Electrifying Vehicle Transportation: Issues and Challenges for Local Planning and Policymaking

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16. Abstract: In the U.S. and around the world as electric powered vehicles (EVs) are increasingly substituting for vehicles powered by internal combustion engines. Vehicle electrification is accelerating across vehicle categories including light and medium-duty vehicle categories and in public transit and school buses. There is broad agreement that it is crucial to systematically develop the charging infrastructure in unison with electric vehicle deployment. Yet this is a highly complex challenge involving different charging modalities (e.g. for personal vehicles, fleet vehicles, buses), numerous institutional actors (auto makers, private firms, utilities, and all levels of government) and evolving charging technologies. U.S. An efficient and inclusive transition to electric vehicles will require energetic and durable coordination, planning and policy development as well as deeper levels of community engagement. Serious economic, technical and informational barriers must be addressed. The needed buildout of the charging infrastructure will require considerable investment and intensive collaboration between public sector organizations and private sector actors. Electric utilities will be critical players in the build out of the charging infrastructure. Recent large scale federal investments and supports will accelerate the scale up of the charging infrastructure, but how the key local institutions come together to leverage these funds will strongly shape outcomes.

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Overview and Summary

Motorized transportation is undergoing a major technological transition in the U.S. and around the world as electric powered vehicles (EVs) are increasingly substituting for vehicles powered by internal combustion engines. In Europe and east Asia electric vehicle shares of all passenger car sales range from 16 percent in China, to 20 percent in England and France, to 86 percent in Norway. The U.S. lags other high-income countries, but sales of plug in electric vehicles (which include plug-in hybrid and all battery electric vehicles) have grown rapidly and constituted about eight percent of new car sales in the first half of 2023. Vehicle electrification is also accelerating in medium-duty vehicle categories (short hall trucks, delivery vans, service vehicles) and in public transit and school buses. As with any major technological transition, the electrification of vehicle transit will involve turbulence, resistance, and ups and downs. There will be considerable frictions in a strong overall trend of increasing adoption.

From one perspective the transition to electric vehicles involves a major transformation of the national transportation system with new power trains in various vehicle classes and a new system of vehicle charging substituting for the established fueling infrastructure of internal combustion powered vehicles (ICEVs). On the other hand, we are simply switching vehicle propulsion systems of established vehicle types and this transition will be relatively slow-moving allowing an incremental build-out of the charging infrastructure. If the U.S. achieves the relatively ambitious goal of plug in electric vehicles (PEVs) constituting 50 percent of new vehicles sales in 2030, this will leave over 80 percent of the nation's total vehicle fleet “unelectrified” at the dawn of the next decade.

The accelerating substitution of plug in electric vehicles (PEVs) for ICEVs is driven by distinct technical, environmental and consumer advantages including:

Reduced greenhouse gas (GHG) emissions. There is a broad consensus that that EVs generally produce significantly less “life cycle” GHG emissions than ICEVs when considering GHGs generated by producing required material inputs, vehicle manufacturing, fuel and maintenance and disposal. There may be very limited exceptions in regions where PEVs rely heavily on electricity generated by coal power. But over time the greening of electric power generation will boost the net benefits of vehicle electrification.

Reduced tailpipe emissions: In addition to contributing to decarbonization, vehicle electrification yields significant environmental gains through reduced tailpipe emissions (particulate matter, carbon monoxide, nitrogen dioxide).

Public health benefits: Numerous studies indicate that reductions in GHG and tailpipe emissions from vehicle electrification translates into important public health benefits, largely through reducing the incidence of respiratory disease.

Lower vehicle ownership costs: Recent estimates of overall vehicle ownership costs strongly indicate that new passenger PEVs have or will soon have significant cost advantages over ICEVs when considering total cost of ownership (including purchase prices, fueling costs, maintenance costs, and insurance costs over vehicle lifetimes).

At the same time, planners and policy makers will be called upon to address real pitfalls and hurdles to broad based vehicle electrification. Numerous critics highlight environmental issues and intrinsic inequities associated with allocating massive public sector support to simply reduce the environmental impacts of personally owned vehicles. Continuing to organize transportation around ubiquitous personal vehicle mobility and road based logistic systems might undermine the deeper decarbonization of transit systems required to meet critical GHG reduction targets and other environmental goals.

In terms of central challenges, a strong transition to PEVs is contingent on managing the fundamental change from a combustion-based fueling infrastructure to an extensive and accessible charging infrastructure. There is broad agreement that it is crucial to systematically develop the charging infrastructure *in unison* with electric vehicle deployment. Yet this is a highly complex challenge involving different charging modalities (e.g. for personal vehicles, fleet vehicles, buses), numerous institutional actors (auto makers, private firms, utilities, and all levels of government) and evolving charging technologies.

Perhaps the most important issue associated with vehicle electrification is developing more equitable access to personal PEVs and affordable and convenient vehicle charging. To date, electric vehicle adoption has been heavily concentrated in higher income, urban households. Low PEV uptake rates for low to moderate income and African American and Hispanic/Latino households can be attributed to higher vehicle prices, spotty access to convenient charging and perception and information barriers. Fostering more equitable participation in the PEV transition will be a seminal challenge for the public and private sectors moving forward. In particular, It is top priority for PEV manufacturers producers to expand their markets beyond consumers who are already likely to consider new PEV purchases.

To address this set of challenges and accelerate the PEV transition, unprecedented federal incentives and supports to have been launched as part of the Bipartisan Infrastructure Law (BIL, 2021) and the Inflation Reduction Act (IRA, 2022). The BIL legislation offers almost $29 billion in grants over the next five years focused on accelerating the build-out of the charging infrastructure and fostering the adoption of electric public transit and school buses. The IRA offers substantial incentives and credits for PEV purchases and to expand and deepen the domestic electric vehicle manufacturing base.

There are important provisions in this legislation that support PEV purchases and charging infrastructure build-out in rural and low income communities. In the case of the BIL states and localities receiving funds must ensure their plans meet Justice40 goals aiming to ensure that 40 percent of BIL investments benefit disadvantaged communities (DACs). Elements in this law require grant recipients to carry out a public engagement process to identify direct and indirect benefits that flow to DACs.

In the IRA, PEV purchase credits for new and used vehicles have been redesigned to allow consumers to receive the credit as a direct rebate at the point of sale. A low to moderate income PEV purchaser with a limited tax liability can immediately enjoy a lower net purchase price and will not have to wait to reap the value of the incentive until tax time. Accounting for these subsidies, the costs of purchasing PEVs is moving toward parity with similar ICE alternatives. As the PEV market expands, increasing economies of scale and incremental technological progress will reduce costs of production and PEV prices – price parity without subsidies is likely to be reached over the next five years.

These major federal interventions strongly supplement existing supports by state and local governments and utilities. Taken together, incentives and supports for accelerated PEV adoption offered by governments and utilities are both comprehensive and complex to navigate. New cross agency and cross institutional collaborations will be required to leverage investments and incentives to drive increased adoption across all vehicle classes and effectively build-out specific types of charging infrastructure with equitable access characteristics.

The build out of the charging infrastructure and the effective leveraging of federal support will require a much deeper level of coordination and collaboration between utilities and an array of local public and private institutions. Many of these actors have limited experience working together. New partnerships and clear regulatory guidance will be required to increase the efficiency of building new charging capacity. Local planners and policy makers will play a critical "on the ground" role in supporting the PEV transition in a number of areas.

- As PEV demand increases developers of commercial and multifamily residential properties will be required to work directly with utilities to assess power connection requirements, the distance between a charging area and the closest utility interconnection point and possible needs for step-down transformers and issues of easements. Since developers have not previously had to consider charging infrastructure as apart of building parking requirements, it is essential that utilities and local government departments create new procedures and allocate trained personnel to ease the time and monetary costs of charger installations in commercial and multifamily properties.
- Metropolitan planning organization (MPOs) and/or other local or regional authorities will be heavily engaged in the siting decisions of public charging stations. Coordination with utilities will be central in this site selection process because utility interconnection options and costs strongly shape the viability of specific sites. Local planning departments will be called upon to provide accurate information about permitting requirements, easements, signage and even demographic information (to meet equity requirements in various federal PEV support programs) for different possible sites. Once again, creating the organizational capacities within these institutions to facilitate site selection processes will be necessary to enhance the efficiency and accessibility of public charging development.
- Within the public sector new cross-agency and institutional collaborations will be needed to effectively build-out the charging infrastructure for public transit and school buses. This will involve constructing larger-scale depot charging centers, which will often require major electrical infrastructure elements linking utility grid interconnections to the depot. Careful planning and coordination between the utility, transit operators and city planning and code departments will be essential. Similarly, installing in-route charging stations for busses will require transit operators to work with city planning departments, utilities, and private property owners to assess easements and find viable on-route charging sites.

Similarly, utilities, and city transportation, planning and public works departments must engage in joint work to develop charging capacity on city streets to supplement other forms of charging access.

There are promising innovations to streamline charging infrastructure build-out. California legislated a requirement that municipalities streamline permitting for PEV infrastructure. The state has also provided a guidebook on streamlined PEV permitting for municipalities through the Governor's Office of Business and Economic Development.

Several reports recommend that public and private utilities create a charging infrastructure team/center offering "one stop" information and coordination services to public and private charging station developers. Such a central point of contact could significantly reduce costs and time delays by offering: detailed information and maps of grid hosting capacity at sites across the utility's service area; assistance with completing utility interconnection applications and speeding their approval; and coordinating the scheduling of utility work as part of site preparation process team.

The American Planning Association has developed a set of recommendations for local zoning standards and other local ordinances to clarify regulations and ease approvals for various charging installation types. This study suggests that local ordinances explicitly permit charging equipment for all residential uses and that other uses should be normally permitted as an accessory use (versus a primary land use). The document highlights existing local ordinances requiring EV ready or EV installed parking space requirements for new multifamily construction or other uses.

Local planners and policy makers also have an important role in advancing equitable access electric vehicle alternatives, especially improving access to convenient, affordable vehicle charging and engaging communities to overcome limited information and exposure to PEV options.

A key challenge is providing charging access at multifamily residential rental developments. Charging at the place of residence is the most economical and convenient means for personal vehicles. A number of cities have developed ordinances that require installation of charging infrastructure at new multi-family developments (typically as percentage of parking spaces). Adding charging capacity to existing multifamily is a much difficult problem. Some state governments and utilities provide significant grants or rebates to install chargers or make-ready infrastructure at existing multifamily complexes. Nine states have used funds from the VW settlement to provide grants or rebates for charging infrastructure at multifamily dwellings. But more broadly, local governments and utilities need to work with communities to improve charging access through a combination of affordable charging at public facilities, commercial establishments and the build-out of charging in multifamily complexes.

Deeply engaging lower income and rural communities is vital to advancing transportation electrification. Normalizing the idea of PEV adoption in these communities will require much more focused education and outreach efforts by manufacturers and public and non-profit institutions. An important component of education and outreach is consolidating and clearly communicating information on the numerous and often bewildering set of incentives and supports that individuals, businesses and communities might utilize to lower the cost an enhance the convenience of PEV ownership.

A number of deeper and more comprehensive public engagement activities are being implemented across the country. Emerging best practice lessons from these community-based public engagement activities suggest that they have a much broader focus beyond education and advocacy for electric vehicle adoption. Since transportation access in general is a barrier and cost burden for many low income and minority populations, public participation starts with a more general discussion of community identified community needs which can encompass the full range of transportation modes. Community participants then lead the process of identifying priority mobility needs in their specific neighborhoods. In the context of assessing needs, the issues and advantages associated with electric mobility including personal vehicles, public and school transit and light and medium duty trucking and delivery can be explored.

I. Introduction

The market share of all battery electric vehicles (BEVs) and plug in hybrids (PHEVs) is rapidly expanding, especially in higher income countries. In this report we put these two types together in a single category, plug in electric vehicles (PEVs). In light of national and international climate action goals and the growing advantages of PEVs for personal and commercial transit, there is strong momentum for a substantial take-off of PEV adoption across the transportation sector.

Climate scientists and leading institutions have identified the next ten years as a make or break period to address the global climate crisis. The transportation sector is a major driver of GHG emissions in the U.S., accounting for approximately 27% of total GHG emissions (U.S. Environmental Protection Agency, 2022). A large-scale conversion from vehicles powered by internal combustion engines (ICEs) to PEVs is an important element in seriously addressing climate change dynamics. Sales of PEVS (both all battery BEVs) and plug in hybrid (PHEVs) have grown dramatically over the past two years across major international markets (China, the U.S. and Europe), with global sales doubling to 6.6 million or about 9% of total vehicle sales internationally (International Energy Agency, 2022). Ownership or registration data suggest that the total number of electric cars in use was roughly 16.5 million by the end of 2021 (Ibid, p. 1). U.S. PEV sales have been increasing at an accelerating rate, although projections for future adoption remain somewhat speculative. However, the recent take off of PEV adoption should be viewed in light of global and U.S. net zero emissions goals which will require an PEV share approximating 60% of new car sales by 2030 (Ibid 2022. p.1).

It is interesting to note that electric powered vehicles held a prominent position in the very small but growing personal vehicle market in the early 20th century, significantly outpacing ICE powered vehicles in the 1900-1910 period (Guarnieri, 2012). Early ICE powered vehicles were unreliable, hard to start and produced noxious smoke and emissions, while electric powered cars were quiet, reliable and easy to start. However, some issues that surround PEVs today, including higher vehicle purchase costs and limited driving ranges stifled more extensive adoption while technological and production advances in ICE powered cars led to their dominance after 1910 (Szabo & Iulia, 2022). The technical and functional differences between ICE and electric powered vehicles remain significant today and pose durable challenges as the substitution of PEVs for ICEVs in various motorized transportation segments accelerates. Recent literature suggests that higher rates of PEV adoption face five significant barriers in the near term:

- **Vehicle purchase prices** which remain higher than ICE alternatives across almost all segments (personal vehicles, commercial and public transit vehicles);
- **Vehicle range** which has been more limited , but is catching up with ICE alternatives;
- **Limited access to convenient charging** which slows wider-scale adoption, especially for inter-city travel;
- **Charging time** which is currently significantly longer than refueling times for ICEs in most cases;

- **Poor information across the consumer base** which is related to existing PEV adopters being concentrated in high-income strata in select urban areas.

As this report will demonstrate, many of the above barriers are coming down, aided by a range of supports and incentives by all levels of government as well as private sector actions from private utilities and vehicle manufacturers. Yet perhaps the most significant current fetter to more rapid PEV adoption are misperceptions about the advantages and disadvantages of electric transport and limited access to convenient and affordable charging, especially in low and moderate-income communities.

This report will review the multiple issues, debates and policy initiatives associated with accelerating the PEV transition. We begin with overview sections detailing some basic adoption patterns in the context of longer-term climate goals and review findings from contemporary literature on the advantages and possible limitations of PEVs across various vehicle classes. To enhance the understanding of planners and policy makers, especially at the local level, recent federal government actions to accelerate PEV adoption will be detailed. In subsequent sections we review the current state of the PEV charging infrastructure highlighting current challenges such as filling major access gaps and forging new institutional collaborations to achieve the major build-out of charging capacity for various vehicle classes and use cases. Finally, we will outline certain policy innovations that could support the systematic development of the charging infrastructure and accelerate adoption of PEVs across all income groups and regions.

II. Electric Vehicle Adoption Across Motorized Transit Segments

The largest and most significant category of motorized transportation is personal vehicles. However, the transition from internal combustion to electric propulsion will affect a wide range of motorized transportation platforms, from heavy trucks to two-wheeled vehicles. It is notable, for example, that the sales of e-bicycles have soared and currently have much higher adoption rates that four wheeled vehicles in the U.S., east Asia, and Europe (Toll, 2021)[1]. In terms of current

[1] The adoption of e-bicycles is a significant phenomenon, but there is limited evidence about net environmental impacts. If e-bikes are substituting for conventional bikes, the net environmental effects might be negative. However, by extending the range and convenience of local trips, they may be reducing miles traveled by four

adoption rates of other vehicles, light duty vehicles are the main category where PEVs are currently significant and rapidly growing in terms of their market shares (see Table 1, below)[2]. There are significant initiatives by manufacturers and customer groups in to introduce electric vehicles for fleet purchases in select medium and heavy duty vehicle categories, but adoption is just beginning to take off (Uddin, 2021). In the heavy duty-long distance category, there are significant projects by manufacturers to introduce electric vehicles, but adoption is currently in the pilot stage (Ibid, 2021). An exception here is in the transit bus category of heavy duty vehicles, were transit authorities and school bus operators are launching significant projects to transition to PEVs. The adoption rates and prospects for these various vehicle classifications will be reviewed below.

Table 1 - Vehicle Types and the Transition to Electric Propulsion Systems

Vehicle Type	Internal Combustion (ICE)	Plug In Hybrid Electric (PHEV)	Battery Electric (BEV)	Prospects for rapid BEV adoption 2023-2030
Two Wheeled Vehicles (e.g. e- bicycles)			■	High
Light Duty (10,000 lbs. or less)	■	■	■	High
Medium Duty (10,001 - 26,000 lbs.)	■	■	■	High
Heavy Duty (over 26,000 lbs.)	■			Low
Public Transit Buses (over 26,000 lbs.)	■	■	■	High

Source: Federal Highway Administration (FHWA), https://afdc.energy.gov/data/10380

wheeled vehicles and producing net environmental gains. Because e-bikes and related alternatives typically do not call for a substantial expansion of the charging infrastructure, they will not be a focus in this report.

[2] In this report we will consider only vehicles that plug into an electric outlet for charging, BEVs and PHEVs. Most analysts predict that all electric BEVs will grow to dominate the market over time and the PHEV market share will shrink.

Personal Light Duty Vehicles

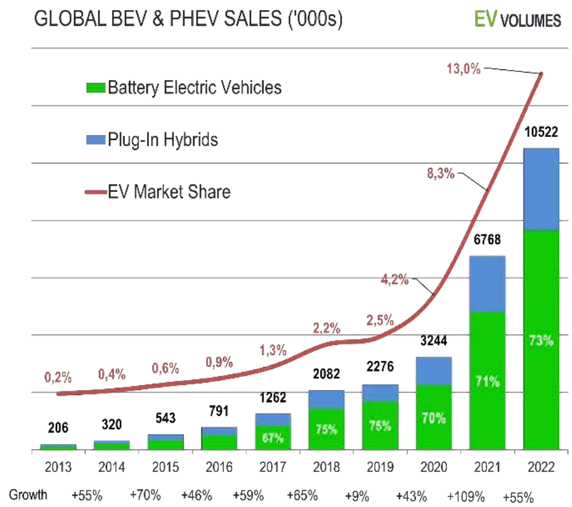
As noted, electric cars predate ICE cars and held a high share of the personal vehicle market until 1910 (Szabo & Iulia, 2022). Interest in electric vehicles was revived in the 1970s, when oil prices increased and the environmental effects of ICE dominated transit emerged as major concerns. The federal government began to actively support research and development on electric and hybrid vehicles with the passage of the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976, authorizing the Energy Department to support research and development in electric and hybrid vehicles (Mattulka, 2014).

Several firms made battery electric vehicles as prototypes or at small scales, but there was little commercial interest (Thompson, 2017). A subsequent boost in activity was prompted by the California Air Resources Board's 1990 standards pushing for zero emissions vehicles. A number of car companies introduced EV models, but again there was very little sales growth due to low 1990s gas prices and skepticism about the demand and profitability of EVs among major manufactures (see Paine 2006).

A more substantial advance came with the larger scale introduction of electric-ICE hybrid vehicles in the late 1990s, most prominently the Toyota Prius that began to be offered in the US in 1999. While these models were hybrids relying on combustible fuel and internal systems (versus external charging) to generate electric propulsion, they drove advances in battery technology, power train engineering and mass production processes associated with mass market sales levels.

General Motors introduced the first mass production plug in hybrid, the Chevy Volt in 2006. Tesla motors began production of an all BEV car in 2008 but began larger scale production with an improved Roadster model in 2011. The all electric Nissan Leaf was introduced in 2010 and launched U.S. production in 2013 in a Tennessee facility (U.S. DOE, 2014; Wilson, 2023). These models were the first to utilize the significant technological advances of lithium-ion battery packs, which extended ranges to 200 plus miles. The cost of lithium-ion batteries experienced substantial declines over the 2008-2014 period, with continued extensions of range (Wilson, 2023). By 2018 Nissan sales equaled 300,000 units worldwide and Tesla sales exploded with the introduction of the Model 3 in 2017. By 2022 Tesla was the largest all-EV maker in the world , with 1.3 million in sales. Over the 2020-2023 period numerous major auto companies, including Chinese companies BYD and SAIC and global companies such as Ford, GM, Volkswagen, and Volvo began rapidly scaling production as sales of PEVs accelerated (Kane, 2023).

Figure 1 – Global Sales of Plug in Hybrids and Battery Electric Vehicles

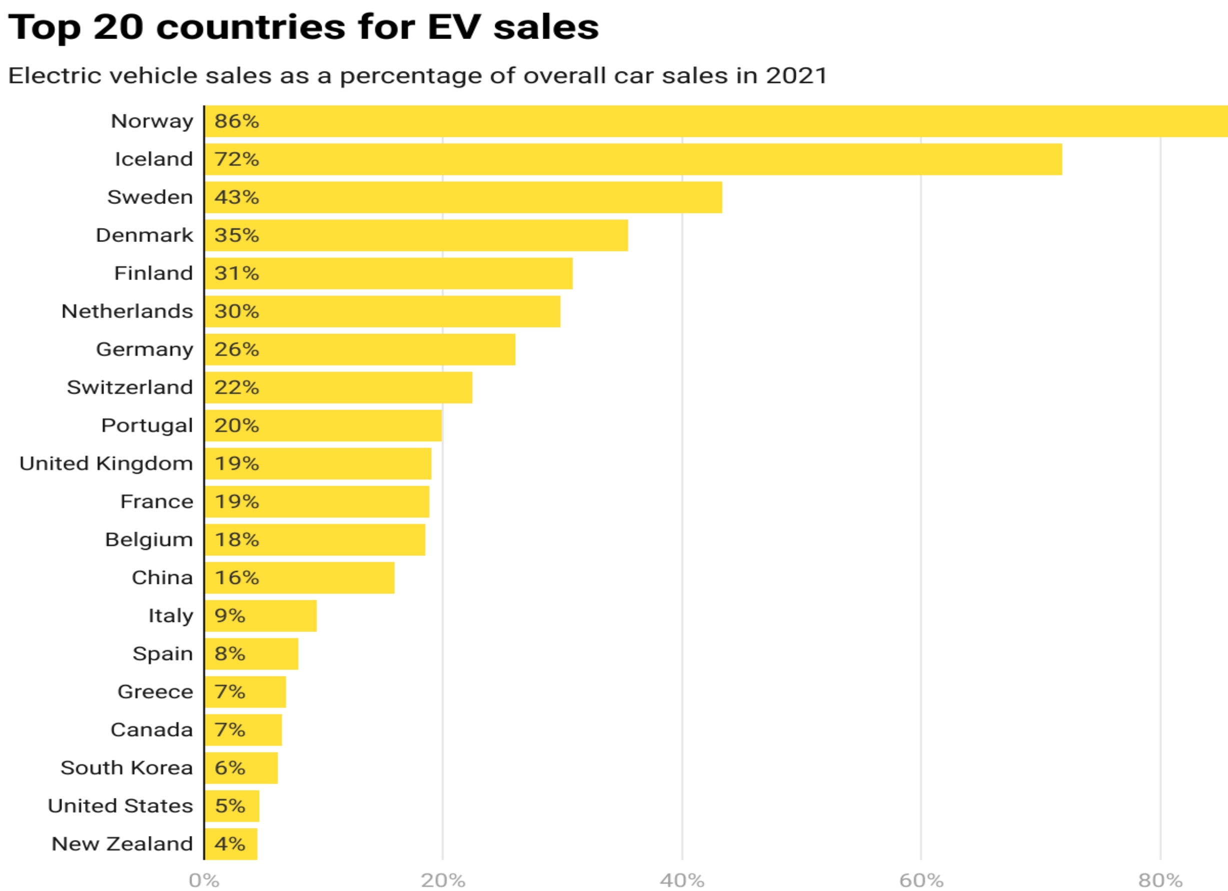


Source: Irle, Robert. 2023. EV-Volumes - *The Electric Vehicle World Sales Database*

After this history of starts and stops, the global sales of PEVs experienced a notable take-off after 2017. In the U.S. (PEV) sales grew from 230,800 units (1.4% of total vehicle sales) in 2019 to 762,900 (5.7% of total vehicle sales) by 2022 (Shahan, 2023). U.S. PEV sales reached over 8 percent of new vehicle sales in the first quarter of 2023, with PHEV sales accounting for 28 percent of sales and BEVs 72 percent (Wood et al., 2023). Through February of 2023 cumulative PEV sales were over 3.4 million vehicles (IbId, 2023). Plug in vehicle sales have risen faster than ICE sales in the U.S. and internationally indicating a process of substitution that is gathering steam.

The U.S. lags far behind many other high-income countries in terms of PEV adoption rates. For example, in Norway new EV sales already dominate the new car sales market, with an 86% market share in 2021. China now constitutes the largest BEV market in terms of total sales volume, with about 4.35 million BEVs sold in 2022, constituting nearly 22% of new vehicles sales (Kane 2023). These differential adoption rates raise a number of interesting issues: have counties with high adoption rates more aggressively built out the support infrastructure for PEVs; are the net costs of PEV purchase and operation relative to ICE vehicles lower high PEV adoption countries; do some countries have stronger policies and incentives supporting EV adoption? Viewed from another perspective, can we say the relatively low adoption rates in the U.S. offer encouraging opportunities to “catch up,” rapidly accelerating the pace of PEV sales.

Figure 2 – EV Sales In Higher Income Countries



Source: International Energy Agency. 2022a, “Global EV Outlook”.

Forecasting future adoption rates remains speculative, but continued technological improvements, increasing production rates, growing competition among major producers and supportive public policies will almost certainly lead to price declines and improved quality and reliability over time. One notable forecast by Bauer et al. (2021) projected that U.S. PEV sale share will “increases from 2% in 2020, to 10% in 2025, to 36% in 2030” based on specific assumptions about market and policy trends. As for total number of PEVs in the U.S, they estimate an increase from 1.8 million in 2020 to 7.1 million in 2025, to 25.8 million in 2030 (Ibid, p.16).

While total ownership costs (vehicle purchase costs, fueling costs, maintenance and repair costs) of light duty PEVs vehicles are already cheaper than ICE vehicles, the falling purchase prices of

PEVs may move them toward parity with ICE sticker prices over the next 3-5 years (Liu et al., 2021) Moreover, a set of strong supportive federal policies were put in place with the passage of the Bipartisan Infrastructure Law in 2021 and the Inflation Reduction Act in 2022. These measures, which will be discussed in detail below, promise to significantly accelerate adoption.

A recent forecast incorporating many of these evolving factors estimates that there will be 33 million plight duty PEVs on the road by 2030 and that new PEV sales will constitute roughly 50 percent of all new vehicle sales (Wood et al., 2023). This forecast estimates that in 2030 BEV sales will be 90 percent of plug in vehicle sales and PHEVs 10 percent (Ibid). This is consonant with the Biden Administration goal for 50% of new passenger vehicles sold in 2030 to have zero emissions. However, to achieve this level of BEV adoption aggressive and complementary planning and policy initiatives will be required from the public and private sectors.

Medium and Heavy Duty Vehicle Classes

Medium and heavy duty vehicles (MHDVs) are a critical segment because heavy duty trucks in particular are outsized contributors to GHG emissions as well as ozone and particulates with highly adverse health effects (Uddin, 2022, Ledna et al., 2022). Moreover, these vehicle classes have been shown to have disproportional local effects on disadvantaged communities (Ledna et.al 2022). Prospects for PEVs adoption in the MHDV categories vary significantly across subcategories in this broad segment (see table 1, above). Currently overall sales in these subcategories remain quite low. According to the International Energy Agency, electric medium- and heavy-duty truck sales totaled roughly 14,200 in 2021,representing less than 0.3% of new registrations for medium- and heavy-duty vehicles worldwide (IEA, 2022). The lion's share of these freight-related vehicle sales have been in China.

However, prospects for a near term take-off in PEV adoption in certain categories of medium and heavy-duty vehicles are significant. In appraising the growth in PEV adoption in this category, it is important to distinguish vehicle size, load weight and travel distances for specific use cases (Ibid. 2022). Three categories in particular are primed for a more rapid transition: medium duty short hall fleet and/or delivery vehicles (averaging less than 250 miles per day in VMT); public transit buses; and school buses.

In the class of medium duty, short hall trucks and vans, Ledna et al. estimate that these PEVs will reach cost parity with ICE platforms (excluding all subsidies) by 2026. Numerous large retail and wholesale companies have aggressive programs to transition their delivery fleets to BEVs. Amazon has launched an aggressive program to electrify its package delivery fleet ordering 100,000 electric vehicles in 2019, and other major companies such as FedEx have significant fleet transition programs (David Gardiner and Associates,2022). A 2022 Environmental Defense Fund report found that corporations deployed or pre-ordered over 150,000 MHD EVs (Environmental Defense Fund, 2022).

In the public sector there are aggressive programs to transition to PEVs for federal, state, and local government fleet vehicles including vans and service trucks. In late 2022 the US Postal Service announced that new fleet acquisitions over the next five years will be 75 percent EV powered and acquisitions of after 2026 will be 100 percent electric (U.S. Postal Service, 2023).In addition, various local governments and utilities are actively electrifying vehicle fleets and work vehicles.

Electric delivery and utility trucks are interesting in terms of charging infrastructure because of the potential for overnight depot/warehouse charging, And in certain cases, these types of trucks can charge while parked and loading/unloading at a retailer or other commercial space (Leung & Peace, 2020; Hall & Lutsey 2019). While there is little solid evidence about projected adoption rates in this category, recent policy changes, user commitments and continued technological advances in EV powertrains make it likely that PEV substitution in this category will be robust over the next five years.

In the category of heavy duty -long hall trucking, the prospect for significant PEV adoption in the next few years is quite limited. A number of vehicle producers are undertaking significant R&D programs and piloting new PEV truck platforms, although commercial models and sales have yet to emerge. However, some forecast a take-off in heavy duty, long hall EVs around 2030 (IEA 2022; Ledna et al 2021)[3].

There is also accelerating momentum toward transitioning public transit and school buses to electric powertrains. A 2022 national survey by CALSTART estimated that zero emissions buses in service, or on order, increased from 1,650 in 2018 to 5,269 by 2022, an increase of about 230

[3] Particularly in the heavy duty vehicle category, hydrogen fuel cell technologies may emerge as a significant alternative zero emission alternative to BEVs (see Deshazo et al 2022).

percent over this five year period[4] (Chard et al 2023). Battery electric buses (BEBs) have significantly higher vehicle purchase costs that are in the neighborhood of double the costs of diesel alternatives, with a price differential of $400-$500 thousand per unit in 2021 (Johnson et al., 2020; Van Oudenaren, 2021). The costs of building the often extensive charging infrastructure necessary to service BEB fleets also pose a major challenge for transit authorities and operators. However, several researchers have argued that the total cost of ownership (TCO) of BEBs is currently competitive with diesel powered buses (Johnson et al. 2020; California Air Resources Board, 2017: Blynn and Attanucci, 2019). Numerous municipalities and school districts are actively working to transition to BEBs and these efforts are now being strongly supported by federal incentives, especially as provided in the Bipartisan Infrastructure Law (Lashof and Gander 2022). However, as will be discussed below, a large scale transition of public transit and school bus fleets will still face technical and institutional challenges in the short term.

III. The PEV Transition – Advantages and Challenges

Since indications point to a fairly rapid transition to BEVs across a number of vehicle transportation classes over the 2023-2030 period, it is important to briefly outline the documented advantages of transitioning to BEVs as well as the problems and uncertainties of this transition. Many of the net benefits of a transition to PEVs are well documented and include contributions to decarbonization and other environmental improvements, net improvements in public heath, lower vehicle ownership costs, and possible specific benefits to low and moderate-income households. Possible downsides and barriers to BEV adoption are also put forward by some researchers and it is important to better understand specific issues and frictions as adoption rates take off.

The benefits of electrifying vehicle transit

Reduced GHG emissions: A key environmental benefit of transitioning to BEVs is a reduction in GHG emissions. There is a fairly broad consensus that that EVs generally produce significantly less "life cycle" GHG emissions than ICEVs when considering GHG emissions generated by

[4] These numbers are for full sized buses (CIT class 7 or 8 transit buses over 30 ft in length). These totals include a small number hydrogen fuel cell buses. Hydrogen based platforms may emerge as a viable alternative to all electric buses in the future, but account for only 211 of the 5,480 Zero Emission Vehicles (ZEV) reported by CALTRANS.

producing material inputs, vehicle manufacturing, fuel and maintenance and disposal (Bieker, 2021; Eichberger, 2021; International Energy Agency, 2022c; Moseman, 2022; Union of Concerned Scientists, 2022). The extent of net GHG reductions associated with vehicle electrification is shaped by a variety for factors, especially the carbon intensity of power grids across nations and regions. A study that estimated a dynamic global average grid carbon intensity by the International Energy Agency (IEA) found that over the lifetime of vehicles PEVs CO^2 emissions were roughly half of similar classes of ICE passenger vehicles (International Energy Agency, 2022c). In the U.S. estimates vary, but a recent analysis suggests that over a 200,000 mile vehicle life cycle, PEVs generate 41% less CO^2 emissions than ICEVs as a national average (using an national average grid carbon intensity (Fuels Institute, 2022).

There are wide variations in net GHG gains across U.S. states and regions associated with local grid carbon intensity. Studies vary in estimating net GHG reductions from vehicle electrification by state or region. For West Virginia, with the most carbon intensive grid relying on coal for 92% of state power generation, one study estimated that PEVs actually generate more GHGs over a 200,000 mile vehicle lifespan (Fuels Institute, 2022). Other sources estimate that even in areas with high grid carbon intensity BEVs generate less CO^2 emissions than ICEVs (Department of Energy-Alternative Fuels Data Center, 2023; MIT 2018).

Two broad trends are likely to increase net GHG reductions from PEV adoption over time. The first is the ongoing greening of the electric power grid in most U.S. states and regions which will bring down GHG emissions of charging over vehicle lifetimes. Second is the prospect of technological advances in battery technology reducing the demand for certain minerals for EVs and other alternative energy systems (IEA 2022b). Technical advances that could reduce the demand key minerals (Cobalt, Lithium, Nickel, and rare earth minerals) for battery production would bring down net GHG emissions and other negative environmental effects of PEV production. There are a variety of incremental improvements with current lithium-ion batteries that will likley reduce demand for critical minerals. More major shifts in battery technology including solid state batteries and sodium-ion batteries are actively being developed and tested by a number of firms (Crownhart, 2023). Third, more robust battery recycling is likley as the BEV market expands, increasing the supply of key minerals and limiting the need for newly mined minerals (Ibid, 2023, IEA, 2022b).

***Reduced tailpipe emissions*:** In addition to contributing to decarbonization, vehicle electrification yields significant environmental gains through reduced tailpipe emissions (particulate matter, carbon monoxide, nitrogen dioxide). Studies show that PEVs eliminate very toxic emissions from engine exhaust and reduce particulate emissions from brakes (due to the use of regenerative braking versus disk braking systems) (Krajinska,2021).[5] It is important to emphasize that low and moderate income communities and African American and Hispanic/Latino households have been disproportionately exposed to tailpipe and related emissions (EPA, 2021). The electrification of fleet delivery vehicles and public transit and school buses will have an especially large effect in reducing more local effects of tailpipe emissions (Gonzales, 2022). For urban residents living close to major transportation infrastructure including highways, ports, or warehouses, tailpipe emissions pose high health risks. A large scale transition to BEVs hence has general environmental benefits as well as significant environmental justice implications(McAdams, 2022).

Public health effects: The reduction of GHG and tailpipe emissions from vehicle electrification translates into important public health benefits (Girardi et al 2020). A comprehensive analysis by the American Lung Association estimated the positive health effects a full transition to BEVs in all vehicle categories (from personal vehicles to heavy-duty long distance trucks) by 2050. The report notes:

> *"Cumulatively, the national benefits of transitioning away from combustion in the transportation sector toward 100 percent zero-emission sales…include approximately 110,000 lives saved, over 2.7 million asthma attacks avoided (among those aged 6-18 years), 13.4 million lost works days and a wider range of other negative health impacts avoided due to cleaner air." (American Lung Association 2022, page 8)*

This report further analyzes other "local' effects on lower-income communities and communities of color noting that these communities experienced highly concentrated doses of pollution, "from diesel hotspots, refineries, power plants and other fossil fuel facilities"(Ibid, page 18).

Lower vehicle ownership costs: Recent estimates of overall vehicle ownership costs strongly indicate that new PEVs are, or soon will be, competitive or hold cost advantages over ICEVs when considering total cost of ownership (including purchase prices, fueling costs, maintenance costs, and insurance costs over vehicle lifetimes). Estimates of total ownership costs (TOC) of PEVs

[5] Tailpipe pollution associated with ICEVs include both direct and indirect emissions and effects. "Secondary particle pollution is by particles not directly emitted out of the tailpipe but form in the air due to other pollutants such as nitrogen oxides (NOx), hydrocarbons (HC) and ammonia (NH3). One study estimates that up to 29% of the total particulate emissions of ICEVs come from these secondary effects (OECD, 2020)

versus ICEVs vary based upon vehicle price, vehicle range, charging location (at home versus public charging) and gasoline prices. Furthermore, TOC comparisons are structured in various ways such as over 15 years of ownership, a 200,000 mile average vehicle lifetime or average annual vehicle miles traveled. Many estimates using various assumptions suggest that the TOC of EVs in many passenger vehicle classes is currently lower than ICEVs (Harto, 2020; Liu et al., 2021; Guo et al. 2022; Taylor and Rosenberg, 2022).

Recent estimates suggest that the purchase prices of new PEVs range from $9,000 to $13,000 above comparable ICEV models (Lindwall, 2022). This differential does not include rebates or other incentives from federal, state, and local governments or utilities. Since higher sticker prices for PEVs are widely recognized as a significant barrier for adoption, a range of rebates and incentives are currently being offered to reduce purchase price differentials. As noted, it is probable that production costs and prices of new PEVs will fall in the near term due to growing economies of scale and technological improvements, especially related to the declining costs of batteries. It is now quite plausible that purchase prices across many personal vehicle classes may reach parity with ICEVs over the next five years (Liu et al., 2021).

The lower TOC for BEV passenger vehicles stems mostly from lower fuel and maintenance costs (Kumar et al., 2021) estimate that savings from fueling of PEVs could be 10-11 cents per mile when compared to ICEVs. A 2020 Consumer Reports study estimated the fuel cost for ICE vehicles compared with PEV vehicles over 15,000 miles in average annual mileage for owners of new vehicles. Their estimate suggests that PEVs "would cost about 60 percent less to fuel than comparable ICE vehicles, resulting in $800 to $1,300 in annual savings, depending on vehicle class." This difference assumes that 92 percent of PEV charging occurs at home, versus 8% at public charging stations (with higher changing costs) (Harto, 2020).

In addition to lower fueling costs, PEVs are likely to have significantly lower maintenance costs than ICEVs. While electric "motors" have a single moving part and a single gearbox, internal combustion engines have several hundred moving parts, all needing regular maintenance. The Consumer Reports analysis estimated that cost of maintenance per mile of PEVs averaged 3.1 cents per mile over the lifetime of the vehicle compared to 6.1 cents per mile for equivalent ICEVs. This differential would yield $4,600 in repair and maintenance savings over the vehicle lifetimes when discounted to the present value (Ibid, 2020).

However, not all recent estimates point to current lower TOC for BEVs. Bauer et al, use a number of assumptions about relative purchase prices, fuel, and maintenance costs to estimate amortized costs over time and find that TOC parity between ICEVs and PEVs across most passenger vehicle categories will be reached by 2025, excluding all public sector subsidies (Bauer et al 2021). One report about the real-world cost of fueling ICEs and PEVs claimed that PEVs could be more expensive. This report found that PEVs can be more expensive to fuel taking into account factors such as charging time cost requirements, costs of level 2 home equipment installation, and charging fees or subscriptions. However, this analysis assumed 70% of EV charging would be at some form of public/commercial charging, with only 30% home charging - an assumption that is eccentric relative to most other studies (Anderson Economic Group, 2021).

A final important TOC comparative dimension is in the used car market. Because of the relatively rapid pace of technological improvement, especially in terms of range, used PEVs tend to depreciate more rapidly that ICEVs (Bauer et al., 2021; Harto, 2020). Used cars in general offer more consumer value than new car purchases since the initial owner experiences the steepest rate of depreciation. Because current new vehicles are expected to log an average of 200,000 miles over their lifetime, used car buyers can capture a large share of a vehicles utility value while paying a fraction of the price of a new vehicle. Because BEVs currently have higher depreciation rates, used EPVs can offer significant value, especially for moderate and low income individuals. Higher depreciation of PEVs partially diminishes the higher purchase price disadvantage of new vehicles, while offering significantly lower fueling and maintenance costs over the life of the vehicle. The used PEV market is currently somewhat thin due to low historic adoption rates. However the variety and availability of used PEVs will grow over time alongside the expanding sales of new PEVs (Bauer et al., 2021). The attractive TOC characteristics of used PEVs will offer expanded ownership opportunities for moderate and low income households as the market evolves. However, over the longer term used PEV prices may exceed those of comparable used ICEVs due to greater value and more robust demand (Ibid, 2022).

By substantially reducing GHGs and other environmental harms of combustion vehicles, electric vehicles will have broad impacts in reducing negative externalities generated by the transportation sector. Because PEVs have, or will soon have lower total ownership costs, substitution for ICEVs also yield household welfare benefits. These advantages justify a variety of public sector subsidies and incentives to lower the purchase price of EVs, more rapidly scale up the charging infrastructure and support research and development to lower costs and increase the performance of batteries.

Pitfalls and frictions of vehicle electrification

There are undoubtedly strong rationales for a relatively rapid transition to PEVs and most trends point to a major take off in numerous vehicle classes. However, this transition in vehicle technology brings with it important questions and significant challenges across modes and infrastructural elements in the transportation system. It is important to pause and consider the possible consequences of the PEV transition for the decarbonization of the transportation sector in general, the numerous challenges associated with the needed build-out of the charging infrastructure and difficulties for ensuring equitable access to electric vehicles for all socio-economic strata.

An inadequate strategy to address broader environmental crises: Numerous critics highlight the environmental problems and intrinsic inequities of allocating massive public sector attention and support to simply reducing the environmental impacts of personally owned vehicles (Bergman et al, 2017; Sheller, 2018; Sovacool et al. 2019, Henderson, 2020). While the net environmental impacts of PEVs may be significantly less that ICEVs, the resource demands to produce the vehicles and the effects of generating the electricity to charge them still produce major environmental harms (Henderson, 2020). Some have emphasized that the transition to PEVs will displace many of negative environmental effects of vehicle transportation spatially – tailpipe emissions effecting urban areas are reduced while emissions around power plants and the negative effects of mineral mining are increased (in places such as Africa, China, and Latin America) (Ibid, 2020).

Continuing to organize transportation around ubiquitous personal vehicle mobility and road based logistic systems undermines the deeper decarbonization of the transit system required to meet critical GHG reduction targets and other environmental needs (Sovacool, 2019). At the same time it is not feasible to expand PEV ownership to some low-income households in richer countries and it is dubious to assume high levels of vehicle ownership in lower income countries. This line of argument sees the current fixation on PEV adoption and personal vehicle mobility as a fetter to broader green mobility strategies. More comprehensive green mobility frameworks would emphasize fewer cars and trucks, reduced vehicle miles traveled and universal access to public transit and non-motorized mobility options. This would be accompanied by more systematic efforts to make cities more compact, with higher local accessibility to work, services and leisure.

Equity concerns: To date, EV personal vehicle adoption has been heavily concentrated in higher income urban households. Numerous studies have demonstrated that PEV purchases have been highly concentrated in households earning more than $100,000 per year (Canepa et al, 2019; Muehlegger and Rapson, 2018, 2019; Atlas EV HUB, 2020; Wee et al., 2020; Bauer et al. 2021). Low adoption rates for low to moderate income households and African American, Hispanic/Latino households can be attributed to cost, perception, and information barriers.

The fact that recent PEV offerings have had significantly higher purchase prices and have until very recently been focused in "luxury" categories has limited access and interest for households in the lower three income quintiles. As PEV range and reliability improve and purchase prices for new and used models decline they will become an attractive option for broader segments of the population. However, like most new technologies, early adoption and experience with the product is more common among higher income individuals with higher levels of formal education (Yozwiak et al, 2022). Studies have further shown that PEV purchases are concentrated by Zip-code (in higher income ZIPs) and interest in adoption is related to neighbors who have acquired an EV (Atlas EV HUB, 2020) Many communities perceive PEVs as "for someone else" and lack interest or access to quality information about PEVs as an option for their personal vehicle needs (Ibid, 2022. Seeing adoption in a community and getting local information about possible advantages of PEVs is a crucial factor for stimulating adoption across wider income strata.

The transition to PEVs offers important advantages to low and moderate income households and communities. They can offer lower vehicle ownership costs for households where vehicle costs consume higher levels of household income. Electrifying transit will. over time, produce significant reductions in local exposures to tailpipe pollutants (McAdams 2022). However, there is considerable evidence that closing the adoption gap associated with income and residential location will require focused and aggressive actions by public and private sector institutions at numerous levels. Targeting incentives more effectively, aggressively expanding convenient and affordable access to quality charging infrastructure in rural and low to moderate-income communities and intensifying education and outreach to specific communities to increase awareness are actions that need to be a major focus moving forward.

The challenging build-out of the charging infrastructure: A key factor and potential bottleneck to accelerating PEV adoption is organizing a rapid transition from a combustion-based fueling infrastructure to an extensive and accessible charging infrastructure. Range anxiety is the term used to explain why expanding the charging infrastructure is necessary for accelerated EV adoption. While it is not exactly accurate to characterize this as a "chicken/egg" problem, there is agreement that it is crucial to systematically develop the charging infrastructure *in unison* with electric vehicle deployment (Hall & Lutsey, 2017). Yet this is a highly complicated challenge involving different charging modalities (e.g. for personal vehicles, fleet vehicles, busses), numerous institutional actors (auto makers, private firms, utilities, all levels of government) and evolving charging technologies.

In terms of personal passenger vehicles, the build-out of public charging stations is largely supplementary for PEV owners that have residential charging access (mostly residents of owner occupied housing). Lopez-Behar et al. (2018) recognize that a dense network of public chargers would reduce range anxiety, but since most charging is done at home, increasing residential charging availability is key. Residential charging has substantial advantages for both PEV owners and utilities. Vehicle owners can conveniently charge overnight at significantly lower cost (than most public charging options) while utilities can gain revenue in off-peak periods when there is typically excess capacity on grids. As will be discussed below, the installation of level 2 chargers in detached owner occupied housing is relatively easy and economical in most cases. However, providing convenient charging access in multifamily, especially in rental properties is a significant challenge.

Mersky et al. (2016) found that in Norway the number of EV charging stations had the highest predictive power for regional per capita EV sales. Likewise, a multivariate regression by Hall & Lutsey (2017) found that Level 2 and fast charging infrastructure (as well as EV purchase incentives) significantly increase electric vehicle uptake. The PEV market is believed to be deep enough and with high projected growth rates, so that charging infrastructure development is not generally hindered by a lack of demand. Instead, the main hurdles for charging infrastructure are financial, regulatory, and technical (location optimization, integration with the grid, etc.). Moreover, many medium and heavy duty vehicle classes will call for distinct charging solutions focused on robust and resilient depot charging with high operation and maintenance standards and supplementary access to specific public charging sites. We will probe these and other issues in detail below.

IV. Building the Charging Infrastructure for Vehicle Electrification

A broad transition from fueling to charging will be needed to support increased PEV adoption across various vehicle classes. To better understand current charging capacity and future needs it is first important to understand the unique charging needs of the various vehicle classes and how they relate to and land uses, building types and the electric power infrastructure. As noted above, privately owned personal vehicles will rely heavily on residential charging, especially for PEV owners in detached single family housing. As vehicle ranges continue to increase "at residence" charging will become increasing dominant.

Recent surveys suggest that the average passenger vehicle driver in the U.S. travels 30-40 miles per day and spends slightly less than one hour on the road, and these averages are even less for drivers in urban areas (U.S. Department of Transportation, 2017, 2019). In light of typical driver behavior, it is therefore very likley that BEV users in owner-occupied housing will rely mostly on economical home charging and will have limited needs for public charging. Residential charging can be fully served by Type 2 chargers which can easily recharge in periods when a vehicle is not in use (commonly overnight). Furthermore, it is generally recommended that to optimize battery longevity owners should maintain a charge between 20% and 80% of battery capacity when possible. Given typical driving patterns a vehicle owner could charge once or twice a week at their residence, requiring no public charging. However, for all types of personal vehicle owners, different forms of public charging access will be an important supplement to ensure convenient access for all circumstances, especially for inter-city travel.

Meeting charging demand with convenient access for multifamily residents or in residential areas with limited off-street parking pose more difficult challenges. Many new multifamily owner-occupied developments will probably incorporate on-site charging capacity as the PEV market expands, but adding charging access in older developments is more difficult and costly. For existing multifamily and moderate to low -income rental properties, on-site charging access will be a major gap to be addressed moving forward. The need for convenient public charging access will be the greatest in this residential category. However, public charging costs will generally be higher so public policy innovation is called for to make BEV ownership attractive and affordable to low and moderate income renters. An additional residential land use form where it is more difficult provide capacity is in denser owner-occupied housing with limited off street parking. This pattern is significant in a number of areas, especially older U.S. cities (e.g. Chicago, Washington D.C., etc.).

Table 2 Basic Charger Types

Charging Level	Power Delivery	Range Added Per Hour	Time to Charge Light Duty Vehicle Battery*
Level 1	1 to 1.4 kW	3-5 miles	30-40 hours
Level 2	3.9 to 19 kW	12-80 miles	2.5-4.5 hours
Level 3-Fast Charger	24-300 kW	75-1,200 miles	20-40 minutes

*There can be significant variation in charging time based upon the amps delivered in each category and how much a vehicle can accept. Also fast charger technology continues to change the time to charge estimates are based upon the time it takes to raise a battery's charge level from 10 percent to 80 percent.
Sources: U.S. Department of Transportation, 2023a.

In various light, medium and heavy-duty categories, charging demand characteristics are distinct. The electrification of light duty vehicles for public sector or commercial use is accelerating. This category will include public sector passenger vehicles and light trucks such as police and EMS vehicles, work vehicles for inspection and metering etc. For these uses some form of depot charging or charging access in public sector parking areas will be the main form of charging, with access to public charging as a back- up. Certain medium to heavy-duty classes (e.g. local delivery vehicles) will likely rely on some form of depot charging but might need supplementary access to public fast charging. Similarly, public transit and school buses will require depot charging and perhaps some in-route fast charging capacity.

Current status and projected demand for PEV charging capacity

Available evidence suggests that the build-out of the public charging infrastructure is generally occurring at pace with the growth in PEV adoption (IEA, 2022). The Alternative Fuels Data Center provides an estimate and maps with available charging stations and port counts in the US, which is filterable by public and private access, charger type, etc. Their spring of 2023 Alternative

Fueling Station Locator (AFDC) report tracks charging infrastructure through the first quarter of 2023. From these data we constructed Table 3 below.

Table 3: Charging Infrastructure in Place 2023 (first quarter)

Public and Private Access - Level 2 and DC fast Charging Ports[6]	Total ports available first quarter 2023
Public Charging Ports	141,907
Level 2 charging ports	110,546
DC fast charging posts	31,361
Private Charging Ports	19,394
Private workplace	10,116
Private multifamily	1,543
Private fleet	7,783

Brown, et al., 2023."Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: First Quarter 2023," Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-86446. https://www.nrel.gov/docs/fy23osti/86446.pdf.

The methodology used to generate the AFDC estimates distinguishes between public charging ports open to public use and private EV charging ports available to certain vehicle owners for restricted purposes such as fleet or employee only charging. The AFDC project does not estimate private chargers in residences. In the case of private charging, the authors of the 2023 report note that their estimates of private charging capacity are likley low since some private providers do not publicly share new installations or expansion of existing charging capacity (Brown et al, 2023). In assessing the relationship between PEV ownership and charging capacity, Brown et al. argue that public DC fast port deployment currently falls short of requirements, while Level 2 ports available deployment is keeping up with charging needs based on the number of EVs currently on the road (Ibid, p. 5)

Forecasts of future demand for charging infrastructure vary significantly based on estimates of future PEV adoption rates. For example, the 2021 forecast of Bauer et al. projected BEV sales to grow to 36% of new car sales by 2030. From this information, they estimate the expected number of chargers that will be necessary to support the projected level of electric vehicle adoption in 2030: 17 million private home chargers, 1 million multiunit dwelling chargers, and 2.4 million

[6] The number of outlets or ports measures an EVSE port providing the power to charge only one vehicle at a time even though it may have multiple connectors.

non-home chargers (public and private) (Bauer et al. 2021). This projection may now be somewhat conservative as it was made prior to the recent federal legislation to more aggressively subsidize PEV purchases and invest in the expansion of the national EV charging infrastructure.

Two recent analyses that post-date recent federal legislation (Bipartisan Infrastructure Law and Inflation Reduction Act) estimate charging requirements under higher PEV 2030 adoption rates. One study assumes that the Biden Administration target that 50 percent of 2030 vehicle sales will be zero emission vehicles (primarily BEVs) (Kampshoff et al. 2022). Meeting this target will require that the number of PEVs on the road grow from about three million in 2022 to 48 million by 2030[7]. Of this total, passenger vehicles would account for 44 million, light commercial about 3.8 million, medium to heavy duty trucks 338 thousand and heavy duty busses about 148 thousand (Ibid, p.4). This 2030 vehicle mix will require 1.2 million public chargers, and over 28 million chargers at residences, retail and other commercial destinations, workplaces and fleet depots (Ibid, pp-6-7). The estimated cumulative cost of providing the required charging infrastructure in this scenario will be over $35 billion (ibid, p 7).

A second 2023 study estimates charging requirements for personal vehicles based on a range of 2030 PEV sales and consumer behaviors such as percent of vehicle owners with home charging access, 2030 BEV/PHEV market shares, workplace charging access levels, etc. (see Wood, et al.2023, pp 14-15). Their person vehicle numbers and requirements include taxi and transport network company (TNC) vehicles. Based upon the midrange forecast of 33 million PEVs in 2030, " a national network of 28 million ports could consist of:

- 26.8 million privately accessible Level 1 and Level 2 charging ports located at single-family homes, multifamily properties, and workplaces;
- 182,000 publicly accessible fast charging ports along highway corridors and in local communities;
- 1 million publicly accessible Level 2 charging ports primarily located near homes and workplaces (including in high-density neighborhoods, at office buildings, and at retail outlets)." (Wood et al 2023, p, vi)

[7] This total includes plug in hybrid electric vehicles, all battery electric vehicles and fuel cell electric vehicles. The lion's share of this projected total in 2030 will be BEVs.

In this midrange forecast, these authors estimate that the cumulative capital investment needed to build out this this charging infrastructure configuration could range from $53-127 billion (Ibid, 2023, p. vii).

There is a significant degree of uncertainty about how the demand characteristics and supply structure of various charging types will evolve as PEVs in different vehicle classes expand their market shares. The build-out of the charging infrastructure will need to adapt to actual use patterns as adoption rates accelerate. However, given the current level of charging availability and capacity, expanding convenient access to charging will require very aggressive efforts to accommodate growth rates of PEVs forecast by most feasible projections. Recent federal initiatives will substantially improve charging access, especially access to public charging stations. But a more complete build out to accommodate projected PEV adoption rates will require coordination and action across numerous institutions including utilities, state and local governments, auto makers, private charging providers and consumers.

Technical and institutional issues for expanding charging access

Expanding Charging Accessibility and Convenience for Personal Vehicles

As emphasized above, charging at home will be the most convenient and economical option for personal vehicles. Most projections suggest that charging at residences will meet much of the demand from individually owned passenger PEVs. Creating more ubiquitous access to residential charging will require action and coordination between existing homeowners, local governments, utilities, builders, and property developers. In addition, to facilitate more rapid PEV adoption, expanded charging options will be required for intercity travel or other longer distance use cases.

For owners of detached residences, access to level 2 (AC-240-volt) charging via an outlet in a garage or parking area will be the core charging mode. With most PEVs now offering 200+ mile ranges, charging vehicles at home when not in use will meet most intracity travel needs. For existing residences that do not have dedicated level 2 capacity for vehicle charging, the cost of installing a charger for a parked vehicle is less than $1,500 in many cases. However, there can be significant variation in installation costs of a level 2 home charger based upon the structure, existing electrical wiring and local codes and utility requirements (Nelder and Rogers, 2019). Expanding level 2 residential charging rarely requires utilities to upgrade hosting capacity (e.g.

new transformers, line extensions, etc.) and maintenance costs for the homeowner are negligible (Ibid, 2019). Currently some utilities and car manufactures are offering subsidies to install level 2 chargers in owner occupied housing (Ehinger, 2022). It is also reasonable to assume that developers and home builders will provide level 2 - EV ready charging in new residential developments in many locales as PEV ownership expands.

Table 4 – Broad estimates of charger installation costs

Type	Charging Time (80% Battery Charge)*	Installation & Equipment Costs**	Utility Equipment Costs
Level 1 – Basic Outlet	30+ hours	Negligible	Negligible
Level 2 – 240 Volt Outlet	2.5-4.5 Hours	$600-$1,400 (residential) $2,500-$6,000 (commercial/public)	Might require grid upgrades (lines and transformers) for larger commercial charging stations (typical costs $35,000-$70,000)
DC- Fast Chargers	15-30 minutes	$50,000-$100,000 (commercial/public)	Normally requires service upgrades and transformer for multi-outlet charging stations (typical costs $50,000-$70,000)

Source: Nelder and Rogers. 2019, *Reducing EV Charging Infrastructure Costs*, Rocky Mountain Institute.

The seminal challenge in expanding "at home" charging access is in segments of the housing market that do not provide ready access to a garage or parking attached to an individual property or housing unit. For owner-occupied multifamily with units offering individual garages or unit adjacent dedicated parking spaces, the costs of installing level 2 charging capacity will be similar to detached housing. However, in denser owner-occupied housing districts with limited off street parking or for multifamily with parking not adjacent to the unit, the costs of providing level 2 charging that is consistently accessible to residents can be difficult and relatively expensive.

Table 5 – Residential Land Uses/Building Types – Charging Access and Cost Barriers

	Charging Installation Cost Barriers
Existing Buildings	
Owner Occupied Housing Units with Attached Parking	Low
Rental Housing Units with Attached Parking	Low
Owner Occupied or Rental Housing Units with On Street Parking Only	High
Owner Occupied or Rental Multifamily with Open Parking	High
New Construction	
Owner Occupied or Rental Housing with Attached Parking	Low
Owner Occupied or Rental Housing without Attached Parking	Medium

In these land use/building forms the developer, resident owners, landlords and utilities will in many cases need to install electric panel capacity with a dedicated branch circuit plus a raceway and wiring from the panel to the PEV parking spot. In most cases a dedicated electric vehicle charging port would have to be installed at each parking spot offering charging for residents (Ross et al., 2022). In light of these requirements, charger installation and maintenance costs might mimic level 2 commercial charging stations and cost up to $6,000 per charger port. Cost could even be higher in older multifamily complexes that may require electric system upgrades and trenching and wiring to parking areas. Moreover, installing multiple chargers for larger multifamily complexes might in some cases require costly grid upgrades by the utility service provider. There may be other options for different land use/building types such as portable chargers and chargers installed on streetlamp posts, but these options are just being tested in a few U.S. cases.

Addressing these potentially expensive requirements presents major difficulties in low to moderate income rental housing where landlords would be key actors. Since PEV adoption is currently skewed to higher income households, many existing property owners see little need to provide charging capacity. Landlords, furthermore, would be uncertain about how to recover costs through service charges or passthroughs to rents. Recent federal initiatives offer limited help for this specific residential type since the significant subsidies to build charging stations in the Bipartisan Infrastructure Law (BIL) require that charging be available to the public, not just residents of a specific multifamily complex. Of course various forms of public charging could be an option for multifamily residents, but in many cases (aside from workplace charging, for example) the cost of public charging is significantly more expensive. This report pinpoints this area as a particular challenge calling for public sector intervention and innovation.

For owners of passenger vehicles access to various forms of public charging is an important supplement to overcome any “range anxiety” issues associated with PEVs. The most obvious need for public charging access is for longer distance and inter-city travel. Taxis and TNC operators will likely also have greater demand for some form of public charging . The term public charging is most commonly used to reference publicly accessible charging stations run by private charging companies who install and manage electric vehicle service equipment (often termed EVSPs) (Nelder and Rogers, 2019). However, there are a number of personal vehicle charging options available to the public or to specific customer bases in addition to company run public charging stations. Public sector parking may offer charging access for employees or the general public, offices may provide charging for employees, retail and destination businesses may offer charging for customers and hotel chains are increasingly providing charging for their guests. All of these options may facilitate charging for many vehicle owners, even for longer distance trips. And in many instances the cost of charging at these access points will be significantly cheaper than public charging stations operated by for-profit EVSP station owners or company networks. Because public EVSP networks can be viewed as a supplementary charging mode for most vehicle classes, the institutional characteristics, access mechanisms, costs of building stations and public sector subsidies for station construction and operation will be considered separately below.

Expanding Charging Accessibility for Commercial and Public Sector Vehicles

Evidence suggests that various categories of commercial vehicles or public sector fleets will likely experience high PEV adoption rates over the next five to ten years. These would include lighter duty passenger work vehicles for public or private sector workers as well as medium to heavy duty work vehicles such as utility repair and maintenance, certain classes of construction vehicles and local delivery vehicles. The basic charging mode for most of these classes will be some form of charging at depots or parking facilities when vehicles are not in use. Developing these charging solutions will incur significant costs and will call for more systematic planning and collaboration between public and private institutional actors. Meeting charging needs with depot charging and supplementary “in-route” charging options will require a careful analysis by different users of several factors including daily vehicle operating schedules, vehicle weights, battery capacities and blocks of service downtimes (Lepre et al, 2022).

For most use cases in these vehicle categories, multiple charging ports involving higher capacity level 2 chargers and DC fast chargers will be required at charging depots or centers. These larger scale charging installations will first incur hardware costs including the costs of the chargers and associated hardware such as distribution feeders, transformers, weatherization, meters, and service drop infrastructure (Nelder and Rogers, 2018). Service drop requirements include a variety electrical infrastructure elements linking the utility grid interconnection to the installed chargers[8]. One estimate suggests that these service drop elements typically constitute between 30-40 percent of the capital costs of an EV charging installation (Ibid, p. 23).

[8] These requirements may specifically include step-down transformers, electric service panels, conduit, wiring, switchgear, and power conditioning units (for DC fast chargers). See Nedler and Rogers, 2019, p.16.

A second major planning and cost dimension of installing stations of multiple chargers at a depot or parking facility are site constraints or new site selection challenges. The charging infrastructure including the chargers and ancillary equipment consume considerable space in facilities that may already be crowded. In some cases depot or parking facilities will need to be expanded or a new depot facility built. These expansions may require costly land acquisition and negotiations with property owners in certain circumstances.

A third factor in installing and managing charging capacity is allocating charging demand as much as possible to low demand hours on a utility grid to minimize charging costs and issues with grid capacity. Scheduling charging can also be informed by matching charging periods to hours when wind and solar generation are most abundant. In many cases, overnight charging is optimal in term of grid efficiency and per kWh costs. An emerging best practice for larger scale public or commercial charging is the installation of "smart chargers" that integrate the charging facility with the utility service provider. The utility or other party can adjust the charging time or rate of charging based upon grid conditions at various times of day or seasonal conditions.

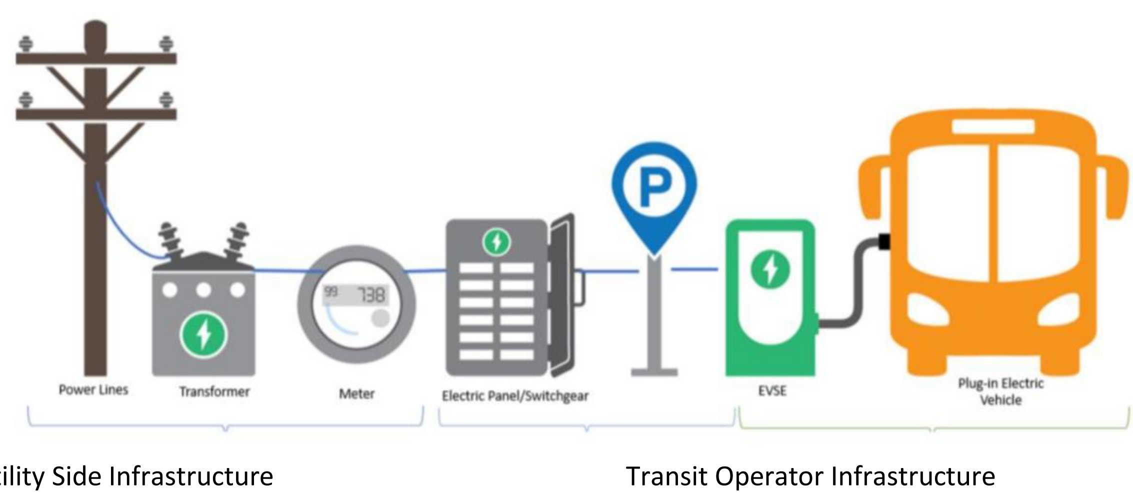
A final key factor shaping the costs of building out more complex installations for light, medium and heavy duty fleets is an array of "soft costs" associated with installing larger scale charging stations at depot facilities. This cost category includes permitting costs, obtaining utility interconnections and utility easements. These costs are often manifested in delays to project plans and schedules (Nelder and Rogers, 2019). While project soft costs vary significantly across individual government jurisdictions, utility service areas and specific sites, they can add up to a significant share of total project costs (Ibid, p 29). It has been reported that in some cases working with electric service providers to determine grid hosting capacity for specific charging sites, applying for utility connections and upgrades and scheduling to needed work with the utility constitutes a time consuming and costly process (Ibid, p.31). Larger scale charging installations may also involve complex and time consuming permitting processes requiring zoning reviews and public hearings. In addition, local regulations on utility easements can also drive costs and time delays. In the category of soft costs, streamlining regulations and approval processes and improving communications between utilities, local governments and firms seeking to expand charging capacity can reduce costs and accelerate PEV adoption of public and commercial fleet vehicles.

Expanding Charging Capacity for Heavy Duty Public Transit and School Buses.

Building the charging infrastructure to transition public transit and school buses to battery electric platforms will require a very specific planning process and set of technical requirements. Designing and building the appropriate charging infrastructure for bus systems depends on vehicle types, route structure and battery performance. For most use cases and routes, depot charging, with some combination of level 2 and DC fast charging will be the main charging strategy (Lepre et al., 2022). However, supplementary on route charging may be attractive for short circulator routes or longer express bus routes to sustain continuous operations.

On route bus charging will normally require dedicated charging ports with higher level DC fast charging capacity (350 kW or more). Public transit operators face significant challenges planning and implementing on route charging where it might be required. An on route charging station must be dedicated to bus transit use. Agencies may be required to acquire additional land or rights of way proximate to the route and might face objections of nearby property owners. Operation and maintenance costs may be high as on route chargers can be subject to damage via accidents by other vehicles, vandalism or wear and tear (Ibid, 2022, p.9). On route charging access is generally less of an issue with school bus operators due to less continuous service and opportunities for depot charging overnight and during off times during the day.

Figure 3 – Utility and Customer Infrastructure Requirements



Transit agencies are experimenting with various mixes of charging infrastructure and learning more effective approaches as BEV deployments increase. Similar to other forms of depot charging discussed above, managing depot space is a significant challenge as facilities are reconfigured from serving diesel bus fleets to supporting BEV buses. As Lepre et al note, "electrical equipment, from transformers and switch gear to power cabinets and dispensers, can take up a considerable amount of space…One of the principal challenges described by transit agencies was to minimize the loss of parking spaces in already crowded depots while making room for the electrical equipment." (Ibid, 2022, p. 15). Transit operators are tackling this problem in a number of ways. They are developing a number of technical solutions to minimize space requirements for depot charging. These include having a number of extendable power dispensers linked to each power cabinet or building gantry systems to charge the busses from above.[9] Overhead charging systems are also likley to be a preferred approach to on route charging due to space saving advantages (Ibid, 2022, p 11).

Numerous studies on heavy duty bus electrification emphasize the critical importance of engaging with utilities very early in the planning process (San Diego Gas and Electric Company, nd., Lepre et al., 2022). Since depot and even some in route charging will require high levels of electric capacity, significant utility service upgrades will typically be required. Such utility upgrades involving grid power and line upgrades, transformers, metering systems, etc. are likley to be significant and may involve significant time to schedule and complete. Certain utilities may offer cost sharing or incentive programs to offset some of these costs. Utility service providers are also crucial partners in designing time of use strategies that can minimize electricity charges for the transit agency. As bus electrification advances, software-based managed charging or smart metering will likley be more common. These charging management systems can reduce coats of charging installations by reducing the total required charging capacity and maximize the use of renewable energy by allocating more charging to periods of high wind and solar generation.

Filling the Gaps – The Development of Privately Owned Public Charging Stations.

There are many charging options available to the public or to specific customer bases in addition to company run public stations. Here we focus on charging stations accessible to the public operated by private charging companies who often install and manage electric vehicle service

[99] Deploying chargers from overhead structures can save considerable space as the power cabinents can be mounted on the overhead gantries instead of consuming space on the parking surface. The overhead charging connection can be through a cord and plug in system or what is called and inverted pantograph system that have prongs that link to a charging port on the top of a bus and do not require any manual plug in to a port.

equipment (EVSPs) (Nelder and Rogers, 2019). In terms of the vehicle classes likely to experience high levels of PEV adoption, the literature strongly suggests that privately operated charging stations will largely serve as a supplementary or back up charging mode for intra-city travel. However, the buildout of these charging stations will solidify confidence that charging is widely accessible for all types of PEV trips and can accommodate the full range of travel needs for users. The evolution of privately owned public charging stations exhibits a complex and rapidly changing pattern of institutional arrangements, technical standards, and business models. There are numerous business models for charging stations open for public use. A 2021 report by PennDOT profiles three models of public charging stations with different ownership and pricing structures:

- *Site-Owned Cost Recovery Model*: the property owner owns the chargers and generates some revenue from customer charging. This is most common in retail or food establishments who may offer DC fast charging at locations where customers may spend 20 minutes to an hour. For the establishment owner, this charging access draws customers to the establishment while the revenue generated from the chargers helps to recover the station and electricity costs.
- *Site-Owned Profit-Making Model*: the property owner owns the chargers and sets charging prices to make a direct profit from vehicle charging, rather than simply recovering the costs incurred to run the station. This model is most common for DC fast charging at locations where customers have limited time or convenient access to other PEV charging options, such as along interstates or major state highways.
- *Hybrid Profit-Making Model*: the property owner and a network EVSE company share costs and seek to make a profit from the charging station. This model is suitable for locations where there is less competition and high EV charging demand, such as targeted locations along major highways or interstates. Blink, ChargePoint, and Greenlots are EVSE companies that participate in some version of this model (Ndimbie, et al 2021).

Some charging companies build and sell EVSE and operate fast charging stations, often as a part of a charging network. In some cases they own the charging station as well. The most prominent charging network is operated by Tesla and has been created to specifically service Tesla owners. By the end of 2022 Tesla operated more than 1,600 Supercharging stations across the U.S. In addition they support a network of level 2 chargers at hotels, restaurants, and other destination sites (Linkov et al., 2023). Tesla owners rely on the Tesla App that has an owner profile, a payment/billing system and a finder that allows owners to locate available chargers. Tesla charging is based upon a standard that has been unique to the brand, the North American Charging System (NACS). The company recently worked to make its charger network available to drivers of other BEV brands that mostly rely on a Combined Charging System standard (CCS). Tesla developed an adaptor (Magic Dock) to allow vehicles with the common CCS charging system to access Tesla chargers.

Outside the Tesla charging network, ChargePoint is the largest charging company. It has level 2 fast chargers and DC fast chargers at its stations and is also an equipment producer selling, for example, residential chargers to install in homes. There are numerous additional networks including Blink Network, EVgo Network, Greenlots, Volta, Electrify America, EV Connect, FLO, LIVINGSTON and many others. These networks operate level 2 and fast chargers in various configurations and have different charging access and price structures that often combine a specific software App, network membership fees and per kWh or time-based charging prices However, there are also many charging stations that are independently owned and non-networked.

The charging price structure for electric vehicle charging is not as straightforward as gas refilling for internal combustion vehicles. A number of commentators have argued that the current set up of the public charging infrastructure is confusing and frustrating for many PEV owners (Kampshoff et al. 2022; Linkov et al., 2023). A 2021 customer survey by McKinsey& Company found that, "Drivers struggle to find chargers because information is limited; mobile apps tend to exclude competitors chargers…Pricing systems can vary considerably – from pricing by the minute or kWh to different rates for membership or pay per use…It isn't always easy to tell which option is a better value, and payment is often a hassle." (Kampshoff et al. 2022, p. 14).

Recently there has been significant progress on improving interoperability and the legibility of the for-profit public charging system. The issue of needing multiple accounts to use and pay for charging has been addressed in recent years. Several companies such as ChargePoint, EVgo, and Electrify America have joined together to allow for roaming between the networks, meaning that drivers can use their ChargePoint account at an Electrify America charging station and vice versa. As noted, some of the car manufacturing networks such as Tesla and Ford's BlueOval network have opened their networks to other brand owners.

Moves toward interoperability and enhanced consumer information are strongly encouraged by provisions in the Bipartisan Infrastructure Law (discussed below). In particular there has been a major breakthrough to move to a single charging standard based upon Tesla's NACS system across various manufacturers and models (Shepardson and White, 2023). Ford and GM have agreed to design future BEV models with the NACS plug and charging system making them compatible with Tesla fast charging stations. Since Tesla, Ford and GM currently account for about 70 percent of U.S PEV sales, this recent agreement indicates a move toward a single standard. However, the U.S. Transportation Department has indicated that adapters should be available to allow cross usage with current and older models that rely on the CCS charging standard (Ibid).

Independent charging station operators as well as the larger charging networks face similar cost considerations and institutional collaboration requirements common to the other forms of charging station development such as depot and subsidized public charging stations. The general consensus is that most for-profit charging networks and stations will increasingly offer DC fast charging capacity and as such will require higher levels of electric power access. This means that significant costs will be entailed in developing new charging stations as well more intensive communication and collaboration with electric utility service providers. Furthermore, site selection will be challenging similar to other forms of depot or larger scale public charging and an array of soft costs will need to be managed. In this regard, general initiatives to streamline local regulations and permitting processes can accelerate the build-out of the for-profit public charging segment.

A central challenge facing the build out of the public charging infrastructure, both free or subsidized public charging and for-profit charging is a current locational pattern heavily biased toward high income areas and owners. To date the location of public charging stations has been shaped by the location and use patterns of BEV adopters, who have been concentrated in high income categories. Public charging stations have been developed in high income neighborhoods or routes or destinations favored by higher income PEV users(e.g. hotels, commercial centers, office parking garages etc.). Public charging station access remains sparse in low and moderate income communities and rural areas (Kampshoff et al., 2022; Yozwaik et.al. 2022). Moreover, the significantly higher costs of charging at a for- profit station versus home charging or subsidized charging at a destination is a significant barrier to PEV access and adoption for low to moderate income households and rural residents (McAdams, 2022).

In sum, the full build out of the public charging infrastructure will largely serve as a supplementary charging mode but is crucial to instill confidence that charging is conveniently accessible for the full range of travel needs. Rapidly expanding public charging access faces two major barriers. It will be costly for developers of charging stations in terms of building station infrastructure, securing need electric power access and meeting a range of local regulatory requirements. The second substantial challenge is developing convenient public access for low and moderate income and rural communities to make PEV ownership practical for all drivers. Addressing the high development costs and uneven access challenges will be aided by a number of supports and subsidies initiated in recent federal legislation as well as a range of actions and incentives at the state and local levels. These initiatives promise to accelerate the build out of the charging infrastructure across various vehicle classes.

Charging Infrastructure Resilience Issues

Resilience in light of specific PEV vulnerabilities and electric power interruptions effecting charging capacity is an important consideration for all classes of PEVs. Vehicle battery performance can be significantly affected by extreme weather conditions as battery life is reduced by very high or very low temperatures. This vulnerability can typically be addressed by higher or more frequent charging during cold weather events and by convenient access to different forms of public charging to top off the battery charge. A more difficult problem occurs when there are local power outages or broader grid failure. In these circumstances, PEVs may be grounded due the lack of electricity to recharge. Outages may stifle personal mobility in various emergency situations (e.g. major storms). In addition, power outages can cause grave problems for a range of critical services provided by public sector vehicles such as buses, police and EMS vehicles, and utility or local government work vehicles. It is important to note, however that gas and diesel fueling station service may also be subject to interruptions in periods of local outage or grid failure.

Increasing resilience to power interruptions is a general issue for widespread PEV adoption but represents a more critical short term concern for public sector vehicles and some classes of commercial vehicles as well as public charging stations. Multiple resilience strategies are being employed for these classes of vehicles and charging stations. The most straightforward means to improve resilience to power outage is engineering in back-up generators. Currently the most economical backup generation systems rely on diesel, propane or other fossil fuel driven power sources. The feasibility of battery generation banks (charged up by electric power prior to an outage) as a backup power source is likley to increase as battery technology continues to improve (National Academies of Sciences, Engineering, and Medicine. 2021). In addition, utilities across the county are engaged in various grid hardening strategies to deal with specific local problems (storm effects, tree falling, vehicles colliding with equipment) and large scale outages (hurricanes, wildfires, snowstorms). Larger commercial and public sector institutions can work with utilities to enhance grid reliability to charging centers reduce the risk of outages (Lepre et al 2022). As battery storage technologies continue to improve, various microgrid possibilities may become more common based on solar generation and local battery storage operating as a major or supplementary power source for PEV charging (VTA, 2022).

V. Public Sector Initiatives to Rapidly Expand the Charging Infrastructure and PEV Adoption.

Reducing the negative externality costs across the transportation system and lowering total vehicle ownership costs for households constitute major justifications for public subsidies, investments and policy supports to accelerate PEV adoption across the various vehicle classes. Various public subsidies from all government levels to encourage PEV adoption have existed for well over a decade. Currently, there is a very complex set of federal subsidies and supports as well as a host of incentives that vary significantly across states and localities. The recently passed Bipartisan Infrastructure Law (BIL) and the Inflation Reduction Act (IRA) have substantially ratcheted up government intervention to boost the transition to PEVs. To provide planners and policy makers with a useful overview of the key provisions in this recent federal legislation we highlight and briefly analyze key elements supporting PEV adoption and the build-out of the charging infrastructure.

Table 6: Key Provisions in the Bipartisan Infrastructure Law of 2021 and The Inflation Reduction Act of 2022

Direct Support for Build Out of the EV Charging Infrastructure – Bipartisan Infrastructure Law of 2021					
Name	Amount (FY 2022-2031)	Type	Eligible uses	Recipients	Federal/ Nonfederal Share
National Electric Vehicle Infrastructure Formula Program (NEVI)	$5,000,000,000	Formula Grant	Acquisition and installation of electric vehicle charging infrastructure; operation and maintenance of EV charging infrastructure; and data sharing about EV charging infrastructure to ensure the long-term success of investments.	States	80/20
Charging and Fueling Infrastructure Grants (Community Charging)	$1,250,000,000	Competitive Grant	Program funds will be made available each fiscal year for Community Grants to install EV charging and alternative fuel stations on public roads, schools, parks, and in publicly accessible parking facilities. Grants will be prioritized for rural areas, low-and moderate-income neighborhoods, and communities with low ratios of private parking, or high ratios of multiunit dwellings. Eligible uses: acquisition and installation of publicly accessible EV charging or alternative fueling stations and infrastructure and operating assistance (for the first 5 years).	States, MPOs, Local gov., Special purpose districts	80/20
Charging and Fueling Infrastructure Grants (Corridor Charging)	$1,250,000,000	Competitive Grant	Deploy electric vehicle charging and hydrogen/propane/natural gas fueling infrastructure along designated alternative fuel corridors and in communities. Eligible uses: acquisition and installation of publicly accessible EV charging or alternative fueling infrastructure, operating assistance (for the first 5 years), acquisition and installation of traffic control devices.	State, MPO, Local gov., Special purpose district	80/20

Secondary Support for Build Out of the EV Charging Infrastructure – Bipartisan Infrastructure Law 2021					
Port Infrastructure Development Program Grants	$2,250,000,000	Formula Grant	Resilience projects to address sea-level rise, flooding, extreme weather events, earthquakes, and tsunamis, reduce or eliminate port-related criteria pollutant or GHGs, **including projects for EV charging or hydrogen refueling infrastructure** for drayage, and medium or heavy-duty trucks and locomotives that service the port and related grid upgrades	Public and Private Ports/Port Authorities	80/20
Smart Grid Investment Matching Grant Program	$3,000,000,000	Grant	Qualifying smart grid investments that allow buildings to engage in demand flexibility or Smart Grid functions. Eligible uses: metering, control, and other devices, sensors, and software; communications and broadband technologies; **technologies and programs to integrate EVs to the grid;** communications networks enabling data sharing between distribution system components; and advanced transmission technologies.	Utilities	50/50
Energy Storage Demonstration and Pilot Grant Program	$355,000,000	Grants, Cooperative Agreement, or Other	Eligible uses: improve the security of critical infrastructure and emergency response systems; improve reliability of transmission and distribution systems, particularly in rural areas; optimize system operation and power quality, including transformers and substations; supply energy at peak periods during periods of significant variation; reduce peak loads; improve and advance power conversion systems; provide ancillary services for grid stability and management; integrate renewable energy resource production; increase the feasibility of microgrids; enable the use of stored energy; and **integrate fast charging of electric vehicles.**	Industry, State and Local Gov., Tribal and Community Based Orgs., National Labs, University, and Utilities	Grants

Energy Efficiency and Conservation Block Grant Program	$550,000,000	Formula and Competitive Grants	To assist states, local governments, and Tribes in implementing strategies to reduce energy use, reduce fossil fuel emissions, and improve energy efficiency. Eligible uses: programs for financing energy efficiency, renewable energy, and zero-emission transportation (and associated infrastructure), capital investments, projects, and programs, which may include loan programs and performance contracting programs, for leveraging of additional public and private sector funds, and programs that allow rebates, grants, or other Program incentives for the purchase and installation of energy efficiency, renewable energy, **and zero-emission transportation (and associated infrastructure)**	States, Local gov., and Tribes	
Funding Support for Alternative Fuel Vehicle Adoption in Bipartisan Infrastructure Law 2021					
Low or No Emissions Bus Program	$5,600,0000,000	Competitive Grant	Funds for the purchase or lease of low-or-no emission busses and the construction of charging infrastructure. Funds can also be used to construct or renovate facilities to accommodate low-zero emission busses. Applicants for zero emission vehicle grants must submit a Zero Emission Transition Plan	States, designated recipients, and local governmental entities that operate fixed route bus services.	Grants
Bus and Bus Facilities (Federal Transit Administration)	$5,100,000,000	Formula and Competitive Grants	Funds primarily for the upgrade or new construction of bus facilities but can also be used for the purchase of buses and charging infrastructure. Funding available for all bus facilities, not only those supporting zero-emissions buses. Applicants for zero emission facilities grants must submit a Zero Emission Transition Plan.	State governments or transit agencies or governmental entities operating fixed bus routs	Combination Formula Grants to States and Competitive Grants to Transit Agencies

Clean School Bus Program (SPA)	$5,000,000,000	Competitive Grant, Rebate, & Contract	Fifty percent of the funds are authorized as rebates to replace existing school buses with clean and zero-emission (ZE) models and fifty percent as grants for the replacement of existing internal-combustion engine (ICE) school buses with electric, propane, or compressed natural gas (CNG) school buses, as well as the purchase of electric vehicle supply equipment (EVSE) infrastructure and EVSE installations. Funds may be prioritized for rural or low-income communities and entities that have matching funds available. The EPA Administrator is authorized to provide funds to cover up to 100 percent of the costs for the replacement of the bus	Local or State Gov; Eligible Contractor; Nonprofit; Or Tribe	Rebate for Purchase or Competitive Grant
Key Provisions in the Inflation Reduction Act of 2022 for Charging Infrastructure or to Directly Encourage BEV Adoption					
EV Charger Tax Credits	Tax Expenditure (No cost estimate)	Tax Credit for Equipment Purchase	The Inflation reduction act extended an existing tax credit through 2032. For individual/residential uses up to a $1,000 credit to install or upgrade charging equipment. For commercial uses the tax credit covers 6% of equipment costs up to $100,000 for equipment installed in low-income or non-urban areas	Tax Credit to equipment purchaser	NA
EV Tax Credit for New Vehicles	Tax Expenditure (Cost estimated at $1.8 billion over the period)	Tax Credit for Purchase	Tax credit of up to $7,500 for purchase of new EV subject to: 1) purchase price of vehicle; 2) household income of purchaser; 3) domestic content (US) of vehicle	Tax Credit to purchaser…beginning in 2024 a taxpayer can transfer credit to a dealer allowing the buyer to receive the credit as a rebate at the point of sale.	NA

EV Tax Credit for Used Vehicles	Tax Expenditure (no cost estimate to date)	Tax Credit for Purchase	Tax credit valued as the lesser of $4,000 dollars or 30% of the purchase price of a used EV subject to: 1) purchase price of the vehicle; 2) household income of the purchaser; 3) some vehicle recharge form external source (plug in capability)	Tax credit to consumer or transfer of credit to dealer for rebate at the point of sale	NA
EV Tax Credit for New Commercial Vehicles	Tax Expenditure (no cost estimate to date)	Tax Credit for Purchase	Credit is available for a vehicle used for a business purpose. The eligible credit is calculated as the lesser of 30% of the vehicle purchase price or the incremental cost of the vehicle defined as the difference the purchase price of an EV and a comparable ICE vehicle. Tax Credit is capped at $7,500 for vehicles with a gross vehicle weight (GVWR) of less than 14,000 lbs. and $40,000 for vehicles with a GVWR over 14,000 lbs.	Tax Credit to Purchaser	NA
Advanced Manufacturing Production Credits for Battery Cells and Modules Produced in the United States.	Tax Expenditure (30.6 billion over the period, CBO estimate)		Tax incentives to domestic battery producers includes $35 per kWh credit for each US-made battery cell, a credit of $10 per kWh of battery module capacity, or $45 in the case of a battery module that does not use battery cells effectively cutting production costs in half.	According to current interpretation for the Dept. of Treasury credits can be monetized so that a producer is eligible for a direct payment from Treasury irrespective of their federal tax liability.	NA

Sources: U.S. Department of Energy - Alternative Fuels Data Center. 2023. "Laws and Incentives,**"** https://afdc.energy.gov/laws; Congressional Research Service. 2022." Tax Provisions in the Inflation Reduction Act of 2022 (H.R. 5376), Report R4702, August 10, https://crsreports.congress.gov; White House - Build.Gov. 2022. *A Guidebook to the Bipartisan Infrastructure Law for State Local, Tribal and Territorial Governments and Other Partners*, May, https://www.whitehouse.gov/build/guidebook/ Lepre et. al. 2022. "Deploying Charging Infrastructure for Electric Transit Busses," Atlas Public Policy, Washington D.C. July, https://atlaspolicy.com/deploying-charging-infrastructure-for-electric-transit-buses/

As of mid-2023, a number of elements in the above laws, and their fiscal impacts, remain the subject of ongoing interpretation with new rules and guidance being promulgated by the various federal agencies overseeing the individual programs. Furthermore, the various incentives and investments in these two major bills do not exhaustively represent all federal incentives and supports for the PEV transition[10]. Taken as a whole, these legislative initiatives represent a massive increase in public resources allocated to bolster the build-out of the charging infrastructure and PEV adoption across all vehicle classes. Furthermore, there are numerous provisions in the two laws that address equity issues and seek to promote PEV adoption and charging access for low and moderate income households. We will first review elements in this legislation that seek to rapidly expand and fill critical gaps in the public charging infrastructure and then examine specific provisions to increase adoption and expand charging access for the various vehicle classes (personal vehicles, commercial light to heavy duty categories and public transit and school busses)

Provisions in the BIL to directly expand public charging

In the Bipartisan Infrastructure Law (BIL) there are a number of initiatives to expand the public charging infrastructure and fill important access gaps. Three key elements in the law allocate a total of $7.5 billion over the 2021-2026 period to directly expand the nation's public EV charging infrastructure. The goal is to install 500,000 publicly accessible chargers supported by this funding. The key mechanisms in the law are the National Electric Vehicle Infrastructure Formula Program (NEVI), Charging and Fueling Infrastructure Grants (Community Charging) and the Charging and Fueling Infrastructure Grants (Corridor Charging) (see table 6, above).

The largest program in this set is the $5 billion NEVI formula grant program to states. A central objective of the NEVI program is to build out a network of charging stations along Alternative Fuel Corridors designated by the Federal Highway Administration (U.S. Department of Transportation, 2022). The priority for early funding is providing comprehensive charging access along all interstate corridors defined as having a charging station every 50 miles and within one

[10] The BIA and IRA include a number of smaller programs and funding streams not in Table 7, above. For example in the BIA there is a $28 million allocation to workforce development/training to assist in the transition to zero emission vehicles in public transit and $74 million in funding for electric vehicle battery recycling and second life applications demonstration projects. See U.S. Department of Energy - Alternative Fuels Data Center. 2023. "Laws and Incentives," https://afdc.energy.gov/laws.under

mile of an interstate exit. To receive funding each state is required to provide a plan demonstrating how the funds are intended to be used under the provisions of the law. To administer the NEVI formula program, the BIL established the joint office of energy and transportation including the Department of Transportation and the Department of Energy (Ibid). This joint office provides guidance for states (particularly on creating the plans) and must submit a report summarizing the state plans and assessing how these plans make progress on building the BEV charging network (Ibid).

The individual state plans must consider: distances between stations; charger characteristics and grid connections (such as smart charging and use of renewable resources); needs for EV charging infrastructure in rural and disadvantaged areas; long term operations and maintenance; existing EV charging infrastructure programs and incentives; coordination with private station developers and operators; and meeting current and future market demand (in terms of power access and charging speeds)[11].

In addition, each state planning process is required to carry-out a public engagement process and identify direct and indirect benefits that flow to disadvantaged communities.[12] The state plans must demonstrate that 40 percent of the direct or indirect benefits of NEVI investments go to disadvantaged communities (DACs)[13]. Once a state's plan is approved, the specific projects in the plan must be included in their Statewide Transportation Improvement Program (STIP) before the allocated funds can be obligated (Ibid).

The main mechanism to fund the development of new charging stations will involve the relevant state agencies contracting with private charging developers and operators. All stations must be

[11] In addition, the joint DOT and DOE office also set minimum standards for things such as installation, maintenance, and operation; interoperability; required signage; data format; and real time info on stations through mapping applications.

[12] State DOTs are required to reference the Electric Vehicle Charging Justice40 map developed by the US DOE and DOT that identifies Census tracts with higher levels of vulnerable populations based on health, transportation access, energy cost burdens, exposure to environmental hazards and other factors. See https://www.transportation.gov/rural/ev/toolkit/planning-resources/equitable-planning

[13] A specific methodology to determine how direct and indirect benefits of NEVI investments flow to DACs is outlined in U.S. Department of Transportation. 2022. "NEVI Program – Federal Highway Administration FAQ," https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/resources/nevi_program_faqs.pdf

open to the public to be eligible[14]. State agencies administering NEVI (typically led by state DOTs) will assess current and future charging demands, identify gaps in charging service, set standards for charging stations (e.g. each individual station must be rated as having a 150kw or greater capacity and a state may require specific smart charging capabilities, interoperability between different charging systems, number of ports per stations, etc.), and evaluate access to required utility services.

Based on a state's assessment of current and future demand and associated gaps in their charging infrastructure, they will solicit and award contracts to EVSP companies or individual property owners to build and operate charging stations at appropriate locations. In the NEVI funding formula, entities awarded the contracts are required to cover 20 percent of the costs while 80 percent will come from NEVI funds (Ibid). Allowable costs under the NEVI formula include the hardware costs (the chargers, distribution feeders, transformers, weatherization, meters) and service drop infrastructure and other costs including signage, payment software and smart metering. It is anticipated that the generous 80 percent cost coverage in NEVI will draw numerous charging station developers into the bidding process.

By the spring of 2023, all 50 states and Puerto Rico had approved NEVI plans and were eligible for funding (U.S Department of Transportation -Joint Office of Energy and Transportation,2023). Each state plan must adhere to NEVI requirements, but they contain specific priorities and build-out strategies unique to a state's current and future needs. While NEVI funding must be first allocated to provide designated service levels along the Alternative Fuel Corridors (station every 50 miles), any remining funds can be used to meet other gaps in a sate's charging infrastructure.

For example in the Texas NEVI plan, it was estimated that only 55 new stations would need to be developed to fully build-out charging capacity along the state's Alternative Vehicle Corridors. The remainder of the estimated $408 million in NEVI funds received can be allocated for other priorities. In the Texas plan the state will allocate 50% of the remaining NEVI funds to expand charging access in rural areas, with the other half going to developing charging station in urban areas (Texas Department of Transportation, 2022). To provide charging service to rural areas the state plan will fund at least one DC fast charging station in every rural county (starting with the

[14] According the NEVI guidance provided by Federal Highway Administration, stations serving just commercial vehicles would be eligible, but must service vehicles from more than one company (U.S. Department of Transportation, 2022).

locality that is seat of county government). For urban areas, the state DOT will work with Metropolitan Planning Organizations to identify suitable locations to install a combination of Level II and DC fast charging infrastructure inside larger MSAs (Ibid).

Novel features associated with needs in each state are present in the individual state plans. In the Arizona plan public agencies (versus private developers) are allowed and funded to build charging stations on public lands adjacent to highways since 51% of Arizona lands are held by federal or state governments (Arizona Department of Transportation, 2022). Because California has the highest level of PEV adoption of any state and already has a relatively extensive charging infrastructure their plan puts more emphasis on upgrading (to incorporate DC fast chargers in some cases) and expanding existing charging stations.[15] The NEVI formula grant program has experienced relatively rapid implementation.

The NEVI program is supplemented by the two competitive grant programs; the Charging and Fueling Infrastructure Grants for communities and corridors (see table 6, above). These grant programs provide funding to strategically deploy publicly accessible electric vehicle charging infrastructure and as well other alternative fueling infrastructure. The Corridor Charging element provides funds to, " deploy electric vehicle charging and hydrogen/propane/natural gas fueling infrastructure along designated alternative fuel corridors," while Community Charging grants are directed "to install electric vehicle charging and alternative fuel in locations on public roads, schools, parks, and in publicly accessible parking facilities" (U.S. Department of Transportation, 2023). Eligible applicants for these two programs include states, tribes, localities, MPOs, and U.S. Territories.

These competitive grant programs had their first solicitation in March of 2023, so there is more limited information on more specific requirements. Like the NEVI program, facilities funded by these grants must meet the National Electric Vehicle Infrastructure Standards and Requirements regarding charger interoperability, minimum numbers of ports, types of connectors, payment methods, and requirements for customer support services, etc. Importantly, the Community Charging grants will prioritize rural areas as well as low-and moderate-income neighborhoods with low ratios of private parking, or high ratios of multiunit dwellings (Ibid). These provisions and

[15] To review the NEVI plans of each state see https://driveelectric.gov/state-plans/

others in the broader NEVI program will facilitate expanded charging access in low to moderate income communities.

An additional provision in the BIL provides grant funding that can, in part, encourage alternative fuel or charging infrastructure at port facilities. The BIL offers grants to port authorities or other local entities for a variety of investments to make port facilities more resilient to climate change effects. These grants can also be utilized to reduce port-related criteria pollutants or GHGs, including projects for PEV charging or hydrogen refueling infrastructure for drayage and medium or heavy-duty trucks. This grant funding can also be used for related grid upgrades that might be required for EV charging of port vehicles.

BIL support for utility capacity expansion, integration and smart charging

At the macro level, expanding the capacity of the electric grid is a major challenge for the PEV transition as well as other alternative energy initiatives . Grid capacity nationwide will have to expand rapidly to accommodate new alternative energy generation projects and demand increases from moves to electrify a range of household and commercial systems and devices (from home heating to manufacturing power and heating systems to PEVs) (Rand et. al., 2023). The transition to PEVs will cumulatively add to grid expansion pressures. However, for a variety of reasons it is likley that the movement to PEVs in the various vehicle classes can be accommodated by electric utilities with minimal frictions.

The first reason that the substitution of PEV for ICE vehicles can be accommodated by utilities is that it will occur over a relatively long period of time, even under rapid adoption scenarios. Under scenarios projecting high BEV adoption rates of 50 percent of new vehicles sold in the U.S. in 2030, this would leave over 80 percent of the nation's vehicle fleet “unelectrified” in 2030 (Kamapshoff et al.,2022). Hence, grid capacity expansion can occur over a relatively long period of time to absorb additional demand from PEV charging. Second, PEV charging demand overall will continue to have an off peak profile as much residential and depot charging will occur after 7 p.m. Third, as vehicle battery capacity increases, time on the grid on a weekly or annual basis for each vehicle will decline with, for example, passenger vehicles needing to charge less than once a week for inter-urban travel. One estimate suggests that if there are 48 million PEVs on the road by

2030, the electricity demand for charging would equal roughly 5 percent of current grid capacity (Ibid, p.4). This suggests that electric grid capacity issues would largely be related to local grid upgrades to accommodate charging station growth.

In the context of utility generation and grid capacity, there are a variety for ways that the evolving charging infrastructure can improve demand management outcomes. Obviously, dynamic pricing that links kWh charging costs to daily and seasonal electricity demand variations would further incentivize off-peak charging. Building in smart charging software and metering as the infrastructure grows can also yield demand management and environmental benefits. PEV smart charging has the potential to help balance the variation of renewable energy sources through smart charging combined with dynamic pricing structures (Canizes et al., 2019). In this way, PEVs can utilize excess renewable energy generated in off-peak periods and help more efficiently integrate renewable energy sources to the larger power grid. An emerging possibility linked to smart charging technologies is Vehicle to Grid (V2G) charging. V2G is a way for EVs to interact with the power grid whereby the batteries in electric vehicles can be used to store energy and discharge energy to balance grid demand an better incorporate energy from renewable sources (Brown & Soni, 2019; Ghotge et al., 2022).

In light of these issues and possibilities, the BIL and IRA legislation provide significant incentives and investments to bolster needed expansions and improvements in the national power grids as well as measures that will facilitate local grid upgrades to accommodate increasing PEV adoption. The BIL provides roughly $65 billion for upgrading the electric grid including grants and incentives to increase grid reliability and resilience, expand transmission lines, and improve grid flexibility. It is estimated that this funding will significantly increase new transmission line deployment. These investments will facilitate connections to new wind and solar power generation facilities (Steinberg et al. 2023).

In addition, there are specific measures in the BIL that can enhance grid capacity and performance as it relates to the BEV charging infrastructure. The $3 billion Smart Grid Investment Matching Grant Program provides a 50 percent match to public and private utilities to expand and integrate smart grid technologies. Eligible investments under this grant program include metering, control, and other devices; sensors and software; technologies and programs to integrate EVs to the grid; communication networks enabling data sharing between distribution system components; and advanced transmission capacity. The $355 million Energy Storage Demonstration and Pilot Grant

Program provides grants to a range of public and private sector institutions to demonstrate solutions and new technologies to improve grid efficiency and reliability including the integration of PEV fast charging into the grid (see table 6, above). Finally, the $550 million Energy Efficiency and Conservation Block Grant Program is largely a formula grant program to state and local governments and tribes that lower energy costs, reduce carbon emissions, improve energy efficiency, and reduce overall energy use. Eligible uses of these grant funds include purchases of zero-emission transportation vehicles and associated infrastructure.

More specific details of these three programs are not available as solicitations have only recently gone out or are going out in the summer of 2023. It is not clear if, and exactly how these funds will be targeted to grid upgrades or other actions that might facilitate expansion of the PEV charging system. However, taken together these programs will certainly complement charging expansions, by providing significant funding to utilities and state and local governments to make upgrades to local grids and more rapidly develop and deploy smart charging capabilities.

BIL grant funding for the purchase of electric transit and school busses and associated charging infrastructure

Supports for Public Transit Bus Electrification

The BIL provides substantial grant (competitive and formula) funding for the purchase of low and zero emission transit buses by entities operating fixed bus routes. $5.6 billion is available under the low or no emissions competitive grant program in the BIL. These funds can be used by transit agencies to purchase busses and to construct or renovate facilities to accommodate low/zero emissions buses. While this funding can be used for other alternative fuel vehicle purchases, given the strong move by public transit bus operators to transition to electric busses, most of this funding is likely to be directed to electrify bus fleets. To be eligible for these grants, transit providers must submit a Zero-Emission Transition Plan. Among other things, this plan must allocate five percent of their grant funding to workforce training for vehicle operation and vehicle maintenance (Lepre et al., 2022).

A second major tranche of funding in the BIL, $5.1 billion, is provided through formula grants to states and competitive grants to states from the Federal Transit Administration’s, Bus, and Bus Facilities program. These funds are targeted to bus facility construction, upgrades, and expansions (not exclusively serving zero emission buses). These funds can also be used to purchase buses and charging infrastructure including utility upgrades to depots (Ibid, 2022). As in the low-no bus purchase program, entities receiving their grants must provide a Zero-Emission Transition Plan.

There are additional provisions in the BIL that fund general transit-related capital projects and air quality improvement that can be leveraged to supplement public bus fleet electrification. The U.S. DOTs $7.5 billion Rebuilding American infrastructure with Sustainability and Equity (RAISE) discretionary grant program is designed to fund an array of surface transportation projects. Charging infrastructure investments and bus purchases can be eligible for RAISE funds as part of a larger transit capital project by an agency. The Congestion Mitigation and Air Quality Improvement Program is a formula grant program that allocates funds to state and local governments to meet Clean Air Act requirements. Under this grant program funds may be used for transit capital improvement programs that have air quality benefits in non-attainment regions. These funds have been used for charging infrastructure construction and bus purchases in specific regions. (Ibid, 2022).

As noted in the above section, the total ownership costs of electric transit busses are converging toward diesel alternatives. However, transit authorities and operators face considerable planning costs, high up-front costs for bus purchases and charger infrastructure build-out (Johnson et al., 2020) . Taken together, these BIL grant programs provide significant direct and indirect federal support for public transit bus electrification that helps offset the considerable costs associated with electric bus purchases, possible depot remodeling or expansion and the construction of the extensive depot charging infrastructure. And as is the case with other vehicle classes, there are additional incentives and supports for bus electrification from select state governments, local governments, and utilities.

Support for School Bus Electrification

The major federal initiative to accelerate the substitution of BEBs for diesel buses for school transport is the $5 billion Clean School Bus Program in the BIL. This program is overseen by the EPA. These grant funds will be dispensed over the FY 2022-2026 period (U.S. Environmental Protection Agency, 2023) With funding from the BIL, EPA’s new Clean School Bus Program provides funding over the next five years (FY 2022-2026) to replace existing school buses with zero-emission and low-emission models. These grant funds can go to school districts or a variety of other local school bus operators. The funds can be used as rebates for the purchase BEBs or other low emissions buses (propane or compressed natural gas) to replace existing ICE school buses. This program also offers grants for the purchase of electric vehicle supply equipment (EVSE) infrastructure and offers support for workforce training for operators and depot personnel on the new technologies (Ibid).

Similar to public transit BEBs, electric school buses currently have significantly higher purchase costs than ICE alternatives and also require investments for the needed charging infrastructure. Early results suggest that the Clean School Bus Program has been very successful in offsetting some of the high upfront costs of BEB bus adoption. As of early 2023 nearly $1 billion in rebates were allocated to over 400 school districts in all 50 states. It is estimated that more than 2,500 buses benefitted from the program, 95 percent of which were BEBs (Richesson, 2023).

Provisions in the IRA to accelerate BEV adoption and charging infrastructure development for various vehicle classes.

There are numerous additional provisions in each of the major federal laws that encourage BEV adoption and promote the development of the charging infrastructure. The IRA offer significant grants and credits that seek to reduce the purchase prices of PEVs in various categories to offset their generally higher upfront costs. We will first examine provisions in the IRA that subsidize PEV vehicle purchases and seek to reduce the production costs of these vehicles.

Credits and Incentives for Passenger Vehicle Purchases

Recent estimates suggest that the purchase prices of passenger all battery EVs $9,000 to $13,000 above comparable ICV models (Lindwall, 2022). While this price differential is likely to fall over time, the IRA offers tax credits and rebates to consumers for PEV purchases that significantly close this differential. The IRA provides a tax credit of up to $7,500 for new PEV purchases, and up to $4,000 for a used BEV. Eligibility for the tax credit for new vehicle purchases is determined by three criteria: household income caps; vehicle purchase prices; and domestic content requirements for battery components and assembly (Safe-EC, 2022)16. The EV credit for used

[16] Eligibility for the full $7,500 credit requires that the vehicle purchase priec is less than $55,000 for passenger sedans or under $80,000 for SUVs, Vans of Pickup Trucks. The income caps for consumers are $150,000 for single tax filers, $225,000 for head of household and $300,000 for joint filers. A vehicle can receive $3,700 if its battery components are manufactured are assembled in the U.S. and another $3,700 if critical minerals for the batteries were extracted or processed in the U.S. of countries with which the U.S. has a free trade agreement. Final

vehicles is subject to lower income and vehicle purchase price caps and the vehicle must be at two years old. However, there are no domestic content requirements for the used vehicle credits.

The new and used vehicle purchase incentives in the IRA contain several provisions that are more equitable than prior purchase credits, more directly benefiting low and moderate income households. The income and vehicle purchase price caps exclude some luxury class vehicles and high income households. A vehicle purchase incentive program based on tax credits earned at purchase and applied by individuals to reduce their federal tax liability has been criticized as providing few benefits for low and moderate income consumers whose tax liabilities may be less than $7,500 (Yozwiak et al., 2022). A critical feature of the IRA vehicle purchase incentives is that beginning in 2024, a consumer can transfer the tax credit to the dealer and receive the credit as a direct rebate at the point of sale. A PEV purchaser with a limited tax liability can hence immediately enjoy a lower net purchase price and will not have to wait to reap the value of the incentive until tax time (Ibid).

Incentives for Residential Charging Equipment

Another provision in the IRA provides a tax credit equivalent to 30 percent of the cost of charging equipment (up to $1,000 per unit) for individual/residential uses (U.S. Department of Energy Alternative Fuels Data Center, 2023). This tax credit is targeted to rural residents or urban residents living in a census tract where the median family income is less than 80% of the state medium family income level.

While this constitutes an important tax incentive to offset the costs of installing or upgrading residential charging capacity for rural and low to moderate income households, a variety of incentives offered by state and local governments and utilities may supplement or in some cases be more attractive than this federal tax incentive.

Credits and Incentives for Commercial Vehicles – Light to Heavy Duty

In IRA the federal government, for the first time, provides significant tax credits for commercial PEV purchases. For vehicles in various classes a tax credit is available for PEVs used for a business purpose. The eligible credit is calculated as the lesser of 30% of the vehicle purchase price or the incremental cost of the vehicle defined as the difference the purchase price of a PEV and a comparable ICE vehicle. The tax credit is capped at $7,500 for vehicles in light to medium duty

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assembly of the vehicle must take place in North America for the vehicle to be eligible for the credit. The credit can apply to all battery and plug in hybrid vehicles.

categories (with a gross vehicle weight of less than 14,000 lbs.). For commercial vehicles over 14,000 lbs., a tax credit of up to $40,000 for PEV purchases is available (SAFE-EC, 2022). Unlike the passenger vehicle purchase incentives, these credits are not subject to any income, vehicle price or domestic content requirements. These credits for commercial vehicles are likley to accelerate already strong moves to transition delivery and work fleets to PEVs by large retail and wholesale companies. These incentives will also serve to encourage PEV adoption by of work vehicles by smaller businesses in the construction related trades and service industries (e.g. landscaping, plumbing, home repair, etc.).

The build out of the public charging infrastructure (detailed above) facilitated by the various BIL grants will be an important development encouraging the adoption of BEVs for commercial uses. The IRA provides additional tax incentives to business owners to install charging equipment or other alternative fueling equipment in their places of business. The credit is only available for businesses if they are located in a rural area or an urban area in census tracts where median household income is less that 80 percent of state median family income (Department of Energy-Alternative Fuels Data Center 2023). This credit could fill gaps in the charging infrastructure by providing tax credits covering 6 percent of fueling or charging equipment costs up to $100,000 for rural businesses or businesses in low and moderate income communities.

This set of federal tax incentive and grants can operate together to accelerate BEV adoption across a range of commercial vehicle classes. They also include tax credits that are targeted to improve access to charging for businesses in underserved areas and lower income communities. As in the case with passenger vehicles, there are other federal incentives and a range of supports from state and local government and utilities that supplement the programs in the BIL and IRA.

Incentives to Scale Domestic Battery Manufacturing

A final specific provision in the IRA promises to lower the purchase prices of all PEVs by substantially subsidizing the costs of U.S based battery manufacturing. Domestic manufacturers can gain a credit on battery cells produced equaling $35 per kilowatt hour of capacity per battery cell, a $10 per kilowatt of capacity for a battery module and, or $45per kWh credit for a module that does not use battery cells (McDaniel, 2023). These credits to battery manufactures are expected to supercharge the already rapid expansion in U.S. battery manufacturing facilities. An Argonne National Laboratory study estimates that current announced new battery production facilities planned in the U.S and Canada will increase production capacity from 177 GWh (energy value) per year in 2023 to 998 GWh per years by 2030 (Gohlke et al., 2022). The cost savings to manufacturers will boost battery manufacturing as well as generate economies of scale and a more competitive market for battery based power trains. One estimate suggests that over time these and other subsidies supporting battery manufacturing could reduce the costs of producing an EVs passenger car by as much as $2,900 (Slowik et al. 2023). If this prospective cost reduction linked to due battery manufacturing incentives is combined with the direct vehicle purchase credits, the purchase costs of passenger BEVs is at close to parity with equivalent ICE models. Furthermore, this strong support to massively expand domestic battery production promises to bring down battery costs for all classes of vehicles and hence reduce purchase costs for the various vehicle types discussed below.

The Complex Ensemble of Incentives and Supports for PEV Adoption

As has been alluded to, the large scale initiatives in the recent federal legislation are in many cases occurring on top of longer-standing incentives and policy actions by state and local governments and public and private utilities to encourage PEV purchases and charging infrastructure development. There are substantial differences in these non-federal policies and incentives across states and localities.

California is widely recognized as having the most extensive set of measures to advance zero emissions vehicle adoption. Some of these actions go back three decades when the California Air Resources Board (CARB) set regulatory requirements for the share of zero emission vehicles to be sold in the state. While the state has had to revise these goals over the years, the early emphasis on ZEV sales put the state in a strong position as PEV technologies matured and became commercially competitive over the past decade. California now offers a plethora of rebates, incentives and charging infrastructure development programs through the state, local air quality management districts and local utilities (US Department of Transportation -Alternative Fuels Data Center, 2023). With the highest rate of PEV adoption across many vehicle categories, the extensive and layered set of policies across jurisdictions facilitate growing demand. The state also launched pioneering efforts to set standards for charging stations and to reduce local regulatory hurdles for charging infrastructure development, producing, for example, and Electric Vehicle Charging Station Permitting Guidebook in 2019 (California Governor's Office of Business and Economic Development, 2019).

Other states, such as Colorado, New York and Oregon also have a relatively robust set of PEV support mechanisms across different levels of government. In other states, local jurisdictions and utilities there are fewer incentives and supports for vehicle electrification. But many state governments ramped up their actions support PEV adoption as a result of the $2.9 billion settlement by Volkswagen related to their emissions cheating scandal in 2016. The German automaker agreed to pay these funds into a trust fund to support emissions-reducing projects across the United States, and the money was allocated to states according to a formula established in the settlement.[17] State and local jurisdictions have drawn upon these settlement funds to carry out a variety of actions to expand the charging infrastructure and purchase PEVs for public sector uses, with a strong emphasis on BEBs and other medium and heavy duty vehicles (National Association of Clean Air Agencies, 2023).

A comprehensive and valuable list of all state and local actions (grants, tax incentives, rebates, exemptions, building code examples, etc.) is available on the U.S, Department of Transportation Alternative Fuels Data Center website (see https://afdc.energy.gov/laws). While this ensemble of non-federal policies to accelerate PEV adoption generally complement or supplement the large and historically unprecedented supports provided in the BIL and IRA, the sheer number and complex rules of these programs can be difficult for local authorities, businesses and consumers to understand and navigate. There is a pressing need to communicate the rules and opportunities associated with the numerous PEV support mechanisms to consumers and public and private institutions on the ground. At the same, enhancing coordination and collaboration among institutions that may have a limited history of working together is a challenge that must be addressed to efficiently leverage funding and new policy supports to lower barriers PEVs adoption across the various vehicle classes. We will now highlight a range of policy and planning challenges at more local levels to an efficient and effective build out of the charging infrastructure to accommodate higher levels of PEV use.

[17] The allocation structure is primarily based on the number of registered affected Volkswagen vehicles within the boundaries of the beneficiary

VI. Policy and Implementation Challenges for Local Planners and Policy Makers

Accomplishing substantial and relatively rapid changes in the national transportation infrastructure to accommodate a broad transition to PEVs can seem as a daunting prospect from a certain perspective. The institutional and technical systems designed to support ICE vehicles evolved over a long period of time as have the habits of vehicle users. The systems supporting vehicle fueling and maintenance are deeply embedded within interregional and local transportation networks. The most fundamental change involves replacing a fuel-based refilling infrastructure with an electricity-based charging infrastructure. The transition to PEVs will further require new or enhanced workforce skills from mechanics to electricians to personnel adept at operating and maintaining charging stations. And the transition will require vehicle operators to adjust to new habits in driving and sustaining their battery charge. Like many new technologies, early PEV adoption has been concentrated in high income households and communities, raising crucial issues of unequal access and disparate impacts

However, it is important to maintain the proper perspective on how deep and quickly these changes these changes will manifest. Even under scenarios projecting relative high market shares of PEV purchases over the next 5-10 years (e.g. 50 percent of new vehicles sold in the U.S. in 2030), only around 20 percent of the U.S. vehicle fleet would be PEVs in 2030. The transition process to a new vehicle powertrain framework will be more of a steady evolution than a sharp shock. There have been minor frictions In European countries with much higher PEV purchase shares, but no evidence of serious bottlenecks or disruptions of any kind. Nevertheless, new thinking, new collaborative partnerships and innovative policy actions will be needed to facilitate the PEV transition in ways that benefit all people and communities.

The large and relatively rapid injection of federal credits and grant funding under the BIL and IRA combined with preexisting state, local and utility supports will turbocharge the PEV transition. As outlined above, the unprecedented level of support being quickly rolled out is characterized by different incentive types, time frames and specific requirements. The federal funding streams press state and local level recipients to mobilize quickly to access these resources and implement successful projects.

Institutions with limited histories of collaboration will be required to organize, communicate, and undertake joint work. For example at the state and local levels, state DOTs, MPOs, local transit authorities, city transportation and planning departments and electric utilities will need to cooperate closely to facilitate an efficient expansion of the charging infrastructure for various use cases. Other collaborative efforts will be necessary to aggregate, package and communicate information to businesses and consumers about PEV purchase incentives, charger infrastructure incentives, technical requirements, and access characteristics. Still other joint work will be needed to enhance the resilience of the charging infrastructure to grid disruptions and local outages. A critical through line to all of these organizational challenges is fashioning aggressive actions to expand affordable PEV purchase options and convenient and affordable access to charging in low and moderate income communities. This will in turn require energetic outreach and public engagement to communities who have to date been largely left out of the PEV market. A number of planning and policy actions involving a range of actors and institutions point the way to more effective implementation.

Planning the charging infrastructure based upon future PEV adoption rates.

The pace of charging infrastructure development has accelerated over the past five years as PEV adoption rates have grown. There remain significant gaps in terms of meeting the diverse charging needs of personal vehicle travelers and the unique charging requirements for other vehicle classes. The early stages of the charging infrastructure build-out provide important lessons that can enhance the efficiency and accessibility of a more accelerated development spurred by the injection of new federal funding.

A key lesson for building charging capacity is that charging facility development should be based on higher future adoption rates rather than simply responding to current demand. Across the broad category of non-residential charging, the installation of more charging capacity on top of what might be an initial set of installed chargers is often an efficient, cost saving strategy. Building to accommodate greater future demand often takes the form of installing a specific number of operative charging stations or ports augmented by a larger number of spaces that are “made ready” for the future installation of an EC charging port. As was noted earlier, a significant cost and time component of building charger capacity at a site is installation of electric panel capacity and trenching to construct a conduit to a junction box that can be linked to a charging port. In cases of a large charging installation or a charging center offering DC fast charging, a forward looking make ready strategy may include oversizing transformers and laying additional conduit to accommodate expansion.

Installing a more extensive EV ready capacity to charging spots where ports could be installed in the future yields substantial cost savings in many types of facilities and allows for a more rapid expansion as charging demand grows (Nelder and Rogers, 2019). For example, an office parking facility might install fully operational charging ports in 10 percent of its parking spaces and another 20 percent of spaces that are EV ready. This facility could quickly and economically expand to offer charging in 30 percent of its parking areas avoiding expensive new trenching though hard surfaces or upgrading panel capacity.

Another basic lesson is that planning new charging capacity in new construction is much more cost effective than retrofitting existing structures. Planning for adding charging infrastructure as construction of new building or parking facility is planned reduces design costs, a range of soft costs (e.g. obtaining utility interconnections, building permits) and installation costs (e.g. trenching through pre-existing hard surfaces). These economies associated with new construction offer a strong rationale for local ordinances and code revisions requiring certain categories of new construction to include operative charging stations and make ready capacity (discussed in more detail below).

An additional aspect of forward looking charging infrastructure development is focusing on smart charging capabilities. Smart charging capability allows for different forms of vehicle-grid integration that can generate significant benefits for both the utilities and the user. Smart chargers are necessary to facilitate time-varying costs or prices tied to utility load management needs. Customers of all types save money charging in off peak periods while the utilities can more easily absorb the net increase in electricity demand as PEV adoption expands. Charging price variations can also be tied to periods of higher alternative energy generation, improving environmental performance. Installed smart charging capacity can further support potential future innovations such as vehicle to grid systems or battery storage to manage loads at large DC fast charging centers (Ibid, 2019).

Forging strong local institutional collaborations

The institutions and actors that will be involved in the build-out of the charging infrastructure are substantially different that those associated with the distribution and sale of combustible fuels. Electric utilities are central institutions in charging infrastructure development. A much deeper level of coordination and collaboration between utilities and an array of local public and private institutions will be required to increase the efficiency of building new charging capacity. Below are just a few examples of the novel institutional coordination and joint work needed for different forms of infrastructure development.

Utilities, local city planning and code enforcement departments, EVSE suppliers, and developers of commercial destination and office properties – Developers of new commercial properties or major upgrades of existing properties will be increasingly pressed by market demand and regulations in install on site charging capacity. To manage the charger installation costs and ensure compliance with codes and regulations, the developer will benefit from working closely with the local electric provider and relevant city departments.

Developers of commercial and multifamily residential properties will be required to work directly with utilities to assess power connection requirements, the distance between a charging area and the closest utility interconnection point (to minimize trenching to lay conduit) and possible needs for step-down transformers. Utilities and EVSE companies will have to be consulted about needs for electric service panels, conduit, wiring, switchgear, and power conditioning units. Local government planning and code departments will often need to be involved in permitting, assessment of any easement issues, compliance with Americans with Disability Act (ADA) requirements and building code compliance. Since developers have not previously had to consider charging infrastructure as apart of building parking requirements, it is crucial that utilities and local government departments create new procedures and allocate trained personnel to ease the time and monetary costs of charger installations in commercial and multifamily properties.

Utilities, MPOs, and City Planning Departments – The role of MPOs in siting and funding public charging stations will vary across the states. In some states, like Texas, MPOs have an important role reviewing and approving proposals from private charging station developers seeking funding through the NEVI program. Even in cases where MPOs have a less direct role, other local or regional authorities will be heavily engaged in the siting decisions of public charging station. Once again, coordination with utilities will be central in this site selection process. Utility interconnection options and costs will strongly shape the viability of specific sites. Local planning departments will need to be able to provide accurate information about permitting requirements, easements, signage, and even demographic information (to meet equity requirements in various federal PEV support programs) for different possible sites. Once again, creating the organizational capacities within these institutions to facilitate site selection processes will be essential to enhancing the efficiency and accessibility of public charging development.

Utilities, local planning departments, local transportation and public work departments, public transit operators – Within the public sector new cross agency and institutional collaborations will need to emerge to effectively build-out specific types of charging infrastructure. Electrifying public transit and school buses will require constructing larger-scale depot charging centers. These will sometimes require major electrical infrastructure elements linking the utility grid interconnection to the depot involving careful planning and coordination between the utility, transit operators and city planning and code departments. Similarly, installing in-route charging stations for busses will require transit operators to work with city planning departments, utilities, and private property owners to assess easements and find viable on-route charging sites.

In addition, utilities, and city transportation, planning and public works departments can also engage in joint work to develop charging capacity on city streets. Some European countries have added significant charging capacity on streets by adding charging ports to street lighting posts. This specific charging solution may be viable on certain thoroughfares with on-street parking and would require close coordination between utilities and local government departments. Similar processes would be required to install a charging station or ports for a subset of paid on-street parking slots.

These are just a few examples of the new forms of institutional coordination and joint work that will be essential to the efficient build-out of a charging infrastructure that also offers a wide range of access options. There are number of interesting examples of institutional reform and best practices that seek to simplify regulatory compliance and reduce the transaction costs of charging infrastructure development.

- California has a requirement that municipalities streamline permitting for PEV infrastructure. These requirements are from two laws: Assembly Bill 1236, and AB970. The first bill requires that all cities and counties adopt the ordinance and provide permitting checklists, and the second adds timeline requirements. The state has also provided a guidebook and factsheet on streamlined EV permitting for municipalities through the Governor's Office of Business and Economic Development. The California NEVI plan states that "as of May 1, 2022, California had 190 jurisdictions with streamlined permitting, 128 jurisdictions in the process of streamlining, and 222 jurisdictions that need to adopt the legislation." Priority for the receipt of NEVI funds might be given to the jurisdictions that have already adopted the permitting guidance or have started the process to streamline permitting (California NEVI plan , page 48)

- Several reports recommend that public and private utilities create a charging infrastructure coordination team/center offering "one stop" information and coordination services to public and private charging station developers (Nelder and Rogers, 2019; Ross et al, 2022). Such a central point of contact could significantly reduce costs and time delays by offering, among other things: detailed information and maps of grid hosting capacity at sites across the utility's service area; assistance with completing utility interconnection applications and speeding their approval; and coordinating the scheduling of utility work as part of the site preparation process.

- The American Planning Association has developed a set of recommendations for local zoning standards and other local ordinances to clarify regulations and ease approvals for various charging installation types. This study suggests that local ordinances explicitly permit charging equipment for all residential uses and that chargers associated with commercial and institutional uses should normally be permitted as an accessory use (versus a primary land use) (Ross et al., 2022). The report also calls for localities to develop mixed use zoning standards for commercial/for profit public vehicle charging stations allowing the combination of various commercial uses (convenience store, food store, car washes etc.) with charging stations. Clarifying and simplifying land use and building code regulations is crucial for reducing costs and time delays for PEV charging infrastructure expansion. The APA document furthermore reviews existing local ordinances requiring EV ready or EV installed parking space requirements for new multifamily construction or other uses (Ibid, page 7). These will be discussed in more detail below in the context of increasing equitable access to charging infrastructure.

Creating more equitable access to PEVs and the charging Infrastructure

The biggest challenge in the PEV transition is overcoming severe disparities across a number of spatial and socioeconomic dimensions. Presently, PEV passenger vehicle owners are "primarily male, high income earners, highly educated, are homeowners, have multiple vehicles in their households, and have access to home charging" (McAdams, 2022, p 6). PEV ownership rates are also much lower for rural residents and residents of multi-family dwellings (Tolbert, 2021). On the other hand, as was shown above, the environmental and economic advantages of PEV ownership and the electrification of public transit and school buses are substantial for low and moderate income communities.

Numerous studies have identified three major barriers to PEV adoption in lower income and rural communities: basic vehicle cost barriers; poor access to convenient, affordable vehicle charging; and certain perceptions or disinterest associated with limited information and exposure to PEV options; (Bauer et al. 2021; Yozwiak et al. 2022; McAdams, 2022).

Reducing PEV Purchase Price Barriers

The basic PEV acquisition cost barrier is perhaps the most likely to fall in the short to medium-term. Market dynamics, including the falling price differential between PEVs and ICE vehicles and the growth and maturation of used PEV markets will expand access to low and moderate income households. The change in rebate policies in the IRA also opens up better purchasing options. Prior to 2023, federal incentives (up to $7,500) for new PEV purchases operated as deduction to reduce an individual's tax liability. Many low and moderate. Consumers can now receive the federal credit for both new and used PEVs as a direct rebate at the point of sale. PEV purchasers with lower incomes can now immediately benefit from a lower net purchase price via the IRA incentives.

Building Convenient and Affordable Charging Access for All Communities

For PEV ownership to expand and generate benefits to rural and lower-income drivers falling purchase prices must be combined with affordable and convenient access to charging. The promise of lower total vehicle ownership costs for PEVs will not be fully redeemed if rural and lower income owners have limited access to mostly higher cost public charging stations. In this regard, recent federal legislation (the BIL and IRA) has a strong focus on filling crucial gaps. As described above, the main BIL provisions for the build out of public charging stations (The NEVI formula grants to states and the Community Charging grants) prioritize rural areas as well as low-and moderate-income neighborhoods. In the case of NEVI grants, the state DOTs have to ensure that their plans met Justice40 goals aiming to ensure that 40 percent of NEVI and other BIL investments benefit disadvantaged communities (DACs). In the NEVI planning process states are required to carry out a public engagement process to identify direct and indirect benefits that flow to DACs[18] In addition, the 2023 NEVI round will require states to produce a community engagement outcome report detailing how the state authorities engaged with communities throughout the development of their state NEVI plans (Patterson et al., 2023).

The BIL investments in charging infrastructure, combined with other federal, state and local programs promise to significantly improve charging access. The investment push provided by these programs will be tilted to rural areas and low and moderate income communities that currently have poor charging access. However, charging station developments that will support PEV adoption in these communities will need to go beyond new for-profit public charging stations. There are numerous opportunities at the local level to leverage BIL funding and other resources to substantially increase access to affordable charging on top of the buildout of for-profit charging stations. A number of approaches have been proposed or currently being piloted.

As local governments and enterprises expand charging capacity for public fleets and in public parking facilities, they could provide free or subsidized charging access for the pubic, especially in facilities located in or near underserved communities. This could include building make-ready and installed charging capacity in public parks, community centers, public health facilities and other public buildings or facilities.

A number of local government entities and utilities are experimenting with providing income based charging credits to reduce charging costs at public stations. The California Air Resources Board is testing ways to provide affordable charging access to PEV owners without access at their

[18] State DOTs are required to reference the Electric Vehicle Charging Justice40 map developed by the US DOE and DOT that identifies Census tracts with higher levels of vulnerable populations based on health, transportation access, energy cost burdens, exposure to environmental hazards and other factors. See https://www.transportation.gov/rural/ev/toolkit/planning-resources/equitable-planning

residences. They provide a $1 thousand prepaid charge account to qualifying individuals that can be used at public charging stations (Yozwiak et al. 2022). This incentive is being combined with access to a portable charging system that can be plugged into a standard outlet but can charge at a faster rate (comparable to a level 2 charger). Such portable charging capability could expand charging options for renters and even multifamily residents (Ibid, p 12).

The biggest hurdle in providing more equitable access to affordable charging is expanding charging options for residents of multi-family housing. Since vehicle ownership is heavily concentrated in owner- occupied single family housing, owners and managers of rental housing may not see significant demand for often costly charging infrastructure from their tenants. However, affordable and convenient charging access for multifamily residents is crucial to expanding access to PEVs for low and moderate income households. To date two strategies are emerging to bring charging infrastructure to multifamily residents.

Expanding Convenient and Affordable Charging Access at New Multifamily Developments - For new multifamily construction, many local governments are crafting ordinances to require a certain percentage of EV ready or EV installed capacity in parking spaces in new multifamily developments over a certain size. These ordinances (which can be based on minimum parking requirements, design or performance standards or other planning elements) can be designed to increase requirements over time as PEV adoption increases. For example, St. Louis started by requiring that 2 percent of spaces in new multifamily developments have installed chargers and 5% percent be EV ready. By 2025 the requirement for EV ready spaces increases to 10 percent. In Chicago new multifamily developments must have 20 percent of parking spaces either EV ready or EV installed (Ross et al, 2022). As previously noted, it is substantially less costly to provide charging infrastructure when it can be planned and organized (with the utility) as part of a new construction project. Furthermore, providing a larger share of EV ready spaces will save considerable costs as demand for charging from multifamily residents increases. This suggest that local governments and utilities work with developers to set higher EV ready requirements than current demand might indicate.

The more difficult problem is providing charging options for existing multifamily rental residents. Retrofitting existing parking areas for the installation of chargers in multifamily developments is typically a costly proposition. As was discussed, the soft costs and installation costs (e.g. trenching through pre-existing hard surfaces) are substantial in are these cases, and passing on such costs to residents, few of whom may currently have PEVs would undermine overall affordability.

There are a few strategies that local governments and utilities are testing to address this critical access gap. Some state governments and utilities provide significant grants or rebates to install chargers or make-ready infrastructure at existing multifamily complexes. For example Austin Energy provides up to $4,000 per level 2 charger and up to $15,000 DC fast charger at existing multifamily developments (Austin Energy, 2023). Nine states have used funds from the VW settlement to provide grants or rebates for charging infrastructure at multifamily dwellings (Yozwiak et al. 2022). While BIL funds seemingly require that charging capacity built using federal subsidies be open to the public, not just residents of a particular development, there may be feasible ways to use these funds to install stations in or adjacent to larger multifamily complexes or clusters of multifamily developments to provide access.

In the shorter term, local governments and utilities need to work with communities to improve charging access through a combination of affordable charging at public facilities, commercial establishments and the build-out of charging in multifamily complexes. Charging at the place of residence is the preferred means for personal vehicles for a variety of reasons. Over time, as adoption of PEVs increases, demand will encourage owners and managers of multifamily properties to provide charging capacity, but efforts to incentivize charging infrastructure in existing multifamily complexes will remain an important priority.

Overcoming Information Gaps - Education, Outreach and Community Engagement

The historic pattern of PEV adoption has limited the exposure of many communities to the issues and opportunities associated with vehicle electrification. As with any new technology, decisions to adopt involves gaining knowledge about the characteristics, performance and relative advantages of the new alternative. Knowledge can be built through learning from information provided through official channels such as PEV manufacturers, government sources or the broader media. However, more tacit knowledge gained from peers or social networks may be more important in the decision to adopt new technologies. In the case of the transition to PEV technologies, the literature suggests that members of many communities in rural or less affluent areas have very limited access to information from both official sources and from peer networks (Coffman et al, 2017, Yozwiak et al 2022).

Normalizing the idea of PEV adoption will require much more focused education and outreach efforts by manufacturers and public and non-profit institutions. Because adoption rates are very low in certain communities, individual perceptions of the capabilities and performance of PEVs may not reflect actual technical and operational characteristics of current vehicles. Misconceptions about vehicle ownership cost, range and charging requirements call for much more aggressive and focused efforts on the part of key institutions involved in the PEV transition. To date education and marketing efforts by PEV manufacturers have been targeted to early adopters who are disproportionately high income urban dwellers.

More legible information about the total vehicle ownership costs of different passenger vehicle platforms, vehicle range, charging requirements and modes and used EV options must be distributed through multiple channels. Specific channels that might reach rural and lower income individuals can be identified and heavily utilized.

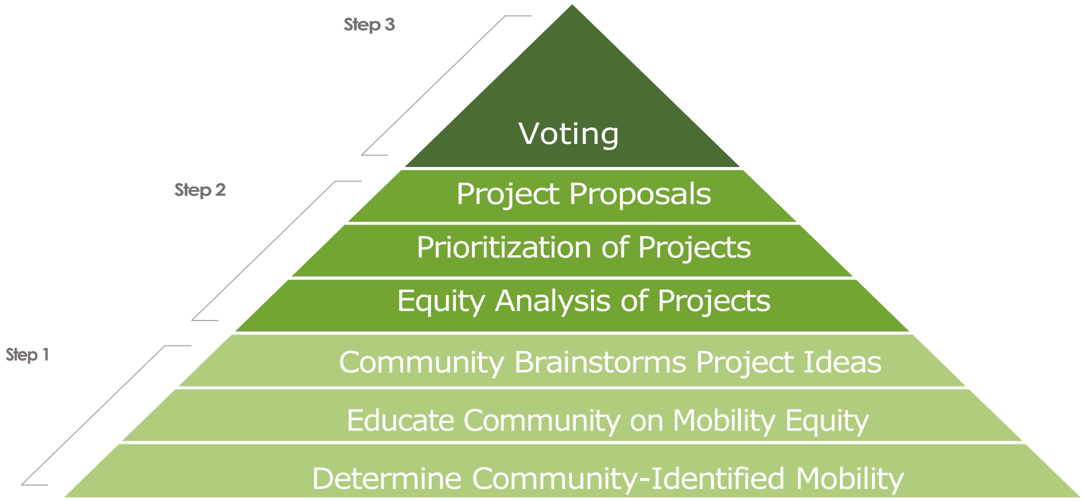
An important component of education and outreach is consolidating and clearly communicating information on the numerous and often bewildering set of incentives and supports that individuals, businesses and communities can utilize to lower the cost and enhance the convenience of PEV ownership. As this report has emphasized, there are a number of incentives, credits and other supports provided by various levels of government, electric utilities, vehicle manufacturers and EV charging providers. Most of these programs vary across states, localities, utility service areas and even neighborhoods. This makes it extraordinarily difficult for consumers or businesses to understand and access incentives and supports for PEV purchases, charger installation or other credits. Partnerships between vehicle manufacturers and dealers, local governments, and utilities to package and distribute clear comprehensive guides tailored to local areas would diminish information barriers and facilitate PEV adoption. Such guides should be distributed through conventional on-line channels, but also more targeted means such as monthly utility bills, public schools and student materials, faith based organizations, etc. An important part of such an initiative would be the creation of support centers staffed by individuals to help customers navigate and apply for various incentives and supports.

Peer-to-peer learning is crucial in overcoming the information deficits slowing PEV adoption, especially in rural and low-income areas. In this regard a number of deeper and more comprehensive public engagement activities are being implemented across the country. Some of these efforts are led by non-profits with an historic focus on equity and environmental justice. A number of community centered engagement processes with a strong focus on equitable electric mobility have received funding from state or local governments or utilities (Shaw and Diaz, 2022; McAdams, 2022; Yozwiak et al, 2022).

Emerging best practice lessons from these community-based public engagement efforts indicate that they should have a much broader focus beyond education and advocacy for electric vehicle adoption. Since transportation access in general is a barrier and cost burden for many low income and minority populations, public participation starts with a more general discussion of community identified community needs which can encompass the full range of transportation modes. Community participants then lead the process of identifying priority mobility needs in their specific neighborhoods. In the context of assessing needs, the issues and advantages associated with electric mobility including personal vehicles, public and school transit and light and medium duty trucking and delivery can be explored. Since it is well known that the negative health effects of tailpipe and other emissions for ICE vehicles are disproportionately concentrated in low income and minority communities, the environmental benefits of electrification will come into relief.

Some of these engagement processes aim to empower the community to prioritize and offer specific plans for higher PEV adoption, including the siting and characteristic of charging stations, the design of community education projects, and the leveraging of incentives and supports. An interesting example of a broad-based community engagement process linked to electric mobility is a model developed by the Greenlining Institute. As seen in figure 4, their process begins with a transportation needs assessment which leads to a consensus plan produced by the community to better meet mobility needs, including expanded capacity for PEV adoption.

Figure 4 – Greenlight Institute Mobility Equity Framework



Source: Creger, H. Espino, J., Sanchez, A. 2018. "Mobility Equity Framework - How to Make Transportation Work for People," The Greenlining Institute, p.5, https://greenlining.org/publications/mobility-equity-framework-how-to-make-transportation-work-for-people/

Other examples of expansive community engagement processes include the Sustainable Transportation Equity project funded by the California Air Resourced Board. This project supports community engagement efforts including a broad needs assessment and community generated proposals to meet mobility needs including BEV adoption (Yozwiak et al. 2022). There are examples of other similar efforts funded by state public utility commissions and individual utilities (McAdams, 2022, pp 12-13) To move the PEV transition forward in a more equitable way these deeper community engagement processes can and should be expanded.

VII. Conclusion

The electrification of transit system has considerable momentum. The move from internal combustion to electric vehicles across many vehicle classes reflects a substantial, but hardly radical change in the how we meet our mobility needs. As this report shows, the substitution of PEVs for ICE vehicles and the development of a charging infrastructure to replace our fueling infrastructure will be a gradual process, not a sharp, quick transition. Other advanced market economies are much further along in electrifying vehicle transit. They have experienced some frictions in implementing needed changes, but have not experienced major problems or disruptions. This basic fact augers well for the transition to PEVs in the U.S.

However, an efficient and inclusive transition to electric vehicles will require energetic and durable coordination, planning and policy development as well as deeper levels of community engagement. Serious economic, technical and informational barriers must be addressed. The needed buildout of the charging infrastructure for various vehicle classes will require considerable investment and intensive collaboration between public sector organizations and private sector actors. Electric utilities will be critical players in the build out of the charging infrastructure. The large scale federal investments and supports in the BIL will accelerate the scale up of the charging infrastructure, but how the key local institutions come together to leverage these funds will strongly shape outcomes.

A central and difficult challenge will be ensuring more equitable access to PEVs and affordable and convenient charging options. The total costs of ownership of PEVs are already lower than ICEVs for most personal vehicles. And purchase price barriers are slowly coming down. General trends in PEV prices and the emergence of a thicker used PEV market will expand ownership possibilities for low and moderate income households. The new "point of sale" subsides made available in the IRA bring PEV sticker prices very close to ICE vehicles in comparable segments of the personal vehicle market. Over time, there is a strong possibility that the sticker prices of many PEVs will fall below ICE vehicles in many vehicle classes.

The bigger equity challenge is in providing convenient and affordable charging across all communities and housing types. Here the "toughest not to crack" is providing charging access in existing multifamily rental housing. Various policies and local experiments to provide charging to multifamily complexes are detailed in this report. But securing quality access to charging in residential settings without parking dedicated to individual units will call for more innovation and additional public and private investment.

A final hurdle to overcome to push vehicle electrification forward is significantly improving the quality and accessibility of information available to consumers and local public and private institutions. Similar to many new technologies, early adopters of PEVs tend to be more affluent, more highly educated urban dwellers. This pattern has limited the exposure of many communities to the issues and opportunities associated with vehicle electrification. Transcending this knowledge deficit is crucial to moving to a mass adoption of PEVs.

More legible information about the total vehicle ownership costs of different passenger vehicle platforms, vehicle range, charging requirements and modes and used EV options will need to be distributed through multiple channels to reach rural and lower income individuals that have had limited exposure to PEVs. An important component of a more aggressive education and outreach efforts is consolidating and clearly communicating information on the numerous and often bewildering set of incentives and supports that individuals, businesses and communities might utilize to lower the cost and enhance the convenience of PEV ownership. Partnerships between vehicle manufacturers and dealers, local governments, and utilities to package and distribute clear comprehensive guides tailored to local areas would diminish information barriers and facilitate PEV adoption.

Finally, new forms of deeper community of engagement are called for to overcome the limited experience of certain communities with PEVs. Promising experiments in outreach and engagement focus on a broader community transportation needs assessment leading to plans to better meet mobility needs. Expanding PEV adoption is only one element in meeting mobility needs. These community based plans also incorporate public transit, non-motorized mobility, paratransit and other mobility options. This approach recognizes that transitioning to PEVs for individual mobility is just one needed change to foster a more equitable decarbonized transportation system.

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