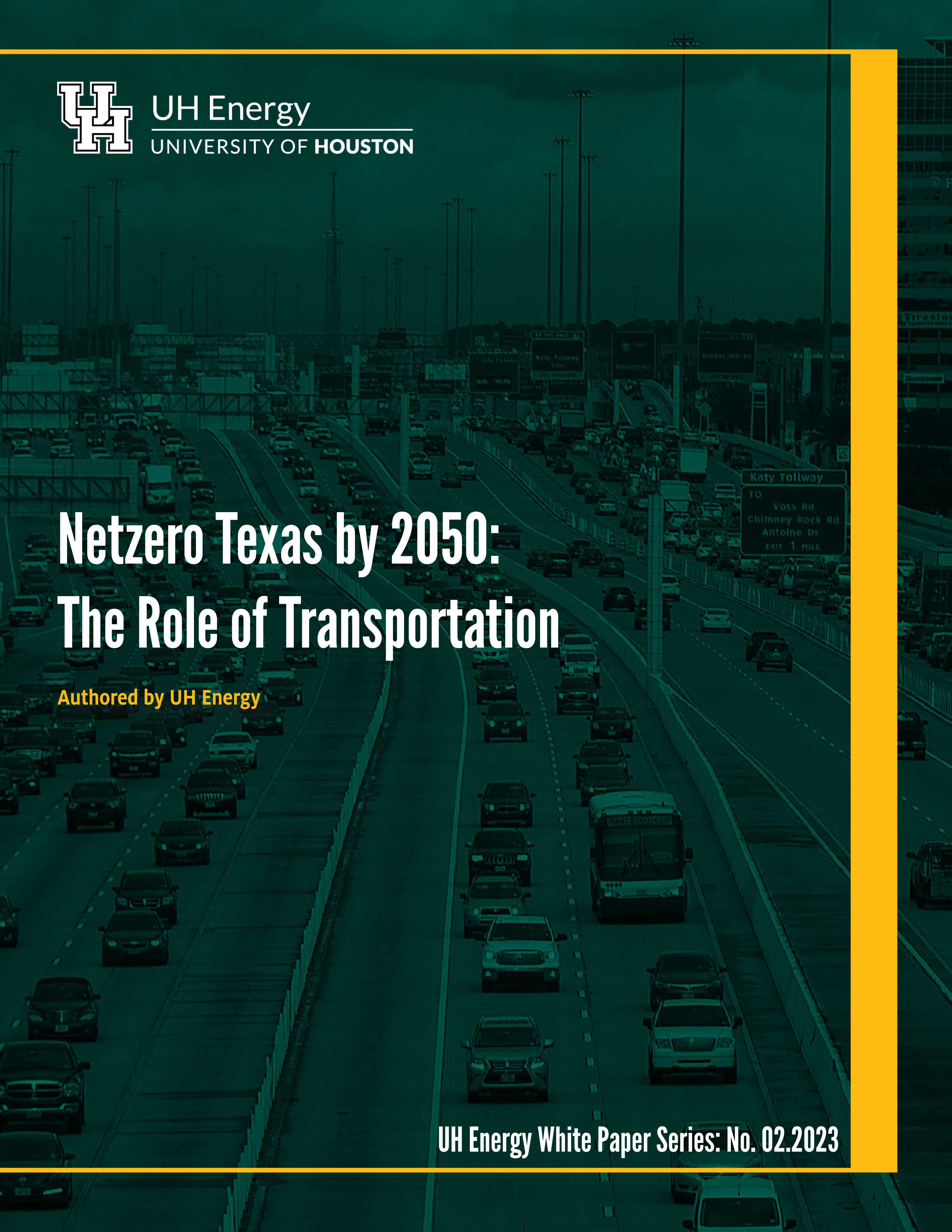

UH Energy
UNIVERSITY OF **HOUSTON**

Netzero Texas by 2050: The Role of Transportation

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WHITE PAPER CONTRIBUTERS

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EXECUTIVE SUMMARY

Cars, trucks, and Texas – the lure of the open road is an indelible part of the Texas mystique, but the state's transportation sector also plays a tangible and much more complicated role in efforts to reduce emissions to net zero by 2050. A growing population and booming economy mean more cars and trucks for personal travel and to transport both the goods the state produces and those it consumes. Cars and trucks traveled 260 billion vehicle miles on the state's roadways in 2021, offering just one measure of the sector's outsize importance to the Texas economy and its equally outsize contribution to greenhouse gas emissions. Rail, air, and marine transportation provide crucial additional transit for people and goods, adding to emissions.

The number of vehicles on the state's roads, rails, and waterways won't drop anytime soon. In fact, with anticipated population growth and the strong correlation between gross economic activity and passenger and freight vehicle miles traveled, the numbers will grow substantially, making it crucial to address transportation emissions if we are to reach net zero targets. The transportation sector currently contributes about one-third of total emissions in Texas.

Unlike industrial and electric power generation, GHG emissions from transportation are widely distributed and dilute rapidly to atmospheric concentrations.

Converting those vehicles to electric or other zero emission vehicles will have real, quantifiable impacts on public health – fewer deaths, fewer asthma attacks, fewer sick days, a boost that can be measured in improved economic output. However, even under the most aggressive policies considered here, requiring all new vehicles sold in Texas by 2040 to be electric or other zero-emission vehicles and assuming the electric grid has converted to net-zero generation, our research shows the transportation sector won't be carbon neutral by 2050. Even under relatively light regulations, the financial costs will go far beyond the purchase price of new vehicles, requiring investments in job training tobolster and maintain the workforce and multibillion-dollar expenditures for charging stations and other infrastructure.

To better understand the complex interplay of factors involved in decarbonizing the Texas transportation sector, we conducted a series of studies to evaluate potential transit-related policies that could guide the state to net-zero emissions by 2050, including a "business as usual" scenario that relies on no substantial policy or market deviations from the current scenario, to boost the electrification of the Texas fleet, made up of light-duty vehicles (LDVs), and medium and heavy-duty vehicles (MDVs and HDVs). We also address possible future scenarios for rail, air, and marine transportation. Here we detail the potential outcomes for emissions, employment, economics, public health, and other factors.

Our main findings are:

- The most significant impact on greenhouse gas (GHG) emissions from the transportation sector comes from the movement of passengers and freight through light, medium, and heavy-duty vehicles. The rapid adoption of electric vehicles in the LDV market has been spurred by an accelerated expansion in the number and type of electric vehicle (EV) models being developed at various price levels.

- Anticipated increases in population and continued economic growth will result in significantly more vehicles on the road, more overall vehicle miles traveled, and a higher total volume of freight transported on state roads. There will be an additional 2.5 million LDVs on Texas roads between 2022 and 2050, assuming the vehicles have an average life of 15 years and travel an average of 11,500 miles each year. EVs in the light-duty fleet are expected to grow from 8% of new car sales in 2022 to about 63% of new car sales in 2050 under a business-as-usual scenario. Alternative scenarios assume EVs make up 100% of all new sales by 2040 or 2050, respectively. Simultaneously, by the year 2050, internal combustion engine vehicles (ICEVs) will make up 60% of the total fleet under the business-as-usual scenario, 32% for the 2050 scenario, and 7% for the 2040 scenario.

- An additional 82,000 medium and heavy-duty vehicles will be on Texas roads by 2050, assuming the vehicles have an average life of 12 years and 25,500 miles of average annual vehicle miles traveled.

- If the current electricity mix were to persist in 2050, under the most aggressive decarbonization target, which would require EVs or other zero-emission vehicles (ZEVs) to make up all new sales by 2040, emissions from on-road vehicles would decline by about 35% for LDVs and 52% for M/HDVs. In contrast, under the business-as-usual scenario, emissions will decrease by about 10% for LDVs and 27% for MDVs and HDVs. If the electricity mix reaches net zero by 2050, emissions for LDVs will drop by 27% compared to current emissions under the business-as-usual scenario and by 68% under the 2040 scenario. For MDVs and HDVs, emissions would drop 21% compared to current emissions under the business-as-usual scenario, and by 76% for the 2040 scenario. Under no scenario examined do we anticipate achieving net-zero emissions by 2050 in the road transportation sector.

- Rail, aviation, and marine sectors contribute about 12% of emissions from the transportation sector in Texas. Electrifying the fleet or producing carbon-neutral fuels using carbon-neutral electricity could reduce rail, aviation, and marine freight-related emissions by as much as 99% by 2050, compared to a 2022 baseline.

- The electrification of the road fleet will be expensive; in addition to the cost of vehicle replacement, the change will require an annual expenditure of $250 million to $640 million for Level-2 (L2) charging stations and between $500 million and $1.3 billion for DC Fast Charging (DCFC) stations in 2040. The cumulative cost for charging infrastructure ranges from $19 billion to $35 billion between now and 2050. That doesn't include the cost of the land or other infrastructure required to deliver electricity to the stations. The switch from ICEVs to EVs will result in the retirement of many gas stations, requiring expenditures of between $2 billion and $5 billion for environmental remediation.

- Based on current battery technology, the total volume of lithium and cobalt necessary for the number of EVs expected in the state by 2050 would exceed the 2021 worldwide production of both minerals. There will also be a significant increase in the consumption of materials including copper, manganese, and graphite.

- The electrification of the on-road fleet and job losses associated with the retirement of the conventional fleet will add more than 130,000 jobs to the Texas economy by 2050 under the business-as-usual scenario. These include direct, indirect, and induced jobs in the transportation, electricity, advertising, retail, data and networking, and maintenance sectors. The policy target of all new sales being EVs by 2050 will add about 40,000 jobs, while the aggressive policy target of all new sales being EVs by 2040 will add about 180,000 jobs by 2050. While prevailing hourly wages in the traditional auto sector range from $26 for auto-service technicians and mechanics to $60 for a unionized auto assembly worker, most jobs in the EV industry are not unionized and range from $17-$21 per hour. Hence, economic gains from the new jobs will require higher wages, and the current workforce will require upskilling and reskilling to offset any loss.

CHAPTER 1: INTRODUCTION

The ability to transport people and goods safely, efficiently, economically, and reliably is an important predictor of quality of life and impacts every aspect of modern life. The quality, access, functionality, and cost of transportation determine if and how people can participate in socioeconomic activities, including connecting them to the workplace, healthcare services, educational institutions, and social events, and providing access to resources and markets. The transportation sector, its relationship and impact on society, and its interdependencies are complex, varied, and dynamic. Figure 1 attempts to capture the transportation value chain, segments, modes, and impact on quality of life. While the needs and goals of the transportation system are likely to change over time, the elements highlighted in Figure 1 are expected to remain relevant.

These elements and functions are decentralized and influenced by often competing forces, including government agencies, individuals, businesses, and different economic sectors. The resulting impacts, in contrast, are felt both within sectors and collectively across sectors. Understanding the scale of these interdependencies and cross-sectoral impacts is key for effective decarbonization of the transportation sector, where the emissions are predominantly non-stationary and distributed, and in Texas, where the transportation sector has an outsized impact on the economy. In this study, we evaluate pragmatic scenarios that can reduce and mitigate transportation emissions to help the sector effectively decarbonize by 2050. Our forward-looking scenarios account for the impact of sociodemographic changes in Texas over the next 28 years on the transportation value chain and how that is expected to affect the state's environment, economy, public health and equity, and workforce. We discuss the implications of our findings and highlight opportunities and challenges for policies that can get the transportation sector in Texas to net zero by 2050.

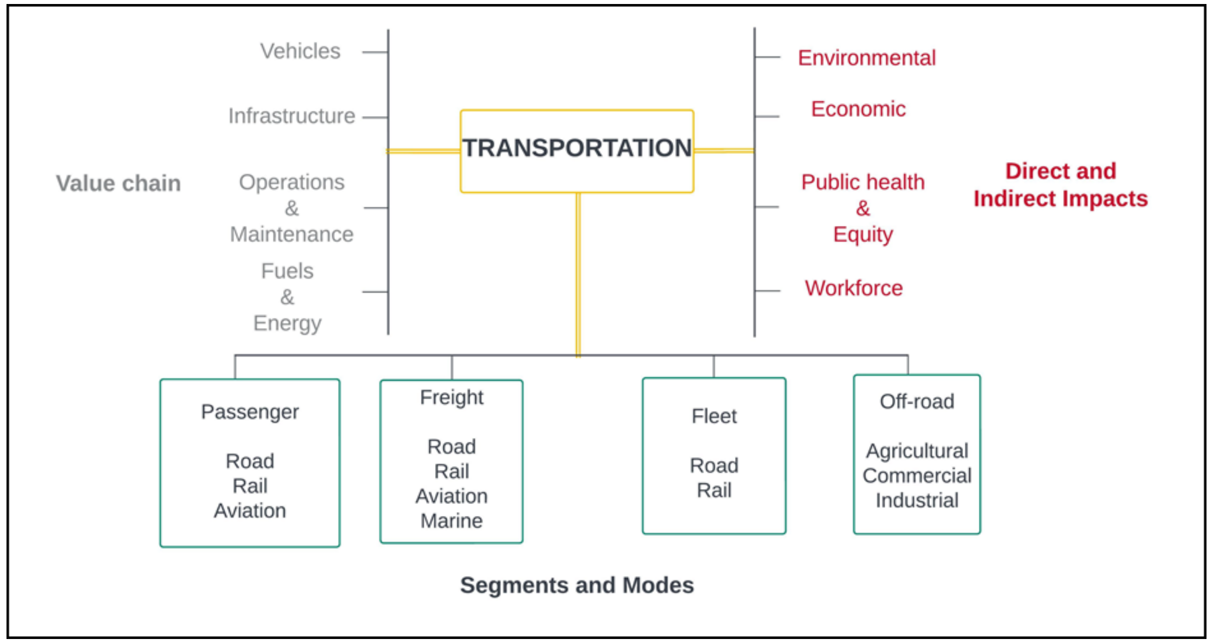

Figure 1. Interdependencies in the transportation sector: the transportation value chain, segments and models, and direct and indirect impacts of the sector.

The rest of this chapter provides an overview of how energy use and emissions from the transportation sector have evolved in Texas as compared to their current state. We evaluate the relationship between transportation emissions with two key socioeconomic indicators – GDP and population change. Next, we analyze the sectoral emissions contribution of different modes of transportation in the state and compare it to national trends.

Chapter 2 discusses the current state of the fleet in Texas across segments and modes for passenger and freight transportation. Chapter 3 highlights the current state of road, rail, aviation, marine, fueling, and energy infrastructure of the state, and quantifies the

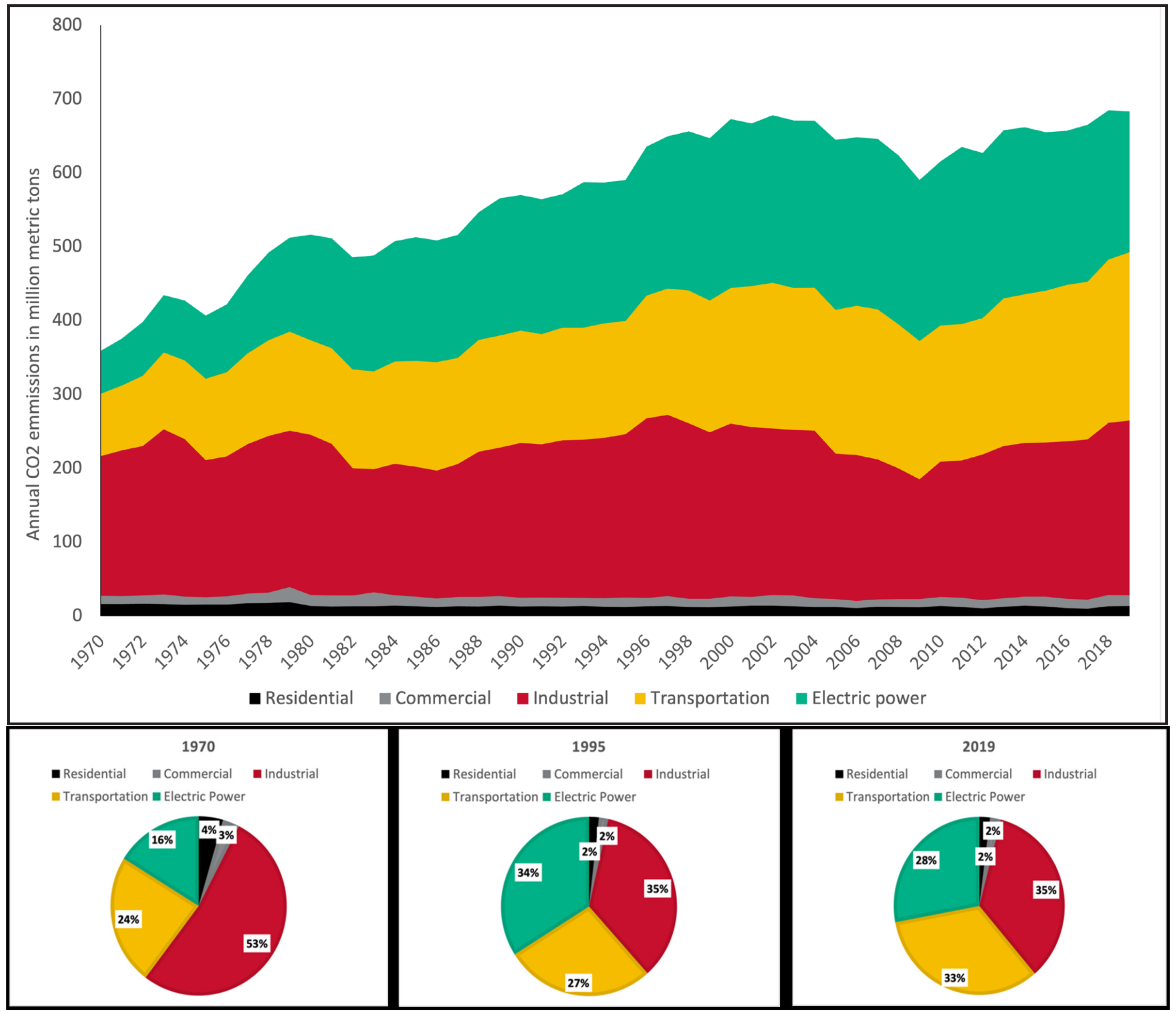

Figure 2. Annual sectoral carbon dioxide (CO2) emissions in Texas from 1970 to 2019 (in million metric tons). The role of transportation and electricity generation as sources of GHG emissions in Texas has grown significantly over the last five decades. Transportation, across Texas, has grown from being responsible for 24% of emissions in 1970 to 27% in 1995 and 33% in 2019. Data source: U.S. EIA.

economic impact of each segment in Texas. Chapter 4 discusses the current state of Texas laws, regulations, policies, and programs in the transportation sector that are directed at decarbonization and emissions reduction, and how the transportation sector, economy, and people stand to benefit from current federal priorities through the Infrastructure Investment and Jobs Act (IIJA). Chapter 5 reviews recent drivers for decarbonizing the transportation fleet in Texas across the on-road, rail, aviation, and marine segments. Chapter 6 details the methodology for the analyses, along with the assumptions and caveats to each approach, while the results are discussed in Chapter 7. Lastly, Chapter 8 highlights the implications of the results, focusing on the most transformative opportunities that can get the transportation sector in Texas to net zero by 2050, along with a discussion on addressing the challenges and gaps.

1.1 Current State of Energy and Emissions

The transportation sector is the second-largest source of greenhouse gas (GHG) emissions and the second-largest energy user in the state of Texas . Transportation closely follows the industrial sector as the two highest emitters of GHGs (Figure 2), and the sector is currently responsible for over 30% of the state's emissions and about 25% of its energy use. The emissions can be attributed to the state's large population, long commute distances, low cost of transportation fuels, in-state trade dependent on road and rail transportation, and consumer preferences for light-duty trucks over passenger cars.

Addressing the emissions from transportation, especially in the short term, requires a distinctly different approach from those associated with industrial and power generation-related emissions. Moreover, the impacts of changes in transportation modalities have wide-reaching impacts on the economy of the state, employment, and alterations in infrastructure that require broad-based acceptance and participation.

In Texas, emissions from the transportation sector have increased by 1.5 times between 1997 and 2019, real GDP from all industries has increased three times, nominal GDP two times, and population by 1.3 times over the same period (Figure 3). Emissions from the transportation sector as a share of the real GDP[1] has reduced from 0.28 in 1997 to 0.12 in 2019, representing a 2.3-fold decrease (1.5-fold decrease with nominal GDP) in the emissions impact despite increases in economic productivity due to major improvements in reducing emissions from on-road vehicles. Per capita emissions from the transportation sector began declining around 2003, were the lowest at ~ 7 MMt CO2 per million people in 2012 and have since steadily increased to ~8 MMt CO2 per million people, representing a 0.9-fold decrease between 1997 and 2019.

Among different sectors of transportation and vehicle types, light-duty vehicles contribute the most to the emissions impact. This is followed by medium- and heavy-duty vehicles (Figure 4), with rail and marine contributing, combined, less than 5% total. The distribution of emissions in Texas and the nation are comparable across the sectors and vehicle types.

Significant emissions reduction and decarbonization in the sector can, therefore, be achieved by targeting light-duty, medium-

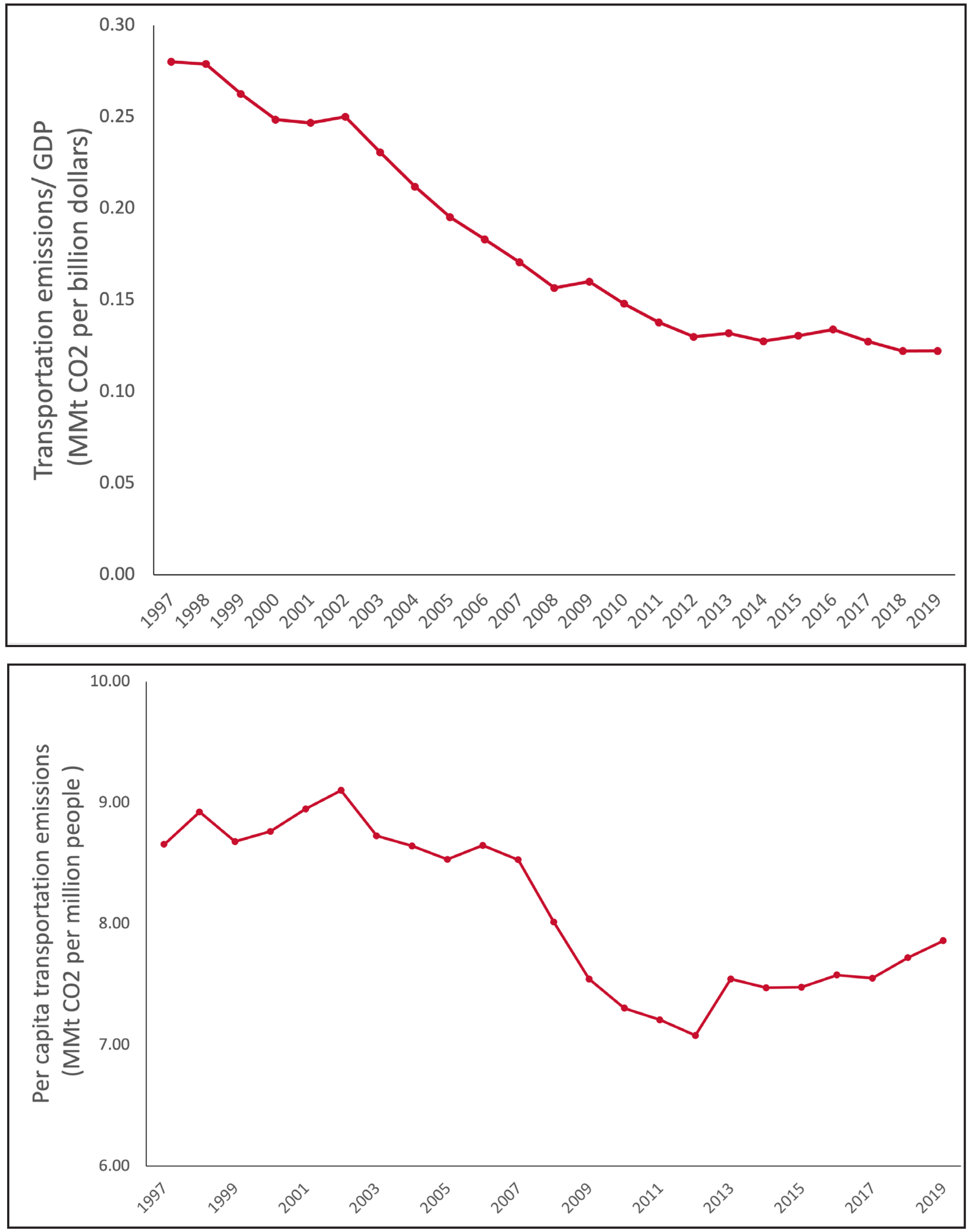

Figure 3. Transportation emissions as a share of the real GDP from all industries in Texas, where emissions are measured in million tons of CO2 and GDP is measured in billion dollars (top) and per capita transportation emissions in Texas, where emissions are measured in million tons of CO2 and the population is measured in million people (bottom). Data source: EIA, Federal Reserve of Dallas, U.S. Census Bureau.

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[1] Annual real GDP from all industries in billion dollars, not seasonally adjusted.

duty, and heavy-duty vehicles. The Texas Department of Transportation reported that in 2021, an average of 712 million vehicle miles was traveled on Texas roads, with a total of 260 billion miles in a year. Almost 75% of all vehicle miles traveled occur on state-owned highways, even though the state owns only a quarter of roadway miles in Texas.

Texas has the second-highest vehicle miles traveled (VMTs) among all U.S. states. Figure 4 presents the growth in daily vehicle miles traveled (total for all types of vehicles on all types of roads) from 1970 to 2020. Total miles traveled increased steadily up to 2007 before declining in 2008, then increasing up to 2019, peaking at about 790 million miles per day. Between 1970 and 220, the vehicle miles traveled per day increased by 282% (Figure 5).

The increasing VMT strongly correlates to the state's growing population. According to the 2020 U.S. Census, the population in Texas increased by 16% between 2010 and 2020, resulting in an average daily 772.7 million miles of VMTs and an annual average of 282.2 billion miles of VMTs on all roadways over the ten-year period. The U.S. Federal Highway Administration's (FHWA) 2022 long-term forecast predicts that light-duty VMTs, the largest component of travel demand, will grow by 17%, combination truck (tractor trucks pulling trailers with three or more axels) VMTs will grow by 57%, and single-unit truck (on a single frame, includes vehicles with two axles or three to four when pulling a trailer, and six tires, usually dual rear tires) VMTs will grow by 101%, resulting in a cumulative growth of 22% in VMTs by 2050. The projected increase represents a convergence with population growth, unlike the growth rate of the last 30 years when total VMTs grew by 51%. Despite the economic downturn in 2001, VMTs continued to grow until the 2008 housing crash. The shale boom in 2009-10 caused daily truck VMTs to grow again, which drove the steady cumulative VMT growth rate until 2020.

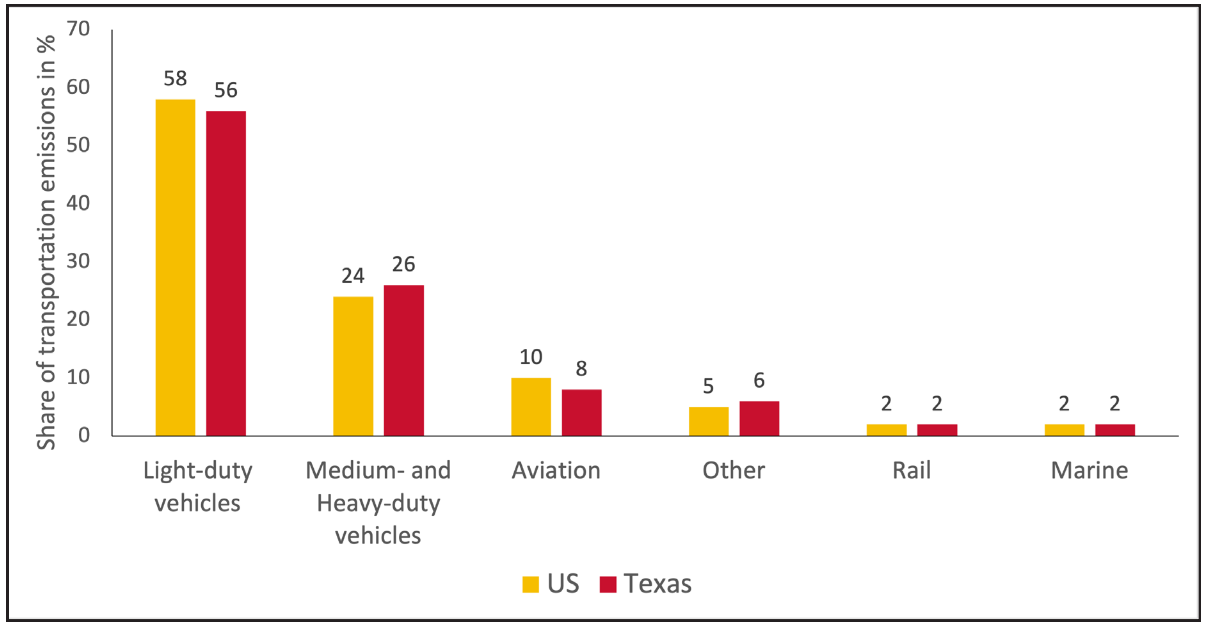

Figure 4. Emissions share by sector and vehicle type in the U.S. and Texas, based on 2019 data. Data source: U.S. EPA.

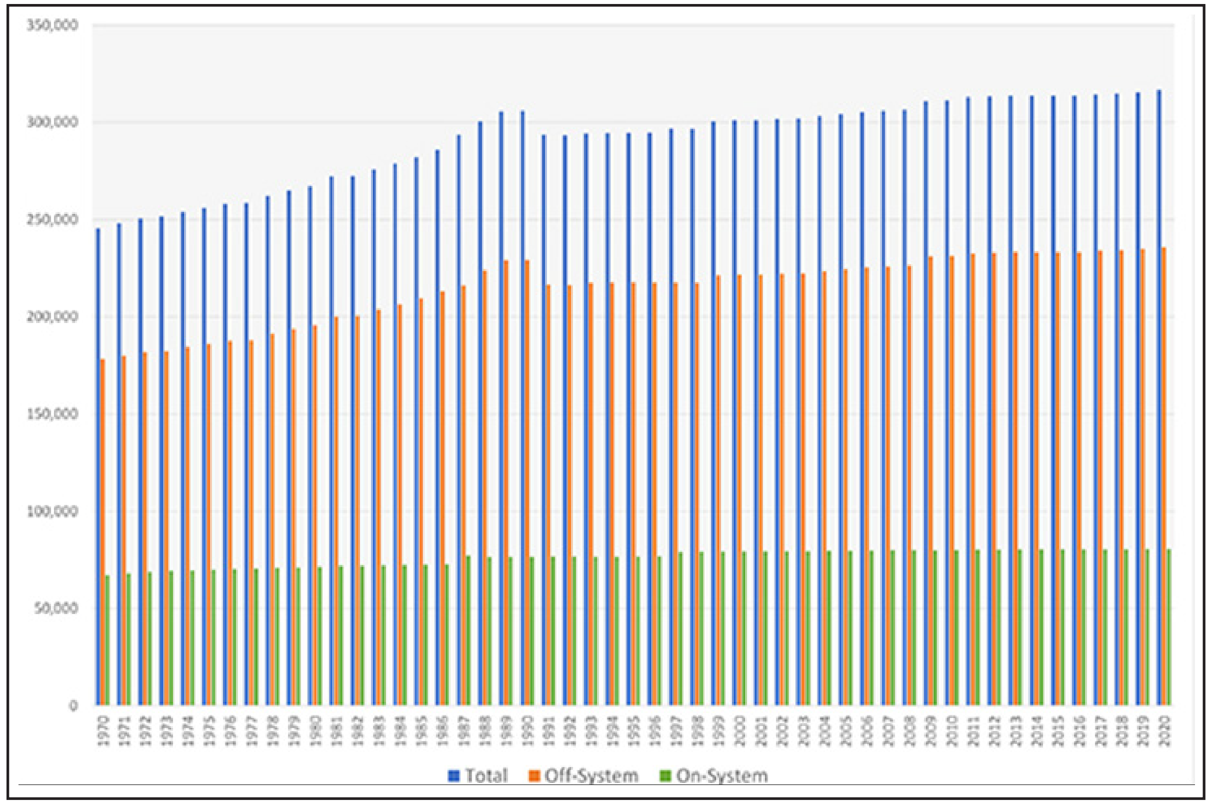

Figure 5. Average total vehicle miles traveled per year between 1970 and 2020 for all vehicle types on all roads in Texas. Off-system roads are not designated on the State Highway System and not maintained by TxDOT, while On-system roads are designated on the State Highway System and maintained by TxDOT Source: Texas Department of Transportation.

CHAPTER 2: CURRENT STATE OF THE TRANSPORTATION FLEET

This chapter provides an overview of the current state of the transportation fleet in Texas, its historical context, and the fuel type used by each of these to provide a baseline considering future evolutions. We discuss on-road vehicles by weight segment, the passenger and freight rail fleet, the aviation, and the marine fleet on parameters ranging from the size of the fleet to ridership and tonnage.

2.1 On-Road Vehicles

The dominant vehicle types in the transportation fleet in Texas are gasoline-powered light-duty vehicles. Texas had 17,244,692 alternately fueled vehicles (AFVs) in 2021. Of these, 80% were hybrid gas vehicles, and about 8% were ethanol-based. EVs currently constitute under 1% of all vehicles registered in Texas, but their numbers grew by 620% between 2016 and 2021. TxDOT reported in July 2022 that 134,072 electric vehicles were registered in Texas; 233 of the state's 254 counties had registered EVs (74% Battery Electric and 26% Plug-In Hybrid Electric). Table 1 provides details of all vehicles registered in Texas between 2016 and 2022 by fuel type, while Table A9 in Appendix A provides details of light-duty vehicles over the same period based on data from the U.S. Department of Energy's Alternative Fuel Data Center.

About 80% of the medium and heavy-duty vehicles (M/HDVs) can be categorized into 17 market segments based on the weight class, from class 2B (heavy-duty pickup and van) to class 8 (regional and long-haul tractor, transit bus, refuse hauler, freight box truck and dump truck). Regional and long-haul class 8 vehicles represent about 15% of the M/HDV segment but account for about 60% of the emissions impact. The other major contributor is class 2B heavy-duty pickup vans and trucks, given the number of such vehicles in the fleet[2]. The 2021 Annual Energy Outlook predicted that M/HDVs will grow at a compound annual growth rate of 0.75% or by about 29% through 2050[3].

Currently, Texas has 70 Zero Emissions Trucks (ZETs). These include all ZETs from class 2b (predominantly used for commercial use such as construction and delivery) up to class 8 (worksite, short-haul, and long-haul trucks). The Zero Emissions Truck Inventory reported in 2021 that the currently deployed ZETs in Texas were funded through the DOE grant program and the state currently has no significant incentives or grant funding for ZET purchases. In contrast, California has over ten times the ZET deployment in Texas and leads the country in the number of ZETs.

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[2] The VIN coding process returned the fuel type as undisclosed

[3] Unknown fuel types are the result of an error in the VIN decoding process or the VIN not designating a fuel type. Trailers were included in the unknown category before 2021.

Table 1. All vehicle types (light, medium, and heavy-duty) in Texas by fuel type, 2016-2021 where AFVs are alternatively fueled vehicles. Data source: Texas Department of Motor Vehicles.

Fuel Type	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Hybrid (Gas)	199,096	217,084	233,645	201,629	201,629	256,654
Electric	8,397	11,724	18,990	36,418	36,418	60,528
Natural Gas	3,889	3,901	3,063	2,836	2,836	3,366
Propane	1,038	1,276	1,310	1,451	1,451	1,835
Ethanol	-	-	54	200	200	211
Methanol	-	-	4	3	3	2
Hybrid (Diesel)	-	-	4	4	4	7
Subtotal (AFV)	212,420	233,985	257,070	259,800	242,541	322,603
Gasoline	16,622,760	17,237,827	17,510,554	16,845,463	15,024,613	17,244,692
Flexible	2,127,669	2,215,878	2,231,880	2,168,253	1,945,689	2,067,804
Diesel	1,327,585	1,369,414	1,258,596	1,276,164	1,188,617	1,343,897
Convertible	6,549	5,756	4,473	-	2,926	2,811
Hydrogen	-	-	-	-	-	-
Undisclosed[2]	555	715	336,527	291,046	291,046	275,206
Unknown[3]	3,734,669	3,084,014	3,012,625	5,319,377	5,319,377	1,570,235
Trailers	-	-	-	-	-	2,393,190
Subtotal (Non-AFV)	23,819,817	23,913,604	24,354,655	24,837,799	23,772,268	24,897,835
Total Vehicles Registered	24,032,237	24,147,589	24,611,725	25,097,599	24,014,809	25,220,438

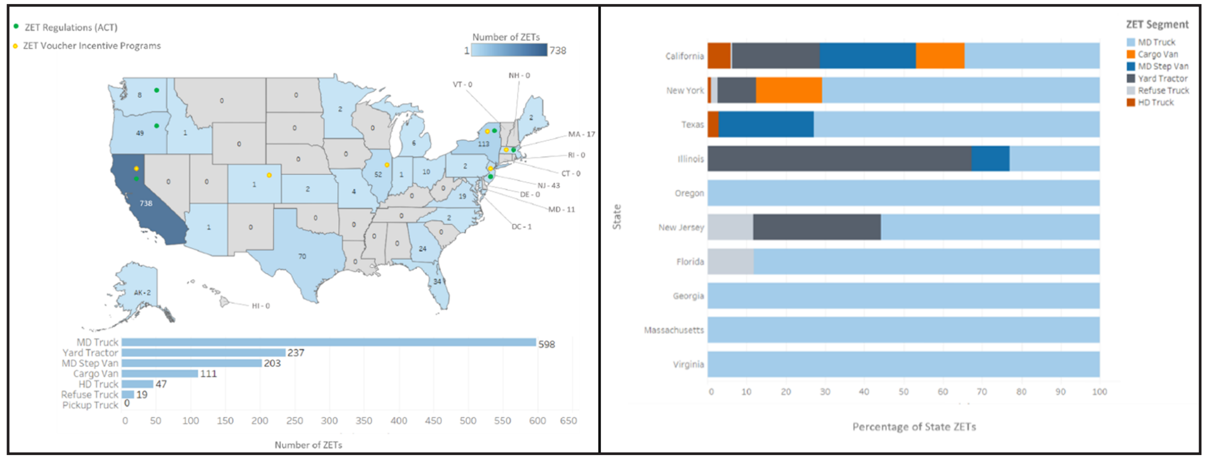

Figure 6. Zero emissions trucks deployment by state (left) and breakdown by segment across the top ten states with ZET deployment. Texas ranks third in ZET deployment among U.S. states after California and New York. ZET deployment in Texas is about less than 10% of that in California and about 60% of that in New York. Medium-duty ZETs are the most prevalent segment in the state. Source: Calstart.org.

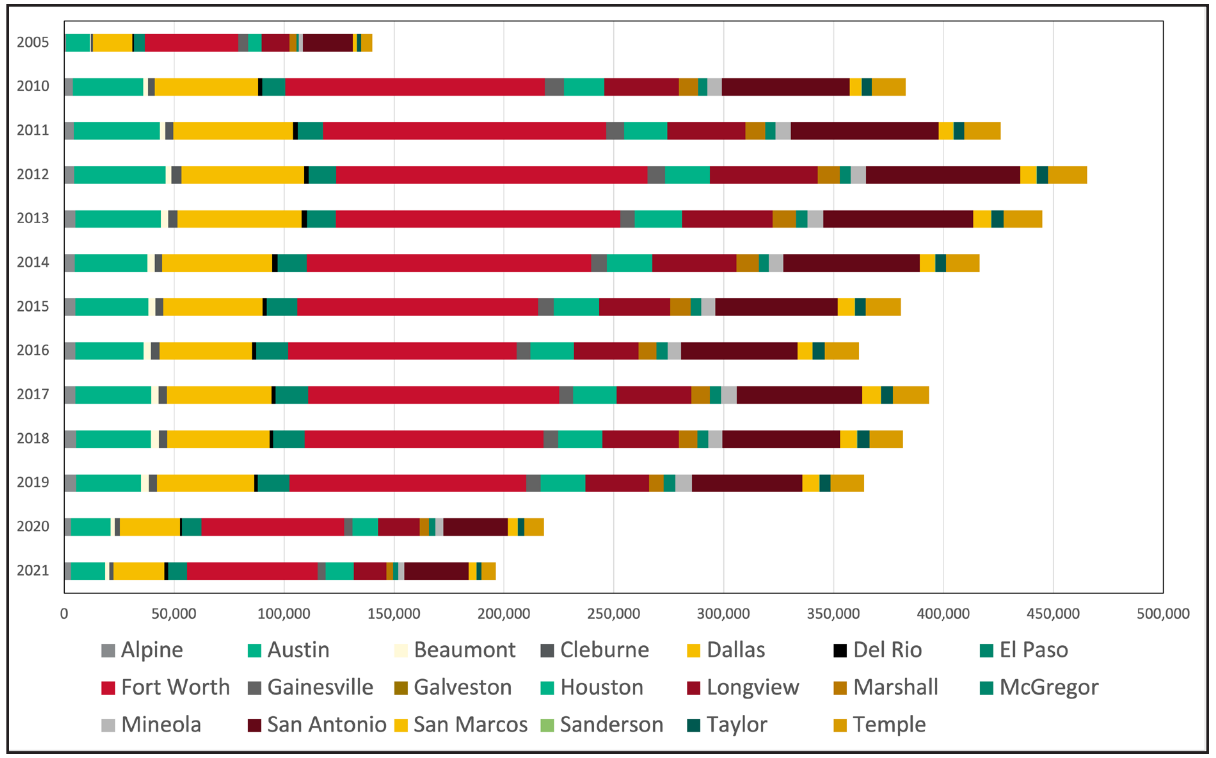

Figure 7. Amtrak Ridership in Texas by station, 2005-2021. Data source: Bureau of Transportation Statistics.

2.2 Rail Fleet

2.2.1 Passenger Fleet

As of 2018, Texas had 3 Amtrak routes with 19 stations and 1539 track miles. Ridership on Amtrak peaked in 2012 at more than 450,000 boardings and alightings (Figure 7).

With new funding from the federal government, Amtrak is expected to expand its services in Texas with three round-trip routes between Houston and Dallas - Fort Worth, three round trips between Houston and San Antonio, and two round trips between Dallas - Fort Worth and Austin -San Antonio.

In addition to Amtrak's intercity and inter-state services, Texas also has 4 commuter rail services, 6 light rail/streetcar transit operations, and 6 tourist railroads. A 2019 assessment for the proposed high-speed rail between Houston and Dallas that would have connected the Greater Houston Area to North Texas estimated that 6 million passengers will use passenger rail in the state each year by 2029 and that ridership will more than double to 13 million by 2050.

2.2.2 Freight Fleet

Texas is currently served by 54 freight railroads and 20 intermodal rail facilities that carry 9.9 million rail carloads each year over 10,460 miles of rail. In 2019 freight rail employed 17,223 Texans, with an average wage and benefits package of $131,850. In 2019, 416 million tons of freight were moved by rail in the state.

According to TxDOT's Freight Transportation Plan outbound freight is expected to grow by 96% and inbound freight is expected to reduce by 3% by 2040 as compared to a 2016 baseline based on expected population growth and growth in e-commerce, which is expected to increase concentrated trucking activity around e-commerce distribution centers.

2.3 Aviation Fleet

Passenger and Freight Fleet

Currently, Texas has over 25,000 registered aircraft making up 9% of the total U.S. registered aircraft fleet.

2.4 Marine Fleet

Passenger and Freight Fleet

Tonnage transported by the marine fleet in Texas grew by nearly 25% between 2010 and 2020. Table 3 provides a detailed summary of tonnage by port and state totals, while Figure 10 presents the year-on-year changes in total tonnage.

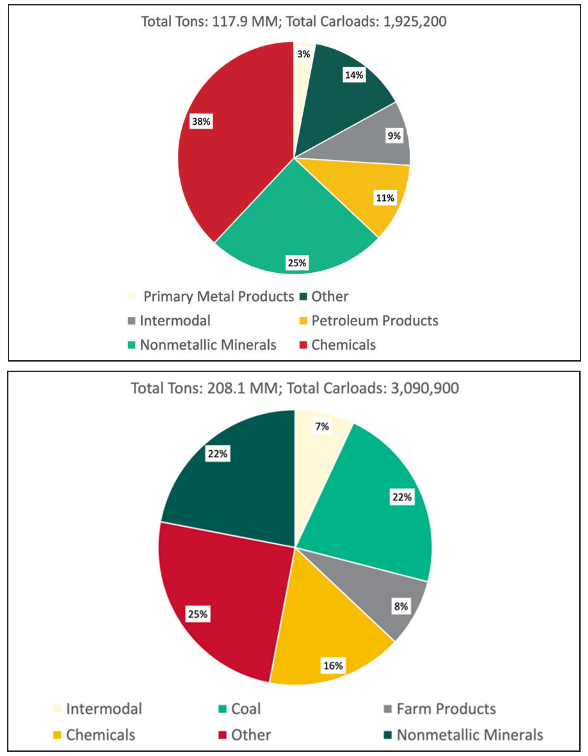

Figure 8. Freight transportation by major commodity category that originated and terminated in Texas in 2019 based on a percentage of total tonnage. Data source: Association of American Railroads.

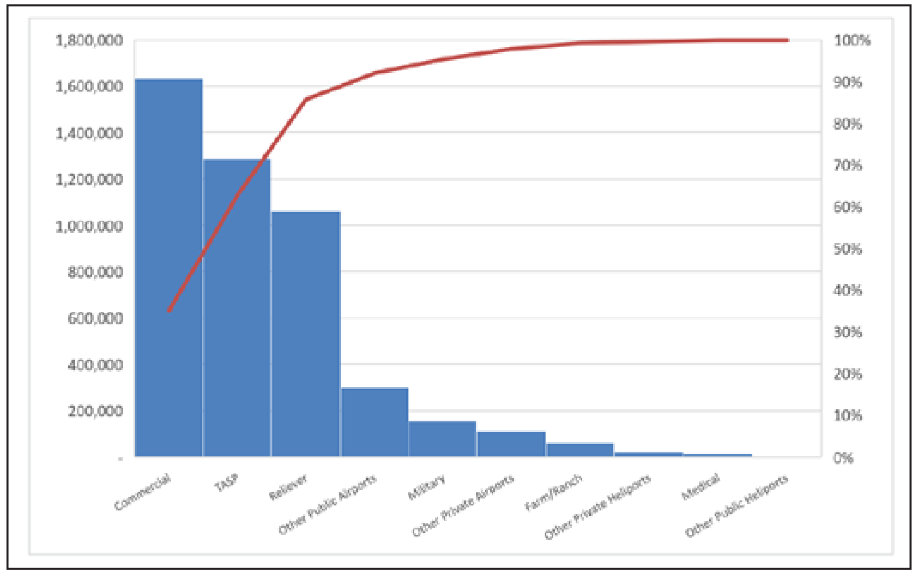

Figure 9. Landing/take-off cycles (LTOs) across airport categories in Texas in 2019. LTOs are driven by aviation demand for passenger travel (correlated with population growth) and freight transportation (correlated with economic activity). An LTO represents the sum of the number of aircraft that take off and land at any airport. Commercial, TASP, and reliever airports accounted for nearly 87% of LTOs in the state in 2019. TASP airports, under the Texas Airport System Plan, serve as general aviation airports providing additional capacity to commercial airports and reliever airports in urban areas and serving smaller communities. Source: Texas A&M Transportation Institute.

Table 2. Yearly change in aviation traffic across passenger, freight, and mail categories, 2010-2021. Data source: Bureau of Transportation Statistics.

	2010	2019	2020	2021
Passengers	66,317,994	88,584,286	40,883,637	29,521,310
Passengers % Change		0.34	-0.54	-0.28
Freight tons	610,730	818,921	855,315	446,947
Freight % Change		0.34	0.04	-0.48
Mail tons	39,673	53,880	53,531	28,657
Mail % Change		0.36	-0.01	-0.46

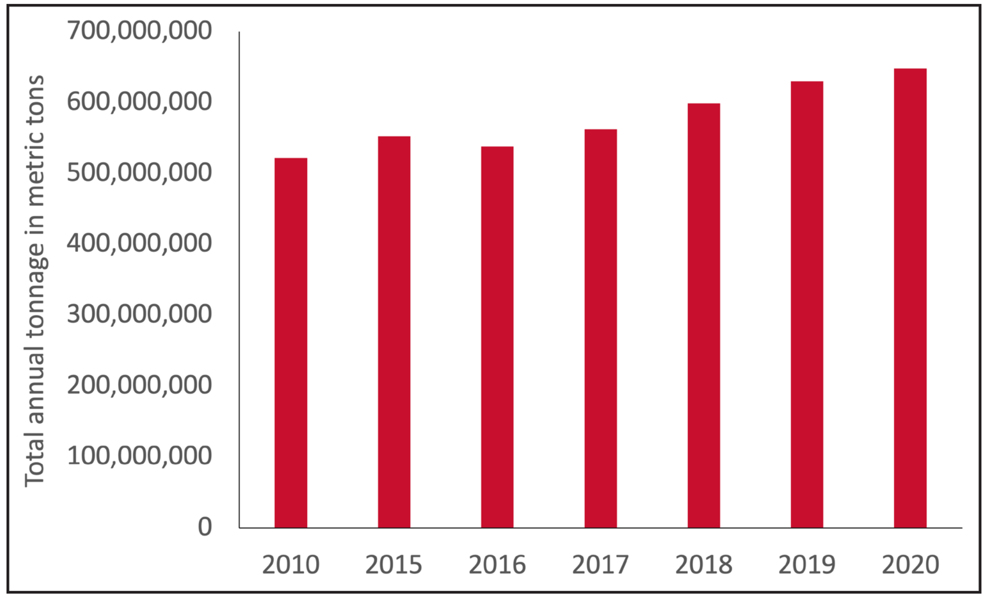

Figure 10. Total annual tonnage in metric tons, 2010-2020. Data source: Bureau of Transportation Statistics.

Table 3. Total tonnage by port and state totals, 2010-2020. Data source: Bureau of Transportation Statistics.

Port Name	Total tonnage by port and state totals each year						
	2010	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Aransas Pass	-	916,985	-	-	-	-	-
Beaumont	76,958,592	87,169,875	84,528,063	89,437,326	100,244,231	101,089,801	70,567,386
Brownsville	4,616,492	7,779,109	7,275,272	7,763,455	8,348,358	6,632,612	6,781,993
Corpus Christi	73,663,432	85,674,966	81,981,061	87,322,735	93,468,323	111,223,976	150,755,485
Freeport	26,675,842	21,132,931	19,635,949	24,484,399	25,446,078	29,844,416	38,748,662
Galveston	13,948,896	10,380,588	9,880,157	7,836,405	9,111,500	10,958,425	11,945,182
Houston	227,133,231	240,933,410	247,981,663	260,070,837	268,930,047	284,944,468	275,940,289
Matagorda Port	8,879,191	11,821,386	4,896,638	4,279,218	5,379,731	5,220,760	4,760,443
Orange		837,869			1,235,508	1,574,470	4,094,815
Port Arthur	30,231,786	35,787,331	35,198,425	39,203,245	39,851,706	33,943,782	41,222,200
Port of Harlingen	-	-	-	-	-	-	1,658,124
Sabine Pass	-	-	-	-	-	-	5,536,974
Texas City	56,590,856	42,923,997	41,260,475	37,751,062	42,682,311	41,338,934	33,721,312
Victoria	2,792,180	6,733,044	5,082,077	4,337,003	3,860,635	2,672,649	2,032,848
Total	521,490,498	552,091,491	537,719,780	562,485,685	598,558,428	629,444,293	647,765,713

CHAPTER 3: CURRENT STATE OF TRANSPORTATION INFRASTRUCTURE

The American Society of Civil Engineers (ASCE)[4] graded the infrastructure in Texas an overall C (mediocre, and requires attention) in 2021, a marginal improvement from C- in 2017. The corresponding infrastructure report stated that the overall grade indicates *below-average conditions in many infrastructure categories, including dams, levees, flood control, highways and roads, and wastewater in the state, all of which received* a D+ (poor, at risk) or below grade. Overall, a third of the categories evaluated by ASCE received unsatisfactory grades. The grading criteria included capacity, condition, funding, future needs, operation and maintenance, public safety, resilience, and innovation. This chapter highlights the current state of the transportation infrastructure in Texas.

3.1 Roads, Highways, and Bridges

TxDOT reported in 2019 that Texas has over 18,000 national highway system (NHS) bridges and culverts carrying an average of 595 million vehicles per day and accounting for 350 million square feet of deck area. Traffic volume on these bridges and culverts increased at a rate of 1.4% year-over-year for on-road systems and 1.2% year-over-year for off-road systems. TxDOT annually invested $1.9 billion to meet the traffic demand and added about 9 million square feet of bridges and culverts to the state's infrastructure each year between 2010 and 2019. Overall, Texas has the smallest share of bridges that are structurally deficient (1.3%) among all U.S. states. TxDOT recommends prioritizing efforts to maintain and improve the national highway system and re-evaluating design standards to better the grade.

ASCE grade 2021

Bridges **B-**

Highways and Roads **D+**

Transit **B-**

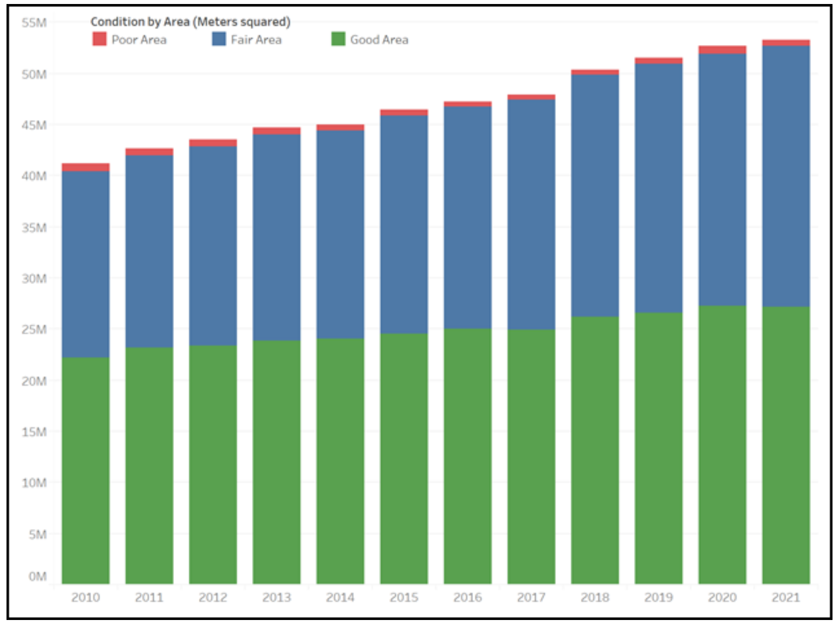

Figure 11. The condition of bridges in Texas, where bridge area is measured in meters squared, 2010-2021. Source: Bureau of Transportation Statistics.

Table 4. The current state of public roads, miles of freight railroad, waterways, and bridges in Texas. Data source: Bureau of Transportation Statistics.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Miles of public road	311,249	312,911	313,210	313,228	313,596	313,596	313,656	314,319	314,648	315,445	316,567
Miles of freight railroad	10,384	10,425	10,469	Data unavailable	Data unavailable	10,539	Data unavailable	10,506	Data unavailable	10,460	10,460
Miles of inland waterway	830	830	830	830	830	830	830	830	830	Data unavailable	Data unavailable
Bridges	51,454	51,878	52,260	52,561	52,937	53,209	53,488	53,869	54,131	54,432	54,682

Table 5. Condition of roads in Texas based on the International Roughness Index, 1995-2020. Data source: Bureau of Transportation Statistics

	1995	2000	2005	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Miles	17,066	65,427	67,172	67,514	Data unavailable	68,814	68,599	12,680	28,126	30,802	18,580	19,721	20,162	88,738	89,266
Acceptable Miles[4]	15,870	54,288	60,774	62,524	Data unavailable	60,511	62,914	12,006	25,251	27,583	16,606	17,732	17,971	69,297	69,269

The agency also reported that traffic on the state's highways and roadways grew by 16% between 2010 and 2016, resulting in greater congestion (the average driver in the state spends 54 hours in traffic each year at a cost of $1,080, calculated as annual cost of delay per commuter in lost productivity, time and fuel costs, and 2 gallons of waste fuel), exacerbated pressure on infrastructure, and deteriorating conditions. Two of the top five congested areas are in Austin and Dallas, while the rest are in Houston. ASCE recommends the state increase its gas tax rate to, at minimum, index the values to current inflation levels, leverage managed lanes and toll roads to increase highway and road funding, emphasize route maintenance and improvements, promote resilience, innovation, and increased stakeholder engagement, and enhance safety practices.

Texas also has four of the nation's top 20 trucking bottlenecks. In 2019, congestion resulted in a 77% increase in traffic delays for commercial trucks as compared to a 2000 baseline[5].

3.2 Freight Infrastructure

TxDOT reported in 2021 that the Texas Multimodal Freight Network includes nearly 22,000 miles of highway, 10,500 rail track miles, 21 water ports, six of the top 50 cargo airports in the U.S., 20 commercial international border crossings, and 448,446 miles of pipelines. The

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[4] Data for 2010 is unavailable. The acceptable miles are measured based on International Roughness Index which quantifies road surface roughness. To derive the IRI score, a continuous longitudinal profile of the road is measured and analyzed to summarize qualities of pavement surface deviations that impact vehicle suspension movement. IRI<^{95} is considered Good, ^{95}>IRI<^{170} is considered Fair, and IRI>^{170} is considered poor.

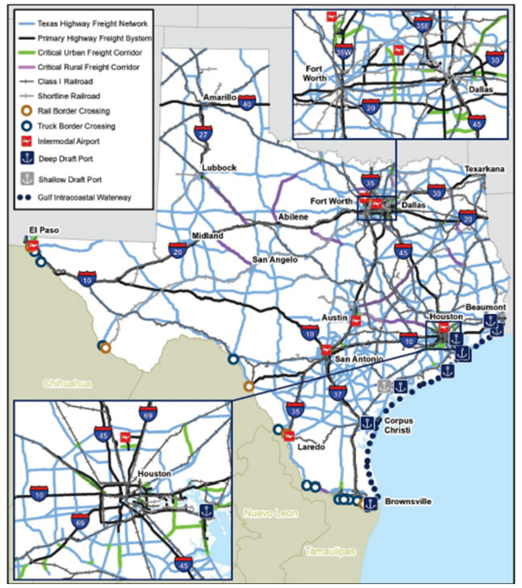

Figure 12. Texas multimodal freight network. Source: Texas Department of Transportation.

Year	Value of freight flow (million $)[5]
2012	1,799,243
2013	1,837,277
2014	1,881,583
2015	1,890,224
2016	1,858,785
2017	1,909,767
2018	2,010,095

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[5] Indexed to 2012 values

economic value of the freight flows within the state of Texas (does not include freight flows to other U.S. states or international exports) totaled over $2 trillion in 2018. The freight transportation industry supports nearly 2.2 million full-time jobs and $145 billion in wages in the state of Texas. The freight and logistics economy is expected to grow by 4% (CAGR)[6] each year between 2022 and 2027.

As discussed above, according to TxDOT's Freight Transportation Plan outbound freight is expected to grow by 96% and inbound freight is expected to reduce by 3% by 2040 as compared to a 2016 baseline. Highway tonnage is expected to double from 1.2 billion tons in 2016 to 2.5 billion tons in 2045, a projected increase of 1.3 billion tons and growth of 108%. During this period, the value of freight moved in Texas is forecasted to grow by 213% from $1.7 trillion to $5.2 trillion. By 2045, freight transportation by air is expected to grow by 236%, truck transportation by 206%, rail transportation by 109%, and marine transportation by 65%, as compared to a 2016 baseline (Figure 13).

Table 7. Transportation costs, in millions of dollars, for freight movement in Texas by sector and mode in 2018. Data source: Texas Department of Transportation.

Industry	Trucks	Rail	Aviation	Marine	Total
Agriculture, forestry, hunting, and fishing	9,849	1,087	41	317	11,294
Mining	22,721	6,041	1	20,940	49,703
Manufacturing	67,083	8,824	1,017	21,602	98,526
Transportation and Warehousing	8,985	2,708	987	3	12,683
Publishing	403	2	52	NA	457
Waste management and Remediation	15,270	191	NA	304	15,765
Total	124,311	18,853	2,098	43,166	188,428

3.3 Transportation Fuel Infrastructure

Gasoline stations in Texas represent 10% of the national share. Similarly, propane stations represent 14%, electricity 5%, E85 6%, and CNG and other alternative fuels 7% of the national share of fueling infrastructure for each category[7]. Figures 14 and 15 track the number of public retail gasoline stations across select U.S. states between 1996 and 2012, and the number of gasoline stations with convenience stores in Texas between 2012 and 2022. Anecdotally, the increase in gas stations with convenience stores represents the increase in overall gas stations in the state, as margins from the sale of gasoline at fueling stations are low (typically less than 2%), and with price volatility, most profits for stations owners can be attributed to sales at convenience stores.

Overall, the number of retail gas stations in the U.S. has steadily declined from about 200,000 in 1994 to 145,000 in 2022[8]. As stations have shut down, remediation costs have become a predominant concern. A 2004 U.S. EPA study of 815 sites found that the mean value of cleanup

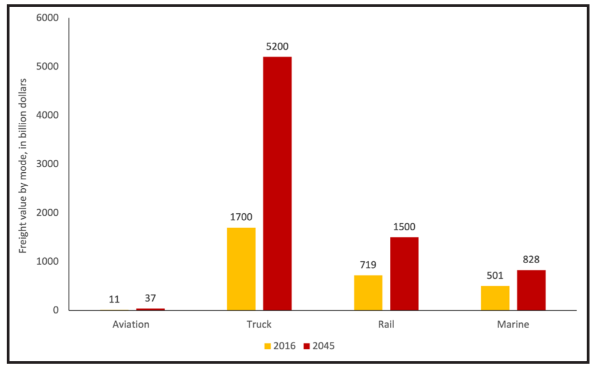

Figure 13. Value of freight transported by different modes in 2016 and projections for 2045. Data source: Texas Department of Transportation.

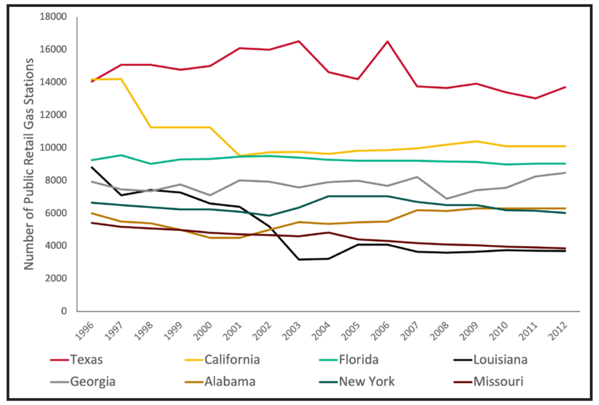

Figure 14. States with the greatest number of public retail gas stations in the U.S., 1996-2012. Texas led the nation over this period with a steady increase up to 2002, a decline up to 2005, and followed by a spike in 2006. Data source: Bureau of Transportation Statistics.

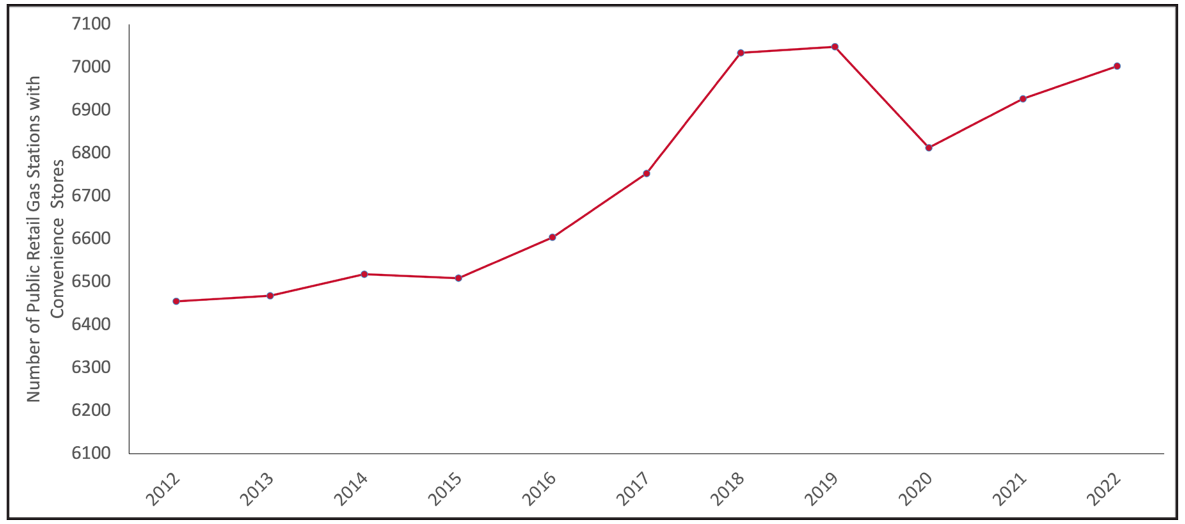

Figure 15. The number of retail gas stations in Texas with convenience stores, 2012-2022. The number of gas stations with convenience stores steadily increased up to 2020. Data from 2022 indicates that they are almost up to pre-pandemic levels after a year of decline in 2020. Data source: IBISWorld.

ASCE grade 2021

Aviation **B-**

costs was $299,673, with the impact on drinking water supplies being the dominant cost element[9]. The mean costs were two to four times higher at sites where water supplies were impacted, compared with sites with no impact on drinking water supplies. Adjusting for inflation, the mean remediation cost would be nearly $474,200 in 2022 dollars.

Electric charging stations in Texas have grown from just three in 2009 to over 5,000 in 2021, growing even between 2020 and 2021 despite the slowdown from the COVID-19 pandemic. Similarly, E85 stations grew by a factor of seven between 2009 and 2021 and continued to grow through the pandemic. Stations for all other fuel types decreased or remained constant through the pandemic.

3.4 Rail Infrastructure

Currently, the rail network in Texas is supported by over 10,500 miles of tracks, which is the highest among all U.S. states. Accounting for the tracks where multiple railroads operate over the same segments, the state is supported by over 14,000 miles of tracks that carry more than 9.9 million carloads each year. Passenger rail services in Texas are carried out by Amtrak for inter-city and inter-state travel, by public transit agencies for regional and local travel, and by private owners for tourist railroads.

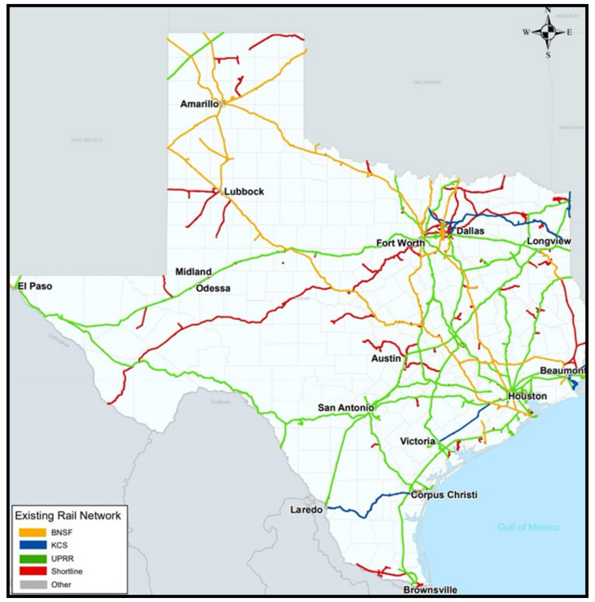

Figure 16. The existing rail network in Texas, including the major (Class I) railroad companies that operate in Texas: BNSF Railway, Kansas City Southern, and Union Pacific, and 49 short lines that provide last-mile connectivity for the major railroads. Source: Texas Department of Transportation.

Table 8. Alternative fuel stations in Texas, 2009-2021. Data source: AFDC.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Electric	3	26	570	1,310	1,599	1,839	2,024	2,440	2,719	3,398	4,141	4,515	5,204
85% Ethanol	41	48	60	80	81	136	197	193	215	222	236	233	265
Liquefied Petroleum Gas	541	520	480	471	458	441	489	487	470	458	453	395	352
Compressed Natural Gas	20	30	34	52	62	97	116	132	127	115	109	72	72
Liquefied Natural Gas	4	4	5	9	10	10	16	20	23	17	16	10	11
Biodiesel	20	17	13	17	20	17	21	17	18	16	25	12	8
Hydrogen	0	1	1	1	1	1	1	1	1	1	0	0	0
Total	629	646	1,163	1,940	2,231	2,541	2,864	3,290	3,573	4,227	4,980	5,237	5,912

3.5 Aviation Infrastructure

Texas has about 400 airports, including 24 commercial airports. The rest are general aviation airports that serve private aircraft and small charter operations. Six of Texas' commercial airports rank in the top 50 nationwide for annual passenger enplanements, with Dallas Fort Worth (DFW) International Airport as the fourth busiest and George Bush Intercontinental Airport as the 14th busiest. The aviation industry is changing, driven largely by fluctuations in consumer behavior, expectations, and rapid shifts in the characteristics and structure of logistic supply chains. Growing aviation demand in Texas will require increased economic investments, ongoing airport redesign, capacity expansion, and service improvement projects throughout the state, at a cost of an estimated $11.2 billion in airport infrastructure demands over the next five years. The ASCE assessed the current state of Texas' airfield infrastructure as good. Specifically, the 2020 National Plan of Integrated Airport Systems (NPIAS) report found that 98% of commercial airports have airfield pavement in fair condition or better. ASCE recommends the state increase the cap on the Passenger Facility Charge (PFC) to fund infrastructure support and improvement, along with planning and implementation for new airspace technologies, increasing the fuel tax cap on air transport and carriers, modernizing and expanding airport facilities to ensure that they are resilient, sustainable, and can accommodate future airline growth. It also calls for additional state funding for the sector, with legislative support for regulatory zoning and development reforms, along with investments in stormwater capacity improvements.

In 2018, TxDOT reported general aviation airports provided more than 48,000 jobs in the state, with $2.5 billion in payroll and $9.3 billion in total economic output. When combined with commercial service airports, aviation in Texas contributed to more than 778,000 jobs, $30.1 billion in payroll, and $94.3 billion in total economic output.

3.6 Marine Infrastructure[6]

Texas has 21 commercial ports, as well as several shallow-draft channels primarily used for fishing and recreation. Texas ranks first in the nation for waterborne commerce, moving more than 607 million tons of cargo in 2020. The ports of Houston, Beaumont, and Corpus Christi are among the nation's 10 busiest in terms of tonnage handled.

TxDOT reported the state's ports have invested nearly $1.7 billion in port facilities and attracted an additional $95.6 billion of private investments since 2017. ASCE says emerging technologies, modernizing port facilities, and adapting to the shifting socioeconomic trends can support the resilience, maintenance, and expansion of ports in Texas. Specifically, port infrastructure system designs need to account for evolving environmental and climate impacts, sea level rise, subsidence, and future population growth that can impact the inflow and outflow of goods in the state.

In 2019, more than 128,000 Texas jobs were directly related to seaport operations, and 5.4 million jobs were related to economic activity dependent on the state's ports. These jobs generate more than $285 billion in personal income and local consumption, while the port industry contributed $80 billion annually in tax revenues.

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[6] ASCE Texas Division does not evaluate ports and waterways. Last available grade.

3.7 Energy Infrastructure

ASCE grade 2021

Ports (Navigable Waterways) **B-**

ASCE used two categories to grade energy infrastructure in Texas: oil & gas and electricity. The Texas section of the ASCE further categorizes the oil and gas infrastructure into oil, gas, and fuel (heat and light) subcategories. Following Winter Storm Uri, the Texas chapter undertook a three-part study to better evaluate the state of the infrastructure and the increasing interdependence between different critical infrastructure elements in the state. Their findings and recommendations focused on the dynamic nature of infrastructure threats and the commensurate dynamic investments required to tackle them, reliability, resilience, recovery, current and future needs, infrastructure capacity additions, expansion and reuse of legacy systems, market competitiveness, and regulations.

As the Texas grid continues to decarbonize, the grid's reliance on natural gas for electricity production is expected to decrease, while renewable electricity energy will increase. Currently, coal and natural gas constitute more than 60% of the fuel mix for current electricity generation, while of the 8,139 MW of new capacity additions in 2021, wind, solar, and natural gas contributed 42%, 40%, and 13%, respectively[10]. ASCE recommends that to maintain present production, preparedness, and progression of energy service in the state, Texas needs to support infrastructure resilience, maintenance, and expansion funding for critical port and related infrastructure, continue to be the nation's leader to support innovation to eliminate gas flaring and reduce environmental impacts by capturing wasted resources, maintain focus on reducing leaks and increasing environmental protection in its safety and infrastructure condition assessments. Further, state regulators must support timely energy infrastructure investment and expansion for new energy sources and storage resources.

The U.S. Energy and Employment Jobs Report found the energy industry had 849,789 employees statewide, representing 17.4% of all U.S. energy employment, 5.4% of all employment in Texas, and 2.6% of all national employment in 2019[11]. Of these, 58,405 jobs were in electric power generation, 279,334 in fuels, 199,800 in transmission, distribution, and storage, 152,111 jobs in energy efficiency, accounting for 7.2% of all U.S. energy efficiency jobs, and 160,139 jobs in motor vehicles, which accounted for 6.9% of all U.S. motor vehicle jobs. In 2019, the median wage for an energy industry employee in the state was $25.15, 31% higher than the national median wage. In 2021, the energy industry employed 880,692 workers in the state, representing 11.3% of all U.S. energy employment, and 7% of all employment in Texas. Of these, 61,331 were in electric power generation; 265,273 in fuels; 202,776 in transmission, distribution, and storage; 158,882 in energy efficiency; and 192,430 in motor vehicles.

From 2020 to 2021, energy jobs in the state increased by 3.6%, or about 31,000 jobs (Figure 17a)[12]. Employment related to motor vehicles accounted for 7.5% of the national total for the segment. Between 2020 and 2021, 32,291 new motor vehicle jobs were added which represented an increase of nearly 20%. Repair and maintenance jobs dominate employment in the motor vehicles segment (Figure 17b).

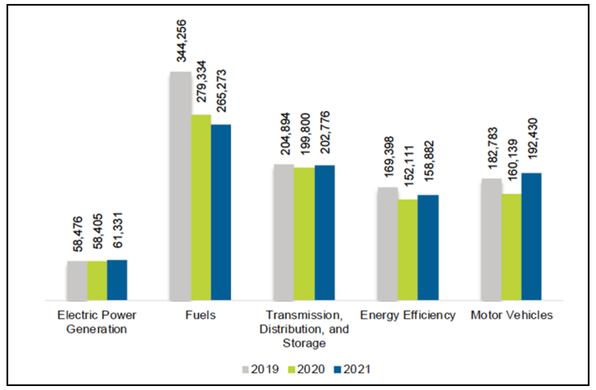

Figure 17a. Employment in Texas by major technology application, 2019-2021. Source: 2022 USEER State Report: Texas.

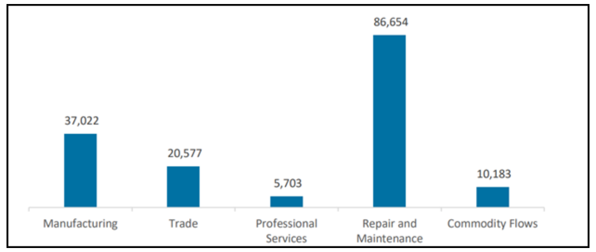

Figure 17b. Employment in motor vehicles segment in Texas by major industry sector, 2021. Source: 2022 USEER State Report: Texas

CHAPTER 4: CURRENT LEGAL AND REGULATORY FRAMEWORK

In August 2022, the State of Texas approved the Unified Transportation Program (UTP), TxDOT's 10-year, $85 billion transportation plan that would guide the programming and development of transportation projects[13] across 12 funding categories over the next 10 years. These include preventative maintenance and rehabilitation, metropolitan and urban corridor projects, non-traditionally funded projects, statewide urban and regional connectivity projects, congestion mitigation and air quality improvement, structures replacement and rehabilitation, safety projects, transportation alternatives, supplemental transportation projects, district discretionary projects, energy sector projects, and statewide strategic priority projects. The projects in the UTP will be funded through legislative and voter-approved initiatives that would allocate shares of oil and gas taxes, sales taxes, and other state money. The program is expected to result in an estimated $15.5 billion per year in economic benefits from increased labor income and business output and add 58,500 direct and indirect jobs to the Texas economy. However, the plan recognizes that it may be challenged by changing funding levels and does not guarantee all proposed projects will be completed.

The UTP is connected to the 2050 Texas Transportation Plan. It simultaneously uses a top-down and bottom-up approach to improve coordination between agencies, comprehensive project evaluation, and performance-based planning compliant with state and federal mandates. The 2050 Texas Transportation Plan was established under Title 6, Section 201.601 of the Texas Transportation Code to develop a long-range plan that included transportation goals for the state and measurable metrics and targets. The Plan is mandated to include:

- Analysis of how funding allocations and project selection decisions help accomplish goals described in the statewide transportation plan
- Information about the progress of each long-term transportation goal
- Status of each project and a summary of the number of completed statewide project implementation benchmarks
- Information about the accuracy of previous department financial forecasts

This chapter outlines the laws, regulations, policies, and programs currently in place to advance the targets of the 2050 Transportation Plan and the Unified Transportation Program that are directed toward emissions reduction and clean air standards. Current federal priorities for transportation and their likely impact on Texas are also discussed.

4.1 Texas Laws Regulations and Policies

Currently, a broad range of laws, regulations, and policies are driving decarbonization and adherence to clean air standards of the transportation fleet.

The Federal Highway Administration (FHWA) categorizes U.S. vehicles based on their Gross Vehicle Weight Rating (GVWR). Vehicles weighing less than 10,000 lbs. are classified as Light Duty (Class 1-2), between 10,001 to 26,000 lbs. as Medium Duty (Class 3-6), and more than 26,001 lbs. as Heavy Duty (Class 7-8).

4.2 Current Federal Priorities

The Infrastructure Investment and Jobs Act (IIJA) was signed into law by President Biden in November of 2021. It authorizes $1.2 trillion in federal spending for transportation and infrastructure. IIJA is expected to provide $31.23 billion in funds for highways, bridges, and transit investments in Texas over the next five years, including a 26% funding increase in 2022. IIJA investment in Texas' roads and transit system will add $6.7 billion to the state's GDP each year. The increased economic activity will benefit Texas residents and increase disposable income by $2.51 billion each year, an average of $225 per household. White House estimates indicate Texas will receive IIJA funding for the following transportation categories:

- Federal highway programs: $26.9 billion. Based on formula funding alone, Texas would receive $26.9 billion for federal-aid highway apportioned programs.
- Public transportation: $3.3 billion
- Airports: $1.2 billion
- Bridge replacement and repairs: $537 million. The state can also compete for a portion of the $12.5 billion Bridge Investment Program for economically significant bridges and nearly $16 billion dedicated to major projects that will deliver substantial economic benefits to communities
- Electric vehicle charging network: $408 million. Texas can also apply for $2.5 billion in grant funding dedicated to EV charging.
- Infrastructure protection: Texas can expect to receive $53 million over five years to protect against wildfires and $42 million to protect against cyberattacks. Texas will also benefit from the IIJA's $3.5 billion investment in weatherization

A recent analysis[14] by IHS Markit found Texas is one of five states receiving the greatest economic impacts from infrastructure investments under the IIJA. Texas, California, Florida, New York, and Pennsylvania account for more than 32% of total investment under the law.

Table 9. Fleet and infrastructure-related laws, regulations, policies (Separated by categories: Green- Infrastructure and Emissions Reduction; Red- Infrastructure; Yellow- Emissions Reduction

Program	Target	Jurisdiction	Agency
Texas' National Electric Vehicle Infrastructure (NEVI) Planning	Submit an EV Infrastructure Deployment Plan to the DOT and U.S. Department of Energy (DOE) describing how the state intends to distribute federal NEVI funds	Statewide	Texas Department of Transportation
Clean Vehicle and Infrastructure Grants –Emissions Reduction Incentive Grants (ERIG) Program and Rebate Grants Program as part of the Texas Emissions Reduction Plan (TERP)	Grants to improve air quality in the state's nonattainment areas and other affected counties. Eligible projects include those that involve replacement, retrofit, repower, or lease or purchase of new heavy-duty vehicles; alternative fuel dispensing infrastructure; idle reduction and electrification infrastructure; and alternative fuel use. The Rebate Grants Program provides grants to upgrade or replace diesel heavy-duty vehicles and non-road equipment. Qualifying projects must reduce emissions of NOx or other pollutants by at least 25% as compared to baseline levels and must meet operational and fuel usage requirements.	Statewide	Texas Commission on Environmental Quality
Governmental Fleet Grants	Up to 10% of awarded funds may be granted for the purchase, lease, or installation of refueling infrastructure or equipment, or refueling services in conjunction with an eligible vehicle purchase or lease for the purchase or lease of new vehicles powered by natural gas, propane, hydrogen, or electricity.	Statewide	Texas Commission on Environmental Quality

Program	Target	Jurisdiction	Agency
Fuel Dispenser Labeling Requirement	All equipment used to dispense motor fuel containing at least 1% ethanol or methanol must be clearly labeled.	Statewide	Texas Department of Licensing and Regulation
Neighborhood Electric Vehicle (NEV) Access to Roadways	NEVs are defined as vehicles that can attain a maximum speed of 35 mph and that must comply with the safety standards in Title 49 of the U.S. Code of Federal Regulations, section 571.500. NEVs may only be used on roadways that have a posted speed limit of 45 mph or less except to cross at an intersection.	Statewide	Texas Department of Motor Vehicles

Program	Target	Jurisdiction	Agency
Seaport and Rail Yard Emissions Reduction Grants and Heavy-Duty Vehicle and Equipment Grants	Provides grants to eligible entities to replace, repower, or purchase drayage and cargo handling equipment. Eligible projects include heavy-duty on-road vehicles with a gross vehicle weight rating of over 26,000 pounds, off-road yard trucks, and other cargo-handling equipment. Eligible engines or motors must be powered by electricity or meet federal emissions standards and reduce NOx by at least 25% compared to the engine being replaced. Eligible replacement on- and off-road vehicles must be powered by diesel, natural gas, propane, or electricity.	Statewide	Texas Commission on Environmental Quality
Light-Duty Motor Vehicle Purchase or Lease Incentive Program	CNG and propane vehicles, including bi-fuel vehicles, are eligible for a rebate of up to $5,000. Electric drive vehicles powered by a battery or hydrogen fuel cell, including plug-in hybrid electric vehicles with a battery capacity of at least 4 kilowatt hours, are eligible for a rebate of up to $2,500.	Statewide	Texas Commission on Environmental Quality
Natural Gas Vehicle Grant	Provides grants to replace existing medium- and heavy-duty vehicles with new, converted, or repowered natural gas or propane vehicles that operate in one or more of the eligible counties for at least 75% of the activity life. Qualifying vehicles must be on-road vehicles with a gross vehicle weight rating of more than 8,500 pounds, operate on at least 60% natural gas or propane, and be certified to current federal emissions standards.	Statewide	Texas Commission on Environmental Quality
Clean Fleet Grants	Grants to replace existing fleet vehicles with alternative fuel vehicles (AFVs) or hybrid electric vehicles (HEVs). An entity that operates a fleet of at least 75 vehicles and commits to placing 20 or more qualifying vehicles in service for use in the Clean Transportation Zone may be eligible. Qualifying AFV or HEV replacements must reduce emissions of nitrogen oxides or other pollutants by at least 25% as compared to baseline levels and must replace vehicles that meet operational and fuel usage requirements.	Statewide	Texas Commission on Environmental Quality
Clean School Bus Grants	Any public school district or charter school may receive the grant to pay for the incremental costs to replace school buses or install diesel oxidation catalysts, diesel particulate filters, emission-reducing add-on equipment, and other emissions-reduction technologies in qualified school buses.	Statewide	Texas Commission on Environmental Quality
Diesel Fuel Blend Tax Exemption	The biodiesel or ethanol portion of blended fuel containing taxable diesel is tax-exempt.	Statewide	Texas Comptroller of Public Accounts
Authorization of Governmental Alternative Fuel Fleet Grant Program	Grants for the purchase or lease of a new vehicle and the purchase, lease, or installation of alternative fueling equipment. Eligible alternative fuels include natural gas, propane, hydrogen, and electricity. State agencies and political subdivisions are eligible to apply for a grant under the program if the entity operates a fleet of more than 15 vehicles. Mass transit and school transportation providers are also eligible.	Statewide	Texas Commission on Environmental Quality
Alternative Fuel Vehicle (AFV) Registration Tracking Program	The Texas Department of Motor Vehicles collects data on the number of AFVs registered in the state and must submit an annual report to the Texas Legislature detailing the results each year.	Statewide	Texas Department of Motor Vehicles
Alternative Fuel Use and Vehicle Acquisition Requirements	State agency fleets with more than 15 vehicles, excluding emergency and law enforcement vehicles, may not purchase or lease a motor vehicle unless the vehicle uses natural gas, propane, ethanol, or fuel blends of at least 85% ethanol (E85), methanol or fuel blends of at least 85% methanol (M85), biodiesel or fuel blends of at least 20% biodiesel (B20), or electricity (including plug-in hybrid electric vehicles). Covered state agency fleets must consist of at least 50% of vehicles that can operate on alternative fuels and use these fuels at least 80% of the time the vehicles are driven.	Statewide	Texas Commission on Environmental Quality
Funding for Hydrogen Program	TxDOT may seek funding from public and private sources to acquire and operate hydrogen vehicles and establish and operate publicly accessible hydrogen fueling stations. TxDOT must ensure that data on emissions from the vehicles, fueling stations, and related hydrogen production is monitored and compared with data on emissions from control vehicles with internal combustion engines that operate on fuels other than hydrogen	Statewide	Texas Department of Transportation, Texas Commission on Environmental Quality

CHAPTER 5: TRANSPORTATION FLEET IN TEXAS: EVOLVING TOWARD THE TRANSITION

5.1 On-Road Vehicles-Light Duty Vehicles

In 2021, 84% of the light-duty vehicles (LDVs) in Texas were gasoline vehicles, followed by 10% ethanol/ flexible, and 3% diesel vehicles. EVs, plug-in hybrids, and hybrid electric vehicles made up less than 2% of all LDVs in the state. In 2021, EVs represented 6% of all new car sales in Texas, placing the state among the top five in the country for EV new car sales.

Across the country, the average fuel economy for all LDVs has more than doubled since 1975 while average peak engine power has increased by 1.6 times over the same period (Figure 18). The fuel efficiency of LDVs increased consistently between 1975 and 1987, then decreased at a rate of 12% between 1988 and 2004, before increasing by 29% between 2005 and 2020[15]. The fuel economy of sedans and wagons has improved from 13.5 mpg to 31.7 mpg since 1975 (234% increase), while SUVs saw a substantial increase of 70% since 2000 (Figure 19).

In 2020, the U.S. had four available models for small battery electric vehicles; five and nine models, respectively, for medium battery electric vehicles and plug-in hybrids; one available model for crossover battery electric vehicles; and two and five available models, respectively, for large battery electric vehicles and plug-in hybrids[16]. Among the manufacturers, Tesla represented about 80% of EV new car sales in 2020 and about 70% of EV new car sales in 2021[17].

Corporate Average Fuel Economy (CAFE) standards[18] are fuel efficiency benchmarks that help reduce energy consumption by increasing the fuel economy of cars and light trucks and are regulated by the U.S. Department of Transportation's National Highway Traffic and Safety Administration (NHTSA)[7]. CAFE standards are fleet-wide averages that must be achieved by each automaker for its light-duty car and truck fleet. NHTSA's last update to the standards in 2021 requires an industry fleet average of 49 mpg for light-duty cars and trucks in the model year 2026. This would mean increasing fuel efficiency by 8% annually for model years 2024 and 2025, and 10% annually for the model year 2026. NHTSA's projections highlighted that these standards would save consumers nearly $1,400 in total fuel expenses over the lifetimes of these light-duty vehicles produced in the model years 2024 through 2026 and lower the consumption of gasoline by about 234 billion gallons between 2030 to 2050.

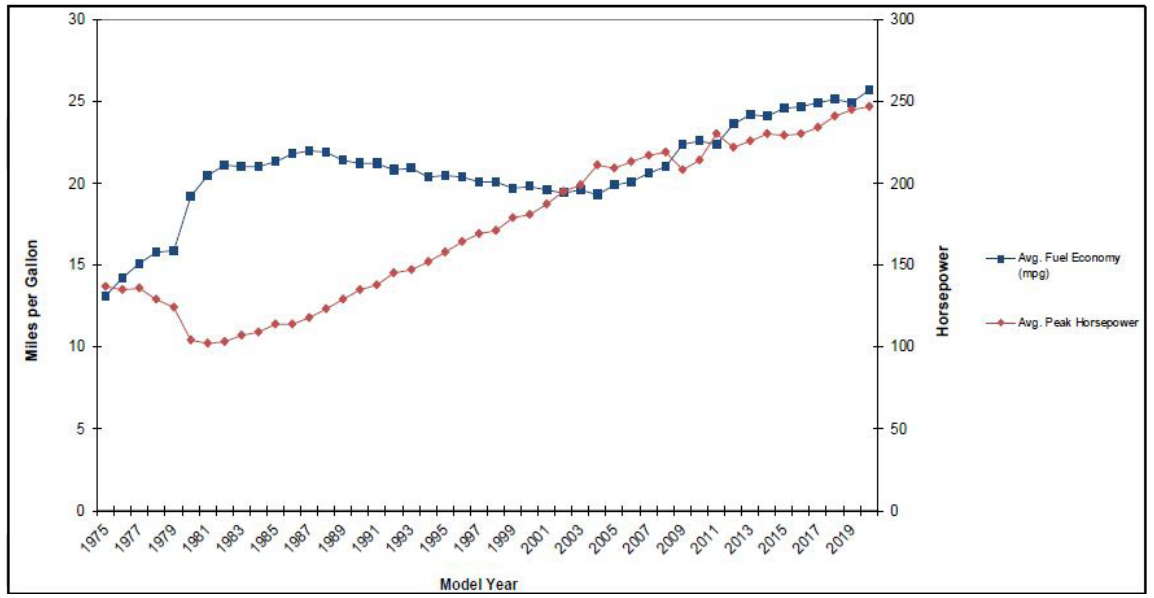

Figure 18. Power and fuel economy of average LDV in the U.S., 1975-2019. Source: AFDC, U.S. Environmental Protection Agency Automotive Trends Report (2020).

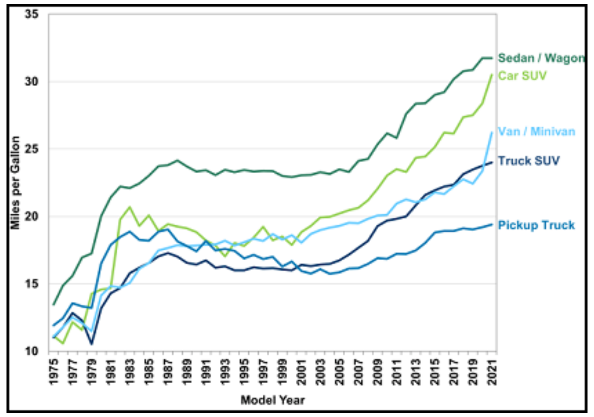

Figure 19. Average new LDV fuel economy, 1975-2021. Source: U.S. Department of Energy.

The failure to meet the CAFE standards results in penalties for automakers and is based on the difference between the automaker's fleet average fuel economy and the annual standard. It costs $14 per one-tenth of a mile per gallon, multiplied by the number of vehicles in an automaker's fleet.

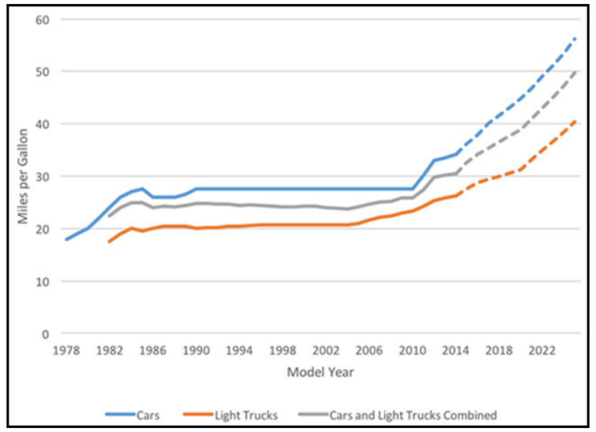

Figure 20. CAFE standards for passenger cars and light trucks, 1978 to 2025[8]. The presented miles per gallon values are laboratory test values used for fuel economy certification, whereas real-world values are typically 20% lower on average. Source: NHTSA, American Council for an Energy-Efficient Economy[19].

By the end of 2024, Honda, BMW, Ford, GM, Hyundai, Kia, Mazda, Mercedes, Nissan, Stellantis (including Jeep), Subaru, Toyota, VW, and Volvo plan to introduce dozens of new lines of battery electric vehicles (BEVs) to complement the current manufacturers of BEVs, including Tesla and Jaguar. Current global average battery pack prices are estimated to be $132 per kilowatt-hour (kWh), with U.S. manufactured prices higher than the global average by 30% to 50%.

BloombergNEF reported in November 2021 that the price of lithium-ion battery packs dropped by 89% to $132/kWh in 2021 as compared to $1,200/ kWh in 2021, and reduced by 6% from $140/kWh in 2020. Their analysis suggested that while prices have reduced over time, increasing commodity prices and cost of raw materials in the near term would result in average battery pack prices of $135/kWh in 2022 and will push the point when prices fall below $100/kWh by nearly two years.

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[7] The U.S. Environmental Protection Agency (EPA) calculates average fuel economy levels for manufacturers and sets related GHG standards.

[8] CAFE standards for light-duty trucks were not introduced until 1982

Table 10. NHTSA's Light-duty fleet-wide fuel economy standards and EPA's CO2 standards for new passenger cars and light-duty trucks. Data source: NHTSA, U.S. EPA.

Vehicle	Standard	2023	2024	2025	2026
Passenger Cars	CO2 (g/mi)	166	158	149	132
	CO2 equiv. mpg	54	56	60	67
	CAFE (mpg)		49.2	53.4	58.1
Light Trucks	CO2 (g/mi)	234	222	207	187
	CO2 equiv. mpg	38	40	43	48
	CAFE (mpg)		35.1	38.2	41.5
Combined Cars & Light Trucks	CO2 (g/mi)	202	192	179	161
	CO2 equiv. mpg	44	46	50	55
	CAFE (mpg)		40.7	44.2	48.1

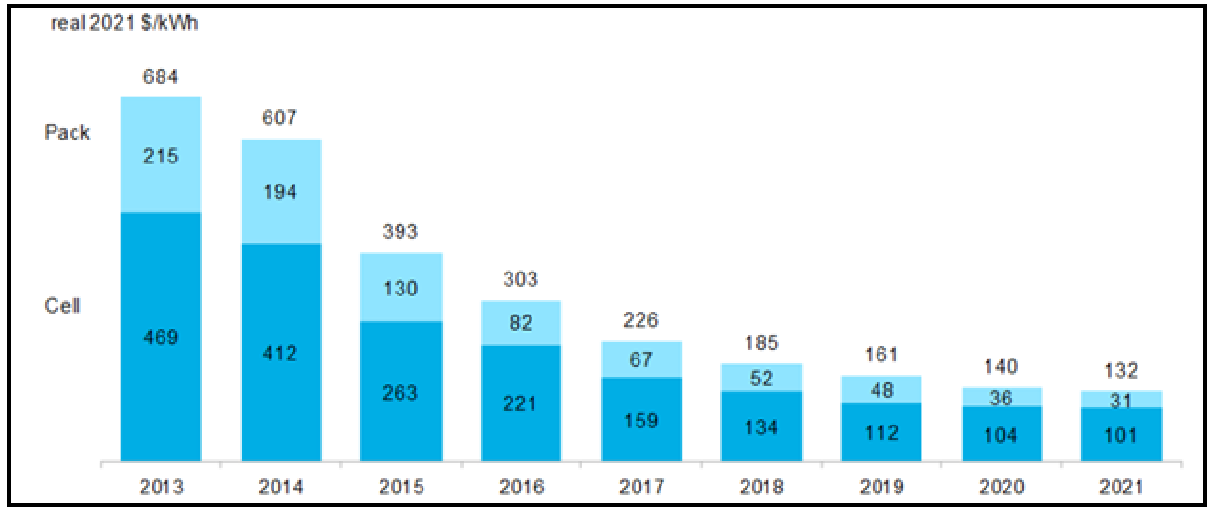

Figure 21. Volume-weighted global average pack and cell price for BEVs in $/kWh. Prices were estimated to be over $1,200 per kWh in 2010. Source: BloombergNEF[20].

5.1.1 On-Road Vehicles-Medium and Heavy-Duty Vehicles

The reliable movement of goods is critical for a vibrant Texas economy, supporting major industrial sectors such as energy, agriculture, and manufacturing. As identified in the Texas Freight Mobility Plan (TFMP), the Texas transportation system delivered 20 tons of freight per household and 12,700 tons of freight per business in 2016, generating $215 billion in economic impact and $49 billion in tax revenue [21,22] .The freight transportation industry supports about 2.2 million full-time jobs and $145 billion in wage income in the state. As of 2021, the Texas freight industry supported 2.2 million jobs that created $155 billion in income and $197 billion in Gross State Product. Additionally, the total impacts of freight employment plus the direct impacts of freight-dependent industries created $102 billion in federal, state, and local tax revenue[23] . To ensure continued opportunity for all Texans as the state's population grows, it will be essential to maintain a transportation system that keeps Texas competitive both nationally and globally. The sector primarily relies on movement by medium and heavy-duty vehicles across nearly 22,000 miles of highways. Table 11 highlights the announced and available zero-emissions MDVs and HDVs in the U.S.

Efficiency standards for medium and heavy-duty trucks were first established in 2007. The heavy-duty national program, or Phase 1 standards, was instated in 2011 and marked the first program that targeted emissions and fuel economy standards for heavy-duty vehicles between the model years 2014-2018. Phase 2 standards were finalized in 2016 and included medium-duty vehicles, in addition to revised standards for heavy-duty vehicles. These standards are divided into the following segments to allow flexibility for automakers to achieve the fuel economy and emissions standards by the model year 2027:

- Combination Tractors (Class 7 and 8 combination tractors) to reduce fuel consumption by 25% from Phase 1 standard levels
- Trailers to reduce fuel consumption by 9%
- Heavy-duty pickup trucks and vans to reduce fuel consumption by 16%
- Vocational vehicles (delivery trucks, buses, garbage trucks) to reduce fuel consumption by 24%
- Engine standards to reduce carbon dioxide emissions by 5%, and vocational diesel and gasoline engines to reduce carbon dioxide by 4% from Phase 1 standard levels.

The IEA's Global EV Outlook for 2022 suggests the number of models available in the U.S. for EV buses will increase from 26 to 34, for medium freight trucks from 62 to 69, for heavy freight trucks from seven to 15, and for the other categories from seven to 21 between 2020 and 2023.

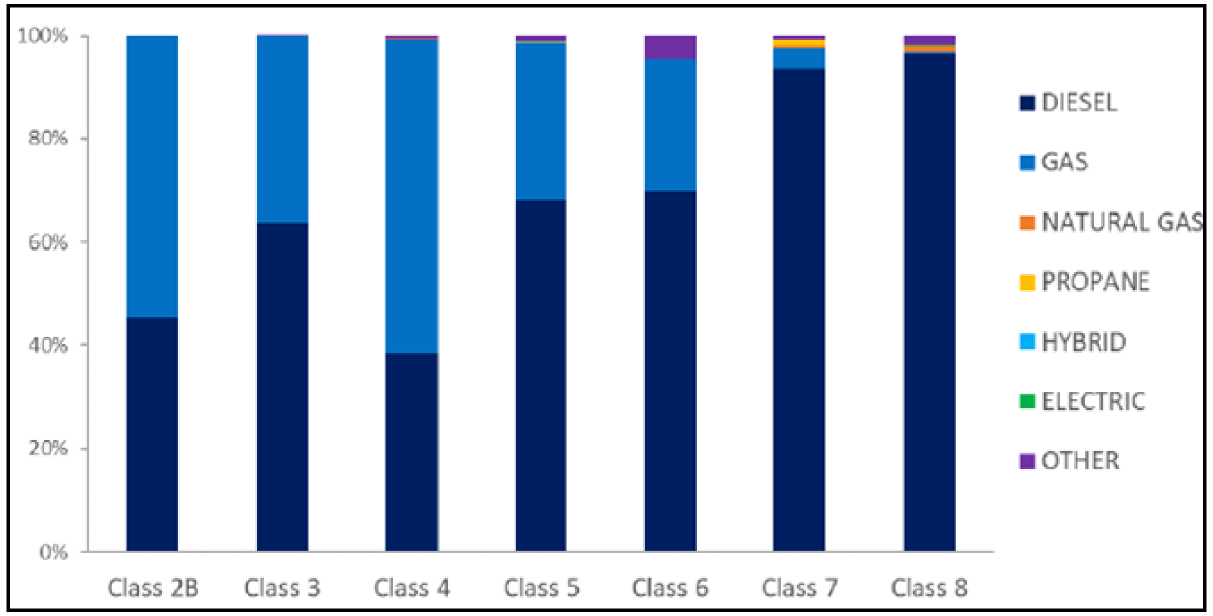

Figure 22. U.S. medium and heavy-duty fuel use by vehicle class. The y-axis presents the share of a fuel used by the vehicle class presented on the x-axis Source: IHS Markit.

Table 11. Announced and available zero emissions MDVs and HDVs in the U.S. Data source: Texas Department of Transportation.

Vehicle type	Regulatory Category (Vehicle, Engine)	Company type	Number of Companies with at least one ZEV model		
			Production	Pre-production	Concept
Transit bus	Vocational urban, Heavy heavy-duty engine	Major OEM	4		
		EV Manufacturer	4		2
		EV Retrofit	3		
School bus	Vocational urban, Medium heavy-duty engine	Major OEM	2		
		EV Manufacturer	2		
		EV Retrofit	2		
Coach bus	Vocational urban, Heavy heavy-duty engine	Major OEM			
		EV Manufacturer	3		
		EV Retrofit	1		
Shuttle bus	Vocational urban, Light heavy-duty engine	Major OEM		5	
		EV Manufacturer	3		
		EV Retrofit	6		
Class 2b-3	Heavy-duty pickup and van/ vocational trucks, Light heavy-duty engine	Major OEM	3		
		EV Manufacturer	11		
		EV Retrofit	4		
Class 4	Vocational trucks, Light heavy-duty engine	Major OEM	1		
		EV Manufacturer	2		4
		EV Retrofit	6		
Class 5-6	Vocational trucks, Light heavy-duty engine/ medium heavy-duty engines	Major OEM		3	
		EV Manufacturer	7		
		EV Retrofit	7		
Class 7-8 Single Unit	Combination trucks, medium heavy-duty engine	Major OEM		6	
		EV Manufacturer	7		2
		EV Retrofit	1		
Class 7-8 Tractor	Combination trucks, medium heavy-duty/ Heavy heavy-duty engine	Major OEM		9	
		EV Manufacturer	3		2
		EV Retrofit			
Terminal Tractor	Combination trucks, Medium heavy-duty/ Heavy heavy-duty engine	Major OEM			
		EV Manufacturer	5		
		EV Retrofit			

5.2 PUPLIC TRANSIT

In 2019, TxDOT reported that the state's public transportation riders took more than 274 million passenger trips using a variety of modes. These included fixed-route city buses, rural dial-a-ride bus systems and regular network bus systems, and light rail in high-density, urban areas.

In 2021, TxDOT reported a 48% decrease in ridership due to the COVID-19 pandemic. The trends in ridership[24] were comparable to the nationwide reduction in public transit ridership. Additionally, the total number of passengers per revenue hour decreased by about 32% in 2021, as compared to 2020, due to lower ridership[24]. Based on this and other demographic shifts, the consensus has been that public transit ridership is likely to drop by 25% over the next 30 years, especially in urban Texas.

A 2017 ridership survey by TxDOT revealed that urban riders were more likely (27%) to use public transit systems to get to and from work than rural riders (21%). At the same time, rural riders (26%) were more likely to rely on public transit to access medical care than their urban counterparts (18%)[25]. A 2021 assessment of the challenges facing public transit in Texas found the impact of the pandemic, declining ridership, population growth and varying population densities across the state, and competing technologies like ride-hailing services and arrangements like remote work, will impact its future[26].

5.3 RAIL

5.3.1 Passenger Rail

A key project aimed at decarbonizing passenger rail in Texas is the high-speed Texas Central Project, which is projected to remove 14,630 vehicles per day from I-45 between Houston and Dallas and in the process save 81.5 million gallons of gasoline. An analysis by the Federal Railroad Administration found that the project would add 1,576 new jobs to the Texas economy once it is operational and every permanent job associated with the project would add 2 to 4 indirect jobs in supporting industries. In June of 2022, the Texas Supreme Court ruled in favor of the project, allowing Texas Central to use eminent domain for land acquisition. Despite the legal assurance and $120 million in funding from private investors, the project has made little progress over the last decade. With the recent sale of some of the land acquired for the project and pre-suit depositions by property owners along the path of the project, its future remains uncertain.

5.3.2 Freight Rail

The Association of American Railroads found that if 10% of freight shipped by the largest trucks was moved by rail instead, GHG emissions would decline by more than 17 million tons annually. Movement of freight by rail has the lowest carbon footprint on a per-ton basis (Figure 23).

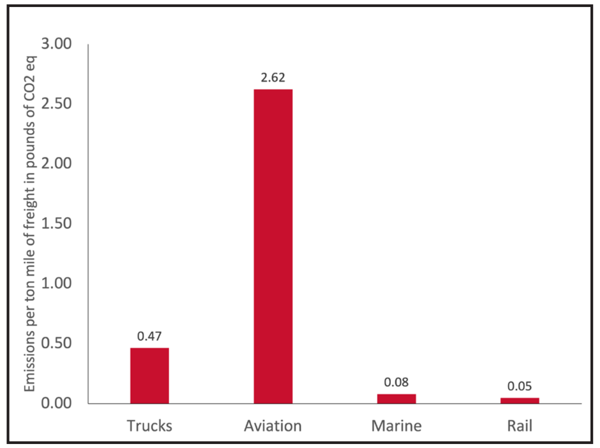

Figure 23. Emissions per ton-mile of freight transported by different modes in pounds of CO2 eq.
Data source: Bureau of Transportation Statistics.

5.4 AVIATION

The major pillars for decarbonizing the aviation sector include:

a. Fuel – Switching to sustainable aviation fuels, adopting hydrogen, and adoption of an electric fleet (less than 500 miles of air travel; all ground support at airports)

b. Airports – Commercial airports, military bases, and vertiport systems buildings and ground support vehicles

c. Aircraft - motors and controllers, powertrain components, batteries, liquid/gaseous fuel tanks, ground support vehicles

The Inflation Reduction Act has made available tax credits that would allow airlines to receive between $1.25 and $1.75 per gallon for Sustainable Aviation Fuel purchases, based on how much the fuel improves upon lifecycle greenhouse gas emissions compared to jet fuel. Texas has pioneered the development of SAF production at scale, including commercial efforts by Neste and World Energy. In August, World Energy, a net zero solutions provider, announced a plan to convert its existing Houston assets to launch a sustainable aviation fuel hub that will enable the company to produce another 250 million gallons of SAF annually by 2025.

5.5 MARINE

In its 2021 A Pathway to Decarbonize the Shipping Sector by 2005 Report, the International Renewable Energy Agency stated that despite comprising about 70% of global shipping emissions and enabling 80%-90% of global trade, marine emissions typically fall outside national, and therefore state, GHG emission accounting frameworks

Table 12. Technology readiness of shipping fuels. Data source: IRENA

	Technology Readiness					Engine Technology
	Fuel	Engine	Scalability and Time to market	Energy Density	GHG Reduction	
Fuel Oil	High	High	High	High	Low	ICE
LNG	High	High	Medium	High	Low	ICE
Advanced Liquid Biofuels	High	High	Low	High	Medium	ICE
Renewable Gaseous Fuels	High	High	Low	High	Medium	ICE
Hydrogen	Low	Low	Medium	Low	High	ICE FCs
Ammonia	High	Low	Medium	Medium	High	ICE FCs
Methanol	High	High	High	Medium	High	ICE FCs

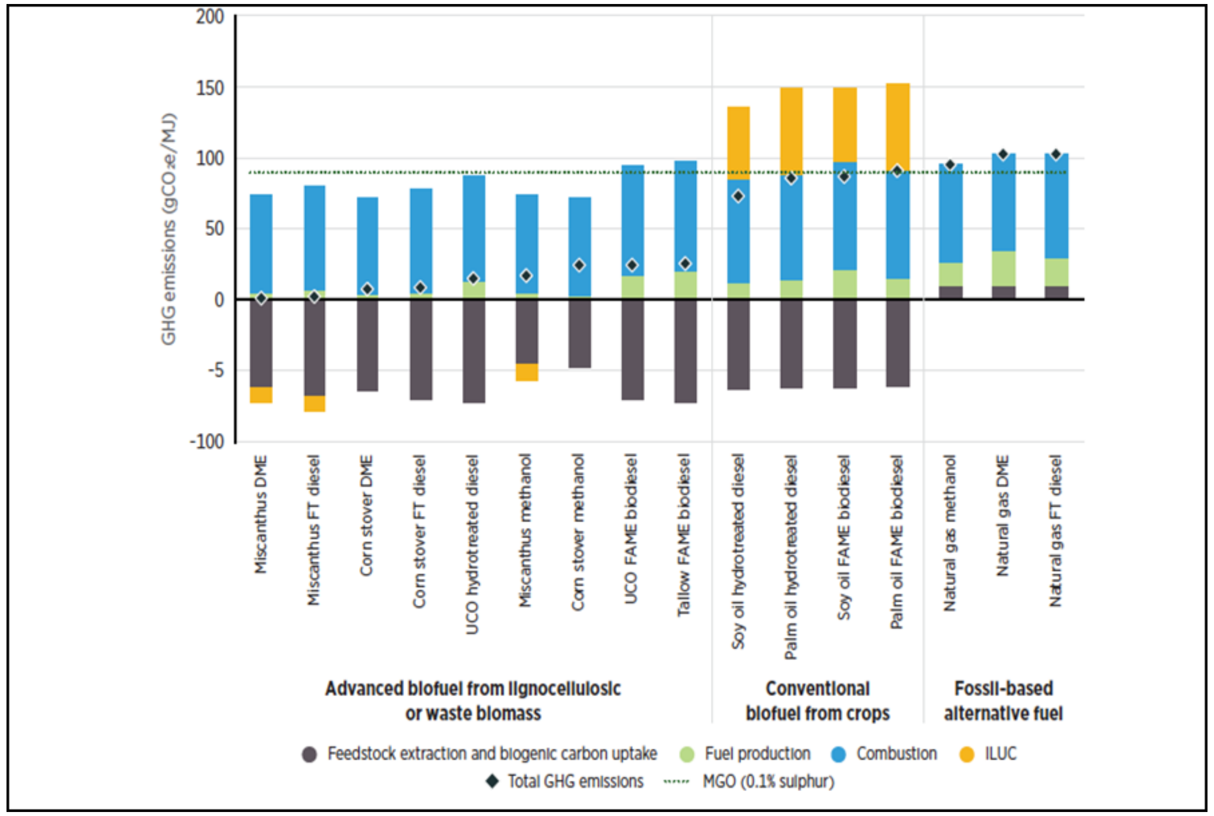

Figure 24. Comparison of different biofuels on a life-cycle basis where emissions are measured in grams of CO_2. Advanced biofuels, those fuels that use second-generation feedstock, produce lower life-cycle emissions than first-generation feedstock biofuels. All biofuels result in emissions reduction and abatement compared to conventional fuels. Source: IRENA, ICCT

CHAPTER 6: PROJECTING SCENARIOS FOR THE EVOLUTION OF TEXAS TRANSPORTATION

The goal of reaching Net Zero by 2050 motivates this work. Given the current wells-to-wheels efficiency and the significant carbon impact of transportation, it is imperative to consider various scenarios to achieve Net Zero and evaluate the economic and societal impact of the same. Here we analyze the impact of decarbonizing the transportation system in Texas for road, rail, aviation, and marine sectors across the passenger, freight, and fleet segments by focusing on the evolution of vehicles and their use of different fuel carriers (fuel and energy). The transportation system intrinsically scales with the population, and economic activity crucially depends on the reach and size of the transportation sector. With the anticipated increase in the state's population from 29.4 million in 2020 to 54.4 million in 2050 and an economy that is likely to grow from $2 trillion in 2020 to $7 trillion by 2050, we anticipate significant growth in the transportation sector. The infrastructure needed to support the transportation sector also needs to be considered, with a significant increase in the size of the sector related to population growth, replacement of aging infrastructure, and upgrade or installation of new infrastructure related to changing fuel and vehicle modalities

6.1 METHODOLOGY

This chapter discusses the methodology for:

- Modeling the interactions between the transportation system, travel demand, and socioeconomic conditions, as outlined in Figure 25, to understand how the size of the fleet, sales, fuel use, and emissions will be affected by population, population density, and changes in demand for freight movement and logistics in Texas through:
    - Regression analysis
    - Survival analysis
    - Life cycle analysis for emissions impact
    - Scenario analyses for electricity grid expansion, fuel switching, and emissions impact
- For the transportation value chain (Figure 23), we quantify vehicle and fuel demand based on travel and freight volume.
- These changes are analyzed across all modes of transportation
    - On-road vehicle fleet: light-duty, medium-duty, and heavy-duty vehicles
    - Rail, aviation, and marine: focused on freight and fleet segment

We discuss the interdependencies with other sectors of Texas' economy and the direct and indirect impacts on workforce and employment in Chapter 8.

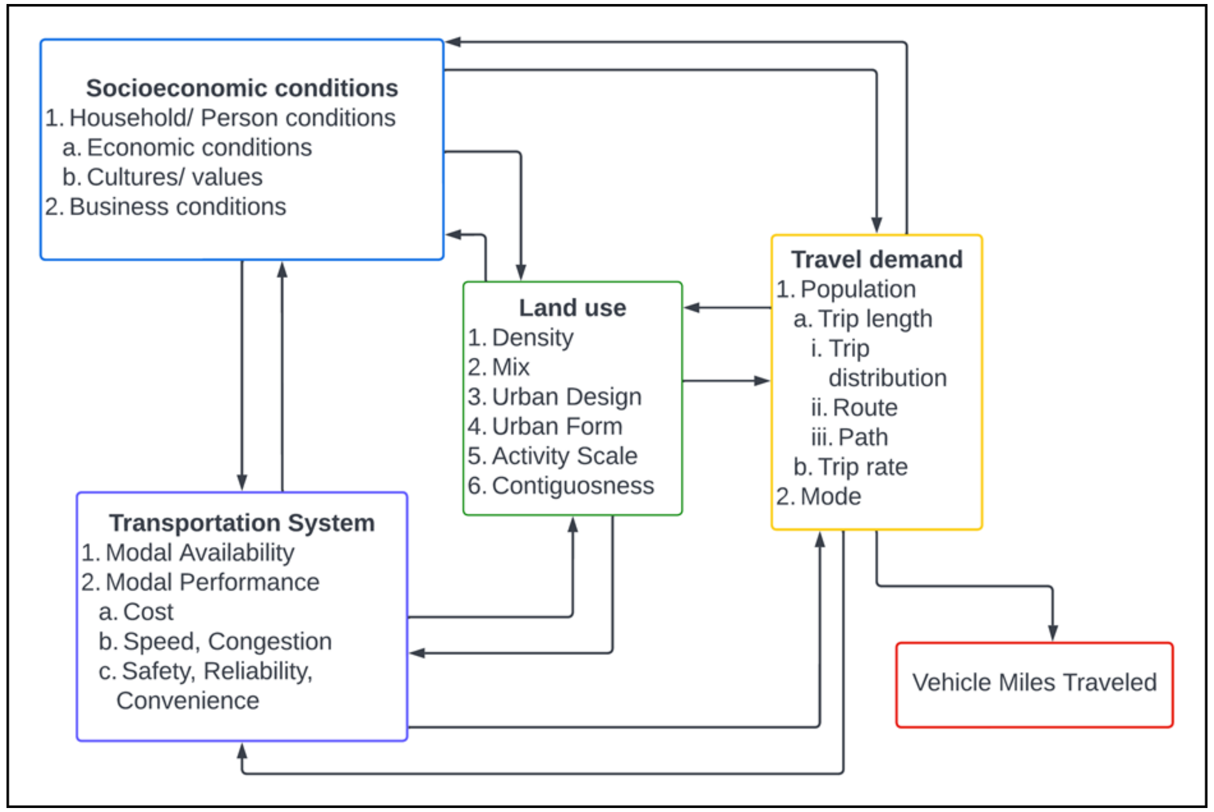

Figure 25. Indirect drivers of passenger travel behavior as an example of how the future impacts on the transportation sector are determined. Adapted from the Texas A&M Transportation Institute, 2015.

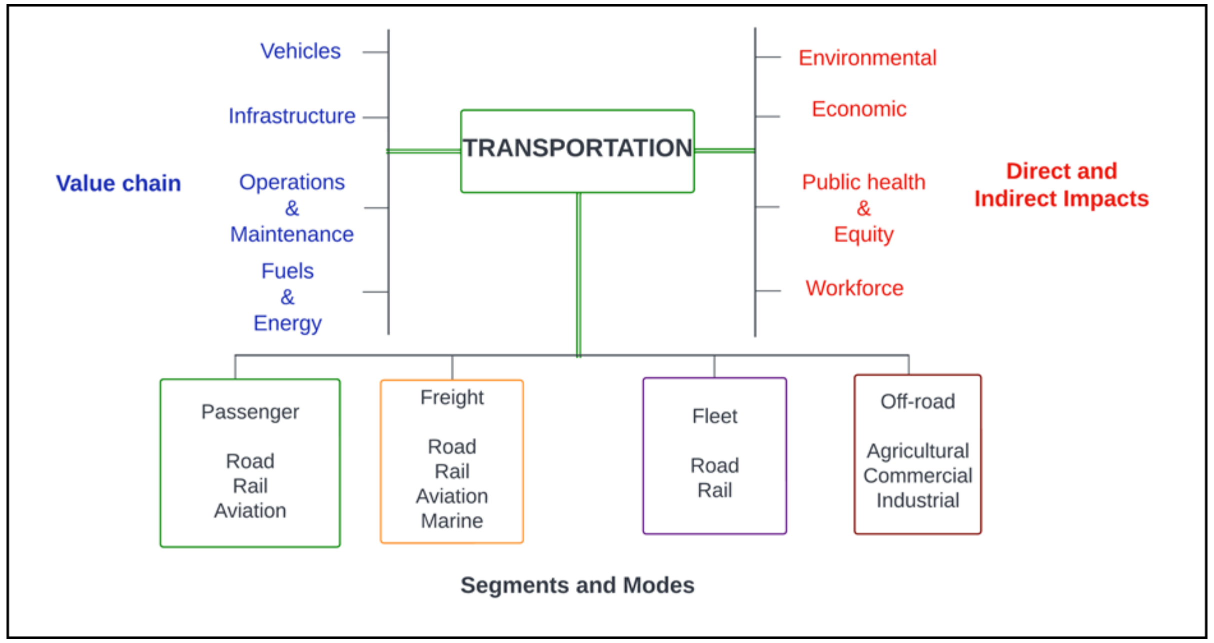

Figure 26. The scope of analysis is highlighted here, based on the discussion of the interdependencies in the transportation sector: the transportation value chain, segments, modes (transportation modalities), and direct and indirect impacts of the sector.

Scope of Analysis

We analyzed the impact of decarbonizing the existing and future transportation system in Texas for the road, rail, aviation, and marine sectors across the passenger, freight, and fleet[9] segments by focusing on vehicles and fuel carriers (fuel and energy). For on-road systems, the life-cycle analysis also includes operations and maintenance impacts. Infrastructure decarbonization is not included in the analysis. This section details the methodology for analyzing the emissions impact of decarbonizing the transportation system. We discuss the interdependencies for the economy, public health, equity, and workforce development in Chapter 8

1. On-road Vehicles – Light, Medium, and Heavy-Duty Vehicles

Among other drivers of travel behavior (Figure 25), we found population to be the most robust predictor of vehicle miles traveled. Therefore, we used county-level population projections for the 254 counties to calculate the daily vehicle miles traveled (DVMT) for light-duty vehicles and for medium and heavy-duty vehicles as presented in Equations 1 and 2. We used a linear regression model to quantitatively project travel patterns in the future based on changes in the population. The population projections are based on a cohort-component projection technique from the 2010 Census data. The technique separates the population into cohorts based on one or more common sociodemographic characteristics to predict changes based on fertility, mortality, and migration.

The projections were based on average birth and death rates but utilized different net migration rates based on alternations of 2000 Census data to 2010 Census data for age, sex, and race/ethnicity differences of the migrating population. Overall, the report found that the population of Texas will increase from 25.1 million in 2010 to 54.4 million in 2050 if current trends of net migration continue[10]. These projections were developed by the Hobby School of Public Affairs at the University of Houston and have been adopted by the Texas Demographic Center to facilitate policymaking on issues that demand state services[27]. Figure 27 presents the year-on-year change in population (in %) between 2022 and 2050.

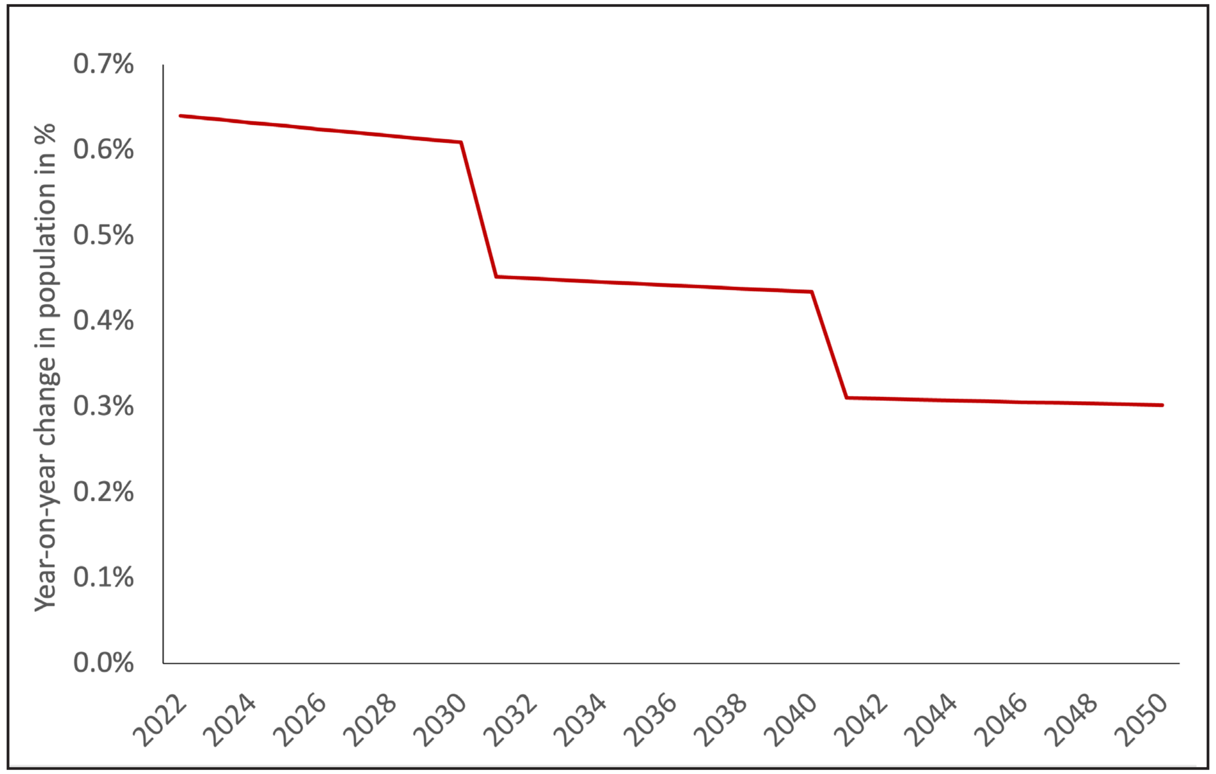

Figure 27. Year-on-year change in population between 2022 and 2050 in Texas

For LDVs, the daily miles traveled (DVMT) can be modeled using Equation 1 (Adjusted R-squared = 0.98)[11]

$$\text{County DVMT} = 22.22 \times \text{County Population} \quad \text{Eq. 1}$$

Similarly, for MDVs and HDVs the DVMT can be modeled using Equation 2 (Adjusted R-squared = 0.87)[12]

$$\text{County DVMT} = 1.48 \times \text{County Population} \quad \text{Eq. 2}$$

---

[10] The projections assume three modeling scenarios. The 0.0 scenario assumes net migration is equal to zero (no new migration or in-migration and out-migration are equal) and population growth occurs because of natural increase (the difference between the number of births and deaths). The 0.5 scenario assumes rates of net migration equal to one-half of the 2000-2010 trend and the 1.00 scenario assumes a continuation of 2000-2010 patterns of net migration. The population of Texas will increase from 25.1 million in 2010 to 31.2, 40.5 or 54.4 million in 2050 depending on the projection scenario.

[11] Unconstrained model: County DVMT=21.87 X County Population+178,235
Adjusted R-squared = 0.94

[12] Unconstrained model: County DVMT=1.386 X County Population+143,531
Adjusted R-squared = 0.89

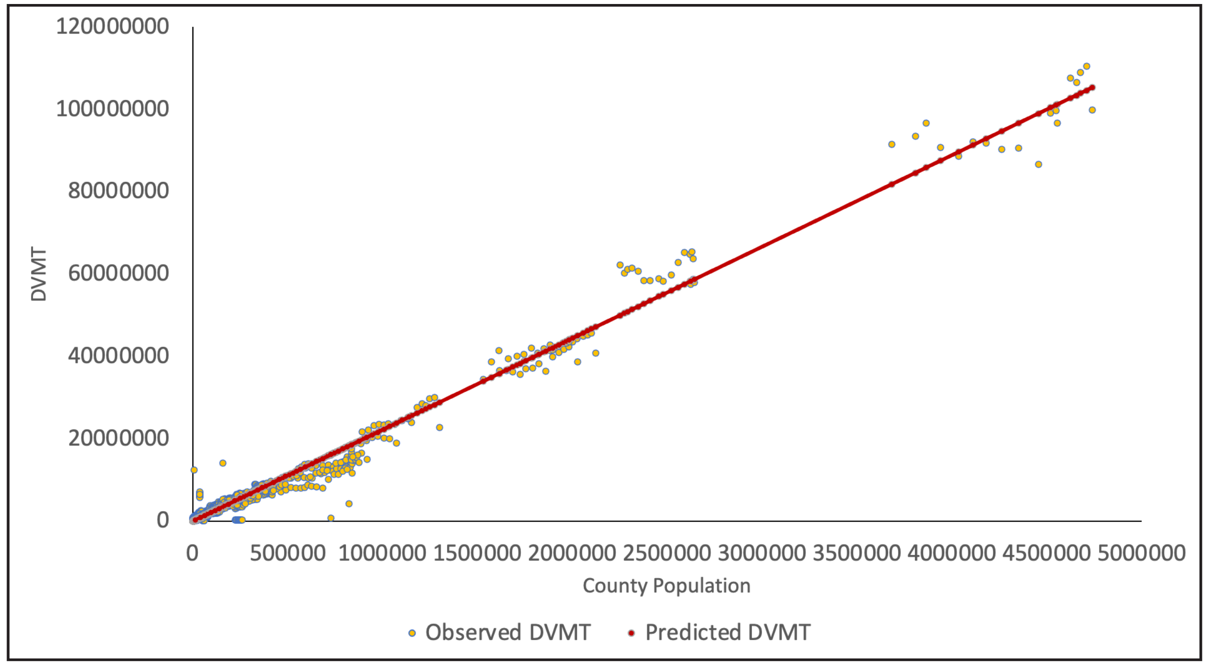

Figure 28. Observed vs predicted DVMT for light-duty vehicles based on the regression model presented in Equation 1.

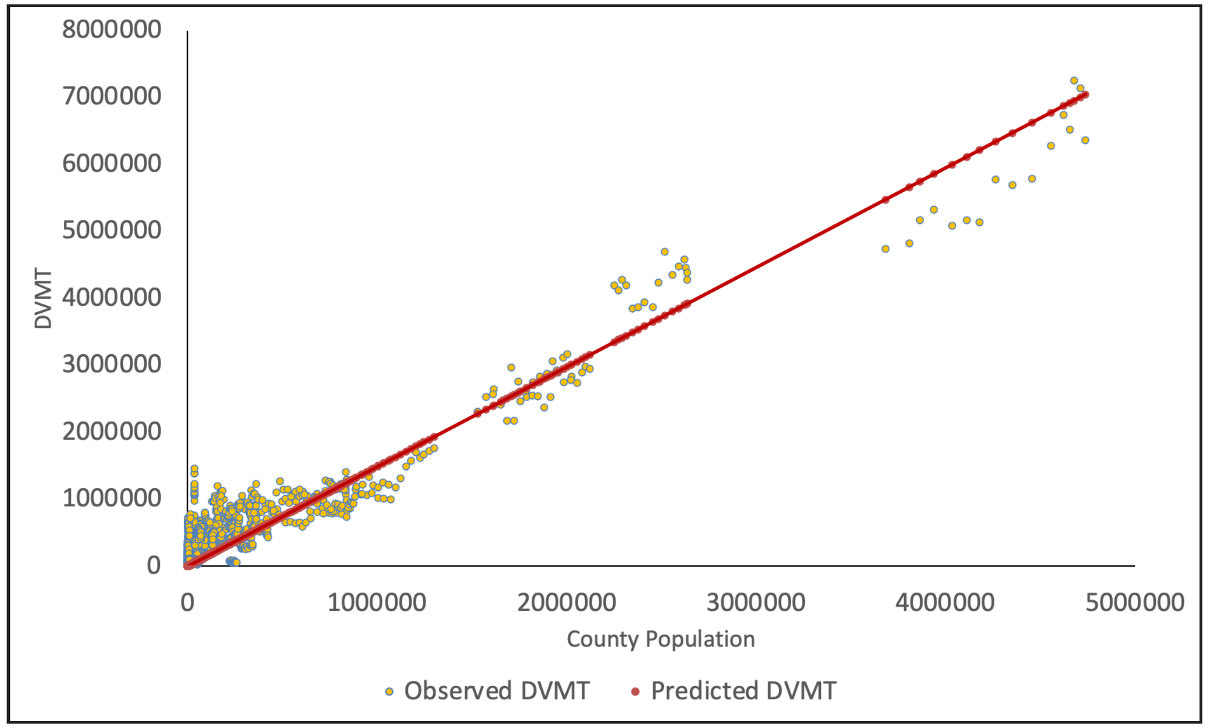

Figure 29. Observed vs predicted DVMT for medium and heavy-duty vehicles based on the regression model presented in Equation 2.

County-level DVMT projections were aggregated to predict state-level DVMT, and subsequently, annual state-level DVMT. Based on the annual DVMT, the LDV and MDV/HDV demand in Texas was modeled for 2022-2050. These average lifetime values for the different classes of vehicles were estimated based on data developed by GREET, U.S. EPA, IHS Markit, and EDF . The data for average annual VMTs per vehicle type and average lifetimes of vehicles are presented in Table 13.

Table 13. Average annual vehicle miles traveled and average lifetime of LDVs, MDVs, and HDVs

Segment	Average annual vehicle miles traveled (miles per year)	Average lifetime (years)
Light duty vehicles	11,500	15 (±3)
Medium and heavy-duty vehicles	25,000	12 (±3)

The annual average VMT and lifetime were used to calculate the number of vehicles in the LDV and MDV/HDV segments between 2022 and 2050. The change in LDV and MDV/HDV fleets each year and fleet retirements each year were used to calculate the total sales of LDVs and MDVs/HDVs between 2022 and 2050 using Equations 3 through 8.

$$(Fleet)_t = Retained\ fleet_t + (New\ sales)_t \qquad \text{Eq. 3}$$

where, Retained fleet_t is the number of vehicles retained at time t from the fleet at time t-1.

$$(Annual\ likelihood\ of\ retirement)_t = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{1}{2}\left(\frac{(t-\mu)}{\sigma}\right)^2} \qquad \text{Eq. 4}$$

Where, for a fleet of vehicles launched in year 0, the average lifetime of the vehicle is μ and σ is the absolute range of uncertainty in the lifetime of vehicles. This leads to an estimation of the remainder of the fleet on the road during any year t after launch and given as $(\text{Fleet})_t$.

$$(Cumulative\ likelihood\ of\ retirement)_t = (Annual\ likelihood\ of\ retirement)_t + (Cumulative\ likelihood\ of\ retirement)_{t-1} \qquad \text{Eq.5}$$

With the $(Cumulative\ likelihood\ of\ retirement)_{t-1}$ in year 0 to be 0.

$$(Retained\ fleet)_t=(Fleet)_{t-1}*(1-(Cumulative\ likelihood\ of\ retirement)_t\ ) \qquad \text{Eq. 6}$$

$$(Retired\ fleet)_t=(Fleet)_{t-1}-(Retained\ fleet)_t \qquad \text{Eq. 7}$$

From these the new sales of vehicles in any year t is estimated (New sales)_t as:

$$(New\ sales)_t=(Demand\text{-}based\ YOY\ fleet\ changes\ )_t+(\text{Retired fleet})_t \qquad \text{Eq. 8}$$

The demand-based YOY fleet changes are modeled for the different scenarios and are shown in Figures 30a and 30b based on the discussion and development in the following section.

Scenarios and Scenario Implications for Transportation Segments

The number and kind of on-road vehicles were analyzed under three scenarios.

a. Business-as-usual

b. All new sales are zero-emissions vehicles by 2050, with a ramp from 2022 to 2050 to achieve this goal

c. All new sales are zero-emissions vehicles by 2040, with a ramp from 2022 to 2040 to achieve this goal

Business-as-usual Scenario: The BAU scenario uses historical data from EIA and the stock of MDVs/HDVs in the U.S., respectively, to model the scenario of fleet electrification and switching to zero-emissions vehicles.

For the alternative deployment scenarios of all new sales to be zero emissions vehicles by 2040 and 2050, respectively, we assumed accelerated growth rates compared to the business-as-usual assumption and that with the impetus for new ZEV models, their market penetration will increase significantly in 2030.

As outlined in Equation 3, the sum of new sales determined by the growth rates presented above and the fleet retained from the previous years resulted in the total fleet for a given year. For LDVs, the average lifetime was 15 years (±3 years) and we assumed the annual average VMTs to be 11,500 miles. For MDVs and HDVs, the average lifetime was 12 years (± 3 years), and we assumed the annual average VMTs to be 25,500 miles based on data from the GREET model.

Limitations of a Population-based Model

The estimates of the fitted coefficients were tested to ascertain that they are reflective of real-world scenarios. While the models presented excellent fits, they could be limited by the exclusion of other important predictor variables. Furthermore, these models are unable to capture the size and impact of the used cars market, which will continue to be dominated by ICEVs. Currently, EVs depreciate faster than ICEVs due to concerns about long-term battery performance. However, this can change with technology improvements and as more EVs are deployed.

Life Cycle Analysis of On-road Vehicles

To quantify the emissions associated with the three scenarios, we use the number and type of vehicles on the road at any given time and the emissions associated with each of them. A cradle-to-grave life cycle analysis (LCA) was performed for LDV internal combustion engine vehicle (ICEV) and electric vehicle (EV) emissions for passenger cars and pickup trucks, and medium and heavy-duty ICEV and EV emissions. The cradle-to-grave LCA methodology has been widely described in publications, especially those from the Argonne National Laboratory and the well-established Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model (GREET) model. It simulates the energy use and emissions impact of various vehicle and fuel combinations and provides additional results for air pollutant emissions and water consumption. The LCA structure appears in Figure 30.

LCA for LDVs

For the LDVs, the life-cycle analysis methodology outlined in UH Energy White Paper Light Duty Vehicles GHG Emissions: A Transparent, Dynamic Model (No. 1. 2022)[28] was utilized. This model builds on the Argonne National Laboratory's GREET model and includes tailpipe emissions, the fuel cycle (oil production, gasoline refining, and gasoline transport to sales), vehicle disposal for ICEV vehicles, and emissions from electricity generation for each generation source, the fuel cycle (for electricity generation, or the production and transport of fuel to generation sites), and disposal for EVs. Assessment of emissions from electricity generation is based on the current electricity mix in Texas and considers the impact of factors that affect electricity demand for EV operation. In addition to EV energy efficiency during operation (referenced here as 3.7 miles per kWh for the Tesla 3 passenger car, 2.1 miles per kWh for the Ford Lightning electric pickup truck), model calculations of the energy requirement for EV operation also include line losses in electricity transmission and distribution, energy loss during battery charging, and battery self-discharge, or "leakage".

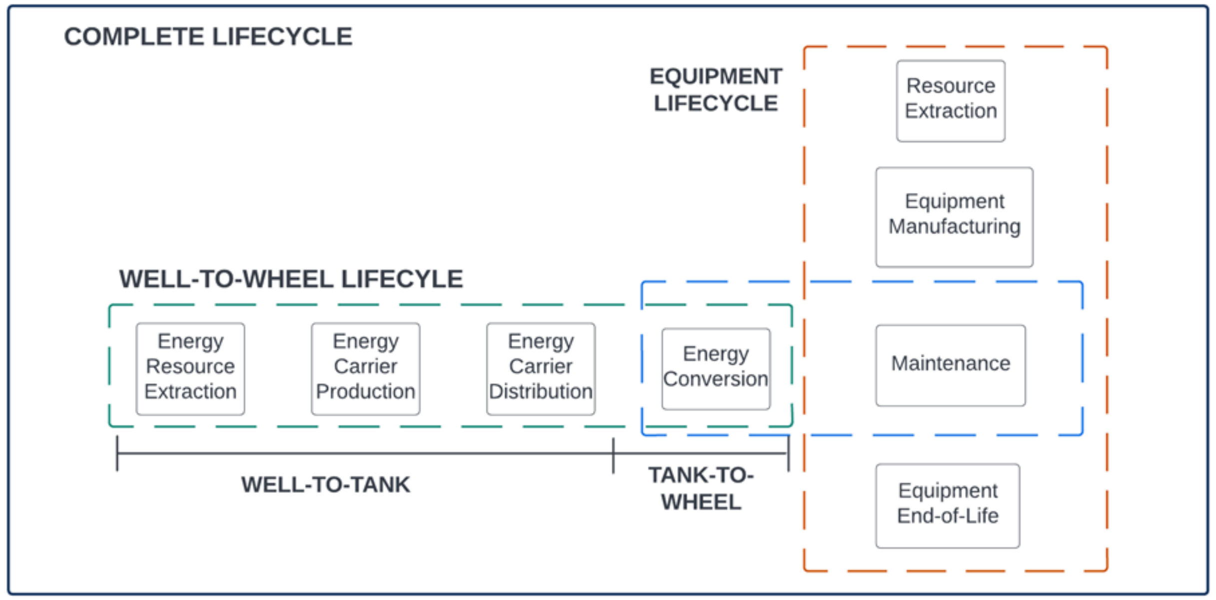

Figure 30. Cradle-to-grave life cycle based on the GREET model

Based on LDV registration data in Texas, we have assumed that 67% of LDVs in the state will continue to be passenger cars while 33% will continue to be trucks and that this distribution will continue to be observed in LDV sales between now and 2050. Table 14 outlines the life-cycle stages and approach for the comparison between ICEVs and EVs, while Tables 15 to 18 outline the model assumptions for ICEV and EV cars and trucks.

The model assumptions and input parameters (outlined above) yielded an emissions impact of 4.9 tCO2 eq/year for ICEV and 2.6 tCO2 eq/year for EV passenger cars and 7.9 tCO2 eq/year for ICEV and 4.4 tCO2 eq/year for EV pickup trucks, on an annualized basis We note that the emissions associated with the manufacturing of the EV cars and trucks were significantly higher than those for the comparative ICEV cars and trucks respectively. Tailpipe emissions and electricity generation were the most dominant emissions category for ICEVs and EVs, respectively.

Table 14. Life-cycle stage and approach for the comparison of LDV passenger cars and trucks.

Lifecycle stages		ICEV	EV	Comment/ Approach	
Component Manufacture, Assembly, Delivery	Lithium battery	--	✓	Significant for EV manufacture	"One-time" values. Spread over vehicle life to estimate per-mile emissions.
	Other manufacturing	✓	✓	Components and assembly apart from lithium battery	
	Delivery	✓	✓	Minor compared to other LCA stages	
Ownership, Operation, Disposal	Tailpipe emissions	✓	--	Significant portion of ICEV 'tank to wheel' emissions	Primarily "indexed" values (emissions per driven mile). Sum over vehicle life to estimate lifetime emissions.
	Emissions from electricity generation	--	✓	Significant portion of ICEV 'well to tank' emissions	
	Fuel cycle	✓	✓	ICEV: fossil-based fuel sourcing and processing EV: fuel sourcing for electricity generation	
	Disposal	✓	✓	Minor compared to other LCA stages	

Table 15. Model Inputs, ICEV and EV cars and pick-up trucks

	ICEV car	EV car	ICEV truck	EV truck
Vehicle life (purchase to disposal) (years)	15			
Distance traveled each year after purchase (miles)	11,500			
Manufacture, assembly, and delivery				
Manufacture and assembly emissions (tCO_2 eq)	5.81	4.83	8.61	7.36
Lithium battery manufacture (tCO_2 eq)	-	5.06	-	8.14
Delivery emissions (tCO_2 eq)	0.24	0.20	0.34	0.30
Operations and Disposal				
Tailpipe emissions				
Emissions per gallon of gasoline (kgCO2 eq/gallon)	8.95		8.95	
Fuel efficiency (miles per gallon)	30.93		18.68	
Fuel cycle (Production, Refining, and Transport to Sales)				
Volume % of ethanol (%)	10.23		10.23	
Upstream (well to refining GHG basis) (tCO2 eq/bbl-crude)	0.07		0.07	
Refining				
Processing (volumetric) gain (%)	6.30		6.30	
Refining GHG emissions basis (tCO_2 eq/bbl-crude)	0.04		0.04	
Distribution (Refining to sales)				
Evaporative loss (%)	1.75		1.75	
Carbon Intensity (GWP 100) of motor gasoline (tCO_2 eq/t)	11		11	
Tank-truck shipment to sales centers (tCO_2 eq/year)	0.016		0.027	
Ethanol fuel cycle basis ($kgCO_2$ eq/ gallon)	2.36		2.36	
Electricity Generation, Transmission, Use				
Efficiency (miles traveled/kWh charged)		3.7		2.1
Battery maximum charge level (kWh)		8.7		125
Efficiency loss on charging (per charge event)		13		13
Battery self-discharge (over vehicle life)		87		0.5
Transmission-distribution line losses (%)		4.9		4.9
Electricity generation profile (% of generated electricity, indicative of average values for Texas)				
Natural gas		42.0		42.0
Coal		19.1		19.1
Nuclear		10.3		10.3
Wind		24.4		24.4
Hydropower		0.1		0.1
Solar (PV)		4.0		4.0
Biomass		0.1		0.1
Electricity generation – fuel cycle (GHG emissions basis)				
Natural gas (gCO_2 eq/ MMBtu Nat. Gas)		9476		9476
Coal (gCO_2 eq/ MMBtu Coal)		6075		6075
Petroleum (gCO_2 eq/ MMBtu Petroleum)		4831		4831
Disposal – GHG emissions (tCO_2 eq)	0.48	0.56	0.52	0.56

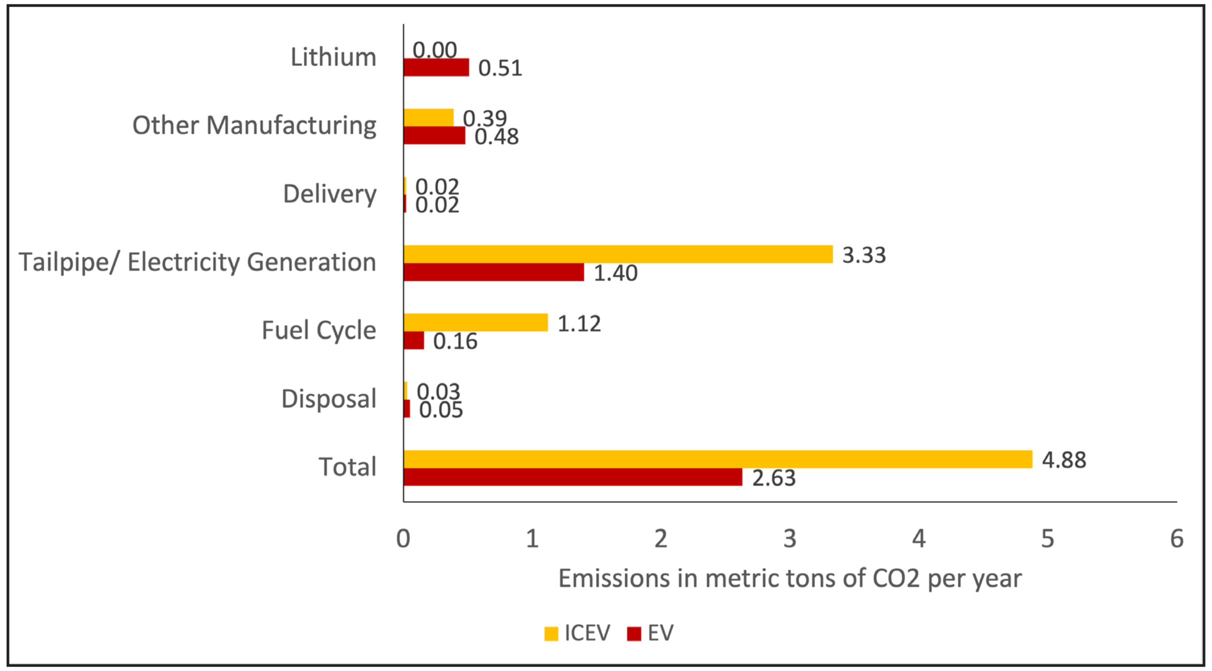

Figure 31. Calculated values of GHG emissions, in metric tons of CO2e emitted per year, for ICEV and EV car types. Source: UH Energy White Paper Series No.1.2022

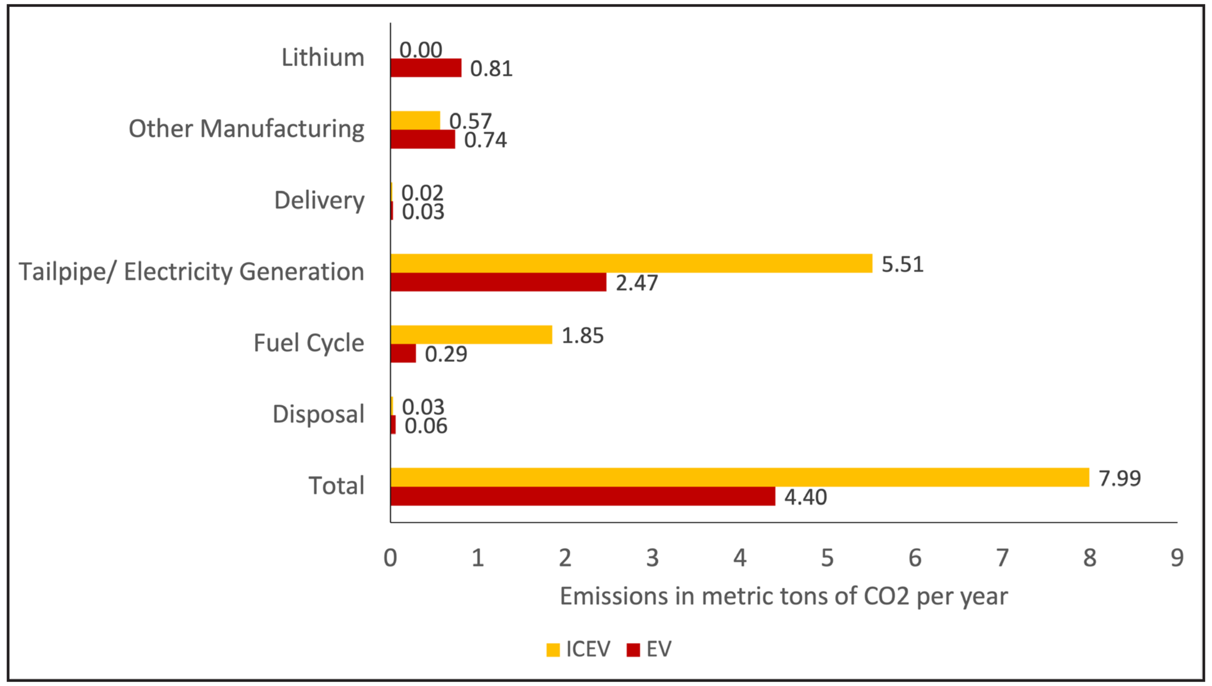

Figure 32. Calculated values of GHG emissions, in metric tons of CO2e emitter per year, for ICEV and EV pickup truck types. Source: UH Energy White Paper Series No.1.2022

Sensitivity and Limitations of the LCA

While the LCA model presented here is based on commonly used assumptions, the results of the LCA are sensitive to these assumptions and any variations in the assumptions can significantly alter the conclusions. For example, changes to fuel economy standards will impact the emissions associated with traveled miles. Additionally, the LCA presented here is representative of the current electricity mix in Texas and does not consider other electricity grid scenarios. Any changes in the electricity mix will impact the electricity generation emissions segment of EVs.

The LCA does not account for alternative fuel mixes for ICEVs. A recent study that analyzed the lifecycle GHG emissions and land impacts of corn ethanol production found that at current prices, $20 billion worth of corn, representing a third of the annual corn production in the U.S., is converted to ethanol. The production requires the land equivalent of all the cropland dedicated to corn in Iowa and Minnesota, the first and the fourth largest corn-producing states. However, it only offsets about 6% of gasoline use, which is equivalent to improving the fuel efficiency of the current average U.S. fleet from 22 miles per gallon to 24 miles per gallon. Separately, and complementary to this work, another study found that under current U.S. Renewable Fuel Standards, the domestic land use change associated with corn production to meet the current standards has resulted in the carbon intensity of corn ethanol to likely be at least 24% higher than that of gasoline. Thus, given the at-best comparable nature of the true carbon intensity of the most mature drop-in replacement biofuel with gasoline, and further complicated by the massive land-use intensity associated with corn ethanol, we have chosen not to consider this fuel switching as a sufficiently differentiated pathway to current hydrocarbon fuels in the transportation sector.

The LCA considers the emissions impact of manufacturing, and it is noteworthy that an EV uses six times the critical minerals used in an ICEV (Figure 34). Hence, EVs have higher impacts in terms of metal and mineral consumption. GREET assumes battery production for EVs is based in the U.S. and that the materials are available in the U.S. market; however, the results of the model can change significantly based on where the battery is produced, and where and how the materials and critical minerals are sourced[29].

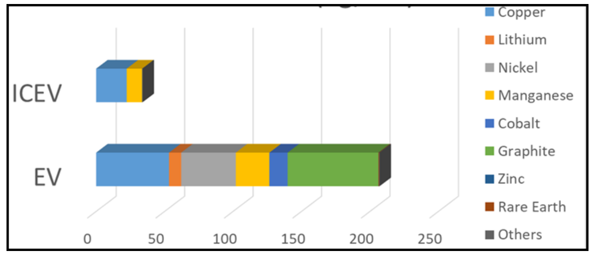

Figure 33. The minerals used in electric and conventional cars in kg/car. Steel and aluminum are not included. The values for vehicles are for the entire vehicle including batteries, motors, and glider. The intensities for an electric car are based on a 75 kWh NMC (nickel manganese cobalt) 622 cathode and graphite-based anode. Data source: IEA[30]

When batteries are removed from EVs after their first life, they are likely to retain about 70% of their original capacity. They could support the electric grid for energy storage, which would allow the lithium-ion batteries to be reused in stationary storage applications and the battery manufacturing footprint to be extended to a more useful battery life. A battery second life of 10 years, at 60% of the battery's original capacity, can increase the lifetime use of the battery by 72%, and therefore reduce the associated emissions by 42% on a per unit distance basis[31].

Materials production is responsible for nearly half of emissions from battery production, which could be greatly reduced through recycling[32]. Typically, recycled materials have a lower GHG impact than the same materials from virgin sources. For example, the production of recycled aluminum creates approximately 95% less greenhouse gas emissions compared to producing aluminum from natural sources. An analysis of several potential battery recycling pathways that could be implemented found that potential net savings of 1–2.5 kg CO2 per kg of battery, or a 7%–17% net reduction in battery life-cycle emissions, or a 4%–10% reduction in battery emissions on a per kilometer basis after can be achieved through recycling. However, the emissions reduction that can be achieved through recycling processes depends on the pathway and the associated energy input, grid composition, and process emissions and are not comprehensively accounted for in the current version of the GREET model.

Existing studies that have used methodologies other than the GREET model have also reported widely different results and use varying methods and systems boundaries. The large variations are primarily driven by differing assumptions related to the energy demand, cell material, conversion losses in the battery, the carbon intensity of the electricity, the location for battery manufacturing, the mode of transportation and the energy required for transporting the weight of the battery, and the carbon intensity of the associated supply chain[33],[34].

LCA for MDVs and HDVs

The LCA for ICEV and EV MDVs and HDVs was performed using the GREET model. The model assumed the average annual vehicle miles traveled to be 25,000 miles across MDVs and HDVs, with an average lifetime of 12 years. As discussed above, the U.S. EIA's MDV and HDV fleet projections were utilized and Texas's share of the national fleet was assumed to be 8%, based on historical data from 2016 to 2020.

The GREET model classifies the emissions into well-to-pump, vehicle cycle, and vehicle operations emissions. The vehicle cycle emissions can be further categorized into emissions from fluids, batteries, vehicle assembly, disposal, and recycling and components. The model assumptions and input parameters outlined above yielded an emissions impact of 48 tCO_2 eq./year for ICEV and 18 tCO_2 eq./year for EV MDVs and HDVs. The emissions related to batteries and components for EVs, included in the vehicle cycle, are significantly larger than those associated with ICEVs.

Table 16. Materials in battery cells of a Chevrolet Bolt and their approximate cost per ton[13]. Data source: ICCT[23]

Material	Percent of battery cell mass	Cost per ton
Aluminum	16%	$1,600
Graphite	14%	$10,000
Steel	13%	$600
Iron	9%	$74
Copper	8%	$6,348
Cobalt	6%	$27,000
Nickel	6%	$10,000
Manganese	5%	$1,700
Lithium	2%	$15,000

Table 17. Potential reductions in emissions resulting from improvements in battery manufacturing and use. Data source: ICCT

Development	Percent change in battery manufacturing emissions	Percent change in lifecycle gCO_2eq/km
Larger electric vehicle battery	+33% to +66%	+18%
Battery second life	N/A	-22%
Battery recycling	-7% to -17%	-4%
Projected grid decarbonization	-17%	-27%
Greater battery energy density	-10% to -15%	-6%

Table 18. Materials in battery cells of a Chevrolet Bolt and their approximate cost per ton[13]. Data source: ICCT[23]

ICEV MDV and HDV	Btu/mile or g/mile			
	WTP	**Vehicle Cycle**	**Vehicle Operation**	**Total**
Total energy	3,657	1,342	20,016	25,014
Fossil fuels	3,539	1,117	20,016	24,672
Coal	159	421	0	580
Natural gas	2,448	491	0	2,939
Petroleum	933	205	20,016	21,154
Water consumption	0.45	0.26	0.00	0.71
CO2 (VOC, CO, CO2)	260	85.55	1,583	1,928
CH4	2.192	0.182	0.042	2.416
N2O	0.004	0.002	0.005	0.011
GHGs	327	93.776	1,585	2,006

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[13] Materials include 3% Polyester and 18% Other materials

Table 19. Summary of energy consumption and emissions of vehicle cycles: Btu or grams per mile from GREET model for EVs (M/HDVs)

EV MDV and HDV	Btu/mile or g/mile			
	WTP	Vehicle Cycle	Vehicle Operation	Total
Total energy	5,123	2,142	4,970	12,234
Fossil fuels	4,073	1,799	3,854	9,726
Coal	1,471	587	1,562	3,619
Natural gas	2,502	909	2,260	5,671
Petroleum	101	304	32	437
Water consumption	0.90	0.40	0.00	1.31
CO2 (VOC, CO, CO2)	598	137	0	735
CH4	1.31	0.29	0.00	1.61
N2O	0.01	0.003	0.00	0.01
GHGs	640	150	0	790

Infrasctructure Impacts

To quantify the costs associated with the charging infrastructure for LDVs, MDVs, and HDVs under all scenarios, we assumed that 70% of LDVs will be charged at home[14], while 30% of LDVs will require public and workplace charging infrastructure. It was assumed that all MDVs and HDVs will require DC charging. Further, based on analysis from the National Renewable Energy Laboratory[35], it was assumed that 36 non-residential L2 plugs are required per 1,000 vehicles, and 1.5 DCFC plugs are required per 1,000 vehicles, with 3.9 per DCFC station. We assumed 80% of LDVs use L2 chargers and 20% of LDVs and all MDVs and HDVs use DCFC chargers.

The infrastructure impacts were analyzed using the JOBS EVSE tool from the Argonne National Laboratory[36]. The economic impact analysis used input-output modeling (using RIMS II-based modeling) and estimates changes in employment, income, and economic output due to changes in expenditures. These effects can be calculated for a state and within a regional economy in a census division. The impacts quantified using JOBS EVSE include expenditures for electricity, network and data fees, operating and maintenance costs, administration costs, and potential revenues, access fees and indirect effects on the economy such as through local spending.

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[14] A conservative estimate of 70% charging at home and 30% charging at public spaces and workplaces was assumed to capture the impact of increased electrification of the LDV fleet. Current state and national trends indicate that about 80% of charging for LDVs are charged at home.

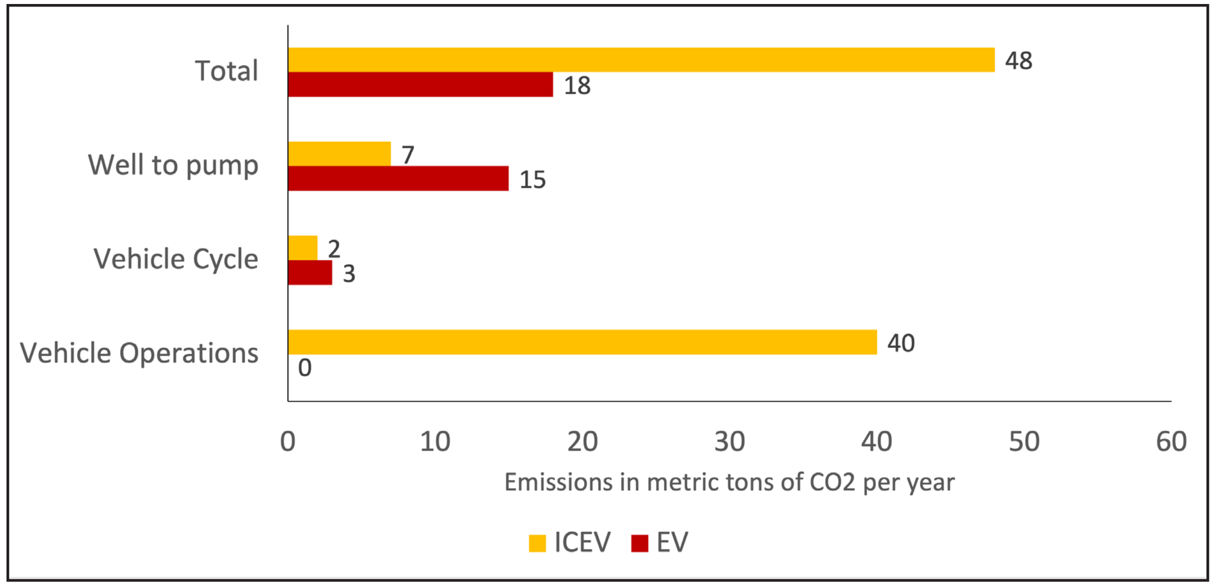


Figure 34. MDV and HDV lifecycle emissions in metric tons of CO_2eq emitted per year based on the GREET model. Data Source: GREET Argonne National Laboratory

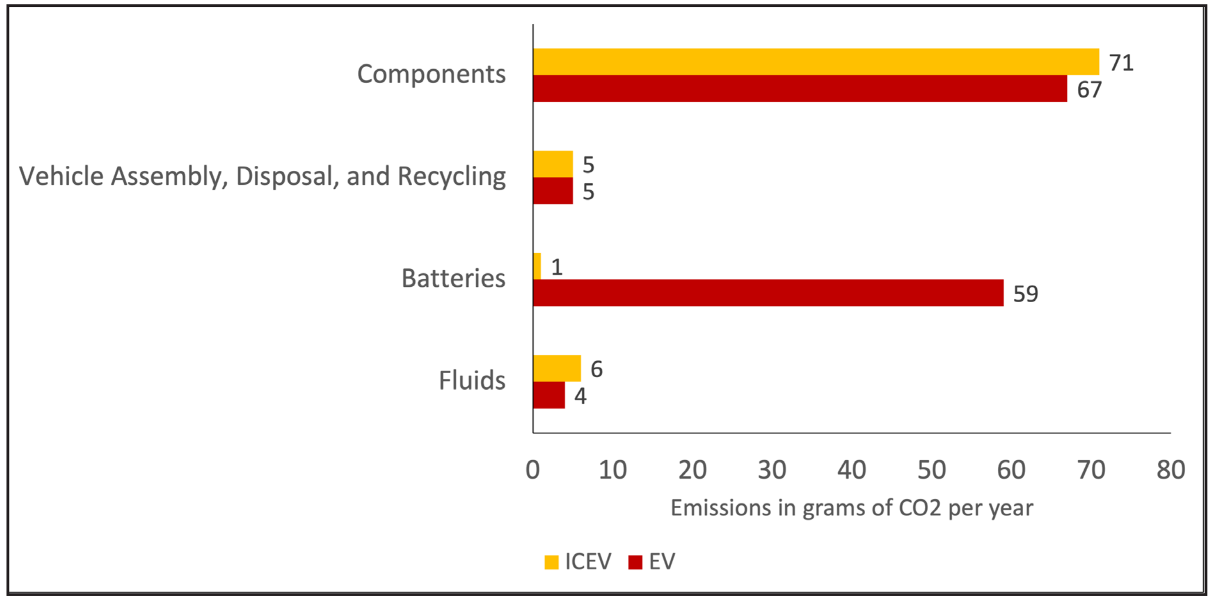


Figure 35. MDV and HDV Vehicle cycle emissions in grams of CO_2eq emitted per year based on the GREET model. Data Source: GREET Argonne National Laboratory

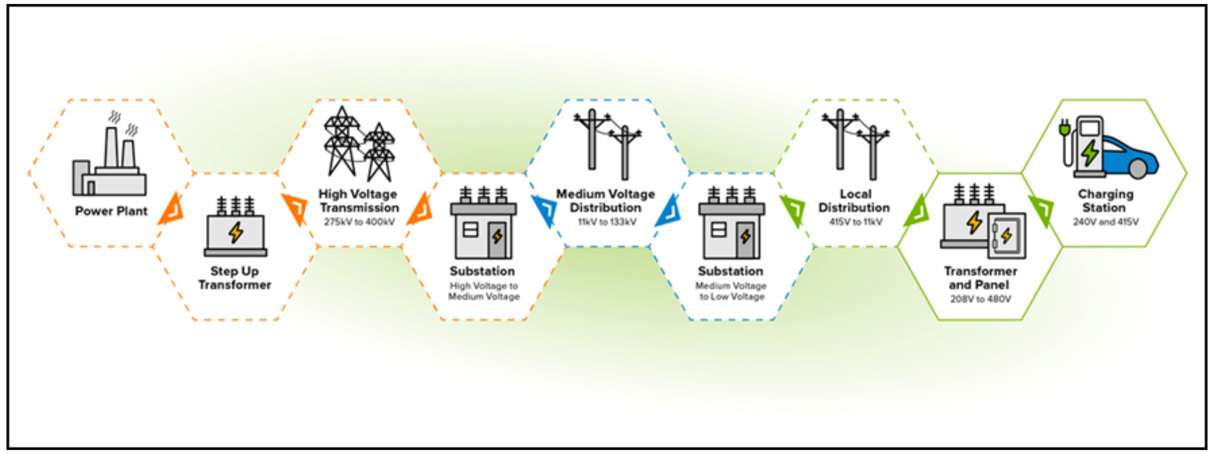


Figure 36. The EV infrastructure value chain considered in JOBS EVSE. Source: Argonne National Laboratory

JOBS EVSE calculates station development equipment expenditures as the sum of the equipment manufacturing, wholesale intermediaries, and shipping prices and includes any wholesale markups. The manufacturing price is the price paid to the manufacturer for the cost to produce the good and an adequate margin. The wholesale markup is the additional value added to a product by a distributor required to bring the product to market. Station development includes seven broad categories of major station equipment expenses. Site preparation expenses include all costs required to mobilize crew and construction equipment, grade the site, and develop basic utilities such as electricity and water needed for construction and installation. Engineering & Design expenses include fees for developing and refining detailed station designs.Installation includes labor and material costs associated with installing all major equipment at the construction site. Up-front permitting includes all costs associated with preparing and obtaining environmental, safety, and other required permits and approvals needed to begin construction. Contingency Expenses include additional unforeseen installation costs due to civil and electrical construction work.

Rail, Aviation, and Marine — Freight-related emissions

To model the emissions associated with freight movement in rail, aviation, and marine sectors, we used projections from the Oak Ridge National Laboratory's Freight Analysis Framework (FAF) projections. The framework integrates data from BTS and FHWA sources to create a comprehensive model of freight movement within and between states and major metropolitan areas by all modes of transportation. The 2017 Commodity Flow Survey (CFS) and international trade data from the U.S. Census Bureau are the basis of the model and are integrated with supplementary data that capture goods movement in agriculture, resource extraction, utility, construction, retail, services, and other sectors. The analysis includes freight moved within, to, and from Texas, to present a comprehensive evaluation of the emissions reduction opportunities in the rail, aviation, and marine sectors, if Texas, and other states, were to implement a cross-border adjustment for emissions for goods and services within or being transported to the state, or those that are transported out of the state. We modeled the emissions impact associated with freight movement based on the volume of freight transported annually via each mode in thousand tons and million ton-miles using the GREET model. Figure 38 presents historical data since 2000 and the FAF projections up to 2050. For all three modes, alternative fuel-mix scenarios were compared against the current baseline fuels assuming a transition scenario of 1% alternate fuel by 2030, 5% by 2025, 20% by 2030, 35% by 2035, 50% by 2040, 75% by 2045, and 100% by 2050.

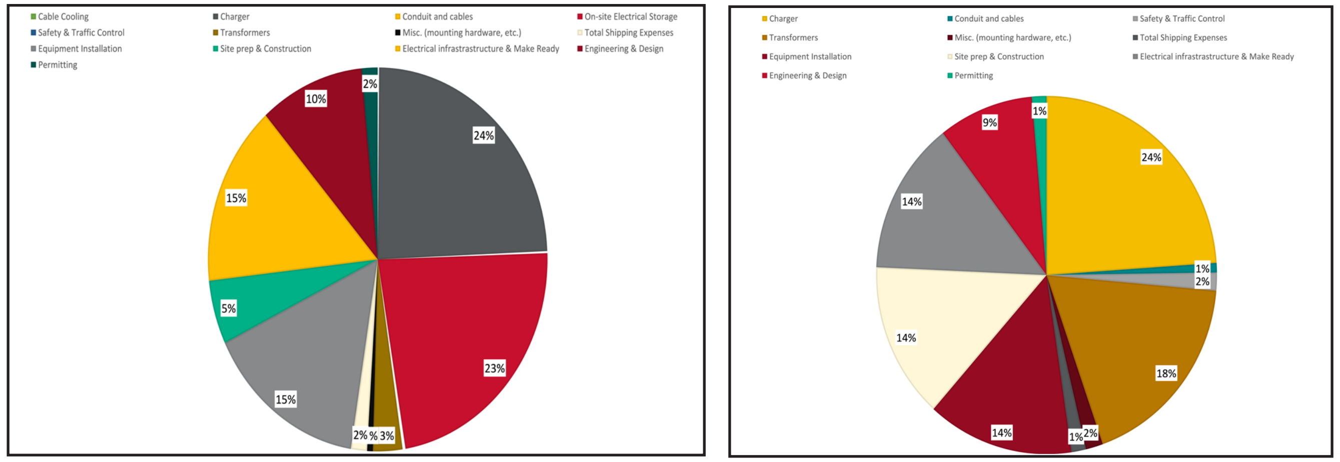


Figure 37. Station expenditure by category in %, for L2 (top) and DCFC 150 kW (bottom), based on the assumptions in JOBS EVSE

The emissions for rail freight were modeled based on five electrification scenarios for the Texas grid and compared against the baseline of continuing to use diesel fuel. The electrification scenarios are:

a. Business-as-usual

b. High End-use Electrification, Unconstrained Energy Supply

c. High End-use Electrification, Constrained Renewables and Storage

d. High End-use Electrification, Unconstrained Renewables and Storage

e. Low End-use Electrification, Constrained Energy Supply

The Business-as-usual scenario was based on the National Energy Modeling System used in the U.S. EIA's 2022 Energy Outlook scenarios. The remaining scenarios were growth scenarios relative to the business-as-usual. For the remaining scenarios, the capacity addition to the ERCOT grid was assumed to be the same as the base case, i.e., the business-as-usual case, up to 2025. From 2026 onwards, it was assumed that the capacity addition would change relative to the base case at the growth rate outlined below in Table 22. For example, renewables were assumed to grow annually at a rate of 2.7% in the "High End-Use Electrification, Unconstrained Energy Supply" scenario (case b), at 1.7% in the "High End-use Electrification, Constrained Renewables and Storage" scenario (case c), at 3% in the "High End-use Electrification, Unconstrained Renewables and Storage" scenario (case d), and at 0.7% in the "Low End-use Electrification, Constrained Energy Supply" scenario (case e).

As an example, the EIA predicts in its business-as-usual scenario that onshore wind would have a capacity of 36.9 GW in 2026. Based on the model described above, the onshore wind capacity is expected to be 37.9 GW (2.7% higher than Business-as-usual), 37.5 GW (1.7% higher), 38.0 GW (3% higher), and 37.2 GW (0.7% higher) for the four scenarios, cases b through e, respectively. Further, based on this model, coal's share of the grid declined under all scenarios and the decline rates were relative to the base case as presented in Table 23. Nuclear and hydropower capacity additions were the same across all scenarios and were assumed to be that of the base case. For new technologies that currently do not contribute to the ERCOT grid capacity and for CCUS and carbon dioxide removal (CDR) methods like direct air capture, we assumed that the state would incentivize deployment to reach a baseline capacity of 0.1 GW in 2025 (Figure 36) following which these new technologies could grow like how onshore wind has grown in Texas between 1999 and now (Figure 35).

For the development of infrastructure and adjacent industry development to support the above scenarios for electrification, we consider the significant government incentives, policies, and mandates like the production and investment tax credits, renewable portfolio standards, renewable energy credit trading program, and investment in Competitive Renewable Energy Zones (CREZ) and transmission infrastructure that have allowed onshore wind capacity additions to the grid to grow rapidly (Figure 35). We have assumed that the federal and state government will support, incentivize, and encourage the growth of pumped storage, hydrogen production, storage and use in fuel cells, solar thermal, offshore wind, CCUS, and CDR in a similar manner to achieve state and national decarbonization goals. These technologies follow the growth of onshore wind up to 2047 and have a 15% year-on-year growth up between 2047 and 2050, which is similar to the growth of wind in the last three years in the state. The growth rates were adjusted relative to the high growth rate case for wind, such that the Highest growth rate scenario was discounted at 3.0%, at -1.7% in the Medium to High growth scenario over the base case, at -2.0% for the Low to Medium growth scenario, at -2.3% in the Low growth scenario, and at -2.7% in the Lowest growth scenario. For example, pumped storage would increase from 0.1 GW in 2025 to 0.6 GW (497% growth, like the growth of onshore wind in 2000 in Texas) in 2026 under the High End-use Electrification, Unconstrained Energy Supply scenario where the growth of storage is high, to 0.6 GW in 2026 (~500% growth, discounted by 2.3%) in the High End-use Electrification, Constrained Renewables and storage scenario where the growth of storage is low. We consider the methodology for the implementation of the five scenarios described above for the deployment and growth of the infrastructure and adjacencies development.

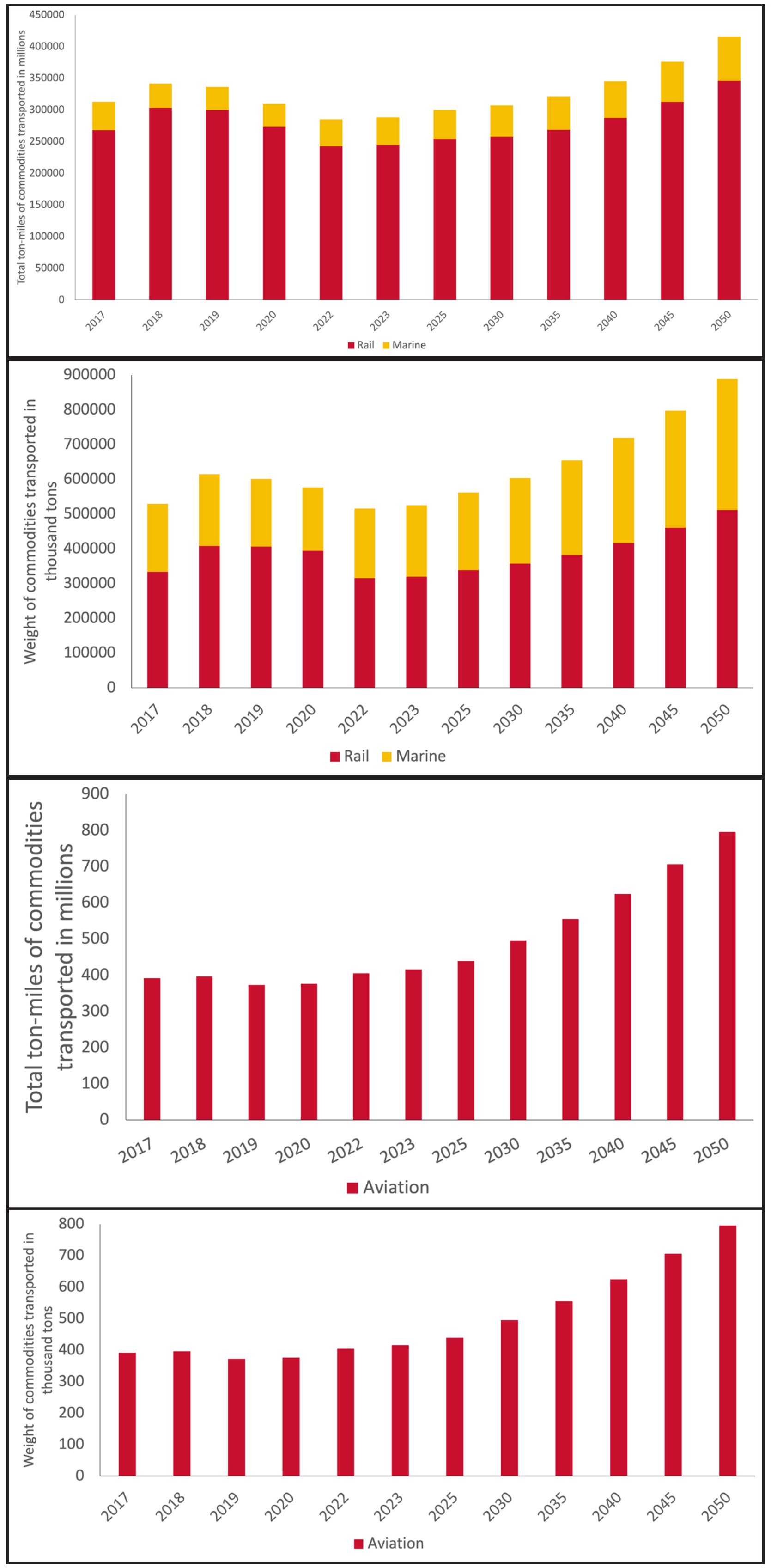


Figure 38. Volume of freight transported by rail, marine (first and second panel) and aviation (third and fourth panel) based on historical data since 2000 and future projections up to 2050. The left panel plots the weight of freight in thousand tons and the right in million ton-miles. The distance miles were estimated for the US domestic portion only. For foreign trade, all cutoff locations are at the border or coastal zones, except for aviation, where the cutoff location is the last airport where shipments leave for exports or the first airport where shipments arrive through imports.

Table 20. Technology penetration and energy supply scenarios, year-on-year growth rates relative to the Business-as-usual scenario of the U.S. EIA's 2022 Energy Outlook.

	Renewables	Storage	Liquid fuels	CCUS	CDR	Biomass	Hydrogen
High End-use Electrification, Unconstrained Energy Supply	High	High	Medium to High	Medium to High	Low to Medium	High	High
	2.7%	2.7%	2.3%	2.3%	1.7%	2.7%	2.7%
High End-use Electrification, Constrained Renewables and Storage	Low to Medium	Low	High	High	High	High	High
	1.7%	1.0%	2.7%	2.7%	2.7%	2.7%	2.7%
High End-use Electrification, Unconstrained Renewables and Storage	Highest	Highest	Low	Low	Low	Low	Low
	3.0%	3.0%	1.0%	1.0%	1.0%	1.0%	1.0%
Low End-use Electrification, Constrained Energy Supply	Lowest	Lowest	Highest	Highest	Highest	Medium to High	Medium to High
	0.7%	0.7%	3.0%	3.0%	3.0%	2.3%	2.3%

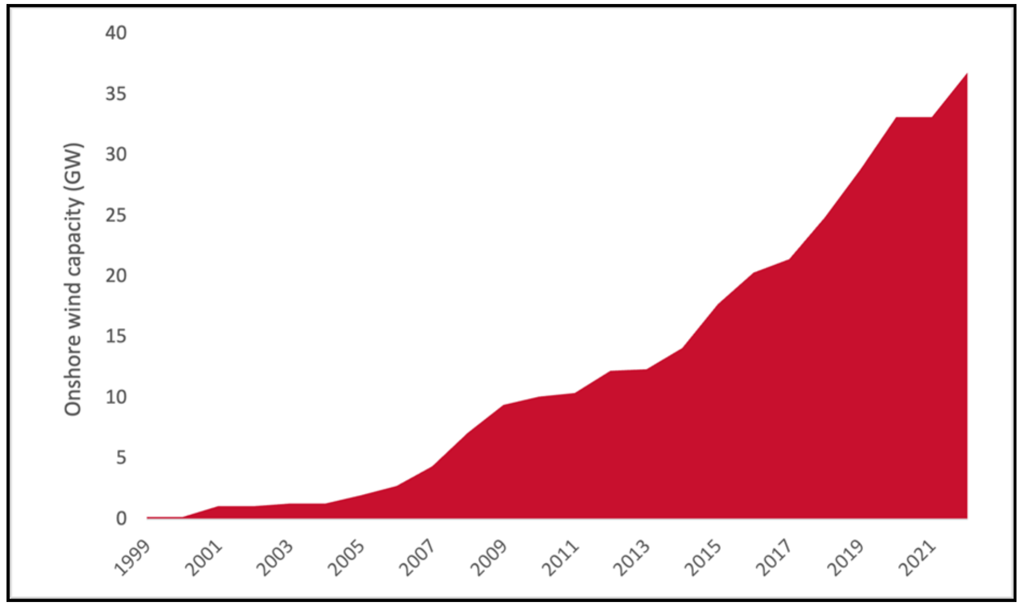


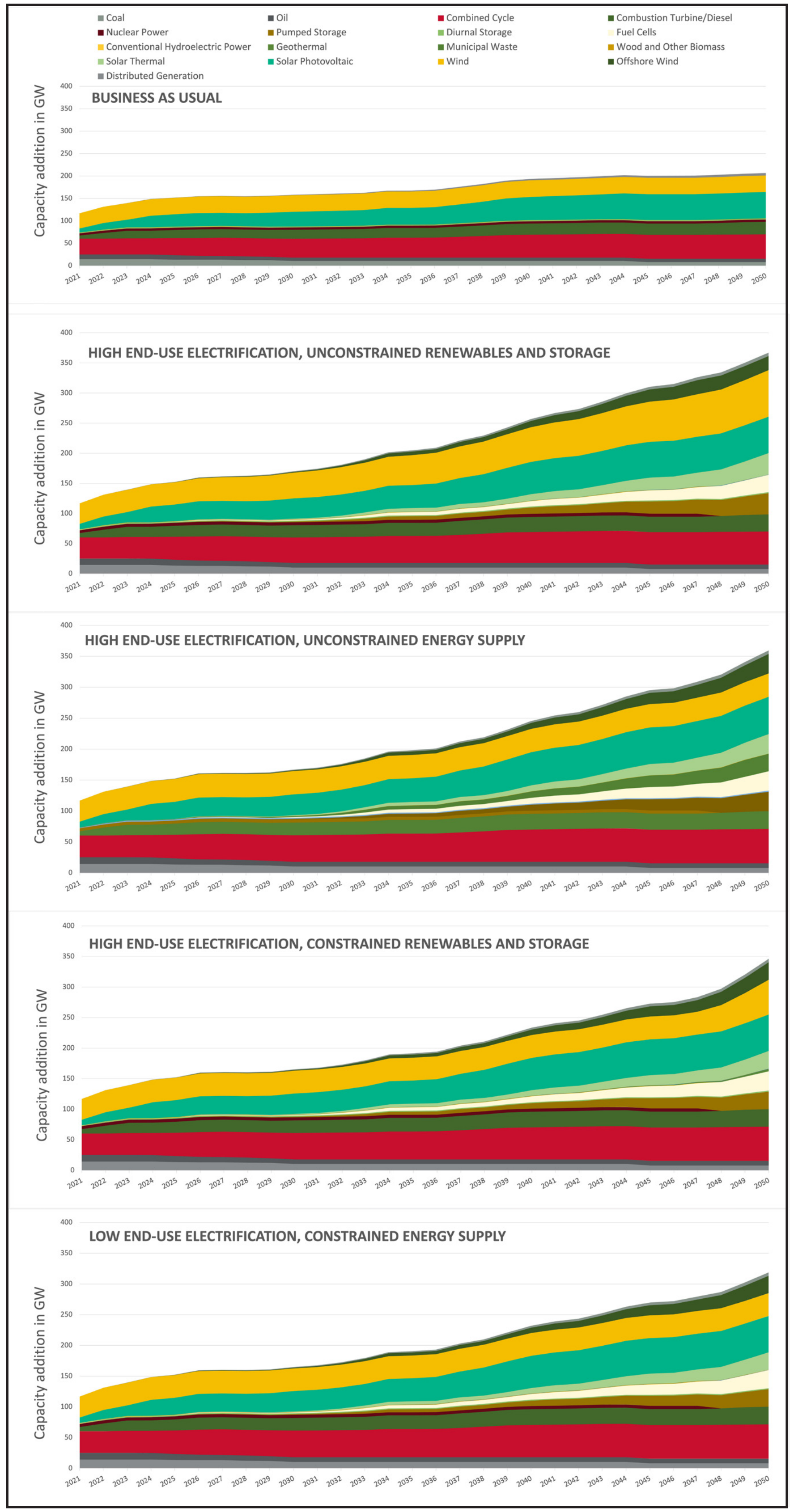
Figure 39. Capacity addition from onshore wind energy in Texas from 1999 to 2022. Data source: ERCOT.

Table 21. Assumed growth rates for different energy sources relative to the base case for existing technologies and relative to the growth rate for onshore wind in Texas for new technologies

	High End-use Electrification, Unconstrained Energy Supply	High End-use Electrification, Constrained Renewables and storage	High End-use Electrification, Unconstrained Renewables and storage	Low End-use Electrification, Constrained Energy Supply
Coal	-2.7%	-2.3%	-3.0%	-1.7%
Oil and Natural Gas Steam	2.3%	2.7%	1.0%	3.0%
Combined Cycle	2.3%	2.7%	1.0%	3.0%
Combustion Turbine/ Diesel	2.3%	2.7%	1.0%	3.0%
Nuclear Power	same as BAU	same as BAU	same as BAU	same as BAU
Pumped Storage	scenario adapted to wind base case	scenario adapted to wind + (-2.3%)	scenario adapted to wind + (3.0%)	scenario adapted to wind + (-2.7%)
Diurnal Storage	2.7%	1.0%	3.0%	0.7%
H2 Fuel Cells	scenario adapted to wind base case	scenario adapted to wind base case	scenario adapted to wind + (-2.3%)	scenario adapted to wind + (-1.7%)
Conventional Hydroelectric Power	same as BAU	same as BAU	same as BAU	same as BAU
Geothermal	2.7%	1.0%	3.0%	0.7%
Municipal Waste to Energy	2.7%	0.03%	1.0%	0.7%
Wood and Other Biomass	2.7%	2.7%	1.0%	0.7%
Solar Thermal	scenario adapted to wind base case	scenario adapted to wind + (2.0%)	scenario adapted to wind + (3.0%)	scenario adapted to wind + (-2.7%)
Solar Photovoltaic	2.7%	1.7%	3.0%	0.7%
Wind	2.7%	1.7%	3.0%	0.7%
Wind (Offshore)	scenario adapted to wind base case	scenario adapted to wind + (2.0%)	scenario adapted to wind + (3.0%)	scenario adapted to wind + (-2.7%)
Distributed Generation	2.7%	1.7%	3.0%	0.7%
CCUS	scenario adapted to wind + (-1.7%)	scenario adapted to wind base case	scenario adapted to wind + (-2.3%)	scenario adapted to wind + (3.0%)
CDR	scenario adapted to wind + (2.0%)	scenario adapted to wind base case	scenario adapted to wind + (-2.3%)	scenario adapted to wind + (3.0%)

The grid capacity additions based on these assumptions are presented in Figure 40

Figure 40. Business-usual electricity ERCOT grid based on the National Energy Modelling System for the 2022 EIA Energy Outlook (top), and grid scenarios High End-use Electrification, Unconstrained Energy Supply (middle left), High End-use Electrification, Constrained Renewables and Storage (middle right), High End-use Electrification, Unconstrained Renewables and Storage (bottom left), and Low End-use Electrification, Constrained Energy Supply (bottom right).



Lastly, the life cycle impacts of each energy source based on the IPCC's Technology-specific Cost and Performance Parameters were utilized to calculate the emissions impact of each of the scenarios. The life-cycle emissions impact, on a metric ton of CO2eq per GWh of electricity produced, is presented below.

For aviation freight emissions, we compared the emissions impact from fuel switching to FT Jet with North American natural gas as feedstock, Ultra Low Sulphur Jet (ULSJ), Hydro-processed Renewable Jet (HRJ), Ethanol to jet, and FT Jet with CO2 E-fuel as feedstock, relative to conventional jet fuel. For the marine freight emissions, we compared the emissions impact from fuel switching to Marine diesel oil with 1.92% sulfur (MDO), FT-Diesel from natural gas, Liquefied Natural Gas (LNG), Biodiesel, FT from electricity with H2 recycling relative to using Heavy fuel oil with 2.7% sulfur.

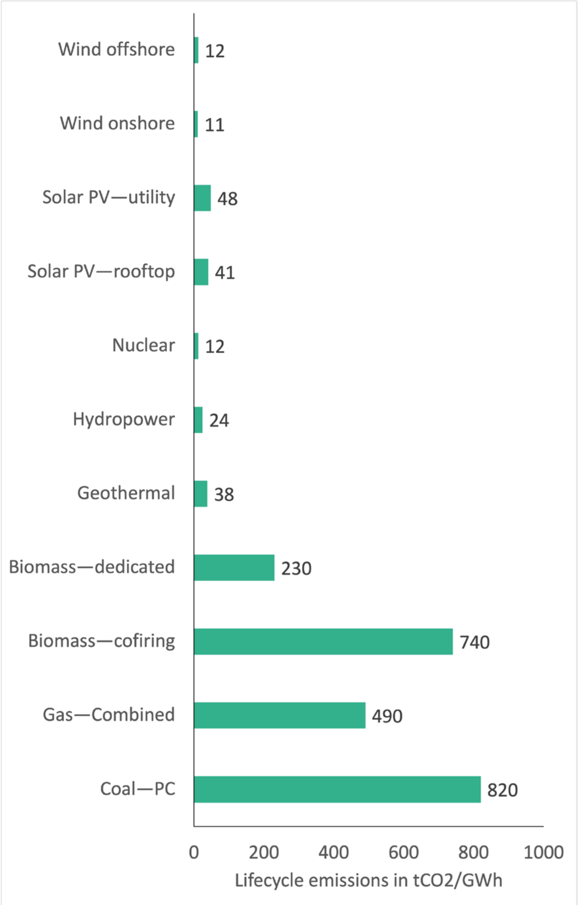


Figure 41. Median life-cycle emissions impact for energy supply sources in tCO2eq/ GWh. The cumulative emissions include direct emissions, infrastructure and supply chain emissions, wherever applicable, biogenic CO2 emissions and albedo effect, and methane emissions.

CHAPTER 7: RESULTS AND POLICY IMPLICATIONS

Here we detail the predictions of the model developed in this work and compare the implications for the transportation sector.

Key assumptions
LDVs: 15 years (±3 years); Annual average VMTs: 11,500 miles
MDVs and HDVs: 12 years (± 3 years); Annual average VMTs: 25,500 miles

On-road vehicles: Light Duty Vehicles

The number of LDVs in Texas would increase by more than 2.5 million vehicles between 2022 and 2050, assuming the vehicles have an average life of 15 years and 11,500 miles of average annual VMTs. The rate of growth is faster between now and 2030 at about 0.7% per year, then drops to between 0.40% and 0.45% between 2031 and 2040, and then remains at 0.30% till 2050.

The size of the LDV fleet will depend on retirements and new sales. The rate of retirement for an LDV that first became part of the fleet in 2022 will increase exponentially by 2037, peak, and then decline as the entire fleet retires.

Figure 45 presents the number of light-duty EVs and ICEVs on Texas roads under each policy scenario analyzed here. As presented in Figures 44 and 45, EVs in the fleet grow from 8% of the total in 2022 to about 63% in 2050 under the business-as-usual scenario, reaching 100% by 2070. EVs grow to 100% of the fleet in 2040 and 2050, respectively for the alternative scenarios. Simultaneously, by 2050, ICEVs will decline by 40% under the business-as-usual scenario, 71% for the 2050 scenario, and 92% for the 2040 scenario.

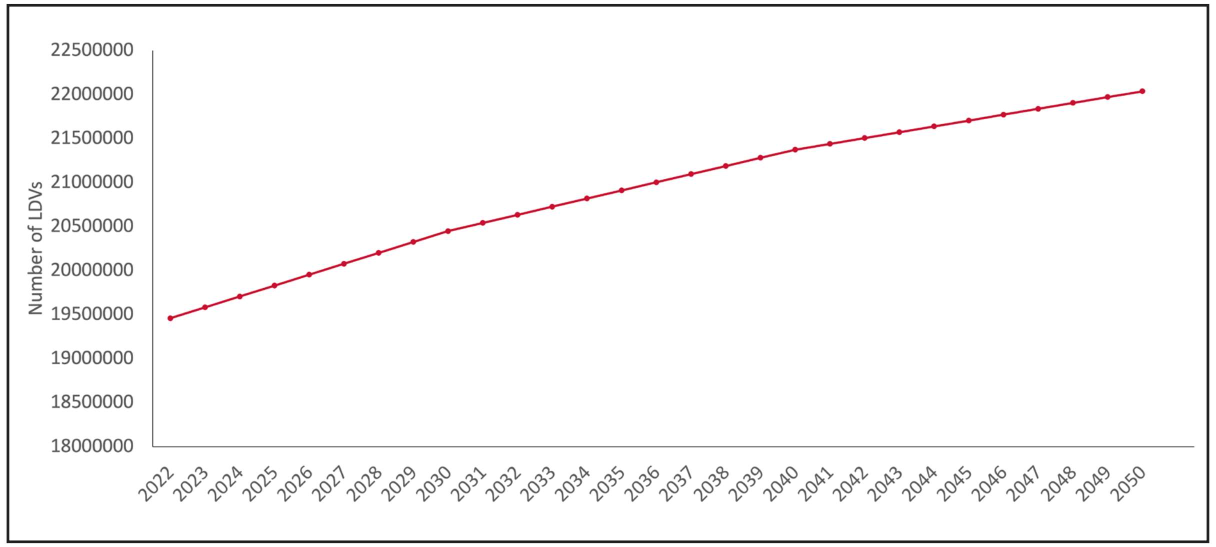


Figure 42. Projection of the number of light-duty vehicles in Texas based on regression model presented in Equation 1 from 2022-2050, assuming an average 15-year lifetime and 11,500 miles of average annual vehicle miles traveled (VMT).

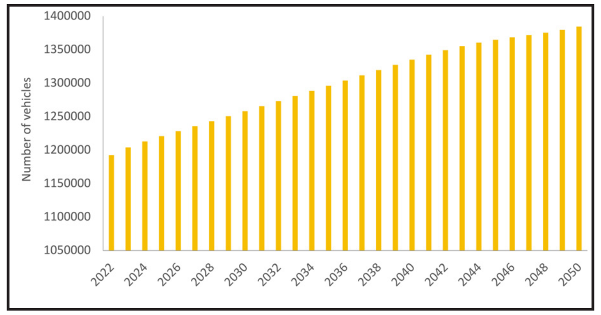


Figure 43. Annual retirement of LDVs between 2022 and 2050 assuming a 15-year lifetime (+/- 3 years).

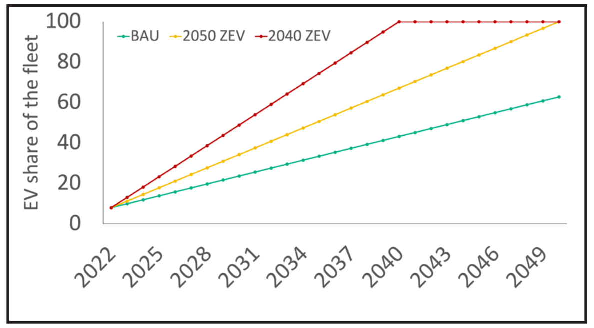


Figure 44. Share of EVs in the LDV fleet for the three policy scenarios in Texas.

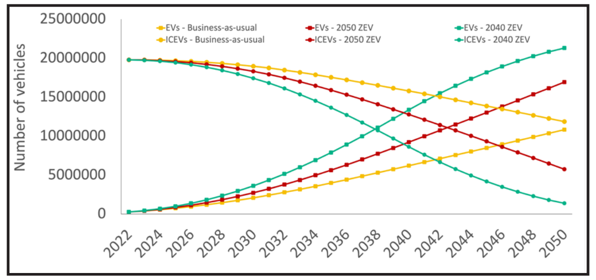


Figure 45. The total number of EVs and ICEVs (LDVs) on Texas roads for the three policy scenarios

Overall, the emissions impact from LDVs will decrease under all scenarios with greater deployment of EVs, even though the demand for more vehicles will grow along with the population. Under the business-as-usual scenario, LDV emissions will decline by 10%, from nearly 117 MMt CO_2eq in 2022 to 105 MMt CO2eq in 2050. Emissions decline by 25% to 88 MMt CO_2eq over the same time frame under the 2050 scenario and by 35% to 76 MMt CO_2eq under the 2040 scenario. Notably, if the electricity mix in Texas does not transition to a lower-carbon portfolio, even under the most aggressive targets for converting the transportation fleet to electric vehicles, cumulative emissions will drop only marginally. But with a lower-carbon electricity mix, the reductions in emissions could be as high as 68% for LDVs under the 2040 scenario (Figure 46b). As Figure 46b indicates, a lower-carbon electricity mix under the business-as-usual scenario will result in 27% emissions reduction, and 50% for the 2050 scenario.

Medium and Heavy Duty

The number of MDVs and HDVs in Texas would increase by more than 82,000 vehicles between 2022 and 2050, assuming the vehicles have an average life of 12 years and 25,500 miles of average annual VMTs. The rate of growth is faster between now and 2030, at about 0.6% per year, then drops to about 0.44% between 2031 and 2040, and then remains at about 0.30% till 2050. The growth up to 2030 is comparable to CAGR estimates for the freight and logistics market in Texas based on the impact of increasing population and demand and expected investment in logistics infrastructure to ease congestion[38].

The size of the MDV and HDV fleet will depend on the retirements and new sales. The rate of retirement for MDVs and HDVs that first became part of the fleet in 2022 will increase exponentially to 2034, peak, and then decline as the entire fleet retires.

Figure 50 presents the number of MDV and HDV EVs sold under each policy scenario analyzed here. As presented in Figures 46 and 47, EVs grow from about 1% of the M/HDV fleet in 2022 to about 52% in 2050 under the business-as-usual scenario, growing to 100% by 2070. EVs grow to 100% of the fleet in 2040 and

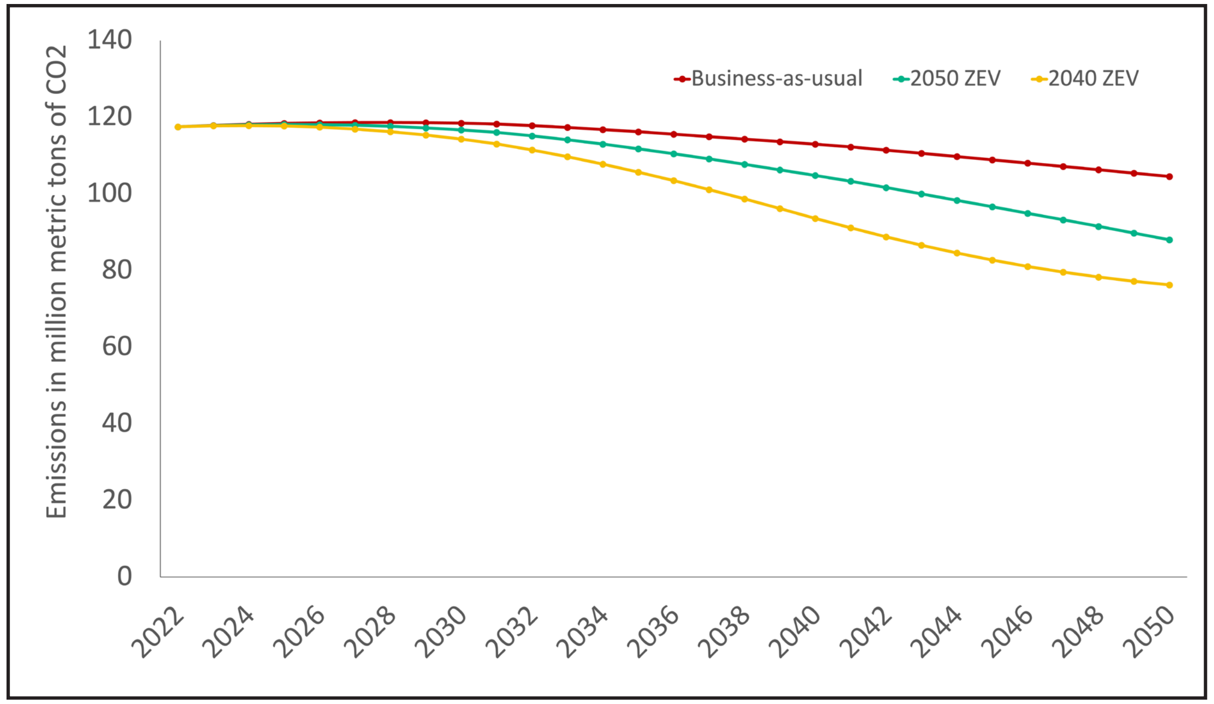


Figure 46a. The emissions impact of LDV fleet under the three policy scenarios for the current electricity mix in Texas.

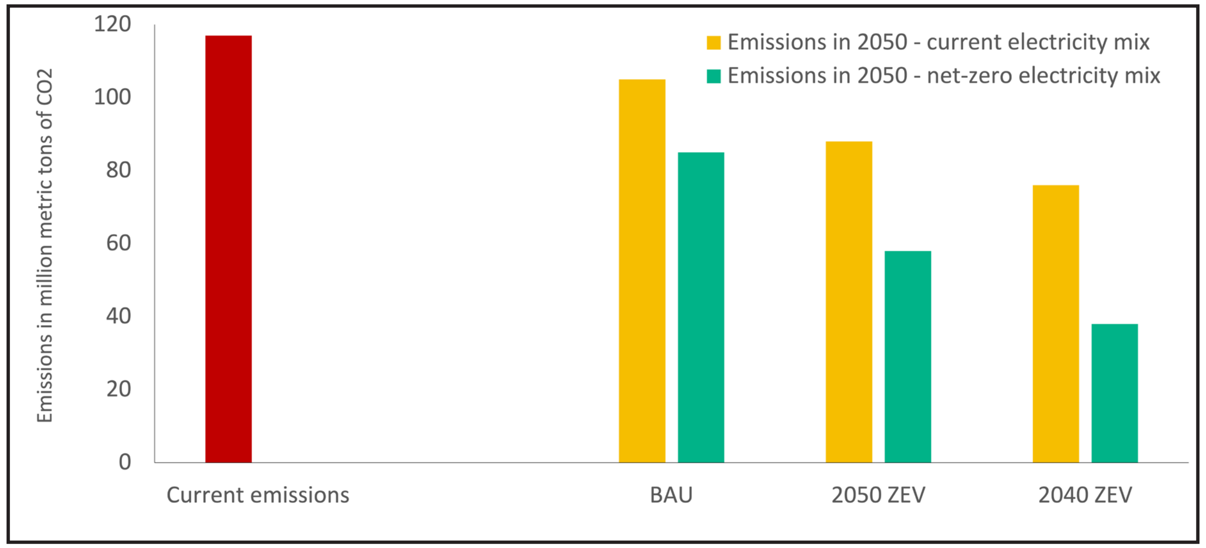


Figure 46b. Comparison of current emissions from the LDV fleet, the emissions impact under the three policy scenarios in 2050 for the current electricity mix in Texas, and if the mix is carbon-neutral by 2050.

2050 respectively for the alternative scenarios. Simultaneously, ICEVs in the M/HDV segment will decline by 27% under the business-as-usual scenario, by 63% for the 2050 scenario, and by 92% for the 2040 scenario.

Overall, the emissions impact from M/HDVs will decrease under all scenarios with greater deployment of EVs, even though the demand for these vehicles will grow with the population. Under the business-as-usual scenario, M/HDVs emissions will decline by 14%, from nearly 29 MMt CO2eq in 2022 to 25 MMt CO2eq in 2050. Emissions decline by 34%, to 19 MMt CO2eq, over the same time frame under the 2050 scenario and by 52%, to 14 MMt CO2eq, under the 2040 scenario. As with LDVs, if the electricity mix in Texas does not transition to a lower-carbon portfolio, even under the most aggressive targets for converting M/HDVs to electric vehicles, cumulative emissions will drop only marginally. But with a lower-carbon electricity mix, the reductions in emissions could be as high as 78% for M/HDVs under the 2040 scenario (Figure 51b). As Figure 51b indicates, a lower-carbon electricity mix under the business-as-usual scenario will result in 21% emissions reduction, and 52% for the 2050 scenario.

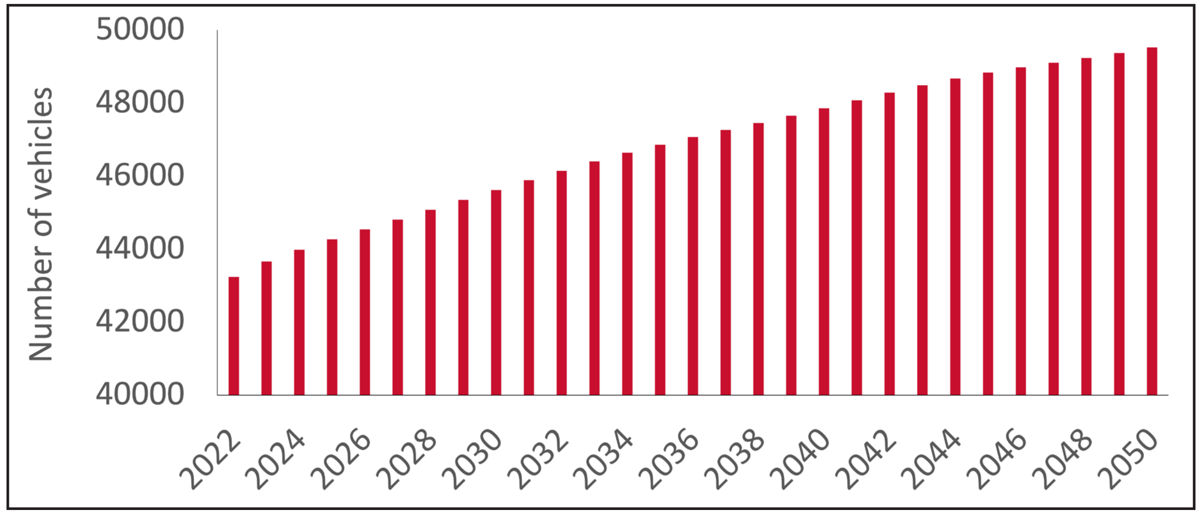


Figure 48. Cumulative retirement of MDVs and HDVs between 2022 and 2050 assuming a 12-year lifetime (+/- 3 years).

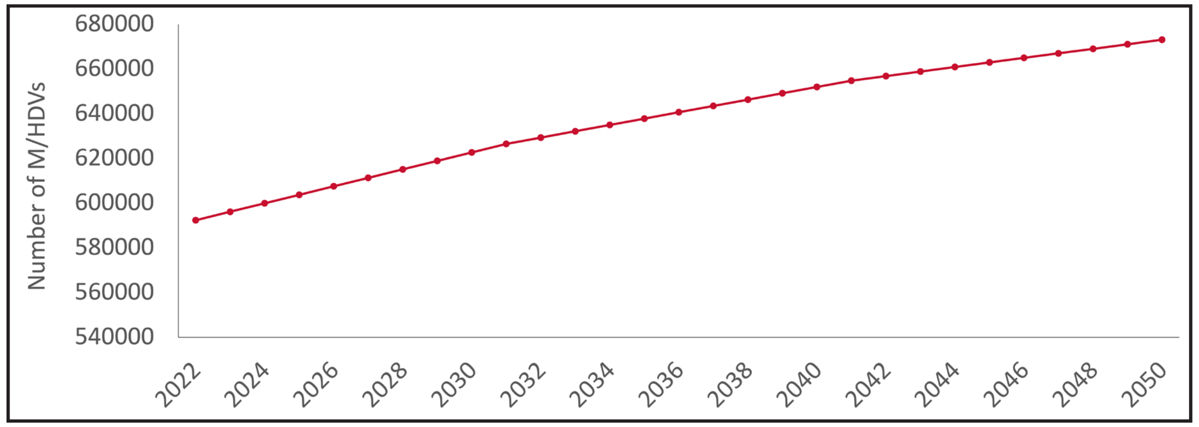


Figure 47. The number of medium and heavy-duty vehicles in Texas is based on the regression model presented in Equation 2 from 2022-2050, assuming an average 12-year lifetime and 25,000 miles of average annual VMT.

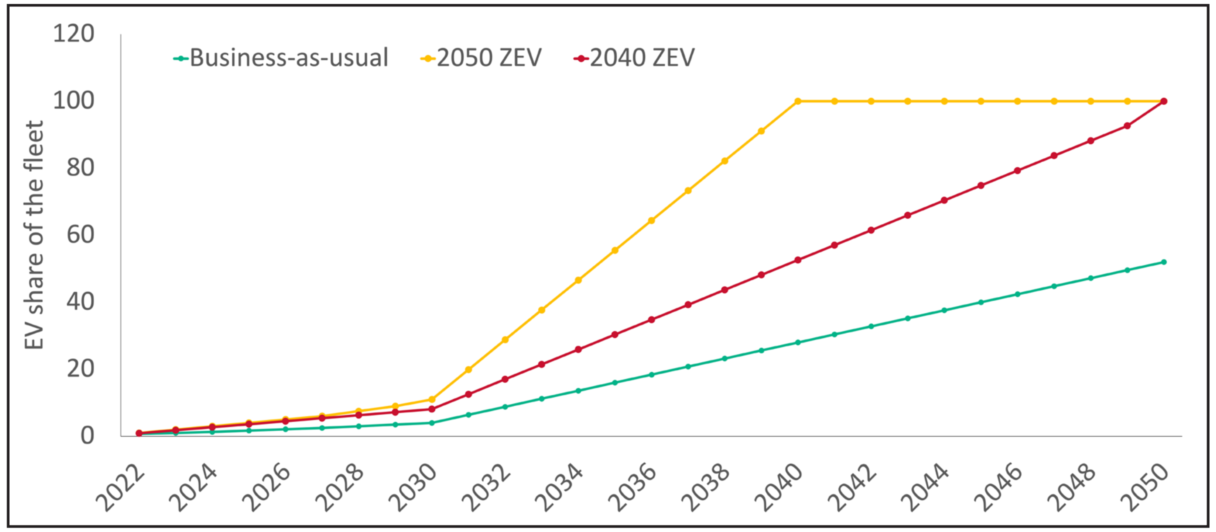


Figure 49. The share of EVs in the M/HDV fleet for the three policy scenarios in Texas.

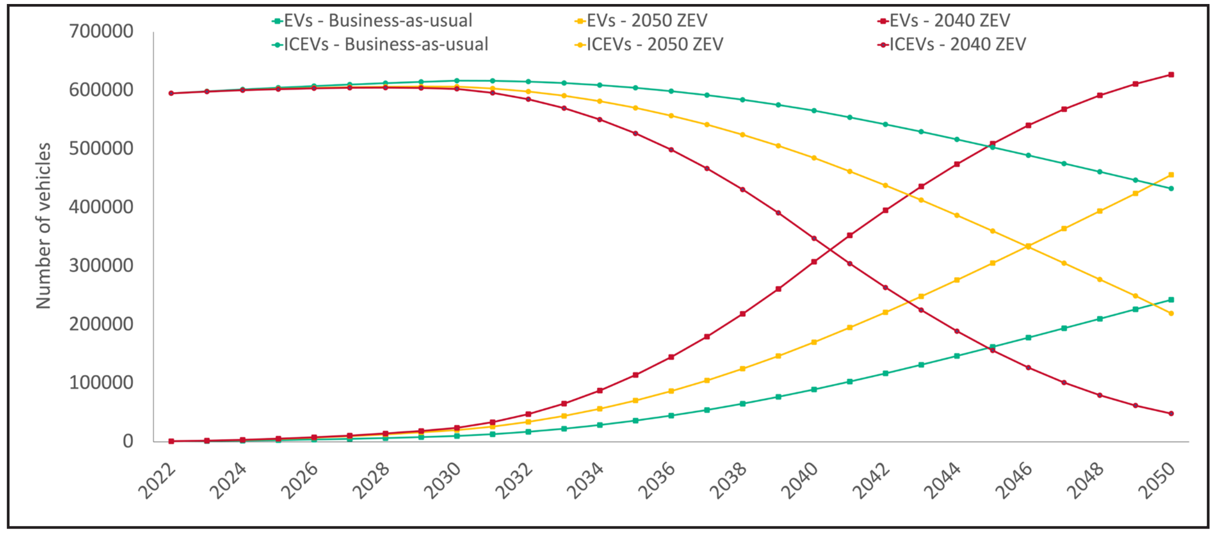


Figure 50. The number of new EVs and ICEVs (M/HDVs) sold for the three policy scenarios in Texas.

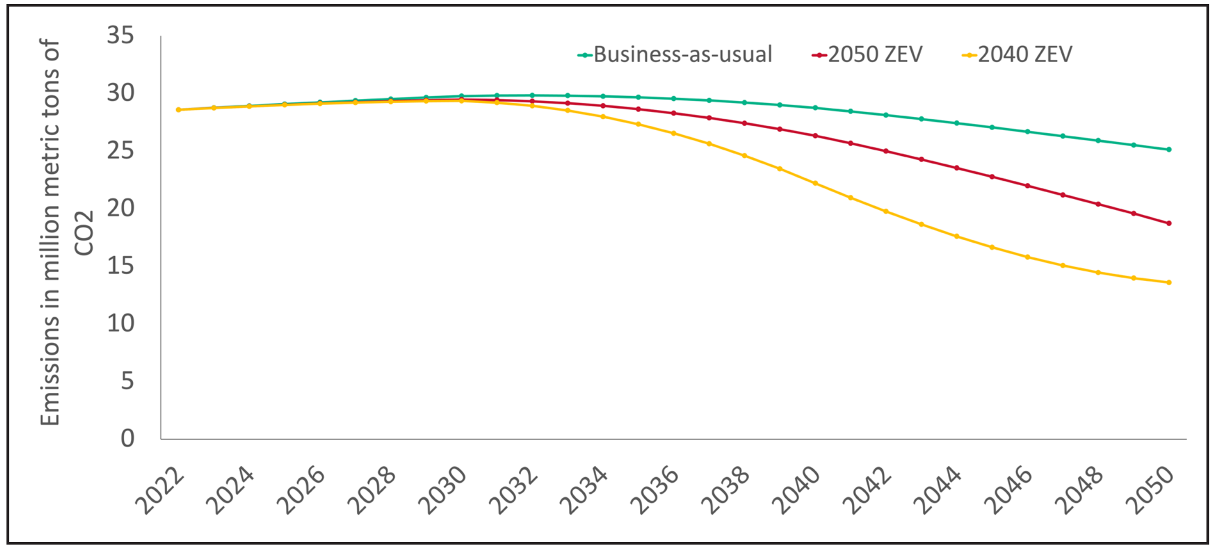


Figure 51a. The emissions impact of the M/HDV fleet under the three policy scenarios for the current electricity mix in Texas.

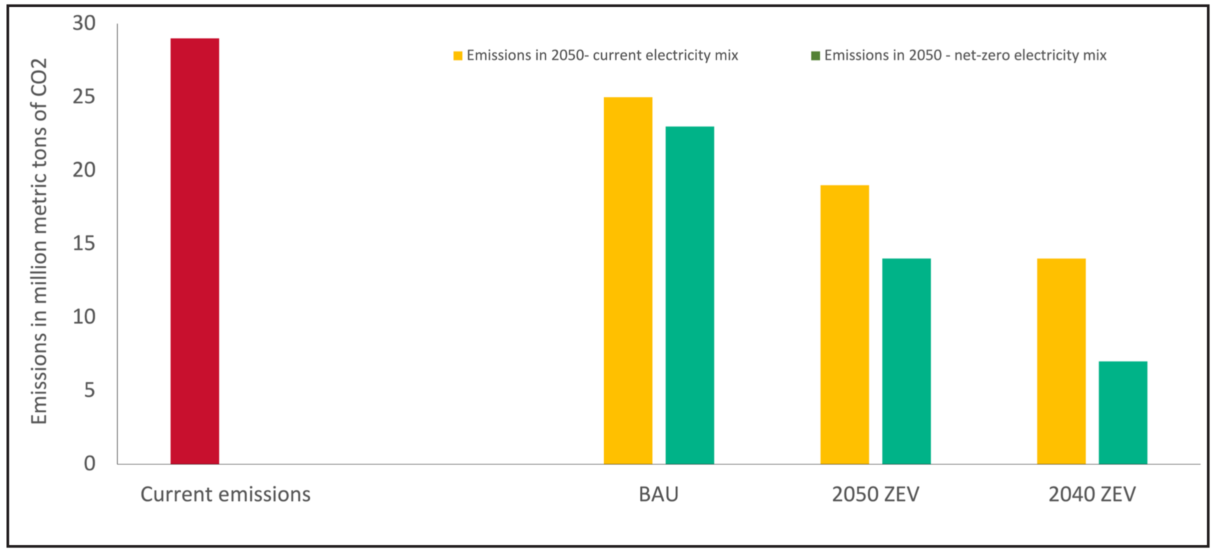


Figure 51b. Comparison of current emissions from M/HDV fleet, the emissions impact under the three policy scenarios in 2050 for the current electricity mix in Texas, and if the mix is carbon-neutral by 2050.

Infrasctructure Impacts

Under the assumptions of our analysis, the number of stations with Level 2 (L2) and DCFC chargers grow nearly 8-fold between 2022 and 2050 under the business-as-usual scenario. In contrast, they grow more than 13-fold under the 2050 scenario and more than 14-fold under the 2040 scenario (Figures 52 and 53).

The total per-station development expense, including pre-construction development, construction, installation, equipment, and shipping expenses, is about $61,000 for L2 charging stations and about $1.1 million for DCFC chargers (150 kW)[15]. However, this does not include land costs. Figures 54 (L2) and 55 (DCFC) present the total station development expenditure for the three scenarios.

Chargers and transformers make up the dominant expenditure categories for L2 stations and would cost $14,700 and $11,220, respectively, per station. For DCFC stations, chargers and on-site electrical storage would cost the most at $263,400 and $249,600, respectively, per station[16]. The job and socioeconomic impact of developing and operating these stations, and the spillover impacts in electricity, advertising, retail, data and networking, and maintenance industries are discussed in the next chapter.

Additionally, Texas currently has one gas station for nearly every 1,800 on-road vehicles (across all weight segments). The retirement and replacement of the ICEV fleet will be accompanied by the closure of gas stations and remediation costs, as discussed in Chapter 3. Under the assumptions of this study and at a mean cost of $474,200 per station, remediation costs will range from $125 million-$270 million in 2050 (in 2022 $).

The current on-road fleet (across all weight segments) contributed $320 million in fuel taxes to state revenue for the month of August 2022, and is representative of the impact fuel taxes play on overall revenues of the state. Assuming the same tax structure until 2050, the retirement and replacement of ICEVs will result in an annual loss of fuel taxes of the order of $46 million in 2050 under the business-as-usual-scenario, $71 million for the 2050 scenario, and $100 million for the 2040 scenario.

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[15] The per station cost for 50 kW DCFC charging stations is about $390,000.

[16] The chargers and on-site electrical storage would cost $83,700 and $83,200, respectively for 50 kW DCFC charging stations.

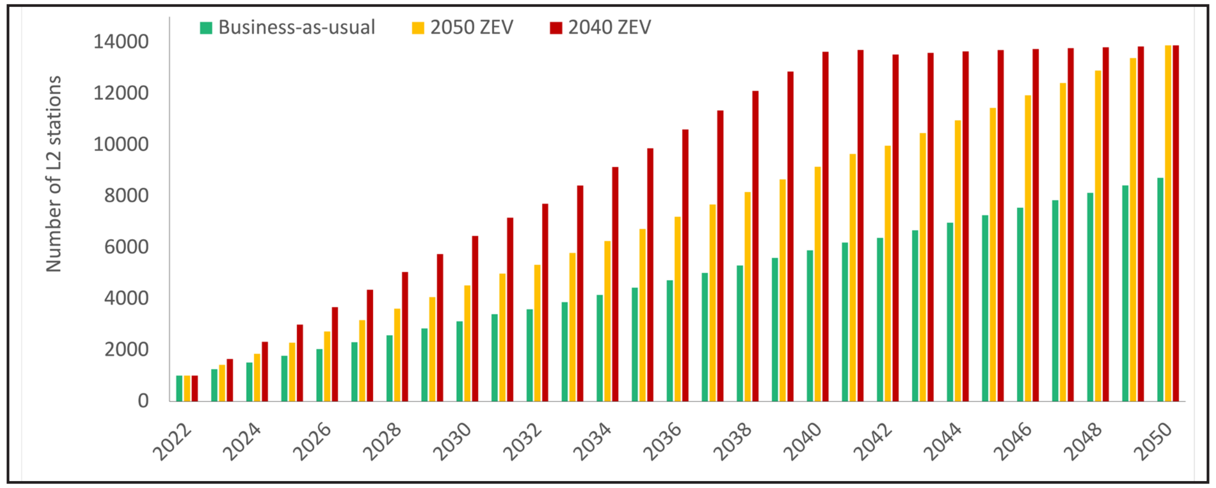

Figure 52. Number of L2 charging stations under the three policy scenarios.

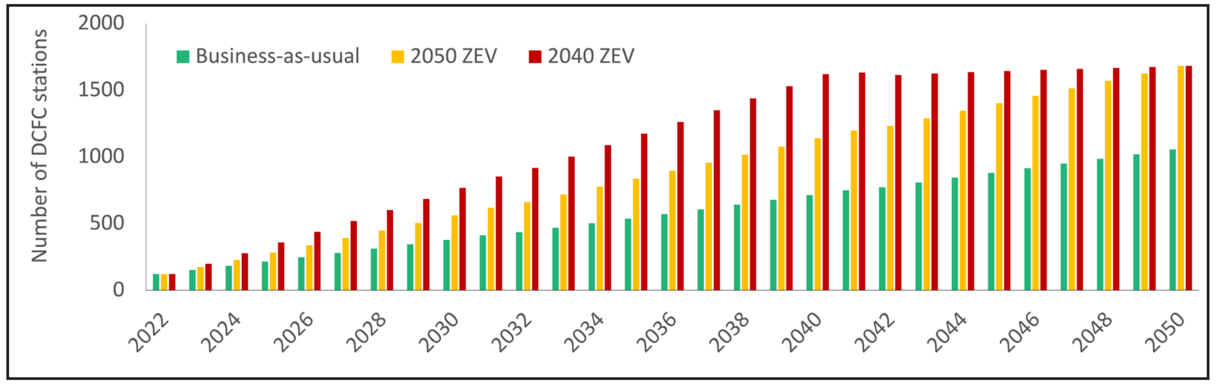

Figure 53. Number of DCFC charging stations under the three policy scenarios.

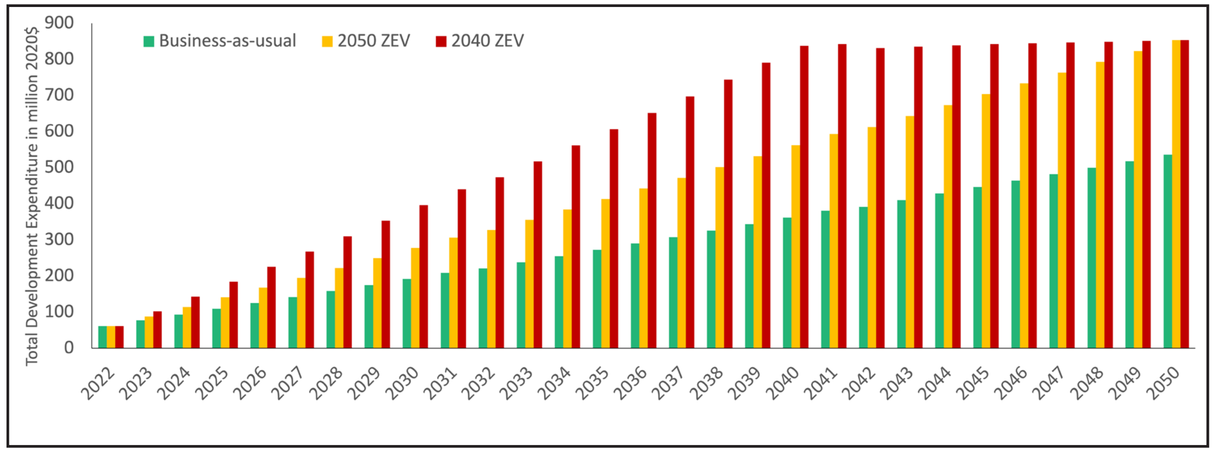

Figure 54. Annual total station development expenditure for L2 chargers under the three policy scenarios.

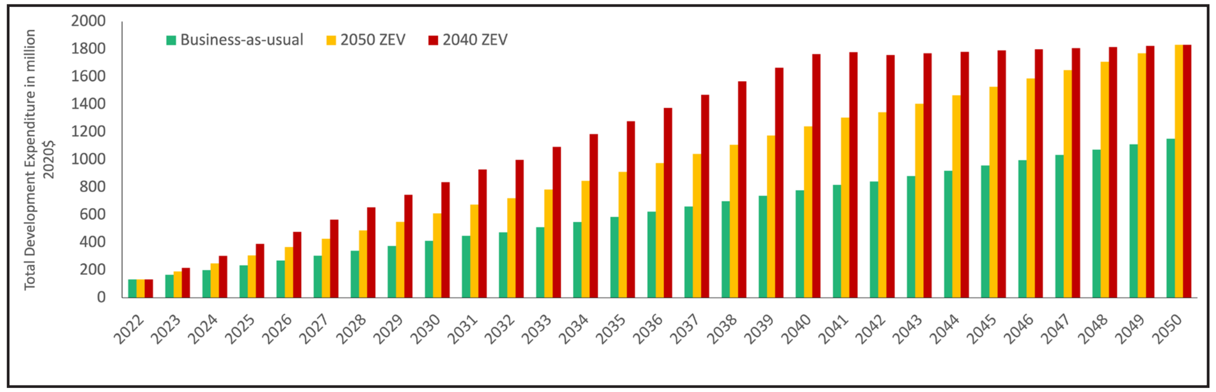

Figure 55. Annual total station development expenditure for DCFC chargers under the three policy scenarios

Table 23. Cumulative station expenditure by category for L2 and DCFC stations

Category		Expenditures	
		L2	DCFC
Equipment	Cable Cooling	$0	$1,500
	Charger	$14,700	$263,400
	Conduit and cables	$525	$1,875
	On-site Electrical Storage	$0	$249,600
	Safety & Traffic Control	$1,000	$3,000
	Switchgear/Panels	$0	$0
	Transformers	$11,220	$30,485
Shipping	Misc. (mounting hardware, etc.)	$1,000	$6,000
	Total Shipping Expenses	$853	$16,676
Other	Equipment Installation	$8,533	$166,758
	Site prep & Construction	$8,702	$58,807
	Electrical infrastructure and make-ready	$8,533	$166,758
	Engineering & Design	$5,547	$108,393
	Permitting	$853	$16,676
Total Per Station Expenditures		$61,467	$1,089,927

TOTAL COSTS FROM STATION DEVELOPMENT, REMEDIATION AND LOSSES IN FUEL TAX

BUSINESS-AS-USUAL: $27 billion
2050 ZEV: $45 billion
2040 ZEV: $49 billion

Rail, aviation, and freight emissions
Rail freight emissions are based on the Freight Analysis Framework's projections of the volume of freight that will be transported via railways within, to, and from Texas up to 2050. Ton-miles are based on the average weighted distance of shipments and are estimated for the U.S. domestic portion only. As discussed in Chapter 6, for foreign trades, all cut-off locations are at the border or coastal zones, except for those involving aviation. The cut-off location for air is the last airport where shipments leave the U.S. for exports or the first airport where shipments arrive in the U.S. for imports. Therefore, these emissions consider the impact of transporting freight to and from Texas to account for the border adjustments that must be made if Texas adopts such a policy.

Emissions (well-to-wheel) from rail transportation of freight increase by 46%, from about 6 MMt CO_2eq to 8.7 MMt CO_2eq in 2050, if the use of diesel continues. In contrast, emissions decrease in all electrification scenarios, despite the increase in freight transportation by rail. These decreases range from 3% to 94% as compared to 2022 emissions, with the highest potential for reduction from the sector to 0.4 MMt CO_2eq under the scenario of High End-use Electrification, Unconstrained Renewables and Storage.

Emissions (well-to-wake) from aviation freight transportation increase by 89%, from about 164193 tCO_2eq to about 311036 tCO_2eq in 2050, if the use of diesel continues. Emissions also increase for FT diesel with natural gas (116% increase), Ultra Low Sulphur Jet (91% increase), and Ethanol to jet fuel (16%) increase, when accounting for the increase in freight transportation volume between now and 2050. However, Hydro-processed Renewable Jet (HRJ) presents an opportunity to nearly halve emissions by 2050, despite the increase in freight volume (a 43% decrease, while carbon-neutral FT jet e-fuels reduce emissions by 99.9% and result in an emissions impact of 80 CO_2eq in 2050.)

Emissions (well-to-hull) from marine transportation of freight increase by 65%, from about 0.25 MMt CO2eq to about 0.42 MMt CO_2eq in 2050, if the use of HFO continues. Emissions also increase for MDO (57% increase), FT diesel (75% increase), and LNG (13%) when accounting for the increase in freight transportation volume between now and 2050. However, biodiesels present the opportunity to cut emissions by more than half by 2050 despite the increase in freight volume (64% decrease), while eFT with hydrogen recycling can reduce emissions by 99% and result in an emissions impact of 1803 tCO_2eq in 2050.

Policy Implications
Based on the results presented in this chapter, several key policy implications arise that can be addressed as legislative priorities are discussed below. These pertain to the emissions reduction potential for the transportation sector, available technologies for decarbonization, and the gaps and bottlenecks that need to be addressed through legislative prioritization.

The analysis assumed that three policy scenarios can unfold in Texas to address transportation sector emissions. The business-as-usual scenario

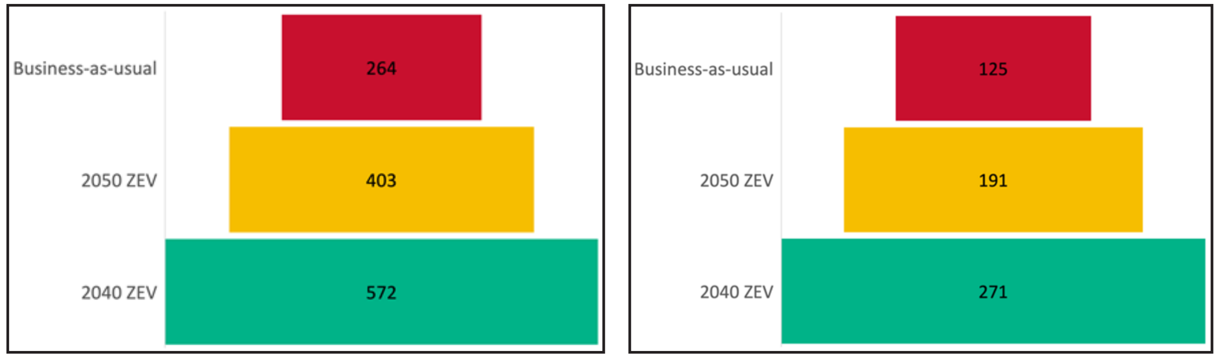

Figure 56. The number of gas stations that are likely to close in 2050 (left) and the associated remediation costs (right), in million dollars, under the three policy scenarios.

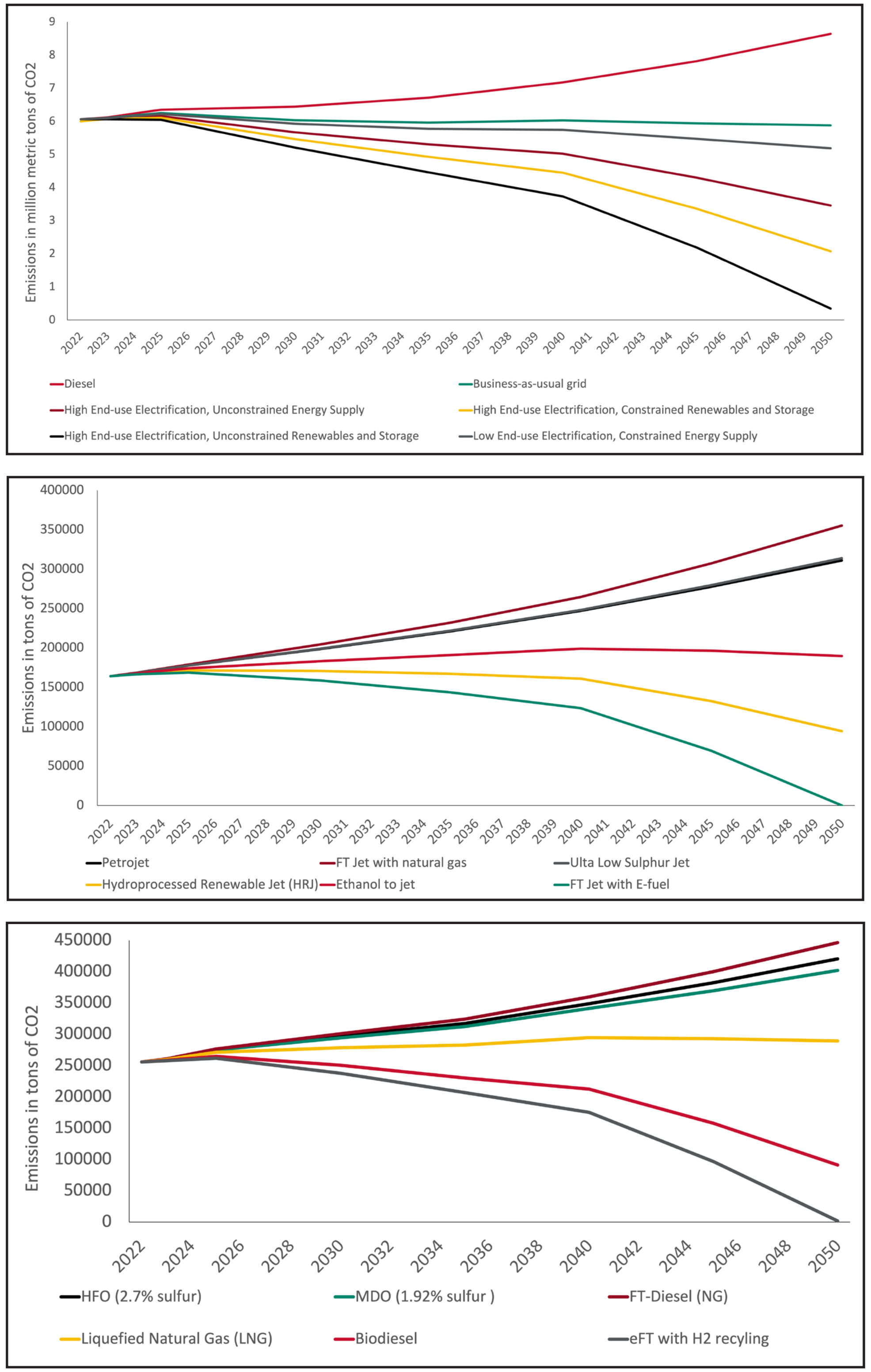

Figure 57. Rail freight emissions (top), in MMt CO$_2$, Aviation freight emissions (middle), in tons of CO$_2$, and Marine freight emissions (bottom), in tons CO$_2$, based on the Freight Analysis Framework's projections of the volume of freight that will be transported via airplanes within, to, and from Texas up to 2050.

assumes status quo investments and policies will continue, with no deviation from the current state of affairs. For on-road vehicles, two alternative policy scenarios were evaluated requiring that all new sales in the LDV, MDV and HDV segments be of zero-emission vehicles by 2040 and 2050, respectively. Results indicate that with the most aggressive decarbonization policy target, emissions from on-road vehicles will decline by about 35% for LDVs and 52% for M/HDVs. Meanwhile, emissions declined by 25% over the same time frame under the 2050 scenario for LDVs and 34% for M/HDVs. Under the business-as-usual scenario, emissions will only decrease about 10% for LDVs and 27% for M/HDVs. However, if the electricity mix in Texas is net zero by 2050, transportation sector emissions will drop by 27% under the business-as-usual scenario, 50% under the 2050 scenario, and 68% under the 2040 scenario for LDVS, and 21% compared to current emissions under the business-as-usual scenario, 52% for the 2050 scenario, and 76% for the 2040 scenario for M/HDVs.

Based on the life-cycle impacts presented in Chapter 6, most of these remaining emissions will be from vehicle operations and will be non-stationary. Hence, these emissions must be abated through technologies like direct air capture (DAC). The country's first large-scale DAC plant that will capture 1 MMt CO$_2$eq is expected to come online in the Permian Basin in 2024. The state would need 160 such plants to mitigate the emissions impact of on-road vehicles. The current cost of DAC ranges from $225-$600[39] per tCO$_2$ captured, with projections that indicate the cost could be reduced to $125 per tCO2 by 2030 based on technology choice and accelerated investments[40].

Second, the results of our study indicate the state can meet the targets for EVs under both the 2040 and 2050 policy scenarios, but at a cost of billions of dollars each year in required investments by 2050. An even more aggressive policy target could require early retirement for older LDVs, and M/HDVs as compared to the current average of 15 years and 12 years, respectively. The AirCheck program in Texas was aimed at getting older and more-polluting cars off the road, providing $3,000 to $3,500 for any running vehicle that was 10 years or older or had failed an emissions test. The program ended in 2021. Some states have recently introduced voluntary early vehicle retirement programs based on the 2009 federal Cash for Clunkers program, which was intended to boost auto sales. While some analyses have indicated the program did not have a long-term impact on car sales, a Congressional Research Service[41] analysis found the program saved about 33 million gallons of gasoline per year and reduced emissions by about 380,000 tCO$_2$ per year. NHTSA estimates indicated the fuel savings and emissions reduction would lead to long-term cumulative benefits[17] of $1.5 billion - $3 billion up to 2034.

The life-cycle impacts presented here are sensitive to the assumptions of the study. Even though widely accepted methodologies and tools were used for the LCA, end-of-life emissions are likely undercounted. The gap in our current understanding can be attributed to two key limitations of LCAs. First, we do not have an accurate understanding of the end-of-life, second life, recycling, and reprocessing impacts of electric batteries, including emissions, land use, water consumption, and toxicity. The second limitation arises from the varying methods and systems boundaries that can be used in

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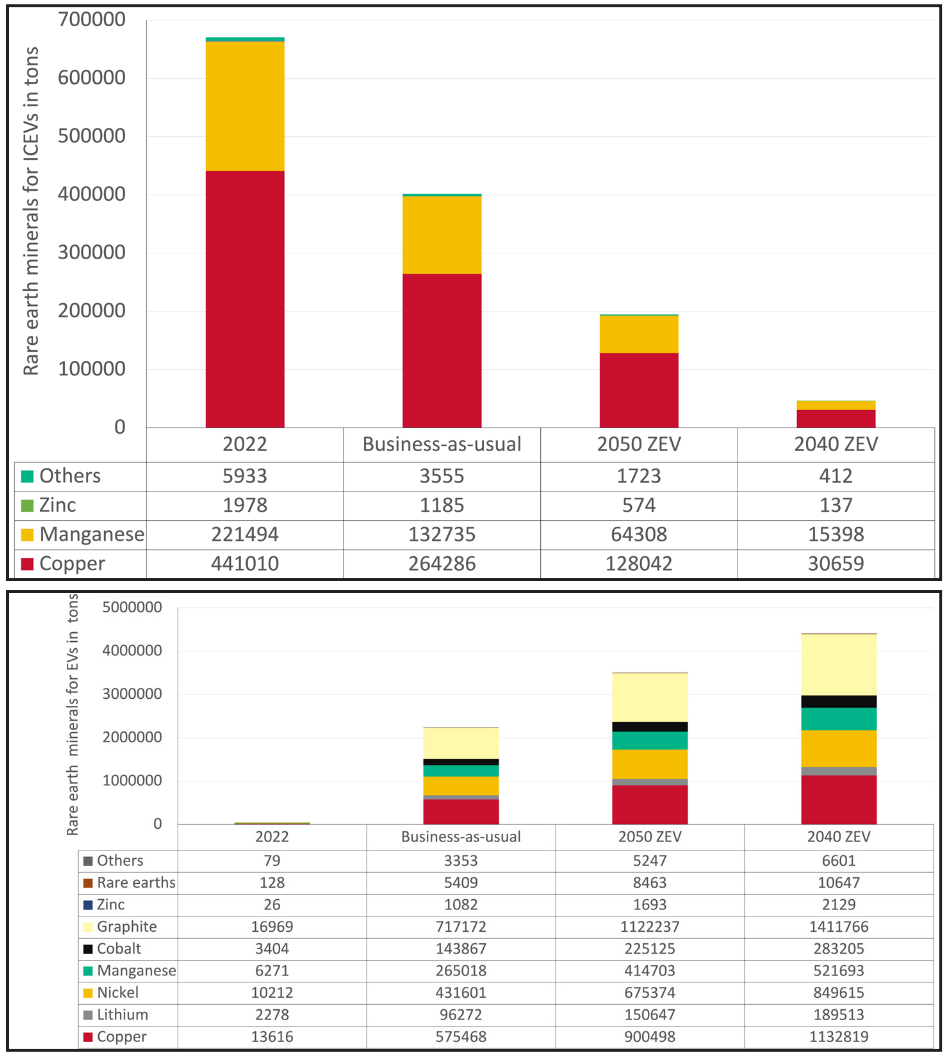
[17] The estimates assumed a mid-range $20 per tCO$_2$ as the social cost of carbon.

LCAs and the sensitivity of the results to these assumptions. Most notably, the results reported here are based on the GREET model's assumption that critical minerals used in electric batteries are available in U.S. markets. This assumption does not account for the impacts associated with mining, processing, procuring, and transporting these minerals from other countries, even though the U.S. relies on imports of foreign materials to support electrification of the transportation fleet. In the last quarter of 2021, imports of electric batteries totaled 103,889 metric tons, which was nearly 130% more than the last quarter of 2020 and 25% from the second quarter of 2021[42]. Location and scenario-specific LCAs are critical to understanding the cradle-to-grave impacts of battery manufacturing, materials processing, sourcing, and recycling, and the sensitivity to changes in the grid. By 2050, under the assumptions of this study and the IEA analysis of minerals used in electric vehicles compared to ICEVs, presented in Figure 34, the demand for critical minerals for EVs will increase by more than 4100%, 6500%, and 8200%, respectively, for the business-as-usual, 2050, and 2040 scenarios (Figure 59). In comparison, for ICEVs, the demand for copper, manganese, and other critical minerals will drop by 40% under the business-as-usual scenario, and by 71% and 93% for the 2050 and 2040 scenarios, respectively. While the analysis presented in this work has accounted for these sensitivities to the extent possible with currently available tools and inventory data, understanding the true benefits associated with electrifying the on-road fleet and the associated infrastructure requirement costs will be key to achieving the objectives of the 2050 Texas Transportation Plan and the Unified Transportation Program.

For medium and heavy-duty vehicles, the results of this study indicate a 13% growth over the next 28 years, with the fastest growth over the next decade. These findings are in line with CAGR reported growth predictions between now and 2027. However, the state's transportation plans, while focused on preserving and enhancing Texas' competitive advantage freight-supportive infrastructure, are focused on design considerations, safety, access, efficiency, and decongestion, and do not have decarbonization targets or account for the projected increases in warehousing, courier express and parcel, value-added services, last-mile logistics, and return logistics. According to TxDOT, the plans are currently being updated to reflect the changes required by the federal Infrastructure Investment and Jobs Act (IIJA).

Concerns about the reliability of the Texas grid have raised questions about the added strain from the electrification of transportation. The bidirectional flow of energy, allowing EVs to charge using electricity from the grid but also to return power to the grid from the vehicle batteries, known as Vehicle-to-Grid, or V2G, is gaining popularity. As EVs remain stationary over 80% of the time, they can act as distributed energy systems. While a single EV may only be able to support residential energy demand (vehicle-to-home) and not be able to generate the volume of energy required for the grid, several aggregated V2G installations can be a significant storage and power source. Currently, such systems are being tested in Austin to understand how they can support ancillary services of the grid. Hardware limitations for vehicles' EVSE aspects can be alleviated by introducing policy mandates with design specifications that support V2G and the ability to connect to the local grid.

While rail, aviation, and marine contribute only about 12% of emissions from the transportation sector in Texas, the state's unique position in the within-state, domestic, and international movement of freight makes these sectors vulnerable to the impact of the energy transition and, as identified in the study, in some cases excellent candidates for nearly 95%-99% emissions reduction by 2050 compared to a 2022 baseline. For each of the three modes, electrifying the fleet or producing carbon-neutral fuels from carbon-neutral electricity can help achieve deep decarbonization.



	2022	Business-as-usual	2050 ZEV	2040 ZEV
■ Others	5933	3555	1723	412
■ Zinc	1978	1185	574	137
■ Manganese	221494	132735	64308	15398
■ Copper	441010	264286	128042	30659

	2022	Business-as-usual	2050 ZEV	2040 ZEV
■ Others	79	3353	5247	6601
■ Rare earths	128	5409	8463	10647
■ Zinc	26	1082	1693	2129
■ Graphite	16969	717172	1122237	1411766
■ Cobalt	3404	143867	225125	283205
■ Manganese	6271	265018	414703	521693
■ Nickel	10212	431601	675374	849615
■ Lithium	2278	96272	150647	189513
■ Copper	13616	575468	900498	1132819

Figure 58. Growth in the demand for critical minerals for LDVs- EVs (top) and ICEVs (bottom) from 2022 to 2050, under the business-as-usual, 2040, and 2050 scenarios based on the mineral impact presented in Figure 30 in Chapter 6

CHAPTER 8: CAN TRANSPORTATION IMPACT OTHER SECTORS

The building of a new segment of the transportation industry – one that is focused on EV (and ZEV) based road transportation - will create an ecosystem of new jobs. The JOBS EVSE tool also quantifies direct, indirect and induced employment from the electrification of the on-road fleet (Figure 59). The direct impacts are classified as the effect on jobs, income, and revenue or sales associated with industries for which initial expenditures have been modeled, while the indirect impacts measure the changes in economic activity in supporting industries that result from the initial expenditures. Lastly, induced impacts relate to spending by workers whose earnings are affected by changes in the final demand, also known as the household-spending effect. The sum of these effects is the total economic impact presented in Figure 60. The jobs in Figure 59 include direct, indirect, and induced jobs for the stations, and in the electricity, advertising, retail, data and networking, and maintenance sectors during the station development phase and operations. Under the assumptions detailed in Chapter 6, more than 378,000 jobs will be added to the Texas economy by 2050 from the electrification of on-road transportation under the business-as-usual scenario. This includes cumulative station operations jobs and an average of 11,000 jobs added annually between 2022 and 2050 for station development. The policy target requiring all new sales to be ZEVs by 2050 will add 1.5 times more jobs than the business-as-usual scenario (more than 556,000 jobs; including an average of 17,000 station development jobs added annually between 2022 and 2050), while requiring all new sales to be ZEVs by 2040 will add twice the jobs compared to business-as-usual (more than 781,000 jobs; including an average of 25,000 station development jobs added annually between 2022 and 2050).

The economic output related to these jobs represents the total value of sales by producing enterprises including the value of intermediate goods used in production. The growth in jobs will add about $690 million to the Texas economy by 2050 in the business-as-usual scenario. The policy target requiring all new sales to be ZEVs by 2050 will add about $1.5 billion, while the policy target of all new sales are ZEVs by 2040 will add nearly $2.5 billion in economic output by 2050.

Job Losses

Jobs gained from electrification of the LDV, MDV, and HDV fleets will be accompanied by losses in jobs related to the traditional auto sector. Analyses from Ford Motors[43] and Volkswagen[44] have indicated the transition to EVs will shrink the auto industry workforce and require 30% fewer workers than ICEVs. Assuming this trend can be extended to indirect and induced jobs, the electrification of the on-road fleet, as modeled in this study would result in an economy-wide (including electricity, advertising, retail, data and networking, and maintenance jobs) loss of more than 250,000, 516,000, and 600,000 jobs in Texas under the business-as-usual, 2050 and 2040 scenario by 2050. Accounting for these job losses will reduce net job gains from electrification of the on-road fleet to nearly 128,000, 41,000, and 181,000 for business-as-usual, 2050 and 2040 scenario by 2050. Even though we anticipate significantly more vehicles on the roads in Texas and with more annual vehicle miles travelled, the number of jobs in the road transportation sector are likely to remain roughly the same in all of these scenarios.

Workforce Equity and Development

Prevailing wages in the traditional auto sector range from about $26 for auto-service technicians[45] and mechanics to $60 for a unionized auto assembly worker[46]. In contrast, most jobs in the EV industry are not unionized and range from $17-$21 per hour[47]. Therefore, the economic impact of the lost jobs could be comparable to, or even offset, the benefits from the increase in net jobs associated with the electrification/ decarbonization of the transportation sector. Even though these impacts will be felt over three decades and will not trigger sudden slowdowns in the traditional auto sector, skills preservation and transferability, workforce upskilling and reskilling that employees can afford or are supported by the government, and prevailing unionized wages will be required to protect the current and future workforce.

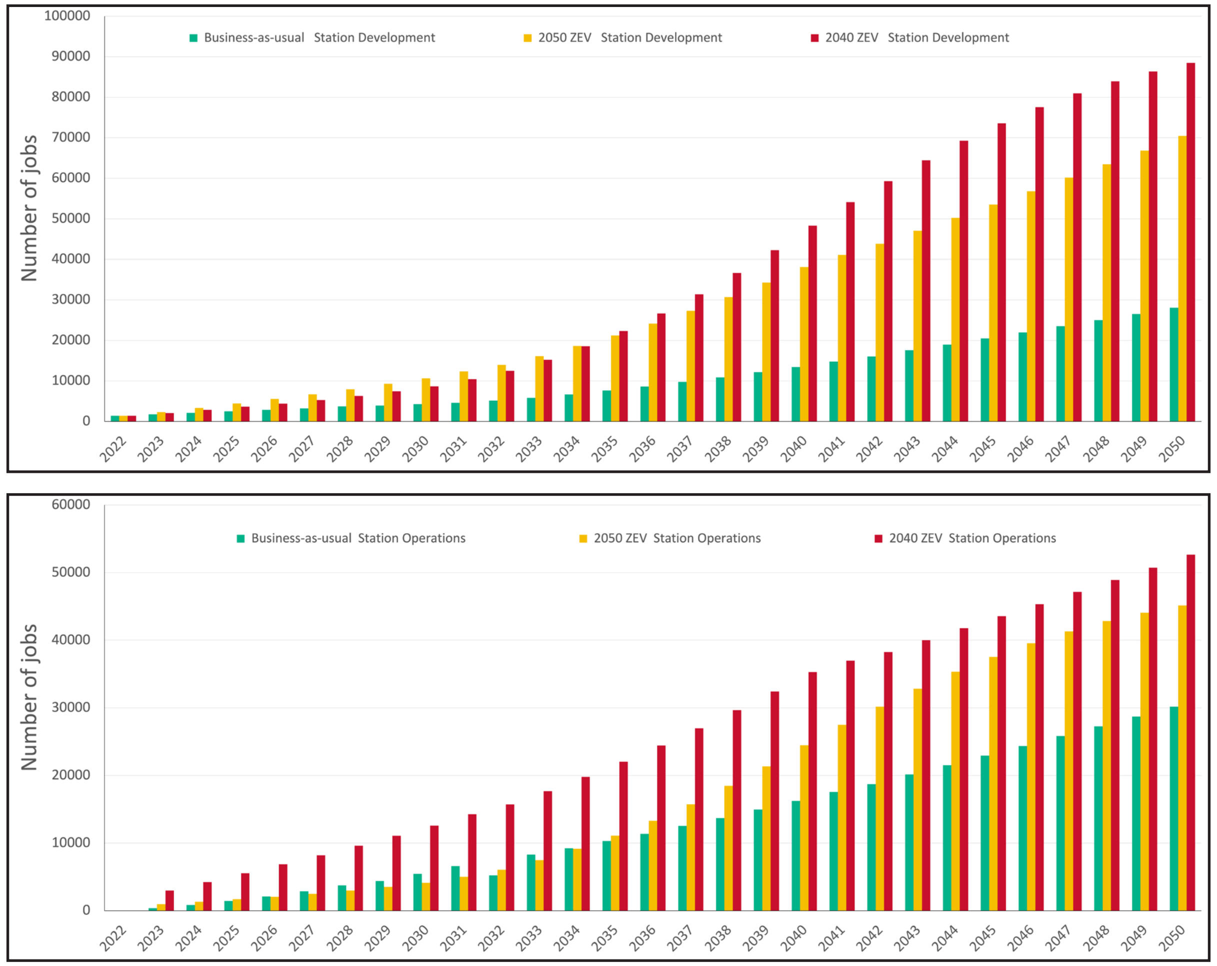


Figure 59. Total employment (incremental) from station development and station operations for L2 and DCFC stations. Jobs include direct, indirect, and induced jobs for the stations, and in the electricity, advertising, retail, data and networking, and maintenance sectors.

NET JOBS ADDED BY 2050 IN THE TRANSPORTATION SECTOR OF TEXAS

BUSINESS-AS-USUAL: 128,000
2050 ZEV: $41,000
2040 ZEV: $181,000

In addition to decarbonization benefits, infrastructure improvements and expansion provide the opportunity to address inequities in the transportation system. This includes increased access to equitable transportation, fair distribution and deployment of transportation resources and infrastructure, with increased investments, as outlined in the Justice40 Initiative of the federal government, in disadvantaged communities, including communities of color, rural, and low-income neighborhoods. Along with infrastructure needs, ownership trends indicate that ZEVs are currently unaffordable for many middle-income and most low-income households, which can further isolate these communities and concentrate the benefits of the transition among a few, exacerbating the generational negative environmental and health consequences faced by these communities. Improving low to no emission transportation access and safety in terms of modes and infrastructure, quantifying the environmental and health impacts and measuring improvements with increased investment over time, interactions with community resilience measures ranging from flooding resilience, air quality, disease incidence and recovery, and workforce impacts, assessing benefits and burdens, and equitable decision making that allows local voices to participate in the process are critical determinants of the process.

Public Health

A 2020 assessment from the American Lung Association found that decarbonizing the transportation sector in Texas[18] could result in $104 billion in public health benefits, including avoiding 9,320 deaths, 346,000 asthma attacks, and 1,520,000 lost workdays in the state between 2020 and 2050. A 2019 study based in the Houston metropolitan area noted that if transportation sector emissions decreased by 50%, 75%, and 95% by 2040 (compared to a 2013 baseline), then 114, 188, and 246 premature deaths could be prevented, respectively, and economic benefits from the improved health outcomes would range from $1.2 billion to $2.7 billion[48]. While these studies suggest a potential improvements in long-term health outcomes due to the transformation of the transportation sector, it is unclear if there would be leading indicators that identify and broadcast the anticipated improved health outcomes associated with the transition to ZEVs.

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[18] The scenarios analyzed by the American Lung Association included a 100% sales of zero-emission passenger cars by 2023 and of heavy-duty trucks by 2040 and shifting to non-combustion electricity generation by 2035.

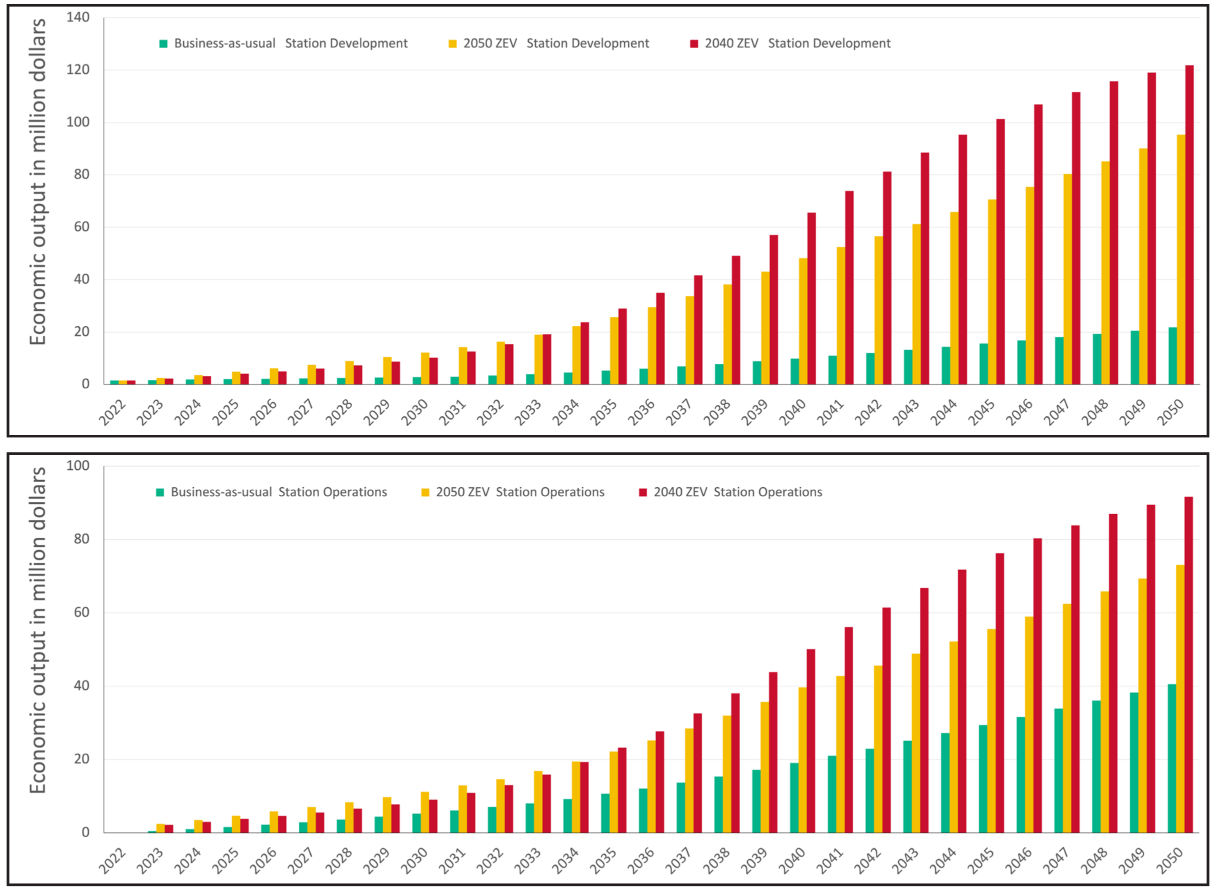

Figure 6o. Economic output in million $ from station development and station operations for L2 and DCFC stations. Impacts include direct, indirect, and induced jobs for the stations, and in the electricity, advertising, retail, data and networking, and maintenance sectors.

APPENDIX A

Table A1. Energy consumption in billion BTUs in the transportation sector in Texas, 1960-2020. Source: Bureau of Transportation Statistics

	1960	**1970**	**1980**	**1990**	**2000**	**2005**	2010	2015	2016	2017	2018	2019	**2020**
All petroleum products	743,157	1,113,212	1,693,995	2,042,758	2,497,663	2,635,616	2,578,598	2,899,507	2,993,949	3,026,042	3,103,475	3,159,155	2,642,451
Aviation gasoline	16,460	10,131	6,380	4,230	3,073	2,579	3,138	1,937	2,054	2,334	2,153	2,097	1,938
Coal	295	29	0	0	0	0	0	0	0	0	0	0	0
Distillate fuel oil	79,051	130,795	281,268	275,924	482,095	609,750	667,266	840,235	828,191	853,295	931,930	949,169	825,832
Fuel ethanol, excluding denaturant	0	0	0	1,960	5,360	1,361	84,231	106,302	118,453	119,961	121,360	124,314	107,669
Hydrocarbon gas liquids	7,774	21,459	2,492	1,841	897	1,798	571	1,247	1,363	1,177	629	648	242
Jet fuel	58,554	135,936	173,277	542,139	582,403	455,765	258,523	296,400	300,657	298,370	301,875	320,520	198,228
Lubricants	10,798	9,842	11,580	11,857	12,084	10,194	16,176	19,619	18,731	17,319	17,113	16,872	14,348
Motor gasoline	459,013	731,700	930,976	1,044,152	1,285,040	1,414,323	1,457,966	1,619,272	1,664,269	1,675,031	1,705,075	1,716,557	1,475,249
Natural gas	54,125	98,827	108,060	110,526	65,177	85,397	84,860	92,418	92,088	88,766	123,124	179,908	196,091
Propane	-	-	-	-	-	-	571	1,247	1,363	1,177	629	648	242
Residual fuel oil	111,507	73,348	288,020	162,615	132,070	141,207	174,956	120,797	178,684	178,516	144,701	153,293	126,613
Electricity	28	0	0	0	104	241	254	613	620	622	639	637	593
Transportation's share of electrical system energy losses	69	0	0	0	212	457	515	1,170	1,188	1,209	1,171	1,164	1,077
Total energy consumed by the Transportation sector	797,674	1,212,068	1,802,055	2,155,244	2,563,155	2,722,996	2,664,227	2,993,707	3,087,844	3,116,638	3,228,409	3,340,863	2,840,211

Table A2. Economic and Workforce Impact of the Transportation Sector in Texas, 2005-2021. Source: Bureau of Transportation Statistics

	Measure	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Total	Gross domestic product (millions)	995,252	1,245,959	1,573,498	1,579,015	1,677,111	1,809,706	1,863,954	1,775,588	1,985,319
	Population	22,778,123	25,241,897	27,468,531	27,914,064	28,291,024	28,624,564	28,986,794	29,217,653	29,527,941
	All Employed	9,583,457	10,182,150	11,655,919	11,805,698	12,014,802	12,302,358	12,590,406	2,916,181	3,020,614
	Transportation Employees	395,293	419,722	492,123	513,090	534,504	554,180	577,888	593,743	623,836
	Annual Payroll (thousands)	17,736,161	22,154,864	29,682,793	29,894,880	31,908,066	34,124,671	36,099,530	36,656,173	39,528,950
	Business Establishments	15,651	17,368	20,746	21,370	21,705	22,504	23,800	24,615	26,221
Air transportation	Transportation Employees	63,716	60,365	58,352	60,719	62,579	62,882	64,237	62,260	61,631
	Annual Payroll (thousands)	3,638,134	4,175,645	5,576,194	5,561,790	5,921,445	6,023,120	6,277,362	6,052,280	6,120,583
	Business Establishments	466	490	491	486	508	504	502	506	512
Couriers and messengers	Transportation Employees	36,380	34,232	45,038	48,701	51,722	55,213	61,493	72,969	83,290
	Annual Payroll (thousands)	1,232,035	1,320,413	1,823,285	1,898,625	2,062,111	2,264,645	2,539,053	3,132,278	3,738,111
	Business Establishments	958	1,143	1,399	1,375	1,293	1,255	1,316	1,423	1,526
Pipeline Transportation	Transportation Employees	12,040	15,936	18,132	18,791	19,079	18,931	19,457	19,451	19,339
	Annual Payroll (thousands)	1,290,778	2,066,663	2,657,552	2,822,287	3,021,749	2,991,263	3,228,917	3,083,216	3,089,553
	Business Establishments	585	598	609	618	646	643	746	764	768
Rail Transportation	Transportation Employees	58	63	36	67	75	49	50	63	46
	Annual Payroll (thousands)	2,543	2,680	1,906	2,918	1,817	1,971	2,480	3,228	2,155
	Business Establishments	11	11	6	10	11	10	10	9	10
Scenic and sightseeing transportation	Transportation Employees	697	786	863	901	998	941	950	715	844
	Annual Payroll (thousands)	13,842	17,246	18,504	19,226	20,925	21,129	22,187	16,841	22,053
	Business Establishments	71	84	102	106	113	109	107	110	115
Support activities for transportation	Transportation Employees	72,588	77,009	90,837	89,759	92,616	96,925	100,375	96,713	96,861
	Annual Payroll (thousands)	3,161,890	3,994,978	5,206,457	5,153,150	5,488,916	6,019,790	6,297,614	6,194,372	6,535,131
	Business Establishments	3,483	3,879	4,404	4,592	4,768	4,936	5,121	5,296	5,498
Transit and ground passenger	Transportation Employees	27,252	30,333	34,989	35,273	35,336	34,921	34,411	29,675	28,573
	Annual Payroll (thousands)	813,518	1,001,943	1,250,711	1,267,988	1,316,570	1,355,035	1,410,563	1,329,511	1,311,872
	Business Establishments	693	756	881	897	924	925	928	917	917
Truck transportation	Transportation Employees	108,080	107,062	143,519	138,589	139,895	146,804	152,863	143,074	145,758
	Annual Payroll (thousands)	4,175,415	4,791,886	7,614,154	7,216,483	7,687,298	8,590,520	9,152,068	8,642,843	9,313,331
	Business Establishments	7,414	7,310	9,681	10,041	10,128	10,740	11,585	12,024	13,208
Water transportation	Transportation Employees	4,371	4,954	5,038	4,757	4,616	4,213	4,009	3,906	3,700
	Annual Payroll (thousands)	314,878	410,168	500,803	468,518	463,195	462,074	426,116	411,107	390,777
	Business Establishments	121	163	170	165	160	160	172	190	201

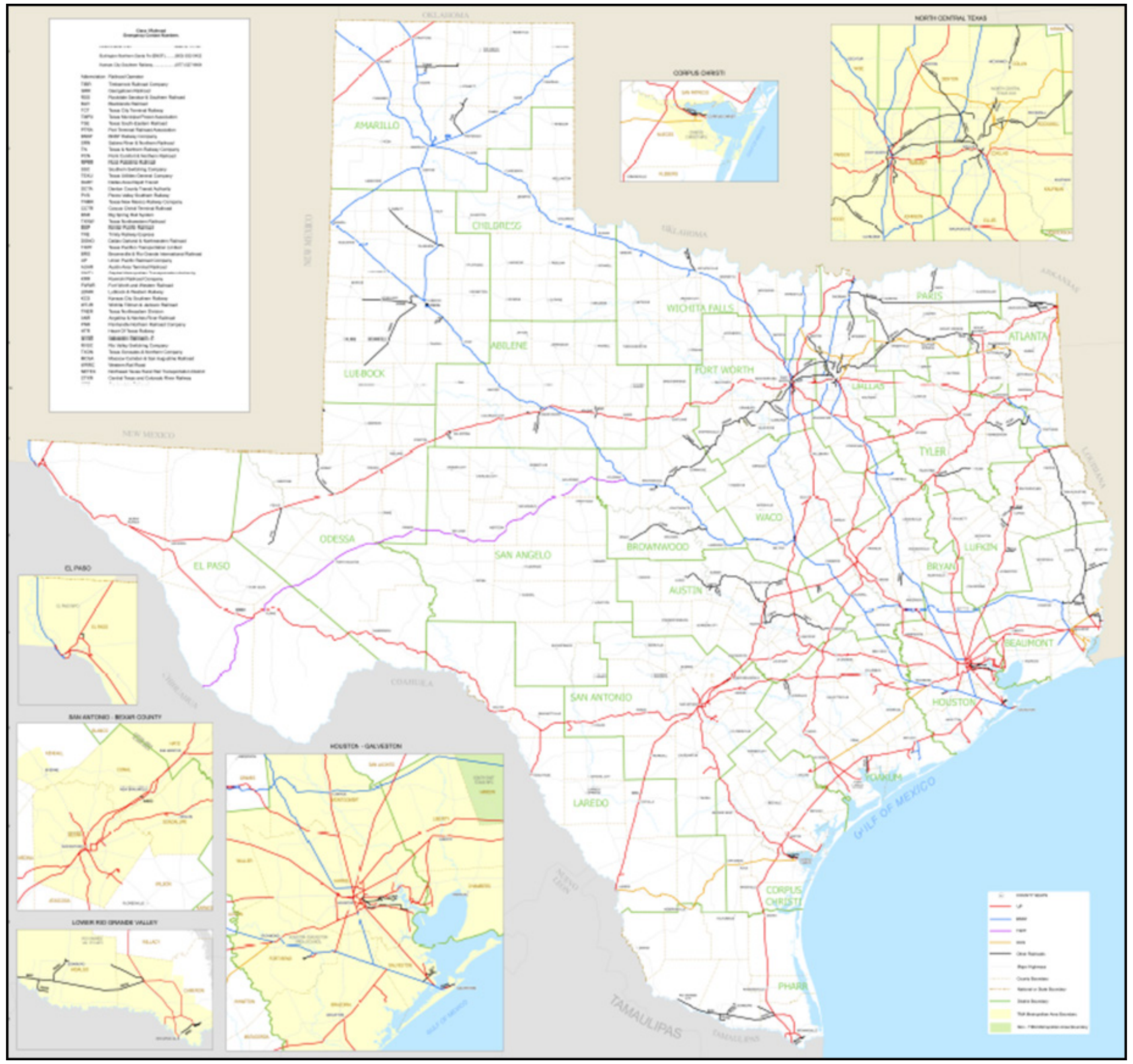

Figure A1. Railroads in Texas as of 2021. Data source: Texas Department of Transportation

Table A3. The employment level in Automotive Body and Related Repairers. Data Source: U.S. Bureau of Labor Statistics

Employment	Employment per thousand jobs	Location quotient[19]	Hourly mean wage	Annual mean wage
11,400	0.93	0.96	$ 24.49	$ 50,940

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[19] The location quotient is the ratio of the area concentration of occupational employment to the national average concentration. A location quotient greater than one indicates the occupation has a higher share of employment than average, and a location quotient less than one indicates the occupation is less prevalent in the area than average.

Table A4. Metropolitan areas with the highest employment level in Automotive Body and Related Repairers. Data Source: U.S. Bureau of Labor Statistics

Metropolitan area	Employment	Employment per thousand jobs	Location quotient	Hourly mean wage	Annual mean wage
New York-Newark-Jersey City, NY-NJ-PA	7580	0.87	0.9	24.62	51210
Chicago-Naperville-Elgin, IL-IN-WI	4380	1.03	1.06	23.6	49080
Los Angeles-Long Beach-Anaheim, CA	4150	0.72	0.74	25.77	53610
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	2920	1.1	1.13	25.3	52610
Houston-The Woodlands-Sugar Land, TX	2730	0.94	0.97	25.6	53240
Atlanta-Sandy Springs-Roswell, GA	2710	1.05	1.07	28.39	59050
Dallas-Fort Worth-Arlington, TX	2660	0.74	0.76	25.89	53850
Washington-Arlington-Alexandria, DC-VA-MD-WV	2510	0.86	0.88	28.63	59550
Miami-Fort Lauderdale-West Palm Beach, FL	2390	0.97	1	24.95	51890
Detroit-Warren-Dearborn, MI	2030	1.13	1.16	25.43	52900

Table A5. Share of major commodities in rail freight traffic originating from and terminating in Texas in 2019. Data source: Association of American Railroads

Commodity	Originating in Texas (%)	Terminating in Texas (%)
Chemicals	38	16
Non-metallic minerals	25	22
Petroleum Products	11	-
Intermodal	9	7
Primary metal products	3	-
Farm products	-	8
Coal	-	22
Others	14	25

Table A6. Business-as-usual emissions from the transportation sector based on fuel category in MMt CO2, 2022-2050

Year	Petroleum	Natural Gas	Electricity	Total
2022	197.55	5.85	0.25	203.64
2023	195.13	5.85	0.34	201.33
2024	195.58	5.80	0.41	201.80
2025	196.23	5.80	0.52	202.55
2026	196.31	5.79	0.63	202.73
2027	195.60	5.68	0.77	202.05
2028	194.92	5.77	0.88	201.57
2029	194.33	5.70	1.02	201.05
2030	193.95	5.57	1.13	200.64
2031	193.65	5.48	1.24	200.37
2032	193.25	5.60	1.34	200.20
2033	193.24	5.63	1.48	200.35
2034	193.26	5.51	1.57	200.34
2035	193.14	5.66	1.67	200.47
2036	193.40	5.76	1.71	200.87
2037	193.85	5.97	1.76	201.58
2038	194.07	6.19	1.82	202.08
2039	194.79	6.31	1.89	202.98
2040	195.73	6.56	1.98	204.26
2041	196.50	6.80	2.07	205.38
2042	197.54	6.97	2.17	206.67
2043	198.43	7.25	2.22	207.90
2044	199.42	7.45	2.27	209.14
2045	200.77	7.57	2.34	210.69
2046	202.22	7.85	2.44	212.51
2047	203.60	8.03	2.54	214.17
2048	204.77	8.25	2.66	215.68
2049	206.22	8.39	2.77	217.39
2050	208.06	8.60	2.90	219.56

Table A7. The number of employees, annual payroll, and the number of business establishments in the transportation sector in Texas, 2005-2021. Data source: Bureau of Transportation Statistics

Industry	Measure	2005	2010	2015	2016	2017	2018	2019	2020	2021
Air Transportation	Transportation Employees	63,716	60,365	58,352	60,719	62,579	62,882	64,237	62,260	61,631
	Annual Payroll (thousands)	3,638,134	4,175,645	5,576,194	5,561,790	5,921,445	6,023,120	6,277,362	6,052,280	6,120,583
	Business Establishments	466	490	491	486	508	504	502	506	512
Couriers and messengers	Transportation Employees	36,380	34,232	45,038	48,701	51,722	55,213	61,493	72,969	83,290
	Annual Payroll (thousands)	1,232,035	1,320,413	1,823,285	1,898,625	2,062,111	2,264,645	2,539,053	3,132,278	3,738,111
	Business Establishments	958	1,143	1,399	1,375	1,293	1,255	1,316	1,423	1,526
Pipeline transportation	Transportation Employees	12,040	15,936	18,132	18,791	19,079	18,931	19,457	19,451	19,339
	Annual Payroll (thousands)	1,290,778	2,066,663	2,657,552	2,822,287	3,021,749	2,991,263	3,228,917	3,083,216	3,089,553
	Business Establishments	585	598	609	618	646	643	746	764	768
Rail transportion	Transportation Employees	58	63	36	67	75	49	50	63	46
	Annual Payroll (thousands)	2,543	2,680	1,906	2,918	1,817	1,971	2,480	3,228	2,155
	Business Establishments	11	11	6	10	11	10	10	9	10
Scenic and sightseeing transportation	Transportation Employees	697	786	863	901	998	941	950	715	844
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	Business Establishments	71	84	102	106	113	109	107	110	115
Support activities for transportation	Transportation Employees	72,588	77,009	90,837	89,759	92,616	96,925	100,375	96,713	96,861
	Annual Payroll (thousands)	3,161,890	3,994,978	5,206,457	5,153,150	5,488,916	6,019,790	6,297,614	6,194,372	6,535,131
	Business Establishments	3,483	3,879	4,404	4,592	4,768	4,936	5,121	5,296	5,498
Transit and ground passenger transportation	Transportation Employees	27,252	30,333	34,989	35,273	35,336	34,921	34,411	29,675	28,573
	Annual Payroll (thousands)	813,518	1,001,943	1,250,711	1,267,988	1,316,570	1,355,035	1,410,563	1,329,511	1,311,872
	Business Establishments	693	756	881	897	924	925	928	917	917
Truck Transportation	Transportation Employees	108,080	107,062	143,519	138,589	139,895	146,804	152,863	143,074	145,758
	Annual Payroll (thousands)	4,175,415	4,791,886	7,614,154	7,216,483	7,687,298	8,590,520	9,152,068	8,642,843	9,313,331
	Business Establishments	7,414	7,310	9,681	10,041	10,128	10,740	11,585	12,024	13,208
Water transportation	Transportation Employees	4,371	4,954	5,038	4,757	4,616	4,213	4,009	3,906	3,700
	Annual Payroll (thousands)	314,878	410,168	500,803	468,518	463,195	462,074	426,116	411,107	390,777
	Business Establishments	121	163	170	165	160	160	172	190	201

Table A8. Registered Light-Duty vehicles in Texas by fuel type, 2016 – 2021. Source: Alternative Fuels Data Center

Fuel Type	2016	2017	2018	2019	2020	2021
Electric (EV)	11,900	16,100	24,500	38,400	52,200	80,900
Plug-In Hybrid Electric (PHEV)	8,000	10,900	14,700	18,100	20,400	30,600
Hybrid Electric (HEV)	205,800	217,100	227,700	244,600	262,300	304,700
Ethanol/ Flex (E85)	2,596,600	2,813,400	3,005,900	3,200,700	3,250,000	2,422,300
Compressed Natural Gas (CNG)	64,700	56,900	51,300	47,300	43,600	2,200
Propane	0	0	0	0	0	1,600
Hydrogen	0	0	0	100	100	0
Methanol	0	0	0	0	0	0
Gasoline	18,245,400	18,252,800	18,453,800	19,293,900	19,609,700	20,599,100
Diesel	961,200	982,900	1,019,300	1,070,200	1,107,000	765,100 Biodiesel: 376,300

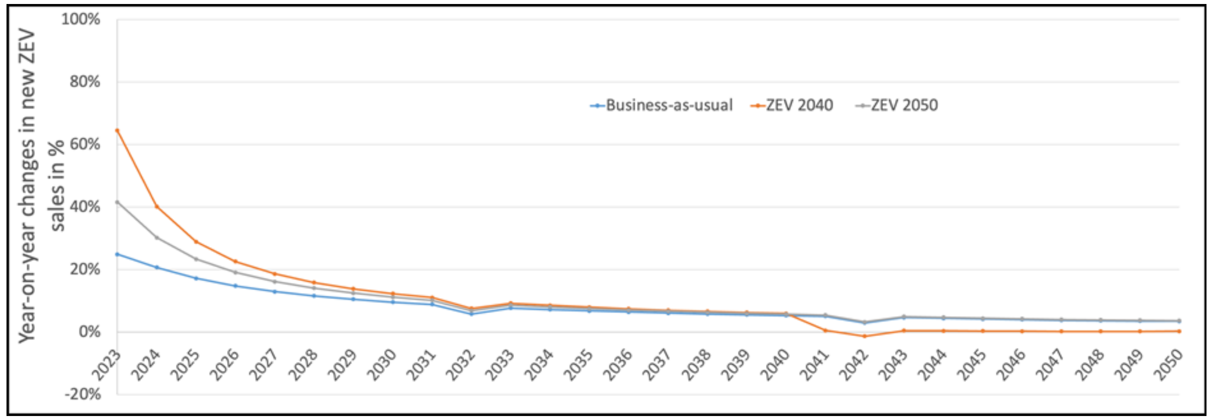

Figure A2. New ZEV sales for LDVs. Growth rates for business-as-usual, all new sales ZEVs by 2050, and all new sales ZEVs by 2040 for LDVs in Texas. The growth rates for the accelerated deployment scenarios were modeled to meet LDV demand in Texas as determined by the population-based regression models presented above. The low penetration of ZEVs before 2020 and the acceleration of new models from 2021 to 2024 along with their improved affordability leads to a sharp decrease in the YOY penetration rates of ZEV. The year-on-year growth rate is calculated as $\frac{ZEVs\ in\ fleet_{t+1} - ZEVs\ in\ fleet_t}{ZEVs\ in\ fleet_t}$, and decreases as the number of ZEVs grow in the fleet from year to year[20]

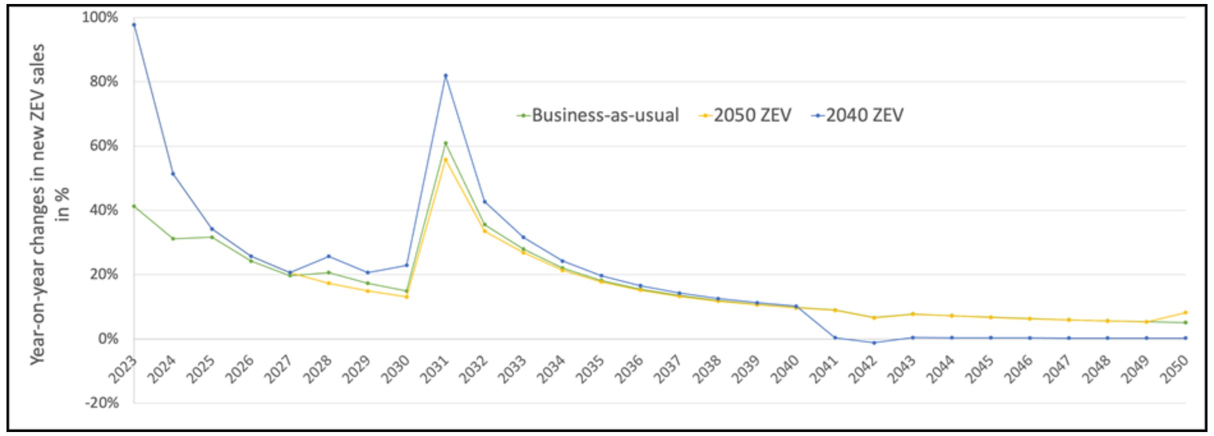

Figure A3. New ZEV sales for M/HDVs. Growth rates for business-as-usual, all new sales ZEVs by 2050, and all new sales ZEVs by 2040 for M/HDVs in Texas. The growth rates for the accelerated deployment were adjusted to meet M/HDV demand in Texas as determined by the population-based regression models presented above. The year-on-year growth rate is calculated as $\frac{ZEVs\ in\ fleet_{t+1} - ZEVs\ in\ fleet_t}{ZEVs\ in\ fleet_t}$, and decreases as the number of ZEVs grow in the fleet from year to year[20].

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[20] For Figures A2 and A3, as detailed in Chapter 6 Section 1, we assumed accelerated growth rates compared to the business-as-usual assumption and that with the impetus for new ZEV models, their market penetration will increase significantly in 2030.

LIST OF ABBREVIATIONS

1. **GHG** – Greenhouse Gas
2. **LDV** – Light-Duty Vehicle
3. **MDV** – Medium-Duty Vehicle
4. **HDV** – Heavy-Duty Vehicle
5. **ICEV** – Internal Combustion Engine Vehicle
6. **GDP** – Gross Domestic Product
7. **IIJA** – Infrastructure Investment and Jobs Act
8. **U.S. EIA** – U.S. Energy Information Administration
9. **TxDOT** – Texas Department of Transportation
10. **VMT** – Vehicle Miles Traveled
11. **U.S. FHWA** - U. S. Federal Highway Administration
12. **AFV** – Alternately Fueled Vehicles
13. **EV** – Electric Vehicle
14. **ZET** – Zero-emissions Truck
15. **U.S. DOE** – U.S. Department of Energy
16. **LTO** – Landing/take-off cycle
17. **TASP** – Texas Airport System Plan
18. **ASCE** – American Society of Civil Engineers
19. **NHS** – National Highway System
20. **CAGR** – Compound Annual Growth Rate
21. **NPIAS** – National Plan of Integrated Airport System
22. **UTP** – Unified Transportation Program
23. **NEVI** – National Electric Vehicle Infrastructure
24. **ERIG**- Emissions Reduction Incentive Grants
25. **TERP** – Texas Emissions Reduction Plan
26. **TCEQ** – Texas Commission on Environmental Quality
27. **NEV** – Neighborhood Electric Vehicle
28. **FHWA** – Federal Highway Administration
29. **CAFE** – Corporate Average Fuel Economy
30. **NHTSA** – National Highway Traffic and Safety Administration
31. **EPA** – Environmental Protection Agency
32. **BEV** – Battery Electric Vehicle
33. **TFMP** – Texas Freight Mobility Plan
34. **IRENA** – International Renewable Energy Agency
35. **ICCT** - International Council on Clean Transportation
36. **DVMT** – Daily Vehicle Miles Traveled
37. **LCA** – Lifecycle Analysis
38. **GREET Model** – Greenhouse gases, Regulated Emissions, and Energy use in Technologies Model
39. **WTP** – Well-to-Pump
40. **L2 Charger** – Level 2 charger
41. **DCFC Charger** – Direct Current Fast Charger
42. **RIMS II** – Regional Input-Output Modeling System
43. **JOBS EVSE** – JOBS Electric Vehicle Supply Equipment
44. **BTS** - Bureau of Transportation Statistics
45. **CFS** – Commodity Flow Survey
46. **FAF** – Freight Analysis Framework
47. **ERCOT** – Electric Reliability Council of Texas
48. **ORNL** – Oak Ridge National Laboratory
49. **CREZ** – Competitive Renewable Energy Zone
50. **CDR** – Carbon dioxide Removal
51. **CCUS** – Carbon Capture, Utilization, and Storage
52. **MDO** – Marine Diesel Oil
53. **LNG** – Liquified Natural Gas
54. **HRJ** – Hydro-processed Renewable Jet fuel
55. **DAC** – Direct Air Capture
56. **V2G** – Vehicle-to-Grid

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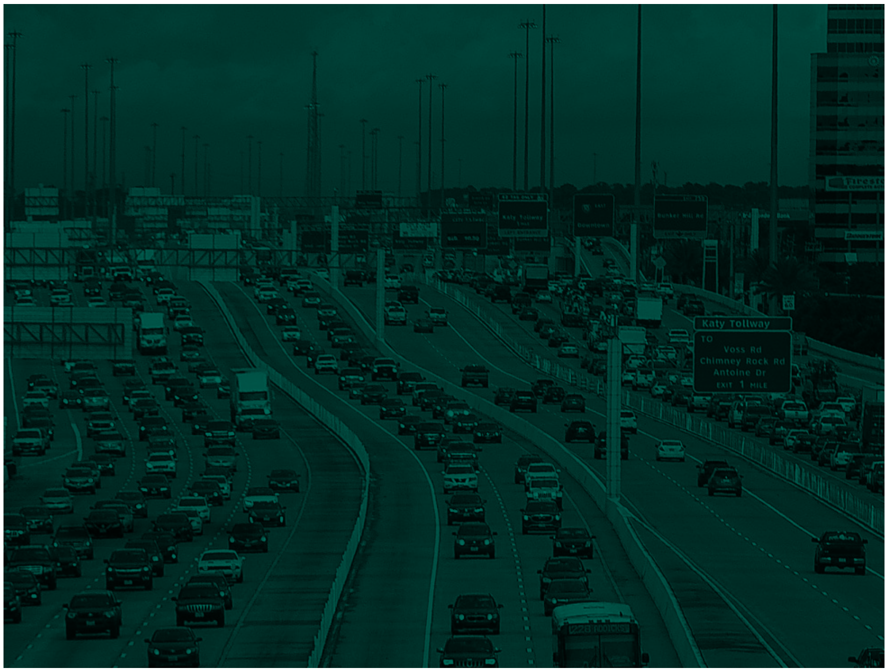

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