Plugging In

Speeding the Adoption of Electric Vehicles in California with Smart Local Policies

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Executive Summary

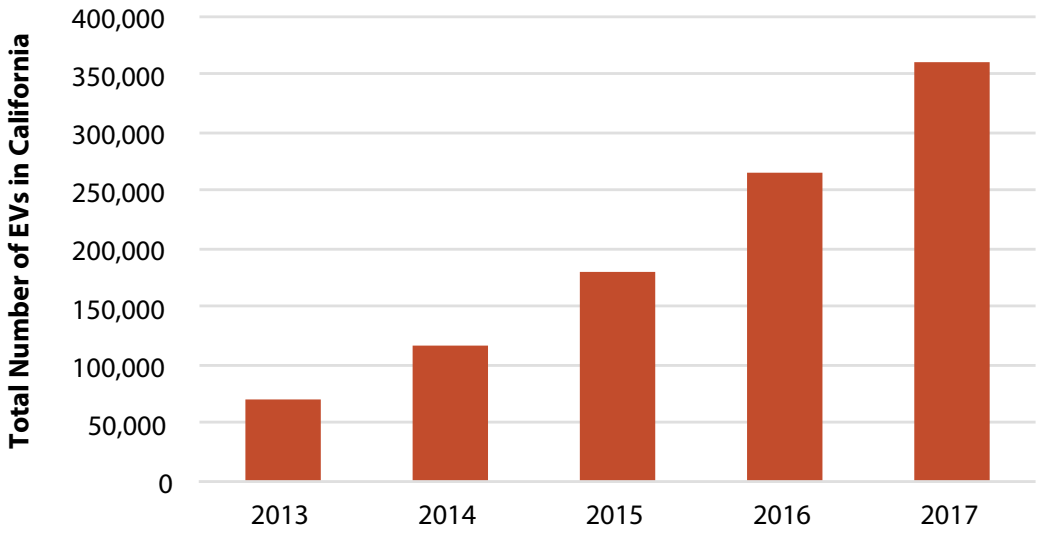
The adoption of large numbers of electric vehicles (EVs) offers many benefits for California cities, including cleaner air and the opportunity to reduce greenhouse gas emissions. Electric vehicles are far cleaner than gasoline-powered cars, with lower greenhouse gas emissions and lower emissions of the pollutants that contribute to smog and particulate matter.[1]

California must speed the adoption of electric vehicles to protect the environment and public health. The state estimates that it won't be able to meet California's long-term climate goals unless nearly all vehicles sold by mid-century are electric vehicles.[2] Shifting to electric vehicles will be a revolutionary disruption and will require smart policy solutions to ensure success.

The number of EVs on California's streets is at an all-time high and rising fast. By the end of 2017, more than 360,000 EVs had been sold in California, making up nearly half of the country's total EV stock.[3] Throughout 2017, the number of electric vehicles in the state increased approximately 34 percent, with nearly 92,000 more EVs estimated to be on California roads.[4] The introduction of Tesla's Model 3, the Chevy Bolt, and other more affordable, long-range electric vehicles suggests that growth in EV sales is just beginning. In fact, Chevrolet's Bolt EV was named *Motor Trend*'s 2017 Car of the Year.[5]

But with more EVs on the road, and many more coming soon, cities will face the challenge of where electric vehicles will charge, particularly in city centers and neighborhoods without off-street residential parking. Moreover, a lack of charging infrastructure could deter prospective EV owners from switching to electric cars, potentially hindering

Figure ES-1. Estimated Number of Electric Vehicles in California by Year[6]



California's efforts to meet ambitious zero-emission vehicle goals.

The good news is that smart public policies, including those already pioneered in cities in the U.S. and around the world, can help California cities lead the electric vehicle revolution while expanding access to clean transportation options for those who live, work and play in cities.

Electric vehicles are poised for explosive growth.

Technological gains that allow electric vehicles to drive farther, charge faster, and be produced more affordably are revolutionizing the vehicle market. With adequate policy and infrastructure investments, Bloomberg New Energy Finance estimates that more than half of new cars sold by 2040 globally will be electric vehicles.[7] California is poised to lead the nation, committing to 5 million zero-emission electric vehicles in the state by 2030, building upon a previous order calling for 1.5 million EVs by 2025.[8] The state could reach even more ambitious targets, as leaders have been considering requiring that all new cars sold in California be zero-emission vehicles in coming decades.[9]

Cities need to be ready for an influx of electric vehicles.

In a few short years, tens of thousands of electric vehicles could hit city streets across California, from Sacramento to San Diego (see Table ES-1). If California chooses to be more aggressive in its goals, the state could have many more EVs than projected, with correspondingly greater infrastructure demands. These vehicles will need places to charge, so access to EV charging stations at home, in public places and at workplaces will be critical. According to the 2015 American Housing Survey by the U.S. Census Bureau, nearly a quarter of residents in the San Francisco metro area lack a garage or carport, along with 20 percent of residents in the Los Angeles metro area (with rates likely much higher within the cities themselves where density is greater), necessitating a broad network of publicly accessible charging infrastructure.[10]

Table ES-1. Possible Number of Electric Vehicles on California City Streets by 2030 and Corresponding Publicly Accessible Charging Infrastructure Needs (Excluding Residential Charging)[11]

		Estimated Number of Public Plugs Needed in City Limits by 2030, by Type				Current Number of Public Plugs in City Limits (2017)
City	Number of EVs Estimated in City Limits by 2030	Level 2 Plugs in Workplaces Needed	Level 2 Plugs in Public Places Needed	Public Fast Charger Plugs (DCFC) Needed	Total L2 and DCFC Plugs Needed	Total L2 and DCFC Plugs Currently
Los Angeles	451,000	8,180	4,834	261	13,275	1,456
Riverside	38,000	852	530	59	1,441	77
Sacramento	61,000	1,367	851	94	2,312	317
San Diego	180,000	3,031	1,819	182	5,032	776
San Francisco	80,000	1,127	644	65	1,836	422
San Jose	137,000	2,108	1,054	106	3,268	485

Major cities will require the installation of hundreds to thousands of publicly accessible electric vehicle chargers in order to serve the increased demand for electric vehicles. Studies conducted separately by the National Renewable Energy Laboratory, the Electric Power Research Institute, and Pacific Gas & Electric estimate that between 1 and 5.2 public fast chargers are needed to support every 1,000 electric vehicles.[12] The National Renewable Energy Laboratory estimates that 36 non-residential Level 2 chargers are necessary for every 1,000 electric vehicles.[13] Cities will also need to facilitate at-home charging since the majority of EV owners will need to park and charge their vehicles overnight at or near where they live.[14]

The world's leading EV cities have adopted key policies that enable urban residents to own and operate electric vehicles. In particular, these cities have been able to deliver electric vehicle infrastructure to urban drivers through innovative parking and planning policies, including:

- **Residential access to on-street EV charging:** Residents in densely developed neighborhoods often do not have access to an off-street parking

Types of Electric Vehicle Charging Infrastructure[15]

There are three primary types, or levels, of electric vehicle chargers – Level 1, Level 2 and DCFC (often referred to as "fast charging").

- Level 1 charging is from a standard wall outlet and provides a slow charge, adding 4 to 5 miles of range per hour. Therefore, with a Level 1 charger, an empty EV battery may need to charge for 10 hours to get 50 miles of range. Level 1 chargers can work well for at-home charging, where EV owners park overnight, and in many workplaces, since the typical commute in many metro areas is less than 10 miles each way.[16] Because Level 1 charging requires only a standard three-prong outlet, it is often the most affordable way to offer charging, with minimal installation costs.
- Level 2 chargers require special installation but can charge an electric vehicle battery 2 to 6 times faster than a Level 1 charger, adding 12 to 25 miles of range per hour of charge, so 50 miles can be added in 2 to 4 hours. If people install a charger in front of their house, in their driveway, or in their garage, it is most likely a Level 2 charger. In public spaces, such as parking lots or on public streets, most chargers are Level 2, allowing EV drivers to charge their car for a few hours while at work or shopping. Level 1 and Level 2 plugs are standard in the United States so all EVs can charge at those charging stations.
- Fast chargers, known as DCFC (for direct current fast charge), can add 100 miles of range or more in an hour of charging – meaning an EV driver can add 50 miles to their battery in just half an hour. Different EV makes and models are compatible with different fast chargers and may require an adaptor to charge. Fast chargers will be especially important for long-distance travel when drivers won't be stopping for hours at a time, so DCFC chargers work well at rest stops and gas stations off highways and are important for the viability of electric shared mobility services, whose vehicles may be used for many trips – and travel many miles – in a given day. However, only pure battery electric vehicles can use DCFC charging, so it excludes plug-in hybrid EVs.

This report recognizes the value of Level 1 chargers as a low-cost option at homes, workplaces, and some public parking areas (like airports), but focuses on Level 2 and fast charging (DCFC) for public spaces, which are the chargers you would expect to find curbside, at workplaces and businesses, in parking garages and in other public areas.

Electric vehicle charging stations on lampposts in Los Angeles. Credit: Los Angeles Bureau of Street Lighting.

spot where they might charge their electric vehicle overnight.[17] Cities around the world are tackling this problem with innovative solutions to install or incentivize residents to install on-street charging infrastructure at curbsides in dense areas. For example, residents in London can ask the city to install, and mostly pay for, EV charging infrastructure at streetlights on their block.[18]

- **Access to public charging stations:** By acting directly or partnering with other entities – such as private garages, public schools and community centers – cities can ensure that there are adequate parking spaces for people to charge their EVs when they aren't at home, for instance, while they are commuting, shopping or traveling. Coordinating with utilities is one promising way that cities can expand local networks of public charging stations.
- **Support for private investment in publicly accessible stations:** "Semi-public" stations can provide EV owners a place to charge at privately owned stations at businesses, parking garages or private driveways. By incentivizing the installation of shared charging stations, cities can optimize use of charging infrastructure.
- **Incentivized EV parking and charging:** Some cities have local government programs or agencies that offer discounted or free charging and parking for electric vehicles in public spaces.

Leading cities are encouraging shared mobility options and reforming parking policies to expand access to electric vehicle travel and reduce conflicts over parking.

- Carsharing services are expanding access to EVs – and to EV charging – around the world. Fleets of shared electric cars, like BlueLA in Los Angeles (scheduled to begin full operation in the spring of 2018), allow people to drive electric vehicles without needing to personally own one. These services can also expand public access to EV charging by opening up their charging infrastructure for the public to use.
- Expanding shared mobility, electrified public transit, safe biking and walking, and other transportation options – as well as implementing parking reforms – can reduce competition for on-street parking that might crowd out space for EV charging, while supporting the creation of walkable communities where people have a variety of low-carbon and zero-carbon transportation options.

Electric vehicles are an essential tool for cities to combat global warming and air pollution, and offer consumer benefits such as lower operating costs. Technological developments mean that EVs are poised to hit the market in record numbers. However, there is a lot left to be done. If cities fail to develop comprehensive plans for EV charging now, they risk being unprepared for the large numbers of EVs that are beginning to hit local streets. **In order to be successful, cities will need to develop comprehensive solutions to accommodate electric vehicles, including convenient opportunities for charging, while fostering the creation of neighborhoods where residents have access to a variety of low-carbon and zero-carbon transportation options.**

Introduction

A revolution is happening on California's streets. And our cities need to be ready.

Affordable electric vehicles (EVs) are hitting the road in increasing numbers. The arrival of the 238-mile, $37,495 Chevy Bolt in early 2017 and the 200-mile, $35,000 Tesla Model 3 in the fall of 2017 signaled the movement of electric vehicles into the mainstream.[19] Demand for vehicles has been high: nearly half a million people have reserved a Model 3 car ahead of distribution.[20] General Motors (GM) plans to launch 20 electric vehicle models by 2023, with two new cars hitting American streets by spring of 2019.[21] Chevrolet's Bolt was named *Motor Trend*'s 2017 Car of the Year, and a number of fully electric and plug-in hybrid electric vehicles were finalists for 2018's award.[22]

Electric vehicles have the potential to address critical public health and environmental challenges in our cities, and are critical for California to meet its climate goals. Electric vehicles are far less polluting than gasoline-powered cars, emitting no tailpipe emissions while driving, producing half the carbon footprint of gasoline-powered cars over their lifetime, and spewing fewer emissions of the pollutants that contribute to smog and particulate matter.[23] Of America's top 10 cities with the worst air pollution, many are in California. According to the American Lung Association, seven California cities are in the top 10 cities for most ozone pollution, eight are in the top 10 for most year-round particle pollution, and six are in the top 10 for most short-term particle pollution.[24] By putting more zero-emission electric cars on the road, cities can help improve public health and reduce global warming pollution.

The first round of Tesla Model 3 cars ready for shipment in July 2017. Credit: Steve Jurvetson via Wikimedia, CC BY 2.0.

Meeting California's long-term climate goals demands a major shift in the state's transportation system, with virtually all cars purchased by mid-century needing to be electric vehicles.[25] The rapid, widespread transition to electric vehicles will require a number of changes and innovative solutions, including connecting charging infrastructure with the electricity grid, updating the grid, and adopting city policies to allocate space for EVs and integrate electric vehicles in the broader transportation system and built environment.

This report focuses on how cities can provide opportunities for residents to charge electric vehicles – especially those residents without access to off-street parking. Unlike traditional gasoline-powered vehicles that can fuel up in a few minutes at a gas station, electric vehicles (absent the widespread availability of fast

charging) need to charge over the course of several hours in locations close to where their owners live, work or spend time. In cities where on-street parking is perceived to be tight, that can be a challenge.

Cities around the world are leading the way in the electric vehicle revolution and have policies in place to ensure that EV drivers can charge their cars where and when they need to do so. California cities must develop comprehensive solutions for electric vehicle charging now, and take action to put those plans into place, if they hope to be prepared for the larger numbers of EVs soon hitting local streets. With smart planning and policy, cities can reap the full benefits of California's electric vehicle revolution.

Electric Vehicles Are Coming to California's Cities

Pollution from cars and trucks harms the health of city residents, contributes to global warming, and makes cities less pleasant places to live. For decades, electric vehicles have held the promise of reducing the environmental, public health and quality-of-life burdens of cars in cities.

Today, electric vehicles are on the verge of delivering on that promise. By the end of 2017, more than 360,000 EVs had been sold in California, making up nearly half of the country's total EV stock.[26] Throughout 2017, the number of electric vehicles in the state increased approximately 34 percent, with nearly 92,000 new EVs on California roads.[27] The year before, between 2015 and 2016, the number of EVs in California increased 32 percent, by putting an additional 60,000 EVs on the roads.[28]

Electric Vehicles Are Ready to Roll

Propelled by technological developments and public policy, recent progress in electric vehicles stems primarily from improvements on four fronts:

- **Battery Cost:** In 2016, a lithium-ion battery for an electric vehicle cost about a quarter as much to produce as it did in 2009, and delivered six times the energy for its size.[30] Batteries have long been the single most expensive part of an electric vehicle and now technology advances are letting EVs travel farther for less money.[31] (See Figure 2.)
- **Travel Range:** Because of battery improvements, mass-market electric vehicles like the Nissan Leaf can travel 150 miles on a single charge and Tesla's

Figure 1. Estimated Number of Electric Vehicles in California by Year[29]

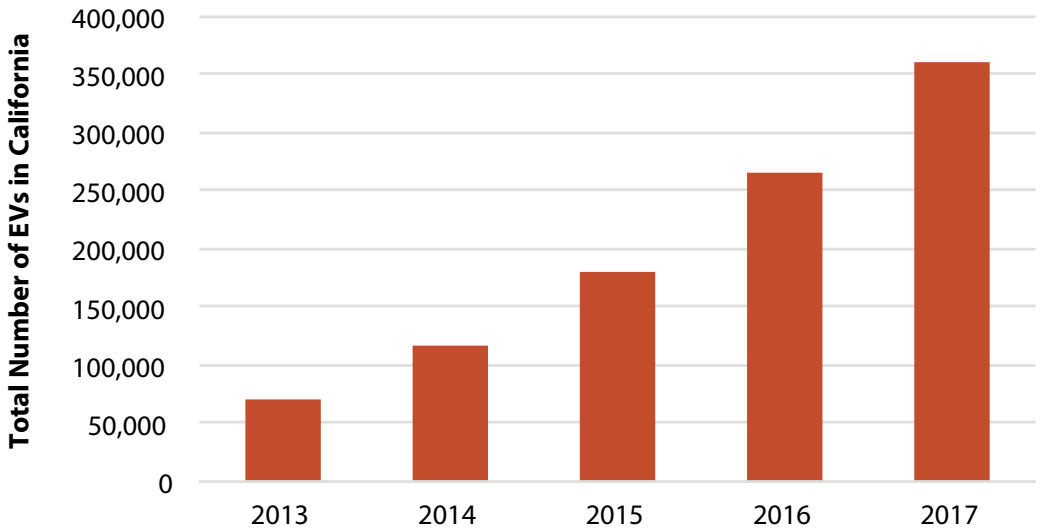
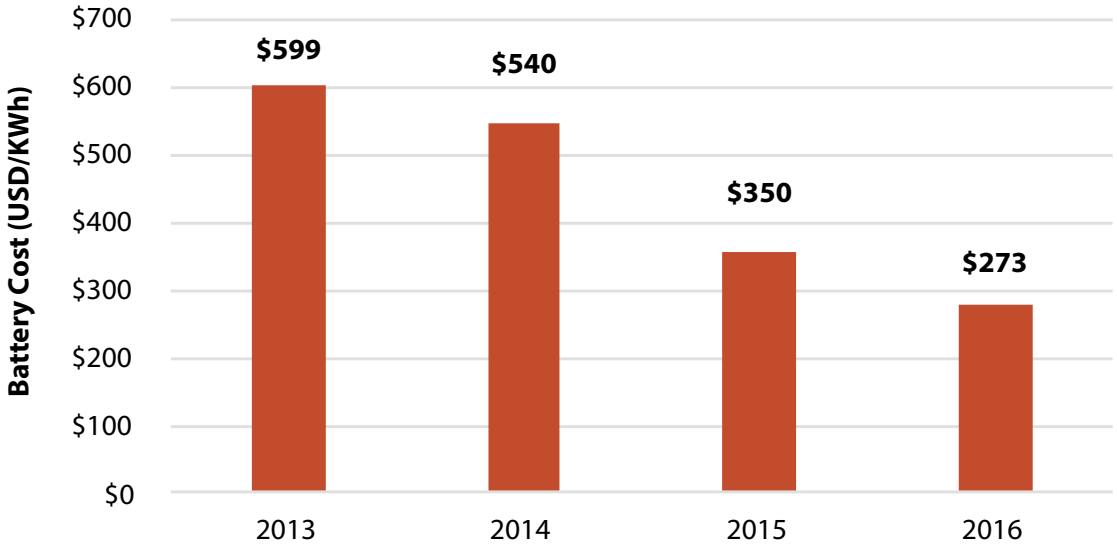


Figure 2. Cost of Lithium-Ion Batteries per Kilowatt-Hour of Energy Capacity, 2013-2016, in USD[32]



top-of-the-line Model S can travel more than 300 miles.[33] Longer-range cars are also becoming more affordable: the 2018 Nissan Leaf costs just $30,000, much less than earlier-generation electric cars. Tesla's Model 3 and the Chevy Bolt both offer over 200 miles of range for only a few thousand dollars more.[34]

- **Charging Speed:** While charging some longer-range electric vehicles like the Model S from empty to its full charge on a Level 2 charger takes up to eight hours, Tesla's Supercharger stations can now fully charge a car in 75 minutes.[35] Advances in battery technology and charging equipment will allow for even faster charging in the future, comparable to filling up a gasoline tank. For instance, Toshiba's next generation of EV batteries, expected to be deployed in 2019, can charge in just six minutes, with a range of 200 miles.[36]
- **Consumer Interest:** Consumers are also growing more interested in EVs. A 2016 survey by the Union of Concerned Scientists and Consumers Union found that more than half of Californians would be likely to consider an electric vehicle for their next car purchase or lease, while 65 percent of people in the state want to see automakers offer more electric options.[37]

A fast charging station at a mall in Ventura, CA. Credit: Paul Gipe. All rights reserved.

Shared Mobility Expands Access to EVs

Another important change in the last decade with implications for EVs is the rise of "shared mobility" services – technology-enabled services that facilitate the sharing of vehicles or rides in a city. Carsharing, bikesharing, and "ridesourcing" services like Lyft and Uber all fall within the definition of shared mobility.

Shared mobility services can be particularly amenable to the use of electric vehicles. Shared mobility services in cities can use smaller vehicles tailored for urban use and vehicles can be monitored centrally to ensure they are charged up for use.

Globally, there are many examples of using EVs for shared fleets, with examples dating back to the early part of the decade. For example, Autolib' carsharing launched in Paris in 2011 and by 2016 had more than half a million subscribers. The program has 4,000 cars and nearly 5,700 docking/charging stations (half of all the electric vehicle charging stations in France).[38] Drivers can reserve cars and parking places from their phones.[39] Paris is also switching 30 percent of its shared bicycle fleet to electric bikes starting in 2018, with the hope that, by making pedaling a bit easier, more residents will replace car trips with bike trips.[40]

The company behind Autolib', Bolloré, launched its first foray into the U.S. in 2015 with electric carsharing service in Indianapolis. BlueIndy now offers 500 EVs and 1,000 charging stations across the city.[41] Bolloré is set to bring 100 electric vehicles and 200 charging stations to Los Angeles through a new carsharing program, BlueLA, which is being funded by California's greenhouse gas emissions cap-and-trade system.[42] Charging stations were being installed as of February 2018, and the program is scheduled to begin operation in the spring of 2018. BlueLA is specifically designed for low-income residents, with stations located in dense low-income communities and a discounted pricing system based on income.[43]

Another all-electric carsharing company in California, Envoy, was launched in 2016, to allow housing developers to provide fewer parking spaces on-site by promoting the use of carsharing to residents.[44] Envoy pays the initial cost of charging station installation, car purchasing, and other overhead.[45] In November 2017, the company was awarded a $1.5 million grant from the California Energy Commission to install electric vehicle charging stations around the Bay Area and Sacramento, as well as to expand its carsharing service, to help reduce air pollution in the area.[46]

A BlueLA car in Los Angeles. Credit: Mayor Eric Garcetti via Flickr, CC BY-NC-ND 2.0.

Sacramento has launched a small program to provide residents of three public housing complexes free access to shared electric vehicles, partially paid for by California's emissions cap-and-trade system and a number of Sacramento agencies.[47] Volkswagen, as part of its emissions cheating settlement, will also invest in a new carsharing program and charging infrastructure in Sacramento.[48]

In 2017, General Motors added 100 fully electric Chevy Bolts to its Maven carsharing program in Los Angeles, which allows users to rent cars in hour-long increments, with plans to offer EVs in its San Francisco and San Diego programs.[49] Maven also supplies electric vehicles, including the Chevy Bolt, to Lyft's Express Drive program, which allows Lyft drivers in some cities to rent GM vehicles for ride-hailing.[50] The Bolt has become the most-requested car by Maven users who drive for Lyft and other ride-hailing

Shared Electric Bicycles: A New Trend in Electric Mobility

Access to shared bicycles can help address many transportation challenges, particularly when paired with other forms of transit and shared mobility. Electric bicycles (e-bikes) make riding a bike even more accessible for the public and can enable more residents to travel without a car. Internationally, a number of cities have large electric bikesharing programs. For instance, Madrid's BiciMAD consists of more than 1,500 e-bikes parked at 123 stations across the city. The city also offers electric scooters for rent, which is helpful for people with impaired mobility.[55]

A number of shared e-bike systems are launching in cities around the United States, with more expected in coming years. In September 2017, Social Bicycles (SoBi) launched the country's first dockless electric bikesharing program in Washington, D.C., called JUMP.[56] Riders can find bikes and unlock them from an app on their phone and can drop off the bicycles anywhere people can legally park a bike. Users are incentivized to return the bikes to stations for charging through a $1 credit on their account. In January 2018, SoBi launched an 18-month pilot program in San Francisco with 250 JUMP bikes. The company is also partnering with Uber in San Francisco so people can reserve the electric bikes through Uber's app on smartphones.[57] SoBi is planning to start other dockless electric bikesharing programs in Sacramento and the city of Davis, CA, by May 2018.

Though their needs are different, electric bicycles also require charging and cities should work to identify ways to promote shared electric bikes through charging infrastructure.

services.[51] While renting a Bolt costs $40 more per week, drivers say that the EV helps them save $70 per week on gas on average, and cite fuel savings as their main reason for choosing the Bolt over GM's traditional vehicle options.[52] As part of the program in Los Angeles, users have free access to a network of EV charging at EVgo Freedom Stations.[53] Uber has announced an electric vehicle program in Portland, OR, that includes partnering with local businesses to provide electric vehicles and electric bikes for Uber's food delivery service, UberEATS.[54]

Cities Can Expect Many More Electric Vehicles Soon

Market analyses anticipate that EVs are poised for even more explosive growth in the near future. By 2040, about a third of the world's vehicles could be electric – almost 530 million vehicles – according to research by Bloomberg New Energy Finance.[58] Global sales in 2040 could be as many as 266 million electric vehicles, according to ExxonMobil.[59]

Estimates for the number of EVs on U.S. roads in 2025 range from 7 million (Edison Foundation), to 7.5 million (Energy Information Administration), to 11.4 million (GreenTech Media).[60] In September 2017, the National Renewable Energy Laboratory (NREL) released a new study estimating that 15 million electric vehicles will be on the road in the United States by 2030, with nearly 3.9 million of the cars in California.[61]

Currently, eight U.S. states, including California – home to about half of the EVs in the U.S. – have signed on to an action plan that calls for 3.3 million EVs on their roads in 2025.[62] The states are taking aggressive steps to meet this goal. The adoption of an emissions reduction strategy by the California Air Resources Board in December 2017 anticipated 4.2 million electric cars in the state by 2030.[63] In January 2018, California Governor Jerry Brown signed an executive order creating a

new target of 5 million zero-emission electric vehicles in the state by 2030, building upon a previous order calling for 1.5 million EVs by 2025.[64] The new executive order also proposed a $2.5 billion initiative to invest in 250,000 EV charging stations and other infrastructure across the state by 2025.[65]

Cities are also taking charge. For instance, Los Angeles' *Sustainable City pLAn* calls for 10 percent of vehicles in the city to be electric by 2025, increasing to 25 percent by 2035 (the city may increase these numbers in the plan's 2019 four-year update).[66] Sacramento anticipates needing to support 17,000 to 74,000 zero-emission vehicles by 2025.[67]

All scenarios point to a rapid increase in electric vehicle sales in coming years, which means we can expect many EVs to hit the roads in cities across California. Downscaling California's target of 5 million zero-emission vehicles by 2030 allows for a calculation of how many EVs could be in different cities in the state by that year.[68] The number of EVs could reach 451,000 by 2030 in the city limits of Los Angeles, 180,000 in San Diego, 80,000 in San Francisco, and 137,000 in San Jose (with entering the cities each day, driven by commuters arriving from outside the city limits). (See Table 1.)

However, some estimates predict even more rapid, widespread adoption of electric vehicles in California and around the world, as some countries are positioning themselves for 100 percent electric vehicle sales in coming decades. For instance, a 2017 report by the Dutch bank ING predicts that all new passenger cars sold in Europe will be electric after 2035.[70] Norway has a goal for all new cars sold in the country to be electric (or hydrogen-powered) by 2025 and appears to be well on its way to meeting it. In 2017, 50 percent of all car sold in Norway were electric or hybrid; France announced all cars sold in the country must be electric by 2040, and Britain has followed suit by saying the country will ban sales of diesel and gasoline-fueled cars the same year.[71] Even India set a target to sell only EVs by 2030 and China is working on a plan to phase out fossil fuel-powered cars.[72] Meanwhile, the carmaker Volvo says they will only sell hybrid, plug-in hybrid or fully electric cars starting in 2019.[73] Leaders in California have also raised the possibility of mandating the sale of zero-emission vehicles only.[74] In January 2018, a bill was introduced in the California Legislature that would require all cars sold to be zero-emission by 2040.[75] Such a policy would swiftly accelerate the transition to electric vehicles.

Table 1. Projected Number of Electric Vehicles in Six California Cities by 2030[69]

City	Number of EVs Projected in City Limits by 2030
Los Angeles	451,000
Riverside	38,000
Sacramento	61,000
San Diego	180,000
San Francisco	80,000
San Jose	137,000

California must speed the adoption of electric vehicles. California estimates that it won't be able to meet the state's long-term climate goals unless nearly all vehicles sold by mid-century are electric vehicles.[76] This will be a revolutionary disruption and will require smart policy solutions to ensure success.

People Will Need a Place to Charge EVs, Including Where They Live

To support these new electric vehicles, California's energy infrastructure will need to adapt. Instead of gas stations, EVs will need charging stations. And because EV charging often takes place overnight, cities will need to ensure that people have access to charging near their homes, as well as at work and in other places where people spend time.

Recently, electric vehicle sales in some areas of the United States have been growing more quickly than the charging infrastructure needed to support them.

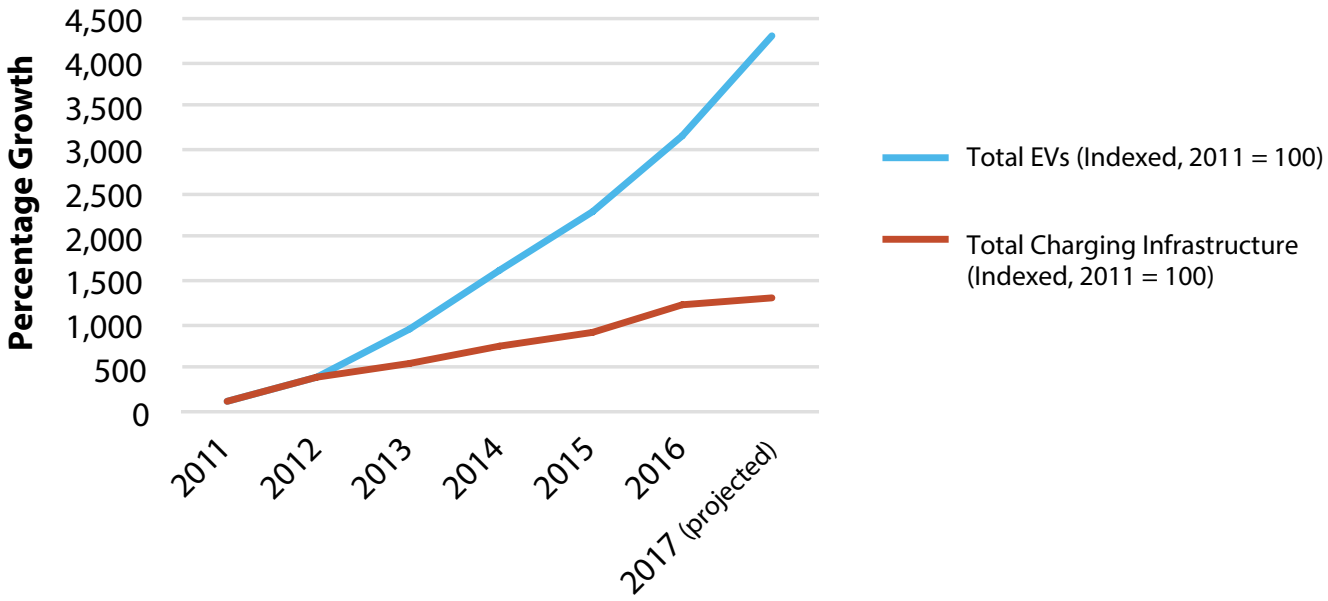
In 2016, the number of publicly available chargers in the U.S. increased 25 percent, while EV sales increased by 37 percent.[77] Without a concerted effort to expand access to charging infrastructure, rapid increases in electric vehicle sales could continue to outstrip the availability of places to charge them. Moreover, a lack of charging infrastructure could deter prospective EV owners from switching to electric cars, potentially hindering California's efforts to meet ambitious zero-emission vehicle goals.

Public access to EV charging stations, particularly in residential areas, will increasingly be critical in order to accommodate large numbers of electric vehicles. According to the 2015 American Housing Survey by the U.S. Census Bureau, nearly a quarter of residents in the San Francisco metro area lack a garage or carport, along with 20 percent of residents in the Los Angeles metro area.[79] Furthermore, many EVs are expected to be within cities, where people may be even less likely to have dedicated parking spots where they can install chargers, and instead will need chargers in multi-unit carports or publicly accessible chargers near their homes.[80]

In many households around the U.S. and within California, people rely on on-street parking (like in San Francisco, above), necessitating dedicated spots where EVs can charge and the provision of charging infrastructure in public places. Credit: M. Weitzel via Wikimedia, CC BY-SA 2.5.

Workplaces offer an opportunity for some EV owners to charge their cars, but many employers and offices have not yet installed adequate infrastructure even for their current number of EV-driving employees.[81]

Figure 3. Growth of Electric Vehicles and Growth of Public Charging Points in the U.S., 2011-2017 (Projected Growth after August 2017)[78]



Types of Electric Vehicle Charging Infrastructure[82]

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- Level 1 charging is from a standard wall outlet and provides a slow charge, adding 4 to 5 miles of range per hour. Therefore, with a Level 1 charger, an empty EV battery may need to charge for 10 hours to get 50 miles of range. Level 1 chargers can work well for at-home charging, where EV owners park overnight, and in many workplaces, since the typical commute in many metro areas is less than 10 miles each way.[83] Because Level 1 charging requires only a standard three-prong outlet, it is often the most affordable way to offer charging, with minimal installation costs.
- Level 2 chargers require special installation but can charge an electric vehicle battery 2 to 6 times faster than a Level 1 charger, adding 12 to 25 miles of range per hour of charge, so 50 miles can be added in 2 to 4 hours. If people install a charger in front of their house, in their driveway, or in their garage, it is most likely a Level 2 charger. In public spaces, such as parking lots or on public streets, most chargers are Level 2, allowing EV drivers to charge their car for a few hours while at work or shopping. Level 1 and Level 2 plugs are standard in the United States so all EVs can charge at those charging stations.
- Fast chargers, known as DCFC (for direct current fast charge), can add 100 miles of range or more in an hour of charging – meaning an EV driver can add 50 miles to their battery in just half an hour. Different EV makes and models are compatible with different fast chargers and may require an adaptor to charge. Fast chargers will be especially important for long-distance travel when drivers won't be stopping for hours at a time, so DCFC chargers work well at rest stops and gas stations off highways and are important for the viability of electric shared mobility services, whose vehicles may be used for many trips – and travel many miles – in a given day. However, only pure battery electric vehicles can use DCFC charging, so it excludes plug-in hybrid EVs.

This report recognizes the value of Level 1 chargers as a low-cost option at homes, workplaces, and some public parking areas (like airports), but focuses on Level 2 and fast charging (DCFC) for public spaces, which are the chargers you would expect to find curbside, at workplaces and businesses, in parking garages and in other public areas.

In order to support growing EV adoption in the U.S., the country will need a rapid expansion of charging infrastructure. Studies project that most electric vehicle charging will happen at home, so cities will need to ensure that residents have access to charging stations at or near where they live. Cities will also need publicly accessible charging infrastructure, on streets and in parking lots in residential neighborhoods, in downtowns, and at destinations like shopping centers. Studies conducted separately by the National Renewable Energy Laboratory, the Electric Power Research Institute, and Pacific Gas & Electric, a utility, estimate that between 1 and 5.2 fast chargers are needed to support 1,000 electric vehicles.[84] The National Renewable Energy Laboratory estimates that 36 non-residential Level 2 chargers are necessary for every 1,000 electric vehicles in cities (with towns and rural areas needing a higher ratio of chargers to vehicles since density is lower).[85] Cities will also need many more chargers at or near people's residences to support at-home charging.

NREL estimates that the U.S. currently has 13 percent of the public, non-residential, charging infrastructure that

will be required to meet demand by 2030 (see Figure 4).[86] There are approximately 42,000 Level 2 and DC fast chargers in the United States, according to the Department of Energy, whereas NREL estimates the country will need nearly 630,000 by the year 2030 to meet demand.[87] On a city level, Los Angeles, for instance, could have as many as 451,000 electric vehicles on the roads by 2030, requiring 13,275 public L2 and fast-charging ports, but the city has only 1,456 public charging ports now. San Diego could have 180,000 EVs and need up to 5,032 ports for public charging by 2030, but there are only 776 public L2 and fast-charging ports currently. (See Table 2.)[88] The City of Sacramento has forecast its own future charging needs, anticipating the need for 900 to 4,000 chargers at workplaces and in public places within the city by 2025.[89]

If California hopes to facilitate more widespread adoption, approaching 100 percent electric new car sales by mid-century, the required investment will be even greater.

Installing public and workplace charging can help urban residents to get the most out of their electric vehicles. These estimates of charging needs, however, do not include the need for overnight charging in residential areas. Considering that these projections assume that 88 percent of EV charging happens at home, cities may need to plan for as many as thousands of additional EV charging locations in residential neighborhoods.[92]

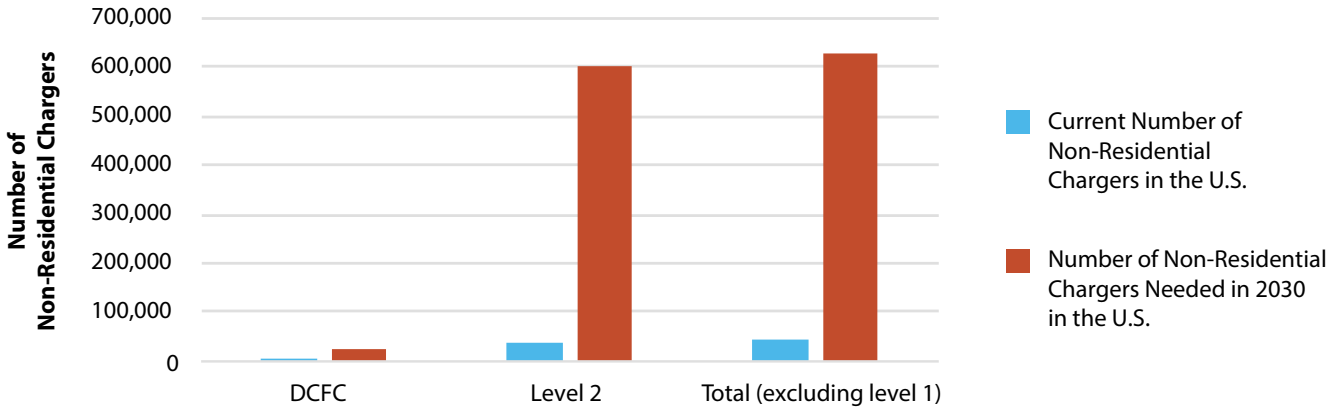
New Mobility Options Could Change Charging Needs

New models of mobility can result in different charging needs. Vehicles used in carsharing and ridesourcing systems, for example, may travel hundreds of miles per day, and need to have access to fast charging. If shared mobility were to reduce the number of privately-owned vehicles in a city, fast charging could become relatively more important.

Table 2. Possible Number of Electric Vehicles on California City Streets by 2030 and Corresponding Publicly Accessible Charging Infrastructure Needs (Excluding Residential Charging)[90]

		Estimated Number of Public Plugs Needed in City Limits by 2030, by Type				Current Number of Public Plugs in City Limits (2017)
City	Number of EVs Estimated in City Limits by 2030	Level 2 Plugs in Workplaces Needed	Level 2 Plugs in Public Places Needed	Public Fast Charger Plugs (DCFC) Needed	Total L2 and DCFC Plugs Needed	Total L2 and DCFC Plugs Currently
Los Angeles	451,000	8,180	4,834	261	13,275	1,456
Riverside	38,000	852	530	59	1,441	77
Sacramento	61,000	1,367	851	94	2,312	317
San Diego	180,000	3,031	1,819	182	5,032	776
San Francisco	80,000	1,127	644	65	1,836	422
San Jose	137,000	2,108	1,054	106	3,268	485

Figure 4. Current Number of Non-Residential Electric Vehicle Charging Plugs in the U.S. Versus Projected Non-Residential Need by 2030, by Type.[91]



In Madrid, for instance, the carsharing service Car2Go launched an electric carsharing service in 2015 with 350 vehicles (up to 500 in 2018).[93] When vehicles need to be recharged, they are taken to a series of centralized fast-charging "hubs" scattered throughout the city.[94] Since then, two other electric carsharing services – the "Zity" service using Renault's Zoe electric vehicle and "Emov," which uses Citroen's C-Zero cars – have found their way onto Madrid's streets, each with an additional 500 vehicles.[95] Carsharing services are incentivized through exemptions from parking and travel bans that apply to private, gasoline-powered vehicles. Seeking to reduce the use of private vehicles to combat air pollution and congestion, the city has banned non-residents from driving in much of Madrid's urban core.[96] Electric vehicles, including shared ones, are allowed to drive in otherwise restricted areas and park in any spot for free.[97] This gives people in Madrid a strong incentive to forgo their private, fossil-fuel vehicle in favor of an emission-free, shared trip. While bans like the one in Madrid have not been implemented in the United States, they are effective, and U.S. cities that are serious about supporting a transition to shared, electric transportation should consider them.

An emov carshare vehicle in Madrid. Staff Photo.

Smart Policies Can Help Cities Accommodate Electric Vehicles

Cities around the world are leading the electric vehicle revolution, often by adopting policies and investing public funds to expand the availability of charging infrastructure. By making it easy for EV owners and users to recharge their vehicles, these cities are positioning themselves to reap the air quality and climate benefits of growing electric vehicle use.

Of the five large metropolitan areas in the world with the greatest market share of EVs in 2015, two were in the Netherlands, two were in China, and one was in Norway. In each of these five cities – Oslo, Utrecht, Amsterdam, Shanghai and Shenzen – EVs accounted for 10 percent or more of new car sales. All of these cities have taken significant steps to facilitate EVs by investing in public charging infrastructure.[98]

Access to public charging is a key factor in the success of these cities: In a survey of Norwegians in 2012, more than 70 percent of EV owners said that having access to parking and charging were important in their decision to purchase an EV.[99] When asked about the importance of different incentives, Norwegians ranked access to public charging most important, with more than 90 percent of respondents ranking it as important.[100]

The world's leading EV cities have several key policies that enable residents to own and operate electric vehicles. In particular, these cities have been able to deliver electric vehicle infrastructure to urban drivers through innovative parking and urban planning policies.

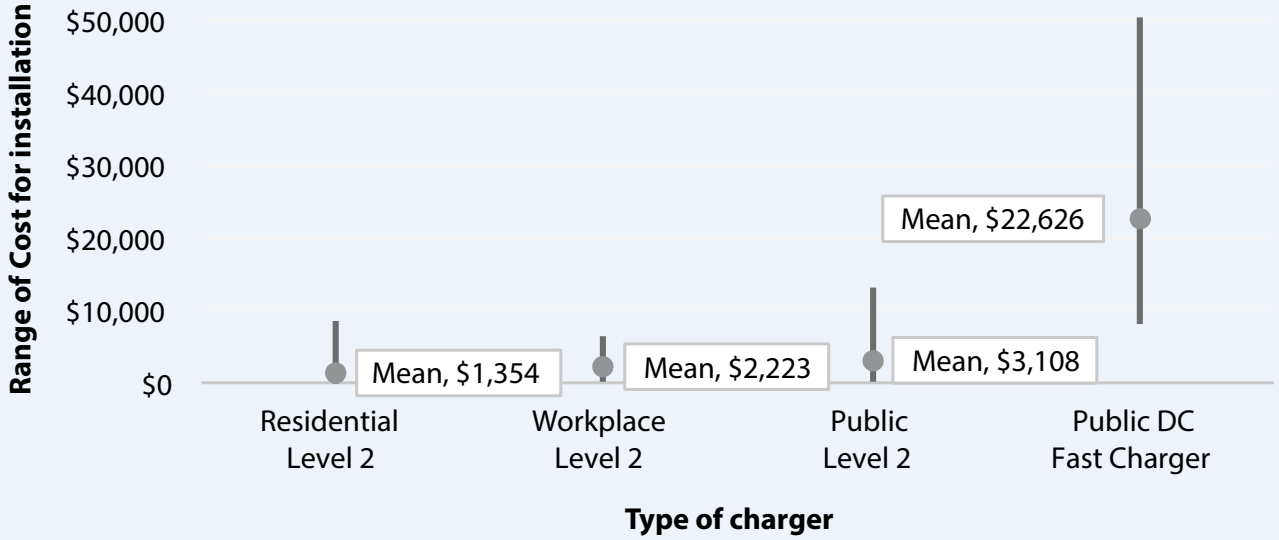
Specifically, leading cities have worked to expand access to:

1. **EV Charging Stations on Residential Streets** – A critical component of the success of electric vehicles will be residents' ability to charge their cars near their homes, even without dedicated off-street parking. These charging stations can be installed by local homeowners, private companies, utilities or by a city itself.
2. **Off-Street EV Charging Stations that Are Accessible to Residents** – Garages and lots with charging infrastructure can help alleviate residential charging demand.
3. **EV Charging in Multi-Unit Housing** – Improving access to charging in multi-family buildings can expand how many people can charge EVs at their homes.
4. **EV Charging at Workplaces** – While EV owners prefer to charge their vehicles at or near where they live, EV chargers at workplaces can help fill gaps and provide drivers another place to charge.
5. **Public EV Charging Infrastructure** – Adequate charging stations in public spaces allow EV owners to run errands and travel, within their city and to other cities, without worrying about whether they will be able to charge their car.

Costs of Electric Vehicle Charging Infrastructure

Many of the policies discussed in this section involve offering subsidies to residents, workplaces, developers, or municipalities to install EV charging infrastructure. The cost to purchase and install a charging station varies greatly—from several hundred dollars for a residential Level 2 installation to tens of thousands of dollars for high-tech public fast chargers—depending on the type of station and the features of the site, including existing electrical capacity.

Figure 5. Costs to Install Electric Vehicle Charging Stations, by Type[101]



EV Charging Stations on Residential Streets

One of the biggest challenges in expanding electric vehicle charging is providing charging in residential areas. Many residents, particularly in large cities, do not have access to an off-street parking spot where they might charge their EV overnight.[102] Cities around the world are tackling this problem with innovative solutions to directly install or incentivize residents to install on-street charging infrastructure in dense areas without off-street parking.

Expanding access to EV charging on residential streets reduces barriers to owning an EV and makes owning an electric vehicle as convenient as – or even more convenient than – owning a gasoline-fueled vehicle. Most of the studies referenced in this report indicate that EV owners prefer to charge at home and EV sales projections assume most charging will happen at people's homes.

However, in the absence of a comprehensive approach to residential parking, it may be hard for cities to overcome the perception that EVs are taking up rare parking spaces, particularly in areas where parking is harder to find. Another obstacle is that the installation of ports requires more work since the spaces are dispersed instead of concentrated in one area (like a parking lot). Finally, charging infrastructure can be expensive, with an average cost of $1,500 to purchase and install a Level 2 station at a California residence, and $3,100 (national average) for a public Level 2 station.[103] Costs can be much higher if the space needs to be retrofitted or if the electrical system needs to be reconfigured. For instance, one study found installa-

tion costs up to $8,000 for a Level 2 residential charger in Los Angeles, and $4,400 in San Diego.[104] Providing incentives for residents to install the infrastructure, or setting aside money for city-run programs, can help spur the installation of more stations.

EV parking spaces on a residential street in Hamburg, Germany. Credit: Vitavia, via Wikimedia, CC BY 2.0.

Expanding Charging Options in Residential Areas

There are many examples of residential on-street charging around the world, although implementation varies in the types of charging provided, the entities responsible for installing the chargers, and the ways in which residents make requests for stations.

Free-Standing Charging Stations: London has partnered with German startup Ubitricity to use existing streetlights to install adjacent free-standing charging stations, allowing the city to expand EV charging access cheaply and quickly.[105] Residents can apply for charging stations on their street and can list in order of preference which streetlight the installation would use. Currently any plug-in vehicle is allowed to park at any station.[106]

Low-Cost Plugs at Streetlights: Ubitricity is also experimenting with Level 1 charging points on lampposts, without a freestanding station. Where streetlights have been switched to LED lightbulbs, there is extra energy available that EVs can tap into, through a simple plug added to the lamppost, which is 10 times cheaper than a standalone station, according to Ubitricity.[107] The company is installing three plugs per customer request in London in order to see if oversupplying an area with low-cost plugs can reduce the need for dedicated parking next to charging stations.[108] Customers are sent a cord that can be used at any Ubitricity charging point and are billed monthly based on their usage, which is monitored by an electronic meter on their cord.[109] The charge from these plugs is slow, but works well for overnight parking.[110]

In 2016, the Los Angeles Department of Water and Power began a pilot program installing EV charging infrastructure on utility poles, the first of its kind in the U.S. The city has also used streetlights for charging infrastructure, noting that using existing electrical infrastructure on streets is simple and doesn't require ripping up pavement to run new lines to charging stations.[111] The city had installed more than 80 charging points on streetlights by the end of 2017, with plans for another 80 by July 2018.[112] Using the stations costs customers between $1 and $3 for an hour of charging, depending on the location of the charger. The city anticipates that the chargers will be useful for the broader public, as well as for city fleet vehicles while out in the field.[113]

Electric vehicle charging stations on lampposts in Los Angeles. Credit: Los Angeles Bureau of Street Lighting.

Managing Residential Charging Stations

Leading EV cities allow for installation of EV chargers by public or private entities, including people living in residential areas.

Owner-Installed Stations: Cities around the world have experimented with policies that allow electric vehicle owners to install charging stations on the curb at or near their homes.

In September 2017, the New Orleans City Council unanimously passed legislation allowing residents to apply for permits to install electric vehicle charging stations in front of their homes, on public property.[114] Residents must pay $300 for the permit and to purchase and install the infrastructure.[115] The bill specifies that parking in front of the station is not restricted to the station's owner.[116]

Seattle started a pilot program to test EV charging and parking in the public right-of-way in July 2017.[117] The program will run for a year and allows residents to apply for permits to install EV charging infrastructure on public streets in front of multi-family dwellings. The plan notably excludes residential streets in front of single-family homes.[118]

Berkeley's curbside EV charging pilot program (which ended in December 2017 and is up for review by the city council in the spring of 2018) distributed up to 25 permits annually for three years so EV owners could install charging stations on local streets, if they lacked an off-street spot.[119] The city waived fees and permitting costs for people to install on-street chargers in residential areas and has a special permitting process to speed up installation. EV drivers had to purchase and install the stations on the curb near their home, which could cost $5,000 to $10,000, and any vehicles (including non-EVs) can use the spaces, reducing the incentive for EV owners to make the investment.[120]

Other municipalities around the world, including Amsterdam, incentivize residents to install charging stations. Amsterdam will give residents up to $1,173 USD for charger installation at homes, public parking spaces or workplaces.[121]

Company-Managed Stations: In the Netherlands, Belgium and Germany, a private company, Allego, partners with municipalities to facilitate charger installation.[122] Residents submit an application to the company, which develops a proposal and submits it for municipal approval.[123] If approved, the company will install the charger in front of a person's house and all costs are borne by Allego as an investment.[124] EV drivers pay Allego a standard rate when charging at the station (to cover installation, maintenance and the electricity), though some municipalities partner with the company to offer subsidies, lowering the cost of charging.[125]

City-Installed Stations: London has allocated nearly $24 million (£18 million) for the development of a network of DC fast charging stations throughout the city, and an additional nearly $6 million (£4.5 million) for boroughs to install Level 2 or fast charging stations.[126]

The city hasn't yet determined how access to the spaces will be governed, but is considering allowing boroughs to issue parking permits and price parking and EV charging as they see fit.[127] Several boroughs have policies in place: Westminster, for example, offers EVs free residential parking permits and discounted on-street parking.[128] The city is also considering a London-wide parking policy that would override existing borough parking, allowing standardized spaces and charging access across the city.[129] By 2020, the city hopes to have charging access at one-fifth of all public parking spaces.[130]

Amsterdam also allows EV owners and businesses to suggest new public charging station locations and has expedited the construction process for installing new, on-street chargers.[131]

To help meet demand for EV charging in downtown Los Angeles, the city plans to install 84 new chargers (bringing the total to 107) at City Hall and City Hall East, which will be open to employees and the public.[132]

Regulating Access to Charging Spaces

Regulating access to parking spaces with EV chargers can be a contentious issue, with formerly public parking spaces being reserved for EV users.

By implementing pilot programs and testing different technologies, cities can discover which model of residential on-street charging will work best. In August 2017, the Oxford City Council in Great Britain began moving forward plans to implement a pilot program to test which kinds of on-street charging will best allow residents to charge EVs.[133] The city will install 10 each of three different kinds of chargers: some reserved for specific households, some open to the general public, and some that require membership in a subscription service. Depending on which best fits

Utilities and Electric Vehicle Charging Infrastructure

Utilities can play an important role in the development of electric vehicle charging infrastructure. Utilities have much to gain from the widespread adoption of electric vehicles – especially at a time when overall electricity demand is stagnant. Across the country and in California, utilities are becoming involved in charging infrastructure development in a number of ways. Cities with municipal utilities can direct the utilities to install charging infrastructure, while those with investor-owned utilities can coordinate closely.

In 2016, California's utility regulator, the California Public Utilities Commission, approved plans submitted by the state's three largest utilities (San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and Pacific Gas and Electric (PG&E)) to build electric vehicle charging infrastructure. In total, the three utilities will invest nearly $200 million in 12,500 charging stations at and near workplaces and multi-family residences, as well as in public spaces.[135]

There are several ways in which utilities can invest in charging infrastructure: they can do the electrical work and let another company or entity own and run the charging station (a "make-ready" investment); they can also provide incentives for hosts to operate the chargers; or, they can own and operate the charging infrastructure themselves. In California, San Diego Gas & Electric will own and operate the stations, whereas Southern California Edison will offer a rebate to site hosts to own and operate the charging infrastructure. Pacific Gas and Electric will own stations only in multi-family residences or disadvantaged communities.[136]

In January 2018, the California Public Utilities Commission approved those same three utilities to invest an additional $43 million in 15 pilot programs.[137] The new plans include:[138]

- PG&E investing in infrastructure to support electric school and transit buses and to electrify refrigeration for long-haul trucks;
- SCE providing rebates for 5,000 residential installations, installing 50 fast charging points, and helping to electrify transit buses;
- SDG&E installing charging infrastructure in Park-n-Ride lots, supporting the charging of 90 electric package delivery trucks and installing charging stations to support buses and for-hire vehicles.

Those three utilities have also submitted other proposals to invest an additional $1 billion total over five years and expect a decision from the commission by May 2018. The utilities' plans center around expanding residential charging infrastructure, building fast-charging ports for EVs and charging stations for non-passenger vehicles like electric buses, delivery trucks and airport vehicles, as well as offering rebates for residential charging installation and rate incentives.[139]

residents' needs (based on feedback to be collected at charging stations), the city will invest more than a million dollars (£800,000) to expand the infrastructure citywide.[134]

It is likely that the type of charging infrastructure will need to vary depending on the neighborhood, but overall, cities will be best served by looking at innovative, flexible and cost-effective models. For example, using existing electrical infrastructure like streetlights speeds implementation and reduces costs.

Off-Street EV Charging Stations that Are Accessible to Residents

City neighborhoods with limited on-street parking often have off-street parking lots that are not fully used during off hours. Pay garages and lots, the parking lots of municipal facilities, and lots owned by private businesses could all be provided to residents during off-hours (overnight) to charge electric vehicles.

Many cities have an abundance of off-street parking lots and garages that could have dedicated charging spaces for electric vehicles. For example, Philadelphia conducted a survey in 2015 of public parking lots and garages in downtown, finding that occupancy was around 74 percent on average.[140] San Francisco's survey of 51 privately owned garages found the average maximum occupancy was less than 70 percent of capacity, with a quarter of the surveyed garages reporting they were rarely or never full.[141]

Making spaces in lots or garages available to nearby residents or EV owners could provide an opportunity for off-street overnight charging. This option would likely face less pushback from communities and streamline installation since the spots can be concentrated. However, it is likely less convenient and attractive for EV owners, is limited by existing distribution of lots, and would require participation from businesses and institutions that may have a variety of concerns about opening their lots to public use.

EV charging spaces in a parking garage in Portland, OR. Credit: Oregon Convention Center, via Wikimedia, CC BY 2.0.

Encouraging Off-Street Charging Options

Off-Hour Partnerships: In many areas, lots may be vacant at night when EV owners would most need to charge their vehicles. Programs could include partnerships with parking lots at workplaces or private lots and garages, along with public facilities like schools and community centers that are vacant in off hours. For example, the University of North Carolina at Chapel Hill, which is surrounded by residential areas, allows any electric vehicle to use charging stations on campus outside of normal university business hours.[142] Conversely, Ulster County, NY, allows the public to use its EV charging stations at nine county government locations during the day, and charges its own fleet at the stations overnight.[143]

Garage-Run Charging Stations: Some garages or lots may choose to install and run a charging station themselves (either Level 2 or fast chargers), potentially making profit from it. For example, the ChargePoint network, run by Coulomb Technologies, allows station hosts (like garages or lots) to set charging prices and collect money from EV drivers using the charging system.[144] This system, while a bit more work for the garage or lot owners, may provide a financial incentive for parking areas to host stations

since they can attract EV drivers and make money off the stations. Furthermore, by offering EV charging stations to residents during off hours (overnight when the garage might not be full but EV owners need to charge their vehicles), garage owners can manage their parking more efficiently. Cities can help encourage this option by facilitating relationships between charging companies and garages or lots.

Third-Party Managed Stations: Some hosts may find it easier to use a charging company that will install and maintain the infrastructure, rather than doing it themselves.[145] Cities can consider incentivizing parking areas to install charging infrastructure by offering benefits, discounts or subsidies to lots that allow stations to be installed.

Cities should also look at the system holistically and consider how the different options will work together – if a driver usually charges at a garage near their home, are they able to charge at a garage across town during a work meeting? Will a driver have to subscribe to multiple systems or can they park across systems?

The model of hosting charging infrastructure at third-party lots and garages will be successful only if EV owners can reliably charge their cars at locations that are not too far from their homes. Cities would need to evaluate existing infrastructure and opportunities to ensure that charging stations are adequately positioned for EV drivers to use them. A good first step for cities looking at this model would be to take an inventory of garages and lots in residential areas, and to identify where such an approach would make a meaningful contribution to residential charging needs and where it would likely fall short.

EV Charging in Multi-Unit Housing

Many residents in California cities live in apartments and multi-family buildings that may have parking available on-site but lack charging infrastructure for electric vehicles. By incentivizing or requiring that owners of these developments offer access to electric vehicle charging in existing or new parking spaces, cities can ensure more residents have access to charge their EVs.

Incentivizing Installation in Residential Buildings: For cities in California, funding for EV charging infrastructure may be available through the federal government's Clean Cities program and the state's allocation of Volkswagen emissions cheating settlement money – $800 million of which will be dedicated to electric vehicle infrastructure.[146] Other funding, rebates or tax credits may be available for different regions, states and cities.[147] For instance:[148]

- The Los Angeles Department of Water and Power provides rebates up to $4,000 for commercial customers to install Level 2 chargers at multi-unit housing and business locations or employee, resident and public use.[149]
- Santa Barbara County's air pollution program offers reimbursements up to $10,000 for public or non-profit entities to install Level 2 chargers ($20,000 for fast chargers), or $7,500 for Level 2 chargers by private entities ($15,000 for fast chargers).
- Sacramento's utility provides $1,500 for workplace or multi-family Level 2 EV charging ports, or up to $100,000 for projects that include two fast chargers and one Level 2 station.
- San Diego Gas & Electric plans to install 3,500 charging stations at workplaces and multi-family residences. The utility will own, operate and maintain the stations, while hosts will pay a one-time fee of $630 per port at workplaces or $235 per port in multi-unit residences.

Including EV Infrastructure During New Construction: Cities can consider requiring a percentage of parking spaces at new residential and workplace developments include EV charging stations or at least be "EV-ready" (running electrical capabilities during construction). The cost of wiring a space for future EV

charger installation or installing stations during construction is significantly less than retrofitting an area after a building is completed. A study by Pacific Gas & Electric on EV charging infrastructure in San Francisco found that the cost of adding one new electric vehicle charging space during construction was around $900, while adding one through retrofits later costs $2,000 to nearly $4,000.[150]

Some cities are already leading the way. San Francisco passed an ordinance requiring that, starting in 2018, all new residential, commercial and municipal construction have EV chargers installed in 10 percent of parking spaces and that an additional 10 percent of spaces be wired with the capacity to have chargers at a later date.[151] In November 2017, Atlanta passed an ordinance requiring that 20 percent of parking spaces in new commercial and multi-family residences be "EV-ready."[152] Oakland and Palo Alto have similar ordinances.[153]

By implementing building ordinances that include electric vehicle charging, cities can ensure residents and workers in future buildings have access to charging.

EV Charging at Workplaces

While studies have shown that most EV owners would prefer to charge at home, offering electric vehicle charging at workplaces can augment and complement residential charging.

Besides charging at home, EV owners who commute by car could be able to charge at their workplaces. This option is not as convenient or as reliable as being able to charge at home, but it still provides an opportunity to offer infrastructure to employees and commuters. In order to be successful, cities need to survey how residents commute and determine whether or not this would suit current and potential EV owner needs.

EV charging garage at Google's Mountain View, CA campus. Credit: Nicolas.boullosa, from Flickr, CC BY 2.0.

Implementing Workplace Charging

Cities will need to implement policies that encourage and enable employers to install EV charging infrastructure. This can come through a combination of incentives, subsidies and partnerships, as well as long-term changes, like building ordinances. For instance, California's building code requires all new commercial buildings to include electric vehicle charging capacity (by at least installing appropriate electrical conduits) in a portion of the new parking spaces.[154]A number of cities in the state, including San Francisco and Oakland, have also passed strong ordinances for electric vehicle charging requirements in residential buildings.

Charger Management: Workplace chargers, like chargers installed in parking garages and lots, can either be on a network and run by another party, or can be run directly by the employer or the commercial property owner leasing the parking lot to employers. By using a third-party to manage the chargers, employers can expect to pay a fee but have less responsibility for running the chargers.[155] If an employer or property owner owns and operates the chargers, they can offer charging for free as a benefit for employees, assess fees based on the cost of the power and/or the cost of the parking, or vary pricing for charging based on demand.[156]

Incentivizing Installation: Cities can also help employers manage the cost of purchasing and installing the charging station through incentives and subsidies. Installing EV chargers at workplaces can cost between $500 and $5,000, with many chargers costing about $2,500 per unit.[157] The Department of Transportation in the UK launched a nearly $10 million program to help workplaces install EV charging stations. Businesses can apply for funding from the government, while the ChargePoint network also offers a discount to employers utilizing the service.[158]

Oslo offers subsidies for the installation of charging points on private property, including for companies, developers and apartment complex owners, making it cheaper for developers to add charging in non-public parking spaces.[159]

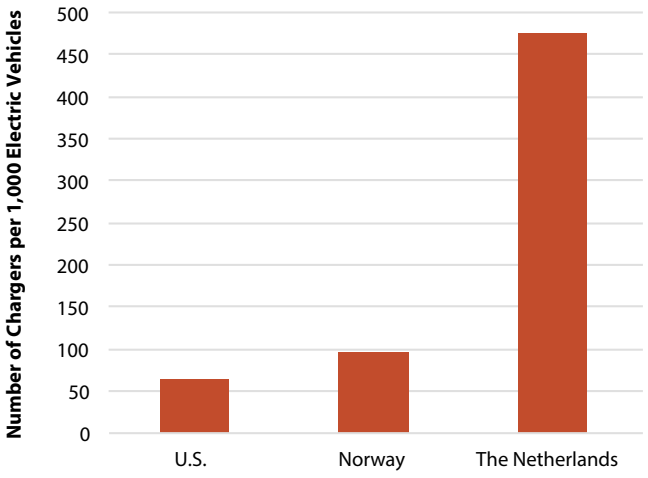
Public EV Charging Infrastructure

Outside of residential and workplace charging, adequate public charging infrastructure in other locations helps fill in the gaps, allowing EV owners to complete errands and travel without worrying about not being able to charge their vehicle.

The two countries in the world with the highest rate of EV sales – Norway and the Netherlands, which also contain three of the top five cities for EVs – have the highest number of public charging points per electric vehicle. While the U.S. has 64 charging points per 1,000 EVs, Norway has 50 percent more, at 96 per 1,000 EVs, and the Netherlands has 476 chargers per 1,000 EVs, almost eight times more than the U.S.[160]

Public charging station in Hillsboro, OR. Credit: Visitor7 via Wikimedia, CC-BY-SA-3.0.

Figure 6: Ratio of Charging Infrastructure to Electric Vehicles, by Country[161]



Integrating Public Charging into Cities

Comprehensive Planning and Evaluation of Charging Stations: During the first phase of charging station construction, Oslo conducted surveys and hired an agency to scout locations, with priority on placing new stations near existing electrical infrastructure to ease installation.[162] During the first phase of infrastructure buildup, most of the charging stations were installed by and at least partially paid for by the city of Oslo or Norway's government.[163] Once stations are installed, Oslo performs annual surveys of usage rates at charging stations around the city.[164] While recent reports indicate that most charging still occurs at home, usage rates of public infrastructure remain high enough that lower ratios of public charging infrastructure would represent a sizable barrier to EV adoption.[165]

In the city's last inventory in 2015, the city of Oslo had more than 2,800 public Level 2 EV charging stations (57 public chargers per 1,000 EVs), 1,100 of which were located on the street; the city planned to add an additional 200 stations by the end of 2017.[166] Residents can charge electric vehicles at any of these stations for free. As of late 2016, the city also had 161 fast-charging stations – where EV owners pay to charge but discounts are offered for electric taxis and electric freight vehicles.[167] Across Norway, there were plans to install stations nearly every 30 miles along the country's main roads by the end of 2017.[168]

Government Coordination with Carsharing: Utrecht has nearly 1,000 public charging spots, at which parking is free while charging.[169] Many of these, as well as about a third of the Netherlands' more than 10,000 public chargers, were installed using public funds available to Foundation E-laad, a government-funded electric vehicle-promotion initiative.[170] In 2016, Utrecht partnered with carmaker Renault to construct and pilot a network of charging stations to be used by a fleet of 150 carsharing vehicles and available for use by private EV owners. The deal is intended to result in more than 1,000 solar-supplied charging stations, with costs shared between Utrecht and Renault.[171] (The program is also testing energy storage by sending energy from the car batteries back into the grid during periods of peak demand.)[172] Arrangements like this can increase public access to electric carsharing and make it easier for private EV owners to recharge their vehicles – addressing multiple challenges at once.

Singapore's electric carsharing program, which launched in December 2017, will have 2,000 charging points across the city by 2020, and 400 of them (20 percent) will be available to all EV drivers needing a charge.[173]

Facilitating the Creation of Semi-Private Charging Stations: Utrecht offers strong subsidies for "semi-public" charging stations, which are located on private property but are available for some public use.[174] Property owners can get up to $1,750 (€1,500) to install a charger on personal property and allow other people to use it, either in front of homes or at businesses.[175] Shanghai has a similar program.[176] In 2015, the Netherlands expanded Utrecht's model, allowing municipalities and their regional partners to apply for part of $8.6 million (€7.5 million) in funding to reduce the price of installing new public charging points to $355 (€300).[177]

In the U.S., an app called PlugShare connects EV owners in need of a charge with private stations that other EV owners are offering to share, similar to an Airbnb model.[178] A similar application has been launched in Sweden – Elnbnb, launched by Renault Group.[179]

Oslo is looking at ways to incentivize homeowners and housing developers to add public charging stations to their properties.[180] Oslo, together with private partners, is teaming up with roadside convenience stores like Circle K and gas stations like Shell to incentivize companies to install fast chargers along roads.[181]

Enforcing EV Charging Spaces for EV-Only Use: If public charging stations are occupied by non-electric vehicles, the primary purpose is defeated and EV

users still can't charge their cars, despite the infrastructure investment.

It is illegal to park a non-electric vehicle in an EV charging space in nine states (WA, OR, CA, AZ, HI, IL, MA, RI, FL), although city-level enforcement varies.[182] Austin, Texas, has at least 200 public parking stations with EV charging points where non-electric vehicles are prohibited from parking for any amount of time.[183] Los Angeles is in the process of developing a local ordinance to allow the citation or towing of vehicles illegally parked in electric-vehicle charging spaces on-street.[184]

Oslo levies a fine on non-electric vehicles that occupy the spots, and allows EV owners to request towing of such vehicles.[185] Amsterdam restricts the use of almost all public parking spaces with charging infrastructure to electric vehicles, and grants free parking to EVs for the entirety of the time the vehicles spend plugged in to the charging point.[186]

A few U.S. cities also enforce time limits on the use of EV parking spaces (even for EVs). In Boulder, CO, for example, it is illegal to charge your EV or occupy an EV charging space for more than four hours, and overstaying results in a $50 fine.[187]

California Cities Are Paving the Way for EVs in the U.S.

In 2016, three large metropolitan areas in the U.S. (all in California) were among the top 15 cities in the world for the number of EVs sold, compared to all new cars sold. In the San Jose metropolitan area, 9.4 percent of cars sold were electric vehicles, in the San Francisco area it was 5.4 percent, and in the Los Angeles area, it was nearly 3 percent. Together, these three areas account for 40 percent of U.S. EV sales.[188]

These and other California cities are laying a foundation for a future of electric vehicles by facilitating the growth of EV charging. However, these cities – along with all other cities nationwide – have a great deal of work to do to prepare for the torrent of EVs that could begin hitting the road within the next several years.

San Jose: San Jose has nearly 500 public EV charging ports, 53 of which are owned directly by the city and located on streets and in garages downtown.[189] Additionally, San Jose offers free parking for qualifying EVs and hybrid vehicles throughout the city, including all parking meters, whether they have chargers or not.[190]

San Francisco: San Francisco has more than 400 publicly available L2 and fast charging plugs and has considered allowing free charging and/or parking at some of the stations.[191] Going forward, the city plans to require infrastructure investments aimed at making future parking EV-friendly, calling for the city to be "100 percent EV-ready."[192] This will involve 20 percent of all new parking spaces in residential, commercial or municipal developments being either EV-ready or "EV-flexible," meaning they will immediately be upgradable to EV spaces at no additional cost, with the remaining 80 percent of spaces able to be converted to EV spaces at a later date. The plan would create approximately 90,000 EV charging ports by 2020.[193]

Los Angeles: LA currently has almost 1,500 public charging points.[194] A $500 rebate is available for home installation of a charging station, up to $4,000 is available for installation of chargers in multi-unit housing, and the city's Department of Water and Power offers discounted electricity rates for EV charging.[195] In October 2017, LA's City Council approved $4.86 million in funding for new electric vehicle charging stations.[196] In June 2017 the council had approved $1.1 million for new stations, to be located near streetlights to utilize existing sources of power.[197]

Rethinking Parking Policy Offers Opportunities for EVs and More

The EV revolution is happening: people are buying electric vehicles in record numbers, and more charging stations are springing up. However, as more and more electric vehicles hit California's streets, a central question remains: where will EVs be able to charge?

In cities where private, off-street parking spaces are often limited, providing EV charging locations can be a particular challenge. One reason is that parking is – or is perceived to be – limited, creating the potential for conflicts between EV owners, owners of conventional vehicles, and other street users (including bicyclists, delivery vehicles and carsharing services) for access to curb space.

Some leading EV cities use the scarcity of parking spaces as an incentive for residents to adopt electric vehicles. Amsterdam, for example, exempts EV owners from waiting lists for parking permits, which can otherwise be as much as 10 years long.[198] The city has stopped issuing new on-street permits for older, high-emitting vehicles, making preferential access to on-street parking an even more important incentive.[199]

But in other cities, forward-thinking approaches to reducing or managing demand for parking can help to reduce political conflict and unlock transformative opportunities, while cities that fail to adopt those strategies can find their efforts to shift from conventional to electric vehicles frustrated.

Parking Is Often More Abundant than Perceived

Everyone has felt the frustration of driving in circles looking for parking and had the thought "we really need more parking spaces." As it turns out, many cities have more parking than they need, but it is not managed effectively.

Estimates of the number of parking spaces in the U.S. fall between 800 million and 2 billion, in a country of fewer than 300 million cars.[200] A study of Los Angeles County's parking availability found that, in 2010, the county had three spaces for every one vehicle: 18.6 million spaces total for 5.6 million cars.[201] A recent analysis by Nelson/Nygaard Consulting Associates of 27 suburbs, cities, and towns in New England and California found that all of the surveyed areas had an oversupply of parking – on average, 65 percent more spaces than were necessary.[202] Of the 27 areas in the study, 10 were in California, including Soledad (253 percent oversupplied), Lancaster (126 percent oversupplied), Ventura (80 percent oversupplied), Oxnard (57 percent oversupplied), and Monterey (56 percent oversupplied).[203]

One reason that parking can often seem scarce is that it is provided for free or at low cost in a particular area, regardless of the level demand. When people drive to a destination in a busy urban area, they expect to park as close as possible to their destination and for free or very cheap. If a free, close spot isn't available, people will cruise around the block, searching for one. Cruising is so prevalent that it might constitute as much as a third of traffic in cities.[204]

The same dynamic occurs in dense residential areas where residents might compete for on-street parking during evening hours, but pay little or nothing for the right to store vehicles on the street.

In other cases, parking spaces may actually be available nearby, but those spaces may be reserved for use by patrons of particular businesses and institutions – even after hours – and sit unused.

Rationalizing parking policy can prevent the addition of EV charging spaces to city streets from provoking conflict, as occurred in 2017 in Philadelphia. (See text box.)

Philadelphia's EV Parking Program Provides a Cautionary Tale

In 2007, Philadelphia launched a program to support EV ownership – the first of its kind in the nation – allowing residents who owned electric vehicles to get a permit to install a charging station in front of their home.[205] A permit did not include exclusive parking rights for the parking spot next to the charger, although the spots were restricted to EVs.[206] The cost of applying for and installing a charger was borne entirely by the homeowner, and could be as much as $3,000.[207] In contrast, a regular parking permit costs $35.[208]

By 2017, 67 electric vehicle spots had been permitted and completed.[209] Overall, the city of Philadelphia had approximately 43,000 permitted or metered on-street parking spaces, at least 46,000 garage or lot parking spaces in downtown, and many more free, unmetered spaces, of which there is no accurate count.[210]

Despite the permitted EV spots taking a small fraction of Philadelphia's available parking, vocal opposition blamed the program for exacerbating parking shortages. In the spring of 2017, the Philadelphia City Council approved a one-year moratorium on new parking permits under the program.[211] Additionally, parking spaces next to existing chargers (that had been paid for and installed by EV owners) were made open for two-hour parking by any vehicle during the day, from 6 a.m. until 6 p.m.[212] Previously, non-electric vehicles could be fined or towed for parking in the permitted charging spots, at any time of day.[213] This piece of the legislation is now being challenged in court by three EV owners who claim they improved public property by adding EV charging infrastructure, while the city is going back on a central part of their agreement – the exclusive right (for any EV) to use the space.[214]

The episode sparked the city to promise to create a new Electric Vehicle Task Force to address further options for promoting EV adoption.[215] In January 2018, the Task Force released a draft report recommending that the city end its EV curbside parking program, without offering concrete solutions to replace it.[216] A final version of the report and recommendations is expected in February 2018, at which point the City Council must vote to decide the final fate of the program.

The Task Force's findings are shortsighted, given the onslaught of electric vehicles expected in Philadelphia in coming years. The program made Philadelphia the first city in the U.S. to allow curbside EV chargers in residential areas (ahead of a similar program in Berkeley, CA, by seven years).[217] While the program supplied only a small number of permits, it was an essential step to facilitate more widespread electric vehicle ownership.

As the Task Force's draft report highlights, EV ownership in the city has grown only 15 percent in the last two years, half the rate of EV adoption in the Southeastern Pennsylvania region, which saw a 33 percent increase between 2015 and 2017.[218] The report also notes that most electric vehicle charging in Philadelphia occurs at home.[219] Ending the program – especially without a specific replacement strategy to get charging infrastructure on the city's streets quickly – disincentives electric vehicle purchases and puts up hurdles for Philadelphia residents to participate in America's electric vehicle revolution.

Shared Mobility Can Reduce Vehicle Ownership

One reason for competition over scarce parking is that many people – even residents of cities with transit service – may feel the need to own a car to meet their mobility needs. Since the typical car is parked and idle 95 percent of the time, dependence on privately-owned vehicles creates tremendous demand for places to store vehicles.[220]

Carsharing and other forms of shared mobility can reduce the need for private car ownership by providing city residents with access to the services provided by a car without having to own one. Research has shown that many participants in carsharing programs sell their vehicles or forgo the purchase of a new vehicle. Researchers at the University of California, Berkeley's Transportation Sustainability Research Center have estimated that each vehicle in a free-floating carshare service such as Car2Go replaces between 7 and 11 private vehicles, while each vehicle in a round-trip carsharing service like Zipcar replaces between 9 and 13 private vehicles.[221]

The success of carsharing systems – especially "free-floating" systems that enable drivers to pick up a car in one location and drop it in another – depends on access to curb space in well-traveled locations, the same curb space that is often in demand for parking for privately owned vehicles. Expanding access to shared mobility services in dense urban areas has the potential to reduce overall competition for parking, creating the potential to use some on-street spaces for EV charging.

Pricing Parking Based on Demand Can Help Create Space for EVs and Other Vehicles

By reducing free parking, and by charging more in areas where there is more demand, cities can address the perceived problem of parking scarcity, ensuring that any surplus of existing spaces can be used efficiently. By creating a demand-based system for pricing parking (along with expanding other mobility options, including biking, walking, public transit and carsharing), cities can reduce overall demand to ensure that there are always a few on-street parking spots available, including spaces dedicated for electric vehicles.[222]

In January 2018, San Francisco became the first city in the country to use demand-based parking citywide, at meters, lots and garages. Prices vary based on time of day, with lower prices when demand isn't as high, and block by block, with lower prices in less busy areas.[223] Starting with a pilot program in 2011, the city used sensors on the street in a number of popular areas to measure in real-time how many on-street parking spots are available. The price for parking automatically increases in areas of high demand and decreases in areas with less demand to incentivize more effective use of the spaces.[224] The two-year pilot program was very successful: average parking costs actually fell overall, while vehicle-miles traveled and time spent searching for parking decreased, as any given block was more likely to have spaces available.[225]

Los Angeles has implemented a similar dynamic demand pricing system in downtown LA.[226] Prices are adjusted every four to six weeks in order to ensure that blocks maintain a near ideal parking capacity.[227]

Residential areas where parking is scarce during overnight hours can consider strategies such as limiting or pricing residential parking permits in order to discourage people from occupying public curb space with vehicles, some of which may be used only infrequently.

Cities can also benefit from encouraging shared parking, in which private parking lots are used for a variety of purposes – for example, for employee parking during the day and residential parking at night. Shared parking eliminates duplicative parking spaces that are tailored for specific uses – for instance, shared parking enables shoppers and office employees to park in a given parking area during the weekday, residents to park overnight, and shoppers and residents to park during the weekend.[228] Studies have found this system can reduce parking needs by 20 to 40 percent.[229]

SFPark smart meters in San Francisco vary the price of parking based on demand, helping manage access to curbside parking in the city. Credit: Carlos Felipe Pardo, via Flickr, CC BY 2.0.

Conclusion and Recommendations

In the next 10 to 15 years, cities across California and the U.S. can expect tremendous growth in electric vehicles – with projections estimating that 20 percent of new cars could be electric as soon as 2030.[230] If cities wish to obtain the environmental, public health and quality of life benefits of electric vehicles – and meet the needs of their residents – they will need to plan for a dramatic expansion of electric vehicle charging infrastructure, including in residential neighborhoods where off-street parking is limited.

Cities should plan for this transition in the context of an overall mobility transition that encourages the use of public transportation, shared mobility services, bicycling and walking. A transition that reduces demand for parking from private vehicles – while creating new charging opportunities for both privately owned and shared electric vehicles – can deliver a powerful "win-win" for cities and help propel California toward a clean, efficient, zero-carbon transportation system.

New Opportunities for Expanding EV Charging in California

Fortunately, California cities have numerous new opportunities and motivations to expand access to electric vehicle charging.

As mentioned previously, California's three biggest utilities are already investing nearly a quarter of a billion dollars in charging infrastructure and have proposed spending an additional $1 billion on projects across the state. This presents a tremendous opportunity for cities to coordinate with the utilities on expanding charging infrastructure locally.

California will also benefit from $800 million in settlement money from the Volkswagen "Dieselgate" case – in which the carmaker was caught selling more than half a million diesel cars that polluted up to 40 times the legal limit of nitrogen oxides (NOx, a key component of smog) – to support zero-emission vehicles, including efforts to expand EV charging infrastructure across the state.[231] U.S. states will receive nearly $3 billion to implement programs to reduce NOx. States can spend up to 15 percent of allocated money to build electric vehicle charging stations.[232] The first $200 million of California's allocation has been approved, with $120 million going towards 350 neighborhood EV charging stations in Los Angeles, Sacramento, San Francisco, San Diego, San Jose and Fresno, and 50 fast-charging stations across the state.[233] An additional $44 million of the first phase will expand zero-emission vehicle projects in Sacramento, including more charging infrastructure and an electric car-sharing program; the final $20 million of the first phase will fund a statewide zero-emission vehicle awareness campaign.[234]

Eight states in the U.S., including California, have also signed a memorandum of understanding (MOU) on zero-emission vehicles, which sets ambitious goals for the number of EVs in each state. Together, the states committed to 3.3 million electric vehicles by 2025 and the MOU allows them to coordinate implementation to ensure that the programs are successful.[235] States and municipalities can consider similar approaches to foster EV adoption.

California has been on the forefront of this issue for decades. In 1990, the state adopted a zero-emission vehicle regulation, requiring that a percentage of vehicles sold in California be zero-emission cars. The mandate was a critical jumpstart for the electric vehicle market in the United States and subsequently, at least nine other states in the country have implemented similar mandates. The goal of the mandates is to ensure that automakers are developing, marketing and selling electric vehicles.[236] In California, nearly 9 percent of BMWs sold are electric cars, as are 7 percent of General Motors cars.[237] If proposals requiring only zero-emission vehicles in the state come to fruition, the need for dramatically more charging infrastructure will become even more critical.

Finally, in the wake of the federal administration withdrawing the United States from the worldwide climate agreement, a growing number of states and cities have joined the United States Climate Alliance, committing to uphold the goals from the global pact to reduce greenhouse gas emissions. Fourteen U.S. states and Puerto Rico joined by October 2017, representing more than a third of the country's population, while 392 mayors (as of February 2018) had also committed to support global climate goals.[238] Reducing emissions through transportation, including through the widespread adoption of electric vehicles and reducing vehicle miles traveled, will be key to meeting these goals.[239]

Developing Comprehensive Plans for Electric Vehicles Will Help Cities Prepare

To facilitate the adoption of electric vehicles locally, cities should develop comprehensive plans for electric vehicle charging, as Sacramento did in December 2017. EV adoption will be most successful if cities develop holistic solutions that create spaces for EV charging, rationalize parking policies generally, and support shared mobility and electric fleets. A broader vision and policy framework will enable cities to take advantage of all of the opportunities presented with EVs, including the synergies that arise from considering infrastructure in tandem with parking policies and transportation planning.

Setting numeric goals will help California cities ensure that they are prepared to meet demand. Cities would benefit from following the lead of top electric vehicle cities, like San Francisco, by setting a goal that 20 percent of parking spaces be "EV-ready," or capable to host EVs in the future, by 2030. Some specific strategies to get there include:

- Expanding access to electric vehicle charging for residents without off-street parking by dramatically increasing the number of charging stations in residential areas. Leading EV cities around the world have demonstrated a variety of approaches for expanding charging access – including networks of publicly and privately-owned chargers and allowances for residents to install their own charging stations on public curbs near their homes. Cities may choose to invest public resources in a network of stations open to everyone, or take part in public-private partnerships with utilities or charging-providers to ensure thorough coverage of EV chargers in all of a city's neighborhoods. Cities that fail or refuse to create citywide networks of public EV chargers should minimally allow residents to invest their own resources to install EV chargers for their use on public curbsides.
- Partnering with businesses and public entities (like schools, community centers and municipal offices) to use their existing parking infrastructure while providing EV charging. This can include partnering with existing workplaces, businesses and destinations at which people spend time, like health care facilities, churches, gyms, shopping centers and movie theaters to ensure patrons can charge while there. It can also include partnering with locations to make charging stations avail-

able to nearby residents during off-hours and overnight.

- Facilitating and encouraging electric shared mobility options like carsharing, ridesharing and bikesharing. Providing options for people to share electric rides allows more people to utilize the benefits of EVs without having to personally own one. Fleets of shared vehicles, as well as shared electric bicycles, also reduce overall demand for parking and space needed to charge EVs.[240]
- Directing municipal utilities to install charging infrastructure and coordinate closely with investor-owned utilities to maximize opportunities.
- Ensuring public investment in electric vehicle charging results in infrastructure that is managed in the public interest. Cities should think long-term to encourage the best deal for the public and avoid missing out on future opportunities.
- Making data available on location and utilization of charging stations to foster the development of apps that people can use to find available chargers and dedicated EV parking.
- Considering a demand-based and shared system for parking. By charging for parking based on where and when people need it and making access to parking shared, cities can better manage their parking resources and free up space for EVs and all vehicles.

Without thoughtful development of new policies, cities stand to not only lose out on opportunities like reduced air pollution and less congestion, but they also risk being unprepared for the impending arrival of thousands of electric vehicles on their streets. By looking to best practices abroad and at home, cities across California can begin to develop a holistic solution that allows them to reap the full potential from the EV revolution.

Methodology

Number of EVs in Cities by 2030

In January 2018, Governor Jerry Brown issued an executive order with a target of 5 million zero-emission vehicles in California by 2030.[241] We used that number as a baseline to estimate how many EVs might be in a number of California cities by the same year.

We calculated a ratio of the number of vehicles that are available in each city compared to California's total by using American Community Survey one-year estimates for 2016 from the U.S. Census Bureau (topic B25046, "Aggregate Number of Vehicles Available by Tenure" in the American FactFinder website).[242] We multiplied that ratio by California's 5 million goal, in order to estimate the number of EVs that might be in the city in 2030. This assumes the ratio of electric vehicles in any given city compared to the number in a state will be the same as the number of vehicles available overall in that city compared to the state.

This report includes the largest cities in California's six most populous metropolitan areas.

Charging Infrastructure Needs

The U.S. Department of Energy's Alternative Fuels Data Center has a list of electric vehicle charging stations in the United States.[243] To determine how many stations were already in the cities included in this report, we used GIS analysis to clip all of the charging points from the Alternative Fuels Data Center by each city's geographic boundary, from U.S. Census TIGER/Line shapefiles.

To estimate future needs, we applied ratios from NREL's 2017 report to the EV projections by city, described above. NREL estimates that cities in the U.S. will need, on average, 1.5 public fast chargers and 36 public, non-residential L2 chargers per 1,000 electric vehicles. For Riverside and Sacramento, we applied those national average ratios to the number of EVs that might be in those cities by 2030. Four metro areas were specifically addressed in the NREL report that were also included in this analysis (Los Angeles, San Diego, San Francisco, and San Jose). For those metro areas, we applied NREL's estimated ratios of charging equipment needed per electric vehicle in each metro area to the principal city included in this analysis.

Unfortunately, NREL's analysis does not include the needs of residential charging and assumes 88 percent of charging happens at home. The estimates here should be seen as a lower bound estimate of the need for public charging, and account for only a small percentage of the total number of chargers needed, including those in private residences and on residential street.

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