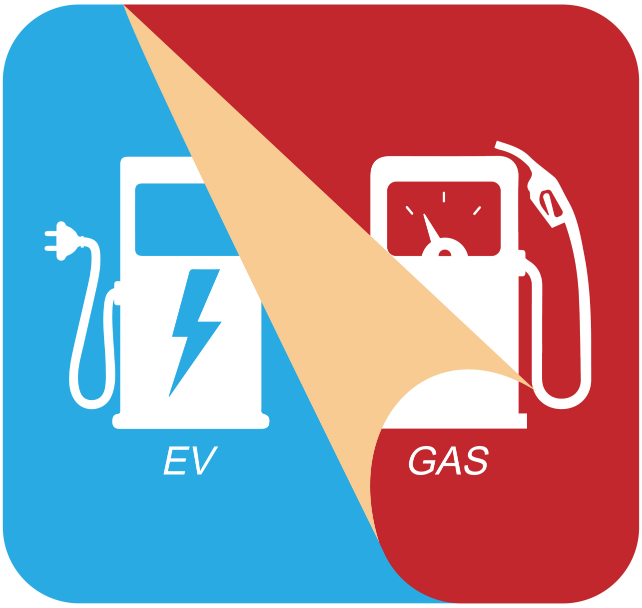



Image by Ruangdej Chulert for iStock

# REPLACING THE GAS TAX

## LEVERAGING THE ELECTRIC VEHICLE TRANSITION TO BUILD A STRONGER TRANSPORTATION FUNDING SYSTEM IN THE UNITED STATES

**MIT Mobility Initiative and JTL Transit Lab**

**James Aloisi, Bhuvan Atluri, Jinhua Zhao,**
**Yunhan Zheng, Seamus Joyce-Johnson**

**July 2023**

# Contents

# ACRONYMS AND ABBREVIATIONS

| Acronym/Abbreviation | Definition |
|---|---|
| AER | All-electric-range |
| BEV | Battery electric vehicle |
| C4C | Cash for clunkers |
| CAFE | Corporate Average Fuel Economy |
| DCFC | Direct current fast charger |
| EV | Electric vehicle |
| FCEV | Fuel cell electric vehicle |
| FY | Fiscal year |
| HEV | Hybrid electric vehicle |
| HTF | Highway Trust Fund |
| ICE | Internal combustion engine |
| IIJA | Infrastructure Investment and Jobs Act of 2021 |
| IRA | Inflation Reduction Act |
| kWh | Kilowatt-hour |
| LDV | Light-duty vehicle |
| MPG | Miles per gallon |
| MPGe | Miles per gallon of gasoline equivalent |
| MY | Model year |
| NEVI | National Electric Vehicle Infrastructure Program |
| OBD-II | On-board diagnostics port |
| OEM | Original equipment manufacturer |
| PHEV | Plug-in hybrid electric vehicle |
| RUC | Road user charge |
| VMT | Vehicle miles travelled |
| VRU | Vulnerable road users |
| ZEV | Zero-emission vehicle |

# EXECUTIVE SUMMARY

The disruption to global ecosystems and economies caused or exacerbated by Climate Change has led many nations to act to reduce the production of greenhouse gas emissions into the atmosphere. Greenhouse gas emissions come from many sources, but increasingly the single largest contributor to these emissions is the transportation sector.

The United States contributes about 6.4 billion metric tons (BMT) of greenhouse gas emissions annually, and eighty percent of those emissions are carbon emissions [1]. The transportation sector was responsible for producing 1.7 BMT of carbon emissions in 2021, a larger share than any other US economic sector. Indeed, the US transportation sector's leading role as a producer of carbon emissions has held steady since 2017, when it replaced the production of electricity as the nation's number one source of CO2 emissions (Figure 1).

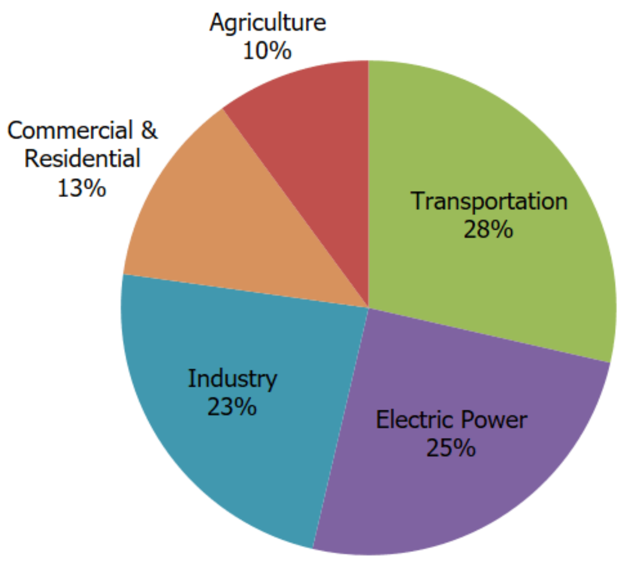



**Figure 1:** Total U.S. Greenhouse Gas Emissions by Economic Sector in 2021 [2]

As a necessary response to the US transportation sector's outsized contribution to carbon emissions, the federal government and many state governments have recently enacted laws and adopted regulatory frameworks that will influence and accelerate fundamental, transformative changes to vehicular travel. Those changes will be shaped by an increasing shift away from the use of fossil fuels to power internal combustion engines and toward hybrids and electric vehicles. This transition will have multiple consequences that will need to be addressed as the movement toward hybrid and electric vehicles grows.

One significant consequence will be the disruption of the gas tax as a reliable, albeit inadequate source of transportation revenue. By definition, as the shift to electric vehicles occurs, the gas tax will become less and less available as a reliable funding source for federal and state transportation needs. This is a significant occurrence because the gas tax has been the mainstay of transportation funding for most states since the early decades of the 20th century, and for the federal government since enactment of the Interstate Highway Act of 1956. Gas tax revenues are often the anchor of a state's transportation revenue resources and, because they have historically been highly stable and predictable, have supported the issuance of revenue bonds to fund highway, bridge and road construction and maintenance [3]. The federal gas tax was essential to the construction of the nationwide Interstate Highway System, and it remains the principal source of revenue supporting federal funding participation in Interstate and non-Interstate Federal-Aid highway reconstruction and rehabilitation projects, and for capital costs for a limited number of transit projects.

At the same time, the gas tax has become an increasingly insufficient source of federal and state transportation revenue. The federal Highway Trust Fund has been in shortfall every year since 2008, and Congress has had to resort to filling the funding gap with General Fund revenues, which are derived primarily from the federal income tax and (unlike the gas tax) are not tied to the use of transportation infrastructure. The Trust Fund was made solvent by the funding made available through the Infrastructure Investment and Jobs Act of 2021 (IIJA), but that solvency will end in federal FY2028 without further Congressional action. At the state level, only a small number of states have been able to raise enough revenue to cover their actual annual transportation needs. Those states relying more heavily on the gas tax for their transportation spending will be hit the hardest during the transition away from ICE vehicles. As the transition to EVs continues, the gas tax at the federal and state levels will steadily and significantly fail to support state transportation revenue needs. This presents an extraordinary opportunity to reconsider how transportation needs are funded, and to replace a legacy gas tax funding system that has proven insufficient to meet actual needs and that is highly inefficient in addressing four key negative externalities of vehicular mobility: (i) traffic congestion, (ii) road wear and tear, (iii) safety, and (iv) emissions.

This report is intended to function as a toolkit for policymakers, advocates and other stakeholders as they undertake a smooth transition to the electric vehicle era, including a transition to new, stable, fair and robust revenue sources to replace the gas tax. In Part 1 we identify the dimensions of the transportation revenue gap that will occur and explore current approaches to taxing or assessing electric vehicles. Part 2 proposes a framework for states to use as they consider appropriate policy objectives and post-gas tax revenue methods, examines a variety of revenue alternatives tied to those policy objectives, and assesses them against a short list of key performance metrics and for their efficiency in addressing costly externalities of vehicular mobility. This examination will include a fresh look at the potential to devise a fair approach to charging for the societal impacts of vehicular mobility, including a vehicle's weight and size.

We observe that an opportunity connected to this task is the development of a more rational transportation funding system, in comparison to the current system that is largely unrelated to the negative externalities of driving. Those externalities carry significant cost burdens that are inequitably distributed among the driving and non-driving population. This inherent irrationality has been known for decades, and this imminent generational shift in the transportation funding system provides an opportune moment to address and resolve it. Finally, in Part 3 we present an interactive system dynamics model we developed as a user-friendly tool to consider a variety of EV adoption scenarios and their impacts on revenues.

# INTRODUCTION

The impetus to decarbonize the US transportation system is rooted in concerns about the national and global impacts of greenhouse gas emissions, often referred to by the overarching term "Climate Change." Climate Change is a shorthand for the variety of changes to global weather patterns that come when human use of fossil fuels causes greenhouse gas emissions to trap the sun's heat. These changes are having serious impacts on global economies, social cohesion, and population well-being as they affect environmental ecosystems critical to food and water supply and infrastructure resilience. The United Nations considers Climate Change to be the "defining issue of our time" [4].

The United States joined one hundred and ninety-two nations and the European Union in ratifying the Paris Agreement of 2015/16, an international treaty designed to limit global warming to ~1.5 °C (2.7 °F) as compared to pre-industrial levels. In 2023, the U.N. Intergovernmental Panel on Climate Change (IPCC) found that the world is likely to miss its climate target—limiting warming to 1.5 °C above pre-industrial temperatures—as soon as the early 2030s [5].

Reduction of global transport sector carbon emissions was a particular focus of the 26th meeting of the Conference of the Parties of the UN Climate Convention (COP). COP issued a Declaration on transport that set ambitious goals regarding the need to shift to zero emissions vehicles [6], including governmental commitments to achieve sales of only zero emission vehicles by 2040, or 2035 in leading markets [7].

In the United States, carbon emissions from the transportation sector represent the largest single sector source of emissions constituting ~38% of all US emissions [1]. What drives US transportation sector carbon emissions? Personal vehicles (cars, SUVs, motorcycles) produce over half the total, some 58% [1]. The EPA estimates that the average passenger vehicle emits about 4.6 metric tons of carbon annually [8]. While the massive pandemic disruption of 2020 temporarily reduced vehicle miles traveled (VMT) in the United States, and consequently carbon emissions, VMT recovered robustly in 2021 and 2022 as shown in Figure 2.

Meaningful action to reduce US carbon emissions cannot be undertaken without a transition from the long-dominant model of internal combustion engines (ICEs) powered by fossil fuels

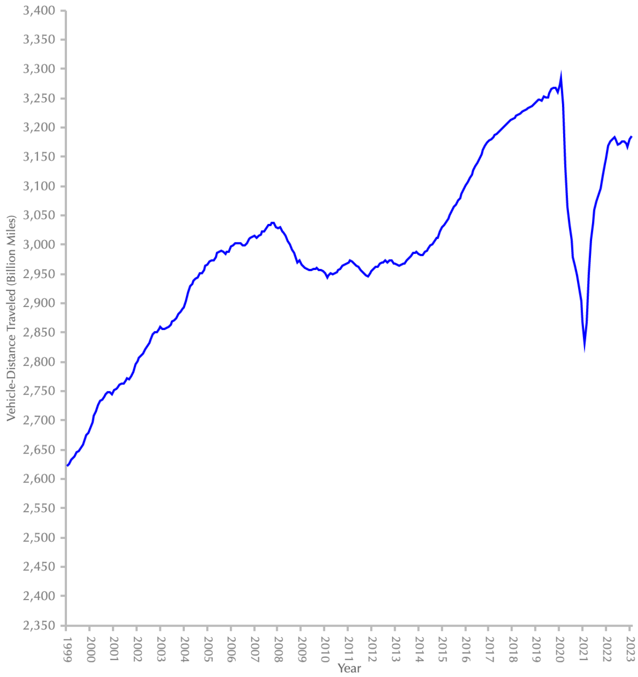



**Figure 2:** Moving 12-Month Total VMT on All U.S. Roads (by Feb 2023) [9]

to a future of vehicular mobility powered by electric vehicles.[1] The potent combination of recent federal and state legislative and regulatory enactments, and US commitments to achieving global climate change targets, will accelerate this transition. Nevertheless, the trajectory of EV adoption rates in the US will depend on many factors beyond the direct control of the public sector, particularly the ability of automakers to meet demand at price points attractive to consumers.

The displacement of ICE vehicles from the US vehicular fleet will upend the funding platform that, since the mid-20th century, has supported the design, engineering and construction of most of the nation's interstate, national and state highway network, provided modest but important capital funding support for public transportation projects, and enabled a baseline level of infrastructure maintenance and improvement. **America thus finds itself at an inflection point that will change two of the foundational components of its surface transportation system: how the vehicular mobility system is powered, and how national and state transportation spending and investment needs are funded.** There are many uncertainties regarding the pace of the ongoing transition, but there is little doubt that the transition is underway and unstoppable. A transition on such a scale will have many intended and unintended consequences.

[1]This paper is intended to address a specific consequence of the imminent transition to electric vehicles. We recognize that the actual impact of electric vehicles, indeed any form of auto mobility, on the production of carbon emissions is not trivial, even if tailpipe carbon emissions are reduced to zero. We also recognize the importance of non-vehicular modes as an essential component of a comprehensive, equitable and urban-friendly transport sector decarbonization initiative. Investments in transit, rail, safe cycling lanes and various forms of micromobility are essential to the overall effort.

In this paper, we focus on the consequences to public sector revenue available for expenditure on transportation needs and initiatives. Those consequences will have impacts on everything from baseline infrastructure needs—construction, operation, and maintenance—to investments in multimodal systems that have a salient effect on externalities like traffic congestion, particulate emissions, and public safety. Many policy choices will be made at the state level, and we provide a framework for decision makers to use as they consider the range of alternatives available to them.

We take this framework to another level as we evaluate those alternatives to test their overall performance as a gas tax replacement and their efficiency in addressing the most severe negative externalities of vehicular mobility. We began writing this report as a way to understand the revenue effects of the transition away from fossil fuels and toward an era of electric powered vehicles. In doing so, we realized that inextricably linked to this task is a rare opportunity to rationalize a transportation funding system that has lacked a fundamental rationality insofar as it is unrelated to the negative externalities of driving, which carry significant cost burdens that are inequitably distributed among the driving and non-driving population. This inherent irrationality has been known for decades,[2] but there has never been a more opportune moment to address and resolve it. This moment therefore presents, and this report is designed to address, the rare opportunity to redesign the transportation funding system to be more rational, introducing a coherent revenue generating framework that addresses, in a multi-dimensional way, the relationship of vehicular mobility to equity, safety, emissions, roadway wear and tear, and traffic congestion.

## The 2020s: A Point of Departure

History demonstrates that decisive government action directed toward advancing technology change in a specific sector will cause rapid engagement by the private sector to bring a new product to the marketplace at scale. This was true for the transition away from leaded gasoline in the early 1990s,[3] and it was more recently true for the transition away from the incandescent light bulb to modern, energy efficient LED lighting.[4]. It is too early to determine the full

[2] Addressing the nation's transportation funding system in 1963, Columbia University Professor William Vickrey said, "I will begin with the proposition that in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation" [10].

[3] The 1990 Clean Air Act Amendments required lead to be removed from automotive gasoline by 1996. The industry achieved this mandate three years sooner, in 1993 [11, 12].

[4] Following the enactment of the Energy Independence and Security Act of 2007, rapid private sector innovation caused a significant reduction in price for LED lighting products, leading to greater public adoption rates. By 2022, 70% of all US sales were LED bulbs [13] Sales are expected to increase as new Biden Administration rules kick in.

impact of recent federal and state initiatives designed to encourage EV adoption, but the levels of investment recently enacted into law at the federal level are unprecedented in size and scope. At the same time, a variety of federal and state regulatory mandates will provide powerful nudges toward EVs to the two central stakeholders of the US vehicular ecosystem: auto manufacturers and consumers. This decade is likely to be the point of departure from fossil fuel-powered automobility.

Examples of recent federal and state government action in this area are abundant. The Environmental Protection Agency (EPA) in April 2023 announced a new proposed Multi-Pollutant Emissions Standard for Light-Duty and Medium Duty Vehicles to achieve by 2027. The EPA estimates that its standards, if implemented, will "accelerate the transition to electric vehicles. Depending on the compliance pathways manufacturers select to meet the standards, the EPA projects that EVs could account for 67% of new light-duty vehicle sales and 46% of new medium-duty vehicle sales in MY 2032" [14].

The Bipartisan Infrastructure Bill, more formally the Infrastructure Investment and Jobs Act of 2021 (IIJA), includes $5 billion in statutory formula funding to states to build out a national electric vehicle charging network in accordance with state-developed plans, and an additional $2.5 billion in competitive grant funding to states and localities in a national effort to build more EV charging capacity along alternative fuel corridors and at the local level. All 50 states, and the District of Columbia and Puerto Rico, have prepared (and received approval for) National Electric Vehicle Infrastructure Plans (NEVI plans) as a prerequisite to receiving federal funding support for the buildout of an initial national EV charging network [15].

The Inflation Reduction Act of 2022 (IRA) complements the IIJA's investments in charging infrastructure by funding federal tax credit incentives up to $7,500 for qualified EVs/plug-in hybrids (PHEVs) and eligible consumers.[5] These credits are expected to have some effect encouraging auto manufacturers to produce more vehicles eligible for the credit, and nudging consumers who wish to purchase EVs [17].

In 2022, California's Air Resources Board mandated that beginning in 2035, all new passenger cars, trucks and SUVs sold in California must be zero emissions vehicles. The importance of this is twofold. First, California plays an outsized role in determining long-term investment and production decisions by US and global manufacturers. As of 2021, over 31 million ICE vehicles were registered in California. Second, 17 other states, acting under the authority of the Clean Air Act, have adopted California's low/zero emissions standards [18]. It is no overstatement to say that as California goes, so goes much of the nation.

[5] The availability of the federal EV credits depends on a number of factors including location of vehicle assembly, source of vehicle battery and critical minerals, and the adjusted gross income of the EV purchaser [16].

These and other federal and state actions will influence EV adoption by addressing both the supply and demand side of the effort. Supply is largely in the control of automakers, and the private sector response has been very encouraging as automakers are going all in on electrification. An AtlasEV Hub report from January 2023 notes auto manufacturers plan to invest $860 billion globally by 2030 to advance the transition to EVs [19]. This will be spent on manufacturing new EV chassis/battery ("skateboard") platforms, building battery plants, conducting further research and design, retooling of existing plants, and helping build out an EV charging network. Jamie Hall, general manager of EV policy and market development at General Motors, (GM) said at the Forth Roadmap Conference in May 2023 that GM will have capacity for 1 million EVs by the end of 2025 [20]. For reference, GM sold 2.3 million vehicles in 2022, meaning that nearly half of GM's capacity will be exclusively for EVs in three years' time [21].

Many automakers are busy integrating vertically up and down the supply chain and are venturing into areas such as mines for batteries, software, and building out charging networks—either by partnering with charge point operators or, as in the case of Tesla and Rivian, building their own charging networks. Automakers are navigating the tricky and uncertain global battery material supply chain by entering into binding agreements with source providers for critical materials supply for many years to come [22]. All this means that, from a supply side perspective, by 2026 the available EV models on sale in the US will likely exponentially increase as these investments and factories come online [23]. This pace of growth will continue until 2035, which is when many states and most manufacturers have set a target to convert to 100% EV for all new vehicle sales.

The biggest hurdles for EV adoption from the demand side will continue to be EV purchase price and range/charging anxiety. These anxieties are caused by two primary concerns: how far your fully charged vehicle can take you, and more importantly, how easily available a functional public charging station is when you need it [24, 25]. With regard to purchase price, recent studies anticipate that the inflection point when the cost of an EV will be less than a comparable ICE vehicle will come later in this decade. The International Council on Clean Transportation (ICCT), in a 2023 report, evaluated a variety of factors and concluded that this inflection point occurs in 2027/28 as shown in Figure 3 [17].

These predictions are not free from doubt as they rely heavily on the availability of federal tax credits that are constrained by provisions limiting vehicle and consumer eligibility.[6] These limitations on eligibility may make it more challenging for manufacturers in the short term to

[6]We have previously noted that the availability of the federal EV credits depends on a number of factors including location of vehicle assembly, source of vehicle battery and critical minerals, and the adjusted gross income of the EV purchaser [16].

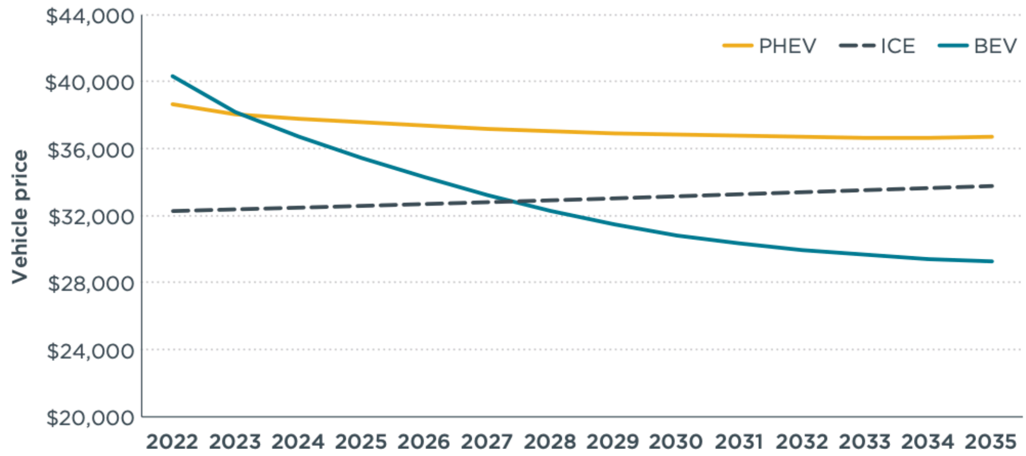



**Figure 3:** Inflection Point When EV Purchase Price is Lower than Comparable ICE Vehicle [17]

produce ample supply for consumers who are waiting to purchase an EV with the financial support or incentive of the credit.[7]

Range and charging anxiety[8] are fueled by several factors, most notably unreliability of current public charging stations, lack of uniform accountability for those stations, challenges to installation of home charging stations especially in dense urban environments, and a still unbuilt (as of 2023) national long-distance charging network.

A 2022 survey of EV drivers conducted by J.D. Power showed that EV owner satisfaction with public Level 2 charging declined based on a year-to-year comparison of driver attitudes. The survey found that one in every five charging sessions failed to deliver a charge to the vehicle, largely a consequence of system malfunction [28, 29]. While automakers and the Joint Office of DOE and DOT are taking steps to fix this,[9] as the adoption curve moves from early adopters to early majority, late majority, and laggards, the charging experience needs to become as uneventful as refueling a car with gasoline. Notably, the IIJA is funding a National Electric Vehicle Infrastructure formula program to deliver on such a national charging network with a total of $7.5 billion in new formula funding ($5 billion) and competitive grant funding ($2.5 billion) tied

[7] The two significant limitations of the IRA relate to the global origin of certain minerals and battery components. Each is worth $3,750. 50% of the value of battery components to be produced or assembled in North America to qualify for a $3,750 credit and 40% of the value of critical minerals sourced from the United States or a free trade partner also for a $3,750 credit [16]. A number of factors, including continued range anxiety and continued inadequate or unreliable charging, will likely have an outsized impact on Ev adoption rates based on relevant recent research [26, 27].

[8] Range anxiety refers to the concern about how far a battery charge can take the driver; charging anxiety refers to concerns over the availability of functioning charging infrastructure during a journey. These concerns are different but interconnected.

[9] In February 2023, the Administration announced the publication of minimum standards for federally funded EV charging stations, including requirements that chargers have "consistent plug types and charging speeds, common payment systems, and accessible pricing information, locations, and availability." [30, 31].

to individual state plans.

The key takeaway is that EV adoption paths will reflect a number of inputs, including the previously mentioned federal and state legal and regulatory nudges, the rollout of a reliable charging network sufficient to keep pace with demand, and the supply of electric vehicles at competitive prices. In addition, car owners have been holding on to their existing internal combustion engine vehicles for longer durations than ever before. It remains to be seen to what extent this slowness of vehicle turnover will be reversed or heavily influenced by recent federal and state government actions [32].

Many PHEVs also qualify for the federal tax credits just like BEVs. PHEVs can be a good stop-gap alternative for customers for whom range and charging concerns act as barriers for BEV adoption. Because they have an internal combustion engine, PHEVs use a smaller battery pack than BEVs, and they can be recharged by plugging in or via the engine. It is therefore tricky to predict how much of a PHEV's running will be fueled by electricity or by gasoline burned by the engine, as it depends on the owner's choice and habits. Recent studies show that many people do not plug in their PHEV and hence are not running them as efficiently and cleanly as designed [33]. When a PHEV is not plugged in regularly, it behaves more like a traditional hybrid, which from a gas tax point of view is simply a more efficient gas car. Our model in Chapter 3 can account for increasing PHEV penetration by increasing the fleet fuel efficiency. That said, most manufacturers have now announced plans to shift focus to BEVs, and more than 50 new pure BEVs are expected to hit the market by 2030 [34]. This is far more than the new PHEVs announced and current ones being manufactured by a select few companies such as Toyota. The prediction is that with the increasing charging infrastructure coming online, PHEVs will remain but a footnote in the ICE to EV transition in the US.

Despite these adoption path uncertainties, the transition to EVs has moved from an "if" proposition to a "when" proposition. Answering "when" is, by definition, a matter of identifying and understanding the various statutory, regulatory and behavioral levers that will advance more widespread adoption. Developing likely adoption scenarios, and understanding their impacts on transportation revenue, is therefore both timely and necessary. We do this in Chapter 3, where we consider a variety of factors informing different EV adoption scenarios, and their impacts on gas tax revenues, through our system dynamics model.

# CHAPTER 1 | THE APPROACHING GAS TAX DISRUPTION

The replacement of the ICE fleet with battery electric vehicles, indisputably a highly effective approach to eliminating tailpipe carbon emissions, poses its own set of unavoidable challenges that must be addressed in order to ensure a smooth, equitable transition. One significant challenge will be the disruption of the single most important and stable source of transportation revenue that has supported US mobility for over a century, the gasoline excise tax.

A transport funding system reliant on taxes and fees on fossil fuels made sense in the 20th century but, by definition, cannot survive a transition to electric vehicles. As the nation transitions to an all-electric light-duty vehicle fleet, federal and state gas tax revenues will gradually reduce and eventually bottom out at zero (this is also true for carbon fuel taxes generating so-called "Transportation and Climate Initiative" [TCI] revenues). The gas tax therefore will increasingly be no longer viable as a stable funding platform for the nation's transportation needs.

## A Brief History of the Gas Tax in the United States

The gas tax has been a mainstay of funding for state governments since the early decades of the 20th century [35]. The federal government first provided some federal matching funding to eligible states for roadway construction and maintenance in 1916, but this funding came from general fund appropriations, not a gas tax.[10] The federal government did not initiate its own gas tax until the economic crisis of the Great Depression triggered a federal effort to find new revenue sources to help balance the budget. The Revenue Act of 1932 imposed a 1-cent per gallon tax on gasoline, and used the money for budget balancing purposes [37]. The use of gas tax revenues for purposes other than strictly transportation needs continued until the landmark Interstate Highway Act of 1956 (1956 Act).

[10]The Federal-Aid Road Act of 1916 required states to form a Highway Department in order to be eligible for federal matching funds [36].

The 1956 Act was a powerful federal response to mid-century post-war growth and suburbanization in America, creating a funding and revenue disbursement framework that proved successful at building out the nation's vast interstate highway network in a relatively short period of time. Title II of the 1956 Act, the Highway Revenue Act, included two key provisions. First, Congress chose to fund the federal share of national transportation infrastructure with a gas tax, deliberately rejecting road pricing as all or part of the funding approach. Second, the Act provided stakeholders the assurance that gas tax and other revenues imposed by the new law would be dedicated solely to pay for national transportation needs. In furtherance of this commitment, the 1956 Act created a Highway Trust Fund, and mandated that all revenue from taxes on fuels (and certain ancillary revenue sources) be dedicated solely to the new Trust Fund for use on the national highway system. The final enactment raised the federal gas tax to three cents per gallon. It also raised additional revenue for the Trust Fund by imposing a new tax on gross vehicle weight. The initial annual heavy-vehicle use tax imposed a tax of $1.50 per one thousand pounds when gross vehicle weight exceeded 26,000 pounds [38]. The federal gas tax was last increased in 1993, to the current 18.4 cents per gallon.[11]

The creation of the Highway Trust Fund helped cast the gas tax as a "user fee" by imposing a federal mandate connecting the payment of a fuel tax (tied to a driver's vehicle miles traveled and the fuel efficiency of the vehicle) to eventual expenditure on federal-aid highways.[12] The Highway Trust Fund has sometimes been misunderstood as a federal commitment to fund all national transportation needs. It does not. Rather, the Fund is simply (as described by the Congressional Budget Office) a "holding device for dedicated funds" [38]. As history has shown, Highway Trust Fund collections alone are often insufficient to pay for national transportation construction, operation and maintenance needs.

At the state level, a gas tax to fund transportation construction and improvement projects has been in use since the first decades of the last century. Most continue to rely on state gas tax revenue to support "pay-as-you-go" projects and serve as stable funding support for the issuance of, and repayment of debt service on, revenue bonds that fund significant capital projects. Some states rely on gas tax revenues for as much as 70-80% of their total state share of transportation funding, including as security for the repayment of principal and debt service on infrastructure bonds (Ulrik Boesen 2021).

[11]Federal tax on Diesel fuel is 24.3 cents per gallon. For each gallon of gasoline purchased, there is an 18.4 cent federal tax. 18.3 cents is transferred to the Highway Trust Fund, and .1 cent goes to the Leaky Underground Storage Tank Trust Fund [37].

[12]For this section generally, see [38].

# An Opportune Moment

As we discuss later in this report, federal gas tax receipts have failed to fully fund the Highway Trust Fund consistently since 2008. At the state level, state gas tax receipts are insufficient to fund all transportation investment needs, and utterly fail to take into account the societal costs of vehicular mobility [39]. As EVs are increasingly adopted, and gas tax revenues decline, this already inadequate funding resource will be even less able to meet the nation's basic transportation infrastructure needs or provide the type of security that capital markets investing in transportation bonds have been accustomed to. **A major transportation funding crisis is imminent unless policymakers and stakeholders address the coming revenue disruption proactively.**

How imminent is imminent? A 2023 ICCT analysis of the effects of the Inflation Reduction Act's EV purchase tax credits, and anticipated EV technology improvements, concluded that "rapid electrification" of the US vehicular fleet is likely over the coming decade, predicting that by the end of the IRA tax credits in 2032, EV sales share in the light-duty sector will range from 56% to 67%. The same analysis predicted a roughly fifty percent EV adoption rate range during the same period for the US heavy-duty fleet [17].

Our system dynamics model (see Chapter 3) shows that all things being equal, gas tax collections will fall by almost half as EV adoption gradually increases in line with currently set state requirements that all new car sales be restricted to EVs from 2035, and adoption rates reach approximately 40% of the total US light vehicle fleet [40]. This is despite Americans holding onto their cars for longer, with the most recent data (2022) revealing that car owners keep their vehicles in average for 12.2 years [41]. If measures to hasten the fleet turnover are introduced via federal or state initiatives like a "cash for clunkers" incentive for owners of older cars, the pace of gas tax revenue losses will increase quite significantly as the model demonstrates. The bottom line: **If no action is taken before then to begin filling the erosion of the gas tax, US gas tax revenue loss under this reasonably likely scenario is almost $25B by 2035** (federal and state volume weighted average).

One thing is certain: the more successful we are in reducing the use of fossil fuels to power US automobility, the faster we move to a potential transportation revenue crisis. This is therefore an opportune moment to consider how to adequately fund transportation needs across modes in a way that is equitable, stable, and scalable over time.

# Existing Conditions: US Transportation Revenue Sources & Spending

## The Federal Context

The federal gas tax has been the cornerstone of national transportation funding since the mid-20th century. It has significant benefits, including its relative ease of administration, its legibility, and the perception of its fairness because of its relationship to use (the more vehicle miles traveled, the more gas tax paid). It also has significant drawbacks, including its regressiveness, its instability (albeit transient) during times of economic slowdowns or societal disruptions, and its inability (due to deliberate federal policy) to keep pace with inflation and increasing fleet efficiency standards.

The federal gas tax rate is currently 18.4 cents per gallon for gasoline and 24.4 cents per gallon for diesel. Unchanged since 1993, these taxes are not indexed to keep pace with inflation, and therefore their purchasing power over time has steadily declined.[13] For example, the current 18.4 cent per gallon federal gas tax, had it been adjusted to inflation, would be approximately 39.6 cents in 2023. This represents a 54% decline in its purchasing power, and if one considers that 18.4 cents as a fraction of the 1993 per-gallon cost of gasoline was a significantly higher tax rate as compared to the same rate applied to the price of gas today, the effective per-gallon rate of decline is orders of magnitude higher than 55% [43].

Gasoline prices (largely driven by global oil cartels and oil companies) have also become a highly charged political topic in the United States, which makes legislators wary of addressing gas tax inadequacies [44, 45]. Indeed, Congress has increased the federal gas tax only four times since 1956 [42]. Despite increasing vehicle miles traveled nationally, the combination of vehicle fuel efficiency gains (largely tied to federal government "CAFE"—corporate average fuel efficiency—targets) and a static gas tax has left the Highway Trust Fund unable to keep pace with growing transportation infrastructure needs.

In this century, the Highway Trust Fund has regularly relied on funds transferred by Congress to fill shortfalls. Since fiscal year 2008 and continuing up to the present, the Highway Trust Fund (HTF) has consistently spent more than the revenues it has generated (Figure 4). In order to ensure timely payment of the Trust Fund's obligations, Congress has enacted various laws that involve transferring funds from alternative sources into the HTF (see Figure 5). While the majority of these funds have originated from the US Treasury's General Fund, certain amounts have also been redirected from other accounts. For instance, in recent years, Congress has

[13] Congress has increased the federal gas tax only four times since 1956 [42].

allocated additional funding from the Leaking Underground Storage Tank Trust Fund to support the HTF. During the covid pandemic, Congress sustained highway spending by transferring $100.4 and $31.2 billion of general revenues to the Highway Trust Fund and Transit Trust Fund, via the Continuing Appropriations Act in 2021 (and Other Extensions Act) and the Infrastructure Investment and Jobs Act in 2022 [3].

(in billions of dollars; reflects sequestration for FY2013 and FY2014)

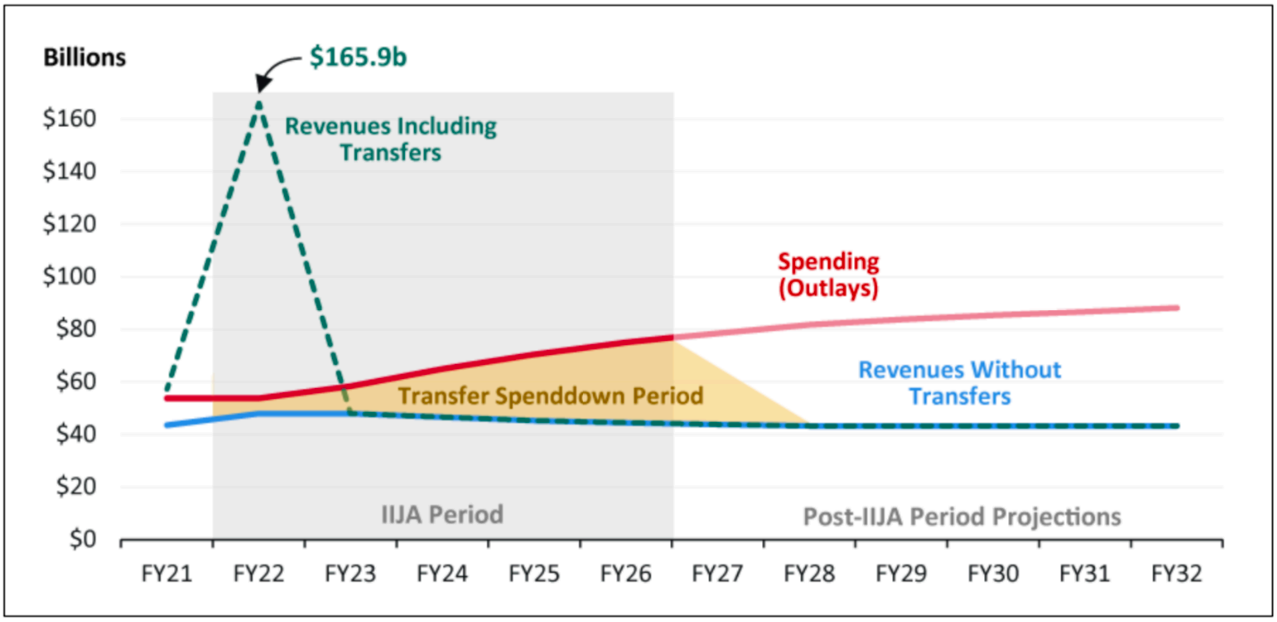
| Public Law | Effective Date | Highway Account | Mass Transit Account | Highway Trust Fund (HTF) Total |
|---|---|---|---|---|
| P.L. 110-318 | Sept. 15, 2008 | 8.017 | 0 | 8.017 |
| P.L. 111-46 | Aug. 7, 2009 | 7.000 | 0 | 7.000 |
| P.L. 111-147 | Mar. 18, 2010 | 14.700 | 4.800 | 19.500 |
| P.L. 112-141 | July 6, 2012 | | | |
| From LUST | For FY2012 | 2.400 | 0 | 2.400 |
| From general fund | For FY2013 | 5.884 | 0 | 5.884 |
| From general fund | For FY2014 | 9.651 | 2.042 | 11.693 |
| P.L. 113-159 | Aug. 8, 2014 | 7.765 | 2.000 | 9.765 |
| From LUST | Aug. 8, 2014 | 1.000 | 0 | 1.000 |
| P.L. 114-41 | July 31, 2015 | 6.068 | 2.000 | 8.068 |
| P.L. 114-94 | | | | |
| From general fund | Dec. 4, 2015 | 51.900 | 18.100 | 70.000 |
| From LUST | Dec. 4, 2015 | 0.100 | 0 | 0.100 |
| From LUST | Oct. 1, 2016 | 0.100 | 0 | 0.100 |
| From LUST | Oct. 1, 2017 | 0.100 | 0 | 0.100 |
| P.L. 116-159 | Sept. 25, 2020 | 10.400 | 3.200 | 13.600 |
| P.L. 117-58 | Nov. 15, 2021 | 90.000 | 28.000 | 118.000 |
| General fund total | | 211.385 | 60.142 | 271.527 |
| LUST fund total | | 3.700 | 0 | 3.700 |
| Total transfers | | 215.085 | 60.142 | 275.227 |

**Sources:** Public laws as indicated. Sequestration amounts from the FHWA.

**Notes:** Transfers are from the Treasury's general fund unless otherwise indicated. LUST refers to the Leaking Underground Storage Tank Trust Fund administered by the Environmental Protection Agency.

**Figure 4:** Transfers to the Highway Trust Fund [42]

The inability of the gas tax to satisfy US federal and state transportation infrastructure funding needs was highlighted in a 2021 USDOT report on the Status of the Nation's Highways, Bridges and Transit: Conditions and Performance Report , assessing the backlog of needed improvements to U.S. transit systems, including vehicles and facilities, as approximately $100 billion. That same report determined that the U.S. would need to increase annual road, highway and bridge investment by 55% to make significant improvements in road and bridge conditions, reduce traffic congestion, and improve traffic safety, while a 31% hike in annual transit investment would be required to make significant improvements in the condition of transit vehicles and facilities and increase ridership. Because transportation infrastructure deterioration accelerates over time, the cost of deferral of maintenance and repair activities due to lack




**Source:** Figure created by CRS based on CBO, *Highway Trust Fund Projections: May 2023 HTF Baseline 2022-2033*. Data for FY2021 and FY2022 are actual revenues and outlays.

**Notes:** Shows highway and mass transit accounts combined. Revenues include interest on Highway Trust Fund (HTF) balances. The shading between spending and revenues indicates the period that the HTF balance is maintained by Infrastructure Investment and Jobs Act (IIJA) transfers from the Treasury general fund.

**Figure 5:** Projected Highway Trust Fund Funding Gap [42]

of funding comes with severe consequences. A 2022 report on transportation funding needs found that every dollar of deferred maintenance ends up costing four-to-five dollars in eventual repair costs. The passage of the IIJA was meant, in part, to begin addressing this backlog but the IIJA alone cannot and will not satisfy the array of legitimate transportation needs faced by states across the nation.

Even with the IIJA's infusion of $118 billion from the general fund to the Highway Trust Fund, the Trust Fund's systemic imbalance will return. The Congressional Budget Office projects that the Highway Trust Fund will remain financially stable until FY 2027, marking the conclusion of IIJA spending authorizations. By the second quarter of FY 2028, it is expected that the combined balance in the HTF will be exhausted without a reduction in the size of the surface transportation programs, an increase in revenues, or further general fund transfers (Figure 6).

(fiscal years, in billions of dollars)

| | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 |
|---|---|---|---|---|---|---|
| Start-of-year HTF balance[a] | 49.27 | 14.53 | -23.83 | -64.27 | -106.34 | -149.71 |
| Revenues minus outlays | -34.74 | -38.36 | -40.44 | -42.07 | -43.37 | -44.91 |
| End-of-year HTF balance/shortfall | 14.53 | -23.83 | -64.27 | -106.34 | -149.71 | -194.62 |

**Source:** CBO, *Highway Trust Fund Projections: May 2023, HTF Baseline 2022-2033*.

**Notes:** Includes combined figures from both the highway account and the mass transit account. Numbers may not add due to rounding of the underlying data.

a. Under current law, the HTF cannot incur negative balances.

**Figure 6:** Projected Negative Cash Flow and Highway Trust Fund Cumulative Shortfalls [42]

## The State Context

Motor fuel taxes make up a large proportion of revenue available for investments in and operation of transportation assets and infrastructure in most states. On average, the gas tax makes up 53% of state infrastructure revenue (ranging from a high of 82% in Louisiana to a low of 14% in New Jersey). In comparison, tolls and charges only account for a very small proportion of total revenue. In FY 2018, only four states (California, Indiana, Montana, and Tennessee) raised enough revenue to cover their highway spending [46] (see Table 1a and 1b).

**Table 1a:** Share of state & local road spending covered by state & local tools, user fees, & user taxes (FY2018) [46]

| State | State Infrastructure Revenue (in millions) | Motor Fuel Tax Revenue as % of Infrastructure Revenue | License Revenue as % of Infrastructure Revenue | Tolls and Charges as % of Infrastructure Revenue | State Share of Highway Spending (in millions) | % of Highway Spending Funded with Transportation Taxes, Licenses, and Fees |
|---|---|---|---|---|---|---|
| Alabama | $1,005 | 74% | 24% | 1% | $2,096 | 48% |
| Alaska | $181 | 26% | 32% | 42% | $1,050 | 17% |
| Arizona | $1,122 | 77% | 21% | 2% | $1,897 | 59% |
| Arkansas | $666 | 74% | 25% | 1% | $1,475 | 45% |
| California | $11,994 | 53% | 39% | 8% | $12,029 | 100% |
| Colorado | $1,777 | 38% | 39% | 23% | $2,772 | 64% |
| Connecticut | $735 | 66% | 32% | 1% | $1,624 | 45% |
| Delaware | $515 | 26% | 11% | 63% | $584 | 88% |
| District of Columbia | $66 | 40% | 59% | 1% | $433 | 15% |
| Florida | $7,256 | 50% | 20% | 30% | $9,150 | 79% |
| Georgia | $2,286 | 79% | 17% | 4% | $3,041 | 75% |
| Hawaii | $589 | 30% | 69% | 1% | $700 | 84% |
| Idaho | $612 | 59% | 33% | 7% | $735 | 83% |
| Illinois | $4,587 | 33% | 36% | 31% | $6,351 | 72% |
| Indiana | $1,815 | 78% | 21% | 1% | $1,609 | 100% |
| Iowa | $1,359 | 49% | 50% | 0% | $2,414 | 56% |
| Kansas | $852 | 54% | 30% | 16% | $1,300 | 66% |
| Kentucky | $994 | 71% | 22% | 8% | $1,568 | 63% |
| Louisiana | $769 | 82% | 11% | 7% | $1,396 | 55% |
| Maine | $513 | 49% | 22% | 29% | $785 | 65% |
| Maryland | $2,347 | 46% | 21% | 32% | $3,073 | 76% |
| Massachusetts | $2,240 | 34% | 20% | 46% | $2,820 | 79% |
| Michigan | $2,914 | 50% | 45% | 5% | $3,561 | 82% |
| Minnesota | $1,956 | 48% | 42% | 10% | $4,155 | 47% |
| Mississippi | $623 | 71% | 25% | 3% | $1,229 | 51% |
| Missouri | $1,064 | 67% | 30% | 3% | $1,561 | 68% |
| Montana | $447 | 57% | 36% | 7% | $434 | 100% |

**Table 1b:** (Cont.) Share of state & local road spending covered by state & local tools, user fees, & user taxes (FY2018) [46]

| State | State Infrastructure Revenue (in millions) | Motor Fuel Tax Revenue as % of Infrastructure Revenue | License Revenue as % of Infrastructure Revenue | Tolls and Charges as % of Infrastructure Revenue | State Share of Highway Spending (in millions) | % of Highway Spending Funded with Transportation Taxes, Licenses, and Fees |
|---|---|---|---|---|---|---|
| Nebraska | $618 | 60% | 33% | 7% | $1,322 | 47% |
| Nevada | $836 | 75% | 24% | 1% | $1,717 | 49% |
| New Hampshire | $419 | 44% | 20% | 37% | $587 | 71% |
| New Jersey | $3,376 | 14% | 19% | 67% | $3,983 | 85% |
| New Mexico | $460 | 50% | 47% | 3% | $572 | 80% |
| New York | $7,836 | 21% | 20% | 59% | $13,035 | 60% |
| North Carolina | $2,995 | 66% | 32% | 2% | $4,639 | 65% |
| North Dakota | $336 | 59% | 37% | 5% | $1,150 | 29% |
| Ohio | $3,162 | 60% | 29% | 11% | $4,608 | 69% |
| Oklahoma | $1,586 | 31% | 49% | 20% | $1,931 | 82% |
| Oregon | $1,231 | 47% | 45% | 8% | $1,581 | 78% |
| Pennsylvania | $6,004 | 56% | 20% | 24% | $9,079 | 66% |
| Rhode Island | $147 | 54% | 14% | 32% | $316 | 47% |
| South Carolina | $1,211 | 53% | 35% | 12% | $1,642 | 74% |
| South Dakota | $316 | 59% | 37% | 4% | $666 | 47% |
| Tennessee | $1,614 | 67% | 33% | 0% | $1,603 | 100% |
| Texas | $8,591 | 43% | 32% | 25% | $11,542 | 74% |
| Utah | $737 | 68% | 30% | 2% | $1,666 | 44% |
| Vermont | $158 | 52% | 46% | 1% | $453 | 35% |
| Virginia | $2,756 | 40% | 25% | 35% | $4,485 | 61% |
| Washington | $3,525 | 49% | 36% | 16% | $3,717 | 95% |
| West Virginia | $600 | 75% | 1% | 24% | $846 | 66% |
| Wisconsin | $1,777 | 59% | 30% | 11% | $3,936 | 45% |
| Wyoming | $238 | 48% | 48% | 5% | $410 | 58% |
| U.S. | $101,773 | 49% | 30% | 21% | $145,331 | 70% |

States rely on gas tax revenues for both pay-as-you-go transportation projects as well as for the payment of principal and interest on transportation bonds issued for large capital projects. These data suggest the magnitude of the imminent depletion of gas tax revenues at the state level, and the unavoidable challenge facing state decision makers as they seek to advance the transition to electric vehicles while also ensuring a continuation of financial resources necessary to fund essential infrastructure projects and transport policy objectives. Figures 7a and 7b show the dimension of dependence on gas tax revenues relative to other revenue sources in twelve states.

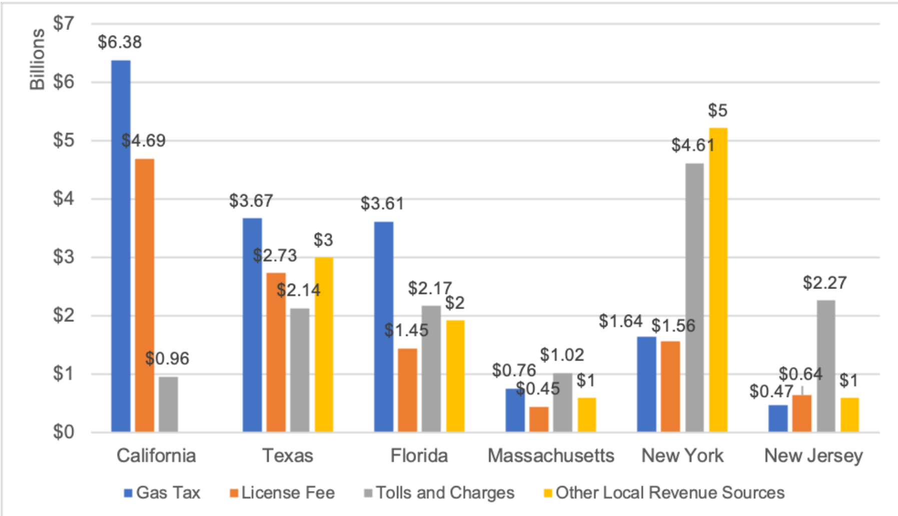



**Figure 7a:** Breakdown of local revenue sources in CA, TX, FL, MA, NY, and NJ (data source: [2])

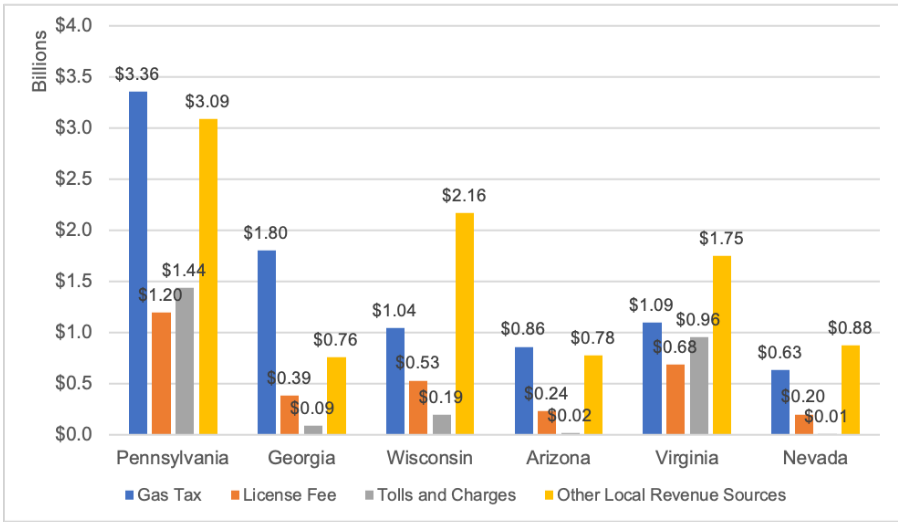



**Figure 7b:** Breakdown of local revenue sources in PA, GA, WI, AZ, VA, and NV (data source: [2])

# CHAPTER 2 | FRAMEWORK FOR ASSESSING ALTERNATIVES TO THE GAS TAX

## Framework for Assessing Alternatives to the Gas Tax

We consider the question of revenue alternatives by proposing a highly adaptable framework that reflects policy choices most state decision makers will likely confront as they determine their pathway to replacing the gas tax. States will be drawn to new revenue alternatives that can reasonably satisfy three conditions: raising revenue sufficient to fill the gas tax gap, promoting positive behaviors, and receiving high levels of public and political acceptance.

We assess these revenue alternatives through a **performance** lens and an **efficiency** lens. The performance lens considers (i) ease of administration, (ii) resistance to easy evasion, (iii) stability over time, and (iv) fairness, with equity being an overarching consideration. The efficiency lens considers how well or poorly certain revenue alternatives are positioned to address key negative externalities of vehicular mobility: (i) traffic congestion, (ii) road wear and tear, (iii) safety, and (iv) emissions.

The efficiency lens analysis looks at the inherent attributes of these revenue alternatives without delving into how the money will be spent. Assessing gas tax alternatives through an **expenditure** lens is beyond the scope of this report, but could be a useful way to model outcomes based on strategic investments geared toward reducing the negative impacts of vehicular externalities like traffic congestion, particulate emissions, public safety and infrastructure wear and tear. The expenditure outcomes and their consequential results on parameters such as driving behavior, safety, congestion can be significant and will need to be studied in future research.

Many states, particularly those with large, dense urban/metropolitan areas, will likely be motivated to explore gas tax replacement policies that are more robust than a simple dollar-for-dollar replacement of lost fossil fuel revenues. These states will look at reducing or mitigating the negative externalities of vehicular mobility, factors that persist even with an all-EV vehicular system. These externalities have significant societal and economic impacts that are unrecovered by the legacy gas tax revenue framework. We assume that each jurisdiction will evaluate its unique revenue needs and policy values and determine the right individual or combination of methods to meet those needs.

As a methodology, we look at two categories of transportation-related revenue sources: those that assess the *ownership* of a vehicle, and those that assess the *use* of a vehicle. This methodology is not novel; it derives from how the transportation system is funded today. States generally assess ownership through sales or excise taxes and registration fees, while the federal government and all states impose a user fee in the form of the gas tax.[14] For purposes of public and legislative acceptance, identifying alternatives to the gas tax may be best undertaken as a logical reformulation of established methods rather than an exploration of untested or cutting-edge devices. Any replacement of the gas tax will be required to pass muster not simply as a stable and sufficient revenue source but also as a viable alternative that can gain popular acceptance and political support.[15]

## Building Public Acceptance

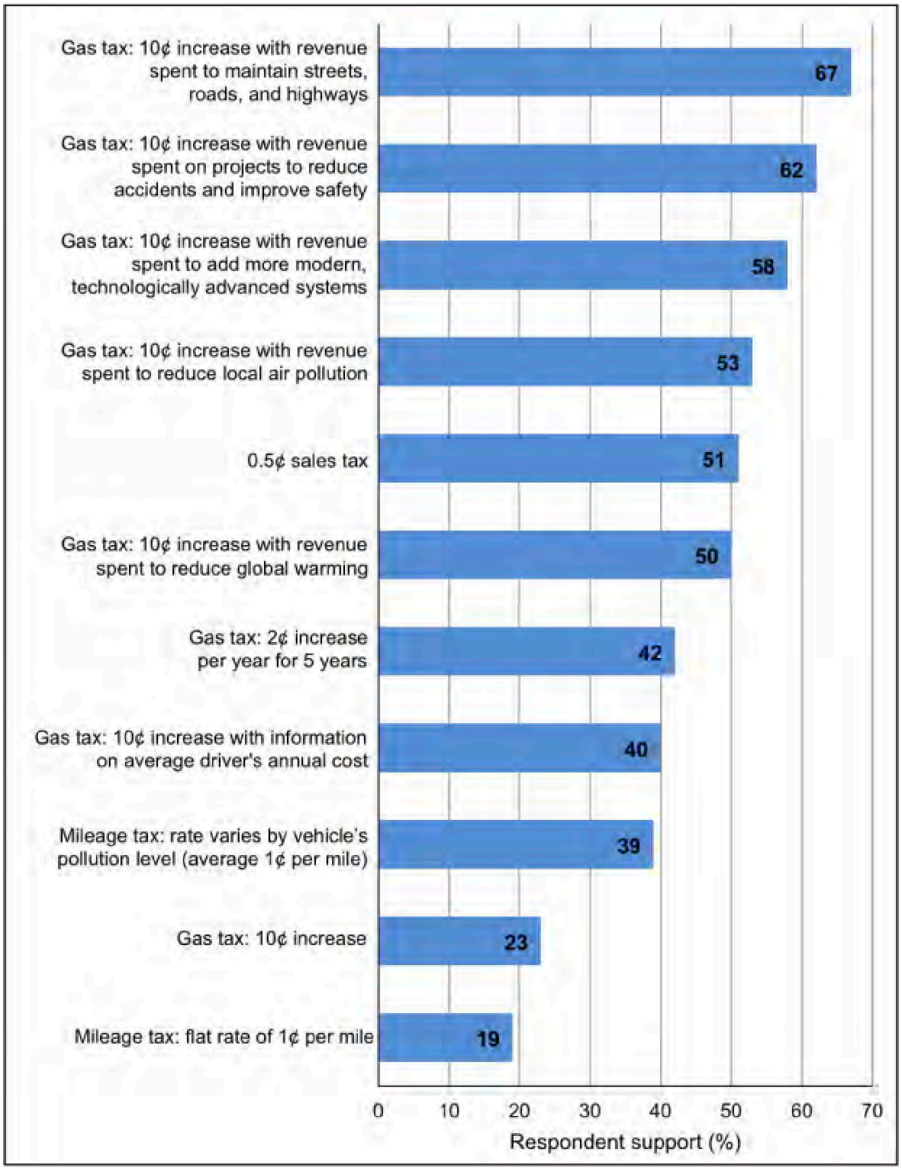
Political acceptance is an overarching consideration for any approach to replacing the gas tax. Drivers have adapted their behavior and attitudes to largely accept status quo revenue methods like annual registration fees and gas taxes. Generally with regard to public expenditure requirements, people are comfortable with the status quo and resist the feared losses of any disruption to the status quo. The "tendency to view any deviation from the status quo as an aversive loss" is a behavioral reality that decision makers will need to address [49, 50]. This loss aversion may lead many people to place more weight on their perceived loss (paying new taxes or charges) relative to the needs (the gas tax needs to be replaced) or gains (net new revenue dedicated to transportation needs can improve their access and journey experiences) associ-

[14]States have required motor vehicle owners to pay annual auto registration fees since the practice began in New York state in 1901. See [47].

[15]This informs our decision to focus on transportation related sources only. Reaching outside the transportation sector for revenue places the transportation sector in direct competition with many other sectors and stakeholders (public health, education and public safety to name a few) who depend on general fund revenues for their funding needs. Moreover, sales and income taxes are highly charged politically, see [48].

ated with new revenue sources. Replacing the gas tax will require effective political messaging about the status of gas tax revenues and the need to replace them, tied to the choices made by federal and state decision makers, ranging from a simple dollar-for-dollar replacement or a replacement plus net new revenue to fund policy goals that reflect transportation needs and societal values.

Despite general public acceptance of the gas tax as a form of generating transportation sector revenue, gas tax increases are generally unpopular, although the framing of proposed gas tax increases can move more people to support them. The Mineta Transportation Institute reviewed over 50 polls taken between 2005 and 2013 and found that when presented with a range of potential gas tax increase or other pricing scenarios, people reacted generally favorably when the proposed increase was tied to specific transportation benefits (see Figure 8 on the following page ).




*Note:* "Support" is the sum of those who said they strongly or somewhat supported the tax option.

**Figure 8:** Support Levels for the Tax Options Surveyed in 2013 (source: [51])

Certain strategies have been shown to have a positive effect on popular attitudes toward potentially unpopular enactments. A 2010 Harvard Business School analysis (Bazerman and Shu) suggested two notable strategies [49]. Policy bundling, for example combining a road pricing authorization with a series of enactments requiring investments in needed and potentially popular infrastructure improvement initiatives, could mitigate the loss aversion expected to be generated by the road pricing authorization alone [49]. Similarly, phasing or delaying implementation of new revenue approaches can be a "useful strategy for policymakers who are trying to bolster support for policies that people feel they should support but do not want to support" [49].

A 2016 study of the introduction of a congestion road pricing charge in Gothenburg, Sweden, revealed that while only about 33% of the public supported the charge prior to implementation, about 50% supported the initiative post-implementation. This change in attitude was attributed to riders experiencing the system as less negative and easier to use than they had expected. This assumes a jurisdiction with the political will to implement a congestion charge even with minority public support, but the outcome demonstrates that smooth operations and effective messaging can overcome initial opposition by reducing the loss aversion experienced by most people prior to implementation [52].

A 2013 study of Shanghai's vehicle license auction policy is informative. Shanghai's vehicle control policy utilizes monthly license auctions to limit new car totals. The authors of the study found that maximum public acceptance could be realized if the license auction was tied explicitly to congestion reduction policies and the auction process itself was made more transparent. The authors recommended specific actions to bolster public support for the license auction policy, including improving the overall transparency of the auction process and restricting vehicle use in congested areas [53]. Figure 9 and 10 illustrate the positive effects of linking the unpopular license auction process with traffic congestion policies.

State decision makers will also be mindful of studies that have shown that public acceptance of taxes, charges or fees is tied in part to whether the assessment is opaque rather than transparent [54]. The factor of salience is important and highly relevant in an environment where many of the gas tax alternatives, such as road pricing or VMT, can be assessed as a technology-driven transaction, thus removing the pre-electronic irritant of stopping to pay cash at a toll booth.

Replacement revenue for the gas tax can come from transportation sources and non-transportation sources. Decision makers will need to decide whether the imminent reductions, and eventual

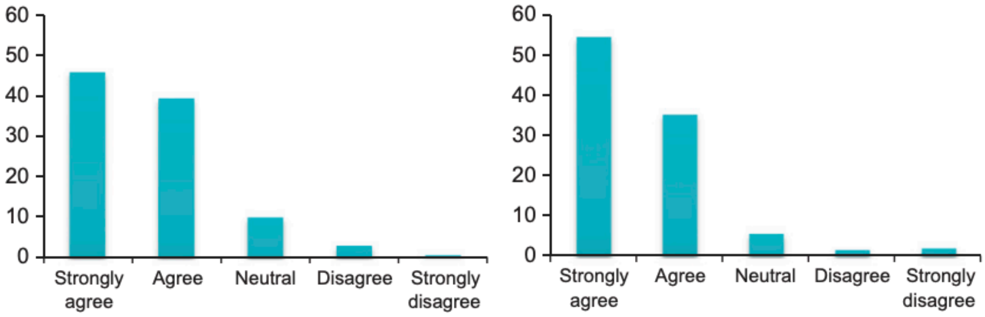



**Figure 9:** Perception of current congestion levels (left) and need for further government actions on congestion mitigation (right) [53]

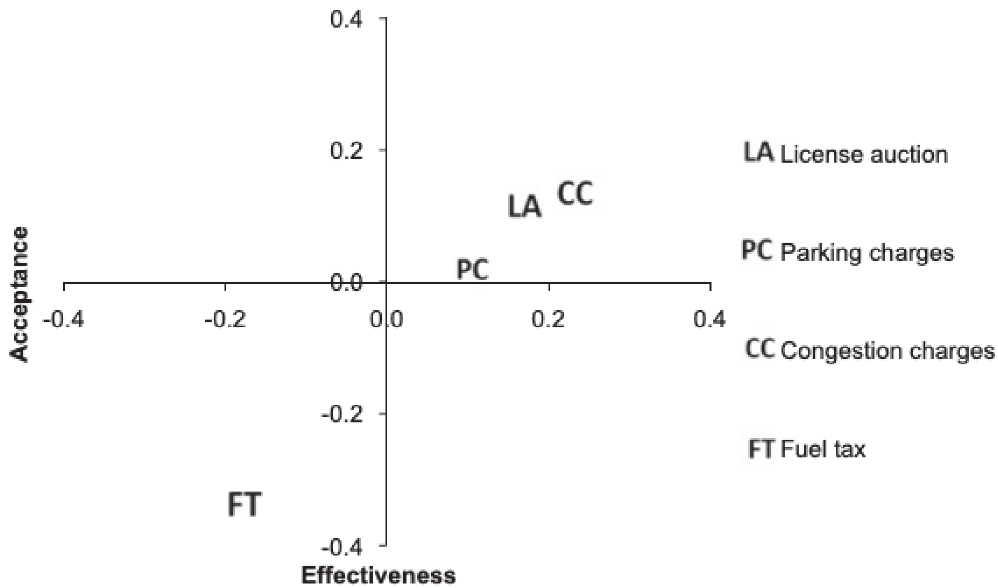



**Figure 10:** Perception of current congestion levels (left) and need for further government actions on congestion mitigation (right) [53]

loss, of gas tax revenues should be addressed by looking solely or primarily to transportation sources (thereby following the use-based premise of the gas tax), or whether they wish to include non-transportation sources of revenue in the mix (e.g. sales or income taxes). Studies have shown that political leaders who introduce non-transportation revenue increases pay a penalty at the ballot box [48].

States seeking to connect transportation revenue to promoting behavior in line with societal needs or values (e.g., reducing traffic congestion or promoting a more multi modal transportation system) will also be drawn to transportation source revenue as a preferred method of replacing gas tax revenues. Our focus in this report is therefore on transportation sources of revenue, as we view this as the most likely pathway for most decision makers to take.

It is not within the scope of this report to suggest how elected officials should frame their messaging to the public. We point out the looming need for those officials to begin the inevitable process of replacing gas tax revenues.

## Assessing Vehicle Ownership | Fixed or Variable Fees

All states charge various registration and title fees, which could be increased to replace all or a portion of lost fuel tax revenue [55]. A fee or fees imposed on the vehicle could be structured in various ways.

- A **point-of-sale "one-time" fee, fixed or variable** depending on policy choices. Such fixed fees already exist in various forms around the world [56, 57].
- A **periodic (annual) fixed fee** assessed as an annual registration fee based on a calculation designed to raise revenue sufficient to, at a minimum, replace lost gas tax revenues. Such a calculation could be based on an amount representing the average gas tax paid by drivers in a certain baseline year, adjusted for factors like VMT trends and/or inflation.
- **Variable fees tied to vehicle characteristics** like size and weight, reflecting disparities in negative impacts on infrastructure and public safety.
- **New periodic fees.** For example, Shanghai implemented a License Plate Auction Program which manages vehicle numbers by auctioning a limited number of license plates to

prospective owners. Individuals bid for available plates, with the government determining the quantity for each auction. The highest bidders gain the right to register a vehicle with the won license plate, regulating ownership and distribution [57].

## Policy Considerations

A fixed fee charged at point of sale, or annually at registration, has many advantages. It is relatively easy to administer, highly resistant to evasion or leakage as payment is a precondition to ownership or the privileges of ownership, and can be structured to generate stable, robust and recurring revenue streams. A significant disadvantage is the potential for extremely high (and therefore politically and equitably unviable) fees if they are chosen as the sole or primary replacement of gas tax revenues. All things considered, fees on vehicle ownership, whether a one-time fee or an annual recurring fee (or both), are more likely to be a partial solution to filling the gas tax gap.

Ownership assessments are less useful as tools to discourage undesired behaviors or reduce negative externalities unless they are designed as variable fees. For example, the fee for a smaller light-duty vehicle might be set lower than the fee for a light-duty vehicle of greater size and weight. This would add some fairness to the charge as it would reflect some of the negative impacts of heavier vehicles on road infrastructure and public health and safety (see the discussion of weight impacts later in this chapter), and it would raise additional revenue for investments in that infrastructure.

Fixed fees do not perform well under a fairness or equity analysis. There is an inherent unfairness associated with fixed fees based on ownership insofar as they penalize the light or occasional driver and reward the heavy or frequent driver. A person who purchases a vehicle for the convenience of a weekly trip to purchase groceries or visit family or friends is charged as much as the person who drives to multiple destinations daily. Fixed fees will be highly regressive unless they are made means-tested to account for income differences.

Fixed fees for EVs already exist in many states (as a substitute for "lost" gas tax revenue), thus establishing a built-in framework to which car owners are accustomed. It is therefore an approach that benefits from its lack of novelty. Thirty-one states have laws requiring a special registration fee for plug-in electric vehicles. Eighteen of those states also assess a fee on plug-in hybrid vehicles. These fees are typically in addition to traditional motor vehicle registration fees. A full list of state EV registration fees can be found in Table 2a and 2b.

As mentioned earlier, fixed or variable fees might need to be set at levels that might be considered too high for public acceptance in order to singlehandedly replace the gas tax. Today, states with EV fees are not achieving even a minimum dollar-for-dollar replacement of lost gas tax revenues. We calculated the average annual gas taxes paid per vehicle in 2022 based on the fuel economy, the average annual miles, and the gas taxes of a vehicle by state. Table 2a and 2b show that even in states where the annual EV registration fees are imposed, the EV fees currently in place are not equivalent to what the driver would have paid, on average, in gas taxes for the same period.

The blue bars in Figure 11 show the ratio of annual EV fees collected to the average annual gas tax paid statewise. As of the time of writing of this report all states had a gap with the average annual gas tax collection per vehicle being higher. The gap in dollars is highlighted via the orange line on the secondary axis. States with a higher ratio of EV fees to gas tax have a lower gap.

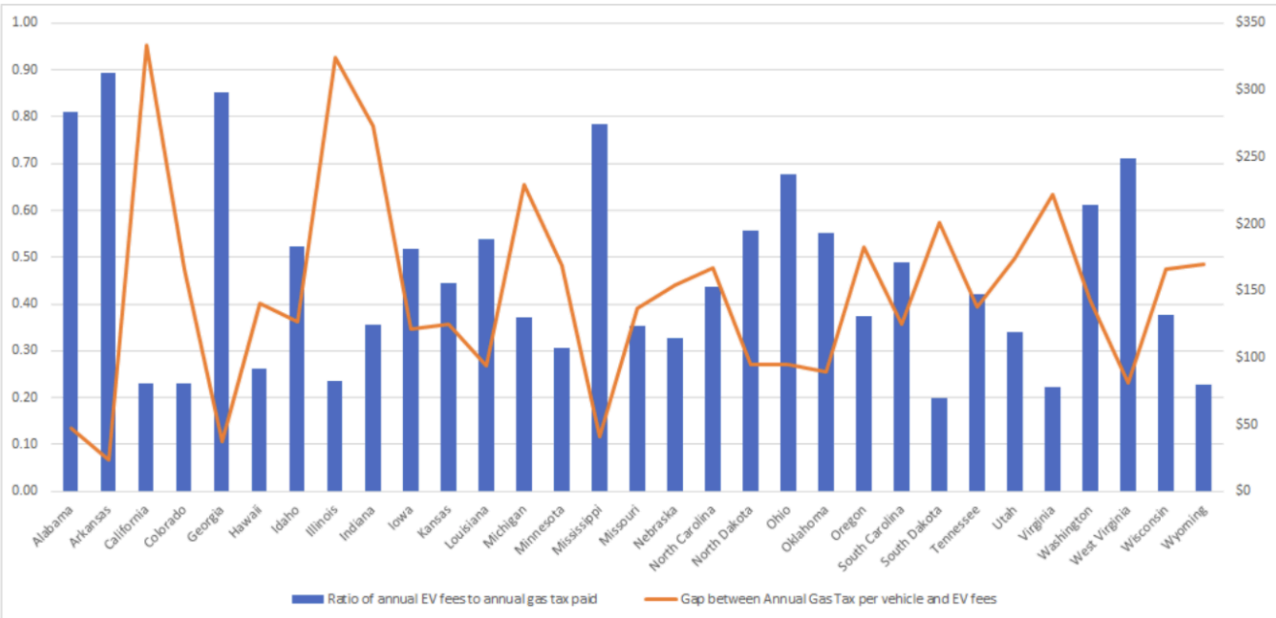



**Figure 11:** Gax tax v.s. EV fees

Even though EV fees currently do not serve as a dollar-for-dollar replacement of the gas tax paid per vehicle, there is some evidence that the adoption of EV fees have discouraged some from purchasing an EV, although this apparent disincentive for some consumers will be a transient phenomenon as state governments set fixed time mandates prohibiting the sale of new vehicles other than electric and hybrid vehicles [58].

**Table 2a:** Average annual gas taxes paid per vehicle and EV registration fees by state

| State | Average annual gas taxes paid per vehicle | EV registration fees |
|---|---|---|
| Alabama | $247 | $200 EV/$100 PHEV |
| Alaska | $142 | |
| Arizona | $194 | |
| Arkansas | $224 | $200 EV/$100 HEV |
| California | $433 | $100 EV (increase in accordance with the consumer price index) |
| Colorado | $216 | $50 EV/$50 PHEV |
| Connecticut | $225 | |
| Delaware | $215 | |
| District of Columbia | $271 | |
| Florida | $280 | |
| Georgia | $250 | $212.78 EV |
| Hawaii | $191 | $50 EV and PHEV and HEV |
| Idaho | $267 | $140 EV/$75 PHEV |
| Illinois | $424 | $100 EV |
| Indiana | $423 | $150 EV/$50 PHEV and HEV |
| Iowa | $251 | $130 EV/$65 PHEV |
| Kansas | $225 | $100 EV/$50 PHEV and HEV |
| Kentucky | $230 | |
| Louisiana | $204 | $110 EV/$60 HEV |
| Maine | $258 | |
| Maryland | $318 | |
| Massachusetts | $235 | |
| Michigan | $364 | $135 EV up to 8,000 lb; $235 EV over 8,000 lb; $47.50 HEV up to 8,000 lb; $117.50 HEV over 8,000 lb |
| Minnesota | $244 | $75 EV |
| Mississippi | $191 | $150 EV/$75 HEV |
| Missouri | $212 | $75 EV/$37.50 PHEV |
| Montana | $271 | |
| Nebraska | $229 | $75 EV |
| Nevada | $219 | |
| New Hampshire | $219 | |
| New Jersey | $316 | |
| New Mexico | $193 | |
| New York | $187 | |
| North Carolina | $297 | $130 EV |
| North Dakota | $215 | $120 EV/$50 PHEV |
| Ohio | $295 | $200 EV and PHEV/$100 HEV |
| Oklahoma | $199 | $110 EV/$82 PHEV, up to 6,000 lbs; $158 EV/$118 PHEV, 6,000 – 10,000 lbs; $363 EV/$272 PHEV, 10,000 – 26,000 lbs; $2250 EV/$1687 PHEV, over 26,000 lbs |
| Oregon | $293 | $110 EV |

**Table 2b:** (Cont.) Average annual gas taxes paid per vehicle and EV registration fees by state

| State | Average annual gas taxes paid per vehicle | EV registration fees |
|---|---|---|
| Pennsylvania | $400 | |
| Rhode Island | $278 | |
| South Carolina | $245 | $120 biennial fee EV/$60 biennial fee HEV |
| South Dakota | $251 | $50 EV |
| Tennessee | $238 | $100 EV |
| Texas | $199 | |
| Utah | $264 | $90 EV/$15 HEV/$39 PHEV |
| Vermont | $287 | |
| Virginia | $286 | $64 EV |
| Washington | $367 | $225 EV/$75 PHEV and HEV |
| West Virginia | $281 | $200 EV/$100 PHEV |
| Wisconsin | $266 | $100 EV/$75 HEV |
| Wyoming | $220 | $50 EV annual |

Note: The average annual gas taxes paid per vehicle is calculated based on a vehicle with an average fuel economy of 22.2 mpg driven 11,520 miles in 2019. Gas taxes include federal and state gasoline tax, along with other per-gallon fees, such as leaking underground storage tank fees in July 2022.

Of course, whether EV fees alone will be able to fully replace lost gas tax revenue depends on the political appetite to impose what might be a large one-time or recurring fee, and the political viability of an approach that has the inherent unfairness of not being tied to use. To underscore the potential weakness of an approach that relies solely on EV fees, Harto, C., & Baker-Branstetter, S. (2019) estimated that if EVs achieve an 11 percent market share by 2025, existing and proposed EV fees will generate only an estimated average of less than 0.3 percent of the expected state highway revenues [58]. Slowik, P., & Lutsey, N. (2018) estimated that the current electric vehicle fees on average account for far less than 0.1% of annual motor fuel sales tax revenues as shown in Figure 12 [59].

In any event, if a state chooses to adopt only an "assess ownership" approach to replacing the gas tax, the current data on EV fees indicates that the level of such fees may need to be adjusted upward to make up existing gaps between the revenues generated versus what the owner would have paid as annual gas tax revenues.

| State | Motor fuel sales tax revenue in 2016 (million) | 2017 electric vehicle fee (per vehicle) | Approximate annual revenue from electric vehicle fee (million) | Electric fee revenue as percent of annual motor fuel sales tax revenue |
|---|---|---|---|---|
| **Colorado** | $667 | $50 | $0.21 | 0.031% |
| **Georgia** | $1,655 | $200 | $0.51 | 0.031% |
| **Michigan** | $1,029 | $135 | $0.55 | 0.053% |
| **Missouri** | $717 | $75 | $0.08 | 0.012% |
| **North Carolina** | $1,936 | $100 | $0.21 | 0.011% |
| **Tennessee** | $898 | $100 | $0.10 | 0.011% |
| **Utah** | $420 | $44 | $0.05 | 0.012% |
| **Virginia** | $896 | $64 | $0.19 | 0.021% |
| **Washington** | $1,458 | $150 | $1.07 | 0.073% |

**Figure 12:** Annual fees for electric vehicles relative to state motor fuel sales tax [59]

# Assessing Vehicle Use | Road User Charging, VMT, Electricity Tax, Parking Pricing & Impacts Pricing

Assessing vehicle use is a method for charging drivers for two broad categories of impacts: occupancy impacts (use of a finite asset to the exclusion or inconvenience of others, most notably contributing to traffic congestion and pavement wear and tear) and public health and safety impacts (externalities based on vehicle weight and size, including degradation of transportation infrastructure and continued emissions, particularly particulate emissions). Each of the revenue generation instruments discussed in this section is geared toward responding directly to one or both of those categories of impacts.

## Road User Charging

Road user charging (RUC)[16] can be designed in many ways. In a conventional road pricing scenario, tolls are levied on limited access facilities. Before the introduction of electronic systems, tolls were collected at toll plazas that were located at designated highway exit or entrance points, or designed as barrier tolls at certain points along the limited access highway. These systems degraded traffic conditions by forcing vehicles to slow down and stop at the designated exit or barrier plazas. They also promoted animosity among many drivers who were required to stop and pay cash one or more times during each journey.

Since the late 20th century, electronic toll collection has reduced or eliminated the use of toll barriers and made the process of charging tolls and collecting toll revenue more efficient and opaque. Because RUC in this century is (or can be) largely implemented as an electronic system, it can remove negative impacts on traffic flow associated with toll plazas and avoid the political pitfalls of revenue collection transparency, while raising stable revenue for purposes of road operations and maintenance and other initiatives identified by policy makers.

Toll facilities are typically built and maintained without reliance on public funds. Instead, toll authorities raise private sector investment capital to support a system's infrastructure needs. Road pricing revenues provide security for payment of principal and interest on debt raised by private sector investors to support the construction or rehabilitation of toll facilities, and raise

[16]We use the shorthand "road user charging" in this report to cover road pricing of various types of vehicular infrastructure: roads, highways, tunnels, and bridges. Often referred to as "tolls", road pricing can take many forms.

sufficient additional revenue to cover "pay-as-you-go" costs of routine operation and maintenance activities.

Of course RUC can take many forms beyond conventional tolling. Public discussions regarding RUC are often cast in terms of "congestion pricing". Such pricing is designed as a traffic management technique, influencing traffic flow by dissuading some drivers from using a facility at certain times of day or under certain conditions. Congestion pricing can be put into place at certain fixed times of day when traffic is heaviest, or it can be designed as a more dynamic system that imposes a congestion charge when traffic flows reach a predetermined threshold. Several states, including Florida, Texas, California and Minnesota, have toll systems that are dynamic [60].

Some states use High Occupancy Toll (HOT) lanes as interventions to speed up some traffic while raising revenue from drivers willing and able to pay a premium for use of the designated lane.[17] HOT lanes are sometimes derided as "Lexus lanes" because of the equity consequences of allocating premium road space and better levels of service only to those who can afford to pay for it. Some leading proponents of HOT lanes note that drivers in areas without road pricing already pay a price in the form of time lost to congestion, and that free roads represent a subsidy to the wealthy (since they can afford the monetary costs of more driving) [62]. A HOT lane may exclude some drivers, but the time loss from congestion on free roads, and the monetary loss of fuel wasted, is suffered by low and high-income drivers alike.

Cordon pricing, another form of congestion pricing, is utilized in congested urban areas like London, Stockholm, and Singapore. New York City's proposed congestion pricing initiative is also based on a cordon pricing model. Cordon pricing is a fixed or variable fee charged once a delineated perimeter is crossed. Cordon pricing can be implemented as variable or fixed charge, but in all cases it is designed to reduce traffic within a highly congested urban district, usually one that has ample transit and rail alternatives for access.

## Policy Considerations

Unlike fixed or variable fees, RUC has the potential advantage of being more opaque to the payor, and therefore politically easier to implement. Traditional toll collection in the years before electronic tolling was a prime example of a highly transparent approach to road pricing,

[17] HOT lanes have been used in California, Minnesota, Colorado, and Washington [61].

which was unpopular. Drivers had to slow down, stop and take out cash to pay a toll booth attendant. In contrast, electronic tolling permits speeds to remain unaffected and payment to be transacted without human interaction. The salience effects of any RUC regime have an impact on public (and therefore political) acceptance [54].

RUC revenues can be dedicated to funding the infrastructure on which they are collected, which can ensure sufficient funding for routine (non-capital) maintenance and repair, enabling a higher level of overall system state of good repair. In addition, a portion of RUC revenues collected from congestion pricing or cordon pricing (or any form of dynamic pricing) can be dedicated to initiatives designed to encourage and support mode shift (e.g. improvements to transit and rail alternatives). Mode shift can be a useful approach to reducing traffic volume and other negative vehicular externalities while improving modal, regional and social equity.

While RUC can be dynamic, enabling adjustment of the charge to respond to time of day, location, and/or real-time roadway conditions, the flexibility of use of RUC revenues is both a legal and policy matter. Use of toll facility revenues are often restricted by enforceable contractual arrangements (often called trust agreements) that establish the terms and conditions governing the expenditure of toll revenues and guaranteeing repayment of the facility's construction or rehabilitation debt. The revenue use provisions of toll authority trust agreements are typically structured as a hierarchy of obligations, beginning with funding a debt repayment reserve requirement (referred to as meeting a "coverage test"), followed by funding operations and maintenance accounts, and then (in some cases) one or more flexible spending accounts. If this revenue bond authority model continues under a new broader-scale national RUC network, state law and/or trust agreement provisions would need to be drafted (or revised) to permit, for example, use of RUC revenues for investments that reduce traffic congestion by encouraging mode shift (e.g., funding intercity rail improvements).

RUC can potentially create equity issues, as lower-income drivers may be disproportionately affected by the charge, especially if they live in areas with limited transportation alternatives. These harms can be mitigated with means testing as previously discussed. It can also be mitigated by policy choices regarding how RUC revenues are spent and invested [62].

RUC requires building and maintaining the infrastructure needed to collect tolls, including toll booths, electronic toll collection systems, and other related infrastructure (electronic systems require gantries to read transponders, and a full backend IT system to process payments).This can reduce the net revenue available for transportation infrastructure projects.

## Policy Considerations: Federal Law Barriers to Road Pricing

Federal law currently acts as a serious impediment to states choosing to use road pricing on their respective interstate and non-interstate federal-aid highways. The federal law animus toward road pricing traces back to the Federal-Aid Road Act of 1916, which provided that "all roads constructed under the provisions of this Act be free from tolls of all kinds."[36]. Stakeholder antagonism toward road pricing (mostly driven by the trucking industry) during the Congressional debates and negotiations leading to enactment of the 1956 Interstate Highway Act helped enshrine into law the current restrictions on tolling the nation's vast interstate highway network [35]. Two years later, Congress codified the toll restrictions in a so-called "Freedom from Tolls" enactment.[18] As a result, the approximately forty-seven thousand mile interstate network includes about 2,900 miles of toll facilities, largely legacy state toll highways or bridges that were grandfathered into the interstate system through the 1956 Act [63].

The federal law barriers to road pricing are formidable. Codified in Title 23, Section 129 of the US Code, federal law prohibits the use of federal funding for the entire Interstate highway system as well as all non-Interstate Federal-aid highways, subject to certain exceptions. These exceptions can be encapsulated as permitting tolling on these highways only in the following circumstances: (1) for the construction of new highway projects, (2) for the reconstruction or replacement of existing highways, where reconstruction means "major improvements to pavements or interchanges, including replacement of the entire existing pavement structure . . . [or] the reconstruction of interchanges", or (3) additions to existing lane capacity. In practice, these exceptions require such massive investments in highway reconstruction, or environmentally prohibitive additions of lane capacity, that conversion to tolling is simply untenable in most circumstances.[19]

Even if a state could meet one of these exceptions for each of its Interstate and non-Interstate Federal-aid highways, there are further limitations on how the revenue can be used, depriving the state of critical flexibility in the use of the revenues.[20] These federal law limitations would,

[18] "Except as provided in Section 129 of this title with respect to certain toll bridges and toll tunnels, all highways constructed under the provisions of this title shall be free from tolls of all kinds."

[19] See, generally, [64].

[20] As specified in 23 U.S.C. 129(a)(3), these uses are limited as follows: debt service with respect to the projects on or for which the tolls are authorized, including funding of reasonable reserves and debt service on refinancing; a reasonable return on investment of any private person financing the project, as determined by the State or interstate compact of States concerned; or any costs necessary for the improvement and proper operation and maintenance of the toll facility, including reconstruction, resurfacing, restoration, and rehabilitation; If the toll facility is subject to a public-private partnership agreement, payments that the party holding the right to toll

if they continue, deprive states of the flexibility they would likely want to have in adopting gas tax replacement policies and approaches.

In addition to the statutory exceptions, Congress has authorized states to participate in a Value Pricing Pilot Program (VPPP). The VPPP is, by definition, a program designed to permit pilot projects that seek to demonstrate the efficacy of road pricing on reducing traffic congestion. There is no significant federal funding available for states choosing to use the VPPP, and the program is not actively soliciting new projects [65]. However, the program is enabling at least one significant pricing initiative, New York's congestion/cordon pricing plan. In May 2023, FHWA approved the release of New York's Final Environmental Assessment for its congestion pricing plan, as part of a required completion of a comprehensive review process under the National Environmental Policy Act (NEPA). FHWA has set completion of the NEPA process as a prerequisite for New York's VPPP application. Final approval was granted by FHWA in June, 2023. This process perhaps illuminates the full extent of the time, process and legal/regulatory issues states will face, assuming no changes in federal law, as they engage road pricing on federal-aid highways on a national scale as a strategy to replace all or part of anticipated gas tax revenue losses.[21] Whether, when and how these challenges will be addressed in ways that make transition to RUC easier and more viable will be key questions for Congress and others to answer.

Presumably the legal barriers in 23 USC Section 129 will be discontinued in a post-gas tax world. If the IIJA is any indication of Congressional intent, some form or forms of RUC are likely to be adopted as federal gas tax replacement measures at some point during the next decade. Sections 13001 and 13002 of Title III of the IIJA direct the US Transportation Secretary to establish both a road user charge program and an explicit VMT program. The IIJA commits a relatively modest amount of funding to support these pilots, but its candid acknowledgement that new approaches will be needed to "restore and maintain the long-term solvency of the Highway Trust Fund" is a major policy breakthrough.

For purposes of RUC, Section 13001 authorizes states, local governments and metropolitan

revenues owes to the other party under the public-private partnership agreement; and if the public authority certifies annually that the tolled facility is being adequately maintained, any other purpose for which Federal funds may be obligated by a State under title 23, United States Code.

[21]See, e.g.,Letter of New York FHWA Division Deputy Administrator to MTA and NYDOT, dated May 5, 2023; and Letter of Deputy FHWA Administrator to Congress dated February 16, 2022. https://ops.fhwa.dot.gov/congestionpricing/value_pricing/pubs_reports/rpttocongress/vppp20rpt/index.htm

planning agencies to serve as recipients of grant funding to implement RUC pilots.[22]. The law specifically asks the Secretary to ensure that RUC pilots are taking into consideration a number of factors including differing income groups and the differences between urban and rural drivers.[23] Significantly, revenues collected in connection with a pilot are not limited by the restrictions on toll revenue established in Title 23.

Section 13002 directs the Secretary to establish a pilot program to demonstrate a national motor vehicle per-mile user fee using volunteer participants. All revenue generated by the pilot would be deposited in the Highway Trust Fund. The Secretary must first establish and convene an advisory board to provide recommendations regarding implementation of the pilot. The board has not yet (as of June 2023) been formed, and therefore progress on advancing this VMT pilot has been slow.

These sections of the IIJA appear to be a pathway to a new federal funding paradigm that may enable a widespread national RUC or VMT system to provide both federal and state funding to replace all (or, more likely, a portion of) gas tax revenues. The outcomes of any pricing pilot programs implemented under the IIJA, including specific recommendations from lessons learned, will be transmitted to Congress within three years from the enactment of the IIJA (or, more likely, three years from the commencement of the pilots). Those outcomes and recommendations will help guide further Congressional action on the future of a RUC approach to solving at least a part of the Highway Trust Fund solvency concern.

### Other Potential Barriers to RUC

Beginning with the 1916 Federal-Aid Road Act, the entire thrust of the federal transportation funding system has been one of cost sharing. The 1956 Interstate Highway Act incentivized states to build the national Interstate Highway network by providing a 90% share of construction costs on a "cost-to-complete" basis.[24] This framework, which proved highly successful advancing the building of a vast national "super highway" system, meant that there was virtually no limit on the federal funding that would be contributed toward any given Interstate Highway construction project, as the final cost of the project was not capped but largely open-ended (with periodic FHWA reviews) and determined by the actual "cost-to-complete" it. In the 1970s and 1980s, federal funding at the same 90% matching level was approved for Interstate "4R"

[22] IIJA, Section 13001, B(4).
[23] IIJA, Section 10331, B(3)(a).
[24] See, generally, https://www.fhwa.dot.gov/infrastructure/intmaint.cfm.

projects (rehabilitation, reconstruction, resurfacing and restoration). States continue to rely on federal funding at 90 and 80 percent federal share levels for highway maintenance and improvement projects.

There will need to be clarity regarding the federal role in funding the national surface transportation system in a zero gas tax environment. The national Interstate system, and the national highway system, are largely fully constructed. States will likely desire to continue to benefit from significant federal funding support for expensive roadway rehabilitation and reconstruction projects, and for initiatives directed toward reducing vehicular externalities like traffic congestion. If the system of cost sharing is to continue, and if federal funding will continue to be tied at least in part to dedicated transportation-source revenue, then road pricing (or other alternatives) as a replacement for the gas tax will need to be structured so that the revenues will be shared as well.

With regard to RUC, questions abound: how to ensure nationwide interoperability? Will there be federal funding support for installation and maintenance of systems? If so, who procures the systems? Will there be federally-imposed limits on the use of RUC revenues? Will there be federally-imposed or state-imposed limits on the total RUC charge to drivers? None of these questions ought to pose insurmountable barriers to deploying a road pricing network (or any other alternative) to replace the gas tax, but they must be answered and resolved well in advance of developing a nationwide RUC system that can support a continuing federal role in highway cost sharing on a scale and in a manner similar to the system that has been in place since the mid-20th century.

## VMT Charge

A payment based on vehicle miles traveled (VMT) is a form of user fee that charges a driver based on the number of miles they travel on roads, bridges and tunnels, rather than the amount of fuel they consume. VMT pilots of varying scales have been deployed in several states, notably Oregon, in efforts to explore its efficacy and public acceptance. More recently, Congress in Title III Section 13002 of the IIJA has directed the USDOT Secretary to develop a national pilot to test this approach as a method of restoring the solvency of the Highway Trust Fund. The overarching challenge will be the development of a technology platform to charge and collect for individual vehicle miles traveled that (i) can be implemented at scale, (ii) is easy (and not prohibitively costly) to administer, (iii) is protective of reasonable personal privacy concerns, and (iv) is highly accurate and resistant to tampering or evasion.

The IIJA specifically identifies certain tools for VMT collection, including third-party on-board diagnostic devices (OBD-II), smartphone applications, telemetric data collected by automakers, and motor vehicle data obtained by car insurance companies.[25] Any approach would need to avoid the obvious pitfalls of a self-reporting system, like self-reporting odometer readings annually at time of registration, which will present a high likelihood of evasion. We discuss three VMT options below:

- OBD-II based: On-board diagnostics may offer a solution that is capable of resolving and responding to the four challenges outlined above. This would require new EV manufacture (as well as retrofits of prior owned EVs) to accommodate an on-board system that serves as a mileage metering device capable of cellular communications to maximize the functionality of the VMT system.[26] We expect that the national pilot deployed under Section 13002 of the IIJA will respond to these challenges and help the federal government and state governments more effectively assess the efficacy of VMT as a part of an overall transportation revenue solution. There is always the option of a manual OBD-II based mileage check (via the standardized 16 pin connectors present in all cars sold after 1996)[67] at the time of annual inspection/renewal, but as outlined above this can face implementation bottlenecks and have significant evasion risk tied to self-reporting. The manual method can possibly serve as a stopgap measure until the majority of cars can communicate this data wirelessly.
- Vehicle Telematics Data collected by the automaker: Software is increasingly becoming the major component in cars. OBD-II is not present in electric vehicles and most have their own proprietary diagnostic softwares and protocols. A recent BCG report observed that 2/3 of new cars sold now are connected vehicles; that is, they have embedded vehicle wireless telematics [68]. Data such as miles driven and average vehicle efficiency can easily be communicated to the automaker and (via various reporting frameworks) to public authorities for VMT calculation purposes. We note that while 2/3 of new cars are connected, the same BCG report estimates that only 17% of vehicles in the current US fleet are connected. Hence, just as in the OBD-II scenario, a suboptimal manual intervention will be required as a stopgap measure to collect the VMT data. Given the com-

[25] IIJA, Title III, Section 13002(d)(1).

[26] A thorough consideration of VMT options was conducted for the National Cooperative Highway Research program in 2009 [66].

plexities of data sharing agreements with automakers, and the necessity of performing manual checks for the non-connected vehicles, an OBD-II-based system seems simpler from an execution standpoint.

- Smartphone Apps: Insurance companies have long used OBD-II based devices and smartphone based apps to offer savings to drivers by tracking their driving habits and incentivizing safe driving practices [69]. A key difference to note: in the case of insurance smartphone apps, the driver is incentivized to use it in order to qualify for the savings. In contrast, in the case of VMT, the driver will be charged whenever they drive.[27] Other concerns remain a deterrent, including privacy concerns over sharing of precise GPS location data via the smartphone, battery drain, and configuring the smartphone for multiple vehicle households. Taking into account these concerns and drawbacks, this option is the least attractive option among the three options listed.

### Policy Considerations

Each option discussed above will require some upfront costs to build the backend IT system, and additional protocols at a state's department of motor vehicles, but the benefits are significant insofar as such a system can increase the amount of detail collected by the system, thus enhancing the efficiency and transparency of the charge. These options can each be fashioned to not retain origin and destination data, thus responding to the public acceptance barrier of concerns over "tracking."[28]

VMT is a highly adaptable tool that can be charged in a variety of ways. For example, VMT can be charged for every mile driven or VMT could be charged only on designated facilities if the state were able to design and procure a smart system that only read miles driven on those facilities. Further, this charge could be as a base fee-per-mile, or as a base fee plus a premium tied to time of day, location, or traffic level of service (thus functioning as a congestion or cordon measure). As a matter of policy, it could also be flexible in many other ways. For example, at a state level, there could be a policy to provide every driver with a "VMT budget" allowing a limited number of miles to be driven without charge on a daily or weekly basis.

[27] It is possible to develop a VMT technology platform that only charges a driver after they used a predetermined daily "mileage budget" - for example, the first three miles each day are not charged. It is also possible to instrument specifically designated roadways to limit the VMT charge to certain roads, but this would come with a potentially prohibitive level of complexity and could redirect travel to coingest non-designated roads.

[28] A standard onboard diagnostics port can be designed to only query from the vehicle diagnostics distance driven, store this information and transmit it as needed.

The VMT charge is based on the number of miles traveled by a vehicle, which is less likely to be affected by changes in fuel economy, fuel prices, or driving patterns. This can provide a more stable revenue stream compared to fuel taxes. If the VMT charge is implemented at the federal level, it could provide a consistent and uniform funding source for transportation infrastructure across the country. On the other hand, if the VMT charge is implemented at the state level, it could allow for more local control and customization, with each state able to design a VMT charge program that meets its specific needs and priorities. Advanced on-board technologies can provide accurate, automated recording of vehicle mileage, removing data collection from the control of the driver and thus reducing the potential for evasion.

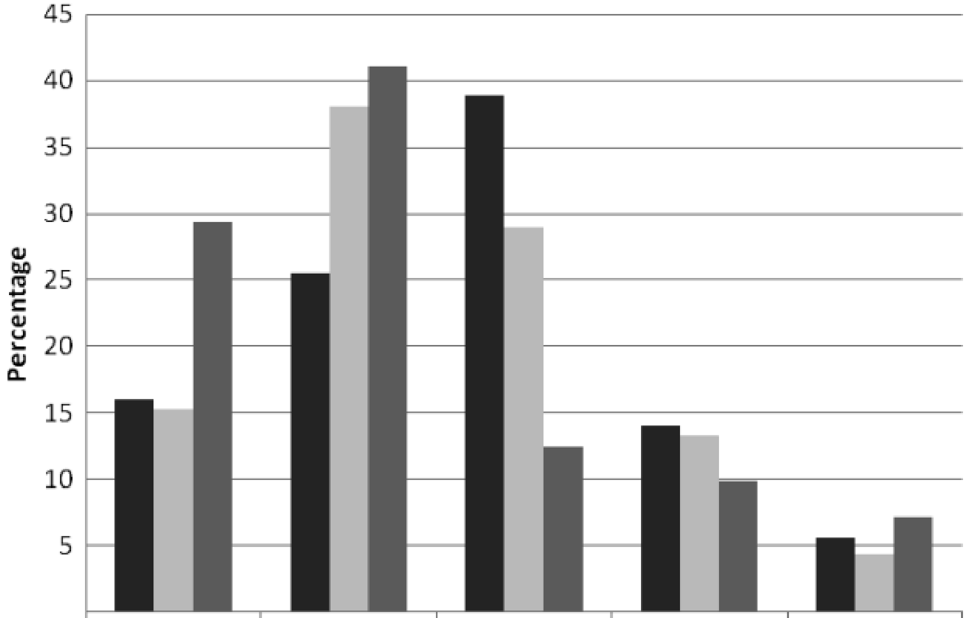
The VMT charge can respond to equity concerns because it can be means tested. It can also be adjusted to account for journey patterns in, for example, rural areas where people may have no practical choice about the length of their travel to essential destinations.

Given the ubiquitous presence and public acceptance of transponder devices for E-ZPass and similar electronic tolling systems, and the similar ubiquitous presence of smartphone apps, the options identified in this report that could be used to record mileage for a VMT program would likely be highly unobtrusive to the average driver. Messaging and transparency of use is also important. Based on an annual national transportation tax survey launched by the Mineta Transportation Institute [70], **Americans' support for a mileage fee grew from 33% in 2010 to 53% in 2021.**

Other findings from the 2021 Mineta report include:

- About two-thirds (62%) thought that if a mileage fee is adopted, low-income drivers should pay a reduced rate.
- Just over half of respondents (52%) thought mileage fee rates should be lower for electric vehicles than for gas and diesel vehicles.
- Approximately half of respondents also supported the idea of a "business road-use fee" that would be assessed on the miles driven by commercial vehicles on the job: 52% of people supported such a fee on delivery and freight trucks, 50% supported such a fee on ride hailing vehicles, and 49% supported such a fee on taxis.

Studies on the pilot programs also suggest that many participants had a generally positive view of the mileage-based tax after experiencing them [71, 72]. Based on a national evaluation of a mileage-based road user charge, the opinions of the participants became more positive as they drove with the mileage-based charging system, increasing from 41% favorable at the beginning of the study to 70% (Figure 13).




| | Very positive | Somewhat positive | Neutral | Somewhat negative | Very negative |
|---|---|---|---|---|---|
| ■ Baseline | 16.0 | 25.5 | 38.8 | 14.1 | 5.6 |
| ■ Interim | 15.3 | 38.0 | 29.0 | 13.4 | 4.3 |
| ■ Exiting | 29.4 | 41.1 | 12.5 | 9.9 | 7.2 |

**Figure 13:** Participants' responses to "How do you feel about the idea of replacing the gas tax with a mileage-based road user fee?" [72]

Concerns about personal privacy and the possibility of vehicle "tracking" can be effectively addressed by anonymizing and aggregating the VMT data. This approach to privacy protection is on display today in states with real-time highway messaging information systems that read bluetooth signals but do not track or identify individual drivers.

## Electricity Tax for Home and Public Charging

A tax on the electricity used for vehicle charging would closely mimic the approach of the gas tax, yet its implementation comes with significant complexities and potential barriers. Adding a universal fixed tax or surcharge to all electricity units consumed would be grossly unfair, as people who do not own cars, or drive very little, will subsidize all drivers, regardless of the extent of their use. There is therefore a need to differentiate between the units of electricity used for charging versus those used to run other household devices. There are two scenarios to be explored. Unlike the gas tax, where all drivers fill up and pay at a gas station, EV charging can take place at home and/or at a public charging station. These two scenarios need to be looked at independently given the vast differences in cost, access, fairness and implementation.

### Home Charging

The biggest challenge with home charging is that most currently installed metering technologies are unable to differentiate between what units are consumed for charging a vehicle versus those that are used by other household devices. Even if such a capability was developed and installed, homeowners may be tempted to bypass the installed charging equipment and use a regular wall-plug to charge their EV in order to escape paying this tax. Furthermore, as many homes begin to use solar panels and captive battery storage to charge their EVs, they may again bypass the system and not pay this tax, while still contributing to road wear and the other societal externalities of driving an EV. With more keenly developed smart metering functionality, drivers could also be incentivized to charge at certain times of day, for example during off peak times and/or when the electricity mix is cleaner. This might have a positive effect on consumers and utilities, but it would negate the ability of this tax to influence driving behavior, and it could have negative equity impacts if disproportionately, lower income drivers were unable to take advantage of price reduction periods. While conceptually, with smart metering technologies in place, this tax can be a suitable alternative to the gas tax as it scales with use and charges the user at the source of the fuel, the complexities of implementation and potential for evasion currently prevent it from being a viable alternative that can be pursued actively by states and municipalities.

### Public Charging

Taxation at the point of public EV charging lacks the implementation complexities of home charging, and the opportunity for evasion is extremely low as the tax would be bundled with the fuel and made at the point of sale. This will also scale up as one consumes more and/or drives a heavier or more inefficient vehicle. However, public EV charging will be required by a disproportionate number of low and middle income households who do not have garages or reserved spots for home charging. Indeed, only an estimated 56% of vehicles have a dedicated off-street parking space in the US [73]. Adding any tax to public charging will disproportionately burden these low and middle income households and slow down the EV adoption rate, forcing them to drive older, polluting ICE cars which are expensive to maintain and which have their own ramifications to carbon and particulate matter emissions. Further, public EV charging is already twice as expensive as home charging, and adding a tax on top of that will add to the burden of inequity [74]. States may work with utilities to satisfy a policy goal of establishing parity between home and public charging costs, but the gap is too large currently and basing the public charging electricity tax on the assumption that this gulf will be covered by incentives may not be feasible.

## Parking Pricing

Parking is the *sine qua non* of auto mobility, an essential component without which the entire system could not function. A motor vehicle has no value to its owner or driver if there is no place to park or store it. Parking facilities and their impacts on land use, housing costs and emissions (carbon and particulates) are often overlooked as a significant contributor to the negative externalities of a mobility system dominated by auto mobility. These negative externalities are largely independent of vehicle power source [75]. We do not consider parking pricing as a feasible solution for federal revenue purposes, but it may prove feasible as one component of a comprehensive state-level solution for post-gas tax revenue generation.

Adopting a parking pricing policy could help fill a state's gas tax gap while also addressing certain negative externalities of motor vehicle ownership. Such policies could take into account the land value taken up for the storage of motor vehicles, which may be undesirable from an urban design and property tax maximization perspective, the carbon intensity of the materials used to construct and maintain garages and surface parking facilities, the increase in impervious surface generating stormwater runoff, as well as other societal costs associated with the necessity to build and maintain ample parking. Those societal costs include impacts on housing prices, which often bear the burden of accommodating parking minimums imposed in local zoning codes. Because the construction of parking spaces is expensive, it influences both cost and availability of housing. Figure 14 is from a 2022 analysis conducted by the Victoria Transport Policy Institute [76]:

| City | Cost per Sq. Ft. | Cost per Space |
|---|---|---|
| Atlanta | $65.65 | $21,926 |
| Baltimore | $69.06 | $23,065 |
| Boston | $87.06 | $29,078 |
| Charlotte | $61.95 | $20,690 |
| Chicago | $87.28 | $29,153 |
| Cleveland | $73.57 | $24,574 |
| Denver | $68.38 | $22,842 |
| Dallas | $63.27 | $21,134 |
| Detroit | $76.01 | $25,392 |
| Houston | $64.53 | $21,555 |
| Indianapolis | $68.90 | $23,015 |
| Los Angeles | $79.79 | $26,653 |
| Miami | $64.61 | $21,580 |
| Minneapolis | $80.83 | $27,000 |
| Nashville | $64.91 | $21,679 |
| New York | $97.14 | $32,444 |
| Philadelphia | $85.20 | $28,460 |
| Phoenix | $65.49 | $21,876 |
| Pittsburgh | $75.65 | $25,267 |
| Portland | $74.31 | $24,822 |
| Richmond | $63.79 | $21,308 |
| St. Louis | $75.57 | $25,242 |
| San Diego | $77.87 | $26,009 |
| San Francisco | $90.77 | $30,316 |
| Seattle | $76.31 | $25,490 |
| Washington D.C. | $72.98 | $24,376 |
| *National Average* | *$74.09* | *$24,748* |

(Carl Walker 2016 updated to 2022 values)

*This table indicates average construction costs for basic parking structures in various U.S. cities. Costs are higher for:*

- *Below grade (underground) construction.*
- *Site conditions that require deep foundations or grading.*
- *Extra wide spaces for increased convenience.*
- *Higher quality construction, design and materials.*
- *Enclosed or underground structures that require mechanical ventilation and fire sprinklers*
- *Energy efficient Green Garage Certification.*
- *On-site storm water retention.*
- *Enclosed stair towers.*
- *Mixed use development where the parking is integrated with office, retail, residential, or other uses.*
- *State-of-the-art parking access and revenue control system.*
- *User amenities such as pedestrian facilities, wifi and wayfinding.*

**Figure 14:** Parking Structure Construction Costs, 2022 [76]

To address this, several American cities have reduced or eliminated parking mandates, with some even converting their minimums to maximums [77].

Parking pricing is currently used at the municipal level in one form or another. The question for purposes of this report will be whether parking pricing can be made to work as a state-imposed levy, and if so, how to structure such a charge. For example, a state-imposed charge might be an annual recurring charge assessed on commercial parking facilities on a per-parking space basis in excess of a certain baseline capacity. This would be relatively easy to administer, and it would generate a stable, recurring revenue stream for state governments.

## Infrastructure/Safety Impact Fees

Passenger vehicles have trended larger in weight and size in the 21st century. The transition to battery-electric drivetrains has exacerbated the explosion in vehicle weight. Meanwhile, a "size race" fueled by CAFE emissions standards and automaker response to perceived (and often encouraged) consumer preference, has greatly increased the average size of American passenger vehicles. There are serious consequences to this size race, as vehicle weight and size are key contributors to a number of negative externalities associated with driving in the United States. These externalities carry with them significant economic and societal costs.

As states in particular consider the full range of new revenue alternatives available to them in connection with the transition away from the gas tax, they may take into account those economic and societal costs that are embedded in the auto mobility system. Those costs, in the case of electric vehicles, are exacerbated by their additional weight. Electric vehicles weigh more than their internal combustion engine (ICE) counterparts. For example, at 6,500 lbs, the Ford F-150 Lightning electric pickup truck weighs 35% more than the ICE model. We propose an approach to assist state decision makers as they undertake these considerations, that begins with understanding the externalities and their relationship to vehicle weight and size (Table 3).

Fees based on vehicle weight and size have already been implemented in many states and could be expanded as a means to address both vehicle externalities and declining revenue from the gas tax. In 2022, Washington DC raised its annual registration fee from $155 to $500 for vehicles weighing over 6,000 lbs in an effort to address road maintenance, environmental, and safety concerns related to heavy vehicles [85] (Table 4).

Most states already charge scaling registration fees based on weight and overall dimension (vehicle class) for commercial vehicles. However, these fees often scale linearly, even though road damage scales with at least the second power of vehicle weight. Research by the American Association of State Highway Transportation Officials (AASHTO) in the 1960s established a fourth-power relationship between vehicle weight and road damage (e.g., a vehicle that is twice as heavy causes 16 times the damage), but more recent research has called this assumption into question. However, studies generally agree that the relationship is non-linear, so we have used a (likely conservative) second-power assumption for purposes of this report[29]. To take the example of the F-150 Lightning, even though it weighs 35% more than the ICE version, it causes at least 180% more road damage. The non-linear relationship between vehicle weight and road wear also implies that while light-duty vehicles make up the bulk (around 90%) of annual vehicle miles traveled in the U.S., most roadway damage (at least 80%) is attributable to heavy-duty vehicles such as trucks.

Pricing for externalities from vehicle dimensions could also be worked into updated fees for passenger vehicles. While the shapes of trucks, buses, and many other commercial vehicles have remained relatively constant, passenger vehicles have exploded in size in the 21st cen-

[29] See [80, 87] for further discussion of the appropriate scaling factor for road wear based on vehicle weight.

**Table 3:** Externalities from motor vehicles affected by vehicle size and weight

| Externality | Weight | Size |
|---|---|---|
| Traffic safety (for car occupants & vulnerable road users) | ✓[a] | ✓[b] |
| Roadway maintenance | ✓[c] | |
| Congestion | | ✓[d] |
| Land use/parking | | ✓[e] |
| Energy consumption | ✓[f] | ✓[g] |
| Particulate matter pollution | ✓[h] | |
| Noise pollution | ✓[i] | |

[a] See [78]. The study found that for every 1,000 lb increase in vehicle weight, the baseline fatality probability increased by 47%.

[b] See [79].

[c] See [80].

[d] Average vehicle occupancy has stagnated [81], while vehicle footprints increased 5% from 2008 to 2021 [82], implying a worsening per-passenger effect on roadway occupancy and thus traffic congestion.

[e] Ibid. Increasing vehicle footprints take up more space in continuous on-street parking and encourage the adoption of larger sizes for demarcated on- and off-street parking.

[f] Ibid.

[g] Ibid.

[h] The OECD notes that heavier cars have more particulate matter emissions. In particular, while EVs have lower PM10 emissions (mainly from exhaust) than ICE cars, heavier EVs emit 3-8% more PM2.5 (from brakes, tires, and road surfaces) [83].

[i] Research suggests that higher tire load is moderately correlated with increased noise levels; see [84].

tury, especially with the rising popularity of SUVs. Even within the same model lines, car sizes have increased. For example, the platform base (length multiplied by width) of a Toyota Camry sedan has increased more than 20% since the model was first introduced in the 1980s [88]. These size increases across the passenger fleet have counteracted a substantial portion of the improvements made in ICE efficiency over the last three decades.

Larger vehicles have drastic implications for safety and pedestrian safety in particular. Higher front-end heights on SUVs and cars increase the likelihood that pedestrians are struck in the chest and/or dragged under the car, rather than being thrown onto the hood [89]. While death rates have declined for motorists and passengers since the 1990s, they have increased by nearly

**Table 4:** Passenger vehicle registration fees, Washington DC [86]

| Weight (lbs) | Fee (pre-2023) | Fee (from 2023) | Common ICE cars | Common EV cars |
|---|---|---|---|---|
| Under 3,500 | $72 | $72 | Honda Civic, Hyundai Elantra, Subaru Forester | Nissan Leaf (pre-MY 2023) |
| 3,500-4,999 | $115 | $175 | Ford F-150, Toyota RAV4 | Chevy Bolt, Hyundai Ioniq 6, Tesla Model Y, Mustang Mach-E |
| 5,000-5,999 | $155 | $250 | Chevy Suburban | Tesla Model X, Lucid Air |
| 6,000+ | $155 | $500 | Ford F-350 Super Duty | Ford F-150 Lightning, Rivian R1T, Hummer EV |

20% for pedestrians and bicyclists [90]. Heavier vehicles are far more lethal: for every additional 1,000 pounds of weight (roughly the increase seen between comparable ICEs and EVs), the probability of a fatality in a crash increases by 47%.[30]

Larger vehicles also carry externalities in terms of land use and congestion. Larger vehicles require larger parking spaces and take up more space in lanes, even though the average passenger vehicle is occupied by just 1.5 persons [91]. As passenger cars creep closer to the maximum legal width of 8.5 feet, they force cities to widen parking lanes and increase turn radii, often at the expense of sidewalk space [92]. To avoid or offset these expenses and other externalities, states may wish to implement scaled fees for light-duty vehicles to incentivize the purchase of lighter cars, which have a host of benefits (for safety, pollution, energy consumption etc.) beyond lower road wear.

[30] See [78]. The study found that for every 1,000 lb increase in vehicle weight, the baseline fatality probability increased by 47%.

## WEIGHT FEE EXPLORATION: A CASE STUDY

What would it look like if a state (we take Massachusetts as an example) replaced its gas tax with a VMT charge scaled by vehicle weight? And how might such a fee be distributed between cars (which weigh little, but constitute 89% of VMT) and heavy trucks (which are extremely heavy but constitute only 11% of VMT)? A recent study of the cost of the vehicle economy in Massachusetts from Harvard's Kennedy School of Government provides an instructive framework for considering how to take vehicle weight and impact into account. The study breaks out those costs as shown in Figure 15a.

Most existing weight-based fees in the US are scaled roughly linearly ("first-power") with weight; however, as mentioned above, we believe infrastructure impacts and other externalities scale with at least the square of vehicle weight ("second-power"). When considering this approach, we determined that in order to develop a weight-based system that accurately captured these "second-power" effects but did not assess heavy-duty vehicles in an implausible way, we needed to focus on a certain subset of the externalities shown on the chart above. As an illustrative example, we assumed that states might wish to take into account the annual cost of roadway construction and operation. In the example of Massachusetts, this represents $5.7 billion in annual spending (see Figure 15b).

In order to cover the $5.7 billion annual outlay statewide for roadway construction and operation, Massachusetts would have to implement a weight based VMT charge of $0.01/mile for cars and $0.72/mile for trucks. The typical car driver would pay $110 per year (compared to $213 in gas tax) and the typical truck operator would pay $15,902 (compared to $1,576 in gas tax).

Such a fee would mimic the approach taken by Washington, DC in raising their registration fees—the amount paid by light-duty vehicle owners would change little, but heavy-duty vehicle owners (mostly corporations owning trucks) would pay more to reflect their vehicles' outsize effects on road infrastructure, safety, and other externalities. State policies implementing such charges could take into account whether a truck was owned by a small owner-operator, as opposed to a larger corporation or entity, and scale the charges via a form of means testing.[a]

[a] The Owner-Operator Independent Drivers Association reports that 16% of US truckers are owner-operators. See `https://www.ooida.com/who-we-are/`.

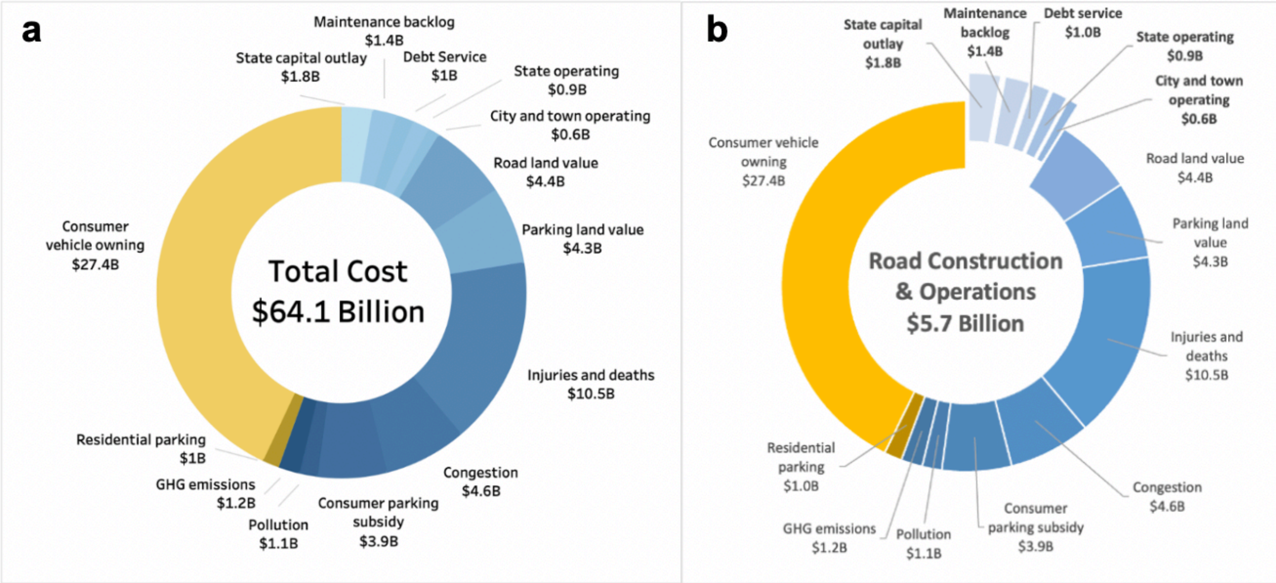



**Figure 15:** **(a)** Annual cost of the vehicle economy in Massachusetts; **(b)** Breakout of the state's annual cost of roadway construction and operation [93]

# Assessing the Alternatives

## A Multi-Dimensional Process

Real-world decision making in the context of replacing the gas tax will be highly dependent on the development of public and political acceptance. The gas tax alternatives that will have the highest likelihood of adoption are those that will be modeled after the revenue methods that gained public acceptance since the beginning of widespread auto mobility in the 20th century: fees associated with the ownership of a vehicle (imposed at point-of-sale and/or annually), and a gas tax (or in limited circumstances a toll charge) connected to the use of the vehicle.

The methods identified below are based on the ownership of a vehicle, the use of transportation infrastructure, and the impacts a given vehicle has on that infrastructure. As described earlier in this report, those impacts can be understood broadly as occupancy impacts (use of a finite asset to the exclusion or inconvenience of others, most notably contributing to traffic congestion and pavement wear and tear) and public health and safety impacts (externalities based on vehicle weight and size, including degradation of transportation infrastructure and continued emissions, particularly particulate emissions).

Considered within this broad framework, electric vehicle use can be assessed for its occupancy impacts by imposing a cost on driving, or on the actual miles one drives on those facilities, or by the length of time one drives, or by what time(s) of day one drives, or by the traffic conditions (levels of service) during the time(s) one drives (or any combination of those approaches). Electric vehicle use can also be assessed for its negative impacts on traffic congestion, degradation of infrastructure, and public health and safety by imposing a fee on the attributes that contribute most to those impacts, such as vehicle weight and size.

We consider the likely transportation source alternatives by using a multi-dimensional process:

1. **Identify the Method**
   Our framework considers two methods: assessing ownership and assessing use.

2. **Identify the Instruments for Raising Revenue**
   Our framework considers six instruments to generate revenue: a vehicle-based fixed or variable fee, road user charging, VMT charging, electricity pricing, parking pricing, and impact fees.

3. **Identify the Implementation Tools**
   We consider implementation tools for each instrument, which take into account vehicle typology as well as spatial, temporal, and road condition (level of service) factors.

4. **Assess each Implementation Tool through a Performance lens**
   How does each implementation tool perform against four key metrics?

5. **Assess each Implementation Tool through an Efficiency lens**
   How does each implementation tool respond to key externalities of vehicular mobility?

Table 5 shows how each implementation tool can be applied in connection with the various revenue generating instruments.

**Table 5:** Revenue generating instruments for various implementation tool

| **Implementation Tools**→ | Vary by vehicle typology [size & weight] | Vary by location | Vary by time | Vary by level of service (congestion level) | Vary by scope (limited corridors vs. system wide) |
|---|---|---|---|---|---|
| **Instruments** ↓ | | | | | |
| Vehicle Fee | Fixed or variable fee | | | | |
| RUC | Can charge differentially according to typology | Cordon Pricing | Congestion Pricing | Dynamic Pricing | RUC scope variations |
| VMT | Can charge differentially according to typology | Cordon Pricing | Congestion Pricing | Dynamic Pricing | VMT scope variations |
| Electricity Tax | Fixed fee | | Potential for variable charge depending on time of day and source of electricity. | | |
| Parking Fee Assessed on Parking Facility Owner | | | | | Variable fee on parking facility owner scaled to capacity. |
| Impact Assessments | Can charge differentially according to vehicle typology | | | | |

We assess each alternative through a **performance lens** and an **efficiency lens**. The performance lens considers (i) ease of administration, (ii) resistance to easy evasion, (iii) stability over time, and (iv) fairness. The efficiency lens considers how well or poorly certain revenue alternatives address key negative externalities of vehicular mobility: (i) traffic congestion, (ii) road wear and tear, (iii) safety and (iv) emissions. As explained in this report, this efficiency analysis does not take into consideration how the revenue might be spent in order to influence and reduce the effects of those externalities. An expenditure lens analysis would be a useful next step to take in an effort to more precisely understand the effects of transportation spending decisions on driving behavior.

**A note on equity:** We consider equity an overarching consideration for each of these alternatives. A major downside of the gas tax is its inherent regressiveness because, as a fixed fee per gallon, it taxes lower income drivers the same as it taxes wealthy drivers [94]. By their nature, transportation-sourced revenues are regressive unless they are means tested. Most of the alternatives discussed in our evaluation can be responsive to equity concerns if fees or charges are scaled to account for income inequality and other factors. Transport equity and justice are also served by decisions regarding how money is spent, and this could be factored into a future expenditure analysis.

Finally, there is no one-size-fits-all answer for replacing gas tax revenues at the state level. Our framework respects regional and other differences and enables policymakers and stakeholders to craft solutions that most effectively address their revenue needs and respond to their policy values.

## Performance Assessment

We test each instrument for its performance potential in Table 6a-6c. The examples given are meant to be illustrative, not exhaustive.

**Table 6a:** Performance Assessment (Part 1)

| | Ease of Administration | Resistance to Easy Evasion | Stability Over Time | Fairness |
|---|---|---|---|---|
| **Gas Tax**: the Base Case | ✓Payments made by wholesalers based on predetermined calculations of demand | ✓Drivers cannot avoid payment of the tax at the gas pump | In the pre-EV era: ✓the gas tax has been durable over time albeit historically volatile in times of economic slowdown or disruption. ✕ In the post-EV era, the gas tax gradually diminishes and eventually reduces to zero. | ⟷ The gas tax is inherently and highly regressive. However most drivers accept the gas tax as a fair way to charge for their use of public infrastructure. |
| Assessing Ownership: **Fixed and Variable Fees** | ✓Annual payment at point-of-sale or recurring payments tied to annual vehicle registration. | ✓Payments are tied to specific requirements that are prerequisites to vehicle ownership and/or use. | ✓Revenues tied to the size of the vehicle fleet, which is generally stable over time, with steady growth. | ✕ A fixed fee is regressive. Also, there is an inherent unfairness associated with fixed fees based on ownership insofar as they penalize the light or occasional driver and reward the heavy or frequent driver ⟷ Fixed fees can be made variable to account for vehicle typology (weight/size), and/or vehicle owner income status. |
| Assessing Use: **Road User Charge** | ✓System based on existing technologies, and easy to administer. Note: there are non-trivial costs associated with deployment, including the backend IT system, and managing operations and maintenance. | ⟷ Drivers can choose to avoid priced roads, but leaking due to re-routing will be less viable in a more expansive road pricing environment. States implementing road pricing will need to consider their approach to capturing revenue. A transponder-based system is inherently more stable and less prone to evasion than a license plate recognition system which is subject to drivers obscuring plates with coverings easily obtainable in stores and online. | ✓RUC is directly connected to demand (measured as vehicle miles traveled), and this metric has historically been stable, with short-term reductions during times of significant economic downturn or social disruption. RUC is agnostic to vehicle engine technology or energy source. | ✓To improve equity beyond means testing, a portion of revenues can be directed to support sustainable mobility options in disadvantaged areas and where people are unable to afford car ownership. RUC can also be customized to charge differently based on vehicle typology, and to be dynamic based on a variety of factors: spatial (cordon pricing), or roadway service conditions, or time of day (congestion pricing). |

Note: ✓ : strong or effective; ⟷ : mixed; ✕ : low or ineffective

**Table 6b:** Performance Assessment (Part 2)

| | Ease of Administration | Resistance to Easy Evasion | Stability Over Time | Fairness |
|---|---|---|---|---|
| Assessing Use: **VMT charge** | ✓System is based on existing technologies and easy to administer. Note: there are non-trivial costs associated with deployment, including the backend IT system, and managing operations and maintenance. | ✓Evasion risk is limited by use of advanced on-board technologies that remove the need for self-reporting and provide accurate, automated calculation of vehicle mileage without “tracking” vehicle origin and destination data. | ✓The VMT charge is based on the total miles traveled by a vehicle, which is reasonably stable over time. Potential volatility during times of severe economic slowdown or other societal disruptions. It is also agnostic to the vehicle engine technology or energy source. | ✓VMT can be customized to charge differently based on vehicle typology, and to be dynamic based on a variety of factors: spatial (cordon pricing), or roadway service conditions, or time of day (congestion pricing). To improve equity beyond means testing, a portion of VMT revenues can be directed to support sustainable mobility options in disadvantaged areas and where people are unable to afford car ownership. |
| Assessing Use: **Electricity Tax for Home Charging** | ✕ Differentiating between home electricity usage units is difficult and will require implementation of smart metering and other technologies. Vehicle 2 grid complicates this further. | ⟷ Evasion risk is limited if a specific line is metered to tax EV charging. Some homeowners may attempt to use a different, non-metered line to charge the vehicle in order to avoid the tax. | ✓If implemented in a manner less susceptible to manipulation by the homeowner, this tax can generate stable revenues | ⟷This tax may be considered fair insofar as it scales as a person drives more miles, or drives a less efficient vehicle. However, it cannot easily differentiate between spatial or income-based differences. Providing time-based price reductions for off peak charging could help some drivers and harm others unable to take advantage of the time window. More research would be required to understand these effects more keenly. |

Note: ✓ : strong or effective; ⟷ : mixed; ✕ : low or ineffective

**Table 6c:** Performance Assessment (Part 3)

| | Ease of Administration | Resistance to Easy Evasion | Stability Over Time | Fairness |
|---|---|---|---|---|
| Assessing Use: **Electricity Tax for Public Charging** | ✓Customers pay a specific rate per minute or per kWh at the charging station. A tax can be added and collected at the point of sale. Some complexities associated with accounting and transfer to the appropriate public sector recipient. | ✓As the tax is bundled in with the charging bill, there is no easy way to avoid paying the tax. | ✓Likely to provide a relatively stable source of revenue as public chargers will be an essential component of the EV ecosystem for the foreseeable future. | ✗ Public EV charging will be required by a disproportionate number of low and middle income households who do not have garages or reserved spots for home charging [95]. Further, public EV charging is almost twice as expensive as home charging. States may work with utilities to satisfy a policy goal of establishing parity between home and public charging costs, but this cannot be assumed. |
| Assessing Use: **Parking pricing** (evaluated as a state-imposed fixed or variable fee on parking facilities over a certain capacity). | ✓This state-based approach is easy to administer, charging a recurring annual parking fee on owners of parking garages, lots and facilities based on the number of spaces in excess of a baseline capacity. | ✓A state-based charge directly on parking facility owners as described in this report would be difficult to evade. | ✓Revenue expected to be stable and predictable as commercial parking demand is a daily reality for most drivers, and parking is a non-negotiable necessity for every driver. | ⟷ Parking charges, as proposed in this report, are fair in the sense that they put a price on a feature of vehicular mobility that places a significant burden on emissions and other externalities. However, the equity measure would be low as costs could be passed along to the driver without differentiation and regardless of income level. |
| **Impacts-based Fees** | ✓Certain states currently collect weight and size information via vehicle registration and can use it to scale fees. | ✓Vehicle registration, which would be the point of assessment, is required for all vehicles in all states. | ✓While new vehicle dimensions may change somewhat in response to technology advances, the overall typology of the US fleet is unlikely to change drastically or rapidly. | ✓Larger and heavier vehicles have greater impacts on road infrastructure, safety, and a host of other externalities. |

Note: ✓ : strong or effective; ⟷ : mixed; ✗ : low or ineffective

We explored how efficiently each of the gas tax alternatives would respond to key vehicular externalities. Note that this evaluation does not consider the question how the revenues are used. For example, if larger portions of revenue are invested in providing people with better transit or rail alternatives, a revenue instrument may be highly effective encouraging mode shift away from driving, thus having a positive impact on one or more of these externalities. Testing the relationship of strategic multi modal investments to the elasticity of demand for vehicular mobility is beyond the scope of this report.

## Efficiency Assessment

We test each instrument for its potential efficiency responding to specific vehicular externalities in Table 7a-7c. The examples given are meant to be illustrative, not exhaustive.

**Table 7a:** Efficiency Assessment (Part 1)

| | Traffic Congestion | Road Impacts / Wear & Tear | Safety | Emissions |
|---|---|---|---|---|
| **Gas Tax** as Base Case | ✗ The gas tax has historically not limited driving or VMT. | ✗ The gas tax has historically not influenced people to drive lighter cars. Fuel economy improvements have supported purchase of heavier, bigger ICE vehicles. | ✗ The gas tax has historically not influenced people to drive lighter cars. Fuel economy improvements have supported purchase of heavier, bigger ICE vehicles that have worsened safety issues. | ✗ The gas tax has historically not reduced VMT or had a measurable impact on reducing carbon or PM emissions. In the gas tax era, the transportation sector has risen to being the top sector contributor to US carbon emissions. |
| **Fixed fees** | ✗ Doesn't influence day-to-day driving behavior. | ✗ Doesn't influence day-to-day driving behavior. | ✗ Doesn't influence day-to-day driving behavior. | ⟷ Particulate emissions continue, and may be exacerbated by the additional weight of EVs [96]. EVs reduce carbon tailpipe emissions but do not have any effect on the significant carbon intensity of transport infrastructure construction and maintenance. |
| **Variable Fees** (variable by vehicle typology) | ✗ Doesn't influence day-to-day driving behavior. | ⟷ Can be scaled by vehicle typology (weight/size) but such scaling would need to be adjusted to avoid untenable fee levels for most heavy-duty fleet vehicles. | ⟷ Has the potential to cause behavior change on the part of some EV buyers who may consider purchasing a smaller/lighter vehicle that may be safer in crashes (including with vulnerable road users) | ⟷ Particulate emissions continue, and may be exacerbated by the additional weight of EVs [96]. EVs reduce carbon tailpipe emissions but do not have any effect on the significant carbon intensity of transport infrastructure construction and maintenance. |

Note: ✓ : strong or effective; ⟷ : mixed; ✗ : low or ineffective

**Table 7b:** Efficiency Assessment (Part 2)

| | Traffic Congestion | Road Impacts / Wear & Tear | Safety | Emissions |
|---|---|---|---|---|
| **Road User Charging - Fixed Charge** | ⟷ The effects on reducing traffic congestion will be determined by state pricing policies, but fixed charge below a certain cost threshold is unlikely to significantly reduce driving. | ✗ Fixed RUC below a certain cost threshold is unlikely to significantly reduce driving. | ✗ Fixed RUC below a certain cost threshold is unlikely to significantly reduce driving. | ✗ Fixed RUC below a certain cost threshold is unlikely to significantly reduce driving. |
| **Variable Road User Charging** | ✓Can target traffic conditions by time of day, or spatially, or by levels-of-service, and dynamically charge to change behaviors of some drivers and cause some to mode shift to transit or rail (although some may shift driving times or locations). | ✓Can charge more for certain vehicle typologies and change purchase decisions of some drivers. If properly calibrated may change behaviors of some drivers and cause some to mode shift to transit or rail (although some others may shift their driving times/locations). | ⟷ Can charge more for certain vehicle typologies and change purchase decisions of some drivers. Also may reduce driving in dense urban areas, increasing safety. However, reducing driving does not guarantee or imply greater levels of safety. | ⟷Potential mode shift to non vehicular modes could reduce emissions. As mentioned above, the way the money collected is spent (better transit, bus service) can have large impacts. |
| **Fixed VMT charge** | ✗ Fixed charge below a certain cost threshold is unlikely to significantly reduce driving. | ✗ Fixed VMT charge below a certain cost threshold is unlikely to significantly reduce driving. | ✗ Fixed VMT charge below a certain cost threshold is unlikely to significantly reduce driving. | ✗Fixed VMT charge below a certain cost threshold is unlikely to significantly reduce driving. |
| **Variable VMT charge** | ✓Can target traffic conditions by time of day, or spatially, or by levels-of-service, and dynamically charge to change behaviors of some drivers and cause some to mode shift to transit or rail (although some others may shift their driving times/locations). | ✓Can charge more for certain vehicle typologies and influence EV purchase decisions of some drivers. If properly calibrated may change behaviors of some drivers and cause some to mode shift to transit or rail (although some others may shift their driving times/locations). | ⟷ Can charge more for certain vehicle typologies and influence EV purchase decisions and/or driving behavior of some drivers. May reduce driving in dense urban areas, increasing safety. However, reducing total VMT does not guarantee or imply greater levels of road safety. | ⟷Potential mode shift to transit or rail could reduce emissions. As mentioned above, the way the money collected is spent (better transit, bus service) can have large impacts. |

Note: ✓ : strong or effective; ⟷ : mixed; ✗ : low or ineffective

**Table 7c:** Efficiency Assessment (Part 3)

| | **Traffic Congestion** | **Road Impacts / Wear & Tear** | **Safety** | **Emissions** |
|---|---|---|---|---|
| **EV electricity charging tax** (public and in-home) | ⟷ The effects on reducing driving, and therefore easing traffic congestion, will be determined by pricing policies. | ⟷ Incentivizes purchasing a more efficient vehicle, which is likely lighter, with less impact on road wear and tear. | ⟷ Incentivizes purchasing a more efficient vehicle, which is likely lighter and may be safer in an incident with vulnerable road users. | ⟷ EVs have lower carbon impact than ICE but contribute to same or higher levels of PM2.5 particulate emissions. This tax may incentivize purchase of more efficient lighter vehicles, or reductions in driving. If it incentivizes purchase of lighter vehicles, it may reduce PM emissions. |
| **Parking Pricing** (evaluated as a recurring fixed or variable fee imposed by the state on parking facilities over a certain capacity) | ⟷/✗ Increasing the cost of parking may help limit the demand for driving. | ⟷/✗ Increasing the cost of parking may help limit the demand for driving; no significant impact on the decision to purchase vehicles of certain size or weight. | ✗ No significant impact on the decision to purchase vehicles of certain size or weight. | ✗ Particulate emissions continue, and in certain respects may be exacerbated by EVs. Carbon intensity of building and maintaining parking facilities is high. |
| **Impact-Based Fees based on vehicle typology** | ✗ Does not influence day-to-day driving behavior | ✓Designed to charge specifically for vehicle typology, weight and its impacts on infrastructure wear & tear. May change EV purchase decisions on part of buyers looking to reduce overall costs of ownership by purchasing lighter EVs. | ✓Designed to charge specifically for vehicle typology, size, weight and its impacts on public safety. May change EV purchase decisions on part of buyers looking to reduce overall costs of ownership by purchasing lighter EVs. | ✓Designed to charge specifically for vehicle typology, efficiency and its impacts on particulate emissions. May change EV purchase decisions on part of buyers looking to reduce overall costs of ownership by purchasing lighter EVs. |

Note: ✓ : strong or effective; ⟷ : mixed; ✗ : low or ineffective

# CHAPTER 3 | MODELING THE DECLINE OF GAS TAX REVENUES

The decline of the gas tax and the measures to combat the transportation revenue gap need to be looked at from a systems point of view. Any policy change, driving behavior change, purchasing trend change or manufacturing change will impact the system in ways that make it difficult to model on a static sheet. There are various reinforcing and balancing loops in this whole system that further add to the complexity and make variables dependent on each other in ways that are difficult to formulate. Hence, we developed an interactive system dynamics model to best represent the light duty vehicle (LDV) market, the various parameters (variables) that impact it and model this whole system dynamically over time for the next 27 years till 2050.

The assumptions made for the system dynamic model that estimates the EV adoption, fall in gas tax collections and impact of new alternatives are given below. It is to be noted that most of the parameters and assumptions made can be dynamically edited to simulate different scenarios, geographies, behaviors and responses to different policies. However for the sake of this report and to showcase a few illustrative and likely outcomes we have made the following assumptions and highlighted these as snapshots. These assumptions are valid for all the scenarios described below. In certain cases where the assumptions differ from those mentioned below, like Scenario 6 where we explore state-wise trends, the assumptions are mentioned in the scenario.

**A. Industry Assumptions:**

1. Light duty vehicles only: The analysis is focused on light motor vehicles which form almost 90% of VMT [97].
2. Gasoline vehicles only: Given that diesel passenger vehicles sales are in low single digit percentages, and the reducing options of diesel cars (due to the higher particulate pollution concerns), the forecast analysis focuses primarily on gasoline cars and sales. Diesel vehicles sold in the U.S. Q1 2023 were 3.7% of total sales, which reduces further if we remove the commercial sales of vans [98].

3. US fleet = 266 million LDVs: cars and light trucks currently registered in the US [99].
4. New annual car (light duty vehicles < 8500 pounds) sales taken as the 2016-2020 average = 16.68 million as the initial value for total new car buyers [100].
5. 6% of US new car sales are currently assumed to be BEV [101]. This is ramped up linearly to reach 100% of new car sales by 2035 as defined per many state and EPA mandates. This impacts the models output of ICE vs EV new car sales significantly.
6. We only consider purchase of new cars, and do not look at used cars which is very small currently for BEV's.
7. 28% of new car-buyers are assumed to be first time car buyers based on the fact that millennials' share of the new-car market jumped to 28% in 2015 [102].
8. The average light-duty vehicle in the United States has a useful life of about 17 years [103].
9. Vehicle Weight: Average ICE car weight = 4094 lbs [104]; average EV car weight = 5094 pounds (1000 pounds more than equivalent ICE, Volvo XC40 ICE vs EV [105].

**B. Driving Behaviour & Gas Tax Assumptions:**

1. U.S. drivers drive an average of 13,475 miles per year according to data from the Department of Transportation's Federal Highway Administration (FHA) most recent published numbers from 2022.
2. 22.8 mpg average US light duty vehicle fuel efficiency based on 2021 figures from Bureau of Transportation Statistics.
3. Federal + state gax tax collection used for deficit calculations = $105B (Year 2020 [106]). This has been reduced to $90 billion in the simulation below as we are only looking at the VMT from LDVs as stated in assumption A.1. The model however incorporates the flexibility to dynamically change the current gas tax collections to account for different deficit scenarios for varying geographies.
4. Volume weighted average of state gas taxes is taken and added to the 18.4 cents per gallon federal gas tax to give a total of 57.09 cents per gallon for the overall analysis [107]. Separate analysis is performed for the federal gas tax tax only, and state-wise which take the exact numbers in those cases.
5. $331.4 Average annual federal + state gas tax paid per LDV per year: Calculation based on assumptions B.1, B.2 and B.4 ((13475 miles / 22.8 mpg) * $.5709)
6. Average of 2.5 cents per mile ($331.4 / 13475 miles) paid to the federal and state gas tax per vehicle

T = 0 is the year 2023 for the simulation and the simulation ends at T = 27 which is the year 2050.

Figure 16 presents a snapshot of the model.

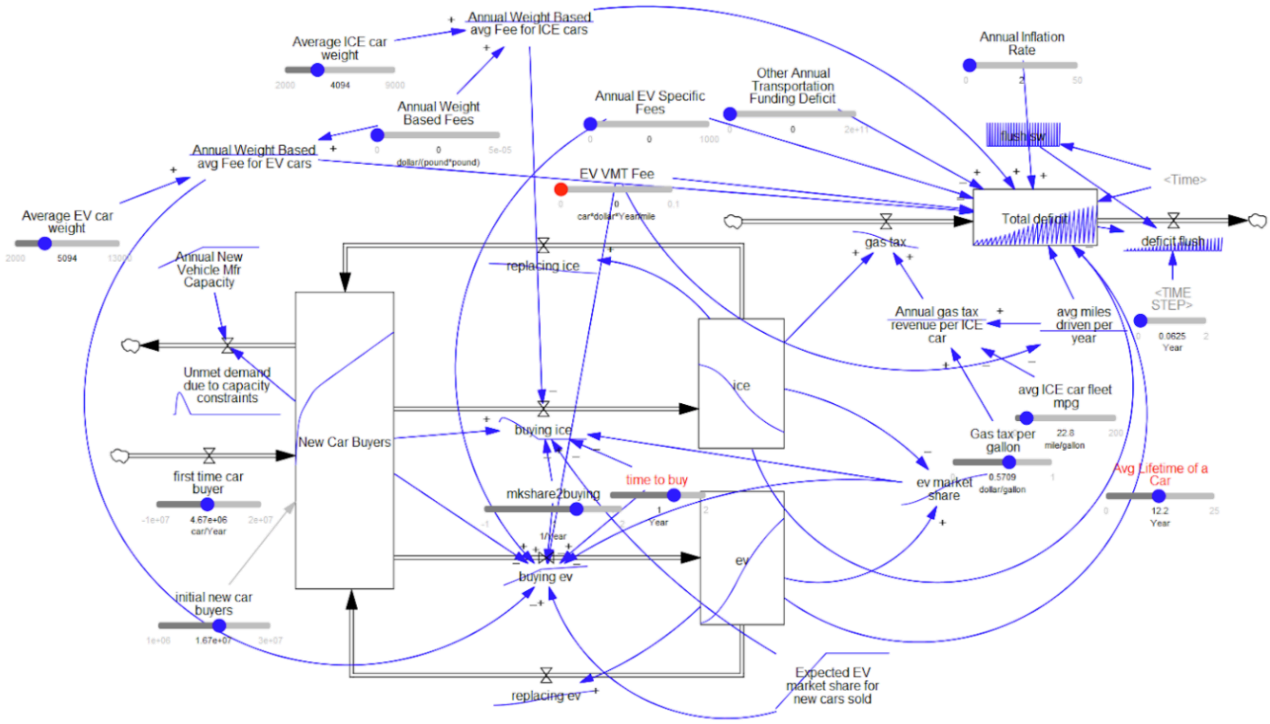



**Figure 16:** System dynamics model

## Scenario 1: No VMT Charge, No EV Fees, No Weight Fees

This scenario mimics a "do nothing" scenario. Here the increase in EV sales is primarily driven by the various state mandates that will allow only new EV sales from 2035. The mandates will also impact the availability of the EVs which we assume to be mostly EVs as automobile manufacturers move over from ICE to EV manufacturing.

The fleet turnover from ICE to EV takes time and it is only after 15 years that we see the EV share crossing the 50% of total vehicles in the US (as denoted by the arrow in Figure 17) and hit 80% by year 27 (2050). This is due to the long asset life of vehicles which is at 17 years and also because of the limited availability of EVs as a share of new vehicles during the first few years. As there are no fees throttling growth, the overall light duty vehicle fleet size balloons and reaches 380 million vehicles by 2050 (300 million EVs + 80 million ICE).

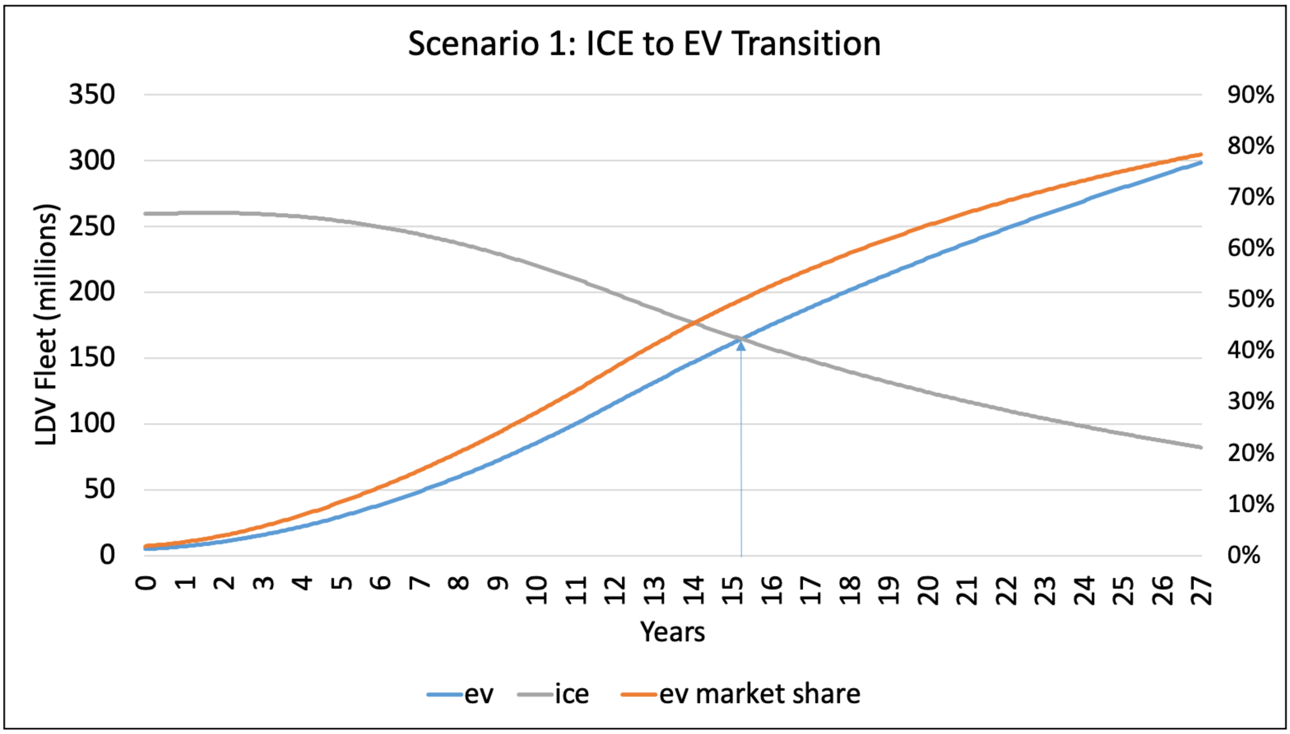



**Figure 17:** Scenario 1

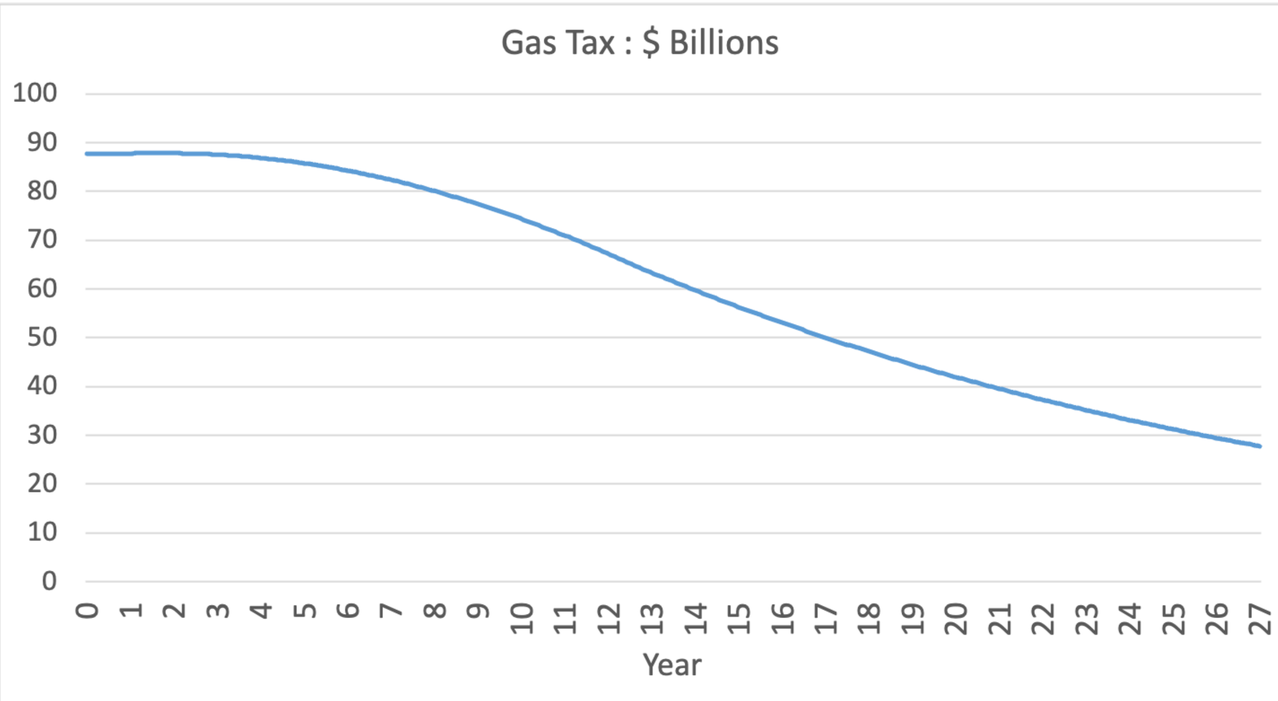



**Figure 18:** Projection of Gax Tax Revenue

This will result in a rapid drop in gas tax collections from year 6 onwards, once EVs start replacing ICE cars at a more rapid pace. The drops in billions can be seen in Figure 18. In 14 years we can see almost a 30% erosion in the gas tax. Further, with improving vehicle fuel economy standards, faster replacement of the existing fleet with EVs and more fuel efficient vehicles this can further be accelerated.

As this is a do-nothing scenario the deficit will keep increasing. Next we present scenarios to tackle the deficit and observe its results on the uptake of EVs.

## Scenario 2: Adding an Annual EV Fee of $331.4 - the Average ICE Vehicle's Annual Gas Tax Payment

While the model does not differentiate between this fee for EVs being flat or distributed depending on weight/size of the EV, doing so will definitely make the fees more fair. We also understand that it is unlikely that the Federal government will charge a flat fee to recover its share of the gas tax and that this will mostly be a state level policy. However for a fair comparison with the other scenarios we have included the Federal component here in the analysis.

As we can see in Figure 19, adding an annual EV fee slows the uptake of EVs. The fixed fee paid by EVs is equal to the average annual gas tax paid - $331.4 (Assumption B.5). It now takes an additional year (15 to 16) for the EV fleet to cross ICE numbers, though by 2050 the share of EVs at 77% is close to scenario 1. The assumption for elasticity is that adding an annual EV-specific fixed fee of $0.66, slows down the sale of EVs by 1%. The threshold where EV sales fall to zero is twice the annual average federal + gas tax paid by the ICE vehicles ($662). As the EV fixed fee limits growth, the overall light duty vehicle fleet size grows slower and reaches 370 million with around 15 million fewer EVs and 5 million higher ICE vehicles on the road compared to scenario 1 (285 million EV's + 85 million ICE) by 2050.

While the drop in the gas tax is similar to scenario 1, we can now see the impact of how fixed fees tackle addressing and reducing the deficit (Figure 20). Note: the deficit builds up during the year and is assumed to start from zero for the next year, i.e. deficit or surplus are not carried forward. We can clearly see that replacing the $331.4 avg annual gas tax being paid by ICE vehicles currently with a flat annual EV fee of the same amount will be insufficient in reducing

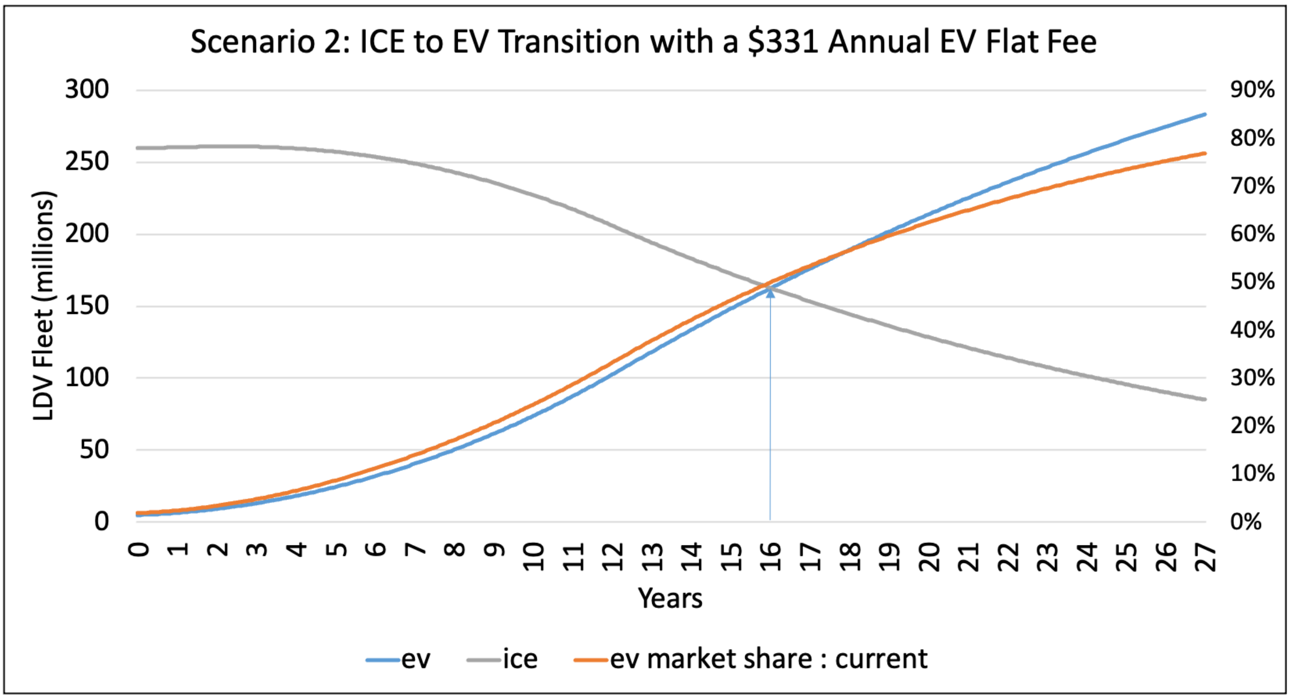



**Figure 19:** Scenario 2

the deficit even with a somewhat conservative 2% annual inflation rate.

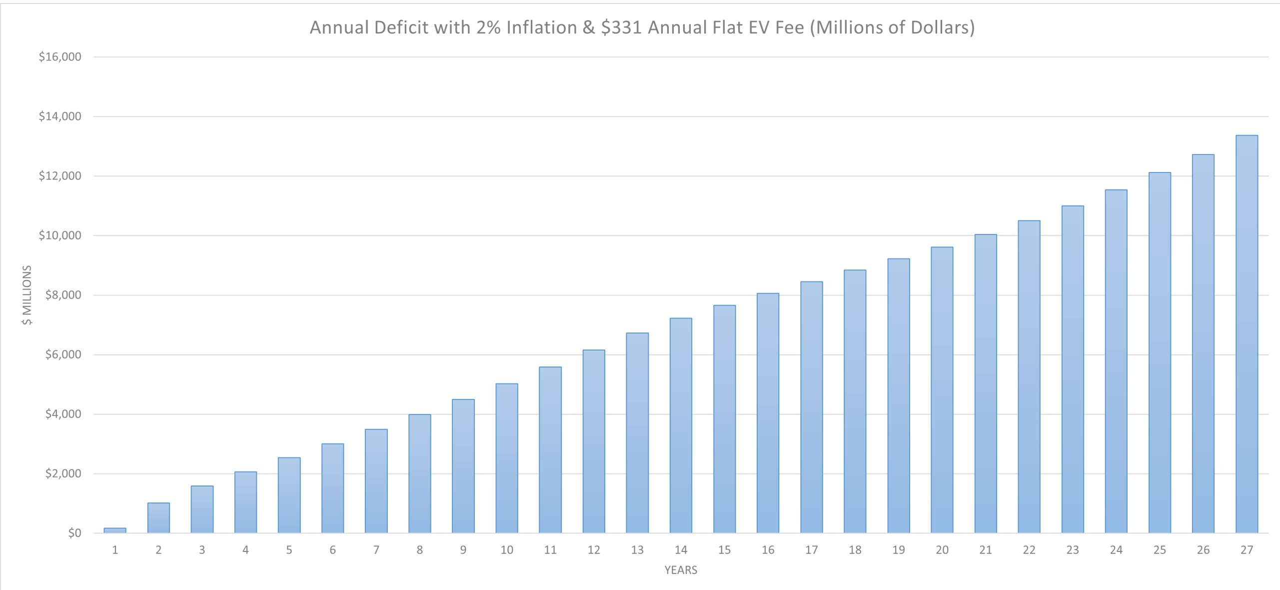



**Figure 20:** Annual Deficit with 2% Inflation & a $331 Annual Flat EV Fee

We require a fixed annual fee of $415 per EV to bring it to zero by 2035 and ensure a budget surplus within controllable levels during the following years. (Figure 21). Note that a $415 annual fixed fee will be met with significant resistance from drivers who are accustomed to paying a significantly smaller amount, divided into even smaller payment tranches at each visit to the gas station. Hence, just using the fixed fee to cover the deficit may not give ideal results. Further, a flat fee not being linked to inflation will always fall behind the required funding needs for state and federal project needs.

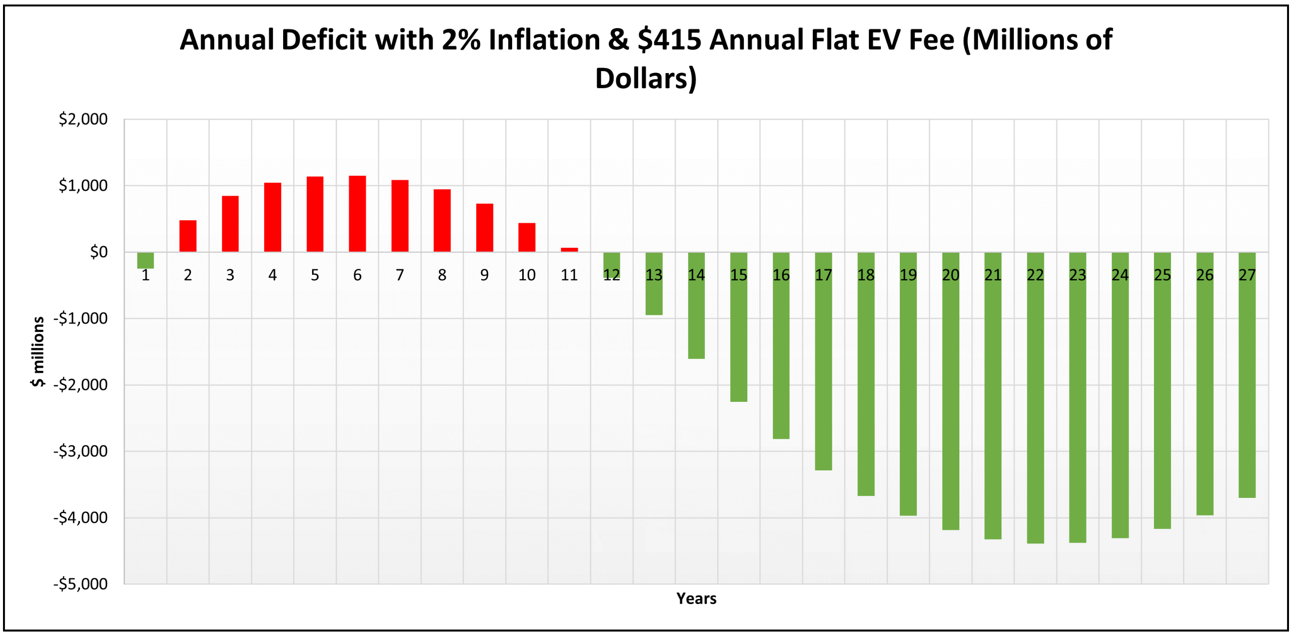



**Figure 21:** Annual Deficit with 2% Inflation & a $415 Annual Flat EV Fee

## Scenario 3: Adding an EV VMT Charge

We evaluate the addition of a VMT charge. As the gas tax is inherently a VMT charge, this additional VMT charge is not levied on ICE vehicles. Again, how efficiently a person drives or how efficient their car is, is a matter of implementation of the policy and while the model will not differentiate, charging a Hummer EV driver three times or more the price in cents per mile driven as compared to a Chevrolet Bolt driver will increase fairness. We made the annual EV fees zero to make for a better comparison with what ICE drivers currently pay, this equalizes the impact of any difference between an annual few for ICE/EV vehicles and evaluates the impact solely on the basis of an EV VMT charge.

An EV VMT charge slows the uptake of EVs compared to Scenario 1 which has no fees for EVs, but it is faster than Scenario 2 which has a fixed annual fee equivalent to the avg gas tax paid by an ICE vehicle. The assumption for VMT pricing elasticity for EVs is that a 0.5cent/mile increase in the VMT charge reduces new EV sales by 1%.It now takes 15.5 years for the EV fleet to surpass the ICE fleet, this is compared to 16+ years for Scenario 2 and 15 years for scenario

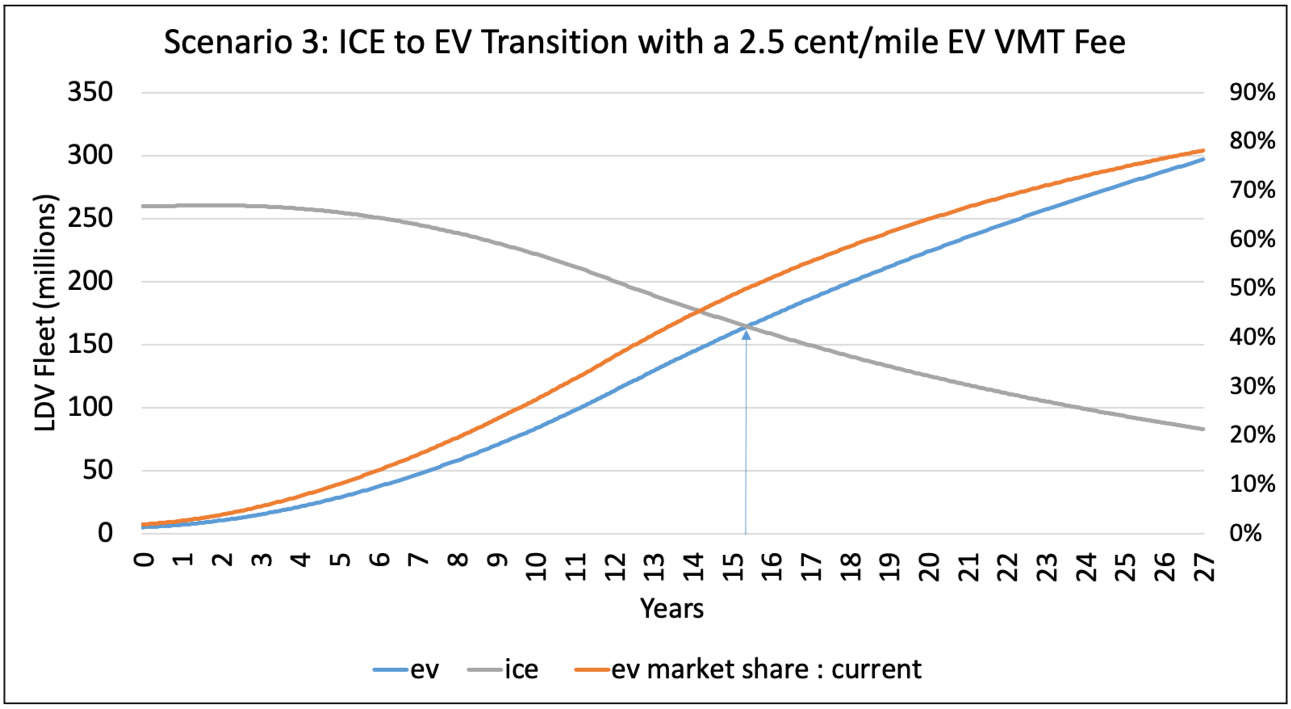



**Figure 22:** Scenario 3

1. A VMT charge collected in smaller amounts at regular intervals like the gas tax and not as a lump sum annual fee will help adoption and lessen the burden on vehicle owners. This is also reflected in overall light duty vehicle fleet size growth that reaches 380 million vehicles by 2050 (297 million EVs + 83 million ICE), similar to scenario 1.

Here also we see that the drop in the gas tax is similar to scenarios 1 and 2, led by the gradual reduction in replacement of ICE vehicles in the overall light duty vehicle fleet. On adding an EV VMT charge of 2.5 cents (assumption B.6, above) per mile with an annual inflation of 2%, the annual deficit keeps on creeping up and reaches $12 Billion per year by 2050. Note – the deficit builds up during the year and is assumed to be made zero for the next year and is not carried forward. It requires an EV VMT charge of 2.9 cents per mile which is 16% higher than the derived VMT paid currently by ICE drivers via the gas tax, for the deficit to reach zero in 22 years by 2045 as can be seen in Figure 23.

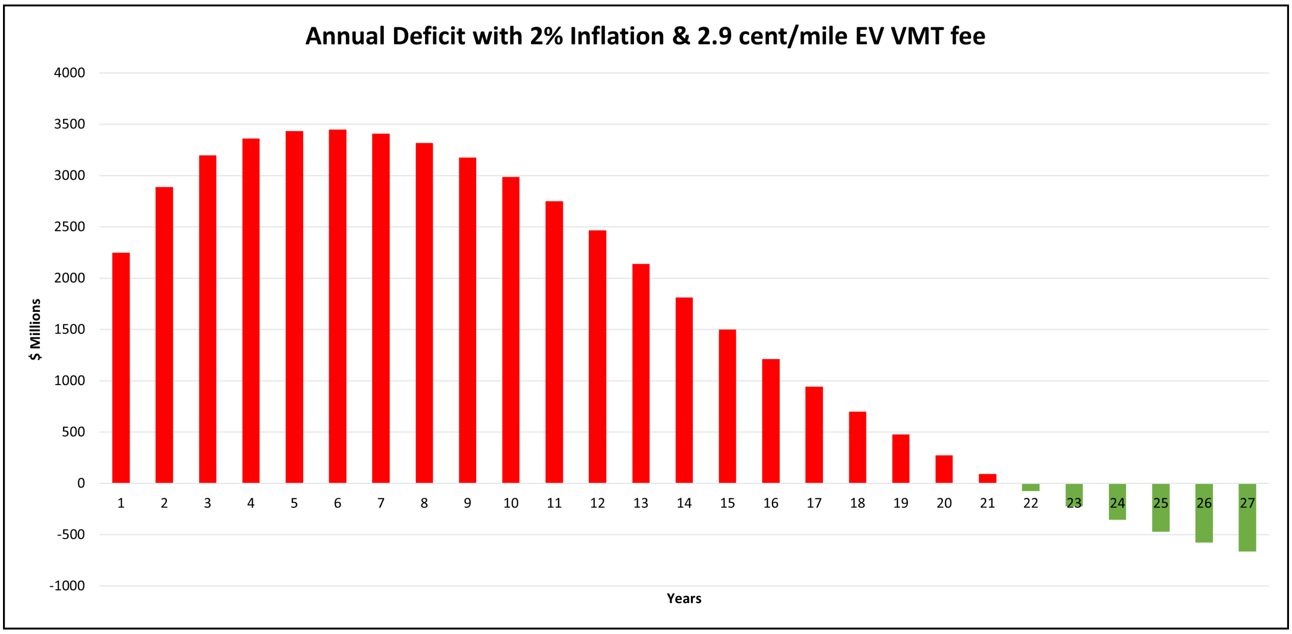



**Figure 23:** Annual Deficit with 2% Inflation & 2.9 cent/mile EV VMT fee

## Scenario 4: Adding Weight Based Fees

We evaluate the addition of a Weight based fee which charges EV drivers depending on how heavy their vehicle is. Heavier vehicles will be charged more as per the design of this scheme, and based on the infrastructure impact the squares of the weights are used to calculate the annual fee paid. Further, the model accounts for the loss in sales due to increasing the weight based fees. ICE drivers are assigned a 20% higher sensitivity to increasing weight based fees and see a steeper drop in sales as the fee increases, as their cars are lighter, and they already pay the gas tax unlike EV car owners. For this scenario we turn off the weight based fee for ICE vehicles, for the sake of fairness as they are already paying the gas tax. We also set the other options mentioned above i.e. fixed fee and VMT fee to zero.

The drop in gas tax is similar to the above scenarios which is not a surprise, given that this is mainly driven by the 2035 switchover to 100% EV sales. An average annual EV weight based fee of $280 brings the deficit to zero by 2050. The assumption on elasticity is every $10 increase in the weight fee reduces EV sales by 1%. Adding a 2% annual inflation to the $105B federal plus state gas tax calculations increases the deficit, and no amount of increase to the EV weight fee bridges the gap, as beyond a point the increase in the fee is counter productive and reduces the number of EV buyers. Hence, measures like fixed weight fees might have to be combined with usage based VMT charge to strike the right balance of EV sales/adoption and bridging the deficit. This will also ensure both ownership via a fixed weight based annual tax, and usage via a VMT charge are assessed and taxed.

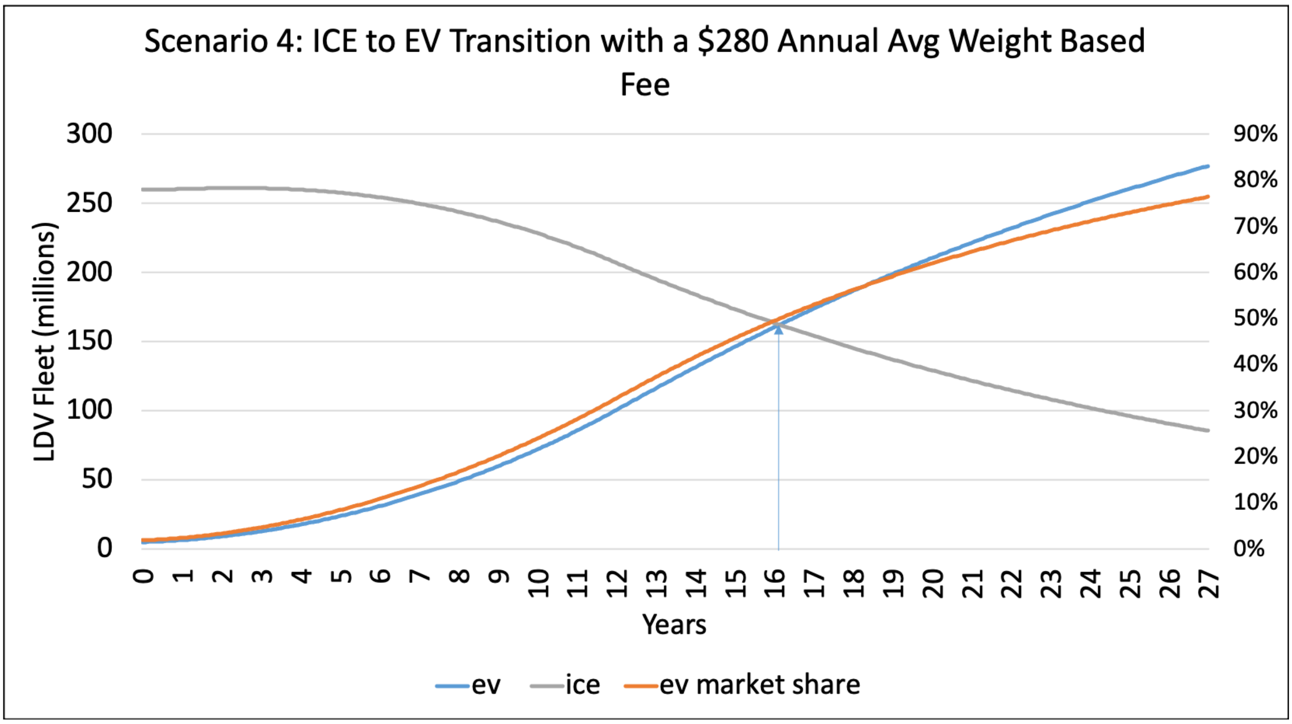



**Figure 24:** Scenario 4

It takes almost 16.5 years for the EV market share to cross 50%, the slowest among all scenarios. As the weight fee limits growth, the overall light duty vehicle fleet size grows marginally to 320 million vehicles by 2050 (272 million EVs + 48 million ICE). As the EV weight fee limits EV replacement and growth, the overall light duty vehicle fleet size grows slower and reaches around 363 million vehicles with around 15 million fewer EVs and 6 million higher ICE vehicles on the road compared to scenario 1 by 2050 (277 Million EVs + 86 million ICE). This scenario has the lowest number of EVs and highest ICE vehicles remaining on the road by 2050.

## Scenario 5: Faster Vehicle Fleet Turnover

The age of the US light vehicle fleet is increasing and is currently at 17 years. [assumption A.8] People are holding onto their vehicles longer and this is a key factor that can slow down this transition. Federal and state governments can introduce new policies to accelerate the turnover of the vehicle fleet. While the incentives to buy new EVs are well known and discussed earlier in this paper, "cash-for-clunkers" (C4C) policies can be introduced to focus on hastening the retirement of the oldest and the most polluting vehicles from the fleet. This can reduce the age of the fleet, speed up replacement of older, polluting vehicles with newer, cleaner, zero-tailpipe emission EVs. However, this will greatly exacerbate the fall in the gas tax. As an example we will consider that the average age of the fleet falls from 17 years by half to 8.5 years due to introduction of an aggressive C4C scheme. We will explore below its resultant impact, and possible supply chain constraints that the automobile industry may run into.

The gas tax falls rapidly and is reduced to only 10% of the original collection by 2050 (Figure 25). In all the previous scenarios the fall for the first 12 years till 2035 was slow, but now it loses more than 50% of its value by 2035, compared to around 15% loss in previous scenarios. Faster replacement of ICE fleet by new EV's, results in very few ICE vehicles being around that pay the gas tax.

In 12 years, EVs will replace ICE vehicles as the majority of the fleet in this scenario. This rate may be faster if not for the limited manufacturing capacity that would come online, leading to between 2-4 Million unmet new car sales every year. By 2050 we are left with a smaller, younger fleet of 290 million to 270 million EVs and the lowest number of ICE vehicles under all scenarios at 20 million.

It must be noted that it is highly unlikely that the C4C scheme will operate for the full duration of 27 years, and the removal of the scheme after 10 years may result in a slowdown of this fleet turnover. This is a matter of policy and needs to be carefully thought out in an industry where the battery technology, range and weight reduction of EVs are constantly improving by the year.

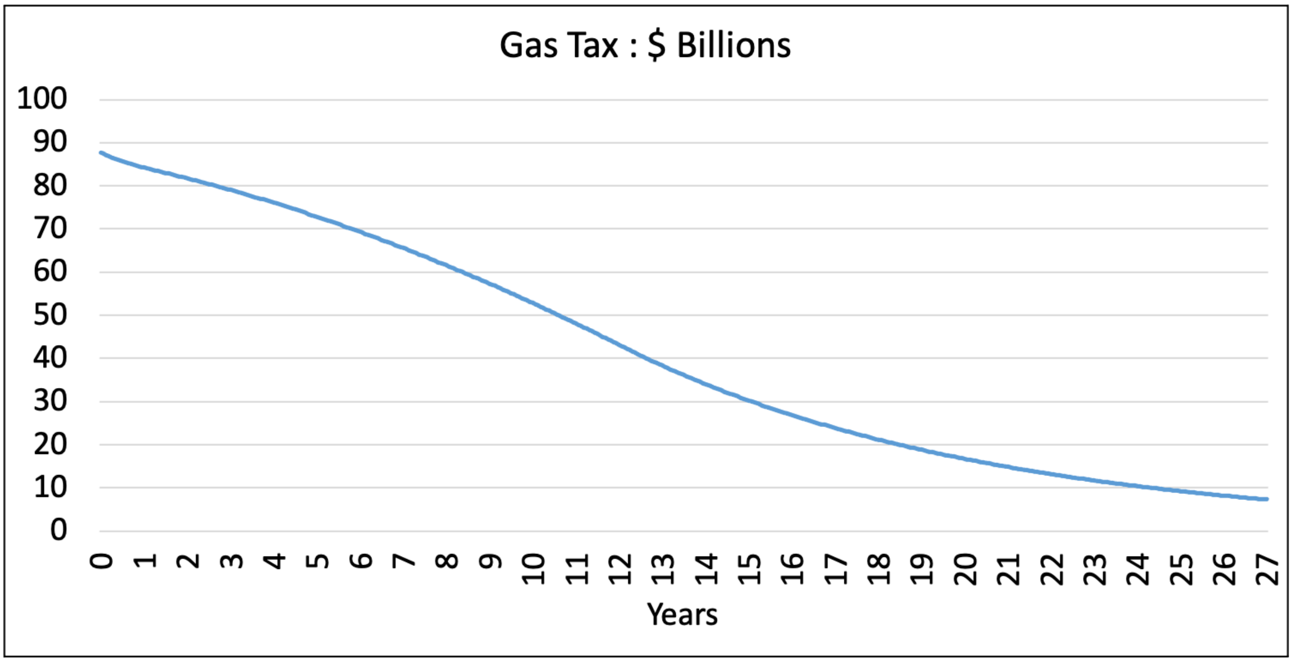



**Figure 25:** Scenario 5: Gax Tax Revenue Projection

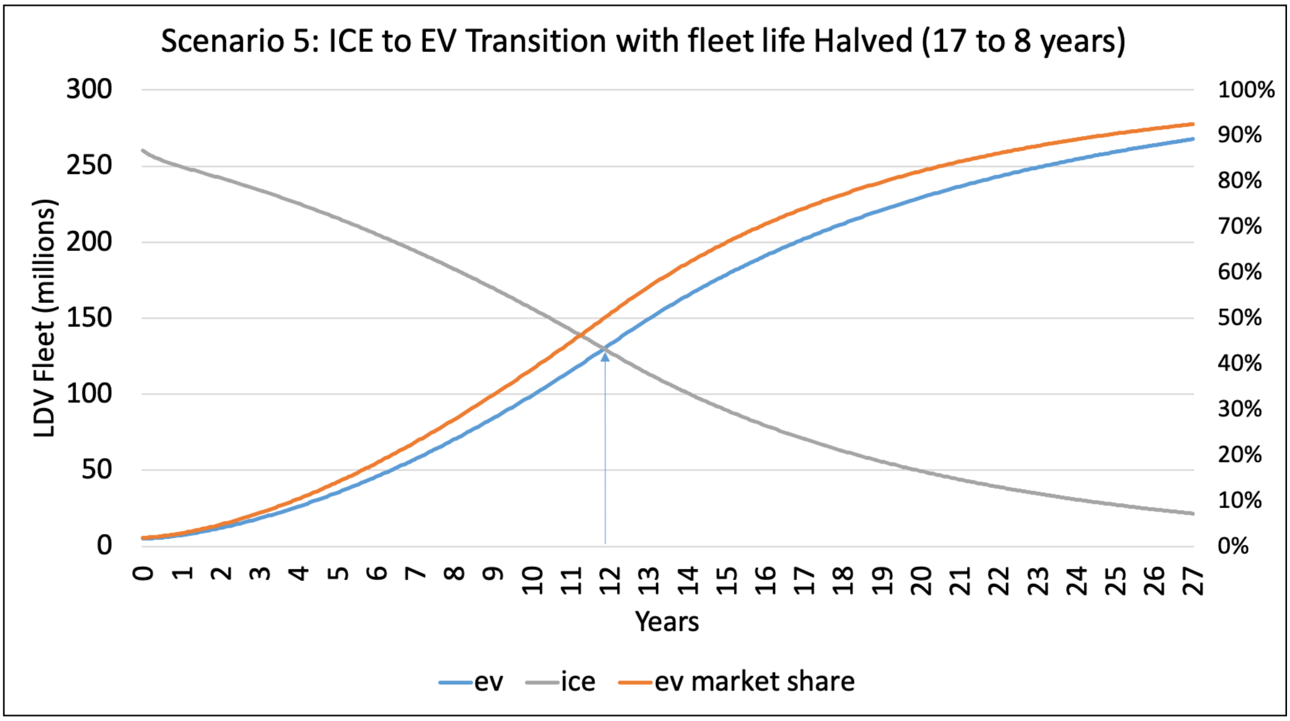



**Figure 26:** Scenario 5

## Scenario 6: Comparison of Gas Tax Drop Across 3 States

California, Georgia and Texas were chosen for this comparison to highlight the possible differences in EV adoption and gas tax drop. Age of the fleet was assumed to be the same for the 3 states. Fuel efficiency for CA was taken as 10% above the national average as the percentage of cars to trucks is higher compared to TX & GA, which have more trucks and the efficiency was taken as 10% below national average. Data for average miles driven per year were taken from the 2019 Federal Highway Administration (CA - 12524, GA - 18334, TX - 16172) [108]. Respective states' gas tax rates (CA - 66.98, GA - 36.09, TX - 20 cents per gallon) were incorporated into the model. California has a mandate for 100% ICE sales by 2035 and this was incorporated into the model. For Georgia this year was assumed to be 2045 and for Texas 2050. Even if some states do not have mandates, as most automobile manufacturers in the US shift away from ICE vehicles, it will be very difficult to buy a new ICE vehicle in 2050, or even earlier. Share of new vehicle buyers and first time car buyers was weighted in the ratio of state wise sales to total country sales, and multiplied by the country figures to arrive at the numbers.

As shown in Figure 27, California sees the biggest drop with the gas tax shrinking by 2/3rds by 2050. The decline steepens around the 7 year mark as the 2035 mandates get nearer, with more EV sales happening by a large margin. CA also has the heftiest gas tax among these 3 states, so it will need to weigh the various alternatives carefully to prevent a financial disaster. Texas and Georgia barely see any reduction in the gas tax for the next 10 years and even by 2050 the reduction is not as drastic as California's almost 70% reduction. Texas sees its gas tax collections shrink by 40% and Georgia sees its gas tax collections shrink by 55% by the year 2050.

This behavior is reflected in the EV adoption rates (Figure 28). California leads the pack with a healthy S curve, converting the bulk of its ICE vehicles via its 2035 mandate. As per the model California will convert a whopping 40% of its fleet to EV's in the 10 year period 2030-2040 and end 2050 with a 80% market share. Georgia is 7 years behind in adoption and Texas is a full 10 years behind California in EV adoption. What sort of impact this will have to the climate and pollution in different states is beyond the scope of this report, but industry can also play a role here by shifting capacities to EV manufacturing and thereby quicken the EV transition in states without mandates.

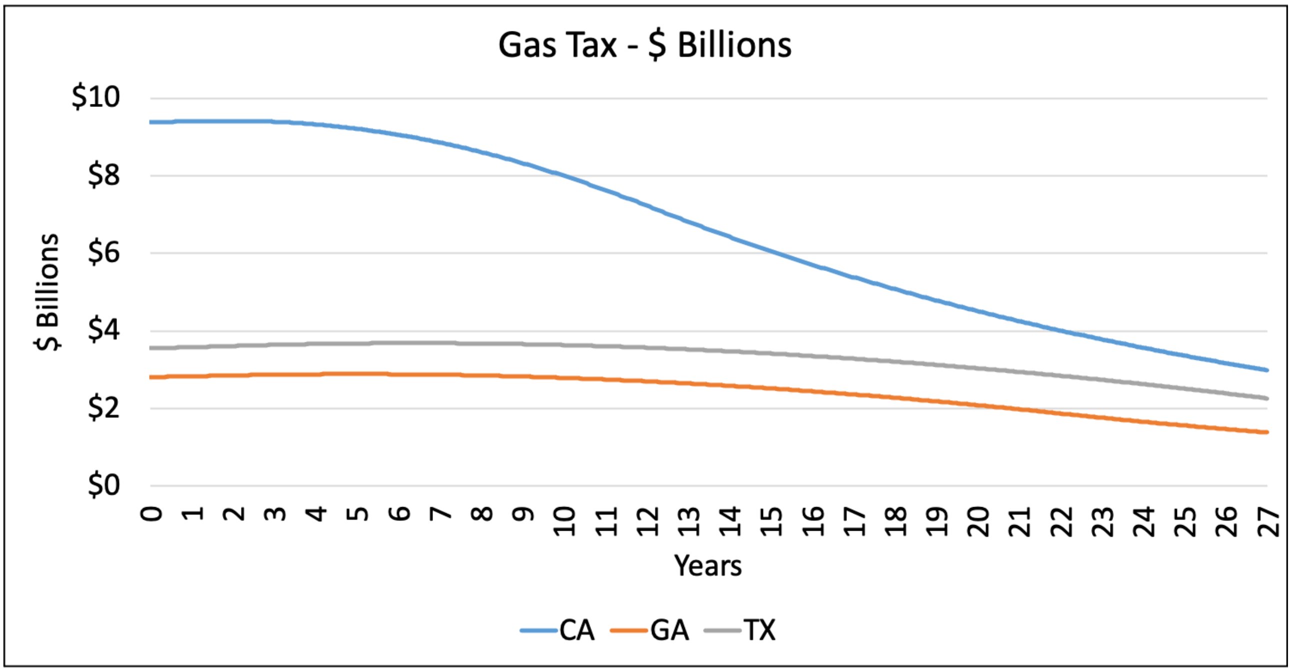



**Figure 27:** Scenario 6: Gas Tax Projection

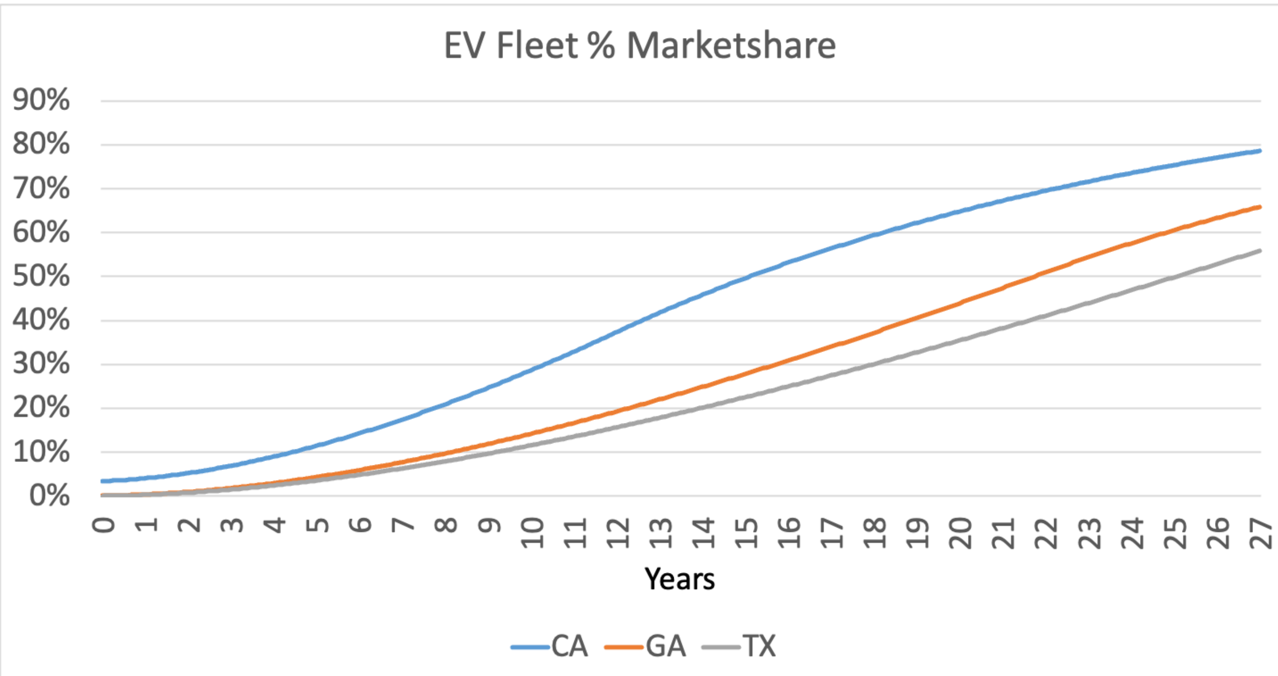



**Figure 28:** Scenario 6: EV Fleet % Marketshare

# CONCLUSION

The movement to reduce tailpipe carbon emissions in the United States has taken on a new energy as a result of recent federal funding and policy interventions directed toward encouraging manufacturer and consumer adoption of electric vehicles. After years of slow, incremental progress, the EV era of American automobility is upon us. An unavoidable consequence of this transition will be the gradual reduction and eventual elimination of gas tax revenues to support transportation infrastructure initiatives.

A national mobility funding system that has been inextricably linked to tax revenues from the sale of fossil fuels must begin now to explore revenue alternatives that are equitable, scalable, politically acceptable and sufficient to meet national, state and local transportation needs. Those needs, in the 21st century, will likely include investments above and beyond highway maintenance and repair. A question for both federal and state decision makers, and the stakeholders whose support will be critical, will be whether this rare opportunity to remake the US transportation funding system will be leveraged to bring a level of rationality to a mid-20th century funding paradigm that was not designed to reduce the negative externalities of vehicular mobility.

Many states will wish to raise transportation-source revenue to invest in more active and sustainable modes of travel, including public transit, intercity rail, safe urban cycling and walkable "15-minute" neighborhoods. Many of these decisions will be made at the state and local levels, and the choices made over the coming decade by federal and state decision makers will heavily influence the degree to which there will be the sufficiency and flexibility of revenue available to support those decisions.

This report seeks to provide both decision makers and stakeholders with a user-friendly framework for thinking through these issues, and an interactive tool to enable more thoughtful, data-based decisions. In that sense, this report may help open up the process of considering the post-gas tax world to include legislators, thought leaders, advocacy groups and other stakeholders who wish to have a meaningful voice in the conversation about how we will pay for our transportation future. This is an opportune moment for those conversations to begin in earnest.

# Endnotes


[1] Congressional Budget Office, Emissions of Carbon Dioxide in the Transportation Sector, Online, https://www.cbo.gov/system/files/2022-12/58566-co2-emissions-transportation.pdf (2022).

[2] EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002, Online, https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-andsinks-1990-2021 (2023).

[3] Congressional Budget Office, Highway Trust Fund Accounts, Online, https://www.cbo.gov/data/baseline-projections-selected-programs#8 (2020).

[4] United Nations, Climate Change, Online, https://www.un.org/en/global-issues/climate-change.

[5] AR6 Synthesis Report, Climate Change 2023, Online, https://www.ipcc.ch/report/ar6/syr/ (2023).

[6] UN Climate Change Conference UK 2021, TRANSPORT, Online, https://webarchive.nationalarchives.gov.uk/ukgwa/20230105153249/https://ukcop26.org/transport/ (2021).

[7] The White House, Remarks by President Biden at the 27th Conference of the Parties to the Framework Convention on Climate Change (COP27), Online, https://www.whitehouse.gov/briefing-room/speeches-remarks/2022/11/11/remarks-by-president-biden-at-the-27th-conference-of-the-parties-to-the-framework-convention-on-climate-change-cop27-sharm-el-sheikh-egypt/ (2022).

[8] EPA, Tailpipe Greenhouse Gas Emissions from a Typical Passenger Vehicle, Online, https://www.epa.gov/greenvehicles/tailpipe-greenhouse-gas-emissions-typical-passenger-vehicle (2023).

[9] U.S. Federal Highway Administration, Moving 12-Month Total Vehicle Miles Traveled [M12MTVUSM227NFWA], Online, https://fred.stlouisfed.org/series/M12MTVUSM227NFWA/ (2023).

[10] W. S. Vickrey, Pricing in urban and suburban transport, The American Economic Review 53 (2) (1963) 452–465.

[11] R. G. Newell, K. Rogers, The us experience with the phasedown of lead in gasoline, Resources for the Future 32 (4) (2003).

[12] Encyclopedia of Physical Science and Technology (Third Edition), Clean Air Act Amendments, https://www.sciencedirect.com/topics/engineering/clean-air-act-amendments (2003).

[13] The Associated Press, U.S. speeds up phaseout of incandescent light bulbs in favor of energy-efficient ones, https://www.npr.org/2022/04/26/1094871850/light-bulbs-led-energy-incandescent (2022).

[14] EPA, Biden-Harris Administration Proposes Strongest-Ever Pollution Standards for Cars and Trucks to Accelerate Transition to a Clean-Transportation Future, Online, https://www.epa.gov/newsreleases/biden-harris-administration-proposes-strongest-ever-pollution-standards-cars-and (2023).

[15] Joint Office of Energy and Transportation, State Plans for Electric Vehicle Charging, Online, https://driveelectric.gov/state-plans/ (2023).

[16] U.S. Department of Energy, Federal Tax Credits for Plug-in Electric and Fuel Cell Electric Vehicles Purchased in 2023 or After, https://fueleconomy.gov/feg/tax2023.shtml/#requirements (2023).

[17] P. Slowik, S. Searle, H. Basma, J. Miller, Y. Zhou, F. Rodríguez, C. Buysse, R. Minjares, S. Kelly, L. Pierce, et al., Analyzing the impact of the inflation reduction act on electric vehicle uptake in the united states, Energy Innovation and International Council on Clean Transportation (2023).

[18] California Air Resources Board, States that have Adopted California's Vehicle Standards under Section 177 of the Federal Clean Air Act, Online, https://ww2.arb.ca.gov/resources/documents/states-have-adopted-californias-vehicle-standards-under-section-177-federal (2022).

[19] Noah Gabriel, $210 Billion of Announced Investments in Electric Vehicle Manufacturing Headed for the U.S., Online, https://www.atlasevhub.com/data_story/210-billion-of-announced-investments-in-electric-vehicle-manufacturing-headed-for-the-u-s/#:~:text=Vehicle%20manufacturers%20and%20battery%20makers,than%20in%20any%20other%20country. (2023).

[20] Kalea Hall, GM, battery materials supplier to team up on $1 billion North American facility, Online, https://www.detroitnews.com/story/business/autos/general-motors/2023/06/02/gm-posco-future-m-to-expand-na-battery-supply-chain-with-new-complex/70280619007/ (2023).

[21] Tomi Kilgore, GM sales rise to 2.3 million vehicles in 2022 as EV sales soar, Online, https://www.marketwatch.com/story/gm-sales-rise-to-2-3-million-vehicles-in-2022-as-ev-sales-soar-11672853709 (2023).

[22] Camila Domonoske, Automakers partner with mines as electric cars rely on raw materials for batteries, Online, https://www.npr.org/2022/03/11/1085670133/automakers-partner-with-mines-as-electric-cars-rely-on-raw-materials-for-batteri (2022).

[23] Fred Meier, Here Are the New Electric Vehicles Planned by 2026, Online, https://www.cars.com/articles/here-are-the-new-electric-vehicles-planned-by-2026-461674/ (2023).

[24] A. K. Sasha Lekach, EV Survey Shows Range Anxiety High While Charging Costs Remain Low, Online, https://www.forbes.com/wheels/features/ev-range-cost-confidence-survey/ (2022).

[25] Citibeats, Explaining Range Anxiety and the Future of EVs, Online, https://www.citibeats.com/center-for-knowledge/explaining-range-anxiety-and-the-future-of-evs (2022).

[26] S. Hardman, G. Tal, et al., Discontinuance among california's electric vehicle buyers: Why are some consumers abandoning electric vehicles?, Tech. rep., University of California, Berkeley. Institute of Transportation Studies (2021).

[27] D. Chakraborty, K. Buch, G. Tal, Cost of vehicle ownership: cost parity between plug-in electric vehicles and conventional vehicles is at least a decade away (2021).

[28] J.D.Power, Growing Electric Vehicle Market Threatens to Short-Circuit Public Charging Experience, J.D. Power Finds, Online, https://www.jdpower.com/business/press-releases/2022-us-electric-vehicle-experience-evx-public-charging-study (2022).

[29] POLITICO, Why America's EV chargers keep breaking, Online, https://www.politico.com/news/2023/04/12/america-ev-chargers-keep-breaking-heres-why-00089181 (2023).

[30] Department of Energy, Biden-Harris Administration Invests $51 Million in America's Electric Vehicle Charging Network, Online, https://www.energy.gov/articles/biden-harris-administration-invests-51-million-americas-electric-vehicle-charging-0 (2023).

[31] U.S. Department of Transportation, Biden-Harris Administration Announces Latest Steps to Deliver a National Network of Convenient, Reliable, Made-in-America Electric Vehicle Chargers, Online, https://www.transportation.gov/briefing-room/biden-harris-administration-announces-latest-steps-deliver-national-network (2023).

[32] Hart Schwartz, America's Aging Vehicles Delay Rate Of Fleet Turnover, Online, https://soltron-gtr.com/wp-content/uploads/2018/07/America%E2%80%99s-Aging-Vehicles.pdf (2018).

[33] U.S. News, Study Shows That Plug-In Hybrid Owners Aren't Plugging In, Online, https://cars.usnews.com/cars-trucks/features/phev-owners-not-plugging-in (2023).

[34] U.S. News, Future Electric Cars: 2024-2030 EVs, Online, https://cars.usnews.com/cars-trucks/advice/future-electric-cars (2023).

[35] M. H. Rose, Interstate: Express highway politics, 1939-1989, Univ. of Tennessee Press, 1990.

[36] Richard F. Weingroff, Public Roads - Summer 1996, Online, https://highways.dot.gov/public-roads/summer-1996/federal-aid-road-act-1916-building-foundation#:~:text=Serious%20consideration%20of%20a%20federal,nor%20more%20than%2050%20percent (1996).

[37] B. Francis, Gasoline excise taxes, 1933-2000, Statistics of Income Bulletin (2000) 140–46.

[38] P. K. Wheeler, Highway assistance programs: A historical perspective, Congress of the United States, Congressional Budget Office, 1978.

[39] S. Gössling, J. Kees, T. Litman, The lifetime cost of driving a car, Ecological Economics 194 (2022) 107335.

[40] Ivan Pereira, States' registration plans could accelerate electric vehicle adoption, Online, https://abcnews.go.com/Business/states-registration-plans-accelerate-electric-vehicle-adoption/story?id=83788121 (2022).

[41] Andrew Krok, The Average US Car Is Now 12.2 Years Old, Report Says, Online, https://www.cnet.com/roadshow/news/average-us-car-age-2022-report/ (2022).

[42] Congressional Research Service, Funding and Financing Highways and Public Transportation, Online, https://sgp.fas.org/crs/misc/R47573.pdf (2023).

[43] Federal Reserve Bank of Minneapolis, Consumer Price Index, 1913-, Online, https://www.minneapolisfed.org/about-us/monetary-policy/inflation-calculator/consumer-price-index-1913- (2023).

[44] The Washington Post , A key election metric for Democrats is on a sign in your neighborhood, Online, https://www.washingtonpost.com/politics/2022/10/18/gas-prices-election-biden/ (2022).

[45] Camila Domonoske, Whether gas prices are up or down, don't blame or thank the president, Online, https://www.npr.org/2022/10/27/1131675651/gas-prices-oil-fuel-rising-president (2022).

[46] Ulrik Boesen, How Are Your State's Roads Funded?, Online, https://taxfoundation.org/state-infrastructure-spending/ (2021).

[47] U.S. Government Printing Office Publication, Relationship of Toll Facilities to the Federal-Aid Highway Program, 1966.

[48] S. L. Kone, R. F. Winters, Taxes and voting: Electoral retribution in the american states, The Journal of Politics 55 (1) (1993) 22–40.

[49] L. L. Shu, M. H. Bazerman, Cognitive barriers to environmental action: Problems and solutions, Harvard Business School NOM Unit Working Paper (11-046) (2010).

[50] C. R. Sunstein, Endogenous preferences, environmental law, The Journal of Legal Studies 22 (2) (1993) 217–254.

[51] A. W. Agrawal, H. Nixon, et al., What do americans think about federal tax options to support public transit, highways, and local streets and roads? results from year four of a national survey., Tech. rep., California. Dept. of Transportation (2013).

[52] B. van Wee, J. A. Annema, S. van Barneveld, Controversial policies: growing support after implementation. a discussion paper, Transport Policy 139 (2023) 79–86.

[53] X. Chen, J. Zhao, Bidding to drive: Car license auction policy in shanghai and its public acceptance, Transport Policy 27 (2013) 39–52.

[54] W. J. Congdon, J. R. Kling, S. Mullainathan, Behavioral economics and tax policy, National Tax Journal 62 (3) (2009) 375–386.

[55] National Conference of State Legislatures, Vehicle Registration Fees By State, Online, https://www.ncsl.org/transportation/vehicle-registration-fees-by-state (2020).

[56] Y. Zheng, J. Moody, S. Wang, J. Zhao, Measuring policy leakage of beijing's car ownership restriction, Transportation Research Part A: Policy and Practice 148 (2021) 223–236.

[57] S. Chu, Car restraint policies and mileage in singapore, Transportation Research Part A: Policy and Practice 77 (2015) 404–412.

[58] C. Harto, S. Baker-Branstetter, Rising trend of punitive fees on electric vehicles won't dent state highway funding shortfalls but will hurt consumers, Consumer Reports, September (2019).

[59] P. Slowik, N. Lutsey, The continued transition to electric vehicles in us cities, White paper. The International Council of Clean Transportation (ICCT) (2018).

[60] U.S. FHWA, Toll Facilities in the United States, Online, https://www.fhwa.dot.gov/policyinformation/tollpage/t1part3.cfm (2015).

[61] U.S. FHWA, High-Occupancy Toll Lanes (Partial Facility Pricing), Online, https://ops.fhwa.dot.gov/congestionpricing/strategies/involving_tolls/hot_lanes.htm (2022).

[62] M. Manville, E. Goldman, Would congestion pricing harm the poor? do free roads help the poor?, Journal of Planning Education and Research 38 (3) (2018) 329–344.

[63] U.S. FHWA, Why Does The Interstate System Include Toll Facilities?, Online, https://www.fhwa.dot.gov/infrastructure/tollroad.cfm#:~:text=Inclusion%20of%20the%202%2C102%20miles,be%20used%20for%20their%20improvement (2017).

[64] U.S. FHWA, Federal Tolling Programs, Online, https://www.fhwa.dot.gov/ipd/tolling_and_pricing/tolling_pricing/section_129_faqs.aspx (2023).

[65] U.S. FHWA, Value Pricing Pilot Program, Online, https://ops.fhwa.dot.gov/congestionpricing/value_pricing/index.htm (2022).

[66] P. Sorensen, L. Ecola, M. Wachs, M. Donath, L. Munnich, B. Serian, Implementable strategies for shifting to direct usage-based charges for transportation funding, National Cooperative Highway Research Program, Web-only Document 143 (2009).

[67] California Air Resources Board, On-Board Diagnostic II (OBD II) Systems Fact Sheet, Online, https://ww2.arb.ca.gov/resources/fact-sheets/board-diagnostic-ii-obd-ii-systems-fact-sheet (2019).

[68] K. S. et al., Will Connected Cars Be a Boon or Bust for the Automotive Aftermarket?, Online, https://www.bcg.com/publications/2023/software-defined-cars-boon-or-bust (2023).

[69] A. Tobin, Which car insurance companies have the best car tracking device programs?, Online, https://clearsurance.com/blog/car-tracking-devices-which-car-insurance-companies-are-the-best (2022).

[70] MINETA, Public support for a mileage fee grows to 53%, Online, https://transweb.sjsu.edu/press/Public-support-mileage-fee-grows-53 (2021).

[71] J. Witty, Oregon's mileage fee concept and road user fee pilot program, Tech. rep. (2006).

[72] P. F. Hanley, J. G. Kuhl, National evaluation of mileage-based charges for drivers: Initial results, Transportation research record 2221 (1) (2011) 10–18.

[73] E. J. Traut, T. C. Cherng, C. Hendrickson, J. J. Michalek, Us residential charging potential for electric vehicles, Transportation Research Part D: Transport and Environment 25 (2013) 139–145.

[74] WIRED, EV Charging Costs Penalize Urban Drivers, Online, https://www.wired.com/story/electric-car-charging-cost-income/ (2022).

[75] I. W. H. Parry, M. Walls, W. Harrington, Automobile externalities and policies, Journal of economic literature 45 (2) (2007) 373–399.

[76] T. Litman, Comprehensive parking supply, cost and pricing analysis (2022).

[77] Parking Reform Network, Parking Mandates Map, Accessed June 14, 2023, https://parkingreform.org/resources/mandates-map/ (2023).

[78] M. L. Anderson, M. Auffhammer, Pounds that kill: The external costs of vehicle weight, Review of Economic Studies 81 (2) (2014) 535–571.

[79] J. Tyndall, Pedestrian deaths and large vehicles, Economics of Transportation 26 (2021) 100219.

[80] R. Johnsson, The cost of relying on the wrong power—road wear and the importance of the fourth power rule (tp446), Transport Policy 11 (4) (2004) 345–353.

[81] US Department of Energy, Average Vehicle Occupancy Remains Unchanged From 2009 to 2017, Online, https://www.energy.gov/eere/vehicles/articles/fotw-1040-july-30-2018-average-vehicle-occupancy-remains-unchanged-2009-2017 (2018).

[82] Environmental Protection Agency, Highlights of the Automotive Trends Report, Online, https://www.epa.gov/automotive-trends/highlights-automotive-trends-report (2022).

[83] V. R. Timmers, P. A. Achten, Non-exhaust pm emissions from electric vehicles, Atmospheric environment 134 (2016) 10–17.

[84] T. Li, Influencing parameters on tire–pavement interaction noise: Review, experiments, and design considerations, Designs 2 (4) (2018) 38.

[85] Mark Segraves, DC Vehicle Registration Will More Than Triple for Some SUVs, Trucks by 2024, Online, https://www.nbcwashington.com/news/local/dc-vehicle-registration-will-more-than-triple-for-some-suvs-trucks-by-2024/3063961/ (2022).

[86] Luz Lazo, D.C. Drivers Will Pay Higher Car Registration Fees under New Policy, Online, https://www.washingtonpost.com/transportation/2022/06/25/dc-higher-vehicle-registration-fees/ (2022).

[87] S. B. Anani, S. M. Madanat, Highway maintenance marginal costs: What if the fourth power assumption is not valid?, Transport Policy 17 (6) (2010) 486–495.

[88] Susan Meyer, Study: Average Car Size Is Increasing — Will Roads Still Be Safe for Small Cars and Pedestrians?, Online, https://www.thezebra.com/resources/driving/average-car-size/ (2023).

[89] IIHS HLDI, New study suggests today's SUVs are more lethal to pedestrians than cars, Online, https://www.iihs.org/news/detail/new-study-suggests-todays-suvs-are-more-lethal-to-pedestrians-than-cars (2020).

[90] The New York Times, The exceptionally American problem of rising road deaths, Online, https://www.nytimes.com/2022/11/27/upshot/road-deaths-pedestrians-cyclists.html (2022).

[91] S. C. Davis, R. G. Boundy, Transportation energy data book: Edition 40, Tech. rep., Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States) (2022).

[92] Aaron Gordon, American Cars Are Getting Too Big For Parking Spaces, VICE, https://www.vice.com/en/article/y3pyzx/american-cars-are-getting-too-big-for-parking-spaces (2023).

[93] S. Olson, P. Berkaw, L. Charland, E. Patton, L. Bilmes, The $64 billion massachusetts vehicle economy (2019).

[94] P. S. Nivola, R. W. Crandall, The extra mile, The Brookings Review 13 (1) (1995) 30.

[95] EVgo, Power up With kWh and Time of Use (TOU) Pricing, Online, https://www.evgo.com/pricing/tou/ (2023).

[96] Betsy Reed, Car tyres produce vastly more particle pollution than exhausts, tests show, Online, https://www.theguardian.com/environment/2022/jun/03/car-tyres-produce-more-particle-pollution-than-exhausts-tests-show (2022).

[97] U.S. FHWA, 2022 FHWA Forecasts of Vehicle Miles Traveled (VMT), Online, https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.cfm#ftn3 (2022).

[98] Diesel Technology Forum, Q1 2023 U.S. DIESEL VEHICLE SALES COMMENTARY AND INSIGHT BY BAUM ASSOCIATES, Online, https://dieselforum.org/vehicle-sales-dashboard (2023).

[99] U.S. Department of Transportation, Motor Vehicle Registrations Dashboard data, Online, https://catalog.data.gov/dataset/motor-vehicle-registrations-dashboard-data (2022).

[100] Statista, New light vehicle sales in the United States from 2002 to 2020, Online, https://www.statista.com/statistics/274929/new-vehicle-registrations-in-the-united-states/ (2022).

[101] Zachary Shahan, US Electric Car Sales Increased 65% In 2022, Online, https://cleantechnica.com/2023/02/25/us-electric-car-sales-increased-65-in-2022/ (2023).

[102] Knowledge at Wharton, Demographic Shifts: Shaping the Future of Car Ownership, Online, https://knowledge.wharton.upenn.edu/article/demographic-shifts-shaping-future-car-ownership/ (2017).

[103] D. R. Keith, S. Houston, S. Naumov, Vehicle fleet turnover and the future of fuel economy, Environmental Research Letters 14 (2) (2019) 021001.

[104] Josh Noel, How Much Do Cars Weigh?, Online, https://www.autolist.com/guides/average-weight-of-car (2023).

[105] Peter Valdes-Dapena, Why electric cars are so much heavier than regular cars, Online, https://www.cnn.com/2021/06/07/business/electric-vehicles-weight/index.html (2021).

[106] Tax Policy Center, Motor Fuel Tax Revenue 1977-2020, Online, https://www.taxpolicycenter.org/statistics/motor-fuel-tax-revenue (2022).

[107] American Petroleum Institute, Gasoline Tax, Online, https://www.api.org/oil-and-natural-gas/consumer-information/motor-fuel-taxes/gasoline-tax (2022).

[108] Susan Meyer, Average miles driven per year in the U.S., The Zebra, https://www.thezebra.com/resources/driving/average-miles-driven-per-year/#average-miles-driven-per-year-by-state (2023).