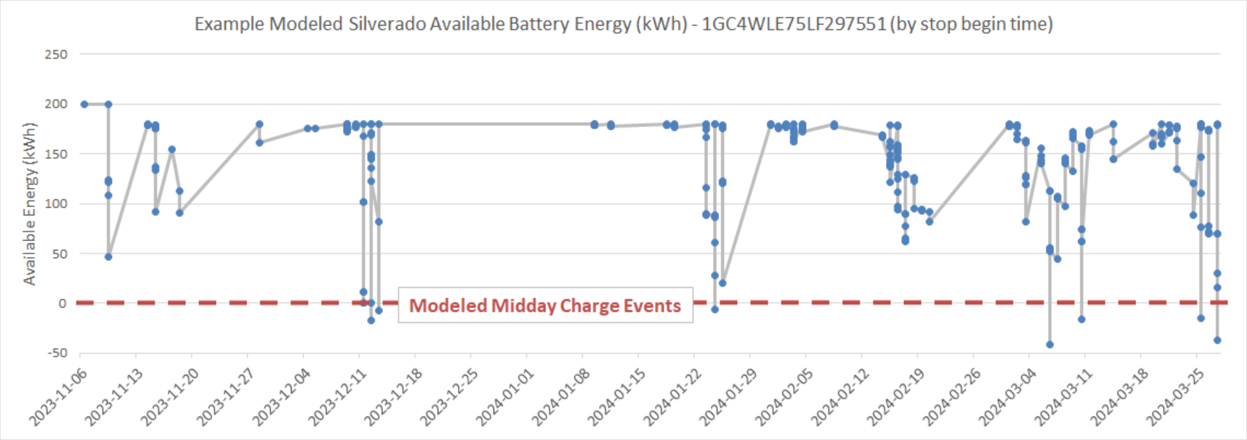


**Figure 17. Example vehicle modeled available battery energy**

## 4.4 Charger Cost Estimates

The authors estimated costs to install bidirectional chargers using NREL's EVI-LOCATE tool (Hodge and Desai 2024)( evi-locate.nrel.gov/). The designs of the installations are documented in Section 7.1. The assumptions for project costs are documented in Hodge, Desai, and Boyce (2022). The costs of GM charging stations are in Table 18. The component-level costs are sourced from GSA, RSMeans, and industry experts (GSA 2024; Gordian 2024). The cost adjustment factors were developed by the U.S. Army Corps of Engineers (2023).

## 4.5 System Optimization Model

REopt (reopt.nrel.gov/tool) is a mixed-integer linear program that optimizes behind-the-meter distributed energy resource (DER) system sizes to provide the maximum net present value (NPV) of cost savings through energy bills over the analysis period. It compares different types of DERs, including V2X. REopt is used for this study because it provides a techno-economic and resilience analysis for sites considering adding EVs to their fleets. This section provides details on model inputs, outputs, and capabilities that will be utilized to answer questions raised in this study.

Table 9 lists the key inputs and outputs associated with REopt in the context of this analysis. A site's location is used to determine a site-specific renewable energy resource profile for all time steps, whereas past electric utility bills are used to understand the existing rate structure and identify any gaps in provided data. Next, a site's electricity consumption interval data are fed into the model as the load that must be met as part of the cost minimization. A site's critical loads, which must be met during an outage simulation, can also be fed as an input. Techno-economic parameters constitute the last set of required inputs, which consist of inflation rates, discount rates, capital costs, and incentives, among others. The model takes these inputs and performs an optimization with a minimization sense. The optimization can consider outages of fixed durations if provided as inputs.

Results from the model consist of any identified DER system sizes that may be cost-effective at a site (i.e., provide cost savings over the analysis period). The results also consist of project economics and any relevant dispatch strategies on how to operate identified DERs. Because it is a mathematical model, REopt has perfect foresight as it identifies the exact load to meet at each time step of the year. Additionally, the model assumes 100% availability of any identified DERs when optimizing. The EV battery capacity availability analysis described in Section 4.3 feeds inputs to REopt that account for where vehicles are at any given point in time and when they will return to base. Otherwise, REopt provides a best-case estimate of cost savings from an investment. REopt results are useful in understanding if DERs make sense at a given site, and how they can help the site accomplish its goals. Results from the model are useful in the planning phase of a project and can be used to inform detailed downstream analyses.

**Table 9. REopt Model Inputs and Outputs**

| Inputs | Model | Outputs |
|---|---|---|
| • Site location<br>• Site's electric utility bills<br>• Site's power consumption history<br>• Site's critical loads<br>• Economic parameters such as inflation rate | REopt optimizes the problem to minimize costs, ensuring the site can survive a predetermined outage of fixed duration | • Identified system sizes<br>• How these systems should be used to maximize cost savings<br>• Utility bill savings<br>• Project economics for investment (rate of return, simple payback) |

REopt models EVs as part of the optimization, where EV SOC requirements must be satisfied prior to the EV departure time step. Given the cost minimization approach, the model is not only able to serve EV loads while minimizing utility bills, but it can also consider vehicle-to-load/building dispatch, where the EVs serve site loads when economical. When EVs are considered in the optimization, the outputs include information on how much energy was sought by an EV, and how that demand was met using a combination of grid and other on-site DERs. The model can also optimize the number of EVSE ports needed from a provided set to serve the EV loads.

Additionally, REopt's outage simulator can consider EVs as part of the simulation. The purpose of this simulator is to quantify the resilience provided by a system for outages starting at any point in the year. The simulator provides average hours of outage survived and probability of surviving an outage of given duration as part of the results. If EVs are considered in the optimization, their provided schedules and optimized SOCs can be used in the outage simulator. The simulator can also accommodate any number of EVs that can be called upon to serve a site's critical loads when an outage begins. Resilience and outage simulation related methodologies and assumptions are discussed further on page 26.

## 4.6 Life Cycle Cost and Resilience Assessment

As discussed earlier in this report, the goal of this analysis is to assess the feasibility of EV-AMP at various TXARNG facilities. The analysis results are meant to quantify the increase in resilience at these RCs in case of outages from fleet electrification, potentially also in tandem with on-site solar and stationary battery storage. These results can also quantify cost savings in EV operations via smart charging and/or V2B relative to a baseline scenario with unmanaged charging. Lastly, these results can be used to understand if on-site solar PV and stationary BESS can provide synergistic benefits of cost savings and increased resilience when deployed with fleet electrification at these sites. the business-as-usual (BAU) scenario acts as the baseline model where only cost of serving electricity to serve existing site loads is considered. The unmanaged EV charging scenarios quantify the electricity cost implications of charging EVs at a given site, and how does this new load impact the peak demand and energy consumption at these sites? Under managed[2] or "smart" EV charging, the same questions are asked but EV charging is flexible to identify cost savings in comparison to unmanaged EV scenario. How do the results from EV scenarios change if V2B is enabled to serve peak loads at the RCs? The implications of solar PV and BESS on EV charging are also considered in this analysis. Table 10 details the scenarios being considered for each RC along with the questions that can be answered from the results of that scenario. The resilience implications of EVs are also analyzed in this analysis and related scenarios are explained in detail later in this section. For each site, a site-specific load profile and electric tariff were used, which are further detailed in Appendix C.

**Table 10. Scenarios Considered for Each Building**

| # | Scenario | Consider EVs | Solar PV | Stationary BESS | Smart charging |
|---|---|---|---|---|---|
| 1 | Business-as-usual analysis | | | | |
| 2 | Unmanaged EV charging | X | | | |
| 3 | Unmanaged EV + solar PV + BESS | X | X | X | |
| 4 | Managed EV charging | X | | | X |
| 5 | Managed EV + solar PV + BESS | X | X | X | X |

Table 11, Table 12, and Table 13 detail the techno-economic assumptions fed into REopt for this analysis. This analysis considers net metering (exporting PV power to the grid for revenue/credits) as necessary. Given the focus of this analysis on resilience, only direct ownership of DERs was considered at the RCs. Additionally, like past REopt analyses performed for TXARNG, this analysis continues to use data sources from these prior analyses for techno-economic input parameters used in the optimization. The model was asked to select the least-cost number of EVSE required for each scenario with a maximum 5 EVSE available.

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[2] Managed charging refers to shifting the charging demand of an EV to times with lower cost of electricity. This enables the EV to charge to desired departure SOC while minimizing the associated cost if possible.

**Table 11. Economic Input Parameters**

| Input | Assumption |
|---|---|
| Technologies evaluated | PV, battery storage, EVSE |
| Model objective | Minimize life cycle cost of serving electricity (includes present value of electricity purchased from the grid, as well as cost of purchase, installation, and operations and maintenance for a renewable system) |
| Ownership model | Direct ownership |
| Analysis period | 25 years (standard analysis period and conservative life estimate) |
| Inflation rate (operations and maintenance) | 2.3%/year per Congressional Budget Office (CBO) |
| Discount rate (nominal) | TXARNG: 4.2% per Office of Management and Budget (OMB) |
| Electricity cost escalation rate (nominal) | 1.7%/year for South Central U.S. per EIA Annual Energy Outlook, Table 3 |
| Tax rates | 0% |
| Net metering | Not considered |

**Table 12. PV Input Parameters**

| Input | Assumption |
|---|---|
| System type | Ground-mount PV, fixed, standard module |
| Technology resource | Typical meteorological year weather data from the National Solar Resource Database |
| Inverter efficiency | 96% |
| System losses | 14%, accounts for system losses in addition to charge controller losses that occur due to factors not considered by PVWatts. More information available in REopt manual Section 10.2.3.5. |
| Installed capacity density | 10 DC-watts/ft$^2$ (0.01 kW/ft$^2$); PV capacity that fits in given area |
| Tilt | 20° |
| Azimuth | 180° (south-facing) |
| DC-to-AC size ratio | 1.2 |
| System capital cost | $1,790/kW DC (includes equipment costs and labor costs) |
| Operations and maintenance cost | $18/kW/year per NREL Annual Technology Baseline |
| Incentives under third-party ownership | Not considered due to direct ownership |

**Table 13. BESS Input Parameters**

| Input | Assumption |
|---|---|
| Battery type | Lithium-ion |
| Battery AC-AC round-trip efficiency | 95% internal efficiency loss |
| Minimum SOC | 20% (battery charge is managed to stay above this minimum) |
| Capital costs | $910/kW + $455/kWh based on Wood Mackenzie U.S. Energy Storage Monitor |
| Replacement costs (year 10) | $715/kW + $318/kWh based on Wood Mackenzie U.S. Energy Storage Monitor |
| Allow the utility grid and any on-site PV to charge the battery? | Yes |
| Incentives under third-party ownership | Not considered due to direct ownership |

**Table 14. EVSE Infrastructure Assumptions Considered in REopt**

| Input | Assumption |
|---|---|
| EVSE maximum charge rate | 19.2 kW |
| EVSE maximum discharge rate | 11.5 kW |
| EVSE maximum available count | 5 |
| EVSE and offboard equipment cost | $7,199/EVSE unit |
| EVSE installed costs | Generated by EVI-LOCATE analysis in Section 5.4 |
| Vehicle to building (V2B eligible) | Yes |

**Table 15. EV Assumptions Considered in REopt**

| Input | Assumption |
|---|---|
| EV energy capacity kWh | Silverado: 200 kWh, maximum charge at 19.2 kW<br>Blazer: 102 kWh, maximum charge at 11.5 kW<br>Equinox: 85 kWh, maximum charge at 11.5 kW |
| EV maximum AC c-rate | $\frac{\text{EV maximum AC charge rate [kW]}}{\text{EV energy capacity [kWh]}}$ |
| EV on-site schedule | Derived from modeled EV schedule |
| EV arrival SOCs | Estimated from derived EV schedule |
| EV departure SOCs | Estimated from modeled unmanaged charging load profiles |

Key outputs from REopt scenarios consist of system sizes, economic dispatch plots, the all-inclusive life cycle cost, NPV, simple payback period, internal rate of return, energy/peak demand/emissions changes, and other project economics. Note that REopt optimizations are performed using the time resolution used by utilities to determine peak demand. Therefore, REopt results do not consider the power surges and dips that can happen within a time step. This ensures electric utility bills are accurately calculated, which is essential to how REopt functions. Additionally, REopt as a mathematical model has perfect foresight. Its results are meant to identify the opportunities for DER investment and their project economics to inform downstream detailed analyses.

The resilience scenarios considered in this analysis consider an outage that begins at a predetermined time step. If any EVs are present at the site, they immediately begin supplying power to the critical load at a site. As other EVs arrive, more power reserve builds up, allowing the critical load to be served.

If REopt is being used to model an outage with an ending time step, the EVs will charge after the outage ends and depart the site per the provided schedule. In this case, REopt may choose to oversize on-site solar PV and BESS if the value of lost load is high enough. This sequence of events is visualized in Figure 18.

Alternatively, REopt can be used to model an open-ended outage to quantify the minimum and maximum resilience provided by the model. In this case, once an EV arrives on-site, it remains on-site for the entire duration where critical load can be served. This outage simulation is simply concerned with identifying metrics associated with resilience provided by the EVs being considered. This section explains how resilience simulation was modified from this explanation as per EV-AMP site constraints.

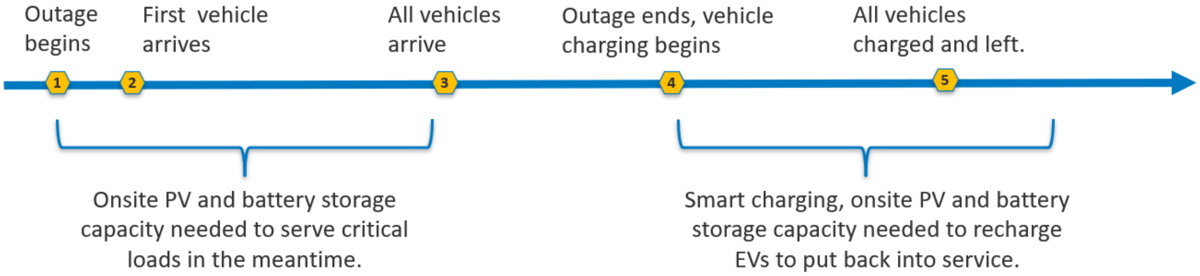

**Figure 18. Sequence of events in modeling a closed outage in REopt**

The presence of EVs on-site provides resilience benefit that can be quantified using the outage simulator built into REopt. This simulator estimates the number of hours (ranging from 0 to 8,760) on-site DERs and EVs can sustain an outage where site critical loads must be served in each time step survived. In response, the simulator outputs valuable metrics such as average hours of outage survived, shortest and longest outage survived, and probability of surviving an outage of various durations. Although these results are useful in understanding the kind of resilience such a system can inject to a site, it is important to keep in mind that these results are a simulation and do not factor in reliability of any technologies. System reliability is considered in Section 6.1.

The outage simulator was used for the Camp Swift RC, Bee Caves SOD-A, and San Marcos RC to determine resilience provided by the batteries built into the EVSE (assuming the batteries in EVSE are purchased at sites irrespective of EV-AMP to establish a BESS-only base case). A comparative BESS and EV case was considered where batteries within EVSE and a varying number of EVs are considered.

Upstream modeling of the entire EV stock estimates total energy available (total EV SOC) in EVs that can offer resilience to the RCs. Mean, minimum and maximum total EV SOC can occur at multiple times in the analysis where each individual EV may have different states of charge and different distances from an RC. Therefore, the EV inputs used for resilience assessment are only a snapshot in time where total EV SOC is important. This analysis assumes that the RCs do not require backup power immediately and that any on-site assets begin supporting the critical loads at the end of an outage's first hour. Therefore, all EVs arriving within an hour are assumed to be present on-site at the end of the first hour, when the simulator begins. Any EV used in comparative EV case resilience assessment was identified as one which could arrive at a RC with positive SOC per upstream EV energy modeling.

The outage simulator is operated at 15-minute time steps since detailed critical load data is available at these sites. All critical load at these sites must be served by on-site technologies and EVs. All three stackable BESS sizes were considered at each RC to understand their impact on resilience. Furthermore, this analysis considered a full efficiency and a reduced efficiency scenario for EVs, with the latter being a sensitivity case representing extreme conditions where vehicles may not perform optimally. Additional assumptions related to the outage simulations are highlighted in Table 16.

**Table 16. Outage Simulator Assumptions**

| Input | Assumption |
|---|---|
| Technologies considered | Stackable BESS built into EVSE<br>Solar PV (23.6 kW) at Bee Caves RC only<br>EVs |
| Total EVSE to load discharge rate | 11.5 kW |
| Critical load profiles | Obtained from site data |
| Stackable BESS parameters | Round-trip efficiency: 89.8%<br>SOC in beginning of outages: 80% |
| EV parameters | Roundtrip efficiency: 89.8%<br>SOC in beginning of outages: determined by detailed EV modeling completed in Section 5.2<br>EV arrival delay: determined by detailed EV modeling completed in Section 5.2 |

Once the outage simulations are completed, results are processed programmatically. The authors determined how many EVs and what stackable BESS size could allow an RC to survive 8-hour, 24-hour, and 72-hour outages with 100% confidence at a chosen point in time for both the BESS-only case and the BESS plus EV case. Additionally, the authors assessed the number of hours each RC can survive with 100% confidence by various quantities of EVs. The difference in number of hours survived between cases is the resilience duration benefit provided by EVs. This benefit is then used to quantify the avoided cost of a stationary BESS system capable of providing equal benefit. It is assumed that the battery must serve the average critical load at the RC for the duration of the resilience benefit identified above. BESS replacement costs are not considered because the analysis also excludes any EV BESS maintenance costs.

Since Bee Caves RC has existing solar PV, the authors estimated the value of stationary BESS differently. The authors assumed that the backup power system would be able to sustain maximum overnight critical energy requirements even after the worst PV production day. Therefore, the maximum energy required at Bee Caves RC between 1600 – 0900 hours was calculated assuming these as the overnight hours without solar PV. The highest net critical energy requirement (after PV served load) was calculated to identify critical load that must be served by BESS on the PV's worst performance day such as when the panels are covered by snow in a winter storm. Both numbers were added to an estimated BESS energy capacity, which was used to estimate the desired capital cost. Similarly, maximum critical energy requirements for 8 hours, 24 hours and 72 hours were calculated, increased to account for worst PV performance and costed to determine cost savings from EV-AMP compared to investment in stationary BESS.

The authors also assessed the point in time when the ten pickup trucks would have arrived at the bases with the lowest total SOC and considered alternative cases based on the EVs driving to base at their rated efficiency and at 50% of their rated efficiency (based on the coldest recorded temperature in Austin).

Lastly, the authors compared the cost of a replacement stationary BESS against EVSE infrastructure investment cost to understand the cost savings of the investment. These processing steps were repeated for the sensitivity scenario as well.

# 5 Results: EV-AMP Feasibility

There were several facets to ensure that EV-AMP is appropriate for TXARNG applications. First, we explored whether the loads we were meeting could feasibly be met by EVs for 24 hours with a single charging port and five or fewer vehicles. Second, we identified whether the TXARNG fleet had enough vehicles operating within approximately 1 driving hour of the TXARNG facilities. Third, we assessed whether additional charging stations would provide a positive NPV for the facilities and whether we should incorporate additional PV and BESS. Fourth, we estimated the costs to install the required charging stations at the TXARNG facilities where EV-AMP was deemed appropriate. Finally, we explored the resilience value of EV-AMP at each of the individual facilities.

## 5.1 EV Power and Energy

### *5.1.1 Camp Mabry B8 JOC*

The Camp Mabry B8 JOC could be segmented from the rest of the power supply to form a critical load circuit. Due to its importance to Army National Guard functions, TXARNG and NREL treated the entirety of the JOC as the critical load at B8. Figure 19 displays the critical load and a 24-hour average of the critical load from August 2023 through April 2024, as well as an excerpt of the highest load week during that time period. The critical building load averaged 12.7 kW during this time period and peaked at 25.9 kW, and the 24-hour critical load average peaked at 22.8 kW.

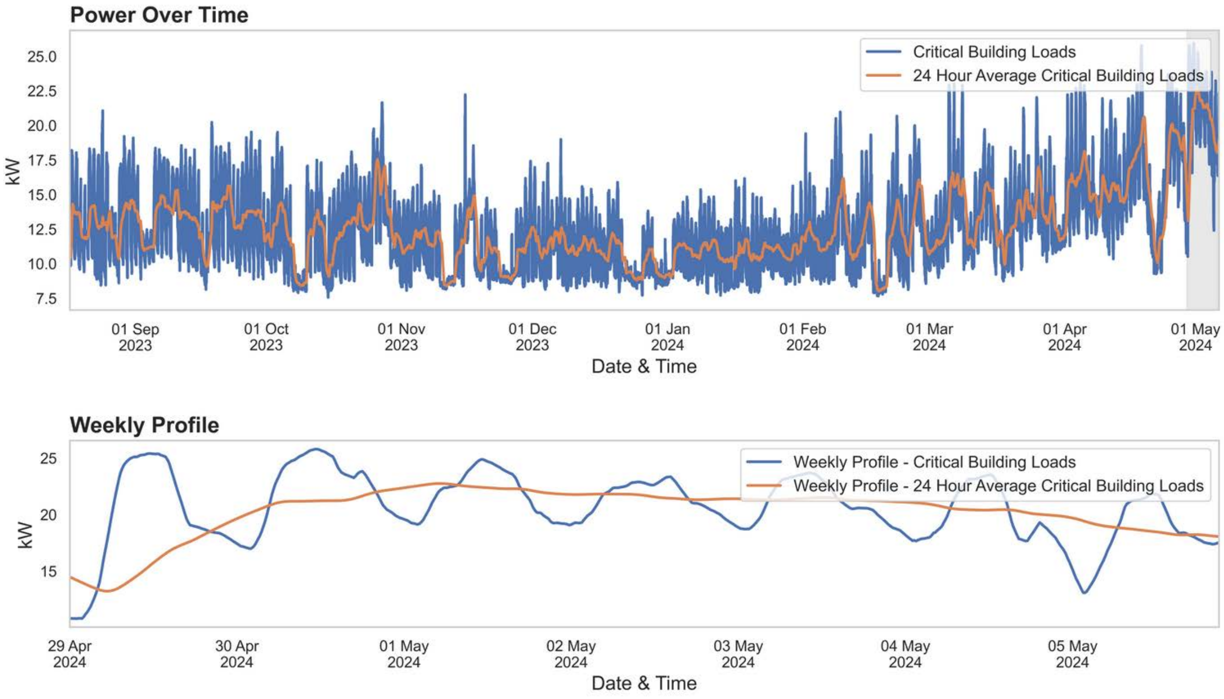

**Figure 19. Camp Mabry B8 JOC power from August 2023 through April 2024 and peak weekly profile**

NREL completed a screening analysis of the critical load to determine the energy requirements required to support functionality during grid power outages of 8-hour, 24-hour, and 72-hour duration at the Camp Mabry B8 JOC, as shown in Figure 20. The maximum energy storage needed during this period for the JOC is 202 kWh for 8 hours, 547 kWh for 24 hours, and 1581 kWh for 72 hours. While the 8-hour energy storage is manageable for a fully charged Chevrolet Silverado and the GM Energy 10.6 kWh battery pack, a 72-hour outage would require 8 fully charged Silverados and more if they arrived without fully charged batteries, which would become difficult from a logistical perspective.

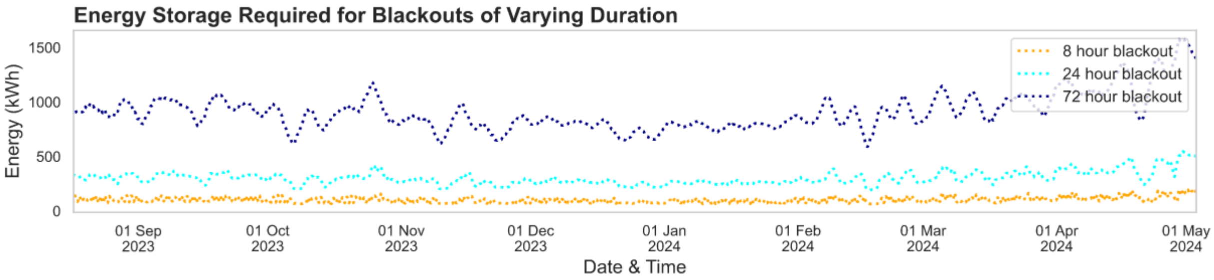

**Figure 20. Camp Mabry B8 JOC energy storage required to support power outages for critical loads**

Camp Mabry B75 has a large footprint (approximately 55,000 square feet), placing it beyond the reasonable range of support for light-duty bidirectional chargers capable of exporting 11.5 kW. However, the SCIF within B75 could be segmented from the rest of the power supply to form a critical load circuit. Due to its importance to Army National Guard functions, TXARNG and NREL treated the entirety of the SCIF as the critical load at B75. Figure 21 displays the critical load and a 24-hour average of the critical load from December 2023 through April 2024, as well as an excerpt of the highest load week during that time period. The critical building load averaged 49.1 kW during this time period and peaked at 67.1 kW, and the 24-hour critical load average peaked at 59.6 kW. The occasional drops to a 0-kW load indicate metering or network issues.

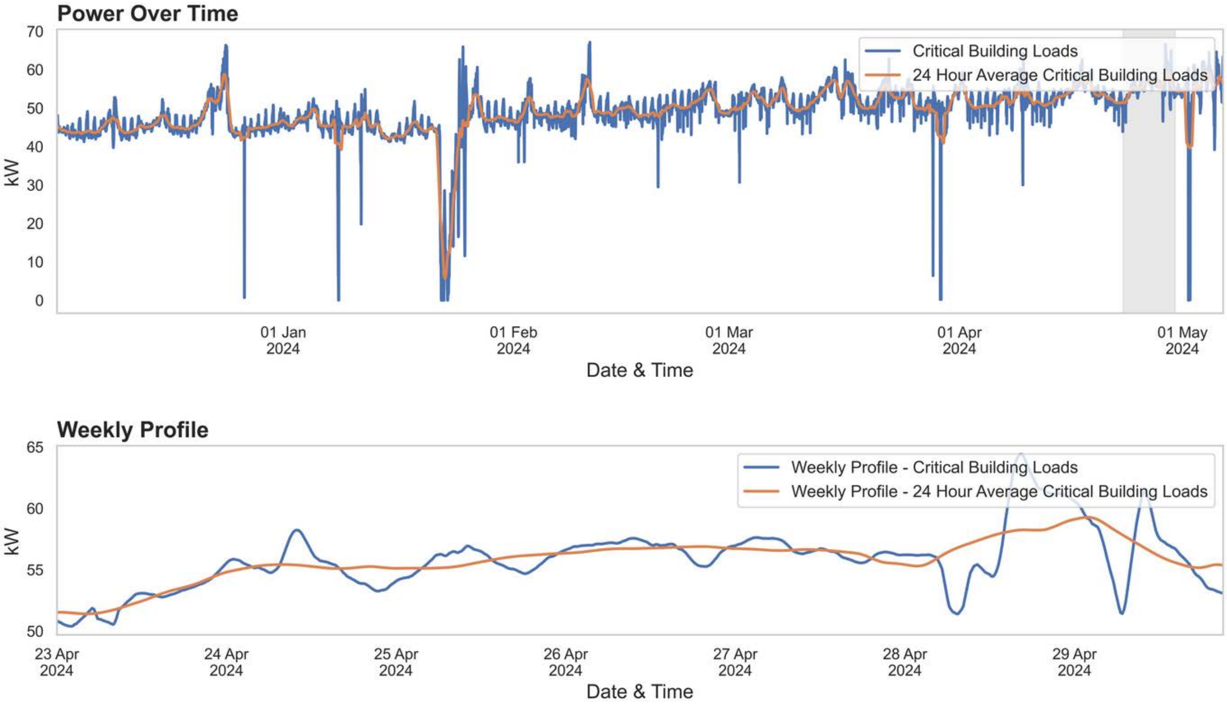

**Figure 21. Camp Mabry B75 SCIF power from December 2023 through April 2024 and peak weekly profile**

NREL completed a screening analysis of the critical load to determine the energy required to support functionality during 8-hour, 24-hour, and 72-hour power outages at the Camp Mabry B75 SCIF, as shown in Figure 22. The maximum energy storage needed during this period for the SCIF is 507 kWh for 8 hours, 1,429 kWh for 24 hours, and 4,147 kWh for 72 hours. While the 8-hour energy storage is manageable for three fully charged Chevrolet Silverado, a 72-hour outage would require 21 fully charged Silverados and more if they arrived without fully charged batteries, which would become difficult from a logistical perspective. Due to the challenges supporting multiday outages with EV-AMP at the Mabry B8 JOC and B75 SCIF, NREL did not complete the more detailed assessments that were completed for the San Marcos RC, Camp Swift RC, and Bee Caves SOD-A.

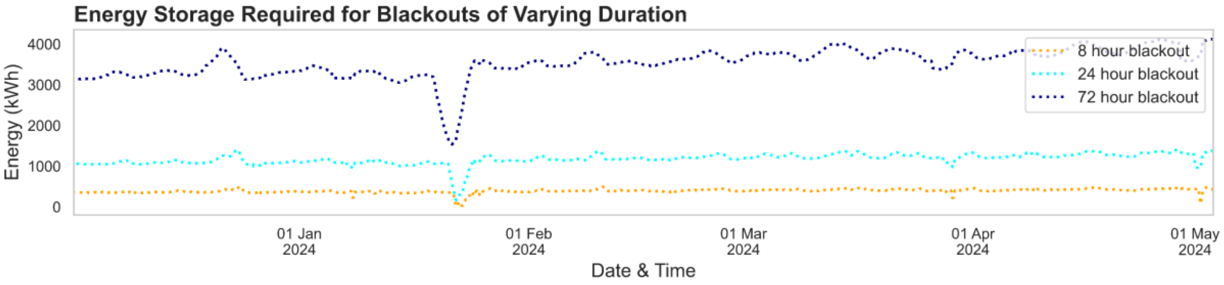

**Figure 22. Camp Mabry B75 SCIF energy storage required to support power outages for critical loads**

### 5.1.2 Camp Swift

The Camp Swift RC was newly renovated, and metering went offline for a time during this study. However, from Feb. 1 to May 1, 2024, data were collected and reported consistently using the eGauge meters described previously. In summary, the team collected data from the main distribution panel representing the total building load in addition to data on the telecommunications room and the whole building ventilation and lights. The telecommunications, ventilation, and lights were deemed critical loads for the purposes of sustaining the RC. Figure 23 displays the total building load, critical loads, and a 24-hour average of the critical loads throughout February, March, and April, as well as an excerpt of the week with the highest critical load during that time period. The critical building load averaged 5.3 kW during this time period and peaked at 11.5 kW, and the 24-hour critical load average peaked at 8.4 kW.

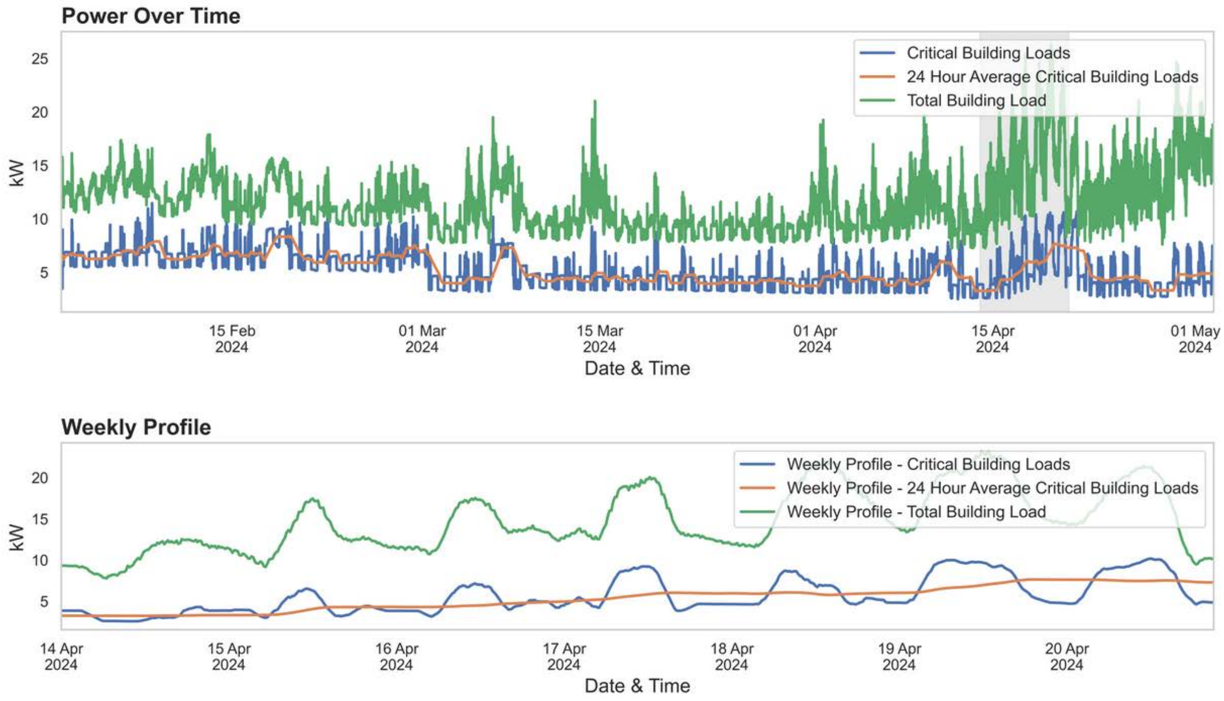

**Figure 23. Camp Swift RC power from February through April 2024 and peak weekly profile**

NREL completed a screening analysis of the critical load to determine the energy required to support functionality during 8-hour, 24-hour, and 72-hour power outages at the Camp Swift RC, as shown in Figure 24. The maximum energy storage needed during this period for the critical loads at the Camp Swift RC was 78 kWh for 8 hours, 202 kWh for 24 hours, and 557 kWh for 72 hours. The 8 and 24-hour energy storage requirements could be met by a single fully charged Chevrolet Silverado plus the base GM Energy 10.6 kWh backup battery used as part of the company's bidirectional charging system. However, the actual behavior of the TXARNG vehicles varied as explored in later sections. Energy storage requirements for the entire Camp Swift RC building were similar to the San Marcos RC; the maximum energy storage needed for the entire building load was 177 kWh for 8 hours, 450 kWh for 24 hours, and 1,242 kWh for 72 hours.

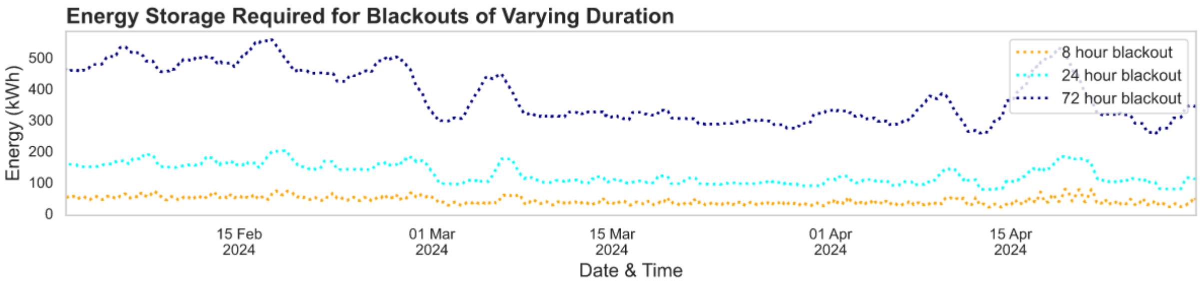

**Figure 24. Camp Swift RC energy storage required to support power outages for critical loads**

### *5.1.3 Bee Caves SOD-A*

Bee Caves SOD-A is a relatively small building and has a rooftop PV array that generates as much as 16 kW of power, significantly offsetting the building load. The critical building loads at SOD-A include everything except for the heating and cooling system. There were issues calibrating the meters correctly and then getting the solar PV system reactivated at Bee Caves. Reliable load data were not collected until February 1, and the PV system was not reactivated until March 6.

Figure 25 displays the critical loads, solar generation, net of loads and solar, and a 24-hour average of the net throughout February, March, and April, as well as an excerpt of the highest load week during that time period. The net load averaged 0.8 kW during this time period, peaked at 6.9 kW, and dipped to −13.7 kW (accounting for the solar generation), and the 24-hour critical load average peaked at 4.0 kW.

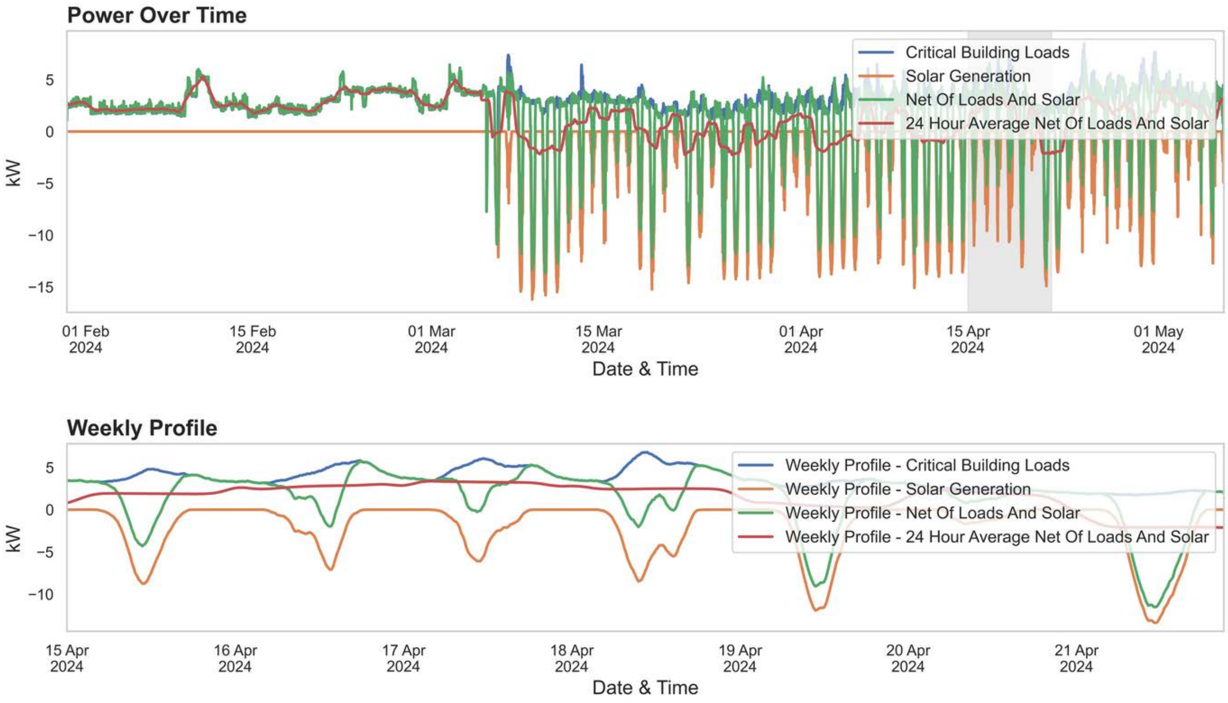

**Figure 25. Bee Caves SOD-A power from February through April 2024 and peak weekly profile**

NREL completed a screening analysis of the critical load to determine the energy required to support functionality during 8-hour, 24-hour, and 72-hour power outages at the Bee Caves SOD-A, as shown in Figure 26. The maximum energy storage needed during from February 1 to May 1 for the critical loads at the Bee Caves SOD-A was 45 kWh for 8 hours, 127 kWh for 24 hours, and 301 kWh for 72 hours. Even without the solar generation, a single fully charged Silverado EV could support an 8-hour or 24-hour blackout. Accounting for solar generation, as shown in Figure 27, a single fully charged Silverado EV could support a 72-hour blackout as well.

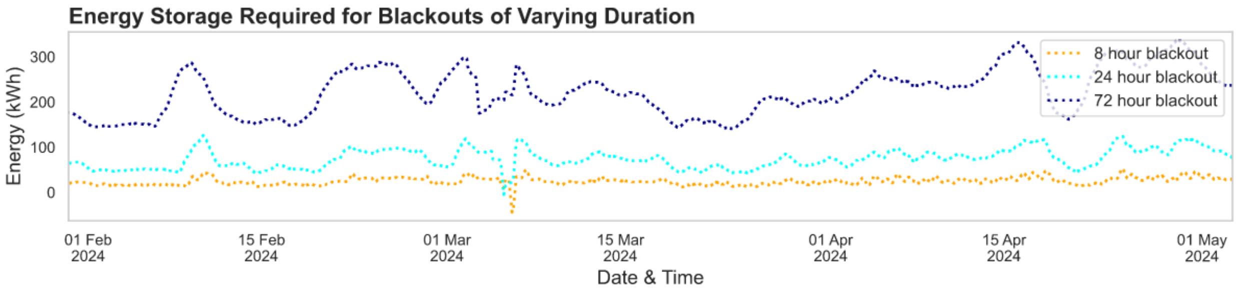

**Figure 26. Bee Caves SOD-A energy storage required to support power outages for critical loads without accounting for solar generation**

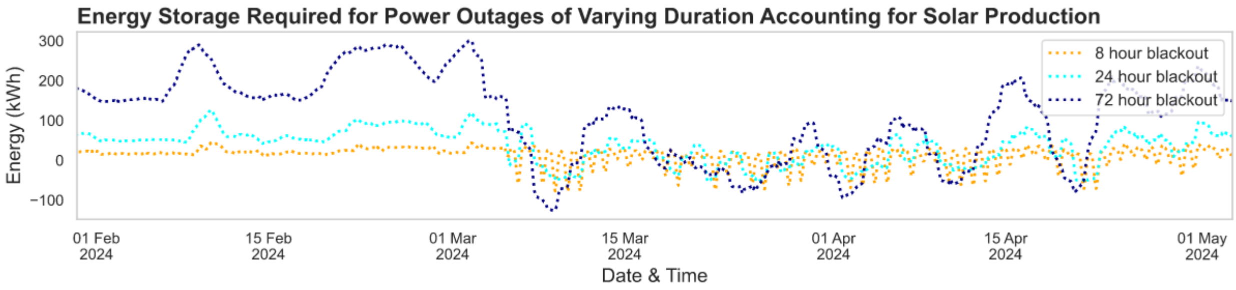

**Figure 27. Bee Caves SOD-A energy storage required to support power outages for critical loads accounting for solar generation once restored on March 6, 2024**

### *5.1.4 San Marcos*

The San Marcos RC represents the type of facility found throughout the Texas Military Department and other National Guard sites. The load peaked at 29.4 kW between Feb. 1 and May 1, 2024. NREL treated the primary lighting circuit and IT room as the critical loads at San Marcos, which never exceeded 3.1 kW during the period of investigation, and the 24-hour average of the critical load peaked at 1.45 kW. The critical loads were very flat, as shown in Figure 28.

**Figure 28. San Marcos power from February through April 2024 and peak weekly profile**

NREL completed a screening analysis of the critical load to determine the energy required to support functionality during 8-hour, 24-hour, and 72-hour power outages at the San Marcos RC, as shown in Figure 29. The San Marcos RC critical energy loads were relatively small, even after ramping up in late February. The maximum energy storage needed during this period for the critical loads at the San Marcos RC was 23 kWh for 8 hours, 64 kWh for 24 hours, and 159 kWh for 72 hours. Each of these energy storage quantities could be met by a single fully charged Chevrolet Silverado. Moreover, the energy storage for the entire building could be met for 24 hours by three Silverados. The maximum energy storage needed for the entire building load was 196 kWh for 8 hours, 489 kWh for 24 hours, and 1,340 kWh for 72 hours. Therefore, the team analyzed the San Marcos RC in more detail in subsequent sections of this report.

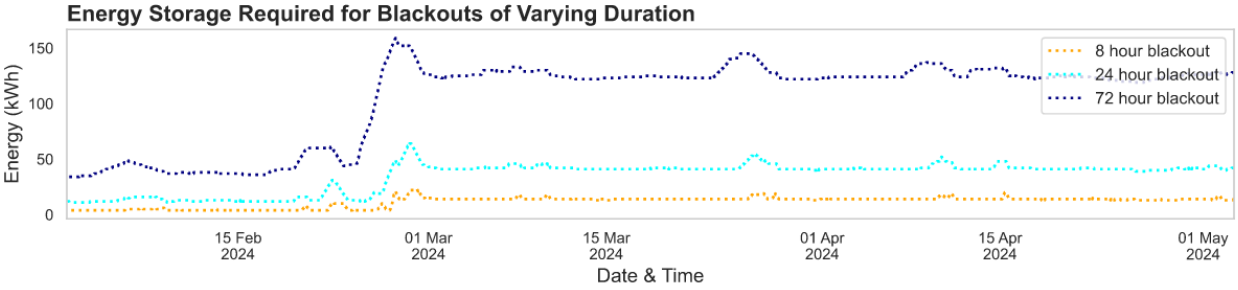

**Figure 29. San Marcos RC energy storage required to support power outages for critical loads**

## 5.2 Vehicle SOC Availability

If all 21 vehicles were charged to 100% on-site and staged in advance of an event, the 3,037 kWh of energy noted in Section 4.2 could be available. NREL evaluated the effects of fleet operations on the expected SOC available at any given time to determine the distribution of the total vehicle SOC available and the amount of time it might take for the vehicles to respond to an event. SOC and time delays arriving to serve critical loads were considered in 1-hour time-step increments. NREL focused the date range of analysis from Nov. 16, 2023, to March 20, 2024, when all vehicles displayed at least one trip before and after the date range, indicating all vehicles were actively operating during this time period.

At each time step studied, the SOC of each vehicle is determined by the SOC at the beginning of the most recent vehicle stop. If the vehicle completed a charge prior to the time step during the most recent stop, the charged vehicle SOC is returned. If the vehicle is in the middle of a charge event at the time step, the vehicle SOC prior to the charge event beginning is returned. Finally, if the vehicle is driving at the time step, the vehicle SOC at the beginning of the next stop is provided—assuming the vehicle would complete the current trip before responding to the request. The 21 vehicles considered were stopped 97% of the time. This results in rare time steps where the vehicle is driving at a specific time step.

NREL accounted for the travel from the vehicle stop location at the time step to the destination by leveraging a MapQuest API that returns driving distance and drive time. The SOC returned from evaluating the vehicle stop data was further decreased by the estimated energy needed to complete the driving distance. If the vehicle would not have sufficient SOC to complete the driving distance, it is not included in the total available SOC for the location and time step.

The time delay for each time step was determined by the MapQuest drive time. If the time step occurs while a vehicle is driving, the difference between the time the vehicle arrives at the next stop and the time step is added to the drive time delay.

Results were developed for the Camp Swift RC, the San Marcos RC, and the Bee Caves SOD-A. The time delay is reported as the kilowatt-hour weighted average of the individual vehicle delays. The Bee Caves SOD-A would have an average of 2.3 MWh available with a range from 1.536 to 2.598 MWh. The Camp Swift RC would have an average of 2.2 MWh available with a range from 1.488 to 2.523 MWh. The San Marcos RC would have an average of 2.1 MWh available with a range from 1.385 to 2.406 MWh. More complete distributions of energy availability are presented in Figure 30. The average time delays of arriving battery capacity weighted by the total arriving kilowatt-hours were 24 minutes for Bee Caves SOD-A, 30 minutes for Camp Swift RC, and 44 minutes for San Marcos RC.

**Figure 30. Distribution of all time steps showing energy available from nearby fleet vehicles if replaced with equivalent EVs operating at 100% efficiency**

Battery-electric vehicle efficiency varies greatly by temperature, with evidence that light-duty vehicles can lose significant range when temperatures are extremely cold. To determine the effects of reduced range on available SOC, a scenario was run with vehicle efficiency and range falling by 50% (corresponding to -2˚F, which is the recorded all-time low temperature in Austin on January 31, 1949. (Argue 2020; National Weather Service). Under this scenario, the Bee Caves SOD-A would have an average of 2.0 MWh available with a range from 1.220 to 2.445 MWh. The Camp Swift RC would have an average of 1.9 MWh available with a range from 1.102 to 2.288 MWh. The San Marcos RC would have an average of 1.7 MWh available with a range from 0.994 to 2.059 MWh. More complete distributions of energy availability are presented in Figure 31. The average time delays of arriving battery capacity weighted by the total arriving kilowatt-hours were 23 minutes for Bee Caves SOD-A, 28 minutes for Camp Swift RC, and 44 minutes for San Marcos RC.

**Figure 31. Distribution of all time steps showing energy available from nearby fleet vehicles if replaced with equivalent EVs operating at 50% efficiency**

## 5.3 Utility Programs and Interconnection Requirements

The sites are serviced by three different utilities. Camp Mabry and Bee Caves are serviced by Austin Energy, a community-owned utility that has significant experience with DER development and integration. Austin Energy's Sustainable and Holistic Integration of Energy Storage and Solar Photovoltaics (SHINES) includes two utility-scale energy storage systems, multiple customer-sited energy storage systems at residential and commercial properties, smart inverters, real-time data feeds, and a DER software platform to optimize energy use. Austin

Energy also has a demand response incentive that could be utilized for revenue generation within the scope of this project (Austin Energy 2024).

**Commercial Demand Response Incentives**

| | Standard DR | Fast DR* |
|---|---|---|
| **4:00 – 7:00 p.m.** | $50/avg kW | $65/avg kW |
| **1:00 – 7:00 p.m.** | $55/avg kW | $70/avg kW |
| **1:00 – 7:00 p.m**<br>**(summer weekdays + EEA Emergencies 24/7/365)** | $70/avg kW | $80/avg kW |

**Figure 32. Austin Energy commercial demand response incentives.**

Source: Austin Energy, savings.austinenergy.com/commercial/offerings/load-management/commercial-demand-response

Austin Energy and partner Pecan Street, a clean energy data and technology provider, have completed and continue to develop DER projects. A relevant study was completed in 2022 that analyzed the grid impacts of a winter storm that began to impact the region on Feb. 12, 2021. This study identified the application of V2X technologies in supporting residential loads during grid outages, highlighting how a single Ford F-150 Lightning extended range battery pack could provide 83 hours of backup power to an average home in Austin (Pecan Street 2022). The report also noted that rooftop solar PV could provide valuable resilience benefits, but only if tied to a transfer switch, grid-forming inverter, and battery storage such as could potentially be used at Bee Caves as part of an EV-AMP deployment.

San Marcos is serviced by city municipal power and does not appear to have a renewable energy or energy storage program currently in place. The utility rate structure varies based on facility size, with Medium General Service and higher having an associated demand charge, which bidirectional charging could significantly mitigate by timing vehicle discharge to coincide with facility peak demand.

Camp Swift is serviced by Bluebonnet Electric Cooperative. Bluebonnet has a standard interconnection application form for less than 50 kW that provides for both solar PV and energy storage connection requests (www.bluebonnet.coop/sites/default/files/Under_50_Bluebonnet-interconnection-packet%20(1).pdf). It is likely that Camp Swift could leverage this form and Bluebonnets standard practices to get approval for a bidirectional charging system that could backfeed the grid. During power outages, EV-AMP would not backfeed the grid.

In all of these potential applications at Camp Mabry, Bee Caves, San Marcos, and Camp Swift, TXARNG owns the electrical equipment that would be directly tied to the bidirectional charger and associated system. However, TXARNG will need to meet with the local power provider to inform them of their plans, and they may need to secure utility permission, depending on the terms of their agreement.

## 5.4 Economic Value of EVs Under Routine RC Operations (Nonemergency)

Preceding sections of this report highlight the anticipated vehicle operations schedule collected from existing vehicle telematics data, where various EVs are expected to make stops at the RCs as part of routine business. This section presents the economic value of smart charging these EVs, pairing smart charging with on-site solar PV and stationary BESS, and allowing vehicle-to-load discharging while these EVs are available at these RCs per modeled schedule.

As described in previous sections, REopt is a mathematical model which can find the least cost way of serving electrical loads and was used to understand the electric utility bill impact of charging EVs at these RCs. San Marcos does not see routine EV charging activity as modeled per telematics data, and hence is only considered from a resilience perspective.

Bee Caves is a smaller site with only 51.75 kWh of power drawn from EVs collectively over 218 out of 8,760 hours in the year (1.25%). The REopt results from Bee Caves indicated negative NPV of cost savings over the 25-year analysis periods because the EVs are not present on-site long enough to make a positive economic impact based on existing operating conditions. However, parking an EV at Bee Caves could generate substantial savings from participation in a demand response program offered by Austin Energy. With an 11.5 kW bidirectional charger, participating in 20 demand response events per year between 4:00 pm and 7:00 pm at a compensation rate of $65/kW, and a discount rate of 2.5%, the Austin Energy demand response program could generate $130,843 in revenue to Bee Caves.

Camp Swift is a comparatively larger site where five EVs may charge per routine operational schedule. In total, these EVs spend 31,264 hours at this site out of maximum possible 43,800 hours (71.37%), which allows the vehicles to have a substantial impact when financially feasible.

Table 17 presents the REopt analysis results for this site. Note that REopt results depend on the underlying electric load profiles, input assumptions and electric tariffs, and these results only reflect the inputs used in this analysis. Changes in power consumption or cost of electricity can change the REopt results and increase the value of PV or BESS at this RC.

Table 17. Critical Questions for Economic Analysis of EV-AMP and Alternative Solutions

| Scenario | REopt Identified Solution | Project Economics |
|---|---|---|
| Business as usual (BAU) | Given the site's electric load and electric utility rates, do PV and BESS make economic sense at this site?<br>Yes, a 16.3 kW PV system is cost-effective, but stationary BESS is not cost-effective. | Modest cost savings (NPV) of $5.3k compared to having no PV over analysis period with simple payback of 13.7 years at 6% rate of return. |
| Unmanaged charging for five EVs | What is the economic impact of unmanaged charging?<br>A 15 kW PV system is cost-effective. Added EV demand is not enough to justify investment in a stationary BESS. | Cost savings of only $1.9k compared to no PV with simple payback in 15 years at 5% internal rate of return. |
| Smart charging for five EVs | Are there economic benefits of smart charging?<br>Yes, smart charging with long residence times can effectively provide energy arbitrage and peak demand reduction compared to unmanaged charging, thereby reducing the value of solar PV and stationary BESS. | Compared to unmanaged charging, smart charging saves the RC $18.5k.<br>Two EVSE ports were found to be cost-optimal at this RC. |
| Smart charging for five EVs with vehicle to building (V2B) | Allowing vehicle-to-building dispatch does not provide considerable additional cost savings in scenario. Results for V2B at this RC can change with changes in underlying inputs. | Compared to unmanaged charging, a NPV of $17.3k (nearly identical as smart charging only). |
| Smart charging with on-site PV | Does on-site PV provide savings in addition to smart charging?<br>Yes, a small PV system of ~2 kW is cost-effective in this scenario. The cost savins from smart charging far outweigh those from only PV. | Compared to unmanaged charging, a NPV of $20.2k (slightly higher than smart charging only). |
| Smart charging with on-site PV and V2B | Does V2B provide more cost savings on top of smart charging and on-site PV?<br>Addition of V2B did not result in a jump in cost savings compared to previous scenario. | Compared to unmanaged charging, a NPV of $24.8k. (Slightly more than smart charging only). |

## 5.5 Cost to Deploy Chargers

The authors estimated the cost to install chargers including a 20% contingency for the sites with promising load profiles for installing EVSE: two chargers at Camp Swift, one at Bee Caves, and one at San Marcos.

### *5.5.1 Charging Equipment Cost Estimate for Camp Swift RC*

At Camp Swift, the general value and need for charging infrastructure was sufficient for the expected EVs that NREL recommended installing two charging units, even though a second charger was not necessary to for the critical load service provided by EV-AMP. Both of the units in this case would be capable of charging vehicles at up to 19.2 kW depending on the EV onboard charger capacity and discharging back to the building at 11.5 kW. Table 18 displays the estimated costs for installing charging infrastructure, and Figure 33 shows the costs in graphical form.

**Table 18. Cost Estimate of EVSE Infrastructure for Camp Swift**

| Entity | Component Cost ($) |
|---|---:|
| EV Charging Stations: Two Units | $14,400 |
| Service Panel and Breakers | $7,700 |
| Conduit and Housing | $2,100 |
| Conductors | $500 |
| EV Charging Station: Protection | $200 |
| Signage and Painting | $300 |
| EV Charging Station: Mounting | $200 |
| Trenching | $1,400 |
| Permits | $600 |
| Engineering and Administration | $5,700 |
| Taxes and Bond | $3,000 |
| Contingency | $3,300 |
| Total | $39,400 |

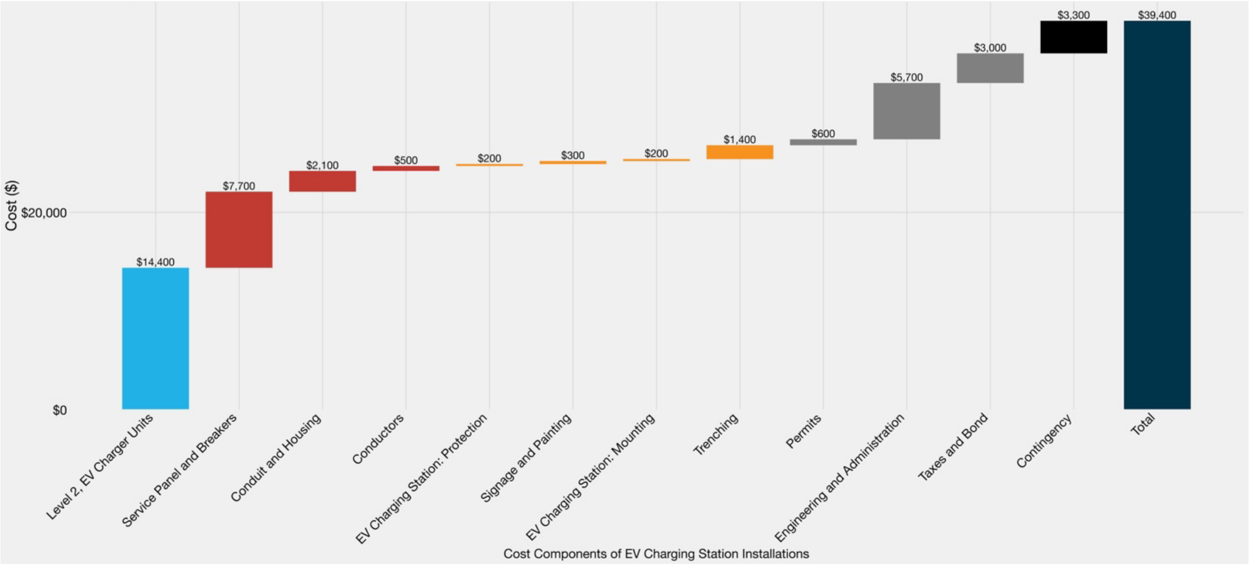

**Figure 33. Detailed cost estimate for Camp Swift**

### 5.5.2 Charging Equipment Cost Estimate for Bee Caves SOD-A

Only one charging unit is required at Bee Caves as the fleet requirements for the site are low and a single charging unit could supply sufficient power to support the SOD-A critical load in conjunction with the solar panels for an extended period of time. Table 19 displays the estimated costs for installing charging infrastructure, and Figure 34 shows the costs in graphical form.

**Table 19. Cost Estimate of EVSE Infrastructure for Bee Caves SOD-A**

| Entity | Component Cost ($) |
|---|---:|
| EV Charging Station: One Unit | $7,200 |
| Service Panel and Breakers | $4,300 |
| Conduit and Housing | $2,800 |
| Conductors | $1,000 |
| EV Charging Station: Protection | $100 |
| Signage and Painting | $100 |
| EV Charging Station: Mounting | $100 |
| Trenching | $3,700 |
| Permits | $400 |
| Engineering and Administration | $4,200 |
| Taxes and Bond | $2,100 |
| Contingency | $2,400 |
| Total | $28,400 |

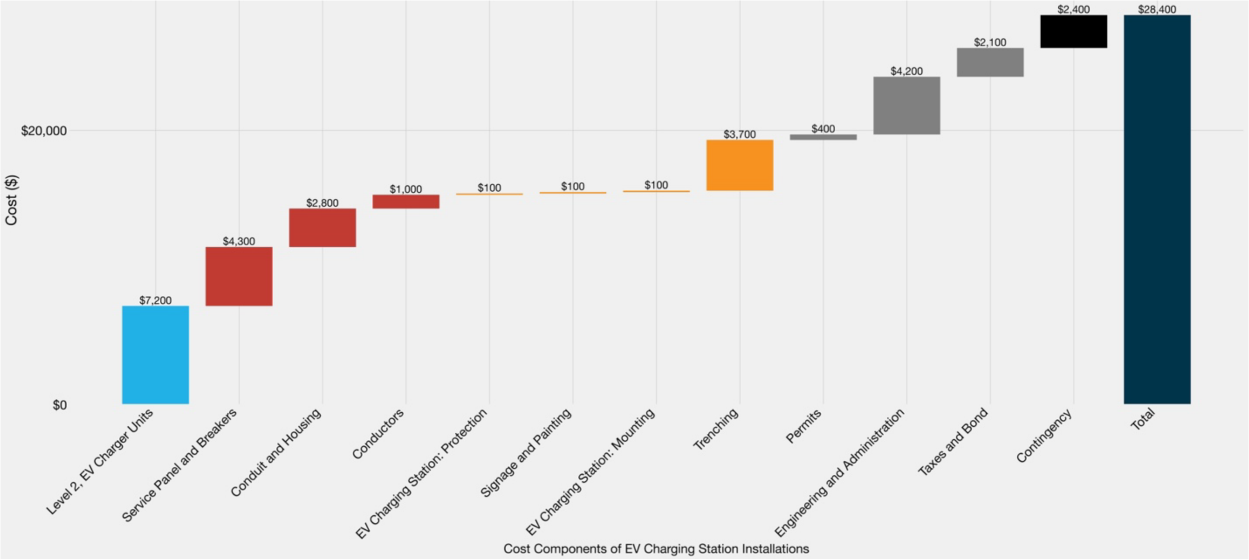

**Figure 34. Detailed cost estimate for Bee Caves**

### 5.5.3 Charging Equipment Cost Estimate for San Marcos RC

Only one charging unit is required at the San Marcos RC as the fleet requirements for the site are low and a single charging unit could supply sufficient power to support the RC critical load in for an extended period of time. Table 20 displays the estimated costs for installing charging infrastructure, and Figure 35 shows the costs in graphical form.

**Table 20. Cost Estimate of EVSE Infrastructure for San Marcos**

| Entity | Component Cost ($) |
|---|---:|
| EV Charging Stations: One Unit | $7,200 |
| Service Panel and Breakers | $4,300 |
| Conduit and Housing | $2,500 |
| Conductors | $800 |
| EV Charging Station: Protection | $100 |
| Signage and Painting | $100 |
| EV Charging Station: Mounting | $100 |
| Trenching | $2,300 |
| Permits | $400 |
| Engineering and Administration | $3,800 |
| Taxes and Bond | $2,000 |
| Contingency | $2,200 |
| Total | $25,800 |

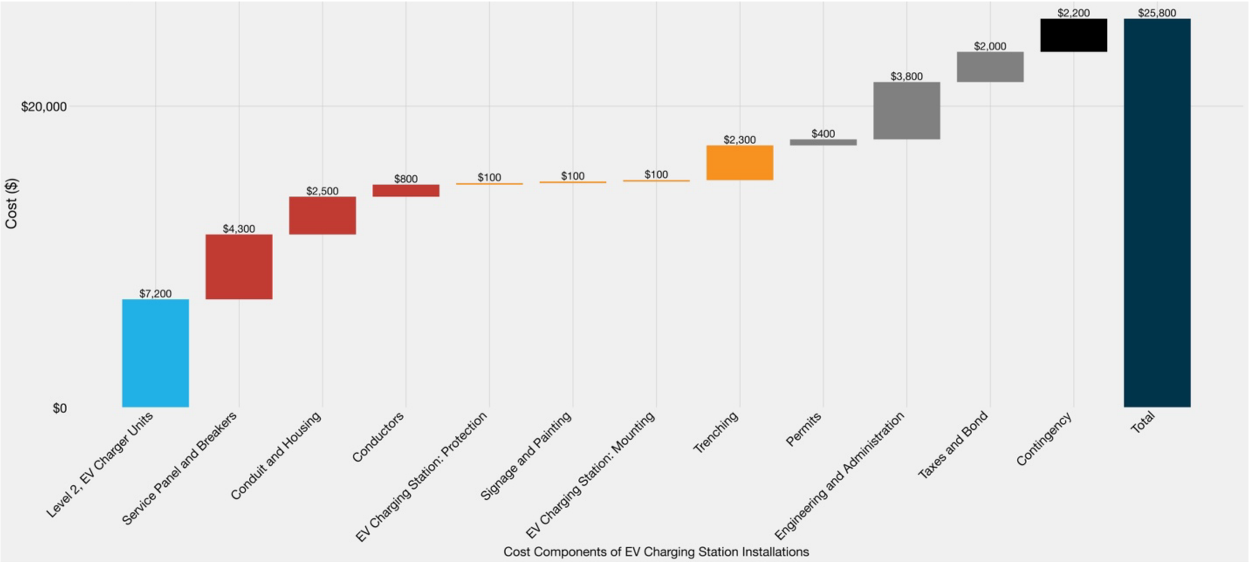

**Figure 35. Detailed cost estimate for San Marcos**

## 5.6 Resilience Value in Representative Time Step

As described in the analysis methodology section, REopt's outage simulation capabilities were used to understand the resilience delivered by EV-AMP. This step relies on the upstream analysis performed in Section 5.2 on the SOC when EVs would arrive to the buildings being supported and the amount of time it may take the EVs to arrive at a specific site given an outage notification. This SOC analysis step considered the total energy (in MWh) that would be available to RCs from all EVs across all time steps.

The authors identified a representative time step for the REopt analysis. The representative time step was the first 15-minute period when the mean available energy storage was available. The SOC and time delay for all 21 EVs at this time step are used as an input into the outage simulation and are presented in Table 21. Individual EVs may have diminished battery storage capacity at any given time step due to their fleet operations. The REopt analysis only included EVs with sufficient capacity to support the critical load at a particular site during the representative time step.

The sensitivity case of reduced EV efficiency uses a different representative time step (the first 15-minute period when the mean available energy storage was available based on 50% degraded EV efficiency) and results in different conditions for all 21 EVs. Note the expected reduction in arrival SOCs under sensitivity scenario. The sensitivity scenario does not necessarily mean increased time delay as the EV conditions are two separate snapshots in time where maximum energy capacity can be made available to the RCs.

**Table 21. Average EV Arrival Conditions in Representative Time Steps**

| Site | San Marcos RC | Bee Caves SOD-A | Camp Swift RC |
|---|---|---|---|
| | ***Full EV efficiency*** | | |
| Number of EVs arriving at RC | 20 | 19 | 19 |
| Average arrival SOC | 75% | 82% | 78% |
| Average arrival delay | 0.7 hours | 0.4 hours | 0.7 hours |
| | ***Reduced efficiency (extreme weather)*** | | |
| Number of EVs arriving at RC | 19 | 19 | 19 |
| Average arrival SOC | 64% | 79% | 70% |
| Average arrival delay | 0.8 hours | 0.4 hours | 0.5 hours |

### 5.6.1 Resilience Value for EV-AMP at Rated EV Efficiency

This subsection presents outage simulation results at rated EV efficiency. Table 22 presents the resilience at Camp Swift under the base case and EV case for all stackable BESS sizes. Under the base case with no EVs, larger stackable BESS corresponds to better resilience outcomes. For example, the 35.4 kWh BESS size can ensure that Camp Swift's critical load can be met with 100% confidence for up to 2 hours. On average, this BESS can support the site critical load for 5 hours, with up to 11 hours of maximum support possible.

When EVs are considered, results are presented as a range as of 1 through 19 or 20 EVs (depending on how many EVs could support resilience at each site in each scenario in Table 21. The range value represents results for 1 EV and the maximum number of EVs. For example, with 10.6 kWh stackable BESS, 1 EV ensures that Camp Swift RC can sustain its critical load for 18 hours with 100% likelihood, and 20 EVs ensures load sustainment for 320 hours. On average, this configuration supports 29 hours of critical load, with the possibility of supporting outages up to 49 hours. On average, 1 EV supports 27 additional hours of critical load compared to the base case with only a small BESS. This additional resilience provided by the EV amounts to installing a stationary BESS for approximately $46k.

**Table 22. Camp Swift EV Resilience Benefit (up to 19 EVs)**

| BESS Size | 10.6 kWh | 17.7 kWh | 35.4 kWh |
|---|---|---|---|
| ***BESS Only*** | | | |
| Average hours survived | 2 hours | 3 hours | 5 hours |
| Hours survived with 100% confidence | 0 hours | 1 hours | 2 hours |
| Maximum hours survived | 4 hours | 6 hours | 11 hours |
| ***BESS Plus EVs*** | | | |
| Average hours survived | 29–413 hours | 30–414 hours | 33–417 hours |
| Hours survived with 100% confidence | 18–320 hours | 18–320 hours | 20–322 hours |
| Maximum hours survived | 49–538 hours | 51–540 hours | 54 hours–543 hours |
| Estimated installed cost of BESS with equivalent resilience | $46,000–$814,000 | $43,000–$811,000 | $46,000–$814,000 |

Bee Caves RC has existing on-site solar PV which means the RC can sustain its critical load for 1 to 4 hours with 100% likelihood with only a small BESS (Table 23). Including EVs, this site can sustain its critical load with 100% likelihood for much longer durations than Camp Swift due to the presence of on-site solar PV which has a synergistic effect on outage survival. This is due to surplus PV being available to charge the EV during the day, allowing the EV to serve the site during overnight hours. As the number of EVs increases, so does the ability of Bee Caves RC to sustain its critical loads. In fact, 10 EVs along with existing solar PV and stackable EVSE BESS can allow this RC to serve its critical loads for the entirety of the year. Given the presence of solar PV, a stationary BESS system in lieu of EVs must be ready to serve the largest overnight load and account for the worst PV performance. The maximum overnight critical load kWh requirement between 4 pm and 9 am is 88 kWh. On its worst day, critical load can be 32 kWh more than total solar generation. Therefore, a 120 kWh BESS should be able to serve the most overnight critical load after the worst PV production day.

**Table 23. Bee Caves EV Resilience Benefit (up to 19 EVs)**

| BESS Size | 10.6 kWh | 17.7 kWh | 35.4 kWh |
|---|---|---|---|
| ***BESS Only*** | | | |
| Average hours survived | 7 hours | 10 hours | 31 hours |
| Hours survived with 100% confidence | 1 hour | 1 hour | 4 hours |
| Maximum hours survived | 25 hours | 31 hours | 272 hours |
| ***BESS Plus EVs*** | | | |
| Average hours survived | 860–8,760 hours | 867–8,760 hours | 966–8,760 hours |
| Hours survived with 100% confidence | 52–8,760 hours | 54–8,760 hours | 57–8,760 hours |
| Maximum hours survived | 3,190–8,760 hours | 3,193–8,760 hours | 3,202–8,760 hours |
| Estimated installed cost of BESS with equivalent resilience | | $55,000 | |

Like Camp Swift, San Marcos (Table 24) benefits from presence of EVs. The site can sustain its critical load for substantially longer time periods under the EV case than in the base case. Resilience provided by EVs can be provided at this RC by stationary BESS with capital costs ranging from $44k to $709k (similar to Camp Swift).

**Table 24. San Marcos EV Resilience Benefit (up to 20 EVs)**

| BESS Size | 10.6 kWh | 17.7 kWh | 35.4 kWh |
|---|---|---|---|
| ***BESS Only*** | | | |
| Average hours survived | 9 hours | 15 hours | 30 hours |
| Hours survived with 100% confidence | 2 hours | 4 hours | 10 hours |
| Maximum hours survived | 19 hours | 31 hours | 60 hours |
| ***BESS Plus EVs*** | | | |
| Average hours survived | 164–1,684 hours | 169–1,688 hours | 181–1,698 hours |
| Hours survived with 100% confidence | 77–1,219 hours | 80–1,222 hours | 88–1,230 hours |
| Maximum hours survived | 318–2,055 hours | 327–2,059 hours | 351–2,067 hours |
| Estimated installed cost of BESS with equivalent resilience | $44,000–$709,000 | $44,000–$709,000 | $45,000–$711,000 |

Figure 36 visualizes how duration of outages that are survived with 100% probability increases with number of EVs on site at each RC for all three stackable BESS combinations during our representative time step. At Camp Swift, outage survival benefit increases with number of EVs, albeit the rate of this increase slows down if more than 10 EVs are available. At Bee Caves RC, 6 or fewer EVs provide similar outcomes. However, the added resilience benefit increases quite steeply for each EV added in addition to 6, up to total 10. Per this analysis, there is no added resilience benefit of having more than 10 EVs respond to Bee Caves RC. Lastly, at San Marcos, the resilience benefit increases linearly with number of EVs without much change in the rate of increase.

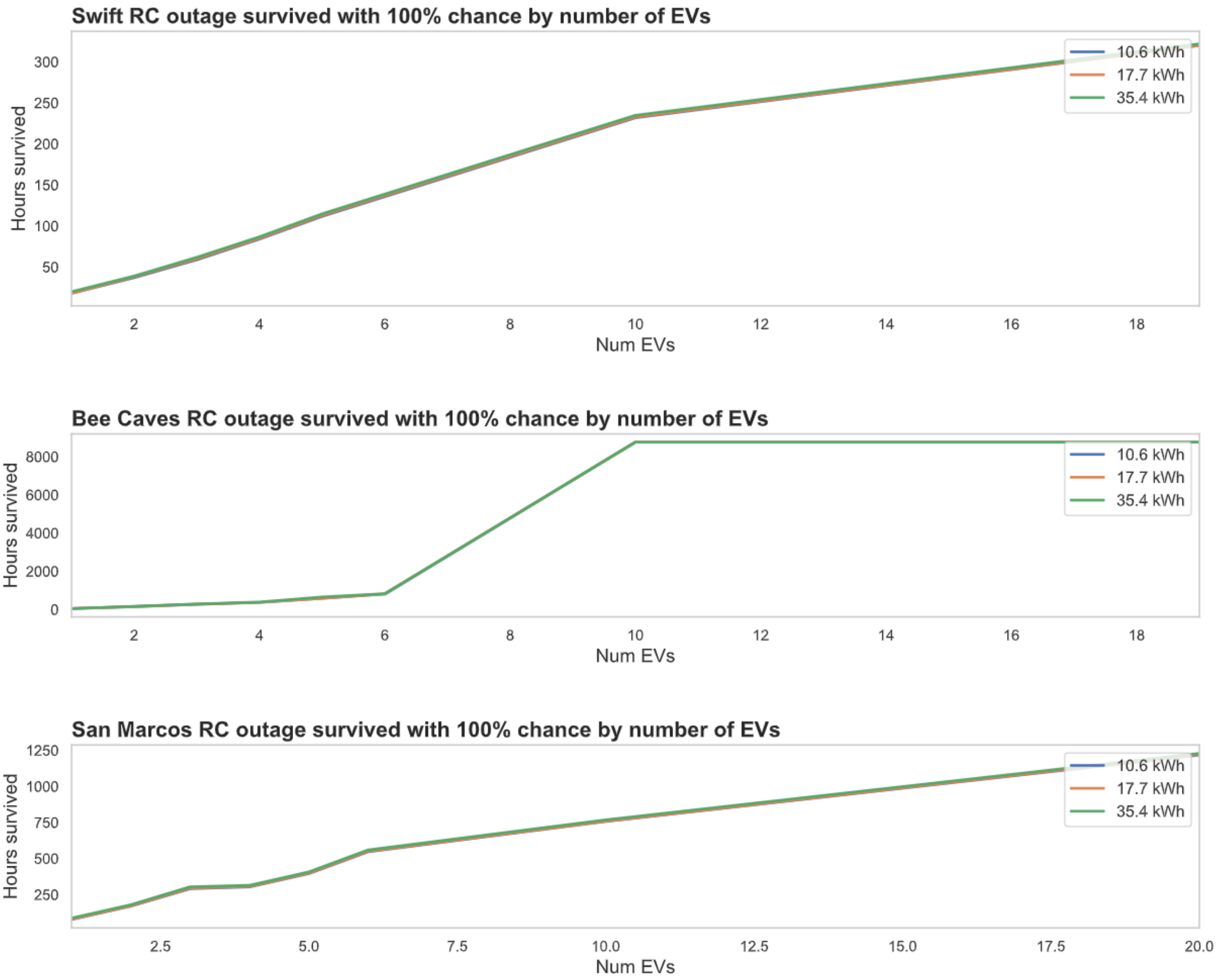

**Figure 36. Hours of power outage survived per number of supporting Silverado EVs operating at rated efficiency**

Figure 37 presents the outage survival traces for each RC for each combination of EVs considered under the EV Case for 10.6 kWh stackable BESS option. These traces visually highlight how increasing number of EVs impacts the probability of surviving outages of longer durations. For example, Camp Swift can sustain its critical load for 100 hours with 40% likelihood with three EVs whereas it can survive ~135 hours at 40% confidence if four EVs are considered. Similarly, the resilience benefit of three or four EVs at San Marcos is nearly identical if outages survived with 40% or more chance are considered.

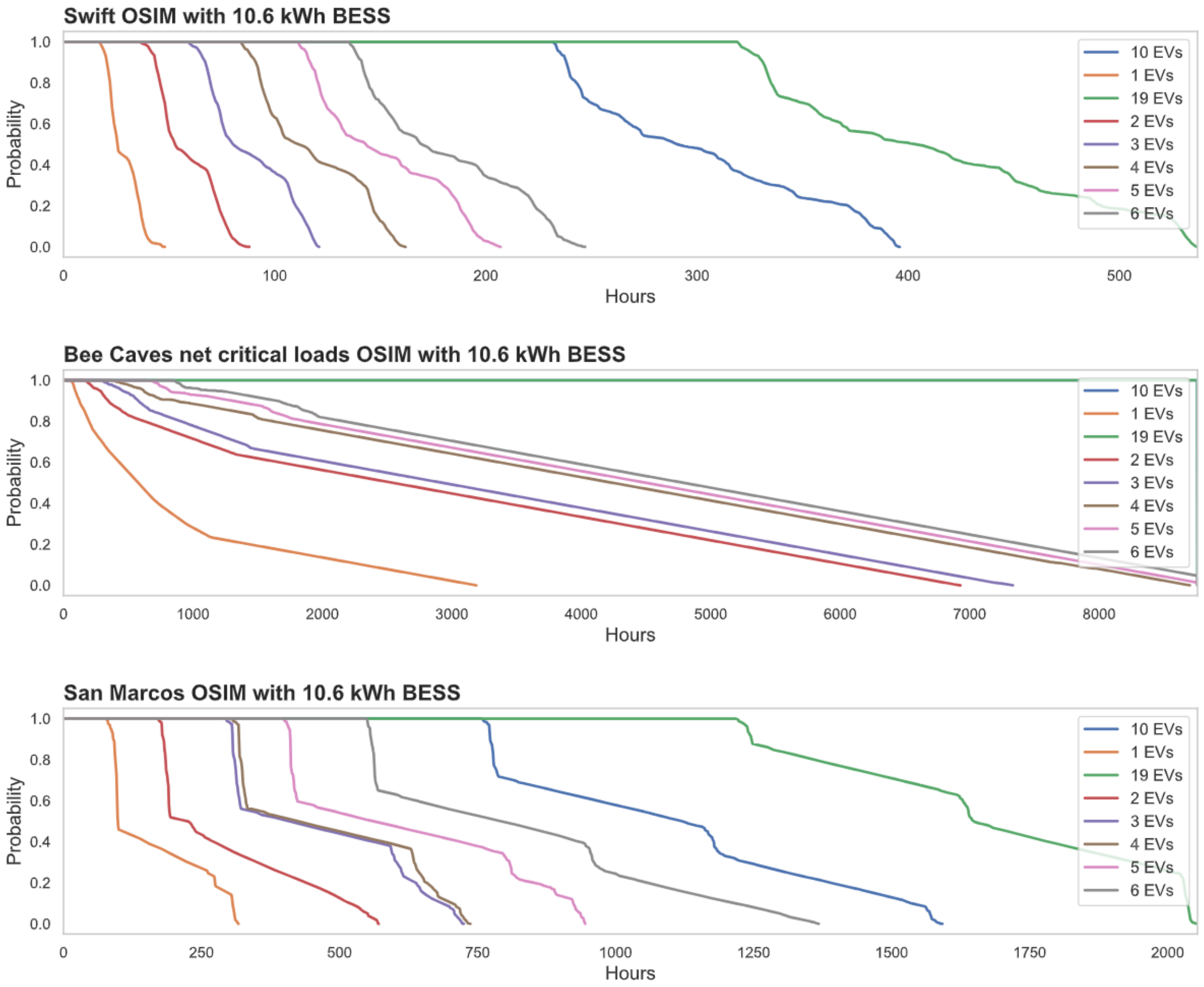

**Figure 37. Probability of surviving an outage of various durations by the number of EVs**

Finally, Figure 38 quantifies the number of EVs needed to survive outages of predetermined durations with 100% likelihood across the three RCs. For example, a total of four Chevrolet Silverado EVs can provide enough resilience at these RCs to sustain 24-hour concurrent outages with 100% likelihood (two deployed to Camp Swift, one to Bee Caves, and one to San Marcos). Similarly, seven Chevrolet Silverado EVs can sustain 72-hour outages at all three RCs simultaneously. The Camp Swift loads cannot be supported for two weeks even by 19 EVs, but the number of EVs required to support Bee Caves and San Marcos for that amount of time are shown in Figure 38.

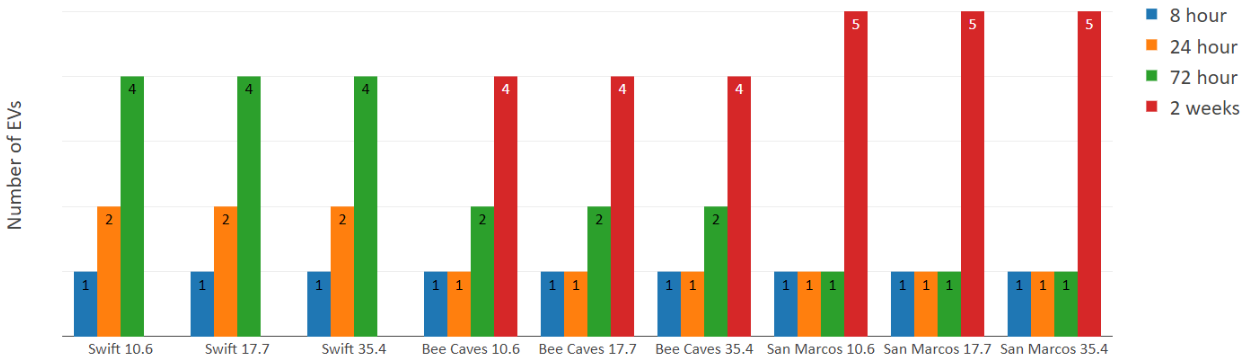

**Figure 38. Number of Silverado EVs at mean SOC needed to survive outages at peak load requirements**

### 5.6.2 Resilience Value for EV-AMP at Extreme Temperatures

The authors completed a sensitivity analysis of the EVs operated at 50% efficiency during extreme weather (approximately -2°F) using REopt's outage simulator capability and related methodology identified earlier in this report. The results for this sensitivity follow similar format as full efficiency EV results and are detailed in Table 25, Table 26, and Table 27. Lower available SOC in EVs results in slightly lower outage survival across scenarios. Most noticeably, 10 EVs at Bee Caves do not ensure outage survival for an entire year anymore, with the likelihood of completely uninterrupted power supply dropping to ~80% as the outage duration increases.

**Table 25. Camp Swift EV Resilience Benefit (up to 19 EVs)**

| BESS Size | 10.6 kWh | 17.7 kWh | 35.4 kWh |
|---|---|---|---|
| | ***BESS Only*** | | |
| Average hours survived | 2 hours | 3 hours | 5 hours |
| Hours survived with 100% confidence | 0 hours | 1 hours | 2 hours |
| Maximum hours survived | 4 hours | 6 hours | 11 hours |
| | ***BESS Plus EVs*** | | |
| Average hours survived | 28 – 355 hours | 29 – 356 hours | 32 – 358 hours |
| Hours survived with 100% confidence | 16 – 274 hours | 17 – 275 hours | 19 – 277 hours |
| Maximum hours survived | 46 – 465 hours | 48 – 467 hours | 53 – 471 hours |
| Estimated installed cost of BESS with equivalent resilience | $40,000 – $697,000 | $40,000 – $697,000 | $43,000 - $700,000 |

**Table 26. Bee Caves EV Resilience Benefit (up to 19 EVs)**

| BESS Size | 10.6 kWh | 17.7 kWh | 35.4 kWh |
|---|---|---|---|
| ***BESS Only*** | | | |
| Average hours survived | 7 hours | 10 hours | 31 hours |
| Hours survived with 100% confidence | 1 hour | 1 hour | 4 hours |
| Maximum hours survived | 25 hours | 31 hours | 272 hours |
| ***BESS Plus EVs*** | | | |
| Average hours survived | 860 – 8760 hours | 868 – 8760 hours | 966 – 8760 hours |
| Hours survived with 100% confidence | 52 – 8760 hours | 54 – 8760 hours | 57 – 8760 hours |
| Maximum hours survived | 3190 – 8760 hours | 3193 – 8760 hours | 3202 – 8760 hours |
| Estimated installed cost of BESS with equivalent resilience | $55,000 | | |

**Table 27. San Marcos EV Resilience Benefit (up to 19 EVs)**

| BESS Size | 10.6 kWh | 17.7 kWh | 35.4 kWh |
|---|---|---|---|
| ***BESS Only*** | | | |
| Average hours survived | 9 hours | 15 hours | 30 hours |
| Hours survived with 100% confidence | 2 hours | 4 hours | 10 hours |
| Maximum hours survived | 19 hours | 31 hours | 60 hours |
| ***BESS Plus EVs*** | | | |
| Average hours survived | 146 – 1376 hours | 151 – 1380 hours | 164 – 1391 hours |
| Hours survived with 100% confidence | 66 – 982 hours | 69 – 985 hours | 77 – 994 hours |
| Maximum hours survived | 283 – 1819 hours | 293 – 1822 hours | 318 – 1830 hours |
| Estimated installed cost of BESS with equivalent resilience | $37,000 – $571,000 | $38,000 – $572,000 | $39,000 – $573,000 |

Figure 39**Error! Reference source not found.** visualizes how duration of outage survived increases with the number of EVs on site at each RC. In contrast to Figure 36, this plot shows the impacts of EVs operating at 50% efficiency. The slope of the lines and the magnitude of the benefit varies based on the load profile of the buildings in question, with the same number of EVs supporting Camp Swift for a shorter duration than the other two locations and Bee Caves benefiting from the synergy of rooftop solar PV.

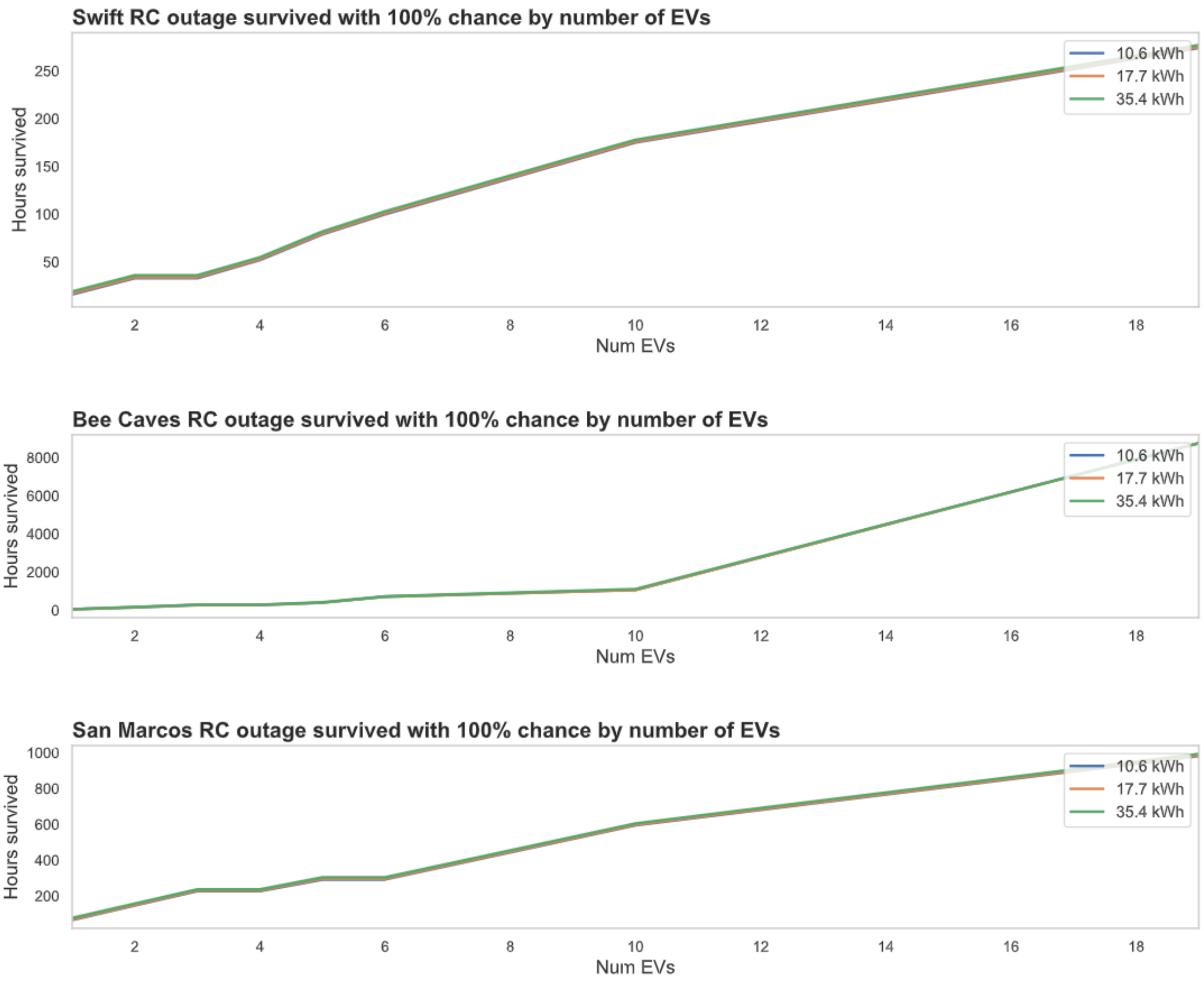

**Figure 39. Hours of power outage survived per number of supporting Silverado EVs operating at 50% efficiency**

Figure 40 presents the outage simulation traces for each combination of EVs assessed in this section. These traces highlight how increasing number of EVs impacts the probability of surviving outages of longer durations. The shape of these curves is similar to Figure 37; however, the duration of outage survived is less in all cases for a given probability due to EV operation at 50% efficiency in this simulation.

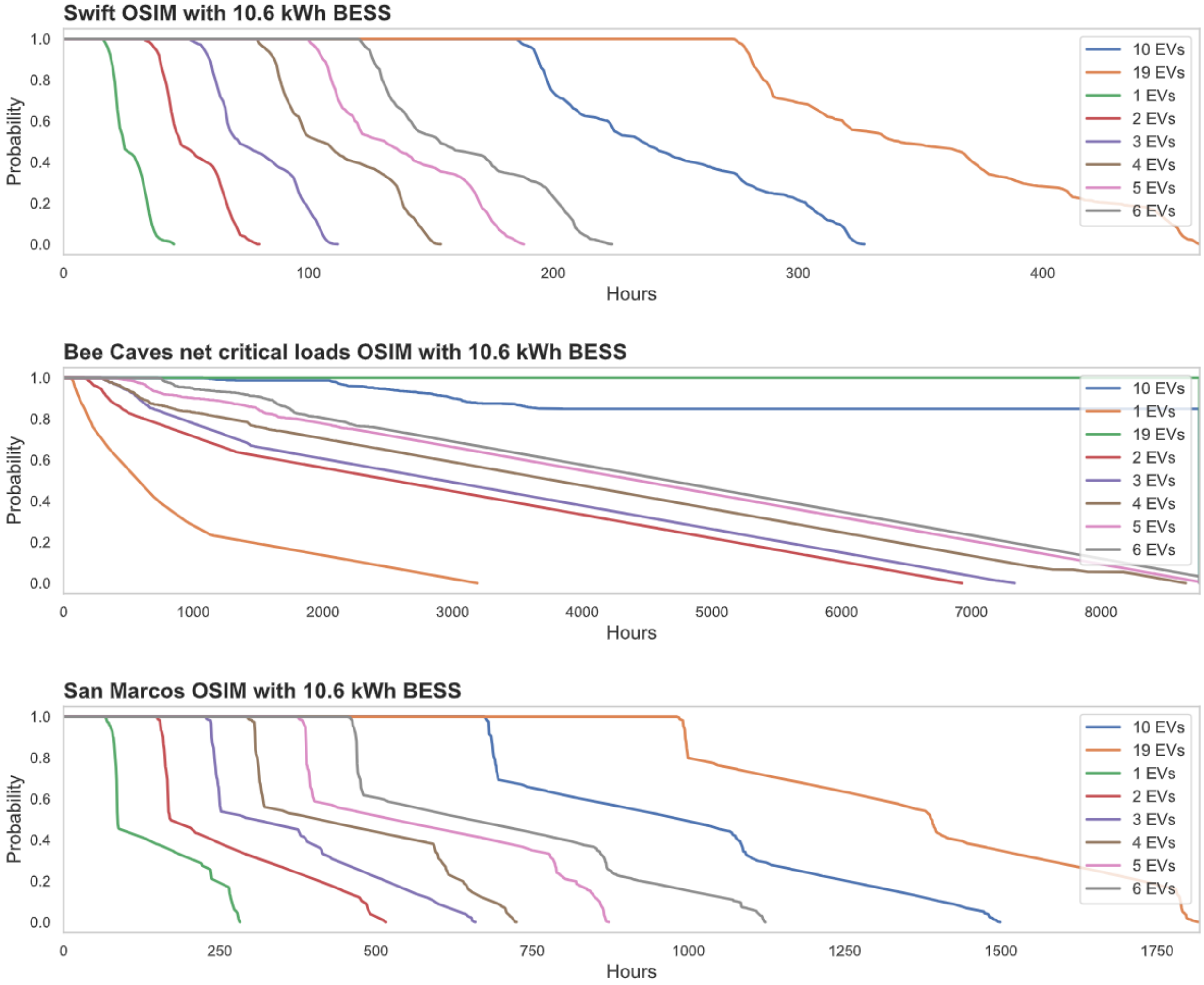

**Figure 40. Probability of power outage survival by period of duration based on specified number of Silverado EVs operating at 50% efficiency**

## 5.7 Worst-Case Scenario

The REopt simulation begins at a specific snapshot in time (the first 15-minute period when the mean available energy storage was available from EVs). It then applies the variations in building critical load requirements over the entire period for which data was captured, effectively capturing the worst-case building load scenario in the process. However, there may be cases in which EV batteries are more depleted at the beginning of an outage. To address the potential for EVs arriving with a lower state of charge at the same time that the building critical load was peaking, the authors identified the worst-case scenario for vehicle SOC, assuming the fleet operates the acquired EVs consistently with how the replaced vehicles operated during the analysis time period referenced in section 5.2. Based on the results of the REopt analysis suggesting that fewer than ten vehicles would be required to service loads and the existence of ten TXARNG pickup trucks operating in the Austin region, the authors focused on the ten vehicles listed in Table 28.

**Table 28. TXARNG Pickup Trucks Operating in Austin Region**

| VIN | Existing Vehicle Make and Model |
|---|---|
| 1GCXXXXXXXXXXXX18 | Chevrolet Silverado |
| 1N6XXXXXXXXXXXX18 | Nissan Titan |
| 3C6XXXXXXXXXXXX66 | Ram 3500 |
| 3C6XXXXXXXXXXXX66 | Ram 3500 |
| 1GCXXXXXXXXXXXX51 | Chevrolet Silverado |
| 3C6XXXXXXXXXXXX58 | Ram 3500 |
| 1FT8XXXXXXXXXXXX96 | Ford F-350 |
| 1FT8XXXXXXXXXXXX03 | Ford F-350 |
| 1GCXXXXXXXXXXXX53 | Chevrolet Silverado |
| 1GCXXXXXXXXXXXX81 | Chevrolet Silverado |

At their lowest total SOC, each of those vehicles would arrive to Camp Swift, Bee Caves, and San Marcos with a reduced SOC, in some cases as low as 0 kWh, completely limiting their ability to power critical loads. This would be a much more significant problem if the vehicles were operating at an extremely low 50% efficiency as shown in Table 29.

**Table 29. Energy Available (kWh) Upon Arrival to Building in the Worst-Case Time Step**

| VIN | Swift Rated Efficiency | Swift 50% Efficiency | Bee Caves Rated Efficiency | Bee Caves 50% Efficiency | San Marcos Rated Efficiency | San Marcos 50% Efficiency |
|---|---|---|---|---|---|---|
| 1GCXXXXXXXXXXXX18 | 6 | - | - | 120 | - | 100 |
| 1N6XXXXXXXXXXXX18 | 42 | - | 60 | - | 40 | - |
| 3C6XXXXXXXXXXXX66 | 61 | - | 60 | - | 40 | - |
| 3C6XXXXXXXXXXXX66 | 78 | - | 60 | 100 | 60 | 80 |
| 1GCXXXXXXXXXXXX51 | 85 | - | 80 | 180 | 80 | 140 |
| 3C6XXXXXXXXXXXX58 | 180 | 180 | 160 | 80 | 160 | 60 |
| 1FT8XXXXXXXXXXXX96 | 163 | 140 | 180 | 40 | 160 | 20 |
| 1FT8XXXXXXXXXXXX03 | 162 | 140 | 180 | 140 | 160 | 120 |
| 1GCXXXXXXXXXXXX53 | 163 | 140 | 180 | - | 160 | - |
| 1GCXXXXXXXXXXXX81 | 163 | 140 | 180 | 180 | 160 | - |

At the rated efficiency and minimum SOC starting the trip return to base, a total of three EV pickup trucks can support Camp Swift RC, Bee Caves SOD-A, and San Marcos RC peak critical loads for 8 hours, four EVs for 24 hours, and six EVs can support the loads for 48 hours. However, even with all ten vehicles assigned to deliver EV-AMP, the Camp Swift RC loads can only be supported for 48 hours while Bee Caves SOD-A and San Marcos RC can be supported for the full 72 hours.

At 50% efficiency and minimum SOC starting the trip return to base, four EV pickup trucks can again support each of the aforementioned loads for 24 hours, and six vehicles can support the loads for 48 hours. However, they cannot support the Camp Swift RC and San Marcos RC for more than 48 hours; there is no benefit to deploying more than six EV pickup trucks in these scenarios.

Table 30 displays the minimum number of electric pickup trucks required to support peak critical load at Camp Swift RC, Bee Caves SOD-A, and San Marcos RC. Table 31 indicates which eight vehicles would be best assigned to the individual locations to support a 72-hour power outage when the vehicles are operating with their rated efficiency.

**Table 30. Minimum Number of EVs Required to Support Peak Loads in Worst-Case Scenario at All Locations**

| Time Period of Power Outage (Peak Critical Load) | Minimum Number of Vehicles at Rated Efficiency | Minimum Number of Vehicles at 50% Efficiency |
|---|---|---|
| 8 Hours | 3 | 3 |
| 24 Hours | 4 | 4 |
| 48 Hours | 6 | 6 |
| 72 Hours | 8 | Infeasible |

**Table 31. Best Vehicle Assignment in Worst-Case SOC and 50% Efficiency Scenario**

| VIN | Site Assignment |
|---|---|
| 3C6XXXXXXXXXXXX66 | Camp Swift |
| 3C6XXXXXXXXXXXX66 | Camp Swift |
| 1GCXXXXXXXXXXXX51 | Camp Swift |
| 3C6XXXXXXXXXXXX58 | Camp Swift |
| 1FTXXXXXXXXXXXX03 | Camp Swift |
| 1FTXXXXXXXXXXXX96 | Bee Caves |
| 1GCXXXXXXXXXXXX53 | Bee Caves |
| 1GCXXXXXXXXXXXX81 | San Marcos |

These results present a key caveat to the REopt analysis. Even though 72 hours of critical load could be met by seven pickup trucks at average SOC and efficiency and nine pickup trucks at average SOC and 50% efficiency, only 48 hours of critical load could be met if the power outage began at the moment when the group of EVs was operating at their lowest net SOC and RC critical loads then peaked. Combining the peak critical loads of the buildings, lowest total SOC of the EVs, and historically impacted EV efficiency provides an absolute worst-case scenario for EV-AMP. Even in that case, six EVs could support three bases over 48 hours.

## 5.8 Net Resilience Value of EVSE Compared to BESS

The net resilience value analysis assumes that EVs are purchased as part a fleet electrification effort, and bidirectional EVSE units are purchased to support facility resilience. Given the cost of a bidirectional EVSE and the estimated capital costs of stationary BESS which can provide similar resilience as EVs, this section quantifies the net resilience value (cost savings) of using V2X chargers at the TXARNG facilities. Per Table 32, cost savings from installation of EVSE over stationary BESS range from $6.4k to ~$174k across sites. Camp Swift has the highest cost of EVSE infrastructure which results in lowest cost savings if 8-hour outages are targeted. The cost savings increase to $174k if 72-hour outages are considered. At Bee Caves, assuming no PV presence, planning for 8- or 24-hour outage survival results in same cost savings, but planning for 72-hour resilience can lead to almost $139k in cost savings. San Marcos can save ~$18k by planning for EV-AMP regardless of outage duration.

These cost savings can be compared against the cost of purchasing the required EVs to justify investments. Additionally, the avoided BESS costs only represent capital costs of an installed system, and replacement costs are not yet considered. As BESS degrades over time, it must be replaced with an equivalent system at a future cost. Like in Section 5.6, these results are based on EVs operating at their mean SOC in the representative time step chosen for REopt analysis.

**Table 32. Summary REopt Results and Estimated Cost Savings Associated With EV-AMP**

| Duration of power outage | Camp Swift | Bee Caves | San Marcos |
|---|---|---|---|
| | **How many EVs needed to sustain outage?** | | |
| 8-hour outage | 1 | 1 | 1 |
| 24-hour outage | 2 | 1 | 1 |
| 72-hour outage | 4 | 2 | 1 |
| | **What is the avoided capital cost of BESS with similar resilience?** | | |
| 8-hour outage | $45,800 | $38,600 | $43,700 |
| 24-hour outage | $94,100 | $72,000 | $43,700 |
| 72-hour outage | $213,700 | $167,300 | $43,700 |
| | **What are the EVSE costs at each RC?** | | |
| Cost of EVSE infrastructure | $39,400 | $28,400 | $25,800 |
| | **What are the net cost savings from EV-AMP?** | | |
| 8-hour outage | $6,400 | $10,200 | $17,900 |
| 24-hour outage | $54,700 | $43,600 | $17,900 |
| 72-hour outage | $174,300 | $138,900 | $17,900 |

# 6 Discussion: Critical Implementation Considerations

## 6.1 Reliability

The default backup power solution for TXARNG and the Army National Guard more broadly is diesel generation. Unfortunately, diesel generation is unreliable, especially over longer-duration outages. Marqusee and Jenket (2020) found that diesel generators have a 50% probability of failing within 48 hours (Figure 41). The TXARNG diesel generator assessed in this study failed to function properly from the very beginning of two blackouts despite attempts to maintain it properly.

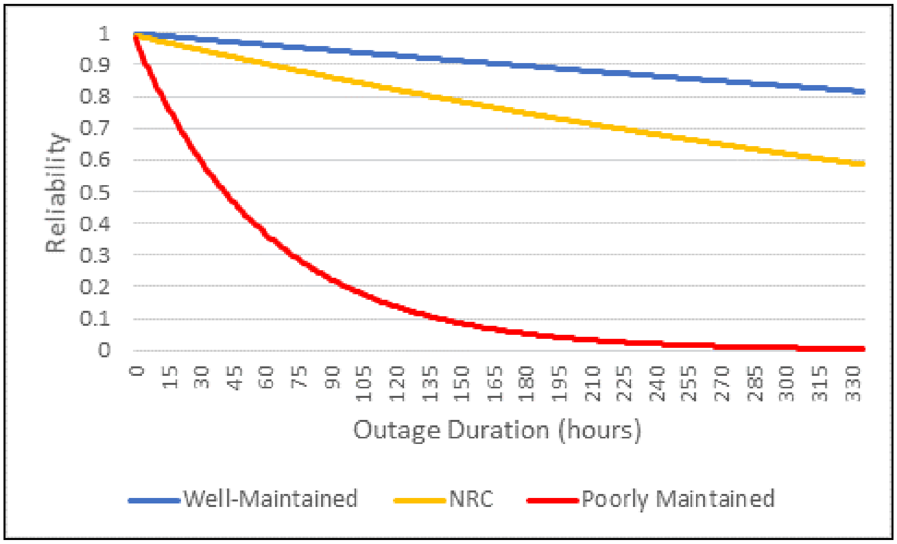

**Figure 41. Failure rate of well-maintained, poorly maintained, and Nuclear Regulatory Commission (NRC)-maintained diesel generators**

Bidirectional EV charging is less established than diesel generation. However, the embedded technologies are not novel. Bidirectional chargers use the well-established charging connectors on EVs, EVSE chargers, grid-forming inverters, dark-start batteries, and automatic transfer switches. Each element of this technology is well established.

Furthermore, established vehicle manufacturers such as Ford and GM offer warranties on their chargers, and they are working with veterans of inverter manufacturing such as Delta Electronics that offer up to 20-year warranties on their products. Researchers have investigated the reliability of inverters and found that the reliability depends heavily on whether critical alerts are provided to the operators (and the operators respond accordingly) (Figure 42). While this chart would indicate a 0.011% chance of inverter failure on any given day in contrast to a 25% failure rate for diesel generators on a given day, it is not a true apples-to-apples comparison to the failure rates in Figure 41.

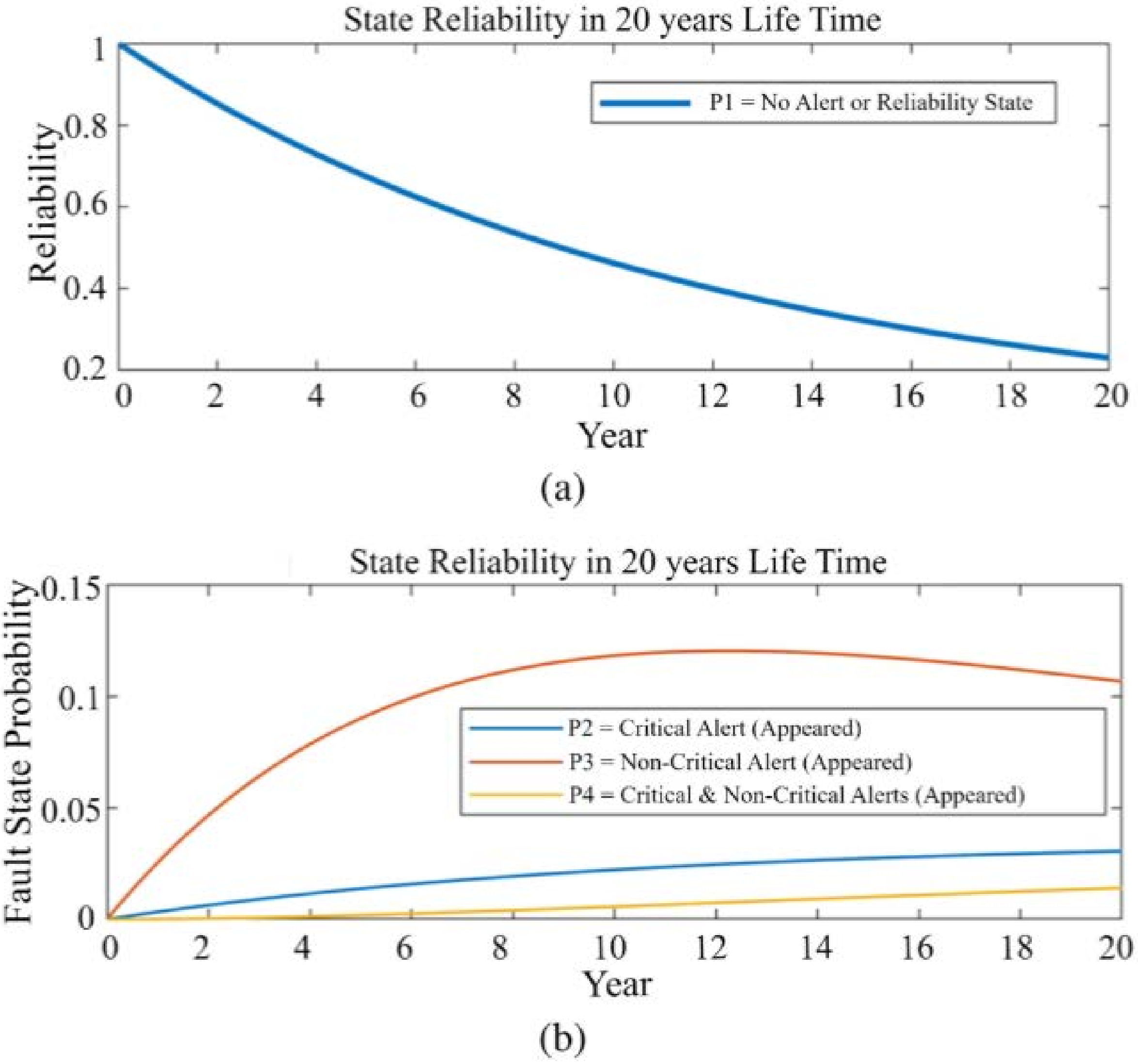

**Figure 42. Twenty-year reliability result of inverter functionality: (a) healthy state of net reliability and (b) fault state probabilities.**

Source: Roy et al. 2024

Marqusee and Stringer (2023) explored reliability during outages of emergency diesel generators, natural gas reciprocating engines, natural gas turbines, solar PV, and wind turbines, as shown in Figure 43. In the report, they note that the primary failure point for a solar PV system is the inverter, accounting for 95.8% of the total failure rate. Nevertheless, solar PV systems function 98% of the time per their analysis of the literature. They also note in the appendix that BESS are available between 95% and 99% of the time per several analyses including actual tracking, industry guarantees, and analytical modeling. For both batteries and inverters, the problems appear during steady-state use rather than showing the steep falloff after an outage begins, shown by emergency diesel generators.

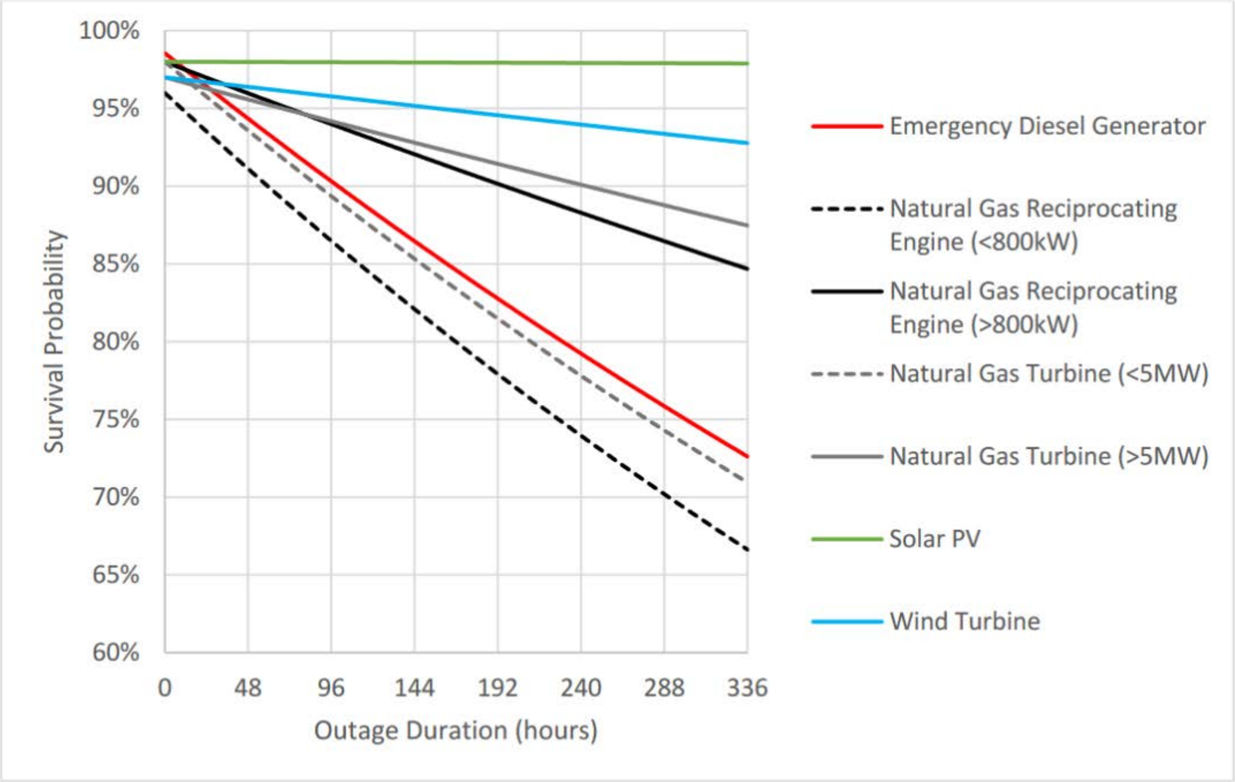

**Figure 43. Survival probability by outage duration for different backup generation technologies.**

Source: Marqusee and Stringer 2023

Ultimately, the full bidirectional charging system must be piloted in the Army National Guard environment to truly determine its reliability for that application. TXARNG can reduce its risk by monitoring the V2B systems for functionality throughout steady-state operations and bringing in repair staff quickly when maintenance is required. A dedicated cellular link would help ensure that the monitoring system functions properly and alerts critical staff such as the energy manager. Ultimately, the full bidirectional charging system must be piloted in the Army National Guard environment to truly determine its reliability for that application.

## 6.2 Technical Risks

The technical risks associated with the EV-AMP implementation focus on physical maintenance and service of EVSE hardware and activities supporting cybersecurity.

Mitigating the technical risk associated with EV-AMP implementation will rely on establishing the requisite training to operate, troubleshoot, and coordinate maintenance, repairs, and updates of supporting EVSE infrastructure. Servicing the hardware and ensuring updated system software and firmware will be critical to maintaining peak operational efficacy and system security. Establishing a coherent working relationship and a clear understanding of the system's service intervals and terms between the TXARNG and the EVSE service providers will be critical in minimizing operational disruptions of EVSE as a vehicle charger and the bidirectional charger's ability to power mission-critical facility infrastructure during a human-made or natural disaster.

Additional technical risks associated with EV-AMP programming implementation center on the risks associated with cybersecurity standards between the commercial EVSE service provider, original equipment manufacturer vehicle hardware and software, and requirements for integration into the building automation system and meter data management system update/Enterprise Energy Data Reporting System operating on the Department of Defense Information Network (DODIN). Risk mitigation will entail undergoing a comprehensive RMF process to achieve an authorization to operate (ATO). Once the ATO is established, modifications made to physical hardware will require RMF before installation. Coordinating system upgrades between the EVSE service provider, the system administrator for the TXARNG Energy Branch's building automation system, and the TXARNG's J-6 will allow the reconciliation of required updates at the weekly change control board meeting sponsored by the TXARNG J-6.

## 6.3 Cybersecurity Considerations

The authors identified the major considerations of DOD's RMF process as outlined in DOD Instruction 8510.01 specific to EVs, EV charging stations, and any associated control networks that would enable EV-AMP in the future. This involved close coordination with the TXARNG team to outline the required inputs, roles, and responsibilities during the RMF approval process of an EV-based control network.

There are two potential avenues to deployment, and the risks are described separately for each:

1. Independent EVSE communications operating between the EVSE cloud service provider and the charging unit control system.
2. EVSE communications connected to, and operational within, the DODIN.

Prior to installing building metering equipment, the authors obtained cybersecurity approval from the Information Management Division J-6 change control board. The application described the equipment installed (Appendix A) and the building loads identified for monitoring (Section 2.1).

### *6.3.1 Independent EVSE Communications*

Regardless of connection to the DODIN, any cloud-connected backup power system carries an element of cybersecurity risk. The connections to the EV manufacturer and EVSE vendor could be compromised by bad actors, disabling a charging or backup power event.

#### *EV and EVSE Cybersecurity Risks*

EV/EVSE communications can add cybersecurity risks, especially with V2G bidirectional functionalities, for various reasons (Hodge et al. 2019; Moghadasi et al. 2022). Some of them are highlighted below:

- EV threats in relations to compromised vehicle electronic control units and the potential to tamper with firmware and leak sensitive information.
- Communication protocols such as plug-and-charge can exchange financial information, vehicle and user identity, and battery SOC.

- Tampered charging stations can potentially mislead charge network operators with false data, altered business logic, and access to back-end infrastructure control parameters.
- Building or energy management systems also play a crucial role in coordination between charging station requests and utilities for various peak shaving and forecasting. Manipulated data through these management applications can disrupt operations.
- Compromised network devices can also lead to operational failures with cyberattacks such as denial of service and man-in-the-middle attacks.

Various software-related risks have been identified and documented as part of the Federal Risk and Authorization Management Program (FedRAMP) authorization process for vendors. These failures can result in negative impacts on charge site operations and have the potential to damage equipment and increase the risk to personnel safety.

### *EVSE System Capabilities and Functions*

Communication and data exchanged between EVs, chargers, charging network operators, grid operators, vendor/manufacturers, and aggregators share information such as the vehicle battery SOC, charging session duration, payment processing information, electricity price, and load control. Not only do these data run on different protocols and standards such as IEC 61850, ISO 15118, IEEE 2030.5, Open Charge Point Protocol, and many more, but there are also several entities requiring access to more and more information to perform analysis.

With regard to functionalities that enable advanced control, either to manage loads or perform ancillary services, Figure 44 depicts an overview of data flow between interconnected components that can be leveraged for authorization boundaries. These nodes communicate via different standard protocols and share a variety of information:

- Vehicle/user information.
- Vehicle identification and SOC.
- Authorized/whitelisted information (optional).
- Power delivery (voltage, current, and frequency).
- Building load.
- Aggregator command and control.
- Firmware patch/maintenance info to/from vendor and manufacturer cloud server.

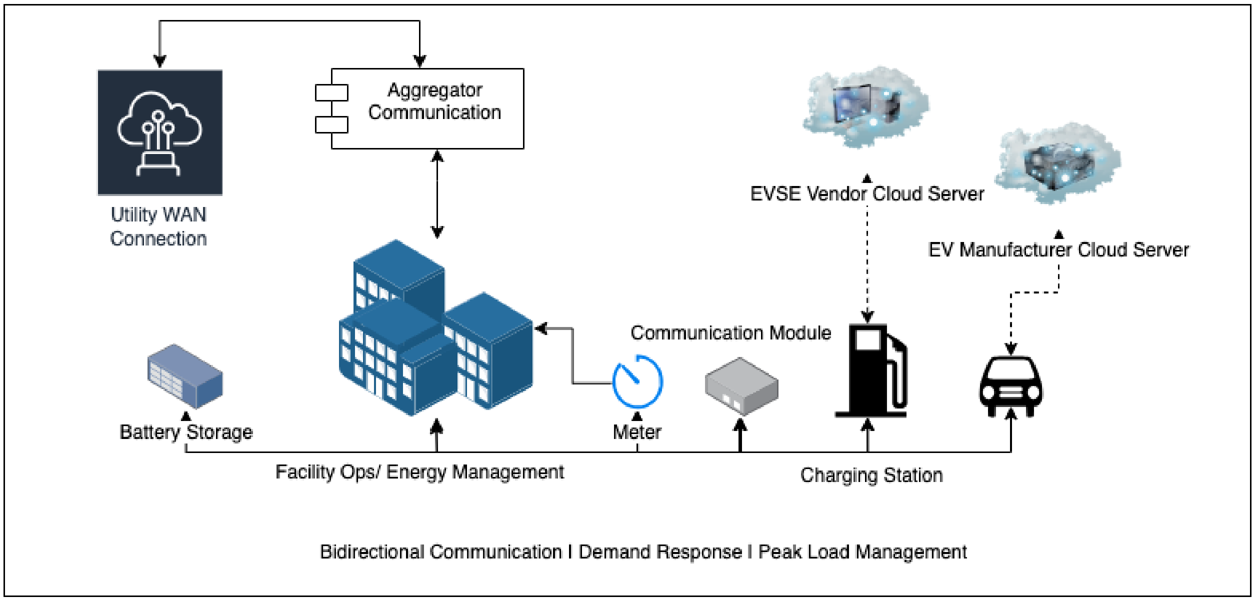

**Figure 44. Conceptual data flow/interconnection for EV, EVSE, and energy management system communication architecture**

### 6.3.2 EVSE Interaction With DODIN

DOD has adopted NIST SP 800-37 to document, identify, defend, contain, and respond to cybersecurity risks specifically for ATO on the DODIN. Additional resources for consideration when classifying systems as national security systems are directed by the Committee on National Security Systems instructions 1254 and 1253 for leveraging the NIST RMF process for national security systems, where definitions for moderate and high impact are refined from the Federal Information Processing Standards that NIST uses.

As defined in UFC 4-010-06, systems that do not classify as information technology or information systems will be included in a category called "platform information technology systems." EVSE can have interconnected communications and data elements with energy management systems that can operate within the DODIN, in which case the research team would document potential risks that charging stations add to the overall federal network. These systems, including control systems, use specifically tailored security control sets and require the authorizing official to have expertise in the system. Training materials for the authorizing official on EVSE systems are likely needed to help with consistency across DOD installations and risk assessments.

With significant diversity of EVs, EVSE, network operators, manufacturer/vendor cloud connections, DER management systems, and integration with grid components, there is an interdependency between the critical nodes for information exchange and decision-making. Even though there are benefits to this topology, cybersecurity concerns surface due to assumptions between interconnected devices. Software and hardware dependencies require the charging system owners to assume that the given firmware, application, and cloud software are trusted and securely connected with high availability and integrity. These assumptions are the root of cyber risks in the form of malware injections and remote code execution, making any trusted component of a system prone to exploitation. Charging stations and the back-end network-operated services are often connected to third-party hardware and software components requiring accurate data exchanges, external libraries, and modules to operate efficiently and could fail if the information is manipulated.

### 6.3.3 Cyber and Risk Mitigation Considerations Unique to EVSE With V2G Functions

For cybersecurity risk to be clearly articulated and have mapped consequence, it is important to identify support functions of the V2G components:

- Demand response: adversarial impacts through high-wattage loads.
- Current/voltage fluctuations: potential disruption of connected loads.
- Excessive demand during peaks: manipulation of peak loads and utility bills.
- Open Automated Demand Response (OpenADR) 2.0: standard for smart grid communications.
- Building energy management systems.

Physical architecture components that support vehicle-to-everything (V2X) or EVSE-to-everything (EVSE2X) include understanding security gaps within the controller area network (CAN) bus, Open Charge Point Protocol and Open Charge Point Interface, CHAdeMO, CCS, power line communication, cellular comms, protection circuits, etc. With this added functionality comes the added risk of monitoring the network communication and verifying if authorized vehicles, charging stations, and users have only the required level of access. EVSE system owners have an added ownership of risk delineation when producing contracts, service-level agreements, and maintenance requests.

Mitigation approaches that inform the risk management process of documentation benefit from highlighting and tailoring security controls for each EVSE, back-end server, and cloud connection intercommunication:

- Network segmentations and security zones.
- Implementation of Transport Layer Security.
- Application-aware firewalls.
- Digital certificate for authentication.
- Data integrity verification through hashing.

In the system design stage, this project should incorporate Unified Facilities Criteria (UFC) requirements; reduce dependency on the network through isolation, segmentation, zones, and other mitigation measures; and apply the principles of least functionality.

# 7 Deployment Plan

Based on the availability of 21 vehicles that could be replaced with bidirectional EVs operating consistently in the vicinity of the greater Austin area, the power requirements of three sites never exceeding more than 10 kW, the lack of reliability for existing resilience solutions, and the cost benefits of bidirectional chargers for resilience compared to alternative approaches, the authors recommend proceeding with EV-AMP for Camp Swift, Bee Caves, and San Marcos. Due to the larger power requirements at the Camp Mabry B8 JOC and B75 SCIF, the authors recommend considering alternative solutions such as stationary BESS.

Camp Swift should have two chargers installed to take advantage of the smart charging benefits to the site, but Bee Caves and San Marcos only require one charger for each location. The authors recommend transitioning seven pickup trucks to bidirectional electric Silverados with the extended-range pack (or an equivalent quantity of energy provided by different EVs with smaller batteries). That would enable TXARNG to support 72 hours of grid outages at Camp Swift, Bee Caves, and San Marcos simultaneously. TXARNG should consider the mix of vehicles up for replacement and the limited inter-compatibility of OEM V2X solutions at present.

## 7.1 Conceptual Design

The conceptual design is shown in Figure 45 using GM's balance-of-system components. Once a power outage occurs, the dark-start battery is used to ensure the system is still running. The transfer switch is essential for disconnecting the system from the grid and preventing backfeeding to the grid. The inverter contains controls to begin discharging from the compatible EV through the charger and sends power to the critical subpanel to provide power to the critical loads in the building.

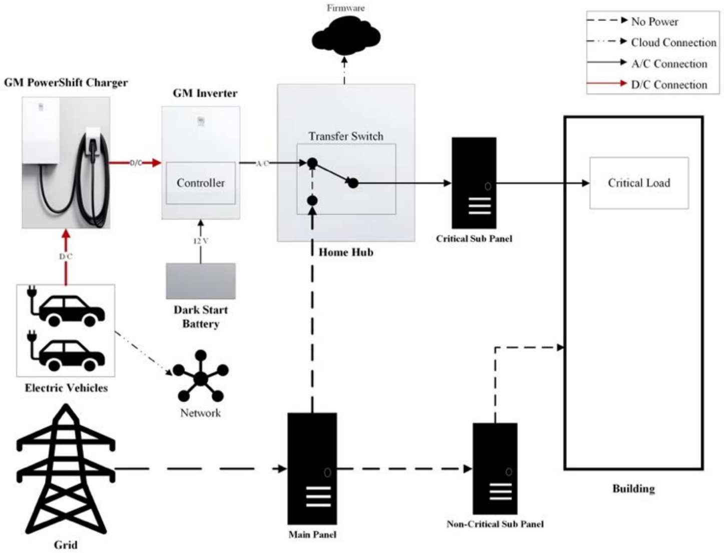

Figure 45. One-line diagram of system configuration

After meeting with manufacturer representatives, it was determined that the easiest method to handle the large building loads would be by connecting one EV to one charger at a time. When that vehicle's battery becomes depleted, TXARNG can switch the plug to a second EV, and later a third if necessary. The dark-start battery allows the system to continue providing power to the buildings for an hour or more during this transition period.

A second option for larger loads would require feeding the chargers to separate subpanels. This also allows multiple vehicles to be plugged into and feed their respective loads at the same time. Another key design takeaway is the use of offboard energy storage, which allows multiple vehicles to inject power into a microgrid setup that provides smoother power whenever the grid no longer does. This design would be essential for scalability to larger sites, but it is not required at Bee Caves, Camp Swift, or San Marcos.

Figure 46–Figure 48 present the site drawings prepared by Arcos for the three primary site selections: Camp Swift RC, San Marcos RC, and Bee Cave SOD-A. These drawings provide a comprehensive overview of the essential components for each location:

- Electrical room: The central hub for managing electrical connections and control systems.
- Underground service cabling: The necessary infrastructure to connect various components and ensure reliable power distribution.
- Service mount (if needed): A structure to support electrical equipment and ensure safe operation.
- Location of the bidirectional charger: Strategic placement of the charging units to optimize efficiency and accessibility.

Additionally, the site layouts will incorporate the offboard equipment depicted in Figure 45. For further technical details, a more in-depth one-line diagram is included in Figure B-3, which specifies the components used and their respective specifications.

Figure 46. Camp Swift RC site layout

**Figure 47. San Marcos RC site layout**

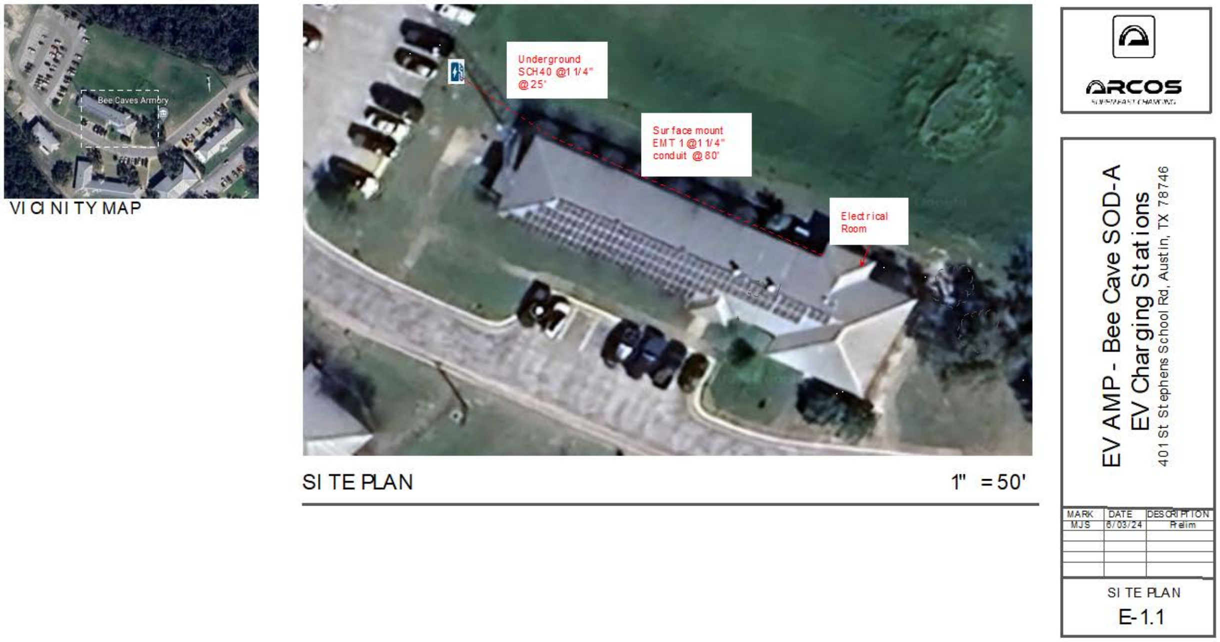

**Figure 48. Bee Cave SOD-A site layout**

## 7.2 Cybersecurity Pathway to ATO

Full demonstration of capabilities, once built, would require an RMF ATO by the eventual system owner, to be granted by the relevant cybersecurity authority for the network to which the system may be connected. These authorizations typically take between 1 and 3 years.

NREL can assist TXARNG in the development of a detailed RMF ATO process document outlining a detailed list of the requirements from the engineer of record to be submitted into Step 1 of the RMF process. Initial discussions will also be outlined with TXARNG, Army, and DOD personnel to fully understand and initiate the longer process flow.

During the deployment phase, the NREL team recommends performing cybersecurity testing using scaled control networks, such as those found at NREL's Energy Systems Integration Facility. The cybersecurity team will leverage existing hardware and procure additional chargers on which to perform cybersecurity analysis. A test case document will be developed that details cybersecurity scenarios specifically aligned with the Army National Guard's mission for V2G-enabled EVSE infrastructure.

The experimental setup will inform the specific RMF process required documentation as highlighted below:

- Identified EV, EVSE, and energy management system risks documented within the system security plans.
- Tailored security controls from NIST SP 800-53 and 800-82 that would need to be developed, documented, and implemented.
- Guidance on system authorization boundaries, system information data types, and system impact categorization.
- Recommended security control implementation details to ease ATO workflow and accelerate achieving and maintaining authorizations.
- Guided documentation within the Distributed Energy Resource Risk Manager (NREL 2022) and version-controlled ATO package reports.

NIST SP 800-82 would need to be applied along with the NIST fast charging cybersecurity profile (NIST 2023) and the EVSE cybersecurity best practice and procurement language reports developed by the U.S. Department of Transportation Volpe Center, Naval Facilities Engineering Systems Command, and others (Harnett et al. 2018) to tailor NIST SP 800-53 controls to EVSE systems and assets with V2G capabilities. To systematically evaluate and manage cybersecurity risk, various RMF requirements and documentation would be needed:

- System security plans.
- Risk assessment reports.
- Security assessment reports.
- Plan of action and milestone reports.

The testing conducted at the Energy Systems Integration Facility would address Army National Guard needs for smooth operation of the EVSE ecosystem, ensuring proper management of added risks and any associated incident response strategies.

## 7.3 Procurement

TXARNG's optimal procurement pathway would be through the GSA's indefinite demand, indefinite quantity (IDIQ) EVSE unit and construction contract. However, there are no bidirectional chargers meeting the TXARNG specifications on the GSA schedule at this time.

For the purposes of a test project, NREL could procure hardware and installation services for TXARNG through a partnership with GM. For expansion beyond the pilot, TXARNG would leverage its own procurement authority to select and install chargers. The TXARNG Energy Team will be responsible for the hardware delivery, interim storage, site access, labor scheduling, and facility maintenance staff coordination.

## 7.4 Operations and Maintenance

A maintenance plan is necessary for smooth operation of the bidirectional chargers. This can greatly increase the reliability of the system and ensure that an inverter or other critical piece of equipment has not failed during the ensuing time period so that TXARNG is prepared in the event of an actual emergency and power outage. TXARNG would adhere to the following schedule:

### 7.4.1 Monthly Maintenance

1. Visual inspection
    A. Check for physical damage, wear, or vandalism.
    B. Ensure the connectors and cables are in good condition.
    C. Verify that all indicators and displays are functioning correctly.
2. Cleaning
    A. Clean the exterior of the EVSE units to remove dirt, dust, and debris.
    B. Inspect and clean connectors and cables to ensure proper connection.
3. Software monitoring
    A. Review system logs for any anomalies or error codes.
    B. Monitor network connectivity and data transmission integrity.

### 7.4.2 Quarterly Maintenance

1. Functional testing
    A. Perform a full functional test to ensure the EVSE is operating correctly.
    B. Check charging speed and performance metrics.
2. Safety checks
    A. Inspect and test safety features such as emergency stop buttons and grounding systems.
    B. Ensure compliance with local safety regulations.
3. Firmware and software updates
    A. Apply minor firmware updates and patches as needed.
    B. Update software for user interface and back-end management systems.
4. Connectivity testing
    A. Test the EVSE’s connection to the central management system.
    B. Verify communication with payment and authentication systems.

### 7.4.3 Biannual Maintenance

1. Comprehensive inspection
    A. Conduct a thorough inspection of internal components.
    B. Check the integrity of power supply connections and circuit boards.
2. Performance evaluation
    A. Evaluate the performance logs and user feedback for potential issues.

    B. Test for efficiency and any signs of degradation.
3. Major software updates
    A. Implement significant software updates that improve functionality or security.
    B. Ensure all updates are compatible with existing hardware and other software components.
4. Firmware cyclical updates
    A. Conduct scheduled cyclical firmware updates to ensure all EVSE units run the latest stable firmware.
    B. Test all features post-update to verify proper operation.

### 7.4.4 Annual Maintenance

1. Full system audit
    A. Perform a comprehensive audit of the entire EVSE system, including hardware, software, and network components.
    B. Document all findings and rectify any issues found.
2. Component replacement
    A. Replace any components showing signs of wear or nearing the end of their life cycle.
    B. Update internal hardware components if newer, more efficient versions are available.
3. Firmware review and update
    A. Review the firmware update cycle and apply for any significant firmware releases.
    B. Validate the entire system's operation post-update.
4. Compliance and certification
    A. Ensure the EVSE meets all regulatory and certification requirements.
    B. Perform any necessary upgrades or changes to maintain compliance.

### 7.4.5 Additional Considerations

1. Emergency maintenance protocol for emergency repairs and updates
    A. Maintain a stock of critical spare parts for quick replacements.
2. User training
    A. Provide regular training for maintenance staff on new updates and procedures.
    B. Ensure all staff are familiar with emergency protocols and safety procedures.
3. Documentation
    A. Keep detailed records of all maintenance activities, updates, and inspections.
    B. Use these records to inform future maintenance schedules and improvements.

# 8 Conclusion

EV-AMP has the potential to offer a backup power solution with improved reliability with significant financial cost savings for TXARNG. There are several key elements to success for EV-AMP:

1. The critical loads at certain TXARNG buildings—including standard RCs like those at Camp Swift and San Marcos and other office buildings like Bee Caves SOD-A—are fairly low, never exceeding more than 10 kW in those cases.
2. The peak power loads at the Camp Mabry B8 JOC and B75 SCIF make EV-AMP challenging from a logistical perspective to implement at those locations.
3. Several manufacturers have begun building mass-market bidirectional charging systems. The Ford-Sun Run and GM-Delta solutions are particularly apt for this application with 11.5-kW bidirectional capabilities and small backup power batteries (10.6–37.7 kWh).
4. Some newer EVs have very large battery packs, reaching up to 131 kWh for the extended-range 2024 Ford F-150 Lightning and 200 kWh in the case of the extended-range 2024 Chevrolet Silverado.
5. Seven to nine extended-range 2024 Chevrolet Silverados could power the Camp Swift RC, Bee Caves SOD-A, and San Marcos RC during an emergency. A combination of Chevrolet Blazers and Equinoxes could replace the Silverados, but they have smaller energy storage systems, and therefore more would be required.
6. In nearly all cases of historical data, EVs could arrive at Camp Swift, Bee Caves, and San Marcos within 1 hour and provide backup power to the sites.
7. The literature is clear that emergency diesel generators and most other backup power solutions are limited in terms of reliability. The literature indicates that inverters are the most likely failure point for BESS and bidirectional charging systems. However, inverters have a higher probability of operating over the course of an extended blackout than diesel generators. The new generation of dark-start bidirectional chargers has not been studied extensively, and a pilot would be an important contribution to understanding EV-AMP resilience.
8. A solid maintenance plan such as that described in Section 7.4 can ensure that the bidirectional chargers are in optimal condition and highly likely to function properly during an emergency.
9. Installing two bidirectional chargers at Camp Swift, one at Bee Caves, and one at San Marcos is projected to cost approximately $93,600. A preliminary engineering design was completed as part of this project.
10. The NPV of using two bidirectional EVSE at Camp Swift to participate in energy arbitrage is $24,800. A combination of minimal parking time at Bee Caves and flat rates at San Marcos means there is no value to be gained from energy arbitrage at those sites.
11. The net resilience and energy arbitrage benefits of EV-AMP at the Camp Swift RC, Bee Caves SOD-A, and San Marcos are $486,700 (Table 33). Deployment of this approach has the potential to significantly improve resilience at TXARNG sites and demonstrate a new approach to resilience across DOD.

Table 33. EV-AMP Costs and Benefits by Site for 72-hours of Resilience

| Site | Equipment Installation Costs | Resilience Benefits | Energy Arbitrage Benefits | Demand Response Benefits | Net Benefit |
|---|---|---|---|---|---|
| **Camp Swift RC** | ($39,400) | $213,700 | $24,800 | $0 | $199,100 |
| **Bee Caves SOD-A** | ($28,400) | $167,300 | $0 | $130,800 | $269,700 |
| **San Marcos RC** | ($25,800) | $43,700 | $0 | $0 | $17,900 |
| **Total** | **($93,600)** | **$424,700** | **$24,800** | **$130,800** | **$486,700** |

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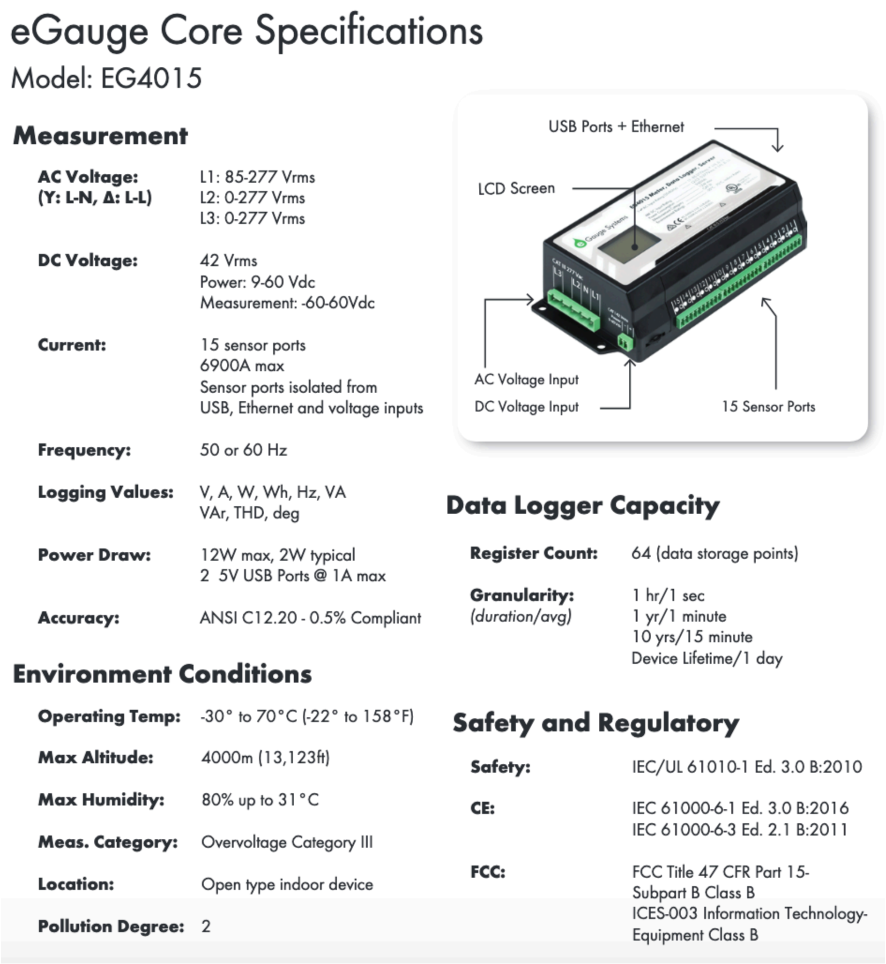
# Appendix A. Metering Equipment

Arcos Mobility installed the following equipment to meter the TXARNG charging loads:

- **eGauge EG 4015:** This data logger is flexible on input voltages, allowing it to meter voltages from 85 to 277 V on any leg of the system. NREL requires 1-minute data collected for up to 1 year in duration, which this system is capable of storing as a backup to cellular transmission.
- **eGauge ESH044:** The eGauge Sensor Hub can connect up to four sensors to EG4015 meter inputs. Any combination of powered and unpowered sensors can be used. This device allows connecting voltage sensors at a different voltage than directly connected to the EG4015 data logger.
- **eGauge EV1000:** The eGauge EV1000 is a fully isolated, high-voltage transducer that measures up to 1,000 VDC or 707 VAC. This device allows measurement of 480-V three-phase circuits.
- **Magnelab Rope CT AC Current Sensor:** These current transformers are accurate within 0.5% of reported current between 100 and 1,500 amps, which is sufficient for the EV-AMP assessment.
- **IBR 200 Series Router:** This router contains an embedded modem with two SMA cellular antenna connectors. It connects to the eGauge EG 4015 data loggers through an ethernet cable and broadcasts to a back-end eGauge system. It is not connected in any way to the DODIN.

Product sheets from each of the companies are provided below for reference.



# eGauge Core Specifications

Model: EG4015

## Measurement

| | |
|---|---|
| **AC Voltage: (Y: L-N, Δ: L-L)** | L1: 85-277 Vrms<br>L2: 0-277 Vrms<br>L3: 0-277 Vrms |
| **DC Voltage:** | 42 Vrms<br>Power: 9-60 Vdc<br>Measurement: -60-60Vdc |
| **Current:** | 15 sensor ports<br>6900A max<br>Sensor ports isolated from USB, Ethernet and voltage inputs |
| **Frequency:** | 50 or 60 Hz |
| **Logging Values:** | V, A, W, Wh, Hz, VA<br>VAr, THD, deg |
| **Power Draw:** | 12W max, 2W typical<br>2 5V USB Ports @ 1A max |
| **Accuracy:** | ANSI C12.20 - 0.5% Compliant |

## Environment Conditions

| | |
|---|---|
| **Operating Temp:** | -30° to 70°C (-22° to 158°F) |
| **Max Altitude:** | 4000m (13,123ft) |
| **Max Humidity:** | 80% up to 31°C |
| **Meas. Category:** | Overvoltage Category III |
| **Location:** | Open type indoor device |
| **Pollution Degree:** | 2 |

## Data Logger Capacity

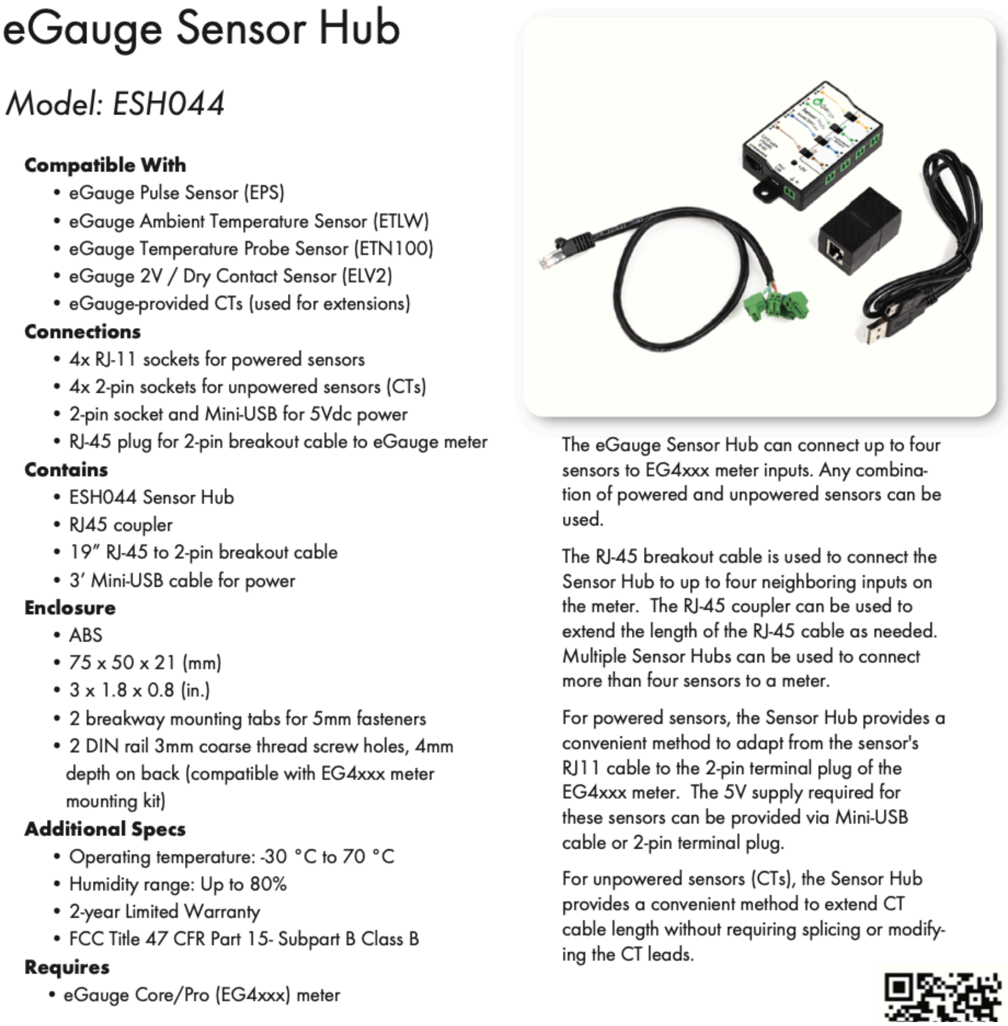
| | |
|---|---|
| **Register Count:** | 64 (data storage points) |
| **Granularity:** *(duration/avg)* | 1 hr/1 sec<br>1 yr/1 minute<br>10 yrs/15 minute<br>Device Lifetime/1 day |

## Safety and Regulatory

| | |
|---|---|
| **Safety:** | IEC/UL 61010-1 Ed. 3.0 B:2010 |
| **CE:** | IEC 61000-6-1 Ed. 3.0 B:2016<br>IEC 61000-6-3 Ed. 2.1 B:2011 |
| **FCC:** | FCC Title 47 CFR Part 15-Subpart B Class B<br>ICES-003 Information Technology-Equipment Class B |

**Figure A-1. eGauge EG4015 specifications.**

Source: eGauge



# eGauge Sensor Hub

## *Model: ESH044*

**Compatible With**

- eGauge Pulse Sensor (EPS)
- eGauge Ambient Temperature Sensor (ETLW)
- eGauge Temperature Probe Sensor (ETN100)
- eGauge 2V / Dry Contact Sensor (ELV2)
- eGauge-provided CTs (used for extensions)

**Connections**

- 4x RJ-11 sockets for powered sensors
- 4x 2-pin sockets for unpowered sensors (CTs)
- 2-pin socket and Mini-USB for 5Vdc power
- RJ-45 plug for 2-pin breakout cable to eGauge meter

**Contains**

- ESH044 Sensor Hub
- RJ45 coupler
- 19" RJ-45 to 2-pin breakout cable
- 3' Mini-USB cable for power

**Enclosure**

- ABS
- 75 x 50 x 21 (mm)
- 3 x 1.8 x 0.8 (in.)
- 2 breakway mounting tabs for 5mm fasteners
- 2 DIN rail 3mm coarse thread screw holes, 4mm depth on back (compatible with EG4xxx meter mounting kit)

**Additional Specs**

- Operating temperature: -30 °C to 70 °C
- Humidity range: Up to 80%
- 2-year Limited Warranty
- FCC Title 47 CFR Part 15- Subpart B Class B

**Requires**

- eGauge Core/Pro (EG4xxx) meter

The eGauge Sensor Hub can connect up to four sensors to EG4xxx meter inputs. Any combination of powered and unpowered sensors can be used.

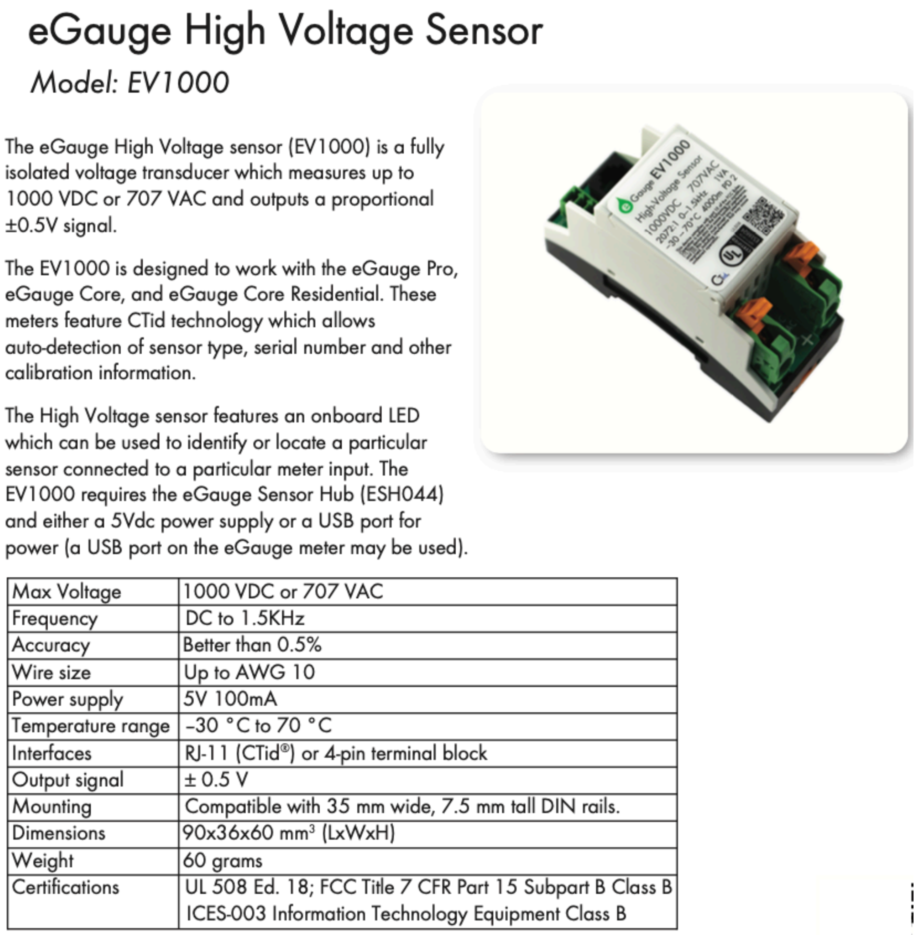
The RJ-45 breakout cable is used to connect the Sensor Hub to up to four neighboring inputs on the meter. The RJ-45 coupler can be used to extend the length of the RJ-45 cable as needed. Multiple Sensor Hubs can be used to connect more than four sensors to a meter.

For powered sensors, the Sensor Hub provides a convenient method to adapt from the sensor's RJ11 cable to the 2-pin terminal plug of the EG4xxx meter. The 5V supply required for these sensors can be provided via Mini-USB cable or 2-pin terminal plug.

For unpowered sensors (CTs), the Sensor Hub provides a convenient method to extend CT cable length without requiring splicing or modifying the CT leads.

**Figure A-2. eGauge ESH044 specifications.**

Source: eGauge



# eGauge High Voltage Sensor

*Model: EV1000*

The eGauge High Voltage sensor (EV1000) is a fully isolated voltage transducer which measures up to 1000 VDC or 707 VAC and outputs a proportional ±0.5V signal.

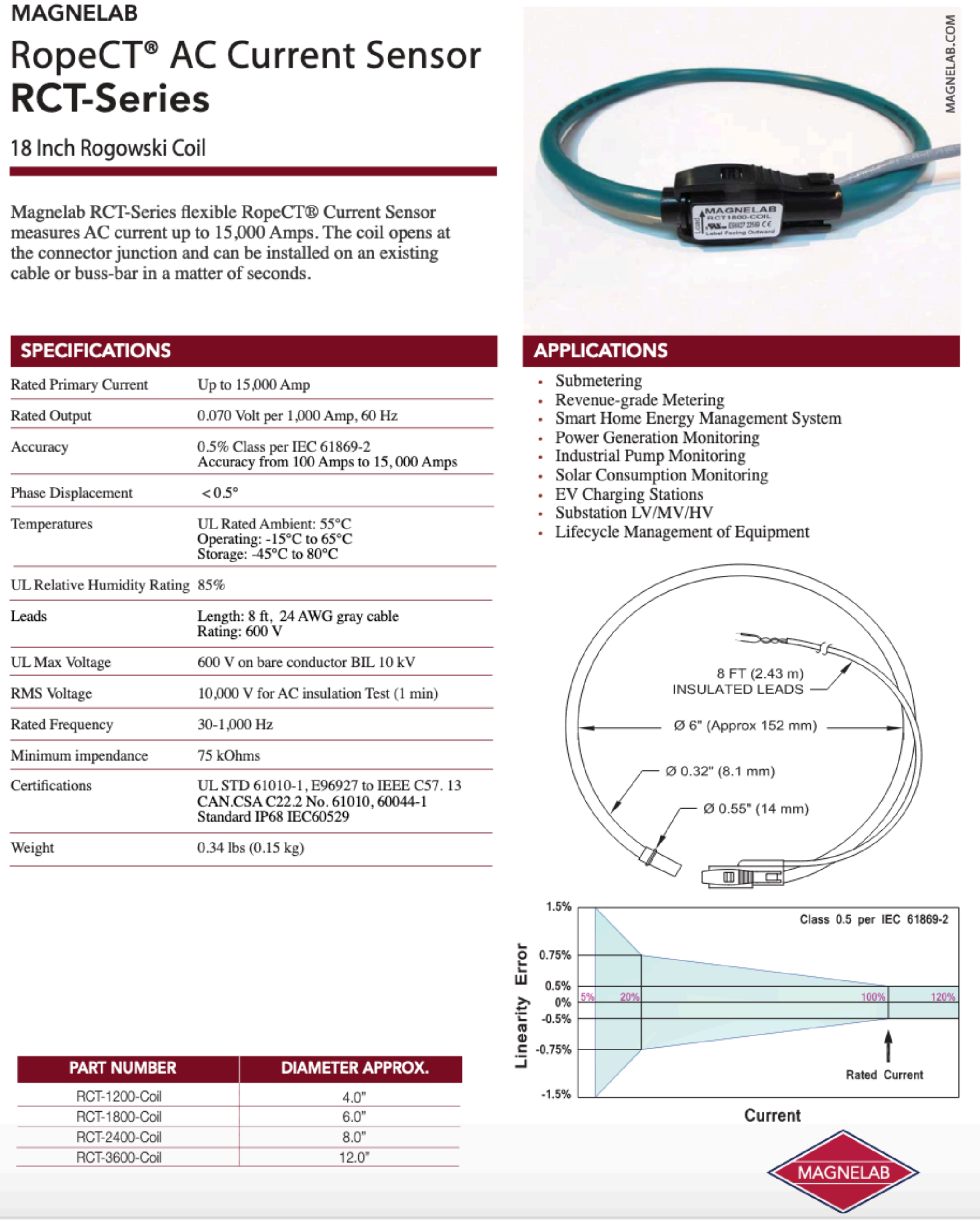
The EV1000 is designed to work with the eGauge Pro, eGauge Core, and eGauge Core Residential. These meters feature CTid technology which allows auto-detection of sensor type, serial number and other calibration information.

The High Voltage sensor features an onboard LED which can be used to identify or locate a particular sensor connected to a particular meter input. The EV1000 requires the eGauge Sensor Hub (ESH044) and either a 5Vdc power supply or a USB port for power (a USB port on the eGauge meter may be used).

| | |
|---|---|
| Max Voltage | 1000 VDC or 707 VAC |
| Frequency | DC to 1.5KHz |
| Accuracy | Better than 0.5% |
| Wire size | Up to AWG 10 |
| Power supply | 5V 100mA |
| Temperature range | –30 °C to 70 °C |
| Interfaces | RJ-11 (CTid®) or 4-pin terminal block |
| Output signal | ± 0.5 V |
| Mounting | Compatible with 35 mm wide, 7.5 mm tall DIN rails. |
| Dimensions | 90x36x60 mm$^3$ (LxWxH) |
| Weight | 60 grams |
| Certifications | UL 508 Ed. 18; FCC Title 7 CFR Part 15 Subpart B Class B<br>ICES-003 Information Technology Equipment Class B |

**Figure A-3. eGauge EV1000 specifications.**

Source: eGauge



**MAGNELAB**

RopeCT® AC Current Sensor
**RCT-Series**

18 Inch Rogowski Coil

Magnelab RCT-Series flexible RopeCT® Current Sensor measures AC current up to 15,000 Amps. The coil opens at the connector junction and can be installed on an existing cable or buss-bar in a matter of seconds.

**SPECIFICATIONS**

| | |
|---|---|
| Rated Primary Current | Up to 15,000 Amp |
| Rated Output | 0.070 Volt per 1,000 Amp, 60 Hz |
| Accuracy | 0.5% Class per IEC 61869-2<br>Accuracy from 100 Amps to 15, 000 Amps |
| Phase Displacement | < 0.5° |
| Temperatures | UL Rated Ambient: 55°C<br>Operating: -15°C to 65°C<br>Storage: -45°C to 80°C |
| UL Relative Humidity Rating | 85% |
| Leads | Length: 8 ft, 24 AWG gray cable<br>Rating: 600 V |
| UL Max Voltage | 600 V on bare conductor BIL 10 kV |
| RMS Voltage | 10,000 V for AC insulation Test (1 min) |
| Rated Frequency | 30-1,000 Hz |
| Minimum impendance | 75 kOhms |
| Certifications | UL STD 61010-1, E96927 to IEEE C57. 13<br>CAN.CSA C22.2 No. 61010, 60044-1<br>Standard IP68 IEC60529 |
| Weight | 0.34 lbs (0.15 kg) |

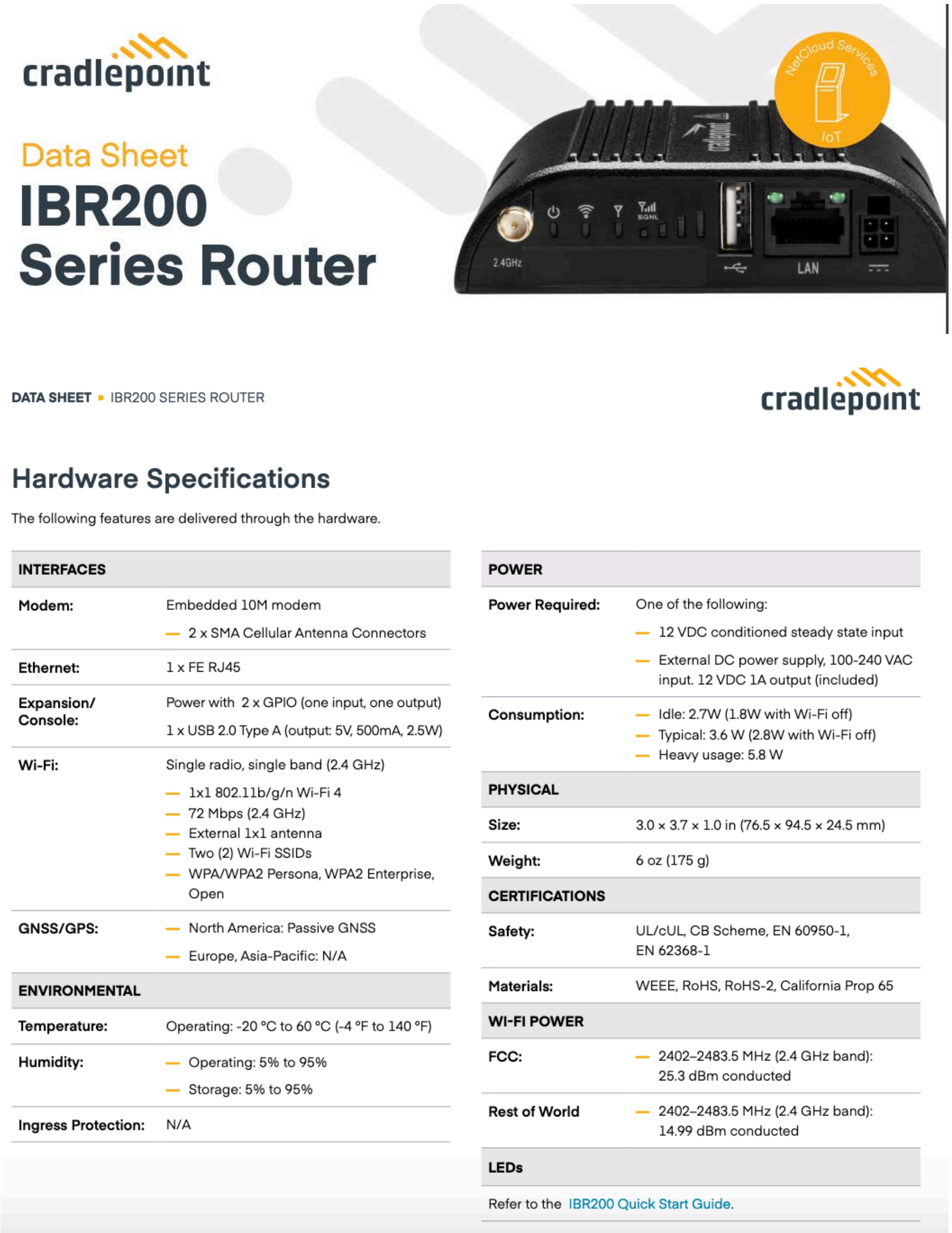
**APPLICATIONS**

- Submetering
- Revenue-grade Metering
- Smart Home Energy Management System
- Power Generation Monitoring
- Industrial Pump Monitoring
- Solar Consumption Monitoring
- EV Charging Stations
- Substation LV/MV/HV
- Lifecycle Management of Equipment

| PART NUMBER | DIAMETER APPROX. |
|---|---|
| RCT-1200-Coil | 4.0" |
| RCT-1800-Coil | 6.0" |
| RCT-2400-Coil | 8.0" |
| RCT-3600-Coil | 12.0" |

Figure A-4. Magnelab RopeCT specifications.

Source: Magnelab



cradlepoint

Data Sheet

IBR200
Series Router

DATA SHEET ▪ IBR200 SERIES ROUTER

cradlepoint

## Hardware Specifications

The following features are delivered through the hardware.

| **INTERFACES** | |
|---|---|
| **Modem:** | Embedded 10M modem<br>— 2 x SMA Cellular Antenna Connectors |
| **Ethernet:** | 1 x FE RJ45 |
| **Expansion/ Console:** | Power with 2 x GPIO (one input, one output)<br>1 x USB 2.0 Type A (output: 5V, 500mA, 2.5W) |
| **Wi-Fi:** | Single radio, single band (2.4 GHz)<br>— 1x1 802.11b/g/n Wi-Fi 4<br>— 72 Mbps (2.4 GHz)<br>— External 1x1 antenna<br>— Two (2) Wi-Fi SSIDs<br>— WPA/WPA2 Persona, WPA2 Enterprise, Open |
| **GNSS/GPS:** | — North America: Passive GNSS<br>— Europe, Asia-Pacific: N/A |
| **ENVIRONMENTAL** | |
| **Temperature:** | Operating: -20 °C to 60 °C (-4 °F to 140 °F) |
| **Humidity:** | — Operating: 5% to 95%<br>— Storage: 5% to 95% |
| **Ingress Protection:** | N/A |

| **POWER** | |
|---|---|
| **Power Required:** | One of the following:<br>— 12 VDC conditioned steady state input<br>— External DC power supply, 100-240 VAC input. 12 VDC 1A output (included) |
| **Consumption:** | — Idle: 2.7W (1.8W with Wi-Fi off)<br>— Typical: 3.6 W (2.8W with Wi-Fi off)<br>— Heavy usage: 5.8 W |
| **PHYSICAL** | |
| **Size:** | 3.0 × 3.7 × 1.0 in (76.5 × 94.5 × 24.5 mm) |
| **Weight:** | 6 oz (175 g) |
| **CERTIFICATIONS** | |
| **Safety:** | UL/cUL, CB Scheme, EN 60950-1, EN 62368-1 |
| **Materials:** | WEEE, RoHS, RoHS-2, California Prop 65 |
| **WI-FI POWER** | |
| **FCC:** | — 2402–2483.5 MHz (2.4 GHz band): 25.3 dBm conducted |
| **Rest of World** | — 2402–2483.5 MHz (2.4 GHz band): 14.99 dBm conducted |
| **LEDs** | |
| Refer to the IBR200 Quick Start Guide. | |

**Figure A-5. Cradlepoint IBR200 series router specifications.**

Source: Cradlepoint

# Appendix B. Miscellaneous Diagrams and Images

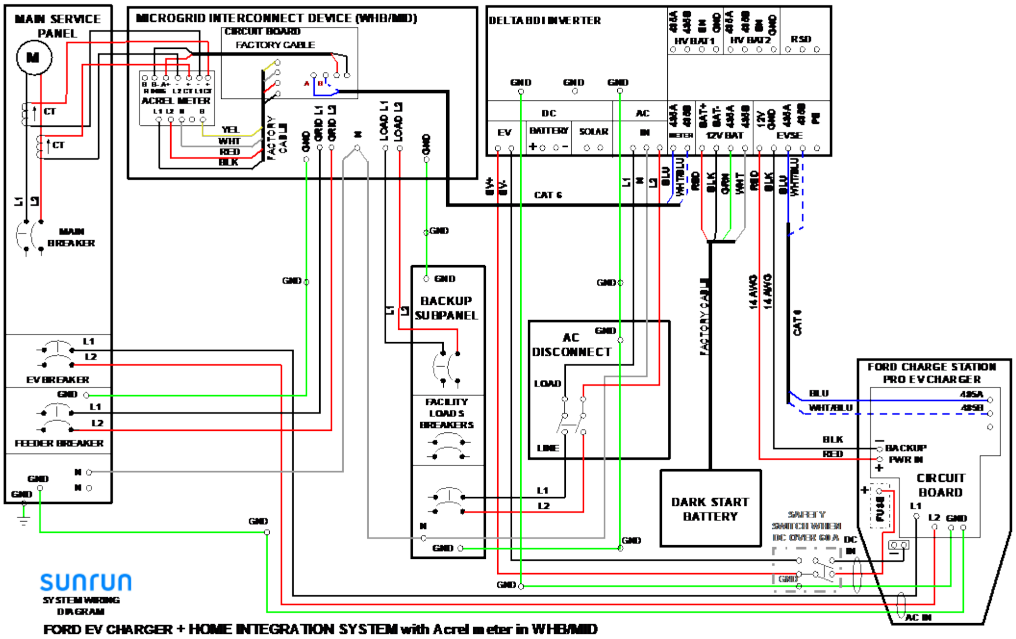


**Figure B-1. Ford Home Integration wire diagram.**

Source: sites.google.com/sunrun.com/sop/sops/ev-chargers/ford-ev-charger/diagrams?authuser=0

**Figure B-2. GM Energy V2H Bundle.**

Source: gmenergy.gm.com/for-home/products/gm-energy-v2h-bundle

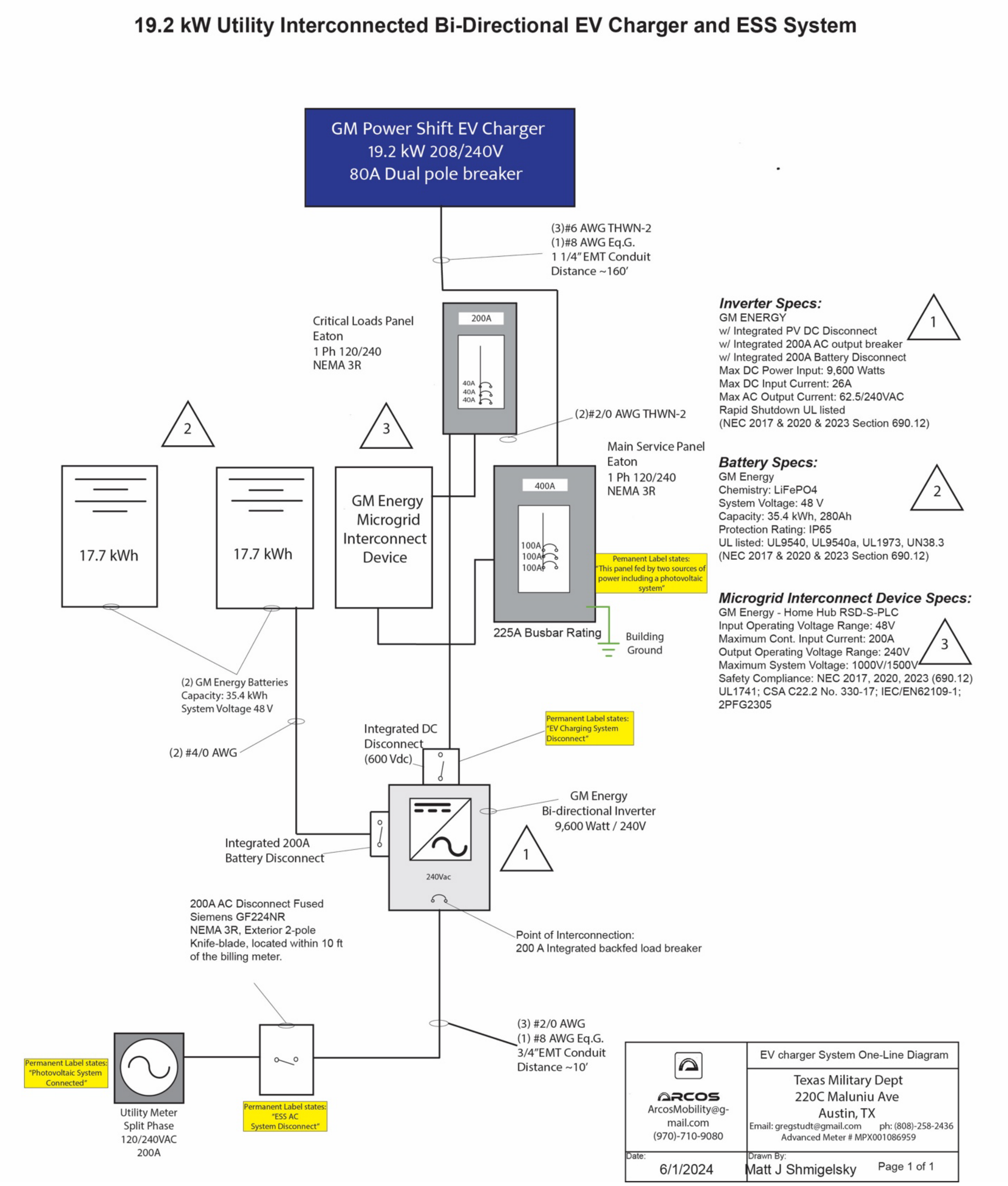


**Figure B-3. EV charger one-line diagram**

# Appendix C. Electric Load Profiles and Tariffs

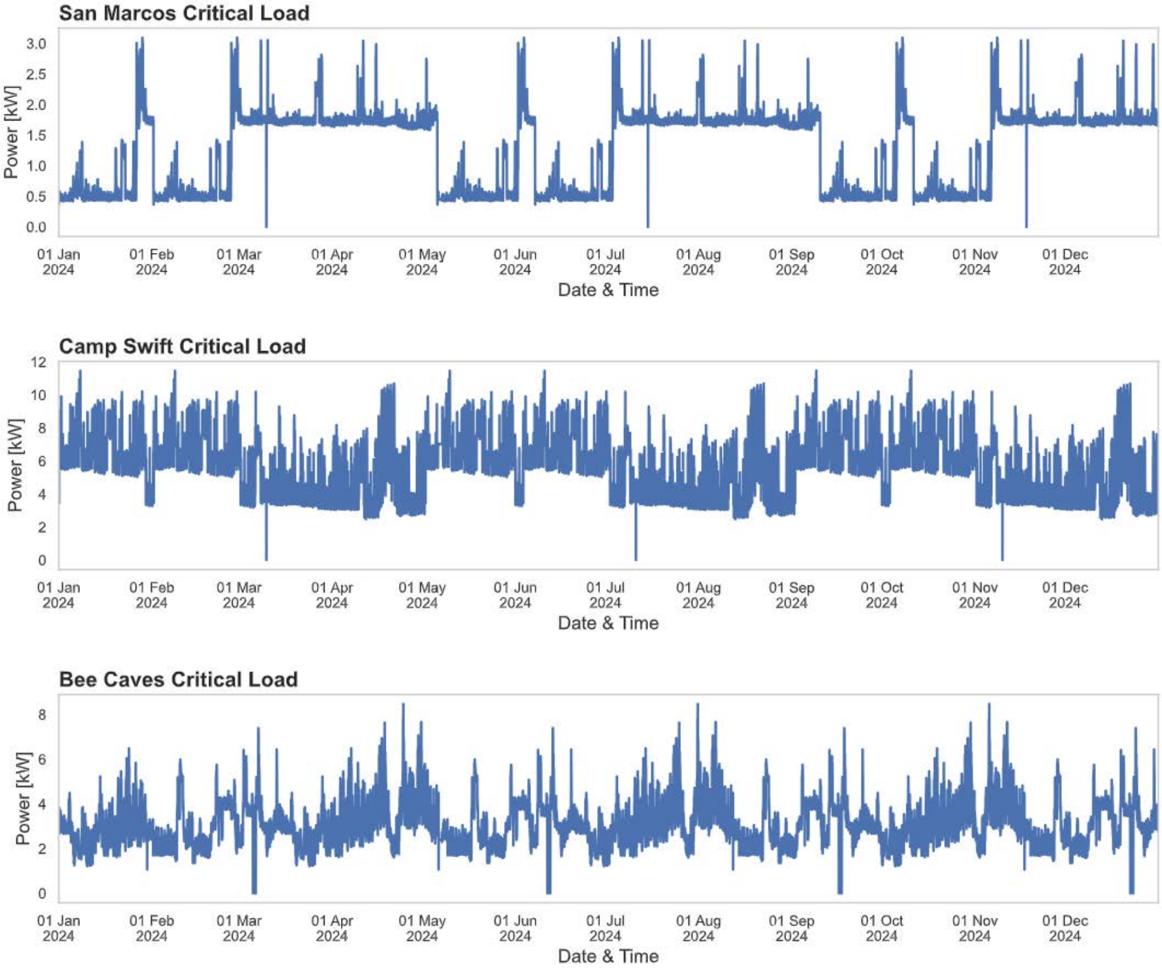


**Figure C-1. Forecasted critical load time series at RCs extrapolated from known load**

The following rate schedule was used for Bee Caves life cycle electricity cost minimization.

**Table C-1. Austin Energy's Commercial Secondary Voltage (10 – 300 kW) rate**

| | Value | Adjustments |
|---|---|---|
| Fixed charges | $56.10/month | N/A |
| Demand charges | $9.18/kW | $3.83/kW |
| Energy charges | $0.01804/kWh | $0.05049/kWh |

The following rate schedules were used for Camp Swift life cycle electricity cost minimization.

**Table C-2. BlueBonnet Coop's Commercial Three-Phase Service Rate**

| | Value | Wholesale Energy Charge/Adjustments |
|---|---|---|
| Fixed charges | $50.00/month | N/A |
| Energy charges | $0.039114/kWh | $0.058936/kWh |

If a site's billed demand exceeds 50 kW and is less than 250 kW, it is served by Blue Bonnet Coop's Large Power rate.

**Table C-3. BlueBonnet Coop's Commercial Large Power rate**

| | Value | Wholesale Energy Charge/Adjustments |
|---|---|---|
| Fixed charges | $75.00/month | N/A |
| Energy charges | $0.015091/kWh | $0.058936/kWh |
| Demand charges | $5.00/kW | N/A |

Camp Swift's load profile used as an input in the life cycle electricity cost minimization:

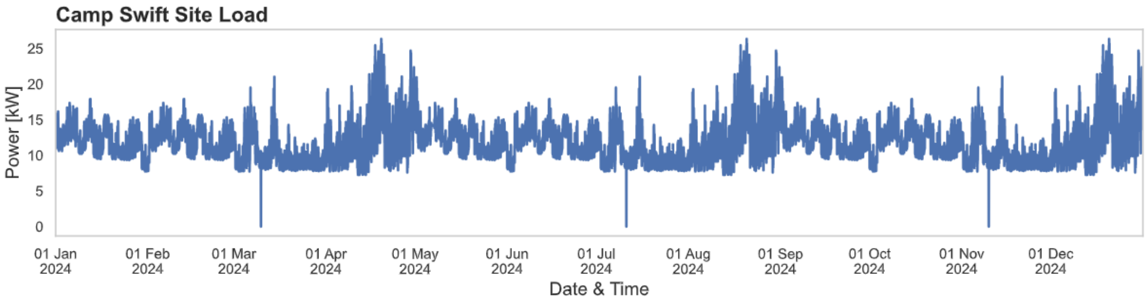


**Figure C-2. Forecasted site load time series at Camp Swift extrapolated from known load**