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ELECTRIC VEHICLE CHARGING IN CHINA AND THE UNITED STATES

ANDERS HOVE AND DAVID SANDALOW
FEBRUARY 2019

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EXECUTIVE SUMMARY

At least 1.5 million electric vehicle (EV) chargers have now been installed in homes, businesses, parking garages, shopping centers and other locations around the world. The number of EV chargers is projected to grow rapidly as the electric vehicle stock grows in the years ahead.

The EV charging industry is a highly dynamic sector with a wide range of approaches. The industry is emerging from infancy as electrification, mobility-as-a-service and vehicle autonomy interact to produce far-reaching changes in transportation.

This report compares EV charging in the world's two largest electric vehicle markets -- China and the United States – examining policies, technologies and business models. The report is based on more than 50 interviews with industry participants and a review of the Chinese- and English-language literature. Findings include:

1. The EV charging industries in China and the United States are developing largely independently of the other. There is little overlap among the key players in the EV charging industries in each country.
2. The policy frameworks with respect to EV charging in each country differ.
   - The Chinese central government promotes the development of EV charging networks as a matter of national policy. It sets targets, provides funding and mandates standards. Many provincial and local governments also promote EV charging.
   - The United States federal government plays a modest role in EV charging. Several state governments play active roles.
3. EV charging technologies in China and the United States are broadly similar. In both countries, cords and plugs are the overwhelmingly dominant technology for charging electric vehicles. (Battery swapping and wireless charging have at most a minor presence.)
   - China has one nationwide EV fast charging standard, known as China GB/T.
   - The United States has three EV fast charging standards: CHAdeMO, SAE Combo and Tesla.
4. In both China and the United States, many types of businesses have begun to offer EV charging services, with a range of overlapping business models and approaches. A growing number of partnerships are emerging, involving independent charging companies, auto manufacturers, utilities, municipalities and others.
   - The role of utility-owned public chargers is larger in China, especially along major long-distance driving corridors.
   - The role of auto maker EV charging networks is larger in the United States.

5. Stakeholders in each country could learn from the other.

- US policy makers could learn from the Chinese government's multiyear planning with respect EV charging infrastructure, as well as China's investment in data collection on EV charging.
- Chinese policymakers could learn from the United States with respect to siting of public EV chargers, as well as US demand response programs.
- Both countries could learn from the other with respect to EV business models

As the demand for EV charging grows in the years ahead, continued study of the similarities and differences between approaches in China and the United States can help policymakers, businesses and other stakeholders in both countries and around the world.

INTRODUCTION

We are in the early stages of a major infrastructure build-out. In China, the United States and other countries around the world, hundreds of thousands of electric vehicle chargers are being installed in homes, businesses, parking garages, shopping centers and other locations. The number of chargers is projected to grow rapidly in the years ahead as the electric vehicle stock grows.

This build-out will require new behavior patterns and business models. For more than a century, the vast majority of vehicles have been refueled at retail stations dispensing gasoline and/or diesel. Electric vehicle charging is different than this familiar model for a number of reasons, including:

- Most recharging of electric vehicles takes place at home or work.
- EV charging is slower than filling a conventional vehicle with liquid fuel.
- EV charging is cheaper than filling a conventional vehicle with liquid fuel (which is good for the driver but means less revenue potential for businesses that provide charging).
- Electric utilities are more central players in EV charging than traditional fueling.
- Many governments are supporting the growth of EV charging infrastructure to help achieve a range of social objectives.

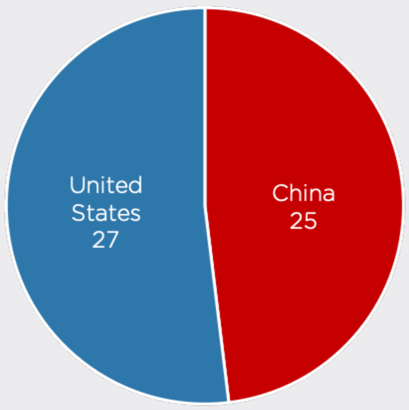
As a result of these and other factors, the EV charging industry is currently a highly dynamic sector with a wide range of approaches. The industry is emerging from infancy as electrification, mobility-as-a-service and vehicle autonomy interact to produce some of the most far-reaching changes in the transportation sector in a century.

This report compares electric vehicle charging in the world's two largest electric vehicle markets—China and the United States—based on more than 50 in-person interviews and a review of the Chinese- and English-language literature. The report starts with background on electric vehicles and EV charging infrastructure today. The report then explores three questions:

1. What policies are shaping the growth of EV charging?
2. What technologies are being used?
3. What business models are emerging as the EV charging industry grows?

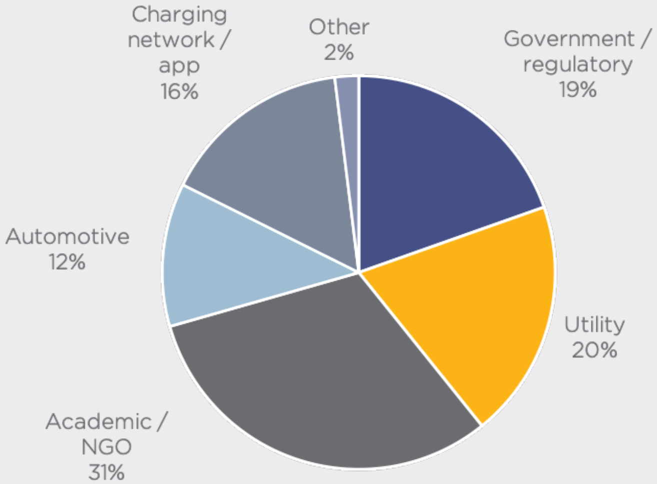
A final section offers conclusions and lessons each country could learn from the other.

Figure 1A: Breakdown of interviews for this report - country



Source: Authors

Figure 1B: Breakdown of interviews for this report - sector



Source: Authors

RMB-U.S. Dollar Conversion

During January 2019, the Chinese RMB and U.S. dollar exchanged at a rate of roughly RMB 6.8 to $1. During the past 10 years, the two currencies have exchanged within a range of roughly RMB 6.0 to $1 to RMB 7.0 to $1, with an average exchange rate of just over RMB 6.5 to $1.[1]

GLOSSARY

Term	Abbreviation	Explanation
Electric vehicle	EV	A vehicle propelled solely or in part by an electric motor powered by batteries that can be recharged from a source outside the vehicle. (Includes both all-electric vehicles and plug-in hybrids.)
All-electric vehicle / battery electric vehicle	AEV/BEV	A vehicle propelled solely by an electric motor powered by batteries that can be recharged from a source outside the vehicle.
Plug-in hybrid	PHEV	A vehicle propelled in part by an internal combustion engine and in part by an electric motor powered by batteries that can be recharged from a source outside the vehicle.
Internal combustion engine	ICE	An engine that runs on liquid fuels including gasoline or diesel.
New energy vehicle	NEV	A term used in China for vehicles not powered by an internal combustion engine. Last year roughly 99% of NEVs sold were plug-in electric vehicles (all-electric or plug-in hybrids).
Electric vehicle supply equipment / Electric vehicle service equipment	EVSE	Charging infrastructure for electric vehicles. This broad term encompasses all types of charge posts and levels of charging stations.
Charging point / charging post		A piece of equipment for charging an electric vehicle, other than an unmodified wall outlet
Charging station		A location with multiple charging points/posts.
Level 1 charger	L1	An EV charger using a standard 120 volt outlet. Often referred to as "trickle charging," this is the slowest type of charger.
Level 2 charger	L2	An EV charger using a 240 volt electrical circuit, similar to a dryer or an electric stove top.
DC fast charger	DCFC	A 480 volt charger that can deliver as much as hundreds of kWs of power. This is the fastest type of charger.
Combined Charging System	CCS	An EV charging standard that originated in the EU; supported by many automakers including Volkswagen, General Motors and Hyundai.
Charge de Move	CHAdeMO	An EV charging standard that originated in Japan; supported by many automakers including Nissan and Mitsubishi.
Tesla Supercharger		A proprietary EV 480 volt supercharger network deployed by Tesla, with its own proprietary standard.

BACKGROUND: ELECTRIC VEHICLES

A. Electric Vehicle Deployment Today

In 2018, roughly 1.25 million electric vehicles were sold in China—a 62% increase over 2017 sales. Electric vehicles were roughly 4.5% of light-duty passenger vehicles sold.[2]

As of January 2019, there were roughly 2.6 million electric vehicles on the roads in China.[3]

In the United States, roughly 361,000 electric vehicles were sold in 2018—an 81% increase over 2017 sales. Electric vehicles were roughly 2% of light-duty passenger vehicles sold.[4]

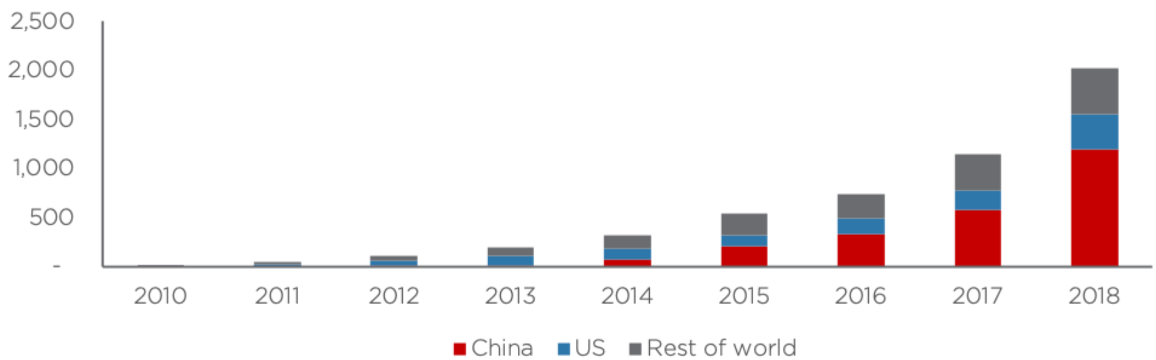
As of January 2019, there were roughly 1.1 million electric vehicles on the roads in the United States.[5]

The figures above do not include either low speed electric vehicles (LSEVs) or electric bicycles.

- LSEVs have top speeds of roughly 40 kilometers per hour/25 miles per hour. In 2016, more than 500,000 LSEVs were sold in China.[6] In the United States, LSEVs are largely confined to gated communities, golf courses, malls, airports, public parks and tourist facilities.[7]
- Electric bicycles are wildly popular in China. Roughly 200 million electric bicycles are in use, with roughly 30 million sold each year.[8] Sales of electric bicycles in the United States are in the range of 200,000 units per year.[9]

The average range of Chinese EVs is much less than the average range of U.S. EVs. In China, the average range of the top 10 selling all-electric vehicle models is less than 200 km/124 miles. In the United States, the average range of the top 10 selling all-electric vehicles is more than 400 km/248 miles. This suggests a need for greater density of EV charging infrastructure in China.[10]

Figure 2: Electric Vehicle Sales



Source: IEA (2010-2017); Inside EVs (2018)

Table 1: Comparison of China and U.S. light-duty EV sales

	China	U.S.
Electric vehicle sales (2018)	1,250,000	361,000
Growth in 2018 vs prior year	73%	81%
EV market share (new sales)	4.5%	2.1%
All-electric vehicle sales (2018)	984,000	235,700
Growth in 2018 vs prior year	50.7%	227%
Total Electric vehicles on road	**2.6 million**	**1.1 million**

Source: China Car Association, Xinhua, China Passenger Car Market Information Alliance, Inside EVs

B. Electric Vehicle Deployment Projections

Forecasts of EV deployment vary widely. Some recent examples include:

- The Organization of Petroleum Exporting Countries (OPEC) forecasts that 11.6% of passenger cars worldwide will be EVs by 2040.[11]
- The International Energy Agency's 2017 World Energy Outlook projects 280 million EVs on the road by 2040, which would represent 14% of the global fleet of roughly 2 billion vehicles at that time.[12] The IEA's 2018 Global EV Outlook projects 125 million EVs on

the road by 2030 under the IEA's New Policies Scenario (representing 6% of the global light-duty vehicle stock).[13]

- BP's "Evolving Transition" scenario suggests that 15% of vehicles will be EVs by 2040, but 30% of vehicle miles traveled will be powered by electricity.[14]
- Morgan Stanley forecasts that EVs will represent around 25% of global vehicle stock by 2040 and surpass 55% of vehicle stock by 2050.[15]
- In its 2018 EV Outlook, Bloomberg New Energy Finance projects that 55% of new car sales and 33% of the world's vehicle fleet will be EVs by 2040.[16]
- A "fast adoption" scenario set forth in one International Monetary Fund working paper suggests 90% penetration by 2042.[17]
- The analysts at RethinkX, a consulting firm working on disruptive technology, project that transport-as-a-service and autonomous vehicle technology will enable EVs to replace virtually all privately owned and commercial vehicles as early as 2030.[18] In contrast, a 2016 Mckinsey study projects a 15% market share for autonomous vehicles and less than 10% for shared vehicles (autonomous or not).[19]

The wide range of forecasts reflects different assumptions concerning battery costs, public policies and the impacts of mobility-as-a-service and vehicle autonomy, among other factors.

EV deployment rates in China will be strongly affected by government targets. The Chinese government new energy vehicle targets currently include sales of 2 million per year by 2020 and 20% of total vehicle production and sales—or over 7 million vehicles annually—by 2025.[20] According to a technology road map of the Ministry of Industry and Information Technology (MIIT), EVs could reach 40% of new vehicle sales in China by 2030.[21] The projections in other studies vary:

- A 2017 Tsinghua University study estimated EVs would account for 7% of vehicle sales in Beijing in 2030 without policy supports or technology breakthroughs and over 70% of sales and half the vehicle stock with aggressive policy support and technology progress.[22]
- Bloomberg New Energy Finance forecasts EVs to reach 10% of Chinese new vehicle sales by 2025 and surpass 50% by 2035.[23]
- The World Wildlife Fund expects China to reach over 90% of EV sales within 10–20 years.[24]

Forecasts of EV penetration in the US market vary:[25]

- In the US Energy Information Administration's 2018 "Reference Case," EVs reach 7% of new vehicle sales in 2025 and 19% in 2050.[26]
- The consultancy Energy Innovation estimates that EV sales will reach 10% of new US vehicle sales soon after 2025, 20% around 2030 and 65% by 2050.[27]

- Bloomberg New Energy Finance forecasts that EVs will reach 10% of new US vehicle sales by 2025 and 50% by 2035.[28]

C. Electric Vehicle Policies

i. China

The Chinese government promotes electric vehicles with a variety of policies including subsidies, rebates, quotas for vehicle manufacturers and tax exemptions. Many provincial and local governments do the same. City policies favoring EVs in obtaining license plates have been especially important.

National subsidies have been a major incentive for consumers to purchase EVs. China's central government began subsidizing EV purchases for government and public fleets in 2009 and individual car buyers in 2013. Subsidies in 2013 ranged from RMB 35,000 to RMB 60,000, depending on the vehicle's electric range, and have been reduced regularly since.[29] Subsidies were paid directly to manufacturers, based on vehicle registrations and sales. These subsidies attracted many companies into EV manufacturing, including some with no car manufacturing experience. Criticism of the subsidies, along with reports of fraud by companies receiving subsidies, prompted a policy redesign.[30]

In early 2018, the Chinese central government updated its EV subsidies, linking automaker fuel economy credits with new electric vehicle (NEV) production targets.[31] Subsidies are now available for vehicles with range over 150 km on the test cycle used in China, which is based on the New European Driving Cycle (NEDC).[32] An NEDC range of 400 km is needed to receive the highest subsidy.[33] Requirements tied to battery performance were also made more stringent: batteries must have energy density over 105 Wh/kg to receive a subsidy and at least 140 Wh/kg to receive the full subsidy.[34] Local governments are permitted to offer additional subsidies up to 50% of the level of national subsidies.[35] Government officials have said EV subsidies should phase out by 2020.[36]

In addition to subsidies, China has promoted EVs with nonfinancial incentives, including exemption from city license plate lotteries or restrictions. This has been an especially important incentive since applicants often wait years to acquire a license plate for a conventional vehicle. (In Beijing in 2016, 2.7 million people registered for a license plate lottery with only 90,000 plates available for conventional vehicles. In 2018, the number of conventional vehicle license plates available fell to just 40,000.[37] In Shanghai, EV plates are available for free, while regular plates cost over $12,000.[38]) Initially, license plates for EVs were available through a simple queue.[39] Today, EV plates are distributed by lottery, with more plates available for EVs than conventional vehicles.

In addition, cars with EV plates may have privileges such as access to restricted traffic zones. Many large Chinese cities, including Beijing, restrict drivers of passenger cars from entering the city on certain days based on license plate number, while exempting EVs from such limits. A few cities in China use special parking access or discounts, lane access and congestion zone discounts to promote EVs.[40]

In September 2017, the Ministry of Industry and Information Technology finalized its new energy vehicle (NEV) quota, which requires all carmakers with over 30,000 annual vehicle sales in the country to produce 10% NEVs in 2019 and 12% in 2020. The policy also integrates NEV quotas with new corporate average fuel consumption (CAFC) requirements. A trading mechanism incorporates mandates for both NEV and CAFC attributes. An analysis by the International Council on Clean Transportation (ICCT) suggests the credit trading mechanism will enable carmakers to meet the 2020 quota with about 4% NEVs.[41]

Fleet EVs remain a sizeable portion of China's EV market. Cities including Taiyuan and Shenzhen continue to electrify taxi, bus, ride-hailing and bus fleets at a rapid pace. In May 2018, Shenzhen announced it would allow EVs only in taxi and ride-hailing fleets and require all commercial trucks to be EVs—along with installing over 5,000 dedicated taxi charging posts by 2020.[42]

Chinese policy makers have several motivations for pursuing policies related to electric vehicles, including promoting domestic manufacturing of batteries and vehicles, decreasing dependence on imported oil and reducing emissions:

- In 2014, President Xi Jinping said that electric mobility is an emerging technology in which China has the ability to leapfrog other global automakers.[43] Many of China's EV policies benefit domestic manufacturers and promote use of Chinese-made batteries in vehicles while encouraging foreign carmakers to share technology with Chinese joint-venture partners.[44]
- Reducing oil imports is a second important objective of Chinese EV policies. Since 2017, China has been the world's largest oil importer.[45] Oil accounts for over 10% of China's import volume by value.[46] Gasoline demand is rising quickly due to increased car ownership and driving.
- Cutting emissions of urban air pollutants and greenhouse gases is another motive for pursuing EVs. Transportation sector emissions are a major contributor to ambient PM2.5 haze in major cities of China.[47] Adopting EVs has significant potential to benefit urban air quality, even though much of China's electricity presently comes from coal. Over the medium to long term, vehicle electrification will be essential to decarbonizing the transportation sector in China.[48]

ii. United States

The US federal government offers EV purchasers a tax credit of $2,500 to $7,500 per vehicle, depending on battery size. The tax credit is available for the first 200,000 vehicles sold by each manufacturer, after which it begins to phase out for that manufacturer.[49] Federal fuel efficiency standards also provide incentives for manufacturers to sell electric vehicles.[50]

Many US states have tax credits or rebates for the purchase of EVs. Among the most generous are Colorado, California, Delaware and Massachusetts. Georgia, Illinois, Maryland, South Carolina and Tennessee have offered tax credits or rebates in the past but have now retired or scaled back those programs.[51]

Many observers consider the multistate zero emissions vehicle (ZEV) program to be the most important EV policy in the United States.[52] The program requires ZEVs to account for roughly 8% of vehicle sales in ZEV states by 2025. (The ZEV states are California, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island and Vermont.) To date the mandate has mostly encouraged EV sales in California, which accounted for 50.7% of EV sales in the United States in 2016. This is due in part to a "travel provision" that allowed automakers to earn credit for vehicles sold in California in the other seven states with ZEV mandates. This travel provision is now being scaled back, and EV sales in other ZEV states may grow as a result.[53]

High occupancy vehicle (HOV) lane exemptions have been an important incentive for EV purchases in the United States. More than 10 states (including California, Colorado and New York) allow EVs access to HOV lanes.[54]

Federal and state government goals in promoting electric vehicles include reducing emissions, improving fuel economy and promoting US technology leadership.

1. EV CHARGING TODAY

A. EV Charging in China

In January 2019, the Chinese Electric Vehicle Charging Infrastructure Promotion Agency (EVCIPA) reported 808,000 EV chargers in China. Of these, roughly 330,000 were public chargers and 480,000 were home chargers. The number of chargers reported by EVCIPA grew 80% since January 2018.[55]

(Other data suggests the number of EV chargers in China could be even higher. According to EVCIPA as well as interviews conducted for this report, most EVs sold for personal use in China are accompanied by a home charging unit. Roughly 1.5-2 million EV's have been sold in China for personal use. Although not all home charging units sold with EVs are installed, this suggests the number of home EV chargers could be higher than 480,000.)

China's first-tier cities have taken the lead in EV charging infrastructure. This partly reflects the legacy of earlier central government policies, in particular the EV pilots that began in 2009 under the Ten Cities, Thousand Vehicles program. At the end of 2018, Beijing, Shanghai and Guangdong Province (home to Shenzhen and Guangzhou) accounted for just under 40% of charging posts nationwide.[56]

Nevertheless, EV charging infrastructure is growing rapidly throughout China. The majority of provinces added over 1,000 new charging posts in 2018. Several provinces grew the number of charging posts by over 100%. Most provinces in China now have more than 2,000 public charging posts.[57]

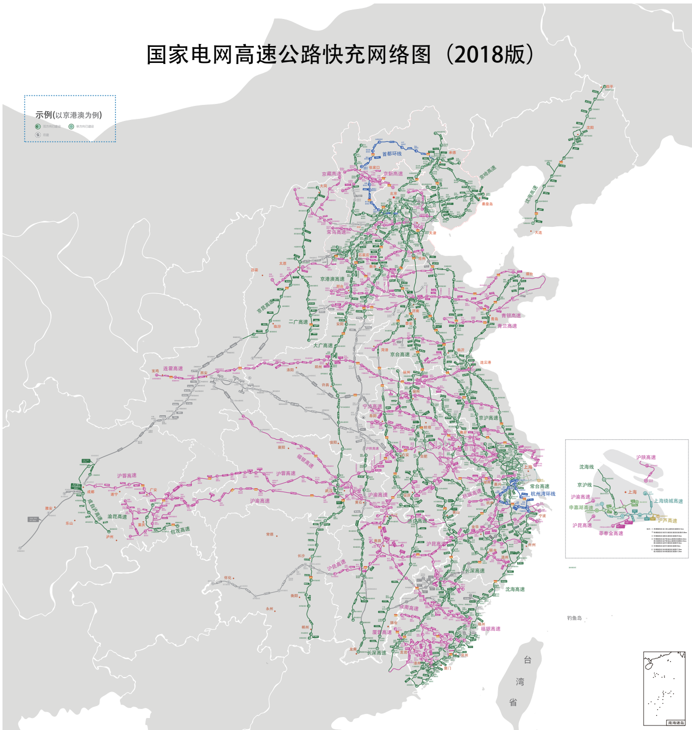
According to industry experts interviewed for this study, most home EV charging in China takes place with chargers distributed by carmakers at the time of purchase and installed according to official procedures. Nevertheless, in some Chinese cities it is not unusual to see informal "fly-line" charging with extension cords passed through windows and doors to vehicles parked at the curb.[58] Fly-line charging to the curb reflects a shortage of private parking and lack of access to charging even when private parking is available. Such practices, if left uncontrolled, could create distribution grid reliability issues, as many older Chinese urban neighborhoods have insufficient distribution capacity for heavy volumes of EV charging.[59]

Figure 3: Photos of informal "fly line" charging in Beijing

Source: Anders Hove (left, March 2018) and Rob Earley (right, July 2017)

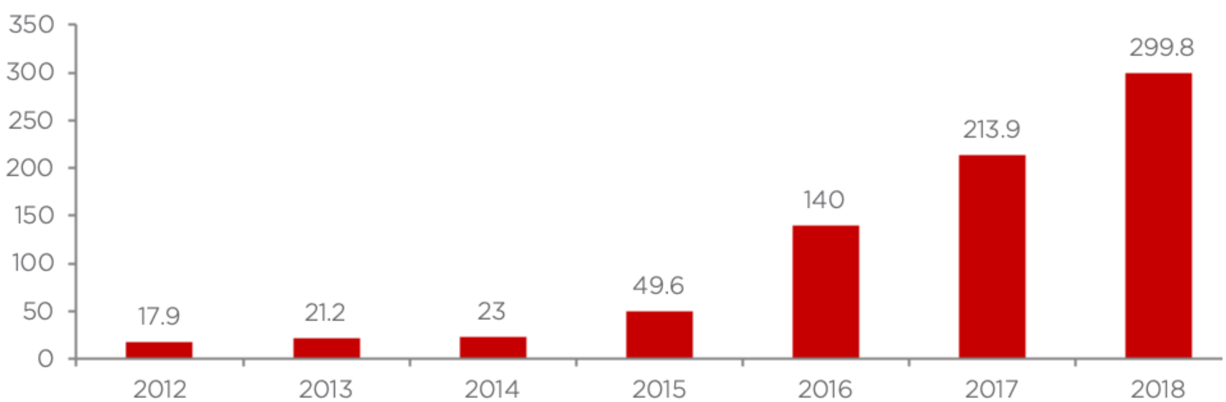
Highway corridors for EV charging have now been installed between Beijing and Shanghai as well as other major cities. Utilization of these facilities is heaviest on weekends and major public holidays. During February 2018, the amount of electricity consumed at State Grid chargers along highways more than doubled versus the prior month due to the annual Spring Festival holiday.[60]

Figure 4: China State Grid highway charging corridors as of early 2018



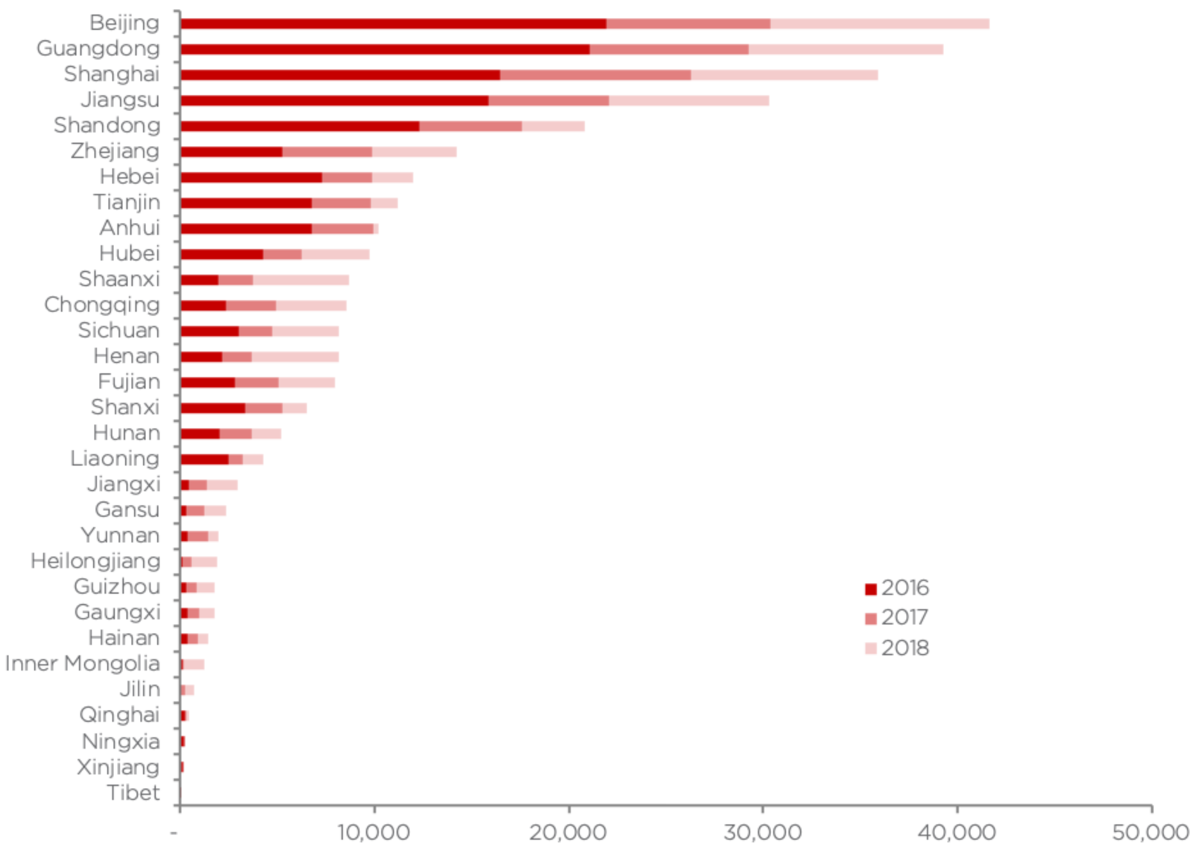
Source: State Grid Corporation of China 2018; colors indicate east-west, north-south, and urban cluster routes

Figure 5: Number of China public and dedicated fleet EV charging posts, in thousands



Source: China EV Charging Alliance, January 2019

Figure 6: Number of China public and dedicated fleet EV charging posts by province



Source: China EV Charging Alliance, January 2019

B. EV Charging in the United States

We estimate there are at least a half million electric vehicle chargers in the United States today.

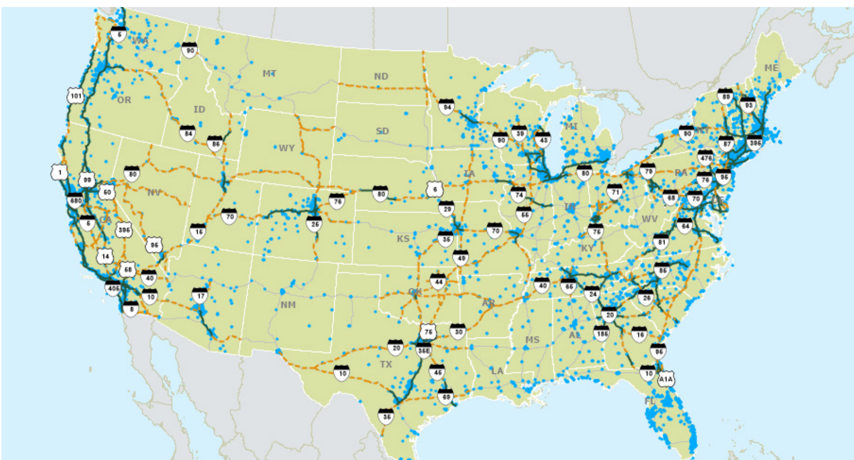
- The overwhelming majority of these are home chargers. Exact figures with respect to the numbers of home chargers are not available, however if just under two-thirds of electric vehicle owners in the United States have installed home chargers, as suggested by one survey,[61] there would be more than a half million residential charging posts in the United States. (Survey data suggest that more than 80% of EV charging in the United States takes place at home.[62])

- In addition, as of January 2019, the United States had over 67,000 nonresidential EV charging posts located at approximately 24,000 charging stations, according to US Department of Energy data. (In 2018 the number of non-residential stations increased by 33%, according to DOE data.[63] Workplace charging is growing in the United States.[64])

As of January 2019, California had 5,600 nonresidential EV charging stations (24% of the national total), hosting over 21,000 charging posts (32% of the national total). Only three other states—Texas, Florida and New York—had over 1,000 charging stations, according to the DOE. The average among all 50 US states was around 450 stations and around 1,300 charging posts.[65]

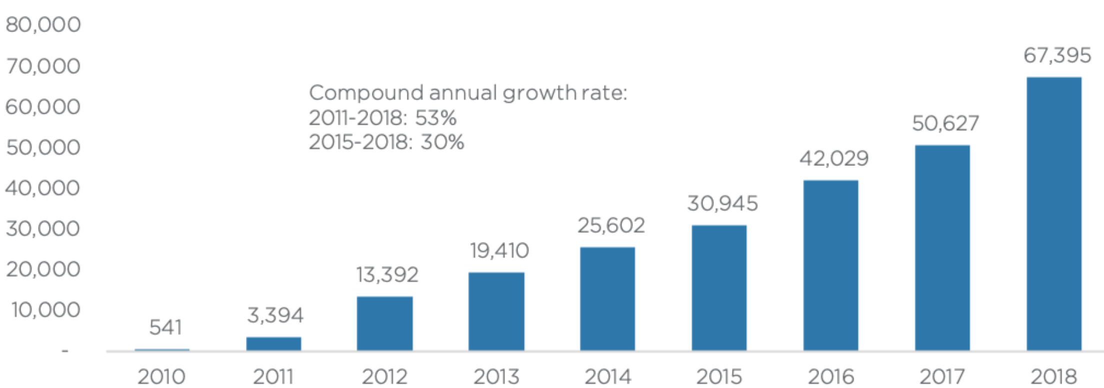
Of the approximately 22,000 charging stations in DOE's database in January 2019, 11% offered some form of DC fast-charging. 91% of stations offered Level 2 charging, and 6% offered Level 1 charging. Most stations have more than one charge point. Approximately half of stations with DC fast charging also have a Level 2 charger available.

Figure 7: U.S. electric vehicle charging stations (light blue) and EV signage corridors (green, orange pending)



Source: Federal Highway Administration, 2019

Figure 8: Number of charging posts at non-residential charging stations, United States 2011-2018



Source: Alternative Fuels Data Center, US Department of Energy, January 2019

C. Role of Charging Infrastructure in EV Purchase Decisions

In both China and the United States, most EV charging takes place at home or work.[66] Nevertheless, EV drivers and potential EV drivers express strong interest in the availability of public charging infrastructure. Some studies suggest a "chicken and egg" problem, in which more public EV charging infrastructure is required for growth in EV sales and more EV sales are required for growth in public EV charging infrastructure.[67]

Availability of public EV charging infrastructure is an especially important consideration for many potential Chinese EV purchasers for several reasons. First, many Chinese households lack access to a dedicated parking spot near home. Some Beijing-area EV dealers responsible for installing home EV chargers report that as few as 40% of households have such access.[68] Second, for drivers with such a dedicated parking spot, installing home chargers may take as long as eight months and require visits and paperwork submissions to the grid company, district management department and the civil preparedness bureau.[69]

Studies suggest the availability of public EV charging is an important factor in decisions on EV purchases in the United States as well.[70] A 2017 online survey of U.S. EV owners found that public charging and access to fast charging were viewed as top criteria when buying an EV.[71] A 2016 survey of potential EV buyers found that "lack of charging facilities in my area" was the third-ranked reason for not purchasing an EV and "lack of quick charging stations" the fourth. Eight of the top 30 reasons cited for not purchasing an EV related to public charging.[72] A 2015 study by the US National Academies of Science found that charging infrastructure was critical to EV adoption, with home charging as most important, followed by workplace charging and then by public charging within urban areas, and lastly by fast-charging along major highways. Citing data from Japan, the study noted that availability of public charging doesn't necessarily result in more charging at public locations but can result in greater EV adoption.[73]

D. Comparison—China and the United States

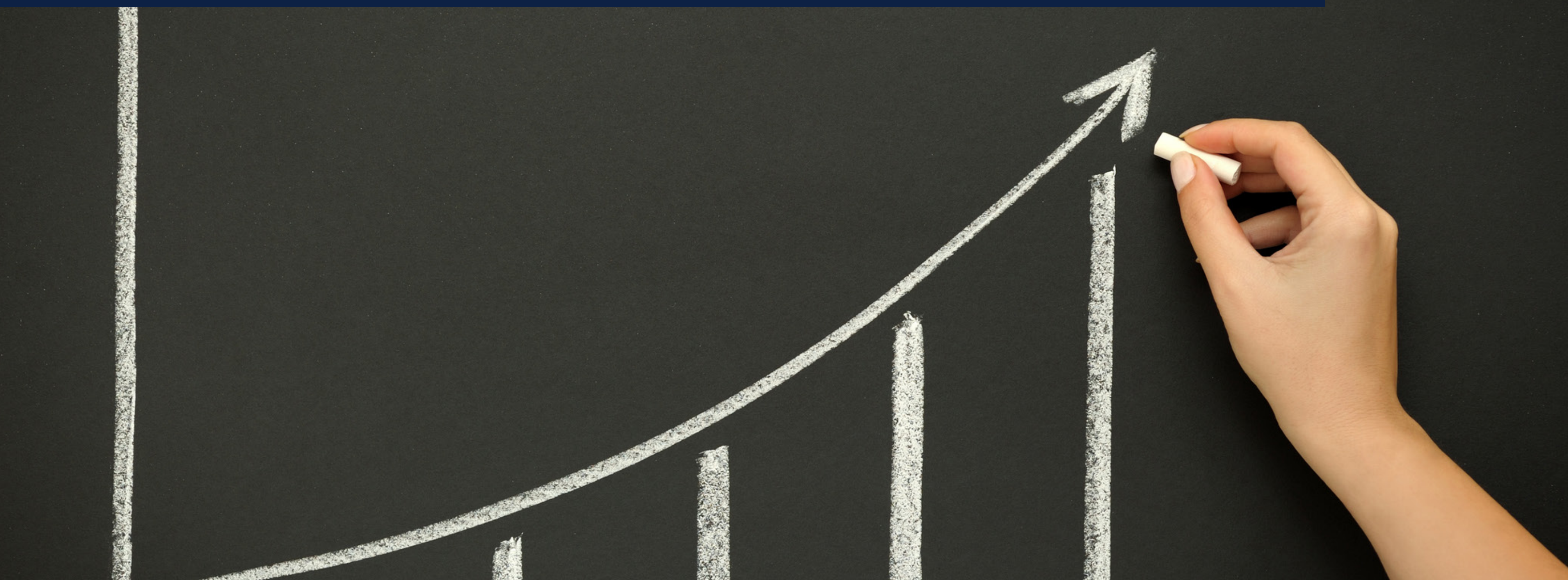
In both China and the United States, EV charging infrastructure is growing at double-digit rates. The percentage of EV charging stations with DC fast-charging is higher in China than the United States. In both China and the United States, charging infrastructure is concentrated in cities and states with favorable policies and high rates of EV adoption.

Table 2: Comparison of China and U.S. EV charging infrastructure

	Period	China	U.S.
Number of public or fleet charging points	2018 year-end	330,000	67,500
	2017 year-end	210,000	50,600
Annual growth rate of public + fleet charging points	2017 to 2018	43%	33%
Number of charging stations	2018 year-end	70,000 (est.)	24,000
	2017 year-end	50,000 (est.)	20,000
% DC fast charging	2018 year-end	36%	14%
	2017 year-end	24%	11%

Source: China EV Charging Infrastructure Promotion Alliance, U.S. Department of Energy

2. EV CHARGING PROJECTIONS



Future demand for EV charging infrastructure will depend on a number of factors. Many of these are highly uncertain:

- One important factor is the number of electric vehicles sold, yet projections for EV sales vary widely (as discussed in the Background section above).
- Driving patterns are another important factor, yet mobility-as-a-service and autonomous vehicle technology could change driving patterns in the decades ahead in significant and potentially unpredictable ways. Drivers may be less prone to own vehicles, for example, and vehicles' average time on the road each day may increase.
- A third factor is the progress of technologies such as wireless charging and EV battery swapping (discussed in Sections 4E and 4F below). At present wireless charging has little or no commercial presence in China or the United States. Battery swapping is used in some Chinese taxi fleets but has little or no presence in the United States.[74] If either technology becomes more common, that would affect the development of EV charging infrastructure.
- A final factor is government policies supporting EV charging.

In China, the growth of EV charging infrastructure will be largely determined by government targets. NDRC's *Guidelines for Developing Electric Vehicle Charging Infrastructure (2015–2020)*, issued in October 2015, calls for at least 120,000 EV charging stations and 4.8 million

EV charging posts by 2020.[75] The government has also announced dedicated funding for this infrastructure.[76] This suggests a very rapid scale-up of EV charging infrastructure in China in the next several years.

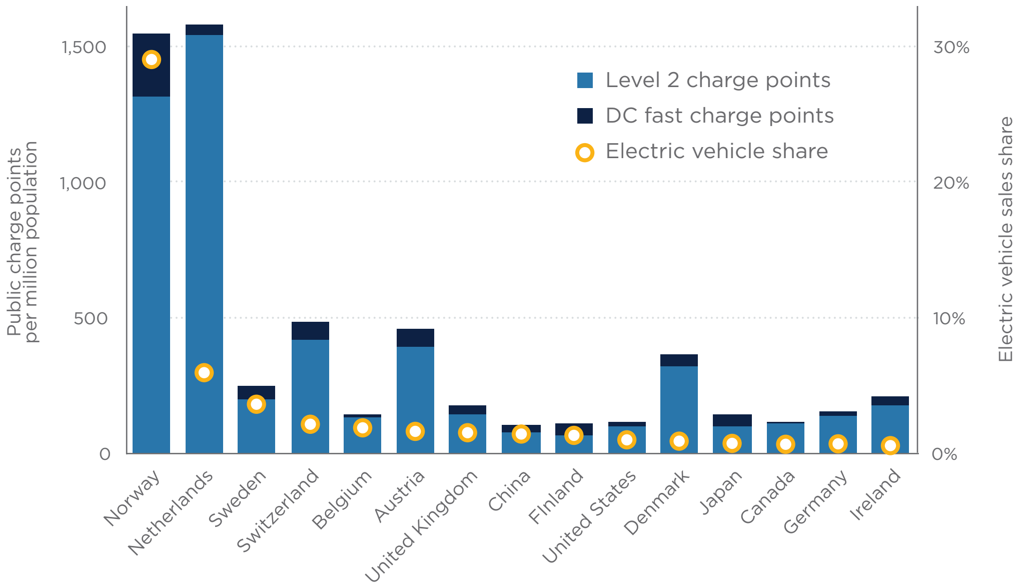
In the United States, the growth of EV charging infrastructure will be determined by a more complicated combination of factors. Studies have produced a range of estimates:

- A 2017 study by the US National Renewable Energy Laboratory (NREL) forecasts demand for 8,500 DC fast-charging stations and approximately 600,000 nonresidential Level 2 chargers in the United States in 2030, based on an assumption of 15 million plug-in EVs on US roads. (NREL also found that that approximately 400 DC fast-charging stations spaced 70 miles apart on average across the US interstate highway system could provide convenient access for all-electric vehicles along major corridors.) Parameters including average electric range of EVs and the share of charging taking place at home had large effects on the demand for public EV infrastructure.[77]
- Another 2017 National Renewable Energy Laboratory study estimated that 37,000–45,000 workplace chargers and 5,000–44,000 public chargers would be needed to support 400,000 EVs in Massachusetts. The study noted that while most EV drivers in Massachusetts would charge at home or work, "a large segment of the vehicle fleet operates with atypical travel patterns on any given day of the week," meaning public charging infrastructure would be essential to support mass adoption of EVs.[78]
- A 2018 report by NREL and the California Energy Commission found a need for 99,000–133,000 workplace and public Level 2 chargers in California and 9,000–25,000 DC fast chargers, plus tens of thousands of chargers at multiunit dwellings.[79]
- Navigant Research has published several studies about EV infrastructure markets in the United States. Its "DC Charging Map" shows the need for just 95 DC fast-charging stations along major intercity highway corridors—far fewer than exist today—and that 408 DC fast-charging stations would suffice to charge EVs in the 100 largest metropolitan areas of the United States.[80]

In projecting future demand for public EV charging, one potential method is to analyze ratios such as the number of public EV chargers per electric vehicle in different areas. However, this ratio varies greatly across regions: California has 25–30 EVs per public charger; China has roughly eight EVs per public charger; the Netherlands has two to seven EVs per public charger. Because of differences in vehicles, driving patterns and availability of home and workplace charging, there is no global rule of thumb with respect to this ratio.[81]

Analysts have employed a wide variety of methodologies to estimate future EV charging infrastructure needs, from simple ratios to complex algorithms. The highly dynamic nature of the industry and increasing availability of data on EV charging behavior make it likely that many of the methodologies and estimates will need revisions in the years ahead.[82]

Figure 9: 2016 EV sales and public charge posts per million population in various EV markets



Source: International Council on Clean Transportation 2017

Table 3: Estimated U.S. Station and Plug Count to Support 15 million PEVs in 2030

		Cities	Towns	Rural Areas	Interstate Corridors
All-electric vehicles		12,411,000	1,848,000	642,000	-
DCFC	**Stations** (to provide coverage)	4,900	3,200	-	400
	Plugs (to meet demand)	19,000	4,000	2,000	2,500
	Plugs per station	3.9	1.3	-	6.3
	Plugs per 1,000 all-electric vehicles	1.5	2.2	3.1	-
Non-Res L2	**Plugs** (to meet demand)	451,000	99,000	51,000	-
	Plugs per 1,000 all-electric vehicles	36	54	79	-

Source: National Renewable Energy Laboratory, 2017

3. EV CHARGING POLICIES

A. Charging Infrastructure Policy in China

i. General

The Chinese central government promotes the development of EV charging networks as a matter of national policy. It sets targets, provides funding and mandates standards. In addition, many provincial and local governments promote EV charging networks with financial incentives, requirements that residential building owners provide EV charging spaces and mandates for a percentage of commercial parking spots to have EV charging.

Central government policies are set forth in at least five documents:

- In September 2015, the State Council issued the *Guidance on Accelerating the Construction of Electric Vehicle Charging Infrastructure*. The guidance calls for charging infrastructure sufficient for 5 million EVs by 2020, all new residential construction to be equipped EV charging, 10% of parking spaces in large public buildings to be available for EV charging and at least one public charging station for every 2,000 EVs. The guidance also calls for public-private partnerships to develop charging infrastructure, specifically mentioning shopping malls, grocery stores and major parking facilities as places that should be incentivized to install public chargers.[83]

- In October 2015, NDRC issued the *Guidelines for Developing Electric Vehicle Charging Infrastructure (2015–2020)*. The guidelines call for at least 120,000 EV charging stations and 4.8 million EV charging posts by 2020. The guidelines divide China into three regions with varying degrees of EV infrastructure promotion and call for establishing a grid of EV-charging-enabled highways covering the most populous coastal provinces of East China.[84]

- In January 2016, the National Energy Administration released a notice summarizing five new national standards for electric vehicle charging interfaces and communications protocols. The standards were issued in late 2015 by the National Standards Committee, the Ministry of Industry and Information Technology and others.[85]
- In January 2016, the Ministry of Finance, Ministry of Science and Technology, Ministry of Industry & Information Technology (MIIT), National Development and Reform Commission (NDRC), and National Energy Administration (NEA) published the 13th *Five-Year Plan for New Energy Vehicle Infrastructure Incentive Policies*. The plan included RMB 90 million in funding for installation of charging infrastructure, specifying that charging stations should have a minimum number of charging posts, chargers would be installed at government buildings and the procurement of chargers would be open to any charging manufacturer.[86]
- In July 2016, NDRC published a *Notice on Accelerating Residential EV Charging Infrastructure Construction*, setting out standards and procedures for residential charging as well as designating the Jing-Jin-Ji, Yangtze River Delta and Pearl River Delta regions as demonstration zones for residential charging infrastructure development.[87]

Many provincial and local governments also support EV charging with financial incentives, requirements with respect to new building construction and other policies:

- The city of Shenzhen offers purchasers of EVs subsidies of up to RMB 20,000 for vehicle insurance and installation of charging equipment.[88]
- Over 30 other cities offer some form of subsidy for home or public EV charging.[89]
- As early as 2014, Guangzhou adopted a requirement that new buildings must have 18% of parking spots either equipped with EV charging or enabled for future installation.[90]
- In 2017 the Beijing municipal government began mandating that all parking spots in new residential developments set aside space for EV chargers, with new government or state-owned enterprise buildings required to install chargers at 25% of parking spots.[91]

China's central government has recently recognized the importance of making public charging a viable business as part of an overall strategy for promoting EV usage. The central government is considering a shift from incentives for equipment installation to incentives that encourage EV charging at public stations, possibly through a reduction in the per-kWh EV charging fee.[92] Residential charging would remain the cheapest option since it has no service fee and residential rates are lower than public charging rates.

ii. Utility Rate Design

China's electric power sector is dominated by two large grid companies: State Grid Corporation of China (State Grid) and China Southern Grid. Central government regulatory officials set overall policies with respect to retail electricity rates, often including rules with respect to minimum and maximum prices for electric vehicle charging. Local officials set retail electricity prices consistent with these policies. This market and regulatory structure enables policy makers to adopt sweeping changes that cover regions or even the whole country. Pilot projects are often used to experiment with different approaches.

In 2014, the National Development and Reform Commission issued a *Notice on EV Charging Policy* clarifying EV charging rates for three classes of customers. First, residential customers pay the residential rate, which is typically one of the lowest tariffs. Second, dedicated central EV charging and battery swap stations pay the large industrial customer rate, except they are exempt from the basic charge (demand charge). Third, government offices, public parking lots and other businesses pay the commercial and small/medium industrial (C&I) rate, which is typically the highest tariff. As of 2016, at least three provinces (Jiangxi, Hebei, Hunan) and 24 cities (including Beijing, Shanghai, Guangzhou, Tianjin, Shenzhen and Chongqing) had set regulations regarding commercial and public transit EV charging fees, with most of these setting a maximum charging fee per kWh. Maximums ranged widely, from RMB 2.36/kWh in Jiangxi to RMB 0.45/kWh in Taiyuan.[93]

In general, EV charging rates in China have been set at relatively low levels in order to encourage uptake of EVs. In early 2018, however, the Beijing municipal government removed caps on EV charging tariffs.[94] This reflects a shift in approach by Chinese policy makers, who are now increasingly concerned about ensuring that public EV charging is a viable business. The shift responds to complaints from some EV charging stations owners, who report that EV charging rates are too low for them to make money in light of high land prices and low utilization.[95] However, one constraint on raising rates is that EV drivers have proven highly price sensitive. Some EV rental agencies have complained that high charging rates keep rental volumes low and prevent agencies from making money.

Many Chinese provinces and cities have time-of-use rates for EV charging. State Grid uses time-of-use pricing at its own charging stations. In Beijing, State Grid charges RMB 1.0044/kWh at peak periods, RMB 0.6950/kWh at shoulder periods and RMB 0.3946/kWh at valley periods while adding a uniform RMB 0.8/kWh service fee.[96]

China has very few if any demand response programs for EVs. Such programs would be challenging in China since China lacks a wholesale power market. (In the United States, wholesale power prices fluctuate continually, creating a real-time market for demand-response aggregators to cut power consumption when demand is high.)[97]

Electric Utility Rate Definitions	Explanation
Time-of-use rate	A rate that varies based on the block of time it is consumed. The price schedule is fixed and predefined based on the season, day of week and time of day.
Variable peak pricing	A rate that varies based on both the block of time it is consumed and bulk power system conditions during that period of the day.[98]
Dynamic pricing (also known as real-time pricing)	An electricity price that reflects wholesale price and grid conditions, revised on a constant basis, providing the best available signal about the marginal value of power at each location.
Critical peak pricing	A pricing plan under which consumers receive an alert message before a major demand peak such as a cold or heat wave, with price increases to encourage load reduction during those periods
Demand response	Programs that encourage or require customers to reduce electric use at times of high wholesale market prices or when system reliability is jeopardized.[99]
Demand charge	A charge based on the greatest amount of electric power during any interval—typically an hour or a fraction of an hour—in a billing cycle. (The demand charge is in addition to energy charges, which cover the total kWh consumed, as well as service fees.)

B. Charging Infrastructure Policy in the United States

i. General

The US federal government plays a minor role with respect to the development of EV charging infrastructure. State and local governments play much more important roles in this area.

Federal policies have included the following:

- A 30% tax credit for the cost of installing an EV charging station up to a maximum of $1,000. The tax credit, which applied to the station owner as opposed to the site host, expired at the end of 2017.[100]
- Voluntary programs to support workplace and municipal EV charging run by the US Department of Energy. These programs provide a forum for employers and municipalities to learn from one another about their experiences with EV charging.
- Designation of EV charging corridors on US highways. In November 2016, the US Federal Highway Administration designated 48 EV charging corridors along 25,000 miles of US highways, based on suggestions submitted by states. The corridors include Interstate 5, from San Diego to the Canadian border; Interstate 80, from Nebraska to New York City; and many corridors within states.[101] While the corridors mostly provide signage for existing chargers, the federal government is authorized to provide up to $4.5 billion in loan guarantees for EV charging infrastructure along the corridors. No loan guarantees have been issued to date under this program.[102]

Many states offer incentives for the installation of EV charging equipment. These include rebates, tax credits, tax exemptions, grants and loans.

- The Charge Ahead Colorado program, for example, offers businesses tax credits up to $16,000 for installing public chargers.
- California offers a low-interest loan program for businesses installing chargers.[103]

Many city governments and electric utilities also offer rebates, grants, city land or rights-of-way for EV charging:

- The Los Angeles Department of Water and Power (LADWP) offers an incentive of up to $4,000 per charger installed at businesses.
- Idaho Power offered an incentive of $2,500 for stores installing EV charging infrastructure for a limited time.[104]

Table 4: U.S. state government EV charging incentive programs

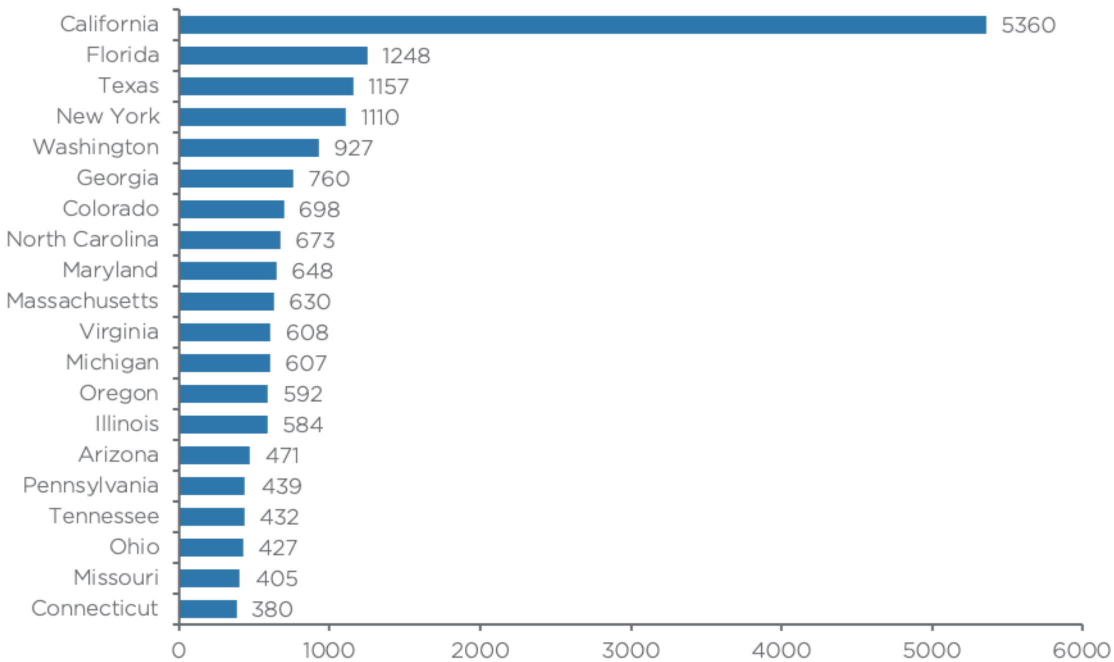
	Rebate	Tax credit	Grant	Load
AR	✓			
CA	✓		✓	✓
CO			✓	
CT			✓	
DC		✓		
DE	✓			
FL	✓			✓
GA		✓		
IL			✓	✓
LA		✓		
MA			✓	
MD	✓		✓	
NC			✓	
NE				✓
NJ			✓	
NV			✓	
NY	✓	✓	✓	
OH	✓		✓	
OK		✓		
OR				✓
PA			✓	
RI	✓			
TX			✓	
UT			✓	✓
VA			✓	✓
WA		✓		

Source: Alternative Fuels Data Center, U.S. Department of Energy, 2018

In addition to financial incentives, some states are promoting EV charging through standards, mandates and codes. Oregon requires homeowners' associations to approve applications for new residential EV chargers within 60 days. California's CalGreen Code goes further, requiring residential buildings with over 17 units to have a minimum of 3% of all parking spaces ready for future installation of EV chargers. The Code specifies wiring practices, labeling, EV charging space dimensions and markings, and accessibility. The CalGreen Code also provides guidance on the minimum number of required electrified parking spaces for commercial, retail and nonresidential locations.[105]

States have also taken the lead in preparing highway corridors for EV charging. Interstate 5, which runs from San Diego to Canada, was the first major EV corridor, designated as the West Coast Electric Highway. The first stations on the system broke ground in 2011, and the West Coast Electric Highway was declared open in 2012.[106] The system now also includes hundreds of DC fast-charging posts operated by a variety of charging networks.[107] The program is structured as a public-private partnership. Much of the funding for building the network came from state and federal government grants.[108]

Figure 10: U.S. non-residential charging stations by state, January 2019



Source: Alternative Fuels Data Center, US Department of Energy, January 2019

ii. Utility Rate Design

The United States has a highly decentralized electric utility system, with hundreds of utilities operating retail electric grids. The Federal Energy Regulatory Commission regulates wholesale power markets but has no direct power over retail electric rates.

US regulators and electric utility companies are at an early stage in evaluating rate design for EV charging. A 2018 report by the Smart Electric Power Alliance (SEPA) found that only 47 of 447 utilities surveyed had adopted EV-specific tariffs. Fourteen utilities had conducted EV charging pilot projects. Only about 25% of US utilities had taken EV-related actions beyond what SEPA termed "early stage."[109]

However, many US utilities are now considering EV tariffs. SEPA's 2017 report found that 69%

of US utilities were evaluating EV tariffs or other changes to rate structures to help manage EV load.[110]

Time-of-use pricing for EVs is receiving growing attention in the United States. Until recently, time-of-use pricing for residential customers in the United States was minimal, in part because of the cost of smart meters. Residential time-of-use rates were mostly limited to a small number of customers who opted into the programs.[111] Recently, however, several states have been moving toward TOU rates for residential customers, including for EVs. Over a dozen utilities offer some forms of time-of-use tariffs for residential EV charging.

- Several TOU programs, including in Colorado, Michigan, Minnesota and Wisconsin, subsidize the cost of purchasing EV chargers for users who opt into a residential time-of-use rate for all household electricity usage.[112]
- Alaska Electric Light and Power offers a special TOU EV charging rate for those with compatible EVSE equipment, and the utility subsidizes EVSE purchases.[113]
- Hawaii offers a residential whole-house TOU rate for EV owners and also applies TOU rates to public fast-charging stations.[114]
- Nevada has offered time-of-use rates for residential EV owners since 2009, and lists the program as an "electric vehicle rate" on its website. Like many states, the rate applies to the energy consumption of the entire house. The program charges a lower rate for off-peak energy consumption. The utility is studying expanding the program to include EV charging into demand response programs and distributed resource planning.[115]
- Utilities in Michigan are evaluating separately metered time-of-use EV charging rates.[116]

Several studies provide useful data on time-of-use rates:

- A project directed by the Idaho National Laboratory from 2009 to 2013 found that in Washington State, with no time-of-use pricing, charging use peaked in the early evening. In San Diego and San Francisco, which introduced an evening off-peak rate reduction of around $0.10/kWh, a daily charging spike coincided with the time when off-peak rates began. In Los Angeles, which had a time-of-use rate but a pricing differential of just $0.025/kWh, the charging curve showed more modest shifting of charging to the off-peak rate.[117]
- A 2017 NREL study using PG&E data showed a spike in charging coinciding with the beginning of off-peak rates each day. The study recommends that "at high EV penetration levels, dynamic rates and automated control will better smooth charging loads."[118]

Several pilot programs in which EVs provide demand response are underway in the United States. The state of California has approved an EV demand response program under which eMotorWerks will aggregate 1,000 EVs to ensure that their charging times can respond to grid requests.[119] Vermont's Green Mountain Power offers an EV charger in exchange for participation in a demand response program that will interrupt charging at super-peak times.[120]

US charging network executive:

"Fleets have good characteristics in terms of flexibility...That gives you better control than in the residential charging case, because you can build a schedule for charging, as in midday when you have negative electricity pricing due to solar."

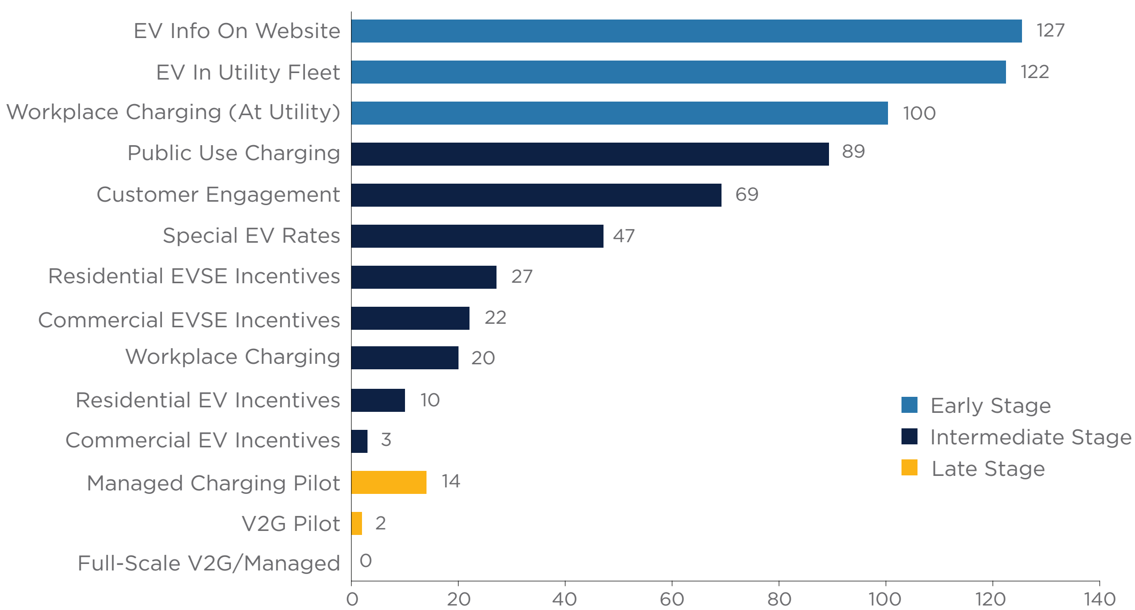
US utility regulator:

"We see controlled charging as the end game. You have flexibility to not get locked into just relying purely on the off-peak pricing signal. By using controlled charging, you recognize that sometimes people need to charge during the day, and you can even encourage that."

In addition, California regulators have approved a dynamic pricing pilot for San Diego Gas & Electric (SDG&E) that will incorporate hour-ahead wholesale prices into EV charging rates, enabling EVs to absorb electricity when wind and solar output are at their peak.[121]

The potential for EV chargers to incur significant demand charges is receiving growing attention. California and Hawaii have temporarily suspended demand charges for EV charging and other states including New York and Maryland have taken up the issue.[122] A 2017 report study by the Rocky Mountain Institute recommended reducing or waiving demand charges for EV charging.[123]

Figure 11: Actions taken by U.S. utilities to prepare for EV adoption



Source: Smart Electric Power Alliance, March 2018

C. Comparison—China and the United States

The Chinese central government is far more active than the US federal government in promoting EV charging. In both countries, subnational governments (state, provincial and local) play important roles in EV charging. Policy tools used in both countries include subsidies for installing charging infrastructure—via tax credits, grants and low-cost loans—as well as mandates and standards.

Time-of-use tariffs to promote off-peak charging are becoming more common in both China and the United States. In China, time-of-use EV charging rates apply to public charging in some areas but not to residential charging. In the United States, a growing number of utilities offer time-of-use pricing for EV owners (often applied to energy consumption for the EV owner's house as a whole).

Demand response programs for aggregated EV charging are less common. In China, demand response for aggregated EV charging is still some ways off and would likely depend on power market reform in areas such as spot markets and ancillary services. In the United States, California has the largest EV demand response programs. Other states are experimenting with pilot programs as well.

Table 5: Comparison of China and U.S. EV charging policies

	China	U.S.
Subsidies for EV purchase	Yes, central government and some provinces	Yes, federal government and some states
Subsidies for EV charging installation	Yes, mainly provincial and municipal	Yes, mainly state and local
National charging infrastructure plan	Yes, set in 2015	No
National EV highway plan	Yes, being implented	Yes, but only in certain states
National EV charging plug standard	Yes, both slow and fast-charging	No
Policies requiring home or multi-unit building charging	Yes, for new buildings, but limited to space requirements	Yes, in some states and cities
Policies requiring charging at government or govt-related facilities	Yes, set in 2018	No national requirement
Policies on EV charging tariffs	Yes, with most localities setting maximum EV charging tariffs	At state or local level, but many states do not allow charging operator electricity sales
Time-of-use charging tariffs	Common, depends on locality	Common, depends on locality
Dynamic time-of-use charging tariffs	No	No
Charging demand response programs	No	Growing number of pilots

Source: Authors

4. EV CHARGING TECHNOLOGIES

EV charging technologies in China and the United States are broadly similar. In both countries, cords and plugs are the overwhelmingly dominant technology for charging electric vehicles. (Wireless charging and battery swapping have at most a minor presence.) There are differences between the two countries with respect to charging levels, charging standards and communications protocols. These similarities and differences are discussed below.

A. Charging Levels

In the United States, a great deal of EV charging takes place at 120 volts using unmodified home wall outlets. This is generally known as Level 1 or "trickle" charging. With Level 1 charging, a typical 30 kWh battery takes approximately 12 hours to go from 20% to a nearly full charge. (There are no 120 volt outlets in China.)

In both China and the United States, a great deal of EV charging takes place at 220 volts (China) or 240 volts (United States). In the United States, this is known as Level 2 charging. Such charging may take place with unmodified outlets or specialized EV charging equipment and typically uses about 6–7 kW of power. When charging at 220–240 volts, a typical 30 kWh battery takes approximately 6 hours to go from 20% to a nearly full charge.

Finally, both China and the United States have growing networks of DC fast chargers, commonly using 24 kW, 50 kW, 100 kW or 120 kW of power. Some stations may offer 350 kW or even 400 kW of power. These DC fast chargers can take a vehicle battery from 20% to a nearly full charge in times ranging from roughly one hour to as little as 10 minutes.

Table 6: Most common charging levels in U.S.

Charging Level	Vehicle Range Added per Charging Time and Power	Supply Power
AC Level 1	4 mi/hour @ 1.4kW 6 mi/hour @ 1.9kW	120 V AC/20A *(12-16A continuous)*
AC Level 2	10 mi/hour @ 3.4kW 20 mi/hour @ 6.6kW 60 mi/hour @19.2kW	208/240 V AC/20-100A *(16-80A continuous)*
Dynamic time-of-use charging tariffs	24 mi/20 minutes @ 24kW 50 mi/20 minutes @ 50kW 90 mi/20 minutes @90kW	208/480 V AC 3-phase *(input current proportional to output power; ~20-400A AC)*

Source: U.S. Department of Energy

B. Charging Standards

i. China

China has one nationwide EV fast charging standard. The US has three EV fast charging standards.

The Chinese standard is known as China GB/T. (The initials *GB* stand for *national standard*.) China GB/T was released in 2015 after several years of development.[124] It is now mandatory for all new electric vehicles sold in China. International automakers, including Tesla, Nissan and BMW, have adopted the GB/T standard for their EVs sold in China. GB/T currently allows fast charging at a maximum of 237.5 kW of output (at 950 V and 250 amps), though many Chinese DC fast chargers offer 50 kW charging. A new GB/T will be released in 2019 or 2020, which will reportedly upgrade the standard to include charging up to 900 kW for larger commercial vehicles. GB/T is a China-only standard: the few China-made EVs exported abroad use other standards.[125]

In August 2018, the China Electricity Council (CEC) announced a memorandum of understanding with the CHAdeMO network, based in Japan, to jointly develop ultra-fast charging. The goal is compatibility between GB/T and CHAdeMO for fast charging. The two organizations will partner to expand the standard to countries beyond China and Japan.[126]

ii. United States

In the United States, there are three EV charging standards for DC fast charging: CHAdeMO, CCS SAE Combo and Tesla.

CHAdeMO was the first EV fast-charging standard, dating to 2011. It was developed by Tokyo Electric Power Company and stands for “Charge to Move” (a pun in Japanese).[127] CHAdeMO is currently used in the United States in the Nissan Leaf and Mitsubishi Outlander PHEV, which are among the highest-selling electric vehicles. The Leaf’s success in the United States may be due in part to Nissan's early commitment to roll out CHAdeMO fast-charging infrastructure at dealerships and other urban locations.[128] As of January 2019, there were over 2,900 CHAdeMO fast chargers in the United States (as well as more than 7,400 in Japan and 7,900 in Europe).[129] In 2016, CHAdeMO announced it would upgrade its standard from its initial charging rate of 70 kW to offer 150 kW.[130] In June 2018 CHAdeMO announced the introduction of 400 kW charging capability, using 1,000 V, 400 amp liquid-cooled cables. The higher charging will be available to meet the needs of large commercial vehicles such as trucks and buses.[131]

A second charging standard in the United States is known as CCS or SAE Combo. It was released in 2011 by a group of European and US auto manufacturers. The word *combo* indicates that the plug contains both AC charging (at up to 43 kW) and DC charging.[132] In Germany, the Charging Interface Initiative (CharIN) coalition was formed to advocate for the widespread adoption of CCS. Unlike CHAdeMO, a CCS plug enables DC and AC charging with a single port, reducing the space and openings required on the vehicle body. Jaguar, Volkswagen, General Motors, BMW, Daimler, Ford, FCA and Hyundai support CCS. Tesla has also joined the coalition and in November 2018 announced its vehicles in Europe would come equipped with CCS charging ports.[133] The Chevrolet Bolt and BMW i3 are among the popular EVs in the United States that use CCS charging. While present CCS fast chargers offer charging at around 50 kW, the Electrify America program includes fast charging of 350 kW, which could enable a nearly complete charge in as little as 10 minutes.

The third charging standard in the United States is operated by Tesla, which launched its own proprietary Supercharger network in the United States in September 2012.[134] Tesla Superchargers typically operate at 480 volts and offer charging at a maximum of 120 kW. As of January 2019, the Tesla website listed 595 Supercharger locations in the United States, with an additional 420 locations "coming soon."[135] In May 2018, Tesla suggested that in the future its Superchargers might reach power levels as high as 350 kW.[136]

In our research for this report, we asked U.S. interviewees whether they considered the lack of a single national standard for DC fast charging to be a barrier to EV adoption. Few answered in the affirmative. The reasons that multiple DC fast charging standards are not considered to be a problem include:

- Most EV charging takes place at home and work, with Level 1 and 2 chargers.
- Much of the public and workplace charging infrastructure to date has used Level 2 chargers.
- Adaptors are available that allow EV owners to use most DC fast chargers, even if the EV and charger use different charging standards. (The main exception, the Tesla supercharging network, is only open to Tesla vehicles.) Notably, there are some concerns about the safety of fast-charging adaptors.
- Since the plug and connector represent a small percentage of the cost of a fast-charging station, this presents little technical or financial challenge to station owners and could be compared to the hoses for different octane gasolines at a fueling station. Many public charging stations have multiple plugs attached to a single charging post, allowing any type of EV to charge there. Indeed, many jurisdictions require or incentivize this.

Some carmakers have said that an exclusive charging network represents a competitive strategy. Claas Bracklo, head of electromobility at BMW and chairman of CharIN, stated in 2018, “We have founded CharIN to build a position of power.”[137] Many Tesla owners and investors consider its proprietary supercharger network a selling point, although Tesla continues to express willingness to allow other car models to use its network provided they contribute funding proportional to usage.[138] Tesla is also part of CharIN promoting CCS. In November 2018, it announced that Model 3 cars sold in Europe would come equipped with CCS ports. Tesla owners can also purchase adaptors to access CHAdeMO fast chargers.[139]

C. Charging Communication Protocols

Charging communication protocols are necessary to optimize charging for the needs of the user (to detect state of charge, battery voltage and safety) and for the grid (including distribution network capacity, time-of-use pricing and demand response measures).[140] China GB/T and CHAdeMO use a communication protocol know as CAN, while CCS works with the PLC protocol. Open communications protocols, such as the Open Charge Point Protocol (OCPP) developed by the Open Charging Alliance, are becoming increasingly popular in the United States and Europe.

In our research for this report, several U.S. interviewees cited the move toward open communications protocols and software as a policy priority. In particular, some public charging projects that received funding under the American Recovery and Reinvestment Act (ARRA) were cited as having chosen vendors with proprietary platforms that subsequently experienced financial difficulties, leaving broken equipment that required replacement.[141] Most cities, utilities, and charging networks contacted for this study expressed support for open communications protocols and incentives to enable charging network hosts to seamlessly switch providers.[142]

D. Costs

Home chargers are cheaper in China than in the United States. In China, a typical 7 kW wall-mounted home charger retails online for between RMB 1,200 and RMB 1,800.[143] Installation requires additional cost. (Most private EV purchases come with charger and installation included.) In the United States, Level 2 home chargers cost in the range of $450-$600, plus an average of roughly $500 for installation.[144]

DC fast charging equipment is significantly more expensive in both countries. Costs vary widely. One Chinese expert interviewed for this report estimated that installing a 50 kW DC fast-charging post in China typically costs between RMB 45,000 and RMB 60,000, with the charging post itself accounting for roughly RMB 25,000 - RMB 35,000 and cabling, underground infrastructure and labor accounting for the remainder.[145] In the United States, DC fast charging can cost tens of thousands of dollars per post. Major variables affecting the cost of installing DC fast charging equipment include the need for trenching, transformer upgrades, new or upgraded circuits and electrical panels and aesthetic upgrades. Signage, permitting and access for the disabled are additional considerations.[146]

E. Wireless Charging

Wireless charging offers several advantages, including aesthetics, time saving and ease of use. It was available in the 1990s for the EV1 (an early electric car) but is rare today.[147] Wireless EV charging systems offered online range in cost from $1,260 to around $3,000.[148] Wireless EV charging carries an efficiency penalty, with current systems offering charging efficiency of around 85%.[149] Current wireless charging products offer power transfer of 3–22 kW; wireless chargers available for several EV models from Plugless charge at either 3.6 kW or 7.2 kW, equivalent to Level 2 charging.[150] While many EV users consider wireless charging not worth the additional cost,[151] some analysts have forecast the technology will soon be widespread, and several carmakers have announced they would offer wireless charging as an option on future EVs. Wireless charging could be attractive for certain vehicles with defined routes, such as public buses, and it has also been proposed for future electric highway lanes, though high cost, low charging efficiency and slow charging speeds would be drawbacks.[152]

F. Battery Swapping

With battery swapping technology, electric vehicles could exchange their depleted batteries for others that are fully charged. This would dramatically shorten the time required to recharge an EV, with significant potential benefits for drivers.

Several Chinese cities and companies are currently experimenting with battery swapping, with a focus on high-utilization fleet EVs, such as taxis. The city of Hangzhou has deployed battery swapping for its taxi fleet, which uses locally made Zotye EVs.[155] Beijing has built several battery-swap stations in an effort supported by local automaker BAIC. In late 2017, BAIC announced a plan to build 3,000 swapping stations nationwide by 2021.[156] The Chinese EV startup NIO plans to adopt battery-swap technology for some of its vehicles and announced it would build 1,100 swapping stations in China.[157] Several cities in China—including Hangzhou and Qingdao—have also used battery swap for buses.[158]

In the United States, discussion of battery swapping faded following the 2013 bankruptcy of Israeli battery-swap startup Project Better Place, which had planned a network of swapping stations for passenger cars.[153] In 2015, Tesla abandoned its swapping station plans after building only one demonstration facility, blaming lack of consumer interest. There are few if any experiments underway with respect to battery swapping in the United States today.[154] The decline in battery costs, and perhaps to a lesser extent the deployment of DC fast-charging infrastructure, have likely reduced the attraction of battery swapping in the United States.

While battery swapping offers several advantages, it has notable drawbacks as well. An EV battery is heavy and typically located at the bottom of the vehicle, forming an integral structural component with minimal engineering tolerances for alignment and electrical connections. Today's batteries usually require cooling, and connecting and disconnecting cooling systems is difficult.[159] Given their size and weight, battery systems must fit perfectly to avoid rattling, reduce wear and keep the vehicle centered. Skateboard battery architecture common in today's EVs improves safety by lowering the vehicle's center of weight and improving crash protection in the front and rear. Removable batteries located in the trunk or elsewhere would lack this advantage. Since most vehicle owners charge mainly at home or at work, battery swapping would not necessarily resolve the charging infrastructure issues—it would only help address public charging and range. And because most automakers are unwilling to standardize battery packs or designs—cars are designed around their batteries and motors, making this a key proprietary value[160]—battery swap might require a separate swapping station network for each car company or separate swapping equipment for different models and sizes of vehicles. Though mobile battery swapping trucks have been proposed,[161] this business model has yet to be implemented.

5. EV CHARGING BUSINESS MODELS

As the electric vehicle stock grows, the potential revenue to be earned from EV charging will grow. A wide range of businesses are currently competing for a share of that revenue. Other businesses are investing in EV charging to promote electric vehicle sales, increase electric demand, attract customers to retail outlets, meet regulatory requirements or achieve other goals. The result is a wide range of players experimenting with different overlapping approaches and positions in the market. We describe key market participants and their approaches below.[162]

A. Independent Charging Networks

In both China and the United States, a number of companies now operate and support EV charging networks as their principal business. These companies deliver a wide range of services to property owners and EV drivers, including charging equipment selection, software development, telecommunications, marketing, customer support and payment processing. We refer to charging networks not owned and operated by utilities or auto manufacturers as "independent charging networks."

i. China

There are a number of independent charging networks in China, many of which have a regional focus. The largest is Tgood (Telaidian), with 121,212 charging posts as of year-end 2018, followed by StarCharge, with 54,814.[163]

China's charging networks are generally located in large urban areas, such as the leading EV cities of Beijing, Shanghai and Shenzhen. These networks host charging stations in a variety of locations, including in public parking lots, on street curbsides, at shopping centers and entertainment venues, and on private property. Private charging networks offer both fast charging as well as Level 2 charging, often with proprietary payment systems. Some charging networks allow payment by either or both of China's most popular mobile payment systems, WeChat and Alipay, enabling virtually any user to pay by scanning a QR code. Charging fees are strictly regulated to the published electricity price plus a capped service fee. Given low utilization of public charging posts, many private charging networks report they are presently unable to earn profits under this regulatory structure. Motivations for installing charging posts can include earning equipment subsidies, meeting government targets and capturing market share to take advantage of future policy and market developments.

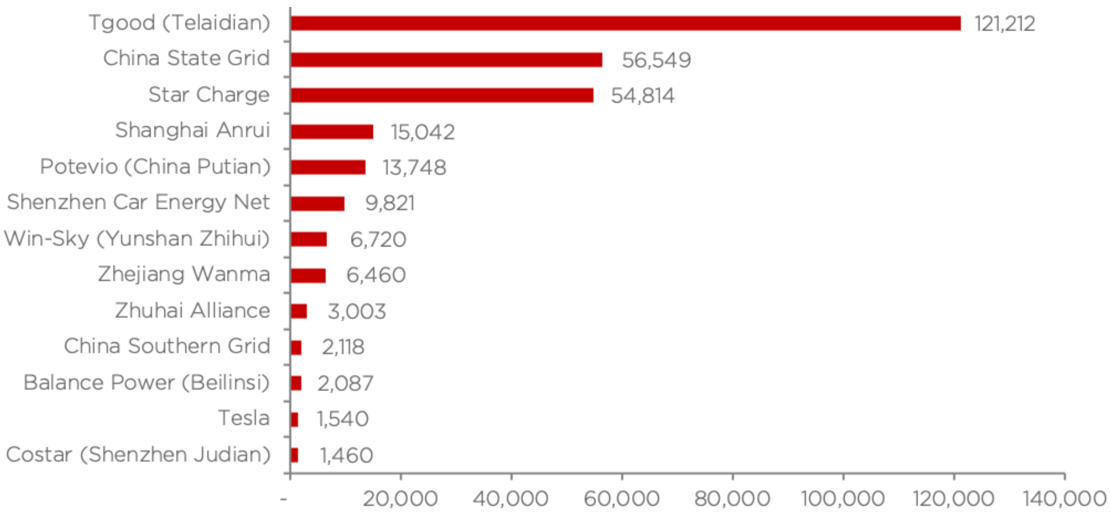
Figure 12: Private charging networks in Beijing

Source: Anders Hove, 2018

China EV industry expert:

"Companies are just installing charging as a kind of land grab, even though they will lose money."

Figure 13: Number of China public or fleet EV charging posts by company



Source: China EV Charging Alliance, January 2019. Tgood (Telaidian) figures include contractor-operated chargers; Star Charge figures include privately-operated shared charging points.

ii. United States

The largest independent EV charging networks in the United States include ChargePoint, EVgo, Blink and Greenlots.[164]

ChargePoint operates the largest EV charging network in the United States, with over 58,000 charging posts in the United States as of January 2019. Most of these are Level 2 chargers at businesses and workplaces. ChargePoint also designs and builds EV charging equipment and has raised funds from BMW, Daimler and Siemens.[165]

EVgo owns and operates the largest public EV fast-charging network in the United States, with over 1,100 DC fast chargers in 66 US metropolitan areas as of January 2019. EVgo reports providing over 110,000 charges to more than 50,000 drivers each month. EVgo partners include Simon Properties, Rite Aid, Whole Foods and CalTrans.[166]

Blink Charging provides public EV charging at thousands of locations across the United States, as well as chargers for home use. The company was founded as Ecotality and received a $100 million grant to build a nationwide charging network under the 2009 American Recovery and Reinvestment Act. The company employs a subscription-based model for EV charging.[167]

Greenlots is an EV charging network and software provider that offers end-to-end EV charging services to businesses, governments, fleet owners, utilities and others. The company has deployments in 13 countries and was selected by Electrify America to deploy Greenlots software for the initiative's 2,000-EV charging station coast-to-coast network as part of the Volkswagen diesel-gate settlement.[168]

B. Utility Companies

i. China

China State Grid and China Southern Grid have built significant numbers of EV charging stations. As of year-end 2018, China State Grid owned 56,549 charging posts.[169] China State Grid has developed an extensive network of public charging stations along the major highway corridors of East China, largely intended for use on long-distance trips. Grid-owned charging points are also located at customer service centers around China. (Visits conducted for this study show that at least some of these charging points are located in areas unsuited for EV charging, such as along a pedestrian-only street in Beijing.)

China's grid companies are also responsible for upgrading distribution-level infrastructure for privately owned chargers for public or fleet use in cities. These investments can be expensive and time consuming and are paid for as part of the grid company's social responsibility budget. Interviews with grid company experts and charging network providers in China suggest that slow grid upgrades to support the charging network have been an issue. State Grid has an annual plan for upgrading distribution infrastructure. Applications for grid upgrades must be made early or they will not be included in the plan for the following year. According to one grid expert, utility incentives are one issue: "Distribution upgrades for EV charging do not earn profit. Instead, they are considered as societal responsibility."

ii. United States

In the United States, some electric utility companies are exploring ways to provide EV charging. There are various motivations. Regulated transmission and distribution companies that earn a return on allowed investments in infrastructure may see EV charging as a way to boost long-term revenue and profits. Power companies with generation assets may see an opportunity to boost electricity sales, especially in an environment of flat or declining electricity consumption. (This model is hardly new: New York Edison established a charging network in Manhattan in the early 1900s, for example.[170]) Some utilities may see a way to improve grid operation and utilization of grid assets with demand response or other programs. Some utilities may see EV charging as a new technology with branding and corporate image-building potential.

California's state's three investor-owned utilities (IOUs) each have EV charging infrastructure pilot programs that have won approval from state regulators. Southern California Edison, whose service territory includes much of Southern California, won approval in 2016 for adding 1,500 chargers at homes, businesses, and public charging locations.[171] San Diego Gas & Electric (SDG&E) also won regulatory approval that year for a 3,500-charger program.[172] Pacific Gas & Electric (PG&E) won approval in January 2018 to install 7,500 Level 2 chargers, mostly at homes, offices and other places where cars sit for long periods.[173] (As of this writing, the impact of PG&E's bankruptcy filing on these installations is uncertain.)

California utilities have also sought approval for installing infrastructure for DC fast-charging stations along highways and at park-and-ride locations, and for chargers for medium- and heavy-duty trucks, school buses, forklifts and other commercial and industrial EV applications.[174] In May 2018, the California Public Utilities Commission approved over $750 million in IOU EV charging investments and related customer rebates. These infrastructure investments will place a special emphasis on building out infrastructure for medium- and heavy-duty trucks as well as charging for multi-unit dwellings and EV infrastructure in disadvantaged communities that suffer disproportionately from poor air quality.[175]

California regulators have not approved all proposals for utility investment in EV charging infrastructure. Ratepayer groups have objected to some spending in this area. However the approved investments represent a significant shift from earlier in this decade, when regulators were more skeptical of utility investment in EV charging infrastructure.

Utilities outside California are also pursuing their own EV charging networks. In Seattle, the city's Drive Clean Seattle Initiative includes plans for 20 utility-owned public DC fast-charging stations and 200 other utility-owned charging stations, to be completed in 2017–2018.[176] Seattle City Light has implemented a DC fast-charging rate of $0.43/kWh at its first DC charging stations.[177]

In Kansas City, in 2015 the investor-owned utility Kansas City Power & Light launched a program to install 1,000 chargers across its service territory. The utility installed chargers in public parking garages, at malls, and along highway corridors, among other locations, initially offering charging for free to encourage EV uptake.[178] Partly as a result, Kansas City saw EV ownership surge 78% in the first quarter of 2017 versus the year prior.[179] The utility had hoped to pay for its charging network through a charge on utility rates, but that has been controversial. Regulators rejected that proposal, although an appeals court then overturned the regulators' decision.[180] Another Missouri utility, Ameren, is also pursuing regulatory approval for including EV charging infrastructure in the rate base.[181]

U.S. charging network executive:

"Utilities have captive customers, and utilities see a clear benefit of boosting electricity sales by substituting electricity for gasoline."

U.S. utility regulator:

"We decided there were opportunities for utilities to own and build specific types of infrastructure and partner with others for capabilities we don't have. It's a team sport: charging networks and others can do their part."

A number of other states have made regulatory decisions on EV charging deployment. In April 2018, the Ohio Public Utilities Commission approved AEP to invest in charging infrastructure across the state, including by offering rebates for private chargers as well as directly installing charging. AEP will install 375 charging stations, of which 150 will be at workplaces and 60 at multifamily housing. The program has the potential to more than double the number of chargers in the state.[182] In May 2018, New York adopted a $250 million, seven-year program to roll out DC fast chargers, add public fast-charging at airports and establish EV model communities.[183]

C. Auto Manufacturer Charging Networks

Two auto manufacturers—Tesla and BYD—operate their own EV charging networks. Several other auto manufacturers partner with independent charging network companies to provide EV charging services.

As of January 2019, Tesla's network included over 12,000 Superchargers at 1,400 locations around the world.[184] This included 188 location in China and 595 locations in the United States. Most Tesla Superchargers are located near highways, however Tesla has begun to build more Supercharger locations in cities. In early 2018, Tesla opened several 50-stall charging locations, including one each in Beijing and Shanghai.[185] Tesla has announced plans to open Supercharger locations with lounges, shops and other amenities.[186] In China, Tesla uses the GB/T standard. Outside of China, Tesla uses its own proprietary charging standard. Customers who bought Tesla cars before 2017 receive free charging at Tesla Supercharger locations.

The full cost of building out Tesla's Supercharger network is not available publicly, but some public documents suggest a cost range of between $150,000 and $250,000 per Supercharger station.[187] If those figures are accurate, the direct costs of Tesla's Supercharger network to date would be in the range of $200-$350 million.

Tesla's late 2017 reveal of the Tesla Semi included plans for "mega-chargers," with power output over 1 MW, that would charge the trucks in just 30 minutes, the time needed for mandatory rest breaks.[188]

BYD operates a charging network in China. BYD's network includes both dedicated fleet charging as well as public charging in Shenzhen and other cities. As of year-end 2018, the BYD network was China's 14th largest, with just over 1,200 charging posts.[189]

Nissan partners with several independent charging networks to provide EV charging services in the United States. Nissan's No-Charge-to-Charge program offers buyers of new Nissan Leafs in certain US markets free charging for two years at qualifying stations including EVgo and Greenlots. Nissan has also partnered with EZ-Charge, whose card works at charging posts at a number of major US charging networks. Customers can charge for free for 30 minutes at DC fast-charging posts and 60 minutes at Level 2 chargers.[190]

BMW has provided owners of its i3 EV and plug-in hybrid lineup with cards to charging networks. In the United States, BMW's ChargeNow program includes both EVgo and ChargePoint stations.[191]

Volkswagen's settlement with California led to the creation of Electrify America. The Electrify America network plans 2,800 Level 2 chargers at apartment buildings, condos and businesses and over 2000 DC fast-chargers located along major highways. 350 kW charging power will be available at some stations.[192] A typical urban location features 3-6 charge points and a highway station from 4-10 chargers, typically with several CCS charge points and one CHAdeMO plug.[193] Terminals allow payment via credit or debit card. In May 2018, Electrify America installed its first 350 kW charging station.[194] As of January 2019, the network map showed 217 chargers online or coming soon across the United States.[195]

D. Shopping Malls, Hotels and Restaurants

i. China

Shopping mall garages are among the most common locations for EV charging infrastructure in China. These garages often serve shoppers as well as workers in nearby office buildings. Some big-box, name-brand suburban stores with their own parking lots—such as Ikea—have also made EV charging available to customers.

In our research for this report, several interviewees said that the main motivations for installing EV charging infrastructure at shopping centers in China are to advertise green credentials and meet government mandates. We were also told that few property management firms enforce parking restrictions to keep dedicated EV charging spots open for EVs, and those spots are therefore frequently blocked during high traffic hours. This situation reflects the severe parking shortage in many Chinese cities.[196] At present, stores located in the malls have little opportunity to advertise or offer promotions connected to EV charging, although this may develop. There are reports that many shopping mall charging networks are poorly maintained.[197]

China's large real estate companies have shown interest in partnering with charging networks (although one media report characterized talks to date as "lots of thunder, not much rain"). In mid-2017 Vanke announced it would invest RMB 200 million to build 30,000 charging posts through 2019, partnering with StarCharge.[198] Other big-name real estate companies have partnered with charging companies on a location-by-location basis. In addition, because many real estate companies have partnered with parking sharing or parking reservation apps and networks,[199] these could eventually become a way to reserve EV charging spots and share revenues with property owners.

Tesla has located chargers at hotels, restaurants and other locations associated with the upcoming 2022 Winter Olympic Games in Zhangjiakou.[200] Several sports venues in the region are deploying chargers to comply with government efforts to boost EV adoption leading up to the Games.

China charging network executive:

"Right now, this is mainly about corporate image. They [mall owners] have to compare themselves to shopping centers nearby."

China EV industry expert:

"EV charging is either owned by the property or the charging network, and how do they make money if they share profits with business owners?"

ii. United States

In the United States, many major store chains offer public EV charging in their parking lots. These include Best Buy, Safeway, Whole Foods, Kohl's, Home Depot, Ikea and Target. Walgreens advertises that it has EV charging at over 400 locations on high-traffic road corridors around the country. Most locations include both Level 2 and DC fast charging. US regional convenience store or small grocery brands are also active, including San Antonio–based Love's Travel Stops, Pennsylvania-based Wawa, Maryland-based Royal Farms, and QuickChek in New York and New Jersey. In April 2018, Target announced plans to deploy 600 electric vehicle charging points at more than 100 US stores within two years.[201]

To draw in customers, some retailers provide free charging. Sometimes charging is provided for free for an initial period, such as one hour. Retailers and other businesses typically study consumer dwell times and spending patterns to determine the optimal mix of free and paid charging to maximize sales revenue. Some smaller convenience stores are adding services such as coffee baristas and higher-end specialty prepared foods that appeal to EV-charging customers who stay longer.

According to ChargePoint, which has partnered with Harris Teeter and Fred Meyer grocery store chains to install charging posts, grocery stores and other retailers use its network to extend product discounts and coupons to those who frequent their store chargers.[202] Store owners also use charging posts to encourage customers to stay longer. A market study by one US retailer showed that EV users spent triple the time in store and increased spending as a result.[203]

Outlet malls are often located in rural areas along freeways—an ideal place for EV chargers that appeal to potential shoppers. An analysis of outlet malls in Cleantechnica in December 2017 showed that of 217 outlet malls in North America, at least 67 already offered public EV charging capability. The two largest outlet mall companies, Simon Property and Tanger Outlets, accounted for 63 of these and had added EV chargers to 44% and 60% of their facilities, respectively. While many malls have just a handful of chargers, many have also installed "make ready" electrical and conduit work to allow the addition of many more chargers if the demand materializes.[204]

Several states offer tax credits and other incentives to retail outlets that install EV chargers. (See discussion in section 3(B)(i) above.)

U.S. charging network executive:

"In the case of retailers, they have their own tools to evaluate how long a customer stays in a store. For one store we studied, customers who stay 20–60 minutes result in more sales."

U.S. EV industry expert:

"For fast charging at 50 kW, based on typical driver behavior and average state-of-charge, they will need 11 minutes of charging, which costs $1 for electricity for an 11-minute charge, and while customers are in the store they spend far more than $1—they are bringing out bags of groceries."

E. Fueling Stations

In Europe, a number of oil majors, including Royal Dutch Shell, have begun to provide DC fast charging at their fueling stations. In China and the United States, this model has yet to emerge except on a very modest scale:

- In China, highway fueling stations at rest areas are tightly controlled by state-owned entities. Grid companies presently have a near monopoly on charging along highways. Independent charging networks have considered mobile charging units at highway fueling stations and rest areas as an option for getting around this obstacle.[205]
- In the United States, fueling station operators such as Sheetz, the mid-Atlantic chain Royal Farms and South Carolina–based Sphinx have partnered with charging network providers.[206] However, in many areas of the United States, fueling stations are unable to offer EV charging due to regulations that prevent resale of electricity.

While drivers mainly stop at conventional fueling stations to fill the tank, most retail fueling station profits come from selling snacks, beverages and other products. In the United States in 2017, for example, nonfuel sales accounted for 62% of profits at U.S. fueling stations.[207] Survey data suggest that roughly 40% of customers walk into the store while refueling their vehicle, and roughly two-thirds of summer gas station customers plan to buy snacks or beverages at gas station/convenience stores.[208] Though most EV charging takes place at home, on long trips EV customers would likely spend more time inside fueling stations even under a fast-charge scenario, giving station owners more opportunities for sales of higher-value food, beverages and services, although many drivers may be reluctant to spend the time required to recharge an EV at a retail fueling station.

F. Sharing Economy

The sharing economy has given rise to a number of apps and services to facilitate EV charging.[209]

In China, a number of apps permit users to make private charging points available for sharing. In January 2018, public officials in Hebei Province noted the difficulty of providing EV charging in rural areas and recommended that rural residents be encouraged to publicly rent or share household chargers. To support sharing models, several companies have developed Bluetooth-enabled parking spot locking devices that unlock when an EV driver arrives; the systems can even link to app-based reservation systems.[210] (These systems and apps are also available for ordinary vehicles.) Chinese equipment providers and charging networks are also getting involved in the sharing model. StarCharge, one of the largest private charging networks, has stated that 11% of the privately owned chargers it has installed are capable of sharing with the public.[211]

The progress of the sharing economy model in China is unclear, however. Interviews for this study showed that residents who would like to offer their charging point for rent perceived the following problems with the model: (1) difficulty ensuring non-EV users didn't occupy the spot, (2) concern that EV charging revenues wouldn't compensate for higher electricity bills, and (3) difficulty maintaining the charging equipment. In addition, alleys in many urban residential compounds are narrow and complex. Given that difficulty locating charging posts is one of the main complaints listed by charging app users, many residential compounds may be unsuited for offering access to charging posts to the general public.

Today PlugShare is one of the largest mobile apps for locating charging stations in the United States. The app began as a way for owners of EV chargers or wall plugs to share their chargers or plugs with other EV owners. PlugShare allows anyone to share information on charger locations and has evolved into an all-purpose, open-source map for EV users and EV charger owners to post charger information.[212]

EVMatch enables EV charger owners to offer their plugs for a fee through an app and website, evmatch.com. The app shows dozens of charge posts located across California, particularly in the Los Angeles area, as well as in Colorado and a handful in other states. The site states that owners typically charge $1–$2.50/hour for the service.[213]

With the exception of PlugShare and Tesla, there appear to be no sharing-economy EV charging apps or partnerships in the United States with a history before 2017, making it too early to assess whether this model might eventually become an important part of the EV charging ecosystem.

China has a large number of urban car-sharing services, many of which employ short-range city cars located for rent at major shopping malls or underground garages. Many of these car-sharing services employ EVs and reserve dedicated charging spaces for the vehicles in commercial garages. Shenzhen mandates that car-sharing networks use EVs, and other cities will likely follow suit. Car sharing is particularly attractive in China given the lack of dedicated parking, limited availability of home charging, and the cost and difficulty of obtaining new vehicle registration.

Car sharing is also a major trend in the United States, albeit typically with traditional vehicles rather than EVs. There have been some announcements concerning EV car-sharing networks. In 2018, GM's Maven car-sharing platform—which employs many Chevrolet Bolts—announced an alliance with EVgo to establish a dedicated charging network for the service, starting in seven major US cities.[214] Maven drivers currently have free access to public EVgo chargers.

G. Mobile Charging Units

In both China and the United States, some companies are experimenting with mobile EV charging units, using smaller units within parking lots and larger units for roadside assistance.

Mobile charging units avoid some challenges associated with EV charging infrastructure. They avoid the need for designated EV parking spaces (and enforcement tools to prevent non-EV users from parking there), can disconnect as soon as charging is complete (allowing EV drivers to depart at will instead of on a set schedule), require less investment upfront investment (no trenching or permitting) and can be repositioned or sold if utilization is low.

In China, a small number of such services are available. Mobile EV charging units—about the size of a small cabinet—are available for purchase online for between RMB 5000 and RMB 40,000, depending on AC versus DC charging and charging capacity. Brands offering these products include ChargeTT, Jingshuo and Shenzhen Huarui Zhihang. In the United States and

Europe, FreeWire's Mobi has been offering mobile charging units to customers for a variety of applications since approximately 2015. The units can be enabled with payment and analytic functions to track usage and revenue patterns.[215]

The downside of today's small, mobile charging units is that they require an on-site attendant for repositioning within a lot in real time—they can only function within a single lot. They appear best suited to sites with large parking lots or larger fleets that require charging when drivers are not around. While the technology benefits from using second-life lithium-ion batteries for its mobile units, and can help manage spikes in demand,[216] this charging technology necessarily entails energy losses, potentially boosting the cost of supplying power.

Figure 14: Photo of Didi mobile charging unit in Beijing

Source: Phoenix Long, 2017

Interviews conducted for this study in China and the U.S. suggested widespread skepticism about the mobile charging model. Some respondents expressed the view that the economics of refurbishing second-life batteries was unfavorable (especially as prices for new batteries fall). Other interviewees noted that EV drivers may be wary of networks that rely on mobile batteries, fearing that the mobile unit will not be present or will be occupied when they arrive to charge. Customers may prefer a fixed, convenient location with a reliable charging experience.

Several companies have experimented with mobile EV charging for roadside assistance. In China, taxi fleet and ride-hailing giant Didi Chuxing offers an EV battery charger unit. The units are the size of a typical three-wheeled delivery vehicle and are advertised as providing emergency charging to EVs, including e-bikes, delivery vehicles and passenger cars. Customers can order a charge through a mobile app or by calling a service number. In the United States, AAA announced in 2011 the launch of a roadside assistance unit for stranded EVs, launching in six states for vehicles with CHAdeMO plugs.[217] Similar services have been launched in Japan and Europe.[218] These types of mobile charging services have several challenges. These include energy losses from charging and discharging the mobile battery and energy loses driving to and from the customer. Interviews for this study suggested that mobile EV charging models are a stopgap measure and are unlikely to become widespread other than in rescue situations.

China EV industry expert:

"Second-life batteries—their quality is too low and refurbishing cost is too high. And batteries of course use energy and have energy losses. When the company's mobile battery drives to a location to charge up a vehicle, that represents significant energy lost in that round trip. So this is mostly for 'rescue' type situations. "

U.S. government official:

"I think of [mobile EV chargers] as temporary solutions, in that they aren't charging pedestals, but it's a cost-effective solution. Utilities only want to increase the rate base. I've been trying to pitch these mobile chargers to utilities, but they're not interested."

H. Commercial Parking Lots

Commercial parking lots are a logical place for EV charging. Such lots—which typically rent parking spaces by the day or hour—serve customers who plan to park for a considerable amount of time while engaged in nearby activities. In commercial lots, EV charging spots are often provided for the same rate as other parking spots. Users may or may not be charged for electricity. Some parking lots offer reservations and designated spots for each user entering the facility.

In the United States, many charging networks already work together with commercial parking lots to provide specialized services. ChargePoint's web page lists 10 different parking lot operators, including ParkFast in New York City, USA Parking and Central Parking Houston.[219] ChargePoint and others point out that parking lot owners realize several advantages by providing EV charging, including attracting additional, high-paying customers, environmentally friendly branding and access to data about usage patterns.

Parking lot owners weigh different considerations when evaluating whether to install charging and what type to install. Some lot owners with high occupancy may feel any EV charging detracts from occupancy. Conversely, if charging demand is sufficiently high, lot owners may install fast charging and charge extra for the service. Lots with lower demand may opt for slow charging and provide charging as a free amenity. Parking lots at high-end hotels or entertainment venues may even provide EV valet service, moving vehicles to charge posts and shifting them when charging is complete.[220]

I. Municipal EV Charging

Cities are among the largest owners of public parking spaces worldwide, including on-street parking as well as city-owned and operated parking garages and other facilities. Often cities are actively involved in managing parking policies, including enforcement as well as operation of meters and collecting fees for street parking and parking garages. Parking is a major source of revenue for many cities, and parking is a key instrument for urban development policy.[221] Many on-street parking spots are located immediately adjacent to city-operated streetlights and parking meters, providing both a potential source of power for EV charging as well as payment options. Similarly, city-owned garages and underground lots also have access to power and payment options.

Many Chinese cities now have policies promoting EVs and EV charging infrastructure. Beijing and Guangzhou require charging installation at government buildings and municipal parking lots. There are curbside charging facilities along public streets in cities such as Beijing and Shenzhen, though charging in private garages remains most common. The city of Wuhu, Anhui, has established requirements for public charging everywhere in the city within a radius of 0.9 kilometers and made city land and curbside space available.[222]

In the United States, many cities offer EV charging in city-owned garages. In February 2018, the city of Seattle opened 156 new chargers at a single downtown parking garage, one of the largest such installations in the world.[223] The City of Baltimore offers EV charging stations in nine municipal parking garages, plus at a handful of EV charging posts at on-street parking locations; the spots are metered (paid spots), but the electricity is free.[224] Similarly, Berkeley, California, offers charging at four municipal garages and lots at hourly rates via ChargePoint.[225]

On-street parking is a major area of interest for cities, especially in areas where residents lack access to home charging. The City of Philadelphia experimented for several years with allowing residents without access to off-street charging to apply to add a charger to a street spot. The policy required a one-time inspection and installation fee plus an annual renewal fee and additional charges if the spot was removed from city metering. The policy required that the spot remain available for all EV users. Applicants were responsible for charger installation and maintenance.[226] Unfortunately, the Philadelphia policy was unpopular: only 68 spots had been designated by 2017 when the policy was suspended,[227] and there were complaints the policy amounted to a cheap way for people to obtain a private parking spot in front of their own house.

Kansas City, Missouri, has partnered with the local utility to offer on-street charging for free. Other cities are partnering with EV charging networks to offer curbside charging. For example, Sacramento has partnered with EVgo to provide six 150-kW DC fast-chargers accessible to 10 parking spots downtown.[228]

China city official:

"There is too little land available for charging infrastructure, and land is very expensive. Lots of public charging stations need to get access to public land. Paying for the actual equipment in that case costs only 10% of the land cost."

U.S. city official:

"What we believe in is the power of the right of way. We own the curb, and that's a good place to provide charging. That means both fast charging in commercial areas, and slow charging when you have long-term storage in residential streets. We're looking at everything from light posts to community charging hubs."

J. Comparison—China and the United States

In both China and the United States, many types of businesses have begun to offer EV charging services, with a range of overlapping approaches. A growing number of partnerships are emerging (such as carmaker networks providing EV charging at hotels and independent charging networks supporting EV charging at shopping centers and municipal parking lots).

At this early stage of the industry's development, there are differences between EV charging networks in China and the United States. These reflect differences in urban layout, economic planning and industrial structure in the two countries.

- The role of utility-owned public chargers is much larger in China, especially along major long-distance driving corridors.
- The role of carmaker EV charging networks is larger in the United States, which currently has one large carmaker-owned network (Tesla), others in development in partnership with private charging networks (Nissan and BMW) and a third in early stages (Electrify America).

Both China and the United States have several independent charging network providers, which own, manage or support charging posts at retail outlets as well as public locations such as city streets and municipal garages.

In both countries, there is initial experimentation with a range of other business models. The United States has some EV chargers located at fueling stations, but this is far from widespread. In contrast, China's state-owned grid companies have deployed fast chargers at rest area fueling stations along major highways. The sharing of privately owned chargers (via the sharing economy, such as through PlugShare) appears to be limited in both countries. The sharing of fleet charging facilities—such as chargers owned by taxi companies or schools—also appears limited. EVs for shared mobility, with associated charging infrastructure, appears to be developing more rapidly in each country, as exemplified by Maven and Didi.

Table 7: Comparison of China and the U.S. business models active in 2018

	China	U.S.
Independent charging networks	Yes, numerous	Yes, numerous
Car manufacturer charging networks	Yes, but smaller, mainly Tesla, BYD	Yes, Tesla largest
Electric utilities	Yes, State Grid and China Southern Grid	Yes, in certain states (CA, MO)
Shopping and retail	Yes	Yes
Mobile charging units	Yes, rescue type	Yes, rescue type and within lot
Filling stations	Yes, mainly State Grid on highways	Yes, but only certain regional chains
Large parking lots	Yes, required under regulations	Yes, in a few U.S. cities
Municipal street-side charging	Yes, but faces barriers	Early state in a few U.S. Cities
Fleet charging for public use	Early stage	Early stage
Sharing economy	Early stage	Early stage

Source: Authors

6. CONCLUSION

China and the United States are the world's two largest electric vehicle markets. Although trade tensions between the two countries are significant, their economies are deeply interconnected, with one of the world's largest bilateral trading relationships. However the EV charging industries in each country are growing mostly independently of the other. As each country invests in EV charging infrastructure in the years ahead, stakeholders in China and the United States may be able to learn from each other.

1. US policy makers could learn from the Chinese government's multiyear planning with respect EV charging infrastructure.

In 2015, the Chinese central government established five-year goals for the deployment of EV charging infrastructure. Such multiyear planning—consistent with broader economic planning under the Chinese government's five-year plans—sends important signals to multiple stakeholders. Policy making in the United States often tends to be more episodic and short-term. For complex infrastructure development involving both the public and private sectors, medium- and long-term planning can provide important benefits. The multiyear nature of China's EV charging policies may provide helpful lessons to US policy makers.

2. Chinese policymakers could learn from the United States with respect to siting of public EV chargers.

Many public EV charging posts in China have been built as a result of mandates that require companies to build EV chargers whether or not those chargers are well-located or likely to be used. This has led to economic waste, with EV chargers built in inconvenient or inaccessible locations. In the United States, in contrast, siting is more likely to be based on market dynamics. Chinese policy makers could learn from the United States approach, letting the market play more of a role in public EV charging siting decisions.

3. US utilities could learn from China's investment in real-time data collection on EV charging.

China State Grid collects real-time data on EV charging throughout most of China, tracking the number of EV chargers and electricity they use. No comparable data platforms exist in the United States. Data analytics are likely to enhance the value of EV charging infrastructure. US utilities could benefit from additional investment in data collection and sharing to better understand nationwide EV charging trends in the United States while respecting driver privacy concerns.

4. Chinese policy makers could learn from US demand response programs.

The potential for demand response programs in China is currently limited by the structure of wholesale power markets. However, as power market reform proceeds, opportunities for demand response may grow. In the medium- and long-term, demand response programs and dynamic charging of EVs could have immense value in balancing electricity markets and providing needed flexibility to the Chinese grid. Chinese policy makers and grid officials could benefit from closely following US demand response programs in California, Vermont and other states considering such programs.

5. Both countries could learn from the other with respect to EV business models.

In China today, few shopping malls or business owners are offering free EV charging as an amenity to attract customers—a model that has grown rapidly in the United States. Although parking may simply be too valuable to offer as an amenity in many Chinese cities, in some the EV-charging-as-amenity model may work well. As EV charging business models evolve rapidly in both countries in the years ahead, stakeholders in each country may be able to learn by keeping a close eye on developments in the other.

A comparison of EV charging trends in China and the United States reveals similarities and differences:

Policies

- Governments in both countries promote electric vehicles and electric vehicle charging to achieve a range of social objectives, including lower emissions, energy security and economic development.
- In keeping with its state-guided approach to economic development, China's central government plays a far more significant role in EV charging policy than the US federal government.
- In both countries, subnational governments (provinces, states and municipalities) play important roles in promoting electric vehicles and EV charging. In China, many urban EV policies are implemented under guidance from the central government. In the United

States, many cities and states have taken the lead from the outset. The Zero Emissions Vehicle mandate, led by California, has played a central role in EV commercialization in the United States.

- Both countries are experimenting with different models for pricing electricity used to power EVs. Time-of-use electricity rates are common for commercial EV charging in China and California. Time-of-use residential electricity tariff options are growing for EV owners in the United States. California and Vermont are experimenting with demand response programs that could aggregate hundreds of vehicles for balancing the needs of the grid, and other states are considering similar programs.

Infrastructure

- EV charging infrastructure is growing rapidly in both China and the United States – although more rapidly in China. In 2018, the number of EV charging posts reported by the Electric Vehicle Charging Infrastructure Promotion Alliance grew by almost 80%. In the United States, the number of non-residential EV charging posts reported by the U.S. Department of Energy grew by roughly 33%.
- In both countries, most EV charging is done at home. In China, many EV drivers lack access to dedicated residential parking or home charging.
- In China there is a single standard for fast charging of electric vehicles. In the United States, three fast-charge standards compete. (Most U.S. experts interviewed for this report thought the lack of a single fast-charging standard will not be a significant barrier to market development in the United States.)

Business models

- China and the United States both have extensive independent EV charging networks. In China, experts we interviewed believe these networks will remain unprofitable until EVs become more widespread. In the United States, these networks have more ways to obtain revenue, including partnering with retailers and filling stations, advertising and participating in demand response programs (although EV demand response programs are at an early stage).
- China's utility market structure—with just two grid utilities—has facilitated rapid deployment of EV charging infrastructure. The motivations leading Chinese and US utilities to invest EV charging infrastructure differ. Such spending by China's state-owned grid companies is considered a social responsibility under government mandates. US utilities may be investing to receive regulated returns, build up future demand for their product or promote a green image.
- In China, many shopping malls offer public EV charging, but lack of parking space and insufficient means of collaboration between charging providers and retailers is an obstacle. In the United States, the retail and shopping center industry has begun to offer EV charging—often for free—as an amenity to attract customers and encourage increased spending.

The EV charging industry is young. Its future will be shaped by many factors, including potential disruptions to driving patterns by ride hailing, autonomous vehicles and other technologies.

- If future driving patterns resemble those today—dominated by privately owned vehicles with limited autonomy parked much of the day—most EV charging may continue to take place at home and workplaces.
- On the other hand, if driving patterns or vehicle ownership change—with ride hailing, mobility-as-a-service and autonomous vehicles dominating vehicle usage—fast chargers at remote locations may become the norm. Home and workplace charging, as well as charging on streets or in municipal garages, may recede in importance.
- In addition, breakthroughs in wireless charging or battery-swapping technologies could disrupt current EV charging models.

The uncertainties and path dependence associated with certain decisions create challenges for policy makers and those committing capital to the industry. Several of those interviewed for this study recommended that policy makers and businesses focus on near-term market needs, especially for facilitating residential and workplace charging, while not neglecting fast charging along highways and in city centers. “Right now, we need more of everything” is a theme expressed by many experts.

As the EV charging industry grows in the years ahead, better understanding of the approaches in China and the United States can help policy makers, businesses and other stakeholders in both countries and around the world.

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ACKNOWLEDGEMENTS

Many thanks to each of the more than 50 people who took time from their busy schedules to be interviewed for this report. Special thanks to CHENG Mengrong, Mark Duvall, Peter FoxPenner, John Halliwell, HUANG Han, David Jermain, Jonathan Levy, LIU Jian, Zane Mcdonald, Chuck Ray, Justin Ren, WANG Qiankun, TAN Xin, ZHANG Shining and several anonymous reviewers for their advice and/or close reading of the text.

We are especially grateful to Bloomberg Philanthropies and Hewlett Foundation, whose generous support makes this work possible. More information is available at https://energypolicy.columbia.edu/about/mission.

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