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News & Highlights

Lagging Charging Infrastructure Threatens to Roadblock Electric Vehicle Future

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In August 2021, US President Joe Biden signed an Executive Order calling for half of all new vehicles sold in 2030 to be zero-emissions vehicles, including battery electric, plug-in hybrid electric, or fuel cell electric vehicles (EVs) [1]. Meeting that goal would amount to an estimated 48 million EVs on US roads. However, the country's network of public EV fast charging stations is woefully unprepared to meet the needs of a fleet that large. To address this coming deluge of demand, an informal consortium of public agencies and private companies is hastily trying to build out charging station infrastructure—as well as electric grid capacity to support it—while engineers work to make charging EVs faster, cheaper, and more efficient.

Until now, range anxiety—the concern that an EV's battery will run down to empty before making it to a charging station—has primarily affected early adopters [2], many of whom have access to the slowest type of charger (Level 1) in their own garages or parking spaces. Those owners can wake up with a full battery and mostly need to rely on public chargers only when they leave home on extended trips. Still, a 2022 survey of EV owners indicated that 62% are anxious enough about the range of their EVs that it has affected their travel plans [3].

But as California leads a coalition of 14 states (and counting) in rolling out zero-emission vehicle mandates over the next several years that would target 2035 for 100% of new vehicles sold being EVs [4], anxiety may graduate to open resentment. "Some consumers are expressing fears that they are going to be forced to buy EVs that will impact their daily lives by requiring hours to charge," said Brian McCarthy, chief technology officer of EV battery startup company EC Power (State College, PA, USA). "If we do not figure that out as an industry, it is going to throw a real wrench in the plans to switch over to electric."

Not including the Level 1 chargers that take 24 hours or longer to fully charge EV batteries when plugged into the 120 V outlets found in most garages, as of February 2023 there were about 50 000 public EV charging stations in the United States hosting a total of nearly 130 000 individual ports [5]. About 44 000 of these are Level 2 with just over 100 000 charging ports. Only 6000 are Level 3, or direct current (DC) fast charging stations, which house about 30 000 charging ports. Fully charging a 60 kW·h battery using a standard 7 kW Level 2 charger takes from 4 to 10 hours. For EVs that can access and use a Level 3 port operating at 250 kW, that same capacity battery charges in 20–60 min [6]. But this increased speed comes at a much higher cost: The typical 700 to 2000 USD for a Level 2 charger is far less than the 150 000 USD needed to install a DC fast charger [7].

"Owners of single-family homes can charge in their garages, but most everyone else will either need on-street Level 2 charging or opportunity fast charging (charging for short intervals as opposed to fully charging all at once)," said Dave Mullaney, principal on the Carbon-Free Transportation team at the Rocky Mountain Institute (Boulder, CO, USA), a non-profit organization focused on accelerating the global transition to clean energy. "Which model works best will depend on your city's unique geography," said Mullaney. "Either way, right now, public infrastructure is just completely unable to cater to the expected needs."

In its November 2021 Bipartisan Infrastructure Investment and Jobs Act, US legislators earmarked 7.5×10^6 USD toward creating a network of 500 000 charging stations across the country by 2030 [8]. Accompanying the funding were rules set forth by the US Joint Office of Energy and Transportation (JOET) requiring the installation of at least four public charging ports every 80 km along every highway in the country. To overcome the lack of charger interoperability that has plagued the industry [9], the rules also stipulate that all ports be able to recharge all types of EVs at a minimum of 150 kW and operate on compatible software that allows secure remote monitoring, control, and updates [10]. "This money will help to get things going," Mullaney said. "But before long it will have to be commercial, and companies will have to identify the price points that will enable private sector investment." According to the JOET, 500 000 charging stations will ultimately require a roughly 9.0×10^7 USD investment, with the bulk of that coming from the private sector [11].

Europe is also scrambling to close the gap between the number of EVs expected on their roads and the number of charging stations in operation. As of September 2020, Europe had 250 000 charging ports—half of them located in just two countries, the Netherlands and Germany [12]; it would need to add 265 000 per year to get to the region's goal of 2.9 million ports to support 30 million EVs by 2030 [13,14]. China has done better. As of October 2022, the

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country hosted 1.15 million public charging ports, with about half of those built in just the previous year (2021). The Chinese government plans to have enough chargers in place to support 20 million EVs by 2025 [15].

In the United States, EV manufacturer Tesla (Palo Alto, CA, USA) has led private sector efforts to create a nationwide charging network, building about 1660 charging stations to date that collectively host around 17 700 ports (Fig. 1) [16]. But these chargers currently work only with the company's EVs. In early 2023, the carmaker's chief executive, Elon Musk, said that by the end of 2024 Tesla plans to make 7500 of its proprietary ports—including 3500 or so 250 kW versions—available to non-Tesla EVs [16], as has long been the case for Tesla charging stations in other markets, including the European Union and China. The first US Tesla Supercharger station with a "Magic Dock" port that charges the batteries of all EV models opened in New York City in February 2023 [17]. Other major car manufacturers that have jumped on the EV bandwagon—including Ford [18], General Motors [19,20], Mercedes-Benz [21], and Volkswagen [22]—have announced partnerships with firms such as ChargePoint (Campbell, CA, USA), Electrify America (Reston, VA, USA), and EVgo (Los Angeles, CA, USA) to build tens of thousands of charging stations across the United States.

And how will EV owners know where to find all these new charging stations? Google Maps now can point users to the nearest fast charging station [23]. EV drivers will also soon be able to ask Amazon's voice assistant, Alexa, to locate public charging spots; EVgo will be the first charging company to partner with Amazon to offer this service in late 2023 [24].

Building a nationwide network of charging stations is just one challenge, though. While it takes only a few months to install EV chargers, it can take years for state agencies and utilities to approve and build the major transmission grid extensions that will be needed to power them. Only a handful of truly megawatt-scale charging hubs are currently operating in the United States, and new ones are facing delays in getting the grid connections they need [25]. Accounting for potential weaknesses in the grid, a growing number of EV-charging sites now house batteries that can store power at times when chargers are sitting idle and provide it when charging loads exceed available grid capacity [26].

The demands on the grid will only continue to increase in the future. According to a 2023 study by National Grid Plc [27], a London, UK-headquartered utility company that provides power to New York and Massachusetts, by 2030 high-traffic stations in the United States will need 10–20 charging ports capable of each supplying 350 kW. These would pull up to 7 MW during peak load, roughly equivalent to the power demands of an outdoor sports stadium [27]. And as more electric trucks hit the road, the projected power needs for a big truck stop by 2035 will equal those of a small town. By 2045 medium- and heavy-duty trucks will represent three-quarters of the EV market and the largest truck stops will need to provide power equivalent to that consumed by a major industrial site.

"The US grid is not ready in terms of its infrastructure and capacity, and this problem will only be exacerbated by the future of all-electric homes and all-electric buildings," said Scott Samuelsen, professor emeritus of mechanical and aerospace engineering and founding director of the Advanced Power and Energy Program at the University of California, Irvine (Irvine, CA, USA). "Smart grids will be required to manage all of the chargers, whether they are in the home or outside the home." Such smart grid technology will essentially throttle energy delivery to ensure the grid does not exceed capacity, which may mean some owners will face variable charge times or tiered pricing. "The extent to which we can deploy smart grid technology will reduce the amount of capacity and infrastructure that will otherwise be required," Samuelsen said.

While delivering power to chargers will remain a challenge for the foreseeable future, new developments on the vehicle side could help pick up the slack in charger availability. Engineers are working on innovative technology that will allow EV batteries to charge more quickly and less frequently.

Changing batteries to and keeping them at precisely the optimal temperatures for charging and discharging has presented a major challenge for engineers. "The colder it is outside, the slower the battery charges, not because you cannot physically pump more electricity into the battery, but because you can damage the battery by quickly charging it at lower temperatures," said EC Power's McCarthy.

One way around this limitation is to use a battery management system—a microprocessor module that monitors voltages, currents, and temperatures of battery cells, and adjusts those levels to maintain optimal vehicle performance [28]—to pre-heat cells in the battery so they are at the optimal temperature to receive the quickest charge possible. To regulate battery temperature, most EVs now on the road rely on external, bulky heating and cooling systems, which respond slowly and waste energy. To better

Fig. 1. A Tesla Supercharger station in the United States with four proprietary ports capable of charging Tesla vehicles at 250 kW. Before the end of 2024, Tesla plans to modify many of its US stations, like this one, so its ports can charge any EV, as they already do in Europe and China. Credit: Tesla, Inc. (public domain).

Fig. 2. The black box topping EC Power's innovative EV battery controls the 10 to 25 μm thick sheets of nickel foil layered within the battery that heat it from the inside out. Compared to the external thermal management systems used in most of today's EV batteries, this internal system more effectively and efficiently controls the temperature of the battery to improve its operation, including facilitating faster charging. Credit: EC Power (public domain).

address this issue, EC Power layers its fast-charging EV battery (Fig. 2) with 10 to 25 μm thick sheets of nickel foil that function as internal heating elements [29]. "Because you are heating from the inside out, you can heat, at a minimum, 30 times faster than with existing EV battery thermal management systems," McCarthy said. The novel system more efficiently achieves the higher temperature condition needed for fast charging.

The nickel foil system can also help EVs capture braking energy. To boost range, most EVs are designed to capture the energy from braking. But they do not capture all they could, because the braking energy is usually much greater than the battery cells can safely accept. "Our technology captures all the energy by quickly warming the cells to improve their performance while recharging them," said McCarthy. He said the company is currently working to scale up the manufacturing of its battery.

Other battery manufacturers are innovating to boost the range of EVs. For example, the world's largest battery manufacturer, Contemporary Amperex Technology Co., Ltd. (Ningde, China), has designed a cell-to-pack battery called Qilin that uses a single structure for the battery pack rather than connecting a group of individual modules together like traditional EV batteries. The third generation of Qilin, recently named one of Time Magazine's Best Inventions of 2022 [30], promises a record-breaking volume utilization efficiency of 72% and an energy density of up to 255 $W \cdot h \cdot kg^{-1}$, enabling a range of 1000 km on one charge [31]. The battery is currently being offered in Zeekr 001 model EVs [32], built by the multinational car manufacturer Geely (Hangzhou, China).

But while such improved vehicles could curb range anxiety and spark more EV purchases, the lack of chargers and delivering sufficient power to operate them still present substantial roadblocks to achieving the EV future now envisioned by most countries. "We cannot sleepwalk our way into our conversion to EVs," said Mullaney. "If we are not investing in technology and infrastructure for our future needs over the next five to ten years, we will miss the boat."

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