CHARGING STATION DESIGN GUIDANCE TOOLBOX

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Island Regional Vehicle Electrification Study
MAKERS architecture and urban design | DKS Associates

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INTRODUCTION

PROJECT OVERVIEW

The Island Regional Vehicle Electrification Study is intended to support a region-wide policy that supports increased adoption of electric vehicles (EV), improved charging infrastructure accessibility, adoption of EV-ready building codes among local jurisdictions, and fleet electrification for municipalities, businesses, and other agencies and organizations. This project involves:

A. Public outreach to engage residents and gather charger needs information,
B. Documenting emerging electromobility trends to develop a strategic assessment of municipal fleet electrification potential,
C. Supporting outreach with private businesses as potential future charging station hosts,
D. Developing a charging station design guidance toolbox,
E. Researching local, state, national, and international EV-ready codes, and
F. Developing model electrification policies to be considered for adoption by participating jurisdictions.

DOCUMENT ORGANIZATION

The "charging station design guidance toolbox" provides the following information to assist municipal fleet and facility managers and potential charging station hosts in installing charging stations and supporting EV adoption:

Section 1: Reviews EV charger types including Level 1, Level 2, Direct Current (DC) Fast Charger, and High-Powered Chargers.

Section 2: Explains key considerations when determining EV charger size or power rating.

Section 3: Summarizes important considerations when selecting a charger and compares charging speeds, power rating, features, and approximate cost of existing charger models.

Section 4: Lists recommendations for placing and installing chargers.

Section 5: Reviews operations and maintenance strategies.

Section 6: Discusses existing and near-future electric vehicle charging technologies.

Section 7: Describes and evaluates five different charging strategies and lists recommendations specific to municipal fleets.

Sections 1-5 are intended for use by potential charging station hosts. All seven sections are intended for use by municipal fleet and facility managers.

This industry is quickly evolving, and information provided in this document is current as of April 2021.

1. CHARGER OVERVIEW

Electric Vehicle Supply Equipment (EVSE) is the equipment used to deliver electricity to an EV to ensure that an appropriate and safe flow of electricity is supplied.

EVSE is classified into categories based on the rate at which the EV's batteries are charged. Level 1 and Level 2 provide alternating current (AC) to the vehicle, with the vehicle's on-board equipment converting AC to the direct current (DC) needed to charge the vehicle's batteries. DC fast charging (or DCFC) provides DC electricity directly to the vehicle.

Charging times can range from 30 minutes to 20 hours or more, depending on the type and power of EVSE, the vehicle battery's capacity, state of charge, and the vehicle's acceptance rate or charging speed.

EV chargers are identified by their input voltage and are designed and sold by different manufacturers with different prices, applications, and functionality. Figure 1 below illustrates the difference in charging speeds (hours required for optimum battery charge) between Level 1, Level 2, and DC chargers.

EV Battery Charging Times

Electric Vehicles (EV)	Battery Capacity in kWh	Acceptance Rate in kW		Time Required for Optimum (80%) Battery Charged Based on Charger Loads in Hours											
				Level 1 Chargers		Level 2 Chargers						DC Fast Chargers			
		AC	DC	1.4[1]	1.9[1]	3.6	6.6	7.2	9.6	12	19.2	50	100	150	175
Nissan Leaf	40	6.6	150	22.9	16.9	8.9	4.9	4.9	4.9	4.9	4.9	0.7	0.4	0.3	N/A
Chevrolet Bolt	66	7.2	50	37.8	27.8	14.7	10.9	7.4	7.4	7.4	7.4	1.1	N/A	N/A	N/A
Lordstown Endurance	109	11	150	62.3	45.9	24.2	13.2	12.1	9.1	9.1	9.1	1.8	0.9	0.6	N/A
Tesla Model X/S	100	11.5-17.5	200	57.2	42.2	22.3	12.2	11.2	8.4	6.7	4.7	1.6	0.8	0.6	0.5
Ford Mach-E	98.8	10.5	150	56.5	41.6	22.0	5.1	11.0	8.3	8.3	8.3	1.6	0.8	0.6[2]	N/A
Ford E-Transit	67	11	100	38.3	28.3	14.9	8.2	7.5	5.6	4.9	4.9	1.1	0.6	N/A	N/A
Nissan Ariya	65	7.2	130	37.2	27.4	14.5	7.9	7.3	7.3	7.3	7.3	1.1	0.6	N/A	N/A

Note 1: Level 1 chargers include 16A (1.4kW) and 20A (1.9kW) breaker ampacity.

00.0 = kW

Note 2: The base Select Ford Mustang Mach-E modal is capable of up to 115 kW of fast-charging capability, while all other Mustang Mach-E models will go to 150 kW.

Figure 1: EV Charger Speed Comparison

LEVEL 1 CHARGING

Level 1 EVSE provides charging through a standard three-pronged 120-volt (V) AC house plug with a J1772[1] standard vehicle connector and requires a dedicated branch circuit. Most, if not all, EVs come with a Level 1 EVSE cord set such that no additional charging equipment is required. Level 1 is usually used for charging when there is only a 120V outlet available, typically seen in most single-family residential homes.

The main advantage of Level 1 EVSE is that it requires no additional infrastructure or investment, while the main disadvantage is that it is slow compared to other options.

Level 1 charging is the most cost-effective way to provide low-speed charging for small numbers of vehicles with longer parking times; however, it is not recommended to meet most municipal fleet charging needs.

[1] J1772, also known as a J plug, is the North American standard for electrical connectors for electric vehicles maintained by SAE International

LEVEL 2 CHARGING

Level 2 EVSE offers charging through 240V (typical in residential applications) or 208V (typical in commercial applications) AC plugs with a dedicated electrical circuit and uses the same vehicle connector as Level 1 equipment. Depending on the vehicle's battery type, acceptance rate[2], and the charger's circuit capacity and configuration, Level 2 charging typically adds about 10-25 miles of range per hour of charge time.

Level 2 EVSE is available at a range of price points, from the relatively low speed (3.8-7.7kW) entry level AmazingE chargers from Clipper Creek, to relatively fast (19.2 kW) hard-wired "smart chargers", such as Blink's IQ 200. High-end smart chargers typically use WiFi or cellular connections to transmit and track charging and financial data.

The advantages of "dumb chargers" (earliest model of vehicles chargers that do not have advanced capabilities) are their low cost and simplicity. The advantages of higher cost smart chargers include faster charging and the ability to manage and share power loads, schedule charging at reduced time-of-use for lower electric rates, and monitor charging data through online dashboards and smartphone apps.

Level 2 charging is typically the most appropriate way to provide medium-speed charging for the general public or fleet vehicles with moderate parking dwell times.

DC FAST/HIGH POWERED CHARGING

DC fast chargers or DCFC (480V input to the EVSE) enable rapid charging. A 50kW DCFC, among the most common public fast chargers, adds 60-80 miles of range to a light duty vehicle in as little 20 minutes.

High-powered chargers are high amperage DCFC (150-350 kW or more) that are the fastest and most expensive type of EVSE. Tesla, EVgo and Electrify America all deploy these in their public charging networks; they can provide 75 miles of charge in about 10 minutes. However, actual charging speeds are limited by each vehicle's acceptance rate.

Lower cost EVs such as the older Nissan LEAF and Kia Soul models, Chevrolet Bolts, Volkswagen e-Golfs, and the Honda Clarity can charge no faster than at 50kW. Newer and higher end Nissan LEAF models and Jaguar's I-Pace can charge up to 100kW. Only luxury EVs by Tesla, Audi, and Porsche can charge at rates of 250 and 350kW respectively.

Acceptance rates will likely improve in the future as more high-power chargers are deployed and more EVs enter the market[3].

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[2] EVs have on-board chargers that converts alternating current delivered by a charger to direct current to recharge the vehicle's battery pack. These on-board chargers have a maximum acceptance rate that determines how fast a battery can accept electricity while recharging. Higher acceptance rate indicates faster battery charging capabilities.

[3] https://insideevs.com/news/348233/electric-car-dc-fast-charging-comparison/

2. CHARGER SIZING

The critical factors in evaluating the size (or power in kW) of EV chargers are the intended vehicle's battery capacity, charging acceptance rate, energy consumption, dwell time, and the quantity of EVs to be charged.

- **BATTERY CAPACITY.** The capacity of the battery is measured in kilowatt hours (kWh). EVs commonly purchased by fleets and the general public typically have batteries ranging in size from 40-100kWh. Larger battery sizes can typically require longer charging durations, but greater storage capacity means reduced charging frequency.
- **CHARGING ACCEPTANCE RATE.** Each EV has a maximum acceptance rate for both AC and DC charging. Since this rate is the vehicles' maximum charging speed, it should be used to calculate charging duration. While there is no current benefit for fleets and the public charging station hosts to purchase higher speed chargers, future EVs may become available with higher acceptance rates that may require installation of high-power chargers.
- **EV QUANTITY.** In general, if a site is planned to be used by multiple EVs, charger quantities and speed should be calculated to ensure reasonable charging times. This is particularly important if chargers are planned to be shared between multiple EVs, vehicles have long overnight dwell time, and/or low or medium speed chargers (up to 7.2 kW) are planned for installation.
    - For municipal agencies, fleet managers should consider the frequency that they plan to rotate EVs though shared chargers and ideally plan an efficient charging schedule. Charging management software can automate or assist in rotating EVs through chargers or sharing electric capacity between chargers (see section Charging Strategies on page 18).
    - Multifamily housing developments should consider the number of future EVs that are estimated to need to be parked and charged at any given time based on local code requirements and residential demand.
- **DWELL TIME.** Since most vehicles will charge overnight while not in use, the duration of "dwell", or stationary charging time, will determine the maximum charge duration and charger size. Slower chargers (chargers with smaller kW ratings) can be considered for vehicles with longer dwell times.
- **ELECTRICAL CAPACITY.** The critical factor to determine charger sizing is the available electrical capacity. The electrical panel rating and the available electrical capacity at the charging facility will determine the number of chargers that can be installed and their maximum power ratings. Since many existing facilities were built without anticipating the need to charge EVs, unused capacity to accommodate significant charging infrastructure is typically not available.

FOR FLEET OR FACILTY MANAGERS

- **ENERGY CONSUMPTION.** Vehicle energy consumption consists of its average "daily duty cycle" (average miles traveled). For fleet managers the daily duty cycle for each vehicle type can be useful to calibrate the total charging needs for a particular site.

3. CHARGER SELECTION

Key considerations to help guide charger selection are listed below and Table 1 summarizes recommended features and capabilities relevant to these attributes.

- **USABILITY.** The charger should be easy to use by drivers and the charge cord length should reach multiple stalls. The charger face plate should be easy to read in any lighting condition; color-coded lights that indicate charging status increase readability.
- **RUGGEDNESS.** Outdoor charging equipment requires robust hardware as it is exposed to the elements, repeated use, and possibly abuse or vandalism. Chargers installed in garage interiors or with less public use may require less robust and costly hardware. Most charger vendors include at least a one-year warranty; some vendors include or offer optional extended warranties.
- **CONNECTIVITY.** Charging data needs to be conveyed between the chargers, controllers, and management system. Multiple connectivity options are available depending on the charger or site where the chargers are located. These include wired connections using fiber or wireless connections using radio signals such as cellular or WiFi.
- **PAYMENT/DATA COLLECTION.** Collecting payment for charging or tracking energy usage by EVs (or for fleet managers, by departments) can occur through a variety of mechanisms. Not all chargers offer payment functionality.
- **EFFICIENCY.** Chargers with power load management capability are the most energy efficient; ENERGY STAR-rated chargers use 40% less energy in stand-by mode.
- **CERTIFICATION.** Commercially available chargers that are certified ensures product integrity, energy efficiency, and chargers that conform with the highest safety standards. Table 1 lists some current certifications available for EV chargers.
- **FUTURE PROOFING.** Charging technology changes rapidly. To maximize the lifespan of charger investments, consider the following adaptable features:
    - Open Charge Point Protocol (OCPP) compliance allows the use of multiple software options.
    - Modular architecture consists of a singular centralized controller that supports multiple charging heads that can be added over time to provide scalability to meet growing future needs.
    - Demand response capability avoids charging during periods of peak power demand and prioritizes charging when the grid has ample electrical capacity.
    - ISO 15118 Plug-and-Charge technology-ready simplifies the payment process so that the charger recognizes each fleet vehicle and automatically bills the correct account.
    - Bidirectional (V2G) charging[4] based on ISO/IEC 15118 standards and UL 1741-SA and UL 9741 Certification.

FOR FLEET OR FACILTY MANAGERS

- **DATA COLLECTION.** Fleet or facility managers may desire data from chargers to inform future decision-making and require dependable, accessible, secure, and frequently updated systems.

[4] Bidirectional charging refers to charging in both directions; these chargers can charge EVs and draw power from EVs. See Chapter 5 for more information.

Table 1: Summary of EV Charger Selection Attributes

Attribute	Recommended Capability/Features
Usability	• Cable management capability with 25 cable length • Visible charging status lights
Ruggedness	• NEMA-4 rated to operate outdoors and in extreme weather conditions. • Minimum warranty of three years • Field-swappable modular components
Connectivity	• Ethernet • 3G/4G wireless communication • GSM • Wi-Fi • Bluetooth
Payment/Data Collection	• Payment collection options to include RFID or QR code, Credit/debit card tap or swipe, Apple Pay, Google Wallet, or with smartphone app • Compliance with electric metering requirements in the CCR 4002.11 Electrical Vehicle Fueling Systems
Efficiency	• Load management/power sharing capability • ENERGY STAR[5] rated
Certification	• Certified by the Underwriters Laboratories, Inc[6]. (UL), ETL listed or an equivalent certification. • Compliant with Society of Automotive Engineers (SAE) J1772 standard for charging plug connector and operational requirements[7]. • Appropriate IEEE[8] & NEC[9] Ratings
Future Proofing	• OCPP 1.6 compliance and certification • Modular architecture and scalability • Demand Response capable • ISO 15118 Plug and Charge technology-ready • Bidirectional (V2G) charging[10] based on ISO/IEC 15118 standards and UL 1741-SA and UL 9741 Certification.
Data Collection	• Capacity to accurately record and produce the number of unique charging events, average duration of each charging event, kilowatt hours delivered by each charger and downtime at each charger by month • Cloud based dashboard portal

[5] EPA's ENERGY STAR certified EV chargers provide the same functionality as standard products but use 40% less energy in standby mode: https://www.energystar.gov/productfinder/product/certified-evse/results

[6] UL is an OSHA-accredited Nationally Recognized Testing Laboratory (NRTL) that tests products, including EV charging stations, to applicable UL standards for safety. UL has multiple EV safety standards including: 2202 – Electric Vehicle (EV) Charging System Equipment; 2594 – Electric Vehicle Supply Equipment (EVSE); 2251 – Plugs, Receptacles and Couplers for Electric Vehicles; 62 – Flexible Cords and Cables; 2231-1 & -2 - Personnel Protection for EVSEs and 9741 – Bidirectional EV Charging System Equipment: https://www.ul.com/resources/apps/product-iq

[7] Society of Automotive Engineers (SAE) J1772 covers the general physical, electrical, functional and performance requirements to facilitate conductive charging of EV/PHEV vehicles in North America. https://www.sae.org/standards/content/j1772_201710/

[8] IEEE 1547: Interconnecting Distributed Resources with Electric Power Systems and IEEE 1547.1: Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems. https://standards.ieee.org/standard/1547-2018.html

[9] Section 625 of The National Electrical Code regulates electrical conductors and equipment supporting EV charging. https://www.ecmweb.com/national-electrical-code/article/20899765/article-625-electric-vehicle-charging-systems

[10] https://www.charinev.org/news/news-detail-2018/news/the-five-levels-of-grid-integration-charin-ev-grid-integration-roadmap-published/

EV CHARGER MODELS

Table 2 lists currently available Level 2 chargers, charging speeds for multiple models (if applicable), power rating, approximate cost for charging equipment, and unique features or benefits for each. Costs provided here was obtained directly from respective product manufacturers and are current as of March 2021.

Table 2: Electric Vehicle Charger Summary

Product	Charging Speed	Power Rating	Unique Features/Benefits	Approximate Purchase Price	Notes
MARKET LEADERS					
ChargePoint CT 400 https://www.chargepoint.com/	30A	7.2 kW (240V AC @ 30A) x 2 3.8 kW (240V AC @ 16A) x 2 (Power share)	• LCD video screen • Cable management/retractors that automatically keep cable off ground • Mixed use capable – set up and manage access groups for public charging and specific fleet charging. • Integrates with AssetWorks and vehicle telematics systems. • Fuel management and tracking capabilities per vehicle.	$3,604-$6,568 Sourcewell Contract	*ChargePoint is the US market leader in terms of sales volume. ChargePoint is known for quality, reliable products and large service network but also relatively high costs and lack of OCCP, selling hardware with proprietary software.*
SemmaConnect Series 7 for Fleets https://semaconnect.com/	7.2kW	240VAC@ 30A	• Interactive LED lights • Fleet vehicle management • Fleet access control • Fleet manager portal • Late plug-in/plug-out alerts • Schedule charge start time • Session data and analytics • State of health monitoring • Load management ready	$4,590 (1-year service) $5,920 (w/3-year service) $7,110 (w 5-year service)	
Blink https://blinkcharging.com/products/iq-200/ IQ 200	Variable: 2.9-19.2kW	Variable: 12A to 100A	• Load management for 2-20 chargers • Time-based, kWh-based, or session-based fee billing • Payment via RFID, Apple Pay, Google Wallet, and all major credit cards • 7" Daylight color LCD touch screen with auto-dim when not in use and showing transaction details • Multi-colored high visibility illuminator indicates charging station's status • Local load management capability • SAE J1772 charge connector • Open Charge Point Protocol (OCPP) 1.5 and 1.6 support • Cellular and WiFi communication modes • Smartphone app for status updates and notifications • Controllable output to support utility demand response requests • 25-foot cable with cable management storage between uses • Height design conforms with ADA requirements • Fee options include time-based, kWh-based, or session-based billing functionality • Pedestal accessories include single, dual, and triple port options • Modular kiosk can support up to 20 chargers with scheduled management. (5 chargers per circuit is optimal)	$3,500 for single port pedestal	*Blink has recovered from bankruptcy and is making a rebound on its product line but has an unreliable history, especially for fast chargers. No ability to set billing rate. Moderate hardware and poor software.*
Enel X https://www.enelx.com/n-a/en JuiceBox 2.01 Pro 32/40/48 JuicePedestal (Add 2 JuiceBoxes with Cord Management System)	32 amp (7.7KW, 208/240V) 40 amp (9.6KW, 208/240V)	JuiceBox Pro 32 = 208/240 (40-amp circuit).	• Cable management/retractors that automatically keep cable off ground • Load balancing/load management per device or facility • JuiceNet enterprise dashboard & capabilities (Admin Log In) • JuiceNet App. (QR Code/Account Tracking)	ALL MSRP (discounting via quantity ordered): Single Unit, Wall Mounted: 32 ($1,369) 40 ($1,419) 48 ($1,449) JuiceStand ($499)	*Good product and software, simple, reliable, easy to install, OCPP-compliant. Owned by Italian utilities.*

JuiceStand (Add 1 or 2 JuiceBoxes) JuiceNet Enterprise (Software)	48 amp (11.5KW, 208/240V)	JuiceBox Pro 40 = 208/240 (50-amp circuit). JuiceBox Pro 48 = 208/240 (60-amp circuit).	• NEMA-4 Rated • Warranty already included in cost of stations (Base 3-year warranty) • Turnkey, fast-to-deploy charging infrastructure • OCCP 1.6J compliant • Connectivity (WIFI, Ethernet & Cellular) • RFID key fob, QR code scan & or cellphone app payment • Will have plug and charge via ISO15118 in 2021/2022 • UPT (Unattended Payment Terminal for Public/High Volume needs) • Different types (32/40/48) to accommodate any electrical capacity needs. • Mobile app and dashboards include notifications, load balancing, optimized charging schedules. Smart Level 2 chargers eligible for significant rebates via Incentive programs	JuicePedestal ($1,299) Dual-Port Units, Free Standing: 32 (JuiceStand: $3,237/JuicePedestal: $4,037) 40 (JuiceStand: $3,337/ JuicePedestal: $4,137) 48 (JuiceStand $3,397/ JuicePedestal: $4,197) JuiceNet Enterprise Software: +$120 per year/per JuiceBox (1-10-year packages available)	
BTC https://www.btcpower.com/ AC Level 2 30A Dual Port Charging Station AC Level 2 40A Dual Port Charging Station AC Level 2 70A Dual Port Charging Station	7.2 kW	240/208 VAC, 30A	• 25-foot cable • Optional cable retractor with 18 ft cable Management • 4G Modem • 2.4 GHz Wi-Fi • OCPP 1.5 and 1.6 Compliant • RFID Reader with optional credit card reader or scanner	30A Dual Port Charging Station 40A Dual Port Charging Station 70A Dual Port Charging Station	*Known for 100kW DC FC but also for a big, bulky L2 charger.*
INNOVATORS					
Low cost dumb chargers paired with AmpUp and Cyber Switching https://ampup.io/ http://www.cyberswitching.com/power/home/ https://www.clippercreek.com/	7.2kW (Varies by car)	208/240VAC@ 40A	• Aggregated 4 to 1 network connection (lower cost) • Networked smart solution • Interactive app-based charging • Flexible payment options • Per user reporting • Manager reporting • Reservation charging • Group assignment • Priority charging	$2,999 - $4,099 EV Master Control (EVMC) Stand Alone Feature EVMC w/ 2 YR Warranty $1,050 - $1,487 Clipper Creek Additional Pricing may Apply. Available Options: ✓ Protective Enclosures ✓ Network Communication ✓ Power Mgt Dashboard/Tenant Billing Features	*Clipper Creek chargers are low cost reliable dumb chargers that can be enhanced with Cyberswitching hardware and AmpUp software to provide load management for up to 4 chargers per circuit.*
EVSE LLC and AmpUp https://ampup.io/ http://evsellc.com/	7.2kW and 9.6 kW	240VAC@ 30A and 240VAC@ 40A	• Modular hardware that provides many charging options • Unique overhead and light pole mounted chargers • Scheduling and dedicated access to multiple user groups • Manage multiple locations with hierarchical administration capabilities • Achieve net-zero operating costs by opening chargers to the public during off-hours • AmpUp proactive monitoring minimizes ongoing site administration • Schedule charging sessions and dedicate access to fleets during specific hours or day	Retractable Cable: Model 3722: Ceiling Mounted: $2959 - $5103 Model 3704: Single Pole Mounted: $3224 - $3990 Model 3704 Elevated Light/Utility Pole: $4377 - $5,018 Wrapped Cable: Model 3703: Single Pole Mounted: $2437 - $2970 Payment Module: $1100 - $2597	*Known for unique installations including garage ceiling-mounted and utility and light-mounted chargers with automatic cable management. Such applications can result in expensive repairs.*
United Chargers **Grizzl-e** Modular charging systems https://grizzl-e.com/business-products/	9.6 kW	208-240 V, 40A Can also be configured to 16A, 24A, or 32A maximum current output	• Dynamically managed power sharing to limit maximum amperage • Adjustable maximum current output to allow the use of a 50A, 40A, 30A, or 20A dedicated circuits • Demand/response capable • one PCPH and 10-42 Nodes • Collects telemetry of the charging sessions including date/time, user, session duration, KWH consumed, payments, usage, and profitability. • Expandable by adding additional nodes	$1,700-2,000 + $500 per node	*On a per-unit basis, Grizzl-e provides the lowest-cost level 2 chargers.*
Grizzl-e Classic Low-cost residential chargers https://grizzl-e.com/home-products/	9.6 kW	208-240 V, 40A Can also be configured to 16A, 24A, or 32A maximum current output	• Installs to a 14-50R (RV Plug) outlet • Easily transportable mounting bracket allows transport between different locations. • Indoor and Outdoor NEMA rated. • 18-24' cables available	$399-$439	
Power Electronics NB Wall Advanced NB Wall Professional	7.7 kW 2 x 7.7 kW	240 V	• Bluetooth-based authentication activated by device proximity • Multiple payment systems including RFID cards, credit/debit cards and smartphones. • Smart power balancing for fleet management for up to 25+ vehicles	NB Wall Advanced: $2,000 NB Wall Professional: $2,500 With 240/208V $3,000	*Sophisticated line of smart chargers with built-in load management functionality.*

NB City https://power-electronics.com/electric-mobility/	2 x 7.7 kW		• Dual power sharing functionality	NB City with 277V $3,500 Volume discounts available	
Wallbox Quasar DC Bi-directional chargers https://wallbox.com/en_us/	7.4 kW	32A (adjustable amps with dynamic power sharing), 240V input	• V2G/V2H • Available in mid-2021 • Only available in CHAdeMO but will be available in CCS in early 2022. • UL certification in the US anticipated in mid-2021 • Grid-tied only (island due late 2021 for residential)	$4-5K depending on features	*Early entrant into bi-directional charging capability*
Xeal https://xealenergy.com/ Evocharge	32A/7.7kW at	240V, 40A output	• Load Management- Add more chargers with less capacity • Wi-Fi networked system (NFC coming in Q1 2021) • Cloud based dashboard portal (remote reports, monitoring, management.) • Get live updates on battery charge percentage • Smartphone App • Reserve charging sessions function • Mixed use application (private, public or both) • Wall, pedestal or dual mounted • NEMA 4 Rated and UL Certified	$1,500	*Low-cost, smart chargers*
Powerflex https://www.evsolutions.com/ Webasto Turbo DX	32A/7.7kW at	240V, 40A output	• Adaptive Load Management - Monitors entire building's electrical capacity and diverts extra unused available electricity to car charging. • Updates in real time. • No need for additional power/gear at most buildings. • Wireless "mesh network" (ZigBee) or Wi-Fi • Save on demand charges with proprietary algorithms - drivers input miles requested to be charged and time of departure • Smartphone App • 1 LMC (load management controller) can manage up to 100 + charging stations • Cloud based dashboard for reports, monitoring and remote management • Can work with Level 2, DC-Fast chargers, or a combination • NEMA 4 Rated and UL Certified • Wall, pedestal or dual mounted	LMC (load management controller) for entire system = $10,000 Charger= $1,500	*Local load management combination hardware and software purchased by EDF renewables that is good for fleet campuses.*
Tellus Power http://telluspowergreen.com/# Dual Port Level 2	7.2kW	208-240VAC 60Hz., single phase @ 40A x 2	• All models are available in pole, pedestal, or wall-mount versions • LAN: hard wired Cat 5 for master/slave stations. WAN: Cellular network for the master station • Simple design with only the features that are needed • No power sharing required - both chargers deliver a full 7.2 kW charge to both vehicles simultaneously. • Powerful network with no provisioning fees • RFID technology, plus built-in numeric keypad for secure pin number authorization • Field-swappable modular components	Dual charger: $2,495.00 Network fees: Per Port $200.00/yr Monthly Data Charges: $10/month	*Low-cost, dual-port smart chargers*
Engie https://evbox.com/us-en/all-products EV Box	1-phase (32 A) or 3-phase (16 A or 32 A)	230V - 400V Split phase (30 A), 208 - 240V (3rd gen only available)	• Double or single fixed cable • MID certified / UL revenue grade kWh meter • 4th gen: 4G / 3G / GSM, Wi-Fi, Bluetooth • OCPP 1.5 S, 1.6 S and 1.6 J • Hub or satellite station • Activation/payment: RFID / QR code / AutoStart		*Though established in Europe, Engie's EV Box brand is relatively new to the US, but has good design and is one of the chargers selected by PG&E for its EV Charge Network program*
MOBILE CHARGERS					
Freewire Technologies Mobi Dual L2 https://freewiretech.com/	11 kW, split between 2 J1772	Rechargers from 110v/ 220v outlet or directly from a J1772	• Battery integrated charger • Intra site mobility • Inter site mobility via trailer • No infrastructure required • ~320 miles of range per full charge	Rechargers from 110v/ 220v outlet or directly from a J1772	*Innovative and unique approach to charging eliminates infrastructure installation costs, providing flexibility and mobility for fleet applications.*

			• Can discharge and recharge simultaneously • Shifts load, reduces demand charges • Cloud connected for status and reporting		
SparkCharge sparkcharge.io	20 kW	40 ADC, 150 - 500 VDC	• Total Energy: 3.5 kWh • Usable Energy: 3.2 kWh • Power (max continuous) 20 kW • Dimensions: 220 mm x 320 mm x 600 mm • (8.7 in x 12.6 in x 23.6 in) • Weight: 22 kg (48.4 lbs.)	$4,000 per unit or flexible lease to own: $1,000-3000 down + $450/month for 24 months	*Lightweight, portable rescue charger for fleets and vehicle maintenance crews.*
Blink Blink Portable Charger	9.6 kW	240VAC	• Portable and modular • Free-standing, doesn't require installation • Non-networked charging station • Simple plug-in to charge use • Charges up to 0.5 to 1 mile of range per minute depending upon the EV's capabilities • 354 lbs.	$6,500	*Large, heavy truck-mounted rescue charger for fleets and vehicle maintenance crews.*
SOLAR CHARGERS					
Beam Global (formerly Envision Solar) www.BeamForAll.com EV ARC™ 2020 EV ARC™ 2020 DCFC50 (50kW DCFC)	4.2 kW 6 kW 50 kW	25 A 16 A (Adjustable and scalable with dynamic power sharing)	• Turnkey, fast-to-deploy charging infrastructure • Transportable, easy to relocate • No construction, no design, no permitting, no utility, or infrastructure upgrades required • Solar-powered with battery storage • Flood proof, high wind-rated emergency power asset • Compatible with most high-quality chargers	Pricing starts at $59,400 before Federal Incentives (Federal Solar ITC, MACRS) for private entities is applied, which can reduce costs by as much as 40%. Available on CA DGS, GSA, FSA, NYC-DCAS contracts.	*Sophisticated tracking solar-array chargers with built-in energy storage. Provides resiliency, flexibility, and movability but very expensive.*
Paired Power https://pairedpower.com/ SEVO SunStation	Up to 16.8 kW	16.8 kW, 40 amp, 300-500 VDC	• 100% renewable energy (on-site) • Off-grid or grid-connected options (net-meter solar) • Zero utility bills (no demand or energy charges) • Up to 6 configurable DC connectors (e.g. CCS or CHAdeMO) • Fully resilient (still online after power outage or utility shutoff) • Dynamically managed power sharing • Cloud connection (cellular modem) to enable fleet vehicle management and session data and analytics • Payment processor, credit/debit cards • OCPP 1.6+ • NEMA 4 outdoor rating • Integral energy storage to be operational in 2021 • V2G compatible for CHAdeMO connectors	$20k per port (includes solar + installation) or $120K for 6 ports	*Integrated solar power and EV charging for large scale applications using on-site solar canopies or adjacent roof-mounted solar arrays.*
Skyhook Solar https://www.skyhooksolar.com/ D2 D4 D6	Up to 17 kW	D2: 1kW D4: 2kW D6: 3kW	• Islanded but is developing grid-connected features for resiliency • Weighted base but movable with pallet jack • Monitored remotely • Can be equipped with sensors like air quality • Can host advertising to cover cost • No infrastructure upgrades nor permitting other than street use if in ROW • D2: 3'x3' 2 panels 1kW for e-bike and e-scooter • D4: 2kW 3'x6' L1 or L2 for up to 30ebikes or scooters or EVs (see website photo) • D6: Larger 6 modules with 2 3kW L2 plugs for $40 = 60 miles	D2: $15K D4: $25K D6: $40K Can be leased for $300-$400/month	*Small, relatively low-cost modular solar system ideal for micro mobility or small-scale soar EV charging applications*

4. CHARGER PLACEMENT & INSTALLATION

To optimize operational efficiency and reduce installation costs, when planning to place or install EV chargers, consider the five factors below:

ELECTRICAL SERVICE

- Evaluate capacity of electrical infrastructure (utility service and electrical panel) to support immediate and long-term vehicle charging needs. Identify costs for necessary electrical service upgrades in collaboration with local utilities and/or a qualified electrician.
- To help minimize costs, choose charging locations that are as close as possible to existing or proposed electrical service infrastructure and other EV charging stalls.
- Plan electrical raceway or conduit runs for electrical wiring and data cables from the electrical panel serving the chargers and consider a layout that minimizes linear conduit distances to all proposed EV charger-equipped parking spaces.
- If possible, install chargers during construction, remodels, or other facility upgrades planned to reduce costs and minimize construction impacts.
- Charger hosts should consider separate meters for building and electric vehicle charging to reduce peak load impact on the grid and minimize demand charges for electric vehicles.[11]

CHARGER LOCATION AND LAYOUT

- If possible, surface-mount conduit along wall surfaces to avoid more costly trenching under paved surfaces. If wall mounting is not feasible, trench beneath planting strips to reduce cutting and re-paving costs and to minimize disruptions during construction.
- Identify suitable locations with smooth, plumb surfaces for wall mounted charging stations if possible or suitable floor surfaces for pedestal mount stations. If possible, use wall-mounted chargers to avoid the need for pedestals which are more costly and complex to install.
- To maximize charging capacity, consider installing dual-port pedestal mount stations with long charge cords (up to 25'). Many chargers include optional cord management systems such as retracting reels to minimize trip hazards. Depending on parking configuration, a single charger or dual head charger pair can serve up to eight parking stalls.
- To comply with the Americans with Disabilities Act (ADA), the charging station must not block ramps or pathways, and cables should not extend across ramps or pathways when connected to a vehicle.
- Where feasible, avoid locating chargers under trees where sap, pollen, or leaves would fall on the charging station.
- To better accommodate the varied charge port locations on different EVs, use perpendicular (90 degree) parking stalls that allow a vehicle to enter either front-first or rear-first instead of parallel or diagonal stall parking.
- Check local requirements for accessibility and pathway width, sometimes called "path of travel" to ensure charger placement does not restrict sidewalk use.
- Plan locations for easy and cost-effective future charger installation, typically adjacent to other EV charging stalls.

[11] See Snohomish County PUD Public Electric Vehicle Chargers Electric Rates effective January 1, 2021.

OPERATIONAL CONSIDERATIONS

- Provide adequate lighting for safe night-time access and consider lighting activated by motion sensors for energy efficiency.
- If feasible, site chargers in areas with good visibility.
- Securely affix chargers to the ground or wall.
- Closed-circuit television (CCTV) surveillance is an additional option, especially in low visibility public areas, to prevent theft and vandalism.
- Ensure chargers are easily identified and install signage or wayfinding as needed.
- Provide protective bollards and wheel blocks where appropriate, especially on sloped sites. Consider weather protection.

DATA CONNECTIVITY

- Measure cellular signal levels to ensure adequate coverage where smart chargers are planned to be installed. Underground or enclosed parking structures may require cellular repeaters to ensure adequate signal strength to chargers.
- For sites with multiple EVs, to ensure dependable coverage, communication systems should preferably be stand-alone and not dependent on the building's Wi-Fi system.

5. OPERATIONS AND MAINTENANCE

This section summarizes different strategies and cost considerations associated with operations and maintenance of electric vehicle charging infrastructure.

STRATEGIES

There are the following three basic strategies to operate and maintain EV charging infrastructure.

- **OWNER/OPERATOR.** Post-installation operation and maintenance is performed by the owner. This is normal for municipal fleets with electricians on staff able to repair typical electrical issues.
- **CONTRACTED MAINTENANCE.** Typically, maintenance is contracted out for public charging infrastructure when there is no in-house electrician and/or after chargers have exceeded their warranty period.
- **CHARGING-AS-A-SERVICE.** This model assumes chargers are installed and operated by an equipment manufacturer who sells charging as a service to users. This model eliminates upfront capital and ongoing maintenance expenditures for owners. Although most charging equipment manufacturers do not offer this charging-as-a-service (CaaS) business model today, some like ChargePoint or Amply Power, offer a subscription-based plan where the customer is only responsible for site preparation and pays an annual subscription fee. The subscription fee includes the cost of shipping, installing, and activating the charging hardware and network service and covers ongoing operation, maintenance, software upgrades, and monitoring.

COST CONSIDERATIONS

- **OPERATIONS COST.** The highest operational cost among all charger types is the electricity cost to charge the vehicles. This is calculated per the utility provider's kilowatt-hour (kWh) rate schedule and can include a combination of minimum charge, energy charge, and additional demand charges for peak period usage. Smart Level 2 chargers and DCFCs that have load management capabilities and usage analytics will also incur periodic costs for software upgrades and data connectivity.
- **MAINTENANCE COST.** Apart from regular wear and tear, lack of proper care from users is the primary driver of equipment malfunctions, especially for the charging cords and connector nozzles. Although costs can vary, a non-residential charger owner can anticipate an average of approximately $400 per year in maintenance-related needs[12]. These costs are typically covered by the manufacturer during the first one- to three-years per the warranties offered at charger purchase.

[12] Smith, Margaret & Castellano Jonathan, New West Technologies LLC. the U.S. Department of Energy Vehicle Technologies Office. *Costs Associated with Non-Residential Electric Vehicle Supply Equipment Factors to consider in the implementation of electric vehicle charging stations*. November 2015

6. RELEVANT CHARGING TECHNOLOGY TRENDS

This section discusses relevant existing and upcoming technologies that support managing electrical demand and developing resiliency in the system. As municipal agencies electrify fleets, the technologies discussed in this section will assist fleet and facility managers to reduce charger installation costs through power load management and adopt technologies such as mobile back-up generators, stored storage solutions, and bidirectional charging to build system resiliency.

POWER LOAD MANAGEMENT

Power load management uses a combination of hardware and software to distribute electrical power between chargers. Managing the electrical power load is one of the best ways to optimally charge multiple vehicles, reduce cost, and manage the electrical demand.

Charging networks, such as ChargePoint and Greenlots, have dedicated software with customizable algorithms to intelligently share power among networked ("smart") chargers. Every vehicle charging on the network charges as fast as possible without exceeding the site's rated electrical capacity. Networked smart chargers allow for tracking overall electrical consumption and collecting customer payments but are relatively expensive and require monthly data fees.

Cyber Switching, PowerFlex, AmpUp, and Mobility House are examples of load management providers of cost-effective alternatives that could be appropriate for campus applications.

Power load management strategies include:

- **LOAD TRANSFER.** One relatively simple and cost-effective way to power EV charging is to tap existing electrical capacity and redistribute use. For example, the primary electrical demand at many outdoor parking facilities is lighting needed mostly at night, while peak demand for EV charging is mostly during the day. Finding ways to redistribute the load among peak use by function by time of day can reduce infrastructure needs and lower costs.
- **LOAD MANAGEMENT.** Cyber Switching can limit and balance power loads to avoid exceeding circuit capacity and utility demand charges and AmpUp can also reduce power across all chargers. Augmented by AmpUp, the EV Master Controller or EVMC[13] serves as a virtual electric meter, avoiding the need for separate circuits or sub-meters for EV charging and lighting. The precision software can break down electric loads to each output. Depending on the granularity of the utility's electric meter, it may even measure electrical consumption more accurately, collecting data every few seconds rather than 15-minute intervals used by many utility meters.
- **MANAGED CHARGING.** The AmpUp smartphone app identifies the charging status of each charger, allowing users to monitor charger availability in real time and reserve chargers in advance. The software would also allow the fleet or facility manager to limit charging session duration, add an overstay penalty, or implement access restrictions by day or time for specific users.
- **PAYMENT.** The AmpUp software provides multiple features to benefit the charging host as well as EV charging customers, including flexible pricing and ease of payment. AmpUp is PCI compliant, which means it allows payment through all major credit cards and online platforms such as Apple Pay, Venmo, and others. Customers pay through the AmpUp smartphone app which eliminates the need for a credit card reader on the charger. To initiate a charging session, an EV driver scans the QR code printed at a charger.

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[13] EVMC provides intelligent power management to third party chargers by optimizing power usage across the site's charging network such that a single electrical line can support multiple charging stations, with power rotating on a programmable timed basis to each plugged vehicle.

RESILIENCY TECHNOLOGIES

Local power disruption may occur when local power demand exceeds the power system's capacity. The local power supply is also vulnerable to interruption from severe weather or other events causing grid failure. Conventional back-up generators or on-site renewable generation, such as photovoltaic solar panels coupled with on-site energy storage batteries, can protect EV charging operations from power supply interruptions.

BACK-UP GENERATORS

The standard approach to energy resiliency is the use of conventional fuel back-up generators, which are available in sizes up to 2,000 kW. These generators can be permanently installed at facilities for dependability and ease of operations or can be mounted on trailers to provide greater flexibility for fleet operators. They can be powered by diesel fuel, natural gas, or propane. To help achieve carbon reduction goals, renewable diesel—a hydrocarbon diesel fuel produced by hydro-processing of fats, vegetable oils, and waste cooking oils—could be substituted for standard petroleum diesel. According to industry sources like Neste, such a substitution reduces lifecycle emissions by up to 80% compared to petroleum diesel.

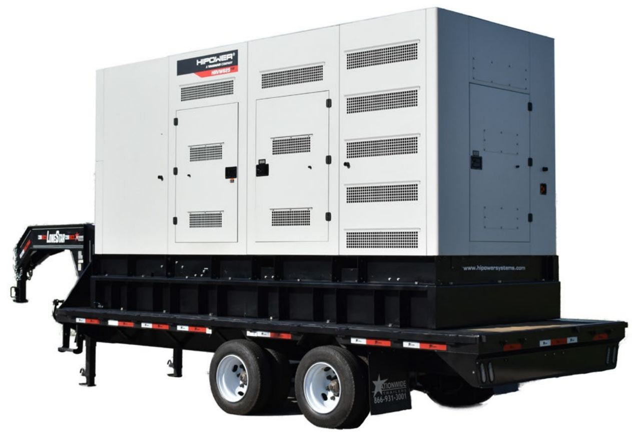

Figure 2:Trailer-Mounted 625-680 KVA mobile generator

SOLAR GENERATION

Solar power is becoming an increasingly viable source of power for EV charging because of improvements in energy collection and storage technology. Solar technologies provide environmental benefits with zero carbon emissions and resiliency benefits by operating independently from the electrical grid during disruptions or emergencies.

An example that could be suitable for multiple non-bus fleet applications is EV ARC, a transportable turnkey vehicle charging station powered by a tracking solar canopy and lithium-ion battery storage (developed by Beam). This modular solar charging platform is designed to operate independently from the grid or be grid-buffered. EV ARC requires no construction or ground-disturbance and can be quickly and cost efficiently set-up at the charging site without permitting.

Beam has developed an upgraded version of the standard EV ARC shown in Figure 3. The High Powered EV ARC can be equipped with 38-51 kWh of battery storage, 40A power supply, and 8.4 kWh level-2 charge for DC fast charging. The charger can support one to six charging plugs. The High Powered EV ARC can be stacked with surface cabling to support 50kWh DCFC, which is able to support 1,000 miles of charge per day on average, depending on site location and amount of sunlight.

The EV ARC can fit inside a standard parking space and can be installed as a single unit or scaled to provide charging for multiple EVs, e-bikes, e-scooters, or electrical equipment.

In addition to facilitating e-mobility, this technology enhances resiliency because it is grid independent and can generate its energy without the need for fossil fuel. It provides access to wireless communications or emergency power access to first responders including backup power for hospitals, police departments, and other mission critical infrastructure. These stations can be moved quickly to avoid being damaged by flooding or to provide power where needed to support the community.

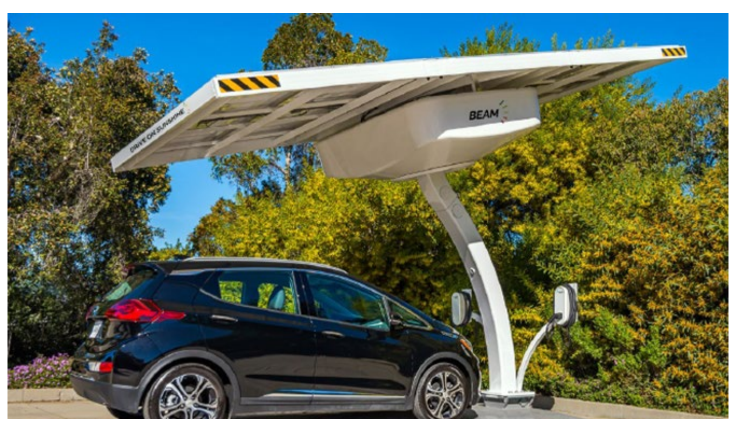

Figure 3: EV ARC solar-powered EV charger with built-in backup energy storage (BEAM)

STORED ENERGY

Along with distributed energy produced by engine-powered generators or photovoltaic panels, energy storage batteries are needed for resilience. EV chargers can use the stored electricity from the batteries when the grid's power supply is interrupted. A smart charger would control the flow of energy and could send energy from the grid to vehicle batteries or draw energy from the car batteries back onto the grid. EV charging hosts should consider associated costs and required physical space to provide adequate battery storage.

BIDIRECTIONAL CHARGING

Bidirectional charging is an emerging field that could benefit municipal fleets by unlocking the significant energy storage potential of EVs. This technology enables EV batteries to share energy with other EVs, buildings, and the electric grid. Since EVs are parked most of the time and offer abundant sources of mobile, distributed, and dispatchable energy, this technology has the potential to harness EV batteries as backup power for emergency services, help avoid peak demand charging, and potentially generate revenues by returning power to the grid.

Bidirectional charging applications include:

- **VEHICLE TO GRID (V2G).** Vehicle-to-grid enables surplus EV battery capacity to be exported back to the grid. Since peak power demand typically occurs between 5PM and 9PM during the work week, there may be demand for utilities to purchase available electrical capacity from EV batteries during those hours.
- **VEHICLE TO BUILDING (V2B).** Vehicle-to-building services refer to the dispatch of power from an EV battery to a commercial or residential building. The main application of V2B is to manage moderate charge demands at sites. International firms Wallbox and Nuvve and domestic startups Fermata Energy and Rhombus introduced V2B technologies in the US and continue to innovate to increase reliance on renewable, intermittent energy sources such as wind and solar. V2B can also provide disaster resiliency/back-up power to buildings by sharing power between buildings co-located with EV parking. Buildings can borrow stored electricity from EV batteries and EVs can act as dispatchable mobile backup power during outages. Building upgrades that conserve electricity, such as replacing windows, installing air barriers, or upgrading lighting, can increase vehicle charging capacity on sites with shared electrical systems.
- **VEHICLE TO VEHICLE (V2V).** Vehicle-to-vehicle charging allows power transfer among EVs. Most fleet vehicles maintain surplus battery range and, in the future, as battery capacity expands beyond the daily range needs of most vehicles, this surplus capacity will likely expand. This power can be shuffled between vehicles via a microgrid or backup generator on an as-needed basis, reducing demands on charging infrastructure and the grid. During power outages, mission critical vehicles, such as police and fire department vehicles, can draw power from non-mission critical vehicles, reducing the need for backup energy storage and emergency generators.

Prior to 2021 there was only one charger capable of bidirectional power flow – CHAdeMO, the charge plug favored by Nissan and other Japanese automakers but not used by most European and North American automakers that lack bidirectional charging standards. Currently, providers like Wallbox and Fermata Energy anticipate producing versions compatible with more vehicles, though few automakers other than Nissan and Mitsubishi currently produce EVs capable of bidirectional charging.

7. CHARGING STRATEGIES

A baseline approach to charging an EV fleet is to provide a dedicated charger assigned to each vehicle. This strategy made sense for early EVs that had relatively small batteries and could plug into low speed chargers overnight. Today, the typical light-duty fleet EV, like the Chevy Bolt or Nissan Leaf Plus, has around a 60-kWh battery which provides well over 200 miles of range. Newer EVs are expected to have even greater range. Due to the relatively low power needs and long overnight dwell times for most fleet vehicles, load management and charger sharing strategies are generally more efficient and cost-effective approaches. Mobile charging technologies augment these strategies and add flexibility and resiliency. Charging strategies are described below.

DEDICATED L1 AND L2 CHARGERS

Providing dedicated chargers means each fleet vehicle has access to a parking stall equipped with a charger. Fleets typically use Level 2 smart chargers to provide adequate range and track electrical use by vehicle or department. In cases where vehicle use is minimal, EVs have long-range batteries, and/or long dwell times, Level 1 chargers are also an option.

<u>Operations</u>: Vehicle operators manually disconnect the charger, pick up the vehicle, and return the vehicle to the stall and reconnect.

<u>Benefits</u>: The primary benefit of this approach is its simplicity and predictability. It also provides flexibility due to the relative abundance of chargers, allowing for future expansion via implementation of load management systems or other options. It is also appropriate for charging multiple vehicle types because dedicated chargers can be sized to meet the unique charging needs of each vehicle.

<u>Disadvantages</u>: The dedicated charger strategy can be less cost effective to install, impact more parking spaces, and be more expensive to operate compared to other options. Dedicated charging of multiple EVs without managed charging or energy storage could result in costly demand charges. Adding smart chargers or third-party load management systems to dedicated charging will also add costs.

<u>General Recommendations:</u> Dedicated chargers make the most sense in the following circumstances:

- Facilities with a limited number of EVs and ample electrical capacity.
- When funds are not constrained.
- When there is an inability to manage shared chargers.

DEDICATED LEVEL 2 CHARGERS WITH LOAD MANAGEMENT

Load management systems distribute power between chargers and allow fleet operators to control when and how each EV is charged.

<u>Operations</u>: From an operations perspective, dedicated chargers with load management function identically to dedicated chargers.

<u>Benefits</u>: The primary benefits of load management are the reduction of peak electrical load, which reduces (or avoids) both the need for electrical service upgrades and the likelihood of incurring high demand charges. Load management can also provide the flexibility to charge medium and heavy-duty vehicles with light or variable duty cycles alongside light-duty vehicles.

<u>Disadvantages</u>: Load management requires either networked smart chargers or third-party load splitting/management systems with non-networked chargers, which increases capital investment and ongoing data and service costs. Level 1 chargers are generally incapable of load management, so this scenario requires Level 2 chargers.

<u>General Recommendations</u>: Adding load management to dedicated chargers generally makes sense on sites with a significant number of EVs with long dwell times.

SHARED LEVEL 2 CHARGERS

This strategy rotates vehicles between shared Level 2 chargers. This should be generally feasible for many municipal fleets given the relatively low miles per day and typical overnight parking duration for most fleet vehicles.

Operations: Sharing Level 2 chargers can be accomplished by rotating parking (for low mileage vehicles) or by using a moveable charge cord between vehicles.

Benefits: The primary benefits of sharing chargers are the reduction in initial investment, leveraging of electrical capacity, and potential avoidance or reduction of peak demand charges.

Disadvantages: Sharing Level 2 chargers requires management to ensure vehicles maintain a sufficient charge for their intended use. Because the vehicles or charge cords would need to be moved, this could increase operations costs and/or require a change in fleet driver behavior.

General Recommendations: Sharing Level 2 chargers makes the most sense under the following circumstances:

- To serve fleet that typically drives less than 40 miles a day and has dwell times of longer than eight hours.
- When there is staff available to manage charging (by rotating charging cord or vehicles) and/or a system to monitor and direct fleet drivers to charging when needed.

SHARED DCFC

Another way to charge EVs is with DCFCs. A standard 50kW DCFC can fill a typical light duty EV's battery in approximately one hour. Higher power fast chargers can charge some EVs in significantly less time, depending on the charger's power and the EV's DC acceptance rate. Medium- and heavy-duty EVs can also charge more quickly using DCFCs.

Operations: There are multiple ways fleets can use DCFCs. For example, drivers could plug into a DCFC-equipped stall following their trip, which would charge until it redeployed and/or dedicated staff could rotate EVs through the DCFCs. Drivers could also use the DCFCs to "top off" or replace energy used on a short trip, similar to how refueling a combustion engine occurs today. In certain cases, additional batteries can be installed with DCFCs to lower the electrical demand for heavy-duty vehicles that require high power charging.

Benefits: The main benefits of DCFCs are faster charging speeds, potentially lower overall costs, and added flexibility, especially for sites with higher numbers of vehicles and/or more medium and heavy-duty vehicles.

- DCFCs can charge light-, medium-, and heavy-duty vehicles and can potentially be more easily shared with other jurisdictions, employees, or the public. Faster charging speeds allow a vehicle to be re-deployed or relocated relatively quickly.
- Given the typical municipal fleet use patterns, fewer DCFCs are needed than Level 2 chargers, which, depending on the circumstance, could reduce costs.

Disadvantages: The main challenges of DCFCs are initial cost, size, and management required.

- DCFCs currently cost more than $20,000 each—several times the cost of a Level 2 charger.
- DCFCs are large, can be challenging to install at physically constrained locations, and can reduce available parking.
- Standard DCFCs will typically require personnel to move EVs or charge cords (it takes approximately one hour to charge a typical light-duty EV battery to 80%). Higher power fast chargers can reduce charging time but are more costly and demand more power.

General Recommendations: Sharing DCFCs makes the most sense under the following circumstances:

- To serve numerous fleet vehicles or various types, with varied duty cycles.
- To provide charging to multiple agencies or diverse users.
- When there is dedicated staff to manage charging.

MOBILE CHARGING

A complement or possible alternative to stationary EV chargers is mobile or semi-mobile charging. Mobile charging consists of energy storage systems that draw power from the grid then dispense the electricity to EVs (in flexible locations) when needed. Two examples are Freewire Technologies, which has two mobile charging units, Mobi and Boost; and Dannar, which has the Mobile Power Station (MPS). The Mobi and MPS units are mobile and equipped with wheels and operator controls. The Boost is stationary and hard-wired but can easily be disconnected and re-located.

Each Mobi can charge multiple light-duty EVs and can be equipped with an optional Hydra unit that simultaneously charges additional vehicles at Level 1 speeds. Boost is a larger unit that has 160 kWh of battery capacity and 120 kW output capable of charging higher number of light-duty EVs.

Dannar's MPS can charge multiple battery types and replicates the function of a mobile generator. The DANNAR 4.00 base configuration comes standard with three 42 kWh Li-Ion battery packs (126 kWh total) and can be easily upgraded with up to nine additional packs for 504 kWh of on-board electricity.

Another example of mobile charging includes portable battery-powered rescue chargers like SparkCharge and portable generators like Blink's mobile charger. SparkCharge is an innovative startup that produces a highly portable, modular DCFC. Its battery-powered chargers snap together like Lego blocks, and provide up to 20 miles of range per battery module. Blink's mobile EV charger is also designed for emergency battery augmentation, allowing otherwise stranded EVs to drive back to a charger by supplying 9.6 kW of continuous power, or 1 mile of range per minute plugged. Fleets can use either of these to augment the capacity of shorter-range EVs or rescue EVs that run out of charge.

Dannar Mobile Power Stations can also be outfitted with auxiliary equipment such as lifts or loaders, allowing these units to function as fully electric off-road equipment. Both the Dannar and Mobi can also function as a generator and power electrical equipment.

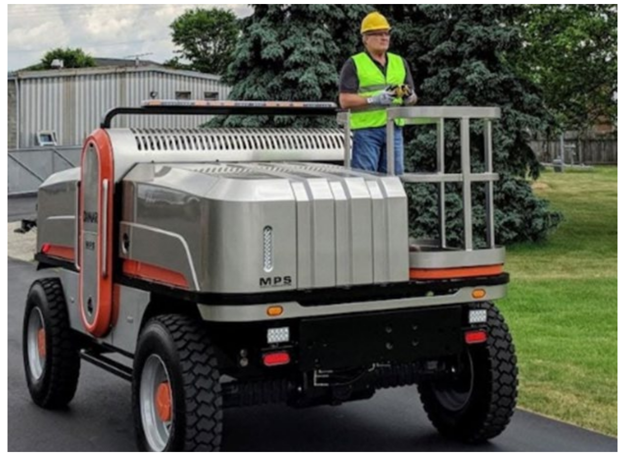

Figure 4: Danner's Mobile Power Station

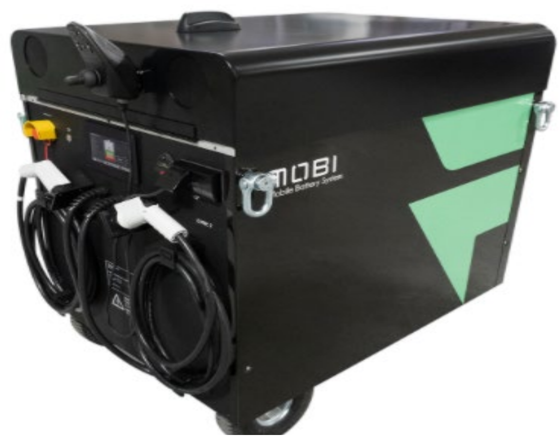

Figure 5: Mobi by Freewire Technologies

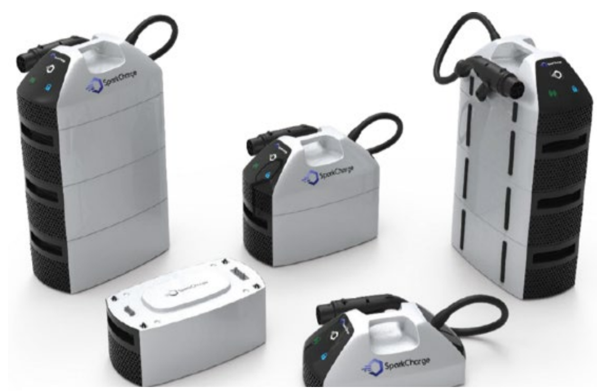
Figure 6: SparkCharge rescue chargers

Operations: Both the Dannar and Mobi products are designed to be operated similar to shared Level 2 chargers. Portable battery-powered chargers like SparkCharge and portable generators like Blink's mobile charger would typically function as rescue chargers. Due to its small size and relative light weight, a SparkCharge could provide backup power and extend EV range for longer trips.

Benefits: Mobile chargers offer flexibility and resiliency benefits due to their ability to:

- Efficiently charge multiple EVs by moving the charger not the vehicles.
- Relocate to service multiple sites.
- Provide backup energy to fleet vehicles during power outages.
- Charge more EVs than the facility's power capacity may support.
- Help avoid demand charges by accepting low voltage power from the grid when electrical demand is low or when grid or on-site energy from renewables is high.

Disadvantages: The main disadvantages of mobile charging are the upfront costs, impact on space needed to store the larger units, and operating costs for staff to use the equipment. Some mobile chargers may be challenging to use in tightly constrained areas.

General Recommendations: Using mobile charging units is recommended in the following situations:

- To add flexibility and resiliency to fleet operations and augment confidence in longer range trips.
- Where they can help avoid costs of installing fixed chargers that will require costly power upgrades.
- Where facilities have space constraints that make installing multiple fixed chargers difficult but mobile charging is feasible.
- Where charging is needed but there will be near-term redevelopment that impacts fixed chargers.
- Where installation of fixed chargers is not be possible due to site constraints, ownership issues, etc.

Table 3 Charging Strategy Summary

	Dedicated L1 & L2 chargers	Dedicated L2 chargers with load management	Shared L2 chargers	Shared DCFC	Mobile charging
Convenience and simplicity	▲▲	▲▲	▼▼	▼	▲▲
Capacity for future fleet expansion	▲▲	▲▲	–	▼	▲▲
Reduces peak demand and resulting service upgrades	▼▼	▲▲	▲	▼	N/A
Costs for hardware purchase, installation, and load upgrades	▼	▼▼	▲	▲▲	▲▲
Requires active parking/charging management	▲▲	▲▲	▼▼	▼▼	N/A
Risk of vehicles not being charged	▲▲	▲	▼▼	▼▼	▲▲
Flexibility for different vehicles and users	▲▲	▼	▼▼	▲▲	▲▲

Charging strategy ranking from excellent to poor for fleet applications - ▲▲ ▲ – ▼ ▼▼