Medium- and Heavy-Duty Electric Vehicle Charging Infrastructure Cost Analysis for California's CALGreen Building Code

PREPARED FOR:

CALIFORNIA STATEWIDE UTILITY CODES AND STANDARDS TEAM

PREPARED BY:

JIM FREY AND ALEX CHASE, **2050 PARTNERS**

RAPHAEL SPERRY, GEOFF GUNN, AND CHRIS KEIFER, **ARUP**

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Acronyms

3ph	Three Phase Power Distribution
A	Amperes (Amps)
AC	Alternating Current
ALMS	Automatic Load Management Systems
CALGreen	California Green Building Code Title 24, Part 11
CARB	California Air Resources Board
CBSC	California Building Standards Commission
DC	Direct Current
DC FC	Direct Current Fast Charger EVSE
eTRU	Electrified Transportation Refrigeration Unit
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment (EV Charger)
FHWA	Federal Highway Administration
GHG	Greenhouse Gas
HD	Heavy-Duty Vehicle
HEVI-LOAD	Medium- and Heavy-Duty EV Infrastructure Load, Operations, and Deployment
HEVI-PRO	Medium- and Heavy-Duty EV Infrastructure Projections
kVA	kilo Volt-Ampere (Apparent Power)
kW	kilo Watt (Real Power)
kWh	kilo Watt Hours (Energy)
LBNL	Lawrence Berkeley National Laboratory (Berkeley Lab)
MD	Medium-Duty Vehicle
MHD	Medium-/Heavy-Duty Vehicle
MW	Mega Watt (Power)
NACFE	North American Council for Freight Efficiency
RSMeans	Robert Snow Means (Construction cost data now offered by Gordian)
V	Voltage (Volts)
ZE	Zero Emission
ZEV	Zero Emission Vehicle

1. Executive Summary

California has set a target that by 2045, 100 percent of the medium- and heavy-duty (MHD) vehicles operating in the State shall be zero-emission vehicles (ZEV), where feasible[1]. Achieving this goal will require many different initiatives working in parallel. It will require new behavior and new investments from actors in the building, utility, service provider, and vehicle ecosystems. In these early days for this nascent market, it is

[1] CA Executive. 2020.

important that regulators give the market clear and steady signals while providing the flexibility to innovate. The building code is a central signal within the highly decentralized and heterogenous buildings sector that all market players can identify as a reliable indicator of minimum future EV-readiness.

1.1 Background

Under a mandate from Assembly Bill 1092 (Chapter 410, Statutes of 2013) authored by Assembly Member Levine, California Building Standards Commission (CBSC) was directed to develop mandatory EV charging infrastructure standards for nonresidential buildings during the 2016 Intervening Code Cycle of the California Green Building Code Title 24, Part 11 ("CALGreen"). The CALGreen standards developed to set requirements for nonresidential buildings have thus far focused on light-duty vehicles.

California Health and Safety Code Section 18930.5(b) as amended by Assembly Bill 341 allows CBSC and other state agencies that propose building standards, allow for input by state agencies that have expertise in green building subject areas. The California Air Resources Board (CARB) has expertise in air quality, climate change, and EV charging infrastructure, and has taken the lead in developing EV-related CALGreen proposals. For the "2022 Cycle," CARB staff has worked with CBSC to develop proposals focused on MHD vehicles in addition to expanding requirements for light-duty vehicles in multifamily and nonresidential buildings.[2]

Recent analysis shows that EV capable infrastructure must support 180,000 MHD zero-emission vehicles by 2030[3]. CARB has adopted, and continues to adopt, regulations requiring sales and purchases of MHD ZEVs. While it is too early to mandate design of depot- or fleet-size battery electric vehicle charging requirements given the lack of data about ZEV fleet operations, and the fleet-specific nature of requirements, it is foreseeable that with the ongoing development of regulations for MHD ZEVs, there will be a need for charging opportunities throughout daily operations that include stops at multiple buildings for loading and unloading.

1.2 Approach

In consultation with CARB staff, the California Investor-Owned Utilities Codes and Standards team provided research project management via 2050 Partners and building

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[2] The focus of this report is on MHD vehicles. A separate report sponsored by the California Statewide Codes and Standards utility program focuses on light-duty vehicles.

[3] CA BSC 2021c. Pg. 6.

design and power system expertise via Arup. Our key research task was to provide data that would inform how to size the charging infrastructure supporting these MHD loading spaces for certain building use cases. With this mandate in mind, the research team interviewed stakeholders as well as Arup's electrical engineers and logistics experts, to configure appropriate power distribution systems. We estimated MHD dwell times that set the minimum incremental power capacity requirements for meaningful EV refueling during loading and unloading. Arup's electrical engineers utilized industry-standard power density averages to select representative power transformer, switchgear, and distribution equipment. Arup's construction cost estimators then utilized industry-standard methods to inform the development of a MHD EV charging infrastructure cost impact model.

1.3 Results

Our findings provide support for the proposed CALGreen building code requirements for MHD EV charging infrastructure.[4] The proposal recommends the inclusion of code language requiring certain new buildings frequently served by MHD vehicles (e.g., grocery, retail, warehouse) install the minimum amount of electrical infrastructure to improve the cost-effectiveness of installing electric vehicle charging equipment later in life, including capacity for delivery trucks as well as forklifts and electric truck refrigeration units (eTRUs). In general terms, buildings with a loading dock[5] for trucks would be required to provide extra electrical panel capacity to accommodate a minimum of 200 – 400 kW of EV supply equipment (EVSE) in the future, run conduits from the panel to the loading dock area, and leave space at the loading dock area for MHD EV charging cabinets and dispensers. We present data indicating that this is a cost-effective requirement in that 1) the avoided future costs of retrofitting additional electrical panel capacity and conduit is substantially higher than the costs of building that infrastructure at the time of construction, i.e., "first cost,"[6] and 2) the additional cost to add the additional electrical panel capacity and conduit is small relative to total

[4] At the time of writing, the "Initial Express Terms" have been released and CALGreen's Code Advisory Committee have met to discuss the proposals and make recommendations to BSC. The next substantive stage is the 45-day public review period is expected to be August 13, 2021, through September 27, 2021. The adoption hearing is expected to occur in December 2021 or January 2022, and the effective date will be January 1, 2023. See Section 2 for additional details.

[5] See section 3.1 for usage of the terms "loading dock" and "off-street loading space" in this paper.

[6] "first cost" is used here to refer to the cost of the electrical system components affected by the proposed code: the transformer and main switchboard in the case of existing code; or the larger transformer, larger main switchboard, and additional conduits required under the proposed code.

building cost (generally <1% of construction cost only). The ratio of retrofit cost to first cost is 135% - 238% and the ratio of additional construction cost to first cost is 0.5% - 2.1% (see section 4.2, Findings and Assessment, for more detail).

1.4 Future Work Recommendations

While the 2022 CALGreen cycle proposal is a good first step toward making California's new commercial buildings better fueling hosts for visiting MHD electric trucks, much work remains to expand MHD charging capacity at existing buildings during renovation activities. The report concludes with recommendations for future research priority areas to support the state's long-term goals.

2. Introduction

2.1 EV Regulatory Landscape for MHD vehicles

On September 23, 2020, Governor Gavin Newsom signed Executive Order N-79-20, setting the target of 2045 for 100 percent ZEV operations for medium- and heavy-duty vehicles, where feasible[7]. The CARB's Draft 2020 Mobile Source Strategy projects the state will need 180,000 medium- and heavy-duty ZEVs in 2030 to achieve state climate and air quality goals and comply with Executive Order N-79-20[8]. Preliminary modeling suggests 157,000 DC fast chargers will be needed to power these vehicles, of which 141,000 are 50 kW and 16,000 are 350 kW but does not identify where or how these are to be deployed[9]. Other California regulations are also driving the increased use of ZEVs for MHD applications, but they do not address where or how the future fleet of MHD EV chargers will be deployed, including:

- **Innovative Clean Transit Regulation** – requires all public transit agencies to transition to 100% Zero Emission Bus fleet. Starting in 2029 all new purchases by transit agencies must be zero emission, with a goal of full transition by 2040[10].
- **Advanced Clean Trucks Regulation** – designed to accelerate a large-scale transition to zero-emission class 2b-8 vehicles. It requires manufacturers to sell

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[7] CA Executive 2020. Pg. 2.

[8] CARB 2020. Pg. 14.

[9] CEC 2021. Pg. 4.

[10] CEC 2021. Pg. 24.

zero emission (ZE) trucks at an increasing yearly percentage and requires company and fleet reporting[11].

- **Zero-Emission Airport Shuttle Regulation** – requires regulated airport shuttle operators to transition to 100% ZEV technologies starting in 2027 and ending in 2035, at a rate of 33% every four years[12]. Airport shuttles have fixed routes, stop and go operations, and maintain low average speeds, making them prime candidates for migration from pollutant-emitting diesel vehicles to ZEVs.
- **Advanced Clean Fleets Regulation** – currently in development, will require larger fleets with vehicles suitable for electrification to accelerate the number of medium and heavy-duty ZEV purchases to achieve a zero-emission truck and bus fleet by 2045.
- **Electrified Transportation Refrigeration Units and Zero Emission Forklift (primarily battery electric) regulations** – currently in development, will drive implementation of more ZE forklifts and eTRUs within California fleets.

CALGreen currently does not address MHD infrastructure. CALGreen does contain requirements for light-duty EV charging infrastructure, for both residential and non-residential buildings. CALGreen is maintained and updated every three years by the California Building Standards Commission, with an intervening cycle at the midpoint.

2.1 Triennial Code Adoption Cycle

CBSC oversees a triennial code adoption cycle to update CALGreen. The 2021 Triennial Code Adoption Cycle will develop updates to the “2019 CALGreen” code for inclusion in “2022 CALGreen,” which becomes effective January 1, 2023. California Health and Safety Code Section 18930.5(b) allows CBSC and other state agencies that propose building standards to allow for input by state agencies that have expertise in sustainable building subject areas. Given’s CARB’s expertise in air quality, climate change, and EV charging infrastructure, it is a key state agency that has developed proposals for EV charging infrastructure codes.

Figure 1 provides a timeline for the current code cycle. In general, the code cycle begins with stakeholder workshops to discuss initial proposals, which are ultimately posted as “Initial Express Terms.” The Code Advisory Committees then meet to discuss the proposals and make recommendations to CBSC. After that, regulatory notice is given and there is a 45-day public review period. For the 2022 CALGreen cycle, the 45-day public review period is expected to be August 13, 2021 through September 27, 2021.

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[11] CARB 2021. Table A-1.

[12] CARB 2019. Table 2.

The adoption hearing is expected to occur in December 2021 or January 2022, and the effective date will be January 1, 2023.

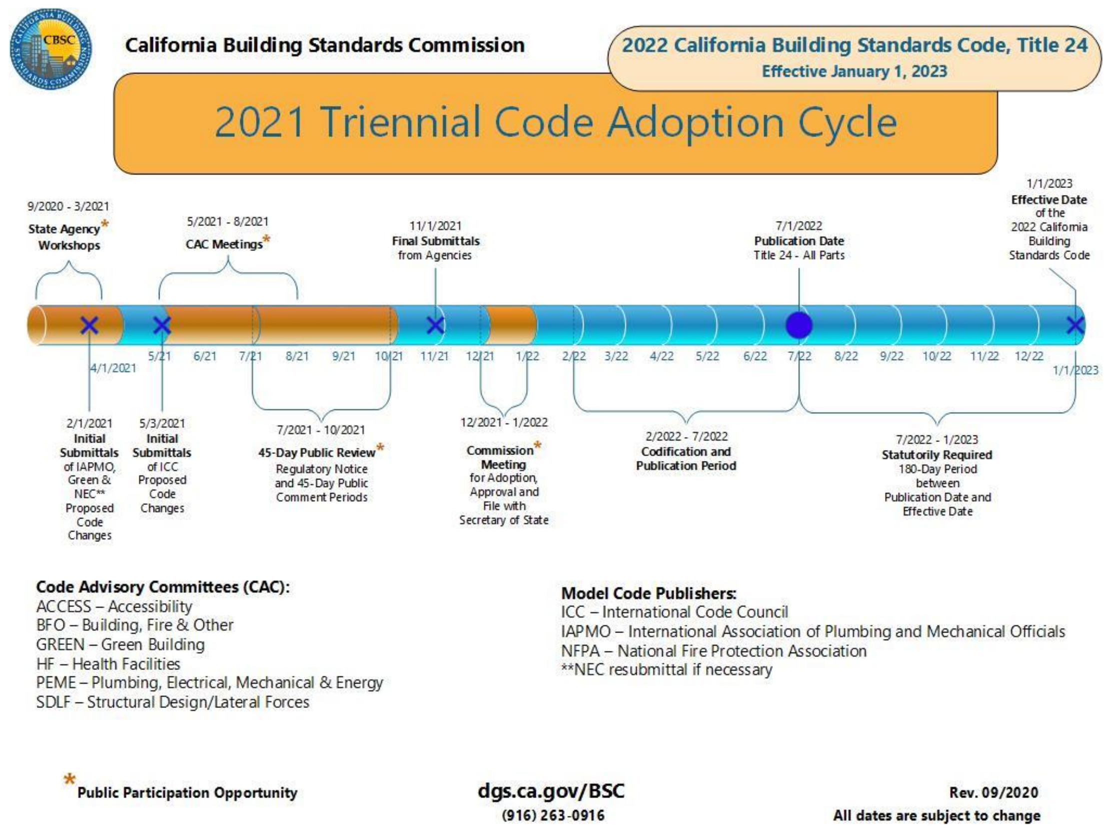

Figure 1. CA BSC 2021 Triennial Code Adoption Cycle[13]

2.2 Goals for 2022 CALGreen Code Cycle Updates

The goals for proposed new MHD requirements are similar to the prior efforts for light-duty vehicles:

- Accelerate the electrification of MHD transportation to address GHG emissions reduction and air quality improvement priorities.
- Mandate that designers of buildings take appropriate measures during initial construction period to prepare to host a minimum level of EV charging infrastructure (to avoid potentially more expensive retrofit costs); and

[13] CA BSC. 2021a.

- Assign minimum levels of required EV infrastructure that are impactful, cost-effective, provide market signals, and can inform future code development cycles.

As the MHD transportation industry is undergoing many coincident changes (including electrification) at a rate much faster than building service life, measures enacted during this cycle will likely require updates during future code cycles.

3. Outline of the Proposed Requirements

In the sections below, we provide recommendations for CALGreen updates that address MHD EV charging infrastructure.

3.1 Building Types Required to Provide MHD EV Charging Capability

For this first code cycle where MHD EV charging is addressed, we recommend providing EV Capable spots for high-power charging at off-street positions (e.g., loading docks or other off-street locations marked for vehicle goods loading) for opportunity charging (e.g., dwell times greater than 15 minutes but less than four hours).[14] "EV Capable" means that an EV charger can be added to the location in question without the need for costly demolition or electrical renovations but does not require the provision of an EV charger itself. The requirements would only apply to warehouses[15], grocery stores, and retail stores that include one or more off-street loading spaces. Other

[14] City of San Jose Municipal Code. n.d. For simplicity and clarity, this report uses the term "loading dock" generically to refer to the broader set of "off-street loading spaces" referred to and defined in the proposed code requirements. "Off-street loading space" means an area, other than a public street, public way, or other property, (and exclusive of off-street parking spaces) permanently reserved or set aside for the loading or unloading of motor vehicles, including ways of ingress and egress and maneuvering areas. Whenever the term "loading space" is used, it shall, unless the context clearly requires otherwise, be construed as meaning off-street loading space." "Each off-street loading space required by this part shall be not less than ten feet wide, thirty feet long and fifteen feet high, exclusive of driveways for ingress and egress and maneuvering areas."

[15] Warehouse may be defined with reference to the American Planning Association's LBCS (Land-Based Classification Standards): "Warehouse or storage services. These service establishments operate warehouse and storage facilities for general merchandise, refrigerated goods, and other warehouse products. They provide the facilities to store goods but do not sell the goods they handle. They may also provide a range of services related to the distribution of goods, such as labeling, breaking bulk, inventory control and management, light assembly, order entry and fulfillment, packaging, pick and pack, price marking and ticketing, and transportation arrangement." https://planning-org-uploaded-media.s3.amazonaws.com/legacy_resources/lbcs/standards/pdf/InOneFile.pdf p.58

building types that might include loading docks, such as corporate, hospital, or university campuses, could also provide opportunity charging; at present it was assumed that these do not get the frequency of MHD visits as warehouses, grocery stores and retail stores, and that they would likely have enough spare main electrical panel capacity to meet the need for MHD EV charging should it arise.

As Figure 2 shows below, “EV Capable” is the first step in preparing a building to accommodate the future installation of EV charging infrastructure. Preinstalling this “raceway” is a critical step to make transportation electrification cost-effective for building owners. See Figure 4 later in this report for “EV Capable” in MHD applications.

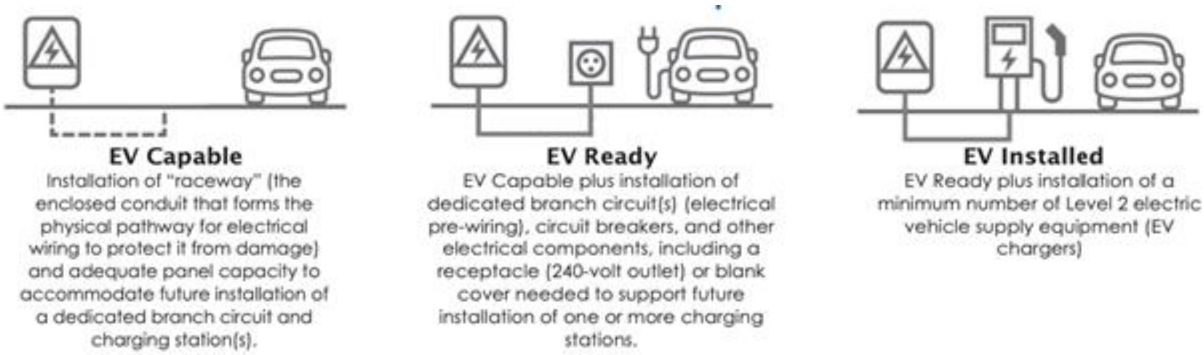

Figure 2. Levels of EV Charging Infrastructure Completeness[16]

3.2 Opportunity Charging Rationale

It is anticipated that opportunity charging locations will serve vehicles that do not need to use these charging facilities as their primary means of charging. Professional experience shows that many buildings with a loading dock contain only one or two loading bays. Buildings with a larger number of docking bays are likely to be fleet charging locations (whether at the building or in a separate location nearby), given that more MHD vehicles operate more frequently at those locations. Conversely, buildings with just one or two loading bays are more likely to be locations for opportunity charging. Stops for opportunity charging are typically short-term, but also do not need to provide a full charge. (Note that further study of routes and duty cycles for charging times is recommended, see Section 6.3.) For an example dwell time of 20 minutes, a 200-kW charger could provide about 28 to 71 miles of additional range, depending on the vehicle type (see

[16] City of Sacramento. 2020.

Table 1 1). Sizing these locations at 200 kW balances the need for an impactful energy contribution against the priority to limit the added infrastructure cost during initial construction.

Table 1. Miles Added During a 20-minute Charging Session

Example	FHWA Class, Gross Vehicle Weight Rating (lbs.), Category		Example Energy per Mile (kWh/mile)[17]	Miles added during a 20-minute charging session[18]		
				7.7 kW typ.[19] AC Level 2 20 min = 2.6 kWh	50 kW DC FC 20 min = 17 kWh	200 kW DC FC 20 min = 67 kWh
Food Delivery	Class 3, 10K-14K	MD	0.8	2.7	18	71
Parcel Delivery Step Van	Class 4, 14K-16K	MD	1.0	2.2	14	57
Linen Delivery, Bucket Truck	Class 5, 16K-19.5K	MD	1.1	2.0	13	52
Parcel Delivery Walk-In	Class 6, 19.5K-26K	MD	1.3	1.7	11	44
Large Moving Truck	Class 7, 26K-33K	HD	1.9	1.1	7	30
Heavy Semi Tractor	Class 8, >33K	HD	2.0	1.1	7	28

Opportunity charging stands in contrast to depot charging. It is anticipated that depot charging will provide the majority fueling service to MHD EVs, especially at early adoption; the proposed opportunity charging EV capable is a future-looking provision. The growth of MHD vehicle fleets will increase the availability of EVs for non-fleet MHD operators, such as local food delivery companies (bakeries, breweries, community farms, etc.) These small operators may need a network of opportunity charging

[17] ORNL. 2019. Figure ES1: Energy use by weight class for Class 3 through Class 8 battery electric vehicles.

[18] Charge acceptance efficiency varies with battery temperature, battery age and battery state of charge. This illustration assigns a charge acceptance efficiency of 85% and assumes the MHD EV arrives for charging with a battery below 80% of its maximum state of charge. The 20-minute dwell time was taken as an example for deliveries such as beverage or baked goods distribution to a grocery store in a suburban setting. In these cases, while the driver may have pallets or roll cages in the vehicle, only a portion of these is delivered to any one grocery store, as the deliveries tend to be part of a multi-stop route. Goods may be unloaded into a supermarket's back-of-house area for employees to shelve later. This process can be fairly quick for the driver. Typical activities during this dwell time include contacting the grocery store staff, opening the loading doors, moving the goods, and signing receipt.

[19] PG&E. 2019. Figure 16 - AC Level 2 circuit at 240V/40A with 80% derating = 7.7 kW.

locations to have the flexibility and reliability to use EVs on less rigid routes than early adopters.

We do not recommend that fleet charging depots be included in requirements for this code cycle. Primarily because EV fleet operators will be well aware of their charging infrastructure needs and can be reliably expected to meet those needs without a code requirement, whereas any code requirement that would meet their needs would also likely impose large burdens (readiness for an entire EV depot) on sites that might not actually use the required equipment. In addition, not enough information is available to accurately identify EV charging needs for fleet depots, which vary depending on vehicle type, depot configuration, and other depot activities. For instance, many freight depot operators may use a charging location that is separate from any building(s) associated with active loading and unloading to avoid blocking a loading dock with a truck that is charging but not actively loading. In addition, many fleet charging projects may engage their electric utility directly, possibly using a separate utility service that may include medium-voltage service and/or distribution, whether inside or outside of a building.

3.3 MHD EV Charging Power Level Requirements

Refueling strategies depend on a combination of recharge scheduling and charger power. MHD EVs in the trucking industry typically have a battery capacity exceeding 200 kWh and are non-operative during recharge time. The proposed code language sets power levels available to the charging cabinets or dispensers at a minimum of 200 kW per required charging location. This electrical capacity can then be used to mix and match whatever best fits a specific site's application, including AC Level 2 charging, charging for zero-emission electric forklifts, and service for electric transportation refrigeration units.

Although this report calls out MHD DC Fast Charging, building owners will be free to use the 200 kW per loading spot capability to mix and match whatever best fits their application, including AC Level 2 charging, charging for zero-emission electric forklifts, and service for electric transportation refrigeration units. Building owners could also use Automatic Load Management Systems (ALMS) at the cabinet level to dynamically allocate power via dispensers at multiple loading spots, if desired. Building owners may also choose to add local energy storage systems that would enable much higher peak power delivery while mitigating utility demand charge impacts. The proposed code sets new buildings with loading docks up for success in supporting a basic amount of MHD EV charging capability with a very moderate impact to initial construction costs.

3.4 Required EV Charging Infrastructure

The proposed requirements for MHD charging infrastructure provides for:[20]

1. "Adequate capacity" to add future EV charging at the building transformer, main service entrance equipment, and subpanels.[21]
2. Electrical raceways (i.e., busways or conduits) from the main service entrance equipment and any subpanel(s) to a final distribution location which is within proximity of the proposed location of the EVSE(s).[22] (In simpler situations, the conduit or busway can terminate directly at the predetermined location of the EVSE).
3. Identification of future locations of the MHD EVSE(s) and leaving room for installing panels, charging cabinets, and dispensers.

The proposed code language uses the following table to set the capacity requirements for different newly constructed building type configurations, building sizes, and scales with the quantity of off-street loading spaces (and loading docks).

[20] At the time of this writing, the draft proposal is included in the "Initial Express Terms" posted by BSC based on recommendations by CARB (see CA BSC 2021a).

[21] "Adequate capacity" for the future does not necessarily mean *additional* capacity; if the design was for a relatively high load building, because electrical service equipment comes in incremental sizes, the main service entrance equipment, for instance, might be 200 or 400 kW over the planned total connected load and have adequate capacity without needing replacement.

[22] Raceways are enclosed channels of metal or nonmetallic materials designed expressly for holding wires, cables, or busbars (NFPA 2020. Article 100).

Table 2. CALGreen Initial Express Terms:
Raceway Conduit and Panel Power Requirements[23]

Building type	Building Size (sq. ft)	Number of Off-street loading spaces	Additional capacity Required (kVA) for Raceway & Busway and Transformer & Panel[24]
Grocery	10,000 to 90,000	1 or 2	200
		3 or Greater	400
	Greater than 90,000	1 or Greater	400
Retail	10,000 to 135,000	1 or 2	200
		3 or Greater	400
	Greater than 135,000	1 or Greater	400
Warehouse	20,000 to 256,000	1 or 2	200
		3 or Greater	400
	Greater than 256,000	1 or Greater	400

"Main service entrance equipment" includes incoming service conductors, the service entrance switchboard, panelboard, or switchgear, and circuit breakers within the service entrance equipment (or a subpanel, if the future EVSE is to be fed from a subpanel).

The impact of the proposed requirements on these components are further described here:

1. **Transformer:** Due to industry norms, many utility transformers will have enough reserve capacity to accommodate the EV charging capability requirements. Some scenarios will require a larger transformer. In building locations where the local distribution grid is currently congested or the

[23] CA BSC 2021a. Table 5.106.4.1.1.

[24] The requirements are written requiring 200 or 400 kVA of service (rather than 200 or 400 kW, as stated here) to make plan review and inspection easier: kVA can be obtained by multiplying the Voltage and Amperage of devices labelled on plans, while Wattage has to include power factor, which is not always apparent. In the great majority of buildings, the difference due to power factor is small enough that the available capacity for EV charging will not be materially affected between 200 kVA and 200 kW.

transformer upgrade too disruptive or expensive, it may be important to allow projects to defer the exterior upgrade portion of the project but continue with adding adequate capacity within the building.

2. **Incoming Service Conductors:** Some scenarios will require upsized conductors.
3. **Main Service Equipment:** The overall size of the service entrance equipment (main switchboard, panelboard, or switchgear) will likely increase to accommodate the EV charging load requirements.
4. **Main Feeder Circuit Breaker(s) for Charger Circuits:** Adding circuit breaker(s) in the main switchboard, panelboard, or switchgear required for the feed to the EVSE(s) at the time of new construction will be less expensive and guarantee the resource will be ready at the time of charger installation.
5. **Raceway or Busway from Main Switchboard, Panelboard, or Switchgear to Location of Future Distribution Panel or DC Fast Charger Cabinet:** Conduit or busway from the main service entrance equipment, switchboard, panelboard, or switchgear must be installed to a location suitable for a final distribution panel which is within proximity of the proposed location of the DC Fast Charger Cabinets. (In simpler situations, conduit or busway terminates directly at the predetermined location of the DC Fast Charger Cabinet).

3.5 Illustrated Additional EV Charging Infrastructure and Final EVSE Installation

The following three figures describe the phases of a project that will support the approach described in the proposed code language. Figure 3 describes the original design showing the pad-mounted transformer and main service entrance equipment, both appropriately sized for the building's initial requirements.

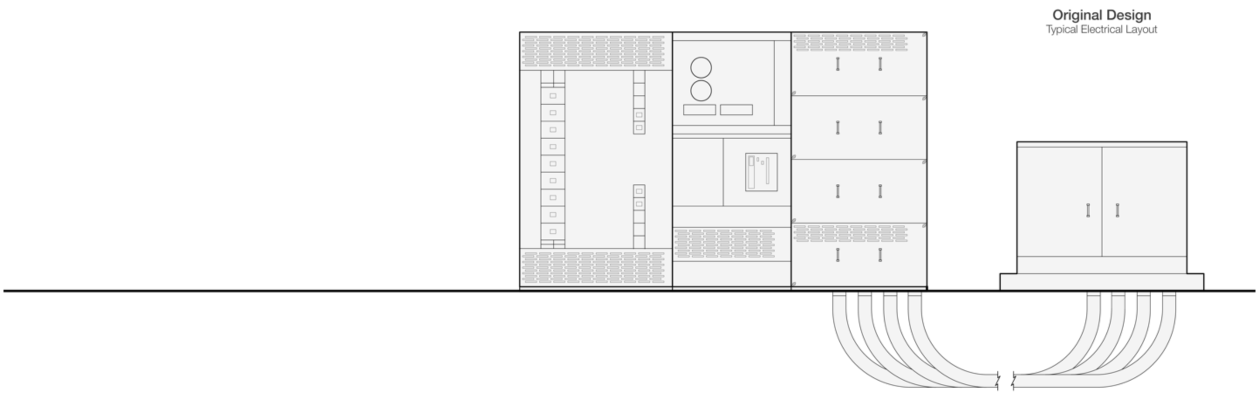

Figure 3. A Typical Electrical Main Service Entrance Equipment without MHD EV Capable Infrastructure

The green items in Figure 4 depict the additional infrastructure required by this building code at the time of first construction to prepare the building for future MHD EV loading space charging equipment. Depending on the project, it may include a larger transformer, additional space to house extra/larger future switchgear and always includes extra raceway routed through the building to support future conductors terminating near the loading spaces for the DC Fast Charging system. All the red-colored items in Figure 5 are examples of equipment added during charging system installation later in building life (but not required by code).

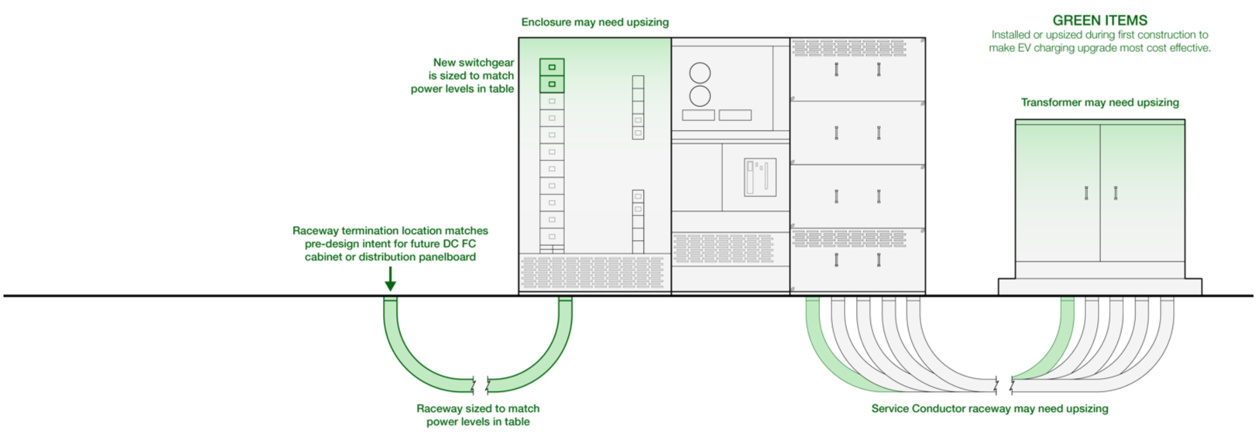

Figure 4. New Equipment During First Construction Required for MHD EV Capable Infrastructure (Required Equipment Shown in Green)

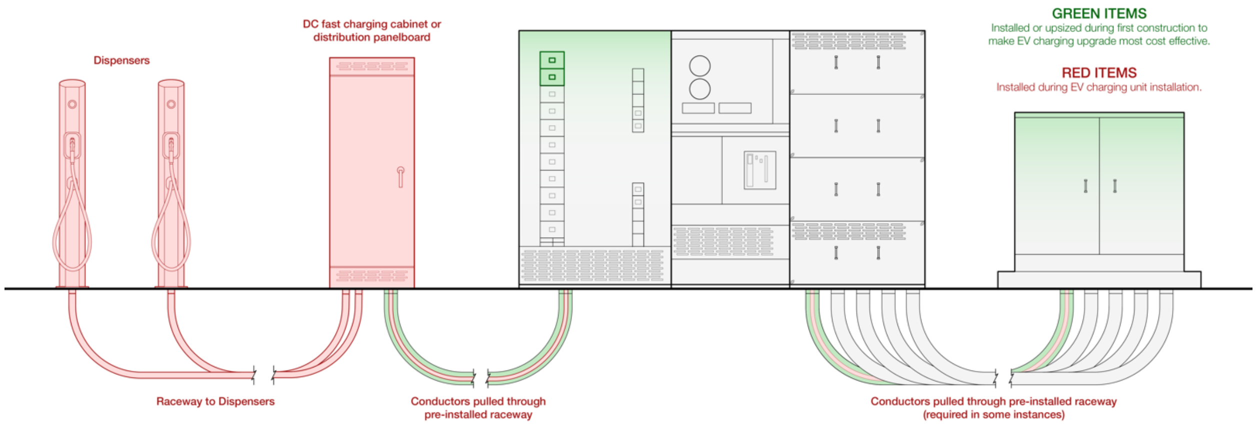

Figure 5. Final EVSE Equipment to be Added in the Future (Shown in Red), Making Use of Previously Installed MHD EV Capable Components.

4. Benefits and Cost Analysis

4.1 Cost Analysis Introduction and Methodology

California Health and Safety Code Section 18930(a) provides the following nine criteria to justify the adoption of a new CALGreen standard[25]:

1. The proposed building standards do not conflict with, overlap, or duplicate other building standards.
2. The proposed building standard is within the parameters established by enabling legislation and is not expressly within the exclusive jurisdiction of another agency.
3. The public interest requires the adoption of the building standards. The public interest includes, but is not limited to, health and safety, resource efficiency, fire safety, seismic safety, building and building system performance, and consistency with environmental, public health, and accessibility statutes and regulations.
4. The proposed building standard is not unreasonable, arbitrary, unfair, or capricious, in whole or in part.
5. **The cost to the public is reasonable, based on the overall benefit to be derived from the building standards.**
6. The proposed building standard is not unnecessarily ambiguous or vague, in whole or in part.

[25] CA BSC. 2019.

7. The applicable national specifications, published standards, and model codes have been incorporated therein as provided in this part, where appropriate.
    a. If a national specification, published standard, or model code does not adequately address the goals of the state agency, a statement defining the inadequacy shall accompany the proposed building standard when submitted to the commission.
    b. If there is no national specification, published standard, or model code that is relevant to the proposed building standard, the state agency shall prepare a statement informing the commission and submit that statement with the proposed building standard.
8. The format of the proposed building standards is consistent with that adopted by the commission.
9. The proposed building standard, if it promotes fire and panic safety, as determined by the State Fire Marshal, has the written approval of the State Fire Marshal.

For our analysis, we focused on criteria 5 as the proposed code requirements are intended to save California building owners money by avoiding excessive retrofit costs to add MHD EV charging equipment in the future. We conducted two specific cost analyses:

1. Retrofit Cost to Additional First Cost ratio.
2. Additional First Cost to Total Cost ratio.

We looked at the thresholds contained in the proposed requirements for each building type: 1) adding 200 kVA of additional initial electrical service to a small building (10,000 sq. ft grocery or retail store, 20,000 sq. ft warehouse) when one or two loading docks are present; or 2) adding 400 kVA to a small building if three or more loading docks are present. See section 8 - Appendix: Input, Calculation and Output Tables for more detail on calculation inputs and outputs.

All the cost analysis findings are conservative in that they include only hard construction costs and exclude soft costs for the retrofit cases that would be quite substantial (as compared to installing the same equipment during initial design, permitting, and construction). Excluded soft costs include additional design fees, permitting fees, schedule risk, and business disruption.[26] If a grocery store, retail store, or active warehouse had to take its main electrical service offline for 1-2 days to add power to accommodate MDH EV charging, the costs would be substantial; however, whether that

[26] RMI 2020 (Pg. 36 Exhibit 13) shows separate permitting fees can be 5 – 7% of total retrofit project cost.

would be required in any case would depend on a number of site- and building-specific factors that cannot be generalized at the high level used in this study.

4.1.1 Retrofit Later vs. Build Now Comparison

To conduct our cost analysis, we estimated the costs of electrical construction and supporting equipment for commercial buildings of different amperage capacity. The proposed code change would require buildings with loading docks to provide an additional 200 kVA (300A+/- at 480V3ph) or 400 kVA (600A+/- at 480V3ph)[27] of electrical capacity depending on building size and number of loading docks, plus conduit or busway to the future charging location. We estimated three sets of costs across a range of building sizes for warehouse, grocery store, and retail buildings: a) the cost to install a typical electrical service installation as part of initial building construction, b) the cost to remove insufficiently sized equipment and install larger electrical service equipment as a retrofit project, and c) the cost to install the larger electrical service equipment as part of initial building construction. The retrofit cost to additional first cost ratio for each building type and size was then calculated as the ratio of (a + b) / (c – a).

Retrofit projects were estimated to have 15% higher unit costs to reflect the lack of purchasing in bulk, and higher General Conditions costs (26% versus 14%) to reflect a smaller project size.[28] We used data from RSMeans for materials and labor. For equipment not listed, we used data gathered from outreach to major electrical contractors and/or cost experience on previous engineering and design projects.

As described earlier, the cost estimates ***do not*** include “soft costs” such as additional design, permits, schedule risk, or business disruption due to construction impacts which would be substantial, making this is a conservative estimate. The cost estimates also do not attempt to discount future costs (as it is not knowable when retrofits might occur in the future), but neither do they attempt to account for construction cost escalation, which has generally risen faster than inflation in most of California in recent years.

4.1.2 Extra First Cost vs. Total Building Cost Comparison

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[27] Nominal VA = 480V x A x 1.73 | Continuous Load VA per NEC = Nominal VA x 125% | Panel Capacity = (Nominal VA x 125%)/(480V x 1.73) | Panel Capacity required for 200kVA = (200kVA x 125%)/(480V x 1.73) ≈ 300A | Panel Capacity required for 400kVA = (400kVA x 125%)/(480V x 1.73) ≈ 600A.

[28] The general conditions costs are generally defined as the total compensation payable to the contractor for his onsite supervision, inspections, coordination, and managing of the work, and for all equipment, utilities, facilities, bonds, insurance, labor, etc. (AGC. 2012. Pg. 29).

The cost comparison of adding EV capability to the base building as a fraction of total building cost is directly related to the base building's size and power requirements versus the added power for EV charging. The power density (watts per square foot) and typical electrical service size were determined using electrical site consumption data for typical building types from the U.S. Energy Information Administration "Commercial Buildings Energy Consumption Survey," which provides typical electrical usage for retail, grocery, and warehouses based on survey data of multiple buildings of each type (U.S. EIA. 2018). The total building cost was then based on per-square foot building costs from RSMeans.[29] The extra cost as a fraction of total building cost was then taken as the cost difference between the larger electrical system and the base electrical system divided by the total building cost.

The total cost includes a cost for electrical transformers. These are often, but not always, paid for and installed by the electrical utility. When they are utility-provided, utilities sometimes recoup the cost through connection surcharges/chargebacks or through higher rates. The model uses the conservative approach that includes the cost of a larger transformer when required by the future EV charging capacity. When the transformer is already large, as for buildings with 3,000 Amp or greater service, the model assumes that the transformer would have enough additional capacity for 200 – 400 kVA of EV charging without needing an upgrade.

The total building cost from RSMeans is a hard construction cost. As noted above, this excludes soft costs such as design fees, permit fees, business disruption, schedule risk, or financing costs, again making this a very conservative comparison.

4.2 Findings and Assessment

Our assessment is that cost to the public is reasonable, based on the overall benefit to be derived from the proposed building standards.

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[29] Typical switchgear sizes for commercial buildings are 400 A, 800 A, 1200 A, 1600 A, 2500 A, 3000 A, and 4000 A (A is Amperes). The nominal power density (Watts/sq. ft) was taken to be 5 W/sq. ft for warehouses, 10 W/sq. ft for retail stores, and 15 W/sq. ft for grocery stores. Converting Amps to Watts includes an estimate for typical power factor and distribution voltage.

Table 3 shows the findings for both cost ratio analyses for all nine scenarios. The benefits increase as building size increases and as building load increases. Relatedly, adding 200 kVA of electrical capacity to a small building is more cost-effective than adding 400 kVA. While theoretically possible, and therefore included in the analysis as case #2 for each building type, the likelihood of a 10,000 sq. ft building having three or more loading docks is very small; the amount of traffic from three docks operating together would generally require a larger space to handle the inflows and outflows of goods from all the delivery vehicles. As an indication of this, California local jurisdictions typically only require three loading docks for buildings over 50,000 sq. ft.[30]

A final indication of cost effectiveness is that among the nine sets of results (three sizes of three building types), the lowest cost effectiveness numbers for the two different tests occur in different case results. The least favorable retrofit cost ratio (127%), for the large grocery store) has a good first cost ratio (0.3%), while the least favorable first cost ratio (2.4%), for the medium warehouse, has a good retrofit cost ratio (222%). So, no building type and size is unduly burdened with the least favorable (but still positive) ratios.

[30] As an example, see City of San Jose Municipal Code. n.d. Chapter 20.90.410.

Table 3. Cost Analysis Results for Nine Cases Studied[31]

Building Type	Sq. ft	Charging Capacity Notes power ~ current (at 480V3ph)	Initial Amps → Final Amps	Retrofit Cost / First Cost Ratio	First Cost / Total Cost Ratio (range)
Grocery store	10,000	200kVA ~ 300A	400A → 800A	**252% (max)**	0.3% - 0.4%
	10,000	Rare three loading spaces 400kVA ~ 600A+/-	400A → 1200A	227%	0.7% - 1.1%
	90,000	Supported by existing switchgear 400kVA ~ 600A+/-	4000A → 4000A	**127% (min)**	0.2% - 0.3%
Retail store	10,000	200kVA ~ 300A+/-	225A → 600A	234%	1.2% - 1.9%
	10,000	Rare three loading spaces 400kVA ~ 600A+/-	225A → 800A	222%	1.6% - 2.6%
	135,000	400kVA ~ 600A+/-	2500A → 3000A	184%	**0.1% - 0.2% (min)**
Warehouse	20,000	200kVA ~ 300A+/=	150A → 600A	216%	1.4% - 2.3%
	20,000	Rare three loading spaces 400kVA ~ 600A+/-	150A → 800A	205%	**1.8% - 3.0% (max)**
	256,000	400kVA ~ 600A+/-	2000A → 2500A	202%	0.3% - 0.5%

It should be noted that not all buildings designated “warehouses” or “grocery stores” have the same level of electrical load. Most notably, refrigerated warehouses have much higher loads than non-refrigerated warehouses. This study made conservative assumptions, making estimates based on the low end of the range for these building types, leading to lower cost-effectiveness ratios. Refrigerated warehouses would be more favorably cost effective than the cases presented here.

4.2.1 Retrofit Cost to Additional First Cost

As described above, there are overall cost savings associated with a “build now” requirement as it takes advantage of the economy of scale of a whole-building

[31] See Section 8 - Appendix: Input, Calculation and Output Tables for more detail on calculation inputs and outputs.

construction project. Higher soft costs and the disruption due to a retrofit project are not included and thus the results are conservative. The most typical results are for the small buildings adding 200 kVA and the retail store adding 400 kVA (as discussed above, small buildings are unlikely to have the three loading docks that would trigger the 400 kVA requirement). The range of retrofit / first cost ratios for these cases is 127% - 252%[32]. The results show that for the large grocery store, the retrofit / first cost ratio is 127%[33]. In this case, all costs are low as no increase to the main electrical service is required. This is because building electrical panels come in standard sizes, which for large buildings are either 3,000 Amp or 4,000 Amp. The threshold sizes in the proposed regulation fall relatively close to 4,000 Amp for the base level of electrical service, leaving enough room to accommodate an additional 400 kVA without changing the panel or transformer. Accordingly, the only costs shown for these building sizes are the additional conduits required by the proposed regulations. These are still more cost-effective to install during initial construction rather than as a retrofit project. Buildings of other sizes would have a profile more like the other results shown, with larger costs for both the "build now" and retrofit cases, and a larger spread between them, leading to a higher cost effectiveness ratio.

[32] See data table #3 in Section 8.2 for details

[33] See data table #3 in Section 8.2 for details

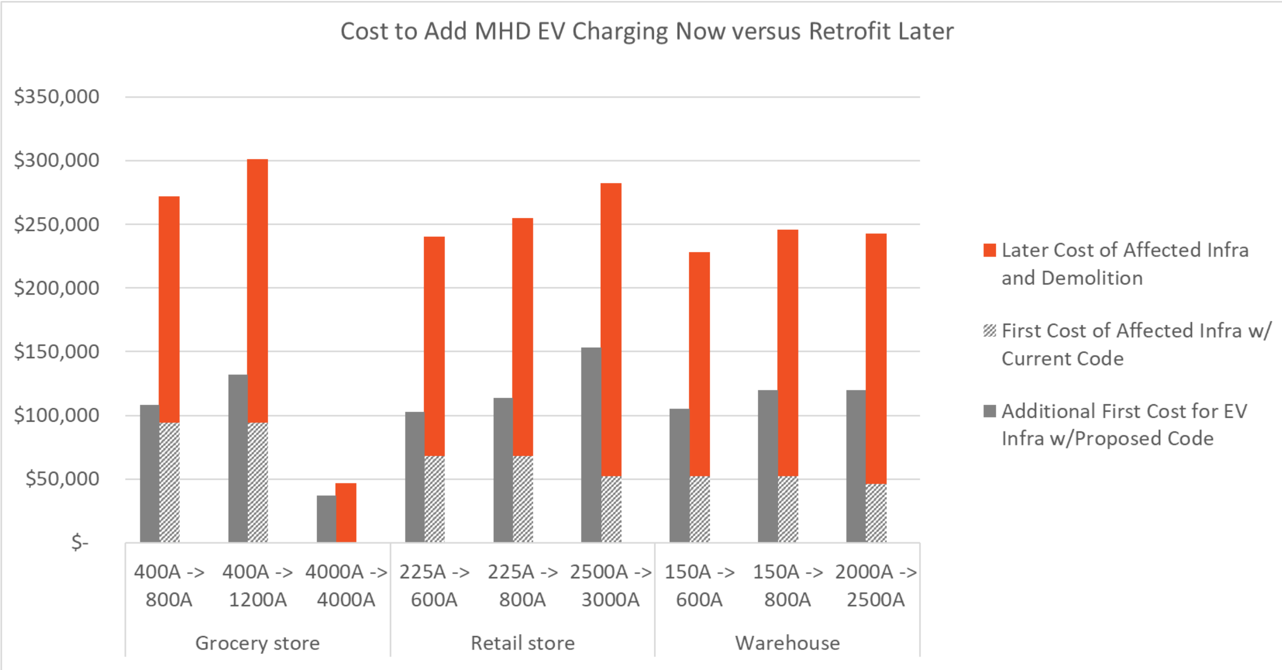

Figure 6 shows the cost comparison of the "build now using proposed code" ("Additional First Cost for EV Infra w/Proposed Code") versus "retrofit later" ("Later Cost of Affected Infra and Demolition" plus "First Cost of Affected Infra w/ Current Code") for all the nine cases studied. The general pattern is clear that "build now with proposed code" is less expensive in total than "retrofit later"; it is also clear that "build now" is more expensive than first cost with current code (as would be expected). The savings from "build now using proposed code" are greatest for scenarios that require a new transformer and/or new switchgear during the upgrade. As noted elsewhere, these estimates exclude most soft costs.

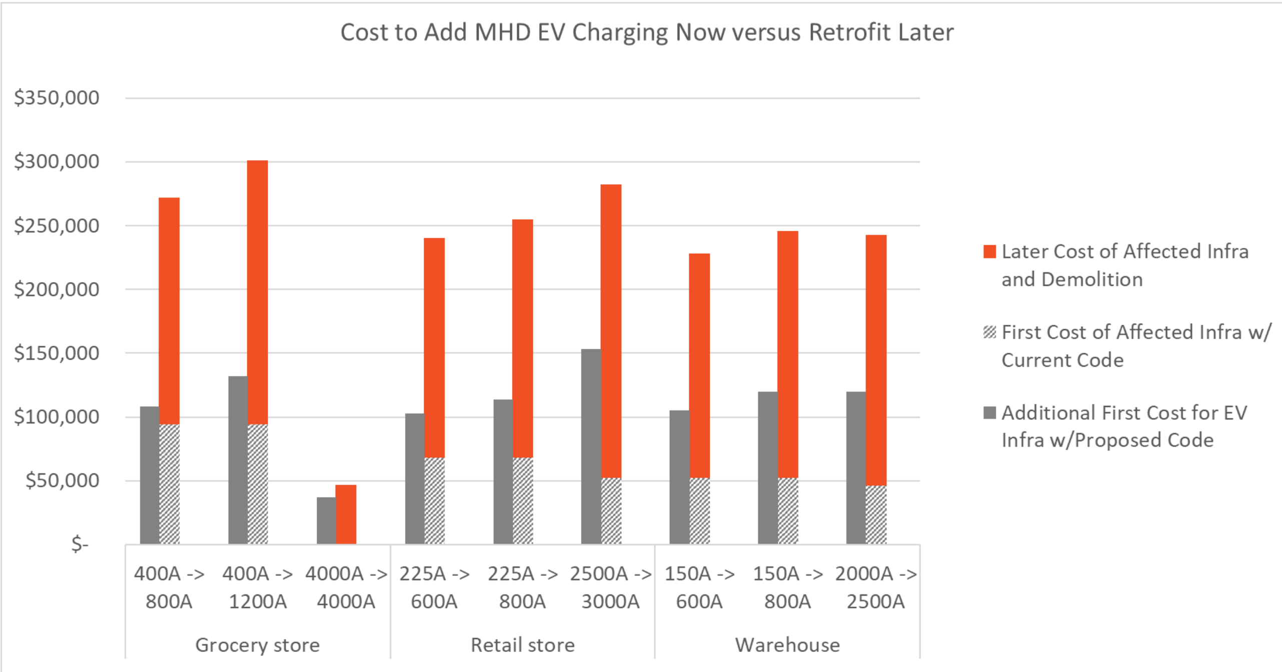

Figure 6. Cost to Add MHD EV Charging Infrastructure[34]

4.2.2 Additional First Cost to Total Construction Cost

The additional first cost test asks if the extra cost to comply with the regulations is large relative to the total building construction cost. The costs shown cover a range for each building type that corresponds to the range of low and high per-square-foot construction costs taken from RSMeans for each building type. The percentages are low (i.e., favorable) across the board for larger buildings, whether or not they are adding electrical capacity to comply with the regulations, as main electrical service cost becomes a smaller fraction of total building cost as the building size increases. For large buildings, the cost of compliance is under 0.5% of total building cost[35].

For small buildings, the cost of compliance for realistic scenarios (adding 200 kVA) ranges from around 0.3% to 1.9% (the very unlikely edge cases of adding 400 kVA top out around 2.4%). The costs are more favorable for the high cost-per-square-foot grocery stores and less favorable for the warehouse and retail store cases. They are also a bit sensitive to the specific sizes of equipment, as the difference between the needed capacity and the next nominal size up in electrical panelboards can result in a

[34] See data table #3 in Section 8.2 for details

[35] Ibid.

larger amount of unused capacity in some cases (the retail store) versus others (the warehouse). Across a full range of building sizes this effect would be less pronounced.

5. Additional Benefits

The proposed requirements meet the public benefit and purpose of accelerating the electrification of MHD transportation to address GHG reduction and air quality improvement priorities by preparing buildings to host a minimum level of EV charging infrastructure. This preparation avoids the potentially much more expensive retrofit costs to install the same equipment in the future. In addition, the requirements will have additional benefits to California communities, businesses, and vehicle owners, including:

1. Improves the economics of serving less dense communities with longer route distances with EVs by making MHD charging facilities locally available, eliminating time and distance accessing charging facilities elsewhere[36];
2. Supports the enabling of fleet electrification (including for small businesses) that cannot fully recharge off-shift due to:
    a. short off-shift dwell times,
    b. delayed investment in depot charging facilities,
    c. limited utility infrastructure at depot charging facilities,
    d. depot space constraints.
3. Benefits building owners by allowing them to:
    a. provide charging resources for tenants,
    b. sell charging services to visiting vehicles during loading/unloading,
    c. sell charging services during off-peak periods to any party.
4. Provides market signals about the extent and type of EV charging equipment that will be needed in the future, allowing original equipment manufacturers to better anticipate demand for MHD EVSE, making EVSE less costly.
5. Additionally, as MHD EV opportunity charging becomes widespread and reliably available, it may further support:
    a. Allowing for MHD EV reduced battery size and weight[37] to:
        i. reduce vehicle first cost and battery replacement cost,
        ii. improve efficiency (reduce kWh per mile),

[36] NACFE 2019. Page 14.

[37] ORNL. 2017. Figure 3.

iii. allocate more weight to value-added payload[38].

b. Improving MHD EV battery service life by avoiding deep-discharge operation below 0.2 minimum State of Charge (see Figure 7).
c. Helping reduce peak solar output curtailment by increasing daytime EV charging opportunities (recognizing that light-duty EVs are expected to mostly charge overnight)

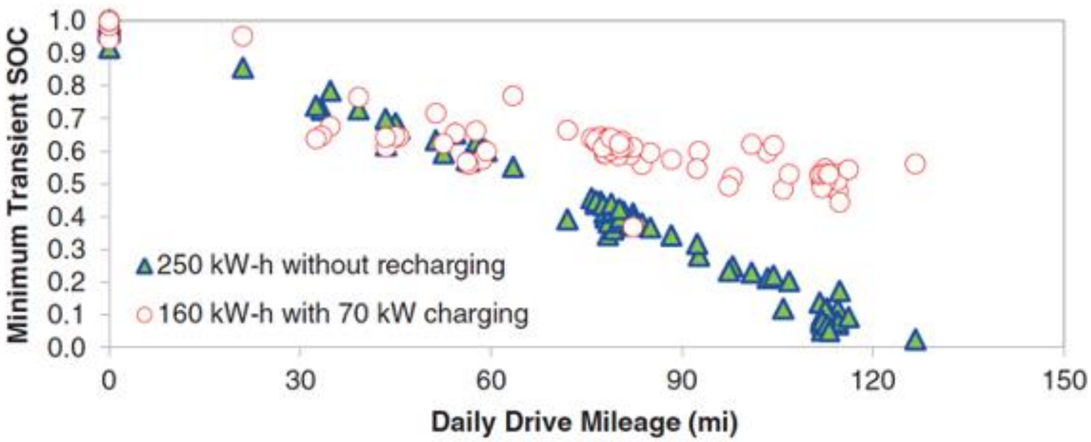

Figure 7. Simulation showing 70 kW opportunity charging reduces battery deep discharge wear and enables smaller batteries.[39]

6. Future Work Recommended

The landscape for electric vehicles is changing rapidly. MHD EVs, in particular, are at the beginning of adoption, with much progress expected in vehicle technology, EVSE technology, and related standards. As MHD EVs are adopted, California will have the opportunity to learn more about how they are used, how they perform under real-world conditions, and adapt to regulations. Accordingly, the proposed requirements will likely need to be updated periodically to support the state's 2045 goals. To continue to improve the code's MHD EV requirements, ongoing study is recommended, including:

- Explore additional building types
- Refine minimum power levels and infrastructure requirements for opportunity charging
- Add route detail and duty cycle modeling

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[38] NREL. 2019. Page 2.

[39] ORNL. 2017. Figure 3.

- Study the benefits of aligning demand with peak solar generation
- Incorporate the needs of light-duty commercial vehicles.

We discuss each recommended topic below.

6.1 Explore Additional Building Types

As noted above, other building types beyond warehouses, grocery stores, and retail stores contain loading docks and could be considered for inclusion in these requirements in the future, such as corporate, hospital, or university campuses. A more detailed study of the frequency of MHD visits to these facilities, including duration of stay, and typical route length and duty cycles, could identify the cost/benefit of extending the requirements to these building types.

6.2 Refine Minimum Power Levels and Infrastructure Requirements for Opportunity Charging

Suitable DC fast charging for MHD vehicles starts at 50 kW and moves into the MW (1,000 kW+) range. Charging power at an opportunity location can be expressed in the number of miles of range added per minute of charging time (assuming a typical vehicle type and route): the higher the power, the more miles added per stop (see Table 1). Future work should identify optimal miles added per minute for opportunity charging for a variety of MHD route types and duty cycles to confirm that the 200-kW minimum capacity per charger is a good long-term standard for California's MHD EV fleet, keeping abreast of other improvements in vehicle efficiencies and battery capacities that will also extend range. Vehicles that will be exclusively charged by fleet operators (e.g., most fixed-route vehicles such as public transportation buses or school buses) would not need to be included in this analysis.

In addition, for the power levels required for the MHD EV application, designers need to consider how the increased future charging capacity may also increase the size of the utility transformer and incoming electrical service conductors and equipment. This could give an opportunity to apply the correct diversity factor(s) to use so that equipment is both able to handle peak loads safely and sized for efficient first cost and operational load levels.

6.3 Add Route Detail and Duty Cycle Modeling

Lawrence Berkeley National Laboratory (LBNL), working for the California Energy Commission, maintains and develops a "HEVI-LOAD" agent-based model of drayage/delivery truck trip-chaining and associated energy requirements (LBNL 2020). As it is improved, this model will be able to inform the next code cycle by estimating the likelihood of different truck types and routes that can benefit from opportunity charging.

This information can be used to target the requirements geographically and/or by building type, size, or other criteria; to adjust the power requirements either up or down from the current 200 kW depending on the distance needed and charge time available; and to better determine the cost effectiveness of the requirements by better estimating the likelihood that actual EVSE will be installed and used where EV capable equipment is required.[40] In addition, more opportunities for MHD vehicles to charge during their service day will offer greater route and service flexibility to a wider range of MHD operators, including near-route public MHD charging infrastructure (like truck stops) that may decrease needs for opportunity charging. Use of the HEVI-LOAD model (or other route modeling tools) could allow for identifying the possible increase in productivity of MHD EVs due to availability of opportunity charging.

6.4 Study the Benefits of Aligning Demand with Peak Solar Generation

Mid-shift MHD EV charging during the day will make greater use of periods of peak solar generation on the electrical grid and potentially reduce nighttime energy demands (when solar is not available) required for off-shift charging of MHD vehicle fleets. Further work could include estimation of the total and net grid impacts of the increasing coincident MHD EV fleet charging and how this aligns with current and projected hourly grid emissions throughout the year. Opportunities for MHD vehicle-grid integration could also be studied for potential grid services.

6.5 Incorporate the Needs of Light-Duty Commercial Vehicles

Some light-duty vehicles could also benefit from the charging capacity provided by DC fast chargers due to the commercial nature of their activity, high utilization factors, and the high total miles per day. These include taxi and rideshare vehicles as well as light-duty commercial delivery and service vehicles. Future work could study the cost/benefit of requiring allocated charging/queueing areas adjacent to commercial buildings for these uses.

[40] Wang Bin, LBNL response during AB-2127 EV Infrastructure Workshop Day One Q&A Session (link).

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8. Appendix: Input, Calculation and Output Tables

8.1 Unit Costs

		Initial Building Construction			Retrofit Construction		
Item Description	**Unit**	**Material Cost**	**Labor Cost**	**Unit Cost**	**Unit Cost Factor**	**Unit Cost**	**Assumption/Source (RS Means unless otherwise noted)**
Remove existing transformer	EA	$0.00	$2,000.00	$2,000.00	15%	$2,300.00	
Remove existing switchgear	EA	$0.00	$9,280.00	$9,280.00	15%	$10,672.00	Assuming $145/hr. for 2 workers in 4 days. No crane assumed.
Demolish wall to accommodate bigger equipment	LF		$45.00	$45.00	15%	$51.75	
Concrete Wall	SF			$50.00	15%	$57.50	
Concrete Pad	CY			$1,500.00	15%	$1,725.00	LBNF
Finishes	SF			$15.00	15%	$17.25	
Conduits, 4" diam.	LF			$9.60	15%	$11.04	Wall mount: assume +20% for supports
Conduits, 4" diam. - 2 sets	LF			$48.93	15%	$56.27	
Conduits, 4" diam. - 4 sets	LF			$109.57	15%	$126.00	Includes trench and duct bank
75 kVA Transformer	EA	$30,000.00	$9,497.87	$39,497.87	-85%	$31,424.68	Source: Supplier quotes
150 kVA Transformer	EA	$39,000.00	$12,347.23	$51,347.23	-85%	$40,852.09	
225 kVA Transformer	EA	$36,000.00	$11,397.45	$47,397.45	15%	$49,107.06	
300 kVA Transformer	EA	$47,000.00	$14,880.00	$61,880.00	15%	$64,112.00	
500 kVA Transformer	EA	$49,600.00	$14,880.00	$64,480.00	15%	$66,712.00	
750 kVA Transformer	EA	$58,000.00	$16,950.00	$74,950.00	15%	$77,492.50	
Transformers 1000 kVA	EA	$72,000.00	$18,420.00	$90,420.00	15%	$93,183.00	
1500 kVA Transformer	EA	$98,000.00	$20,490.00	$118,490.00	15%	$121,563.50	
2000 kVA Transformer	EA	$123,000.00	$21,960.00	$144,960.00	15%	$148,254.00	
2500 kVA Transformer	EA	$150,000.00	$23,100.00	$173,100.00	15%	$176,565.00	
100A Panelboard	EA	$1,902.00	$4,640.00	$6,542.00	15%	$7,238.00	Assuming $145/hr. for 2 workers in 2 days. No crane assumed.
150A Panelboard	EA	$2,282.40	$4,640.00	$6,922.40	15%	$7,618.40	
225A Panelboard	EA	$4,286.00	$4,640.00	$8,926.00	15%	$9,622.00	
400A Main Switchboard	EA	$14,350.00	$6,960.00	$21,310.00	15%	$22,354.00	Assuming $145/hr. for 2 workers in 3 days. No crane assumed.
600A Main Switchboard	EA	$16,155.00	$6,960.00	$23,115.00	15%	$24,159.00	
800A Main Switchboard	EA	$17,960.00	$6,960.00	$24,920.00	15%	$25,964.00	
1600A Main Switchboard	EA	$26,800.00	$6,960.00	$33,760.00	15%	$34,804.00	
2000A Main Switchboard	EA	$31,750.00	$9,280.00	$41,030.00	15%	$42,422.00	Assuming $145/hr. for 2 workers in 4 days. No crane assumed.
2500A Main Switchboard	EA	$36,700.00	$9,280.00	$45,980.00	15%	$47,372.00	
3000A Main Switchboard	EA	$82,300.00	$9,280.00	$91,580.00	15%	$92,972.00	
4000A Main Switchboard	EA	$93,900.00	$9,280.00	$103,180.00	15%	$104,572.00	

8.2 Results

Note that either capacity for one charger at 200kW or two chargers at 400kW is being added, resulting in 300A+/- or ~600A+/- of additional panel capacity required, respectively (see footnote 27 on page 20).

Type of Facility	W/Sqft	Sqft	Charger Capacity Added	Initial Amps → Final Amps	Calculated Amps - Initial	Initial Amps	Calculated Amps - Final	Final Amps
Grocery store	23	10,000	1	400A -> 800A	346	400	647	800
			2	*400A -> 1200A*			*948*	*1,200*
		90,000	***2***	***4000A -> 4000A[41]***	***3,114***	***4,000***	***3,715***	***4,000***
Retail store	11.5	**10,000**	1	225A -> 600A	**173**	**225**	474	600
			2	***225A -> 800A[42]***			***775***	***800***
		135,000	*2*	*2500A -> 3000A*	*2,335*	*2,500*	*2,937*	*3,000*
Warehouse	4.5	20,000	1	150A -> 600A	135	150	436	600
			2	*150A -> 800A*			*737*	*800*
		256,000	*2*	*2000A -> 2500A*	*1,733*	*2,000*	*2,335*	*2,500*

Type of Facility	Sqft	Initial Amps → Final Amps	Total bldg. cost $/Sqft – low	Total bldg. cost $/Sqft – high	Total bldg. cost $ – low	Total bldg. cost $ – high	First Cost Delta $
Grocery store	10,000	400A -> 800A	332	539	3,400,000	5,400,000	13,692
		400A -> 1200A					*38,563*
	90,00041	***4000A -> 4000A[41]***	***133***	***216***	***12,000,000***	***19,500,000***	***37,307***
Retail store	**10,000**	225A -> 600A	**173**	**281**	**1,800,000**	**2,900,000**	34,703
		225A -> 800A[42]					***46,584***
	135,000	2500A -> 3000A	138	224	18,600,000	30,300,000	37,307
Warehouse	20,000	150A -> 600A	115	186	2,300,000	3,800,000	53,178
		150A -> 800A					*67,910*
	256,000	*2000A -> 2500A*	*55*	*89*	*14,100,000*	*22,800,000*	*74,051*

Type of Facility	Initial Amps → Final Amps	Current Code ($)		Proposed Code ($)	First cost/ total cost: low	First cost/ total cost: high	First cost/ total cost: average	Retrofit cost/first cost
		First Cost of building Initial Amps	Cost of later Demolition and building Final Amps	First Cost of building Final Amps				
Grocery store	400A -> 800A	94,421	178,300	108,113	0.3%	0.4%	0.3%	252% (max)
	400A -> 1200A		*207,513*	*132,984*	*0.7%*	*1.1%*	*0.9%*	*227%*
	4000A -> 4000A[41]	*None*	***47,349***	***37,307***	***0.2%***	***0.3%***	***0.3%***	***127%*** *(min)*
Retail store	225A -> 600A	68,410	172,772	103,113	1.2%	1.9%	1.6%	234%
	225A -> 800A[42]		***187,051***	***114,994***	***1.6%***	***2.6%***	***2.1%***	***222%***
	2500A -> 3000A	*52,187*	*230,529*	*153,638*	*0.1%*	*0.2%*	*0.2%*	*184%*
Warehouse	150A -> 600A	52,687	176,271	105,865	1.4%	2.3%	1.9%	216%
	150A -> 800A		*194,175*	*120,597*	*1.8%*	*3.0%*	*2.4%*	*205%*
	2000A -> 2500A	*46,569*	*197,128*	*120,620*	*0.3%*	*0.5%*	*0.4%*	*202%*

[41] See "large building example" in next section.

[42] See "small building example" in next section.

8.3 Case Cost Estimate Calculations

Example large building with high initial capacity (Grocery scenario #3)

(Adding 400 kVA Capacity)	Bldg Area	Initial design 4000A -> final 4000A					
	90,000	Build w/ current code & then retrofit			Build more infrastructure now		
	Unit	Unit Cost	Qty	Construction Cost	Unit Cost	Qty	Construction Cost
				$ 52,879			$ 37,307
Base Building				$ -			$ -
Equipment & Feeders				$ -			$ -
2000 kVA Transformer	EA	$ 144,960	Already included	$ -	does not apply to "build more now" cases		
4000A Main Switchboard	EA	$ 103,180		$ -			
General Conditions				$ -			$ -
Indirects (Supervision, QA, Documentation)	LS	13.5%		$ -			$ -
EV Infrastructure				$ 47,438			$ 37,307
Civil			no demo				$ -
Remove existing Transformer	EA	$ 2,300	0	$ -	does not apply to "build more now" cases		
Remove existing Switchgear	EA	$ 10,672	0	$ -			
Demolish wall to accommodate bigger equipment	LF	$ 52	0	$ -			
Concrete Wall	SF	$ 58	0	$ -			
Concrete Pad	CY	$ 1,725	0	$ -			
Finishes	SF	$ 17	0	$ -			
Equipment & Feeders				$ 37,800			$ 32,870
2000 kVA Transformer	EA	$ 148,254	Already included	$ -	$ 144,960	Already included	$ -
4000A Main Switchboard	EA	$ 104,572		$ -	$ 103,180		$ -
Conduits, 4" diam.	LF	$ 11	0	$ -	$ 10	0	$ -
Conduits, 4" diam. - 4 sets (includes trench and duct bank)	LF	$ 126	300	$ 37,800	$ 110	300	$ 32,870
General Conditions				$ 9,639			$ 4,437
Indirects (Supervision, QA, Documentation)	LS	25.5%		$ 9,639	13.5%		$ 4,437

Example small building with moderate initial capacity (Retail scenario #2)

(Adding 400 kVA Capacity)	Bldg Area	Initial design 225A -> final 800A					
	10,000	Build w/ current code & then retrofit			Build more infrastructure now		
	Unit	Unit Cost	Qty	Construction Cost	Unit Cost	Qty	Construction Cost
				$ 255,461			$ 114,994
Base Building				$ 68,410			$ -
Equipment & Feeders				$ 60,273			$ -
150 kVA Transformer	EA	$ 51,347	1	$ 51,347	does not apply to "build more now" cases		
225A Panelboard	EA	$ 8,926	1	$ 8,926			
General Conditions				$ 8,137			$ -
Indirects (Supervision, QA, Documentation)	LS	13.5%		$ 8,137	13.5%		$ -
EV Infrastructure				$ 187,051			$ 114,994
Civil				$ 42,664			$ -
Remove existing Transformer	EA	$ 2,300	1	$ 2,300	does not apply to "build more now" cases		
Remove existing Switchgear	EA	$ 10,672	1	$ 10,672			
Demolish wall to accommodate bigger equipment	LF	$ 52	25	$ 1,294			
Concrete Wall	SF	$ 58	350	$ 20,125			
Concrete Pad	CY	$ 1,725	1.3	$ 2,236			
Finishes	SF	$ 17	350	$ 6,038			
Equipment & Feeders				$ 106,380			$ 101,317
500 kVA Transformer	EA	$ 66,712	1	$ 66,712	$ 64,480	1	$ 64,480
800A Main Switchboard	EA	$ 25,964	1	$ 25,964	$ 24,920	1	$ 24,920
Conduits, 4" diam.	LF	$ 11	100	$ 1,104	$ 10	100	$ 960
Conduits, 4" diam. - 4 sets (includes trench and duct bank)	LF	$ 126	100	$ 12,600	$ 110	100	$ 10,957
General Conditions				$ 38,006			$ 13,678
Indirects (Supervision, QA, Documentation)	LS	25.5%		$ 38,006	13.5%		$ 13,678