Considerations for Colleges Installing Electric Vehicle Charging Stations

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Abstract: Electric vehicles (EVs) are becoming more prevalent across all major world automotive markets. The growth of EVs is being powered by impressive improvements in new battery technology, along with renewable energy advances that have dramatically lowered the costs for a generation of pollution-free electricity. Colleges and universities are challenged to respond to this change, especially those with legacy automotive and transportation programs and those with clean energy technology programs. This study gathered experiences from several U.S. colleges on the leading edge of this trend. Challenges are identified for the deployment of EV charging infrastructure on campus, and recommendations are provided for those seeking to integrate EV charging technology into the curriculum and instruction of existing science, technology, engineering, and math programs.

Keywords: electric vehicle, charging station, solar photovoltaic, energy storage, infrastructure, STEM education

Introduction

The global transition to renewable energy and the adoption of electric vehicles (EVs) are widely recognized as complementary technological advances that together provide a pathway for the world to reduce greenhouse gas emissions and combat climate change. Over the past decade, both renewable energy [1] and electric vehicles [2] have experienced unprecedented growth, and the convergence of these industries has now reached a tipping point where mass market adoption could rapidly overtake traditional automotive consumer markets.

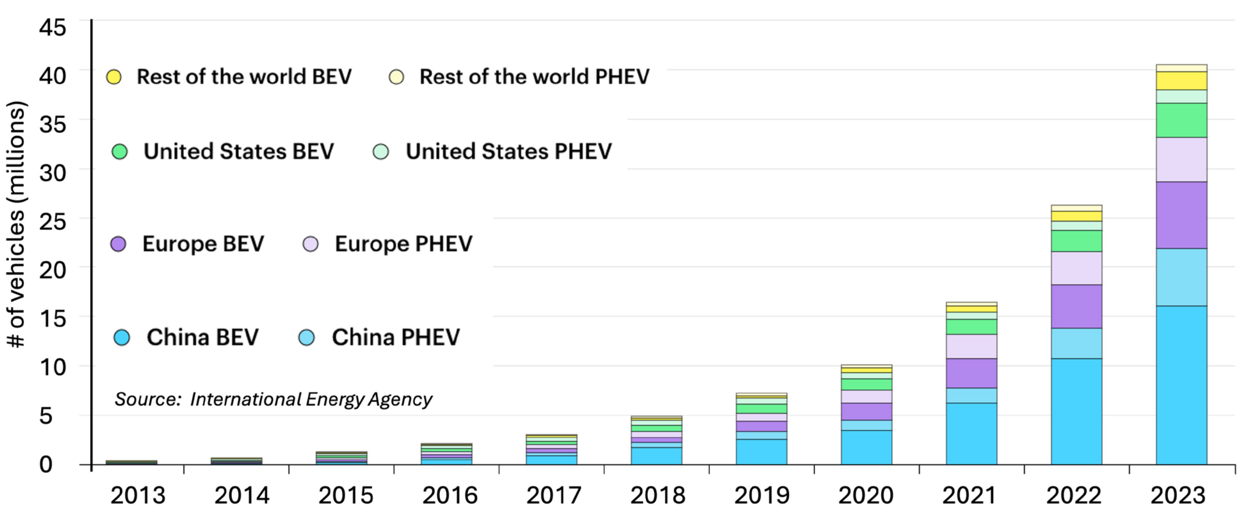

Fig 1. Accelerating pace of global electric vehicle adoption.

The CREATE Energy Center [3], [4] and the National Electric Vehicle Consortium (NEVC) [5], [6] are funded by the National Science Foundation Advanced Technological Education Program. In recent years, these entities have been collaborating to explore the combination of renewable energy electrical generation, battery energy storage, and EV charger technology. CREATE has conducted international faculty programs for many years to help educators learn about best practices in clean energy technology from world leaders [7], [8], [9] and to develop recommendations for U.S. colleges pursuing clean energy deployment on campus [10], [11]. Most recently, CREATE has taken groups of educators to Norway and Iceland to examine the two countries with the highest electric vehicle adoption in the world and to extract lessons that can be applied in the U.S. The NEVC was formed in 2023 and has convened multiple national conferences and workgroups to gather electric vehicle educators, industry experts, and stakeholders to examine challenges and opportunities for electric transportation. This paper outlines some of the issues facing schools seeking to embrace EV charging technology and provides recommendations for incorporating EV chargers into clean energy curriculum and instruction.

Why Install EV Chargers?

There are many reasons a college may consider installing EV charging infrastructure on campus. The college may own and operate (or perhaps plan to acquire) new electric vehicles for the school facilities department, grounds crew, motor pool, or campus police and security departments. Academic programs such as automotive technology and collision repair might seek to incorporate electric vehicle technology into their curriculum and instruction. Electrical programs may be seeking to teach about the deployment and installation of EV charger infrastructure. While engineering, power generation, and building science programs may wish to address the design and interdisciplinary integration of EV charger systems. EV charger access may be requested by staff or students who drive to campus using an electric vehicle, and the availability of EV chargers may also help with student recruitment. For many schools, multiple motivations may exist. Undertaking EV charger infrastructure requires some strategic planning, and most colleges have facility master plans that span 5 to 10 years. Colleges that have not previously addressed EV infrastructure may wish to survey their faculty and staff to assess current and future EV charger interest/demand so that they can forecast accordingly and develop an EV charger deployment plan.

Charging Levels and Equipment Choice

The first question to answer when selecting an EV charger is how much power you want to be able to deliver to a car at any given instant. In general, EV chargers are grouped by power rating into three categories: Level 1, Level 2, and Level 3 [12].

A Level 1 charger is designed to plug into a standard household 120V alternating current (AC) outlet. A Level 1 charger typically draws about 12 Amps (A) of current. This means that a Level 1 charger delivers slightly less than 1.5 kiloWatts (kW), corresponding to only a few miles of EV range when plugged in for an hour. For this reason, Level 1 chargers are best suited to plug-in hybrid vehicles that have a smaller battery size or for overnight charging of electric cars where it is only necessary to "top off" the battery pack. Because level 1 chargers are a relatively small load, these may be suitable for applications with smaller solar PV systems where the amount of solar-generated electricity is likewise limited. They are also well matched to small battery-operated off-grid solar systems; a limited battery bank cannot support more powerful EV chargers.

Level 2 chargers are considerably more powerful than Level 1 and have a wider range of operating parameters. Most level 2 chargers are capable of operating on 240V AC for residential home applications or 208V AC for installations with commercial three-phase power. Most level 2 chargers are also capable of operating at currents of anywhere from 12 to 50 Amps. The installer usually sets the current through the configuration of physical dip switches inside the unit or through the programming of the charger software during the commissioning process. Depending on the electric potential and the current settings, a Level 2 charger may deliver electrical energy anywhere from two to ten times as fast as a Level 1 charger, providing as much as 12 kW of power to the vehicle. Using a level 2 charger, a typical EV sedan can charge from 10 to 80% in about five hours, providing roughly 300 miles of range.

Level 3 chargers, also known as fast chargers, are the most powerful. These chargers operate using direct current (DC) electricity, which allows for much higher electric potentials—up to 1000 Volts. Level 3 chargers also use much larger conductors (wires) to supply large currents—up to 1200 Amps. The most powerful DC chargers on the market in 2024 can deliver electrical energy at rates exceeding 500 kW. One report found that a 500 kW fast charge station could charge an extended range EV from 10 to 80% in as little as twelve minutes, providing as much as 500 miles of driving distance. Although the capability of these high-power units is impressive, Level 3 chargers are probably not suitable for most school applications. A single level 3 charger draws so much electricity that it could easily surpass the peak load of an existing school building. Also known as DC fast chargers, they are also very large units (the size of a gasoline pump), and the sheer weight requires much more extensive earth and concrete work to install. Due to the required power electronics, they are also more expensive. In addition, most schools will not have the necessary infrastructure to support chargers of this type without major upgrades to electric transformers, switchgear, panel boards, wiring, and overcurrent protection devices. For this reason, level 3 chargers are likely cost-prohibitive for schools to pursue.

A new niche in the charger market is more modest intermediate power DC chargers. These are sometimes referred to as Level 2.5 chargers and have gained increasing popularity in some high-adoption EV countries such as Norway and Iceland. Intermediate DC chargers operate at more modest rates in the 20-30 kW range. Some schools may require EV charging capabilities beyond what is available from a Level-2 AC charger - for example, for charging campus police squad cars or emergency vehicles. In those situations, an intermediate Level-2.5 DC charger may suffice.

Regardless of the type/level of charger that is installed and the configuration of the hardware power settings, it is important to recognize that every EV charging event is ultimately controlled by the vehicle. The EV has an onboard charge controller that communicates with the vehicle's battery. Depending on the battery state of charge and temperature, the charge controller will throttle the amount of current supplied by the EV charger. Furthermore, different car manufacturers use different charging software algorithms, so even vehicles of similar size will behave differently, and results may vary.

Weather Conditions and Electrical Ratings

When considering the type of EV charger to install, it is necessary to evaluate the environmental conditions of the installation location. The charger will need to be rated to withstand the environmental hazards that it is likely to encounter. There are two industry standards used to grade electrical enclosures and how resistant they are to materials such as water and dust. National Electrical Manufacturers Association (NEMA) ratings [13] and Ingress Protection (IP) ratings [14] both define degrees of protection against contaminants but use different test methods and parameters to define their enclosure types.

NEMA is a U.S.- based industry group that advocates for safety and standardization across electrical devices. IP ratings are developed by the International Electrotechnical Commission (IEC), an international organization based in the European Union. NEMA ratings are primarily used in North America, whereas IP ratings are applied worldwide. Accordingly, EV chargers that are manufactured in the U.S. will likely have a NEMA rating, whereas those that are manufactured elsewhere will typically have an IP rating.

There is no direct conversion/equivalence between NEMA and IP ratings, but there are similarities between the two systems. Table 1 shows some of the more common NEMA and IP ratings that are observed for manufacturers of EV charging equipment.

A key difference between the two standard systems is that IP ratings cover protection only for solid and liquid contaminants, while NEMA ratings also address corrosion resistance, icing conditions, and hazardous environments such as exposure to fuels and/or flammable gasses.

The biggest difference among EV chargers is between equipment that is designed for installation indoors (i.e., in a garage) vs. those intended for outdoor use. The less expensive indoor chargers may have ratings such as NEMA 2 or IP11, whereas outdoor chargers should be at a minimum NEMA 3R or IP54 rated. For applications in extreme winter climates that are subject to freezing conditions, schools may want to seek out equipment with a NEMA 6 or IP 67 rating.

Table 1. Some common NEMA and IP ratings for EV charging equipment

NEMA Rating	IP Rating	NEMA Definition	IP Protection from Solids	IP Protection from Liquids
2	**IP11**	Indoor use. Protection against incidental contact. Some protection against falling dirt, and against dripping and light splashing of liquids.	1 Protected against objects >5cm in diam	1 Protected against falling water drops
3	**IP54**	Indoor or outdoor use. Protection against incidental contact. Protection against falling dirt, rain, sleet, snow, and windblown dust.	5 Protected against dust (limited ingress)	4 Protected against water spray
3R	**IP54**	Indoor or outdoor use. Protection against incidental contact. Protection against falling dirt, rain, sleet, and snow. Will be undamaged by the external formation of ice on the enclosure.	5 Protected against dust (limited ingress)	4 Protected against water spray
4	**IP66**	Indoor or outdoor use. Protection against incidental contact. Protection against falling dirt, rain, sleet, snow, and windblown dust, including splashing water and hose-directed water.	6 Protected against dust (no ingress)	6 Protected against strong jets of water
6	**IP67**	Indoor or outdoor use. Protection against incidental contact. Protection against falling dirt, hose-directed water, and the entry of water during occasional temporary submersion at a limited depth. Protection against external formation of ice on the enclosure.	6 Protected against dust (no ingress)	7 Protected against submersion for 30 min at a depth of 1m

EV Charging Connector Standards

In recent years, much debate and consternation has surrounded the issue of connector types among the EV community. In the United States, vehicles sold over the last decade came equipped with either CHarge de MOve (CHAdeMO), J1772, Combined Charging System (CCS), or North American Charging Standard (NACS) charger ports [15] (see Figure 2). The CHAdeMO is a DC charging connector, whereas J1772 is an AC connector, while CCS and NACS support both AC and DC charging. The CCS format is compatible with the J1772 AC charging protocol but includes two additional terminals to enable DC fast charging. CHAdeMO is an older standard that was first introduced with the Nissan Leaf EV targeted at cost-conscious consumers. In contrast, the NACS standard is a more recent innovation developed by Tesla and first deployed in their luxury line of EVs. Early adopter EV drivers planning road trips spent significant time researching the locations of EV chargers with the appropriate connector type for their vehicle, and a cottage industry arose providing adapters to allow for interconnection of different types. This situation is now beginning to be resolved. In North America, with the exception of Mitsubishi, all major vehicle manufacturers have recently adopted the NACS format. Most new public EV charging stations being built in the U.S. are using this standard. As early model EVs age and are retired from the U.S. fleet, charging stations that offer standards other than NACS will become more difficult to find in the marketplace.

For colleges, there are some additional considerations when choosing the type of charger to install. Most students are attending school while only having low or modest incomes, and as a result, they tend to drive older vehicles. Colleges intending to provide students with EV charging infrastructure may wish to install some CHAdeMO and J1772 chargers in addition to NACS format to serve students driving older model EVs.

Furthermore, many technical and community colleges have academic programs that teach automotive technicians. These students will enter the workforce and be confronted by older model EVs from a variety of manufacturers. Thus, automotive educational programs will likely want to install a variety of charger types so that students can learn to service a wide range of vehicles.

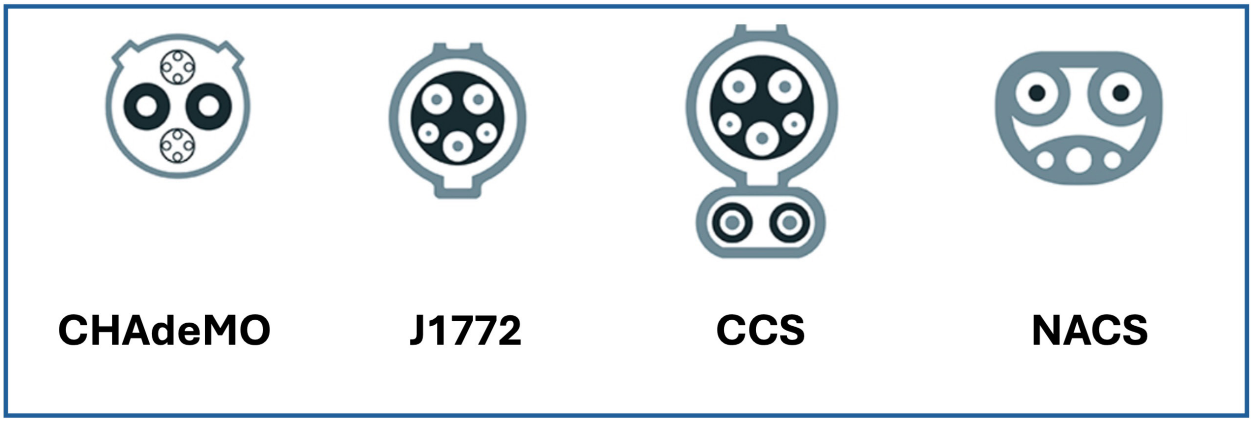

Fig 2. Connector profiles of common EV charging standards in North America.

Dumb vs. Smart Chargers

Many EV charger manufacturers now sell very low-cost, entry-level "dumb" chargers for the residential home market that are little more than a power cord with one end terminated to plug into a household outlet and the other end fitted with an EV charger connector. These budget model chargers typically have very few controls other than an on/off button, and many lack any form of user interface other than a few light-emitting diode (LED) indicator lights to communicate when the charger is operating. While these chargers can provide electricity to a vehicle, unless they are augmented with additional aftermarket metering devices, gathering any meaningful data about their operation is difficult. For this reason, they are not well suited for use in a college environment where faculty, students, and staff typically want to know more about how the device is functioning.

In contrast, "smart" EV chargers gather charger data and provide that information through some type of user interface, often displaying this information in real-time through a display window or a computer-generated graphical user interface. The latter function is typically accomplished using some type of web-based portal or through a user app that can be installed on a mobile device. For schools or businesses that intend to operate multiple EV chargers, some smart chargers can be managed collectively as a system. This can allow for scheduled sequential charging, which can be useful for applications such as the management of a motor pool of vehicles that all require overnight charging. Since schools need to budget for the energy cost of EV charger operation, this smart functionality is especially desirable.

Perhaps surprisingly, the documentation provided with many EV chargers on the market today is somewhat lacking, with minimal installation and operation manuals of only 1 or 2 pages in length. More commonly, you can find chargers with online user guides. For some, technical support is provided in the form of YouTube videos that are streamed. The majority of EV chargers available for purchase today are made outside of the United States, and phone-based technical support may not be available. Individuals specifying equipment for purchase may want to take this into consideration when evaluating EV charger manufacturers, especially if a "smart" charger is selected that will require programming to configure the operation parameters.

Equipment Durability and Longevity

When choosing and installing EV charging equipment, schools will want to consider the durability of the hardware and the potential for damage. Equipment will break because of driver collisions and neglectful behavior by EV users. Thoughtful selection of equipment and design of the EV charging space may help to mitigate these issues and increase the longevity of the equipment.

Much like parking meters, parking signs, and other physical structures commonly found in parking lots, EV chargers are susceptible to collisions with vehicles. To some extent, this can be addressed by placing chargers a few feet back from the parking space to allow additional clearance at the front of the vehicle. Bollards and wheel stops (parking blocks) positioned at the front of the parking space can also help prevent collisions with the EV hardware. Note that these are not foolproof methods; Madison College had a wheel stop cracked in half by a vehicle collision within the first three months of installing their first EV charging station. Fortunately, the EV charger was spared from any damage in this case.

Plug and cord damage is the source of many EV charger failures. Recent studies by JD Power, EPRI, and others have found that upwards of 25% of all EV charging failures can be attributed to issues with cords and connector plugs. There does not appear to be a standard type of plastic resin that is used to form EV connector terminals. However, some polymers are more brittle than others, which can be greatly exacerbated in cold climates. Ideally, when selecting an EV charger, it would be nice to observe the materials used in construction firsthand. However, we realize that most schools will be procuring charger hardware through an online purchase and may not have this opportunity. Polymers commonly used to fabricate EV connectors include polyamides (PA), polybutylene terephthalate (PBT), polycarbonate (PC), high-density cross-linked polyethylene (HDPE) and polyurethane (PU). If a school is purchasing an outdoor charger for operation in winter conditions, they may try to find a charger that uses a connector fabricated from polyurethane. This material is durable even in frigid conditions and is commonly used to manufacture ski boots and other winter sports equipment.

Cord manufacturing by the EV industry leaves a lot to be desired, and cord management by drivers will be a source of frustration for any school installing EV chargers. Some chargers are configured expecting drivers to simply coil the cord and hang it around the charger box itself, which typically does not work well in practice. Other charger manufacturers provide a cord hanger along with the charger grip holster. However, many of these seem undersized for the job. This problem is further compounded for level 2, 2.5, and 3 chargers, which have much thicker cables to accommodate the larger wire gauge necessary to support higher charging currents. Bigger cables require more room for coiling and are much heavier and stiffer. For a level 3 DC fast charger, a 15-foot charging cable can weigh as much as 40 pounds. This can be very difficult for some drivers to manipulate, especially those who have physical limitations. The difficulties are further exacerbated in the winter, as the cables become stiffer in the cold, while users struggle to grapple with them while wearing gloves and mittens. As a result, it is not at all uncommon to see EV charger cables lying on the ground strewn around an EV parking space.

Cord management is especially troublesome in winter because the cable can become encased in ice and snow and freeze to the ground. Madison College recently had an EV charger damaged when a charger cable became buried inside a snow drift. This was then run over by a snowplow driver removing snow from the parking lot, who was unaware that the charger cable was hidden in his path, buried below the snow. Colleges in winter climates will likely want to train their grounds crew to remove snow from around EV charging infrastructure using shovels or other hand tools rather than snowplows or auger-driven snow blowers. Some of the higher-end EV chargers now have pedestals with overhead cable retractor systems that help to support the weight of the cable by suspending it off the ground (see Figure 3). While this introduces an additional cost and another mechanical device to the system, it almost surely will help to extend the longevity of the equipment.

Fig. 3 EV charger cables coiled and lying on the ground at a recent clean energy expo demonstration event, compared with an EV charger deployed in the field equipped with an overhead retractable cable management system.

CREATE faculty noted a novel approach to addressing cable management as part of a recent international visit to Iceland. The majority of public EV charging stations in Iceland are “bring your own cord” variety (See Figure 4). These chargers simply provide an electrical charging port connection for EV drivers, who carry with them a personal charging cable that has connectors on both ends, one to fit the vehicle and the other to fit the charger. By putting the burden of cable management on the driver, this strategy eliminates the need for cable coiling and storage on-site with the charger. It also eliminates the issue of charger failures and downtime caused by cable damage or theft. Unfortunately, as of 2025, this type of “cord-free” charger installation is uncommon in the United States, but the method may find more adoption as colleges and other EV charging host sites grapple with the challenges of maintaining charger cables.

Fig. 4. Bring your own cord EV chargers in Reykjavik, Iceland. Photo courtesy of EV Box.

Colleges embracing EV charger technology should expect to repair or replace the chargers frequently. In two years, Madison College has had four EV chargers fail. Two were from damaged cords, one was from a damaged connector, and another had a problem with the electrical components. These chargers were from different manufacturers, indicating an issue that appears to plague the whole industry. Thus, the development of regular inspection and maintenance is important for schools installing EV chargers to ensure consistent operation and minimize downtime. Regular maintenance should include inspections of key components such as cables, connectors, enclosures, and mounting systems to prevent wear-and-tear-related failures. Leveraging data from smart chargers can help identify patterns of usage, potential issues, and equipment nearing the end of its operational life. Additionally, schools should train facilities staff or establish agreements with local technicians to perform routine upkeep and minor repairs, ensuring chargers remain functional between major service intervals.

A quick survey of part suppliers shows that the replacement cost of J1772 and NACS 50 Amp level 2 cables ranges from about $150 to $250 per cord. However, this does not represent the true cost of repair. One must also consider the labor time involved and the cost of personnel attending to those tasks. Activities to be accounted for include observing the failed charger and submitting a work order request, disabling/isolating the charger while it is broken so that it is safe, posting "out-of-order" signage to communicate to drivers, procuring replacement parts, scheduling the repair, conducting the actual repair, and testing and re-commissioning. The labor costs associated with this extra work can easily exceed the cost of the part itself. The purchasing process for colleges can be especially time-consuming, and for this reason, schools may wish to buy replacement cords in bulk and maintain an inventory of replacement parts. This can also help limit the downtime for broken EV chargers.

It should also be noted that in some states, EV chargers must be equipped with an emergency "e-stop" switch that, when depressed, will interrupt the circuit and cut the electric power to the charger. These e-stop switches often cannot be simply reset by the user. Instead, the e-stop requires a technician to service the equipment, open the unit, confirm that it is not damaged, and then manually reset the e-stop. While the inclusion of e-stop devices on EV chargers was well-intentioned to provide an extra measure of safety, in practice, it has rendered the chargers vulnerable to a new form of tampering. Mischievous youths have learned about the e-stop switches and have created YouTube and TikTok videos with "EV-stop tutorials" challenging their peers to see how many EV chargers they can disable. For schools considering EV charger installations, it is important to see if your state has adopted this safety requirement, in which case the college's maintenance plan may need to make additional considerations for this sort of nuisance meddling.

Somewhat paradoxically, equipment warranties for EV hardware are likely not that important or relevant to schools installing EV chargers. Warranties are typically voided by misuse, so damages due to driver collision, cable management failure, and dropped connectors surely fall into that category. Even if a warranty policy covers a failure, it may be challenging to recover that loss. There is currently great competition in the EV charger market, and manufacturers are entering and leaving the market on a frequent basis. The firm that sells an EV charger to a school today might not be in business a year later to stand behind a warranty claim. Somewhat counterintuitively, this might not be a bad thing for colleges pursuing EV infrastructure. EV charger technology is changing so rapidly that first-generation equipment from a few years ago has already been superseded by two or three subsequent new models that are greatly improved in design and capability. As mentioned above, EV charger connector standards have been changing over the past decade, and it seems likely that this evolution will continue. Furthermore, the price of EV charger equipment continues to drop at a rapid pace. Thus, colleges installing EV chargers today might be best advised not to be overly obsessed with manufacturer warranties. Instead, it is probably wise to plan and budget to replace EV equipment periodically every few years, as industry standards change and technology improves, rather than planning around manufacturers' warranties.

Methods

Management of Parking & Public Charging Access

Colleges seeking to deploy EV charging infrastructure for public use have many decisions to make beyond the selection of equipment. The first critical question is where to place the EV charger. In most cases, the EV charger will be supplied with electricity from a building, typically requiring underground conduit, wiring, and possibly communication cables to connect the charging station. To minimize the balance of system cost, it is usually necessary to place the EV parking spaces close to the building, typically near the facility's handicap-accessible spaces. The second question that a college must address is whether the school will assess a fee for EV charging. If so, how will this be priced, and how will the fee be assessed/collected? This can quickly complicate providing EV charging infrastructure for a campus.

Since EV spaces are typically located near the building, they are "premium" parking spaces. Furthermore, since the school is providing energy to the EV driver, the natural desire is to establish a means for assigning a fee to be paid for this service. In addition, a permitting and parking enforcement strategy is often necessary to prevent people with ordinary internal combustion engine cars from occupying these parking spaces and preventing EV drivers from accessing them. Costs for EV charging can be assessed in several different ways, each with associated pros and cons.

One strategy is to offer specialized permits for EV drivers that grant them permission to use the chargers. The advantage of this strategy is that most colleges already have a system in place for issuing and selling parking permits, so it does not require significant changes to current practices other than creating a second type of specialized permit for EV drivers. The EV permit typically will be priced at a higher amount since it both grants the driver access to a front-row parking space and provides them with access to electricity. Enforcement for this type of permit is also straightforward. Campus police need only to check to see that the charging car has the appropriately displayed EV parking permit. If priced appropriately, tickets charged to parking violators may offset the cost of parking enforcement. The main disadvantage to the parking permit strategy is that once a driver parks a car in the EV space, there is no incentive for them to move the vehicle until they are ready to depart campus. So, even if the car is fully charged, it may continue to occupy the space for many hours, preventing other EV drivers from using the charger. Another disadvantage is that the amount paid does not scale with respect to the amount of electricity used. An EV driver who visits campus once a week for class pays the same amount for a parking permit as a driver who visits (and charges their car) daily. An argument could be made that this sort of permit structure favors college faculty and full-time students who are on campus more frequently at the expense of part-time students who might only attend one or two days a week. Furthermore, if the permits are priced too low and drivers use the chargers more than expected, the college could still be confronted with large electric utility costs that exceed collected permit revenue.

Another strategy for assigning a cost to EV drivers is to borrow a page from conventional parking meters and charge by the amount of time that a driver has their car occupying the EV charging space. This strategy also has the advantage of being straightforward to implement using conventional parking management techniques. It could be as simple as installing a coin-operated parking meter in every EV space. A more modern approach would be to install an automated parking system with a self-serve kiosk to charge drivers and dispense receipts that serve as permits to display on vehicle dashboards. If a school already has an automated parking system in place, it may be possible to program the computer software to designate certain spaces in the system as EV spaces and charge an appropriately higher parking fee. The advantage of this system is that it encourages the driver to move their vehicle as soon as the battery is charged so that they do not incur any additional EV parking costs. This can help ensure chargers are available for other drivers, increasing the utilization of the charging infrastructure. The main disadvantage is that although the time occupying the parking space is correlated to the amount of electricity consumed, the amount paid still does not scale directly with respect to the amount of electricity used. With this type of strategy, EV drivers whose vehicles are capable of charging at relatively fast rates will be able to draw more electricity in an hour than those whose vehicles are only capable of slow charging. This sort of permit structure favors those with newer and higher priced vehicles that support fast charging while disadvantaging those with older, lower priced, and plug-in hybrid cars that may not be able to charge at rates more than 3.2 kW. The former group of drivers is more likely to include college faculty and administrators, while the latter disadvantaged group is likely to include a larger number of students. Another disadvantage to this approach is the additional cost associated with installing a payment kiosk, and the maintenance issues associated with maintaining network connectivity for the online processing of secure payments with credit card vendors. Much like with self-service gasoline pumps, there is also a risk of criminals attempting to steal credit card information from kiosks by intercepting communications or deploying physical card skimmers, spy cameras, or other illegal devices.

Perhaps the most exact way to assign electricity costs to EV drivers is to price charging access based on the amount of energy in kilowatt-hours (kWh) delivered to the vehicle. In this strategy, a fixed unit price is established. This practice is generally accepted by consumers and other stakeholders who are accustomed to buying gasoline at a fixed price of $/gallon and are accustomed to paying energy charges on electric utility bills in $/kWh. Prices for many charging system operators are typically set in the range of $0.25 to $0.50/kWh. The main advantage of this approach is that the amount paid by the EV owner scales directly with the amount of energy consumed. So, the college will not incur financial losses from utility costs if the chargers are heavily used. This is also an inherently fairer way to allocate costs to EV drivers. Vehicles that consume more energy, either because they are capable of faster charging or because they are plugged in for a longer time, will bear a proportionally larger fee. If a school operates chargers with different power capabilities, the electricity costs can also be priced accordingly. For example, charging more per kWh for electricity delivered by a faster level-2 charger and less for electricity delivered more gradually by a level-1 charger. In this way, the revenue collected by the chargers may also reflect the magnitude of the extra electrical demand added to the college's load for each vehicle being charged. Of course, there are challenges for schools seeking to adopt this methodology. The equipment required to implement this payment structure is more complex and expensive. Revenue-grade electrical metering is necessary to gather data on the real-time delivery of energy to the vehicle. The accuracy of this metering equipment will need to be periodically checked to confirm that the charger is properly calculating the cost assigned to the EV driver. One other limitation is that this type of payment structure has been illegal in some U.S. states where regulatory laws only permit public utility providers to charge for electricity on a per-unit basis. Fortunately, this obstacle is now being alleviated at the behest of the federal government as a requirement for states to participate in the National Electric Vehicle Charging Infrastructure programs [16].

Given the various complications of assessing a fee for EV charging permits, it might appear that the simplest solution is to provide EV charging for free. This could be regarded as a service for college stakeholders and as an environmental benefit provided by the college to the community. The major disadvantage to this strategy is that the college is incurring the cost of electricity, and that cost must be paid by someone. Some schools that have pursued this course of action have come under criticism for "subsidizing" EV drivers at the expense of others who operate conventional internal combustion engine vehicles. This critique also has an equity aspect since EV drivers tend to be more affluent and more likely to be college faculty and administrators, whereas people of more limited economic means (e.g., most students) tend to drive cars running on gasoline. The optics and messaging are particularly bad if a college is raising tuition prices while also providing free charging to EV drivers. In some recent extreme cases, angry individuals protesting against the provision of free EV charging have intentionally vandalized chargers, using bolt cutters or electric reciprocating saws to sever the charger cables, rendering them inoperable.

One situation where free EV charging tends to be accepted is if the electricity is being generated by solar power. Since the sunshine itself is free, if a solar PV system is sized such that it matches the consumption of the EV charging infrastructure, then free EV charging can be provided without incurring any additional utility expense to the college. A similar case could be made for EV chargers supplied with wind energy or hydropower, but there are not nearly as many schools with that type of renewable energy resource. If renewable energy resources are to be used to provide free EV charging, it is important to make this connection tangible to the campus community and members of the public. It works best if the solar array is located directly adjacent and wired directly to the EV chargers. For example, Lane Community College (LCC) in Eugene, OR, and Mid-State Community College (MSTC) in Wisconsin Rapids have deployed EV chargers directly beneath parking canopy structures that host solar photovoltaic panels.

Fig. 5. Solar parking canopies and EV chargers at LCC and MSTC campuses.

By comparison, some schools have purchased solar or wind power through green power purchasing programs offered by their electric utility provider and used this purchase to offset the electricity consumed by EV chargers. However, it is much harder to persuade people of the value of purchasing renewable electricity from a distant solar farm and transporting it across transmission and distribution lines to supply EV chargers on campus. Prominently displayed interpretive signage can also go a long way toward educating both EV drivers and other campus visitors who take an interest in the charging infrastructure. Madison College provides an example of this type of messaging that has been successful with college faculty, students, staff, and visitors (see Figure 5).

Fig. 6. EV chargers and interpretive signage at Madison College.

Integration of EV chargers with Solar Photovoltaics and Energy Storage

For colleges interested in EV charging, integrating solar photovoltaics and battery energy storage systems is an almost ideal marriage of technologies. Solar energy generation helps offset the additional electricity consumed by EV chargers, and the intermittent nature of solar generation is smoothed out when paired with battery energy storage. In this way, energy can be stored when it is sunny, and then EVs can be charged when clouds pass overhead or even after sunset. If a system is designed and sized carefully, the additional burden on the college's electrical system can be minimized.

The consumer audience for these three technologies largely overlaps. Drivers purchasing electric vehicles want their cars to be powered by electricity generated from clean, renewable energy, not by burning dirty fossil fuels. For this reason, one of the strongest motivations for customers to pursue solar for their homes is the recent purchase of a new electric vehicle. Likewise, homeowners with solar on the roof are much more likely to have an EV parked in the garage. EV owners who work at the office often install stationary storage batteries at home to "bank" their solar energy during the day so that when they get home from work, they can "tap" their storage system to charge up their EV overnight.

Businesses working in the clean energy industry have also recognized and championed this convergence of technologies. Almost all solar photovoltaic contractors now offer battery energy storage products and services to their customers, and a strong majority of solar contractors provide EV charging equipment and installation services. For colleges training students to enter this industry, renewable energy programs across the country are rapidly integrating both battery energy storage and EV charging technology into the curriculum.

When creating solar and energy storage instructional labs for college students, the integration of EV charging technology also solves a pertinent problem. In order to demonstrate the functionality of solar plus energy storage, you need to have some type of load that can be applied to periodically "exercise" the storage battery. Although a college campus is essentially an infinitely large load for a small instructional solar + storage system, simply discharging a battery to feed into a college building is not very interesting for students. Additionally, a college building is not "dispatchable." So, if the building is used as a load, students cannot apply and remove it from the system and observe the effect on the energy storage components. By comparison, an EV charger can be wired to a battery storage system, and students can plug in a car to apply or remove that load strategically. Given the energy monitoring functions of most smart EV chargers, this also allows for the merging of data sets from the solar, battery storage, and EV charger components. When combined, this facilitates the study of energy transformations and flows throughout a complex system. Advanced students can apply the first and second laws of thermodynamics to model the transfer of energy from the sun to the batteries and then to the vehicle and can determine the overall efficiency of the process. Thus, the combination of solar photovoltaics, battery energy storage, and EV charger systems is an ideal merging of complementary equipment for the instruction of technical students.

Results and Discussion

Integrating EV Chargers with Student Instruction

Installing EV chargers for the residential market is simple and straightforward. In most cases, a bracket is supplied that is first mounted to a wall or kiosk by a few screws; the charger is then hung and secured to this bracket. In the case of pedestal-mounted EV chargers, if the pedestal is mounted against the side of a building or other structure, this is only slightly more complex. If the EV charger is to be mounted on some type of concrete base or bollard, this is also more difficult due to the need to integrate the electrical wiring with the pouring of concrete.

Many EV chargers sold for the residential market come equipped with a NEMA 14-50 power cord, designed to simply plug into an existing 240V outlet. Even in cases where the EV charger is hardwired, there are only three (or perhaps four) wires to land in the charger – Line 1, Line 2, Ground, and in some cases, a neutral. There is not a lot for students to learn from making these simple connections.

Networking of EV chargers is somewhat more challenging, as this requires an understanding of IP addresses, communication protocols, etc. Troubleshooting these issues can be difficult. Many EV chargers intended for the residential home market are currently sold with embedded WiFi transmitters to make installation easier for the homeowner. If the charger is networked with a solar PV inverter or an Energy Storage Unit (i.e., battery), those may communicate over WiFi or in some cases, over an RS-485 serial communication interface. In this case, the leader control device (likely the inverter) typically has a hard-wired Internet connection. EV chargers intended for the commercial market may have WiFi capability but, more commonly, are hard-wired with Internet access to facilitate user account tracking and, in some cases, to execute secure payment transactions.

Both energy storage and EV charger systems generally are not designed for repeated assembly and disassembly. The terminal blocks used for making these connections in most battery charge control units and EV chargers are not very robust—they are designed to be installed once, and then left in place for operation. These connection points would likely not hold up well to repeated installation and uninstallation, like what might be required for use in an instructional training lab environment. Many parts might fail quickly if used in this manner.

For students to truly learn about energy storage and EV charger commissioning, students need to work with the system software to see and modify charging and discharging settings. It is not easy for more than one person at a time to change system settings. Some vendors will not allow people to change these settings until they have gone through the vendor specific installer training.

For students to learn about the function of battery storage and EV charger systems, they need to be able to access the data to observe charging and discharging behavior. This requires a monitoring platform and a way to make data accessible to students. Ideally, data that is easily exported as .csv files can be distributed to students for analysis using Excel or other spreadsheet and data visualization tools.

If a school operates multiple EV chargers, this creates an opportunity for students to examine large data sets and learn skills such as trend analysis and virtual system modeling. This may allow the school to identify charger locations that are more frequently used than others and to determine times of day when chargers are most heavily active. The data may help in planning for the deployment of future charging stations and, if integrated with a campus energy management system, may help to schedule the dispatch of on-site solar or battery energy storage resources to best serve EV charging loads.

Educational Integration and Cross-Disciplinary Programming

To fully capitalize on the synergy between solar energy systems and EV charging infrastructure, schools could develop interdisciplinary academic programs that encompass both domains. This approach would prepare students for a broader range of career opportunities while addressing the industry's need for skilled professionals who can install, maintain, and integrate these technologies. Programs could combine coursework, in solar PV and EV charger technology, focusing on overlapping areas such as electrical wiring, load management, and system integration. A key common element for this cross-disciplinary education is training in electrical and high-voltage safety. This is an essential component for both solar PV and EV charger installations. Students should learn to identify and mitigate risks associated with high-voltage systems, including proper grounding, arc flash prevention, and the use of personal protective equipment (PPE). Familiarity with standards such as the National Electrical Code (NEC) is fundamental. Specific emphasis on safety measures when working with large capacity AC & DC fast chargers, which operate at voltages up to 1,000 volts, could help technicians work confidently and safely in both fields.

Integrating solar and EV charger education could broaden employment prospects for solar technicians or solar-focused businesses. As the EV industry grows, so does the need for maintenance professionals who can minimize "downtime" by efficiently diagnosing and repairing EV chargers. Solar technicians, already skilled in working with electrical systems and renewable energy technologies, are well-positioned to expand their expertise to include EV charger installation, maintenance, and repair. This dual capability would make them more versatile in the workforce, benefiting employers by reducing reliance on specialized EV charger technicians and enabling faster response times for maintenance issues.

Conclusion

There is no simple formula to determine if, or when, an individual college should pursue the installation of EV charging infrastructure. Schools will have varying adoption rates of electric vehicles, depending on the local climate, the cost of electricity, local EV infrastructure, cultural differences in environmental awareness, and driver preference. However, it is without question that renewable energy and electric vehicle technology is experiencing rapid growth as consumers adopt these sustainable choices for transportation. Over the next decade, colleges with energy and transportation educational programs will need to evolve to integrate these technologies into legacy academic programs, while other schools may create entirely new pathways for students to pursue careers in this area.

Likewise, there is no one-size-fits-all recommendation for the quantity and level of EV chargers appropriate for every institution of higher education. Nor is there a single preferred electricity source, a common mechanism of assigning cost, or a standard method for collecting payment from drivers suitable for every school. Schools, colleges, and universities all have their own unique attributes. Faculty and staff who manage facilities, grounds, and transportation infrastructure will need to make site-specific assessments to determine the best strategy to implement EV charging for their institution. In some cases, for large institutions that operate multiple campuses, the preferred choice for one college location might be different from another. The recommendations contained within this paper should be helpful for campus administrators, facility managers, and faculty members to plan for the build-out of EV charger infrastructure and to facilitate the integration with complementary renewable energy electrical generation.

Acknowledgements. This work was supported by the National Science Foundation under awards DUE ATE 2201631 and 2202050.

Disclosures. The authors declare no conflicts of interest.

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