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An Evolving Regulatory Landscape for Commercial Electric Vehicle Fueling

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Executive Summary

The electric vehicle (EV) charging landscape is presently in a formative period of its evolution. Major investments are facilitating charging infrastructure expansion and significant decisions are being taken that lay out legal frameworks for this relatively new industry. Popularity of EVs and demand for charging sites have grown considerably in recent years. More than 7 % of light-duty vehicle sales in the first quarter of 2023 were plug-in hybrid (PHEV) or "all-electric" battery EV (BEV) that can be charged with energy provided through the electrical grid – a 45 % increase over 2022 first quarter sales. Furthermore, several governments are targeting reductions in vehicle emissions by mandating transitions to zero emission vehicle technology. EVs are well-positioned to fulfill these policy goals and other environmental initiatives, but charging infrastructure must grow accordingly to meet such aspirations. Although most EV charging currently takes place in residences, commercial stations open to the public, especially fast-charging stations, play vital roles in the electrification of transportation in the U.S. Many more publicly accessible stations will be needed to help realize long-distance trips and make EV adoption viable for individuals without access to charging equipment, or "EV supply equipment" (EVSE). "Range anxiety", a commonly cited apprehension that a BEV might run out of power before reaching a charging point, must be alleviated before many potential consumers will comfortably commit to a BEV purchase.

Recognizing these trends, governments, utility companies, and various businesses have taken measures to promote broad and equitable access to fast charging stations and to EVSE in general. One such measure has resulted in the establishment of the National Electric Vehicle Infrastructure (NEVI) Formula Program, a large Federal initiative driving nationwide expansion of public charging networks. Utility companies, perhaps unsurprisingly, also play a central role in providing EVSE access. Where permitted, utility companies deliver financial incentives for EVSE deployment, offer customers discount electricity rate structures specifically for EV charging, invest in costly EVSE infrastructure, and even fully own and operate commercial charging stations. But to meet electrification goals, enterprises such as commercial public charging networks and other retailers will be crucial for rapid and extensive proliferation of public charging stations. To this end, state regulators are addressing key legal ambiguities and requirements that promote broader commercialization of EV charging.

Laws governing the sale of goods and services based on weight or measure are in place in every state to promote consumer protections and facilitate marketplace equity. Prominent among these laws are requirements for the accuracy, design, and usage of weighing and measuring devices used in commerce, such as EVSE, that determine quantities and transactions costs for the sale of commodities. There are also regulations for the "methods of sale" of commodities specifying how particular goods and services can be sold. Yet, while such requirements have been adopted by states for commercial EV fueling, they are not widely enforced throughout the country. These matters are addressed separately by each state and a patchwork of laws and regulations has evolved across the U.S. Nonuniformity in EV charging commerce can stimy expansion of interstate charging networks, curtail equity in the charging marketplace, frustrate price comparisons, and, ultimately, diminish consumer confidence in this rising technology. In

considering these ramifications, several governments within the U.S. and abroad are taking steps to ensure that EV charging transactions are consistently fair and transparent.

Although public EVSE sites play roles comparable to those of familiar gas stations, several circumstances make them unique among vehicle fueling stations. Electricity markets have been regulated by public utility commissions (PUCs) or similar rule-making authorities for nearly a century and sales of electrical power in these markets are primarily conducted through utility companies. Special dispensations and considerations must be made to permit the sale of electricity as a vehicle fuel by non-utility businesses, and in order to achieve this, most states have proactively excluded commercial EVSE sites from the regulative authority of PUC. Furthermore, many of these states presently require EV fuel sales to be based on the quantity of electrical energy that is delivered to the vehicle, measured in kilowatt-hours (i.e., prices in $/kWh). Additional charges may be assessed for the time a vehicle is parked at the EVSE, but those charges must be assessed separately from the charges for electrical energy. EV fueling prices based on the kWh are equitable, transparent and consistent with the method of sale that has been used by utilities to sell electricity for many decades. However, methods of sale for EV charging implemented in the U.S. are far from uniform and a staggering variety of more opaque forms of pricing can be found.

The application of laws and regulations designed to promote sound measurements (referred to as "legal metrology") is also deeply relevant to other aspects of EVSE usage. In addition to deployment at public charging stations, commercial EVSE devices are now being installed for use as submeters in utility billing. Several states are exploring the use of metering EVSE to apply credits for EV-specific electricity rate structures that are part of charging management programs and to measure bi-directional energy flow between a vehicle battery and the grid. While multi-tier pricing and bi-direction sales of energy ("net metering" and "net billing") are not new concepts, utilities are exploring ways to offer comparable rate structrures to their customers specifically for EV charging. The intent of these programs is to help control strain on the electrical grid and temper the amount of costly infrastructure buildout needed for an electrified transportation sector. Since most charging occurs in residences, this can have a profound effect on transitioning to zero-emission vehicle technology.

Another new consideration for the use of EVSE is their role in collecting motor fuel excise taxes. To recover expected losses in road maintenance revenue traditionally obtained through "gas taxes", some states are levying EV fuel excise taxes on a $/kWh basis. EVSE will be required to measure, in units of kWh, the quantity of fuel delivered to vehicles for collection and remittance of the tax. Verified metering accuracy of these EVSE devices will be crucial in facilitating compliance with EV fuel tax laws. To regulate use of EVSE in electric utility billing and in the collection of fuel tax, states are looking to apply requirements for metering devices that conform to national legal metrology standards developed for commercial EV fueling, namely relevant sections of NIST Handbook 44 Specifications, Tolerances, and Other Requirements for Weighing and Measuring Devices and NIST Handbook 130 Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality.

While some key matters in establishing a regulatory framework for commercial EV charging are largely settled, several others are far less so. Precedent set by early approaches to unsettled or emerging issues could shape requirements for this growing industry well into the future. As such, it is important to recognize that uniformity in EV fuel sales and regulations is at a pivotal moment in its progression. Decisions or inaction over the next several years will likely have far-reaching, long-standing impacts on consumer protections and equity in the commercial EV charging market of the U.S.

Abstract

Plug-in electric vehicles (PEV), which include "all-electric" battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), comprise a rapidly growing proportion of the U.S. automobile market – more than 7% of all light-duty vehicles sold in the first quarter of 2023, a 45% increase compared to sales during the first quarter of 2022. In response to projected demands for PEV charging, private companies, utilities, and state and local governments have strived to develop policies and infrastructure that promote broad access to electric vehicle supply equipment (EVSE) used to fuel electric vehicles (EV). However, long-standing regulatory oversight of retail electricity distribution and sales through utilities has presented ambiguities and constraints regarding the sale of electricity for vehicle fueling, particularly via public charging stations. As these matters are addressed separately by the responsible authorities in each state, a patchwork of policies and rules has evolved across the U.S. concerning regulation of public EVSE sites and charging-related transactions. These policies, or lack thereof, have influenced permissible EVSE site ownership models, methods of sale and pricing for charging sessions, and requirements for metrological control of EVSE. Nonuniformity in EVSE operations across the U.S. can stimy expansion of interstate charging networks, hinder equity in the charging market, frustrate price comparison, and diminish consumer confidence. Thus, it is advantageous that many states in recent years have begun to adopt consistent policies and regulatory measures that facilitate EV charging station deployment. However, significant gaps and variation in oversight remain as charging networks expand. Considering these developments, this publication summarizes the current, albeit evolving, commercial EVSE regulatory landscape in the U.S. and explores the increasingly relevant role of legal metrology in PEV charging. The implications of these topics and their relation to other currently evolving issues, including submetering for utility charging management programs and for PEV fuel excise taxes, are also discussed.

Keywords

Electric vehicle charging; electric vehicle supply equipment; commercial charging stations; DC fast-charging; legal metrology; EV incentives; National Electric Vehicle Infrastructure Formula Program; fuel sale regulation; method of sale; electric utilities; weights and measures; submetering; fuel tax; zero-emission vehicles; International Organization of Legal Metrology.

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List of Abbreviations

AC	alternating current
ANSI	American National Standards Institute
BEV	battery electric vehicle
CCS	combined charging system
CDFA	California Department of Food and Agriculture
CDFA DMS	California Department of Food and Agriculture, Division of Measurement Standards
CENELEC	European Committee for Electrotechnical Standardization
CHIPS	Creating Healthful Incentives to Produce Semiconductors (and Science Act)
CNG	compressed natural gas
CPUC	California Public Utilities Commission
CTEP	California Type Evaluation Program
DC	direct current
DCFC	direct current fast-charging
DRIVE	"Driving on Road Infrastructure with Vehicle of Electricity" (Act)
EGIA	Electricity and Gas Inspection Act (Canada)
EN	European Standard ("European Norm")
EPA	United States Environmental Protection Agency
EU	European Union
EV	electric vehicle
EVF	electric vehicle fueling
EVFS	electric vehicle fueling system
EVSE	electric vehicle supply equipment
FERC	Federal Electricity Regulatory Commission
FHWA	Federal Highway Administration
GDA	Georgia Department of Agriculture
ICE	internal combustion engine
IEC	International Electrotechnical Commission
IOU	investor-owned utility
LNG	liquid natural gas
MID	Measuring Instruments Directive 2014/32/EU
NACS	North American Charging Standard
NCWM	National Conference on Weights and Measures
NEVI	National Electric Vehicle Infrastructure (Formula Program)
NGV	natural gas vehicle
NIST	National Institute of Standards and Technology
NMi	Netherlands Measurement Institute
OCC	Oklahoma Corporation Commission
OIML	International Organization of Legal Metrology (Organisation Internationale de Métrologie Légal)

PEV	plug-in hybrid electric vehicle
PHEV	plug-in hybrid electric vehicle
PSC	public service commission
PTB	Physikalisch-Technische Bundesanstalt
PUC	public utility commission
PURPA	the Public Utility Regulatory Policies Act
SP	special publication
TOU	"time-of-use"
USDOE	United States Department of Energy
USDOT	United States Department of Transportation
USNWG	U.S. National Working Group (on Electric Vehicle Fueling and Submetering)
ZEV	zero-emission vehicle
ZEVIP	Zero Emission Vehicle Infrastructure Program

1. Introduction

Having traversed the country's roads and highways in internal combustion engine (ICE) vehicles for more than a century, the American public is increasingly embracing electric vehicles (EV). Technological advancements and economies of scale in recent years have made EVs more practical and accessible alternatives to ICE vehicles, boosting their popularity among U.S. consumers. In some locations even casual observers might notice EVs on the road, parked at the homes of friends or relatives, or connected to newly installed public charging stations more frequently than they did just a year or two ago. No longer acclaimed only by EV technology enthusiasts, interest and appreciation for electromobility has grown for a variety of reasons; many owners claim convenient and low cost fueling at home, better driving performance, and emissions-free operation as reasons for their decision to go electric. Following suit, several government policy makers and auto manufacturers have ventured to set ambitious goals to eliminate auto emissions in the coming years.

Plug-in electric vehicles (PEV), i.e., vehicles that use electrical energy stored in on-board batteries recharged by 'plugging in' to an external power source, have been considered a viable zero emission (ZEV) technology for broad adoption by the public. Types of PEV available on the market include "all-electric" battery powered electric vehicles (BEV) as well as plug-in hybrid electric vehicles (PHEV) that can utilize both electrical energy and traditional motor fuels. For the first quarter of 2023, it is estimated that 7.2 % of all light-duty vehicle sales in the U.S. were of PEVs, an increase of 45 % over 2022 first quarter sales [1]. Strong sales trends in Europe are also reported. Passenger PEV sales in Germany, the largest automobile market in the European Union, comprised over 31 % of total sales in 2022, up 22 % compared to 2021 [2]. In Norway, nearly 80 % of all new cars sold in 2022 were electric [3], [4]. Many states in the U.S. have plans to significantly increase ZEV sales over the next several years, primarily of PEV; some of these plans will require 100 % of auto sales to be ZEV by 2035. With assistance through expanded U.S. tax credits for some EV purchases, as provided by the "Inflation Reduction Act of 2022", the net cost of many high-volume PEV models is now below the average cost of a new car in the U.S. [1], [2].

			PEVs (Plug-in Electric Vehicles)	
Power Sources & Charging	**ICE** (Internal Combustion Engine) Vehicles	**HEVs** (Hybrid Electric Vehicles)	**PHEVs** (Plug-in Hybrid Electric Vehicles)	**BEVs** (Battery Electric Vehicles)
Conventional & Alternate Fuel	X	X	X	
Regenerative Braking & Internal Combustion Engine		X	X	
Plug-In Charging of Battery			X	X

Fig. 1. Electric-powered vehicle types. Source: U.S. Department of Energy at www.cleancities.energy.gov

While it has been forecast that electromobility will transform transportation in the coming decade and beyond, it is recognized that this outcome is largely conditioned on expansion of charging infrastructure. Convenient access to reliable charging ports will be needed in both residential and public areas, especially along roads and highways. The feasibility of widespread electrification is conditioned on proliferation of electric vehicle supply equipment (EVSE), which are devices that deliver electrical energy for EV battery charging. Although most (approximately 80 %) of PEV charging occurs in private residences, not all would-be PEV drivers have ready access to such equipment and not all vehicle operations, such as long-haul trips, are amenable to residential recharging sessions. Expansion of public charging networks is under way, especially those that accommodate rapid charging sessions; however, it is expected that many more will be needed throughout the U.S.

In addition to incentives to purchase EV and electrify heavy duty and fleet vehicles through the Inflation Reduction Act, the U.S. Federal Government has recently taken other substantial measures to promote EV use. The President of the U.S. issued an Executive Order [13] in August 2021 outlining policies to fast-track EV adoption, targeting 50 % of all new passenger cars and light trucks sold in 2030 to be ZEV. To help achieve this goal, the Administration is uniting automakers and autoworkers to advance American leadership in ZEV technologies. Also in 2021, the U.S. Congress signed into law the Bipartisan Infrastructure Bill (H.R. 3686) which provides $7.5 billion for building out a national network of EV chargers provided through the National Electric Vehicle Infrastructure (NEVI) program and competitive grants issued by the U.S. Department of Transportation (USDOT). An EV Charging Action Plan was announced in December 2021 that focuses on increased domestic manufacturing of batteries and charging infrastructure. This plan also established a Joint Office of Energy and Transportation to ensure that federal agencies of the USDOT and U.S. Depart of Energy (USDOE) work to meet the electrification goals set forth in the Bipartisan Infrastructure Law, and to develop new standards and requirements for states using federal funds in deploying affordable and widely accessible charging networks. These standards are intended to promote uniformity in charging reliability and ease-of-use across the U.S. Several U.S. companies and nonprofits have also made commitments to expanding EV fleets, commercial and multifamily community charging, and consumer education.

Rates of EV charging are generally characterized with respect to three levels.

- Level 1 is the slowest level adding approximately 3 to 5 miles of range per hour, utilizing common 120 V outlets to deliver alternating current (AC).
- Level 2 is an intermediate level adding approximately 10 to 80 miles of range per hour, often using 208 V to 240 V AC supply equipment.
- Level 3 is the fastest charging level, adding up to 20 miles of range per minute, via 400 V to 900 V DC supply equipment. Level 3 is sometimes further divided into DC Fast Charging (DCFC) and DC ultra-fast charging (power exceeding 150 kW).

A sizable proportion of publicly accessible EVSE presently installed, mainly AC Level 2 chargers on public property or in business parking lots, provide charging sessions free-of-cost. These are offered as perks or incentive to customers, employees, residents, and visitors. Free charging has also been provided in the past by some auto manufacturers to spur demand in sales of their electric vehicles. Although EVSE delivering electricity gratis are convenient resources for PEV drivers, they are often used as supplementary fuel sources and are not expected to meet demand for public charging as more EVs take to the road. Commercial public charging, especially DC fast charger (DCFC) stations, is a growing market sector that can help fill this gap. However, expansion of commercial public charging networks raises many issues concerning variation in relevant laws and policies across the U.S. Because the nature of PEV battery charging is different from any other type of vehicle fuel and because systems for electrical energy delivery as a utility has long been established, states have had to make special considerations regarding the sale of electricity as a vehicle fuel. Furthermore, although many states in the U.S. have adopted legal requirements for metrological control of commercial EV charging systems, such as accuracy requirements for meters used to bill customers, few states have begun active enforcement. This is in sharp contrast to the mostly uniform set of requirements and enforcement practices placed on traditional motor fuel stations that provides a level playing field across the market. Presently, there are well-recognized inconsistencies in the methods of sale of EV fuel and in requirements for the accuracy of EVSE measuring devices [5].

Consistency in legal metrology frameworks for the sale of commodities across different economies facilitates trade by promoting use of mutually compatible measuring instruments and ensuring protections for consumers and industry competitors alike. While some states have made substantial effort to establish these frameworks for EV fueling, many have not yet done so. This heterogeneity in requirements for commercial charging stations impacts transparency in transactions and can affect competition across the national market, as well as the international market. Coherent and consistent regulations for commercial EV charging throughout the U.S. can advantage not just consumers, but also commercial charging station owners and EVSE manufacturers that wish to sell products across different market areas. In this respect, aligning government rules and policies, including those at the state, federal, and international level, can play important roles in the expansion of commercial EVSE networks. To that effect, technical standards such as the National Institute of Standards and Technology (NIST) Handbook 44 Section 3.40 (developed in 2012) and the International Organization of Legal Metrology (OIML) Guide 022 (published in 2022) have encouraged harmonization in establishing technical requirements for EV fueling systems.

There are also new commercial applications of EVSE, both in the home and at public charging stations, that are germane to or even driving some of the evolving regulations and policies concerning EV charging. These applications, namely use in submetering for utility billing purposes and in tabulating EV fuel excise tax, are gaining traction in several states. While primarily conducted in residences, EVSE submetering allows utility customers to take advantage of EV-specific incentive rates for charging at off peak hours and to accommodate bi-directional energy flow to and from an EV battery. Both of these measures aim to reduce strain on the electrical grid and limit the need for new infrastructure as EV fuel demand increases. The use of metering EVSE at public stations is also gaining utility in some states' revenue departments by helping to recover increasing losses in government transportation revenue that is otherwise collected through "gas tax".

This publication describes some key issues that are helping to evolve the commercial EV charging landscape in the U.S., especially those related to regulations and technical requirements for commercial sale of EV fuel through EVSE. Topics relevant to this discussion include present drivers for EV adoption and charging network expansion, historical perspective and trends in the regulation of utilities and electric vehicle fuel sales, and burgeoning commercial EVSE applications. Standards and regulations for EVSE measuring systems in nations other than the U.S. are also examined. While a handful of these matters are largely settled, many are not, drawing attention from regulators, industry stakeholders, and the American public. Through decisions taken on these matters, along with increasing EV adoption and other drivers for increased electromobility, the next several years could be formative for the commercial EV charging market.

2. Drivers and incentives for charging network expansion

2.1. Environmental Awareness and Zero Emission Vehicle Policies

The transportation sector is the largest source of greenhouse gases emitted in the U.S. and in 2019 it accounted for over 37 % of carbon emissions from fossil fuel combustion. Transportation emissions increased 23% in the previous three decades, largely because of increased travel and use of light-duty passenger vehicles [6]. Although vehicle fuel economy has improved, it has not outpaced demand increases arising from population growth, economic growth, and geographic expansion of communities. To reverse these trends, the Federal Government and several state governments have enacted policies that incentivize PEVs or require manufacturers to increase the proportion of new ZEVs produced and sold in the U.S. [7]–[9].

Presently, there are fourteen states that adhere to California's Zero Emission Vehicle Program designed to improve air quality and reduce greenhouse gas emissions. California, the largest EV market in the U.S. and where 16 % of new cars recently sold are ZEV or PHEV models, has also made a rule mandating that the sale of new ICE vehicles be completely phased out by the year 2035 [10]. Several other states participating in California's Program, including Maryland, Massachusetts, New Jersey, New York, Oregon, and Washington, intend to follow suit in prohibiting ICE vehicles sales after 2035. Separate plans for tapered ICE vehicle phase-out have also been announced in other states.

Additionally, the President of the U.S. issued an Executive Order [11] in August of 2021 to establish new government policies aiming for 50 % of all new passenger cars and light trucks sold in 2030 to be ZEV. Driven by one of the directives (Sec. 2) in this order, the U.S. Environmental Protection Agency (EPA) proposed new rules in April 2023 [12] that would set the most stringent tailpipe emission standards to date. Complying with the proposed air pollution regulations would require a major transformation of the auto industry; it is estimated that up to two-thirds (67 %) of all new light-duty passenger vehicles produced by 2032 would need to be ZEV. A proposed companion rule has also been designed that could lead to ZEV comprising 46 % of medium-duty vehicles, 50 % of busses, and 25 % of heavy trucks produced by 2032. While the regulations would not mandate all-electric auto sales themselves, the Clean Air Act (42 U.S.C. 7401-7671q) grants the EPA authority to limit the amount of pollution produced by the total number of cars that each manufacturer sells. To meet the new restrictive requirements, manufacturers would need a significant proportion of their total sales to be ZEV. If enacted as proposed, the combined effect of these two rules is expected to drastically reduce air pollution and is projected to put the U.S., the world's largest economy, on a track to substantially reduce greenhouse gas emissions and avoid the most disastrous effects of climate change.

Although these plans for reducing emissions hinge upon a resource-intensive shift toward vehicle electrification, several major automakers have reported production strategies that accommodate them. Anticipating increased consumer-driven demand for BEV and similar rules elsewhere throughout the country, some have expressed aims to sell only new "all-electric" BEV models by 2035 or sooner [13], [14]. Yet even though many auto manufacturers have made large investments to offer electric models, many companies and their workers are concerned about the rapid changes necessary to realize a revolutionary shift in the automotive industry. Manufacturers are concerned about demand for BEV and PHEV models, which tend to be more expensive, and the supply of car batteries. Workers are worried about job losses as production shifts to EV models. Furthermore, most stakeholders, including consumers, have concerns about the rate at which charging infrastructure might be built over the next several years to make EV use widely convenient and practical. While success in accelerating EV adoption to the degree intended by the proposed regulations would hinge upon several critical factors and overcoming major obstacles, there is reason to anticipate that significantly impactful rules and standards promoting ZEV use throughout the country are on the horizon. Although the final form of these potential rules is undecided, they are one of the most ambitious proposed regulatory drivers yet for ZEV adoption. Naturally, the importance and size of the EV charging industry is likely to correlate with demand for these vehicles.

2.2. EV Charging Infrastructure Funding and incentives

Publicly accessible charging stations have a critical role in making EV viable replacements for ICE vehicles. Reliable, secure, and geographically dispersed charging stations, particularly fast-charging stations, can help allay a major concern of would-be BEV adopters: uncertainty in the ability to maintain adequate battery charge throughout long-haul trips, sometimes causing apprehension referred to as "range anxiety." Furthermore, such networks can offer greater opportunity for BEV use by drivers that currently cannot charge a vehicle at their residence or workplace. In general, charging infrastructure along public streets, in many parking garages and lots, and at large multi-unit dwellings is presently limited. Federal and state government plans for the future of electrification hinges upon EVSE access for those that are largely restricted to parking in these settings. Public charging sites are also convenient for providing short sessions that "top off" the state of charge while a PEV is parked at destinations like shopping centers or other businesses.

Although public EVSE can deliver substantial benefits to some drivers, high up-front costs for installing electrical infrastructure and EVSE are major impediments to deploying charging stations. Since most PEV charging is currently conducted in residential settings and only a relatively small proportion of vehicles in the U.S. are PEV, the net revenue generated by commercial public stations in many locations have not attracted a large amount of private investment. In some rural areas, it has been estimated that EV charging stations will not be able yield a profit for a decade. Public and commercial investment initiatives have complementary roles in overcoming this substantial economic barrier.

Many incentives for using and deploying EV technology are available [15]. While owners of vehicles can enjoy benefits for purchasing or leasing PEV's, there are also substantial funds available to incentivize the growth of EV charging networks, especially those that are publicly accessible or open to multiple businesses. Given that access to reliable EVSE is a major concern for many current and potential PEV users, these incentives can play an important role in making EVSE more accessible and in reducing some prevalent consumer misgivings about EV adoption. A key component of this charging infrastructure is fast charging stations, which deliver electrical energy via direct current at power levels significantly greater than those offered by AC level 2 EVSE. Sometimes referred to as "DC fast charging stations (DCFC)" stations, these stations allow drivers charge their vehicle battery much more rapidly. Fueling time can obviously be a crucial factor for consumers on long trips or those without EVSE at their residence or workplace. To that end, many incentive and funding programs prioritize fast-charging stations and highway corridor charging network growth. As such, commercial DCFC stations are poised to become a more prominent element of the EV charging landscape.

2.2.1. Federal Funds

The U.S. Federal Government has recognized the need for greater investment in EV charging infrastructure. In 2021, passage of the "Infrastructure Investment and Jobs Act" established the National Electric Vehicle Infrastructure (NEVI) formula program administered by the U.S. Department of Transportation's Federal Highway Administration. This program is designed to provide funding to states for the deployment of new charging stations primarily along interstate highways. A total of five billion dollars is scheduled to be appropriated between the years 2022 and 2027 to establish a nationwide network of 500,000 charging stations along designated EV corridors [16]. In particular, the NEVI Formula program aims to deploy thousands of new DCFC units. Charging stations developed with the Formula program funds must have at least four DCFC ports, each capable of delivering at least 150 kW of power to four EVs. Chargers delivering power at this level or higher, which are sometimes referred to as "ultra-fast" chargers, have become preferred by both the DCFC industry and consumers alike [17]. These systems can typically provide up to 80 % battery charge during sessions lasting twenty minutes to an hour, although charging rates also depend on the vehicle's battery type, battery state of charge, and other charging conditions [18]. Compared to AC Level 2 EVSE, which provide for similar states of charge in approximately four to ten hours, it is apparent that "ultra-fast" stations can have a vital and increasingly important role in expanding EV adoption by improving user convenience.

Projects eligible for NEVI Formula funding shall contribute directly to the development of charging infrastructure that is open to the public or to commercial vehicle operators from more than one company. As required by the NEVI Formula program, all fifty US states, the District of Columbia, and Puerto Rico submitted EV infrastructure deployment plans to the USDOT describing how NEVI funds they might receive will be distributed [19]. In September 2022, the Biden-Harris Administration announced that all plans were approved, granting access to fiscal year 2022 and fiscal year 2023 funds. This accounts for the first $1.5 billion out of $5 billion total to be made available over a five-year period for the development of a more accessible and robust charging network across the country [20].

A rule published by the U.S. DOT FHWA, NEVI Standards and Requirements, establishes regulations for public EV charger construction projects funded under the NEVI Formula program and any federally funded EV charging infrastructure project along a roadway supported by the Federal-aid highway program [21]. This rule is intended to harmonize charging station installation and operation across the U.S. by setting standards and minimum requirements for connector types, availability, payment methods, security, and pricing information. Given the current diversity of devices and operations employed at EV charging stations, this rule was established to set some basic nation-wide standards that promote consistent user expectations and experiences at any location – much like those enjoyed by traditional motor fuel consumers. Included in this rule is a requirement that EVSE must meet a 97 % “uptime” standard, whereby the time that a station’s hardware and software are both online and available for use must be calculated. Inoperability or damaged condition of DCFC EVSE is a common convenience issue for consumers and equipment failure rates have been estimated to be approximately 20 % [22]–[25]. The NEVI requirement is aimed at ensuring charging station reliability and robust maintenance and repair operations, thus bolstering consumer confidence that EV fuel will be deliverable when demanded. Ultimately, these improvements are intended to make EV adoption a much more practical and attractive alternative to ICE vehicles.

In addition to the NEVI Formula program, there are several other sources of federal funding for developing charging infrastructure along the National Highway System [26]. These include the $2.5 billion Discretionary Grant Program for Charging and Fueling Infrastructure established through the “Infrastructure Investment and Jobs Act” and the $3 billion Neighborhood Access and Equity Grant Program established through the Inflation Reduction Act of 2022 [27]–[29]. Both grant programs align with the Administration’s EV charger deployment priorities, such as improving equity in charging access in rural, underserved, overburdened, and economically disadvantaged communities. Additional sources of support include federal government incentives and strategies to strengthen supply chains for EV component manufacturing. This includes those available through the “CHIPS Act of 2022” [30] for semiconductors and $7 billion for battery manufacturing available through the “Infrastructure Investment and Jobs Act” via the Department of Energy [27]. In short, there are billions of dollars of Federal funds dedicated to supporting electromobility, including over $10 billion for deploying charging infrastructure.

2.2.2. State Grant Programs and Incentives

Federal funds are not the only source of support for developing EV charging infrastructure. A total of more than $500 million has been invested through state infrastructure programs [31], many offering substantial incentives for deploying public charging stations. DCFC chargers are typically eligible for the largest incentives and rebates. In Colorado, up to $9,000 in costs for installing dual port Level 2 public charging stations can be recovered through the Charge Ahead Colorado program, while 100 kW or higher capacity DCFC stations can recover up to $50,000 [32]. Oklahoma and Missouri offered incentives for Level 2 stations and DCFC stations having at least 100 kW capacity of up to $240,000 and $360,000, respectively [33][34]. The Maryland Department of Environment Electric Corridors Grant Program has offered up to $150, 000 per

DCFC station deployed along FHWA-designated alternative fuel corridors, with a limit of $600,000 per applicant [35].

Other state and regional programs across the country also provide substantial support, such as the San Joaquin Valley Air Pollution District's Charge Up! Program that offers up to $6,000 for Level 2 dual port EVSE and up to $25,000 for DCFC EVSE within the California region [36]. In the urban District of Columbia, where a large proportion of the population resides in condominiums and housing co-ops, the governing council has passed laws aiming to substantially increase the number of EVSE that are publicly available (with a target of at least 7,500 stations), including requirements that they be installed in new and renovated commercial and apartment buildings [37], [38]. The District's Department of Transportation also created rules that allow EVSE charging cords to be placed across sidewalks for dwellings with only public street parking; however, such rules are not a practical or viable solution for many in large multi-unit structures without out direct access to the street. In short, a robust, fast charging network is key to widespread BEV adoption and there are many state and local level initiatives to progress charging infrastructure deployment. These examples are just a small sample of the many regional, state, and local programs throughout the country that assist EV infrastructure development. Information regarding these offerings, including available tax credits, are provided by the respective state; many are listed in [39] by the National Conference of State Legislators, and within the U.S. Department of Energy's Alternative Fuels Data Center [9].

Some of the state EV infrastructure incentives and grant programs mentioned have been funded, at least in part, through settlement of a civil enforcement case against Volkswagen AG, Audi AG, Dr. Ing. h.c. F. Porsche AG, Volkswagen Group of America, Inc., Volkswagen Group of America Chattanooga Operations, LLC, and Porsche Cars North America, Inc. ("Volkswagen") for alleged violations of the Clean Air Act [40]–[42]. Partial settlements of the case involving these allegations (for 2.0 liter and 3.0liter engines, May 2017) required the company to provide nearly $3 billion for establishment of the Volkswagen Environmental Mitigation Trusts, which are administered by an independent trustee. Under one agreement, a "State Mitigation Trust" has been established, of which all fifty (50) U.S. states, the District of Columbia, and Puerto Rico are beneficiaries. Another agreement established a separate trust for Federally Recognized Tribes. These mitigation funds are available for eligible actions that replace diesel emission sources with cleaner technologies, helping to offset emission of nitrogen oxides (NOx). Trust fund allocation to the beneficiaries for Eligible Mitigation Actions is based on the number of registered affected Volkswagen vehicles and on consideration of plans submitted by states for zero emission investments within their boundaries. The beneficiaries may use up to 15 % of their allocated funds for installing light duty vehicle EVSE.

2.2.3. Commercial Investments

Several companies have made substantial commercial investments that contribute to the development of expansive multi-state charging station networks across the U.S., especially those with DCFC capacity. These investments are key factors in the development of EV infrastructure that can support ambitious goals for increased electromobility.

Chargepoint is the largest overall charging network in the U.S., providing access primarily to AC Level 2 and some DCFC stations. The Tesla Supercharger network is currently the largest DCFC charging network in the U.S., primarily serving Tesla EV models. However, this network will be opening to many non-Tesla EV models in 2024, including several produced by U.S. auto manufacturers Ford, General Motors, and Rivian [43]–[45]. In turn, each of these manufacturers announced that they will switch to producing vehicles that use Tesla's North American Charging Standard (NACS) connector in 2025 [44], [46]. The decisions are intended to provide Ford, General Motors, and Rivian EV drivers access to Tesla's charging network. Given the large EV market shares of these four manufacturers, the switches to Tesla's NACS are notable developments that might contribute to the advancement of the NACS as a de facto charging connector standard in the U.S. Although the NACS is already the most common standard in the U.S., widespread use by other large EV manufacturers could clearly have significant implications for the deployment of charging infrastructure in the future. Many DCFC stations owned by other companies are already equipped with both Tesla and Combined Charging System (CCS) standard plugs and adapters can be used to couple some equipment that have been designed for different connector standards.

In July 2023, seven major global automakers, including BMW Group, General Motors, Honda, Hyundai, Kia, Mercendes-Benz Group, and Stellantis NV, announced creation of a joint venture to develop a charging network comprising at least 30,000 DCFC points in North America [47]. Such a network would be larger than any currently existing network in North America and would nearly double the number of DCFC stations presently available in the U.S. The network, aimed at facilitating increased EV sales, is also intended to be powered entirely by renewable energy. Other companies, including Volta and Blink Charging, also have many EV charging stations located throughout the country and have invested hundreds of millions of dollars, in total, in public charging infrastructure.

In addition to funding the Environmental Mitigations Trusts as part of the Clean Air Act Civil Settlement, Volkswagen is also required to invest an additional $2 billion over a period of ten years for construction of ZEV charging infrastructure, ZEV access, and promotional campaigns that raise public awareness of ZEV technology. To implement this requirement, Electrify America, LLC was created by its parent company, Volkswagen Group of America, Inc. As of 2020, investment by this charging service provider in support of the settlement constituted nearly three quarters of the total private investment in U.S. charging infrastructure [31]. Of the $2 billion for ZEV, Electrify America will spend $800 million within California and the remaining $1.2 billion throughout the rest of the country. Much of this pays for rapid expansion of a large network of commercial charging stations, especially ultra-fast DCFC (up to 250 kW) stations [48], [49]. EVGo, Inc., owner of another large EV charging network in the U.S., was established as a subsidiary of NRG Energy, an American company involved in electricity generation and retail. To fulfill terms of a legal settlement between the California Public Utilities Commission and the California Natural Resources Group, EVGo Inc. was created to invest over $100 million in charging infrastructure in the state.

Aside from automakers and companies established principally as EV charging networks, other large retailers are striving to become major players in the market. In April 2023, Walmart announced that it will build, own, and operate its own EV fast-charging network, deploying stations at thousands of its Walmart and Sam's Club locations across the U.S. by 2030 [50]. The company already currently operates nearly 1300 fast charging stations. Plans to develop a DC charging network have also been announced by 7-Eleven, which currently has stations in four states [51]

Each of these business enterprises, regardless of the drivers for investment, represent an important element for improving domestic EVSE access, be it rural, suburban or urban, and it is hoped these investments will collectively help overcome a primary source of hesitancy for EV adoption.

2.2.4. Utility investment and charging station ownership models

Other key players expanding EV charging infrastructure are electric utilities who have invested billions of dollars in its development. The National Electric Highway Coalition was founded as a collaboration of U.S. investor-owned and municipal electric utility companies with the goal of establishing a network of DCFC stations along travel corridors across the U.S. Members of the Edison Electric Institute, an association representing all U.S. investor-owned utilities, have invested more than $4 billion in projects and programs to deploy charging [52]. Many utilities offer substantial incentives for EVSE deployment, including for both residential and non-residential sites. Like state grant programs, these incentives are available in utility service areas across the U.S. and provide the largest sums of money for eligible DCFC infrastructure. For example, Ameren Missouri, one of many energy providers incentivizing charging infrastructure, offers up to $5,000 for installing level 2 stations and up to $20,000 for installing DCFC stations at workplaces, multi-family buildings or publicly accessible locations [53].

In addition to providing monetary incentives for EVSE deployment, utilities have engaged directly in the charging market. Under a "traditional" model for distributing electrical power service, a utility customer owns all components of infrastructure "behind" the primary utility meter. For charging station owners that are not utility companies, this means that they must cover the up-front costs for installation of electrical panels, conduit, and the EVSE on the customer-side of the primary meter. Compared to other types of motor fuel stations, the EV charging industry currently has a smaller customer base and recovering all these fixed costs could require a charging site to operate at a net loss for several years. In some locations, this can significantly hinder charging infrastructure deployment by commercial retailers and limit the viability of broad EV adoption. Considering this, authorities in several states, including some with goals that all new cars and light-duty trucks sold by 2035 are ZEV, have permitted utilities to invest in charging station infrastructure [54].

Mixed models of ownership for public charging station infrastructure are found in various forms throughout the U.S. and typically involve some combination of utility companies, charging station site owners, or third parties that install, operate, and maintain the equipment, but which do not own the site.

A few models of charging station ownership currently approved by various states around the country are shown in Figure 2.

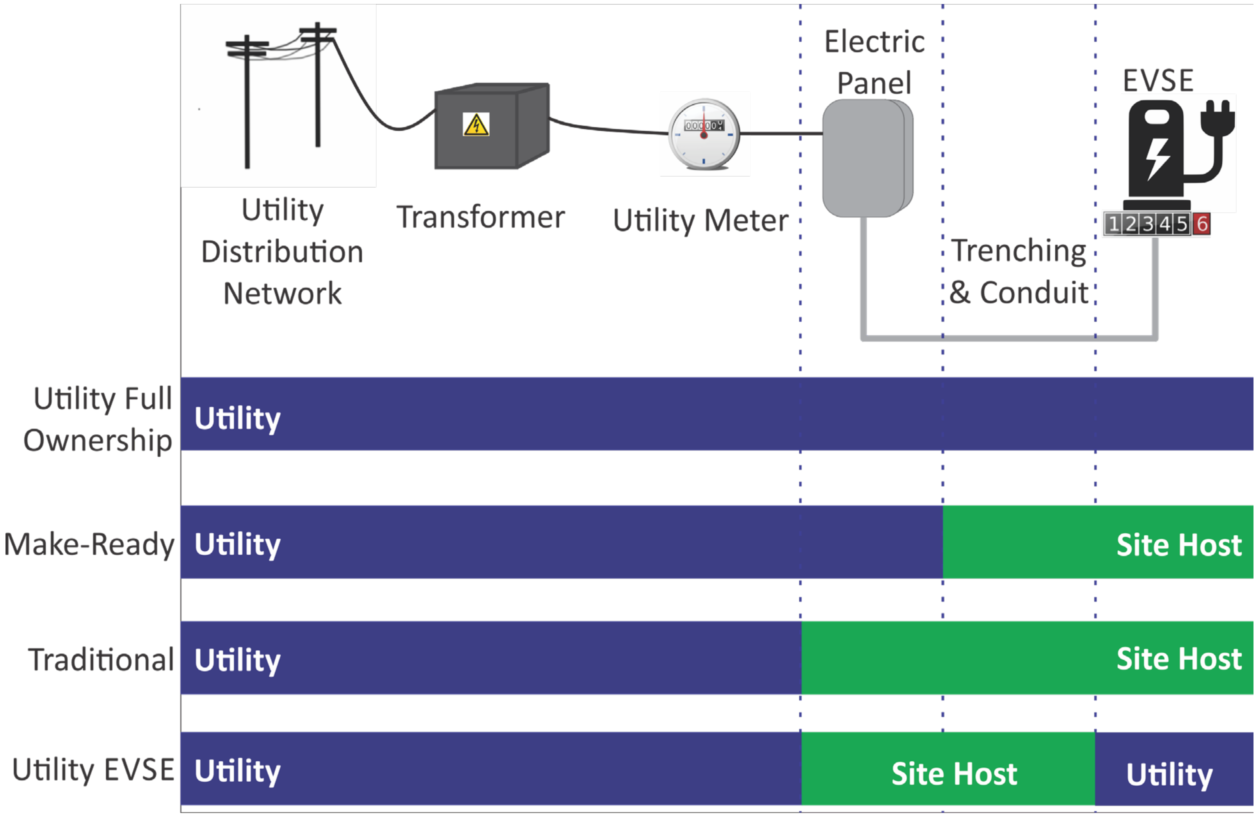

Fig. 2. EV charging station site infrastructure ownership models. Adapted from U.S. DOT [55]

Typically, the EVSE installed at public stations are owned either by the owners of the charging station site or by separate third parties that are only responsible for the operation of the EVSE [36]. Where permitted, utility companies can own various components of a charging station as well. In several states, utilities can own all aspects of public charging stations and sell EV fuel directly to customers, while in several others they cannot. Such restrictions on utility involvement in charging station deployment, where they exist, are typically imposed through rulings by the state's public utility commission (PUC).

The matter of public EVSE ownership models and their impacts on the U.S. charging market has been debated [31][56]–[61]. A major justification provided for restricting utility ownership of EVSE sites is concern that it could reduce competition in the commercial charging market. Proponents of this position claim that utilities, including monopolies, have a competitive edge and can offer profit-yielding prices for EV fuel that are much lower than those feasible for other commercial station owners. The primary reason for this, it is argued, is that utilities can more easily absorb up-front infrastructure costs through recovery from a broad general customer base, including non-users of the EVSE. This ability to sustain smaller operational profit margins might allow utilities to undercut rates offered by private site owners, thus disincentivizing much-needed charging network growth. Additionally, charging sessions require power surges, which in public stations are often during times of high electricity consumption. Non-utility station owners and their customers can be subject to additional demand charges for energy consumption during these periods, further hindering profitability.

Despite the potential for stifled competition, utility companies are often recognized as having an important role in the build-out of charging station networks. Few entities are better equipped with resources and experience for building EV charging infrastructure than utilities, which might be better positioned to shoulder fixed costs and deploy charging networks on a scale that many would-be private EVSE site hosts cannot. Proponents of utility ownership of EVSE infrastructure therefore argue that these companies can expand charging infrastructure to regions where its development is lagging, especially areas where the number of public stations and interest from other owners is insufficient to meet potential demand, e.g., in remote rural areas. Nascent markets and those where profitability of private charging stations is not expected to be realized for decades could be served many years earlier than they otherwise would be, promoting more rapid and uniform opportunity for EV adoption in the U.S. Infrastructure for high-power DCFC stations has the highest up-front cost and overhead, and therefore it is argued that utilities can play an especially large role in much-needed DCFC market penetration and extending fast charging services to remote and underserved areas.

In California, where approximately half of all PEVs in the U.S. are registered, utilities are permitted to own and operate charging stations on a case-by-case basis, setting a precedent followed by many other states in recent years. The CPUC initially prohibited (2011) utility investment in EVSE in order to protect charging market competition, however this decision was overturned (2014) in order to accelerate charging station deployment. Proposals by utility companies for EVSE investment have been met with concern or been withdrawn in states such as Kentucky, Michigan, Missouri and Kansas [61]. This has largely been the result of views that transportation electrification costs should not be shared by all utility customers, the majority of which do not presently drive PEV, and that competitive market forces should drive charging infrastructure expansion.

Given the outspoken arguments for either side of the utility EVSE ownership issue, it is unsurprising that a solution to this issue favored by many states is to allow for a mixed approach, i.e., 'make-ready' installations, as depicted in Figure 2. For these mixed-ownership models, utilities provide all electrical infrastructure up to the EVSE, including panels and all conduit and conductors needed to connect and service the EVSE. This approach is expected to facilitate EVSE deployment by reducing the burden of up-front cost to site owners, while at the same time fostering an equitable charging market - at least until such a time that economies of scale can improve profitability of charging stations for other commercial enterprises [60].

3. Trends in Commercial EV Fueling Regulations

While the imminent need for more charging infrastructure is appreciated, so too is the importance of paving way for network expansion strategies that buttress consumer protections and promote equity in the charging market. Rules and controls for dispensing conventional motor fuels are long-established and uncomplicated by a history of regulation as essential public services. EVs, on the other hand, are propelled by a type of energy that traditionally has been supplied by utility companies subject to regulation by the relevant authorities. Considering the ambiguities and regulatory gaps that ensued as commercial EV charging became more prevalent, several states and some policy advisors [62] suggested that clarification of the following two issues, especially in a uniform manner across the country, is critical to fostering EV charging infrastructure expansion: 1) whether commercial charging stations are exempt from the definition of “public utility” and regulation as such by a public utility commission (PUC) or similar governing body, and 2) whether EV fuel dispensed by non-utility commercial charging stations can be sold on the basis of measurement units for electrical energy, i.e., prices in $/kilowatt hour ($/kWh). Positions on these matters have significant impact on the growth of public charging networks, uniformity and transparency in EV fuel sales, and consumer experiences. Furthermore, accuracy in electricity metering, historically within the remit of PUCs, is valuable for promoting consumer confidence in commercial charging. As such, technical standards establishing metrological requirements for measuring devices used with EVSE are becoming increasingly relevant.

3.1. Electricity retail regulation

3.1.1. U.S. Historical Context

In the U.S., generation, transmission, distribution, and sale of electricity to customers are roles generally performed electric utility companies. Interstate transmission and wholesale of electricity is regulated at the federal level by the Federal Energy Regulatory Commission (FERC), while individual states and their PUC have jurisdiction over low-voltage distribution networks and retail sale to individual customers [50]. A majority (>70 %) of electricity provided is sold by private investor-owned utilities (IOU), which are PUC-regulated monopolies, and by power marketers that engage in interstate electricity wholesale markets [48]. Today, depending on laws of the territories that they serve, utilities can be publicly owned, IOU, federal power agencies, cooperatives, or power marketers.

Construction of infrastructure that serves a reliable electrical grid is expensive. Naturally, duplication of this infrastructure within a given market could lead to unnecessarily high energy prices. To avoid this overinvestment, utility companies were established across the U.S. as vertically integrated natural monopolies that provide and control all aspects of their energy supply, with exclusive rights and obligations to serve a specified geographic territory. In the absence of competitive market interactions within these exclusive service areas, state laws and regulatory authorities were established to control reasonable price setting, infrastructure investment, and terms of service to customers. Such monopolistic markets have existed across the country since the early 1900s. In the latter half of the 20th century, competition was introduced to U.S. power markets. An oil embargo in the 1970s led to volatility in oil and natural gas prices and the Federal government aimed to diversify fuel sources for power generation. To that effect, the Public Utility Regulatory Policies Act (PURPA) was passed in 1978 to improve efficiency and reliability of electricity services and ensure that enough electricity could be produced at relatively low cost. The law required utilities to purchase energy from small power generators and pried an opening in the monopolistic structure of the U.S. electricity market.

Prior to the 1990’s, electricity price regulation was largely cost-based rather than market-based, meaning prices should be based on how much it costs to generate and distribute electricity. By the 1990’s, it was clear that this regulatory approach was ineffective in keeping costs low and relatively uniform among neighboring utilities. Inspired by declines in natural gas prices achieved through price deregulation of that market, a small number of states in the 1990s began to restructure electricity retail markets to promote competition. These efforts intended to disincentivize overinvestment in power generation and infrastructure and reduce rates paid by consumers. Utilities were required to sell their generating assets to independent energy suppliers while retaining their regulated transmission and distribution infrastructure. Retail prices in these areas are set by the competitive market but electricity is still distributed by utilities and subject to regulatory oversight at the state or local level. Although market deregulation trends have slowed in recent years, several states have been restructured to allow consumers to select electricity retail service providers and very few completely vertically integrated utilities remain in the U.S. [63] Precedent for competition, retail sale of electricity directly to consumers, and dispensations from price control has been widely established.

3.1.2. EVSE Utility Definition Exemption

Commercial charging sessions have given rise to some ambiguities and constraints that are not relevant to other types of fuel sales. Simply put, charging stations exist primarily for the purpose of dispensing electricity directly to consumers – an activity historically reserved for utilities. Though the electricity is usually delivered to an EVSE site, at least in large part, by a utility through regulated distribution networks, these companies are not necessarily party to the transaction involving the EV customer. For these reasons, it was not always abundantly clear whether each charging station owner or host shall be considered a utility and subject to the relevant regulatory regimes. New times, technologies and public sentiment guided government officials in most states take decisions on this issue. Increasing prevalence of public charging stations and demand for greater flexibility in the way these sites can operate urged many states to clarify that public charging sites are not utilities. Whereas utilities provide essential service to the public, mainly for customers at fixed locations such as a homes or business, EV charging stations, it is argued, do not. According to this view, it ought to be permissible to sell electricity for the purpose of vehicle fueling as a tradeable commodity by commercial businesses that are not utility companies.

Regulation of utilities is generally economic in nature and aims to ensure delivery of adequate services at reasonable costs. State PUC have a range of responsibilities in this regard, including the setting of prices in regulated retail markets. However, unlike utility companies, EV charging stations can only recover costs from discrete transactions for individual charging sessions. With price caps congruous to those applied to utilities, third party-owned stations subject to these controls have not been expected to yield sufficient, if any, profit margins large enough to incentivize a large number of private stations. If a state does not clearly address whether public charging site owners or hosts are utilities, by default, they could be identified as such. It is also generally recognized that obtaining approval and meeting PUC-imposed requirements for each public EVSE site would be prohibitively cumbersome. It is hypothesized that each of these restrictions could significantly hamper EV infrastructure deployment.

State have taken varied and mixed approaches to addressing this issue. The most common approach taken has been to exclude public charging stations from the regulative authority of PUC by expressly excepting public EVSE site owners and hosts from the definition of “public utility” within the relevant governing codes. To date, forty-five (45) states have affirmatively made these exceptions. Comments collected from government authorities and stakeholders during rulemaking procedures have overwhelmingly supported these decisions. Most exceptions took effect within the past decade, a large proportion of which were enacted over the past five years. Legislation to address this issue is under consideration in some of the other states, including Louisiana and Michigan, though it has not been signed into law. Though less common, some states have refrained from establishing any specific regulatory policy whatsoever. Although no known cases have been brought against public charging site owners for failing to operate with a public utility status, the justification for such a case could exist in these states.

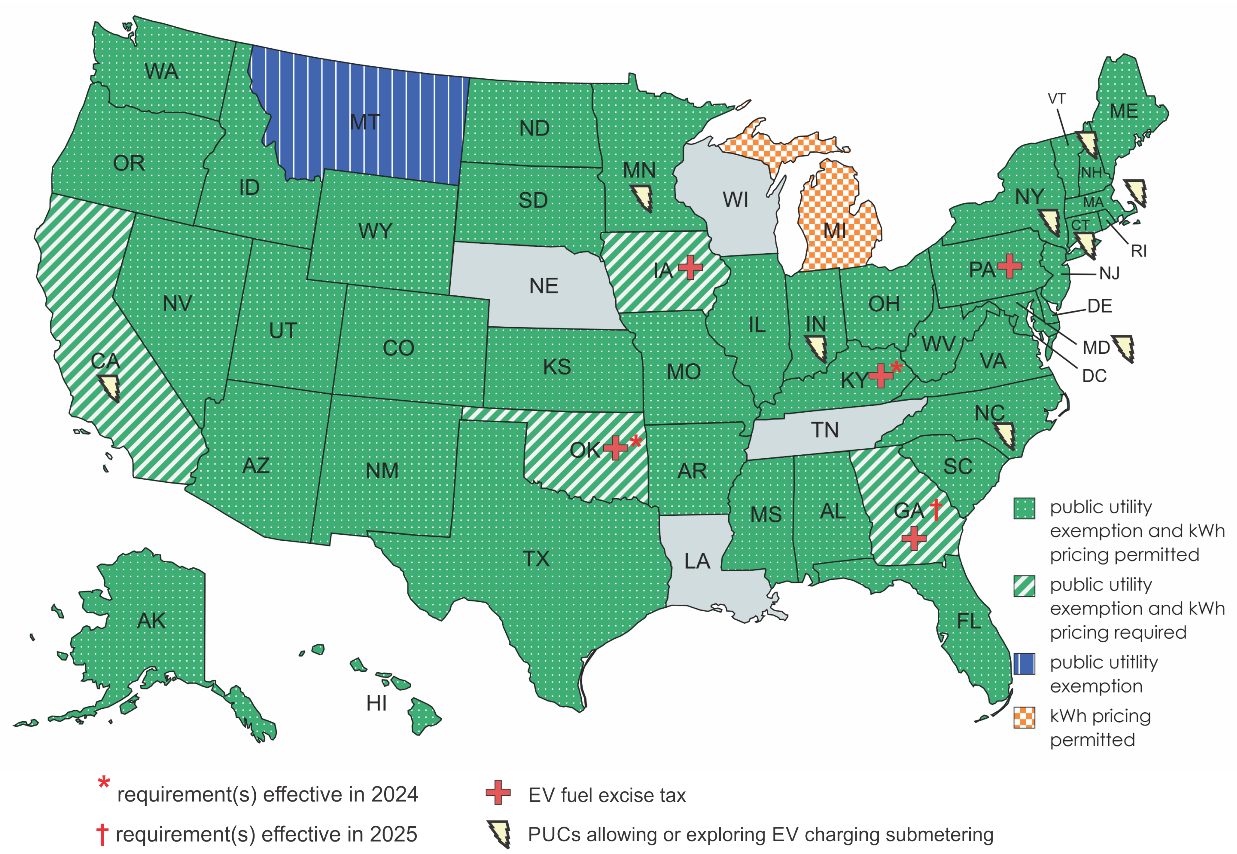

Fig. 3. U.S. map indicating adoption of state policies regarding the sale of electric vehicle fuel (created in part via MapChart, www.mapchart.net).

Affirmation of the non-utility status of public EV charging stations in many states is intertwined with a second matter: are commercial public charging sites not operating as utilities permitted to sell electricity itself as a fuel? In other words, can charging session costs be based on the measured amounts of electrical energy delivered to a vehicle, such as $/kWh? Yet another matter arising from the exception of EV charging stations from the regulative authority of PUC is how these fuel providers can compete fairly with one another and with those dispensing other types of motor fuels. How are consumers to be assured of clear, transparent and accurate measurement in transactions? Although regulation of EV charging is not under the jurisdiction of PUC in most states, all trade activities in any type of market are typically subject to some general requirements for fair competition and rules that prohibit anti-competitive acts. If charging stations are not subject to authority of PUC, that does not mean that, by default, there are no governing laws that aim to ensure fair commerce.

Although language of laws establishing that EV charging stations are not public utilities vary from state to state, two results have effectively been achieved in most states: 1) EVSE owners/operators are not subject to the regulative authority of PUCs and 2) non-utility entities can sell electricity on a per kilowatt hour basis ($/kWh). Legislation to this effect has been proposed and failed in some other states for a variety of reasons, including in Wisconsin, which conditioned the exception on prohibiting the use of on-site renewable energy generation (e.g., solar). However, the Wisconsin PUC aims to address permitting the sale of electricity via EVSE in order to comply with the relevant requirements for receiving NEVI funds. A U.S. map depicting whether states have proactively addressed issues concerning PUC regulative authority over public charging stations and $/kWh pricing is provided in Figure 3. Exceptions are being considered in some states, such as Louisiana and Michigan, however the pending status of these proposals are not indicated in Figure 3. In the state of Montana, entities operating electric vehicle charging stations are not considered public utilities, however, unlike in most other states that have excluded charging stations from PUC authority, charges pertaining to fueling electric vehicles in Montana may not be based on the cost of electricity. [47] This figure also addresses additional EVSE applications described in Section 4.

3.2. Uniformity in method of sale

Use of consistent methods for selling products and services or "methods of sale" help ensure that accurate and adequate information is provided about the commodities so that purchasers can make price and value comparisons. Basing transactions on consistent units of measure facilitates trade by allowing the terms of a transaction to be clearly understood by all parties involved and helps to ensure fair competition among businesses. Namely, standard units of measure enable meaningful comparison of prices offered by different market providers or at different times. This capability is critical for sound decision making by both consumers and sellers alike. For these reasons, laws and regulations imposing uniform methods of sale, i.e., pricing based on standard units, are vital to fair and robust markets.

Pricing in the present U.S. commercial EV charging landscape

Deployment of commercial charging sites across the U.S. has occurred in a market environment in which heterogenous forms of pricing are being used. A variety of pricing methods can be found within every state. Furthermore, some prices are based on measurement units for fundamentally different kinds of quantities (e.g., the quantity of electrical energy delivered vs. the time an EV is connected to an EVSE). If visiting several charging stations across the country, one is likely to observe multiple incomparable rates offered and a variety of fees charged for ancillary services or network subscriptions. Details of pricing structures observed for a small sample of stations scattered across the U.S. are shown in Table 1, which demonstrates the complexity in pricing across the commercial EV charging landscape and difficulties in making accurate price comparisons. The survey was conducted in part through

Table 1. Results of a small survey of cost and fee structures for public EVSE charging in the U.S.

Station Location	Charger Level	Power (kW)	Energy Pricing	Membership Discount	Other fees
Arizona	DCFC	62	$0.08/kWh		
Arkansas	DCFC	50	$13.80/hour		
California	AC L2	6.5	$2/hour for 4 hours, $4.00/hour after 4 hours		
California	DCFC	50	$0.43/kWh, 12 am - 8 am $0.51/kWh, 8 am - 4 pm, 9 pm - 12 am $0.59/kWh 4 pm - 9pm	lower rates for members	$3 for reservations; or $6.99-$12.99/month membership;$1.00 session fee w/o membership (≥$0.99/month level)
Colorado	AC L2	6.5	$0/kWh		parking: $1.00/hr for first 135 min, $2.50/hr after 135 min ($1.00 min fee; $50/day max fee)
Colorado	DCFC	62	$0.45/kWh		parking: $0.25/min after first 30 min
Connecticut	DCFC	50	$0.35/min	$0.04 - $0.07/min; $4.99 prepaid charging credit	$3 for reservations; or $6.99-$12.99/month membership; $1.00 session fee w/o membership
Florida	AC L2	6.5	$0.35/kWh		idle parking fee: $3/hr after 30 min
Florida	AC L2	6.5	$0.36/kWh		idle parking fee: $2.40/hour after first 30 min
Georgia	AC L2	6.5	$1.00/hour		parking: $0/hour for first four hrs, $20.00/hour after first 4 hrs ($24 max fee)
Indiana	DCFC	90	$0.16/min	$0.04/min discount	$4.00/month membership
Indiana	DCFC	350	$0.32/min	$0.06/min discount	$4.00/month membership
Iowa	DCFC	50	$30/hour		parking: $30/hour while not charging after first 20 min
Maryland	AC L2	7.2	$0, parking basis		$0 - 5.00/hour, 15 min accrual intervals
Maryland	AC L2	7.2	$0 - $0.05/kWh		parking: $0 - $0.50/hr, 15 min accrual intervals
Minnesota	AC L2	6.5	$0.14/kWh		$1.00 flat fee; parking: $0 for first six hrs, $1.00/hr after first 6 hrs ($1000.00 max fee)
Mississippi	DCFC	62	$0.30/kWh		idle parking fee: $18.00/hour after first 10 min
Missouri	DCFC	50	$0.30/min	$0.03 - $0.06/minute; $4.99 prepaid charging credit	$3 for reservations; or $6.99-$12.99/month membership; $1.00 session fee w/o membership (≥$0.99/month level)
New Mexico	AC L2	7.2	$0.12/kWh		
New York	AC L2	10.4	$0.59/kWh		
North Carolina	AC L2	6.5	$0, parking basis		parking: $2.12/hour for first 3 hrs; $6.00/hour after first 3 hrs
Ohio	AC L2	7.4	$2.50/session (flat fee)		
Oklahoma	DCFC	62	$0.29/kWh, 12 am - 7:15 am $0.43/kWh, 7:15 am - 9:15 am $0.38/kWh, 9:15 am - 11:45 am $0.43/kWh, 11:45 am - 1:30 pm $0.38/kWh, 1:30 pm - 4:45 pm $0.43/min 4:45 pm - 6:15 pm $0.35/min 6:15 pm - 11:59 pm		idle parking fee: $0.27/min after 5 min minutes ($40 max)
Pennsylvania	AC L2	6.5	$0.12/kWh		parking: $0 for first 4 hrs, $5.00/hour after first 4 hrs
Pennsylvania	DCFC	50	$2.20/kWh		
South Dakota	DCFC	120	$0.29/kWh		$5.00 flat fee; idle parking fee: $20.00
Texas	AC L2	6.5	$3.00/hour		parking : $5.00/hr while not charging after 30 min grace period
Texas	DCFC	50	$0.17/kWh		
Virginia	DCFC	150	$0.43/kWh	$0.12/min discount	$4.00/month membership
Washington	DCFC	50	$21.00/hour + tax		

Survey performed in part through ChargeHub [64]

As suggested in Table 1, the most common methods of pricing for EV charging are $/kWh and $ per unit of time that an EV is connected to the charging port. Since the general physical quantities and units that these rates are based upon are not directly comparable, a market area in which both types of rates are offered challenges consumers and charging station owners in making sound decisions; consumers lack adequate knowledge in selecting a station more advantageous to their needs while station owners might struggle to set transparent rates that are both competitive and reasonably profitable. For these reasons, many stakeholders of the EV charging industry claim to prefer the transparency of energy-based pricing [66]–[68]

The technical merit of this method of sale was emphasized by the NIST U.S. National Working Group (USNWG) on Electric Vehicle Fueling and Submetering (a group comprised of regulators, EV manufacturers and users, and other technical experts) in 2012 when it recommended this method of sale to the National Conference on Weights and Measures (NCWM). The method of sale was adopted by voting members (weights and measures regulators) of the NCWM in 2013 and added to the NIST Handbook 130 Uniform Regulation for the Method of Sale of Commodities which is described in the next section. However, as discussed earlier, jurisdiction over EV charging systems remains inconsistent and unclear in many states, adding to the proliferation of practices and methods of sale that fail to provide adequate information and transparency to consumers and sellers about the EV transaction.

Similar to paying for gallons of a traditional motor vehicle fuel at a dispenser, $/kWh pricing allows customers to pay for the amount of fuel delivered to their EV within a required limit of accuracy. Customers have recognized that this simplified method of sale instills a sense of fairness to the transaction and readily allows price comparison. In response, charging stations offering commercial transactions on this basis have become more prevalent in recent years, where permitted.

Conversely, the amount of energy delivered during a given period of time by the EVSE can vary greatly; the rate at which EVs charge is conditioned by a number of factors, including battery temperature, EV voltage and current limits, battery condition, EVSE voltage and current limits, and power quality. A savvy customer could potentially have the means to estimate how much energy has been delivered to an EV during a session of known length, however, such determinations remain estimates rather than verified quantities and it is not generally considered a reasonable expectation that an average consumer should make such determinations themselves for the sake of price comparison. To analogize, envision a hypothetical situation in which gasoline is priced according to the measured time that fuel is being dispensed from a pump (e.g., $/min, $/s). Considering that different pumps could operate at substantially different non-standard flow rates, like how different EVSE can and do deliver electrical energy to EV at different and varying magnitudes of power, there would not be a reasonable expectation for fair transaction values across different stations. In short, battery charging rates are highly variable and the measured time an EV is connected to the charging port is a highly inconsistent indication of the quantity of energy that a consumer receives. Some stations, as can be seen in Table 1, offer charging sessions for a flat fee; no matter how much energy the customer consumes, the price remains the same. This is a highly irregular billing method for commodities such as vehicle fuel, yet such prices are offered at some commercial EV charging sites in the U.S.

Under the standard method of sale for EV fuels, it is notable that fees can be assessed for ancillary services associated with EV charging. Common fees of this type are time-based parking costs that discourage idle vehicles with charged batteries from blocking access to the charging station by other customers. NIST Handbook 130 provides that "*In addition to the fee assessed for the quantity of electrical energy sold, fees may be assessed for other services; such fees may be based on time of measurement and/or a fixed fee.*" However, such fees must be separate from those assessed for the cost of electrical energy.

Standardization of method of sale of EV fuel

Presently, only a handful of states have made efforts to enforce standardize methods of sale for EV fueling. Although the legality of selling electricity by non-utilities has had significant impact on the uniformity in pricing methods for EV charging, most states have now addressed this matter. Since such sales are now widely permitted, a new opportunity is rising to harmonize the way that EV fuel is sold, namely on the basis of $/kWh prices that are preferred by many consumers.

The NIST Handbook 130 Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality is a national standard comprising model laws and regulations that are adopted annually by the National Conference on Weights and Measures. The purpose of this standard is to "*achieve, to the maximum extent possible, uniformity in weights and measures laws and regulations among the various states and local jurisdictions in order to facilitate trade between states, permit fair competition among businesses, and provide uniform and sufficient protection to all consumers in commercial weights and measures practices*." Within NIST Handbook 130 is Section IV. Uniform Regulation for the Method of Sale of Commodities. In this regulation, clause 2.34 Retail Sales of Electricity Sold as a Vehicle Fuel specifies that "All electrical energy kept, offered, or exposed for sale and sold at retail as a vehicle fuel shall be in units in terms of the kilowatt-hour (kWh)." In other words, in jurisdictions that adopt this regulation, prices for commercial electric vehicle fueling are required to be in $/kWh. Section II of NIST Handbook 130 contains a table of adoption statuses for each state.

A review of requirements implemented in various states over the past few years revealed the following:

- **California:** In 2020, California approved amendments to the Electric Vehicle Fueling Systems Specifications in the California Code of Regulations Title 4, affirming that EV charging shall only be priced in $/kWh (rather than based on charging session duration) and was the first state to actively enforce such a requirement. These requirements were effective for new AC L2 EVSE installed after January 1, 2021 and new DC EVSE installed after January 1, 2023. Effective dates for AC and DC equipment installed prior to those dates are January 1, 2031 and January 1, 2033, respectively.
- **Iowa:** Legislation enacting a new excise tax on EV fuel is expected to take effect in Iowa in July 2023 [65]. In remitting the tax ($0.026/kWh), licensed public charging station owners will be responsible for measuring and reporting to the Iowa Department of Revenue each unit of electrical energy (in kWh) dispensed for EV charging.

- **Oklahoma:** In October 2022, the Oklahoma Corporation Commission (OCC), Oklahoma's regulatory authority for utilities, oil and gas production, intrastate transportation, and petroleum fuel storage, adopted new rules for electric vehicle charging stations [66], under which "*all public charging stations are required to follow the Uniform Regulation for the Method of Sale of Commodities, as it pertains to retail sales of electricity sold as vehicle fuel in NIST Handbook 130, and its future amendments…*" Enforcement dates for this rule are as follow: January 31, 2024 for all new stations beginning operations on or after this date; beginning in November 2041 for stations in operation prior to November 1, 2021; beginning January 31, 2028 for all stations beginning operation between November 1, 2021 and January 31, 2024.
- **Georgia:** Beginning in 2025, prices for EV charging sessions in Georgia must be in terms of $/kWh, also aligned with a new excise tax on electricity sold at public EV charging stations that will take effect that year.

Other States have adopted varying approaches, if any, to this matter. In contrast to states like California and Oklahoma, Washington exempts the method of sale requirements for EV fuel specified in NIST Handbook 130 Section 2.34. Some states adopt the current NIST Handbook 130, yet the requirements in Section 2.34 might not be uniformly or widely enforced.

While adoption and enforcement of NIST Handbook 130 laws and regulations is addressed individually by the states, initiative to harmonize pricing methods at public charging stations has been taken at the Federal level. Regulations in the National Electric Vehicle Infrastructure Standards and Requirements [21] stipulate that for stations developed through the NEVI Formula program or Federal-Aid highway project funds, "The price for charging must be displayed prior to initiating a charging transaction and be based on the price for electricity to charge in $/kWh." These requirements directly contribute to standardization of commercial EV fueling and aim to mitigate the burdens of pricing heterogeneity in the public charging market. Notably, some state laws currently prohibit this method of sale of electricity by non-utilities, including in states that have applied to receive NEVI funds. However, the FHWA has made allowances for funds to be disbursed to these states on the condition that the laws are modified to permit $/kWh pricing by February 28, 2024. Given the scale of the NEVI Formula Program and its huge initiative in expanding nation-wide infrastructure, compliance with this requirement could help drive standardization of pricing across the country.

Aside from the huge assortment of price and fee structures that customers can find at charging stations, many locations offer service subscriptions or require use of a dedicated mobile electronic device application (i.e., mobile app) to view transaction details, such as prices and the quantity of energy consumed, and to provide payment. While a convenient means to conduct transactions for many consumers, such restrictive payment methods are not solely implemented in other vehicle fuel markets. These matters could have implications concerning the equitability, transparency, and complexity of EV charging transactions, especially for consumers that use a particular network intermittently or only once on a non-routine trip. To ease constraints that these limited payment methods can place on accessibility, the NEVI Standards and Requirements stipulate that stations deployed through NEVI and Federal-Aid highway funds must also provide a contactless payment method that accepts credit and debit cards, as well as payment through an automated toll-free phone number or short message system. Additionally, use of these NEVI- and Federal-Aid funded stations shall not require a membership.

With standardization of prices in terms of $/kWh, it follows that devices used to measure electricity delivered for each sale can play a significant role in commercial EV charging. Demonstrating the accuracy and reliability of these measuring systems is important for fostering confidence in the transparency and fairness of EV charging transactions.

3.3. Weights and Measures Standards and State Regulatory Programs

Electrical utility regulators are tasked with establishing allowable electricity prices and adopting a variety of standards for quality assurance in electricity distribution. Such standards typically include specifications for voltage, metering, and other technical requirements in electric service. These requirements are applied primarily to ensure that equipment performs properly and that customers fairly pay for precisely the amount of electricity that they consume. Given that most states of the U.S. have now exempted EV charging stations from utility regulations, steps have been taken to consider how market equity and consumer protections for commercial charging transactions can be ensured. With the current rate of EV adoption and other new potential drivers for electromobility taking shape, the importance of these stakeholder protections is obvious.

In areas where the public utility authorities have indicated they will not regulate EVSE at public commercial charging stations, it falls to other regulatory agencies (unless otherwise specified by the state's legislature or a court decision) to verify that such devices accurately measure quantities of electricity sold to a customer. State and local weights and measures programs across the U.S. regulate commercial weighing and measuring equipment such as grocery store scales and gasoline dispensers to ensure their accuracy, suitability, and proper operation, helping ensure that consumers get what they pay for and that businesses receive fair payment for the goods and services they sell. This regulation also ensures a level playing field for market competition. Weights and measures regulators are tasked with ensuring transparency and protecting consumers in the sale of a wide variety of commodities and goods; most businesses are, to some degree, impacted by weights and measures laws. These laws are intended to uniformly apply standards to commercial activities in which the value of a sale is based on the quantity of product delivered to the customer. Note that even in the absence of laws and regulations from entities such as the PUC or state weights and measures agencies, there are other types of laws and regulations in place in most states to ensure consumer and business protections and prevent fraud and unfair business practices.

Weights and measures programs have long regulated commercial measuring devices, including those delivering gasoline, diesel, liquefied petroleum gas, compressed natural gas, and other motor fuels. They are well positioned to help instill public confidence in EV charging transactions. Much of the public immediately recognizes or searches for weights and measures seals placed on devices like fuel dispensers, indicating that the equipment has been inspected and approved for fair use. Many weights and measures jurisdictions have authority over utility submeters (e.g., electricity, water, and gas meters) that are used in multi-unit dwellings, mobile home parks, and business complexes to submeter electricity, water, and gas. While most weights and measures jurisdictions (other than in California) do not routinely inspect and test these devices, they generally have the authority to do so should consumers or businesses question the accuracy or operation of their meters.

While each U.S. state establishes its own weights and measures laws, all 50 states have adopted requirements for commercial weighing and measuring devices in an edition of NIST Handbook 44 Specifications and Tolerances, and Other Technical Requirements for Weighing and Measuring Devices and some requirements in NIST Handbook 130 Uniform Laws and Regulations in the Areas of Legal Metrology and Fuel Quality. These standards are adopted annually by state and local weights and measures programs through the National Conference of Weights and Measures and are intended to promote uniformity in the making and enforcement of weights and measures law throughout the U.S. States can elect to adopt these standards in part or their entirety through reference in relevant statutes.

USNWG on EVF and Submetering

In 2012, the NIST USNWG on Electric Vehicle Fueling (EFV) and Submetering began developing national legal metrology standards for commercial EV charging and EVSE. This group comprises regulators, EV and EVSE equipment manufacturers and users, federal agency officials, and other electrical energy industry representatives and stakeholders. Based on the recommendations of the USNWG, new sections have been added to the NIST Handbooks regarding commercial EV fueling:

> 1) Handbook 130 Uniform Regulations Section IV Uniform Regulations B. 2.34, concerning Retails Sales of Electricity Sold as Vehicle Fuel and requirements for Method of Sale (kWh unit pricing), labeling, and signs and advertisements; and
>
> 2) Handbook 44, 3.40 Electric Vehicle Fueling Systems (EVFS), added as a "tentative code" in 2015 and adopted as a "permanent code" in the 2023 version. The NIST Handbook 44 code for Electric Vehicle Fueling Systems contains specifications for EVSE, including indicating elements, operating requirements, markings, and design of measuring elements and systems. The code also specifies accuracy and load testing tolerances, as well as repeatability requirements and requirements directed toward owners and operators of EVSE for operation and use. Separate requirements are specified for AC measuring systems and for DC measuring systems. These standards aim to ensure fueling device reliability and foster consumer confidence, but they also aim to facilitate equity and transparency in the commercial charging market.

Application of national standards for commercial EVSE

The change in status of the NIST Handbook 44 Section 3.40 EVFS code from "tentative" to "permanent" made it applicable and enforceable in states that, absent any exemptions from or additions to Section 3.40, adopt the 2023 or the latest version of the Handbook. Similarly, the several states that adopt the most current version of NIST Handbook 130 can maintain regulations establishing that EV charging transactions shall be conducted according to the standard method of sale ($/kWh pricing). The relevant regulatory bodies in these states, usually weights and measures programs, have authority to test and inspect commercial EVSE. Notably, some requirements for EVSE within the NIST Handbooks, such as the method of sale, are consistent with Federal requirements [21] for charging stations deployed using NEVI Formula Program funds. Therefore, many charging stations installed over the next several years are expected to conform to some federal requirements that are like those in the NIST Handbook codes, even if the states in which they are located do not enforce the relevant sections of the NIST Handbook. This could help stimulate increased uniformity in the requirements for commercial EV fueling within the U.S.

However, it is important to observe that some key elements of the current version of the Section 3.40 code are presently applicable only to charging equipment with AC measuring systems. These include requirements for EVSE Accuracy Testing, Load Test Tolerances, and Indication of Delivery. As the Section 3.40 code currently stands, all DC EVSE, which mainly includes fast-charging stations, are exempt from these requirements until January 2028. This decision to exempt DC measuring systems from the EVSE requirements was taken in July 2022 at the National Conference of Weights and Measures, along with the decision to change the Section 3.40 EVFS code status from “tentative” to “permanent”. While it can be argued that limiting regulations on fast-charging EVSE can foster more rapid charging infrastructure expansion, it is notable that some basic consumer and market protections established for other types of commercial vehicle fueling, as well as many other types of commodities sold on the basis of measure, will not be enforceable for several more years. The impacts that this circumstance could have on consumer confidence in commercial EV charging, as well as EV adoption more generally, are unknown. With the current drivers to accelerate EV charging infrastructure expansion in the U.S., it is reasonable to expect that many new public fast-charging stations will be installed before 2028, for which the accuracy in metering and customer billing has not been verified.

California

The state of California has been a leader and trendsetter in the U.S. for promoting ZEV technology use and in developing environmental policies over the past several decades that aim to reduce pollution. Residents of the state have the highest rate of EV adoption in the country and more EVs, by far, are registered in California than any in other state. Furthermore, California officials played a major role in the work of the USNWG on Electric Vehicle Fueling and Submetering by bringing key experts to the forum, hosting meetings, and promoting adoption of the proposed EV fueling standards across the U.S. Perhaps it is unsurprising then that California leads the U.S. in establishing regulations for commercial EV charging stations.

The California Business and Professions Code, Division 5 grants authority to the California Department of Food and Agriculture (CDFA) to supervise weights and measures laws and weighing and measuring devices sold or used in the state. The department’s Division of Measurement Standards (DMS) has responsibility for enforcing these laws and regulations and to coordinate these activities with county sealers. The California Code of Regulations (CCR) Title 4 Division 9 (4 CCR §§ 4000. – 4900.) contains requirements enforceable by the CDFA DMS. Chapter 1 of this CCR Division specifies that commercial weighing devices shall conform to the latest requirements of NIST Handbook 44, with some exceptions (4 CCR § 4001.), as well as additional requirements to be enforced throughout the state (4 CCR § 4002.). Although the NIST

Handbook 44 Section 3.40 – Tentative Code was added to the standard in 2015, until it became permanent in 2023, its tentative status rendered it unenforceable without additional actions by a state. In step with California's general advancement of EV adoption, the CDFA DMS established rules that effectively removed the tentative status of Section 3.40 EVFS code within the state several years before it became permanent within NIST Handbook 44, allowing these requirements to be enforced. A California regulation (4 CCR § 4002.11. Electric Vehicle Fueling Systems), primarily comprising NIST Handbook Section 3.40 requirements but with some modifications, was finalized in 2019 and became effective January 2020. These rules also include the requirement that electricity delivered as a motor vehicle fuel shall be measured in kWh and sold at $/kWh billing rates. California does not adopt the most current Method of Sale regulation in NIST Handbook 130 yet was the first state in the U.S. to enforce a $/kWh unit pricing requirement for commercial charging stations.

In enforcing weights and measures standards for EVSE years earlier than any other state, California is the first in the U.S. to develop and oversee a comprehensive legal metrology system for commercial EV charging. The weights and measures programs within the state have authority and infrastructure to conduct EVSE type approval and inspections of charging stations. The California Type Evaluation Program (CTEP) tests EVSE against CA CCR requirements and, in just the past couple years, has issued certificates for more than thirty measuring EVSE devices [67] that are approved for commercial use in the state. These certificates verify that devices are suitable for intended use, accurate, and have all required markings and fraud prevention protections. More information about the regulations and enforcement dates for different kinds of EVSE can be found in the CA CCR and via the DMS.

Other States

While California is the first state to begin regulating commercial EVSE, with the adoption of the NIST Handbook 44 EVSE code as "permanent", it is likely that other jurisdictions will soon begin actively regulating EVSE. Iowa is also relatively advanced in preparing to enforce metrological control of EVSE. In 2019, the Iowa legislature passed a law [65] creating a new section in the Iowa Code (§ 452A.41) for levying and collecting excise tax on EV fuel. This Act took effect July 1, 2023 and the tax is to be imposed on each unit (kWh) of EV fuel dispensed at commercial retail and fleet charging stations. As part of this directive, a bill [68] was unanimously passed by both chambers of the Iowa General Assembly in May 2023 that grants authority to the Department of Agriculture and Land Stewardship (Weights and Measures Bureau) to conduct biennial inspections of all licensed commercial charging stations. These inspections are intended to verify the accuracy of EVSE metering and correctness of billing at charging stations that collect the tax. Prices of electric vehicle fuel shall be in $/kWh and charging stations shall conform to the national standard specifications, tolerances, and other technical requirements specified in NIST Handbook 44. Under the new legislation, the effective date of inspection requirements is the same as the rest of Iowa Code § 452A.41, July 1, 2023. Both AC and DC equipment fall within the jurisdiction of the Department of Agriculture and Land Stewardship, which has authority to regulate public commercial and fleet charging stations.

More recently, the Georgia General Assembly passed a bill in May 2023 (SB 146) amending Chapter 1 of Title 10 of the Official Code of Georgia Annotated (concerning selling and other trade practices). This amendment excludes EV charging stations from regulative authority of the Georgia Public Service Commission, establishes new regulations for public EV charging stations, and grants regulative authority to the Georgia Department of Agriculture (GDA) over the sale of electricity used as EV fuel [69]. As it does for other types of motor fuel stations, the GDA shall require and conduct inspections of public EV charging stations throughout the state. Inspectors of the GDA shall test metering devices against established accuracy tolerances for the measure of electricity dispensed to consumers, as well as assess charging station compliance with other weights and measures rules and regulations provided in the amended Code. Additional rules and regulations necessary for administration and enforcement of this Article may be promulgated by the GDA, which shall also provide for consistency with EVSE standards in NIST Handbooks 130 and 44. The new code for regulation of EV charging stations will be effective January 1, 2025. Passage of the bill also establishes an excise tax on electricity sold at public stations in Georgia.

With the change of NIST Handbook 44, Section 3.40 to a permanent status in 2023, the EVSE requirements can be applied in states that adopt the current version of the standard. Many state government agencies that regulate commercial fueling will need to establish the capability, including purchasing test equipment and providing training to regulators, to begin routinely enforcing the requirements. Several state weights and measures agencies are reportedly already doing so. Some states that adopt current versions of NIST Handbook 44, such as Virginia, Nevada, and Washington, have issued temporary dispensations that delay enforcement of the requirements for EVSE [70], [71]. These periods of exemption vary in length and are intended to provide additional time for weights and measures programs to secure resources and develop capabilities to test commercial EVSE. They also allow more time for manufacturers to take steps toward complying with requirements in NIST Handbook 44, NIST Handbook 130, and other state laws and regulations. As another example of state government planning for possible future regulation of EVSE measuring systems, the Vermont Agency of Agriculture Food and Markets is exploring viable technologies and resources to perform inspections and conduct testing at public charging stations [72]. Among states that do not adopt the latest version of NIST Handbook 44 by reference in the relevant statutes (i.e., automatically), some governments are currently conducting or finishing rulemaking procedures [73], [74] to adopt the 2023 version of the Handbook 44 with permanent Section 3.40 EVFS code and intend to subsequently enforce these requirements. Notably, this includes New York and Florida, which have, after California, the largest numbers of known charging stations.

Funding sources for EVSE inspection programs are expected to vary; as they do for other types of regulated measuring instruments, inspections costs could be recovered through a State’s general fund, through charging station licensing and registration fees, other fees, or a combination thereof.

3.4. Natural Gas Vehicle Fueling: An Analogy

PEV fuel and fueling procedures have physical and technological characteristics that are clearly distinct from those of traditional motor fuels. Furthermore, the convenience of charging vehicles in private residences, cost savings over petroleum-derived fuels, and the environmental impact of zero-emission driving have stimulated evolution of the EV charging landscape to a point that it no longer comprises a nascent industry. Yet, as with the sale of any other type of fuel, consumer confidence and fair market competition is conditioned on assurances that transactions are transparent and that costs determined through measuring fuel quantities are reasonably accurate. Differences in physical nature and technology aside, sales of electricity as a vehicle fuel share several key attributes with the delivery and sale of any other type of vehicle fuel. Interestingly, several notable aspects of the compressed natural gas (CNG) alternative vehicle fuel market parallel those of the EV charging market. Despite these similarities, legal requirements for the sale of CNG and for the accuracy of metering devices are widely and uniformly enforced at CNG fueling stations across the U.S. by weights and measures officials, while comparable requirements are largely unenforced at public commercial EV charging stations in most states. Inconsistencies in the regulation of these two fuel industries is especially conspicuous given that EV charging stations and EVs on U.S. roadways are already much more prevalent, by multiple orders of magnitude, than CNG stations and CNG vehicles. It remains to be seen how requirements for the sale of EV fuel that provide market protections comparable to those enjoyed in other fuel markets, such CNG, will be uniformly enforced.

The history of electric utilities regulation shares many milestones with that of natural gas utilities. These two energy sectors have been regulated at the local, state, and federal level, often by the same laws and authorities, and been subject to some of the same market forces and policy shifts over the past century. Both industries were brought under rules of the Public Utilities Holding Company Act, which was deeply impacted and transformed by the 1970s energy crisis and restructured for competitive markets across much of the U.S. Natural gas, primarily in the form of compressed natural gas (CNG) and sometimes liquid natural gas (LNG), is used as an alternative to gasoline and diesel fuels for passenger vehicles, trucks, and various types of fleet vehicles. While still comprising a hydrocarbon mixture (mainly methane) like that delivered by utilities in gaseous form at atmospheric pressure, these forms of natural gas occupy volumes small enough for practical use in appropriately engineered ICE vehicles. In the U.S., natural gas vehicles (NGVs) are most commonly large fleet vehicles such heavy duty trucks, refuse trucks, and transit vehicles that consume large quantities of fuel [75].

There are approximately nine hundred (900) commercial CNG stations across the U.S. [76]. Most of these CNG stations dispense natural gas that has been supplied through the established U.S. natural gas distribution system [77], [78]. Some stations are owned by utilities companies while many others are owned by retailers that purchase the natural gas from a utility serving the geographic area. These stations have equipment that then compresses the fuel on-site and delivers it to vehicles at high pressure. Like commercial EV charging stations, retailers that sell CNG for use as vehicle fuel have also been excepted from the regulative authority of PUCs. For example, the CPUC excepted EV and NGV fueling stations through the same decision. The California Code, PUC § 216 provides that "A corporation or individual that owns, controls, operates, or manages a facility that supplies electricity to the public exclusively to charge light-, medium-, and heavy-duty all-electric and plug-in hybrid electric vehicles, compressed natural gas to fuel natural gas vehicles, or hydrogen as a motor vehicle fuel is not defined as a public utility." Notably, utility companies own and operate many such facilities. However, accuracy of commercial measuring devices dispensing CNG motor fuel to vehicles is not necessarily covered under utility regulatory regimes. As with EV charging stations, this exception left a gap in enforcement of uniform requirements for accurate billing. In most states this gap was filled through adoption and enforcement of requirements for CNG fuel dispensers in NIST Handbooks 44 and 130. In several respects, parallels can also be drawn between the fundamental design of systems used to retail NGV fuel and those of EV charging stations. NGV, like EV, can also be fueled in residences via supply equipment that compresses natural gas purchased through the residential utility account.

Although natural gas purchased from a utility undergoes some processing (compression) to convert it to a form practically usable by vehicles, the composition of the fuel is effectively unchanged. The same general notion is arguably analogous to AC power that is converted to DC power and sold at DCFC stations. Similarly, NGV fuel stations offer ‘fast fill’ services that deliver stored, pre-compressed CNG to fill a vehicle tank in a matter of minutes, as well as ‘time-fill’ services that deliver CNG slowly to fill a fuel tank over several hours [79], [80]. Fast-fill equipment, which is available at all public CNG stations, are suited for traditional retail purposes whereby customers arrive at their own discretion and short fueling times are needed. For these applications, the dispensing equipment contains a device, i.e., mass flow meter, that measures how much fuel is delivered and billed for each transaction, much like gasoline pumps and commercial DCFC EVSE.

States across the U.S. have largely uniform weights and measures laws applicable to NGV fueling, as well as programs for inspecting and verifying CNG meters used at fueling stations. Retail sales are uniformly conducted using standard units of measurement, in accordance with NIST Handbook 130 Uniform Laws and Regulations Section IV 2.27 to improve transparency and facilitate price comparisons. These method of sale and technical requirements also have implications for collection of federal and state motor fuel excise taxes levied on sales of CNG and LNG [9], [81]. Though there are just nine hundred NGV fueling facilities in the U.S. serving approximately 175,000 NGV, there are more than 50,000 public charging stations and over three million EVs on U.S. roads [82]–[84]. As BEV adoption is projected to accelerate, this difference could grow considerably over the next several years.

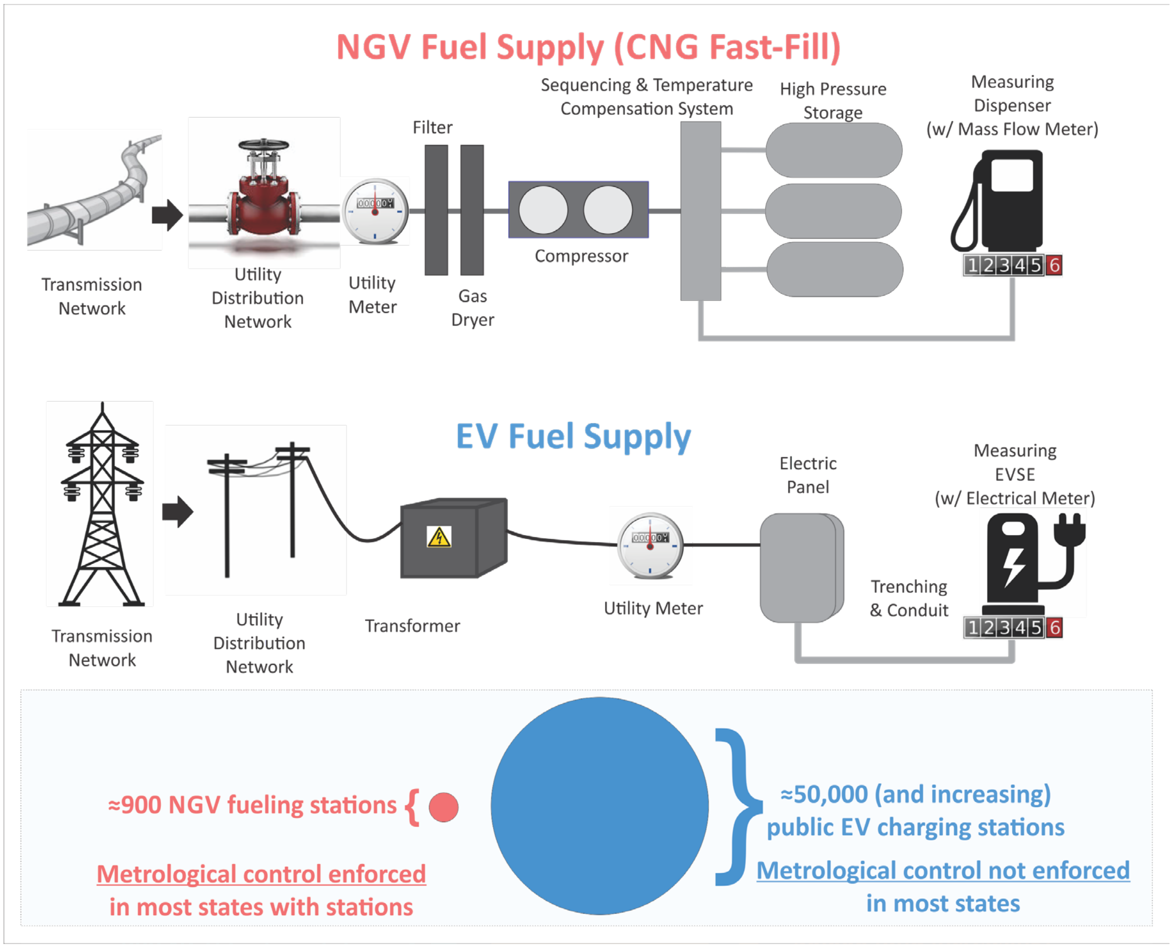

Fig. 4. Comparison between commercial NGV fuel supply and infrastructure (CNG Fast Fill Station) and those of commercial EV charging stations.

Granted, there are numerous fundamental differences between the physical natures of electrical energy and petroleum-derived motor fuels. Applying metrological controls for devices that measure electricity as a tradeable commodity has, by and large, not been a responsibility traditionally fulfilled by weights and measures authorities. Compared to other types of motor fuel stations, EV charging stations operate using different delivery technologies, types of infrastructure, practical and safety considerations, etc. Appropriate expertise and resources are required to verify the performance of EV fueling equipment. Yet, EVSE serve some of the same primary functions in commercial transactions as any other type of commercial metering technology relevant to weights and measures laws. Assurances that commodities are accurately measured and sold in a uniform manner are universally relevant and valued by customers and market providers.

3.5. Legal Metrology for EV charging systems outside of the U.S.

Many nations in addition to the U.S. have set directives to increase adoption of ZEV technology to reduce vehicle emissions. These include major U.S. trading partners such as Canada, Mexico, Japan, the United Kingdom, members of the European Union, and Taiwan. Deployment of more charging infrastructure will be essential to meeting these goals. The European Commission, for example, agreed to ensure that all new cars and vans registered in Europe will be ZEVs by 2035 [85]. Another EU Directive (2014/94/EU) is driving ZEV infrastructure build-up and development of a standard framework of requirements for deploying and operating charging stations across EU member states [86]. By 2030, DCFC for use with light duty passenger vehicles shall be installed every 60 km along the EU's main transportation corridors. Some industry experts estimate that installation of an average of approximately 6,000 new public charging stations per week is needed to meet these requirements.

As in the U.S., other nations are also grappling with approaches to regulating sales conducted through EV fueling systems. Standards development organizations are rising to this challenge and establishing new requirements for measuring EVSE based on technical knowledge and other practical insight provided by industry experts, government officials, and informed consumers. Although legal metrology and other regulatory systems within the U.S. are distinct from those in place elsewhere, harmonized international standards and requirements for commercial EV charging could have significant implications for American EV technology manufacturers that sell products both in the U.S. and abroad.

Canada

Governments within the U.S. are not the only ones in North America developing regulations and standards for measuring devices used in commercial EV charging. The Government of Canada has proposed regulations that set tiered sales targets for ZEVs through 2035. In support of these goals, and comparable to the NEVI Program in the U.S., the Government's Zero Emission Vehicle Infrastructure Program (ZEVIP) is an initiative providing $680 million toward deployment of EVSE sites and hydrogen fueling stations across the country.

In Canada, EV charging stations that conduct sales on the basis of electrical energy (i.e., $/kWh billing rates) are subject to the Electricity and Gas Inspection Act (EGIA). This federal law establishes performance requirements for all measuring devices used in the sale of electricity throughout Canada. Administration and enforcement of this law is conducted by Measurement Canada, a special operating agency of the Government of Canada that is also responsible for enforcing the country's Weights and Measures Act. As in much of the U.S., time-based and flat fee billing methods for charging sessions are currently allowed in Canada, however electricity sales based on energy consumption play an important and growing role in the EV charging landscape. To accommodate consumer and industry demands for more charging stations that offer transparent $/kWh rates, and therefore requiring EGIA compliance, Measurement Canada is establishing conformity assessment and regulatory frameworks to ensure the accuracy of electricity meters used for billing at these stations [87].

Applying technical standards with specifications and testing procedures for type approval of measuring devices is key to enforcing the EGIA. In consultation with industry and other stakeholders, two new standards for commercial AC Level 1 and Level 2 EVSE were developed and placed into effect in December 2022: S-E-EVSE-01—*Specifications for approval of type of electric vehicle supply equipment* and P-E-EVSE-01—*Procedures applicable to specifications for approval of type of electric vehicle supply equipment*. Equipment installed prior to 2024 are exempt from these requirements until 2030 [88]. Like existing AC devices, DCFC devices will be exempt from standard requirements until December 31, 2029 or an earlier date decided by Measurement Canada [89]. Even with temporary dispensations presently in place for some devices, Canada is well on its way to having a nation-wide regulatory program to ensure that all commercial EVSE, including DCFC devices, will be compliant with Canada's legal metrology standards issued under the EGIA by the end of 2029.

Germany

Germany is currently the largest EV market in Europe and has had dedicated legislation for metrological control of EVSE in place since 2015. At the Federal level, authority for regulating measuring devices marketed in Germany is established through the Measuring and Verification Act (Mess und Eichgesetz; MessEG) [90] and the Measuring and Verification Ordinance (Mess- und Eichverordnung; MessEV)[91]. The requirements for billing meters used at public charging stations were added to these laws in 2015. This revised legislation, known as the German Calibration Law (2015-2019/04), or "Eichrecht" measurement and calibration law, aims to provide transparency in each commercial public EV charging transaction. Key requirements include: 1) prices for charging sessions must be on a per kWh basis (e.g., €/kWh), 2) kWh electricity meters used for billing must be certified and periodically verified by appropriate authorizes, 3) data and software security measures must be taken, and 4) the quantity of energy measured for each sale must be locally displayed, in kWh, on the station. This Federal law also grants regulatory authority to the German National Metrology Institute, Physikalisch-Technische Bundesanstalt (PTB), which has a central role in the design, administration, and implementation of Germany's national legal metrology systems.

The PTB is the highest authority in Germany for calibration of electrical and other metering devices and leads the national Eichrecht conformity assessment scheme [92]–[94]. The organization has laboratories that conduct type and pattern approvals for EVSE and designates Federal State offices that monitor the local market to coordinate inspections of charging stations with local inspection bodies. As the country's national metrology institute, PTB also develops national measurement standards used in establishing metrological traceability of results produced by measuring instruments. Furthermore, the PTB presides over the Rule Determination Committee ("Regelermittlungsausschuss", REA) that decides on rules, technical specifications for measuring instruments, conformity assessment procedures, and other matters related to Eichrecht law. The REA comprises representatives of state governments, conformity assessment bodies, testing laboratories, consumer groups, and industry stakeholders.

The REA committee has developed a standard document, PTB REA 6-A, specifying the regulations and technical requirements for both AC and DC measuring instruments, as well as ancillary equipment [95]. Another German standard, VDE-AR-E 2418-3-100:2020-11 Electric Mobility – Measuring Systems for charging stations, was published in 2020. This standard specifies minimum requirements for testing the accuracy of AC and DC measuring systems and is also used in assessing compliance of EVSE with Eichrecht laws [96]. Figure 5 presents the generic conformity assessment scheme for commercial EVSE deployed throughout Germany. This is presently the most comprehensive national legal metrology framework for commercial EVSE in Europe, and quite possibly in the world.

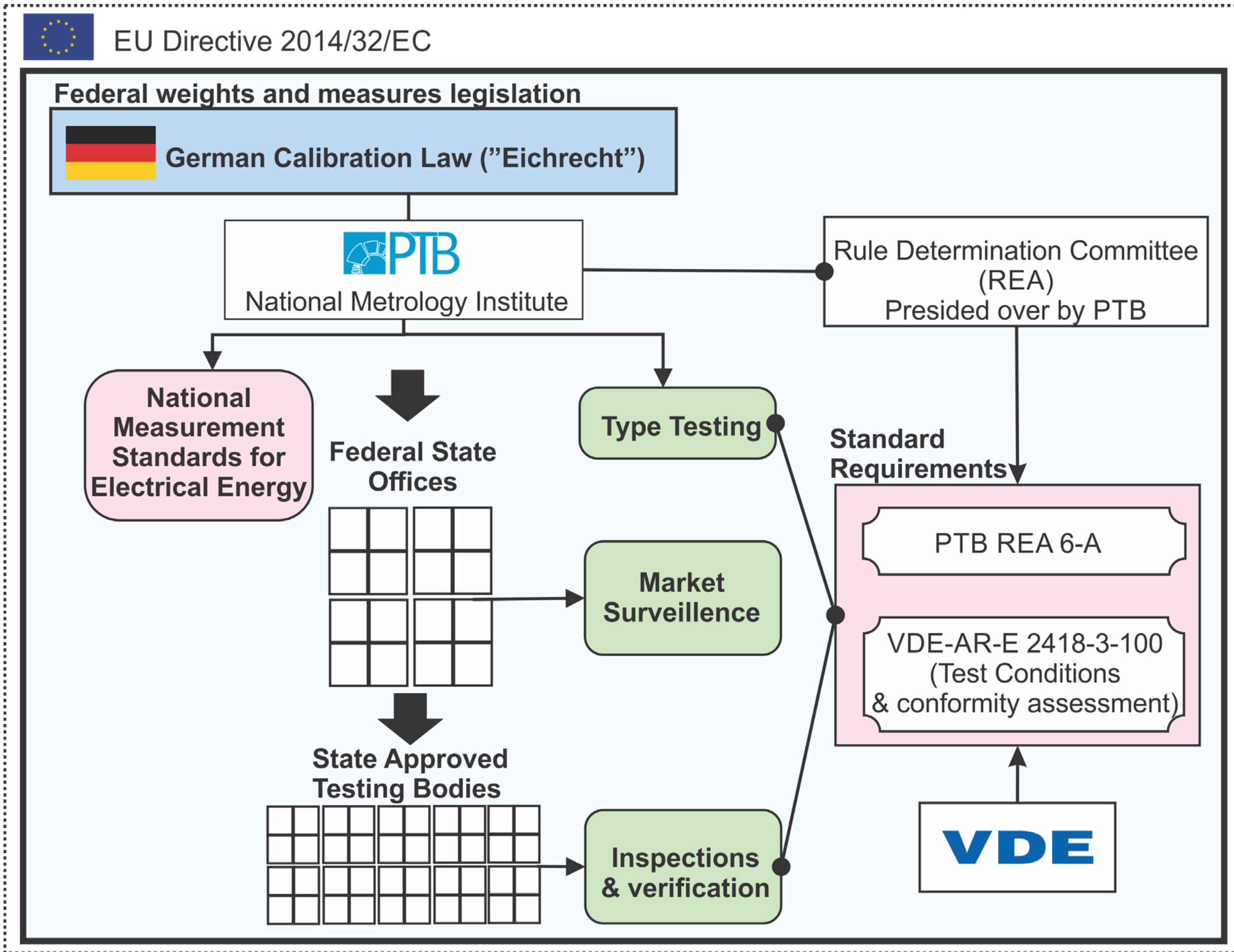

Fig. 5. Nationwide conformity assessment scheme for commercial EVSE under German measurement and verification law, "Eichrecht"

International Standards

Germany is presently unique among EU members in enacting metrological legislation for EVSE. Within Europe, the EU Measuring Instruments Directive 2014/32/EU (MID) serves as the legal basis for harmonizing national metrology laws concerning type approval of many kinds of measuring devices, including active electricity meters. The premise of this directive is that devices meeting standard performance requirements for a particular application can be used across all EU countries. While it has been found that this EU law is applicable to EV charging systems, the MID only covers electricity meters used by utilities. Dedicated requirements for commercial EVSE are missing. To fill this gap, as well as others like it around the world, international efforts to harmonize and develop appropriate legal metrology standards for EVSE are underway. Much of this activity is taking place within the International Organization of Legal Metrology (OIML), an intergovernmental standards-setting body that develops model regulations for metrological control of many types of measuring instruments.

Member States (nations) of the OIML are obliged to implement model regulations, known as "Recommendations", via legislation as far as possible. There are currently sixty-three (63)

Member States, including all but one of the twenty largest economies in the world. International adoption of OIML standards is intended to ensure development and use of mutually compatible measuring systems and remove potential barriers to international trade. A recently published guide by OIML, Guide 022 Electric Vehicle Supply Equipment (EVSE), is intended to serve as the basis for harmonized legislation applicable to EV charging systems and includes requirements such as accuracy tolerances, testing procedures and conditions, and means of providing transaction data to the customer. This standard was developed with a high level of urgency due to rapid increases in rates of EV use, particularly in some European countries. Efforts to convert this Guide to an OIML Recommendation, or model law, are underway and expected to substantially impact the future regulatory landscape for commercial EV charging and EVSE certification.

International DC EVSE standards

Evolution of the EV charging market and increasing abundance of fast charging stations has prompted another recent international effort in legal metrology for EVSE: development and application of standards for testing DC billing meters. Already, multiple commercial DC measuring systems have been certified by PTB for use in the German market and throughout Europe by demonstrating conformity with requirements in the VDE-AR-E 2418-3-100:2020-11. In 2021, the International Electrotechnical Commission published the international standard IEC 62053-41, which is specifically applicable to type testing of DC meters. The European electrotechnical standards organization, CENELEC, has just published a European version of this breakthrough standard for DC meters, EN 50470-4 (2022), that is virtually an exact copy of the IEC 62053-41 and can be used in conjunction with IEC 62052-11:2021 to establish testing requirements for DC meters. Considering this development, the certification body of NMi (Netherlands), which is a leading MID certificate issuing body, has made the decision that DC meters meeting requirements of the VDE and EN standards can be issued MID type approval certificates [97], [98]. This is a significant development toward international harmonization of requirements for commercial DC EVSE. While directly relevant to harmonizing legal metrology requirements across Europe, this decision has broader implications for other governments that look to Europe as an example on this matter and for any EVSE manufacturers or charging station owners/operators that conduct business within these markets.

4. Burgeoning Commercial EVSE applications

4.1.1. Submetering for EV Charging

While there is general agreement that U.S. utilities can generate enough electricity to meet EV charging demand over the next several years, logistics for fueling a mostly electrified transportation sector still requires extensive and careful planning. Long-term grid reliability would depend upon adequate distribution and grid management frameworks that limit strain on electrical infrastructure. Given that buildout of new infrastructure is costly to both service providers and consumers, many utilities are aiming to minimize these costs through programs that avoid power demand surges. These programs are designed to shift EV charging demand to off-peak times of the day or away from periods of energy conservation events. Grid management programs can be implemented actively, whereby the utility company directly manage rates of electricity consumption for EV charging, or they can be implemented passively. Through active implementation, utilities can directly control energy distribution to EV loads via the EVSE, onboard vehicle telematics, circuit breaker, or panel. These management programs can be event-based or continuous when EV are connected to EVSE. By contrast, passive programs aim to influence consumer charging behavior with “time-of-use” (TOU) rates that incentivize energy consumption by utility customers at off-peak times [99]. Networked EVSE or “smart” vehicle telematics are often used to meter energy usage, schedule charging sessions, and manage power levels to control energy consumption. However, these systems primarily assist utilities in balancing load demand and help customers schedule charging times and power levels in order to take advantage of the TOU rates. Under these types of arrangements, all energy used by the customer, including for both PEV charging and the rest of the home or facility, are billed collectively under the same rate, using only the primary utility meter.

In August 2022, California became the first state to allow utilities to offer special rates and tariffs specifically for EV charging [100]. A California PUC ruling issued an EVSE submetering protocol that enables utilities to bill energy measured and consumed for the purpose of EV charging on different rate schedules than the rest of the home or facility. These rate structures are designed to financially incentivize battery charging at off-peak hours, but in a more flexible manner that does not apply to all electricity used by the customer and measured by the primary utility meter. Certain times of the day, such as between the hours of 11 p.m. and 7 a.m., are preferred charging hours for limiting grid strain. Using a vehicle submeter might be particularly advantageous for customers who cannot shift their other energy usage to off-peak hours or who want to monitor EV charging costs separately. Secondary meters are often embedded within EVSE, as they can be for public commercial equipment, or points between the main meter, EVSE, or EV. The CPUC ruling on EVSE submetering only allows this equipment to be used for “net” or subtractive billing. Under this billing scheme, all energy delivered to a customer is first measured by their primary utility meter, in compliance with the usual accuracy standards for these devices. Submeters then measure energy that is directed toward an EV. The sub-metered EV usage is subtracted from the total usage measured by the primary meter to determine non-EV consumption by the customer. Special EV charging rate structures are applied to the measured quantities of energy directed toward the EV while the rest of the energy consumed is subject to the regular rates. This protocol does not supplant the need for a main utility meter, but it can promote favorable charging behavior, facilitate lower energy bills, and ultimately increase the appeal of BEV ownership.

Although some customers can financially benefit from these electricity rates for EV charging, installation of a second costly utility-grade meter could be a deterrent to their implementation. Other types of metering devices owned by utilities or customers participating in charging management programs could include residential EVSE and vehicle telematics. Although utility meters are subject to PUC regulations and stringent accuracy tolerances, such as those specified by ANSI C.12 electricity metering standards, adequate standards specifically for EV fuel measuring devices used in utility billing are less established. Submetering and communication protocols for technologies enabling charging management programs must be in place to ensure that they are reliable and fit-for-purpose. The CPUC investigate protocols for accuracy testing of both EVSE and on-board vehicle telematics.

The CPUC has decided to apply accuracy tolerances specified in NIST Handbook 44 Section 3.40 for type acceptance, initial use, and maintenance of EVSE submeters. Although the accuracy tolerances in the Handbook 44 are less stringent than in utility revenue-grade standards, they facilitate the pragmatic use of economic and widely available EVSE for this purpose, while still applying reasonable metrological controls. Furthermore, many EVSE devices have already received type approval certificates from the California Type Evaluation Program (CTEP) for commercial use at public charging stations in California [101]. The CTEP tests these devices for conformity to NIST Handbook 44 requirements. NIST Handbook 44 Section 3.40 accuracy tolerances were adopted to ensure uniformity of metering EVSE requirements across the state and to avoid the use of multiple standards in different regions. For AC EVSE, which are those installed in homes and commonly installed in many public facilities, these tolerances are ± 1 % for type acceptance testing in a laboratory setting and ± 2 % for maintenance testing of EVSE already placed into service. Applying the same accuracy requirements to metering devices installed in residences and those installed in public stations facilitates fair competition among all EV fuel providers in the state.

Submetering and communication protocols could also be applied for charging management programs that leverage bidirectional EV battery charging and discharging. Vehicles capable of bidirectional energy transfer can redistribute electricity to the grid in in times of need (i.e., “vehicle to grid”, V2G technology) or serve as power backups to buildings or other loads (“vehicle-to-everything”, V2X technology) [102][103]. Although there are currently a limited number of bidirectional EVSE and PEVs available, appropriate metering protocols used to credit energy flow from the vehicle will be critical for realizing the potential role of these technologies in promoting grid resilience and demand-response capabilities. Therefore, it will be important that measuring devices facilitating the use of these technologies meet the same accuracy requirements as other EVSEs. Some utility companies are initiating exploratory V2X programs to assess how it can be effectively employed and optimize benefits to both consumers and the grid. Although different in some ways, these programs are comparable to net metering protocols implemented for customers that own solar energy systems and deliver excess energy to the grid to reduce their electricity bills. Net metering has mandatory rules in forty-one states, DC, and three U.S. territories [104]. Net metering mechanisms credit customers by essentially running the utility meter backwards when energy is added to the grid. Networked V2G and V2X EVSE submetering and communication protocols, on the other hand, would require a greater degree of complexity because they apply EV-specific rate structures, are used to manage EV charging schedules, must accurately measure energy transfer to and from EV batteries, and utilize onboard vehicle telematics data.

Other states have followed California in exploring the use of networked measuring and communication devices with managed EV charging programs. PUC investigations to assess accuracy testing protocols for these technologies have been initiated or completed in several states including Connecticut, Indiana, Maryland, Massachusetts, Minnesota, New Hampshire, New York, and North Carolina. As in California, measuring protocols proposed for EV charging management programs generally aim to use submetering devices for subtractive billing. Recognizing the importance of uniformity in EVSE accuracy standards and that several EVSE manufacturers already produce products that meet NIST Handbook 44 requirements, public utility commissions for these states are also considering alignment of accuracy testing requirements for EV fueling measuring devices with those in NIST Handbook 44, Section 3.40. In July 2022, the New York State Public Service Commission (PSC) approved the implementation of managed EV charging programs and ordered the “Joint Utilities of New York” to propose a method for testing the accuracy of EV submetering equipment, including EVSE and EV on-board telematic systems [103]. Alongside Minnesota [105], Maryland [106], Connecticut, Massachusetts, and New Hampshire [107], New York is investigating suitable standards for the use of EV and AC L2 residential EVSE in submetering. Recommendations to the PSC regarding appropriate accuracy testing protocols shall be provided by Oct. 2024. Many stakeholders have suggested that the Joint Utilities consider implementing testing specifications in NIST Handbook 44, Section 3.40 for EVSE, though new protocols will be required to test and compare EV telematics.

The standards landscape for EV fuel metering technologies used by utilities is evolving rapidly as more states allow for managed EV charging programs and EV-specific energy rate designs. Uniformity in the application of fit-for-purpose submeter accuracy standards and communications protocols is becoming increasingly relevant. Considering that 80 % of EV battery charging occurs in residences, not to mention the potential market value of energy flowing from V2G and V2X equipment, metrological control of meters facilitating managed EV charging programs are of significant interest to both energy providers and their customers.

4.1.2. Recovery of “gas tax” revenue lost to electrification

Motor fuel excise tax, i.e., “gas tax”, is a key source of revenue that governments use for transportation-related spending. They especially help fund expensive construction projects and maintenance of roads and highways across the country. Both the federal government and state governments levy excise tax on each sale of traditional motor fuel in the U.S., including gasoline, diesel, and gasohol mixtures of gasoline and ethanol. The federal tax on gasoline and diesel are $0.184/gallon and $0.244/gal, respectively, however rates for fuel tax collected by the states vary considerably. In 2019, state motor fuel tax accounted for approximately twenty-six percent of highway and road expenditures in the U.S. Although states’ tax rates and expenditures differ, motor fuel taxes are crucial to transportation budgets; after adjusting for inflation, spending on transportation has increased two-fold across the U.S. over the last forty-five years [108].

Since EVs do not utilize traditional motor fuel, no gas tax is collected through operation of an EV. Thus, commensurate use of traditional ICE vehicles and EVs have different implications for collection of revenue. Given the importance of fuel taxes in supporting roads and highways, some have become concerned over the impact that EVs will have on future government funds and how EV users can equitably contribute to it. Use of EVs, which are typically at least several hundred pounds heavier than their ICE counterparts, raise concerns regarding their impact on road surfaces and other existing infrastructure. Tax based on quantities of fuel consumed has historically been treated as a relatively fair way to raise revenue for transportation purposes. Fuel consumption can correlate to miles driven and vehicle weight, which in turn can correlate to use-related wear on roads and the degree of utility that they serve to a consumer. However, varying degrees of ICE fuel efficiency weakens these correlations, especially the growth in popularity of hybrid vehicles.

To compensate for reductions in fuel tax collected from EV users, states have imposed alternative fees and taxes for owning and using these types of vehicles. The most common approach taken has been to impose annual special EV registration fees, in addition to the usual vehicle registration fee. The fee schedule structures vary considerably from state to state according to defined vehicle types [109] and are applied to different categories termed “hybrid”, “plug-in hybrid electric”, “battery electric”, “all electric”, “electric” vehicles”, “zero emission” and “alternative fuel” vehicles. Thirty-one (31) states currently apply such fees on EV ownership and eighteen (18) of those states impose other fees, such as “highway use fees”. This concept is not without precedent in supplementing fuel tax revenue, as some states collect higher registration fees on any vehicle, including ICE, that are considered fuel-efficient [110], [111].

Another approach considered for recovering gas tax revenue shortcomings is to levy an excise tax on electricity sold at public EV charging stations. Although most charging occurs within private residences, some states have taken this measure to implement at least some form of “pay-as-you-go” fee for highway usage, akin to the familiar gas tax. Such an approach necessitates a degree of standardization for some basic aspects of EV fuel sales, including methods of pricing and metering of quantities of fuel on which the tax is collected.

Iowa excise tax

Over the past four years, the state of Iowa has been preparing to levy a new excise tax on non-residential vehicle charging. In May 2019, a law [65] was passed to impose a tax of $0.026 on each kilowatt hour of EV fuel delivered by providers licensed by the state’s Department of Revenue, beginning July 1, 2023 (Iowa Code § 452A.41). This tax will only be applicable to sales at commercial retail stations available to the public and to company-owned fleet charging stations. The tax shall not be collected on electric vehicle fuel distributed to residences or by utilities unless they are also licensed electric fuel providers. The legislative act was passed in response to a study conducted by the Iowa Department of Transportation which forecast a reduction of $39,975,000 - $241,316,000 in the Road Use Tax Fund, the primary funding source for improvement and maintenance of Iowa’s public roads, by 2040 due to EV and special fuel vehicle adoption [112]. The 2019 Iowa Act also established electric vehicle registration fees and an excise tax on hydrogen fuel, both of which began in January 2020. Although most EV charging is currently performed at residences and the estimated tax revenue losses in Iowa are expected to be largely recovered through special EV registration fees, the EV fuel excise tax makes up for much of the remaining projected shortfall. This tax, unlike registration fees, can also be paid by out-of-state PEV drivers that use Iowa’s roads and charge their vehicles at public stations.

The effective date of the excise tax was set four years out from the passage of the Act to allow time to deploy EVSE that are capable of measuring electricity based on the kilowatt-hour (kWh). In May 2023, the Iowa General Assembly passed additional legislation [68] granting authority to the Department of Agriculture and Land Stewardship (Weights and Measures Bureau) to conduct biennial inspections of all licensed commercial charging stations collecting the fuel tax, testing the accuracy of electricity metering and billing. Prices of electric vehicle fuel shall be in $/kWh and charging stations shall conform to the requirements specified in NIST Handbook 44. Both

AC and DC EV charging equipment are within the jurisdiction of the Department of Agriculture and Land Stewardship.

Oklahoma excise tax

In November 2021, Oklahoma appended state tax code by passing the "Driving on Road Infrastructure with Vehicles of Electricity (DRIVE) Act of 2021". Under this law, a tax of \$0.03/kWh will be imposed on the sale of electricity used to charge EV batteries, beginning January 1, 2024. The purpose of this tax "is to provide revenue for general government expenditures" and is applicable to sales conducted at commercial public charging stations. The tax is not to be imposed on residential charging nor on sales provided via "legacy chargers", defined as those in operation prior to November 1, 2021, without metering systems to measure electrical energy or active charging time. Any commercial public station beginning operations on or after November 1, 2021, must use a metering system capable of determining costs on a per kWh basis or comparable measure determined suitable by the Tax Commission, such as one based on active charging time. However, since the passage of the DRIVE Act, the OCC established rules that the method of sale of electricity for vehicle fuel must conform to NIST Handbook 130, i.e., applying rates in terms of kWh of energy sold [66]. Under these statutes, all commercial charging stations will be required to register with the OCC, which has authority to also require, at the expense of the charging station operator, inspections, periodic third-party testing, and calibration of the EVSE.

Kentucky excise taxes

The state of Kentucky in 2022 passed legislation to levy a tax on EV fuel, whereby charging station operators must pay to the State Treasurer a combined excise and surtax fee of \$0.03/kWh of electricity sold. The effective date for this tax, as in Oklahoma, is January 1, 2024 [113]. However, unlike the taxes in Iowa and Oklahoma, any charging station operator that provides electricity to the public for free via EVSE installed after June 30, 2022, will also be responsible for remitting the fuel tax. The tax rate will be assessed and adjusted yearly in accordance with the most recent National Highway Construction Cost Index 2.0 value, with the change in value relative to the previous year not to exceed five percent.

Georgia excise taxes

In May 2023 Georgia passed SB 146, significantly altering the regulation of public EV charging in the state. Expected to go into effect in 2025, the law establishes an excise tax of \$0.0284/kWh sold at public EV charging stations that will go into effect in 2025. Other provisions address issues key issues such as excluding EV charging stations from regulative authority of the Public Service Commission and granting of regulative authority to the GDA over sales of electricity used as EV fuel [69].

Mileage tax pilots

Modification or initiation of new pilot programs are being considered in several states to generate transportation revenue through taxes on mileage traveled by EVs. Under these programs, a meter can be installed in the vehicle to measure distance driven. Alternatively, the program can rely on EV drivers to report distances driven each year based on odometer readings. State legislative bills for these programs have been considered in Hawaii, Massachusetts, Minnesota, Tennessee, Utah, Vermont, Virginia, and Washington. Some issues have been raised in response to such proposals, including privacy concerns regarding data collection of individual behavior. Critics of these programs also cite complexities and fairness of implementing different mileage tax programs in different states, considering that many vehicles can and do conduct a significant amount of road travel outside of the states in which they are registered.

5. Summary

EV adoption is poised to significantly alter the transportation sector in the U.S. The recent growth in EV ownership has made clear that public sentiment for EVs is becoming more favorable as market choice and prices for EV models improves. Governments across the U.S., including at the federal, state, and local levels, with support from several industries, have prioritized facilitating electromobility and ZEVs in the coming decade. EV purchasing incentives, large public charging infrastructure funds, environmental initiatives, and an array of other policies supporting EV use have already helped advance substantial gains for these priorities. While many policies aim for complete conversion to ZEV technologies by 2035, it is widely recognized that more infrastructure is required to realize these goals. The U.S. federal government and corporations are currently investing billions of dollars to establish an interconnected EV charging network that fosters confidence in long range EV travel and improves accessibility to reliable EVSE. Federal standards and requirements for EV charging infrastructure deployment further advance public ZEV directives. In addition to the deployment of new EV charging infrastructure in homes, along highways, and throughout electrical grids of the U.S., policies are being created and modified to ensure these processes are adequately protected and promote equity in expanding markets.

Expansion of public charging networks, especially of fast charging stations, is presently recognized as a critical condition for broad EV adoption. A diverse ecosystem of public and commercial investments has been promoted to keep pace with EV charging demand and government ZEV policy goals. To this effect, most U.S. states have recently changed laws concerning the sale of electricity to allow non-utility station owners to conduct EV fuel sales. This nationwide trend has removed a regulatory barrier to the deployment of commercial EV charging stations and enabled more transparent, fair, and consumer-preferred methods of pricing (i.e., $/kWh). Naturally, utility companies are also recognized as a key stakeholder in the rapid expansion of charging infrastructure. In addition to ensuring adequate grid capacity and reliable distribution of electricity, utilities also have considerable resources for assisting with charging infrastructure deployment. In many states, these companies have been permitted and encouraged to install and own key components of EV charging stations and in some cases, they fully own and operate these stations. A relationship between utility and non-utility commercial entities that has both symbiotic and competitive facets has developed within the EV charging market.

While expansion of public and commercial charging networks is a clear priority, it is also important to ensure transparency and equity in EV fuel sales as this marketplace develops; the next decade may be formative for commercial EV charging. Since non-utility EV charging stations are exempt from regulations imposed on utilities as well as many of those imposed on the sale of other types of vehicle fuel, there exists a significant gap in public oversight of consumer and market protections. In particular, standard methods of sale and verification of adequate metering device accuracy are core requirements typically imposed on the sale of fuel and other commodities. State and local weights and measures programs develop and enforce requirements for the sale of such commodities and have been considered appropriate authorities to fill this regulatory gap in commercial EV charging. National weights and measures standards in NIST Handbooks 44 and 130 contain model legal requirements for electric vehicle fuel sales and fueling systems that can promote uniformity in requirements for public commercial EV charging. Other international standards and guidelines outline comparable requirements that could help promote harmonization of EV fuel sales and measuring device performance among international trading partners, providing benefit to EVSE manufacturers engaged in markets outside of the U.S.

California, through authority granted to the Department of Food and Agriculture's Division of Measurement Standards, is the first U.S. state to have a regulatory program actively inspecting public EV charging stations and verifying proper performance of equipment used to measure and sell electricity at these stations. However, growth of the charging market and its role in facilitating electromobility have added some urgency to applying standards that ensure consumer protections. NIST Handbook 44 Section 3.40 Electric Vehicle Fueling Systems was adopted as a tentative code in 2015 and was adopted as permanent code in the 2023 Edition by the National Conference of Weights and Measures in July 2022. Several states in addition to California are preparing and poised to use this standard as a basis for the weights and measures regulation of commercial charging stations. Enforcement of these legal metrology requirements seems likely to commence in the coming year in some jurisdictions that are preparing to levy fuel excise tax on electrical energy sold or delivered at public charging sites.

Although public EV charging has a key role in supporting U.S. electromobility, 80 % of PEV charging takes place at home. Residential charging is expected to remain the prominent means of EV fueling for the foreseeable future. To help manage strain on the U.S. electrical grid, PUCs and the companies they regulate are exploring programs that help manage EV charging behavior. These programs will utilize commercial submeters to measure electricity offered by utilities under special rate designs that encourage charging at off-peak hours. Metering EVSE are expected to be implemented for this purpose, similar to public EVSE used commercially. The managed EV charging programs are under authority of PUCs, however many states refer to national standards (i.e., NIST Handbook 44) for metering accuracy of commercial EV fueling systems. This could help harmonize requirements for EVSE manufacturers that produce devices used in both public stations and in utility billing. Testing protocols and suitable devices for facilitating managed EV charging programs are currently being evaluated in several states.

6. Conclusion

The evolution of the commercial EV charging landscape in the U.S. is accelerating in response to multiple drivers for broad EV adoption. Although many regulatory matters have largely been settled in order to facilitate its expansion, several others are still being urgently addressed to establish adequate legal frameworks during a period of substantial growth. Ideally, these frameworks will foster a thriving market for consumers and providers alike, retaining flexibility necessary to meet needs and circumstances of the future. This could be especially important as EV charging infrastructure reaches new levels of scale and the implications of rules (or the absence thereof) become clearer. It is essential that laws, regulations, and enforcement practices are uniformly adopted and implemented to ensure clear, transparent, and accurate transactions that promote consumer confidence and ensure fair competition among businesses. A widely accessible, fair, robust, and reliable commercial EV charging market is likely to play a key role in broadening public embracement of EV technology and ushering the U.S. through a potentially transformative era for zero emission transportation.

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