Perspectives on Expanding EV Charging Infrastructure in the United States

BY TIMOTHY C. COBURN, THOMAS H. BRADLEY, JEFFREY LOGAN, AND CHARLES F. KUTSCHER

The path to decarbonization and sustainability in the transportation sector requires vehicle electrification to become dominant in every sector and every application.[1] This demands more extensive adoption of electric vehicles (EVs), along with development and deployment of supporting transportation systems and networks, market-promoting and system-supporting policies/regulations, and cooperative and innovative financing mechanisms.

In 2018, the U.S. reached the milestone of having more than one million EVs on the road.[2] Sales of light-duty EVs (plug-in hybrid electric vehicles, or PHEVs, and battery electric vehicles, or BEVs) have risen rapidly since 2016, increasing from 159,616 that year to 361,315 in 2018. While projections about future growth in the light-duty EV sector vary, most place the market share at 7%-10% by 2025-2026. U.S. sales of all vehicles, including those of EVs, have wavered since late 2019 as the COVID-19 pandemic has progressed, but the overall market is expected to recover in due time, with new EV models (including SUVs, trucks, and mid-sized sedans) continuing to drive growth in total EV sales.[3]

Ready access to battery recharging facilities is among the most critical elements in an electrified transportation system. So, although electricity as a transportation energy source has great advantages in terms of its consumer preference, ubiquity, and safety, individual consumers and fleet managers must be convinced that EVs can be "refueled" essentially on demand similar to refueling gasoline or diesel vehicles, thereby eliminating "range anxiety."[4]

While rapid strides have been made in the development of charging infrastructure throughout the U.S., in recent years, the pace of deployment still lags the pace of EV sales. As of mid-2020, there were over 25,000 public and non-residential private (e.g., businesses) EV charging stations across the U.S. with more than 80,000 connectors (outlets or charging units)[5], an increase in stations of more than 50%, and an increase in connectors of more than 85%, from 2016.[6] In contrast, as noted above, there are more than one million plus EVs of all types on U.S. roads. Further, the number of charging stations is somewhat overshadowed by the 100,000 or more gasoline/diesel fueling stations around the country, although this is somewhat of an apples-to-oranges comparison since official counts of EV charging units do not include the untold number of residential charging outlets.

Counting the numbers of stations and connectors can be somewhat confusing because there are different levels. Level 1 charging (similar to a residential 120V outlet plug) adds two to five miles of range per hour of charging, or up to 40 miles of range in eight hours of charging for a mid-sized vehicle. Level 2 charging (similar to a residential 240V plug) adds 10-20 miles of range per hour of charging, or up to 160 miles of range in eight hours of charging. Typical DC fast charging (DCFC) adds 60-80 miles of range for every 20 minutes of charging.[7] These estimates may differ depending on the vehicle-battery combination in question.[8] All told, roughly 82% of the connectors available in mid-2020 were Level 2 units and the remainder were DCFC units.[9,10]

In the U.S., ownership and operation of charging networks are dominated by a few major players who provide access to charging largely on a subscription or pay-as-you-go fee basis. ChargePoint has the most extensive network in the country. Tesla, with the second largest U.S. network, primarily provides proprietary services for its own vehicle owners, but does maintain some multi-user business partnerships. Significant expansion of other existing networks (e.g., EVgo, EV Connect, Electrify America, Blink) is also being planned, in some cases involving joint ventures or collaborative efforts with travel-related entities such as major truck stop companies and convenience store chains. ChargePoint and Electrify America have announced plans to allow joint roaming access to their mutual networks in much the same way that wireless communications companies share cell towers.[11] Facilitating interoperability of this type among network providers is one of the keys to optimizing the charging experience. All these initiatives suggest that non-residential EV charging has the potential to become a significant industry, with even the major auto makers, oil companies, and power providers getting onboard.[12]

Despite the many positive developments, edge issues pertaining to scarcity of charging resources often dominate a prospective EV buyer's thinking, such as (1) how far it is to the next/closest charging station and (2) how long it takes to get to the next charging point. For individuals traveling cross-country, access to charging (especially, fast charging) is an important concern, particularly when not traveling on major thoroughfares

Timothy C. Coburn is a Research Affiliate at the Renewable and Sustainable Energy Institute, University of Colorado-Boulder, and Professor of Energy and Operations Management, School of Energy Economics, Policy and Commerce, The University of Tulsa
Thomas H. Bradley is Woodward Professor and Chair, Department of Systems Engineering and The Energy Institute, Colorado State University.
Jeffrey Logan is Associate Director and Fellow, Renewable and Sustainable Energy Institute, University of Colorado-Boulder.
Charles F. (Chuck) Kutscher is a Fellow, Renewable and Sustainable Energy Institute, University of Colorado-Boulder

See footnotes at end of text.

or interstate highways. In addition, individuals who live beyond urban/suburban areas are relatively unlikely to have access to charging outside their own homes. Hence, development of a comprehensive, national charging network, or absent this, regulated or greater voluntary cooperation among network providers, is an absolute necessity if full electrification is the goal.[13]

While the foregoing points are largely centered on cross-country transportation, the need for an intra-urban, optimally situated charging network is not diminished. The U.S. Department of Energy's Vehicle Technologies Office (DOE/VTO) has recommended that city drivers should not be farther than three miles to the closest charging station,[14] but others have suggested that improved battery technology may mitigate the need for such density.[15] It may be unrealistic to think that every existing gasoline/diesel station in the country will be retrofitted with an EV charging station, but it is certainly within reason to expect that a large segment of those within urban/suburban/near-urban areas will be. In fact, they must—or there must be new stations constructed—in order for the vehicle population to approach full electrification. While public charging stations are necessary for long distance travel and transportation of goods, they are also a prerequisite for individuals who want to purchase an EV, but for one reason or another, cannot charge at home (e.g., street parking only). The jump to a more widespread charging network—even a national charging network—seems well within reach, at least for light-duty vehicles, since Tesla, which today has a majority of the U.S. EV market, has largely solved the infrastructure problem for its drivers.[16]

The ability to recharge an EV at home is the ideal situation for most everyday activities. In fact, the need for a public charging network notwithstanding, the ability to conveniently recharge a vehicle has always been, and will continue to be, mostly about charging at home—in the garage, using a wall plug or overhead charging connector, or at a free-standing driveway charging port.[17,18,19] For multi-occupancy dwellings, such as apartment buildings, university dormitories, and living facilities for independent senior adults, the situation is not so clear-cut. Some of these housing arrangements may come with access to garages (attached or detached units, or multi-level parking facilities) that can accommodate charging units, but many do not. For such environments there are unresolved questions about who pays for the infrastructure (procurement, installation, operation, and maintenance) plus issues concerning how vehicle electricity usage is billed (assuming it is not automatically linked to an individual housing unit's consumption). Cooperative charging for occupants of self-contained communities (e.g., homeowner associations, over-55 adult neighborhoods, or resort commons such as RV parks) and their guests/visitors, in which the costs of infrastructure and electricity may be shared through covenant requirements, is a feasible model for some, but not all, situations.

To achieve full electrification, private businesses, public corporations, and non-profit entities (e.g., churches and schools) should be incentivized to provide charging facilities at work, recreation, entertainment, shopping, and related venues. Urban and city center parking garages will need to be reimagined and reconfigured in order to incorporate sufficient charging capabilities. A number of companies (e.g., Walmart, Whole Foods) are already moving in this direction, but more capacity will need to be added as EVs become more ubiquitous. Again, the issue of who pays for infrastructure deployment, which in the public sphere can involve individuals, local/regional/national businesses, utility companies, and governmental jurisdictions, remains unresolved in many situations and may have to be addressed statutorily.[20] Utility ownership may raise questions concerning the appropriate use of customer money on public charging facilities and whether investment in such facilities by regulated monopolies gives them an unfair competitive advantage.[21] Further, participation of private entities will depend on creation of innovative business models likely involving partnerships that leverage risk to guarantee a return on investment.[22]

Within the vision for an expanded charging network it will not be sufficient for most public stations to be Level 2. While Level 2 charging will certainly be adequate for many situations and applications, the majority of prospective vehicle buyers will not want to spend any more time charging their EVs than when refueling a typical gasoline or diesel vehicle. The goal of DOE/VTO is to decrease charging time to 15 minutes or less,[23] but even 10 minutes is more than most people spend refueling a gasoline vehicle. Currently, most DCFC units can fully charge an EV battery to at least 80% of full range within 30 minutes (Tesla's superchargers can be even faster), whereas Level 2 charging takes about three and a half hours to fully charge an 80-mile battery and about eight hours for a 200-mile battery.[24] On the other hand, most drivers do not need to fully charge their vehicle's battery every day given daily travel demands, in the same way that most gasoline or diesel vehicle owners do not need to refuel every day. Some compromise acceptable to the vast majority of prospective EV buyers will need to be reached, perhaps through culture-building, educational, and outreach programs. Over time, as EV ownership increases, the capabilities of recharging systems will undoubtedly improve and evolve as business models adapt to driver preferences and requirements.

Reducing charge time is not solely a facility or infrastructure issue. In addition to the power of the charging station, it has to do with the ability of the battery itself to accept the charge and the type of charging port available on the vehicle. Lithium-ion batteries, which power most EVs today, do not perform optimally in extreme temperatures, and are more difficult to fully charge in these conditions. Unfortunately, these are some of the situations under which drivers do not want to be waiting for their battery to charge. Further, continuous and repeated fast charging is not recommended because it can stress the battery thermally and chemically and lead to more rapid degradation.[25] Research into alternative stationary and non-stationary charging strategies (wireless inductive charging, dynamic charging,[26] charging-while-driving,[27,28] and catenary charging),[29] as well as battery structures and chemistries that are both practical in size and more amenable to fast charging, is proceeding, but technology development, standards development, and financial support must work together to achieve more progress.[30] Charging will inevitably still take longer than filling a gasoline tank, but fast charging is both a fundamental and systems problem that must be addressed because it constrains progress towards full electrification.

To one degree or another, expansion of charging infrastructure in the U.S. is also confounded with (1) vehicle-to-building integration and (2) the cost of electricity to the vehicle owner/consumer. To accommodate appropriate and sufficient charging infrastructure, buildings must be EV-ready; meaning that garages, parking areas, etc. must be wired appropriately and provide sufficient space for placement of charging facilities. Ensuring EV-readiness will likely require changes in code restrictions, at least for new construction, along with funding and/or financial incentives for retrofitting existing structures. With regard to electricity cost, consumers are more likely to consider an EV purchase if EV-friendly electricity pricing scenarios are available. While time-of-use (TOU) or dynamic pricing provides an important incentive to EV purchasers who primarily intend to charge their EVs at home, those same advantages are not necessarily enjoyed while charging elsewhere and should be expanded. Other incentives such as the elimination of demand fees, whether charging at home or away, also create a more EV-friendly market scenario that will, in turn, support a more prolific charging infrastructure network.

Developing and deploying an expansive charging network to support electrification of the transportation sector will not come cheaply. This is true whether stationary or non-stationary solutions become the norm, but it would be particularly costly to build out an entirely new infrastructure system such as inductive charging on a widespread basis. The estimated need for capital investment in the U.S. through 2030 is at least $11 billion,[31] assuming current projections hold true, with more than $2.5 billion needed in major U.S. metropolitan areas through 2025.[32] These costs must be balanced against the many benefits of electrifying mobility, including improved energy security, air quality, environmental justice, and greenhouse gas mitigation, among others.

Relative to other countries in the world, the U.S. is behind in terms of charging capacity infrastructure[33] and it will need to make a major investment relatively soon in order to satisfy demand and meet transportation-related GHG emissions reduction goals. The challenge is substantial, but so are the opportunities, both in terms of economic development and climate impacts.[34]

Footnotes

[1] Global Battery Alliance, 2019, A vision for a sustainable battery value chain in 2020: unlocking the full potential to power sustainable development and climate change mitigation. World Economic Forum and McKinsey & Company, Insight Report, www3.weforum.org/docs/WEF_A_Vision_for_a_Sustainable_Battery_Value_Chain_in_2030_Report.pdf. Accessed July 13, 2020.

[2] Edison Electric Institute, 2018, EEI celebrates 1 million electric vehicles on U.S. roads. www.eei.org/resourcesandmedia/newsroom/Pages/Press%20Releases/EEI%20Celebrates%201%20Million%20Electric%20Vehicles%20on%20U-S-%20Roads.aspx. Accessed July 12, 2020.

[3] Argonne National Laboratory, 2020, Light duty electric drive vehicles monthly sales updates. www.anl.gov/es/light-duty-electric-drive-vehicles-monthly-sales-updates. Accessed July 9, 2020.

[4] Narassimhan, E., Johnson, C., 2018, The role of demand-side incentives and charging infrastructure on plug-in vehicle adoption: analysis of US states. Environmental Research Letters, v. 13, No. 7, 074032, https://iopscience.iop.org/article/10.1088/1748-9326/aad0f8. Accessed July 15, 2020.

[5] Alternative Fuels Data Center, n.d., Electric vehicle charging station locations. U.S. Department of Energy, Energy Efficiency and Renewable Energy, https://afdc.energy.gov/fuels/electricity_locations.html#/analyze?fuel=ELEC&country=US. Accessed July 17, 2020.

[6] Lambert, F., 2019, US now has over 20,000 electric car charging stations with more than 68,800 connectors. Electrek, https://electrek.co/2019/07/09/us-electric-car-charging-station-connectors. Accessed July 18, 2020.

[7] Alternative Fuels Data Center, n.d., Developing infrastructure to charge plug-in electric vehicles. U.S. Department of Energy, https://afdc.energy.gov/fuels/electricity_infrastructure.html. Accessed July 5, 2020.

[8] For example, Tesla's new V3 supercharging stations, primarily designed for its popular Model 3 vehicles and operating at 250 kW, reportedly add 75 miles of range in five minutes.

[9] Alternative Fuels Data Center, n.d., Electric vehicle charging station locations. U.S. Department of Energy, Energy Efficiency and Renewable Energy, https://afdc.energy.gov/fuels/electricity_locations.html#/analyze?fuel=ELEC&country=US. Accessed July 17, 2020.

[10] Again, this excludes at-home residential charging options.

[11] Korosec, K., 2019, Charging an electric car in America is about to get a little less painful. TechCrunch, https://techcrunch.com/2019/06/11/charging-an-electric-car-in-america-is-about-to-get-a-little-less-painful. Accessed July 8, 2020.

[12] Valdes-Dapena, P., 2019, A game changer is coming for electric car owners. CNN Business, www.cnn.com/2019/08/01/cars/future-of-electric-car-charging/index.html. Accessed July 13, 2020.

[13] It is worth noting that Tesla owners are less impacted because they have access to the company's extensive proprietary network, a distinct advantage for prospective Tesla buyers.

[14] Wood, E., Rames, C., Muratori, M., Raghavan, S., and Melaina, M., 2017, National Plug-In Electric Vehicle Infrastructure Analysis. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of Vehicle Technologies, DOE/GO-102017-5040. Washington, DC, www.nrel.gov/docs/fy17osti/69031.pdf. Accessed July 15, 2020.

[15] Wenig, J., Sodenkamp, M., Staake, T., 2019, Battery versus infrastructure: tradeoffs between battery capacity and charging infrastructure for plug-in hybrid electric vehicles. Applied Energy 255/113787, https://doi.org/10.1016/j.apenergy.2019.113787.

[16] Shahan, Z., 2020, Tesla gobbled up 78% of US electric vehicle sales in 2019. CleanTechnica, https://cleantechnica.com/2020/01/16/tesla-gobbled-up-81-of-us-electric-vehicle-sales-in-2019. Accessed July 15, 2020.

[17] InsideEVs, n.d., Where will EV charging stations of the future be located? https://insideevs.com/news/343589/where-will-ev-charging-stations-of-the-future-be-located. Accessed July 6, 2020.

[18] National Research Council, 2015, Overcoming barriers to deployment of plug-in electric vehicles. Washington, DC: The National Academies Press. https://doi.org/10.17226/21725. Accessed July 12, 2020.

[19] Muratori, M., Wood, E., 2019, Charging infrastructure: what, where, and how many? NREL perspective. National Renewable Energy Laboratory Presentation, National Governor's Association Meeting, Seattle, WA (April 4), www.nrel.gov/docs/fy19osti/73733.pdf. Accessed July 17, 2020.

[20] EVConnect, 2020, Who pays for electric car charging stations, www.evconnect.com/blog/who-pays-for-electric-car-charging-stations. Accessed July 7, 2020.

[21] Khan, S., Vaidyanathan, S., 2018, Strategies for integrating electric vehicles into the grid. American Council for an Energy Efficient Economy, Report T1801, www.aceee.org/sites/default/files/publications/researchreports/t1801.pdf. Accessed July 10, 2020.

[22] Nigro, N., Frades, M., 2015, Business models for financially sustainable EV charging networks. Final Report, Center for Climate and Energy Solutions, www.c2es.org/document/business-models-for-financially-sustainable-ev-charging-networks. Accessed July 16, 2020.

[23] U.S. Department of Energy, n.d., Batteries. Office of Energy Efficiency and Renewable Energy, Office of Vehicle Technologies, www.energy.gov/eere/vehicles/batteries. Accessed July 14, 2020.

[24] ChargePoint, n.d., Driver's checklist: a quick guide to fast charging, www.chargepoint.com/files/Quick_Guide_to_Fast_Charging.pdf. Accessed July 5, 2020.

[25] Coren, M. J., 2019, Fast charging is not a friend of electric car batteries. Quartz, https://qz.com/1768921/how-to-make-electric-car-batteries-last-longer. Accessed July 11, 2020.

[26] Zhao, H., Wang, Q., Fulton, L., Jaller, M., Burke, A., 2018, A comparison of zero-emission highway trucking technologies. Research Report UC-ITS-2017-50, University of California-Davis, Institute of Transportation Studies. https://escholarship.org/uc/item/1584b5z9. Accessed July 9, 2020.

[27] Andrews, E., 2020, Stanford researchers one step closer toward enabling electric cars to recharge themselves wirelessly as they drive. Stanford News, https://news.stanford.edu/2020/05/04/wirelessly-charging-electric-cars-drive. Accessed July 20, 2020.

[28] Limb, B., Asher, Z., Bradley, T., Sproul, E., Trimko, D., Crabb, B., Zane, R., Quinn, J., 2019, Economic viability and environmental impact of in-motion wireless power transfer. IEEE Transactions on Vehicle Electrification 5:135-146.

[29] Other non-stationary options such as battery swapping and mobile charging continue to receive periodic consideration in the contexts of heavy duty fleet vehicles such as buses, garbage haulers, snow plows, and long-haul tractor-trailer rigs used in supply chain and logistics applications, but are largely considered to be impractical today for light-duty vehicles because of the way the battery packs are being integrated into a vehicle's chassis.

[30] Infrastructure-to-vehicle interoperability is also key to optimizing the charging experience, requiring station-to-vehicle charging mechanisms to be standardized in the same sense that refueling of gasoline and diesel vehicles is standardized.

[31] Engel, H., Hensley, R., Knupfer, S., Sahdev, S., 2018, Charging ahead: electric vehicle infrastructure demand. McKinsey & Company, www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Charging%20ahead%20Electric-vehicle%20infrastructure%20demand/Charging-ahead-electric-vehicle-infrastructure-demand-final.ashx. Accessed July 10, 2020.

[32] Nicholas, M., 2019, Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas. International Council on Clean Transportation (ICCT) Working Paper, https://theicct.org/publications/charging-cost-US. Accessed July 15, 2020.

[33] For example, as part of its economic recovery plan related to the COVID-19 pandemic, Germany has recently announced a requirement for all petroleum refueling stations to also offer EV charging.

[34] Additional information from the authors concerning EV charging infrastructure and related issues can be found at www.colorado.edu/rasei/sites/default/files/attached-files/accelerating_the_us_clean_energy_transformation_final.pdf.

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