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# Driving the Market for Plug-in Vehicles - Developing PEV 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 PEV drivers' garages or on their driveways, but also publically 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 BEVs and PHEVs, and the number of consumers without their own dedicated charger. Additional infrastructure must be installed in regions with a high proportion of 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.

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# Introduction

Plug-in electric vehicles (PEVs) are more efficient and less polluting than internal combustion engine vehicles (ICEVs). PEVs will need to increase market shares quickly to have the most significant impact on urban air pollution, energy consumption, and climate change. PEV success is partially reliant on the development of reliable recharging infrastructure. The development of this infrastructure should be carefully considered so that it leads to increased PEV sales, increased PEV usage, and so that the infrastructure meets the needs of PEV users. PEV charging infrastructure should be developed by policy makers, OEMs, utilities, employers, housing developers, charging infrastructure companies, and any other stakeholders. Policy makers have significant opportunities in ensuring the right infrastructure is developed. Policy makers can mandate or regulate how infrastructure it deployed.

This guide provides policy makers and stakeholders with the information they need to understand considerations for the development of infrastructure to support PEV market development. The guide provides information on charging levels, charge points, location, charge point access and payment, recharging costs, considerations for households with on street parking, the number of charging stations, charge point dependability, charge management, and implications for public transit.

# Lessons from Academic Research & Empirical Data

In the following, we refer to *charging points* as a device suited for charging a PEV and that only charges one PEV at a time. A *charging station* may contain one or several charging points and a *charging site* one or more charging stations.

## Charging Levels

Depending on the charging level it is possible to charge a PEV at different speeds. Table 1 shows the different levels of PEV charging. The slowest charge is from level 1 chargers. Level 1 charging is only done in nations with 110-120v grid power (e.g USA). These charge a PEV with 100 miles of range in around 24 hours. These chargers are mostly located at home and are used for overnight charging. Level 2 (208-240v) charging has a wide range of charging speeds based on the charging equipment and the vehicle capability. Level 2 charging can charge a PEV with 100 miles of range in 4-12 hours. Dedicated charge points are typically needed for level 2 chargers in the USA. In nations with 220v grids (e.g in Europe) this is the standard for a domestic plug socket. These chargers are often installed at homes, and are preferred to level 1 chargers as they can charge a PEV faster. They are also used at work places and public locations with long dwell times. DC Fast chargers charge PEVs in the fastest possible time. Even though DC fast chargers are the fastest way to charge, they are considerably more expensive than level 2 chargers (sometimes ten times more). They have very high power demands, therefore should not be considered as the main charging option. They 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.
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.

There are also several types of charge 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 can use these chargers. Tesla DC fast chargers (also known

as Superchargers) are only accessible by Tesla vehicles. 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 should have charge connectors that all PEVs can use. In Spain charge point installers are regulated by law to install multiple charge point connector types. Even when OEMs install their own charge points, they must install charge connectors for all PEVs from all other OEMs.

| 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.

## Charge Point Activity and Locations

Charging opportunities are derived from PEV owners' travel patterns. 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 is used for 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 home or near to home, around 75-85% of all PEV charging occurs here overnight [7]. Home charging has been found to be the most important piece of infrastructure 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]. Policy makers, utilities, and OEMs should 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. Policy makers may also need to facilitate the installation of charge points in apartment buildings so that people who reside here have the option to purchase a PEV. In some cases, especially with a PEV with a small battery, regular domestic plug outlets can be sufficient. However, these outlets are often insufficient and in some regions, it may not always be safe to charge a PEV off these outlets. It is therefore generally recommended that these are not used frequently to charge a PEV. In these cases, the installation of additional charge equipment is recommended. Policy makers should offer grants or subsidies to consumers who purchase home charging equipment.

Work or commute location charging is also an important piece of infrastructure for PEV drivers [2,11]. When consumers commute in their PEV, around 15-25% of charging occurs at work. Policy makers can financially contribute to the development of workplace charging, encourage businesses to install chargers, or mandate workplaces (of a certain size or with a certain number of parking spaces) to install dedicated charging infrastructure.

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.

Around 5% of charging occurs at DC fast chargers. DC fast chargers are critical in allowing PEV drivers to travel long distance and allowing for unexpected travel. They also encourage consumers to purchase

PEVs. Policy makers may have to support the rollout of this infrastructure as there may not be a viable 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 they are locations that are likely to be correlated with existing grid infrastructure that can support charging. For short range PEVs, 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 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 charge point 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]. Policy makers should 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 as a 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 internal combustion engine vehicles (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 '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 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 administrating a paid system. Free work charging has been shown to encourage PEV sales [1,2,13]. However, it also has negative impacts. Free work 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 day time 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

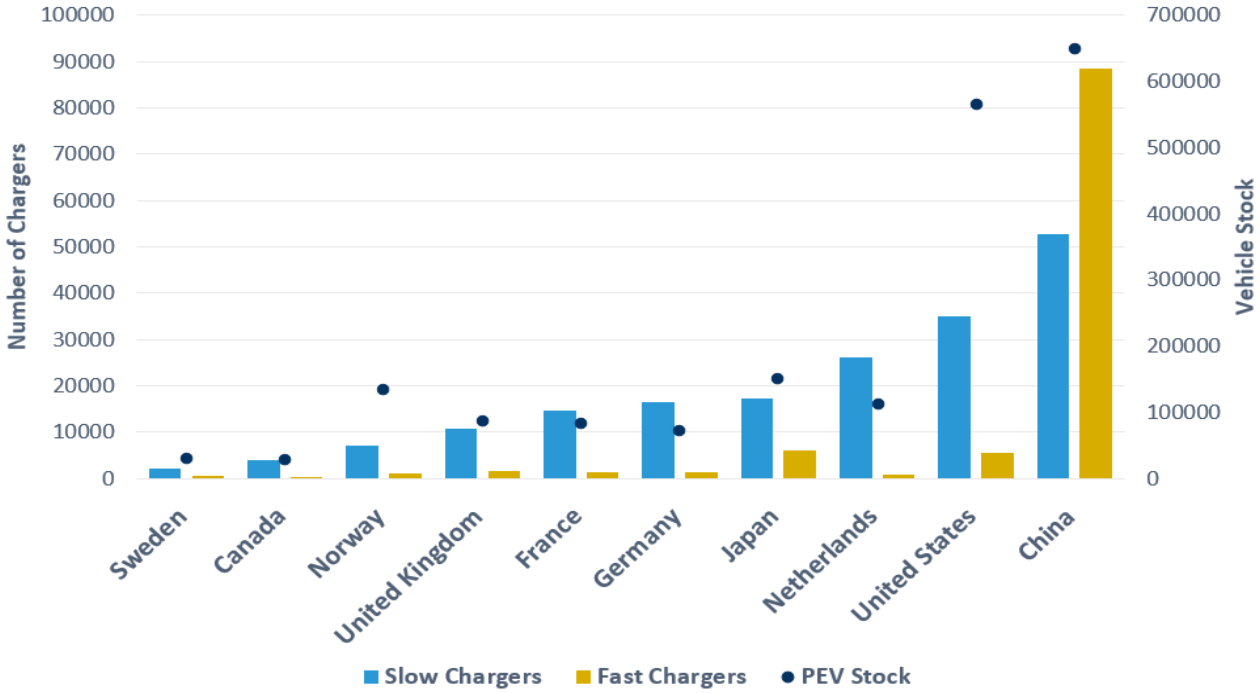


Figure 1: Number of slow and fast chargers, and number of PEVs registered in the top 10 PEV markets.

congestion [2,16]. An alternative pricing work charging could be for employers to set rules on the amount of time chargers can be used for. 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 street, in off street public parking garages, or in private parking lots. Policy makers need to work towards developing charging infrastructure that can serve these consumers' needs. This includes on street charging, charging in parking garages, and charging in private parking lots. If infrastructure is not developed for these consumers, the PEV market will be unable to grow beyond a certain size. Charging sites, known as 'charging plazas', are being piloted in the Netherlands. At these sites, multiple PEVs can be charged at one time. These plazas can be situated near to where people live.

## Number of Public Charging Stations

The number of public charging stations depends upon factors such as the number of work place

chargers, 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 1000 PEVs and in the United States, there are 72 public chargers per 1000 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 charge points per 1000 PEVs and in the Netherlands, there are 239 charge points per 1000 PEVs. On average, globally there are 153 chargers per 1000 PEVs. Stakeholders will need to consider the local market conditions when considering the number of public charging stations.

## Charging Infrastructure Dependability

Infrastructure dependability refers to how often PEV drivers can access a given charge point. Low dependability can be due to broken chargers, grid power outages, charge point congestion, and ICEVs parking in charging bays. Consumers are also 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 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 charge point dependability to be an issue. Most cases of poor dependability are due to congestion (all charge points being occupied). Investing in more infrastructure to eliminate charge point congestion is costly and not practical especially with DC Fast chargers. Pricing and policies that prevent charge point congestion must be part of the solution. As was previously mentioned this means public, workplace, and DC fast chargers should not be free to use. 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

TThe 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 will 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 to control charging is using a timer set for charge completion time rather than start time. In this case, the charging start time will vary based on the vehicles state of charge and when the vehicle will be used next. Another 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. The most effective system would combine TOU with a system that allows drivers to enter a charge completion time. This would allow a system to optimally charge a PEV with off peak electricity, while making sure the vehicle is fully recharged. 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 work 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 at the beginning of PEV market entry. 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 home, work, and public charging increases the spatial and temporal distribution of charging events [29]. This availability of charge 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, work 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 charge points by PEV owners, which increases the overall electric miles driven by PEVs [15,30,31].

## Summary

This guide provides policy makers with an overview of considerations for the development of PEV recharging infrastructure. Policy makers will need to develop infrastructure, provide financial incentives, provide reoccurring incentives (e.g. free parking, toll fee waivers, etc.), educate consumers, and may need to require automotive OEMs to sell PEVs. This all-encompassing approach will ensure PEV market entry is a success.

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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:
Introduction to PEV Policy Guides
1. Regulatory Mechanisms and Implementation
2. Government and Industry
3. Financial Purchase Incentives
4. Non-financial and in use incentives
5. Information, Education and Outreach
6. Electricity Grids and PEV Infrastructure

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