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Driving the Market for Plug-in Vehicles: Developing Charging Infrastructure for Consumers

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Key Takeaways

1. Policy makers should play a central role in developing infrastructure that consumers can access at home, at workplaces, in public locations, and on travel corridors.
2. The most important infrastructure are chargers that allow for overnight charging. These include private chargers in plug-in electric vehicles drivers' garages or on their driveways, but also publicly accessible chargers in residential areas.
3. Charging level should be optimized for specific uses. At locations with long dwell times, chargers should be level 1 or 2. At locations with medium dwell times, chargers should be level 2. At locations with short dwell times chargers should be DC fast chargers.
4. Access and payment for charging should be standardized to avoid confusing consumers. Payment should be as simple as possible and harmonized across regions.
5. The optimal number of publically accessible charging stations depends on several factors including average trip lengths, number of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), and the number of consumers without their own dedicated charger. Additional infrastructure must be installed in regions with a high proportion of plug-in electric vehicles (PEV) owners without a dedicated home charge point.
6. Charge point congestion can become an issue with significant PEV uptake. Policy makers and practitioners should ensure that people do not charge unnecessarily or for too long. This can be done with pricing strategies or by using charge time limitations.
7. The time that consumers charge should be managed so that charging does not coincide with existing electricity demand peaks. This can be done with smart charging.
8. Education and awareness initiatives are necessary to increase knowledge of PEV charging infrastructure. Consumers should be aware of how to install a home charger, where to access infrastructure, how much it costs to charge, and how to access public charging.

Introduction

Plug-in electric vehicles (PEVs) are more efficient and less polluting than internal combustion engine vehicles (ICEVs). For PEVs to have the most significant impact on urban air pollution, energy consumption, and climate change, their market share will need to increase quickly. A robust and reliable PEV charging infrastructure is needed to help grow the market. Moreover, PEV charging infrastructure must meet the needs of PEV drivers, so it requires careful consideration. All PEV stakeholders, including automakers, electric utilities, PEV drivers, employers, housing developers, charging station manufacturers and service providers, and any other stakeholders, need to communicate and coordinate on the development of charging infrastructure. Policymakers can play a central role in ensuring that infrastructure not only meets consumers' needs and helps drive the PEV market, but also serves the broader community, is efficient, and thoughtfully planned.

This guide offers considerations for charging infrastructure to support PEV market development. It provides information on charging levels, charging points, location, access and payment, costs, considerations for households with on-street parking, the number of public charging stations needed, dependability, charge management, and implications for public transit.

Lessons from Academic Research & Empirical Data

In this brief we refer to a *charging point* as a device suited for charging a PEV and that only charges one PEV at a time. A *charging station* may provide one or several charging points, and a *charging site* may offer one or more charging stations.

Charging Levels

The speed at which a PEV charges depends on equipment both on and off the vehicle. The term, charging level, refers to different charging speeds, as shown in Table 1. Level 1 charging, the slowest speed, is only done in countries with 110-120V grid power (e.g. United States). With Level 1 charging, a PEV with 100 miles of range will charge in around 24 hours. Level 1 charging is most commonly used at home, for overnight charging.

Level 2 (208-240V) charging has a wide range of charging speeds based on the electrical circuit, charging equipment and vehicle capability. Level 2 charging can charge a PEV with 100 miles of range in 4-12 hours. Dedicated electric vehicle charging equipment is typically needed for Level 2 charging in the US. In countries with 220V grids (e.g. Europe) this is the standard for a domestic plug socket. Level 2 chargers are often installed at homes, and are preferred over Level 1 chargers because they are faster. They are also used at workplaces and public locations with long dwell times.

In some cases, especially with a PEV with a small battery, regular domestic plug outlets can be sufficient. However, these outlets can be insufficient to recharge BEVs with larger batteries and can be unsafe in some regions, often those that have 220V power as standard (e.g. in Norway). It is therefore recommended that in these cases standard outlets are not frequently used to charge a PEV. Dedicated home PEV charging equipment should be installed. Policymakers can offer grants or subsidies to consumers who purchase home charging equipment.

DC fast chargers charge PEVs in the fastest possible time, but are considerably more expensive than Level 2 chargers (sometimes ten times more). They also have very high power demands, therefore should not be considered as the main charging option.

In Europe, chargers are also designated based on their communication protocol. Either mode 1, 2, 3, or 4 charging is possible. This topic is not considered in this brief.

Level	Voltage, Amps	Typical location	Time to charge 100 miles
Level 1	110v, 20A,	Home	24 hours
Level 2	240v, 20A	Home, Work, Public	10 hours
Level 2	240v, 100A	Work, Public	2 hours
DC Fast	240v- 480v, 2 or 3 phase 20A-200A AC	Corridor	<15 minutes

Table 1: Different levels of charging, the power associated with these levels, typical locations and the time to charge 100 miles.

There are also several types of charging point connectors. Most PEVs use a standardized connector for Level 2 charging (J1772). For DC fast charging several different connectors are currently in use (e.g. CHAdeMO, CCS). Most PEVs with fast charging capability can use these chargers, however Tesla vehicles use their own connector and have access to the company's proprietary DC fast chargers (known as Superchargers).

DC fast chargers should only be installed in locations where they are needed, such as on travel corridors. Level 2 chargers are sufficient for charging at work, public locations, car parks, shopping centers, etc. as drivers have long dwell times in these locations.

When constructing DC fast charge stations infrastructure providers should seek to support charging from all connector types.

Charging stations should also be accessible by all PEVs. This will mean each location will have charge connectors that all PEVs can use. In Spain, charging point installers are regulated by law to install multiple charging point connector types. Even when auto manufacturers install their own charging points,

they must install charge connectors for all PEVs from all other automakers.

Charging Point Activity and Locations

There are four main locations at which charging occurs; 1) at or near home (usually overnight), 2) at work or commute location (e.g. a transit hub), 3) at publicly accessible locations other than work, and 4) on travel corridors where drivers stop between the trip origin and destination during long-distance travel [1–4]. In many cases the same charging station has many different uses. For some people a charger may be a public charger, while for others it is a travel corridor charger [5,6].

When drivers have access to charging at or near home, around 75-85% of all PEV charging occurs here overnight [7]. Access to home charging has been found to be the most important factor in convincing consumers to purchase a PEV. Without access to charging at home or close to home, consumers are less willing to purchase a PEV [6,8–10]. Policymakers, utilities, and automakers can support consumers in installing their own charger at home.

Efforts should also include developing public charging infrastructure in residential areas, especially in regions with low levels of private home parking. Policymakers may also need to facilitate the installation of charging points in apartment buildings so that people who reside here have the option to purchase a PEV.

Work or commute location charging is also an important infrastructure component for PEV drivers [2,11]. When consumers commute in their PEV, around 15-25% of charging occurs at work. Policymakers can designate funding for workplace charging, encourage and incentivize businesses to install chargers, or mandate that employers (of a certain size or with a certain number of parking

spaces) install dedicated charging infrastructure at their workplaces.

Around 5% of charging events occur at public locations. These charging events are important as a safety net for other charging options [5,12]. Public charging infrastructure also encourages consumers to purchase PEVs.

Currently, around 5% of charging occurs at DC fast chargers. DC fast chargers allow PEV drivers to travel long distances and can provide a level of comfort to drivers by allowing fast charging in unforeseen circumstances. They also encourage consumers to purchase PEVs. Policies may be needed to support the rollout of DC fast charging, given the uncertain business case in the early stage of PEV market entry. Charge points should become profitable as the PEV market grows.

Public and DC fast chargers should be situated at locations where drivers already stop. For example, near rest areas, cafés, restaurants, shopping malls, etc. In addition to being areas people visit, these locations correlate with existing grid infrastructure that can support charging, which can lower installation costs. For short-range PEVs (100 miles or less), DC fast charge points will be needed mostly at intra-urban locations. For longer range PEVs (200 miles and more), DC fast charge points will also be needed at inter-urban locations [3]. Charge points in public locations and on transportation corridors should be clearly signposted to ensure PEV drivers know where to access them [13].

Pricing and Interoperability

Consumers typically need to use a membership card to access most publically accessible charging. In most regions, there are several charging infrastructure providers (sometimes more than 20 different providers in the same region). If consumers wish to access all stations, they may be required to

hold a membership card for each company. This situation creates confusion, causes difficulties for consumers, and can be a barrier to purchasing a PEV [14]. Policymakers can find ways to harmonize PEV charger access, so all PEV owners can access all charging stations. Such harmonization has been done in the Netherlands and Portugal, is a requisite for public charging in Germany, and has been proposed in legislation in the UK. A simple payment method that is easy to understand, such as phone identification or credit card, should be implemented in all PEV markets.

A major barrier for consumers is the lack of clear information on how payments work [15]. Payments for charging usually include one or more components: a onetime connection fee, charge time-based payments, kilowatt-hour (kWh) based payments, and charging cost based on parking cost. This is significantly different from refueling a conventional vehicle where consumers are aware of exactly what they are paying in all refueling locations, and how much each unit of fuel costs. Communicating the cost per kWh will help users make the best economical decision regarding the time and location of their charging events. Finally, charging speed is not usually guaranteed and in many cases not clearly marked. Charging station providers should indicate this information to consumers.

Cost of Charging

A fundamental benefit of a PEV is low operating costs compared to ICEVs. The cost to charge a PEV, or cost-per-mile to drive a PEV, should always be lower than that of an ICEV. Time of use and smart charging tariffs (explored in the section on *Charge Management*) can be used to further lower the cost to charge a PEV, thus enhancing their financial benefits to consumers.

In many regions, workplace charging is provided for

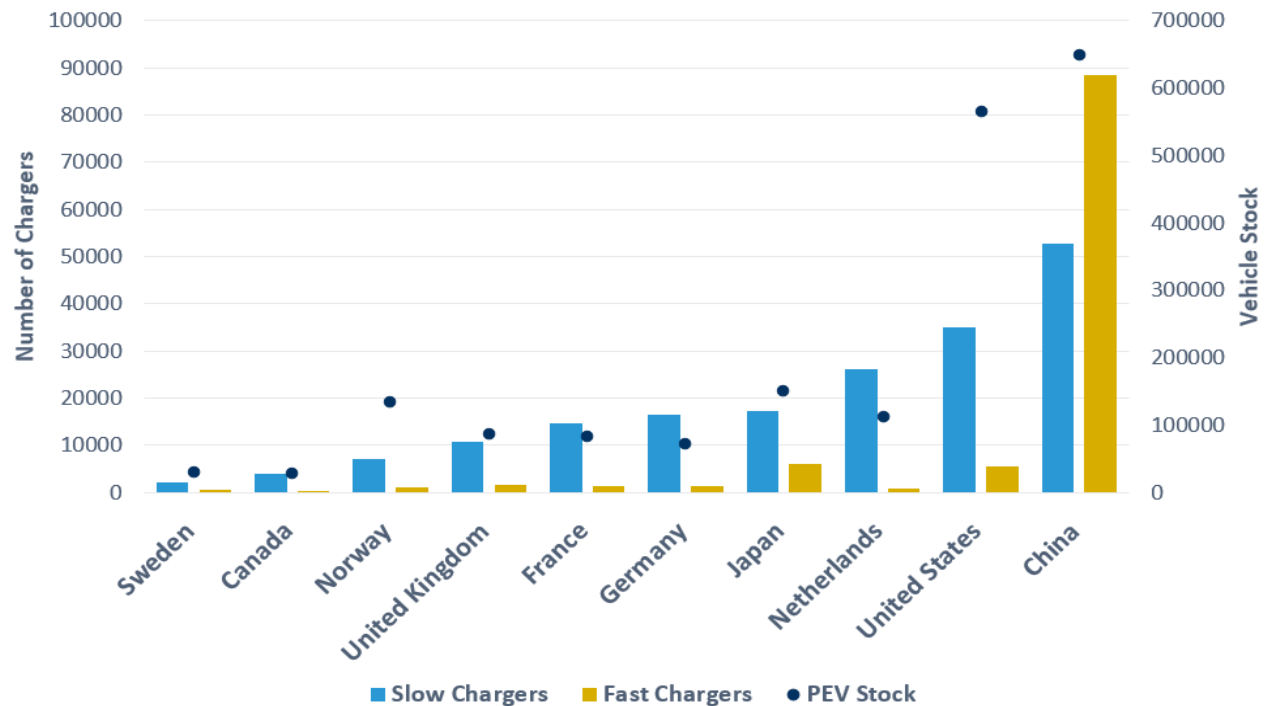


Figure 1: The number of slow and fast chargers, and number of PEVs registered in the top 10 PEV markets.

free. Reasons for employers to offer free charging include providing employees a perk, the low value of the power sold (meaning paid charging has a low business value), and the high cost of administering a paid system. Free workplace charging has been shown to encourage PEV sales [1,2,13]. However, it also has negative impacts. Free workplace charging encourages consumers to recharge even when they do not need to do so. This causes chargers to be congested (meaning there are more PEVs wanting to charge than there are chargers), shifts night charging to the daytime peak, means businesses need to install more chargers, and can put additional strain on local grid infrastructure. Studies have shown that ensuring there is a cost to charge at work can alleviate congestion [2,16]. An alternative to pricing workplace charging could be for employers to limit the number of daily hours an employee can charge. Public (non-DC fast) charging infrastructure should be priced in the same manner as workplace charging.

DC fast charging should not be free. Free DC fast

charging may encourage consumers to charge when they do not need to. Consumers may also substitute overnight home charging for DC fast charging at peak power demand times. DC fast charging should only be used by consumers when they need to charge their vehicle quickly or when they are undertaking longer distance travel. The cost to charge a PEV using DC fast charging will come at a premium to consumers due to the higher cost of charging equipment. This higher cost is permissible due to faster charge times possible with DC fast charging.

Households Without Off-Street Parking

In some regions, most households have their own dedicated off street parking. This is the case in Norway where 75% of households have their own dedicated parking [17] and in California where over 80% of new car buyers can park their car in their garage or driveway [15,18]. In many other regions drivers park their vehicles on the street, in off-street public parking garages, or in private parking

lots. Policymakers need to take into consideration charging infrastructure that can serve these consumers' needs. If infrastructure is not developed for these consumers, the PEV market will be unable to grow beyond a certain size. The Netherlands is testing the development of charging plazas, where multiple PEVs can be charged at one time. These plazas can be situated near people's homes.

Number of Public Charging Stations Needed

The number of public charging stations needed depends upon factors such as the number of workplace chargers, drivers' access to home charging (often dictated by housing type), travel patterns, and the market share of PHEVs and BEVs. Figure 1 shows PEV stock, and the number of slow and DC fast chargers in the top 10 PEV markets. In Norway and the United States most consumers have access to home charging. In Norway, there are 61 public chargers per 1,000 PEVs and in the United States, there are 72 public chargers per 1,000 PEVs. In places where private home charging is less common (e.g. China and the Netherlands) more public infrastructure is needed to support the rollout of PEVs. In China, there are 217 charging points per 1,000 PEVs and in the Netherlands, there are 239 charging points per 1,000 PEVs. On average, globally there are 153 chargers per 1,000 PEVs. Stakeholders will need to consider the local market conditions when considering the number of public charging stations needed.

Charging Infrastructure Dependability

Infrastructure dependability refers to how often PEV drivers can successfully access a given charging point. Low dependability can be due to broken chargers, grid power outages, charging point congestion (all charging points being occupied), and ICEVs blocking charger access by parking in

a space designated for PEV charging. Consumers are less likely to purchase a PEV if they cannot depend on infrastructure. PEV owners, especially BEV owners, are less likely to use their car if they cannot depend on charging infrastructure [2]. When dependability is low, the only PEV drivers that use infrastructure are those who can complete their days driving without recharging. BEV drivers use public or workplace charging to supplement home charging. PHEV drivers will charge to add more electric miles to their daily travel [2,21]. BEV owners who would need to charge to complete their daily travel do not risk driving their vehicle if they perceive charging point dependability to be an issue. Most cases of poor dependability are due to congestion. Investing in more infrastructure to eliminate charging point congestion is costly and not practical, especially with DC fast chargers. Pricing and policies that prevent charging point congestion must be part of the solution. As noted previously, public, workplace, and DC fast chargers should not be free. In particular, congested DC fast charging stations can be a significant issue for drivers of BEVs who rely on the infrastructure to complete their journey.

Charge Management

The early introduction of PEVs is unlikely to have negative impacts on the grid. This is due to the low numbers of vehicles being charged [22,23]. With greater numbers of PEVs in the market, charging needs to be managed to ensure it does not negatively impact the low-voltage (local) grid [22]. With uncontrolled charging, consumers will charge their PEVs when they arrive at work, in the afternoon at public locations, and when they arrive home in the evening. Large numbers of PEVs charging at these times could cause demand spikes at times when power demand is already high [24]. BEVs have significant flexibility in when they charge since they are parked for long periods of time, particularly overnight [25]. Therefore, it is possible to control PEV charge times.

One method of controlling home charging is by using time-of-use (TOU) domestic electricity tariffs [26]. These are currently being used in the United States. During off-peak hours (often at night), consumers pay a lower per-kWh electricity rate. This gives households a financial incentive to charge their vehicles at night. Another method to control charging is using a timer set for charging completion, rather than charging start, time. In this case, the charging start time will vary based on the vehicle's state-of-charge and when the vehicle will be used next. The most effective charging regime would combine TOU rates with a system that allows drivers to enter a charging completion time. This regime would optimally charge a PEV with off-peak electricity, while making sure the vehicle is fully recharged in time for use. In California, TOU tariffs have been effective in shifting PEV charging to off-peak times. Different regions will require different TOU structures depending on their existing supply and demand profiles. Even within each region different TOU tariffs may be needed. If every driver is given the same TOU tariff, a PEV charging peak could occur at that time. Utilities should provide TOU tariffs with the off-peak period beginning over a range of times.

Smart charging is a more advanced method of controlling charging times. This involves managing PEV charging based on real-time electricity supply and electricity demand [27]. According to data from the Netherlands, smart charging can allow existing electricity grids to support ten times more PEVs compared to unregulated charging [14,28]. During periods of low electricity supply and high electricity demand, smart charging would limit PEV recharging. During periods of low demand and high supply, PEVs would be allowed to charge freely. At smart charging locations, consumers should be able to opt out of smart charging in case they want to immediately charge their PEV. This charging event should be at a higher cost than the cost of regulated charging. Smart charging is effective at home, at

public, and at workplace charging locations. With DC fast chargers it may not be possible to utilize smart charging due to PEV drivers wanting to charge their vehicles quickly.

Smart charging may not be needed during the early PEV market stage. A long-term strategy would be to ensure that all chargers are smart chargers or they can be converted into smart chargers. This will mean that the infrastructure will be able to continually support the market introduction of PEVs.

More opportunities for PEV drivers to charge can help with controlling when charging occurs. Having access to home, work, and public charging increases the spatial and temporal distribution of charging events [29]. This availability of charging points reduces the number of peaking events and reduces strain on local grids.

Transit Considerations

PEV infrastructure should be developed in such a way that it does not reduce transit use. An abundance of free workplace or free public charging can encourage PEV drivers to commute via car rather than by transit. To prevent this scenario, workplace and public charging should not be free. However, if the goal is to increase transit use, providing free charging at transit hubs will encourage more PEV drivers to use public transit. Level 2 charging can be installed in parking garages at transit hubs. At drop-off and pick-up locations DC fast chargers could be installed.

Information, Education and Outreach

Information, education, and outreach programs should be used to educate consumers about PEV infrastructure. Consumers will be encouraged to adopt PEVs if they are more aware of their charging options. Education increases the use of charging points by PEV owners, which increases the overall electric miles driven by PEVs [15,30,31].

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Further Reading

This policy brief is part of a series of briefs. Each brief concentrates on a specific aspect of PEVs.

The following briefs are available:

1. Regulatory Mechanisms and Implementation
2. Financial Purchase Incentives
3. Non- financial and in use incentives
4. Information, Education and Outreach
5. Electricity Grids and PEV Infrastructure

Briefs are available at: <https://phev.ucdavis.edu/international-ev-policy-council-policy-briefs/>

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