Photo by Dennis Schroeder, NREL

Connecting Electric Vehicle Charging Infrastructure to Commercial Buildings

Introduction

Electric vehicles (EVs) are growing in popularity and gaining meaningful market share with record sales year over year in the last decade.[1] EV charging equipment, also known as EV chargers (EVC) or EV supply equipment (EVSE), must proportionally match the growing number of new EVs on the road for a comparable experience to gas-powered vehicles.[2] The majority of EV charging currently happens at residential buildings.[3] However, demand for EV charging at commercial buildings will significantly increase with wider mainstream EV adoption and as businesses return to more normal operation following COVID-19 pandemic disruptions. Charging equipment can include various sub-systems like power conditioning module, control software, safety devices, metering, communication, cooling, connectors, and its wiring. EV charging at commercial buildings could be used for public, workplace, and commercial fleet charging.

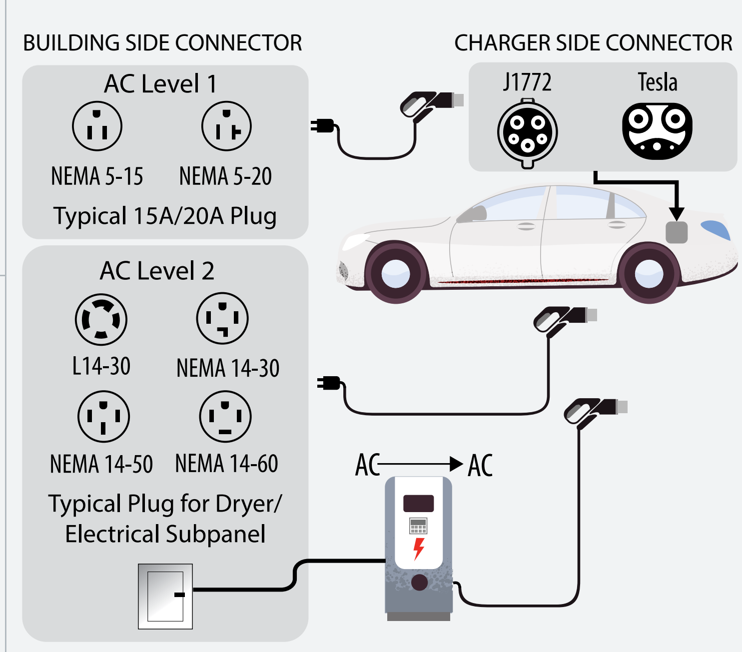
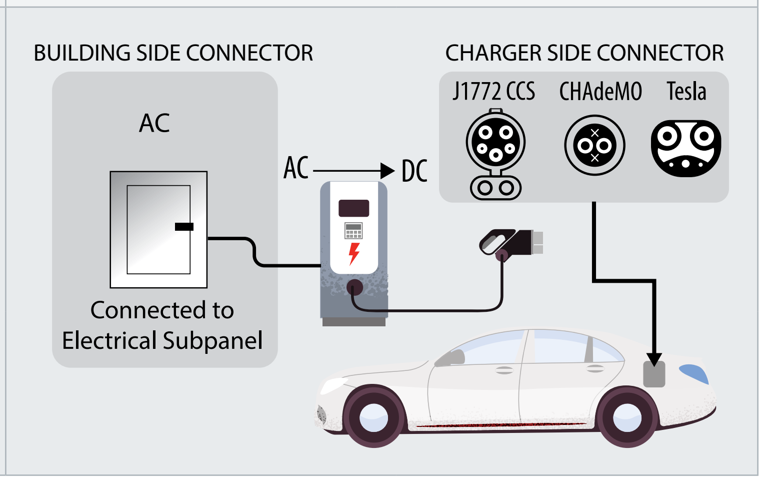
This document aims to describe how EVC can be connected to commercial buildings, including considerations for facility managers, and the effects that charging will have on the buildings electrical distribution system. More specifically, this resource provides an overview of:

- Understanding EV charging basics: how charging equipment connects to the building and to EVs.
- Required infrastructure updates needed at the building site to connect EVC to existing distribution systems
- Network strategies for cost-effective operation.
- Metering and utility considerations for billing and incentives.
- Charging equipment ownership options.
- Future trends in EVC connection to buildings.

Understanding EV Charging Basics

EV Charger Types

The power distributed by the electrical grid is alternating current (AC), while EV battery operation is direct current (DC). AC from the grid is converted to battery-usable DC by either the EV's onboard hardware or through external converter equipment. This AC-to-DC conversion location, connector protocol, and the rated maximum power transfer during EV charging are the main classifications for commercial EVC types. Figure 1 illustrates currently available charging equipment organized by electrical characteristics and connectivity options to both buildings and EVs. It should be noted that these EVC options are presently available to the commercial building sector. Future charging equipment technologies are mentioned in a later section to showcase upcoming potential opportunities for commercial buildings.

Charger Technology		EVC Output Voltage/ Max Current	Max Power Levels*	Max Charge Rate*	U.S. Market Share[a]	Building Side Connector	Charger Side Connector Type
AC	AC Level 1	120V AC / 15 A - 20 A	1.44 kW /1.92 kW	2-6 mi/hr	<5%		
	AC Level 2	208V - 240V AC / 30 A-100 A	5 kW- 19.2 kW	10-60 mi/hr	80%		
DC	DC Fast Chargers	50V-1000V DC / 80 A	80 kW	24-90 mi/hr	15%		
	DC Extreme Fast Chargers (XFC)	50V-1000V DC / 400 A	400 kW	80% of capacity in 30-40 mins			
	Tesla Super-charger	50 - 410 V DC / 330 A	140 kW	Up to 170 miles in 30 mins			

* Depends on various factors including (but not limited to) the EV make, model and battery charge level

a. The market share refers to available "public charging ports", https://afdc.energy.gov/fuels/electricity_infrastructure.html

Figure 1. Commercially Available EVC Categorization

Most EVs are supplied with cordset to connect to a common three-prong household plug. This 120-V wall outlet-connected AC Level 1 charger has the slowest charging rate and is generally utilized in residential applications or emergency charging situations. AC Level 2 is currently the most implemented EV charger type for residences and public/workplace charging, comprising over 80% of the installed EVC share.[4] Residential Level 2 chargers connect to a NEMA-14 wall outlet (a typical electric clothes dryer receptacle) and operate at higher current levels (30- or 50-A capacity) than Level 1. Homeowners normally add additional electrical circuits in their garage for Level 2 charging equipment, provided they have sufficient capacity in their main electrical panel and service. Commercial Level 2 EVC are connected to a dedicated electrical circuit and can charge at much higher maximum rates (up to 100-A capacity). This higher charging rate requires a minimum of a three-phase 208-V connection.

The DC fast chargers which are sometimes referred to as Level 3 chargers convert AC voltage from the grid to output DC voltage and are available with a wide input voltage range for connecting to buildings' electrical distribution systems. They require a minimum of a three-phase 480V AC circuit (or higher voltage connection) and a dedicated electrical panel within a building because it can consume significant power.

Typical EV Battery Charging Cycle

EV charging speed depends on factors like EVC hardware design, the EV's onboard electrical system configuration, the connector rating, the battery state of charge (SoC), individual component temperatures, battery chemistry, and user-selected charging priority. Any given EVC will not consume its rated power demand continuously, even if an EV is actively plugged in. For instance, the onboard battery management system (BMS) may curtail charging speed to maximize battery life by monitoring battery temperature and voltage trends.

When a charger plugs into an EV, the charging parameters are communicated between the EV and EVC to determine the optimum charging speed before any power transfer begins. If the battery has a low charge level and cell temperatures are within appropriate ranges, the BMS signals to transfer maximum rated power. The EVC monitors safety parameters and usually ramps up the power transfer rate gradually to avoid any damage to the charging hardware. After the initial ramp-up, the charging rate remains constant to the maximum possible value for the EV and EVC. As the battery reaches 80% of its full capacity, the power transfer rate drops to protect the long-term battery health. Typically, the last 10%–20% of the battery capacity is trickle charged at very low power levels, even if higher capacities are available.

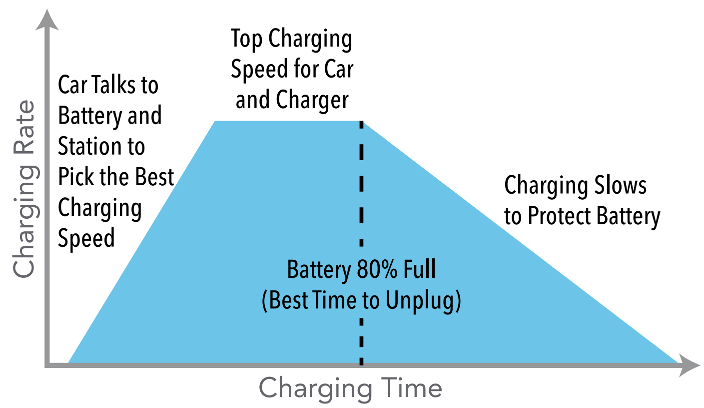


Figure 2. Typical EV Battery Charging Curve

Image from https://www.chargepoint.com/sites/default/files/inline-images/DC-Fast-Charging-Curve_2_0.jpg

EVC SELECTION FOR DIFFERENT BUILDING TYPES

The selection of EVC type and quantity depends on user requirements like average daily EV mileage, battery charging patterns, expected charge time, and number and type of EVs expected to be connected in the building.

- Level 1 and 2 chargers are most suitable for buildings with high average parking durations, like residential and office buildings.
- Level 2 or DC fast EV charging stations would be ideal in commercial buildings where average parking durations are short, such as grocery or retail stores, restaurants, and medical office buildings.
- Level 2 and DC fast chargers are also suitable for overnight charging for commercial EVs, like short-haul delivery trucks and buses at fleet facilities and parking garages.
- High-power DC fast charger is most suitable for long-distance interstate EV travel and for vehicles with high battery storage capacity like electric long-haul trucks and buses charged at the commercial buildings along highway corridors or truck depots.

Connecting Charging Equipment to the Electrical Distribution System

Considerations for Buildings

Based on the current market share of EVC, commercial buildings are most likely to consider a fleet of Level 2 chargers with a dedicated electrical panel to support EV charging needs. Many commercial buildings have limited additional capacity for Level 2 charging equipment and would require significant infrastructure changes to accommodate them.[5] Changes to the building electrical distribution may include new wiring, panel modifications, installation of an additional panel(s), and increased transformer capacity. **Before any EVC installation, a thorough review of the building's existing electrical hardware, power, and energy consumption is recommended.** An electrical design consulting firm (EV charging equipment provider in some cases) can be contracted to conduct this evaluation if in-house expertise is not available. This evaluation helps determine whether the existing infrastructure can support new charging equipment or if modifications to the building-level electrical distribution are needed along with estimating the quantity and type of EVC options that could be installed.

Figure 3 shows where different types of EVC are typically connected within a building electrical distribution system. The charging equipment will require independent electrical circuits for operation at different voltage levels depending on the charger type. National Electrical Code (NEC) Article 625 covers detailed charging equipment installation requirements for building electrical distribution systems.[6] There could be additional local and state codes or regulations for safe equipment operation to consider, depending on the building location. The code also mentions maximum cable lengths and physical installation guidelines for safety. Furthermore, cable and connector specifications for EV inlets and EVC outlets are outlined in the Society of Automotive Engineers (SAE) J-1772 standard,[7] which includes charging connector pin functionality and protocols for both power and communication (or controls).

Panel and Service Upgrades

Dedicated circuits, along with safety equipment, can be added to an existing building electrical panel if adequate capacity on the system is available. However, in previous studies, about 72% of Level 2 commercial installations required updates to the electrical panels.[5] Once the modifications to the existing electrical distribution system are determined by the building owners, the electrical utility will also have to evaluate if the new electrical service requirements can safely deliver the proper voltage and power requested once new charging equipment is installed.

Avoiding Panel and Service Upgrades

Service upgrades in buildings can be avoided by improving the overall energy efficiency of existing building equipment through retrofits, retro-commissioning, or installation of new energy-efficient equipment. These building performance improvements could allot the additional electrical capacity to support EVC loads. Additionally, building electrical infrastructure can take advantage of the EVC variable power consumption to limit and coordinate power draw by individual EVC through supervisory control software, which is becoming more widely available on the charging equipment market.

Worker installs new vehicle chargers at the National Wind Technology Center. Photo by Dennis Schroeder, NREL

Electrical Requirements for EV Charging Equipment

- Dedicated circuit capacity on the electrical panel where EVC hardware is added.
- Correct sizing of electrical components like wiring, panels, and circuit breakers.
- Sufficient electrical capacity for the utility feed to the building main electrical distribution panel.

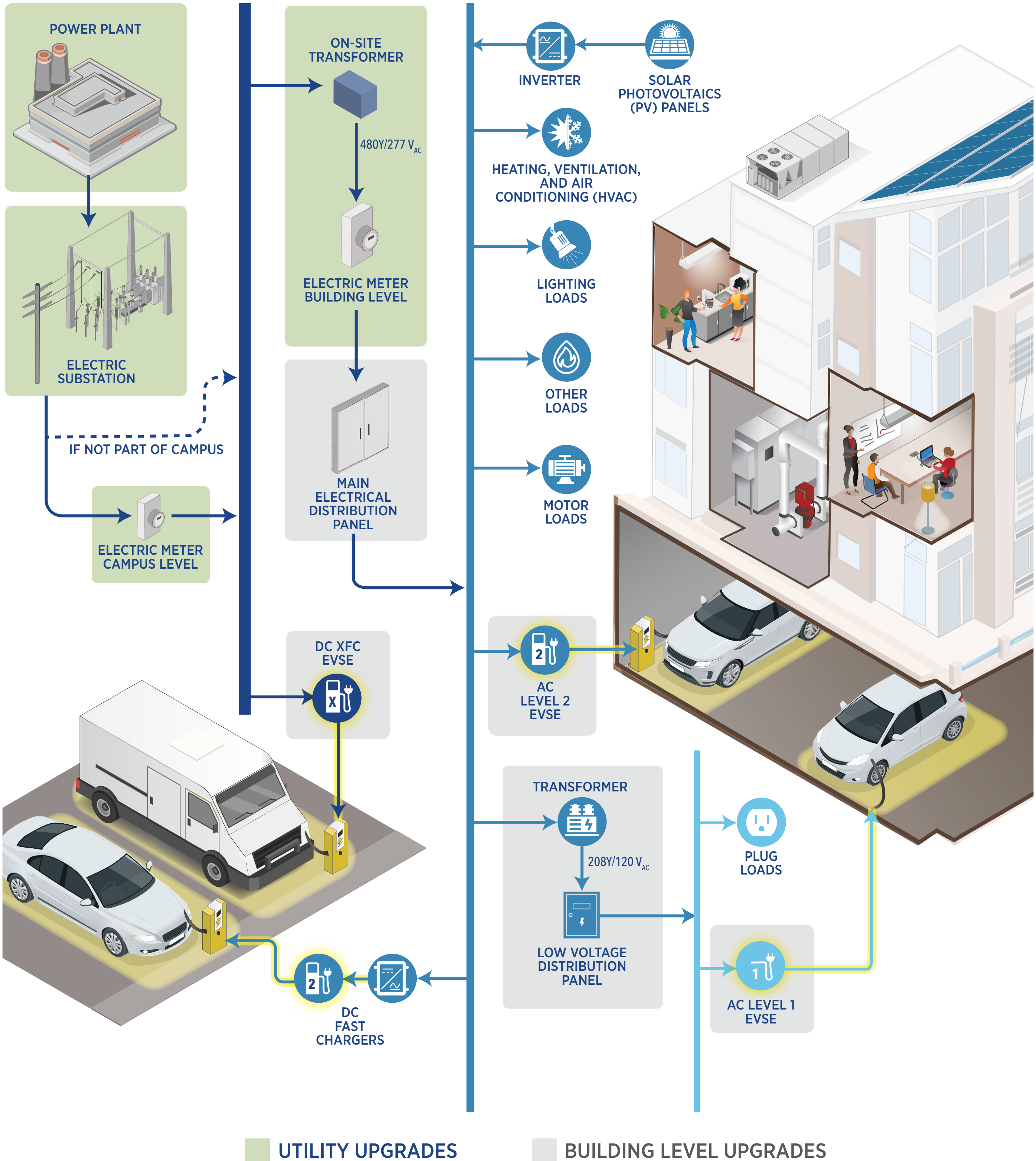


Figure 3. EVC Connection to a Building Electrical Distribution System

Image by Marjorie Schott, NREL and Pond5.com

Potential Hardware Upgrades to the Electrical Service to Add EVC (If Capacity is Deemed Inadequate)

- Installing a new transformer on-site and/or for the utility.
- Upgrading electrical service conductor from the utility connection to the customer.
- Installing new electrical panels, safety devices, and connections to EVC.
- Installing communication hardware for networked EVC.

Networking Capabilities for Capital Gains

Most residential Level 1 and 2 chargers are basic non-networked EVC with no communication capabilities except for supplying and controlling power to an EV. Some utilities are now offering residential DR (demand response) incentive programs for EV customers which will necessitate the installation of a networked charger. Commercial use of non-networked EVC is limited to the locations where the charging is offered free of cost or if EVC is assigned to a specific user where a dedicated metering system records its usage. Networked chargers enable additional benefit to the commercial sector in that they provide methods for collecting revenue for EVC operators and can interact with the user. The ability to have a direct revenue stream from usage charges and (if applicable) monthly or yearly user subscription fees can help offset installation costs.

Networked chargers are more expensive than non-networked counterparts but provides ability to interface real-time EVC operation with users, operators, payment services, maintenance, and utilities. Some networked chargers are designed to self-diagnose problems or test for safe operation and can communicate out-of-service information to either users or maintenance personnel. Advanced networked chargers can also offer the ability to communicate with other chargers on the same site using supervisory controls to predict and coordinate charging operations among various chargers.

Utility Incentives and Metering

Utilities primarily charge commercial customers based on their service type, maximum demand for a fixed period within a month (demand charges), and energy usage. Depending on the time of use (TOU) during the day, utilities typically charge tiered energy usage pricing with a higher cost during excessive demand periods and lower energy cost during low demand periods. A supervisory control system to predict and control the peak demand for EVC is highly beneficial to avoid coincidence with the building peak electric demand. If the building has distributed energy resources (DERs) like photovoltaic (PV) panels and/or an energy storage system, load management software with the capability to integrate those DERs with building loads and EV charging needs can further optimize the operating cost to result in higher financial returns.

Studies show that fully operational EVC can become the highest electrical load in a commercial building, surpassing heating, and cooling loads.[8] Options for electrical metering in a typical commercial building for EVC load include:

- EVC and building loads under a single utility meter.
- Dedicated utility meters for EVC.

Having the EVC under the same utility meter as the building provides more load diversity behind the meter, offering greater possibilities for more effective load integration and management. Commercial-grade EVC usually includes metering hardware for monitoring energy use during charging events. EVC charging systems may incorporate a configuration of tiered electrical rates for billing customers according to the peak utility rates, and the capability to decide the charging priority for various on-site chargers. When utilities can provide special commercial rates and incentives for EVC[9], a dedicated utility service can be beneficial. Sometimes, a new dedicated service for EVC is recommended if a new panel upgrade is economically unfeasible compared to adding a new utility service. Dedicated revenue-grade metering could be useful for some buildings that outsource EVC operation to a third party for fixed lease-based revenue.

Cost Associated with EV Charging Equipment Installation

The total ownership cost of the EVC includes the initial capital investment, operational charges, and maintenance expenses. Initial capital investments cover EVC asset expenditure and overheads associated with installation. The price of EVC hardware will depend on its charging capacity, networking features, and mounting type. Commercial charging equipment can range from $596-$3,127 for AC chargers and $28,400-$140,000 for DC fast chargers.[10] Hardware costs comprise labor costs, installation costs to connect charging equipment to electrical service, potential electrical service upgrade equipment (like transformers, electrical panels, and meters), and potential auxiliary EVC like payment systems, network connectivity equipment, and radio frequency identification/credit card readers. Capital costs should also consider the land, parking space purchase or lease cost, permitting, inspection, engineering design review, and drawings.

Operational costs will include the electrical utility costs (electricity consumption rate, time-of-use charges, demand charges), payment transaction fees, networking, internet connection charges, and any operator/support expense. Using an on-site renewable energy source like solar PV can offset part of the electrical utility costs by syncing EV charging with solar availability. Preventative or corrective maintenance and unplanned repairs are some of the recurring expenses associated with the upkeep of the EVC hardware. Planning and cost estimation for EVC installation is not trivial, and it is important to think through this thoroughly to avoid unexpected project costs.

Ownership Options and Business Models for EVC

Adding EV charging stations in a commercial establishment can offer multiple benefits to the host site. Along with direct charging fee revenue, the charging stations can offer indirect benefits associated with customer inclination to support "environmentally conscious businesses," higher customer dwell time, and potential revenue opportunities from EVC on-screen advertisements. Various business models exist to maintain and operate charging stations. These include:

- Full ownership, where the host site operates and maintains the charging stations.
- Lease options, where the host site uses an external EVC management company to supply hardware, operate the EVC, and maintain the equipment for a fixed cost.
- Hardware ownership, where the host site owns the EVC and contracts the operation and maintenance to an external company for a fixed cost.

Each operating model has its set of benefits and drawbacks. The selection depends on the level of engagement and expertise the host site is willing to commit. If the entire charging system operation is outsourced, the third party will handle the customer billing, operational overheads, and maintenance.

The Valley Hospital, in Bergen County, New Jersey, has installed five EV charging stations for staff use; in addition to improving local air quality, the chargers complement the hospital's broader sustainability goals. Photo from The Valley Hospital

Future Trends in EVC Connection to Buildings

Currently, most research on EVC is focused on decreasing charging time to match traditional gas station refueling times. These high-power chargers enable long-distance interstate travel for EVs. Consequently, the exponential rise of EV charging stations is projected to add strain to the aging electrical grid. A solution to this is to take advantage of on-site solar PV generation along with short-term local energy storage. As mentioned previously, the electrical grid currently operates on AC and must be converted to DC for battery charging. Most of the localized solar PV and energy storage also operate natively on DC. Thus, if EVC input is modified to feed by PV and energy storage on a DC distribution rather than a conventional AC system, the overall system can be more efficient, reliable, and resilient.[11] This setup can also benefit stand-alone EVC stations on interstates and other locations with limited access to the grid. Two-way, or bidirectional operation of EV battery systems is yet another scenario currently under development and pilot studies are being conducted for feasibility evaluation. Many EVs have hardware capabilities that enable them to provide power back to their local electrical distribution system, known as vehicle-to-grid (V2G) operation. V2G capabilities are currently being explored more for residential use, but commercial buildings could also greatly benefit from this feature for load flexibility, resiliency, and during emergency purposes. Another future form of EV charging is continuous charging (either through overhead charging cables or wireless charging), which remains under development and testing for campuses with fixed EV routes. If expanded throughout the road network, it can help reduce user "range anxiety" and eliminate the required building-connected, high-power, stand-alone charging stations.

Steps to Integrate EVC Into Commercial Buildings

1. **Determine EVSE needs for the building occupant (number of EVs and dwelling pattern)**
2. **Decide EVSE levels, quantity, and location to calculate additional electrical capacity for designing electrical infrastructure updates. Assess energy efficiency opportunities in buildings to allocate additional electrical capacity for EVSE**
3. **Evaluate various EVSE ownership and operation options. Check and apply for government/local utility incentives and tax credits for new EVSE installation**
4. **Obtain all necessary permits and apply for utility upgrades if required**
5. **Install, commission and test the entire system**

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