Background and Considerations for Planning Corridor Charging

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This document summarizes background of electric vehicle charging technologies, as well as key information that stakeholders need to consider when planning corridor-charging facility based on research results, testing data and literature.

Highlights:

- Public fast charging is becoming more important as 30 200-mile range BEV models are expected to be introduced by OEMs by 2020.
- Corridor high-power DCFC for long-range battery electric vehicles (BEVs) was important to overall BEV success in 2015/2016 in 7 Midwest states.
- Electric range of BEVs is reduced far more significantly than gasoline vehicle range in extreme cold and hot weather conditions, up to 50%.
- Negative weather effects on range were strongest for the mass-market and market overall; mid-market and luxury/performance PEVs' range suffered less.
- There are three types of fast charging standards co-existing in the U.S.: Tesla, CHAdeMO, SAECombo. So far only two plug-in hybrid vehicles (PHEVs) can be fast charged, BMW i3Rex and Mitsubishi PHEV.
- Extreme fast charging (> 350 Kw), which can charge a 200-mile BEV to 80% in less than 10 minutes, is still in the R&D stage. Initial cost analysis done by Argonne shows demand charges to push up $/kwh cost significantly. Total cost of ownership of a BEV with only extreme fast charging could exceed the cost of a gasoline vehicle.
- In general, PHEVs tend to be more popular than BEVs in areas with extreme temperatures (warm and cold). However, most of them cannot be fast charged.

Charging Infrastructure Overview

Charging infrastructure is evolving with the electric vehicle technology. At the outset of the market, expectations were that nearly all charging would occur at home and that public or workplace charging would be of limited use. Those assumptions have proven accurate with the first generation of the technology as 80 percent of all charging is likely to be residential (INL 2015, see https://avt.inl.gov/sites/default/files/pdf/arra/PluggedInSummaryReport.pdf).
As the market expands out of early adopters and the vehicles sold can travel further on a charge, public charging will grow in importance. Auto manufacturers have announced that by 2020, about 30 BEVs with over a 200-mile range will be introduced into the market. Although most charging should still occur at home, long range BEVs will need reliable access to fast charging infrastructure for some trips. In addition, drivers without easy access to home charging, such as multi-unit dwellers, garage orphans, and renters, may rely on fast charging or workplace charging to accommodate their daily driving needs. Furthermore, as used vehicles are adopted by the mass market with battery range reductions, the demand for DCFC or workplace charging could also increase.

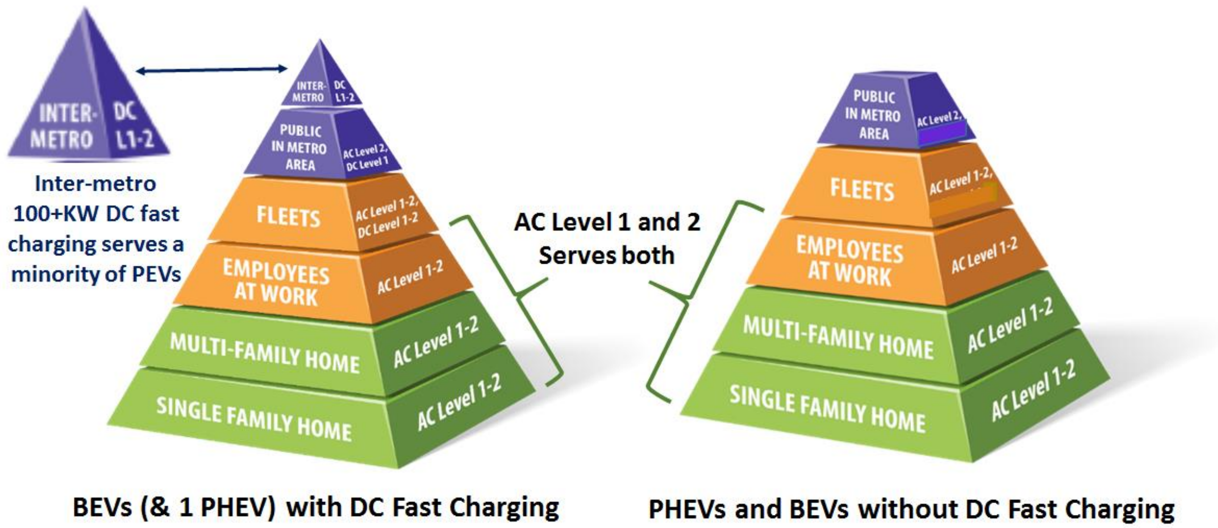


FIGURE 1: Plug-in Electric Vehicle Charging Pyramids: PEVs with and without Fast Charging
Source: Argonne National Laboratory

Future Battery Advancements

DOE R&D is bringing down costs of Plug-in Electric Vehicles (PEVs) and with that battery pack energy density is rising, bringing consumers faster and longer range electric vehicles, as noted above with the numerous announcement for long-range BEVs by auto manufacturers. Figure 2 shows the latest DOE and auto manufacturers' targets of battery cost for BEV and PHEV. Figure 3 shows DOE set a target to reduce the cost of electric drive system to $6/kW, 50% decrease from 2015 baseline.

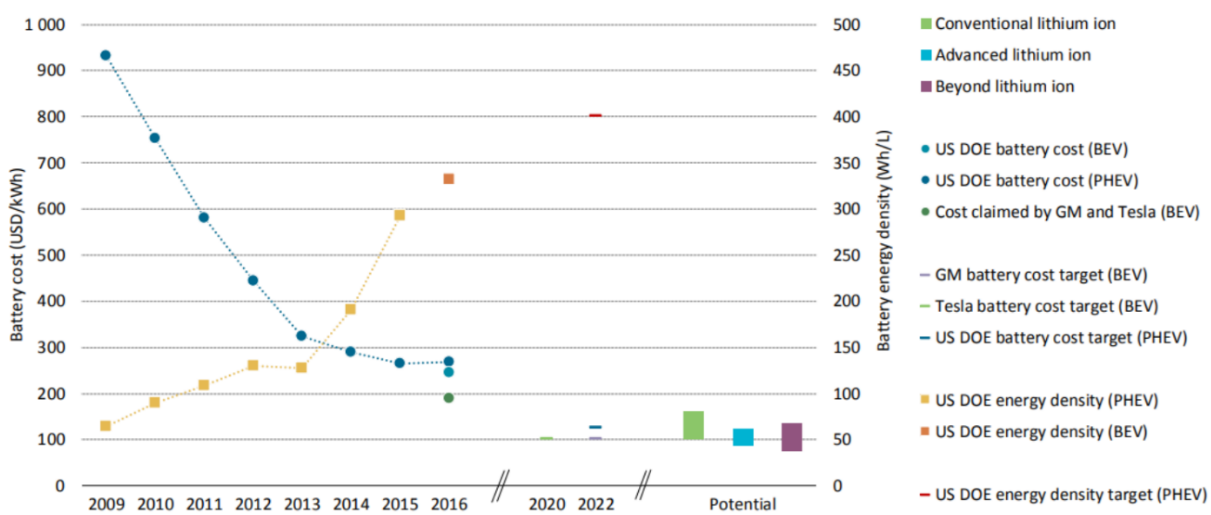


FIGURE 2: Evolution of battery energy density and cost
(Source: *Global EV Outlook, 2017, International Energy Agency)*

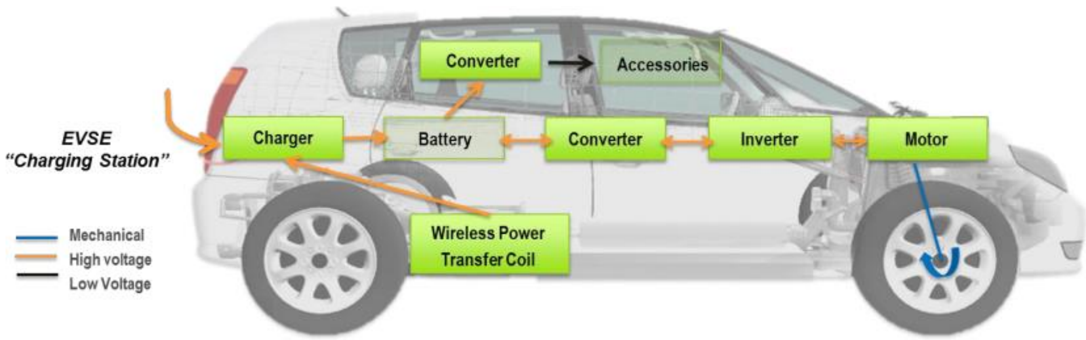


FIGURE 3: DOE R&D target for vehicle electric drive system
(Source: *https://www.energy.gov/sites/prod/files/2017/03/f34/QTR2015-8E-Plugin-Electric-Vehicles-15Mar2017.pdf*)

Mix of PEVs and Charging Types and Future Power Needs

Planners should determine the best selling vehicles in their locations. Are there more BEVs than PHEVs sold? Figure 4 is a snapshot of the bestselling vehicles in the Midwest by the end of 2016. In general, PHEVs tend to be more popular than BEVs in areas with extreme temperatures (warm and cold).

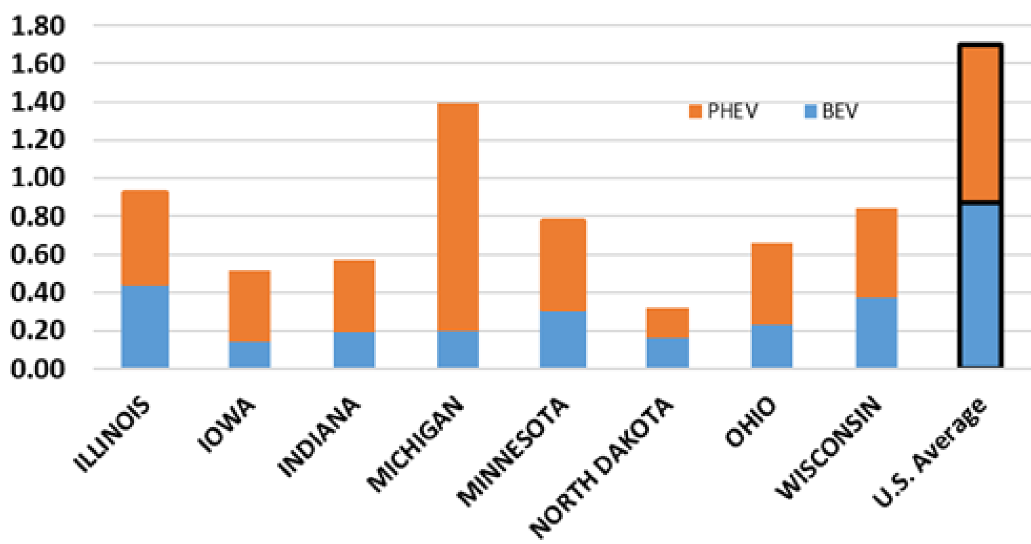


FIGURE 4: 2016 PEV registration per capita (1000 people) in Midwest

Planners need to know that almost all current PHEVs are not capable of DCFC. BMW i3Rex was the first PHEV to be capable of using the DC Fast Charging SAE Combo connect. The new 2017 Mitsubishi Outlander PHEV is the second PHEV can be fast charged through a CHAdeMO connector. Additionally, there are very few DC fast charging locations with more than one charging port of the same connector so drivers need reliable access for these existing stations.

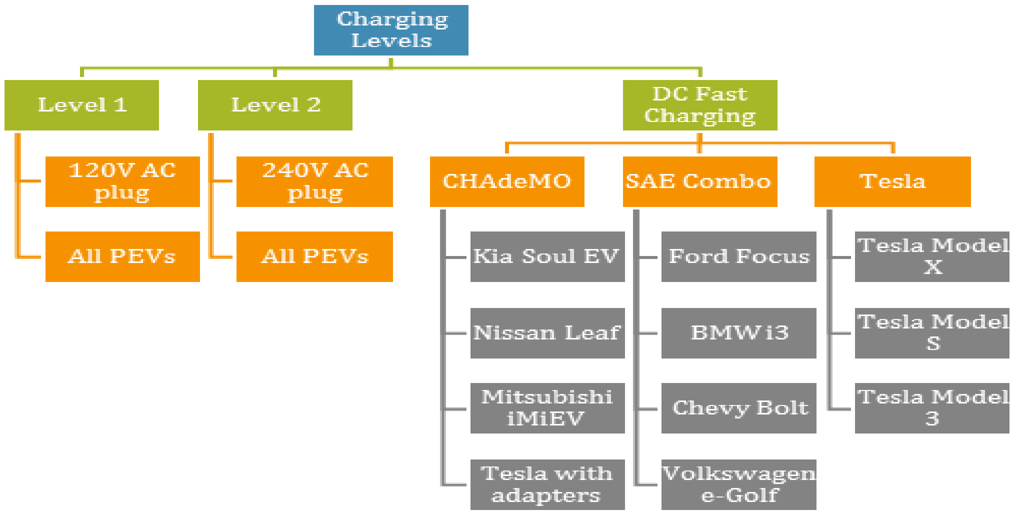


FIGURE 5: Charging levels and types

For a look at future charging times and power needs for increased energy density in BEVs, Table 1 compares the Extreme Fast Charging to current SAE/CHAdeMO DCFC chargers on the. See EERE's *Enabling Fast Charging: A Technology Gap Assessment*, October, 2017.

TABLE 1 Charging Options for Long-Range BEVs

Fast Charger Type	PEAK Charging Power	Range added per 1 Hour of 80% Charging	Charging Time from Empty to 80%
SAE/CHAdeMO DCFC	50 kW	~100 mi	~2 hr
Tesla Supercharger	145 kW	~260 mi	~40 min (to 80%)
Extreme Fast Charging	400 kW	N/A	~10 min (to 80%)

Temperature Effects on Range

Electric range is reduced far more significantly than gasoline vehicle range in extreme cold with snowstorms. The summertime reductions of range are far less significant. Nevertheless, there are effects. Both high speed Interstate highway driving and air conditioning can shorten range very noticeably. Argonne National Laboratory did testing in temperature controlled testing cells on early nine 2012-2015 PEV models, shown in Figure 6 and 7. While rated ranges of 2018 PEV models have jumped since then, on a percentage basis the range losses are still a factor purchasers must consider. If using an EV for inter-city travel, or for occasional long-distance recreational trips, the consumer may want to do some investigation of what the effects are and look for charging stations a bit closer than would be implied from the published typical range. Some EV manufacturers have suggested that repeated fast charging — which is needed for a long vacation trip — is not desirable. Moreover, DC fast charging ratings of charging time are for only 80% of range. The last 20% takes much longer. For instance, the Bolt DCFC at 50 kW only gives 90 miles of range.

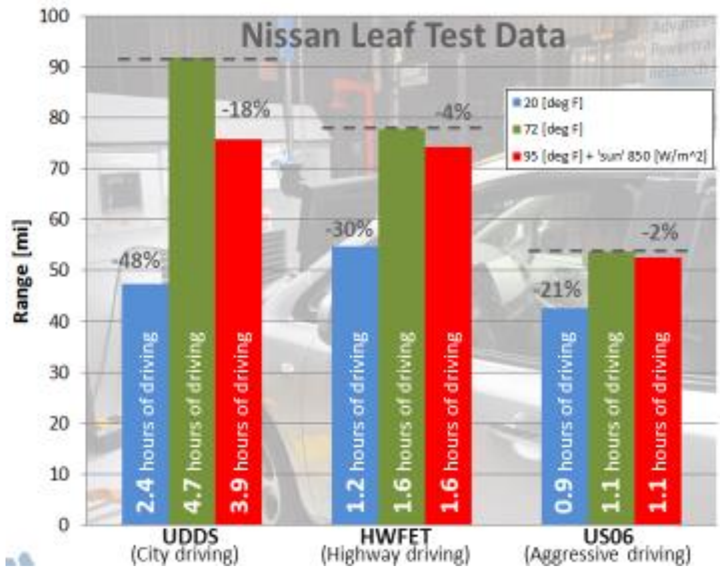


FIGURE 6: Effect of extreme temperature and drive style on the electric range

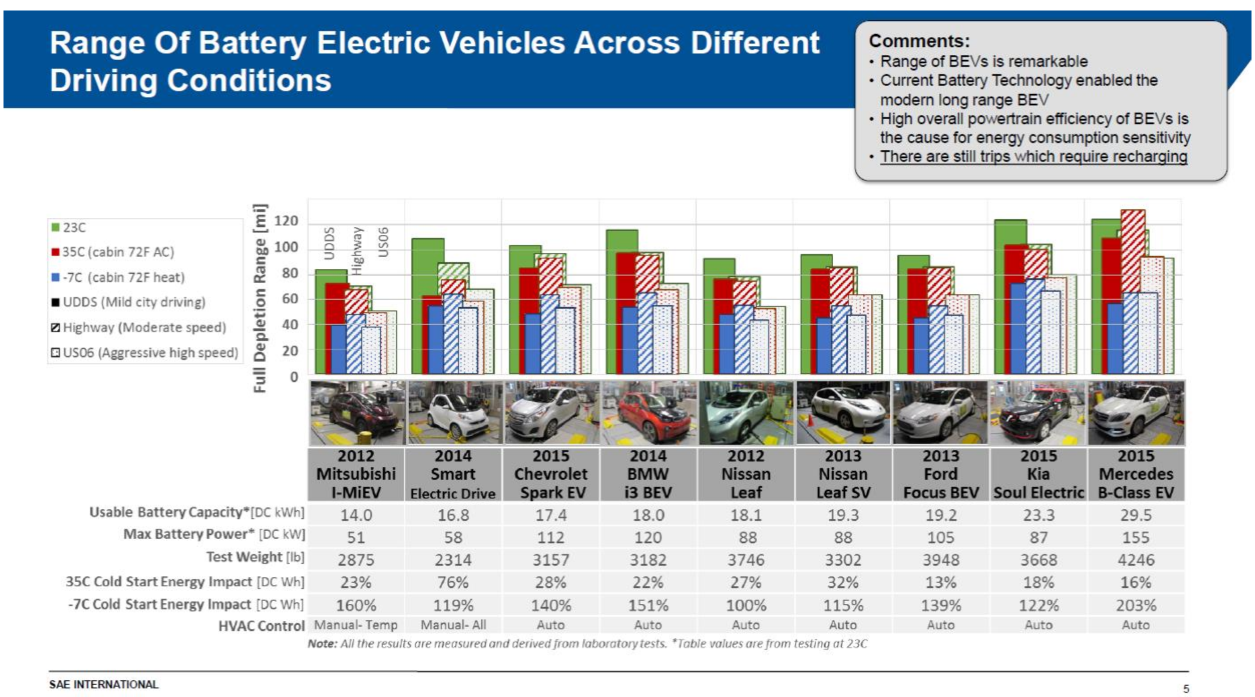


FIGURE 7: Effect of extreme temperature and drive style on the electric range

More recently, Argonne analysts reviewed regional climates and its effect on near-term PEV adoption. EV technologies have exhibited considerably less range in cold climates, which led to much higher PHEV adoption than BEV in northeast regions in general. In the U.S., 3 of 5 highest BEV adoption states are in moderate temperature areas, California, Oregon and Washington. However, GM claimed notable battery improvement on range reduction with their Chevy Bolt. Figure 8 shows the analysis results of hot and cold weather effect on PEV marketability in major metro areas in the U.S. and Europe. Extreme temperature is more problematic in much of the U.S, than in northern Europe (e.g. Oslo). PHEV suffered less extreme temperature marketability damage than BEVs. Tesla's added BEV range helped but did not eliminate the problem in cold areas.

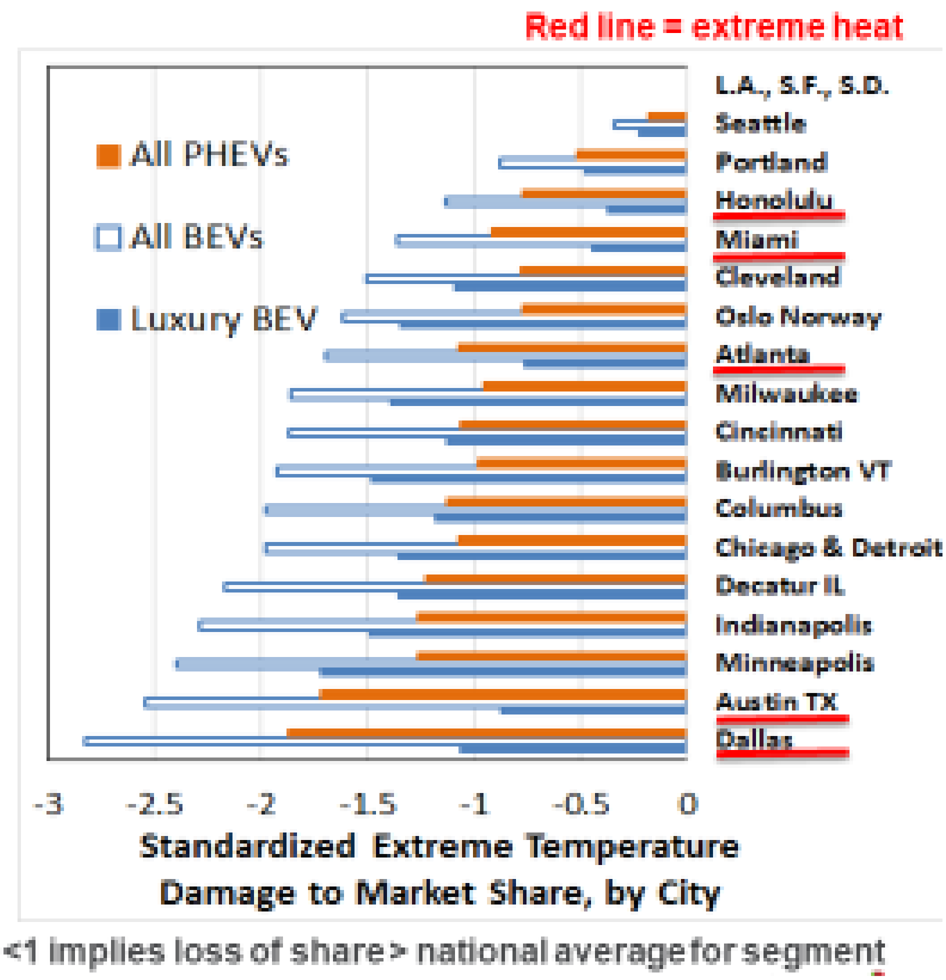


FIGURE 9: Extreme weather effect on PHEV vs. BEV marketability in major metropolitan areas
Developed using coefficients in statistical estimates from:
M. Rood, D. Santini, and Zhou, Y., 2016, Implications of Successes and Failures of BEV-focused Incentive Support for PEVs in U.S., Canada and Europe, EVS29, Montreal, CA.
Zhou, Y., D. Santini, K. Vazquez, and M. Rood, 2017, "Contributing factors in plug-in electric vehicle adoption in the United States: A Metro/County Level Investigation," Transportation Research Board 96th Annual Meeting. Paper No. 17-05472. Washington, DC, Jan. 8–12.

Driving Effects on Range

Driving passively or aggressively affects the range of PEVs. Below, Figure 9, is a chart depicting range depletion dependent on both driving and weather conditions based on testing results of five different BEV models. (See ANL Advanced Powertrain Test Facility test database)

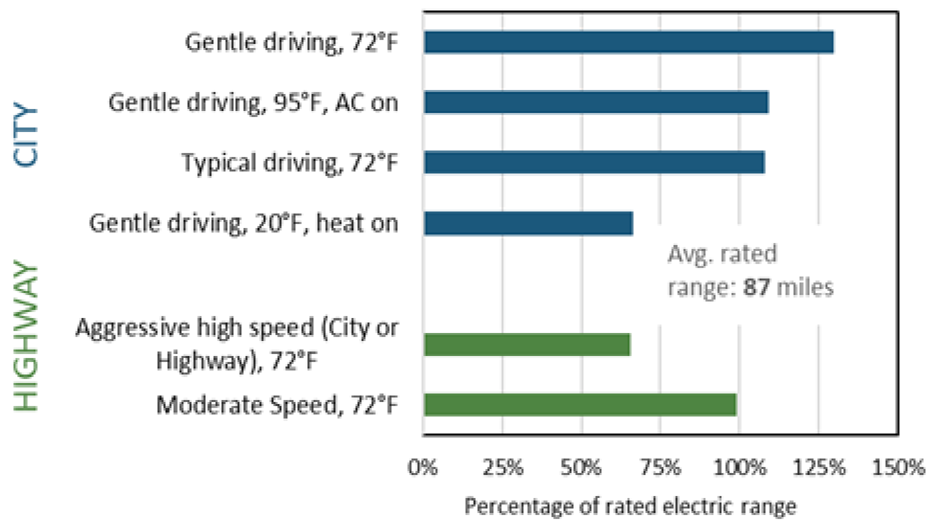


FIGURE 9: Range depletion dependent under different driving and weather conditions (average of 5 different BEV models with average EPA rated electric range 87 miles)

General PEV Adoption Considerations for Planners (based on investigations on 2014 PEV registration*)

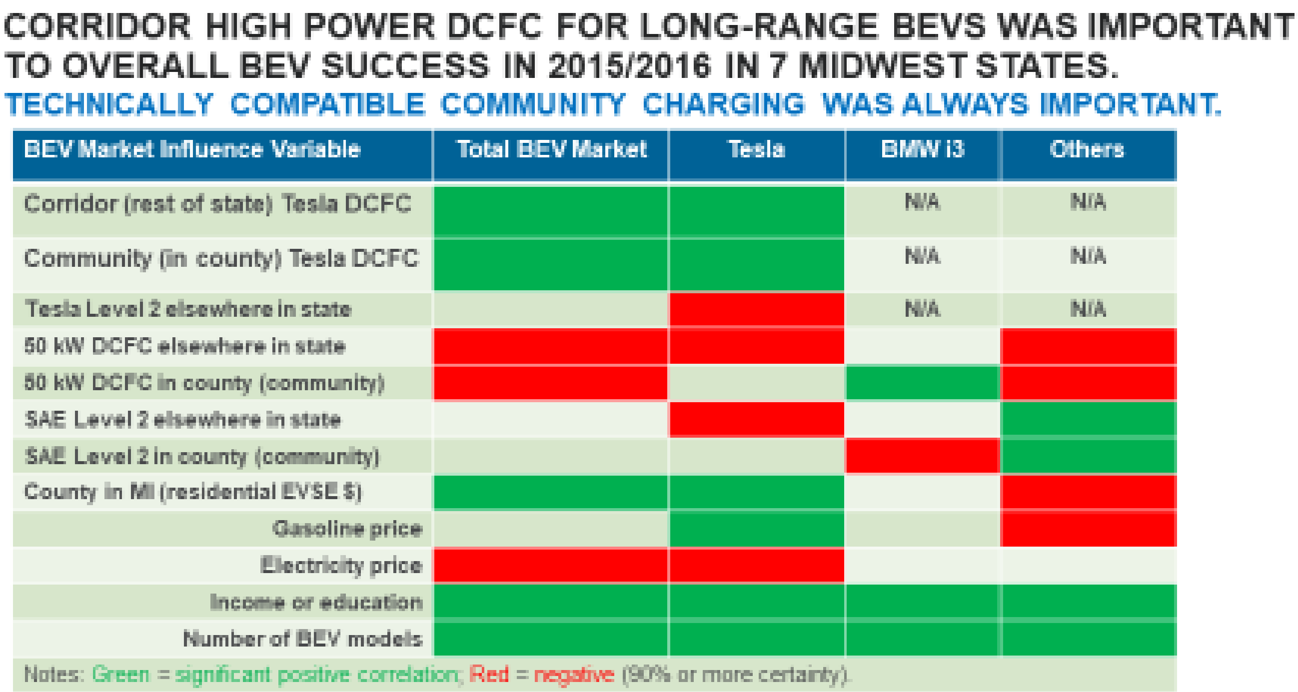
Argonne examined correlations of 18 independent variables on BEV and PHEV success for three price-based market segments (luxury (>$60K), middle ($40–60K), mass (<$40K), at the county level in seven Midwestern states. Variables address policies, socioeconomic factors, climate, and charging infrastructure. Key findings of the analysis include:

- **Extreme Temperature:** Negative effects were strongest for the mass-market and market overall; mid-market and luxury/performance PEVs suffered less damage
- **State and Federal Monetized Benefits:** Twice as important for BEVs as for PHEVs
- **Level 2 Public Charging Availability:** Impacts are significant and positive in the mass and total PHEV markets, but not in BEV markets
- **Workplace Charging:** Coefficient for BEVs is positive, but lower than for PHEVs
- **PEV Readiness Grants:** Impacts are consistently positive and generally significant in all PHEV market segments, as well as for mass-market and total BEVs
- **HOV Lane Subsidies:** Appear to be very important in the mass market
- **Income:** Has significantly positive impacts in *every* market segment, dominating the education effect
- **Fuel Cost:** Gasoline prices are positively correlated to shares of the luxury BEVs, luxury PHEVs, and mid-market PHEVs, but not mass-markets or total markets. Electricity prices consistently have a negative sign and are significant for all BEVs aside from mid-market.

Author interpretations derived from statistical estimates in:

Zhou, Y., D. Santini, K. Vazquez, and M. Rood, 2017, "Contributing factors in plug-in electric vehicle adoption in the United States: A Metro/County Level Investigation," Transportation Research Board 96th Annual Meeting. Paper No. 17-05472. Washington, DC, Jan. 8–12.

Based on so far unpublished county level estimates for seven (7) EVOLVE states for 2015 and 2016, we found out that Tesla success was significantly enhanced by its 145 kW DCFC system, shown in Figure 10. The 50 kW system used by the BMW i3 was only helpful when available locally, not in locations outside the county. A significant fraction of other BEVs did not have DCFC or did not include it as standard, so the estimates of DCFC effectiveness (actually ineffectiveness) are not as meaningful for those shorter range BEVs. Many 2018 and coming 2019+ BEVs will have long range and DCFC capability. The Tesla results imply that technically compatible corridor charging at 145 kW and above will be important to the success of those vehicles. (Tesla BEVs have longest range, BMW i3 next longest range, and others have least range.)



CORRIDOR HIGH POWER DCFC FOR LONG-RANGE BEVS WAS IMPORTANT TO OVERALL BEV SUCCESS IN 2015/2016 IN 7 MIDWEST STATES.

TECHNICALLY COMPATIBLE COMMUNITY CHARGING WAS ALWAYS IMPORTANT.

BEV Market Influence Variable	Total BEV Market	Tesla	BMW i3	Others
Corridor (rest of state) Tesla DCFC	Green	Green	N/A	N/A
Community (in county) Tesla DCFC	Green	Green	N/A	N/A
Tesla Level 2 elsewhere in state		Red	N/A	N/A
50 kW DCFC elsewhere in state	Red	Red		Red
50 kW DCFC in county (community)	Red		Green	Red
SAE Level 2 elsewhere in state		Red		Green
SAE Level 2 in county (community)			Red	Green
County in MI (residential EVSE $)	Green	Green		Red
Gasoline price		Green		Red
Electricity price	Red	Red		
Income or education	Green	Green	Green	Green
Number of BEV models	Green	Green	Green	Green

Notes: Green = significant positive correlation; Red = negative (90% or more certainty).

FIGURE 10: Corridor high power DCFC for long-range BEVs was important to overall BEV success in 2015/2016 in 7 Midwest states